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SURVEY OF INVESTIGATIONS FOR A HIGH-LEVEL WASTE REPOSITORY AT NEVADA TEST SITE

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U.S. Nuclear Regulatory Commission

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INTRODUCTION

Purpose of Trip

Between February 16 and 24, 1981 members of the Nuclear Regulatory Commission (NRC) staff undertook a technical survey of studies done by the Department of Energy (DOE) at the Nevada Test Site (NTS) relative to a location for the safe storage of high-level radioactive waste. This DOE activity is referred to as the Nevada Waste Storage Investigations (NWSI).

The trip is one of several to survey DOE investigations for the siting of a high-level waste repository. The purposes are:

(1) To familiarize the NRC staff with the geology of NTS.

(2) To survey the nature and thrust of the DOE-sponsored investigations.

(3) To develop contacts with specialists familiar with the geology of southern Nevada.

(4) To develop technical knowledge that will assist in the preparation of various NRC documents.

It should be noted that the trip is not intended as an evaluation of NTS suitability for a waste repository; nor is it part of any current licensing action by NRC.

Organization of Trip

On February 17, participants in NWSI discussed their respective investigations at DOE headquarters in Las Vegas. The discussions were continued on February 19, following a field visit to NTS on February 18.

On February 20, 23, and 24 members of the NRC group held discussions with representatives of the Desert Research Institute (Las Vegas), University of Nevada (Las Vegas), Nevada Bureau of Mines and Geology (Reno), Desert Research Institute (Reno), and U.S. Geological Survey (Denver).

NRC participants in the trip were:

F. L. Doyle	Hydrology
Clayton L. Pittiglio, Jr.	Civil engineering
Linda Lehman	Hydrologic modeling
Paul Prestholt	Geophysics
Robert J. Wright	Exploration geology

In addition, under a NRC-U.S. Bureau of Mines technical assistance agreement, the group was joined in Las Vegas by:

Vernon Hooker	Mining engineering, U.S. Bureau of Mines

Previous History of the Project

The NWSI investigations benefit greatly from the large amount of geologic, hydrologic, and geophysical work done over more than a quarter century in connection with nuclear weapons testing. This work started in the early 1950's, with the U.S. Geological Survey (USGS) taking the lead in geology and hydrology. Sandia National Laboratory (SNL) was responsible for geophysical monitoring of the nuclear tests. Certain specific geologic studies were undertaken by Lawrence Berkeley National Laboratory (LBNL) and Lawrence Livermore National Laboratory (LLNL). Thus, a substantial background of geotechnical knowledge was available when, in 1974, work was initiated toward repository investigations. To implement the repository program, the scope of the investigations was greatly broadened and other participants were added, including Los Alamos National Laboratory (LANL). Counting separate units within one institution, at least a dozen organizations are now involved.

Since 1974 several localities within NTS have been investigated for repository suitability and rejected for one reason or another - Eleana, Climax, Calico Hills, and Wahmonie. In 1978 a rectangular area in the southwest corner of NTS was identified as a research and development area, within which a repository could be located without interference with the primary mission of NTS. In the following year, 1979, the USGS identified the southern extension of Yucca Mountain (Figure 1) as attractive for further study, based on relative sparcity of faulting as compared with the surrounding region (Figure 2). Here a four square mile study area has been identified, and present investigations are focussed here (Figure 3). Seven holes have been drilled in, or on the margins of, the study area:

Hole No.	Total Depth (feet)	Purpose
UE 25a1	2500	Geologic test on east side of study area
UE 25a4	500	Hydrology test in alluvium
UE 25a5	500	Hydrology test in alluvium
UE 25a6	500	Hydrology test in alluvium
UE 25a7	800 (inclined)	Hydrology test in alluvium
G1	6000	Geologic test in the study area
H1	6000	Hydrology test in the study area

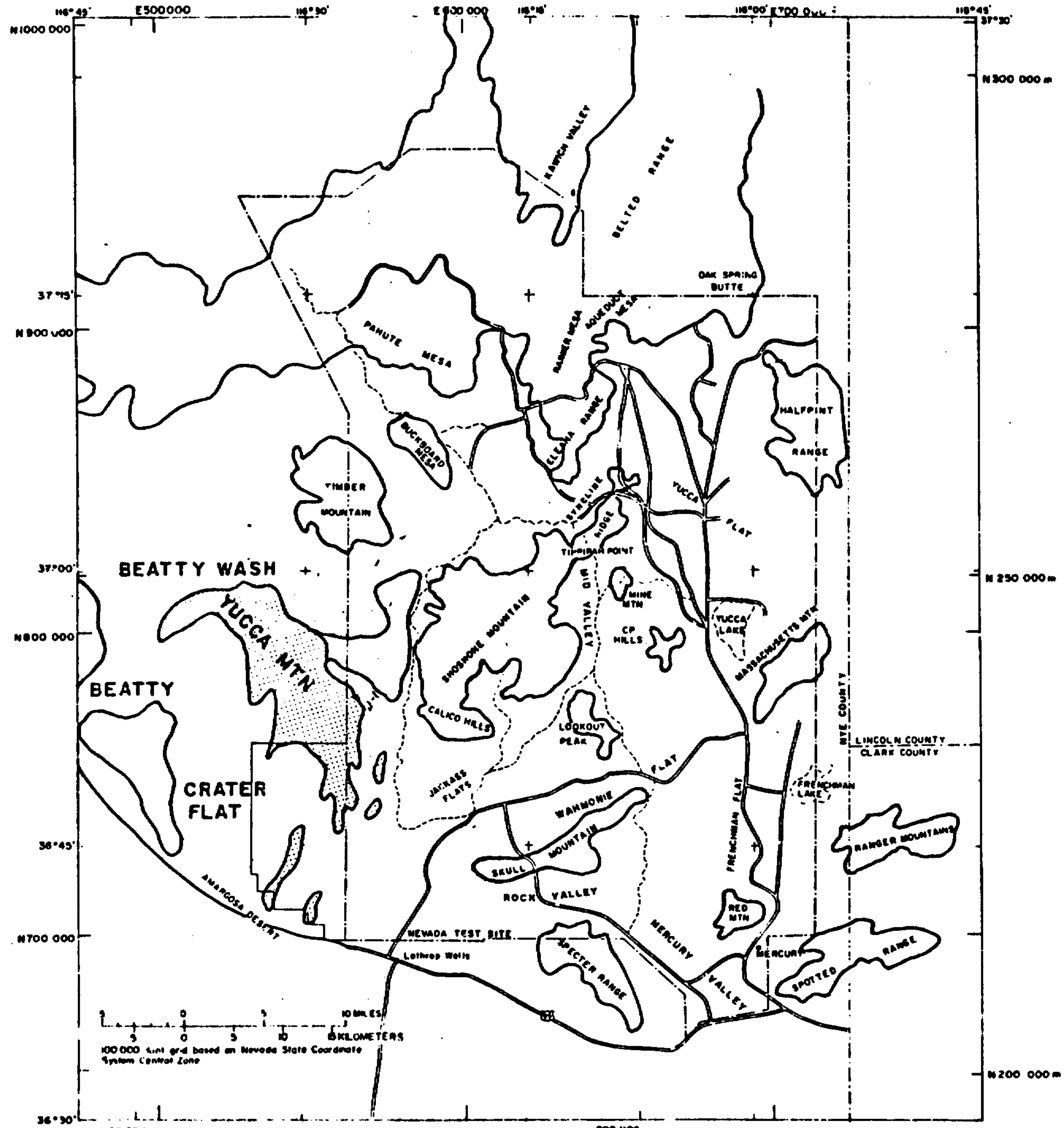

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Figure 1.--Index map of the Nevada Test Site and vicinity showing the location of Yucca Mountain.

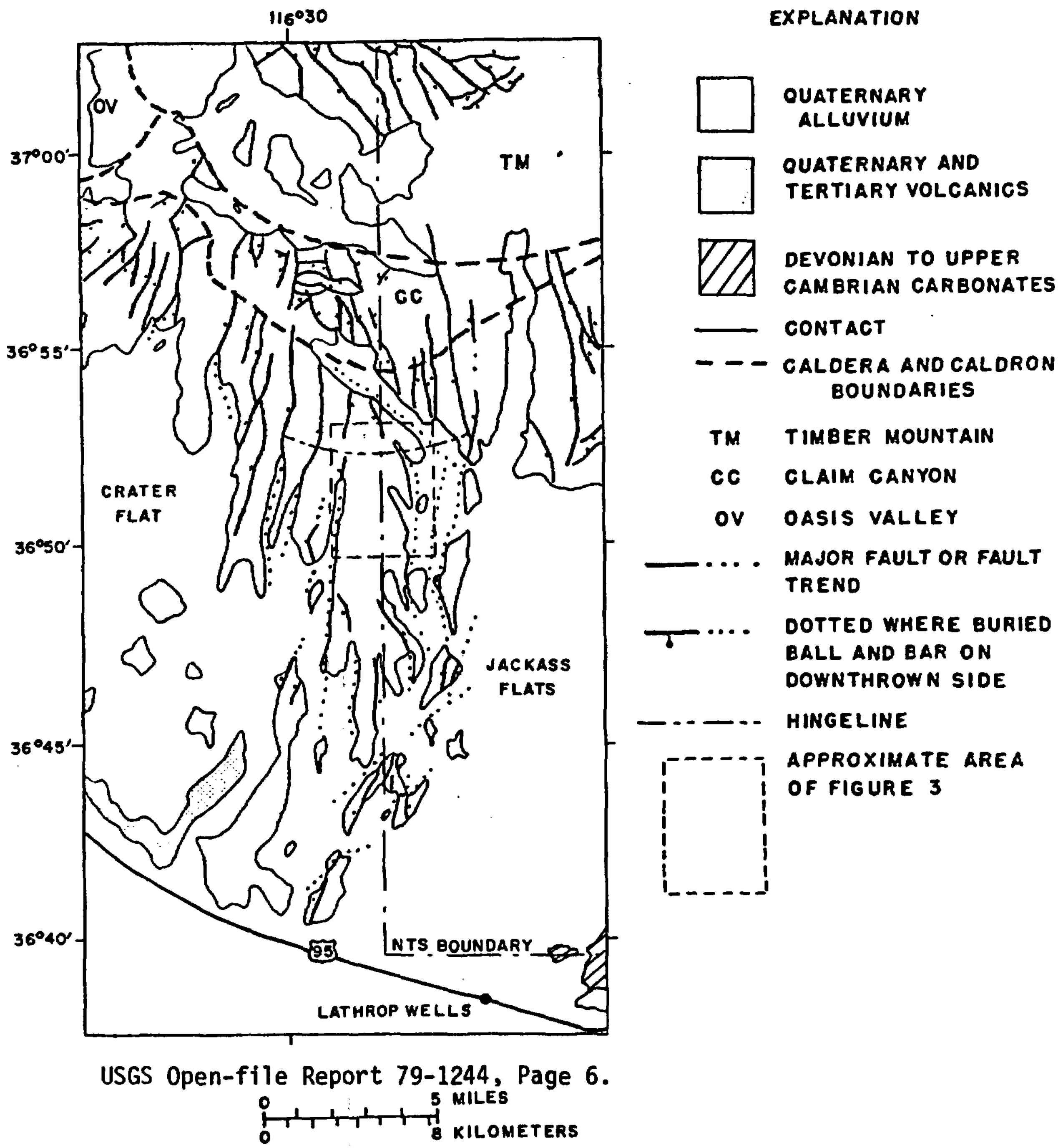

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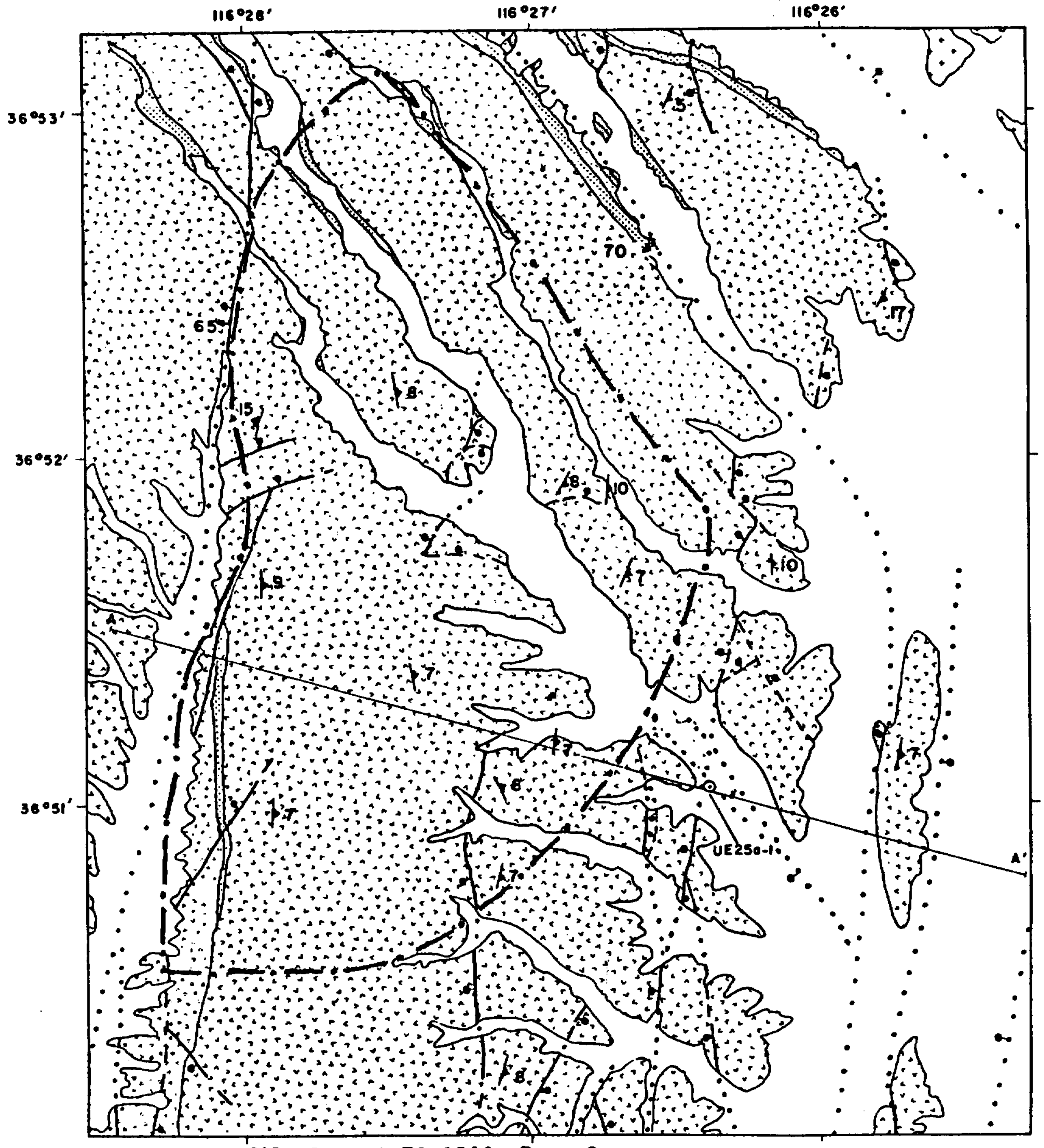
Figure 2--Generalized structure map of Yucca Mountain.



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0 1.0 MILES
0 1.6 KILOMETERS

Figure 3--Generalized geologic map of Yucca Mountain.
Outline of study area

GEOLOGY

General Statement

Described briefly, the geology of NTS comprises three main elements:

(1) a basement of folded Precambrian and Paleozoic sedimentary rocks;

(2) an overlying section of Tertiary and Quaternary volcanic rocks; and

(3) late Tertiary and Quaternary alluvium.

The basement rocks are exposed at various places, but in the study area on Yucca Mountain, they are at considerable depth, estimated by gravity and magnetic data to be on the order of 10,000 feet. The rocks are mostly carbonates-limestone, dolomite). These are important in repository considerations because in many places throughout Nevada they provide a pathway for deep groundwater flow. The flow is controlled by solution openings; where not affected by solutioning the rocks are relatively impermeable.

The volcanic rocks are of particular interest because they include the units that are now under consideration as a repository medium. The most common rock type is tuff, i.e., indurated volcanic ash. Yucca Mountain consists of several widespread and voluminous beds of tuff which came from volcanic centers to the north. In the study area the tuff is believed to have a thickness of 10,000 feet or more.

The volcanic centers are located at Timber Mountain, about 15 miles north of the study area. A major feature here is the Timber Mountain caldera which formed about 11.3 million years ago. It is believed that broad doming preceded the collapse which formed the caldera, and this collapse caused the dominant north-south pattern of faults on Yucca Mountain. The study area is bounded on the east and west by such faults, and the beds dip easterly at seven to ten degrees (Figure 4).

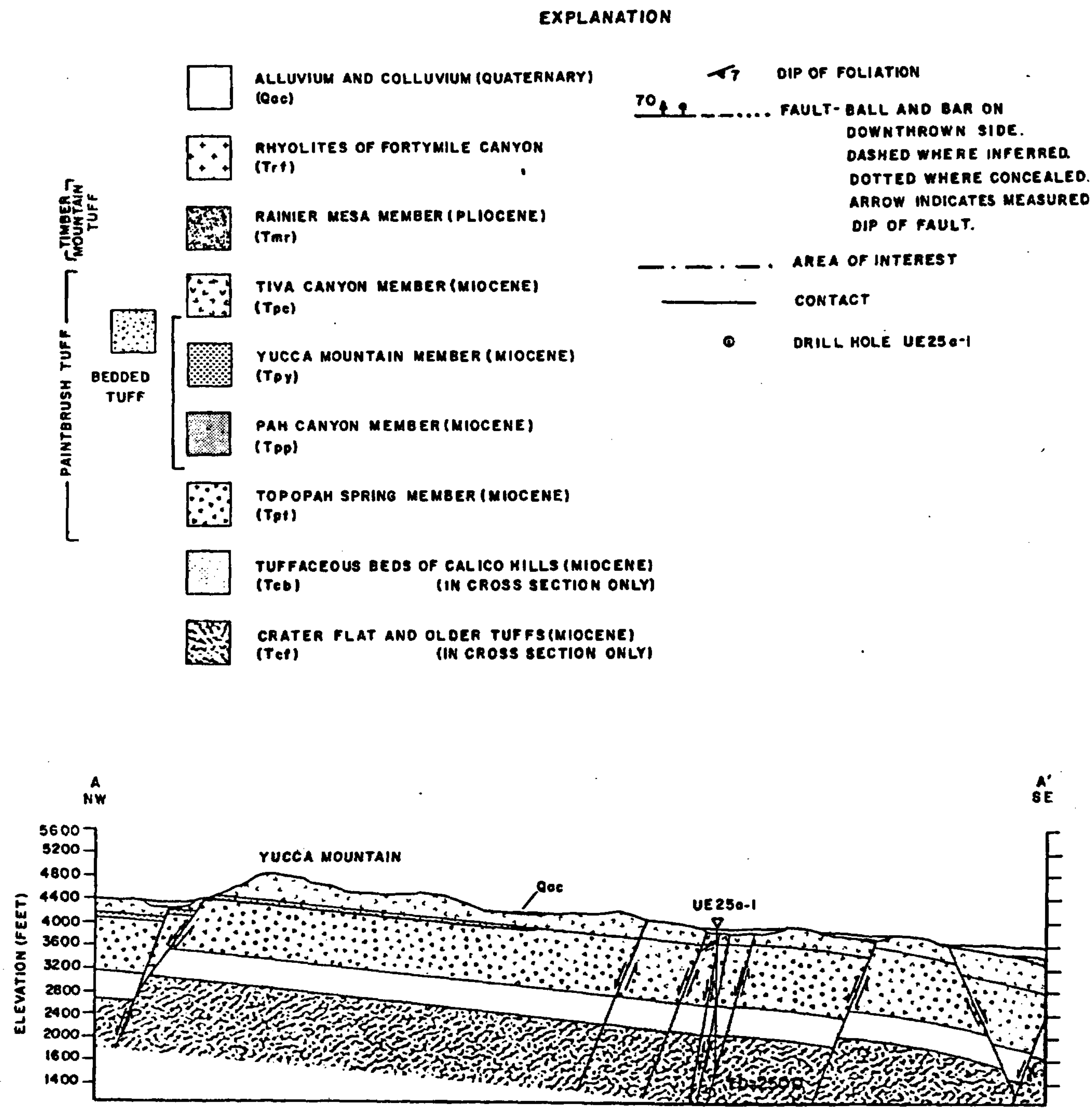

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Figure 4--Geologic cross section.

The alluvium covers the basins and valleys. In some deep basins on NTS the alluvium is more than a thousand feet thick.

Properties of Tuff

A typical, thick tuff bed contains various types of material. The center zone consists of welded tuff, a glass rich rock that has been indurated by the melding of glass particles under the combined effects of the heat retained by the particles and the weight of overlying material. The rock is characterized by thin, subparallel streaks of glass. Above and below, the welded tuff passes through partially welded into nonwelded tuff. Nonwelded tuff is more granular and porous and contains more secondary minerals, such as zeolites and clays.

Some of the differences in physical properties between welded and nonwelded tuff can be summarized as follows. All values are approximate.

	Welded Tuff	Nonwelded Tuff
Porosity (assuming no secondary mineralization)	10%	40%
Bulk Density	2.4	1.5
Compressive Strength	Higher	Lower
Tensile Strength	Higher	Lower
Sorptive Property	Lower	Higher
Thermal Expansion	Positive, uniform	Negative, complex
Primary Fractures	Numerous	Less numerous
Predictability of Physical Properties	Higher	Lower

Based on the present state of knowledge, the welded tuff is the preferred host rock for a repository. Ideally, the repository would be in a thermally conductive, strong welded tuff enclosed by low permeability, sorptive nonwelded tuff. Perhaps the main shortcoming, from the waste isolation standpoint, is the widespread fracturing in welded tuff, which can be expected to promote groundwater movement.

The units now under consideration as a repository host are the Bullfrog and Tramm members of the Crater Flat Tuff formation (Figure 5). Each is a welded tuff with zeolite-bearing nonwelded tuff above and below. The Bullfrog tuff is known primarily from core taken at a depth of about 2500 feet in drill hole G-1. It was also intersected by holes H-1 and UE 25a1. The Tramm tuff is found in holes G-1 and H-1 but is too far below the surface to be cut by UE 25a1.

The effect of heat on welded tuff was examined during 1980 by a test in G Tunnel. The tuff here is above the water table, but it is largely saturated with water and contains about 10 percent. The main purpose was to investigate the possibility of hydrofracing by steam developed by heat from waste canisters. The test results are interpreted to show that water moves as vapor through the rock toward the nearest free surface, i.e., down the pressure gradient. While the test tends to mitigate against the possibility of steam hydrofracing, it raises another possible problem: movement of groundwater toward the rock faces around emplaced waste canisters. This places certain requirements upon the water control system during operations and upon the overpack, backfill and seal systems upon decommissioning.

Evaluations of tuff as a repository medium were presented to the National Academy of Science in 1979 and 1980. These offered the viewpoint that nothing now known about the physical and chemical properties of tuff eliminates it from further consideration.

Volcanism

Many of today's features on the NTS landscape are the result of volcanic activity.

Volcanic activity was intense during the period 10 to 16 million years ago and was centered in a region about 15 miles north of the study area. A succession of volcanoes scattered silicic ash and other ejecta widely over the region. The Paintbrush Tuff, more than 1000 feet thick in drill hole UE 25a1, was

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 ' to 6×10 ' 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, silt*stone, 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		
		([2])				
		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		

Bullfrog-------------------

Tramm----------------------

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Figure 5--Stratigraphic and hydrogeologic units at Nevada Test Site and vicinity.

deposited about 12.5 to 13 million years ago from the Claim Canyon and Oasis Valley volcanic centers. The Paintbrush is overlain by the Timber Mountain tuff, about 11.3 million years old, which forms the surface in the study area. During the waning stages of this volcanic phase, large scale collapse took place with formation of the Timber Mountain caldera.

Silicic eruptions ceased about 8 million years ago. Since then, volcanic activity has consisted of small-scale outpourings of basaltic (low silica) lava. The youngest known feature near the study area is a small cinder cone, dated at 300,000 years before present and located in Crater Flat about 12 miles southwest of the study area.

A study has been made of the age and frequency of basaltic eruptions in an effort to estimate the future risk to a repository. Current estimates place the probability of volcanic activity at the site as one in 10^{-8} to 10^{-10} per year. This is based on the distribution of cones over time, as determined by potassium/argon dating.

Structure

The study area (Figure 3) is on a north-south trending extension of Yucca Mountain, bounded on the east by Jackass Flats and on the west by Crater Flat, and roughly centered on latitude 36°72'N.

Yucca Mountain is composed of a series of northward-trending and eastward-tilted structural blocks. The study area occupies one of these structural blocks. North of a hinge line located at 36°52'N latitude there is dense north-south normal faulting, creating north to northeast trending structural blocks that are broken into smaller blocks by randomly oriented secondary faulting. This is postulated to be the result of subsidence and resurgence within the Claim Canyon caldron during eruption of the Paintbrush tuff. South of the hinge line, major faulting is less abundant and displacements are of lesser magnitude. Steeply dipping, north-south normal faults outline a system of horsts and grabens along the eastern flank of Yucca Mountain. On the western flank, north-south trending fault block margins display prominent scarps. Northwest-trending faults are believed to extend into canyons along the eastern flank of Yucca Mountain adjacent to the study area (Figures 2 and 3). However, some investigators believe that the northwest-trending canyons may not be fault controlled.

The study area is situated along the east-west hinge line and is bounded by major Tertiary faults. These faults are steeply dipping and it is believed that repository construction activity within the block would avoid intersecting the faults at depths less than about 4000 feet.

No evidence of Quaternary faulting has been found in the southwest quadrant of the NTS, but the information is quite limited. The major north-south faulting bounding the study area has been dated at 11.3 million years before present. An angle hole drilled through a fault near boring UE 25a1 (Figure 4) found undisturbed calcite crystals in the fault plane which were dated at 400,000 years before present. Nevertheless, the presence of Quaternary volcanism within 12 miles of the study area and of Holocene faulting in the N.E. and S.E. quadrants of the NTS underscores the need for a thorough study of the faults and related features so as to characterize their stability, as required in 10 CFR 60.

HYDROLOGY

Source of Information

For the Yucca Mountain study area, hydrologic data comes primarily from three drill holes: UE25a1 (2,500 feet total depth) and G-1 and H-1 (each 6,000 feet deep).

Regional Groundwater Flow System

The hydrologic regimen of the region, including the Yucca Mountain area, is characterized by internal drainage. The ultimate destination of the groundwater is not a major stream, such as the Colorado River; rather, the flow ultimately discharges in an intermontane basin, such as Death Valley. The regional faulting and the attendant Basin and Range topography, are partial causes of restricted drainage in southern Nevada. The low rainfall is also a factor, however, in that surface drainage integration of intermontane basins can not easily develop.

The internal drainage sets the Yucca Mountain area apart from other locations under consideration for a repository by DOE.

In general, three water-bearing rock types occur in southern Nevada: volcanic rocks (tuffs), marine sedimentary rocks (carbonates such as limestone and/or dolomite), and alluvium. Tuffs are at the surface in the uplands of the Yucca Mountain area with alluvium at the surface in the valley bottoms. In the study area the water table is in the tuff below the alluvium. Throughout much of southern Nevada carbonate rocks underlie the tuffs or other volcanics. The presence or absence of carbonate aquifers below the tuffs under the study area is a question that remains to be resolved.

The groundwater flow system of NTS is being defined by field studies, supplemented by synthesis of the data through the use of computer-based models. The models provide insight into the flow system but are not intended for predictive use. The field studies include hydraulic measurements such as water pressures, hydrologic budgets, and water chemistry studies in which the proportions of dissolved solids, and other chemical parameters of water, are evaluated in terms of the source of the water sampled.

Briefly, groundwater from the Yucca Mountain site is believed to travel southerly and discharge in intermontane valleys at Ash Meadows, the Amargosa Desert, and/or Death Valley (Figure 6). Thus, no external flow to through-flowing streams would occur. This conclusion derives from inferences based on water pressure data aided by water chemistry and by insights gained from approximations of regional flow produced by the computer-based models. Only a part of the water discharging at Ash Meadows (up to a maximum of about 20 percent) comes from tuff. The balance originates at several recharge points throughout the greater NTS area, with about one-third expected to originate as far away as the Pahranagat Valley near the northeast corner of Figure 6. Other recharge points, including the Spring Mountains and Sheep Range, are to the north and east of the three discharge areas.

Present Water Levels and Climatic Studies

Extremely deep water tables occur at the Nevada Test Site. Depths to groundwater are 650 to 2000 feet in the intermontane basins with greater depths possible in the mountains. Depth to water in two test boreholes in the study area (G-1 and H-1) was 2090 feet. A potentiometric surface map of water in tuff (Figure 7) shows elevations above mean sea level and displays a low gradient south of the study area. The higher gradient in the uplands north of the study area is largely inferred.

Past hydrologic conditions may serve as a guide in estimating future conditions. The presence of spring deposits at higher elevations than those of the present discharge points is evidence of water table stands 30 to 165 feet higher than present. Clay mineralogy and the fossil seeds or spores found in packrat middens indicate a previous pluvial climate 5-8°F cooler than present and with about 25 percent more precipitation. This supported the higher water

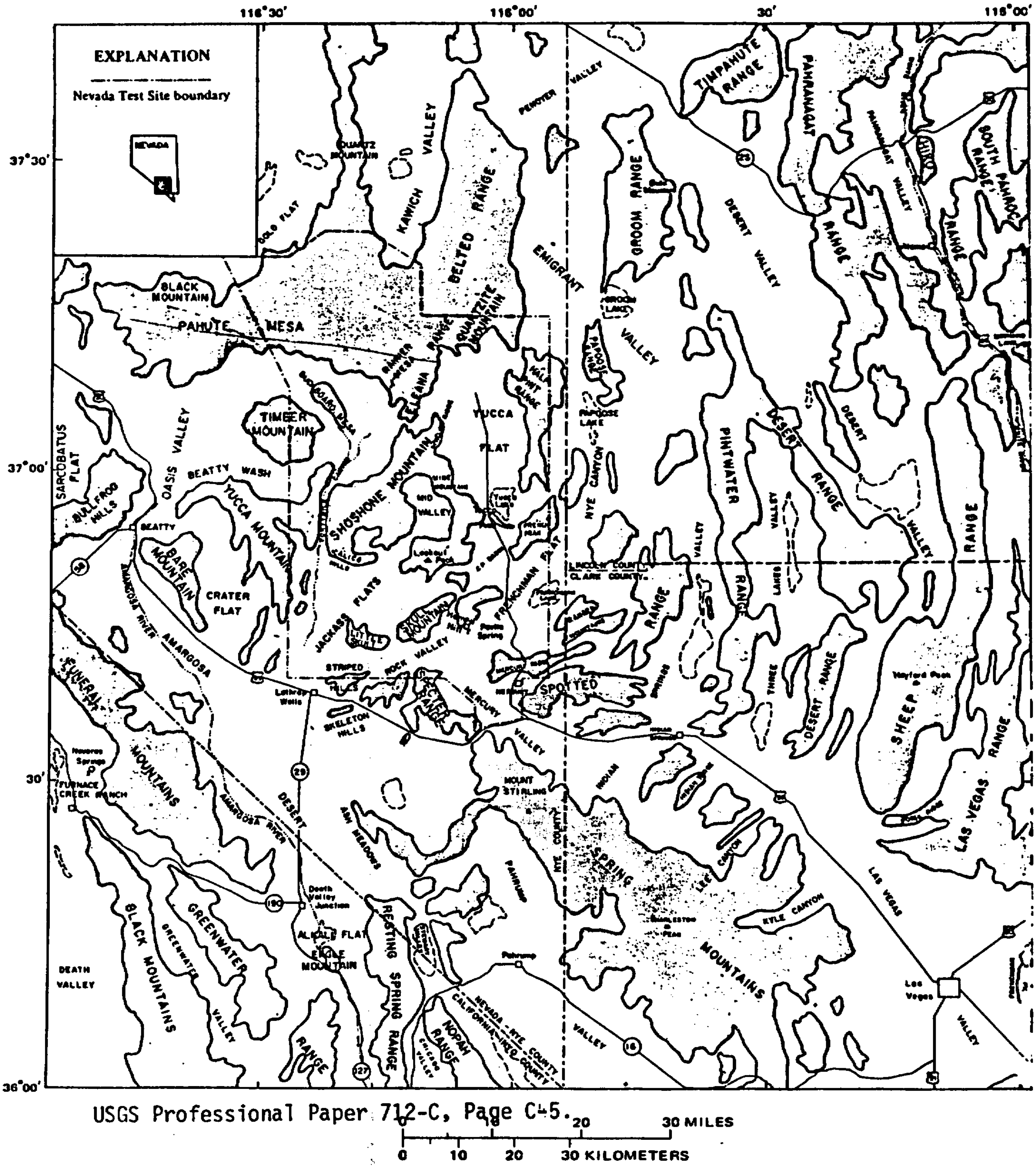

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Figure 6--Index map of Nevada Test Site and vicinity.

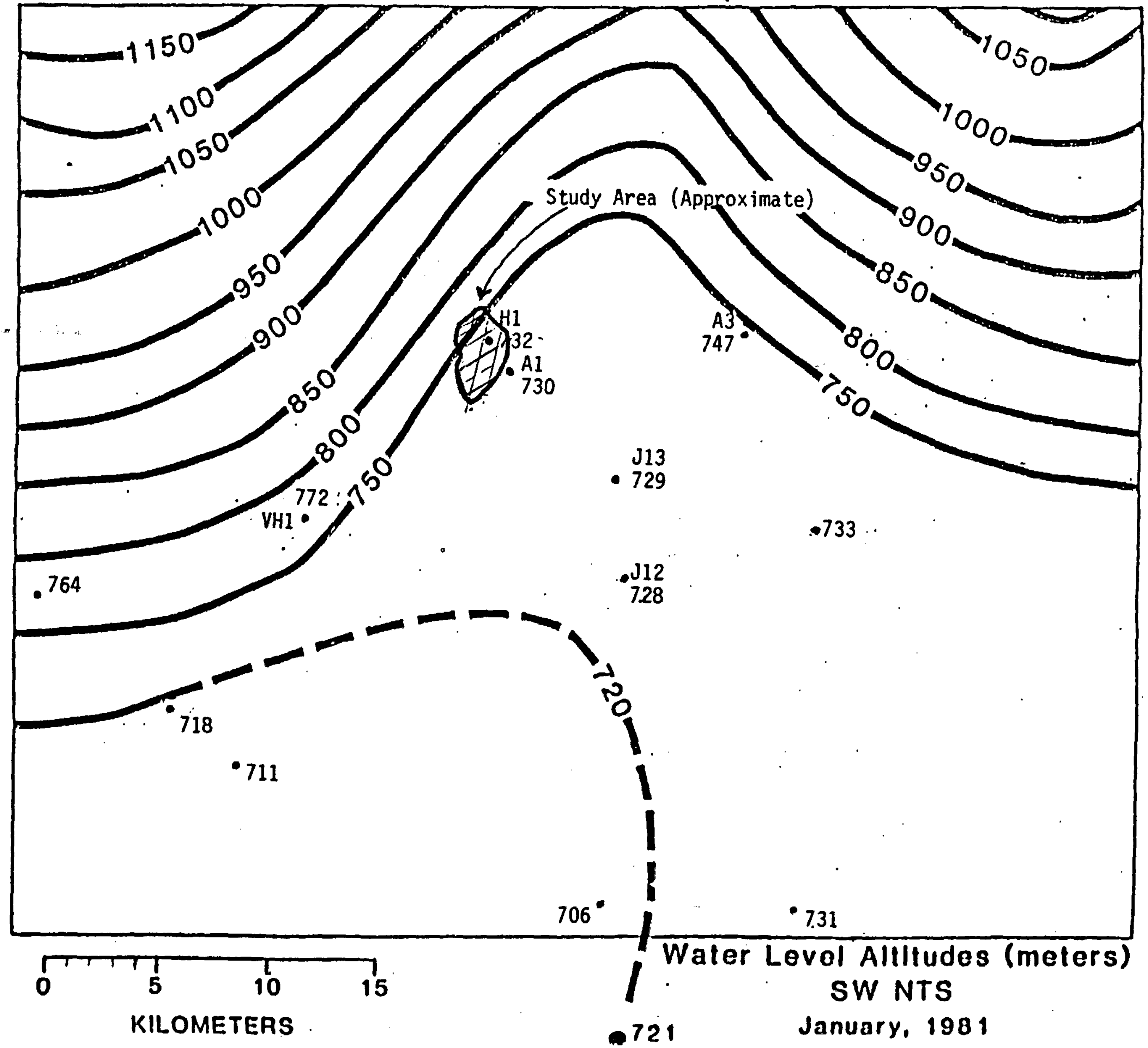

Figure 7
(From U.S. Geological Survey)

table. The past climate was generally similar to today's. Extrapolated over the next few thousand years, this suggests a future climate generally similar to that of the present.

Ground water Recharge

Precipitation either a) runs off down slope toward an intermontane valley, b) infiltrates and/or c) evaporates. The intermittent streams and playa lakes are of low volume, but thunderstorms can cause flash flooding. Much of the rain either evaporates or infiltrates about a meter and then evaporates. Snow meltwater contributes more than rainfall to the recharge of groundwater, especially by infiltrating in the coarser alluvial channel deposits near the canyon mouths.

Old groundwater is expectable under the climatic conditions at Yucca Mountain. Partial confirmation of this comes from the 8,000 to 12,000 years before present date on groundwater from tuff in water supply wells J-12 and J-13 about 5 miles southwest of the study area.

A limited amount of research is directed toward investigating the features of the unsaturated zone in alluvium. Instrumented lysimeters are used to characterize the water to a depth of about 10 feet. This research may prove helpful if alluvium is later considered for the repository. The experiments are outlined in Appendix B.

Carbonate Aquifers and Underground Drainage Systems

The recharge to the groundwater system enters the alluvial deposits of the intermontane basins, the tuffs, and also the limestone/dolomite aquifers underlying the volcanic rocks. This carbonate system extends beneath both the ranges and basins in parts of southern Nevada. In this way water falling in one surface drainage system can flow to other basins. Interbasin transfer of groundwater is an important aspect of the hydrology of NTS.

In places the carbonates are known to be fractured and to have developed solution channels, which permits faster groundwater flow than under intergranular flow conditions. The presence or absence of carbonate aquifers under or near Yucca Mountain is a critical question and is under investigation.

A gravity low in the Yucca Mountain area was originally interpreted to represent a carbonate aquifer at about 6000 feet. Later drilling showed only tuffs at that depth, but density data showed denser materials than expected. On the basis of revised density assumptions, the depth of the horizon in question was recalculated to be about 10,000 feet. Whether the low gravity values represent a carbonate aquifer, and whether the new density assumptions are representative, is not yet known.

Flow Paths and Discharge Points

The discharge of groundwater from the tuffs at Yucca Mountain is believed to be through carbonates to Ash Meadows (about 35 miles SSE from the drilling area), at the Amargosa Desert (about 16 miles SSW), and at Death Valley (about 36 miles SW). Interpretations of hydraulic and isotopic data within the Ash Meadows system may indicate the presence of a highly transmissive zone in the carbonates which may allow more rapid groundwater movement than intergranular flow would indicate. At Crystal Pool spring, concentrations of carbon-14 larger than normal have been measured. Numerous explanations of this carbon-14 anomaly have been presented in Winograd and Pearson (1976), one of which is aquifer-scale solution channeling.

The vertical flow pattern is not simple, as suggested by both upward and downward components in hole H-1. Pressure tests, not yet fully analyzed, will permit fundamental interpretations, and temperature measurements will supplement the pressure data. Closely controlled temperature logging of boreholes is being planned to confirm the data.

Groundwater flow interpretations will need to take into account anomalous heat flow results measured at Calico Hills, 8 miles east. The 3.1 heat flow units (HFU) measured there in borehold UE 25a3 is not compatible with the 1.5 HFU Eureka Low of southern Nevada, whereas the 1.3 HFU measured in borehold UE 25a1 at Yucca Mountain is compatible. A possible interpretation of the anomaly is a large vertical component to groundwater flow. Knowing potential directions of flow, especially the likelihood of flow into or out of a carbonate aquifer system, is essential to evaluation of the area.

Hydrologic Characteristics of Tuff

Primary porosity in welded tuffs is on the order of 5 to 10 percent, whereas in nonwelded tuffs it is 38 to 40 percent. Primary permeability of the tuffs, i.e., excluding fractures, is low (10^{-8} cm/sec), but secondary permeability depends on the degree of fracturing. Fractures are present in both welded tuff and in nonwelded tuff; however, the welded tuff is more brittle and permeability is mainly controlled by the degree of fracturing. Interfragmental and intergranular permeability is more important in the nonwelded tuff than in welded, but fractures may still control the flow volume and velocity.

Pore water in the unsaturated zone is released by heat. The significance of such water, whether found under tensional forces or under gravitational force, is a factor to be considered in the hydrologic budget.

Transmissivity is a function of gross permeability. Aquifer testing results are not yet completely analyzed, but preliminary field estimates suggest maximum Yucca Mountain tuff transmissivities that are moderate by water supply standards (say 10,000 gallons per day per foot of aquifer).

Drilling Plans as of February 1981

Future drilling (FY 1981 through FY 1984) includes plans for two geologic holes (to 6000 feet depth) and five hydrologic holes: deepening UE 25a1 by 1500 feet to a total depth of 4000 feet; one 500 foot slant hole to intersect a fault bounding the study area; and, three holes of undetermined depth for data specifically needed for input to the hydrologic models. Some observation holes are planned. Specific planned measurements include vertical heads, dispersivity from tracer tests, temperature, and fault characteristics.

HYDROLOGIC MODELING

Background

The USGS has for the past several years been investigating the regional hydrologic flow systems at NTS. Included in the work are modeling studies which integrate present knowledge and predict flow and transport characteristics. Through the use of hydrologic models, the following questions are addressed:

1) What is the length of time for groundwater to flow from Yucca Mountain to the nearest accessible environment or to the discharge areas?

2) What would be the concentration of radionuclides in groundwater reaching the accessible environment or discharge areas from a breached Yucca Mountain respository?

3) What would be the responses of the hydrologic system to imposed stresses such as a change in climate?

4) What is the capability of the hydrologic system at Yucca Mountain to contain nuclear wastes?

Approach

The approach is to first construct a NTS regional flow model. This step is largely complete. Secondly, a Yucca Mountain regional transport model is developed and, lastly, a repository transport model. Each of these models looks, sequentially, at a smaller area.

To date, only the regional flow model has been used. It is a two-dimensional finite element flow code that was used on a regional basis to match observed head measurements and determine flow paths. The model covers an area much larger than the NTS. Boundaries include the Spring Mountains to the south, the Sheep Range to the east, and the Pahranagat and Timpahute Ranges to the north. Pahute Mesa and the Funeral Ranges are the western boundaries.

The boundary conditions used in the regional model are all no-flow boundaries with the following exceptions to account for interbasin flow as described by Winograd (1975).

1) Pahranagat Range and Resting Spring Range have flux boundary conditions.

2) Recharge across Pahute Mesa is lumped in with recharge values for Pahute Mesa and distributed over Pahute Mesa (applied at nodes).

3) Recharge is also introduced in the Sheep Range, Spring Mountains, and the Timpahute Range.

4) Discharge is simulated through Oasis Valley and Ash Meadows as a distributed flux.

5) Death Valley discharge is simulated as a flux boundary at a point source.

6) Alkalie Flats discharge is simulated by wells and a constant head node.

Figure 8 is the potentiometric surface computed by the flow model. The gradient near Yucca Mountain is very steep and the gradient of the carbonate system is very flat. In this model no attempt is made to separate the Pahute Mesa flow system from the Ash Meadows system. One system is assumed, due to lack of information on the boundaries.

An error analysis of the results of the modeling indicates that the average amount of error (difference between modeled and measured values) in head measurements is 20 meters and that 64 percent of the total error was contained within 25 meters. The maximum error is 80 meters. A sensitivity analysis was done on the model to determine the sensitivity of the computed head to changes

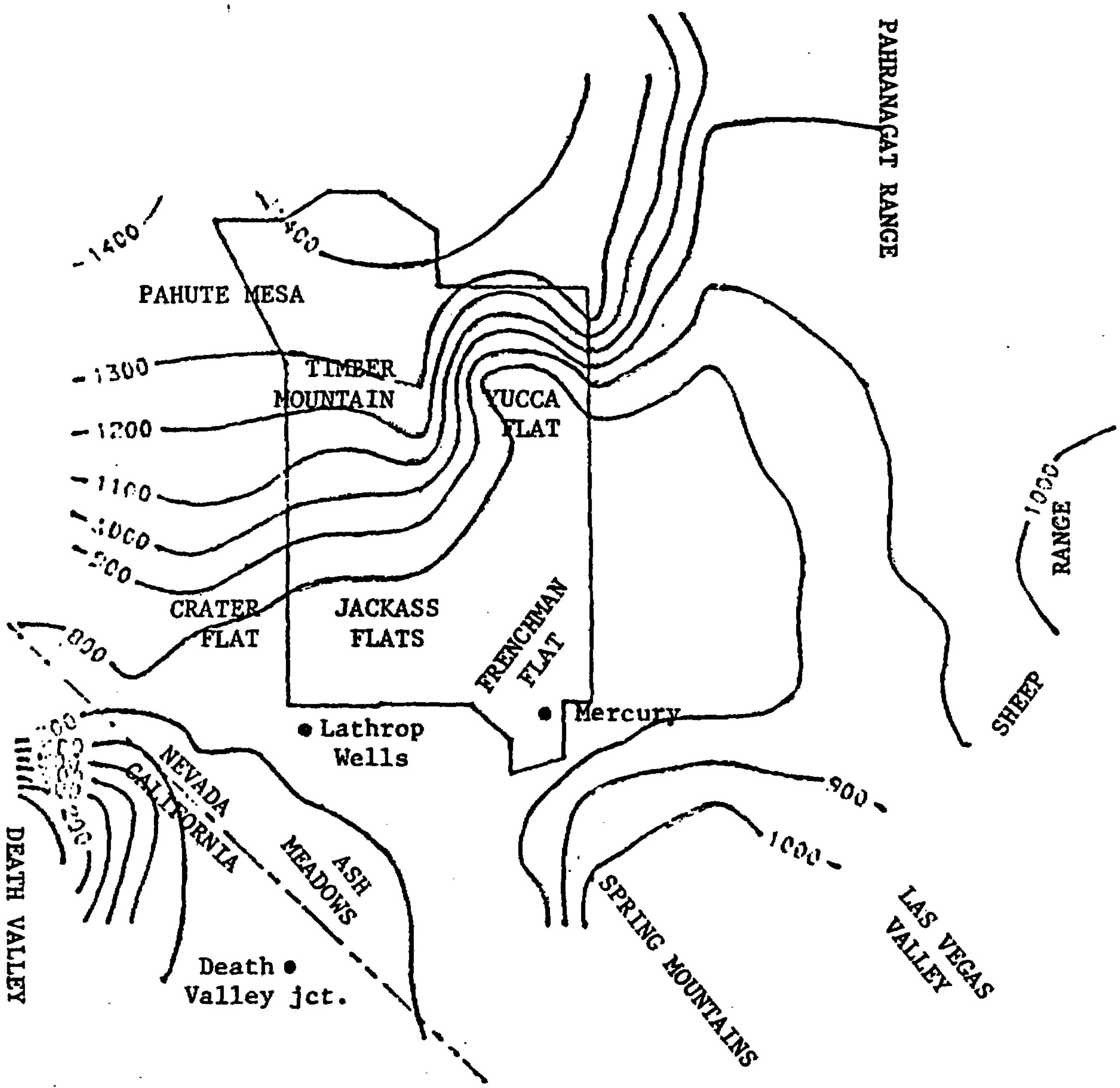

Figure 8--Calculated potentiometric distribution (in meters above sea level).

in other parameters. The results show that the model is most sensitive to recharge at Pahute Mesa, the transmissivity of the tuffs near Yucca Mountain and Forty Mile Canyon, and the transmissivity of the Eleana Argillite.

Heavy reliance is placed on sensitivity analyses to decide which parameters are the most important in terms of affecting model results. Those that are most sensitive will require the most data. Some of the modeling data needs will be fulfilled through communications with the laboratories doing field or laboratory measurements. Other data needs such as dispersion coefficients will be more difficult to ascertain. Field tracer tests are planned at several horizons in holes H-1 and H-1A. Further, nearby sites which have been contaminated in the past and where a contaminant plume has developed will be studied and dispersion will be estimated for the models. Two such sites are nearby: Beatty, Nevada, which has fluoride contamination; and Wahmonie, Nevada, which has sulfide contamination. This should be informative, but unfortunately these sites are in the alluvial aquifer, not in the tuff or carbonate.

Future Plans

Future plans for the Yucca Mountain area include modeling a smaller area surrounding Yucca Mountain. The code selected for this analysis is a flow and transport code, originally developed by the USGS, that is in the process of being modified to include radionuclide transport. It is a two-dimensional finite element code; it is isothermal; and it does not have a density dependence. This means that thermal effects cannot be simulated and density of the water is assumed to be constant.

It is planned that the following steps will be taken in future modeling efforts:

1) Sensitivity analyses will be stressed (relationship of variables to other variables);

2) Work on code development and documentation of the USGS code will be completed;

3) The field data will be synthesized; and

4) Finite element mesh will be designed.

Conclusion

It is not clear whether the codes under development by the USGS or the codes under development by ONWI will be used in the site characterization report on NTS. In either case the selected code(s) will require verification and documentation for NRC review and benchmarking. The considerable time required for these activities suggests that a selection of codes be made soon.

GEOCHEMISTRY

Geochemical work in support of the Yucca Mountain study is mainly in three areas: geochemical properties of tuff; groundwater flow; and radionuclide transport.

Geochemical Properties of Tuff

Some tuffs are favorable from the radionuclide sorption standpoint because they possess high cation attraction properties, due to the presence of large quantities of zeolites and clays. Tests have indicated 60 to 80 percent clay or zeolite content in certain tuffs. Miocene and Oligocene rhyolitic tuffaceous rocks up through the Wahmonie Formation (Figure 5) are generally massively altered to zeolite (clinoptilolite, mordenite and analcime) or to clay minerals (montmorillanite and illite). A vertical zonation of these mineral groups is commonly observed. The units above the Wahmonie Formation, by contrast, are glassy, or the glass has devitrified to cristobalite and feldspar, or less commonly to zeolite or clay.

Most welded tuff does not contain a high percentage of zeolites and is thermodynamically stable. Typically a welded, devitrified tuff contains as little as 1 to 2 percent absorbed water, and constituent phases are mostly anhydrous and stable at high temperatures. Nonwelded tuffs contain more zeolites and because of high porosity may contain up to 18 percent structurally bound water. They are thermodynamically unstable at relatively low temperatures.

Because of the difference in properties of the two types of tuff (welded and nonwelded) a repository could be located to utilize the favorable characteristics of each. For example, the repository itself would be excavated in the welded tuff for thermal and strength reasons, with the surrounding units of nonwelded tuff providing sorption.

Geochemical Analyses for Determining Regional Groundwater Flow

Geochemical analysis of the groundwater flow system can provide hydraulic potential data and an insight into probable recharge and discharge areas of the system. From the chemical quality of water discharging at Ash Meadows, Death Valley and the Amargosa Desert, inferences have been made regarding the sources of this water (Figure 6).

1) The water discharging at Ash Meadows is a calcium, magnesium, sodium bicarbonate type. It is thought that the sodium is derived mainly from the tuffs. However, the contribution from downward percolation through tuffs into the lower carbonate system is only a few percent to perhaps as much as 20 percent of the total discharge.

2) Some interbasin movement of water must occur between Pahrump and Stewart Valleys and Ash Meadows because of the significant head difference between the two areas. However, the quantity of water probably doesn't exceed more than a few percent of the total discharge at Ash Meadows. This estimate is based on the quantities of sodium, potassium, chloride and sulfate in the water.

3) Judging from the geochemistry, underflow from Pahranagat Valley into the Ash Meadows groundwater basin is possible. As much as 35 percent of the total discharge at Ash Meadows could come from Pahranagat Valley.

4) Underflow from the northwest side of the Ash Meadows flow system amounts to 4 percent or less of the total discharge at Ash Meadows. (This estimate is based on hydraulic data).

5) Additionally, the system is recharged from precipitation in the highly fractured Paleozoic carbonate rocks of the Sheep Range, northwestern Spring Mountains and the Pahranagat Range, and to a lesser extent the Pintwater, Desert and Spotted Ranges.

Areas other than Ash Meadows may provide discharge points for the regional flow system, based both on hydraulic data and geochemistry. A very large gradient is known to exist between Ash Meadows and Death Valley and also between Ash Meadows and the Amargosa Desert. The geochemistry of the water discharging into the Amargosa Desert indicates it is probably derived from at least three sources. Earlier work suggested that the spring discharge at Death Valley comes directly from Ash Meadows. More recent work indicates a somewhat different chemical quality than that at Ash Meadows. Thus, water may be a mix of water from Oasis Valley and Ash Meadows.

Radionuclide transport parameters will be obtained through a project being conducted in G Tunnel on Rainier Mesa in an unwelded (unsaturated) tuff. The tests will be conducted first in horizontal and then in vertical fractures. Sheet flow will be induced under pressure (as low as possible) in the fractures. Then stable and short-lived nuclides will be injected as tracers. Tracer water which has moved through the fracture will be collected and analyzed for tracer concentration. Later, the entire fracture will be removed (in a block of rock) and analyzed in the laboratory for sorption/desorption parameters and mechanisms, ion exchange capacity, and other transport parameters. Models will be constructed to predict the transport of radionuclides through the fracture, based on information obtained in the tests.

Other related, ongoing work is the radionuclide migration study in the Climax Stock granite. The experiment is designed to:

1) Study radionuclide migration in fractured granite;

2) Compare retardation factors measured in-situ with laboratory results;

3) Model fracture flow in granite and calibrate the model using in-situ parametric values; and

4) Develop a reliable in situ retardation test that can be used at any repository site.

In the Climax Stock granite the high angle fractures are considered to be best suited for this type of test, as the low angle fractures are sealed with quartz and pyrite.

Other studies in support of radionuclide migration work at Climax are as follows:

1) Characterization of groundwater - Water is being collected from a natural seep in the rock wall near the test area so that an artificial groundwater may be manufactured and used for the tests. Yields from the natural seep are of insufficient quantity. Quantities are less than one liter per day.

2) Lab core sorption studies - A jell is being tested to preserve the geometry of fractures in cores and large blocks excavated from the underground workings.

3) Petrographic studies are under way by microscopic means, x-ray analysis of fracture minerals, scanning electron microscope and microprobes.

4) Hydrologic modeling will be validated by using in-situ parameter values.

Kinetic Analysis

Some interesting viewpoints on the hydraulic characteristics of the Paintbrush tuffs are under development by the USGS in Denver. Preliminary results (Claasen and White, 1978) suggest that the major transporting pores constitute only a small fraction of the total interconnected pore spaces. This is significant when determining effective aquifer surface area, especially when flow is through undetected fractures and the unit has been described as a hydraulic system of primary porosity. Estimates of effective aquifer surface area could be overestimated by orders of magnitude, if based only on laboratory analyses of crushed samples. This technique has the potential to predict the aquifer surface area that is effective in sorbing waste nuclides.

<u>Conclusions</u>

1) While a lot of valuable work has been started, it is still a quantum leap from the scale of one fracture to a regional scale for regional transport parameters. It is questionable whether parameters which have been determined in a noncontinuum situation (a single fracture) can be used in a continuum model (regional). A plan is needed for acquiring these regional parameters.

2) While reference was made to kinetic parameters, it is not clear what type of kinetic analyses are planned.

GEOPHYSICS

Historical

To date, Yucca Mountain geophysical work includes magnetometer surveys, resistivity surveys, a gravity survey with a one-quarter mile station spacing, electromagnetic surveys, geophysical borehole logging, seismic surveys (including 2 seismic refraction lines and a vibroseis reflection test), and heat flow measurements. This work has been done under the direction of several investigators. No report has been published which details the various surveys and integrates them.

Seismic

Seismic work accomplished to date consists of two refraction lines shot on the east side of Yucca Mountain using dynamite as an energy source. Also, a series of vibroseis reflection profiles were recorded in the same area to test the applicability of the vibroseis energy source in the study area.

The refraction lines were successful in yielding profiles to a depth of about 1000 feet below the surface. Data quality is said to have been fair to poor. The main difficulty was in getting energy to the far geophones. The two most noteworthy results of the refraction program were the delineation of a horst at the southeast end of line Yucca C and the measurement of the large horizontal velocity variations on both refraction lines. These large horizontal velocity variations are important in the processing of the seismic reflection data. Additional refraction lines are planned for fiscal year 1981.

The study area is made up of layers of welded and nonwelded tuff that have physical properties that should result in a significant acoustic impedence contrast. Therefore, it was thought that the reflection seismic technique would be useful in mapping the geologic structure across the study area. A series of seismic reflection lines was recorded to determine whether or not a surface energy source, in this case a single vibroseis unit, was capable of providing sufficient seismic energy. Standard CDP (common depth point) line geometry and conventional data processing techniques were employed. The results were completely negative.

There are a number of geologic and procedural reasons that could account for this failure. Some geologic reasons include: 1) random scattering of seismic energy, due to closely spaced fault and fracture zones and to clastic rock textures; 2) propagation and conversion effects related to extreme velocity contrasts (both vertical and horizontal velocity contrasts as shown on the refraction profiles); 3) generally large and unmeasurable static shifts; and 4) strong absorption of energy owing to a thick aerated zone in unconsolidated sediments. Procedural reasons include: 1) the use of a single vertical vibration source; 2) recording with a two milisecond sample rate while using short geophone spacings as in shallow, high resolution recording, thereby possibly losing high frequency events; and 3) not using shallow refraction weathering spreads to help resolve the statics problem (item 3, above). These tests show, however, that standard reflection surveying techniques will not be adequate in the study area. If reflection surveying is to work, the survey techniques must be tailored to the specific geologic properties of the study area.

Other Geophysical Techniques

Residual gravity maps have been completed for the one mile regional grid established over southern Nevada. These data show a gravity low under Yucca Mountain and Crater Flat to the west. This suggests that the carbonate and possibly crystalline basement is deeper under Yucca Mountain and Crater Flat than it is to the east. Gravity highs were observed under Calico Mountain and Wahmonie. These highs possibly indicate the presence of granitic intrusives.

A two-level aeromagnetometer survey was flown over Yucca Mountain, Crater Flat and Jackass Flat. These data indicate a magnetic high trending roughly east-west under Yucca Mountain, and also under Calico Mountain and Wahmonie, corresponding to the gravity highs at those locations. The low-level aeromagnetic data clearly shows known faulting in the Topapah Springs member. Some ground magnetometer profiles have been run, with final interpretations due in about 6 months.

The magnetometer and gravity data provide conflicting conclusions with regard to depth to basement in the study area. The magnetometer data indicate a depth to carbonate basement of about 8000 feet while the gravity data show basement at about 12,000 feet in the vicinity of borehole G-1. This situation is under study, and finished interpretations of all magnetic and gravity data are expected in about six months.

Resistivity data indicate that electrical conductivity is higher in fault zones than in unfaulted rock. Future resistivity surveys may be used to help define fault zones.

Heat Flow

There is an anomalous heat flow condition between an area adjacent to the study area and Calico Hills. A measurement in drill hole UE 25a1 gave 1.3 heat flow units (H.F.U.) while a measurement at Calico Hills in drill hole UE 25a3 gave a reading of 3.1 H.F.U. It has been suggested that vertical water flow might account for this condition as the distance between the borings is too short for a deep seated condition to account for the difference in temperature readings. Additional work is needed to determine the exact cause of this anomaly.

Future Activities

Geophysical activities scheduled for the next several fiscal years include teleseismic P-delay studies with the addition of 5 new stations on Yucca Mountain to the 55 station regional seismic net; a long deep refraction line between Bare Mountain and 40 Mile Wash; P-delay studies from nuclear shots, using portable seismographs set up in the study area for each event; vertical seismic profiling (VSP) in borings; stress measurements in the vicinity of the study area to aid in the evaluation of possible Quaternary movement along known faults; and a complete set of down-hole geophysical logs in each drill hole.

Conclusions

A multimillion dollar geophysical program, to be accomplished over the next several fiscal years, has been scheduled. A large portion of the budget is slated for seismic reflection surveying, with the initial effort focussed on selecting an energy source and field recording parameters.

This scheduling presents some procedural problems. One problem is the fact that in order to make the best use of resources (money and time) the program should be in two phases: 1) reconnaissance, to help in the planning of the drilling program; and 2) detailed, to correlate units over the study area in conjunction with the drilling program. By spreading the geophysical program over several years, much of its value will be lost.

A second problem is the fact that by spreading the field program over several years the same contractor personnel may not be available each year, with a probable loss in effectiveness. Also, in mobilizing the field crew several times, data recording and processing costs will be greater.

MINING ENGINEERING

Based on the general properties of NTS tuff, as now known, there appears to be no serious reason to doubt that a repository can be designed with tuff as a host rock. On the other hand, little is yet known about the specific properties of the Bullfrog tuff and Tramm tuff at Yucca Mountain. These are under investigation.

Physical Properties of Tuff

Laboratory and field investigations are under way to examine the properties of tuff, of which two appear to be of particular importance in repository design: (1) unconfined rock strength and (2) response to heat.

With completion of borehole G-1, core from the Bullfrog and Tramm has become available for testing. We understand that tests, still under way, on unconfined compressive strength (saturated core at 200°C.) give values between 2,900 and 8,000 pounds per square inch (psi) for the Bullfrog. Such figures suggest two potential problems. First, the range of values indicates that the rock properties may be difficult to predict with limited information, as from boreholes. More importantly, customary design criteria indicate that the range of strengths is inadequate to marginal for an excavation 2,500 feet below surface.

Another important matter is the response of the rock to heat. Many of the rock components - glass, clays, zeolites - undergo phase transformations at temperatures as low as 85°C. The change in rock properties over a range of temperatures is, therefore, a key element in design considerations. For the moment, a maximum rock temperature of 100°C has been set as a repository design parameter.

Experience in various excavations at NTS shows that even above the water table the tuff may contain interstitial water. An experiment on the effects of heat was run in welded tuff in G Tunnel. The results suggest that in a thermal field the rock tends to dry out, the water moving in the vapor phase to the nearest cool, free surface where it condenses into liquid form. This effect has important design implications for the water control system during repository operation and for the overpack/backfill/seal system after decommissioning. A related problem is the long-term corrosive effect of high humidity in the underground environment. Such conditions are apt to be damaging to instrumentation, rock bolts, emplacement and retrieval equipment, as well as to monitoring systems.

Underground Test Facility

A preliminary plan for an underground test facility has been developed for consideration at NTS. Some of the details are tabulated below. It should be noted that the cost and time requirements are based on preliminary estimates, and no decision has been made by DOE on the plan or whether it will be implemented.

The scheme comprises an Early Shaft which is linked to a Test Facility to be excavated at a later time. Each unit consists of a single bored shaft, 3,500 feet deep, with a room at the bottom for use as a drill station and test center. From each room eight drill holes, 2,000 feet long, will be fanned horizontally to test the repository host rock.

Notes on Preliminary Underground Test Facility

	Early Shaft	Test Facility
Depth	3500 feet	3500 feet
Cost	approx. $20 million	
Shaft diameter	6 feet	12 feet

	Months	Months
Design, bore and line shaft	15	17
Excavate room, drill 8 holes	14	12 (excavation only)
Do experiments and data analysis	24	34
	53	61

Thermo-Mechanical Models

A group of computer codes have been developed for NTS tuffs in order to predict the thermal and mechanical responses. For reference, these are tabulated below.

Models in present use

ADINA (Automatic Dynamic Incremental Nonlinear Analysis) - is a general purpose, finite element code which performs linear and nonlinear static and dynamic analysis as applied to structural and rock mechanics stress analysis.

ADINAT - performs thermal analysis for repository related problems. It is a finite element, heat transfer program that is compatible with the stress analysis code ADINA and can be used to input the temperature distributions into that program.

COYOTE - is a finite element program for the solution of 2D nonlinear heat conduction. COYOTE can interface with ADINA to provide the thermal environment.

MARIAH - provides fluid transport capability in 2D for one phase flow in a rigid matrix. The code also can handle a jointed rock mass. This code is only partially checked.

MERLIN - is an interpolation code used to couple COYOTE and MARIAH to ADINA. This code is partially checked out.

HAD - is an evaporation-front drying code with no capillarity.

SHAFT - is a fully saturated dual porosity flow and thermal model for saturated conditions.

Projected modeling capabilities by October 1981

The work is to include coupling various codes, such as:

ADINA-ADINAT - Thermal-mechanical capability in a jointed rock mass for ubiquitous and mesh independent joints with dispersion in 3D.

COYOTE-MERLIN-ADINA (COMIN) - This coupling is complete for 2D axisymetric cases.

MARIAH-MERLIN-ADINA (MERD) - Coupling completed in 2D applicable to single porosity far-field and room and pillar calculations including fluid flow.

HAD-SHAFT - This is presently in the conceptual stage. It would treat single and double porosity fluid flow in saturated and unsaturated porous media applicable to drift dehydration and blast cooling, for partially saturated media.

DUAL FUNCTION OF THE NEVADA TEST SITE

Can NTS function both as a nuclear weapons testing facility and as a site for storage of high level waste? There are two main aspects of such dual use. The first is the effect of ground motion, resulting from the weapons testing, on waste storage; the second is the possible impact of the weapons testing program on response to an emergency at the waste storage facility.

Ground Motion and Impact of Weapons Testing

Weapons testing is a continuing activity at the NTS. Under the Comprehensive Test Ban (CTB) Treaty a 150 Kt limit on nuclear devices has been observed. Testing is expected to continue after expiration or abolishment of the treaty. Further, it is not unreasonable to expect that testing could resume at yields above the 150 Kt threshold to those maximum yields for each of the testing areas, as earlier set by consideration of possible offsite damage. The limits are about 1000 Kt for the Pahute Mesa area, 700 Kt for the Buckboard Area and 250 Kt for Frenchman Flat and Yucca Flat. The limits are not absolute maxima, and it is not impossible that a change in development of the defense program might result in the upward modification of these limits.

A repository must be designed to withstand the ground motion resulting from the nuclear tests. To provide design criteria for such a facility it is necessary to be able to accurately predict, with a high level of confidence, the ground motion as a function of the yield, distance from the source and other factors. The methods of prediction require validation by measurements, both on surface and underground, at the potential repository site.

In fiscal year 1981, five seismic recording stations are to be established in and near the study area as part of the 55 station regional seismic network that is in operation in southern Nevada. This network is using distant earthquake energy to define the pattern of seismicity in the region. The data obtained will be used to study deep crustal and upper mantle structure. P-delay studies, using energy from nuclear sources, when combined with other geophysical and geological data, will help define the shallower structural elements surrounding the study area on Yucca Mountain.

Emergency Response and the Impact of Weapons Testing

Draft 10 CFR 60 has several criteria relating to emergency conditions and emergency response. 10 CFR 60.21(9) requires plans coping with a radiological emergency at any time prior to decommissioning of the repository.
10 CFR 60.132(6) requires development of emergency facilities to ensure safe and timely response to an emergency condition.

To prove the compatability of the two activities, it will be necessary to demonstrate that weapons testing and waste storage will not negatively impact each other under normal or emergency conditions.

Another aspect for consideration is the response by the public to storage of high level waste at a facility which tests nuclear weapons. In addition to the demonstration of technical adequacy, satisfaction of the public on the compatability of the two activities is advisable. The experience of Three Mile Island has demonstrated the psychological stress and general public concern (sometimes overreaction) due to nuclear incidents.

OBSERVATIONS

The repository siting investigations benefit from the extensive geologic and hydrologic studies accomplished over several decades in support of the weapons testing program. This earlier work provided an excellent base for the present multidisciplined program, which is carried out by a group of highly qualified institutions.

However, our review suggests that certain investigations can be better directed toward the licensing interests of NRC and other investigations need greater emphasis, from the licensing viewpoint. These matters are discussed below in the form of observations:

1. Siting criteria
2. Tectonic stability
3. Rock mechanics
4. Borehole location and sealing
5. Exploration strategy
6. Modeling
7. Carbonate aquifer systems
8. Seismic net on Yucca Mountain
9. Quality assurance

1. Siting criteria

To date, the search for a repository site on NTS has been guided by common sense, informal standards. It appears to us that the state of knowledge about the tuff at NTS is such that criteria could now be usefully formalized. These could be derived by applying provisions of draft 10 CFR 60 to the particulars of NTS and relating these to the generic criteria developed by the Office of Nuclear Waste Isolation (ONWI). Through development and application of the criteria, the relative merits and disadvantages of different tuff units in different settings would be analyzed and evaluated. The setting of criteria would tend to focus the exploration activities more toward functional, and less toward scientific, objectives. Also, the criteria would be helpful if two beds (e.g., Bullfrog and Tramm tuffs) or two areas (e.g., Yucca Mountain and Skull Mountain) are under consideration. Finally, the linkage of criteria to requirements of 10 CFR 60 will clarify the elements important to NRC during licensing.

2. Tectonic Stability

It is generally recognized that tectonic stability is one of the key problems in considering Yucca Mountain as a repository site. The study area is in a faulted region and contains a number of known faults. In 10 CFR 60, the projection of future stability is viewed as an extension of the faulting record during the Quaternary (the last two million years). In view of the importance of this issue, an aggressive and intensive effort is needed to date the last movement on each fault that could affect the study area and determine whether it might provide a pathway for groundwater. The approach developed in connection with investigations of nuclear plant sites should be applicable to NTS.

3. Rock Mechanics

Unconfined strength tests on the Bullfrog tuff, the candidate repository host rock, have yielded results in the range of 2,900 to 8,000 pounds per square inch. (These results are from wet core at 200°C; dry core is stronger). As the values are in the low to unacceptable range for an excavation at 2,500 feet below surface, a serious question is raised about the physical suitability of the Bullfrog tuff. Further, the low priority attached to this matter may raise a question about the technical coordination among those concerned with rock mechanics, repository design and geology. An early evaluation of the problem is needed, because of the influence on the future course of the project.

The heater test in tuff of G Tunnel (completed in April 1980) showed that thermally generated stress, in welded tuff, was one-third that predicted by modeling. This problem has significance to repository design, but the planned follow-up tests are not scheduled until 1982.

4. Borehole Location and Sealing

To date seven boreholes have been drilled in or near the Yucca Mountain study area. Two holes, G-1 and H-1 (each 6,000 feet deep), are located in the middle of the study area, which covers four square miles. They are also within the likely limits of a repository that would be constructed here, because the excavations would nominally require an area of about three square miles.

In the placement of boreholes, care is needed to assure that the holes will not provide a ready route for groundwater to reach the accessible environment. For this reason draft 10 CFR 60 establishes certain requirements: 1) sealing so that the hole is not a preferred pathway for groundwater, as compared with surrounding rock, and 2) placement of holes, which are drilled during site characterization within the repository operations area, so the holes coincide with future pillars or shafts of the underground structure. Judgments on location of boreholes which may be drilled in or near the study area would benefit from knowledge of sealing in tuff and understanding of repository conceptual design. As both of these subjects are in an embryonic stage of development, considerable advancement is needed if decisions on boreholes are to be affected.

5. Exploration Strategy

In layered rocks, such as those in the study area, subsurface exploration can be carried out by drilling or by drilling combined with geophysics, particularly reflection seismics. However, reflection seismics has been tried at Yucca Mountain without success. Several plausible explanations are offered, and it is likely that neither the limitations or usefulness of the method were clearly determined during the test.

If effective, reflection seismics (with control by limited drilling) could provide the best representation of the continuity and extent of the tuff beds and the presence (or absence) of faults. There is a reasonable possibility that reflection seismics, properly executed after calibration on the ground, will provide usable results. However, if this is to be an effective technique, judgments are needed now to determine how: (1) to effectively test the seismic approach; (2) to judge its effectiveness; (3) to implement it, if effective; (4) and to integrate the drilling with geophysics, if the latter is effective. The present seismic plan is unlikely to contribute much to the evaluation of the study area, being too stretched out and unintegrated with drilling.

6. Modeling

As nearly as we can determine, the present modeling of groundwater and radionuclide migration is based on a code under development by the USGS. It was not made clear whether this code or one of the ONWI codes will be used during site characterization. Since a comprehensive modeling scheme can require several years for development, validation and documentation, the planning should be in hand now. Further, an early understanding of the codes used to support licensing activities is needed by NRC for use in its benchmarking program, which is now being inaugerated.

7. Carbonate Aquifer Systems

Although the regional groundwater picture suggests that water from Yucca Mountain may discharge at Ash Meadows, field evidence is inadequate to support this conclusion at present. The carbonate aquifer systems in Nevada are known to connect intermontane basins, and such systems may have high water transmitting characteristics. High groundwater velocities and low sorption in the carbonates could prematurely move radionuclides in undesirable concentrations to the accessible environment. The questions of proximity of such an aquifer to a proposed repository, and the likelihood of water flow from the repository to the aquifer, have important bearing on the suitability of Yucca Mountain as a repository. Collection of the relevant data is time-consuming and needs to be aggressively pursued.

8. Seismic Net on Yucca Mountain

One of the key site suitability questions is whether high-level waste can be safely stored on a reservation dedicated to nuclear weapons testing. A large body of information is available on seismic effects in many parts of NTS, but few measurements have been made in the study area. Since the weapons tests are of various types and are carried out in various settings in NTS, a substantial record at depth and on the surface in the study area is needed so that public confidence may be placed on the conclusions by NRC.

9. Quality Assurance

Quality assurance procedures are detailed in the DOE document "Management and Overview Quality Assurance Program Plan," (NVO-196-18, August 1980). This is a useful document. It appears to contain the basic features necessary for successful Q.A. effort. During the site visit, however, it was not clear that Q.A. is systematically applied to data collection by all program participants. Since the information submitted to the NRC for licensing purposes must be collected under Q.A. control, the full implementation of a Q.A. program is important.

Appendix A

Meeting Notes

There follows, in chronological order, a brief summary of each meeting with groups other than DOE and its NTS subcontractors.

University of Nevada, Las Vegas

Las Vegas, Nevada -- February 20, 1981

Attendees: John Willbanks (Univ. of Nevada); Hooker (USBM);
Doyle, Lehman, Wright (NRC)

The discussion dealt mainly with the structural framework of southern Nevada, as expressed around Las Vegas.

Las Vegas is located at an intersection of two major structural belts:

1. The Sevier Orogenic Belt, which extends southwest and curves north-easterly and northerly toward the vicinity of Salt Lake City.

2. The Walker Lane, which extends north-northwest along the western side of Nevada toward Reno.

The Keystone fault, a low angle gravity thrust, is the most easterly of the thrust faults in the Sevier Orogenic Belt. In outcrops west of Las Vegas, it places Cambrian/Ordovician limestone on Jurassic sandstone.

The Walker Lane is represented near Las Vegas by the Las Vegas fault. Several lines of evidence suggest a right lateral displacement of 40 miles, making it second only to the San Andreas rift in magnitude of displacement. To the north-northwest it passes some distance west of NTS.

University of Nevada at Las Vegas, Dept. of Engineering

Las Vegas, Nevada -- February 20, 1981

Attendees: Richard Wyman; Wright, Lehman, Doyle (NRC)

Prof. Wyman has served on peer review panels at NTS for eight years. He believes the hydrothermal alteration at Wahmonie and Calico Hills is not compatible with long-term geological structural stability. The Eleana argillite shows decrepitation under heat load; therefore, ground support conditions would be less than optimal. Yucca Mountain is an acceptable site: the welded tuff is ideal for ground support and shows good compressibility and thermal conductivity values. Any water freed by heat can be drained off. Use of a boring machine can reduce the fracturing problem attendant to welded tuff.

Prof. Wyman evaluated above-water-table storage as a possibility, with future rises in water table being a consideration. With below-water-table storage, water will eventually engulf the repository and radionuclide transport in groundwater will be a problem. Blast tests on NTS would not likely be a problem at a repository at Yucca Mountain. Not enough force to cause breakage at Mercury has been generated by tests to date. Seismic force can be handled by design. Ventilation during operation will dissipate waste heat, but after closure the heat could be a problem.

Desert Research Institute (DRI), at Las Vegas, Nevada

Las Vegas, Nevada -- February 20, 1981

Attendees: A. Elzeftawy, R. French, M. Mifflin, F. Miller, B. Woessner (DRI, Las Vegas); C. Case (DRI, Reno); Hooker (USBM); Doyle, Lehman, Wright (NRC)

The topics discussed at the meeting were: 1) DRI involvement at the NTS, 2) the regional flow system, 3) advantages of NTS, and 4) the effects of nuclear weapons testing on the hydrologic system.

DRI Involvement at the NTS

DRI involvement at the Nevada Test Site started around 1961-62 with project SHOAL, which was a geophysics and hydrology network in cooperation with the Bureau of Mines. This was an offsite study. DRI became involved in the weapons testing, doing hydrologic and radiation transportation studies in the Area 12 tunnel. DRI has also been involved in unsaturated zone studies for low-level waste.

Regional Flow System

The hydrology of northern Nevada differs from that of the southern part. This is in part a reflection of topography. The more mountainous regions in the north tend to support numerous local flow systems; consequently, there are more discharge areas and shorter flow path lengths. Southern Nevada, being less mountainous, tends to have more regional type systems, with interbasin flow possible through the lower carbonate system. These systems are very extensive and have long flow paths and few discharge zones. Consequently, the boundaries of these systems are difficult to define. Recharge mechanisms to the deep carbonate system is an interesting area of study. It is presently thought that recharge is occurring through fractured carbonates in ridges or mountains and also along narrow stream channels. It is not occurring on the flats where evaporation far exceeds the amount of precipitation and hard pan (caliche) is extensive. The mountain tops are more amenable to recharge because of increased precipitation and snow pack conditions on a soil layer which is capable of storing some water.

It is thought that the NTS regional flow system discharges at Ash Meadows and possibly the Amargosa desert and Death Valley.

Dr. Mifflin feels the hydrologic advantages of the NTS are:

1) An arid zone is hydrologically optimum because there is less water to deal with and the flow systems are easier to define (relative to a wet climate).

2) Changes in hydrologic stress are easier to identify.

3) Contaminants, if released to the groundwater system, are not going to discharge into a large surface water system - out of control.

4) NTS has closed basin hydrology.

Certain unsaturated zones may be favorable for disposal of radioactive wastes, such as areas which possess evidence of prolonged geologic stability and thick, old capping caliches which limit recharge. NTS contains some thick, extensive unsaturated zones.

<u>Effects of Weapons Testing on Hydrologic System</u>

Dr. Mifflin felt that it would be difficult for the bomb testing to significantly alter the hydrologic system. First, regional gradients would not be changed and secondly, tests are not conducted in areas considered for high-level waste storage; these areas are not suitable for bomb testing.

There has been some evidence of water level response to seismic waves due to bomb testing at the site but water levels recovered shortly after the event. There is no present data regarding the effect of earthquakes on water levels at the site. In shallow alluvial basins, seismic events may cause transient effects, especially along fractures. This can show up as increased or decreased spring discharges.

Nevada Bureau of Mines and Geology

Reno, Nevada -- February 22, 1981

Attendees: J. Tingly, R. Jones, L. Garside (N.B.M.); Doyle, Lehman, Prestholt, Wright (NRC)

The discussions revealed that the Bureau had done mineral studies at three sites on behalf of DOE and the USGS (Special Projects Branch). Some potential mineral prospects are known on NTS. Timber Mountain may possibly have mineral prospects, as based on theoretical considerations of the caldera concept.

The Eureka geothermal low shows downward groundwater flow and the geothermal area near Beatty may reflect deep circulation or a thinner crust.

At the Divide Mine 1600 feet of tuff are known.

Desert Research Institute

Reno, Nevada -- February 23, 1981

Attendees: P. Fenske, R. Jacobson, D. Schulke (DRI); Doyle, Lehman, Prestholt, Wright (NRC)

There is a consensus among investigators that groundwater from the study area does exist at Ash Meadows. Groundwater from areas further east might exit in Death Valley.

The development of solution cavities in the basement carbonate rocks is variable. Some areas develop extensive cavity systems. The development of a crack in southern Yucca Flat was described. A small playa lake was drained when a system of three cracks developed. Two are now healed but the main crack, 15' wide initially, is still open. It is felt that the water from the playa lake drained away through solution cavities in the carbonates.

The time it takes for water to move through the tuffs was discussed. Instrumentation (lysimeters) at Ranier Mesa indicates that water reaches the tunnels from the surface in a matter of months. It was stated that water moves through the welded tuff faster than through nonwelded tuff. It was also pointed out that the water budget is very low. Mention was made of C-14 dating; however, there is not much confidence in this dating. In Yucca Flat, gradients in the carbonates are low. Pumping from the carbonates at Yucca Flat has been going on for years.

Bounding conditions for modeling groundwater flow on the west, north and east were discussed. Dr. Fenske feels that there is too little data for accurate modeling.

Groundwater recharge is taking place on the NTS. Just how much recharge occurs is not known; more work is needed. Some washes on the NTS carry water (active washes) and may act as recharge areas. There is evidence that 40 Mile

Wash, a feature on the east side of the study area, is a fracture zone and acts as an impermeable boundary.

Appendix B

USGS Caisson Site, Jackass Flats, NTS[1]

I. Experiment 1

A. Objective: To determine the vertical movement of liquid water and water vapor in unsaturated alluvium to a depth of 15 m under natural conditions.

B. Method

1. Measure the gradients in all forces causing water movement as a function of depth and time.

2. Determine the transport coefficients that relate water movement to the gradients in the driving forces.

C. Measure temperature, moisture potential and osmotic potential at least every meter vertically at a distance of about 3 m from the wall of the caisson. Obtain horizontal cores, drilling with air. After emplacing the thermocouples and thermocouple psychrometers, the holes will be backfilled with the excavated material.

D. Samples of excavated material will be analyzed in the laboratory for the transport coefficients.

E. In addition, three shallow holes have been instrumented with thermocouple psychrometers at 15-cm intervals to a depth of 1 meter. These are being used to detail the rapidly changing potential and temperature

[1]Handout prepared by the U.S. Geological Survey

temperature gradients near the land surface as affected by the roots of the creosote bush at the southern end of the instrumented line.

F. Experimental schedule

1. Spring 1981 - Install all instrumentation and take samples for transport coefficient measurements.

2. Spring 1981 to ? - Monitor instruments for at least 2 years under natural conditions.

II. Experiment 2

A. Objective: To determine the three-dimensional movement of water vapor, liquid water and heat in response to 1) a buried heat source, and 2) a combination of the buried heat source and a rare rainfall event.

B. Method: The same theory is used as in Experiment 1, but in this case thermally induced driving forces will be more dominant. The rare rainfall event will be simulated by a sprinkler system.

C. Instrumentation: Tensiometers and thermocouple psychrometers will be installed at various depths in sidewall holes drilled from the. caisson, as shown in Figure 1. Instruments will be emplaced along three rays to provide data in separate r-z planes away from the heater. In addition, thermocouple psychrometers will be placed at various depths at radii of a few centimeters in the heater hole.

D. Experimental schedule

1. Spring and Summer 1981 - Install instrumentation, heater and heater site climatic station.

2. Summer 1981 to Fall 1981 - Monitor background temperatures and pressures without heater.

3. Fall 1981 to Summer 1982 - Monitor temperature and pressure with heater on.

4. Summer 1982 - Construct sprinkler system and install tensiometers for measuring pressure under conditions wetter than those possible with thermocouple psychrometers.

5. Fall 1982 - Monitor temperature and pressure with heater on and during and after simulating high intensity, long duration precipitation with the sprinkler system.

III. Additional Facts

A. Material type: Gravelly sandy silt, more or less homogeneous to about 6 m, below which several zones with large cobbles occur.

B. Moisture content:

0 to 0.2 m, < 1% by volume
0.2 to 1 m, 1 - 3%
1 to 15 m, 3 - 6%

C. Matric potential (soil suction):

At surface, 50-100 atmospheres
1 to 50 m, 20-50 atmospheres