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Geological and Geophysical Investigations of Mid Valley

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Lawrence Livermore National Laboratory

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ABSTRACT

We have conducted geological and geophysical studies of the southern portion of the Mid Valley area of the Nevada Test Site in an attempt to develop a new underground nuclear test area for LLNL that would accommodate tests up to 150 kt. We found that the basin is much deeper than we expected, which means that the yield that could be accommodated is larger than expected. In addition, this depth implies that the northern portion of the basin might also be usable as a test area.

We have identified two problems that may limit the usefulness of Mid Valley for testing: (1) The upper portion of the alluvium is mostly tuffaceous and sloughs badly. Some hole stabilization may be needed to overcome this difficulty. (2) The static water level of about 500 m places an upper limit on the yield that can be accommodated if the working point must be the normal distance above the static water level.

EXPLANATION OF STRATIGRAPHIC SEQUENCE AND GEOLOGIC SYMBOLS

Symbol	Unit		Age
QTa	Alluvium		Tertiary and Quaternary
	Thirsty Canyon Formation		Tertiary
Tt	Ashfall		
Tal	Tertiary Alluvium		
	Timber Mountain Tuff		
Tma	Ammonia Tanks Member		
Tmr	Rainier Mesa Member		
	Paintbrush Tuff		
Tpc	Tiva Canyon Member		
Tpt	Topopah Spring Member		
	Older Tuffs		
Tot	Tuffs		
Tu	Tuffs, undivided		
Pz	Paleozoic rocks, undivided		Paleozoic
Ml	Local Limestone	Mississippian (?)	
MDe	Eleana Formation	Devonian and Mississippian	
Dd	Devils Gate Formation	Devonian	
Dn	Nevada Formation	Devonian	
DSu	Nevada Formation and units F and E(?), Frenchman Flat Quad	Devonian and Silurian	

 Normal fault

 Thrust fault show relative horizontal movement

UE14b Drill hole, showing surface elevation and total depth

S.W.L. Static water level

Seismic station

P.I. Point of intersection of seismic lines

1. INTRODUCTION

The Lawrence Livermore National Laboratory (LLNL) recently conducted geological and geophysical studies of the Mid Valley area at the Nevada Test Site (NTS) in an attempt to develop a new underground nuclear testing area for LLNL that would ideally accommodate tests up to 150 kt. The currently used Pahute Mesa testing area is located some distance from LLNL's Yucca Flat facilities and is subject to winter weather conditions that sometimes delay tests. The Laboratory's Test Program felt that it could economically benefit by developing a new site without these drawbacks.

First, the Laboratory assessed any potentially suitable locations at NTS, relying heavily on the real estate availability study published by the United States Geological Survey (USGS, Fernald, 1977). Based on these data, we determined that Mid Valley held the most promise as a potential alternative testing area, but we found several important, unanswered questions concerning its geological setting. To answer these questions, we began an integrated study of the Mid Valley area, including detailed analyses of the existing geological and geophysical data, a seismic reflection program, an exploratory drilling program, geologic field investigations, and geochemical analyses of cuttings and surface outcrop samples. This report documents the results of the study.

Mid Valley is a basin approximately 6 km west of the Control Point (CP) at the NTS. It is about 10 km long, and its width varies from 3 to 7 km. The elevation of the valley ranges from 1260 m in the southeast to 1580 m in the northwest. It is surrounded by mountains whose elevations range up to 2100 m. The Mid Valley area can be divided into a northern and a southern region. Based primarily on surface gravity data, we selected the southern portion of Mid Valley as the most suitable for exploration because the predicted depth to the Paleozoic rocks was the greatest. Subsequent discoveries indicate that the northern portion of the valley is probably deep enough to be a testing area, but the study described here is mainly concerned with the southern portion.

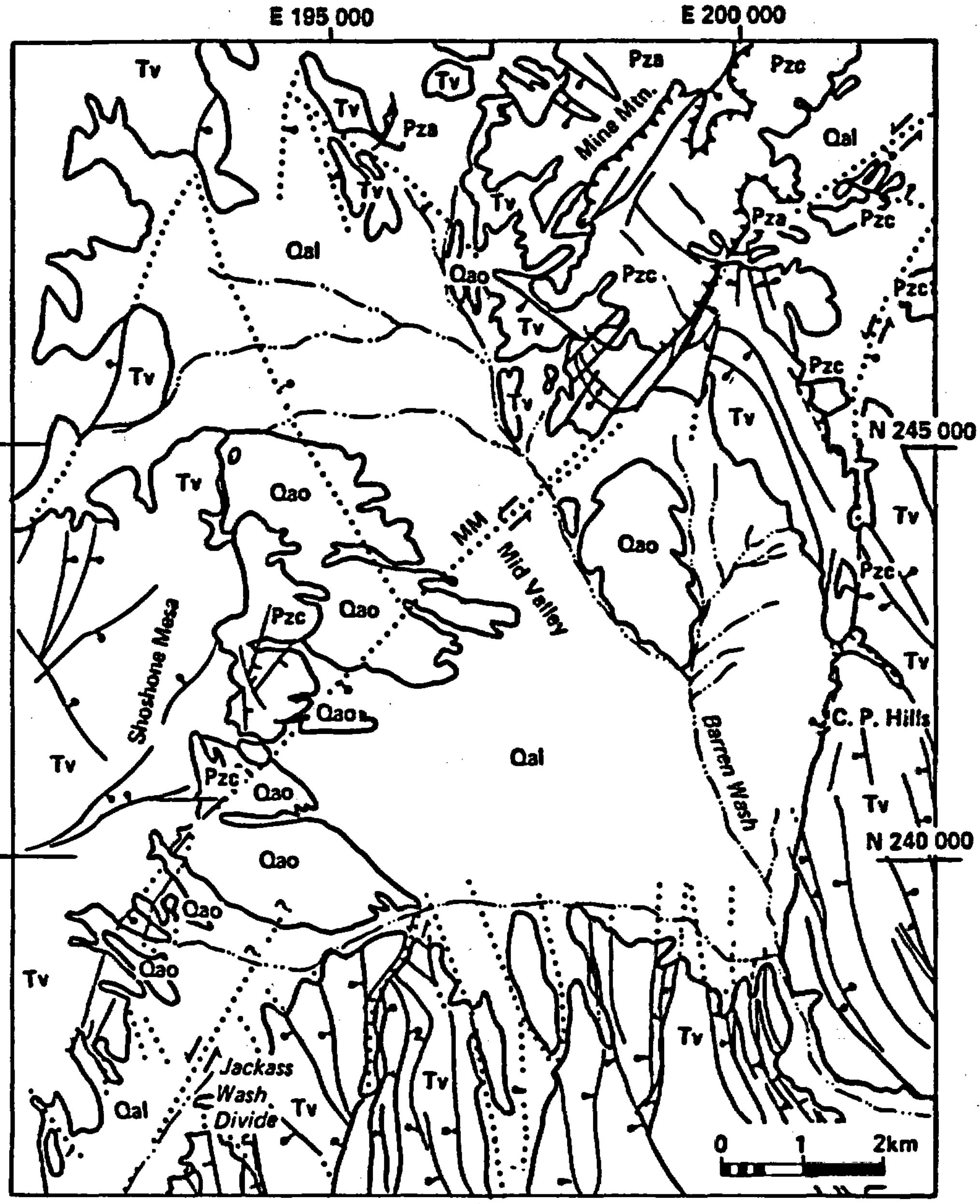
2. GEOLOGIC SETTING

Mid Valley is a block-faulted basin. The area of interest lies within two geologic quadrangle maps: the Mine Mountain Quadrangle (Orkild, 1968) and the Yucca Lake Quadrangle (McKeown, 1976). The geology and topography of Mid Valley are discussed by Orkild (1963), Miller et al. (1966), and Spengler (1977). A generalized geologic map of Mid Valley and the enclosing highlands is presented in Fig. 2.1.

The basin trends N 30 W for 10 km and varies in width from 3 to 7 km. Mid Valley slopes to the southeast; basin elevations range from 1580 m in the northwest to 1260 m in the southeast. Drainage within the basin is controlled by two major washes: the southeastward-trending Barren Wash drains the northern and eastern parts of the basin, and the eastward-trending Jackass Divide Wash drains the southern part of the basin. Both washes empty into Frenchman Flat.

The ranges surrounding the Mid Valley basin are Shoshone Mesa to the west, CP Hills to the east, Mine Mountain to the northeast, and the foothills of the Wahmonie volcanic center to the south. Topographic relief varies from 2070 m in the west to 1675 m in the east.

The alluvial fans flanking the hills to the east and west of the basin exceed a 10% grade. This alluvial slope decreases to less than 1% near the valley axis. Rock exposures in the basin and surrounding hills range in age from Silurian to Quaternary. The Paleozoic rocks range in age from Silurian to Mississippian; they crop out in the western edge of the basin along the flanks of Shoshone Mesa and also form the core of Mine Mountain (Fig. 2.1). Orkild (1963) lists argillite as the predominant Paleozoic rock type, followed by dolomite, limestone, and quartzite. These pre-Tertiary rocks form the structural framework underlying the basin and play a critical role in the geohydrology.



Explanation

Qal	Alluvium
Qao	Older alluvium
Tv	Tertiary volcanics
Pza	Paleozoic argillites
Pzc	Paleozoic carbonates

Fault, dashed where approximately located or inferred, bar on downthrown side, arrows indicate relative horizontal movement.

Thrust fault, sawteeth on upper plate

Figure 2.1. Generalized geological map of the Mid Valley area.

The Tertiary volcanic rocks consist mainly of welded to nonwelded ash flow tuffs with a minor amount of bedded tuffs, dacite lava flows, and flow breccias. The Timber Mountain Formation is the youngest and most widespread of the ash flow tuffs. The underlying ash flow tuffs of the Paintbrush Tuff have extensive outcrops along Shoshone Mesa. Andesitic and dacitic lava flows from the Wahmonie Formation are exposed southwest, south, and east of Mid Valley, and may underlie the deeper parts of the basin. A localized Tertiary basalt flow crops out southwest of the basin near Jackass Divide; it is not observed near the main basin. The general stratigraphic sequence of the Paleozoic and Tertiary rocks is listed in Table 2.1.

Tertiary volcanism around Mid Valley lasted from mid Miocene through lower Pliocene. Silicic magma and pyroclastic material from at least six eruptive centers covered the pre-Tertiary rocks of Mid Valley (Fig. 2.2). A majority of the volcanic rocks in the hills surrounding Mid Valley came from the Timber Mountain-Oasis Valley caldera complex. This caldera is 40 km across and produced voluminous amounts of silicic ash flow tuffs (Byers et al., 1976). Subordinate amounts of the volcanic rock in Mid Valley are from the Wahmonie-Saylor volcanic center and the Black Mountain Caldera.

Several types of Quaternary alluvial deposits are recognized in outcrop in Mid Valley (Orkild, 1963). A stratigraphic column of the alluvial deposits is presented in Table 2.2. An older Tertiary alluvial deposit, discovered in drill holes in Mid Valley, is discussed in a later section.

The older Quaternary alluvium is slightly more indurated than the younger alluvium. Orkild (1963) described the older alluvial deposits as unconsolidated or poorly consolidated and locally cemented with caliche. Topographic highs of older alluvium occur south and east of Mine Mountain and along the flanks of Shoshone Mesa (Fig. 2.1).

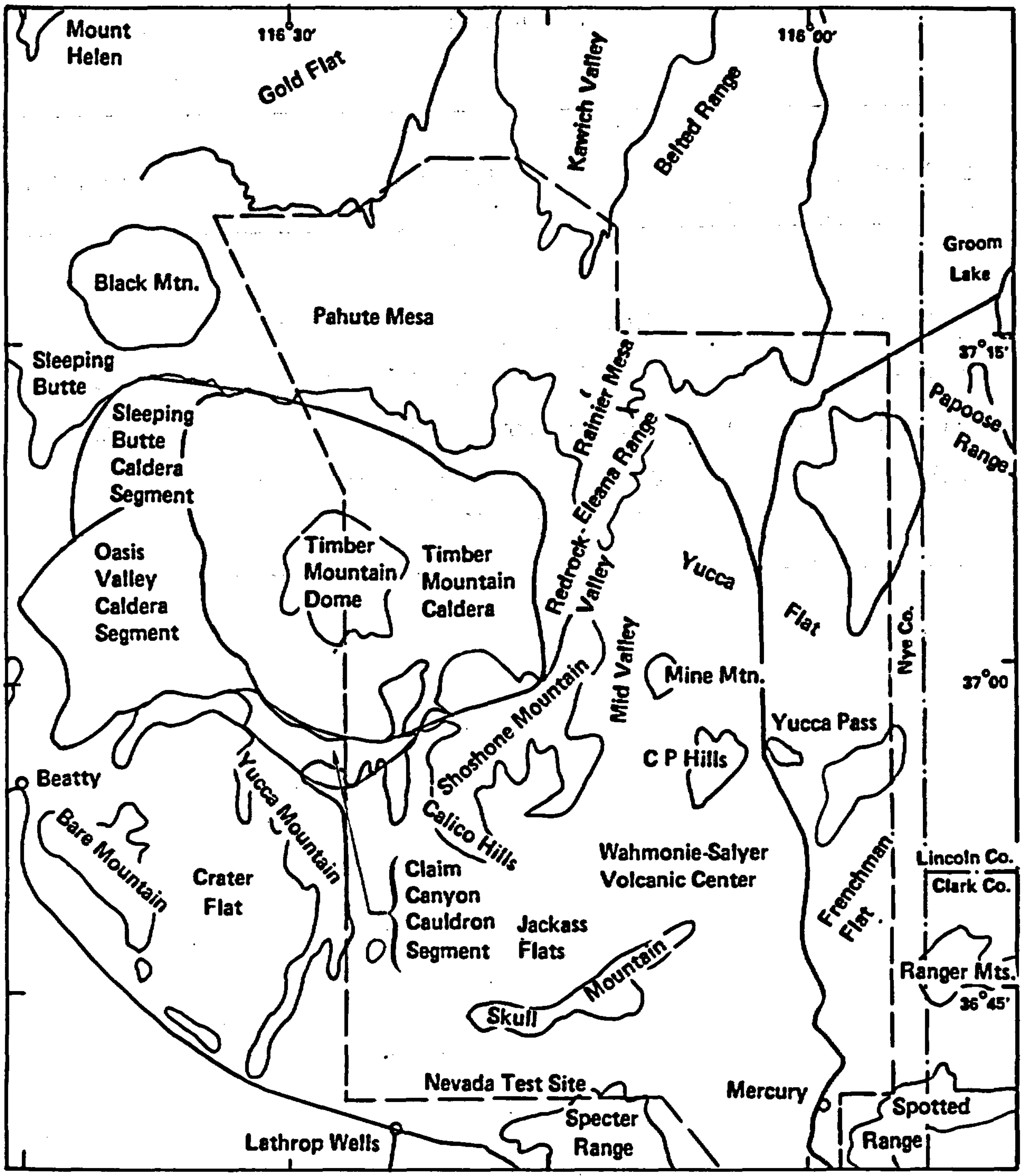
Formation	Member or lithology	Caldera or volcanic center	Period or epoch	Age (Ma)

Table 2.1 General stratigraphy of [illegible]

Formation	Member or lithology	Caldera or volcanic center	Period or epoch	Age (Ma)
Thirsty Canyon Tuff[a]	Spearhead	Black Mountain	Pliocene	7.5
Timber Mountain Tuff	Ammonia Tanks Bedded Tuff Rainier Mesa	Timber Mountain	Pliocene	11.1-11.3
Paintbrush Tuff	Tiva Canyon Pah Canyon Topopah Spring Bedded Tuff	Claim Canyon	Miocene	12.4-13.4
Wahmonie	Lava Flows and breccia flows	Wahmonie-Salyer	Miocene	12.5-12.9
Rhyolite of Calico Hills	Lava flows Ash-flows?	Fortymile Canyon Area	Miocene	13.0-14.0
Redrock Valley Tuff	Ash-flow	Sleeping Butte	Miocene	15.0-16.0
Unassigned Limestone, Siltstone	Limestone, Siltstone	N/A	Mississippian?	
Eleana Formation	Argillite, Quartzite, Limestone	N/A	Devonian/ Mississippian	
Devils Gate Limestone	Dolomite/Limestone	N/A	Upper Devonian Middle Devonian	
Nevada Formation	Dolomite/Limestone	N/A	Upper Silurian	

a Thirsty Canyon Formation is not exposed in the Mid Valley area; an ashfall tuff was identified in drillholes in the basin by geochemical techniques (Jenkins, 1984 and Warren, 1984).

Note: All members are ash-flows unless otherwise designated.



(After Byers, et. al., 1976)

Figure 2.2. General location of eruptive centers related to the volcanic rocks of Mid Valley.

Table 2.2. Alluvial stratigraphic units exposed in Mid Valley. All are of Quaternary Age.

Sediment type	Description	Thickness (m)
Alluvium	Modern stream and fan gravels	0-15
Eolian silt	Silt derived from alluvium	0-30
Alluvium/colluvium	Fan and terrace gravels	0-170
Alluvium	Older fan gravels exposed on the adjacent highlands	0-75

Structure

Tectonic events before the Paleozoic Antler Orogeny are not considered important factors in the formation of Mid Valley. Compressional forces that were active during the Antler Orogeny and throughout the Mesozoic Era, together with the extensional forces that were active during the Tertiary and possibly the Recent, caused the faulting that helped shape Mid Valley.

The Antler Orogeny and its accompanying uplift evolved during the early Devonian. Highlands were created west of the NTS by the Antler Orogeny. After the uplift, a broad depositional basin formed east of the Antler Highlands. This basin continued to deepen throughout the Devonian and Mississippian Periods. Erosional debris from the highlands filled the basin with 2500 m to as much as 4000 m of sediments, which constitute the present-day argillites, quartzites, and limestones of the Eleana Formation (Hoover et al., 1981). Carbonates, including the Tippipah Limestone, were later deposited throughout Permian time during periods of little tectonic activity. Structural deformation during late Paleozoic time is believed to be confined to the margins of the broad basin and had little effect on the Mid Valley area.

Mesozoic Deformation

Compressional deformation of the NTS and surrounding areas occurred during the Nevadan Orogeny of Middle Triassic to Early Jurassic (Burchfiel et al., 1970). In the Mid Valley area, the results of the Mesozoic compressional forces are best observed at Mine Mountain to the northeast and in the CP Hills to the east. The direction of the maximum principal stress during the Nevadan is considered to be west-northwest. Compression during the Nevadan Orogeny produced as many as three major thrust fault systems with related folding, lateral faulting, and high-angle normal and reverse faulting. The major thrust systems have been named by various authors as the CP thrust, the Mine Mountain thrust, and the Tippinip thrust.

Barnes and Poole (1968) originally proposed that the CP thrust system is rooted in the Belted Range, and had thrust older rocks east-southeast over younger rocks. The eastern Mine Mountain and Tippinip thrusts are suggested to be local blocks of Devonian and Silurian carbonates that were detached from the upper plate of the CP thrust and moved in conjunction with the CP thrust over Mississippian and Pennsylvanian rocks. Total displacement of the thrust system is estimated to be 56 km. Sinnock (1983) examined the geographic locations of the thrust plates and argues that three separate thrust systems exist, each having its own deep-seated root zone.

In Carr's (1984) model, the CP thrust system has a root system similar to that described by Barnes and Poole (1968). Carr suggests that the CP thrust system climbs stratigraphically from the root zone until it reaches the weak Eleana Formation in the Eleana Range. At this point, the upper plate of the thrust flattens and becomes a series of large-amplitude folds. To the east the thrust dips below Yucca Flat. The exposed Paleozoic rocks in the eastern and southeastern NTS are believed to be part of the upper plate of the thrust rather than the lower plate. On Mine Mountain and in the Calico Hills southwest of Mid Valley, Carr (1984) considers the Devonian rocks overlying the Eleana Formation to be gravity-glide blocks and/or to represent near-surface thrusting younger than the CP thrust.

The exposures of Devonian carbonate rocks at Calico Hills on the western and eastern flanks of Shoshone Mesa and at Mine Mountain suggest one low-angle thrust system rather than gravity gliding (Fig. 2.3). The Yucca Lake Quadrangle Map (McKeown et al., 1976) suggests that klippen of the CP thrust extend into Mid Valley. Portions of the two thrust systems may underlie the Mid Valley basin.

Thrust faults and Paleozoic rock types control the water circulation beneath Mid Valley. Young (1963) estimated the regional water table in Mid Valley to be about 732 m above mean-sea-level (MSL). This number was derived from interpolating between water elevation control points in Yucca Flat and Jackass Flat. The interpolation assumes that the aquifer is located in a vast system of carbonate rock (Young and Winograd, 1963). Two recently drilled (1983 and 1984) holes in Mid Valley (that did not penetrate pre-Tertiary rocks) showed that the static water level (SWL) is at 818 to 820 m above MSL. The altitude of the SWL is 86 to 88 m higher than was predicted for the area around the drill holes, suggesting that the Eleana aquitard is presently underlying the valley.

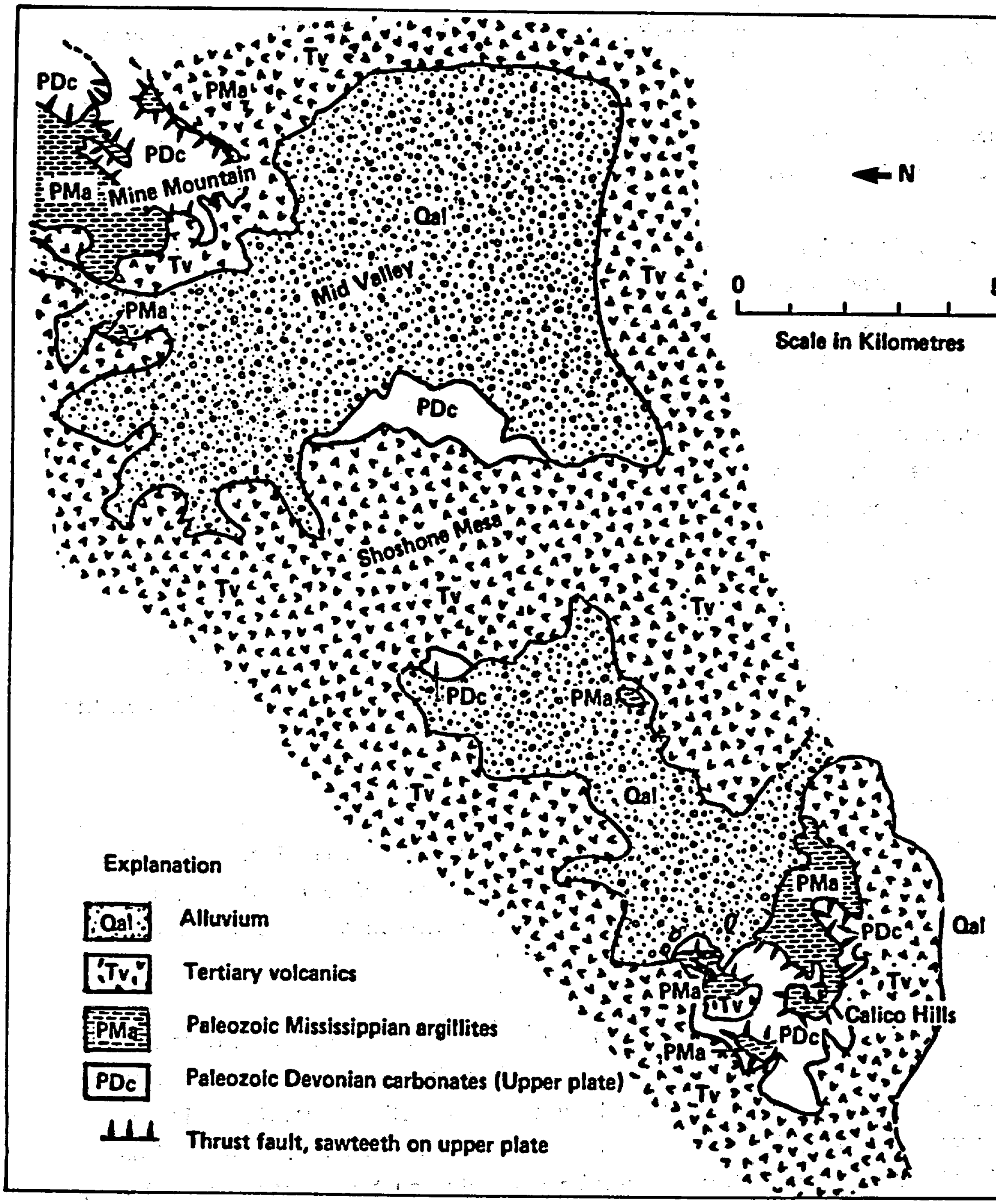


Figure 2.3. Outcrop trend of Mine Mountain Thrust system from Calico Hills to Mine Mountain.

Overthrusts of the permeable Devonian carbonate rock are believed to be thin and/or distributed as irregular erosional blocks overlying the Eleana aquitard. Future drilling in Mid Valley may show deeper water levels in areas where large blocks of carbonate rock (aquifer) are present or where the Eleana Formation (aquitard) has been faulted out.

Cenozoic Extensional Structures

The change from predominantly compressional to predominantly extensional forces at NTS probably started shortly before the deposition of the Horse Spring Formation of Oligocene age, dated at 29 Ma. Carr (1974) states that the Horse Spring Formation in the southern part of NTS shows structural disturbance, but not as much as the underlying Paleozoic rocks. The structural movements that produced basins of deposition had probably already begun but had not developed much by late Oligocene time (Carr, 1974). Ekren et al. (1968) point out that some Basin and Range block faulting was in an early phase as late as 11 Ma. As evidence, he cites the negligible differences in the thickness of the exposed Timber Mountain Tuff (11 Ma) on the ranges and in the present basins; however, as will be discussed later, basin development had started before the Paintbrush Tuff was deposited in Mid Valley.

Mid Valley falls within a Tertiary tectonic system characterized by Carr (1984) as the Spotted Range-Mine Mountain structural zone (Fig. 2.4). The most prominent features are a series of northeast-striking faults with left-lateral displacements of up to 2 km. The Mine Mountain normal fault in Mid Valley is one of these.

Exposures of the Mine Mountain fault, south of Mine Mountain, indicate that the Timber Mountain Tuff and the Paintbrush Tuff have been offset in a left-lateral movement by approximately 1 km. The Mine Mountain Geologic Quadrangle (Orkild, 1968) shows left lateral drag on north-south-trending fault blocks as they approach the Mine Mountain fault or shear zone. Orkild (1968) projects the eastward dipping Mine Mountain fault southwest from Mine Mountain to the eastern flanks of Shoshone Mesa, where it branches into several segments and then dies out near the Jackass Flats Divide. Just south of where the Mine Mountain fault branches, the same fault appears to step right, forming an en-echelon pattern that continues southwest through Jackass Flat, concealed by the younger alluvium.

Ekren and Sargent (1968) show the Mine Mountain fault on the Skull Mountain Geologic Quadrangle, which abuts the Mine Mountain Quadrangle to the south. Oroclinal bending of the volcanic outcrops and faults east of Jackass Divide suggest that the alluvial-covered fault has a left-lateral component, and that the fault extends northeast into the southwest portion of Mid Valley.

Orkild (1968) shows other faults with apparent left-lateral displacement cutting and bending volcanic outcrops south of Mid Valley. Some movement along the Mine Mountain fault is believed to have occurred within the last million years (Orkild, personal communication). This dating is based on the observation of disturbances in the older alluvium along the trace of the fault.

Fault traces in the hills surrounding Mid Valley indicate a complex system of normal faults that strike northwest, north, and northeast, respectively. The vertical displacements of the faults vary from a few metres to possibly 450 m, but probably average less than 60 m.

Orkild (1963) states that the volcanic rocks of the Mine Mountain Quadrangle generally strike N 20° W to N 20° E and dip 6° to 16° to the west. The volcanic rocks that skirt the southern end of Mid Valley indicate a 7.4-km-wide north-trending structural block that dips to the east, terminating in the west near the projection of the Mine Mountain lateral fault zone. To the south it onlaps the older Wahmonie-Salyer volcanic center and terminates in the east near a swarm of north-trending faults. It is probably a structural sag between the Shoshone Mountains and the bench of the CP Hills.

Fault density and block size vary greatly in the volcanic exposures in the south, west, and east sides of Mid Valley. A 7000-m-long east-west cross section (Orkild, 1968) across the generally exposed volcanic section in southern Mid Valley reveals 32 individual faults, or an average of one fault every 219 m. The fault density is biased in that 16 of the faults occur in the eastern 26% of the section. The remaining 16 faults occupy 5170 m of the section and range in width from 90 to 580 m. North of this cross section the volcanic rocks are partially under alluvial cover. However, the density of the major faults appears to decrease to the north, suggesting that wider and less complex structural blocks may exist within the basin.

Jointing and Fracturing

Most densely welded ash-flow tuffs tend to develop cooling joints. Such jointing has been observed in the Timber Mountain Formation, particularly in the Rainier Mesa Member. Orkild (1968) describes the weathering pattern in the Tiva Canyon Member of the Paintbrush Tuff as platy. It is unknown whether this is an inherent feature of deposition and the cooling history of this tuff, or whether it is caused by the unloading of the overburden and the subsequent dilation of the cooling unit. However, as we discuss later, in one drillhole the Tiva Canyon Member tended to erode in flat, plate-like fragments. Jointing in the Topopah Spring Member of the Paintbrush Tuff may be related to both the structural and cooling histories of this unit

Carr (1984) suggests that the whole southwestern Great Basin has been tilted to the south or southeast during the past 8 Ma. Evidence for this is seen in the present-day migration of playas toward the southern parts of their basins. If this hypothesis of regional southeastern tilting is correct, then Mid Valley is also tilting to the southeast.

Carr (1984) characterizes the Spotted Mountain-Mine Mountain structural zone as "seismically active." Seismic epicenters are shown in Fig. 2.4. The Great Basin is still in an extensional phase. At latitude 37 N, the approximate northern boundary of Mid Valley, long-term extension rates across the Great Basin are on the order of 1 cm/y (Wernicke et al., 1982). If this extensional rate is averaged across the province for the last 15 Ma, then highly extended areas within the province may have extended as rapidly as 2 cm/y for several million years (SAIC Workshop, 1984).

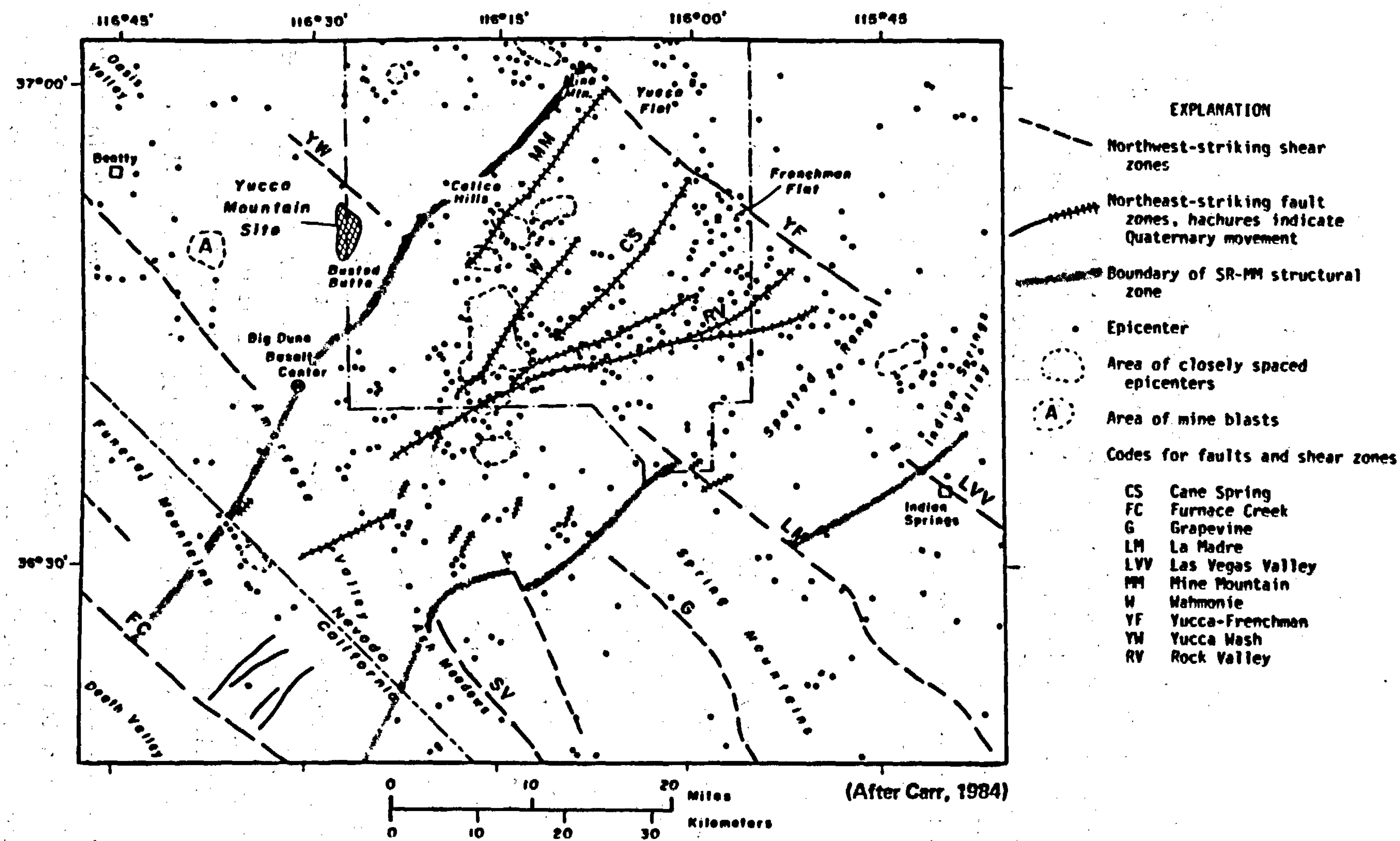


Figure 2.4. Spotted Range-mine Mountain structural zone and included Quaternary fault zones, showing the relationship to seismicity of the southern NTS area, August 1978 through May 1984 (Carr, 1984).

3. GEOPHYSICAL DATA

A large amount of geophysical data has been gathered over the years by the USGS. A summary of the geophysical investigations conducted by the USGS is reported in Hazelwood et al. (1963), which documents the field data collection and the data reduction techniques used for the various data sets. Although techniques for interpreting and the actual interpretations of the various kinds of geophysical data have changed over the years, the data sets gathered are still very valuable. We have relied heavily on these data sets to guide the exploration program, and have tried to develop interpretations that are consistent with all of the available geophysical data.

Surface Gravity

The surface gravity data in Mid Valley were obtained by the USGS as part of the Yucca Flat and contiguous area gravity survey. A summary of the data collection techniques including instruments, surveying, and data reduction techniques, is presented in Hazelwood et al. (1963). The gravity stations in Mid Valley and the values of the gravity are shown in Fig. 3.1. With this irregular spacing, we wanted to determine whether establishing additional gravity stations in Mid Valley would improve our knowledge of the surface gravity field. We used a geostatistical technique called kriging (Journel and Huijbregts, 1978) to address this issue. A contour map of the kriged gravity field is shown in Fig. 3.2. The accuracy of the kriged gravity field is illustrated on the uncertainty map in Fig. 3.3, which shows that except for the southwest and southeast corners of Mid Valley, the kriged gravity field is accurate to no more than 1 mgal. Since the accuracy of the actual surface gravity measurements after reduction is in the range 0.5-0.8 mgal, we believe that taking additional gravity measurements would not significantly increase our knowledge of the variations in the Mid Valley surface gravity field.

A major problem in interpreting the surface gravity field in the Mid Valley area was a lack of good density control. We made preliminary estimates of the depth to the Paleozoic surface assuming a density contrast of 0.7 g/cc between the overburden and the Paleozoic material. However, we found these

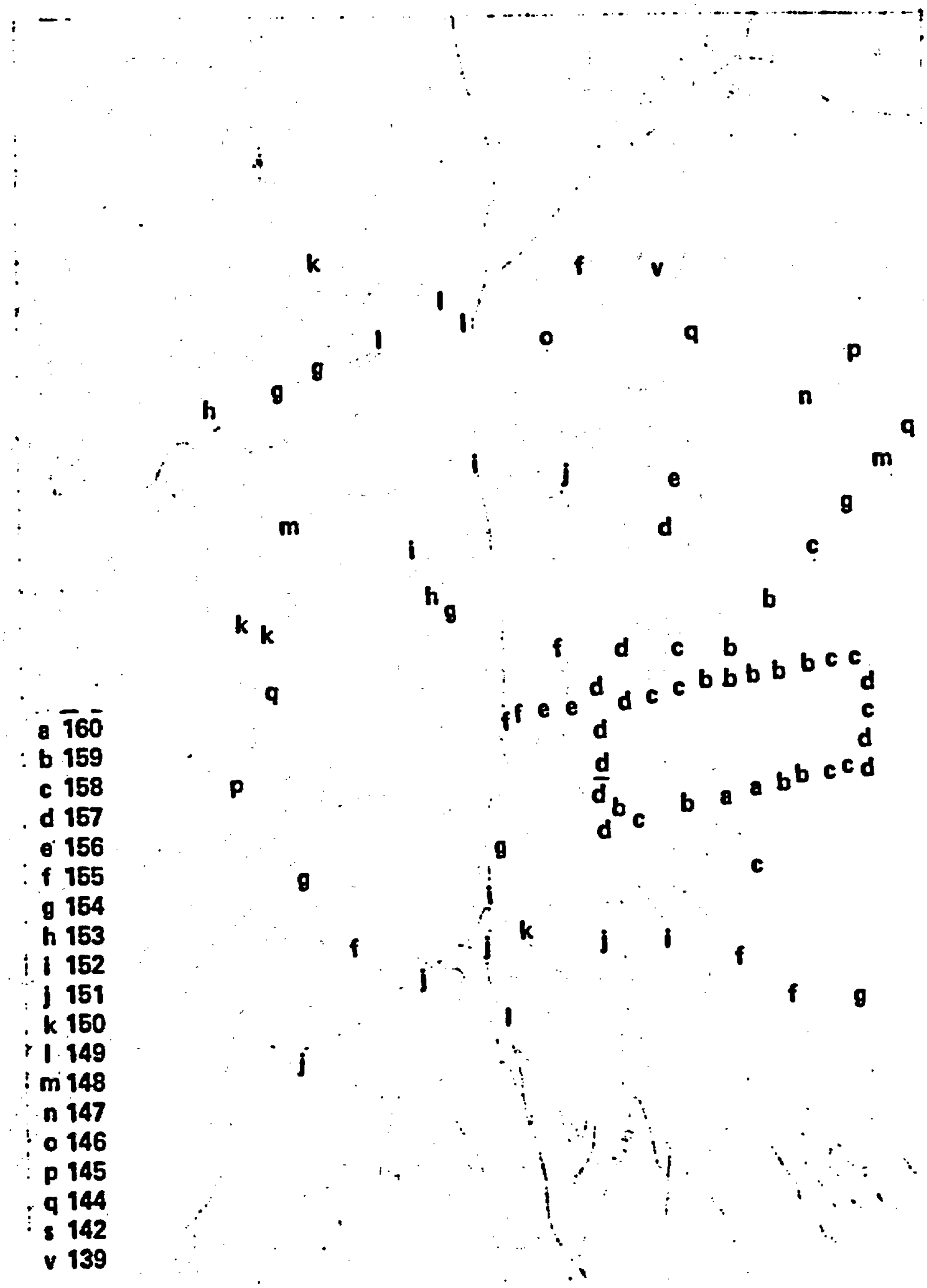


Figure 3.1. Locations of gravity stations in Mid Valley. Gravity values are identified by letters.

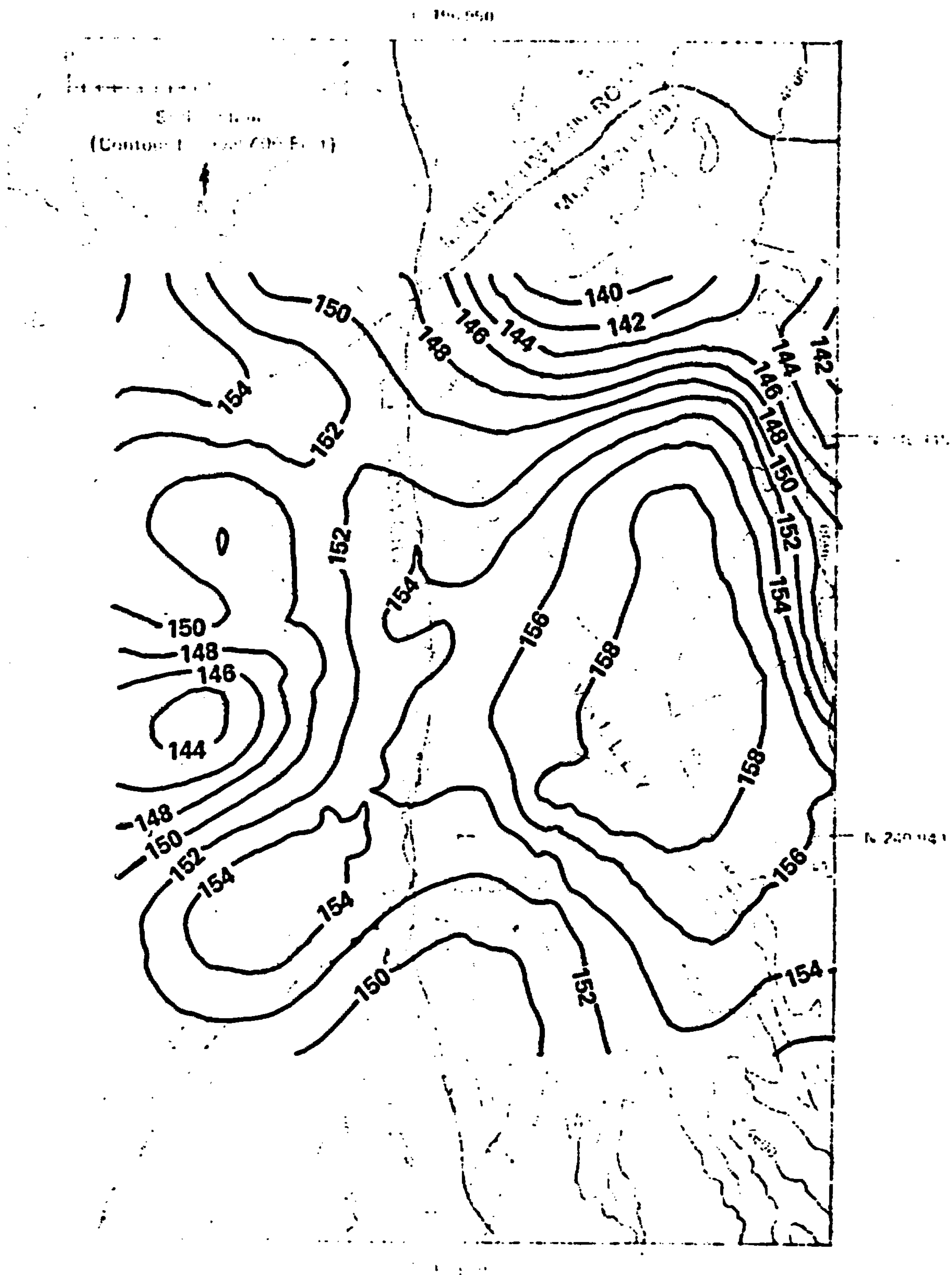


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Figure 3.2. Kriged (interpolated) gravity contours in mid Valley.

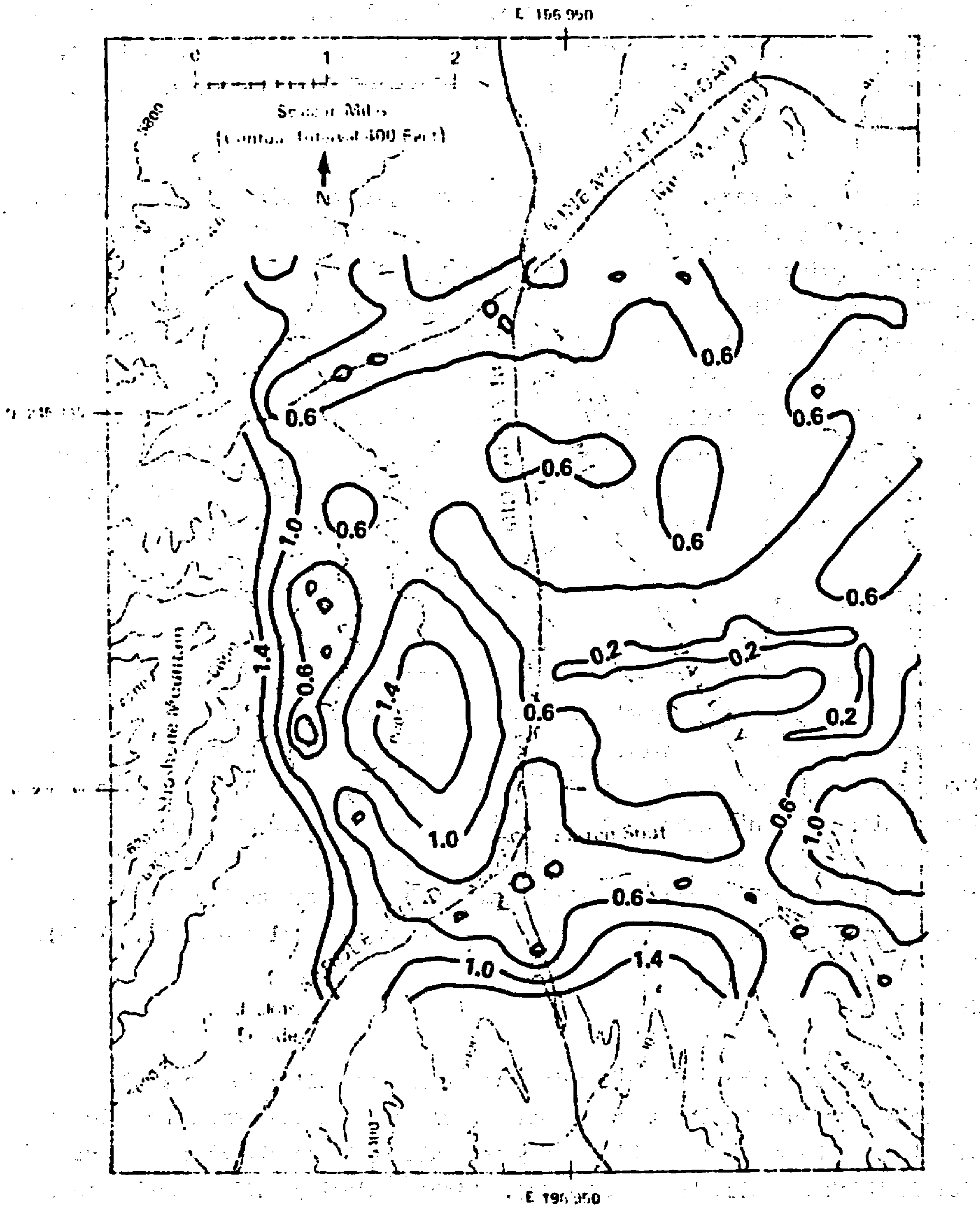

Figure 3.3. Uncertainty of the kriged gravity in Mid Valley.

preliminary depth estimates to be inaccurate; results from drilling and subsequent density logging indicate that a more appropriate density contrast would be in the range of 0.35-0.50 g/cc. We still do not know a better value of the contrast because we never actually drilled into the Paleozoic layer, and so the density of the Paleozoic material underlying Mid Valley was not measured.

Therefore, we have not attempted to do a highly detailed inversion of the surface gravity field. Instead, we have done several two-dimensional inversions using a range of density contrasts. Although the actual depths predicted vary with the density contrast used (they also vary depending on the regional gravity field assumed for Mid Valley), the general shape--or trends--of the Paleozoic surface can be identified. We used these general shapes to guide our interpretation of the seismic reflection data and help identify the major structural trends. An accurate inversion of the gravity field would, at a minimum, require knowledge of the density contrasts and at least one Paleozoic depth tag.

Aeromagnetic Data

The USGS obtained total-intensity aeromagnetic surveys using a fluxgate magnetometer. Remanent magnetism in some of the volcanic units gives rise to distinctive magnetic signatures that are identifiable in the contour maps of the aeromagnetic anomaly (regional trends have been removed). For example, the Rainier Mesa unit gives rise to a significant negative anomaly. No detailed inversion of the aeromagnetic data was done; however, we checked structural interpretations for consistency with the aeromagnetic data. An aeromagnetic map covering Mid Valley can be found in Hazelwood et al. (1963).

Seismic Refraction

The USGS ran a seismic refraction survey in Mid Valley in the 1960s to determine its suitability as a potential nuclear-explosion cratering site in alluvium. The results of this survey indicate that the alluvium is about 1100 ft thick (P velocity = 6400 ft/s). Higher velocity tuff underlies this material. Data are given in Hazelwood et al. (1963).

Seismic Reflection

The Laboratory ran three seismic reflection lines to survey the southern portion of Mid Valley. A layout of the seismic lines is given in Fig. 3.4. The final data are 48-fold common-depth-point (CDP) stack data obtained from recording 96-channel split-spread CDP data with air gun surface sources. These sections reveal structure in the alluvium, the volcanic section, and the Paleozoic. A standard series of CDP processing techniques was applied. Stacking velocities were determined on a very short interval, and constant-velocity stacks were used to help determine the appropriate stacking velocities. Copies of the seismic sections can be obtained from LLNL. These data were used extensively to determine the structural setting of Mid Valley presented in this report.

Well Logs

A standard suite of well logs was run in exploratory holes UE14a and UE14b (shown in Sec. 4). These logs are available from the LLNL Geophysical Data Storage (GDS) system. The roughness of the holes caused considerable problems in obtaining logs that required small sonde-wall gaps.

Surface Magnetics

The Laboratory ran surface magnetic traverses along parts of Lines 1 and 2 to determine the lateral extent of several of the volcanic units. These data were gathered using a proton procession magnetometer, and are stored in the LLNL-Nevada files at the NTS.

Water Table

Before this exploration program began, all estimates of the water table were based on drill hole data from Yucca and Jackass Flats. No measurements of the water table were available from Mid Valley. The SWL was measured in UE14a and UE14b at 502 and 508 m, respectively. The SWL readings were taken over a period of several months so that the water level could stabilize after the holes were drilled.

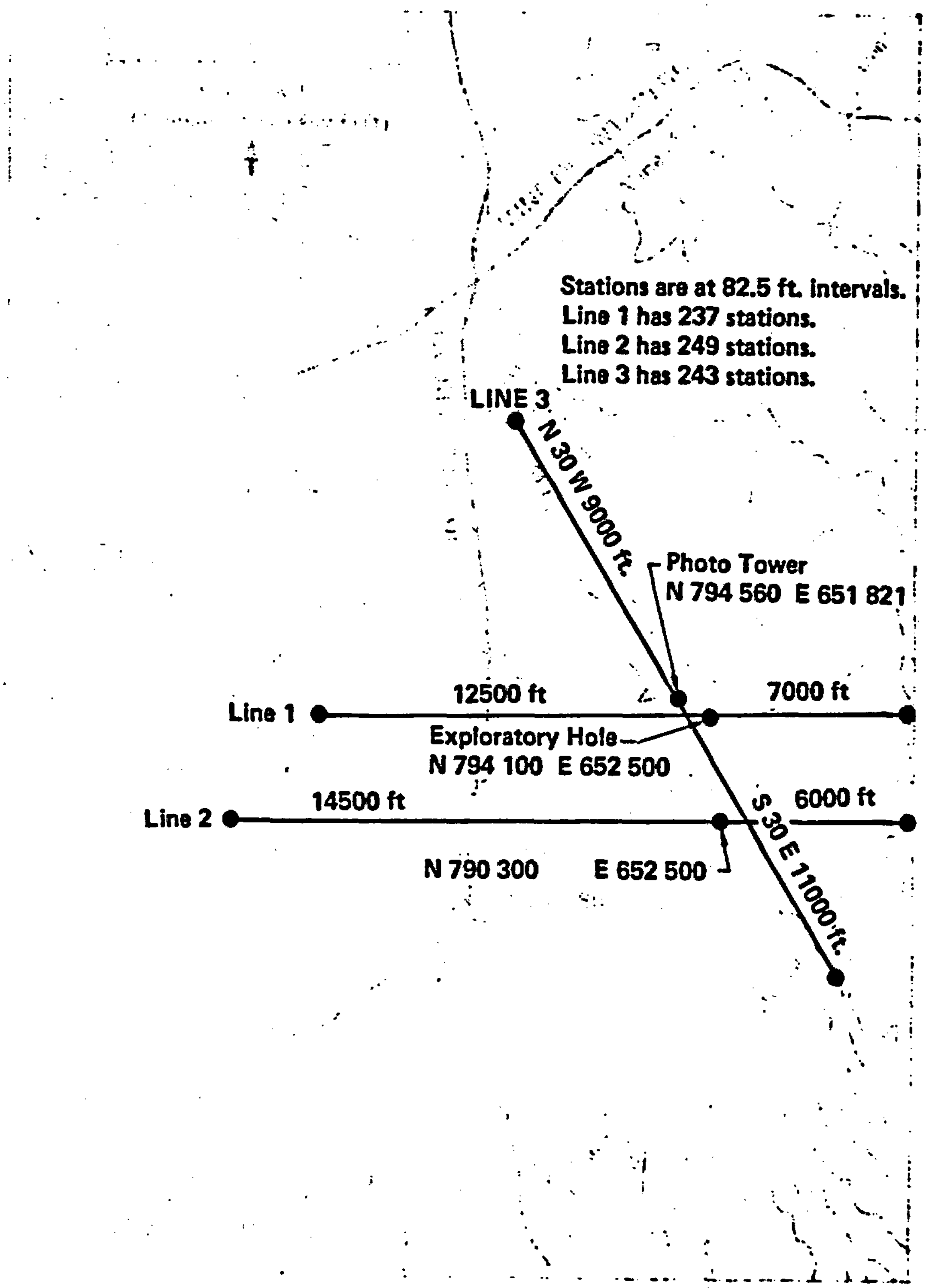

Figure 3.4. Location of seismic lines run by LLNL.

however, are extremely complex lithologic units involving the superimposition of several factors and processes, and a detailed interpretation requires equally detailed lithologic information. Interpretation of geophysical well logs for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 was complicated by the lack of fluid saturation. Partial fluid saturation caused direct correlation between neutron response and porosity, rather than the usual inverse relationship. The partially fluid-saturated rocks also caused abnormally high IP values. The density, and resistivity logs indicate that near-surface fracture zones are least likely to be present near drill hole UE25a-5.

More mineralogic and petrologic work is needed to clarify the causal elements of well-log response in welded tuffs and to shed more light on the unexpected response values of the well-log measurements. Future studies must also include laboratory physical-properties measurements to link the mineralogic and petrologic work to the geophysical well-log measurements.

The IP well logs for the drill holes considered in this study are shown in Figure 17. Unfortunately, these values are unreasonably high and the value of these particular well logs is questionable. Hagstrum and others (1980a) has shown that IP well-log measurements in the fluid-saturated zone of ash flow tuffs have values that are normally in the 0-to-4 percent range. The IP log is apparently strongly affected by the fluid invasion in the undersaturated volcanic rocks.

Magnetic Susceptibility

Magnetic susceptibility is the measure of the intensity of magnetization of a magnetizable substance in the presence of a known magnetic field. The magnetic susceptibility of a rock depends largely on the amount of ferrimagnetic minerals that it contains. Magnetite is the most important ferrimagnetic mineral affecting the magnetic susceptibility measurements. Magnetic susceptibility measurements in welded tuffs have been assumed to be primarily a function of the amount of magnetite contained in a rock. However, Hagstrum and others (1980b) have found that the size of the magnetite grains is also an important factor affecting the magnetic susceptibility of welded tuffs. The magnetic susceptibility well logs for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 are shown in Figure 18. These well logs will be discussed in detail in another paper (Hagstrum and others (1980b).

Conclusions

The broad features of the welded tuff sequence encountered in drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 are readily characterized by their physical properties measured by the geophysical well logs. Welded tuffs,

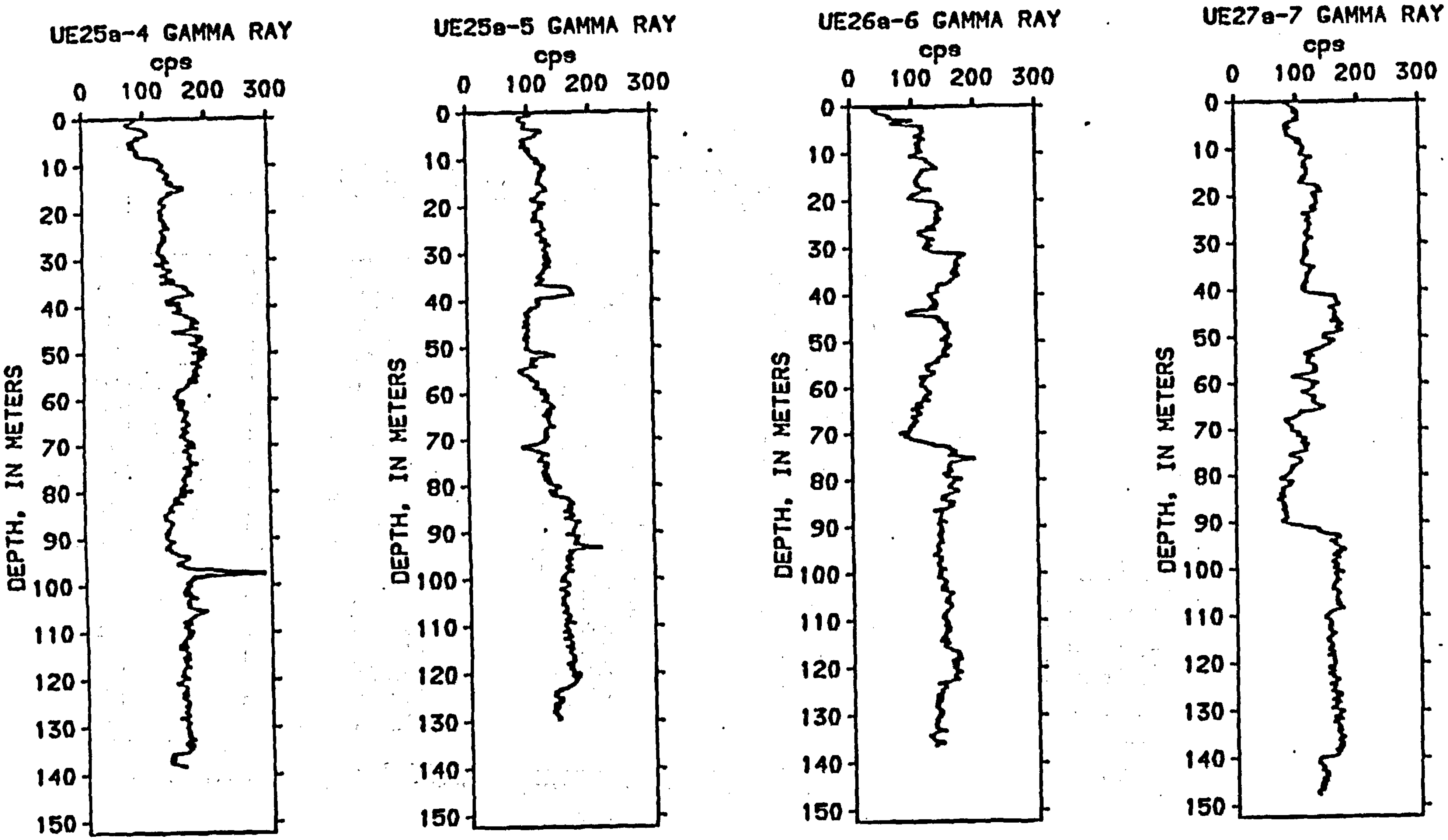

Figure 16.--Gamma ray well-logs for UE25a-4, UE25a-5, UE25a-6, and UE25a-7.

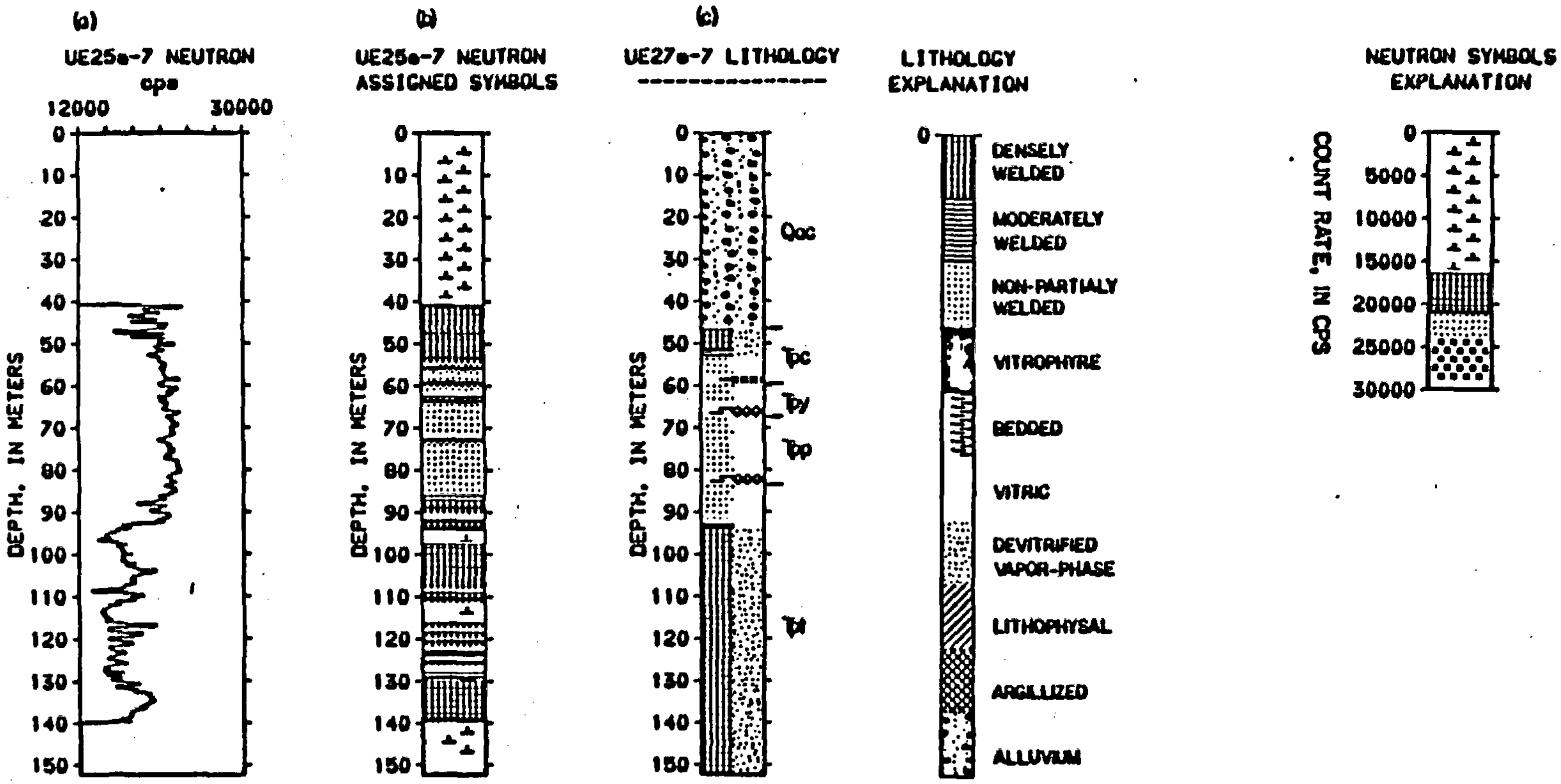

Figure 15.--Neutron well-logs and interpretation for drill hole UE25a-7: (a) neutron well-log, (b) computer assigned symbols, and (c) lithologic well-logs (after Spengler, in press).

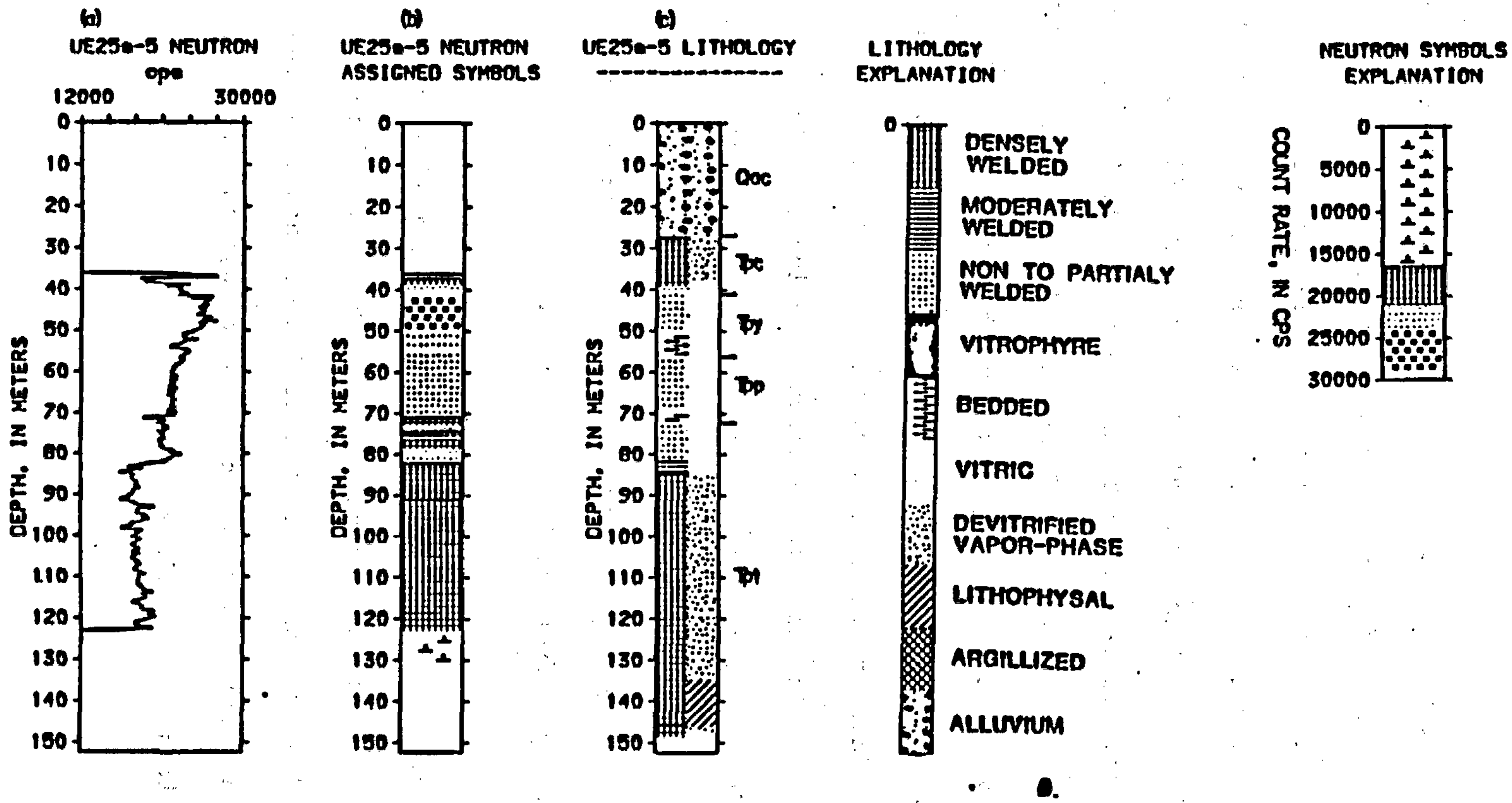

Figure 13.--Neutron well-logs and interpretation for drill hole UE25a-5: (a) neutron well-log, (b) computer assigned symbols, and (c) lithologic well-logs (after Spengler, in press).

Neutron

The neutron well-logging probe consists of a neutron source and detector separated by approximately 50 cm. The number of neutrons counted by the detector is an inverse function of the hydrogen content of the rock surrounding the borehole. In saturated material the neutron count rate is approximately proportional to the degree of welding. However, this is not necessarily true in unsaturated rocks. In fact, the neutron well logs for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 (Figures 12, 13, 14, and 15, respectively) show an inverse relationship between the degree of welding and the neutron count rate! The assigned symbols for the neutron well logs correspond closely to the core-interpreted lithology, when the neutron well logs interpretation is based on this paradox. A constant value for fluid saturation in each of the formations must be assumed in order for this interpretation to be valid. The lithophysal zone located near the bottom of drill hole UE25a-6 (Figure 14) shows a very low neutron count, rate which indicates that the cavities in this zone probably are interconnected.

Interpretation of well logs that are indicative of mineralogy

The measured responses of magnetic susceptibility, induced polarization, and gamma ray well logs are primarily a function of changes in the mineralogy and chemistry of the rocks rather than changes in physical properties. Interpretation of these logs is as follows:

Gamma Ray

The gamma ray probe measures the natural gamma radiation emitted by the rocks surrounding the borehole. The principle natural gamma ray-emitting

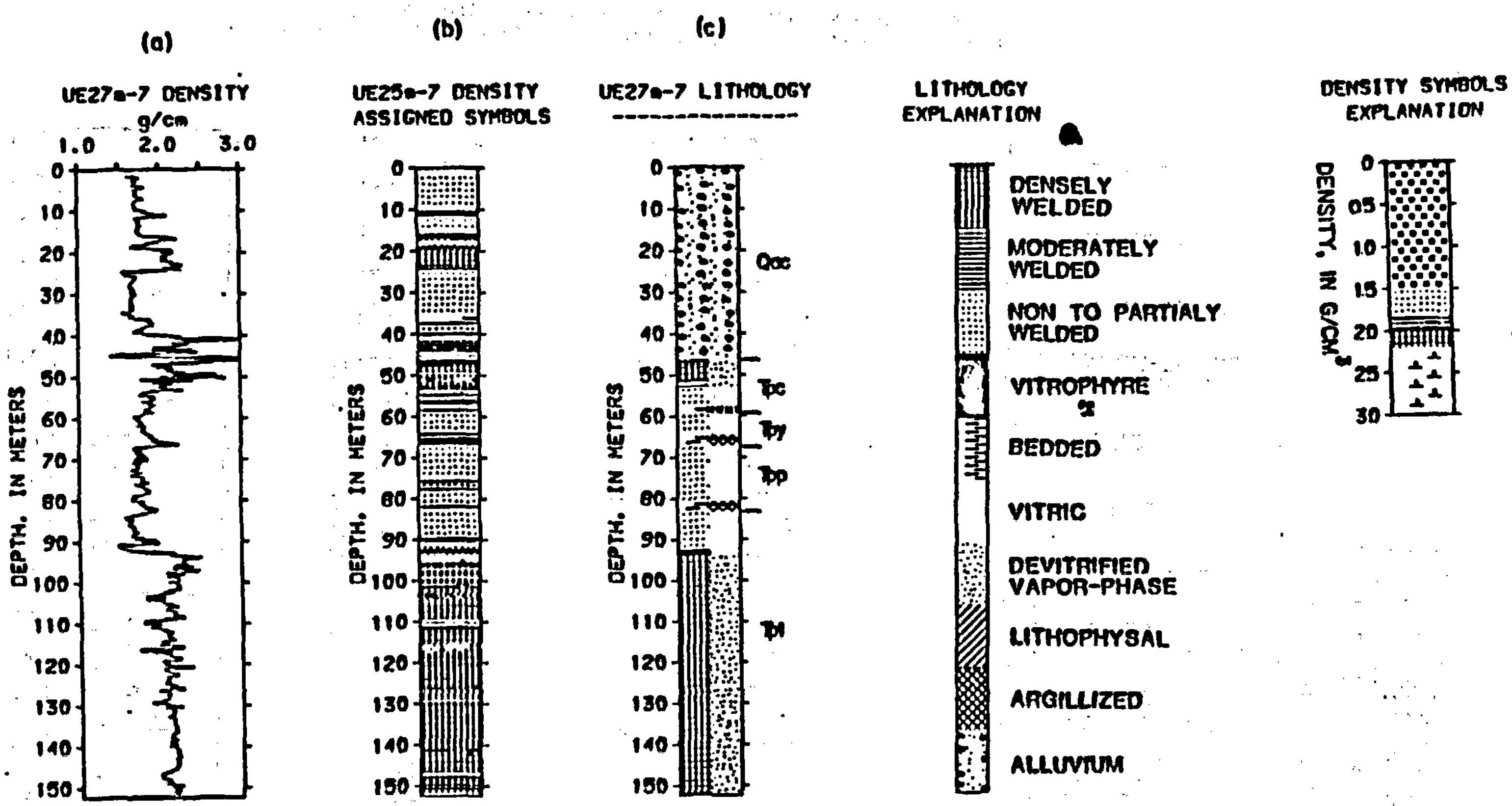

Figure 10.--Density well-logs and interpretation for drill hole UE25a-7: (a) density well-log, (b) computer assigned symbols, and (c) lithologic well logs (after Spengler, in press).

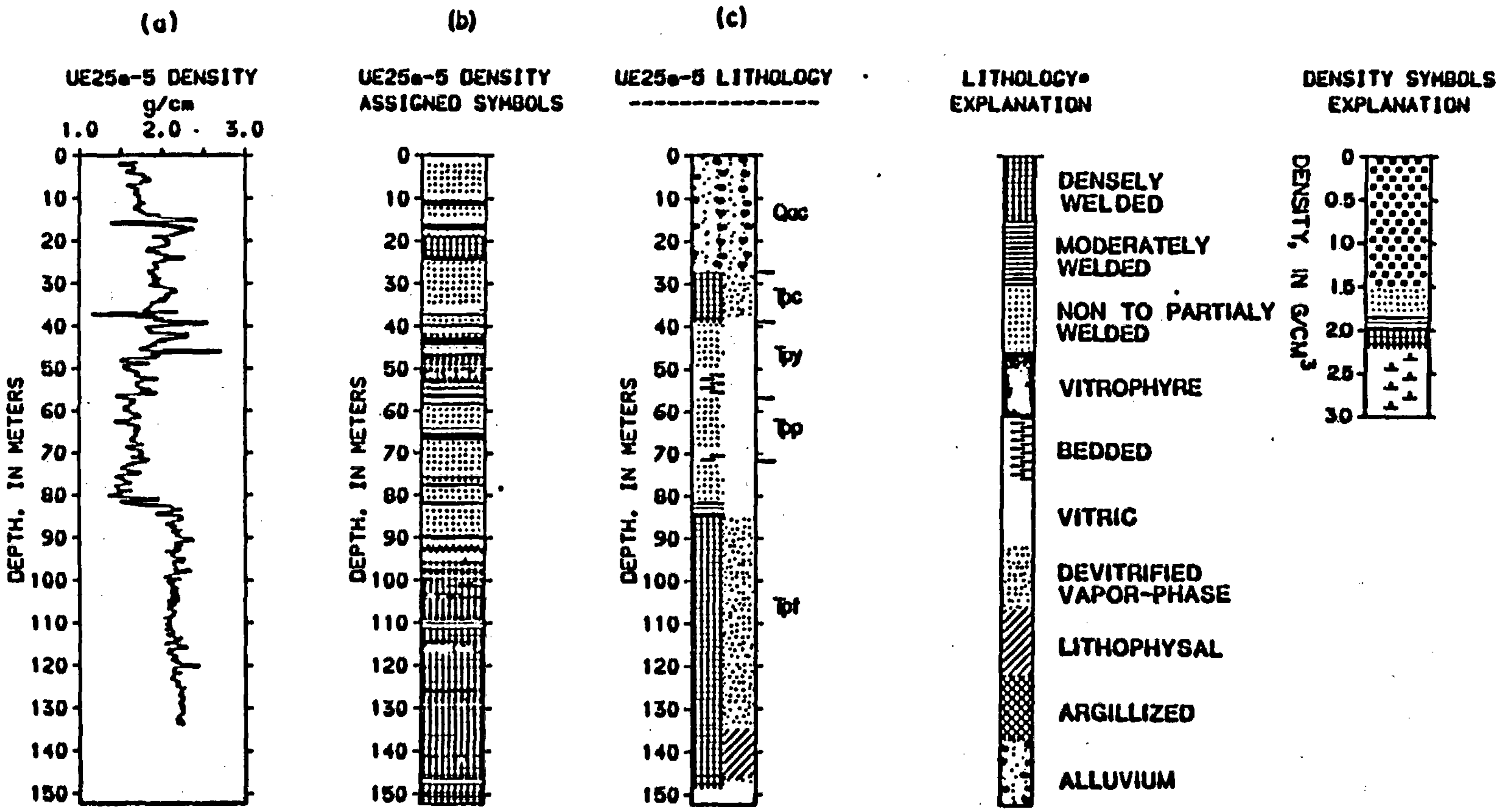

Figure 8.--Density well-logs and interpretation for drill hole UE25a-5:
(a) density well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

Therefore, the density well log should always be interpreted in conjunction with the caliper well log (Figure 11). Non-welded and highly altered units have low bulk densities, while densely welded units have high bulk densities. Devitrified and lithophysal zones should have relatively low densities.

The density well logs for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 are shown in Figures 7, 8, 9, and 10, respectively. Density symbol-logs, obtained by assigning lithologic symbols to density value ranges are also shown in these figures. The high density values in the Topopah Spring Member can be consistently interpreted as being caused by the presence of welded tuffs. In each of the drill holes there is an increase in the density near the top of the Topopah Spring which is probably caused by the vitrophyre indicated on the lithologic log. The lowest densities for the logged interval in each drill hole occur in the non- to partially welded zones in the Yucca Mountain and Pah Canyon Members, while intermediate density values were measured in the Tiva Canyon. However, the Tiva Canyon is classified as a densely welded unit by the lithologic core description. The average bulk density values, computed from the geophysical well logs, for the logged interval below the upper Topopah Spring vitrophyre are as follows: (a) UE25a-4 has an average bulk density of 2.09, (b) UE25a-5 has an average bulk density of 2.16, (c) UE25a-6 has an average bulk density of 2.13, and (d) UE25a-7 has an average bulk density of 2.11. Therefore, the Topopah Spring in UE25a-5 has the highest bulk density, while UE25a-4 has the lowest bulk density. The high bulk density values in drill hole UE25a-5 are consistent with the high resistivity values (and the least amount of fracturing) noted previously in this paper.

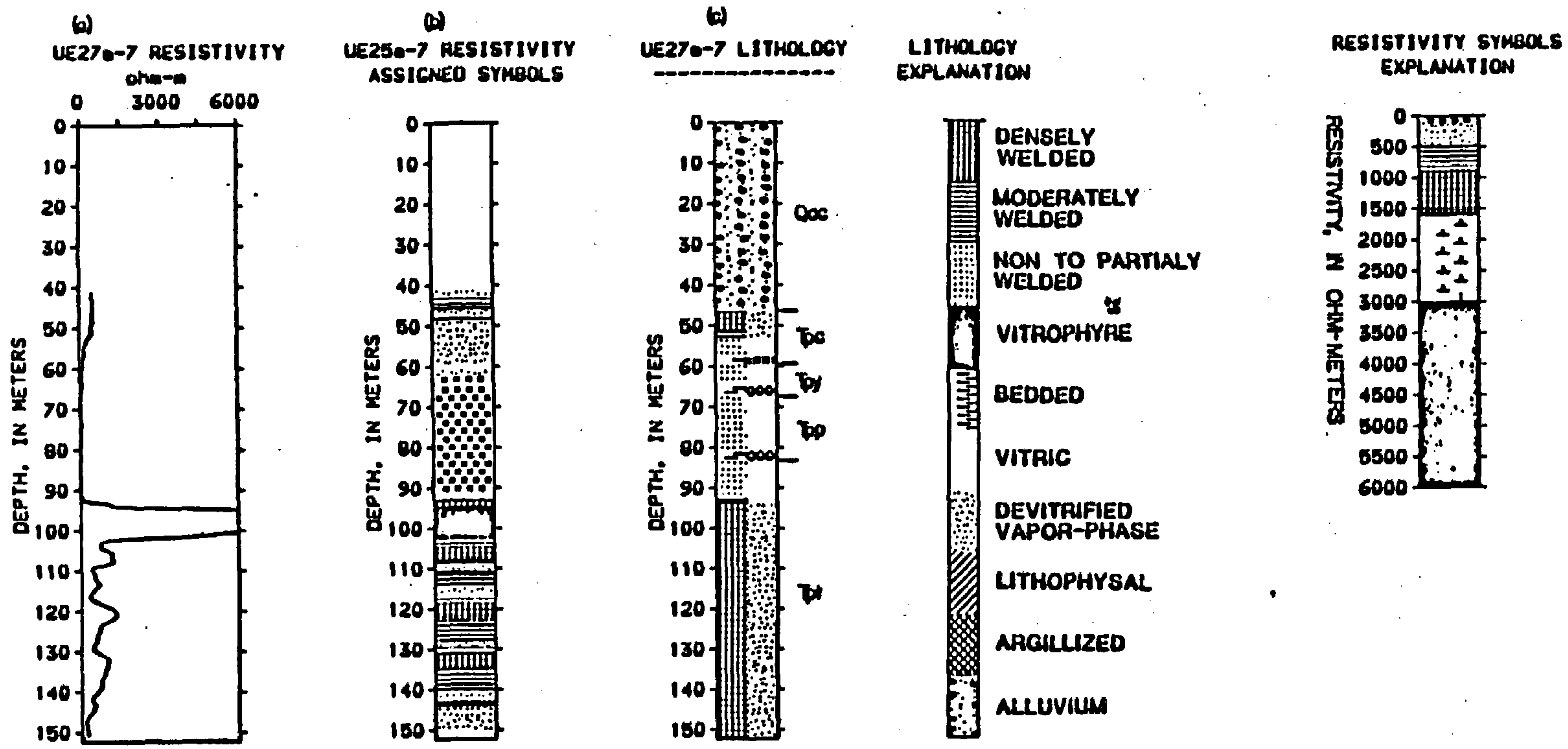

Figure 6.--Resistivity well-logs and interpretation for drill hole UE25a-7:
(a) resistivity well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

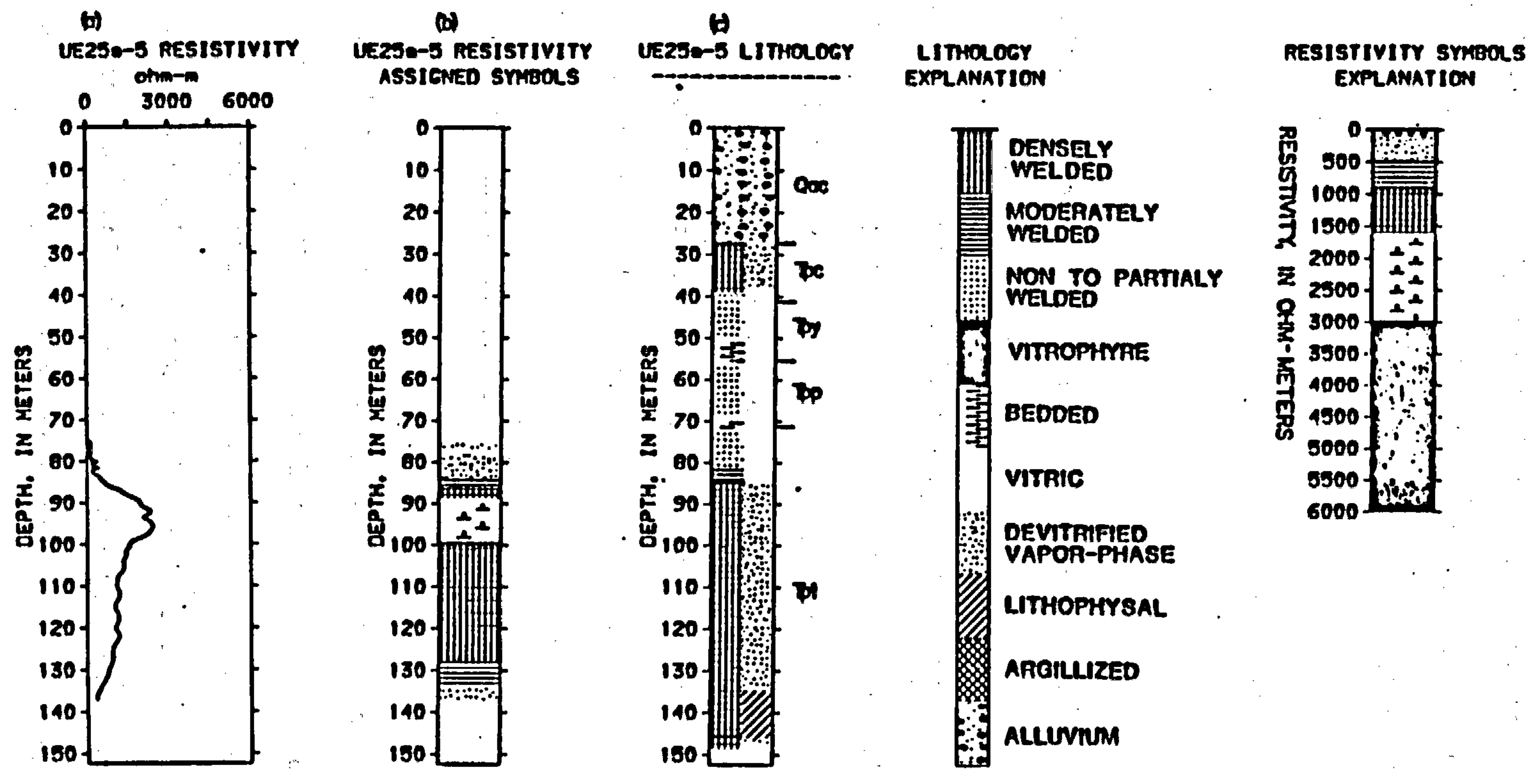

Figure 4.--Resistivity well-logs and interpretation for drill hole UE25a-5:
(a) resistivity well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

Interpretation of individual geophysical well logs is made by assigning symbols to different value ranges on the geophysical well logs. The value ranges are chosen to best correspond with the lithologies given in Figure 2. However, the lithologies in Figure 2 were not chosen on the basis of physical properties and are often different from the computer-assigned symbols for the geophysical well logs.

Resistivity

Resistivity is a measure of the ease with which electric current passes through a material. Borehole resistivity depends upon the porosity, the fluid resistivity and the grain resistivity of the rock. The resistivity of ash-flow tuffs should be a function of (a) welding, (b) devitrification, and (c) void space in the rocks. Resistivity in saturated welded tuffs should increase with the degree of welding and decrease with the degree of devitrification and the amount of void space (including fractures) in the rocks. When the lithophysal zones are unsaturated, the void space may cause an increase in the measured resistivity.

The resistivity well logs (16" normal) for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 are shown in Figures 3, 4, 5, and 6, respectively. Symbol-logs, obtained by assigning lithologic symbols to resistivity value ranges, are also shown in these figures. There is a general correspondence between the lithologic log and the symbol log interpreted from the resistivity values. The high resistivity values for the Topopah Spring Member can be fairly consistently interpreted as welded tuffs. However, in each of the drill holes there is a zone of high resistivity at the top of the Topopah Spring and a zone of low resistivity at the base of the drilled Topopah Spring found mostly as linings or fillings of lenticular vugs. Alteration of the tuffs by ground water has resulted in zones of zeolitization, silicification, and calcitization. The ground water level is well below the bottom depth of each of the drill holes considered in this study. The lithologic intervals and the distribution of crystallization and alteration zones as determined by Spengler (1980) are given in Figure 2.

Lithologic interpretation from the Response Characteristics of Geophysical Well Logs in Ash Flow Tuffs

Each geophysical well-log measurement is affected by the physical properties of the rock, the interstitial fluid of the formation, the conditions in the borehole (fluidity and rugosity), the volume of rock investigated by the probe, the vertical resolution of the probe, and the design characteristics of each probe; and so should be considered an apparent rather than a true physical property value.

The initially unsaturated condition of the rocks surrounding these shallow drill holes makes interpretation of the lithologies particularly difficult. Drilling artificially introduces fluid into the formation, causing the rocks surrounding the drill hole to become partially saturated. Large closed voids in the rocks can remain dry throughout the period of time that geophysical well-log measurements are made. The resistivity and neutron-neutron measurements are sensitive to the degree of saturation of the rocks with fluid. The fluid level could not be maintained to the surface in any of the drill holes in this study. Therefore, the resistivity and neutron well logs are shown for that portion of the drill holes for which a "standing" water level could be maintained.

(under the auspices of the U.S. Department of Energy) at NTS. Exploratory drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 were drilled and cored to depths of 138 m, 133 m, 128 m, and 143 m, respectively, on the northeastern flank of Yucca Mountain to investigate the geologic characteristics of the (listed in order of increasing age): Tiva Canyon, Yucca Mountain, Pah Canyon, and Topapah Spring Members of the Miocene Paintbrush Tuff. Holes UE25a-4, -5, and -6 were vertical core holes, while hole UE25a-7 was drilled at an angle of 26° from vertical. The location of these drill holes is shown in Figure 1. This study discusses the physical properties of the tuff units as measured with U.S. Geological Survey borehole geophysical research equipment.

Geologic Considerations

The sequences of ash-flow and bedded tuffs at NTS have been classified as stratigraphic units primarily on the basis of genetic relationships and cooling histories. The cooling histories of the tuff units determine the degree to which they become welded (i.e., non- to partially welded, moderately welded, densely welded) and are due largely to the temperature of emplacement and the thickness of cooling units (Smith, 1960).

Zones of crystallization and alteration are superimposed on the variously welded portions of the vitric tuffs, although their presence may be dependent on the degree of welding. Devitrification of the pyroclastic flows has occurred throughout almost all of the densely welded portions of the tuffs. Associated with the thickest densely welded zones are inner cores characterized by lithophysal cavities. These are nearly spherical, mainly unconnected voids that are commonly lined with secondary minerals. Vapor-phase minerals that crystallize from the hot volatiles released by the cooling tuff units are

TABLE OF CONTENTS

Open-File Report 81-389

Open-File Report 81-389

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Interpretation of Geophysical Well-Log Measurements in Drill Holes UE25a-4, -5, -6, and -7, Yucca Mountain, Nevada Test Site

by

J. J. Daniels, J. H. Scott, and J. T. Hagstrum

Open-File Report 81-389

1981

Prepared by the U.S. Geological Survey
for
Nevada Opera' 'ons Office
U.S. Department of Energy
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Abstract

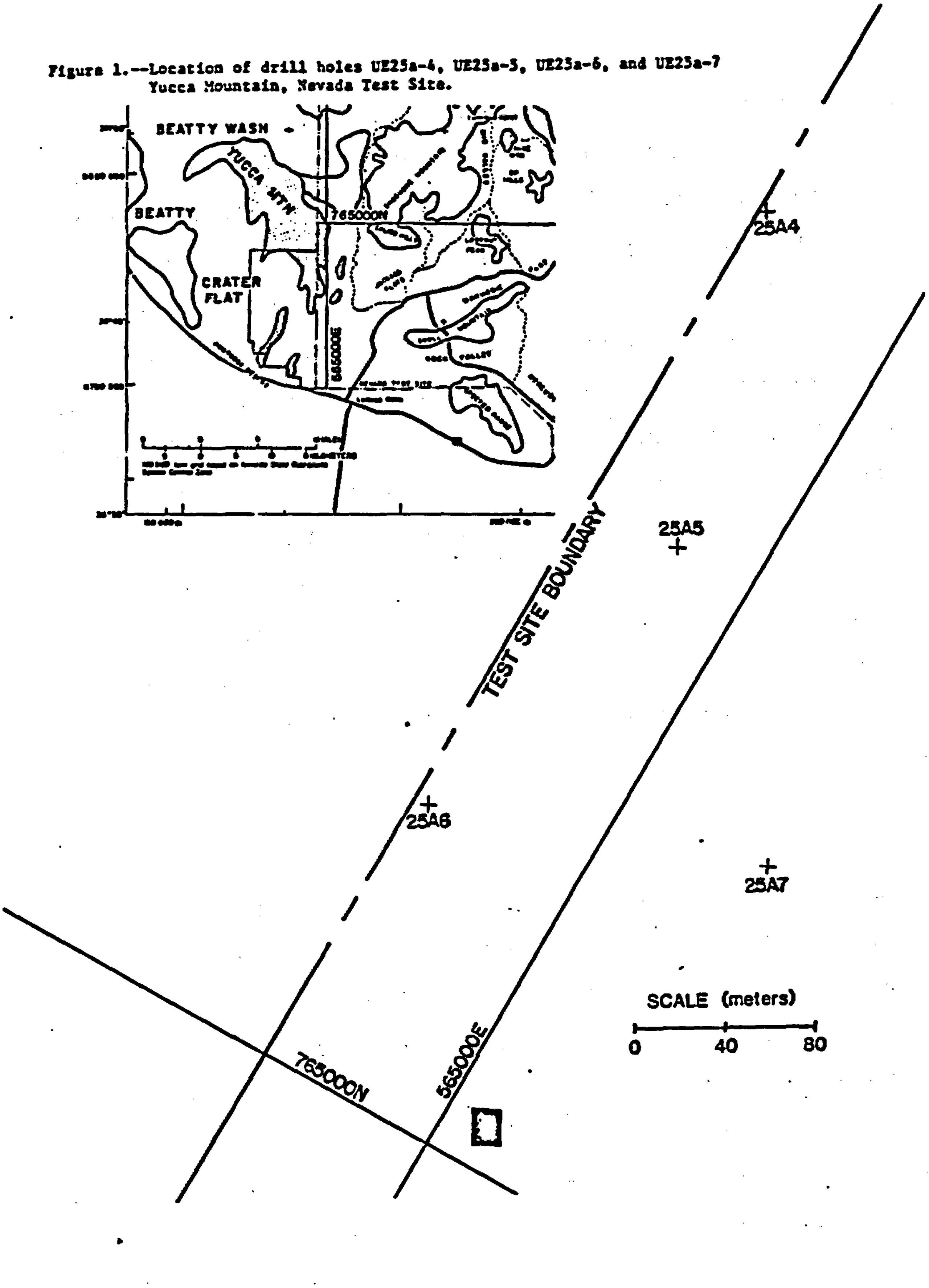
Exploratory holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 were drilled at the Nevada Test Site (NTS) to determine the suitability of pyroclastic deposits as storage sites for radioactive waste. Studies have been conducted to investigate the stratigraphy, structure, mineralogy, petrology, and physical properties of the tuff units encountered in the drill hole. Ash-flow and bedded tuff sequences at NTS comprise complex lithologies of variously welded tuffs with superimposed crystallization and altered zones. Resistivity, density, neutron, gamma-ray, induced-polarization, and magnetic-susceptibility geophysical well-log measurements were made to determine the physical properties of these units. The interpretation of the well-log measurements was facilitated by using a computer program designed to interpret well logs. The broad features of the welded tuff units are readily distinguished by the geophysical well-log measurements. Some mineralogic features in the drill holes can be identified on the gamma ray, induced polarization, and magnetic susceptibility well logs.

Introduction

As much as 3000 m of rhyolitic tuffs that were erupted from the Timber Mountain-Oasis Valley caldera complex (late Tertiary time (16-9 m.y.)) at NTS mantle an eastern portion of the Basin and Range province. The tuff units and their associated calderas have been the subject of mapping and detailed study by the U.S. Geological Survey (Byers, et al, 1976; Christiansen, et al, 1977; and Lipman, et al, 1966).

To study the suitability of pyroclastic deposits as storage sites for radioactive waste, four exploratory holes were drilled in the summer of 1979

Figure 1.--Location of drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7 Yucca Mountain, Nevada Test Site.



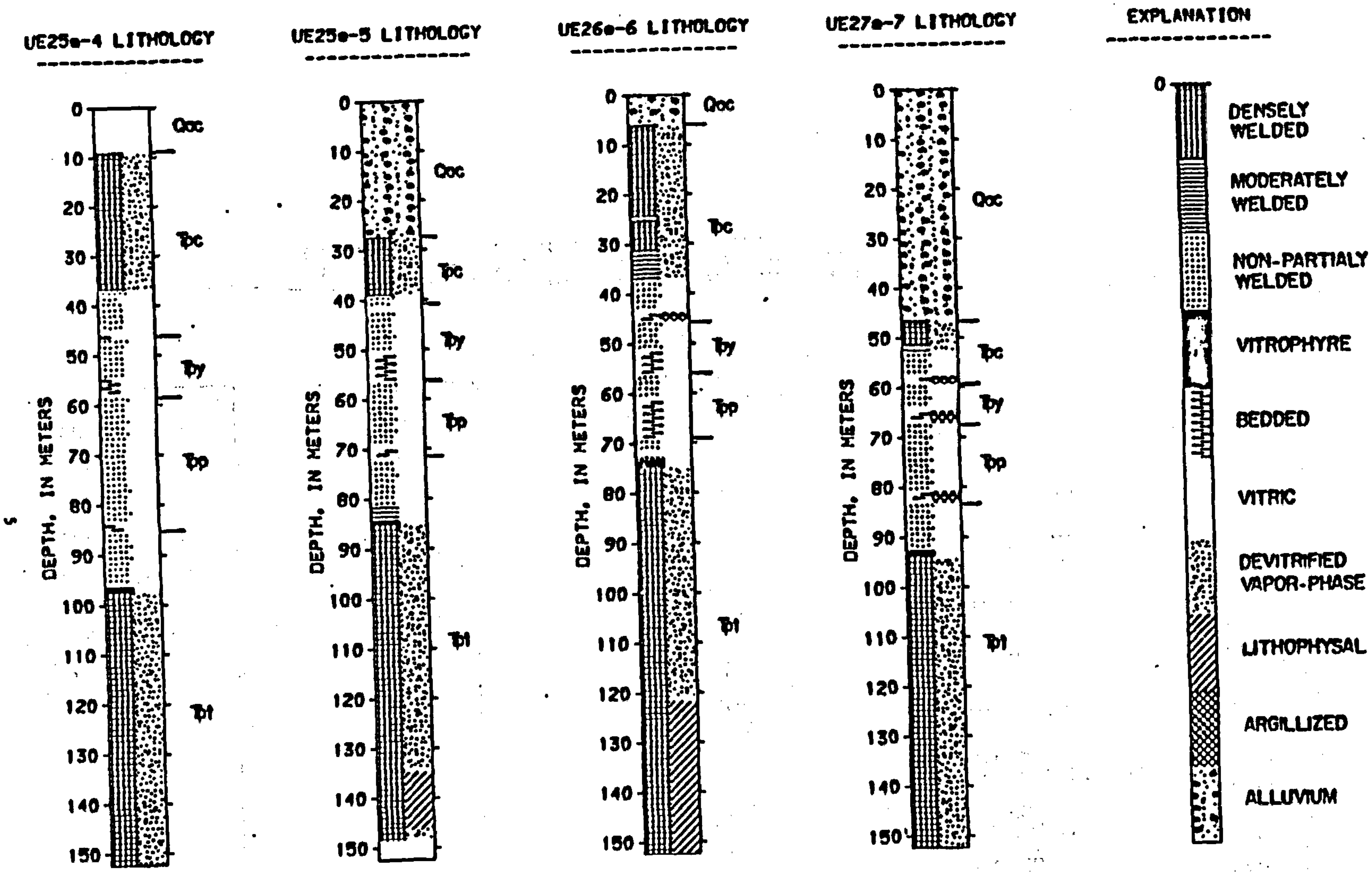


Figure 2.--Lithologic well-logs (interpreted from core) for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7, (modified after Spengler, in press).

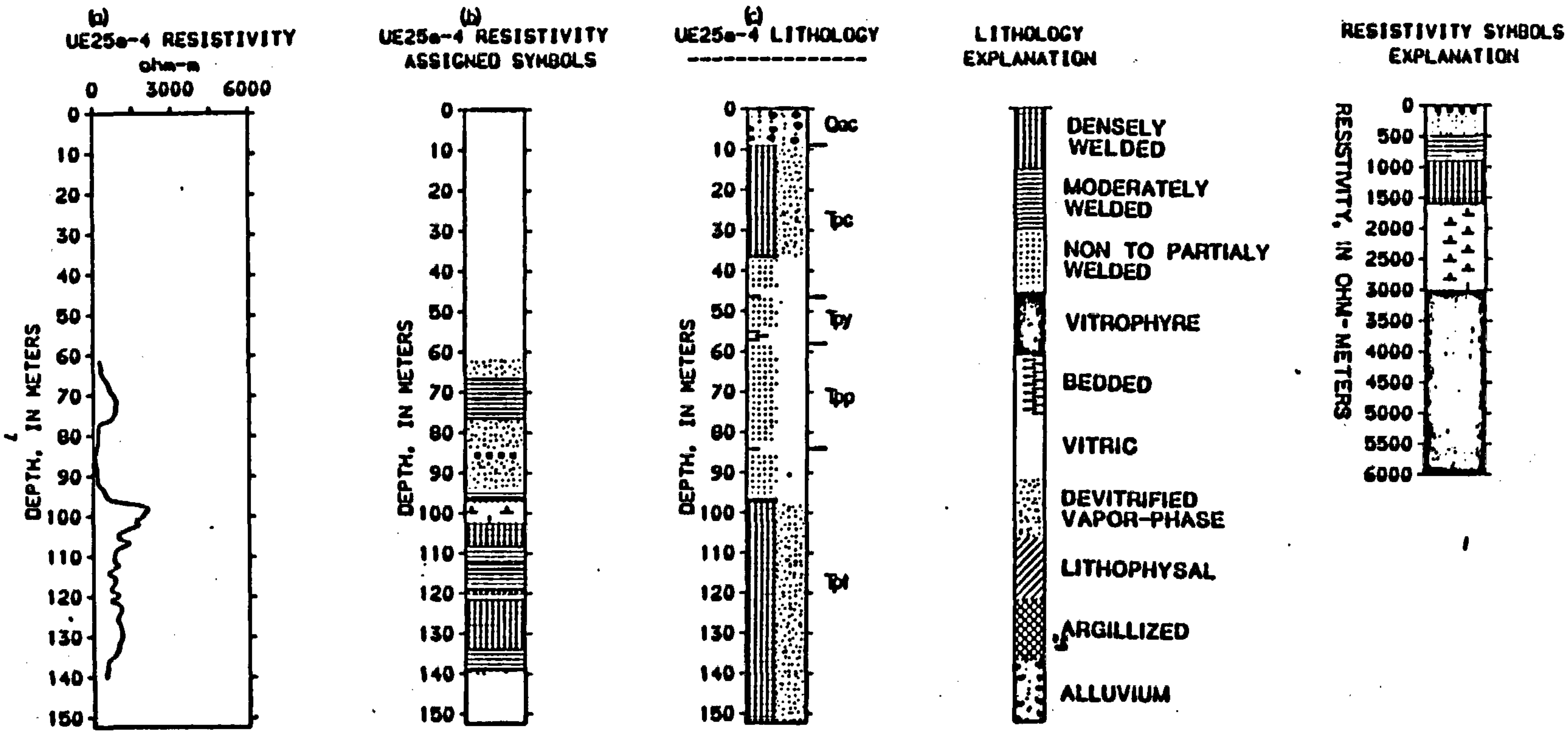


Figure 3.--Resistivity well-logs and interpretation for drill hole UE25a-4:
(a) resistivity well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

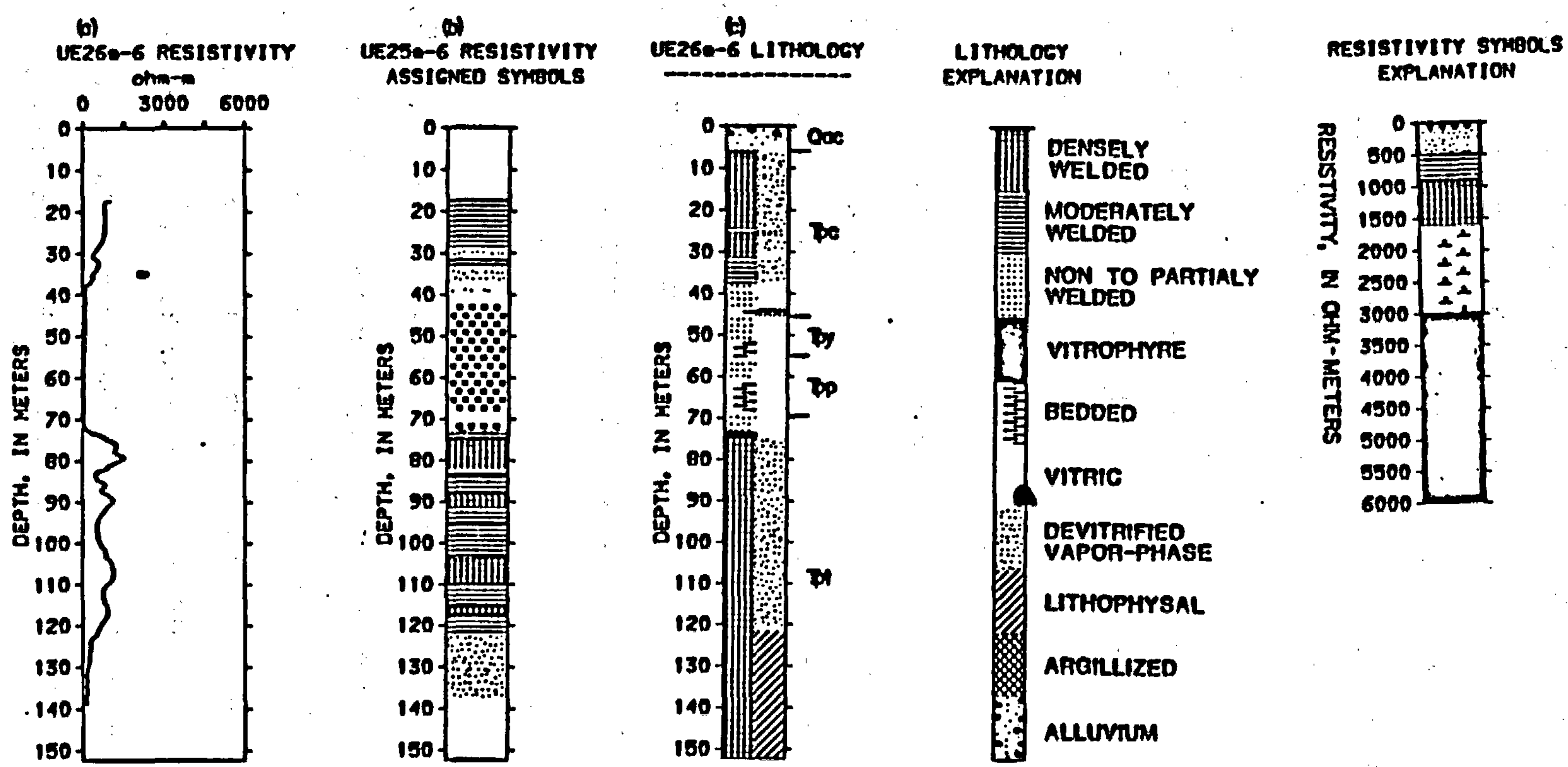


Figure 5.--Resistivity well-logs and interpretation for drill hole UE25a-6: (a) resistivity well-log, (b) computer assigned symbols, and (c) lithologic well-logs (after Spengler, in press).

interval that cannot be explained solely by variations in the degree of welding. It is possible that a vitrophyre causes the high-resistivity zone at the top of the Topopah Spring and a lithophysal zone causes the low resistivities at the bottom of drill holes UE25a-5 and UE25a-6. However, it is also likely that there are variations in the degree of welding which cannot be seen in the drill core but do affect the resistivity. A comparison of the four resistivity well logs for the Topopah Spring Member indicates the following: (a) a high degree of welding (or low alteration and fracturing) for drill hole UE25a-5, (b) an intermediate degree of welding for drill hole UE25a-4, and (c) a low degree of welding (or high alteration and fracturing) for drill holes UE25a-6, and UE25a-7. The stratigraphic members above the Topopah Spring are less densely welded, resulting in low resistivity values. If the degree of welding in the Topopah Spring is approximately the same for each drill hole, then near-surface fracture zones (with increased seasonal ground water percolation) are most likely to occur near drill holes UE25a-6 and UE25a-7 and least likely to be present near drill hole UE25a-5.

Density

The density measurement probe consists of a gamma ray source (Cs^{137}) and one, or more, gamma ray detectors. Gamma rays emitted by the source are scattered by the rock, and the gamma radiation measured at the detector decreases as the electron density of the rock increases. By using two detectors, the adverse effects of fluid invasion, mudcake and rugosity can be minimized, resulting in a computed compensated-density that is approximately equal to the bulk density of the rock. The computed bulk density may be too low when there are large (sharp) variations in the diameter of the borehole.

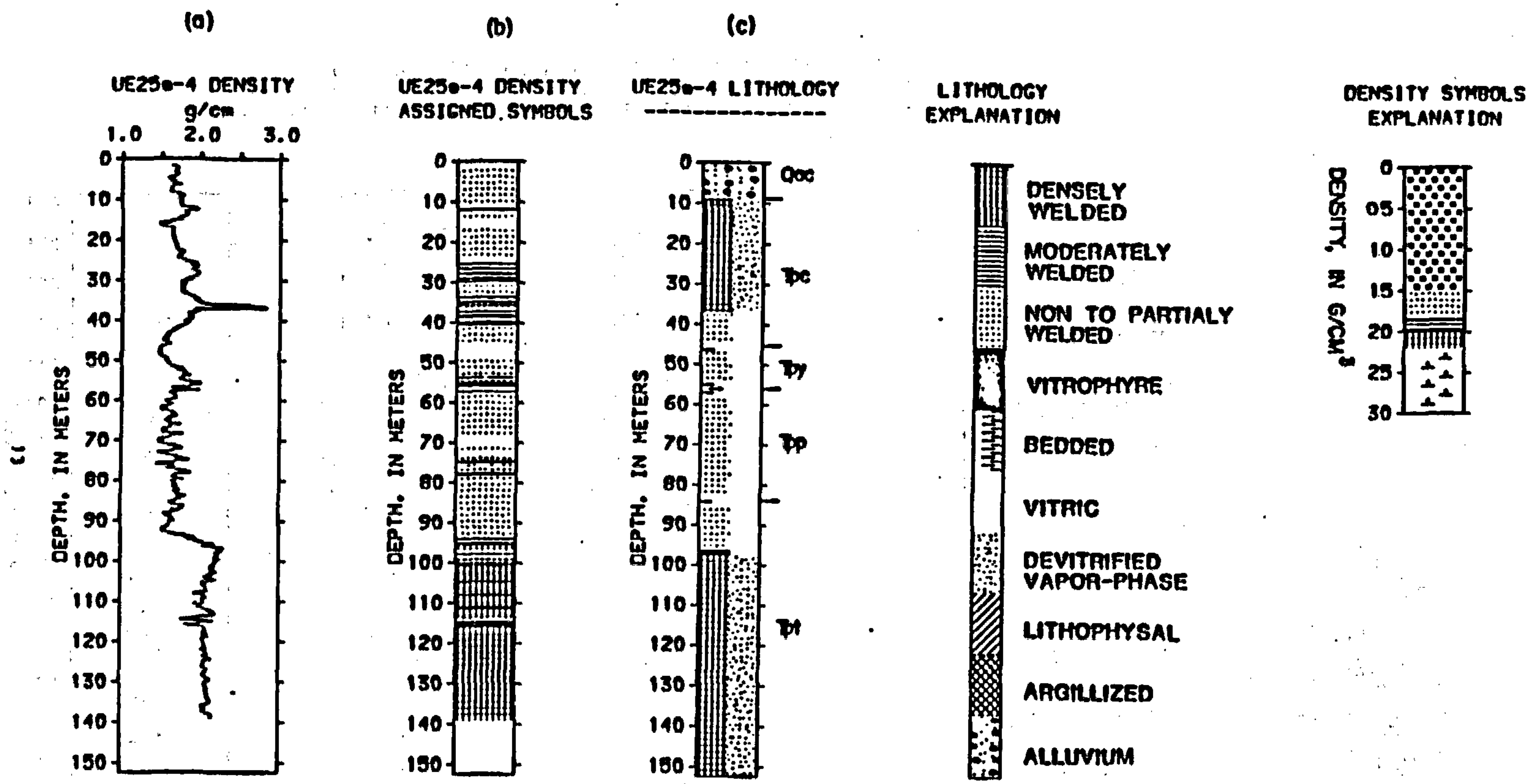


Figure 7.--Density well-logs and interpretation for drill hole UE25a-4: (a) density well-log, (b) computer assigned symbols, and (c) lithologic well-logs (after Spengler, in press).

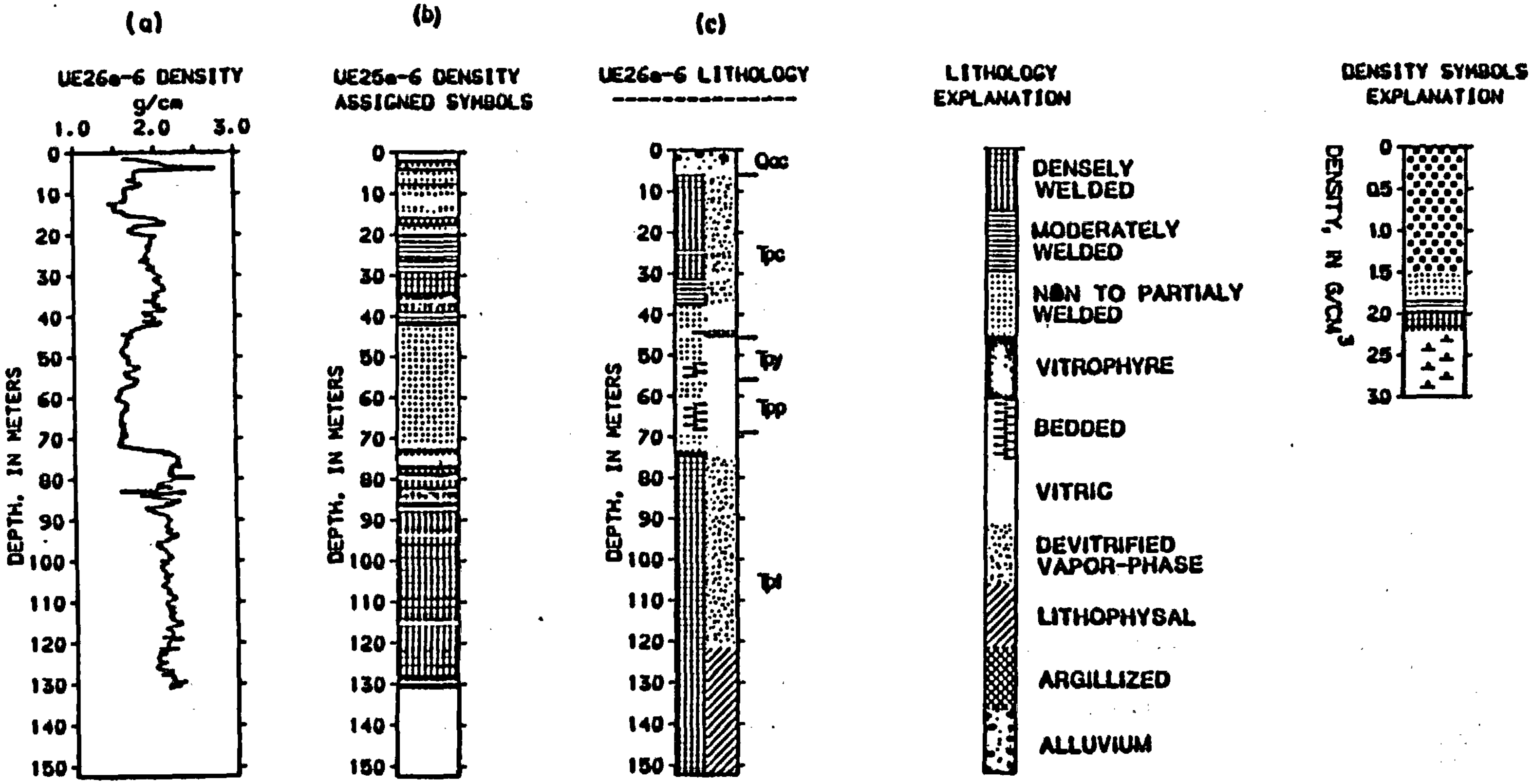


Figure 9.--Density well-logs and interpretation for drill hole UE25a-6:
(a) density well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

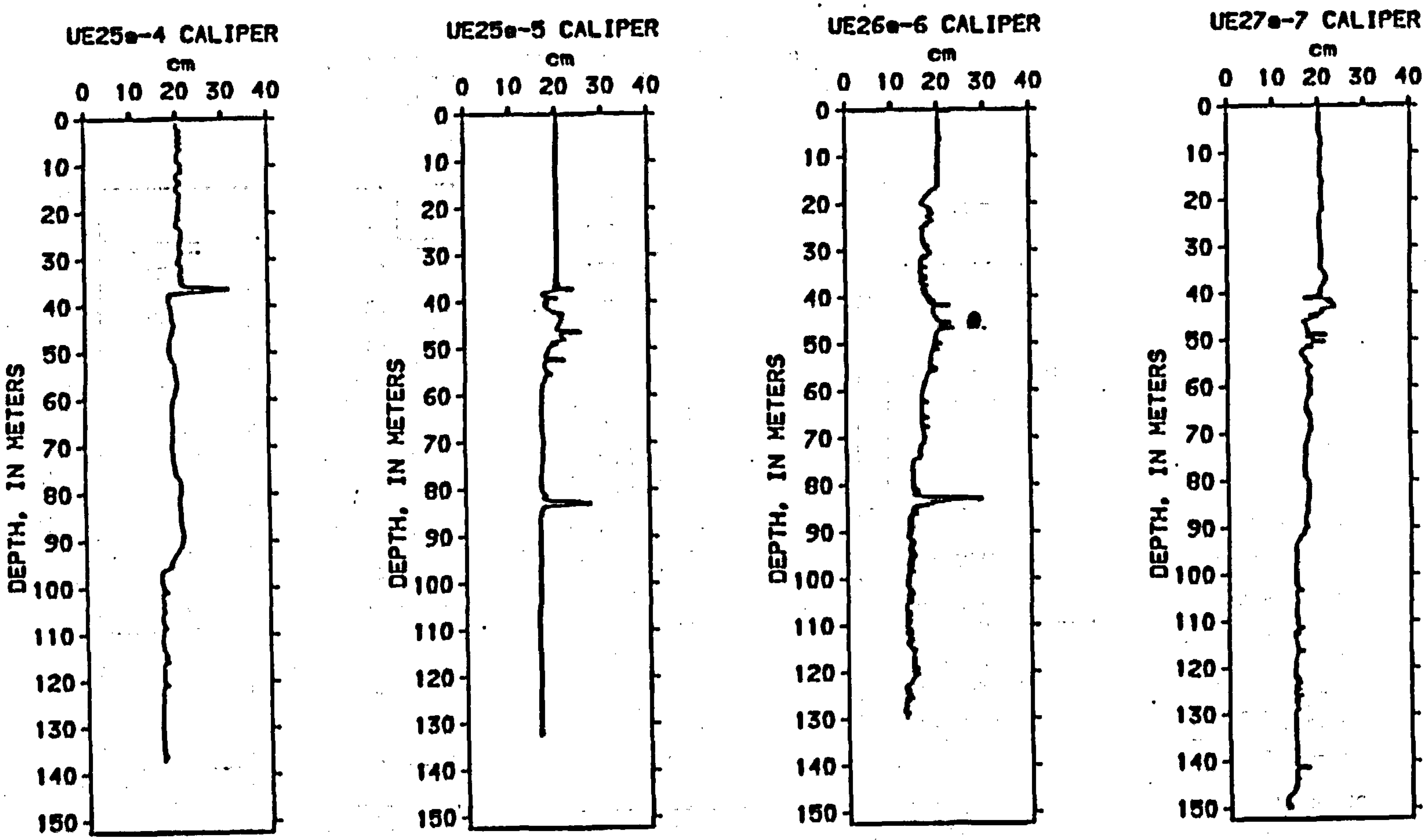


Figure 11.--Caliper logs for UE25a-4, UE25a-5, UE25a-6, and UE25a-7.

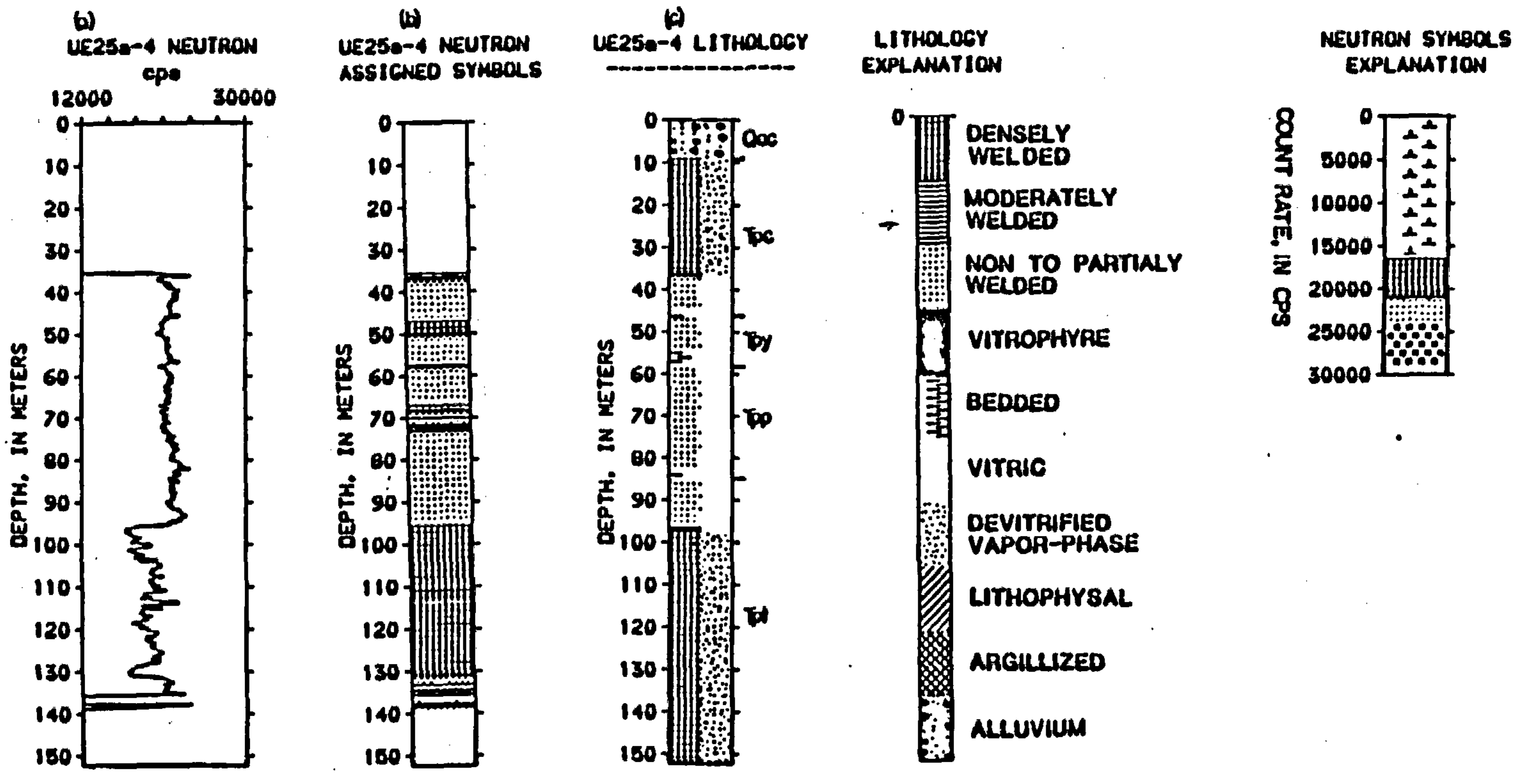


Figure 12.--Neutron well-logs and interpretation for drill hole UE25a-4:
(a) neutron well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

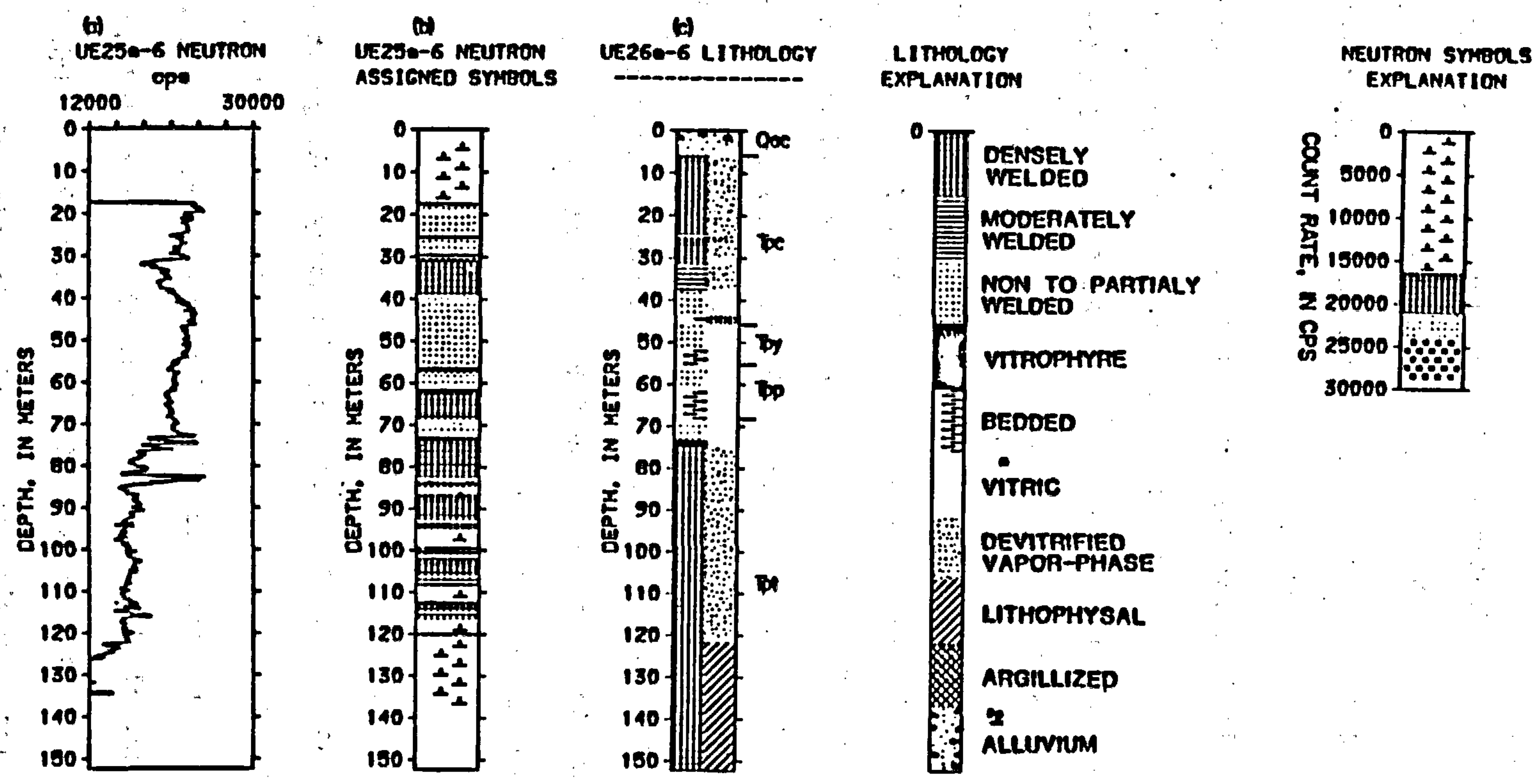


Figure 14.--Neutron well-logs and interpretation for drill hole UE25a-6:
(a) neutron well-log, (b) computer assigned symbols, and
(c) lithologic well-logs (after Spengler, in press).

minerals are uranium-series isotopes and potassium-40. Since potassium bearing minerals are common in both primary and secondary crystallization regimes in welded tuffs, the gamma ray well log measurements are principally a measure of relative abundance of potassium.

The gamma ray well logs for drill hole UE25a-4, UE25a-5, and UE25a-7 are shown in Figure 16. The Topopah Spring Member has a fairly consistent gamma signature that is correlatable between each of the four drill holes. However, the units above the Topopah Spring show that there is a great deal of variation in the potassium content of the four drill holes. The intensity and character of the gamma ray response above the Topopah Spring is approximately the same in drill holes UE25a-6 and UE25a-7 (Figures 16), but is lower than the response in UE25a-4. The intensity of the gamma ray measurements in drill hole UE25a-5 (Figure 17) is the lowest of any of the gamma ray well logs. If the amount of potassium is related to post-emplacement chemical alteration, then these logs indicate that there could be a fairly large differences in alteration between the three drill holes.

Induced Polarization (IP)

The IP measurement is made by recording the decay voltage at a potential electrode from a time-domain current source. The potential electrode is located on the probe at a spacing of 10 cm from the current source. The rate of decay of the potential during the current-off time period is inversely proportional to the electrical polarizability of the rock. A high IP response in volcanics may be caused by the presence of cation-rich clays, zeolites, or pyrite and other sulfides. However, in some cases iron oxide minerals can contribute to the IP response.

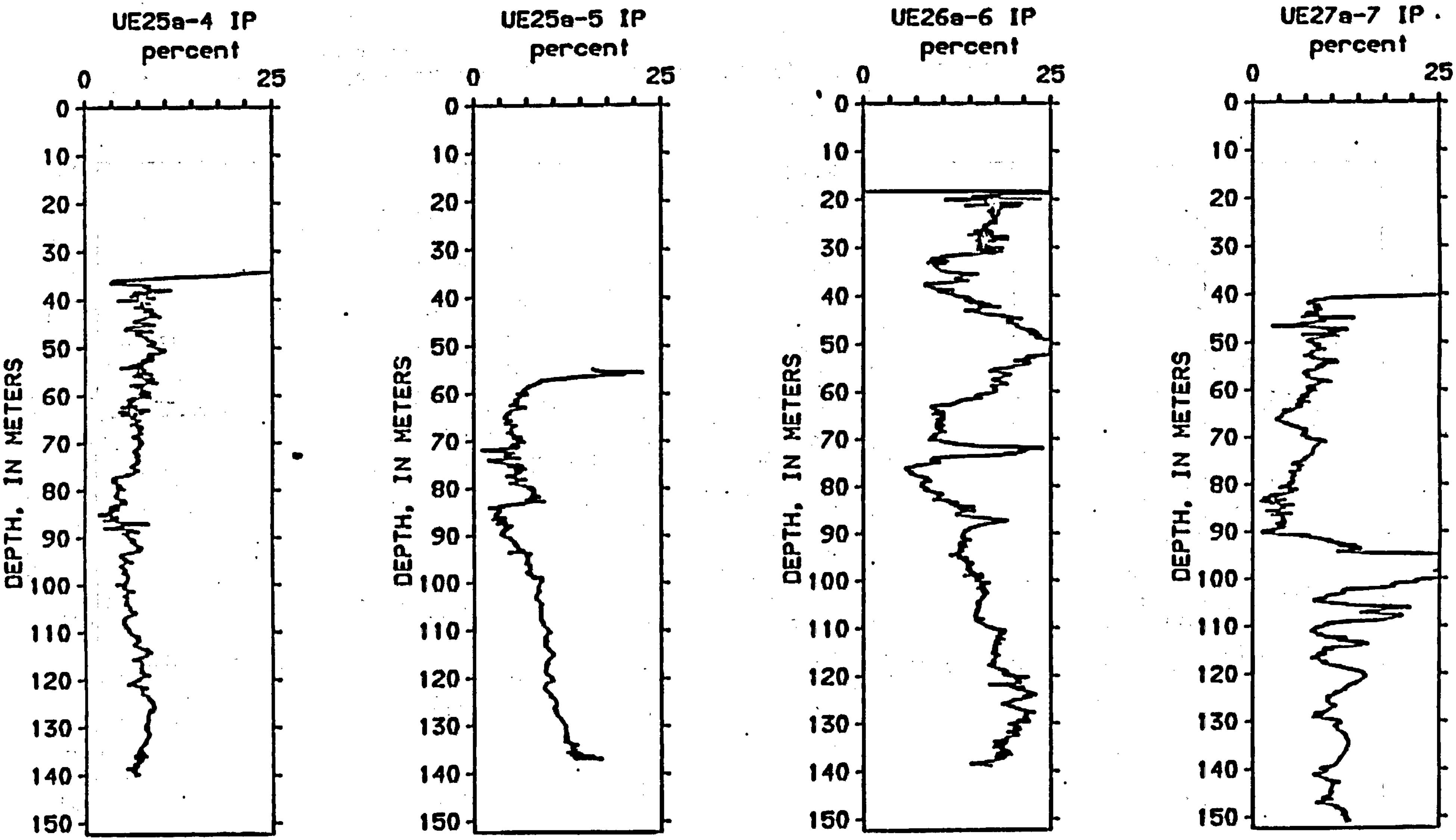


Figure 17.--Induced polarization well-logs for UE25a-4, UE25a-5, UE25a-6, and UE25a-7.

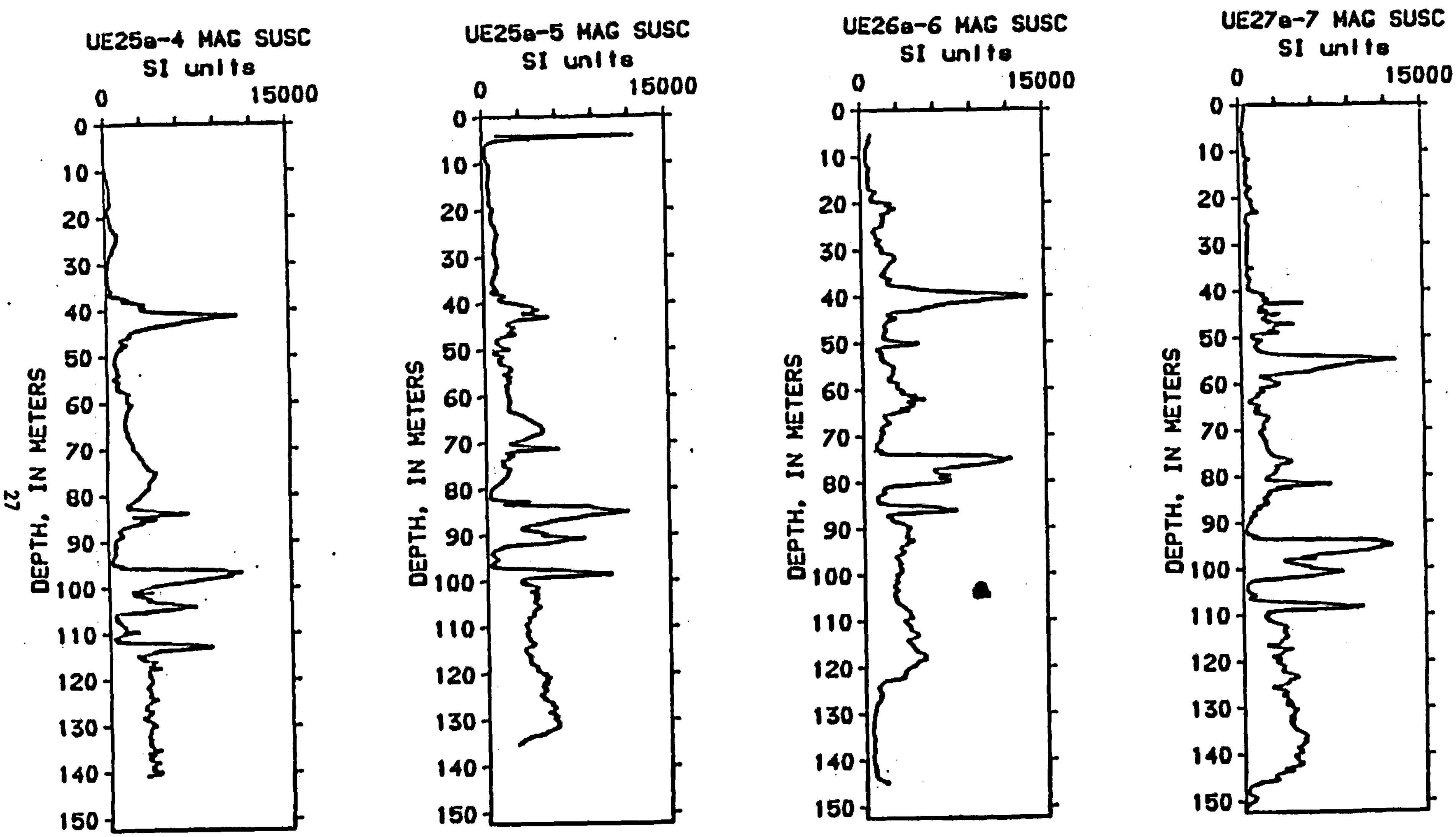


Figure 18.--Magnetic susceptibility well-logs for UE25a-4, UE25a-5, UE25a-6, and UE25a-7.

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GPO 830-378

4. RESULTS OF EXPLORATORY DRILLING

Exploratory holes UE14a and UE14b were drilled to depths of 1006 and 1122 m, respectively. The holes were drilled to: (1) determine the combined thickness of the alluvium/tuff section and the depth and character of Paleozoic rocks; (2) determine the depth to the SWL; (3) assess the degree of hole stability; and (4) determine the physical properties of the alluvium and volcanic rocks. Each hole was collared in alluvium and completed in the Topopah Spring Member of the Paintbrush Tuff.

Exploratory Hole UE14a

Exploratory hole UE14a was planned as a 0.31-m-diameter hole to be drilled using conventional circulation (air-foam) to a depth sufficient to penetrate 30 m into the Paleozoic rocks. This depth was inferred from gravity data to be 730 ± 61 m. Because of a strong water inflow combined with sloughing problems and a stuck drill pipe at 947 m, the hole was terminated at a depth of 1005.8 m. Paleozoic rocks were not encountered. Construction and scientific geophysical logs were run during drilling and after termination. The log data suggest that the density contrast between volcanic and Paleozoic rocks that was used to predict depth to the Paleozoic rocks was erroneous. Hole bridging and fill prevented any geophysical log from reaching the total drilled depth. Table 4.1 gives a summary of these logs. After geophysical logging, a string of 73-mm tubing--slotted in the bottom three joints--was emplaced to 609.8 m to monitor water level. Appendix A gives an abstracted drilling history.

Samples

Standard cuttings were taken at 3.1-m intervals or whenever the drill hole would unload. One conventional core run was attempted without success at the 1005.8-m depth. Fill at the 985-m depth together with the inability to circulate fluid forced the cancellation of the core run. Seven depths in the alluvium were sampled with a percussion gun sidewall sampler to compare water content with that measured by the epithermal neutron tool. The water content results are discussed below.

Table 4.1. Geophysical logs--UE14a.

Log	Run date	Run No.	Logger	Interval top-bottom (m)
<u>Velocity</u>				
Vibroseis	7/10/83	1	Birdwell	46-491
Dry-hole acoustic log (DHAL)	7/31/83	1	LLNL-N	24-447
<u>Density</u>	7/18/83	1	Birdwell	18-504
<u>Other scientific logs</u>				
Electric log-induction	7/18/83	1	Birdwell	18-504
Electric log-induction	7/29/83	2	Birdwell	18-680
Gamma ray	7/16/83	1	Birdwell	15-687
Gamma ray	7/19/83	2	Birdwell	18-702
Magnetometer	7/18/83	1	LLNL-N	30-596
Magnetometer	7/29/83	2	LLNL-N	18-682
Epithermal neutron	7/19/83	1	Birdwell	18-503
<u>Construction logs</u>				
Caliper	7/18/83	1	Birdwell	6-507
Caliper	7/29/83	2	Birdwell	3-681
Nuclear annulus investigation log	8/11/83	1	Birdwell	390-573
Nuclear annulus investigation log	8/31/83	2	Birdwell	454-572
Nuclear annulus investigation log	9/14/83	3	Birdwell	472-533
Fluid density	7/15/83	1	Birdwell	472-533
Fluid density	7/16/83	2	Birdwell	488-503
Fluid density	7/18/83	3	Birdwell	387-506
Fluid density	7/29/83	4	Birdwell	340-370
Fluid density	7/29/83	5	Birdwell	365-387
Fluid density	8/2/83	6	Birdwell	360-399
Fluid density	8/9/83	7	Birdwell	396-572
Fluid density	8/11/83	8	Birdwell	390-573
Fluid density	8/31/83	9	Birdwell	491-572
Fluid density	9/7/83	10	Birdwell	488-509
Fluid density	9/14/83	11	Birdwell	488-509

Lithology and Stratigraphy

Table 4.2 is a lithologic and stratigraphic log of drill hole UE14a. No scientific geophysical logs were obtained below a depth of 689 m. The lithologic log of UE14a from 689 to 1005.8 m is based entirely on cuttings.

Alluvium and Hole Stability

We subdivided the alluvium section into four units according to our thoughts on emplacement-hole-type drilling and hole stability. The cuttings and geophysical logs indicate that each unit grades into the next underlying unit. Averages of geophysical measurements of the interval are given in Table 4.3. Plots of the geophysical parameters are shown in Fig. 4.1. Although Paleozoic rocks currently crop out to the north and west of the drill hole, the alluvium encountered in the drill hole is predominantly tuffaceous.

The occurrence of the Thirsty Canyon ashfall within the alluvium section brackets the age of the underlying alluvium as 7.5 to 11.1 Ma (see Table 2.1). The samples and the caliper log both show that the alluvial section from about 0 to 105 m is poorly indurated (Fig. 4.1). The caliper log was run after the hole had reached total depth. Hole enlargement through this interval ranged from 250% below the surface casing to 20% at 105 m. During the drilling phase the borehole walls were subjected to erosion from both the air-foam and cuttings as well as from the large quantity of fresh water blown from the drill hole at a relatively high velocity. Emplacement-hole-type drilling through this interval using dual-string reverse-air and water would have exposed the borehole walls to 30 to 90 m of standing water. The relatively low calcium carbonate cementation and lack of clay bonding in the alluvium might then have contributed to even more sloughing than was actually observed.

The tuffaceous alluvium section from 105 to 152 m is similar to the interval above it, with minor exceptions. The grain size gradationally decreases with depth and calcareous cementation appears to increase. Near the base of the interval the alluvium becomes slightly more argillized. Hole enlargement through this interval ranges from 15 to 20%. This section of the hole is considered to be more indurated than the preceding interval and might have undergone minor sloughing with emplacement hole reverse-air drilling.

Table 4.2. Lithologic description of hole UE14a.

Coordinates: N 242 042.16 m, E 198 882.40 m

Elevation: 1321.7 m

Depth: 1005.84 m

Static water level: 502.0 m

Depth (m)	Description
0-24	No cuttings or geophysical logs.
	<u>Alluvium (24-324 m)</u>
24-105	Tuffaceous alluvium, medium brown to gray, fine to coarse sand and gravel with 20% cobbles and boulders, 95% welded ashflow tuff fragments in a sand and silt matrix, 5% Paleozoic rock fragments consisting predominantly of quartzite and argillite with a minor amount of dolomite and limestone; matrix is calcareous and some gravel size fragments are caliche-coated, interval is poorly indurated, hole elongation from 24 to 54 m (orientation unknown).
105-152	Tuffaceous alluvium, mottled gray to brown, coarse tuffaceous sandstone with clasts of welded ashflow tuff, matrix is increasingly calcareous toward the bottom of the section, base of the interval is moderately argillized, interval is indurated, gradational decrease in grain size toward the bottom of the interval.
152-262	Tuffaceous alluvium, pale yellowish brown to grayish brown, matrix is coarse to fine sand and silt, pale gray pumice fragments increase toward the base of the section, vugs coated with crystal druses are present; the matrix is calcareous, moderate to high illite-montmorillonite alteration, cemented by clay and colloidal material.
262-273	Thirsty Canyon Tuff, ashfall, bedded, pale yellowish brown to grayish orange, crystals are common to sparse, mafics are sparse, white pumice fragments are sparse, reddish lithic fragments are common; matrix is argillized near the base, noncalcareous, interval is indurated.
273-324	Tuffaceous alluvium, moderate yellowish brown to moderate reddish brown, coarse-grained sandstone; mafics are sparse, crystal fragments are sparse, pumice fragments increase lower in the section, matrix is calcareous and partially to moderately argillized, interval is indurated.

	Timber Mountain Formation (324-411 m)
324-353	Ammonia Tanks Member, ashflow tuff, moderate brown, vitric, partially welded at the top of the section to moderately welded at the bottom of the section; crystals, mafics, and white pumice fragments are common.
353-398	Ammonia Tanks Member, ashflow tuff, brownish gray, moderately welded, devitrified; crystals are common, mafics are sparse, pumice fragments are common.
398-411	Bedded Tuff, ashfall and reworked, very pale orange to grayish orange, crystals are common, mafics are sparse; matrix is argillized and partially zeolitized.
411-473	Rainier Mesa Member, ashflow tuff, pale reddish brown to pale yellowish orange, partially welded; crystals are sparse, mafics are rare, matrix is partially argillized and zeolitized from 411 to 424 m.
473-575	Rainier Mesa Member, ashflow tuff, light brownish gray, moderately welded; crystals are common, mafics and pumice fragments are sparse, iron staining is present on some fragments lower in this interval.
575-616	Rainier Mesa Member, ashflow tuff, moderate reddish brown to very pale orange, nonwelded; crystals are common, mafics are sparse, pumice fragments are common, euhedral vapor phase crystals are present, matrix is zeolitized, iron staining is present on some fragments at the top of this interval.
	Paintbrush Tuff (616-1006 m)
616-627	Bedded tuff, reworked, grayish yellow, crystals, lithic fragments, and mafics are sparse, pumice fragments are common; matrix is slightly calcareous, partially argillized and zeolitized at the base of the interval.
627-641	Tiva Canyon Member, ashflow tuff, moderate reddish brown to very pale orange, slightly welded; crystals are sparse, mafics are rare, matrix is zeolitized and silicified, iron staining is present on some fragments.
641-741	Tiva Canyon Member, ashflow tuff, pinkish brown to gray, partially to densely welded, devitrified; crystals and mafics are rare, matrix is zeolitized and silicified, iron staining on fracture/joint surfaces is prevalent throughout this interval; basal 15 m of interval is a partially welded shardy tuff, yellowish green to tan.

Table 4.2. Continued.

741-765	Topopah Spring Member, ashflow tuff, mottled yellow brown, non- to densely welded, devitrified near the top of the section grading down to densely welded tuff that is mottled reddish brown and purplish gray, crystals and mafics are sparse, interval is generally silicified.
765-917	Topopah Spring Member, ashflow tuff, grayish red to moderate reddish brown, moderately welded, banding from secondary shear is prevalent, crystals are common, mafics are sparse, vapor phase crystals are present, interval is silicified.
917 - 1006 TD	Topopah Spring Member, ashflow tuff, reddish brown to purplish gray, devitrified, silicified.

Lithologic description written from the cutting samples (24-1003 m), geophysical logs (3-682 m), and physical property data.

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Table 4.3. Zonal averages for hole UE14a.

Depth (m)	Water content (wt%)	Bulk density (Mg/m^3)	CO_2 content (wt%)	Acoustic velocity	Seismic velocity	Lithology
0-105	a	1.66	0.28	1060	1143	Alluvium
105-152	20.8	1.87	1.7	1569	1770	Alluvium
152-262	36.4	1.78	3.3	1869	1984	Alluvium
262-273	17.3	1.55	5.2	1617	1879	Thirsty Canyon Tuff
273-324	29.8	1.69	4.6	1925	1903	Alluvium
324-353	13.5	1.92	1.8	1705	2209	Ammonia Tanks Tuff
353-398	6.4	2.19		2887	2965	Ammonia Tanks Tuff
398-411	24.8	1.74		2378	2162	Ammonia Tanks Tuff
411-473	18.8	1.93		1911	2099	Rainier Mesa Tuff
473-575	15.3	2.16			3023	Rainier Mesa Tuff

[a] Data not available.

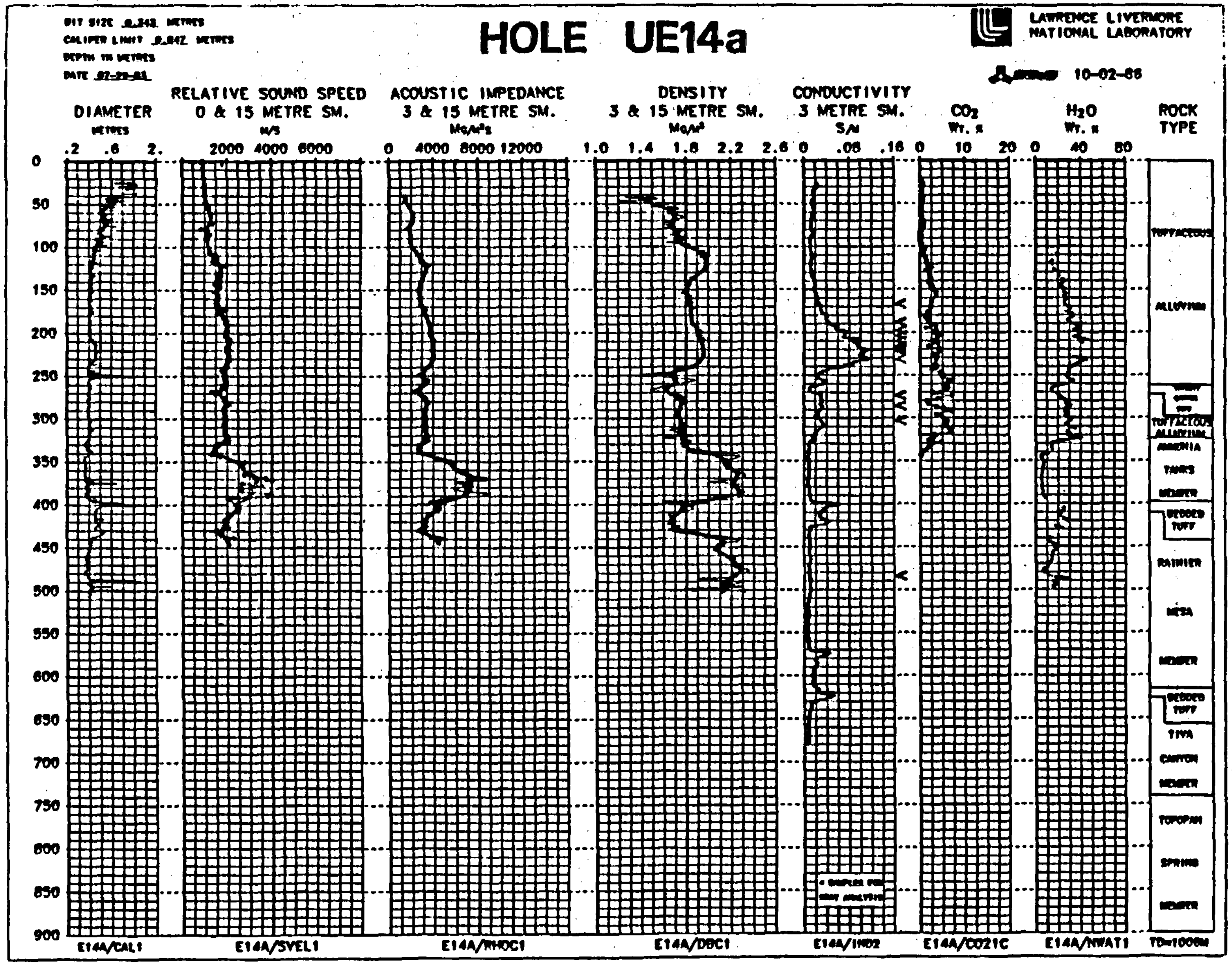

Figure 4.1. Geophysical logs in exploratory hole UE14a.

The tuffaceous alluvium from 152 to 262 m consists of tuffaceous silts and sands that have been moderately to highly altered into an illite-montmorillonite-bearing clay. The caliper log shows a semirounded hole enlargement through this interval that correlates well with the peak of the conductivity log at 225 m (Fig. 4.1). Hole enlargement through this interval ranges from 20 to 25% near the middle of the conductivity peak.

The texture, alteration, and vuggy nature of parts of this interval suggest that sediment was deposited in a placid environment such as a lake and/or playa. Grab samples were taken from Frenchman and Yucca Playas at depths from 1 to 3 m. the samples were analyzed by x-ray diffraction and compared with samples taken from 168 to 232 m in drill hole UE14a. The results are shown in Table 4.4. Evidence for the presence of a playa is inconclusive. No thin section studies have been made to date.

The tuffaceous alluvium between the Thirsty Canyon ashfall and the Ammonia Tanks Member (273 to 324 m) is similar to the basal portion of the preceding alluvium section. The interval is a partially to moderately argillized coarse-grained tuffaceous sandstone with abundant pumice fragments. This alteration tends to bond and indurate the various volcanic rock fragments. The caliper log (Fig. 4.1) indicates negligible hole enlargement through this interval (≈ 15%). We believe this zone of tuffaceous alluvium would remain competent with emplacement-hole-type drilling using proper mud additives.

The epithermal neutron log indicates implausibly high water contents through the illite-montmorillonite-altered alluvium section. Seven horizons within the alluvium were sampled with a percussion sidewall gun. Laboratory analyses of the sidewall samples vs the epithermal neutron log are shown in Fig. 4.2. We have been unable to explain the large discrepancy between the log and samples, but we are not confident of the log calibration in holes of this diameter, and data from sidewall samples are often suspect.

Table 4.4. Mineralogical comparison of drill hole UE14a with Yucca and Frenchman playa samples.

XRD analyses of samples from UE14a (wt%)

Depth ft	Depth m	Sample type[a]	Quar	Mont	Illi	Clin	Cris	Feld	Calc	Dolo	Glas	Horn	Kaol	Musc	Biot
550	168	C	16	11	23	7	0	30	11.4	0	0	0	2	0	0
620	189	C	18	14	28	0	0	32	7.6	0	0	0	0	0	0
650	198	C	13	19	36	5	0	17	3.3	0	0	2	5	0	0
670	204	C	12	19	35	8	0	17	6.4	0	0	2	0	0	0
690	210	C	11	19	36	0	0	24	9.2	0	0	0	0	0	0
710	216	C	15	18	37	0	0	15	15.1	0	0	0	0	0	0
720	219	G	14	10	39	6	0	9	16.7	0	0	0	5	0	0
730	223	C	10	19	36	6	0	17	13.6	0	0	0	0	0	0
760	232	C	9	12	23	0	0	32	25.1	0	0	0	0	0	0
[a]900	274[c]	C	28	0	0	0	26	46	0	0	0	0	0	0	0
[a]940	287	G	17	18	29	0	0	14	21.4	0	0	0	0	0	0
[a]996	304	G	13	0	0	0	0	16	9.3	0	62	0	0	0	0

Total number of samples: 12

Minerals

Quar = Quartz
Mont = Montmorillonite
Illi = Illite
Clin = Clinoptilolite
Cris = Cristobalite
Feld = Feldspars
Calc - Calcite
Dolo - Dolomite
Glas - Glass
Horn = Hornblende
Kaol = Kaolinite
Musc = Muscovite
Biot = Biotite

Analyst: Gayle Pawloski
Sample Date: July 29, 1983
XRD Date: June 8, 1984

[a] C = Cuttings
G = Percussion gun
S = Sidewall
M - Sidewall core
X - Grab

[b] XRD Date: June 7, 1985
[c] Indicates Thirsty Canyon ashfall; all other samples are alluvium.

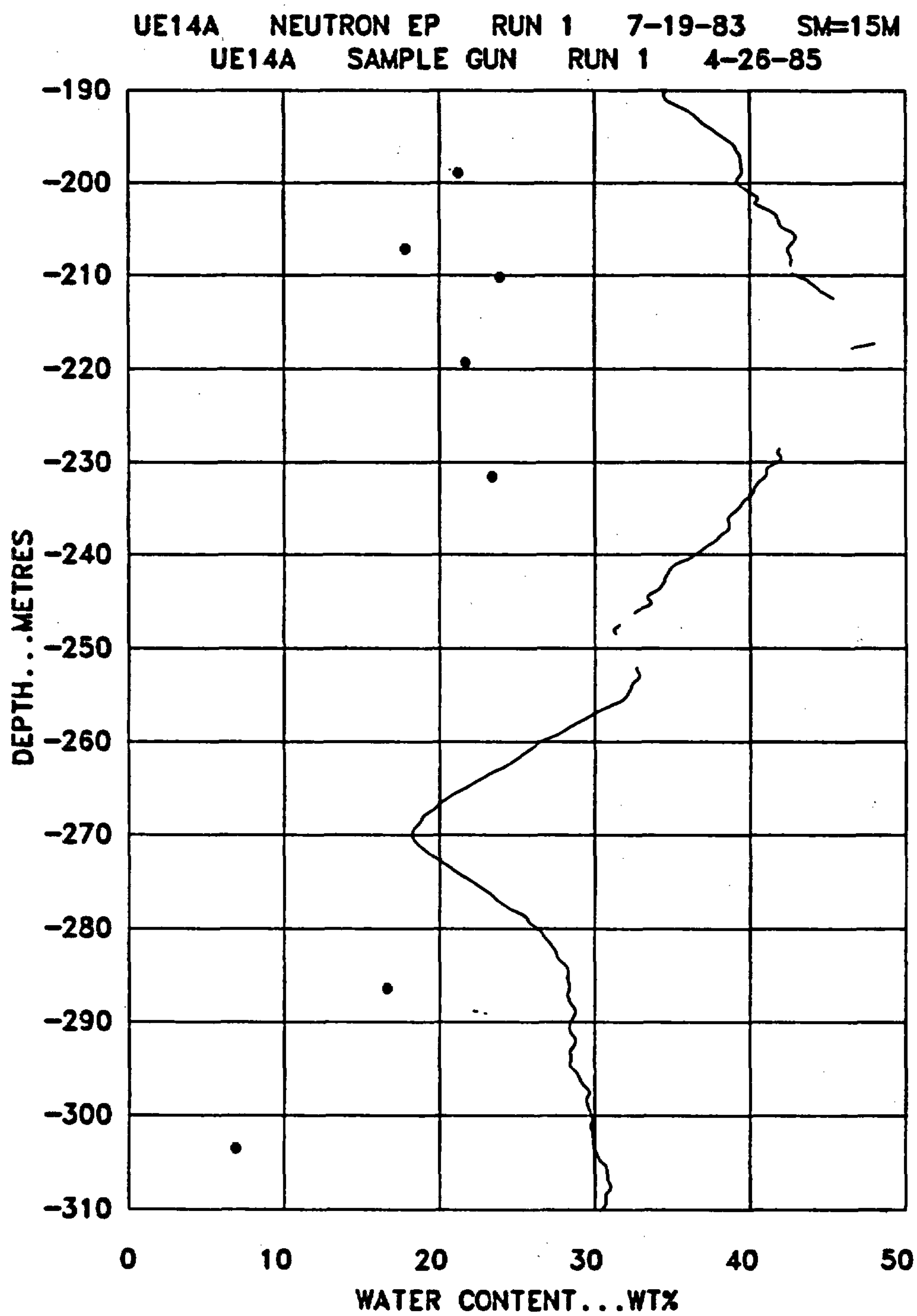

Figure 4.2. Neutron log in UE14a. Sample data are superposed on the log.

Volcanic Section and Hole Stability

The volcanic section has been subdivided into the Timber Mountain Formation including the Ammonia Tanks Member, bedded tuff, and the Rainier Mesa Member; and the Paintbrush Tuff, including bedded tuff, the Tiva Canyon Member, and the Topopah Spring Member. No physical property measurements were obtained from wireline geophysical tools below a depth of about 500 m because of hole bridging. Samples consist of drill cuttings taken at 3.05-m intervals, or whenever the hole would unload.

The Ammonia Tanks Member appears to be more competent and has less hole enlargement than any of the other units encountered in the drill hole. The extent of jointing or fracturing is unknown. Minor hole "break-outs" shown on the caliper log (Fig. 4.1) may represent intervals of jointing. The partially welded upper 18 m of the Ammonia Tanks Member has a maximum hole enlargement of 15%.

The bedded tuff interval separating the Ammonia tanks Member and the Rainier Mesa Member is partially to moderately argillized and zeolitized. Hole enlargement ranged from 250% in the upper 3 m to 30% through the rest of the interval.

The Rainier Mesa Member is partially argillized and zeolitized in the upper 14 to 15 m of the section. This interval and part of the underlying partially welded tuff tended to erode and shows hole enlargement of about 30%. The basal nonwelded section of Rainier Mesa Member also eroded and had hole enlargement ranging from 20 to 35%. The borehole breakouts shown on he caliper log (Fig. 4.1) are the result of jointed and/or fractured intervals.

The bedded tuff unit from 616 to 627 m is an informal unit that includes all reworked tuff or tuffaceous alluvium between the Tiva Canyon and Rainier Mesa Tuff (Warren, 1985). For this report, the unit has been included in the Paintbrush Tuff. This bedded tuff is zeolitized and moderately argillized near the base of the unit. Hole enlargement through the bedded tuff ranged from 20 to 35% with two 1-m breakouts approaching 240% enlargement. As previously mentioned, no geophysical logs reached depths greater than 689 m.
log. The Tiva Canyon Member occurs in the 627- to 741-m depth interval. Cutting samples were used to describe lithology below 689 m. The upper 15 m of the Tiva Canyon ashflow is partially welded and slightly argillized and

zeolitized. This interval had hole enlargement of 15 to 35%. The Tiva Canyon ashflow becomes more welded below 642 m and showed minor hole enlargement to 681 m. The cutting samples have common iron-stained faces indicating jointing and/or fracturing from 642 to 726 m. No data are available on hole stability below 681 m. However, negligible contamination of Tiva cuttings was found in No.
the recovery of samples from the underlying Topopah Spring ashflow member. The lack of Tiva contamination suggests that the Tiva Canyon from 681 to 741 m may be relatively in-gauge. 1

The Topopah Spring Member was encountered from 741 to 1006 m (based on cuttings). No geophysical logs are available through this interval and hole stability is unknown. The strong water inflow and some iron-stained chips indicate that the member is jointed and probably has intervals of hole 2
enlargement. No argillized cutting chips were observed. Sloughing occurred above 869 m, but the interval of sloughing is unknown.

Exploratory Hole UE14b

3

Exploratory hole UE14b was planned to be a 0.58-m-diameter hole drilled to a 716 m using a dual-string reverse-air and water circulating method. The 0.34-m-diameter casing was to have been set at 716 m. From 716 to 1270 m (50 m below the predicted depth of the Paleozoic rock) the hole was scheduled to be drilled with a 0.31-m bit using conventional circulation with air-foam. 4

A 0.58-m hole was drilled to 66 m. From 66 to 628 m the bit size was reduced to 0.44 m. Casing was run to 625 m, and a 0.31-m-diameter hole was drilled to 1122 m using conventional circulation with air-foam. The inability to unload water from the hole and the erosion of cement from the casing forced the hole to be terminated at 1122 m rather than at the planned depth of 1220 m. Appendix B gives an expanded drilling history.

Samples

Standard cutting samples were taken at 3.1-m intervals to 628 m during the reverse circulation drilling. From 628 to 1122 m, samples were taken at 3.1-m intervals, or whenever the hole would unload. Four conventional cores (0.10 m in diameter) were cut in the interval from 421 to 538 m. Core descriptions are given in Table 4.5. A total of 35 "Hunt"-type sidewall samples were taken in the interval from 84 to 450 m. Physical property measurements of the

Table 4.5. UE14b core description.

No.	Depth (m)	Recovery (m)	Description
1	421-427	3.35	Ammonia Tanks Member, ashflow tuff, grayish red, moderately welded, white pumice fragments are abundant, crystals are abundant, mafics are common (bronze biotite), reddish brown lithic fragments are rare, fiamme are sparse, natural fractures are not present, iron staining is rare.
2	429-435	3.05	Ammonia Tanks Member, ashflow tuff, light brownish gray, moderately welded, white pumice fragments are abundant, crystals are abundant, mafics are common (bronze biotite), reddish brown lithic fragments are rare, natural fractures and iron staining are not present.
3	472-475	3.00	Ammonia Tanks Member, ashflow tuff, grayish orange to pale yellowish brown, slightly welded, competent, massive pumice fragments are sparse, crystals are abundant, mafics are rare, lithic fragments are rare, matrix is zeolitized, high angle fractures are common, fractures are iron stained dark reddish brown.
4	532-538	2.44	Rainier Mesa Member, ashflow tuff, grayish orange pink, slightly welded, massive white pumice fragments are sparse, crystals are abundant, mafics are rare, lithic fragments are rare, matrix is slightly argillized and zeolitized, fractures are common, fractures are iron stained dark reddish brown.

conventional core and sidewall are presented in Table 4.6. Triaxial compression tests were performed on core samples from the Ammonia Tanks and Rainier Mesa Members by Terra Tek Research. The results of the tests are shown in Table 4.7.

Lithology and Stratigraphy

Table 4.8 is a lithologic and stratigraphic log of drill hole UE14b. Scientific and construction geophysical logs were run to a depth of 1104 m. The geophysical logs of UE14b are listed in Table 4.9, and the zonal averages of physical properties described in the lithologic log are given in Table 4.10.

Alluvium and Hole Stability

With the exception of the upper 52 m, the alluvium section of UE14b is predominantly tuffaceous, as it is in UE14a. The alluvium section has been subdivided into four intervals. Despite differences in detail, the lithology of the tuffaceous alluvium is generally uniform from the base of the mixed alluvium (52 m) to the top of the Ammonia Tanks Member (408 m). The Thirsty Canyon ashfall also occurs in the alluvium from UE14b and provides a time bracket such as was discussed for UE14a. The major difference between the alluvium of UE14a and UE14b is the lesser illite-monmorillonite clay alteration found in UE14b, which ranges from 4% at 206 m to 35% at 366 m. The argillized base of the Thirsty Canyon ashfall, ≈ 1 m thick at 372 m, was 89% montmorillonite. Selected sidewall samples from UE14b were analyzed by x-ray diffraction. The results of the analyses are presented in Table 4.10.

The caliper log of UE14b is shown in Fig. 4.3. The mixed alluvium from 0 to 52 m is poorly indurated and had hole enlargement exceeding 175%. The caliper arms reached their limit at 0.81 m, and the total extent of the wash-out is unknown.

The tuffaceous alluvium from 52 to 202 m is poorly indurated except for the basal 35 m. Velocities and calcium carbonate content increase through the basal 35 m, suggesting better induration. Hole enlargement through the entire interval varied from 175 to 20% in the basal 35-m interval.

In the interval from 202 to 366 m, hole enlargement is relatively low to 259 m (10 to 20%). Below 259 m to the base of the interval (366 m), hole enlargement ranged from 30 to 50%.

Table 4.6. Bulk density, grain density and water content of conventional cores and sidewall samples from UE14b.

Sample depth (m)	Sample type	Water content (wt%)	Bulk density (Mg/m^3)	Grain density (Mg/m^3)	CO_2 (wt%)	Lithology
100.6	S[a]	9.3	1.65	2.55	1.50	Tuffaceous alluvium
109.7	S	10.9	1.93	2.55	1.80	Tuffaceous alluvium
164.6	S	10.5	--	2.56	1.40	Tuffaceous alluvium
172.2	S	10.5	2.33	2.56	1.95	Tuffaceous alluvium
182.9	S	10.5	2.05	2.56	0.80	Tuffaceous alluvium
190.5	S	10.7	1.95	2.56	3.00	Tuffaceous alluvium
198.1	S	11.8	--	2.58	3.55	Tuffaceous alluvium
205.7	S	10.9	2.13	2.58	3.55	Tuffaceous alluvium
213.4	S	10.6	2.15	2.57	4.55	Tuffaceous alluvium
221.0	S	11.5	--	2.62	2.25	Tuffaceous alluvium
228.6	S	10.4	2.03	2.57	2.95	Tuffaceous alluvium
236.2	S	11.6	--	2.59	5.60	Tuffaceous alluvium
243.8	S	8.6	1.99	2.58	2.95	Tuffaceous alluvium
251.5	S	9.5	2.03	2.59	3.15	Tuffaceous alluvium
259.1	S	12.7	1.98	2.68	1.15	Tuffaceous alluvium
266.7	S	9.5	2.28	2.59	1.85	Tuffaceous alluvium
273.7	S	11.0	--	2.62	1.85	Tuffaceous alluvium
281.9	S	8.3	--	2.60	1.35	Tuffaceous alluvium
289.6	S	10.0	--	2.61	2.65	Tuffaceous alluvium
297.2	S	10.1	--	2.59	2.50	Tuffaceous alluvium
303.9	S	11.4	--	2.61	2.90	Tuffaceous alluvium
312.1	S	9.6	2.24	2.58	2.50	Tuffaceous alluvium
317.0	S	11.3	2.20	2.57	2.35	Tuffaceous alluvium
327.7	S	15.4	2.21	2.65	2.65	Tuffaceous alluvium
339.9	S	11.8	--	2.64	2.95	Tuffaceous alluvium
348.1	S	12.3	--	2.60	2.05	Tuffaceous alluvium
365.8	S	15.8	--	2.77	3.15	Tuffaceous alluvium
371.9	S	30.4	--	2.92	0.50	Thirsty Canyon Tuff
385.6	S	15.1	--	2.63	3.50	Tuffaceous alluvium
396.2	S	19.4	--	2.55	2.50	Tuffaceous alluvium
403.9	S	16.1	--	2.60	2.60	Tuffaceous alluvium
411.5	S	17.1	--	2.76	4.35	Tuffaceous alluvium
420.8	CR[b]	5.6	2.29[c]	2.56	NA[d]	Ammonia Tanks Mbr.
423.8	CR	4.8	2.33[c]	2.55	NA	Ammonia Tanks Mbr.
426.7	CR	6.3	2.21[c]	2.57	NA	Ammonia Tanks Mbr.
434.3	S	12.6	2.01	2.59	0.15	Ammonia Tanks Mbr.
442.0	S	10.9	2.17	2.56	0.10	Ammonia Tanks Mbr.
449.6	S	10.3	2.08	2.56	0.10	Ammonia Tanks Mbr.
471.6	CR	4.7	2.32[c]	2.51	NA	Ammonia Tanks Mbr.
473.1	CR	4.6	2.29[c]	2.53	NA	Ammonia Tanks Mbr.
474.4	CR	2.4	2.34[c]	2.44	NA	Ammonia Tanks Mbr.
531.9	CR	8.0	2.17[c]	2.53	NA	Rainier Mesa Mbr.
534.9	CR	11.0	2.10[c]	2.55	NA	Rainier Mesa Mbr.
538.0	CR	8.5	2.12[c]	2.55	NA	Rainier Mesa Mbr.

[a]S=Sidewall sample.
[b]CR=Conventional core.
[c]Laboratory analysis, all other bulk density measurements are from wire line geophysical tools.
[d]NA--All core samples checked with HCl acid, no effervescence.

Table 4.7. Mechanical properties from triaxial compression tests.

Lithology	Confining pressure (kbar)	Depth (m)	Max. stress difference (kbar)	Young's modulus (kbar)	Bulk modulus (kbar)	Shear modulus (kbar)	Poisso rati
Ammonia Tanks Member	2.5	425.7 426.3	0.83	66.50	58.33	25.38	0.31
Ammonia Tanks Member	2.5	425.7 426.3	5.09	75.00	33.78	33.19	0.13
Rainier Mesa Member	2.5	532.5 532.8	2.39	28.34	15.74	11.81	0.20
Rainier Mesa Member	2.5	532.5 532.8	0.83	153.46	213.14	55.60	0.38
Ammonia Tanks Member	4.0	425.7 426.3	3.84	104.45	133.91	38.12	0.37
Ammonia Tanks Member	4.0	425.7 426.3	8.98	175.38	127.09	69.05	0.27
Rainier Mesa Member	2.5	532.5 532.8	1.39	171.00	570.00	58.97	0.45
Rainier Mesa Member	4.0	532.5 532.8	0.98	114.00	100.00	43.51	0.31

Table 4.8. Lithologic description of hole UE14b.

Coordinates: N 242 042.42 m, E 198 151.18 m
Elevation: 1325.3 m
Depth: 1121.67 m
Static water level: 507.4 m

Depth (m)	Description
	Alluvium (0-408 m)
0-52	Mixed alluvium, grayish brown to brown, 10 to 20% Paleozoic rock fragments consisting predominantly of quartzite and argillite, with a lesser amount of limestone and dolomite; 80 to 90% volcanic tuff fragments; cobbles and pebbles in a sand to silt matrix, manganese staining is common, interval is poorly indurated, caliche cement increases toward the bottom of the interval, hole washed out from 36 to 52 m.
52-202	Tuffaceous alluvium, moderate yellowish brown to grayish brown, predominantly volcanic tuff fragments, 20 to 30% cobble-to boulder-size fragments in a sand and silt matrix, matrix is calcareous; caliche coatings on gravel-size fragments are common; welded tuff fragments are common toward the bottom of the section, hole washed out from 52 to 91 m and from 116 to 179 m.
202-366	Tuffaceous alluvium, medium brown, Paleozoic rock fragments are very rare; 20 to 40% cobble and boulder clasts in a sandy matrix; caliche cement decreases toward the bottom of the section, welded tuff fragments decrease toward the bottom of the section, partially to moderately argillized and zeolitized throughout the interval; general hole enlargement from 259 to 366 m.
366-372	Thirsty Canyon Tuff, ashfall, bedded and reworked, pale yellowish brown to grayish orange, crystals are common to sparse, mafics are sparse, white pumice fragments are sparse, reddish brown lithic fragments are common; matrix is highly argillized at the base of this interval, noncalcareous; hole is enlarged throughout this interval.
372-412	Tuffaceous alluvium, moderate yellowish brown, 10% clasts of welded tuff; pumice fragments are common, matrix is calcareous, partially argillized throughout this interval, opal nodules are rare; hole is enlarged throughout this interval.

Table 4.8. Continued.

	Timber Mountain Tuff (408-690 m)
412-433	Ammonia Tanks Member, ashflow tuff, reddish brown, partially to moderately welded; crystals are common, mafics are sparse to common, white pumice fragments are common, reddish brown to grey rock fragments are common, matrix is zeolitized and slightly argillized.
433-485	Ammonia Tanks Member, ashflow tuff, mottled yellow and gray to pinkish brown, moderately to slightly welded; crystals are common, mafics are common, interval is zeolitized, iron-stained fractures/joints are common in the lower part of this interval.
485-495	Bedded tuff, ashfall and reworked, gray brown, crystals are abundant, mafics are sparse; matrix is zeolitized and argillized.
495-556	Rainier Mesa Member, ashflow tuff, grayish pink to reddish brown, partially welded; crystals are abundant, mafics are sparse, matrix is zeolitized, slight amount of iron staining present in the lower part of this interval.
556-652	Rainier Mesa Member, ashflow tuff, grayish pink to reddish brown, moderately welded; crystals are common, mafics are sparse, matrix is zeolitized, iron staining is prevalent at the top of this interval to faint near the bottom of the interval.
652-690	Rainier Mesa Member, ashflow tuff, pinkish gray to pale yellowish green, nonwelded; crystals are common, mafics are sparse, reddish lithic fragments are sparse, matrix is zeolitized, faint iron staining at the top of the interval.
	Paintbrush Tuff (690-1122 m)
690-701	Bedded tuff, reworked, grayish brown, pre-Timber Mountain welded tuff fragments in sand matrix; crystals are abundant, mafics are sparse, matrix is zeolitized and partially argillized and slightly calcareous, iron staining is present on some fragments.
701-715	Tiva Canyon Member, ashflow tuff, dark yellowish orange to reddish brown, slightly welded; crystals are sparse, mafics are rare, matrix is partially zeolitized and silicified, iron staining is present on some fragments.

Table 4.8. Continued.

Paintbrush Tuff (690-1122 m TD)

715-799	Tiva Canyon Member, ashflow tuff, gray, densely welded, devitrified; crystals are rare, mafics are rare, platy fractures and iron staining are prevalent throughout the section, matrix is silicified and zeolitized.
799-809	Topopah Spring Member, ashflow tuff, moderately welded.
809-813	Topopah Spring Member, vitrophyre, mottled brown and black, crystals are sparse.
814-888	Topopah Spring Member, ashflow tuff, mottled reddish gray, moderately welded, matrix is devitrified, silicified and partially zeolitized. Densely welded tuff from 847 to 855 m, brown to black, phenocrysts are sparse.
888-1091	Topopah Spring Member, ashflow tuff, moderately welded at the top of the section grading down to slightly welded at the bottom of the section, partially zeolitized and silicified.
1091-1122 TD	Topopah Spring Member, ashflow tuff, black to reddish gray, vitrophyre and densely welded tuff; crystals are sparse.

The lithologic description was taken from cutting samples (24-1119 m), augur samples (1.5-25 m), 4-in. core samples (421-432 m, 472-475 m, 532-538 m), Hunt-type sidewall samples (101-450 m), the geophysical logs (3-1103 m), and physical property data.

The cutting samples from the Topopah Spring Member of the Paintbrush Tuff are highly contaminated with debris from units higher in the drill hole; therefore, the geophysical logs were used to determine the lithologic contacts.

Table 4.9. Geophysical logs for hole UE14b.

Log	Run date	Run No.	Logger	Interval top-bottom
3-dimensional sonic velocity, 3-ft spacing	1/18/84	1	Birdwell	471-624
3-dimensional sonic velocity, 3-ft spacing	1/31/84	3	Birdwell	607-1102
3-dimensional sonic velocity, 6-ft spacing	1/18/84	2	Birdwell	472-625
3-dimensional sonic velocity, 6-ft spacing	1/31/84	4	Birdwell	609-1102
Dry-hole acoustic log	1/18/84	1	LLNL-N	40-472
Vibroseis	1/18/84	1	Birdwell	28-622
Vibroseis	2/1/84	1	Birdwell	610-1097
<u>Density</u>				
Density	1/17/84	1	Birdwell	37-626
Density	1/17/84	2	Birdwell	27-176
Density BC	1/31/84	1	Birdwell	619-1103
<u>Other scientific logs</u>				
Electric log--induction	1/18/84	1	Birdwell	27-625
Electric log--induction	1/30/84	2	Birdwell	613-1102
Electric log	1/31/84	1	Birdwell	618-1100
Gamma ray	1/17/84	1	Birdwell	31-625
Gamma ray	4/26/85	2	Dress At.	610-1099
Magnetometer	1/18/84	1	LLNL-N	43-625
Magnetometer	1/30/84	2	LLNL-N	628-958
Magnetometer--3-dimensional	1/30/84	1	LLNL-N	628-1103
Epithermal--neutron	1/17/84	1	Birdwell	30-592
Epithermal--neutron	1/17/84	2	Birdwell	27-176
Epithermal--neutron	1/17/84	3	Birdwell	483-625

Table 4.9. Continued.

Construction logs				
Caliper	1/14/84	1	Birdwell	18-545
Caliper	1/17/84	2	Birdwell	20-624
Caliper	1/26/84	3	Birdwell	585-813
Caliper	1/31/84	4	Birdwell	610-1101
Nuclear cement top locator	1/21/84	1	Birdwell	396-622
Nuclear cement top locator	1/22/84	2	Birdwell	518-623
Nuclear cement top locator	1/31/84	3	Birdwell	305-640
Nuclear annulus investigation log	1/31/84	1	Birdwell	305-640
Temperature	1/14/84	1	Birdwell	3-488
Fluid density	1/14/84	1	Birdwell	276-305
Fluid density	1/14/84	2	Birdwell	408-427
Fluid density	1/18/84	3	Birdwell	435-485
Fluid density	1/21/84	4	Birdwell	427-445
Fluid density	1/21/84	5	Birdwell	433-454
Fluid density	1/26/84	6	Birdwell	500-512
Fluid density	1/30/84	7	Birdwell	451-655
Fluid density	1/31/84	8	Birdwell	494-515
Fluid denisty	2/10/84	9	Birdwell	493-515
Fluid density	5/2/84	10	Birdwell	465-473

Table 4.10. Zonal averages for hole UE14b (generated on 6/14/85).

Depth (m)	Water content (wt%)	Bulk density (Mg/m^3)	Grain density (Mg/m^3)	CO_2 content (wt%)
0-52	*	*	*	*
52-202	5.4	*	2.56	1.99
202-366	7.8	*	2.61	2.75
366-372	*	*	*	*
372-408	6.2	*	2.68	2.28
408-433	4.6	*	2.61	*
433-485	5.5	*	2.53	0.12
485-495	18.8	*	*	*
495-556	13.6	*	2.54	*
556-652	5.5	2.14	*	*
652-690	*	1.89	*	*
690-701	*	1.77	*	*
701-715	*	1.64	*	*
715-799	*	1.76	*	*
799-809	*	1.79	*	*
809-814	*	2.20	*	*
814-888	*	2.26	*	*
888-1091	*	2.16	*	*
1091-1122	*	2.31	*	*

* Denotes data not available.

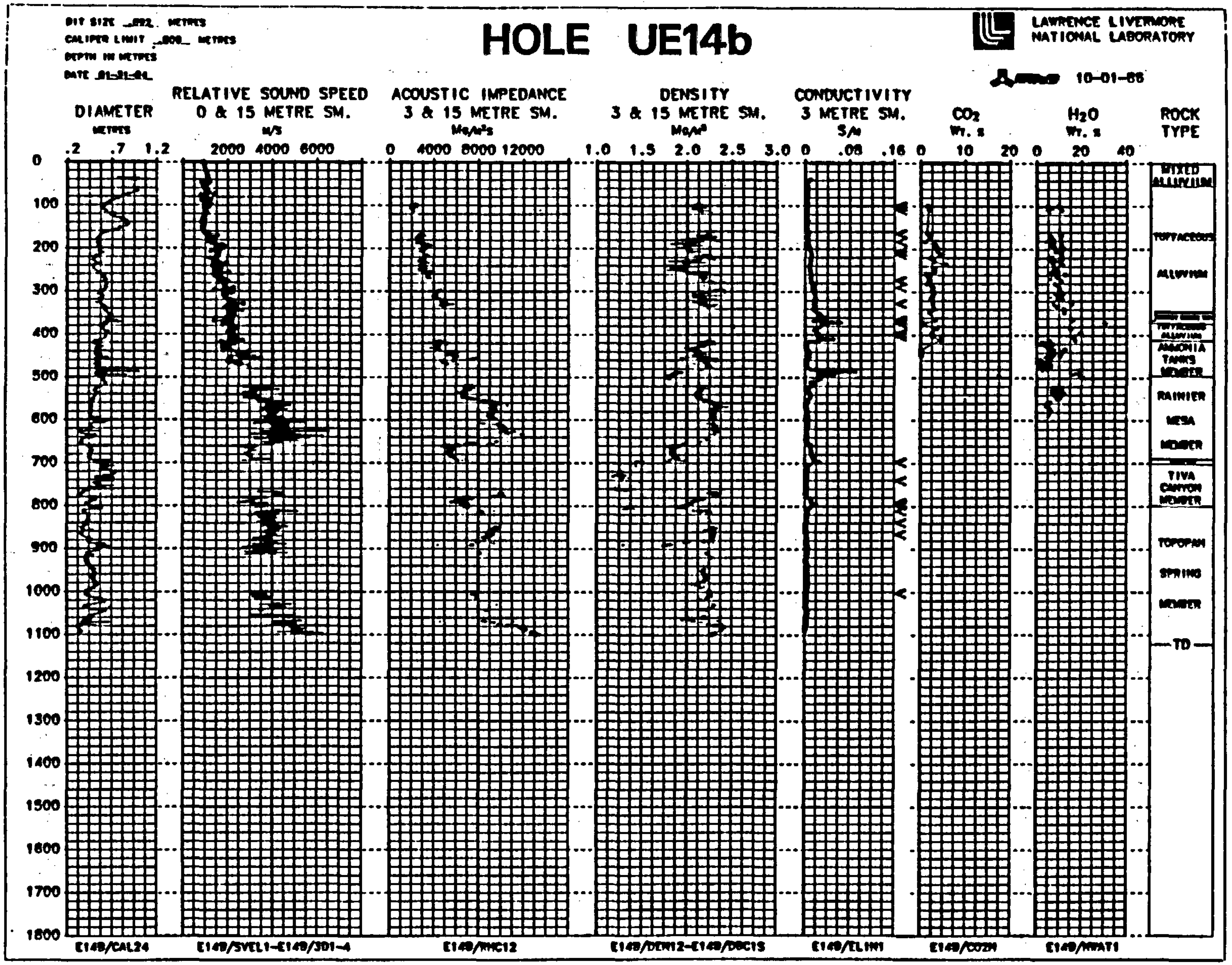

Figure 4.3. Geophysical logs in exploratory hole UE14b.

The combined montmorillonite-illite-kaolinite clay alteration varies from 6% near the top of the interval (202 m), to 26 to 44% near the base (366 m). See Table 4.11. A gradational increase in conductivity occurs from about 275 to 366 m (Fig. 4.3).

The Thirsty Canyon ashfall from 366 to 372 m is relatively unaltered except for the basal 1 to 2 m, which is highly argillized. However, hole enlargement above and below the tuff (ranging from 45 to 60%) caused the unit to slough. The tuffaceous alluvium below the Thirsty Canyon ashfall had hole enlargement of 35 to 40%. Clay alteration through this section is about 17 to 20%.

Volcanic Section

The volcanic rock section of UE14b includes the same members and formations as are found in UE14a: the Timber Mountain Formation including the Ammonia Tanks Member, bedded tuff, and Rainier Mesa Member; and the Paintbrush Tuff including bedded tuff, the Tiva Canyon Member, and the Topopah spring Member.

The Ammonia Tanks Member (408 to 485 m) is relatively in-gauge except for the upper 7 m, which is slightly welded and partially argillized. Most of the remaining interval has about a 10% enlargement, and 1- to 2-m breakouts are believed to be the result of jointing and/or fracturing.

The top and base of the bedded tuff separating the Ammonia Tanks and Rainier Mesa Member are argillized, and both argillized zones show 2-m-wide breakouts.

The upper 30 m of the Rainier Mesa Member is partially argillized and zeolitized. This zone and the following 15 m tended to slough and had hole enlargement of 15 to 40%. Below 527 to 628 m (base of dual-string reverse-air and water drilling) the Rainier Mesa ashflow is generally in-gauge except for some breakouts between 594 to 608 m.

The casing was set at 625 m and the hole was drilled with conventional air-foam. The moderately welded Rainier Mesa ashflow had washouts below the casing varying from 15 to 50% hole enlargement. These washouts are believed to have resulted from the change in drilling methods.

Table 4.11. XRD analyses of samples from UE14b (wt%).

Depth ft	Depth m	Sample type[a]	Quar	Mont	Illi	Clin	Cris	Feld	Calc	Dolo	Glas	Horn	Kaol	Musc	Biot
330	101	S	28	0	0	0	19	50	3.1	0	0	0	0	0	0
360	110	S	13	0	0	0	16	66	2.9	0	0	2	0	0	0
540	165	S	21	0	0	0	18	57	3.1	0	0	0	0	0	0
600	183	S	17	0	0	0	15	66	1.7	0	0	0	0	0	0
675	206	S	28	0	4	10	14	34	8.0	0	0	0	2	0	0
700	213	S	26	0	0	0	17	40	17.1	0	0	0	0	0	0
898	274	S	36	0	0	0	16	43	4.6	0	0	0	0	0	0
898	274	S	29	0	8	4	12	30	3.6	0	0	10	3	0	0
950	290	S	18	0	11	3	10	53	4.3	0	0	0	2	0	0
1075	328	S	20	16	11	0	11	31	10.1	0	0	0	0	0	0
1200	366	S	10	28	16	0	6	32	7.3	0	0	0	0	0	0
1200	366	S	10	15	11	0	5	52	6.0	0	0	0	0	0	0
1225	373	S	4	89	0	0	0	6	0.8	0	0	0	0	0	0
1300[b]	396	S	12	10	10	0	0	20	7.9	0	40	0	0	0	0
1325	404	S	28	17	0	0	6	39	10.2	0	0	0	0	0	0
2290	698	C	58	0	0	9	2	31	0	0	0	0	0	0	0
2600	792	C	36	0	0	18	20	27	0	0	0	0	0	0	0
2620	799	C	20	0	0	39	16	25	0	0	0	0	0	0	0
2660	811	C	20	0	13	20	12	35	0	0	0	0	0	0	0
2750	838	C	39	0	0	13	9	34	0	0	0	0	6	0	0

Total Number of Samples: 20

---------------- Minerals ----------------

Quar = Quartz
Mont = Montmorillonite
Illi = Illite
Clin = Clinoptilolite
Cris = Cristobalite
Feld = Feldspars
Calc = Calcite
Dolo = Dolomite
Glas = Glass
Horn = Hornblende
Kaol = Kaolinite
Musc = Muscovite
Biot = Biotite

Sample Date: March 1, 1984
XRD Date: July 18, 1984

[a] S = Sidewall
C = Cuttings
[b] XRD Date: June 7, 1985

The nonwelded basal shard zone of the Rainier Mesa ashflow (652 to 690 m) washed out with hole enlargement ranging from 40 to 50%. The bedded tuff zone from 690 to 701 m is zeolitized and partially argillized. This zone washed out with hole enlargements of 50 to 65%.

The Tiva Member (ashflow) eroded and sloughed during drilling and continued to erode during the drilling of the underlying Topopah Spring Member. The Topopah Spring drill cuttings contain 60% eroded Tiva ashflow chips.

The Tiva Member is highly jointed and/or fractured with a high percentage of cutting chips showing iron-stained faces. This unit had hole enlargement of 65 to 140% throughout most of the section. A short interval from 764 to 779 m is relatively in-gauge, although the cutting samples are highly contaminated with Tiva erosion up-hole.

The Topopah Spring ashflow is highly eroded except for the interval from 1067 to 1100 m (the base of the caliper run). This basal interval is a moderately to densely welded ashflow tuff and vitrophyre. The remainder of the interval is eroded and has hole enlargement of 30 to 60%. Three intervals within the Topopah Spring Member have wash-outs with 70 to 90% hole enlargement. these intervals may represent zones of jointing and/or fracturing (Fig. 4.3).

Had this hole been drilled to total depth with dual-string reverse-air and water, the erosion of the Tiva and Topopah Spring members might have been considerably less. The volume and air pressure required to unload the hole created an erosional force against the borehole walls that would enlarge any jointed/fractured sections or any less competent units.

Remedial Hole Stability

The future of Mid Valley as a possible test area clearly depends on whether we can achieve emplacement hole stability, and, to a lesser extent, avoid intervals of high clay alteration. We believe that drilling emplacement holes using our present method of dual-string reverse-air water system could lead to difficulties. Our experience is limited in evaluating enlargement of an exploratory hole vs that of an emplacement hole using dual-string reverse-air water for both. In contrast, it is fairly common to drill exploratory holes using conventional air-foam near emplacement holes drilled with the dual-string reverse-air and water method. The exploratory hole (air-foam) will generally show more rugosity and percentage enlargement than the hole drilled using dual-string reverse-air and water. This statement assumes that the medium drilled is fairly competent and does not have abnormal swelling-clay alteration.

The percentages of enlargement from an exploratory hole cannot be directly extrapolated to a large-diameter emplacement hole. For instance, a 100% enlargement of a 0.44-m exploratory hole to 0.88 m does not necessarily mean that a 2.44-m emplacement hole will erode or slough to 4.88 m. The percentages of enlargement in the exploratory hole should serve as a guide to the expected intervals of sloughing in a large-diameter hole.

We have discussed the problems of hole stability in Mid Valley with various drilling and mud engineers. The consensus is that hole stability might be achieved with dual-string reverse-air and water using a low-water-loss polymer-mud circulating medium. In an area such as the UE14b site, it may be necessary to case-off the upper 100- to 150-m section. Similar casing would be prudent at the UE14a site.

Correlation of Drill Holes UE14a-UE14b

Figure 4.4 is a correlation diagram of the alluvium and volcanic members in drill holes UE14a and UE14b. The SWL at UE14a is 819.7 m above MSL and 817.8 m at UE14b. The thicknesses of volcanic units encountered in holes UE14a and UE14b are compared with the thicknesses of these units encountered in outcrops, with values presented in Table 4.12. The thickness of the Topopah Spring Member and underlying units revealed by the seismic profiles indicates Mid Valley was a well-developed basin before Tiva deposition.

The correlation diagram (Fig. 4.4) shows that the pre-Thirsty Canyon alluvium increases in thickness to the east, whereas the later alluvium increases in thickness to the west. The increased thickness of Tertiary alluvium to the east can also be interpreted from seismic lines (discussed in Sec. 5). The base of the Thirsty Canyon airfall in both drill holes is

Table 4.12. Comparative thickness of volcanic outcrops in holes UE14a and UE14b (in metres).

	Mine Mountain Quad	Yucca Lake Quad	Ue14a	Ue14b
Ammonia Tanks Mbr.[a]	27-69	50-80	87	87
Rainier Mesa Mbr.	76-171	30-120	205	195
Tiva Canyon Mbr.	30-107	30+	114	98
Topopah Spring Mbr.	122-169	275	265+[b]	323+[b]

[a]Ammonia Tanks Member includes bedded tuff at base.

[b]Drillholes did not reach base of Topopah Spring Member.

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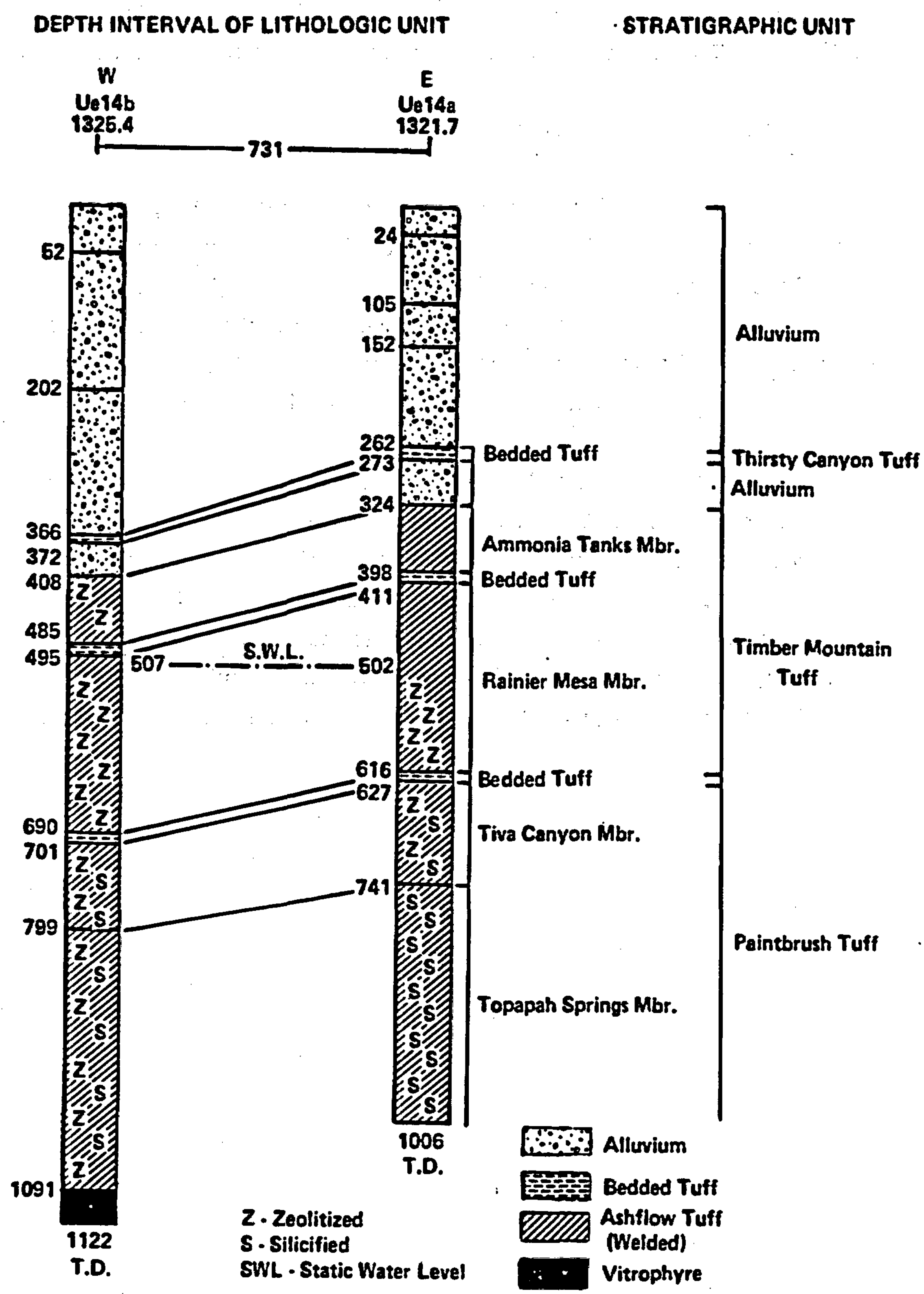


Figure 4.4. Correlation diagram of volcanic members in holes UE14a and UE14b.

moderately to highly argillized, suggesting deposition in standing water, probably in an area of low relief. The change in the alluvium depositional pattern of post-Thirsty Canyon time suggests that the central portion of the basin has undergone major fault rotation to the west in the last 7.5 Ma (Thirsty Canyon age), probably along the Mine Mountain fault system.

Stress Field in Mid Valley

During the coring operations at drill hole UE14b, we attempted to determine the orientation and magnitude of the in situ stress field using anelastic strain recovery of the oriented core (Teufel, 1983). The optical survey during coring operations broke down and no core orientation was obtained. Stress magnitudes were obtained in the Ammonia Tanks Member at depths of 420 and 472 m. These data are shown in Tables 4.13 and 4.14.

During the attempted coring at UE14a, a relatively high air-foam pressure built up in the well bore and the surface subsequently hydrofractured in a S 25 W direction. Such surface hydrofracturing has occurred several times in Yucca Flat. The direction of fracturing has always been in the northeast-southwest quadrants. The fracturing at UE14a suggests that Mid Valley, like Yucca Flat, lies in a northeast-southwest compressive stress field and is undergoing tension in a northwest-southeast direction.

Table 4.13. Summary of anelastic strain recovery data from volcanic tuff in Area 14, NTS.[1]

Depth (m)	Lithology	ϵ_V ($\mu\epsilon$)	ϵ_{Hmax} ($\mu\epsilon$)	ϵ_{Hmin} ($\mu\epsilon$)	$\epsilon_{Hmax}/\epsilon_V$	$\epsilon_{Hmin}/\epsilon_V$	$\epsilon_{Hmin}/\epsilon_{Hmax}$	Azimuth ϵ_{Hmax} [2]
420	welded tuff	216	138	24	$0.62 \pm .10$	$0.09 \pm .06$	$0.15 \pm .07$	NA
472	welded tuff	282	226	56	$0.78 \pm .12$	$0.16 \pm .11$	$0.22 \pm .11$	NA

1. Principal strain magnitudes are the final magnitudes reached during recovery. Ratios of the principal strains are the mean $\pm$ one standard deviation which occurred during recovery.
2. Cores were unoriented

Table 4.14. Summary of in situ stress magnitudes calculated from anelastic strain recovery measurements of Area 14, NTS.[1]

Stress calculated for isotropic case with $\nu = 0.20$

Depth (m)	Lithology	σ_{Hmax}/σ_V	σ_{Hmin}/σ_V	σ_V (MPa)	σ_{Hmax} (MPa)	σ_{Hmin} (MPa)
420	welded tuff	$0.76 \pm .07$	$0.42 \pm .06$	8.24	$6.3 \pm .5$	$3.5 \pm .5$
472	welded tuff	$0.87 \pm .07$	$0.49 \pm .08$	9.26	$8.0 \pm .7$	$4.5 \pm .8$

Stress calculated for transversely isotropic case with $a = 1.2$, $\nu_1 = 0.20$, $\nu_2 = 0.20$

Depth (ft)	Lithology	σ_{Hmax}/σ_V	σ_{Hmin}/σ_V	σ_V (MPa)	σ_{Hmax} (MPa)	σ_{Hmin} (MPa)
420	welded tuff	$0.88 \pm .08$	$0.49 \pm .07$	8.24	$7.3 \pm .6$	$4.0 \pm .6$
472	welded tuff	$1.03 \pm .05$	$0.57 \pm .09$	9.26	$9.5 \pm .5$	$5.3 \pm .8$

1. Ratios of the principal stresses are the mean $\pm$ one standard deviation which occurred during recovery. Magnitude of σ_V is the calculated overburden using an average density of 2.0 gm/cm^3. Magnitudes of σ_{Hmax} and σ_{Hmin} are the calculated mean values $\pm$ one standard deviation.

5. INTERPRETATION OF SEISMIC LINES

This section discusses the interpretation of the seismic data in terms of the structural geology of the pre-Cenozoic rocks and its effect on the Tertiary volcanics and alluvium.

A reflection seismic survey consisting of some 18.3 km was fielded in Southern Mid Valley using an air-gun seismic source. The seismic station interval was 25.2 m. The geometry of the survey lines was designed to best analyze the southern Mid Valley basin with a minimum of total survey length. The design was based on surface gravity data (Hazelwood et al., 1963). The location of the seismic survey lines is shown in Fig. 3.4.

This was the first time that an air-gun had been used as a seismic source at NTS. In general, the quality of the seismic reflections in the volcanic units from the Paintbrush Tuff (Tiva Canyon Member) through the Timber Mountain Tuff units was good to excellent. Surprisingly, the Thirsty Canyon ashfall within the alluvium produced an excellent reflection wavelet. Hydrothermal (?) and zeolitic alteration appear to have decreased the reflection quality in some areas. The effects of apparent alteration on seismic reflection signals are discussed below.

Once the reflection wavelet characteristics of the volcanic units obtained from exploratory drill hole UE14b were established, this typical wave form was used on all seismic lines to interpret the reflection picks of the volcanic units. The quality of the Paleozoic reflections varied from very good to poor in certain areas. However, considering that the seismic signal had to travel through 100 to 400 m of tuffaceous alluvium and as much as 1 km of moderately to densely welded ashflow tuffs and perhaps lavas and then reflect from a possible Paleozoic argillite/lava interface that may have a minor change in the acoustic impedance, the reflection data obtained are considered excellent. An experimental Vibroseis survey attempted in 1968 on Pahute Mesa in a similar geologic environment (without alluvium) produced no usable data.

Because, as we discussed in the previous section, neither exploratory hole intersected the Paleozoic rocks, we have no accurate knowledge of the depth to the Paleozoic interface at any point. Furthermore, since we could not obtain the change in acoustic impedance across the interface from logs, we could not obtain the characteristics of the reflection wavelet. This decreased our confidence in the Paleozoic interpretation. Probable klippen of the Mine Mountain and CP thrust systems also caused all Paleozoic reflection "picks" to be questionable in certain areas.

The velocity surveys using a surface Vibroseis source near each of the two exploratory holes were used to convert the seismic reflection data from time to depth. A computer program was written so that seismic time picks could be converted to depth using the drill hole Vibroseis data. Some extrapolation of the time-depth data was necessary to obtain estimates of the Paleozoic surface from seismic sections (Fig. 5.1). As the time-depth plots indicate, there is a slight lateral variation in velocities.

Both the final stacked seismic sections and the migrated sections were used in the volcanic and Paleozoic interpretations. The migrated sections were given priority whenever possible; however, in certain intervals the nonmigrated final stack displayed a better structural interpretation that may have been lost in the migration processing.

An estimate of the probable volcanic thickness was obtained from exploratory hole UE14b and surface outcrops. From these data and good evidence that the basin was well-developed before Tiva Canyon Member deposition, we estimated the probable depth to the Paleozoic horizon and converted this estimate to an estimate of time. The seismic sections were searched for apparent reflections at that time. The best reflection was seen in the line 3 section. Reflections on lines 1 and 2 were compared at points of intersection with line 3; mis-ties were acceptably small.

Using the estimated Paleozoic reflection from seismic line 3 as a starting point, Paleozoic reflection picks were then carried across seismic lines 1 and 2 with particular attention paid to major reflection wavelets below holes UE14a and UE14b. A problem in correlating Paleozoic wavelets of seismic lines 1 and 2 with seismic line 3 was the presence of apparent fault structures at both intercept points. Some adjustment of the time-depth relationship was necessary to produce a satisfactory geologic interpretation.

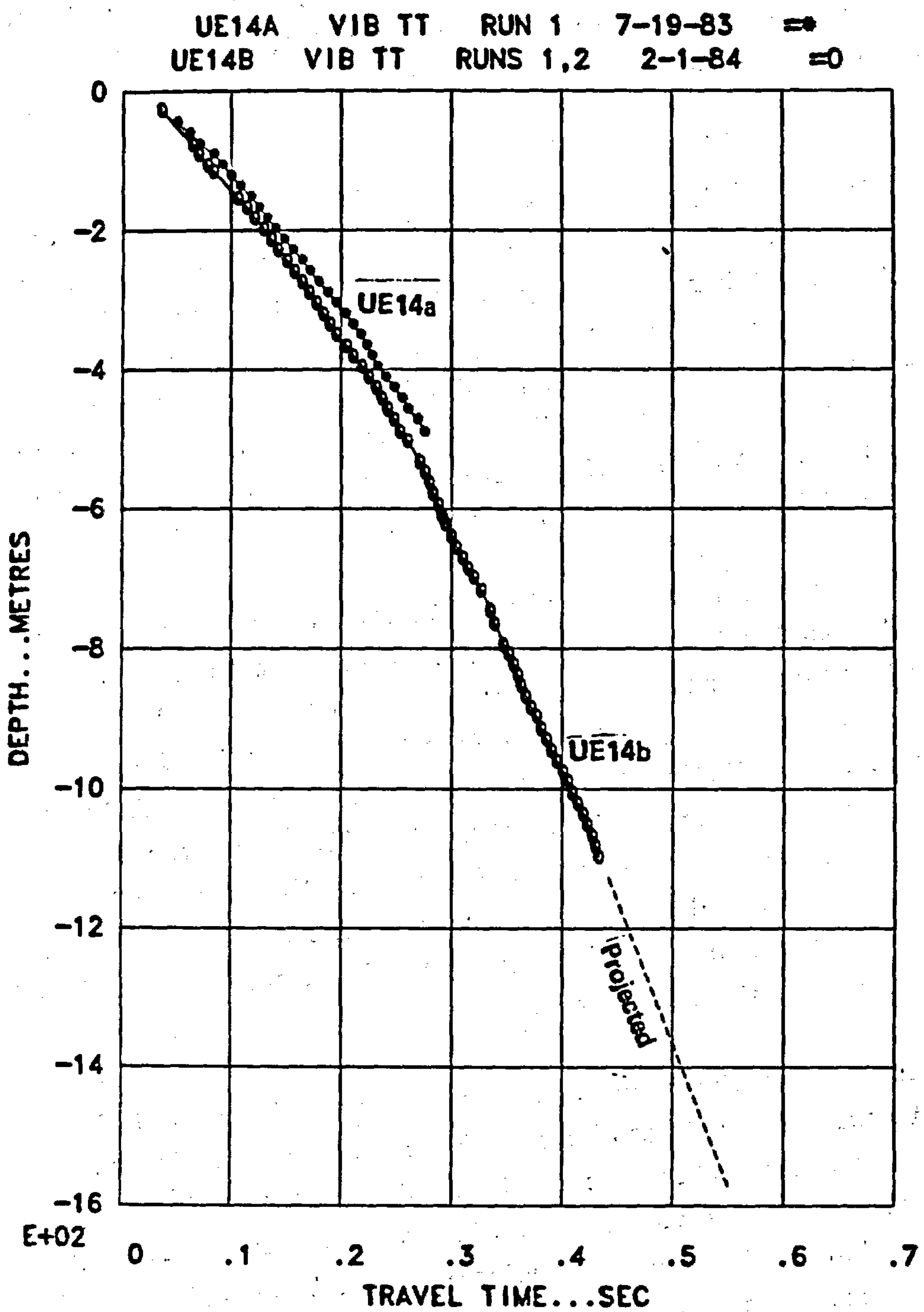


Figure 5.1. Time-depth data from velocity surveys in holes UE14a and UE14b.

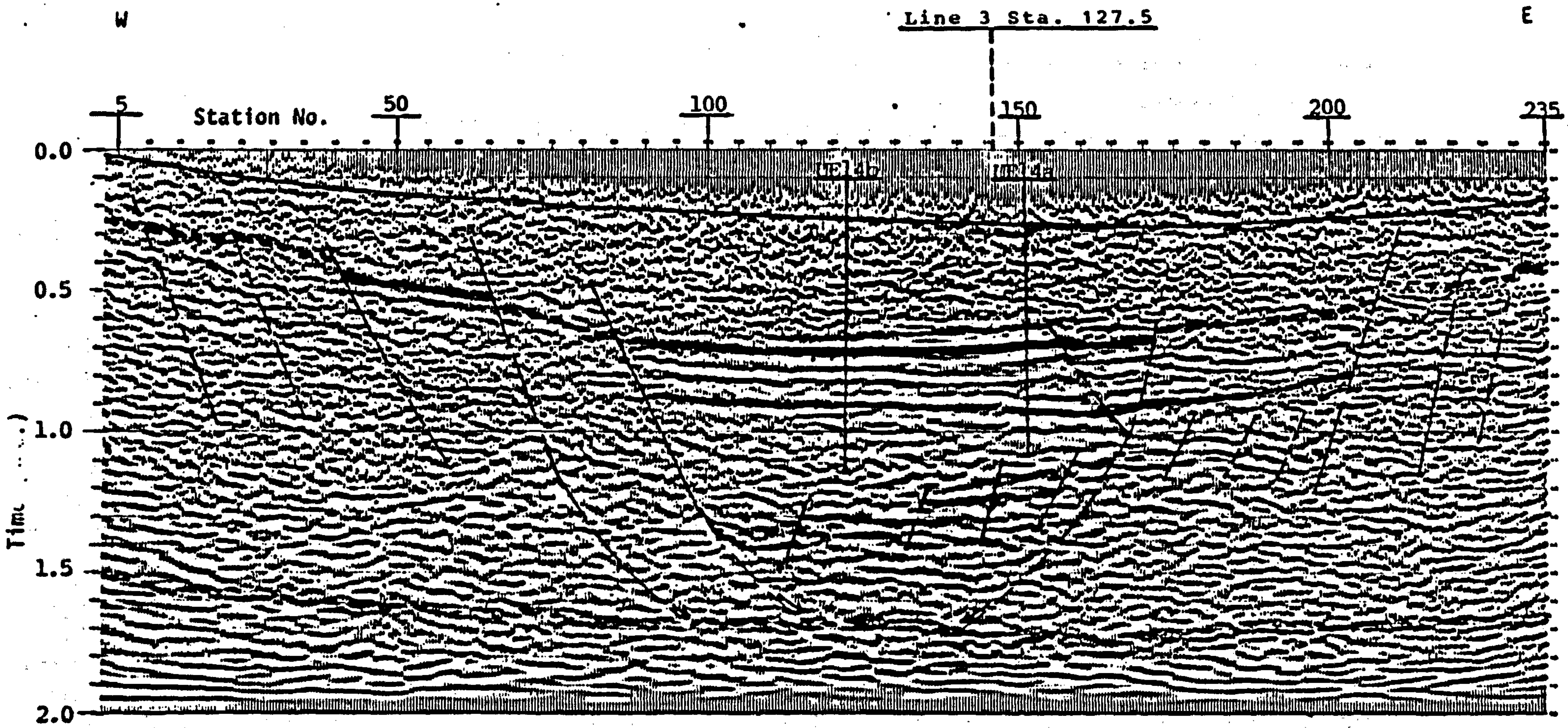
Seismic Line 1

The seismic reflection interpretation of Line 1 is shown in Figs. 5.2 and 5.3. The depths of the alluvium, volcanics, and Paleozoic rocks as well as tectonic structural features are presented in the geologic cross section (Fig. 5.4).

This line, as interpreted, shows the greatest depth to Paleozoic rock within the basin--1500 m, which does not seem unrealistic considering that exploratory hole UE14b reached a depth of 1127 m and was still in the Topopah Spring Member of the Paintbrush Tuff. About 80 m of the Topopah Spring unit may be below the bottom of the hole, and below that is an unknown thickness of bedded tuffs, the Tuff of Redrock Valley, and/or Wahmonie lavas. Evidently, the basin was well developed before Tiva Canyon deposition and should have thicker sections of pre-Tiva Canyon units than are exposed in outcrops.

The major tectonic feature of seismic line 1 is the listric or planar fault near Station 100 (Figs. 5.2 and 5.3). This fault is apparently related to the Mine Mountain normal fault system either as a sub-parallel lateral fault or a splay off the major Mine Mountain fault shown in Plate 1. The loss of volcanic wavelet reflections west of the fault indicates that lateral movement along the fault is highly likely. We believe that the dip of the fault decreases with depth, and that it is possible that the fault eventually merges into a very low-angle extensional normal listric fault feature at depth. All fault structures west of this major fault are considered part of the Mine Mountain normal fault system.

The eastern edge of the major graben is approximately located at Station 165. Cenozoic extensional forces have produced a major west-dipping planar fault with an associated antithetic fault at this location. There is some suggestion that the major west-dipping fault may also flatten with depth and that it merges with the low-angle extensional normal listric fault at depth. The data are inconclusive. Farther east the basin shows distension with a series of west-dipping faults that again may be related to the extensional feature.



Thirsty Canyon ashfall

Tuff/Alluvium

Base Timber Mountain Tuff

Paleozoic rocks

Extensional feature

Figure 5.2 Seismic Line 1, migrated.

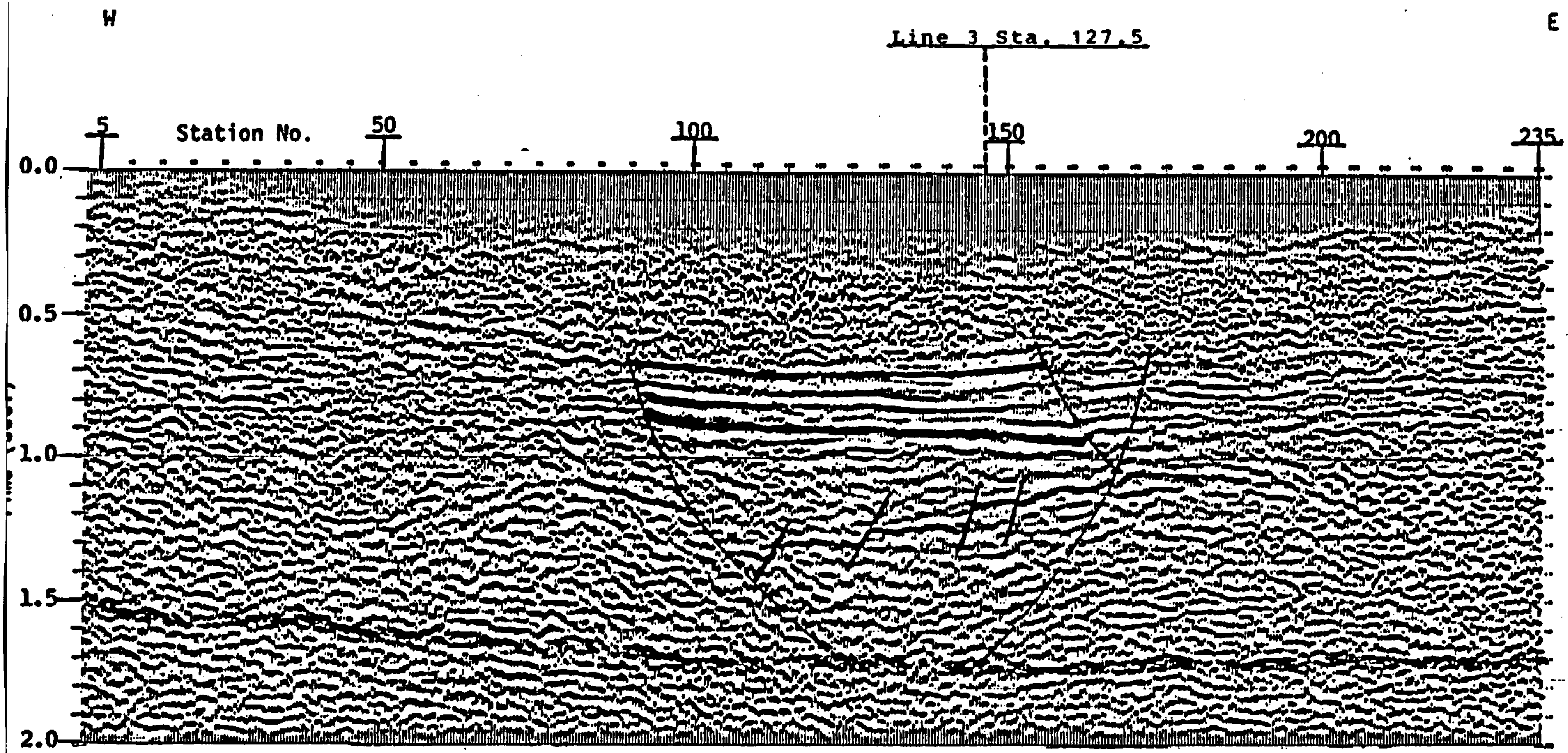


Figure 5.3 Seismic Line 1. Final stack; this line was not used in the geologic interpretation.

Tuff/Alluvium
Base of Timber Mountain Tuff
Paleozoic rocks
Extensional feature

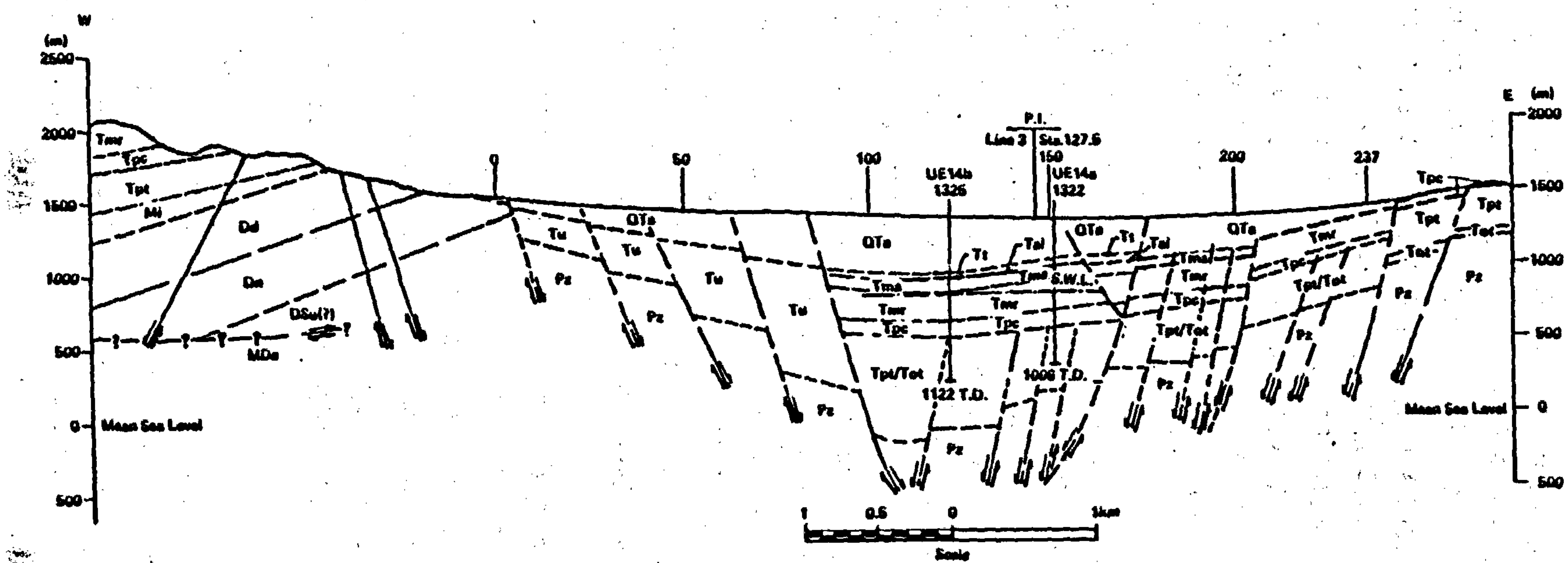


Figure 5.4. Geologic cross section, seismic line 1.

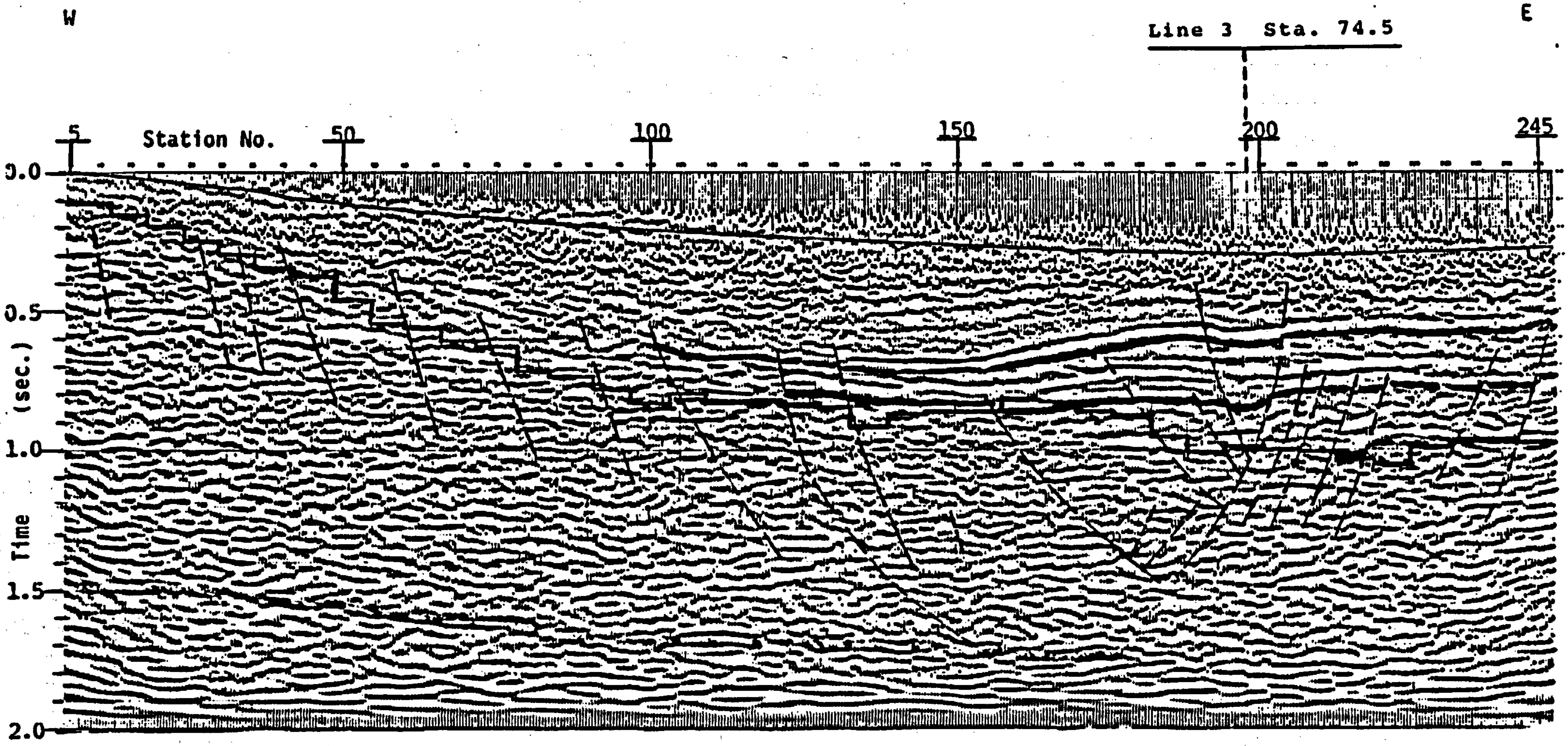
Seismic Line 2

The interpreted seismic lines for line 2 are shown in Figs. 5.5 and 5.6. The geologic interpretation is shown on the cross section in Fig. 5.7. Seismic Line 2 has the poorest Paleozoic wavelet reflections. The data on this line may have been affected by volcanic alteration or problems with field data acquisition.

The seismic line--final stack (Fig. 5.6)--indicates a major planar or listric fault structure between stations 125 and 150. This feature appears to correlate with a similar structure shown on seismic line 1 (Fig. 5.2). The eastern edge of the main basin appears to have one major west-dipping planar fault with associated antithetic faults. Westerly dipping faults "stair-step" the eastern portion of the seismic line up into the CP Hills.

A gravity profile using two-dimensional gravity inversions was prepared from the regional Bouguer gravity map (Hazelwood et al, 1963) using a density contrast of 0.40. It is shown in Fig. 5.8. The gravity plot was converted from isopach thickness (tuff plus surficial deposits) to time and plotted on the seismic profile (Fig. 5.5). The seismic and gravity times correlated fairly well on the western and eastern ends of the line. However, in the deeper part of the seismic basin the gravity profile suggests a gravity high. The seismic interpretation shows the uppermost volcanic unit, the Timber Mountain Formation, deeper than the depth to Paleozoic rocks indicated by the gravity plot. We believe the graben outlined by the two planar or listric faults shown in Fig. 5.5 to be the more correct interpretation even though the Paleozoic "picks" between the two major faults are of poor quality.

One explanation of the conflict between gravity- and seismic-indicated Paleozoic depth is that the Wahmonie lava pile and upper volcanic units along the basin of line 2 have higher densities than observed from the drill holes. The Paleozoic rocks shown on line 2 are believed to be Eleana argillite with an average density of approximately 2.57 g/cc. The measurements from the drill holes of UE14a and UE14b indicated a tuff density of about 2.20 g/cc, and the difference between this density and that of the argillite was used to obtain the contrast used in the gravity calculation. The tuffs of line 2 are probably actually underlain by an unknown thickness of Wahmonie lavas



Thirsty Canyon ashfall
Tuff/Alluvium
Base Timber Mountain Tuff
Palezoics from 2-D gravity
Paleozoic rocks
Extensional feature

Figure 5.5 Seismic Line 2, migrated.

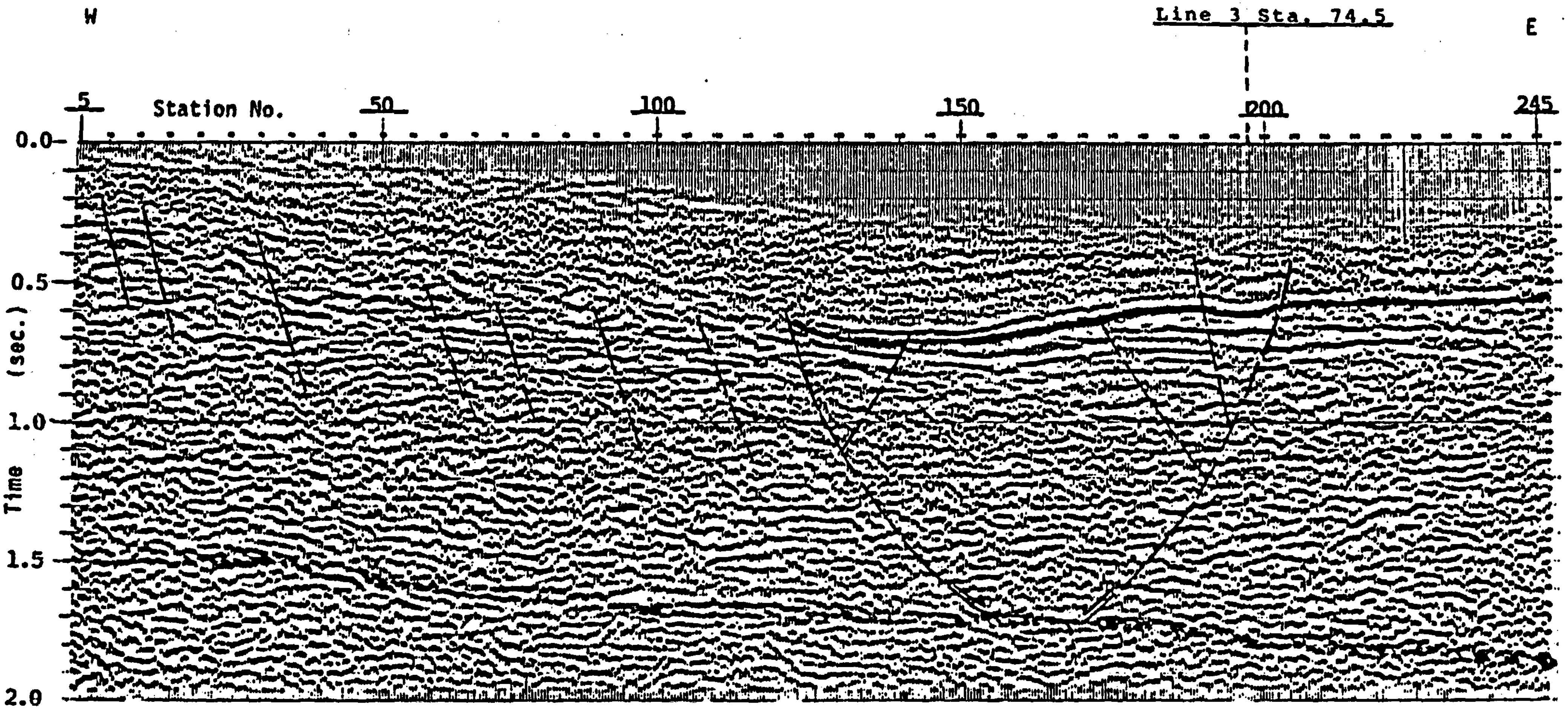


Figure 5.6 Seismic Line 2. Final stack, showing west and east planar faults merging or truncated by an extensional feature

Tuff/Alluvium
Paleozoic rocks
Extensional feature

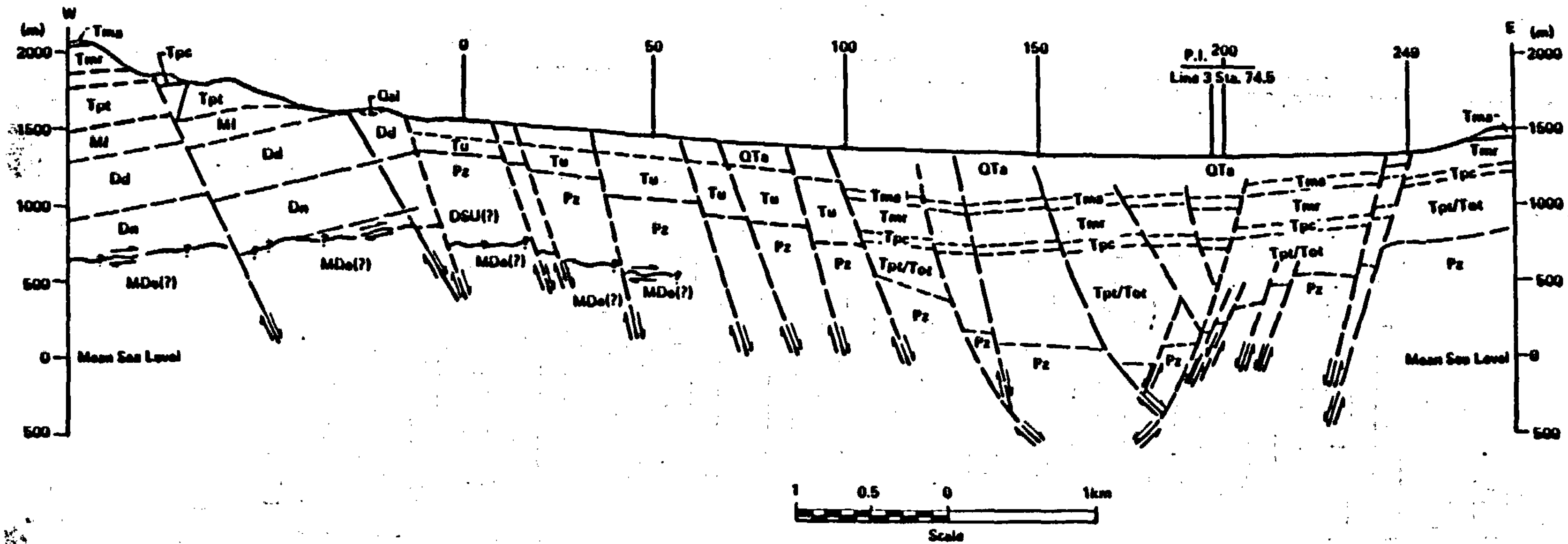


Figure 5.7. Geologic cross section, seismic line 2.

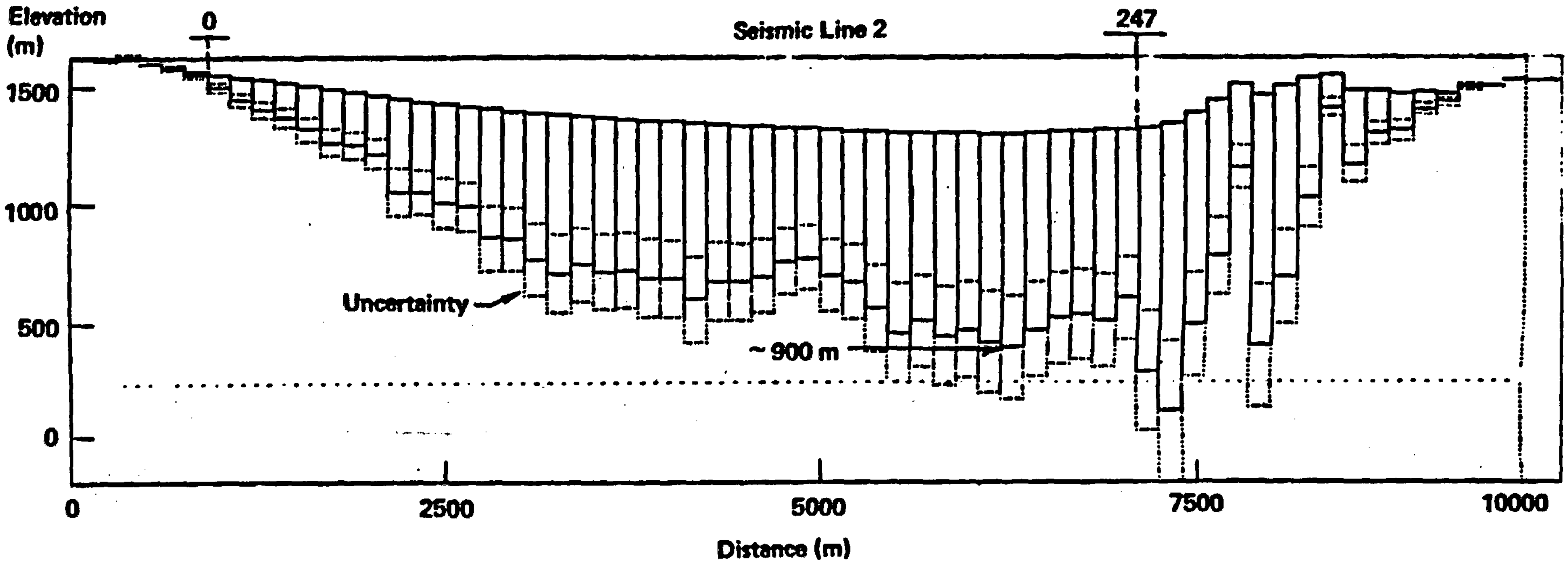


Figure 5.8. Two-dimensional gravity inversion along seismic line 2. A density contrast of 0.4 g/cc was used.

emanating from the Wahmonie-Saylor volcanic center to the south (see Chapter 2), and these probably have a higher density than the tuffs. Thus, the true density contrast would be lower than the value of 0.4 g/cc used in the analysis. If a lower contrast were used, the gravity-indicated Paleozoic depth would be greater.

Conversely, if a Wahmonie lava pile overlies the Paleozoic argillite in Line 2, there would be a neglible change in the acoustic impedance at the Paleozoic/volcanic interface, and therefore a poor reflection wavelet. The excellent reflections from the low-angle feature at about 1.5 to 1.85 s indicate that the air-gun seismic energy was certainly getting to this depth. At this time the evidence is inconclusive and the answer will only be determined by drilling.

Seismic Line 3

The interpretation of seismic line 3 is shown in Figs. 5.9 and 5.10. The geologic cross section derived from the seismic interpretation is presented in Fig. 5.11.

The interpretation of the Paleozoic rocks along seismic line 3 is generally straightforward except near Stations 65 to 75. Apparently much of the seismic line was run on one fault block or partially on the northwestern end of a low-angle listric fault at the Paleozoic-volcanic interface. Excellent volcanic reflections were obtained from Stations 40 to 205.

The major tectonic feature of seismic line 3 is the listric fault occurring approximately at Station 200. This low-angle fault is one of the major Mine Mountain normal faults. Lateral movement is indicated by the loss of volcanic reflections north of the fault. The seismic reflections may suggest a stress buildup in this area. Likewise, the Ammonia Tanks Member of the Timber Mountain Formation appears to be highly jointed and/or brecciated from lateral movement. The total offset of the fault is complicated by either Mine Mountain thrust blocks or imbricate listric block faults. The fault appears to branch ("horse-tail") in the Paleozoic section (Fig. 5.9). Nevertheless, the Mine Mountain left-lateral normal fault is well-defined.

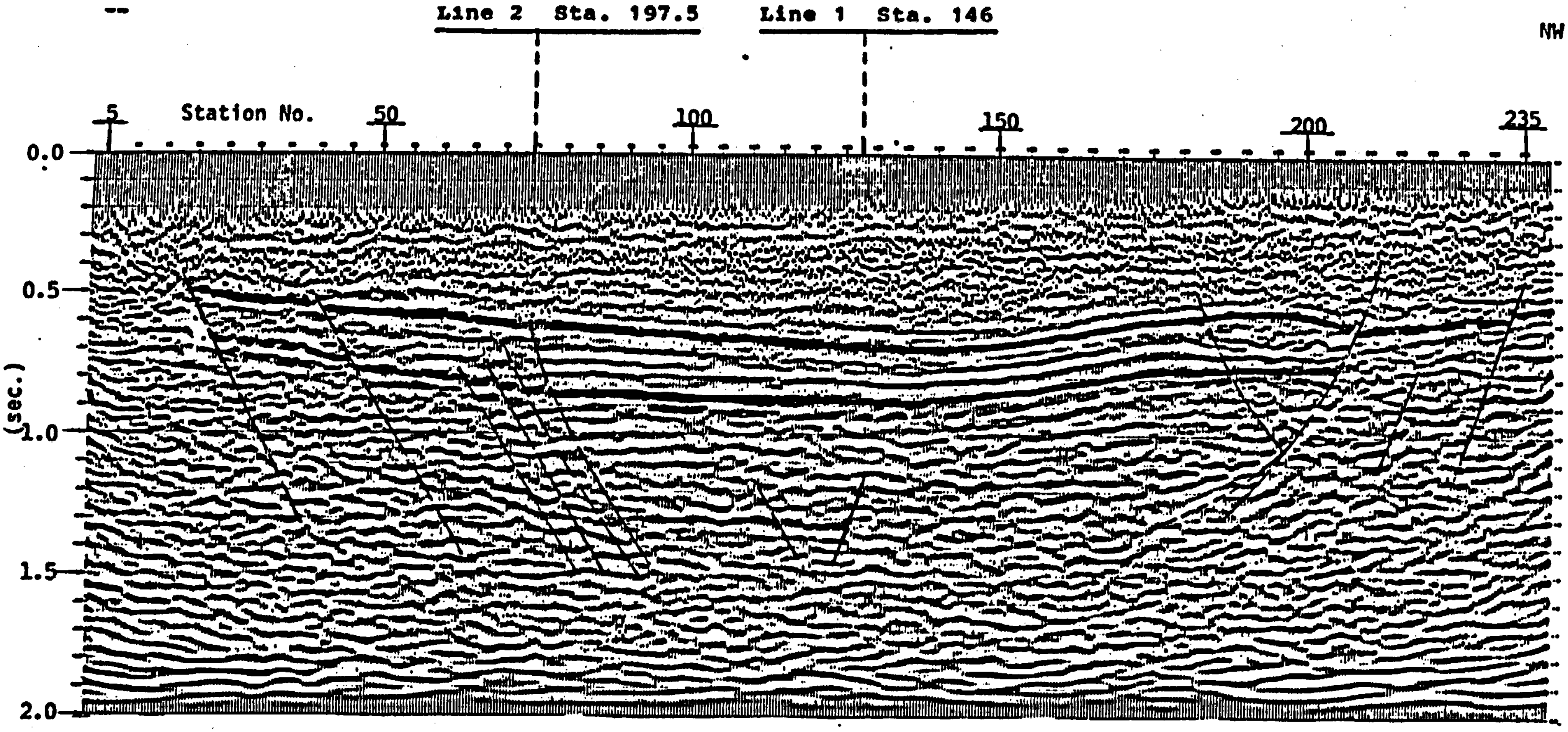


Figure 5.9 Seismic Line 3, migrated: the extensional feature is not shown on this profile because of excessive migration noise.

Tuff/Alluvium
Base Timber Mountain Tuff
Base Tiva Canyon Member
Paleozoic rocks

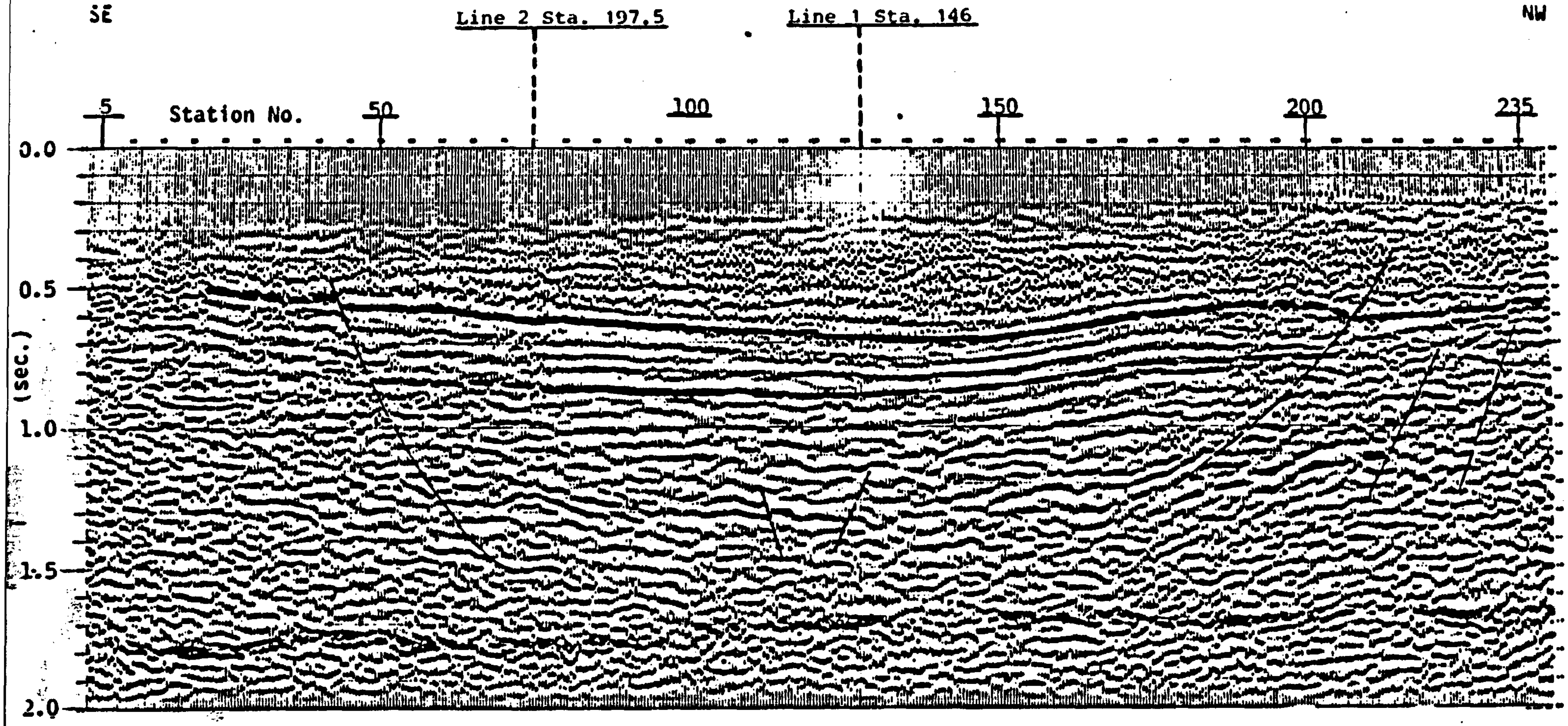


Figure 5.10 Seismic Line 3, Final stack.

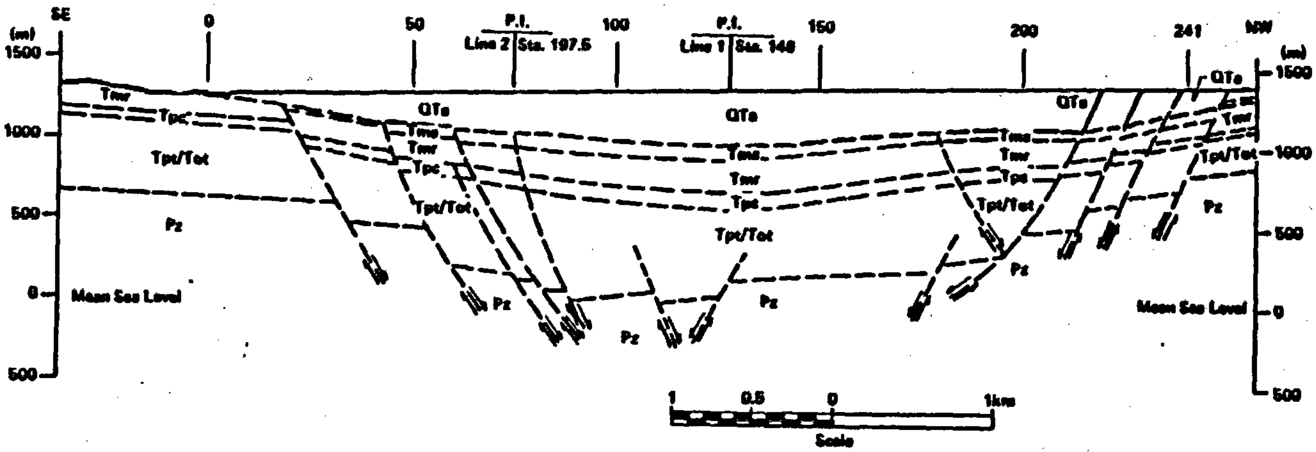


Figure 5.11. Geologic cross section, seismic line 2.

The volcanic section near the intercept with seismic line 2 indicates a series of low angle step-faults (Fig. 5.9). The volcanic offsets are irregular and are difficult to project through the Paleozoic rocks. Whether volcanic alteration is distorting the seismic reflections is unknown. The aeromagnetic surveys have definitely been affected by volcanic alteration, and the seismic reflections are possibly showing similar alteration effects. The integration of seismic lines 1, 2, and 3 is shown on Plate 1.

Plate 1

The drill hole data and seismic interpretations have been combined in Plate 1. The isopach and structural interpretations north of Coordinate N 241 000 are believed to be consistent with the drill hole and seismic interpretation. The isopach thicknesses northeast of Station 160 on line 3 beyond the 1100-m isopach are questionable and may be less than shown.

Area South of Seismic Line 2

The major interpretation problem occurs between seismic line 2 and the southern volcanic outcrops. It is difficult to reconcile the presence of the major east-dipping planar fault, which trends to the south (seen in line 2 of Fig. 5.6), with the presence of an exposed volcanic section to the south of line 2 in which all faults are west-dipping. We can attempt to resolve the contradiction by suggesting that the east-dipping, low-angle, planar, or listric fault may underlie the volcanic section to the south and is therefore hidden, and that the exposed west-dipping faults are a distention feature.

Plate 1 has been constructed to show that the major western fault of line 2 side-steps to the west in an en echelon fashion and either terminates or passes through the Jackass Flats divide beneath alluvium. [Spencer (1985) has illustrated how major faults tend to branch near their ends and show en echelon patterns.]

The gravity profile constructed along line 2 (Fig. 5.8) suggests that west-dipping faults might occur west of the gravity high. The evidence for this is sparse, since only one density contrast was used.

From the available data, any geologic interpretation from seismic line 2 to the southern volcanic outcrops is highly ambiguous. The drill bit always tells the validity of any seismic interpretation. The geologic complexities south of seismic line 2 can only be resolved by exploratory drilling.

Low-Angle Extensional Feature

We suggest that Mid Valley rests on the upper plate or allochton of a major low-angle normal regional detachment fault. Such low-angle, normal extensional faults are well documented in Arizona, California, Nevada, and Utah by Longwell (1945), Davis et al. (1980), Wernicke et al. (1984), and Spencer (1985).

The normal faults of the Mine Mountain system and some of the eastern basin faults may merge with or be truncated by the basal detachment fault. If the low-angle feature observed on the seismic profiles indeed represents the upper and lower allochtons of a low-angle listric extensional fault, the feature may extend east into Yucca Flat and west toward the Yucca Mountain region. We plan future studies to see if a relationship exists between the extensional feature and the Spotted Mountain tectonic zone described by Carr (1984). Such an extensional feature is not believed to be unique to the Paleozoic section underlying Mid Valley. The CP thrust fault in Areas 1 and 3, Yucca Flat, appears to have "backslid" into an extensional low-angle fault because of the change in the tectonic regime. Similar low-angle normal extensional faulting may occur in certain areas of Yucca Flat at the Paleozoic-volcanic interface in the highly brecciated and slickensided interval called colluvium. Further discussion of the extensional features is beyond the scope of this report.

Mid Valley North Basin

The interpretation of the northern basin of Mid Valley is based solely on gravity and surface geology. The major north-south fault interpreted on the Mine Mountain Quadrangle by Orkild (1968) may possibly be visible on an east-west two-dimensional gravity profile that was constructed from the northern-most westerly Paleozoic outcrop to Mine Mountain. The depths shown on Plate 1 are speculative. This area should be investigated in the future as a possible small test area.

6. CONCLUSIONS: MID VALLEY AS A POTENTIAL TEST AREA

This study concentrated on the southern portion of Mid Valley because preliminary studies indicated that this was the most promising portion for our purposes. However, we were surprised. The basin is much deeper than expected, which means that the amount of real estate in the southern portion is larger than thought, and that the yield that could be accommodated for testing is larger than expected.

With this surprising result, we also speculate that the northern portion of Mid Valley, which was thought to be too shallow for testing, might actually be suitable (the depths to the Paleozoics would also be greater than predicted). We have no proof of this; however, the inversions of the gravity field using the density contrasts from the southern portion of the basin would indicate that this speculation may be correct.

We have identified two problems in Mid Valley that limit its usefulness for testing: (1) The upper section of alluvium is not very cemented. It is mostly tuffaceous and sloughs badly. (This occurred in both of the exploratory holes drilled.) Some hole stabilization may be needed to overcome this difficulty. (2) Measurements show the static water level to be about 500 m. This places an upper limit on the yield range that Mid Valley could accommodate if standard scaling rules for depth of burial for tests are used to determine working points above the water table. This is not a problem if liners are used or if working points are available below the water table. But, using current siting practices, it is a real limitation on the yield range that Mid Valley could accommodate.

ACKNOWLEDGMENTS

We would like to thank R. G. Warren of Los Alamos National Laboratory for his petrographic and geochemical analyses that identified the stratigraphic members found in UE14a and UE14b, and J. R Hearst for help in writing this report. We would also like to thank Casey Schmidt for her assistance in writing the lithologic logs, and both she and Bill McKinnis for their field work and assistance in compiling and proofreading the report.

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APPENDIX A: HISTORY OF HOLE UE14a.

Spudded: 7-7-83 Completed: 8-1-83
Circulating media: Air foam
Ground elevation: 1321.7 m Total depth: 1005.8 m
Surface coordinates: N 242042.2 E 198882.4

Bore hole record			Casing record		
Depth (m)			Size	Depth (m)	
From	To	Size (m)	O.d (m)	From	To
0	24.38	0.91	0.51	0	24.08
24.38	697.99	0.34	697.99	1005.84	0.31

Drilling Log

7-7-83	Moved in auger rig and drilled 0.91-m hole from 0 to 13.4 m.
7-8-83	Drilled 0.91-m hole from 13.4 to 24.4. Rigged down and moved out.
7-9-83	Moved in BIR 800 and started rigging up.
7-10-83	Rigged up, ran 0.51-m o.d. casing to 24.1 m and cemented annulus.
7-11-83	Picked up 0.34-m drilling assembly and drilled out cement and hole to 374.0 m, using conventional circulation with air-foam. Tripped out for bit change.
7-12-83	Tripped in and cleaned out 9.1-m fill. Drilled 0.34-m hole from 374.0 to 394.7 m. Tripped out and started replacing rig motor.

7-18-83	Tripped in with core barrel, fill at 985.4 m, stuck barrel, built up air-foam pressure attempting to work stuck tools, and fractured surface pad from sub-base southwest to reserve pit. Tripped out. Ran caliper log, fluid density log, magnetometer log, electric log, compensated density log. Total depths ranged from 508.7 to 503.8 m.
7-19-83	Continued geophysical logging: ran epithermal neutron log, gamma ray log, vibroseis survey on 15.2-m stations, finished logging. Total depths ranged from 503.8 to 500.8 m. Decision made to attempt to drill to Paleozoic rocks. Tripped in, cleaned out bridges to 947.0 m, hole sloughed in, tools stuck at 869.0 m. Pumped in diesel and mud and attempted to free stuck tools. Decision made to terminate hole at 1005.8 m depth.
7-20-83	Worked on stuck tools.
7-21-83	Continued working stuck drill pipe to 1600 hours. Secured rig.
7-22-83 to 7-25-83	Rig secured.
7-25-83	Worked tools up tight hole to 412.4 m, tripped out. Ran sinker bar to 451.4 m, laid down drill pipe, secured rig.
7-29-83	Tripped in and cleaned out bridges to 684.6 m, tripped out. Ran fluid density, caliper, electric, and magnetometer logs to total depths ranging from 681.5 to 684.6 m.
7-30-83	Ran 73-mm Hydrill tubing to 609.8 m for water level monitoring.
8-1-83	Rigged down. Hole completed 8-1-83.
8-2-83 to 9-14-83	Monitored fluid level, fluid level stabilized at 502.01 m.
10-13-83	Pulled 73-mm tubing with crane.
10-16-83	Attempted to run geophysical logs. Hole was bridged at 448.7 m.

APPENDIX B: HISTORY OF HOLE UE14b.

Spudded: 12-2-83 Completed: 3-1-84

Circulated media: Dual-string reverse-air and water to 627.9 m conventional air-foam from 627.9 to 1121.7m

Ground elevation: 1325.4 m Total depth: 1121.7 m

Surface coordinates: N 242042.16 E 198154.17

Bore hole record			Casing record		
Depth (m)			Size	Depth (m)	
From	To	Size (m)	O.d.(m)	From	To
0	38.10	1.22	0.76	0	36.58
38.10	66.14	0.58			
66.14	627.89	0.44	0.34	0	624.14
627.89	1121.66	0.31			

Drilling Log

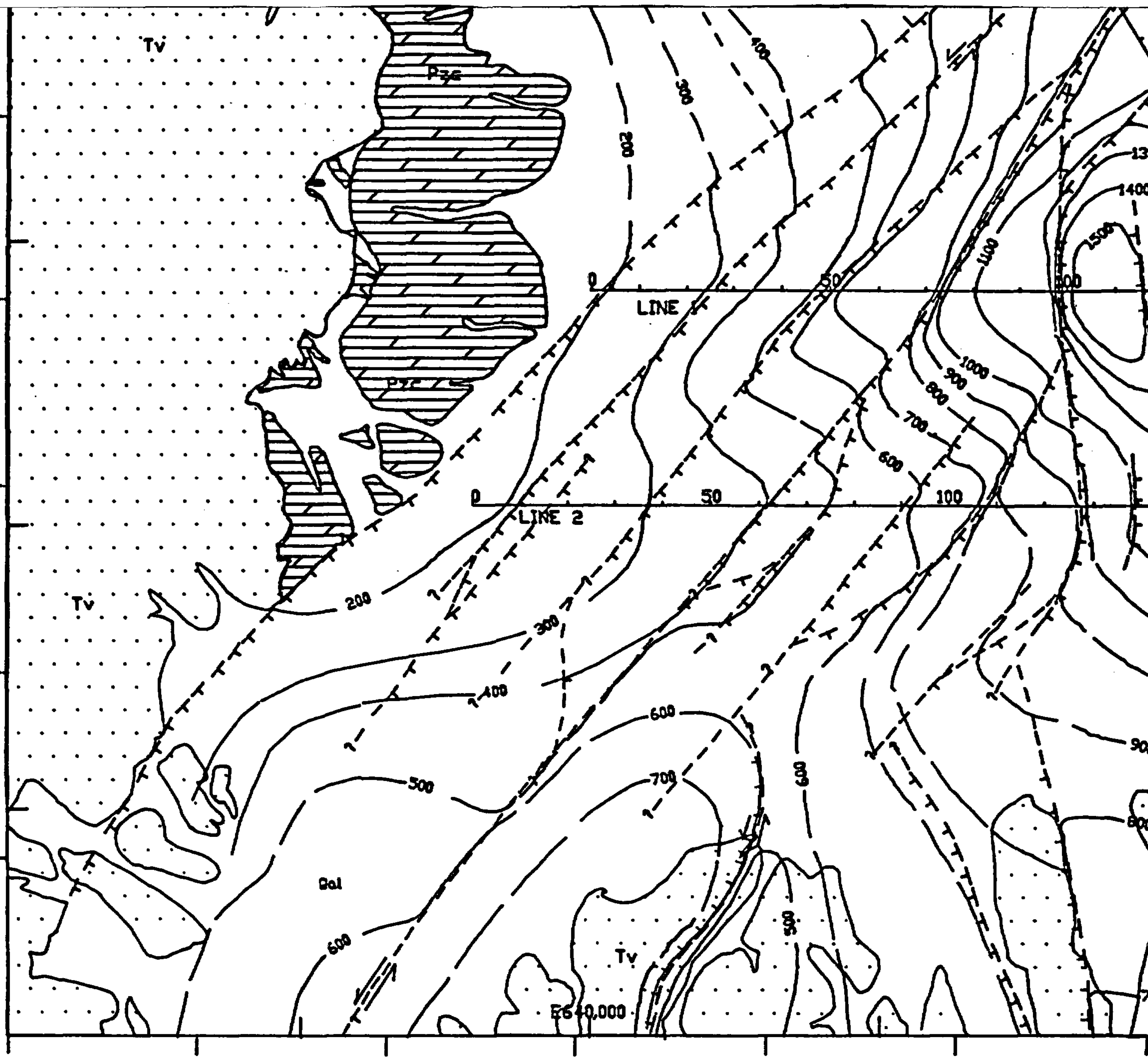
12-2-83	Moved in auger rig, drilled 1.22-m surface hole from 0-7.6 m.
12-5-83	Drilled 1.22-m hole from 7.6 to 25.9 m.
12-6-83	Attempted to straighten hole at 22.9 m without success, opened 1.22-m hole with 2.18-m bit from 0 to 3.1 m and set 1.68 m i.d. casing at 2.7 m.
12-7-83	Drilled mousehole and set casing, rigged down and moved out auger rig. Moved in Ideco 2500 and started rigging up.
12-8-83 to 12-10-83	Continued rigging up and moving in equipment.
12-11-83	Rigged up, tripped in with 1.22-m drill assembly to fill at 20.4 m, attempted to clean fill, plugged up inner string.
12-12-83	Cleaned out fill to 24.1 m, inner string plugged up, sloughed hole, cleaned out fill, drilled 1.22-m hole to 38.1 m, laid down tools.

12-13-83	Set and cemented 0.76-m surface casing to 36.7 m, cemented mousehole, rigged up, secured.
12-14-83	Secured to 1330 hours, drilled 0.58-m hole from 38.1 to 66.1 m, inner string plugging up.
12-15-83 to 12-22-83	Rig secured from 12-15-83 to 12-22-83, worked on rig.
12-23-83	Worked on rig, secured rig for holidays.
1-3-84	Rig secured from 12-23-83 to 0800 hours, 1-3-84; rigged up, drilled 0.44-m hole from 66.1 to 146.6 m, (dual-string with reverse circulation using air and water).
1-4-84	Drilled 0.44-m hole from 146.6 to 280.4 m.
1-5-84	Drilled 0.44-m hole from 280.4 to 409.4 m.
1-6-84	Drilled 0.44-m hole from 409.4 to 420.6 m, blew out fluid and tripped out for core barrel.
1-7-84	Ran 0.22-m diamond core bit in hole and cut core #1 from 420.6 to 426.7 m using conventional air-water, recovered 3.4 m. Tripped in and drilled 0.44-m hole from 420.6 to 428.6 m, blew out fluid and tripped out for core barrel.
1-8-84	Ran 0.22-m diamond core bit in hole and cut core #2 from 428.6 to 434.6 m, recovered 3.1 m, reamed core hole and drilled 0.44-m hole from 434.6 to 471.5 m, blew out fluid.
1-9-84	Tripped out of hole, ran 0.22-m diamond core bit in hole, dropped junk in hole, tripped out, recovered fish, ran 0.22-m diamond core bit in hole and started cutting core #3 at 471.5 m.
1-10-84	Cut 0.22-m core #3 from 471.5 to 474.6 m, recovered 3.1 m, reamed core hole and drilled 0.44-m hole to 487.7 m, tripped out to check seals on inner string.
1-11-84	Tripped in and cleaned 4.6 m of fill, drilled 0.44-m hole from 487.7 to 531.9 m, blew out fluid and tripped out for core barrel, ran 0.22-m diamond core bit in hole and cut core #4 from 531.9 to 536.8 m.
1-12-84	Completed cutting core #4 from 736.8 to 538.0 m, recovered 2.4 m. Reamed core hole and drilled 0.44-m hole to 546.5 m, 3.1 m of fill at 540.1 m connection, tripped out for bit change, tripped in to fill at 540.4 m.

1-13-84	Cleaned out fill and drilled 0.44-m hole from 546.5 to 573.6 m, worked on generators 2 hours and stuck tools, worked stuck tools free and checked inner string for leaks.
1-14-84	Ran temperature log inside inner string to check leaks, ran fluid density log, fluid level at 295.7 m, completed trip out of hole checking inner string for leaks, ran caliper log to 547.4 m T.D. (26.2 m of fill). Tripped in and reamed tight spot in hole from 222.5 to 246.9 m, cleaned out fill from 545.0 to 546.5 m.
1-15-84	Cleaned out fill from 546.5 to 569.4 m, plugged bit, made trip, cleaned out fill from 540.1 to 573.6 m, drilled 0.44-m hole from 573.6 to 614.5 m.
1-16-84	Drilled 0.44-m hole from 614.5 to 627.9 m, tripped out for bit change, tripped in, cleaned out 7.6 m of fill, decided to case hole at present depth.
1-17-84	Started geophysical logging: ran gamma ray log, caliper log, formation density log, epithermal neutron logs; total depths ranged from 624.8 to 626.4 m.
1-18-84	Continued logging: ran fluid density log, electric log, three-dimensional log with 0.91- and 1.83-m spacing, magnetometer, dry hole acoustic log, vibroseis survey at 15.2-m stations; total depths were 625.0 to 626.0 m. Tripped in with Hunt sidewall tool.
1-19-84	Started taking sidewall samples at 449.6 m, tool and wireline problems, tripped to modify sidewall sample tool.
1-20-84	Tripped in and took sidewall samples from 426.7 to 83.8 m, tripped in with 0.44-m drill bit and cleaned fill from 624.8 to 627.9 m, drilled up broken sidewall shoes, tripped out.
1-21-84	Ran fluid density log, fluid level at 438.3 m, rigged up and ran 0.34-m casing from surface to 625.1 m.
1-22-84	Cemented casing up to 579.7 m. Rigged up and drilled out cement to 627.9 m, drilled 0.31-m hole from 627.9 to 635.5 m with conventional circulation using air-foam.
1-23-84	Drilled 0.31-m hole from 635.5 to 737.8 m, tripped for bit change at 712.6 m.
1-24-84	Drilled 0.31-m hole from 737.3 to 813.2 m, strong water inflow, hole sloughing, 3.0 to 4.5 m of fill each connection.

1-25-84	Drilled 0.31-m hole from 813.2 to 854.4 m, hole sloughing, 3.0 to 4.5 m of fill each connection, strong water inflow, tripped for bit change, stage-circulated in and tagged fill at 823.0 m, tripped out and secured.
1-26-84	Ran fluid density log to fill at 814.4 m, checked fluid level at 506.3 m, ran caliper log to 816.0 m, tripped in and stage circulated to fill at 812.6 m, cleaned out fill from 812.6 to 854.4 m, drilled 0.31-m hole to 878.7 m, strong water inflow.
1-27-84	Drilled 0.31-m hole from 878.7 to 1029.3 m, cleaned out 3.0 to 7.6 m of fill on connections between 934.8 and 975.4 m, strong water in flow. Losing cement stage on 0.34-m casing, partial returns coming up drill hole annulus. Returns indicated between 0.34-m casing and 0.79-m surface casing.
1-28-84	Drilled 0.31-m hole from 1029.3 to 1111.3 m, twisted off drill assembly, 6 drill collars, subs and bit in hole, heavy water inflow during drilling, less fill on connections, increasing water returns between 0.34-m casing and surface casing.
1-29-84	Tripped in with fishing tool, recovered all of fish, tripped in and cleaned out fill from 1080.8 to 1111.3 m, drilled 0.31-m hole from 1111.3 to 1116.8 m, increasing returns between casings, eroding cement from bottom of 0.34-m casing.
1-30-84	Drilled 0.31-m hole from 1116.8 to 1121.7 m, unable to unload water from hole, attempted to stage circulate without success, decided to terminate hole at 1121.7 m. Started running geophysical logs. Ran fluid density log, two magnetometer logs; total depths ranged from 1103.1 to 1103.7 m.
1-31-84	Continued geophysical logging. Ran fluid density log, caliper log, 0.91-m and 1.83-m three-dimensional velocity log; total depths ranged from 1103 to 1104 m.
2-1-84	Ran electric log to 1103.4 m, vibroseis survey to 1103.1 m; logged from 1097.3 to 609.6 m on 15.2-m stations, secured rig.
2-1-84	Rig secured. Laid down drill string.
2-10-84 to	Ran fluid density log to 1103.1, checked fluid level at 507.8 m.

2-23-84	Started moving out rig equipment.
3-1-84	Continued moving out equipment and rig. Hole completed 3-1-84.



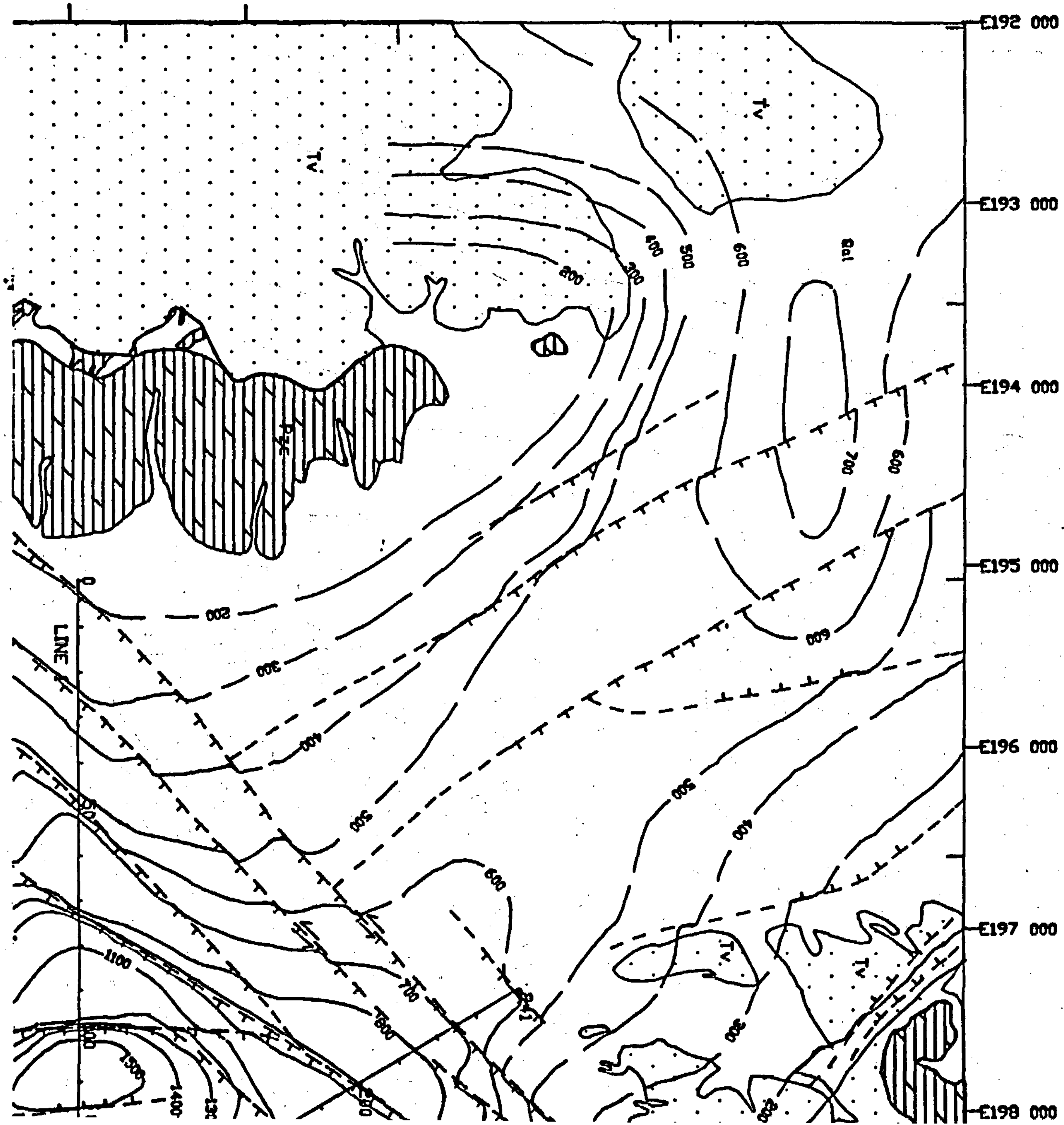
Data for map obtained from seismic lines, gravity, drill holes and geologic interpretation.

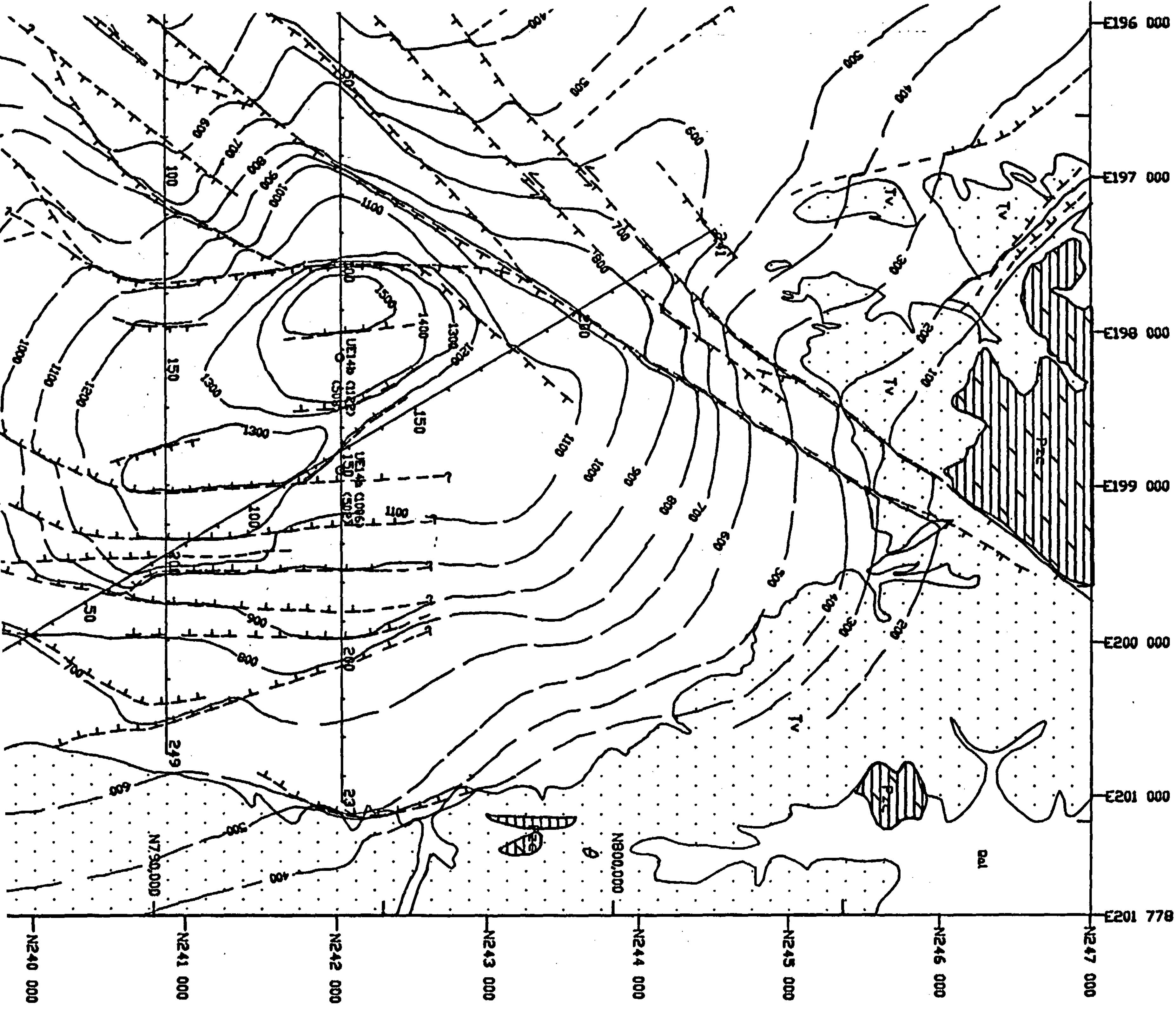
Qal	Alluvium
Tv	Tertiary volcanic outcrops
Pzc	Paleozoic carbonate outcrops

O DRILL HOLE-- Showing drill hole numbe total depth, and depth to Static Wc

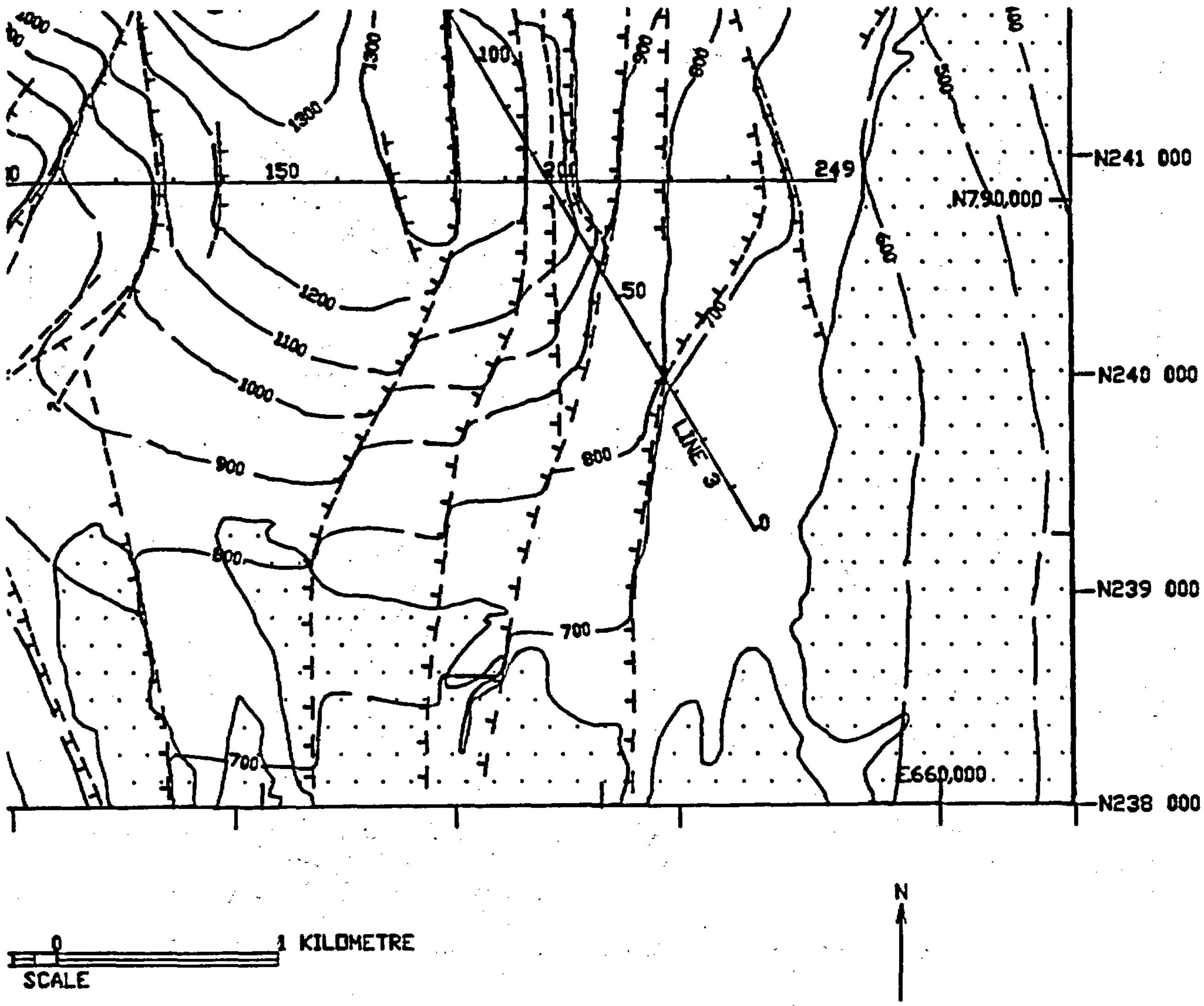
Fault (indicated), bar on downthrown side, dashed where inferred, arrows show relative horizontal movement.

Plate 1. Isopach map of surficial depo
Mid Valley, Nevada Test Si


E192 000
E193 000
E194 000
E195 000
E196 000
E197 000
E198 000
LINE
Tv
Tv
Tv
Tv
Qal
200
300
400
500
600
700
800
1100
1300
1400
1500



E196 000
E197 000
E198 000
E199 000
E200 000
E201 000
E201 778
N240 000
N241 000
N242 000
N243 000
N244 000
N245 000
N246 000
N247 000
N790,000
N800,000
UE14b
UE14b
Tv
Pzc



owing drill hole number,
depth to Static Water Level.

, bar on downthrown
e inferred, arrows
rizontal movement.

—800— Isopach contour showing thickness of surficial deposits and tuff, contour interval is 100 metres.

Line 1 Seismic line.

: surficial deposits and tuff,
Nevada Test Site

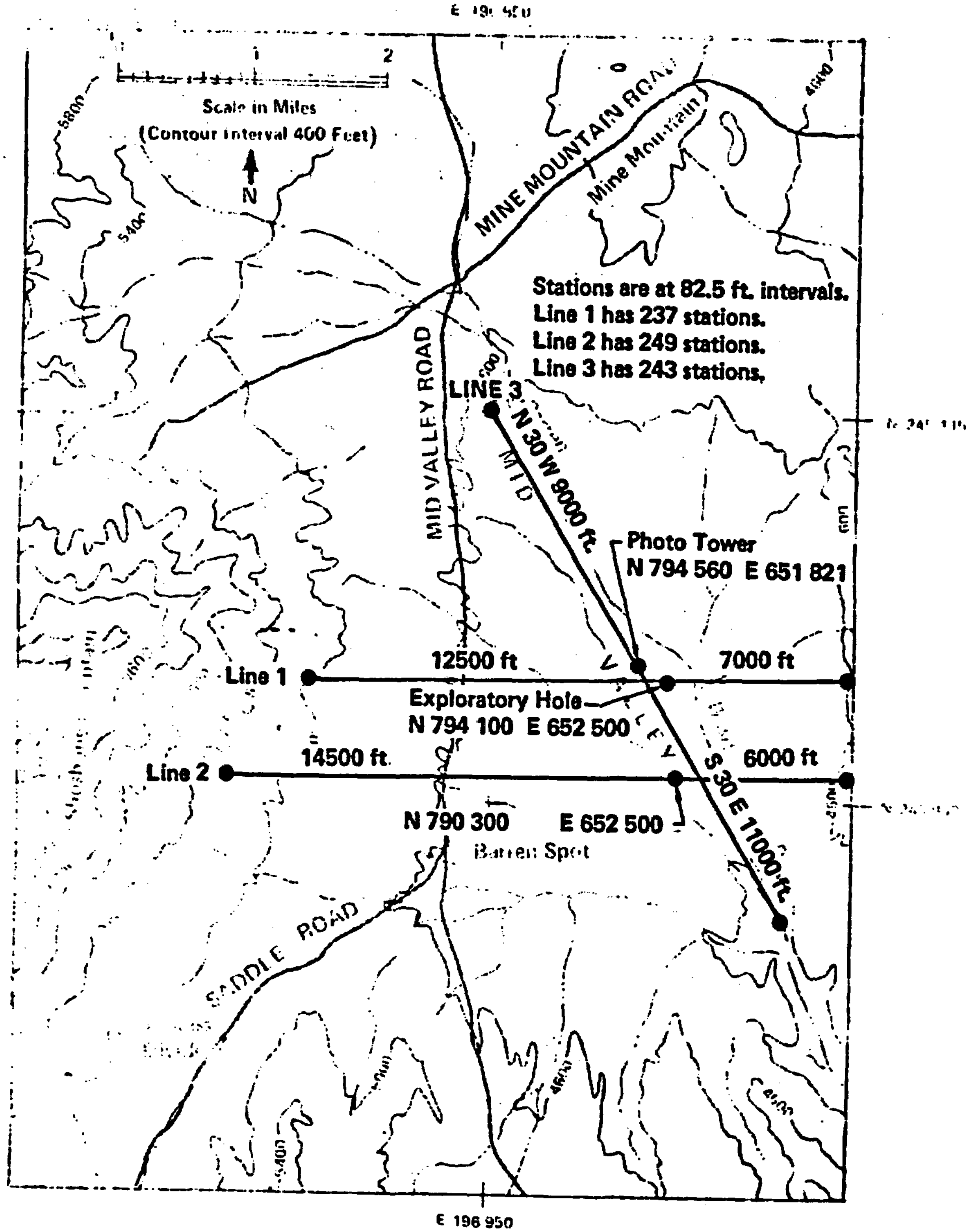


Figure 3.4. Location of seismic lines run by LLNL.