MEASUREMENT OF VERTICAL FLOW IN BOREHOLE UE-3e 4 USING GEOPHYSICAL LOGS, NEVADA TEST SITE, NYE COUNTY, NEVADA

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CONVERSION FACTORS

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
gallon per minute	0.06309	liter per second

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following:

$$°C = 5/9 \times (°F-32)$$

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ABSTRACT

The distribution of vertical flow in a water-filled interval from 2,250 to 1,540 feet in depth in a 2,250-foot-deep borehole was measured using a sensitive thermal-pulse flowmeter to investigate whether fractures intersected by the borehole were serving as pathways for radionuclide emplacement in sediments adjacent to the borehole. The flowmeter measurements indicated vertical flow ranging from 0.12 to 0.24 gallon per minute upflow at numerous points within the fluid-filled part of the borehole. This flow is attributed to the effects of ambient hydraulic-head differences at different depths within the formation adjacent to the borehole. Flow measurements made at two representative depths for about 20 minutes indicated a time variation of upflow nearly as large as the average flow magnitude. Acoustic televiewer logs made throughout the water-filled interval indicated various features that might be related to bedding planes and horizontal or near horizontal fractures. The maximum in radionuclide concentration adjacent to the borehole near 2,230 feet in depth indicated on the natural gamma log appear to be associated with one of these horizontal fractures and does not appear to be associated with vertical fracturing.

INTRODUCTION

Borehole UE-3e 4 (fig. 1) was drilled to a depth of about 2,300 feet to investigate the transport of radionuclides to the vicinity of the borehole from an underground nuclear explosion located about 1,000 feet to the north.

A series of geophysical logs were run to identify potential water-producing fractures penetrated by borehole UE-3e 4, to make measurements that might indicate which of these fractures were actually producing water under ambient hydraulic-head conditions, and to identify the relationship between water-producing fractures and the occurrence of radionuclides within sediments. This report presents an analysis of the geophysical logs, and other information considered relevant to the identification of vertical flow in borehole UE-3e 4.

The general geology of the sediments at the study site include a series of layered volcanic tuffs and sediments derived from such rocks. Most of the sediments penetrated by borehole UE-3e 4 are only partially saturated. However, no information is available on the location of the water table before drilling. The measured water level in borehole UE-3e 4 (2,300 ft) may indicate the depth of the predrilling water table, or upward flow in the borehole could be exiting at fractures at depths above the predrilling water level. Although the saturated volcanic sediments below 1,540 feet in depth may contain substantial porosity, most of this porosity is non-effective, and water flow is thought to occur by means of fractures (Nelson and others, in press).

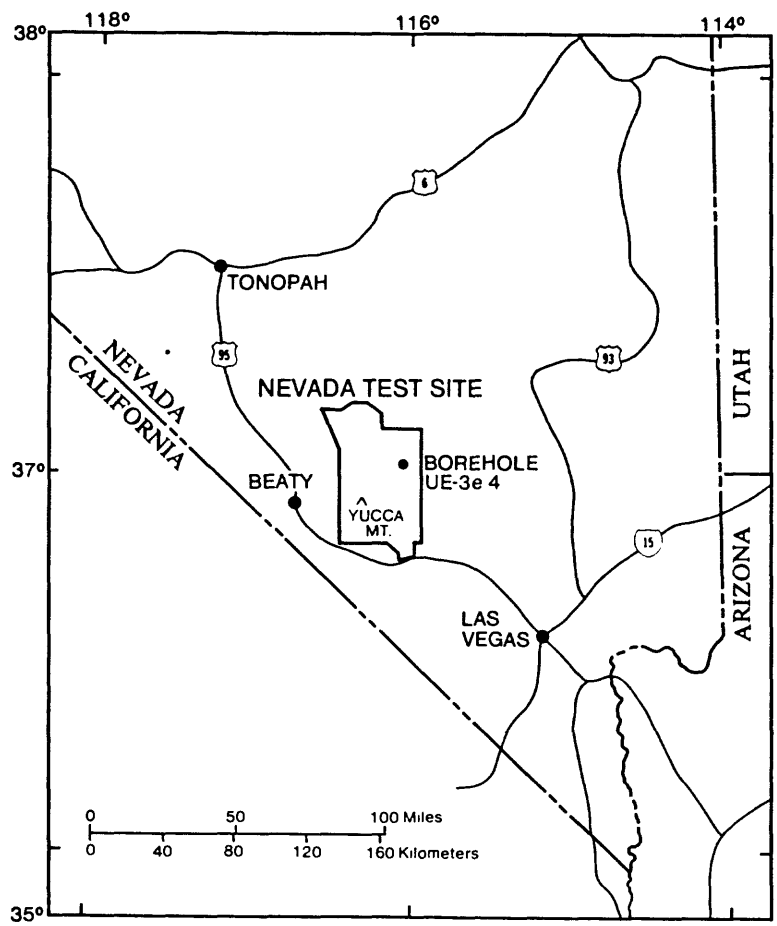


Figure 1. Map showing location of borehole UE-3e 4.

A standard suite of conventional geophysical logs was run in borehole UE-3e 4 shortly after the borehole was drilled in January 1990. Nominal bottomhole depth was 2,300 feet, and the geophysical logs show that logging tools could be lowered to a depth greater than 2,295 feet within a few days after drilling. The conventional suite of logs run after drilling included caliper, compensated density, compensated neutron, deep-induction, gamma spectral, natural gamma, and temperature logs.

The U.S. Geological Survey subsequently ran another temperature log and two additional logs to provide information about the hydraulic conductivity of fractures encountered by borehole UE-3e 4. These two logs were the acoustic televiewer (ATV) and thermal-pulse flowmeter (TPFM) logs. The ATV log provides a photographic image of the pattern of acoustic reflectivity of the borehole wall (Zemanek and others, 1970). The TPFM log uses a short current pulse in a grid arrayed across the instrument flow section to tag a small volume of water, and then measures the time required for that pulse of thermal energy to arrive at a thermistor about 0.8 inch above or below the grid (Hess, 1982, 1986). The ATV and HPFM logs have been used in combination in a number of studies to identify fractures producing flows in boreholes in fractured crystalline and sedimentary rocks (Hess, 1986; Hess and Paillet, 1989).

GEOPHYSICAL LOGS FROM BOREHOLE UE-3e 4

Analysis of Conventional Logs

Conventional geophysical logs indicate the lithological background of borehole UE-3e 4, and can provide a generalized indication of depths where fractures may intersect the borehole. Deep-induction, natural gamma, and caliper logs for borehole UE-3e 4 are shown in figure 2. These logs are presented as typical of the conventional geophysical logs that are routinely used in the geotechnical industry to indicate the lithologic variations adjacent to the borehole. The deep-induction log responds to borehole enlargements, which are indicated by the caliper log, lithology, and porosity. The gamma log can indicate the presence of gamma-emitting radionuclides within lithologic units. The caliper log can be compared to the deep-induction log and other logs (not shown in figure 2) to identify the extent to which variations in borehole diameter affect the quality of lithology logs.

Changes in temperature gradients measured in boreholes may be related to the existence of flow within the borehole being driven by ambient hydraulic-head conditions, so computation of a temperature-gradient log from temperature log data is useful. Therefore, before running the specialized fracture-identification logs (ATV and TPFM) in borehole UE-3e 4, the U.S. Geological Survey ran a temperature log on February 8, 1990, approximately 2 weeks after the conventional logs were run, and less than 3 weeks after the borehole had been drilled. This temperature log is shown in figure 3. Although the digitizing system failed during logging, the original log was digitized by hand afterwards, and the differential temperature log was plotted using this data (fig. 3). This differential log shows a generally uniform gradient of approximately 1 °F per 100 feet, except in the vicinity of 2,100 feet in depth, where the gradient is more than twice as large.

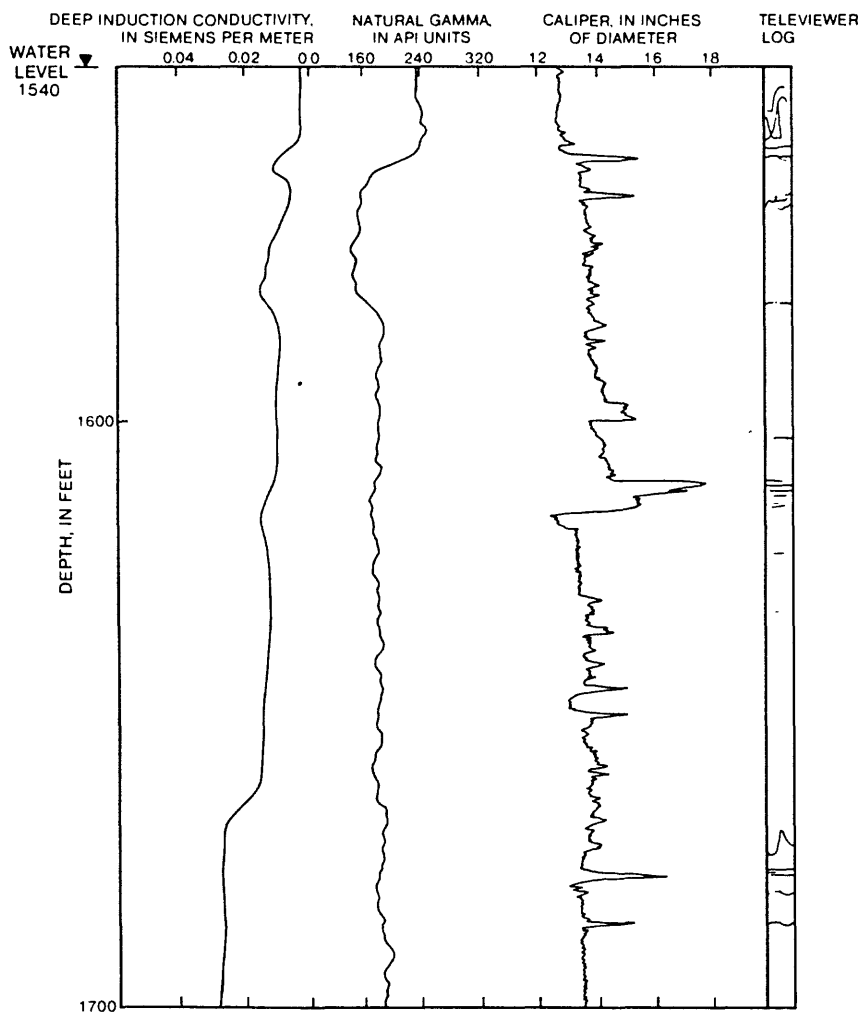


Figure 2. Graph showing conventional geophysical logs compared to acoustic televiewer log data for borehole UE-3e 4.

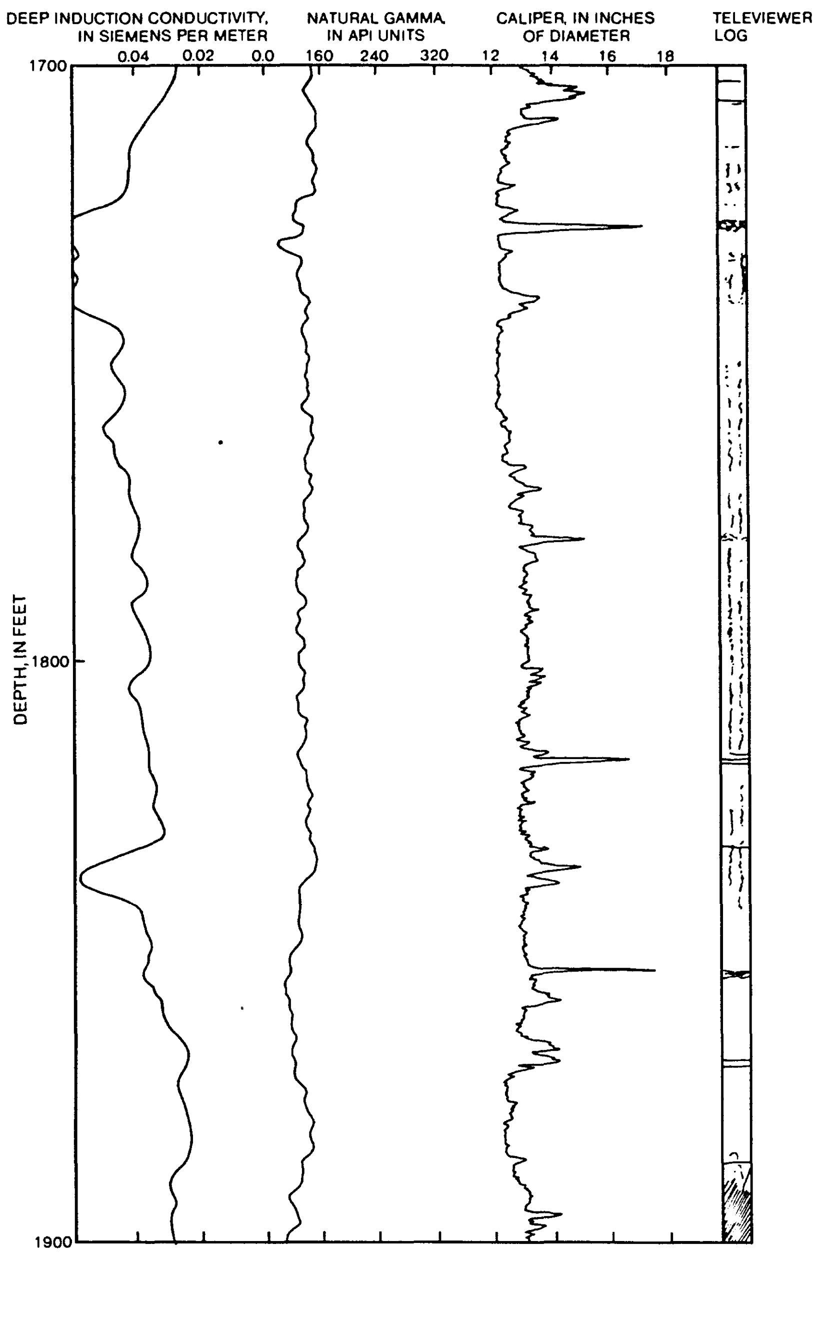
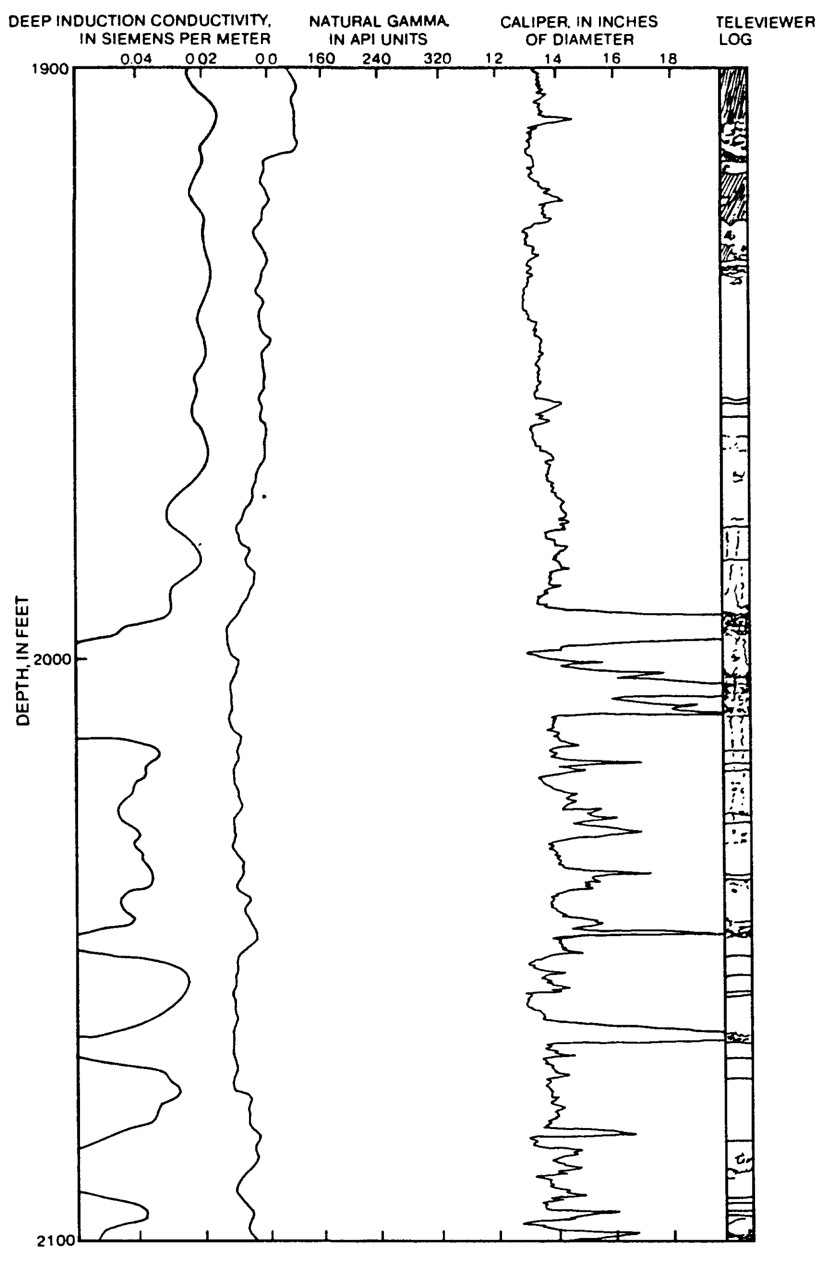


Figure 2 continued



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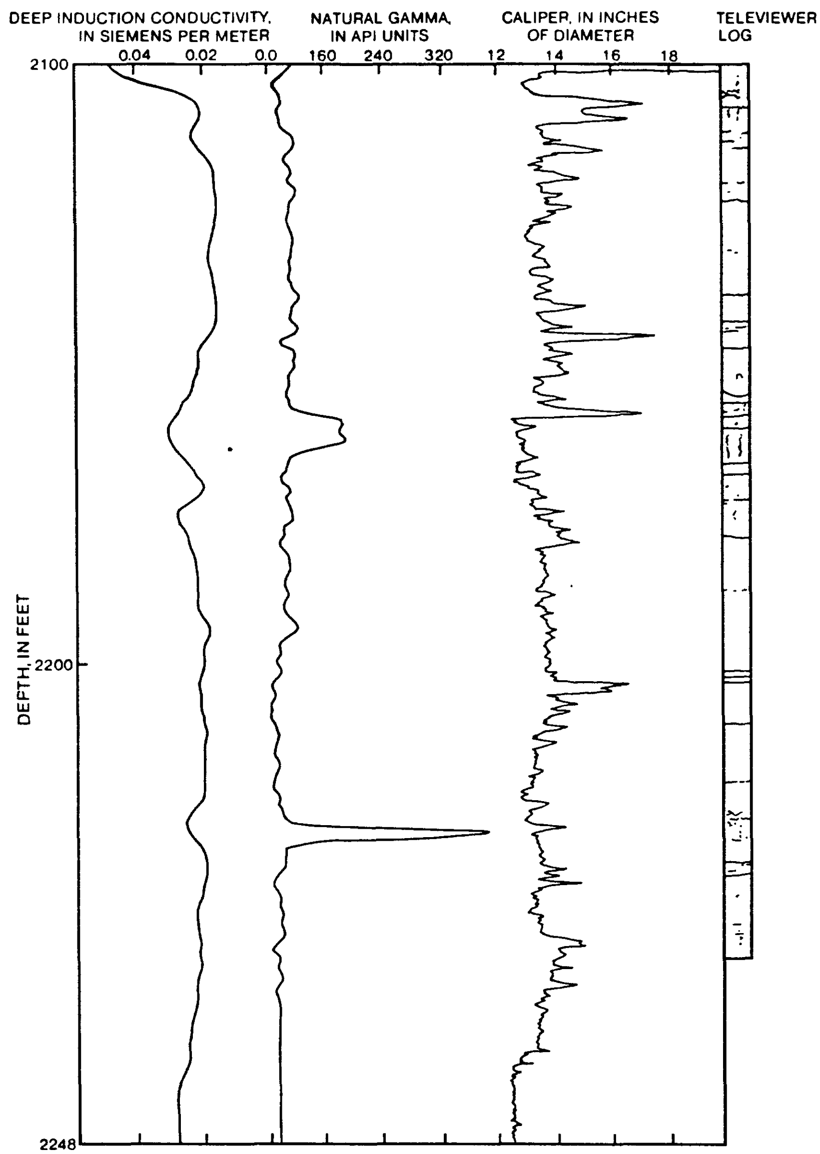

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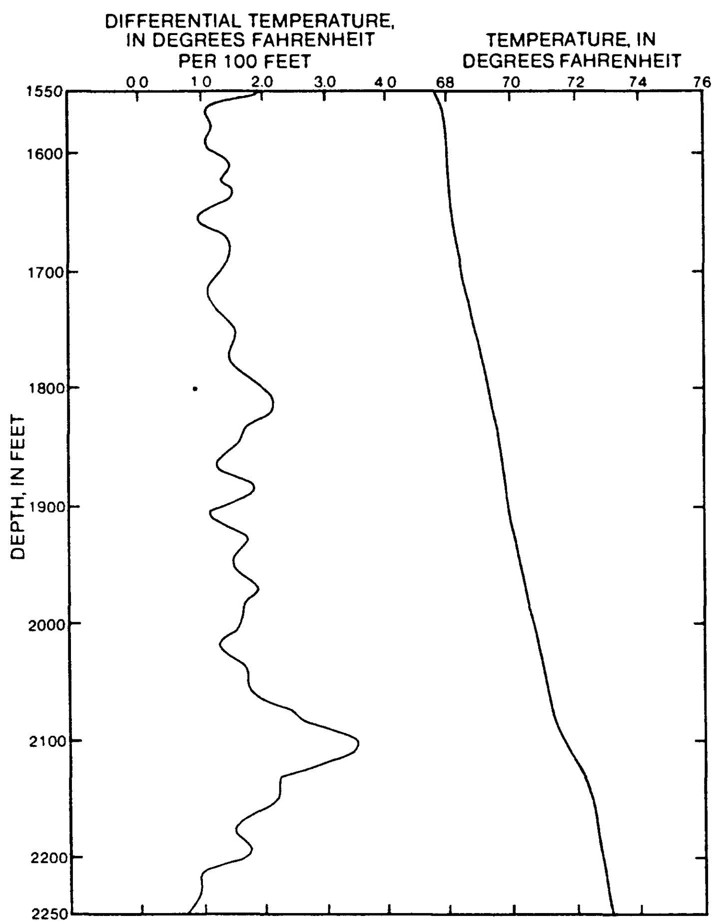

Figure 3. Graph showing differential temperature and temperature logs for borehole UE-3e 4.

Acoustic Borehole Televiewer Logs from Borehole UE-3e 4

ATV logs were run in borehole UE-3e 4 to identify potential water-producing fractures. A direct graphical representation of the original ATV photographs of the pattern of acoustic reflectivity on the borehole wall is shown in figure 4 with no attempt at interpretation. Blank areas represent areas of uniformly large amplitude borehole wall reflections, and density of cross-hatching is used to represent the degree of attenuation of the reflected signal associated with less reflective borehole wall, or scattering by bedding planes, wall roughness, and fracturing. A summary of this representation is shown on the figure.

Minor depth errors almost always occur in comparing one geophysical log to another because cable stretch and other factors produce small but significant depth shifts in the individual logs. Standard adjustments are made by referencing easily identified points such as the bottom of casing, prominent fractures or lithology contacts, and other minor fractures, on each log. In this report, these adjustments were made by comparing the U.S. Geological Survey ATV log shown in figure 4 with the conventional geophysical logs in figure 2. The possibility of significant depth error was anticipated when the ATV logging probe could not be lowered below 2,250 feet because the lower part of the borehole had apparently filled in during the time since the conventional logs were run shortly after completion of drilling. The decrease in logging cable tension associated with unexpected stopping of the tool near 2,250-foot-depth was suspected as a possible cause of depth error because the decreased tension can allow slippage of the cable on the depth measuring wheel. However, comparison of the ATV log with the caliper log indicated that only about 2 feet needed to be added to the U.S. Geological Survey ATV log depths to correspond to the same depths as measured by the conventional geophysical logs. The close correlation between the depth-corrected logs illustrated in figure 2 provides confidence that individual anomalies on the various conventional logs can be related to specified features on the televiewer logs. The large-amplitude radionuclide maximum indicated by the natural gamma log near 2,230 feet in depth in figure 2 appears associated with nearly horizontal fractures or bedding planes, and not with vertical or nearly vertical fractures. However, vertical fractures are not well sampled by vertical boreholes, so that the apparent absence of vertical fractures associated with gamma anomalies may not mean that such fractures are not important in radionuclide emplacement. It is still possible that vertical fractures were involved in the upward movement of radionuclides, which subsequently moved horizontally along bedding planes.

Thermal-Pulse Flowmeter Log from Borehole UE-3e 4

After completion of the ATV logging, the TPFM survey was run in borehole UE-3e 4. Previous studies (Hess, 1986) indicate that the TPFM can detect vertical flows greater than $\pm$ .05 gallons per minute. Individual TPFM measurements are listed in table 1 and the vertical flow distribution measured in the borehole is illustrated in figure 5. Upflow was measured throughout the depth interval from near the bottom of the borehole (2,250 feet) to water level (1,540 feet). This flow is attributed to the effects of

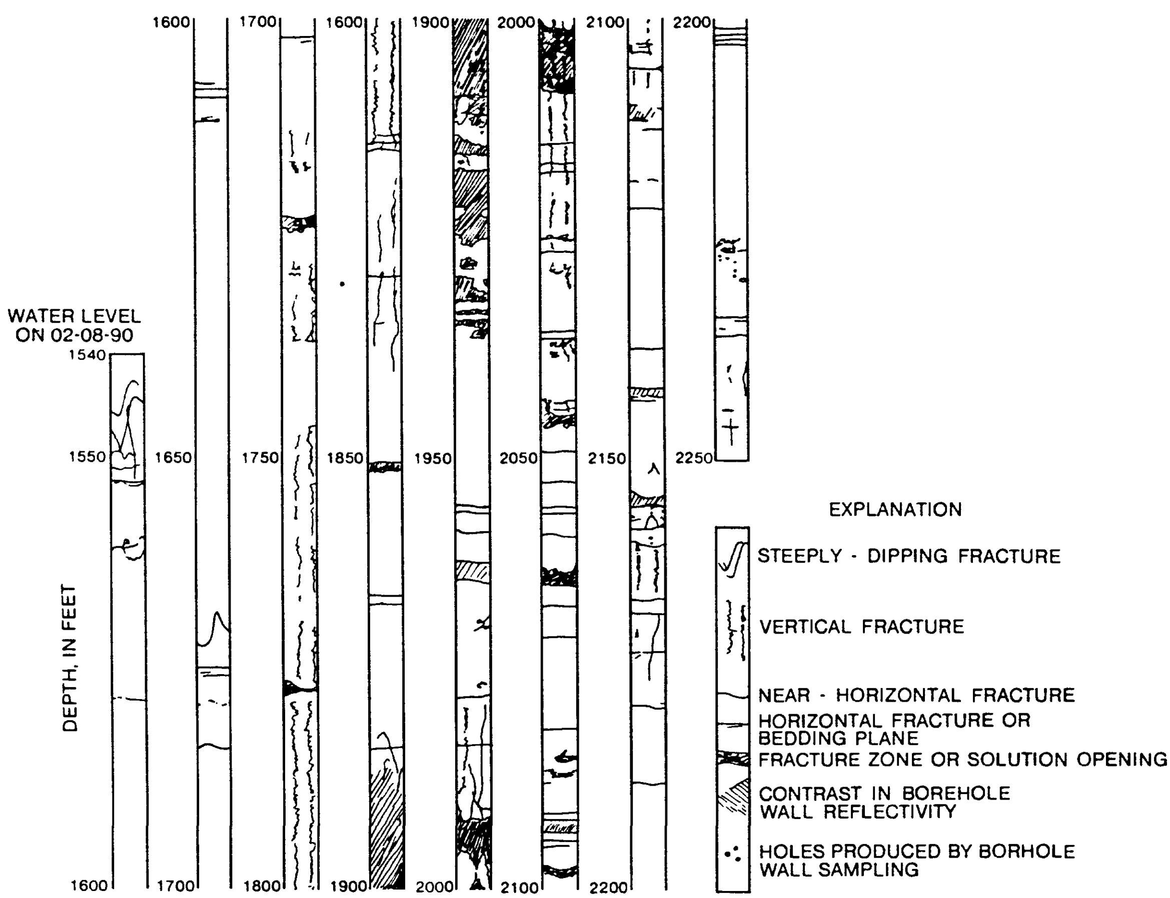

Figure 4. Graphical representation of borehole acoustic televiewer (ATV) log for borehole UE-3e 4.

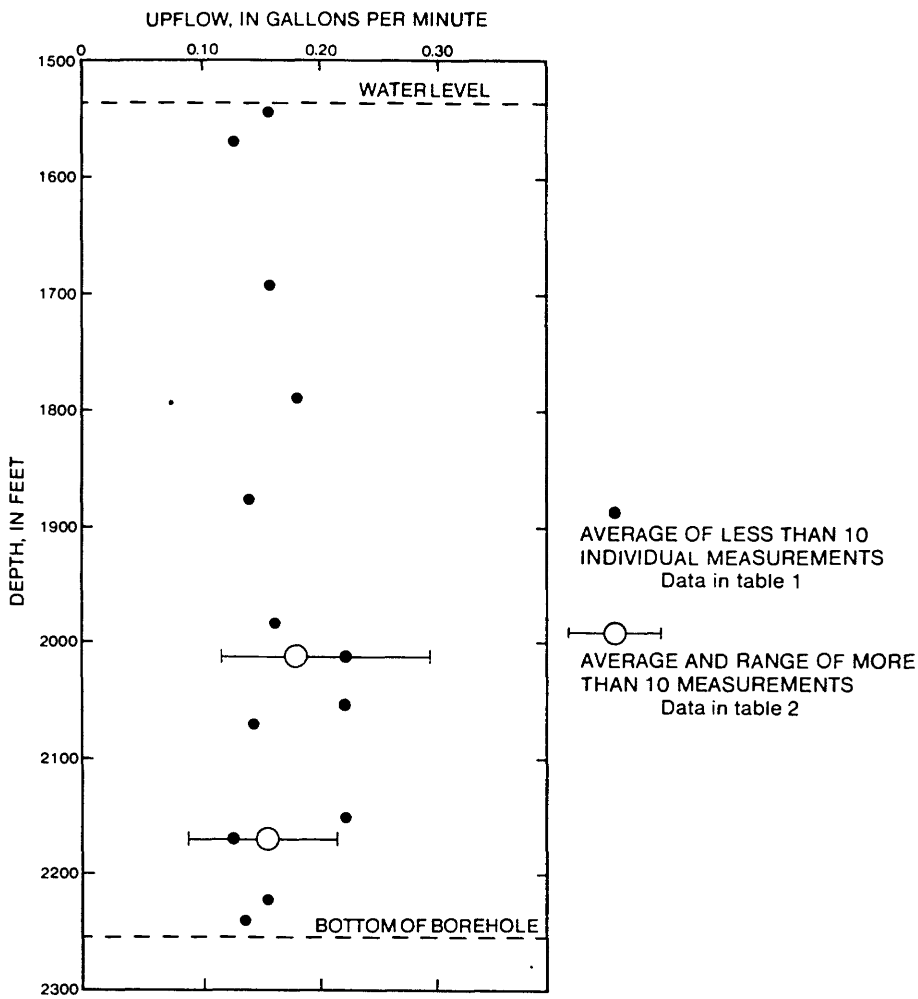

Figure 5. Graph showing thermal-pulse flowmeter measurements of upflow under ambient hydraulic-head differences in borehole UE-3e 4.

Table 1.--Thermal-pulse flowmeter measurements in borehole UE-3e 4

Time of measurement	Depth below land surface (feet)	Number of measurements	Average response Time (seconds)	Calibrated upflow (gallons per minute)
1155	1,575.0	6	6.1	0.13
1452	1,697.5	4	5.3	0.16
1602	1,795.0	3	4.5	0.18
1608	1,880.0	6	5.5	0.14
1643	1,985.0	4	5.1	0.16
1700	2,014.0	3	4.1	0.22
1741	2,053.0	6	4.3	0.21
1812	2,070.0	4	5.8	0.14
1835	2,150.0	5	4.1	0.22
1901	2,169.0	3	7.5	0.12
1942	2,222.0	8	5.4	0.15
2004	2,240.0	9	6.0	0.13
2033	2,053.0	7	4.1	0.22
2114	1,550.0	5	5.3	0.16

ambient hydraulic head differences in the formation adjacent to the borehole. The data in table 1 also indicate variations in the magnitude of upflow, from 0.12 to 0.22 gallons per minute. In many situations, the variations in vertical velocity with depth can be interpreted as the result of inflow or outflow at one or more fractures intersecting the borehole between two measurement points. However, it is also possible that differences in measured vertical flows may be caused by a variation in the rate of vertical flow with time.

In order to check on the possibility of changes in flow rates with time, TPFM measurements were made at two representative depths (2,014 and 2,169 feet) over an extended period (21 and 18 minutes, respectively). Substantial variations in vertical flow were measured at these depths (table 2, fig. 6). The magnitude of these variations (from 0.08 to 0.30 gallons per minute) needs to be considered in evaluating the significance of variations in the vertical distribution of velocity given in figure 5. Vertical connection within the borehole as described by Sammel (1968) and Sorey (1971) are probably not responsible for these variations because the TPFM measurements are made using a downhole packer to prevent flow around the annulus between tool measurements section and the borehole walls (Hess, 1986). This packer would impede any corrections driven by bouyancy by disrupting the convection cell.

SUMMARY

Acoustic televiewer (ATV) and thermal-pulse flowmeter (TPFM) logs were run in borehole UE-3e 4, which penetrates 2,250 feet of tuffaceous sediments at the Nevada Test Site in southwestern Nevada. Conventional geophysical logs such as the caliper, deep-induction and natural gamma logs indicated the general variation of lithology along the borehole. The ATV log indicated sharp contrasts in acoustic impedance that could represent bedding planes, lithologic contacts, and wall roughness, and linear fractures that could correspond to fractures intersecting the borehole. Comparison of the ATV log and the gamma log can indicate the relationship between fractures and the occurrence of radionuclides in sediments. Several distinct maxima in gamma activity appear associated with horizontal fractures or bedding planes and do not appear associated with vertical fractures. The TPFM was used to measure the distribution of vertical flow in borehole UE-3e 4. Measurable upflows were detected over almost the entire depth of the borehole, from 2,240 feet to water level at 1,550 feet. The upflow varied in magnitude from 0.12 to 0.22 gallons per minute within that depth range. However, variation in the flow measured at a single depth point over time indicates that some or all of this apparent vertical variation may be associated with the variation of the entire flow field, and not with exit or entry of flow between 2,250 and 1,540 feet in depth.

Table 2.--Repeated thermal-pulse flowmeter measurements at selected depths

Time of measurement	Response time (seconds)	Calibrated upflow (gallons per minute)
MEASUREMENTS AT 2,014-FOOT DEPTH		
16:59:00	4.0	0.23
17:00:00	4.1	0.22
17:01:00	4.1	0.22
17:12:00	5.9	0.14
17:13:00	7.0	0.11
17:13:30	3.3	0.30
17:14:00	4.6	0.19
17:14:20	5.5	0.15
17:14:40	5.0	0.17
17:20:00	5.1	0.16
17:20:30	5.6	0.14

Table 2.--Repeated thermal-pulse flowmeter measurements at selected depths

Time of measurement	Response time (seconds)	Calibrated upflow (gallons per minute)
MEASUREMENTS AT 2,169-FOOT DEPTH		
19:01:00	7.1	0.11
19:02:00	7.6	0.10
19:02:20	8.5	0.08
19:02:40	5.4	0.15
19:03:00	4.9	0.17
19:03:30	5.0	0.17
19:04:00	5.4	0.15
19:05:00	7.0	0.11
19:05:30	7.0	0.11
19:06:00	9.2	0.08
19:06:30	7.4	0.10
19:07:00	8.1	0.09
19:13:00	7.0	0.11
19:14:00	5.4	0.15
19:14:50	5.6	0.14
19:15:10	4.9	0.17
19:15:25	4.8	0.18
19:15:45	4.1	0.22
19:16:00	4.2	0.21
19:16:20	4.8	0.18
19:16:40	4.4	0.20
19:17:00	4.3	0.21
19:17:20	4.3	0.21
19:17:40	5.9	0.14
19:18:00	5.2	0.16
19:18:20	4.9	0.17
19:18:40	5.2	0.16
19:19:00	7.8	0.09
19:19:30	6.0	0.13

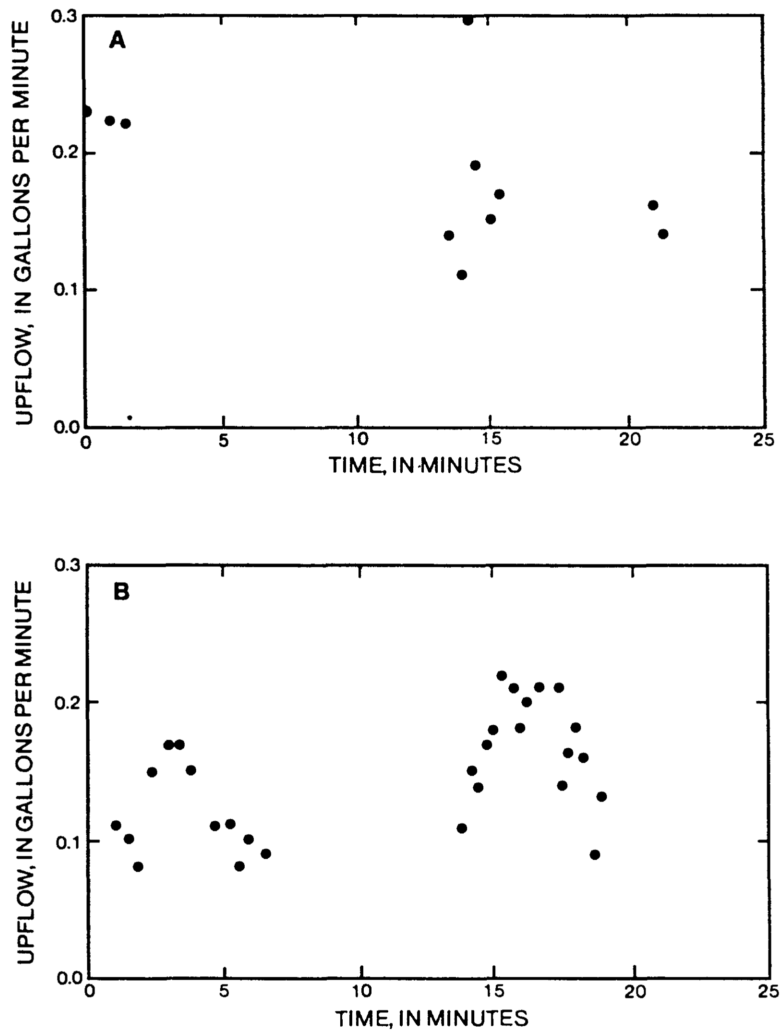

Figure 6. Graph showing thermal-pulse flowmeter measurements of upflow under ambient hydraulic-head conditions times 10-minute intervals at depths of (A) 2,014 feet and (B) 2,169 feet in borehole UE-3e 4.

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