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GEOHYDROLOGY OF VOLCANIC TUFF PENETRATED BY TEST WELL UE-25b#1, YUCCA MOUNTAIN, NYE COUNTY, NEVADA

U.S. GEOLOGICAL SURVEY

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Water-Resources Investigations Report 84-4253

Prepared in cooperation with the

U.S. DEPARTMENT OF ENERGY

HYDROLOGY DOCUMENT NUMBER 22

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By R. G. Lahoud,[1] D. H. Lobmeyer,[2] and M. S. Whitfield, Jr.[2]

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Denver, Colorado
1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

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CONTENTS

ILLUSTRATIONS

CONTENTS

TABLES

METRIC CONVERSION TABLE

For the use of those readers who may prefer to use inch-pound rather than metric units, the conversion factors for the terms used in this report are listed below:

Metric unit	*Multiply by*	*To obtain inch-pound unit*
degree Celsius (°C)	1.8(°C)+32	degree Fahrenheit
gram per cubic centimeter (gm/cm^3)	6.243×10^{1}	pounds per cubic foot
kilometer (km)	6.214×10^{-1}	mile
liter (L)	2.642×10^{-1}	gallon
liter per second (L/s)	1.585×10^{1}	gallon per minute
meter (m)	3.281	foot
meter per day (m/d)	3.281	foot per day
cubic meter per day	3.531×10^{1}	cubic foot per day
meter squared per day (m^2/d)	1.076×10^{1}	foot squared per day
milligram per liter (mg/L)	[1]1.0	part per million
millimeter (mm)	3.937×10^{-2}	inch

[1]Approximate for concentrations of dissolved solids less than about 7,000 milligrams per liter.

GEOHYDROLOGY OF VOLCANIC TUFF PENETRATED BY TEST WELL UE-25b#1 YUCCA MOUNTAIN, NYE COUNTY, NEVADA

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ABSTRACT

Test well UE-25b#1, located on the east side of Yucca Mountain in the southwestern part of the Nevada Test Site, was drilled to a total of 1,220 meters and hydraulically tested as part of a program to evaluate the suitability of Yucca Mountain as a nuclear-waste repository. The well penetrated almost 46 meters of alluvium and 1,174 meters of Tertiary volcanic tuffs. The composite hydraulic head for aquifers penetrated by the well was 728.9 meters above sea level (471.4 meters below land surface), with a slight decrease in hydraulic head with depth.

Average hydraulic conductivities for stratigraphic units determined from pumping tests, borehole-flow surveys, and packer-injection tests ranged from less than 0.001 meter per day for the Tram Member of the Crater Flat Tuff to 1.1 meters per day for the overlying Bullfrog Member of the Crater Flat Tuff. Small values for the Tram Member represented matrix permeability of unfractured rock; large values near the lower part of the Bullfrog Member were associated with the basal bedded or reworked tuffaceous beds, but probably resulted from fracture permeability. Large hydraulic conductivities of the rhyolitic tuffs of Calico Hills, the Prow Pass Member at the top of the Crater Flat Tuff, and the middle of the Bullfrog Member probably resulted from fracture permeability in the ash-flow tuffs.

Chemical analyses indicated that the water is a soft sodium bicarbonate type, slightly alkaline, with large concentrations of dissolved silica and sulfate. Uncorrected carbon-14 age dates of the water were 14,100 and 13,400 years.

INTRODUCTION

The U.S. Geological Survey, in cooperation with the U.S. Department of Energy, is conducting geologic, geophysical, and hydrologic studies at the Yucca Mountain site in the southwestern part of the Nevada Test Site (NTS). These investigations are being conducted under Interagency Agreement DE-AI08-78ET44802 as part of the Nevada Nuclear Waste Storage Investigations to determine the suitability of this site for storing high-level nuclear wastes in an underground mined repository.

Purpose and Scope

The purpose of this report is to describe the hydrologic characteristics of a sequence of saturated tuffs penetrated by test well UE-25b#1. The report includes hydraulic-test data, supporting geological and geophysical information, and hydrologic interpretations. Water-level and basic data for this well are published in Lobmeyer and others (1984).

The authors acknowledge R. W. Spengler, U.S. Geological Survey, for the use of unpublished lithologic data. L. P. Escobar, Fenix & Scisson, Inc., compiled the fracture analysis of the core. The authors acknowledge D. O. Blout, S. J. Waddell, S. L. Koether, J. B. Warner, and other Fenix & Scisson, Inc., geologists for their help in monitoring and testing the well.

Location of Study Area

Test well UE-25b#1 is approximately 145 km northwest of Las Vegas, Nev., on the Nevada Test Site (fig. 1). The well is at latitude 36°51'08"N and longitude 116°26'23"E (N. 765,243.62 feet and E. 566,416.74 feet, Nevada Coordinate System Central Zone) in a major wash that trends northwest from Fortymile Canyon on the east flank of Yucca Mountain. The wash is locally known as Drill Hole Wash. Altitude of the drill pad is 1,200.4 m.

A previously drilled test well, UE-25a#1, is 107 m south-southwest of test well UE-25b#1 in Drill Hole Wash at an altitude of 1,198.7 m. Test well UE-25a#1 was used to observe water-level changes during pumping tests in test well UE-25b#1.

Well History

Test well UE-25b#1 was spudded April 3, 1981, and completed September 22, 1981, at a total depth of 1,220 m. The well was drilled in two phases (fig. 2). A medium-sized rotary drill rig was used in the first phase to drill a hole 222 mm in diameter to a depth of 579 m. Geophysical logs, borehole-flow surveys, and packer-injection tests were conducted while the well was at this depth during the first phase of testing.

A small-sized rotary drill rig was used to cut 64-mm-diameter cores from 579 to 1,220 m. A second phase of testing was conducted when the well was at a depth of 1,220 m. Geophysical logging, pumping tests, borehole-flow surveys, and packer-injection tests were conducted while the well was at this depth.

An air-foam fluid consisting of air, detergent, and water was used as the circulating medium during both phases of drilling. A lithium-chloride tracer was added to all fluid used in drilling and testing the well. Final casing and hole sizes and cemented intervals are shown in the construction diagram of the well (fig. 3).

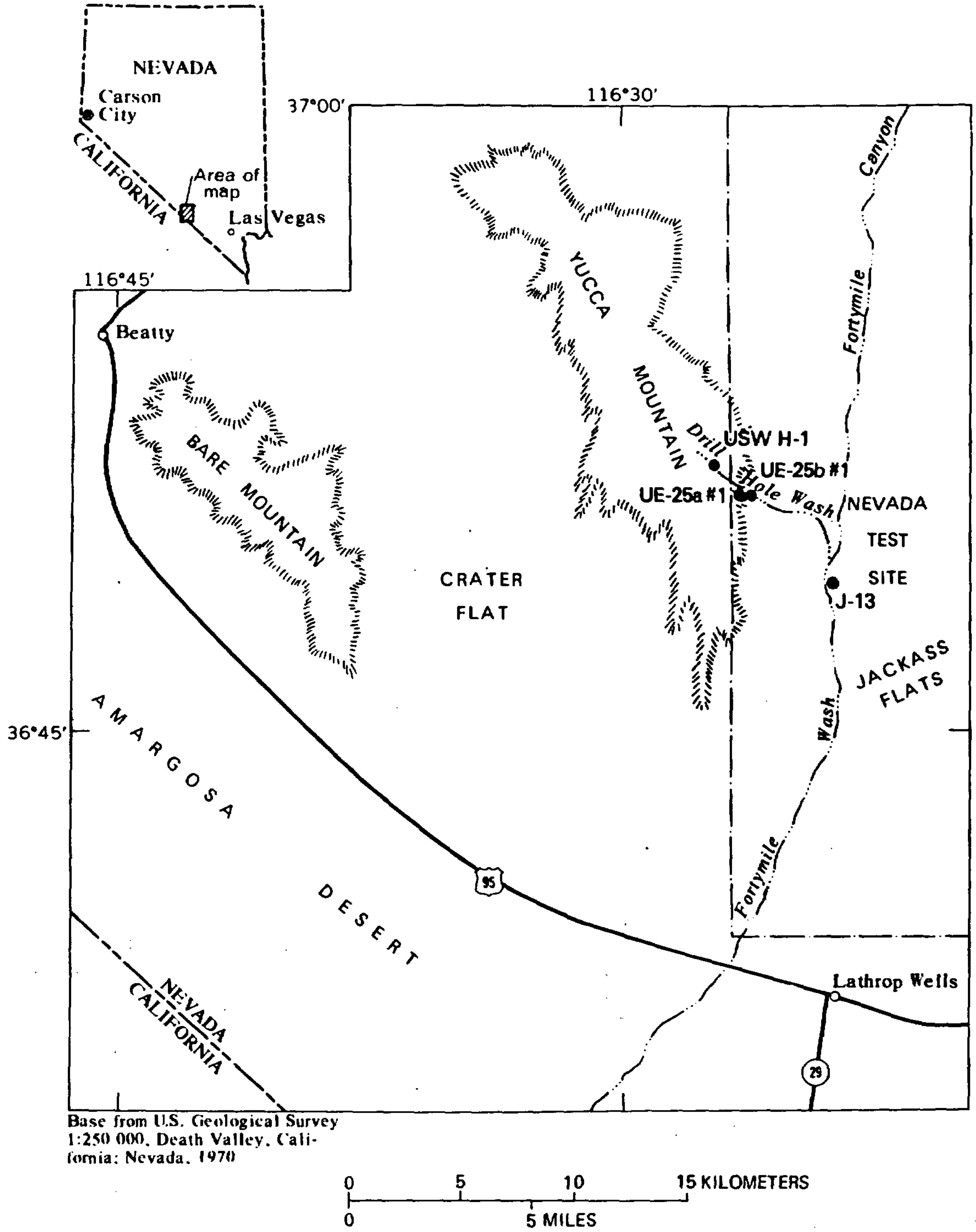

Figure 1.--Location of test well UE-25b#1 and nearby wells and geographic features in southern Nevada.

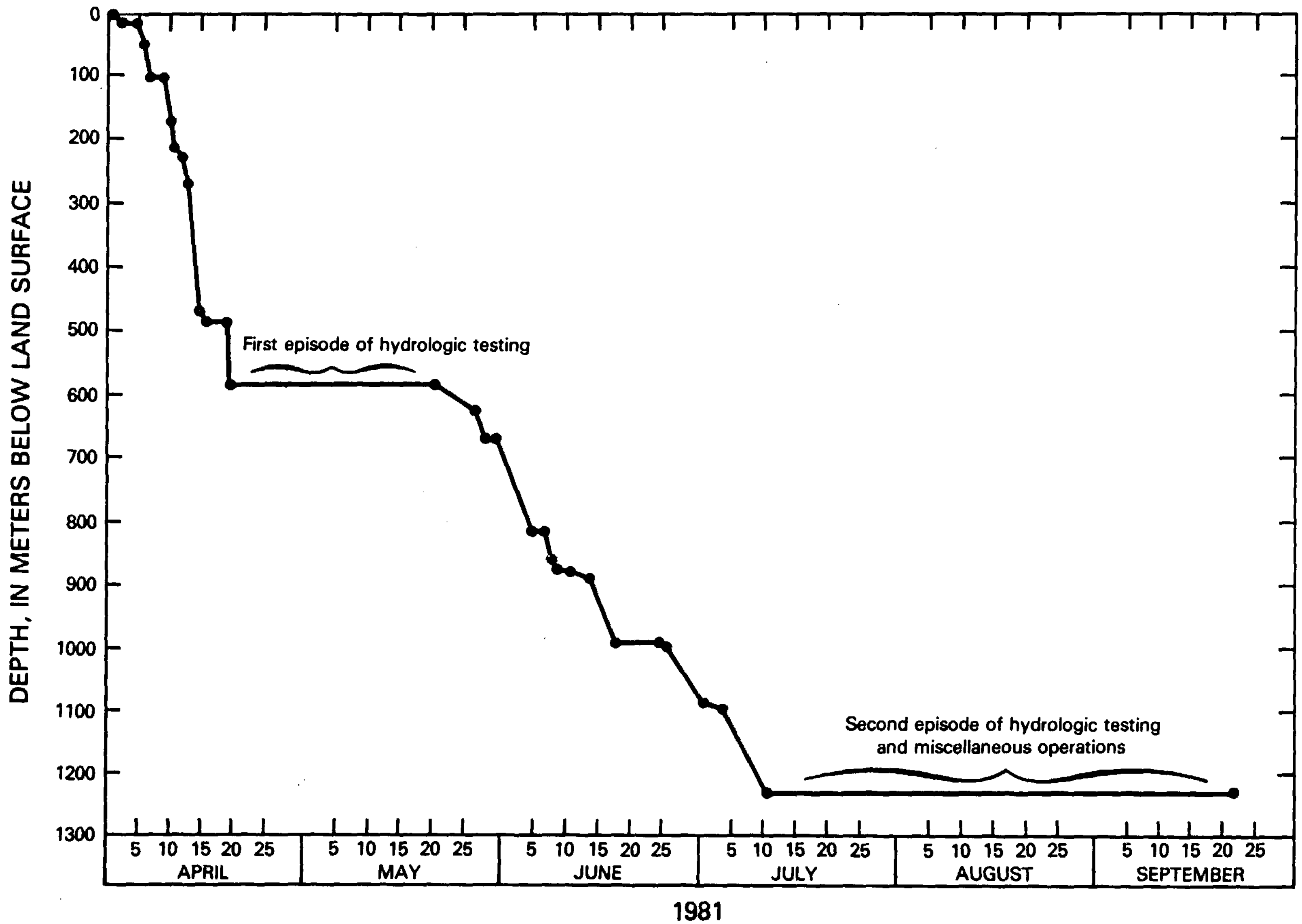

Figure 2.--Drilling and testing chronology of test well UE-25b#1.

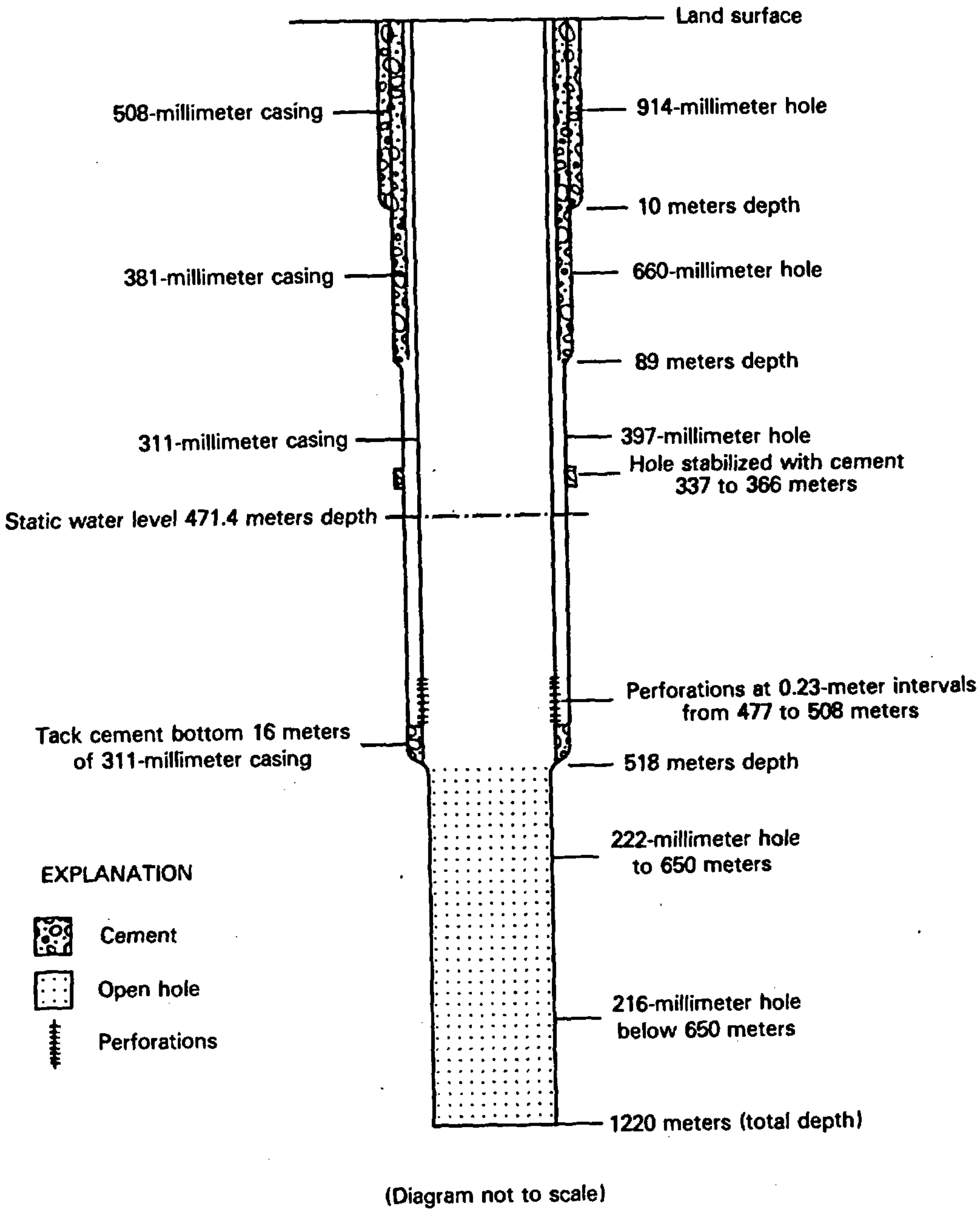

Figure 3.--Construction of test well UE-25b#1.

A detailed drilling history is contained in the files of the engineering consulting firm of Fenix & Scisson, Inc., Las Vegas, Nev., a contractor of the U.S. Department of Energy.

Geohydrologic Setting

The Nevada Test Site is within the Basin and Range province, a physiographic region consisting of north-trending mountains and valleys between the Colorado Plateau to the southeast and the Sierra Nevada to the west. Horst-graben, block, and strike-slip faulting that control the province began in Late Cretaceous time and continue into the present. Paleozoic marine sediments that were thrusted and folded during Mesozoic time, granitic intrusions, and volcanic rocks of Miocene age dominate the topographic highs. Basin fill predominantly is Quaternary alluvium.

Drill Hole Wash is a northwest-trending wash on the east flank of Yucca Mountain (fig. 1). The wash drains into Fortymile Wash which empties into the Amargosa Desert. Annual precipitation (about 130 mm) is predominantly from winter and spring frontal systems and summer thundershowers (Winograd and Thordarson, 1975).

Beds of the washes in the area commonly are a mixture of sand and gravel lenses and boulders that can rapidly absorb the infrequent precipitation. Water discharged into the wash at a rate of 36 L/s during one of the pumping tests disappeared completely within 1 km of the well site. Most of the infiltrated water is returned to the atmosphere or biosphere shortly after runoff, but small quantities percolate below the depth at which evapotranspiration occurs and continue to the water table.

Regional water levels show that most of the water in the ground-water system originates as recharge by precipitation northwest of Yucca Mountain. Lateral migration of ground water from the mountain probably is eastward or southeastward; however, discharge eventually is to the southwest in the Amargosa Desert (Winograd and Thordarson, 1975, p. C119).

LITHOLOGY OF MATERIAL PENETRATED

The rocks penetrated in well UE-25b#1 are tuffs of volcanic and volcaniclastic origin, mostly nonwelded to densely welded rhyolitic ash-flow tuff with 4 percent bedded, reworked, air-fall tuff, which underlie about 46 m of Quaternary alluvium. The tuffs are Miocene in age, extending below the depth of the well (1,220 m), and probably are underlain by Paleozoic sedimentary rock. A summary of the general lithology is shown in table 1. A more detailed lithological description is given in Lobmeyer and others (1984).

Generalized distribution of induration and welding of the tuffaceous rocks is shown in figure 4. Below the water table the degree of zeolitization is inversely proportional to the degree of welding. The upper part of the section below the Pah Canyon Member of the Paintbrush Tuff is densely welded, the lower middle part of the section is nonwelded to partially welded, and the lower part is partially to moderately welded.

Table 1.--*Lithologic log of test well UE-25b#1*

[Modified from R. W. Spengler, U.S. Geological Survey, written commun., 1981]

Stratigraphy and lithology	Thickness (meters)	Depth (meters)
Alluvium		
Gravels, composed of fragments of Tiva Canyon and Yucca Mountain Members of Paintbrush Tuff, subangular to subrounded, few fragments coated with caliche.	45.7	45.7
Paintbrush Tuff		
Tiva Canyon Member		
Tuff, ash-flow, densely welded.	18.3	64.0
Tuff, ash-flow, partially welded to nonwelded.	9.2	73.2
Pah Canyon Member		
Tuff, ash-flow, nonwelded, vitric.	6.1	79.2
Bedded tuff (unnamed)		
Tuff, bedded, reworked, vitric and devitrified.	4.6	83.8
Topopah Spring Member		
Tuff, ash-flow, densely welded (vitrophyre).	1.5	85.3
Tuff, ash-flow, densely welded, devitrified (quartz latitic caprock).	3.1	88.4
Tuff, ash-flow, densely welded, devitrified, (lithophysal zone 170.7 to 178.0 meters).	306.3	394.7
Tuff, ash-flow, densely welded, vitric (vitrophyre).	10.7	405.4
Tuff, ash-flow, partially to moderately welded, vitric.	6.1	411.5
Bedded tuff (unnamed)		
Tuff, bedded, reworked, altered.	10.7	422.2
Rhyolitic tuffs of Calico Hills (informal usage)		
Tuff, ash-flow, nonwelded, zeolitized.	138.6	560.8
Tuff, bedded, ash-fall(?).	8.9	569.7
Crater Flat Tuff		
Prow Pass Member		
Tuff, ash-flow, nonwelded to moderately welded, zeolitized.	8.2	577.9
Tuff, ash-flow, partially welded, devitrified.	4.9	582.8
Tuff, ash-flow, partially welded; vapor phase and devitrified.	18.3	601.1
Tuff, ash-flow, partially to moderately welded, devitrified; interval indicates an increase of near-vertical, iron-stained fractures.	4.5	605.6
Tuff, ash-flow, grades from moderately to partially welded (moderately welded from 605.6 to 614.0 meters), devitrified; interval contains several prominent fractures at 612.3, 613.7, 617.5, and		

Table 1.--*Lithologic log*--Continued

Stratigraphy and lithology	Thickness (meters)	Depth (meters)
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
618.0 meters; fractures commonly are high angle and iron stained, some coated with manganese oxide; staining extends 1-2 centimeters outward from fracture face.	17.6	623.2
Tuff, ash-flow, nonwelded to partially welded, devitrified (slightly argillic).	8.0	631.2
Tuff, ash-flow, nonwelded, devitrified (some vapor phase), partially zeolitized; near-vertical fault containing breccia extends from 632.2 to 633.0 meters; breccia contains vitrophyre fragments from 633.5 to 633.7 meters.	7.3	638.5
Tuff, ash-flow, partially welded, devitrified; fault breccia cuts core from 638.8 to 639.5 meters.	10.2	648.7
Tuff, ash-flow, partially welded, devitrified (slightly zeolitized and silicified).	2.0	650.7
Tuff, ash-flow, partially to moderately welded, devitrified (partially to moderately silicified).	16.1	666.8
Tuff, ash-flow, partially to moderately welded, devitrified (slightly silicified); upper and lower contacts gradational.	1.4	668.2
Tuff, ash-flow, partially to moderately welded, devitrified, moderately to highly silicified and zeolitized; lower contact gradational.	11.6	679.8
Tuff, ash-flow, partially welded, devitrified (upper 4.9 meters slightly silicified); lower contact gradational.	13.6	693.4
Tuff, ash-flow, nonwelded, devitrified, zeolitized.	24.6	718.0
Bedded tuff (unnamed)		
Tuff, bedded/reworked, air-fall, devitrified (some beds silicified or zeolitized, or both); beds range in thickness from 0.1 to 0.4 meter; both gradational and abrupt contacts present; bedding inclined 5° to 8° relative to core axis, basal contact inclined 19°.	1.7	719.7
Bullfrog Member		
Tuff, ash-flow, partially welded, devitrified.	11.5	731.2
Tuff, ash-flow, partially welded, vapor phase; lower contact gradational.	56.2	787.4
Tuff, ash-fall(?), partially welded(?), lower contact gradational.	4.4	791.8
Tuff, ash-flow, moderately welded, devitrified, lower contact gradational.	56.4	848.2
Tuff, ash-flow, nonwelded to partially welded, moderately zeolitized (slightly argillic).	21.3	869.5

Table 1.--*Lithologic log*--Continued

Stratigraphy and lithology	Thickness (meters)	Depth (meters)
Crater Flat Tuff--Continued		
Bedded tuff (unnamed)		
Tuff, bedded and reworked, moderately zeolitized; thick bedded to massive; beds commonly 0.5 to 0.9 meter thick; contacts commonly gradational.	9.1	878.6
Tram Member		
Tuff, ash-flow, nonwelded to partially welded, zeolitized; clay content increases downward within subunit.	19.2	897.8
Tuff, ash-flow, partially welded, devitrified.	45.2	943.0
Tuff, bedded (thinly laminated) tuffaceous sandstone, well-sorted; laminations 2 to 20 millimeters inclined 5° relative to core axis.	0.1	943.1
Tuff, ash-flow, partially welded, devitrified.	17.7	960.8
Tuff, ash-flow, moderately welded, devitrified; upper and lower contacts gradational.	5.7	966.5
Tuff, ash-flow, moderately welded, devitrified (slightly to moderately silicified); upper and lower contacts gradational.	21.7	988.2
Tuff, ash-flow, partially to moderately welded, devitrified.	16.2	1,004.4
Tuff, ash-flow, partially to moderately welded, devitrified (slightly zeolitized and argillic); upper contact gradational, lower contact sharp.	19.8	1,024.2
Tuff, ash-flow, partially welded, argillic and zeolitized; clay-enriched fault zones from 1,076.2 meters to 1,077.2 meters, 1,078.0 to 1,078.2 meters, and 1,080.5 to 1,081.3 meters (lowermost of the three zones is completely healed).	164.8	1,189.0
Bedded tuff (unnamed)		
Tuff, bedded and reworked, moderately to highly indurated, zeolitized, most contacts gradational; where sharp, contacts generally are inclined from 3° to 5° relative to core axis; individual beds commonly range in thickness from 0.1 to 1.7 meters; most beds appear reworked and contain few large pumice fragments; lower contact gradational.	18.1	1,207.1
Lithic Ridge Tuff		
Tuff, ash-flow, moderately welded, devitrified (argillic and zeolitized).	12.8	1,219.9
	TOTAL DEPTH:	1,219.9 meters

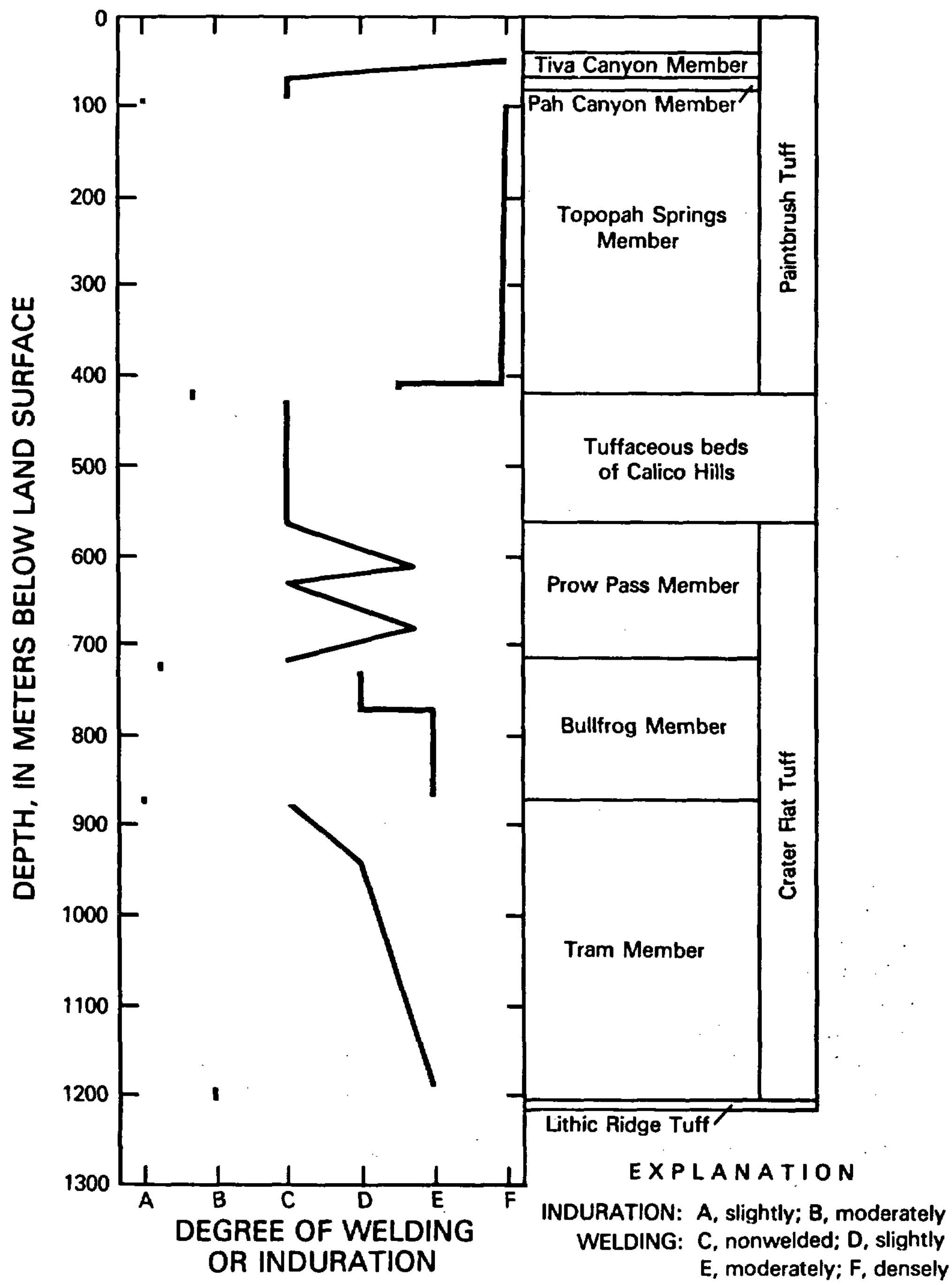

Figure 4.--Generalized distribution of induration and welding of tuffaceous rocks penetrated by test well UE-25b#1.

The bedded and reworked zeolitized unit at the base of the Bullfrog Member of the Crater Flat Tuff is associated with the lowermost producing zone of the test well. Because zeolitized rocks generally are not very permeable, water production probably results from fractures above the basal unit in the overlying ash flow or in the margin between the bedded and reworked unit and the ash flow.

PHYSICAL PROPERTIES OF DRILL CORES

This section describes tests or analyses for the drill cores from test well UE-25b#1. Results of mechanical testing made by Sandia National Laboratory (SNL) and Holmes & Narver, Inc. (H&N), contractors of the U.S. Department of Energy, and a fracture log compiled by L. P. Escobar, Fenix & Scisson, Inc., are included.

Mechanical Testing of Cores

Sandia National Laboratory performed physical-properties tests on 64-mm-diameter cores from test well UE-25b#1. Density matrix porosity and pore saturation were determined for 127 samples from depths of 589 to 1,216 m. This depth interval includes the lower part of the rhyolitic tuffs of Calico Hills, the Crater Flat Tuff, and the Lithic Ridge Tuff. A comparison of the percentage of rocks with more than average porosity determined from geophysical logs and matrix porosity determined from mechanical testing of core samples by SNL is shown in figure 5.

Holmes & Narver, Inc., performed tests of 12 core samples from depths of 479.3 to 1,201.8 m, plus one core from the Topopah Spring Member of the Paintbrush Tuff in the unsaturated zone (depth 225.7 m). Tests of density, matrix porosity, pore saturation, natural-state pore-water content and matrix hydraulic conductivity were made on these cores (table 2).

The matrix porosities calculated from dry-bulk and grain densities for the cores ranged from 5.3 percent (fig. 5) to 28.1 percent (table 2). The rock is uniformly saturated with less than 5.3 percent calculated air voids, according to the SNL data. The H&N tests indicated as much as about 40 percent air voids; however, these larger values probably were the result of moisture loss before the cores were tested. Dry-bulk density of the samples ranged from 1.73 to 2.42 g/cm^3 and averaged 2.1 g/cm^3 (table 2). Horizontal and vertical hydraulic conductivities were all less than 10^{-3} m/d, with some values as small as 8.3×10^{-7} m/d.

The physical properties could not be determined on broken or fractured cores; therefore, the SNL and H&N data indicated only matrix hydraulic conductivity. It is inferred that the water production was not the result of matrix hydraulic conductivity because the SNL and H&N data did not show any large values of hydraulic conductivity. Therefore, the water production in the well is thought to be the result of fracture permeability.

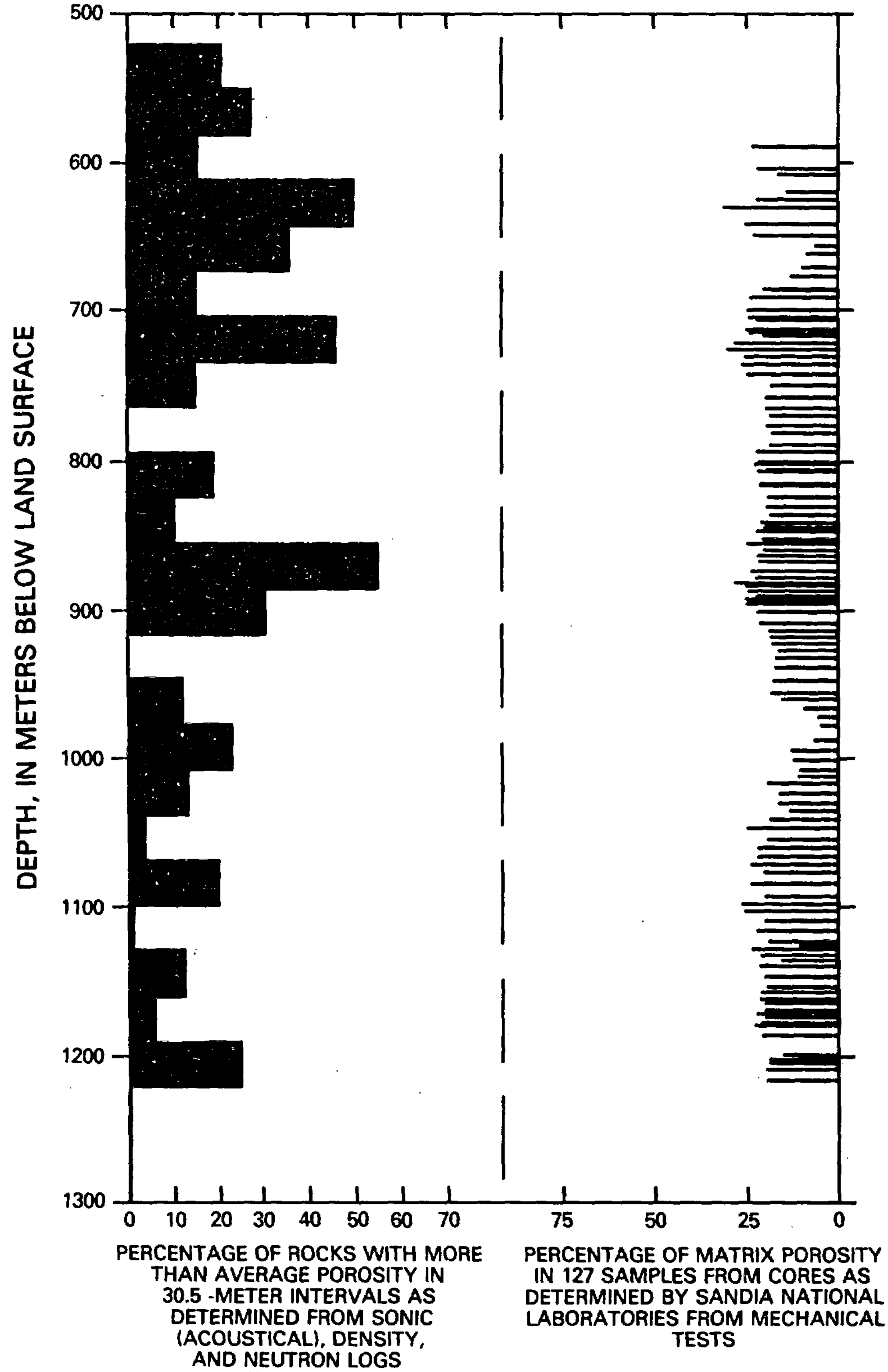

Figure 5.--Comparison of percentage of rocks with more than average porosity determined from geophysical logs and matrix porosity determined from mechanical testing of core samples, test well UE-25b#1.

Table 2.--*Results of laboratory analysis of hydraulic properties of drill core from test well UE-25b#1*

[Analyses by Holmes & Narver, Inc.]

Depth (meters)	Density (grams per cubic centimeter): Natural state	Density: Dry bulk	Density: Grain	Matrix porosity (percent): From dry-bulk and grain densities	Matrix porosity (percent): From helium pycnometer	Pore saturation (percent)	Natural-state pore-water content (weight percent)	Matrix hydraulic conductivity (meters per day): Horizontal	Matrix hydraulic conductivity (meters per day): Vertical
TOPOPAH SPRING MEMBER OF PAINTBRUSH TUFF									
[1]225.7	2.31	2.25	2.55	11.8	11.6	56.8	2.9	8.3×10^{-7}	1.6×10^{-6}
RHYOLITIC TUFFS OF CALICO HILLS									
479.3	1.98	1.75	2.43	28.1	25.2	84.0	11.9	1.7×10^{-4}	3.7×10^{-5}
PROW PASS MEMBER OF CRATER FLAT TUFF									
625.8	2.17	1.73	2.58	25.2	23.8	92.9	10.8	6.6×10^{-5}	1.8×10^{-5}
679.5	2.17	2.09	2.41	13.6	10.1	60.3	3.8	8.3×10^{-7}	1.7×10^{-6}
BULLFROG MEMBER CRATER FLAT TUFF									
752.7	2.23	2.01	2.62	23.3	23.0	93.6	9.8	6.6×10^{-4}	5.0×10^{-4}
788.9	2.26	2.06	2.63	21.6	21.3	92.6	8.8	6.6×10^{-5}	7.3×10^{-5}
814.1	2.22	2.04	2.61	22.1	22.3	82.4	8.2	5.0×10^{-5}	5.0×10^{-5}
843.5	2.22	2.02	2.61	22.7	23.1	88.6	9.1	8.3×10^{-6}	1.7×10^{-6}
TRAM MEMBER OF CRATER FLAT TUFF									
923.9	2.29	2.11	2.62	19.7	19.1	94.9	8.2	2.8×10^{-5}	3.3×10^{-5}
948.8	2.30	2.14	2.61	18.2	18.9	92.3	7.3	1.8×10^{-5}	2.0×10^{-5}
1,141.4	2.36	2.24	2.64	14.9	14.7	80.5	5.1	2.9×10^{-4}	3.3×10^{-4}
1,171.0	2.44	2.32	2.65	12.3	12.5	97.6	4.9	2.8×10^{-4}	1.7×10^{-4}
1,201.8	2.51	2.42	2.72	10.8	10.9	82.4	3.5	1.1×10^{-4}	4.7×10^{-5}

[1]Core from the unsaturated zone.

Fracture Analysis

Fractures in the tuffs penetrated in test well UE-25b#1 were caused by regional tectonic stress within the Basin and Range province, stress from nearby caldera activity, and stress from cooling or compaction of the tuffs themselves (Carr, 1974). A log of shear fractures compiled from the drill cores is shown in figure 6. Shear fractures are defined as fractures showing slickensides; they are considered in this report to indicate probable fault zones. This analysis was used to define five prominent fault zones in the rocks penetrated by test well UE-25b#1, all within the Crater Flat Tuff: (1) 590 to 614 m, in the upper part of the Prow Pass Member; (2) 804 to 807 m, in the middle part of the Bullfrog Member; (3) 962 to 972 m, (4) 1,073 to 1,076 m, and (5) 1,110 to 1,137 m, in the middle to lower part of the Tram Member. Numerous other thin zones of shear fracturing occurred in the lower part of the Bullfrog Member and throughout the Tram Member.

The difference between hydraulic conductivities calculated from core samples from the rhyolitic tuffs of Calico Hills and hydraulic conductivities determined by hydraulic testing in UE-25b#1 provided indirect evidence for fracturing or faulting within the rhyolitic tuffs of Calico Hills. Horizontal hydraulic conductivity for the single analyzable drill core from this unit was 1.7×10^{-4} m/d (table 2). Cores from a similar section of the rhyolitic tuffs of Calico Hills in UE-25a#1 borehole had an average hydraulic conductivity of 7.1×10^{-2} m/d. The two water-yielding zones within the rhyolitic tuffs of Calico Hills, as defined by the second borehole-flow survey (fig. 6), had calculated hydraulic conductivities greater than 1 m/d. The two horizontal hydraulic conductivities calculated from the in situ hydraulic tests probably were much less than the actual values because hole conditions prevented close definition of the actual limits of the producing zones--one zone was behind the casing, producing through perforations, and one zone was in a washed-out 18-m interval of the hole. The difference between the primary, or matrix hydraulic conductivity, as measured by the mechanical core testing, and the calculated hydraulic conductivity, from hydraulic tests, might have been greater than four orders of magnitude. Because of this large difference, it was assumed that the rhyolitic tuffs of Calico Hills were faulted or fractured, and most of the permeability results from this faulting or fracturing.

GEOPHYSICAL LOGS

Geophysical logs were run in test well UE-25b#1 for purposes of: (1) Lithologic definition, (2) correlation with logs of nearby wells, (3) obtaining data for porosity and fractures, (4) obtaining fluid levels, (5) locating casing perforations and cement, and (6) gaging the diameter of the well. Geophysical logs also were used to help select hydraulic-test intervals. A summary of the geophysical logs run in this well is shown in table 3.

Sonic (acoustic), density, and neutron logs can be used under the proper conditions (in-gage borehole, smooth wall, known instrument responses to lithology) to determine the distribution of rock porosity and permeability

(Schlumberger Limited, 1972; Birdwell Division, 1973). Borehole-compensated density and neutron logs respond both to matrix porosity and to fracture porosity. The 3-D variable density (acoustic) log responds to matrix porosity.

The 3-D variable density and density logs of this well produced results that were very similar throughout most of the penetrated sequence. The neutron log gave somewhat anomalous results for the Tram Member and the overlying stratigraphic units, possibly because of the shallow radius of investigation of the neutron tool, which apparently registered shallow fissures and roughness of the borehole as porosity.

In order to define the general distribution of porous rocks, the interval below 518 m was divided into 23 equal zones, each 30.5 m thick. None of the logs previously discussed gave a quantitative analysis of the porosity for the entire well. For this reason, the sonic (acoustic), density, and neutron logs were combined into a single histogram shown in figure 5. This figure graphically presents a subjective analysis of the percent of porous rock for each zone. The analysis was made by defining a normal value approximating the mean porosity on each log. All values greater than the norm were designated as porous. The thickness of porous rock in each zone was divided by the thickness of the zone to give a percentage of rocks of greater-than-average porosity, and this value was plotted in figure 5. Porosity values calculated from physical-property data from drill cores also are included for comparison.

Because most of the hole was out-of-gage, quantitative evaluation of porosity cannot be made from the log data (Muller, 1961). The presence of zeolites (hydrous aluminum silicates that contain water within their molecular structure) also made log interpretation difficult. Water of hydration is measured on some geophysical logs and cannot be differentiated from intergranular water.

A temperature log was run during pumping test 1 immediately prior to the borehole-flow survey. Two types of determinations were made from this log: (1) Temperature changes within a small vertical section of the well were interpreted as contributing points for water, and (2) sections of the well which had no temperature changes were interpreted as noncontributing sections with contributing points immediately above and below the nonchanging section. A no-flow zone was interpreted as starting below the last contributing point and above a point of gradual, constant change in temperature with depth. This log was used to help plan the borehole survey, which later modified these interpretations.

Geophysical logs that can be directly related to the water-yielding zones include the following: (1) Televiewer and seisviewer logs that show multiple slight-angle fractures in water-yielding zones, (2) self-potential log that reverses at the base of the lowest water-yielding zone in the well, and (3) temperature log made while pumping, where gradient changes indicate entrance and movement of water.

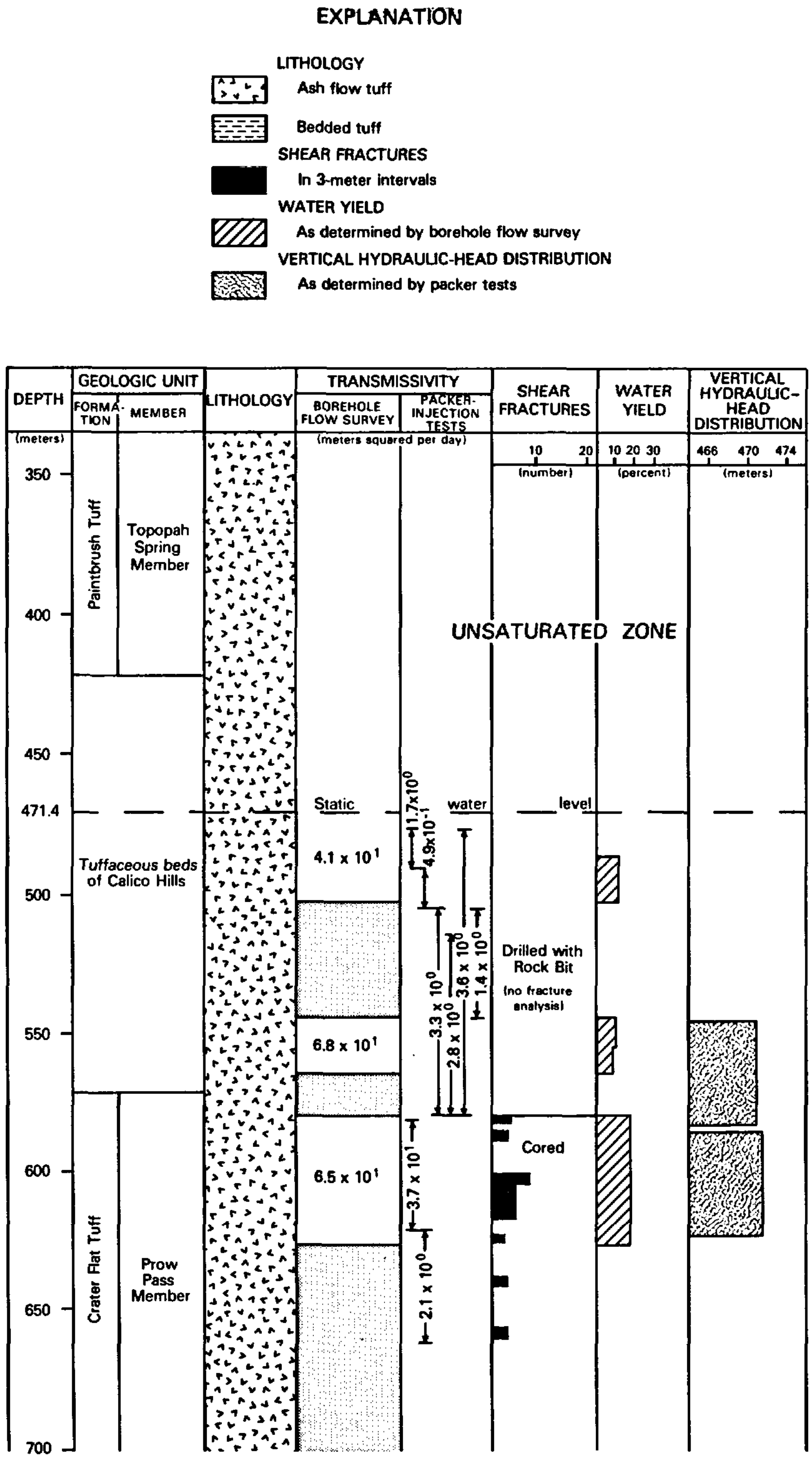

Figure 6.--Geohydrologic summary for test well UE-25b#1.

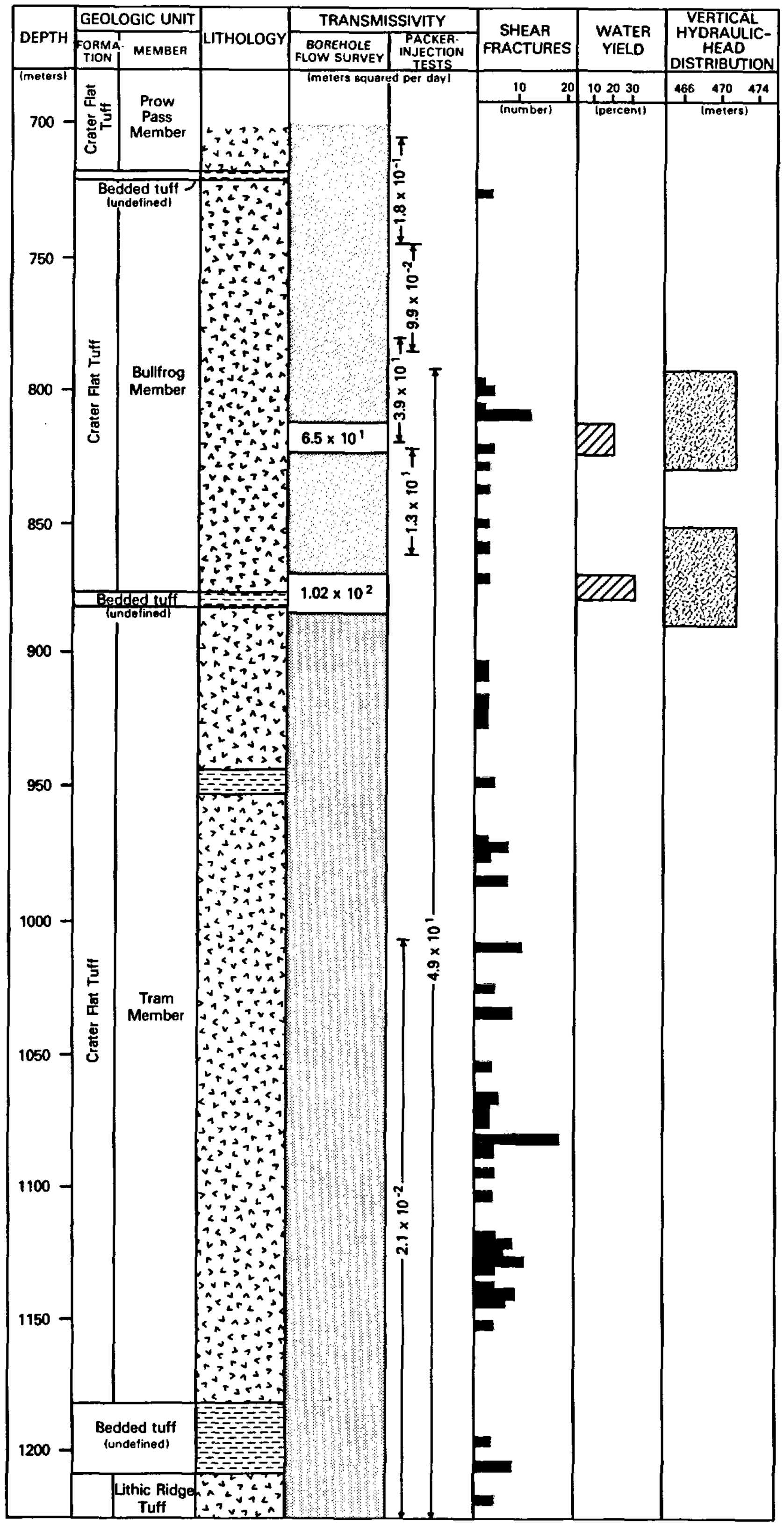

Figure 6.--Geohydrologic summary for test well UE-25b#1.--Continued

Table 3.--*Geophysical logs run in test well UE-25b#1*

Geophysical log	Depth interval (meters)	Geophysical log	Depth interval (meters)
Acoustic	472-573	Geophone	519-1,216
	503-1,218		
		Gyroscopic	0-1,204
Caliper	6-94		
	76-364	Nuclear cement top locater	0-90
	89-576		325-363
	518-1,214		455-536
Density, borehole-compensated	89-575	Nuclear annulus investigation	325-363
	457-1,219		1,069-1,190
Density	10-96	Seisviewer	457-1,215
Electric	468-575	Spectralog	0-574
	506-1,217		503-1,217
	518-1,215		
		Televiewer	0-357
Induction, electric	91-576		518-975
Epithermal neutron	91-575	Temperature	0-575
	518-1,214		
		3-D velocity	469-574
Neutron	469-575		472-575
	502-1,214		502-1,215
			502-1,216
Gamma ray	82-576	Vibroseis	91-572
	487-1,214		518-1,216

HYDROLOGIC MONITORING AND TESTING

This section of the report includes discussions on water levels, pumping tests, borehole-flow surveys, and packer-injection tests. A summary of hydraulic-test data is given in table 4.

The data presented in the preceding sections of this report titled, "Physical properties of drill cores" and "Geophysical logs" indicated minimal matrix hydraulic conductivities for the entire saturated part of the well. These data also indicated fractures or faults in the five producing zones, as defined by the borehole-flow surveys presented in this section of the report. These faults or fractures indicate a point source rather than a homogeneous aquifer for most of the permeability in the well, which limits the effectiveness of standard well-test analysis methods. The following assumptions were made as a conceptual model for the geohydrologic system penetrated by this well:

1. The tuffs containing the primary matrix porosity were homogeneous and isotropic.
2. Hydraulic conductivity of fractures was several orders of magnitude larger than the hydraulic conductivity of the matrix; the early flow to or from the well was through fractures only. The fracture permeability was anisotropic on a local scale (with point sources), but the distances between fractures were small in comparison with the dimensions of the ground-water system being studied.
3. The volume of water stored in fractures was relatively small in comparison with that stored in the matrix.

Unfortunately, all the parameters needed to analyze fracture aperture, spacing, and continuity for the tuff in terms of dual-porosity permeability models were not available. Witherspoon and others (1980), in their hydraulic work in crystalline rock, have assumed that, in general, a fracture system can be treated as a slightly different form of porous-media solution, and equivalent porous-media properties can be measured. The methods used for analyses of the pumping and packer-injection tests (Cooper and others, 1967; Ferris and others, 1962; Lohman, 1972; Papadopulos and others, 1973; and Walton, 1960) are based on the premise that water is supplied to the well via matrix permeability from a homogeneous isotropic aquifer of infinite areal extent. These homogeneous porous-media solutions were used to define general hydraulic values using late-time test data (Kazemi, 1969; Kazemi and Seth, 1969; Najurieta, 1980, p. 1242; Odeh, 1965; Wang and others, 1977, p. 104; and Warren and Root, 1963). Early hydraulic data may be dependent on nonrepresentative, near-well hydraulics, on well-bore storage, and on skin effects (Wang and others, 1977, p. 103). Since the exact time boundary between early time and late time is not distinct for this well, the results need to be used with caution.

Water Levels

Water-level observations and measurements in well UE-25b#1 were made during drilling and hydraulic testing, and following the completion of testing. The purpose of these observations and measurements was to: (1) Locate possible perched-water zones above the water table, (2) determine at what depth water saturation occurs, and (3) ascertain hydraulic heads in the well at specific depths or water-yielding zones.

Table 4.--*Summary of hydraulic-test data, test well UE-25b#1*

[m, meter; m²/d, meter squared per day; m/d, meter per day; L, liter; L/s, liter per second]

Test number	Test date	Interval tested (m)	Transmissivity (m^2/d)	Hydraulic conductivity (m/d)	Remarks
			First episode of testing		
Packer-injection test 1----	5-09-81	514-579 [65]	2.8 ~~4.9~~ x 10^0	[2]~~7.6 x 10^{-2}~~ 4.3E-2	--
Packer-injection test 2----	5-09-81	505-579 [74]	3.3 ~~2.7~~ x 10^0	[2]~~3.6 x 10^{-2}~~ 4.5E-2	--
Packer-injection test 3----	5-10-81	477-579 [102]	3.6 [1]~~5.5~~ x ~~10^1~~ 10^0	[1]~~5.4 x 10^{-1}~~ 3.5E-2	--
Packer-injection test 4----	5-11-81	491-505 [14]	4.9 ~~6.9~~ x ~~10^0~~ 10^{-1}	~~4.9 x 10^{-1}~~ 3.5E-2	--
Packer-injection test 5----	5-12-81	477-491 [14]	1.7 x 10^0	1.2 x 10^{-1}	--
			Second episode of testing		
Pumping test 1-------	8-03-81 to 8-07-81 5,760 minutes (4 days)	471-1,220 [749]	----------	-----------	Water pumped - 4.8 x 10^6 L at 13.8 L/s
Packer-injection test 6----	8-10-81	1,006-1,220 [214]	2.1 x 10^{-2}	9.8 x 10^{-5}	--
Packer-injection test 7----	8-10-81	792-1,220 [428]	[1]4.9 x 10^1	[1] [2]1.1 x 10^{-1}	--
Packer-injection test 8----	8-11-81	820-860 [40]	[1]1.3 x 10^1	[1] [2]3.3 x 10^{-1}	--
Packer-injection test 9----	8-12-81	779-819 [40]	[1]3.9 x 10^1	[1] [2]9.9 x 10^{-1}	--
Packer-injection test 10---	8-12-81	743-783 [40]	9.9 x 10^{-2}	2.5 x 10^{-3}	--
Packer-injection test 11---	8-13-81	703-743 [40]	1.8 x 10^{-1}	4.6 x 10^{-3}	--
Packer-injection test 12---	8-13-81	581-621 [40]	[1]3.7 x 10^1	[1]9.2 x 10^{-1}	--
Packer-injection test 13---	8-13-81	504-544 [40]	1.4 x 10^0	[2]3.5 x 10^{-2}	--
Packer-injection test 14---	8-13-81	621-661 [40]	2.1 x 10^0	[2]5.3 x 10^{-2}	--
Pumping test 2------	8-18-81 to 8-27-81 12,960 minutes (9 days)	471-1,220 [749]	---------	---------	Water pumped - 2.9 x 10^7 L at 26 to 37 L/s
Pumping test 3------	8-29-81 to 9-01-81 4,320 minutes (3 days)	471-1,220 [749]	3.4 x 10^2	4.5 x 10^{-1}	Water pumped - 1.5 x 10^6 L at 35.7 L/s
			Third episode of testing		Water level (m below land surface)
Packer-injection test 1b---	6-08-82	546-583 [37]	---------	---------	471.02
Packer-injection test 2b---	6-09-82	585-622 [37]	---------	---------	471.33
Packer-injection test 3b---	6-09-82	789-826 [37]	---------	---------	471.50
Packer-injection test 4b---	6-09-82	847-884 [37]	---------	---------	471.43

[1]Approximate values.

[2]Tested interval spans two or more zones of significantly different permeability as defined by borehole-flow survey.

Periodic checks for perched water were made while drilling the unsaturated section of UE-25b#1 by air-lifting during a pause in drilling. The well was blown dry at depths of 265 m, 460 m, and 464 m, but no detectable quantities of water were produced from these depths. When the interval 350 to 360 m was being drilled, a small quantity of water was produced; this interval was just above the interval where lost circulation occurred (367 m to 368 m). A fluid-density log for the interval 332 to 360 m indicated no water saturation to this depth. The first indication of reaching the zone of saturation occurred at the depth of 471 m. At this depth, the quantity of fluid coming out of the discharge pipe increased and the viscosity and soap concentration decreased.

At a depth of 472 m, the hole started caving; after reaching a depth of 479 m, drilling was stopped so unstable zones could be cemented. To determine exact location of the caving zones, caliper logs were run prior to cementing.

When the test hole was at a depth of 579 m, prior to running injection tests, a water-level measurement was obtained by using a deep-well measuring device. The water level was 471.2 m below land surface; water level remained stable for 35 minutes. This water level in the lower part of the rhyolitic tuffs of Calico Hills was considered a composite of hydraulic heads for all the producing zones penetrated from the water level to the bottom of the hole at 579 m in the well.

A composite water level of 471.4 m below land surface was obtained when the well was at a depth of 1,220 m. This water level, compared to the one obtained at 579 m, indicates possible minor hydraulic-head changes with depth. Additional water-level measurements were made during a third episode of testing to define these small hydraulic-head differences. Packer-injection tests were performed on the four most productive zones in the well (fig. 6). The water levels for the intervals tested were as follows:

Date	Tested interval (meters below land surface datum)	Water level (meters below land surface datum)
6-08-82	546-583	471.02
6-09-82	585-622	471.03
6-09-82	789-826	471.50
6-09-82	848-884	471.43

Water levels in these intervals indicate a small hydraulic-head decrease with depth.

Pumping tests

Three pumping tests were conducted in test well UE-25b#1 after the well had been drilled to its total depth of 1,220 m. During test 1, the well was pumped at a rate of 13.8 L/s. A borehole-flow survey was run at the end of test 1 after the rate of drawdown had decreased. During test 2, the well was pumped at rates ranging from 26 to 37 L/s. Well UE-25a#1, 107 m south-southwest of UE-25b#1, was used as an observation well (total depth 763 m) during tests 2 and 3. During test 3, the well was pumped at a rate of 35.7 L/s. Residual drawdown was measured after pumping tests 1 and 2; a summary of these tests is given in table 4. Well USW H-1, 2.0 km northwest of the pumped well (fig. 1), was monitored during the tests, but no measurable water-level decline was observed.

The well was allowed to recover for 5 days after packer-injection test 14 (before test 2) and 2 days after test 2 (before test 3) (table 4). The water levels at the start of the first two tests were considered static. Extending the trend during the recovery after pumping test 2 indicated a further recovery of a few hundredths of a meter--negligible compared to the drawdown during pumping test 3.

The drawdown data for test 1 showed fluctuations during the early part of the test that probably were related to well development with variations in pumping rate and fluid density (fig. 7). The residual drawdown for this test is shown in figure 8. These curves were not used to determine hydraulic coefficients.

Test 2, using a larger pump, stressed the aquifer more than test 1. The drawdown curve (fig. 9) showed the effect of continuing well development and a fluctuating pumping rate. Hydraulic boundaries could not be detected from the drawdown curve. Increase in slope of the drawdown curve after 5,000 minutes was attributed to possible dual-porosity effects, although large fluctuations in the pumping rate made this a tenuous conclusion. No effect of pumping was detected in USW H-1. The slope of the residual drawdown curve also indicated possible effects of dual-porosity effects or flow contributions (fig. 10). These curves were not used to determine hydraulic coefficients.

For test 3, the well was pumped at a rate of 35.7 L/s, the same rate as the final 2,900 minutes of test 2. The drawdown curves (fig. 11), as in test 2, showed apparent dual-porosity effects to the end of the test at 3,680 minutes. These curves were not used to determine hydraulic coefficients.

The three tests show drawdown patterns that were strongly influenced by the fractured nature of the aquifer. Tests 1 and 2 were influenced by the presence of airfoam drilling fluid that had penetrated into fractures during drilling. Residual-drawdown curves, showing damped oscillations for the first 20 minutes after the pump was shut off, are typical for tests in fractured rocks (F. S. Riley, U.S. Geological Survey, written commun., 1984). Test 3, conducted after the well was thoroughly developed, showed indications that the observation well and pumped well were in the same fracture system; thus, the drawdown might not reflect drawdown in the fine-grained unfractured matrix.

Numerous dual-porosity solutions for analysis of pumping-test data were investigated (Bredehoeft and Papadopulos, 1980; Ferris and others, 1962; Kazemi, 1969; Kazemi and Seth, 1969; A. F. Moench, U.S. Geological Survey, written commun., 1984; Odeh, 1965; Wang and others, 1977; and Warren and Root, 1963). It was concluded that the geohydrologic data for this well did

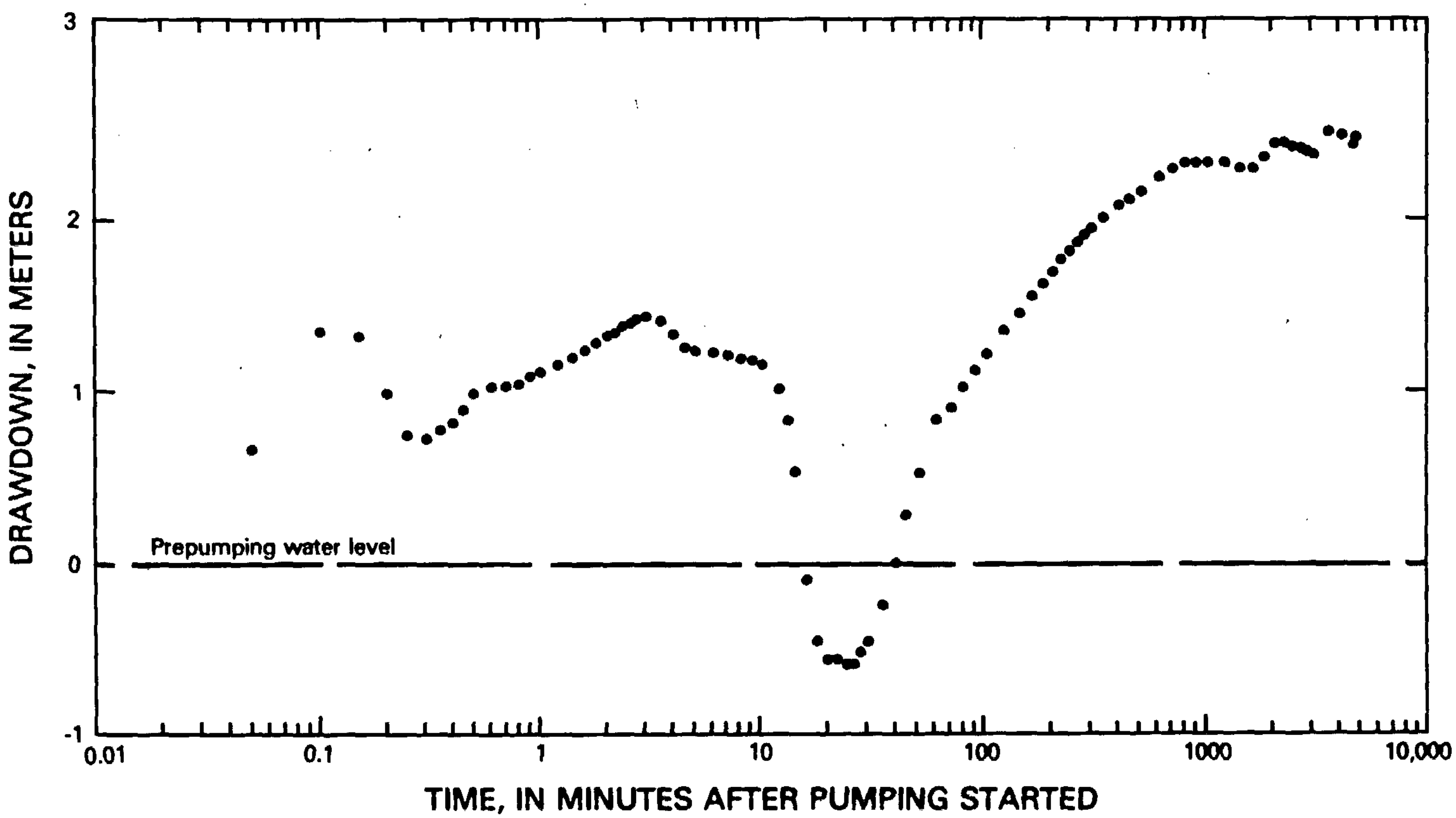

Figure 7.--Drawdown in test well UE-25b#1 during pumping test 1.

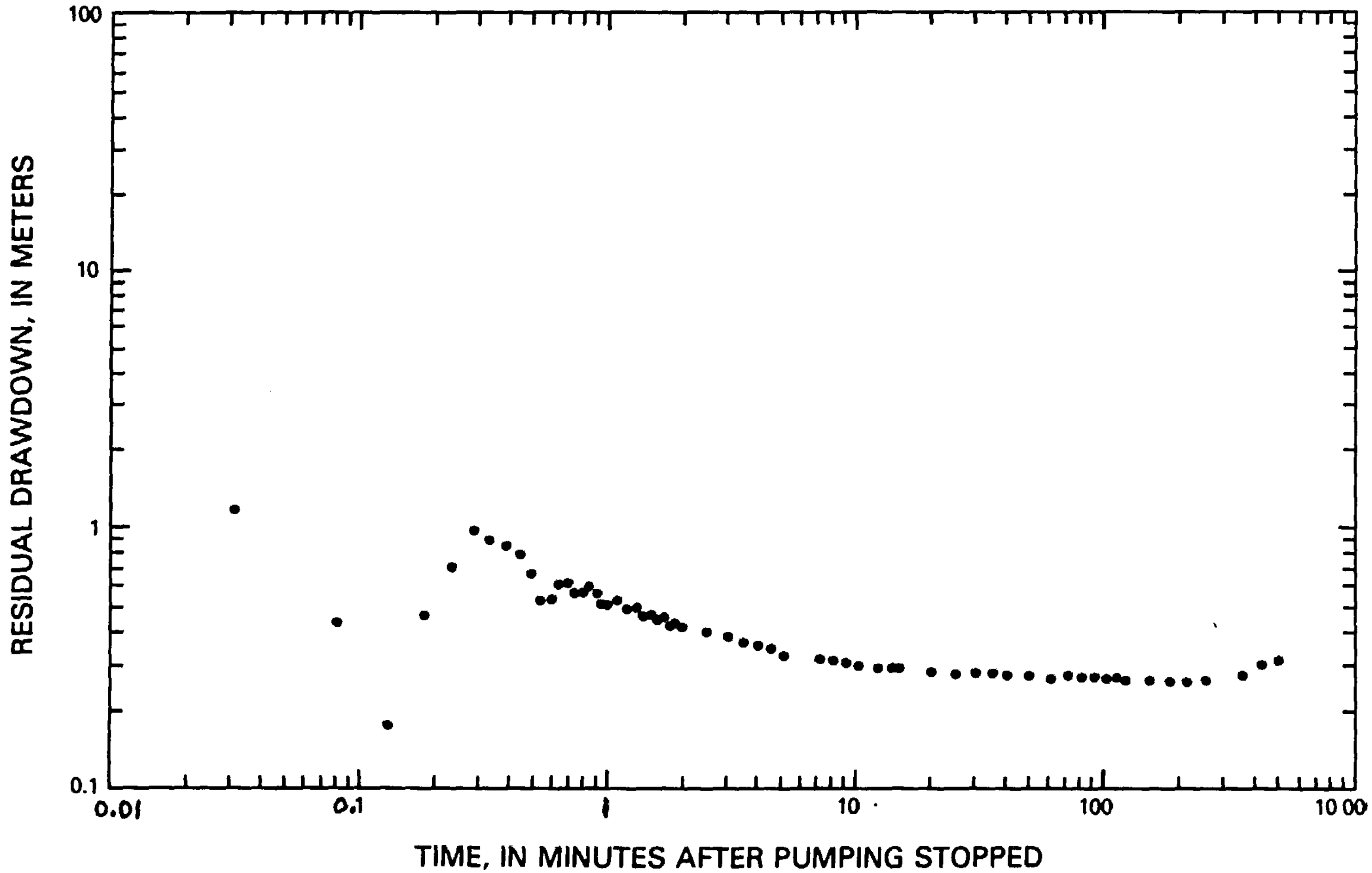

Figure 8.--Residual drawdown in test well UE-25b#1 after pumping test 1.

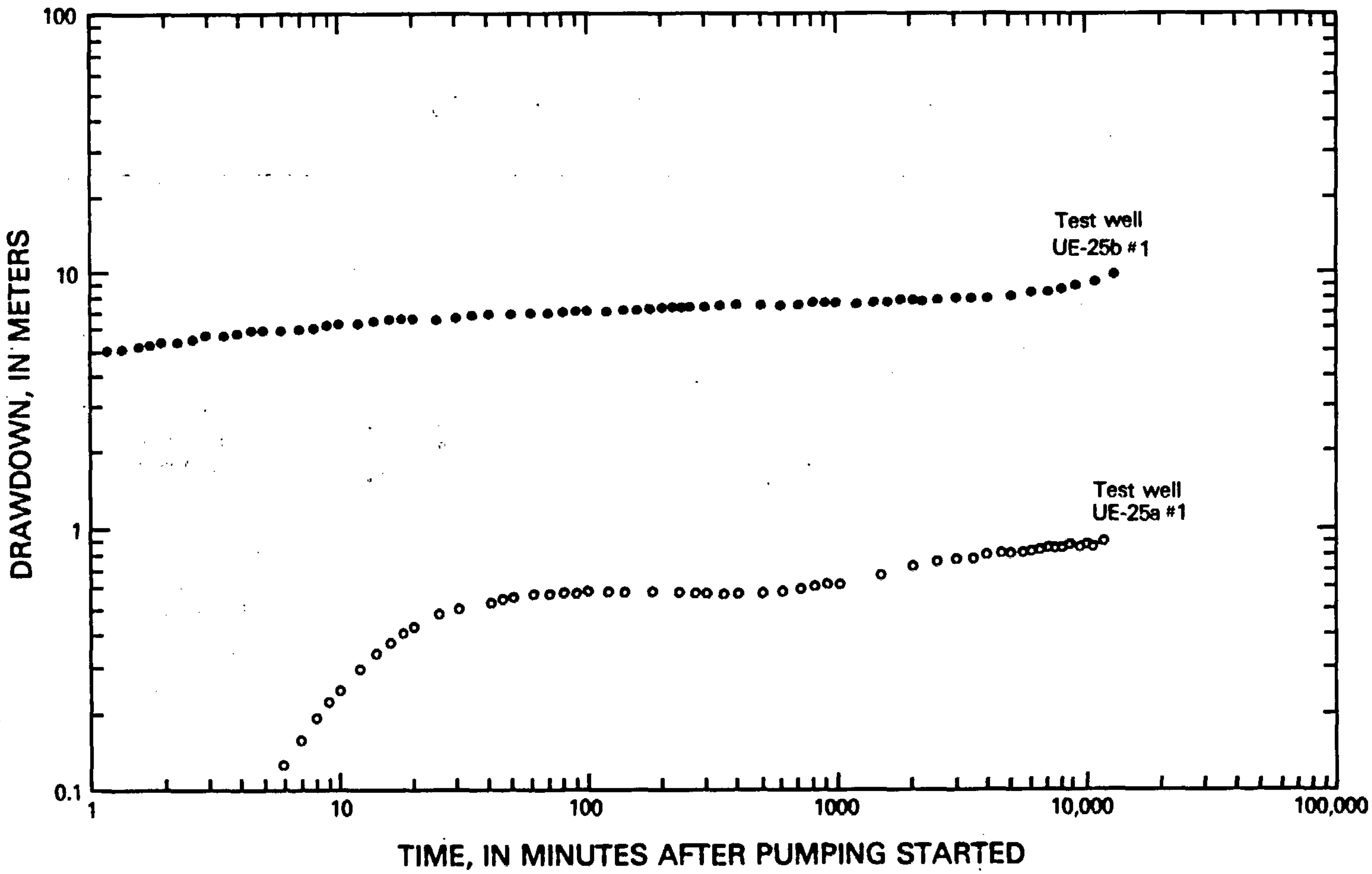

Figure 9.--Drawdown in test wells UE-25b#1 and UE-25a#1 during pumping test 2.

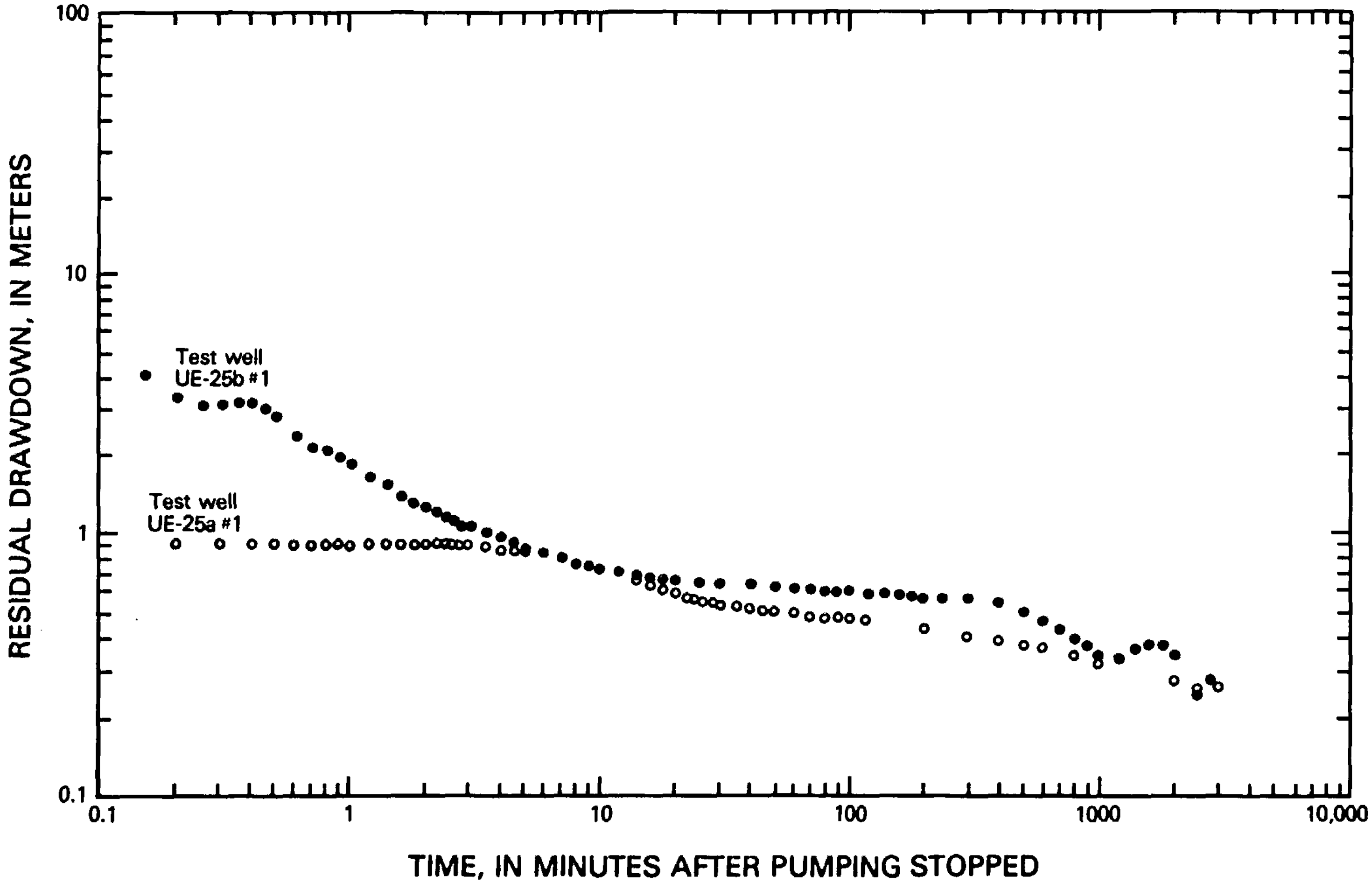

Figure 10.--Residual drawdown in test wells UE-25b#1 and UE-25a#1 after pumping test 2.

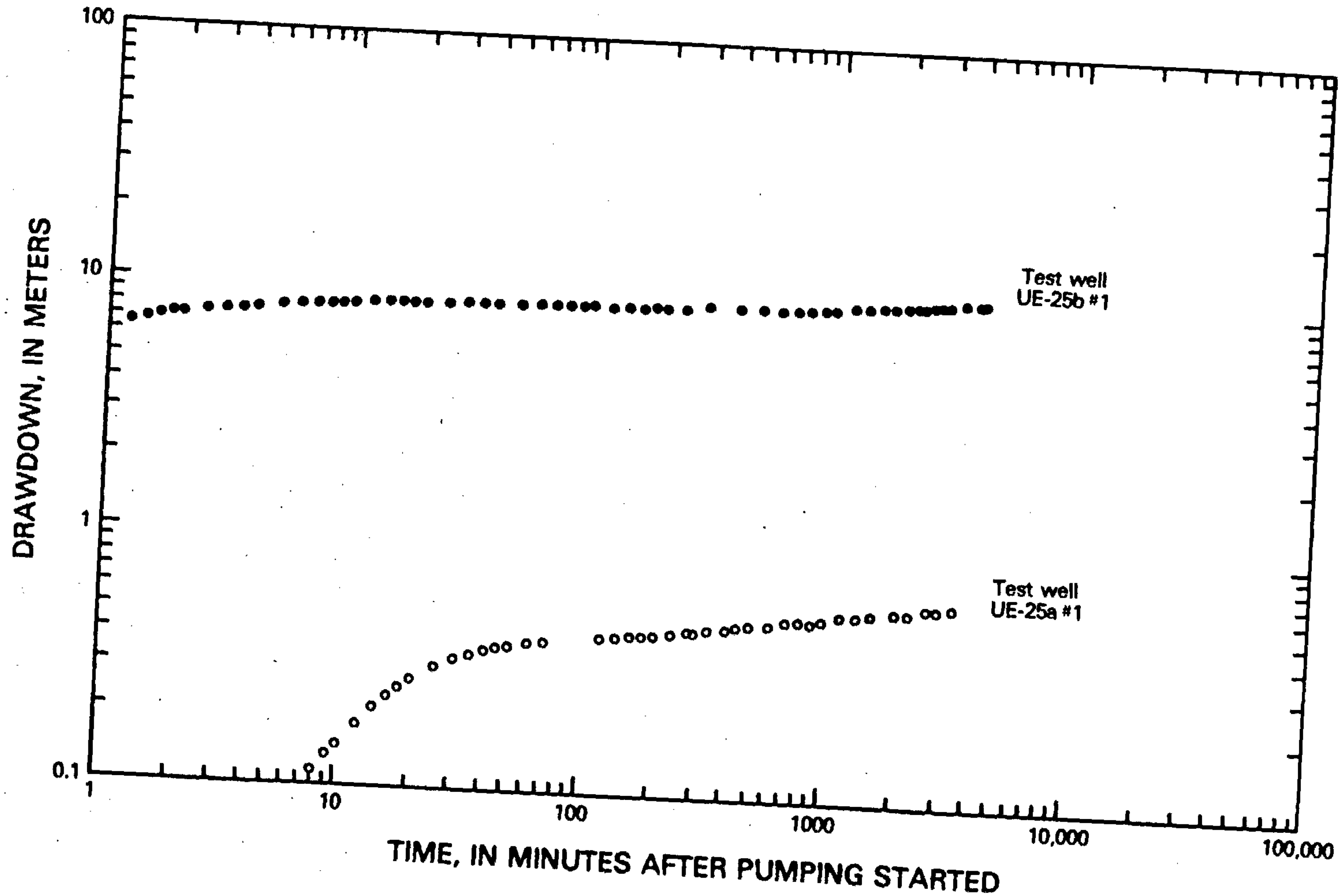

Figure 11.--Drawdown in test wells UE-25b#1 and UE-25a#1 during pumping test 3.

not support any particular solution to the exclusion of the others. In an effort to define hydraulic coefficients, the Thiem equation (Thiem, 1906) was used:

$$T = Kb = \frac{Q}{2\pi(h_2 - h_1)} \ln \frac{r_2}{r_1} \qquad (1)$$

where T is transmissivity, in meters squared per day;
K is hydraulic conductivity, in meters per day;
b is thickness of the tested interval, in meters;
Q is pumping rate, in cubic meters per day;
h_2, h_1 is drawdown in the observation and pumped wells, in meters;
ln is natural logarithm; and
r_2, r_1 is radial distance of the observation and pumped wells, in meters.

Therefore, using data from pumping test 3:

$$T = Kb = \frac{3{,}080}{6.28(10.5 - 0.6)} \ln \frac{107}{0.11} = 340 \text{ m}^2/\text{d}$$

$$K = \frac{T}{b} = \frac{340}{749} = 0.45 \text{ m/d} .$$

Since this system is believed to be controlled by fractures, the values of transmissivity and hydraulic conductivity are for illustrative purposes only and may not have any physical basis. The Thiem equation applies to nonleaky aquifers with steady radial flow, and these conditions are not known to apply at the test site.

Borehole-flow Surveys

Flow surveys were used to determine the location of productive zones and their flow rate while the well was stressed by pumping or injection. A radioactive slug of iodine-131 was released into the well and tracked past two gamma detectors to determine the velocity of the water. Velocity was multiplied by the cross-sectional area to determine the rate of flow in the well at this depth. Rate of flow varied across intervals that contributed to or removed water from the well. Productive zones were identified by these differences.

Two borehole-flow surveys were run in UE-25b#1. The first was made on May 4 and 5, 1981, while injecting water at a rate of 3.34 L/s into the open hole when the well was at a depth of 579 m. The purpose of this survey was to determine productive zones in the well from the water level (471.4 m) to the bottom of the well. No water movement was detected because the injected water probably moved up the borehole annulus and into the unsaturated zone rather than into recoverable parts of the saturated zone.

The second survey was made on August 7 and 8, 1981, in conjunction with the first pumping test which removed water at an average rate of 13.8 L/s; the pumping rate had decreased to 13.4 L/s at the time of the borehole-flow survey. The well was at a depth of 1,220 m. The casing was set at 518 m and was perforated from 477 m to 508 m. The purpose of this survey was to determine water-yielding zones in the saturated part of the well and the quantity of water being produced by each zone. These data were used to determine the zones to be tested by packer-injection tests and to analyze the pumping tests by using the flow rates to estimate distribution of transmissivity. A schematic diagram of this borehole-flow survey is shown in figure 11. Five zones of water production were identified by this survey. Results of this survey are as follows:

Interval (meters below land surface)	Percentage of total water pumped	Formation
471-502------------------ (502 m is top of casing cement)	12	Rhyolitic tuffs of Calico Hills.
546-564------------------	20	Do.
579-626------------------	19	Prow Pass Member of Crater Flat Tuff.
811-818------------------	19	Bullfrog Member of Crater Flat Tuff.
866-872------------------	30	Do.

The above intervals are shown in figure 6 in the column entitled Water Yield.

The shallowest productive zone is located somewhere from the water level (471 m) to the top of the casing cement (502 m); production is from the rhyolitic tuffs of Calico Hills, but the depths where the water enters the borehole are controlled by location of perforations in the casing. The significant permeability of the upper part of the rhyolitic tuffs of Calico Hills probably resulted from faults or fractures (see Fracture Analysis section of this report). This zone yielded 12 percent of the water produced from the well.

The next deepest productive zone, also in the rhyolitic tuffs of Calico Hills, was from 546 to 564 m and produced 20 percent of the water pumped. The significant permeability of this zone also probably resulted from faulting or fracturing, but this was not confirmed because of the lack of drill cores (see Fracture Analysis section of this report).

The next deepest productive zone, at the top of the Prow Pass Member of Crater Flat Tuff from 579 m to 626 m, produced 19 percent of the water in the well. This interval included a fault zone (shear fracture), as defined by the fracture analysis (fig. 6). Water production was attributed to the fault zone because no bedded units or lithologic changes occurred within or adjacent to this interval.

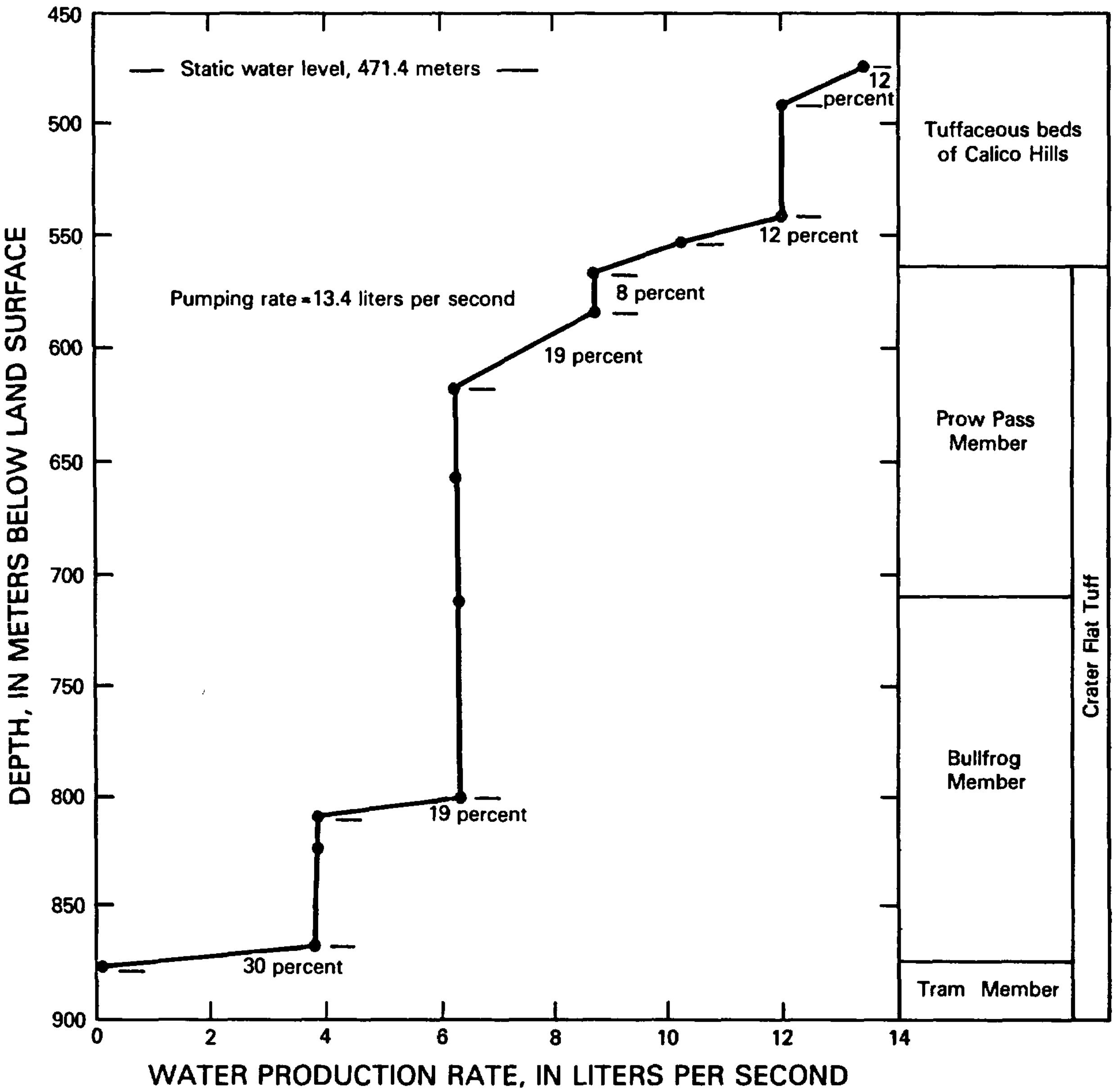

Figure 12.--Borehole-flow survey when test well UE-25b#1 was at a depth of 1,220 meters.

The next deepest productive zone was in the middle of the underlying Bullfrog Member from 811 to 818 m. This interval yielded 19 percent of the water in the well and included a fault zone (shear fracture) as defined by the fracture analysis (fig. 6). Water production also was attributed to the fault zone because no bedded units or lithologic changes occurred within or bordering this interval.

The deepest productive zone included the zeolitized bedded and reworked unit at the base of the Bullfrog Member along with the base of the overlying ash-flow unit. This interval was from 866 m to 872 m and produced 30 percent of the water from the well. The significant permeability of this zone also probably resulted from fracture permeability at the base of the overlying ash-flow unit, or from permeability along a cooling margin between the bedded and reworked unit and the overlying ash-flow unit.

The percent of production of the producing zones obtained from the flow survey was used to estimate the magnitude of the transmissivity (fig. 6). Thickness of the producing zone can be used with the transmissivity obtained in this way to estimate the hydraulic conductivity of the separate zones.

Packer-injection tests

Packer-injection tests were conducted to determine hydraulic coefficients for selected isolated intervals where packers could be set. During each test, a section of the well was isolated between two inflatable packers or between one packer and the bottom of the hole. A slug of water was injected into the interval to produce a virtually instantaneous pulse of increased hydraulic head. Pressure transducers with surface-pressure readouts were used to monitor the decrease of the pulse with time in the isolated interval. Pressure recorders were used to monitor leakage above or below the packer. The ratios of remaining hydraulic head to original hydraulic head at the start of a test, plotted against the log of elapsed time, were compared to a family of type curves to determine transmissivity (Papadopulos and others, 1973). Hydraulic conductivity was calculated by dividing transmissivity by the thickness of the test interval.

Fourteen tests were made during the first two testing episodes; data curves for these tests are shown in figures 13 through 26. Transmissivity values for the tested intervals ranged from about 10^{-1} to about 49 m^2/d. Hydraulic conductivity values ranged from about 10^{-4} m/d for the Lithic Ridge Tuff to about 1 m/d for the fractured water-producing sections of the Prow Pass and Bullfrog Members. Values of nonproducing sections of the Prow Pass and Bullfrog Members were less than 10^{-2} m/d. Results of these tests are summarized in table 4.

Tests that yielded transmissivity values greater than 10^1 m^2/d exceeded the limits of the tool used. Transmissivity and hydraulic-conductivity values for these tests were approximated by matching the first static water-level reading at the end of a test with the first static water-level value on a type curve (Papadopulos and others, 1973).

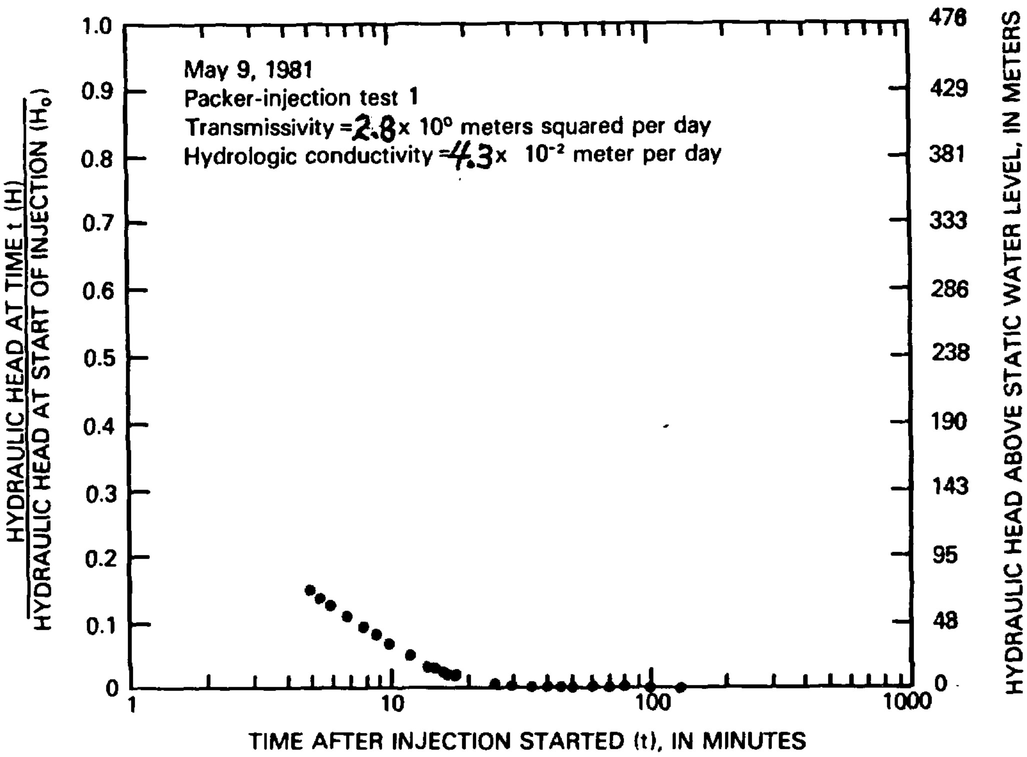

Figure 13.--Packer-injection test data for depth interval from 514 to 579 meters.

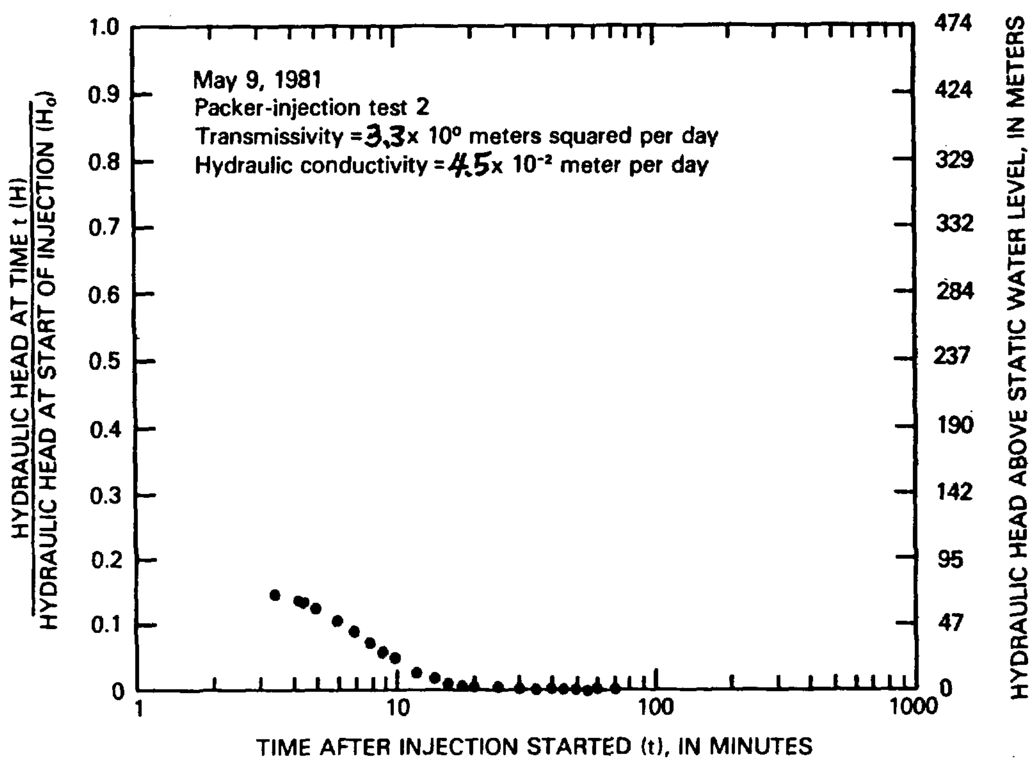

Figure 14.--Packer-injection test data for depth interval from 505 to 579 meters.

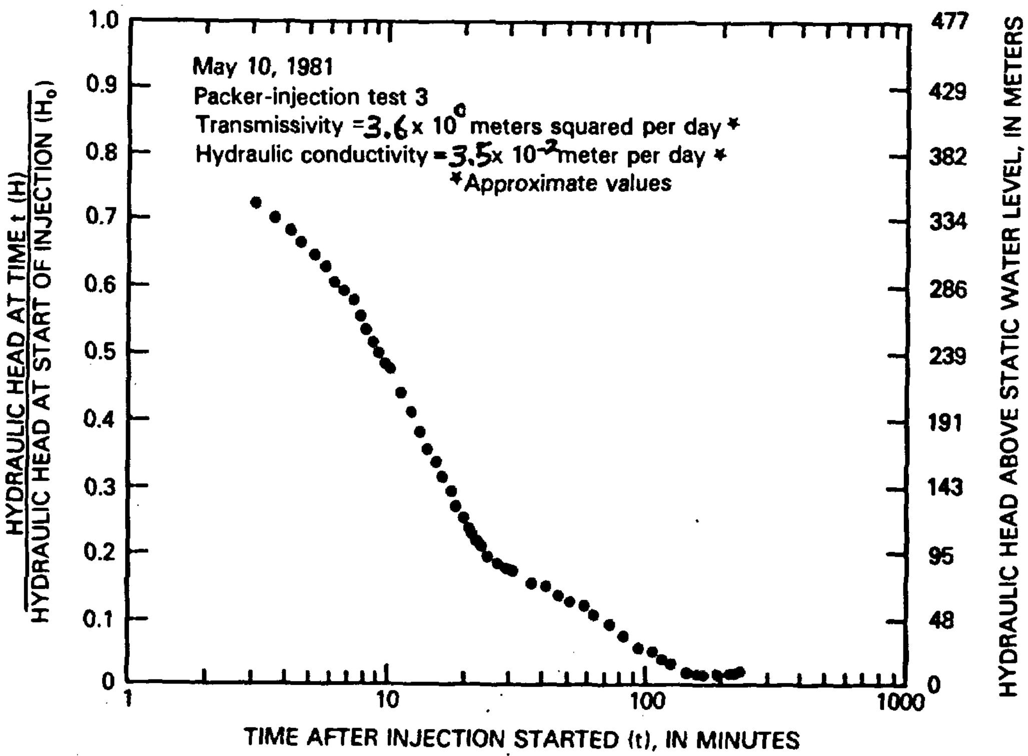

Figure 15.--Packer-injection test data for depth interval from 477 to 579 meters.

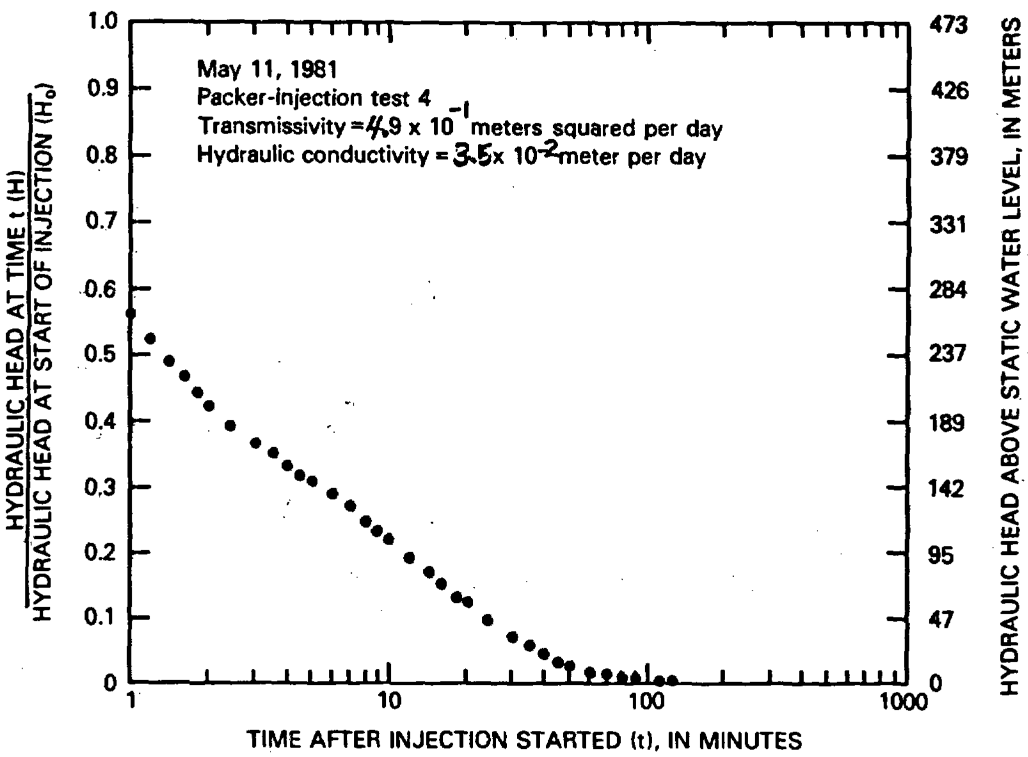

Figure 16.--Packer-injection test data for depth interval from 491 to 505 meters.

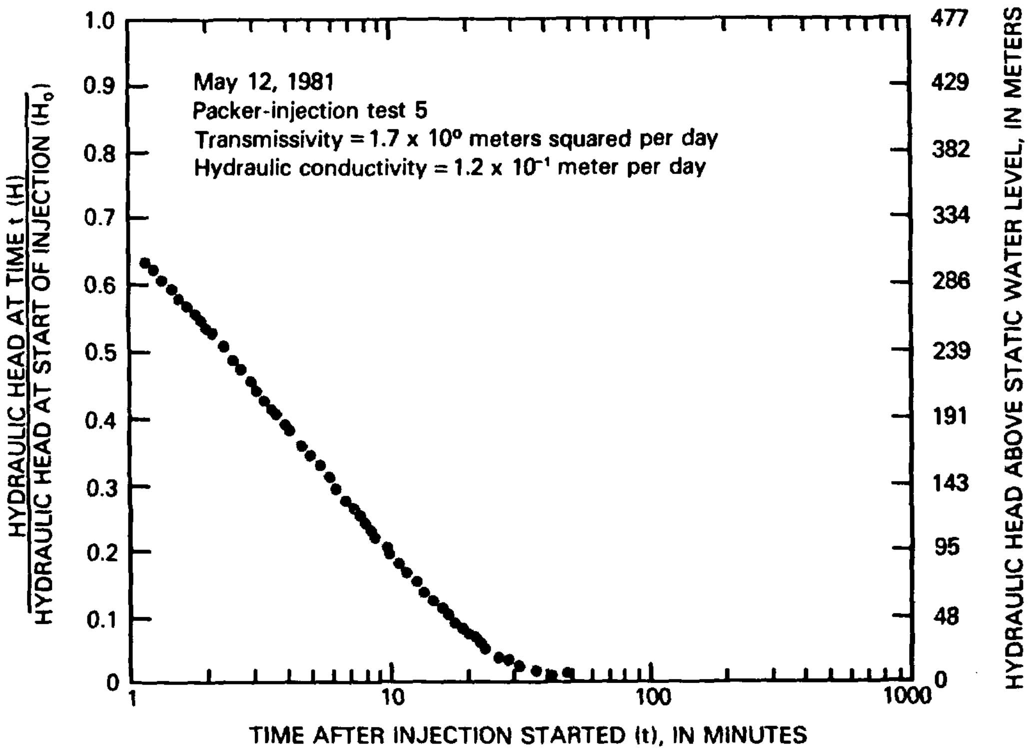

Figure 17.--Packer-injection test data for depth interval from 477 to 491 meters.

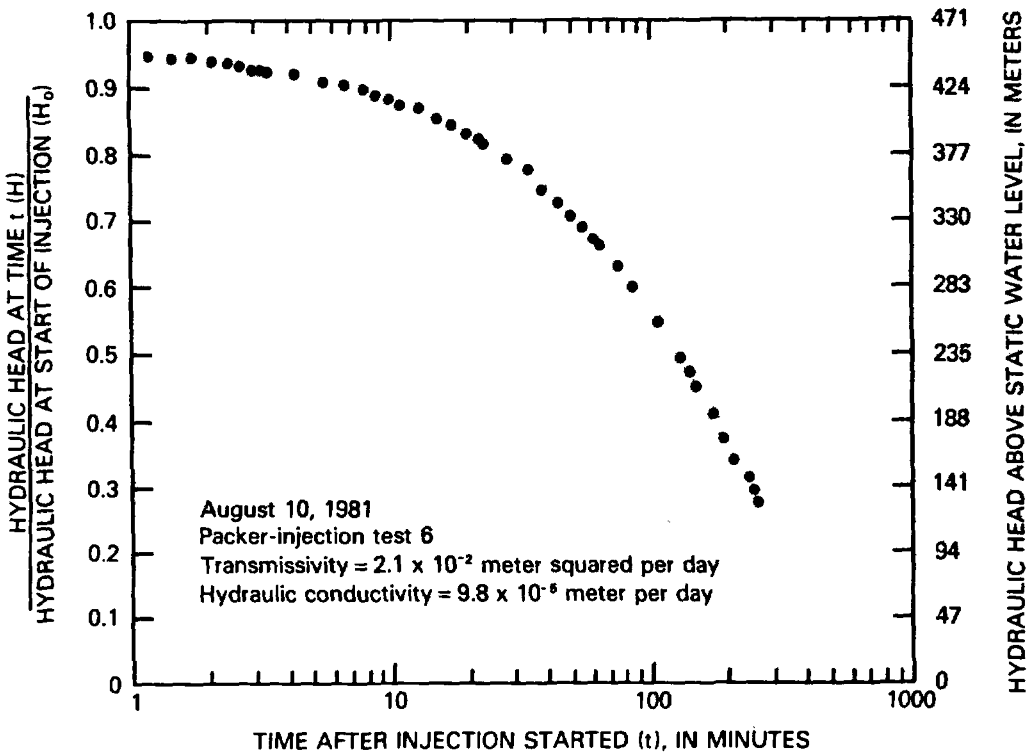

Figure 18.--Packer-injection test data for depth interval from 1,006 to 1,220 meters.

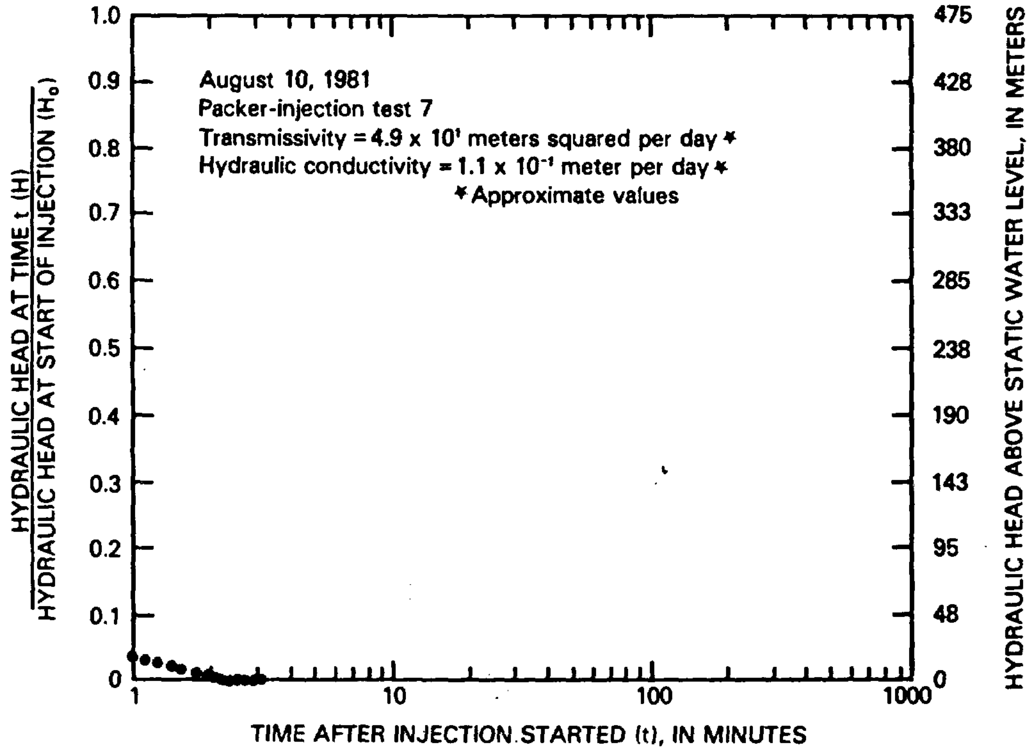

Figure 19.--Packer-injection test data for depth interval from 792 to 1,220 meters.

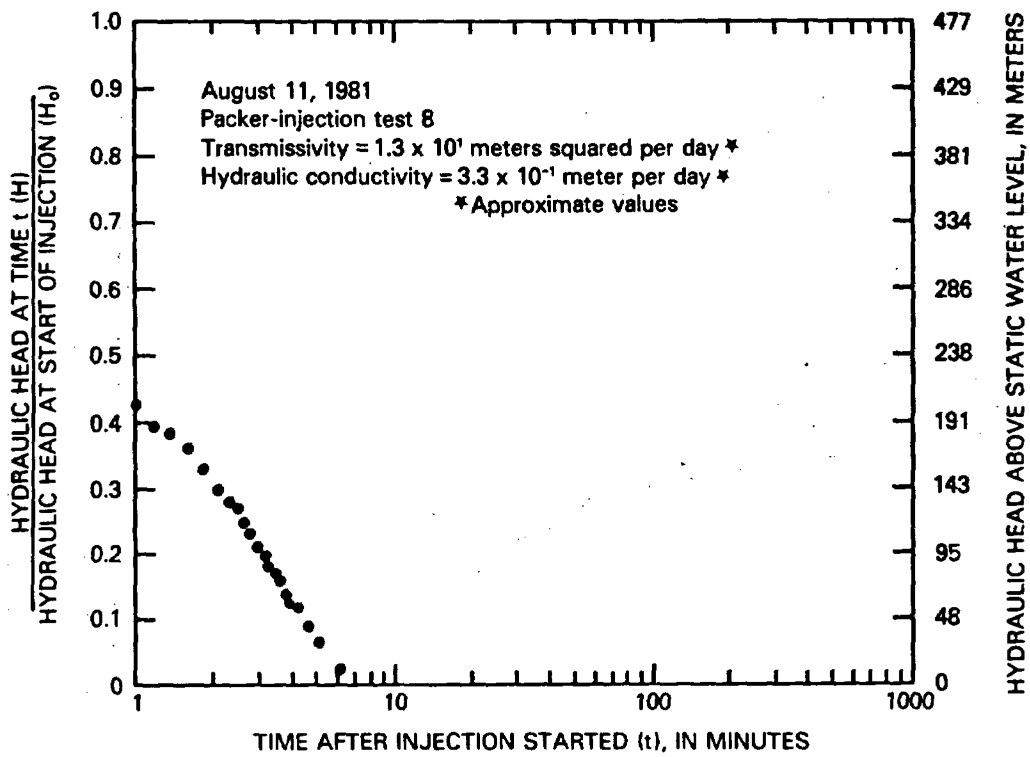

Figure 20.--Packer-injection test data for depth interval from 820 to 860 meters.

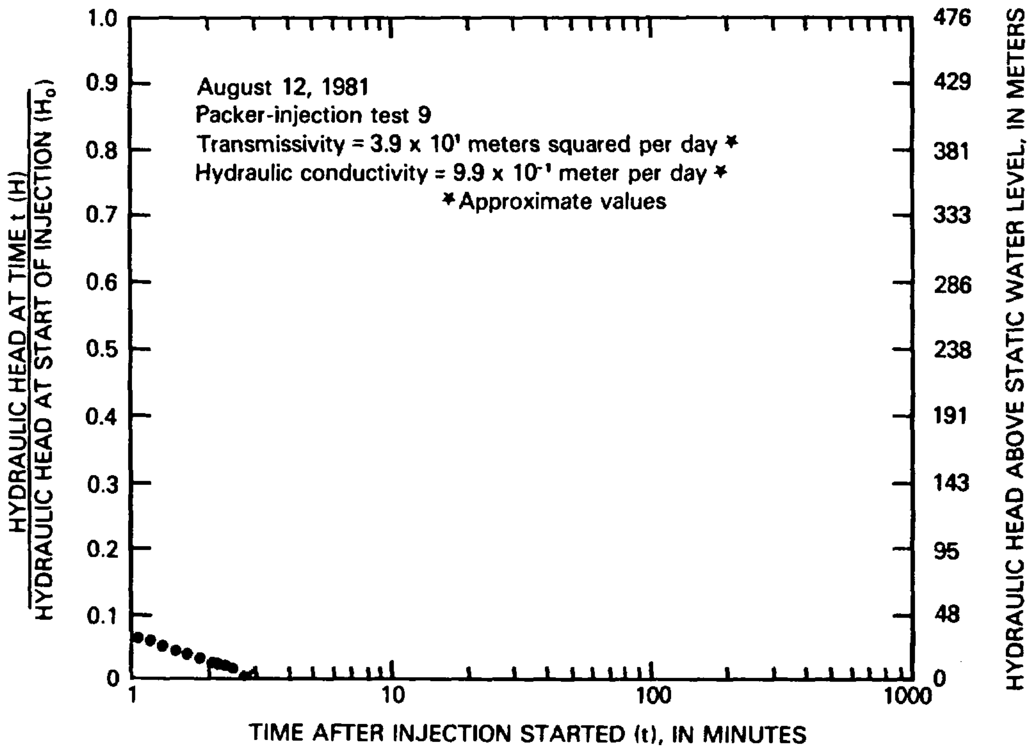

Figure 21.--Packer-injection test data for depth interval from 779 to 819 meters.

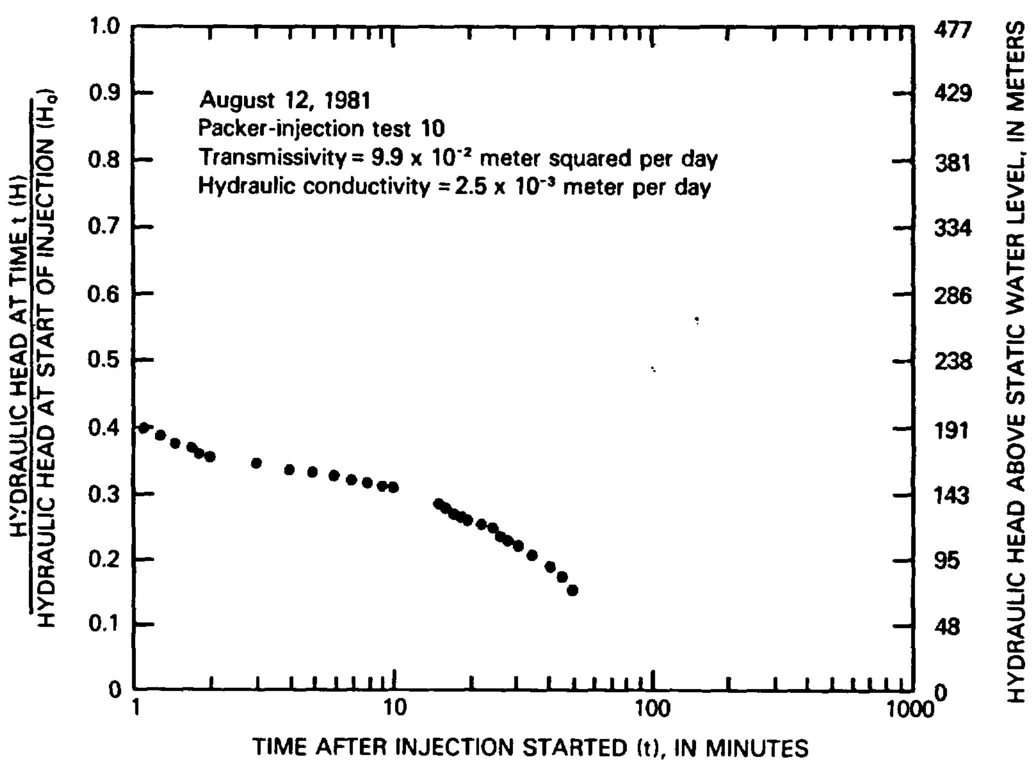

Figure 22.--Packer-injection test data for depth interval from 743 to 783 meters.

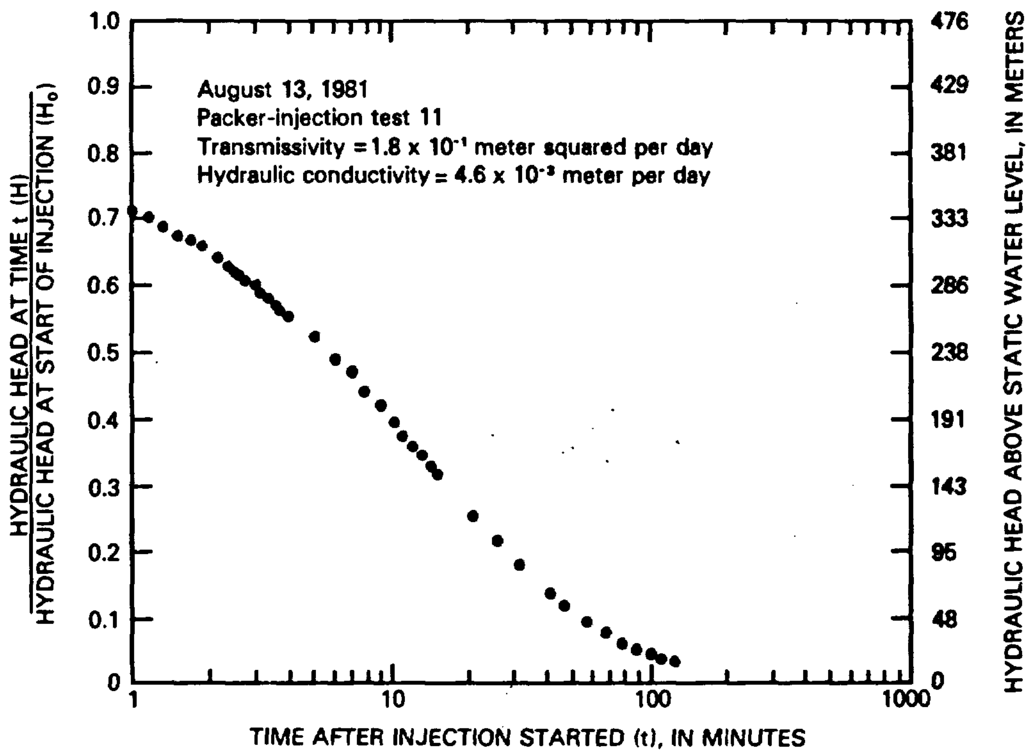

Figure 23.--Packer-injection test data for depth interval from 703 to 743 meters.

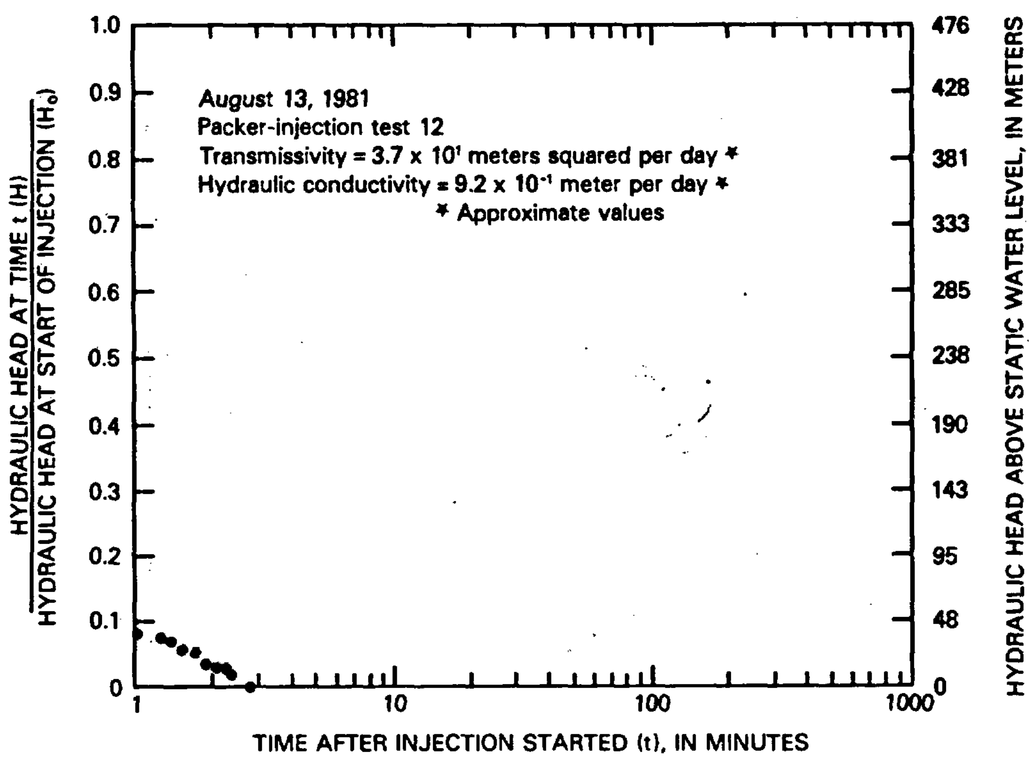

Figure 24.--Packer-injection test data for depth interval from 581 to 621 meters.

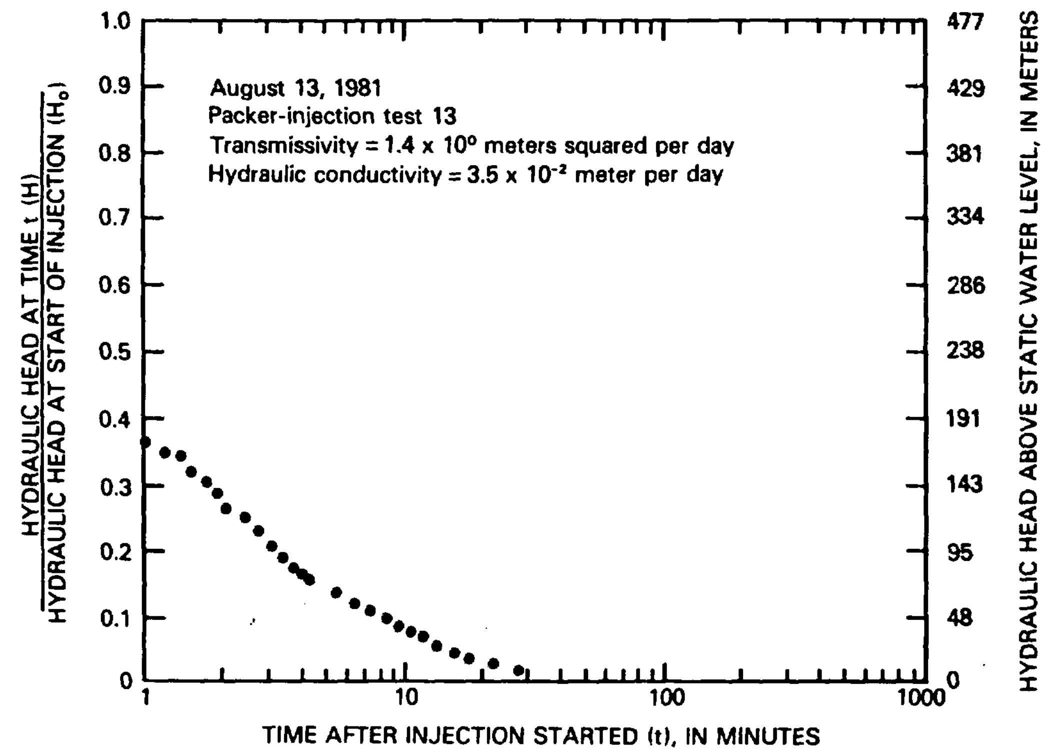

Figure 25.--Packer-injection test data for depth interval from 504 to 544 meters.

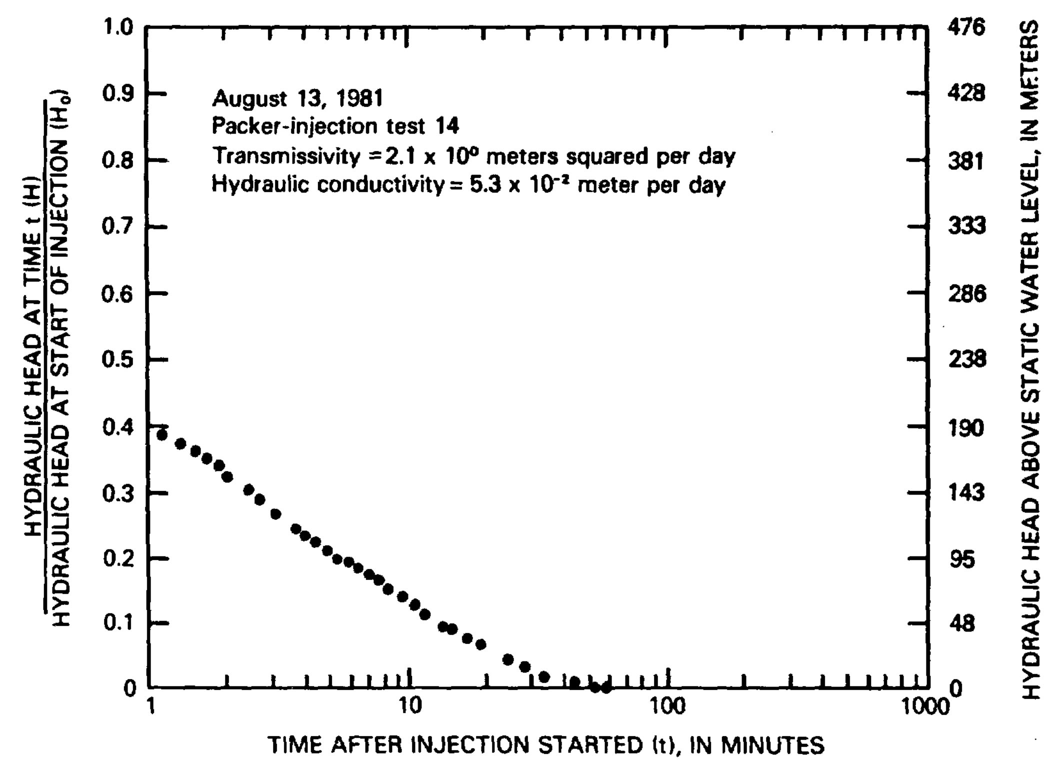

Figure 26.--Packer-injection test data for depth interval from 621 to 661 meters.

Shapes of the H/H_0 curves fall into two categories: (1) Curves that are very steep (relatively large transmissivity), and (2) broken or humpbacked curves. In the absence of a very permeable aquifer, shapes of these types of curves are attributed to fractures. No storage coefficients were calculated from these curves. Steep curves are a function of one or more very permeable fractures, whereas broken curves indicate changing flow paths through one or more fractures as pressure decreased during the test (Wang and others, 1977, p. 102-112).

Water levels for the major water-yielding zones (packer-injection tests 1b through 4b) are given in table 4 (see section of this report titled Water Levels). These injection tests were made during a third testing period which was being conducted to determine vertical hydraulic-head differences.

Hydraulic summary by geologic units

Average hydraulic conductivities for the geologic units tested in the well were determined by using the borehole-flow surveys for the units containing producing zones and the packer-injection tests for the units containing nonproducing zones. These data follow:

Formation	Hydraulic conductivity (meters per day)
Rhyolitic tuffs of Calico Hills	2.6×10^{-1}
Crater Flat Tuff	
Prow Pass Member	9.1×10^{-1}
Bullfrog Member	1.08×10^{0}
Tram Member	less than 10^{-3}
Lithic Ridge Tuff	less than 10^{-4}

These average hydraulic conductivities cannot be used to define hydrostratigraphic units. Nonproducing zones within the Prow Pass and Bullfrog Members were as permeable as the Tram Member and the Lithic Ridge Tuff. The spacing of water-producing fractures did not conform to the stratigraphy; water production in this well was controlled by structure rather than stratigraphy.

A more detailed summary of hydraulic properties of the producing and nonproducing zones is shown in figure 6. Repeated and overlapping values of transmissivity do not agree closely because different tests sample different radial distances into the formation. Some of the tests may have altered the formation so that later tests would give different results. The order-of-magnitude agreement generally shown by these tests is typical for packer-injection tests in the formation being tested.

HYDROCHEMISTRY

Three water samples were collected by the U.S. Geological Survey and analyzed for major inorganic chemical constituents and radioactive elements (table 5). The first sample (not included in table 5 because of drilling fluid contamination) was collected at the end of 4 days of continuous pumping (pumping test 1); the second sample was collected at the end of 16 days of discontinuous pumping (at the end of pumping test 3).

A total of 4.8 million L of water was pumped prior to collection for the first sample; the water was still very soapy. A total of 34 million L of water was pumped prior to collecting the second water sample for age dating and chemical analysis. The second sample was noticeably less soapy than the first sample.

A lithium chloride tracer was added to all water used in drilling, coring, and packer-injection tests to determine when representative water samples could be collected. The lithium chloride tracer was selected because the natural background concentration of lithium in water in the area, as determined from a nearby well, J-13, was approximately 4×10^{-2} mg/L. Well J-13, 6.3 km southeast of UE-25b#1, was the source of all water used in drilling and testing. At the end of the first pumping test (first sample), lithium concentration was 0.82 mg/L. At the end of the third pumping test (second sample), after 16 days of pumping, lithium concentration was 0.22 mg/L. This concentration was approximately 1 percent of the concentration of lithium in the water added to the well (20 mg/L) and the second sample is considered representative of the water in the formations.

A third water sample was collected by the U.S. Geological Survey on July 20, 1982, after the well had been pumped continuously for 28 days. The sampled interval was 853 to 914 m below the surface. After this period of pumping, the water was virtually free of soap. A detailed interpretive analysis of the results of the water sampling during this long-term pumping test was made by Ogard and others (1982).

The first two water samples represented composite water from tuffaceous rocks at a depth of 471 m to the top of the no-flow zone at 877 m. The third sample was mostly from the interval 866 to 872 m below land surface. Laboratory analytical results for the second and third water samples are listed in table 5.

Analysis of the water from the second and third samples indicated that the water was a soft, sodium bicarbonate type with relatively large concentrations of dissolved silica and sulfate, typical of tuffaceous aquifers in the Nevada Test Site area. No major changes in anion and cation values were noted except for iron and manganese, both of which gradually decreased with pumping. The water was slightly alkaline with an onsite pH of 7.1. The pumped water had a temperature of 36° to 37°C at the well head. An uncorrected carbon-14 age of 14,100 years was obtained for the second sample; an uncorrected carbon-14 age of 13,400 years was obtained for the third sample. Deuterium-hydrogen ratio indicated that the origin of the water was precipitation.

Table 5.--*Chemical analyses of water from test well UE-25b#1*
[Analyses by U.S. Geological Survey]

Sample number	2	3
Date of collection	9-01-81	7-20-82
Sample interval (meters)	471-1,220	853-914
Temperature (degrees Celsius)	36.0	37.2
pH (onsite)	7.1 units	
Bicarbonate[1]	139	133
Calcium[1]	17	18
Magnesium[1]	0.59	0.72
Sodium[1]	46	46
Potassium[1]	3.5	2.8
Sulfate[1]	22	21
Chloride[1]	8.5	7.5
Fluoride[1]	1.6	1.6
Silica[1]	52	51
Lithium[1]	0.22	0.12
Uranium[1]	0.038	0.047

[1]Reported in milligrams per liter.

SUMMARY AND CONCLUSIONS

Test well UE-25b#1, located in the southwestern part of the Nevada Test Site on the east side of Yucca Mountain, was hydraulically tested to evaluate the suitability of Yucca Mountain as a nuclear-waste repository. The well was drilled to a depth of 1,220 m.

The test hole penetrated 46 m of alluvium, 376 m of Paintbrush Tuff, 149 m of the rhyolitic tuffs of Calico Hills, 636 m of Crater Flat Tuff, and 13 m of the Lithic Ridge Tuff. With the exception of the bedded and reworked unit at the base of the Bullfrog Member of the Crater Flat Tuff, none of the boundaries defined by hydraulic testing coincided with changes in the lithology.

Drill cores were collected from a depth of 579 m to the bottom of the well (1,220 m). Analyses of the cores included laboratory determinations for density, matrix porosity, pore saturation, natural-state pore-water content, and matrix hydraulic conductivity. The horizontal and vertical hydraulic conductivities determined for these cores were less than 10^{-3} m/d. A fracture analysis of the core defined five zones of fracturing believed to be fault zones within the Crater Flat Tuff--one in the upper part of the Prow Pass Member, one in the middle part of the Bullfrog Member, and three in the middle to lower part of the Tram Member.

The geophysical logs did not show porosity anomalies that could be related to water-yielding zones in the well. Geophysical logs that indicated water-yielding zones were: (1) The seisviewer and televiewer, which showed slight-angle fractures associated with the water-producing zones; (2) the self-potential curve for the electric log, which reversed at the base of the lowermost water-yielding zone; and (3) the temperature log, which indicated gradient changes caused by water movement in the well during pumping.

Water levels were measured during drilling, during testing, and after testing. Measurements also were made in the more permeable zones using inflatable packers. The composite water level was 471.4 m below land surface with water levels of individual zones indicating a small hydraulic-head decrease with depth.

Hydraulic coefficients of the saturated intervals in this test hole were evaluated by pumping tests, borehole-flow surveys, and packer-injection tests. Pumping-test calculations gave a transmissivity of 340 m^2/d for the yielding thickness of 749 m.

The borehole-flow survey provided the best quantitative analysis of the different water-producing zones. Five principal water producing zones were defined in: (1) The upper part of the tuffaceous beds of Calico Hills, (2) the lower part of the Calico Hills, (3) the upper part of the Prow Pass Member, (4) the middle to lower part of the Bullfrog Member, and (5) the bedded and reworked unit at the base of the Bullfrog Member.

Packer-injection tests were made for isolated intervals in the well. Transmissivities for the tested intervals ranged from about 10^{-1} to about 49 m^2/d. Hydraulic conductivities ranged from about 10^{-4} to about 1 m/d. All water-yielding zones exceeded the limits of the method of analysis used, and the values obtained were approximated.

Thirty-eight percent of the transmissivity in this well probably is controlled by local structures (faulting and fracturing). An additional 32 percent probably could be attributed to the same causes, but the lack of drill cores in the yielding zones precluded any definite conclusion. The rationale for the conclusion that at least 70 percent of the transmissivity is controlled by structures is: (1) All water-yielding zones in which core was collected contained fault zones as defined by fracture analysis, with the exception of the bedded and reworked unit below the bottom of the Bullfrog Member; (2) injection tests indicated relatively large values of transmissivity in zones that were known to contain fractures, whereas laboratory tests of unfractured cores indicated very small values of matrix hydraulic conductivity, indicating that fractures provided the major source of water in the well; (3) the seisviewer and televiewer logs showed slight-angle fractures in the borehole at the water-yielding zones; (4) no lithologic boundaries occurred within or adjacent to the water-yielding zones; (5) geophysical logs, which generally indicate differences in matrix porosity, did not give good definition of these water-yielding zones; and (6) core analyses, which excluded fractured rock, did not indicate porosity anomalies in water-yielding zones.

The zeolitized, bedded, and reworked unit at the base of the Bullfrog Member of the Crater Flat Tuff contained the remaining 30 percent of the transmissivity. The presence of zeolites, which usually inhibit permeability, and the absence of anomalies on the geophysical logs indicated that the permeability probably occurred along fractures or along the boundaries of this unit.

Results of chemical analyses of water samples indicate that the water was a soft, sodium bicarbonate type. Uncorrected carbon-14 age dates of 14,100 and 13,400 years were obtained for this water..

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IN REPLY REFER TO:

March 11, 1985

Changes made by N. Coleman

Memorandum

To: NNWSI Distribution

From: Authors R. G. Lahoud, D. H. Lobmeyer, and M. S. Whitfield, Jr.

Subject: PUBLICATIONS--Errata for Water-Resources Investigations Report 84-4253, "Geohydrology of volcanic tuff penetrated by test well UE-25b#1, Yucca Mountain, Nye County, Nevada".

Please make the corrections indicated below to subject report:

Page 16 Replace page with attached revised page 16.

Page 17 Replace page with attached revised page 17.

Page 20 Table 4: Change the transmissivity and hydraulic conductivity values for packer-injection tests 1 thru 4 to the following:

	Transmissivity	Hydraulic Conductivity
Packer-injection test 1	2.8×10^{0}	4.3×10^{-2}
Packer-injection test 2	3.3×10^{0}	4.5×10^{-2}
Packer-injection test 3	3.6×10^{0}	3.5×10^{-2}
Packer-injection test 4	4.9×10^{-1}	3.5×10^{-2}

Page 24 Figure 8: Reduce time scale by one log cycle. [10 minutes becomes 1 minute, 100 minutes becomes 10 minutes, etc.]

Page 29 Paragraph 2, line 2: Change 503 to 502.

Page 31 Paragraph 5, line 3: Change 55 m^2/d to 49 m^2/d.

Page 32 Figure 13: Change the transmissivity value from 4.9×10^0 to 2.8×10^0 and the hydraulic conductivity value from 7.6×10^{-2} to 4.3×10^{-2}.

Page 32 Figure 14: Change the transmissivity value from 2.7×10^0 to 3.3×10^0 and the hydraulic conductivity value from 3.6×10^{-2} to 4.5×10^{-2}.

Page 33 Figure 15: Change the transmissivity value from 5.5×10^1 to 3.6×10^0 and the hydraulic conductivity value from 5.4×10^{-1} to 3.5×10^{-2}. Also, reduce time scale by one log cycle.

Page 33 Figure 16: Change the trasmissivity value from 6.9×10^0 to 4.9×10^{-1} and the hydraulic conductivity from 4.9×10^{-1} to 3.5×10^{-2}.

Page 42 Paragraph 5, line 3: Change 55 m^2/d to 49 m^2/d.

Page 43 Paragraph 1, line 2: Change 14,000 to 14,100.