USGS-OFR-84-063

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOHYDROLOGIC DATA FOR TEST WELL USW G-4 YUCCA MOUNTAIN AREA, NYE COUNTY, NEVADA

by

C. B. Bentley

Open-File Report 84-063

Prepared in cooperation with the
Nevada Operations Office
U.S. Department of Energy
(Interagency Agreement DE-AI08-78ET44802)

Denver, Colorado

1984

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

Chief, Nuclear Hydrology Program
Water Resources Division
U.S. Geological Survey
Box 25046, Mail Stop 416
Denver Federal Center
Denver, Colorado 80225

Copies of this report can be
purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
Telephone: (303) 234-5888

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS--Continued

TABLES

CONVERSION TABLE

Multiply metric unit	by	To obtain inch-pound unit
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
meter (m)	3.281	foot (ft)
milligram per liter (mg/L)	±[1]1.0	part per million (ppm)
microgram per liter (µg/L)	±[1]1.0	part per billion (ppb)
liter per second (L/s)	15.85	gallon per minute (gal/min)
degree Celsius (°C)	°F = 9/5°C + 32	degree Fahrenheit (°F)

[1]Approximate.

National Geodetic Vertical Datum of 1929: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level". It is referred to as sea level in this report.

GEOHYDROLOGIC DATA FOR TEST WELL USW G-4, YUCCA MOUNTAIN AREA, NYE COUNTY, NEVADA

By C. B. Bentley

ABSTRACT

This report presents data on drilling operations, lithology, borehole geophysics, hydrologic monitoring, core analysis, water chemistry, pumping tests, and packer-injection tests for test well USW G-4. The well is one of a series of test wells drilled in and near the southwestern part of the Nevada Test Site, Nye County, Nevada, in cooperation with the U.S. Department of Energy. These test wells are part of the Nevada Nuclear Waste Storage Investigations to identify suitable sites for underground storage of high-level radioactive wastes.

Test well USW G-4 was drilled to a total depth of 915 meters through volcanic rocks, consisting mostly of ash-flow tuff. Depth of water in the well during drilling and testing ranged from 538 to 544 meters below land surface. Static water level after completion of drilling was at an approximate altitude of 730 meters above sea level. Drawdown in the well was about 3 meters after test pumping more than 5,000 minutes at a rate of 16 liters per second. A borehole-flow survey indicated that almost all water withdrawn from the well was contributed by the zone between a depth of about 865 and 915 meters below land surface. A composite water sample collected after well completion contained 216 milligrams per liter of dissolved solids, with relatively large concentrations of silica, sodium, and bicarbonate.

INTRODUCTION

The U.S. Geological Survey has been conducting investigations at Yucca Mountain, Nevada, to evaluate the hydrologic and geologic suitability of the site for storing high-level nuclear waste in an underground mined repository. These investigations are part of the Nevada Nuclear Waste Storage Investigations being conducted in cooperation with the U.S. Department of Energy, Nevada Operations Office. Test drilling has been a principal method of investigation. This report presents geohydrologic and drill-hole data from test well USW G-4.

Test well USW G-4 is located in Nye County, Nevada, about 140 km northwest of Las Vegas, in the southern part of the State (fig. 1). The well is near the base of the slope between the forks of a wash on the east flank of Yucca Mountain (fig. 2). Location of the site is Nevada State Coordinate System Central Zone N 765, 807 and E 563, 082. Altitude of the land surface at the well site is 1270.0 m above sea level.

DRILLING OPERATIONS

Drilling of test well USW G-4 started on August 22, 1982, and was continuously cored below a depth of 12 m. Total depth of 915 m was reached on November 7, 1982, and reaming to allow for hydrologic testing was completed on November 29, 1982. The rotary drilling fluid was air foam consisting of air, detergent, and water. Maximum deviation was 9.5° from vertical. Well construction is shown in figure 3. Detailed drilling history is contained in the files of the engineering consulting firm, Fenix and Scisson, Inc., Las Vegas, Nevada.

LITHOLOGIC SAMPLING AND WELL LOGGING

Lithologic Log

The lithology penetrated by test well USW G-4, as determined from rock-bit cuttings and core, is presented in table 1. Ash-flow tuff is the predominant rock type. Thin beds of air-flow tuffs have various degrees of welding, alteration, and zeolitization induration. In the remainder of the report, shortened names of stratigraphic units are used. For the complete designation of formation and member, see table 1.

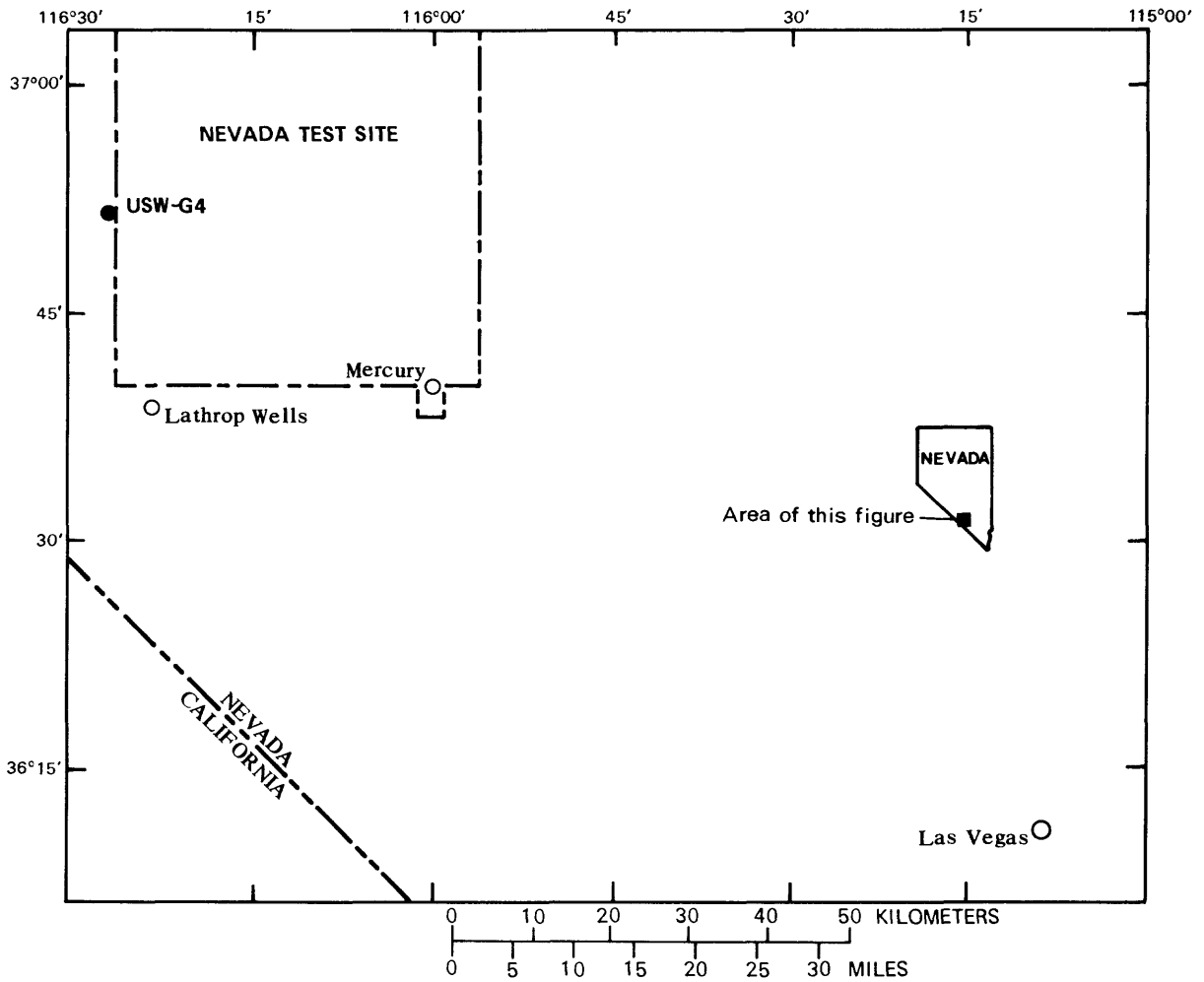

Figure 1.--Location of test well USW G-4.

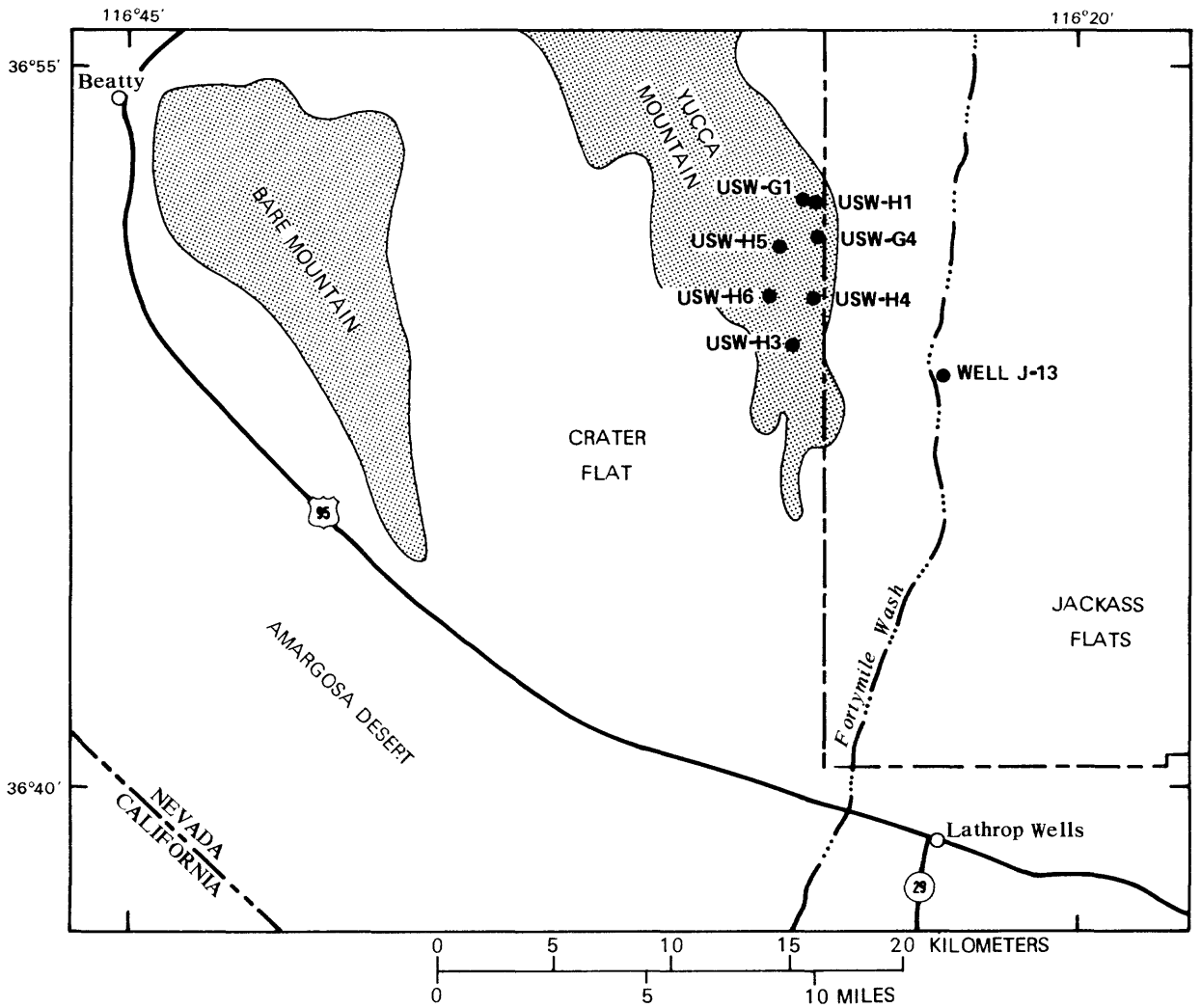

Figure 2.--Geographic features and other wells in vicinity of test well USW G-4.

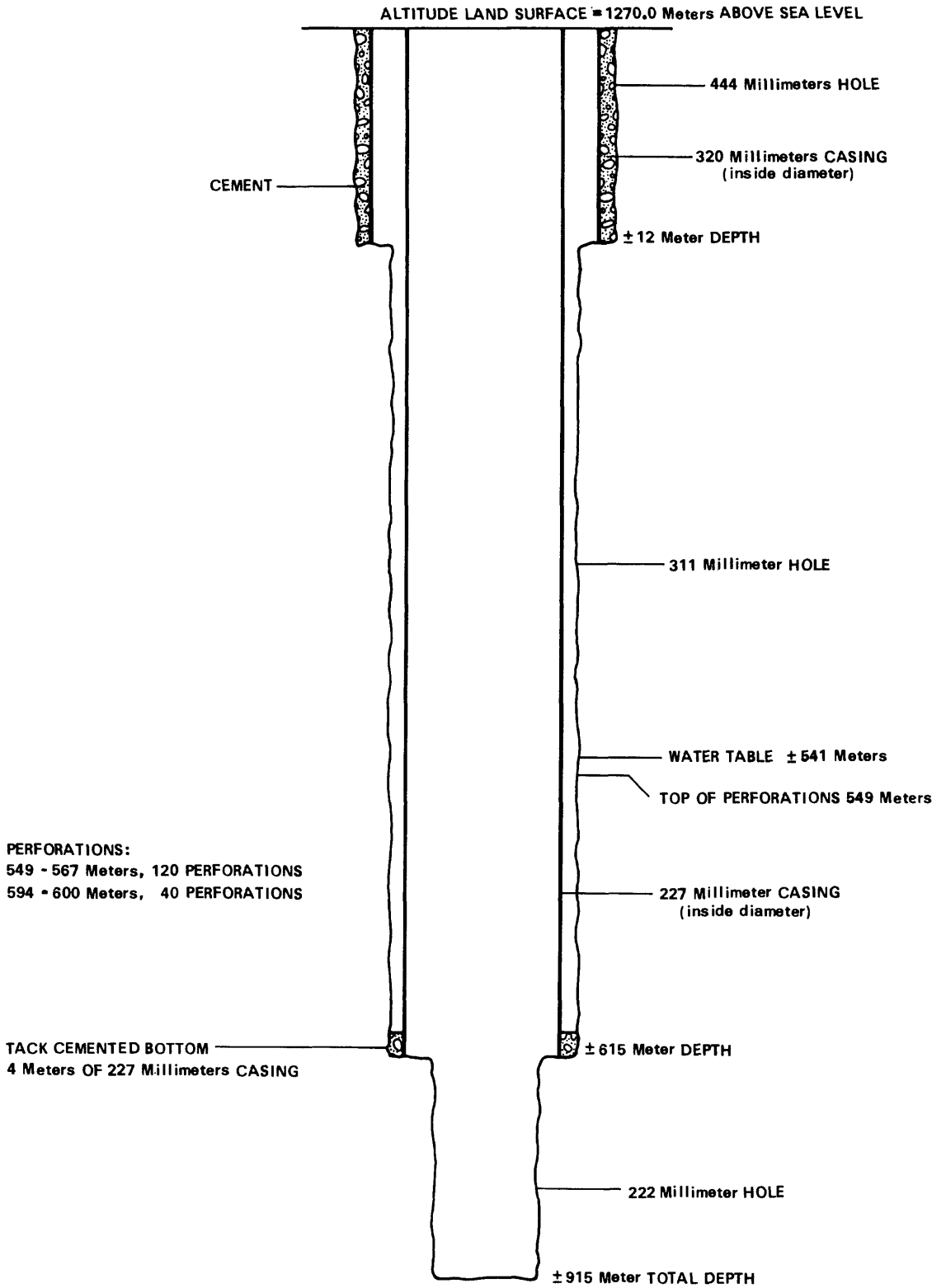

Figure 3.--Well construction.

Table 1.--*Lithologic log*

[Modified from Richard W. Spengler, U.S. Geological Survey, written communication, 1982; m, meter; mm, millimeter]

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Alluvium	6.7	6.7
Paintbrush Tuff of Tertiary age		
Tiva Canyon Member		
Tuff, ash-flow, grayish-red, densely welded, devitrified; pumice, grayish-red, medium gray, devitrified; 2 percent phenocrysts (sanidine): rare very-light-gray rhyolitic lithic fragments; occasional lithophysal cavities (open and flattened), in upper 12 m.	17.5	24.2
Tuff, ash-flow, pale-brown, pale-red, moderately to densely welded, devitrified; pumice, pale-red, brownish gray, devitrified with sparse to abundant moderate reddish-orange pumice altered to smectite (swelling) clay; less than 2 to 4 percent phenocrysts (sanidine and plagioclase); rare very-light-gray to medium-light-gray rhyolitic lithic fragments, commonly less than 5 mm in size.	11.8	36.0
Tuff, ash-flow, dark-yellowish-orange, partially-to-nonwelded, vitric; pumice, grayish-orange-pink, vitric and argillic(?); 1 to 2 percent phenocrysts (sanidine and plagioclase); abundant black and very yellowish-orange glass shards.	6.1	42.1
Bedded tuff, ash-fall, light-brown, moderately indurated, vitric, abundant moderate-orange pink pumice (vitric, argillic) and black glass shards; 2.4 m of core lost, of which part may be from subsequent unit.	3.0	45.1
Yucca Mountain Member		
Bedded tuff, ash-fall, bedded, reworked, pale-yellowish-brown, light-olive-gray, light-brown, slightly indurated, vitric, beds predominantly composed of light-olive-gray vitric pumice and black glass shards, rare light brownish-gray		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Paintbrush Tuff--Continued		
Yucca Mountain Member--Continued		
rhyolitic fragments, bedding planes indistinct (graduation); thickness of beds commonly 30-610 mm.	6.2	51.3
Pah Canyon Member		
Tuff, ash-flow, light-brown, nonwelded, vitric, pumice, yellowish-gray, light olive-gray dusky-yellow, vitric, commonly 10-30 mm in size; 5 percent phenocrysts (sanidine and biotite); rare light-red volcanic-lithic fragments.	6.0	57.3
Bedded tuff, reworked, light-brown, poorly consolidated, vitric, well-sorted, predominantly composed of grayish-orange, vitric pumice, less than 1 mm in size; sanidine and biotite present; light-red volcanic-lithic fragments present, less than 1 mm in size; fault plane at 60.5 m, crushed zone on one side of plane, magnitude of offset unknown; inclination of plane is 55°.	3.5	60.8
Tuff, ash-fall (?), yellowish-gray to light-olive-gray, vitric, poorly consolidated, poorly sorted, predominantly composed of white yellowish-gray to light olive-gray pumice fragments, commonly 10-20 mm in size, black vitrophyric lithic fragments commonly 5-15 mm, as large as 50 mm; minor constituents of sanidine and biotite; in upper 0.9 m reddish-orange clay; fault plane at 61.6 m, truncation of pumice fragments, magnitude of offset unknown; plane dips 76°.	8.7	69.5
Topopah Spring Member		
Tuff, ash-flow, moderate-reddish-brown, nonwelded (poorly consolidated), vitric; pumice moderate-reddish-brown, yellowish-gray, light-olive-gray, vitric; 1 percent phenocrysts (sanidine and biotite); rare grayish-red volcanic-lithic fragments (lower contact gradational).	1.6	71.1

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-fall, light-gray to medium light gray, pale-reddish-brown, fused(?), moderately indurated, almost entirely composed of light-gray, medium light-gray and light brownish-gray pumice, vitric, commonly less than 10 mm in size, rare grayish-red volcanic-lithic fragments.	1.7	72.8
Tuff, ash-flow, light-brownish gray to dark-reddish brown and black, partially to densely welded, devitrified (some vapor phase crystallization); pumice blackish-red, yellowish-gray, devitrified and vapor-phase crystallization, commonly varying size from 5 to 40 mm, 5-20 percent phenocrysts (sanidine, plagioclase, bronze biotite); rare very-light gray rhyolitic-lithic fragments; upper 1.2 m vitrophyre, perlitic.	13.9	86.7
Tuff, ash-flow, grayish-red, densely welded, devitrified and vapor phase; pumice, pale-red, light-brown, grayish-red, light-gray, medium light-gray, yellowish-gray, extremely large grayish pumice, vapor phase, distinctive foliation of pumice, commonly 10-60 mm, 3-5 percent phenocrysts (sanidine, plagioclase, biotite); rare very light-gray rhyolitic-lithic fragments, commonly 10-20 mm in size.	35.3	122.0
Tuff, ash-flow, pale-red, light brownish-gray, densely welded, devitrified; pumice, mixture of very-light-gray, light-gray and brownish-gray, devitrified, commonly 5 to 50 mm in size, brownish-gray pumice commonly the larger size, devitrified and some vapor phase; 1 to 4 percent phenocrysts (sanidine and plagioclase); lithophysal cavities, abundant at top, sparse at base; spherical and flattened parallel to axis of core, commonly open; commonly 20-40 mm in size, as large as 60 mm.	15.5	137.5

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Paintbrush Tuff--Continued		
Topapah Spring Member--Continued		
Tuff, ash-flow, pale-red to grayish-red moderate-brown (mottled), densely welded, devitrified; pumice, pale-red, grayish-red, devitrified; less than 2 percent phenocrysts (sanidine and plagioclase); rare light-gray rhyolitic-lithic fragments; abundant (more than 30 percent) lithophysal cavities, commonly open, cavities subrounded and flattened; in upper 15.2 m, cavities are commonly less than 20 mm in size, commonly lined with feldspar, quartz; below 15.2 m, cavities commonly 10-60 mm in size, with pale-red alteration rims; due to hole problems, no core was collected from 137.8-140.2 m, and only 1.3 m of core was recovered from 140.2-144.8 m, using a globe basket (lower contact gradational).	49.7	187.2
Tuff, ash-flow, pale-brown, light-brown, grayish-red, and pale-red (mottled), moderately to densely welded, devitrified; pumice, pale-red, light-brown, light-gray, devitrified, commonly 5-30 mm, as large as 60 mm in length; 1 to 2 percent phenocrysts (sanidine and plagioclase); rare very-light-gray and light-gray rhyolitic-lithic fragments increasing toward base; lithophysae common, mostly flattened cavities with large alteration rims; fracturing and broken core intervals common (lower contact gradational).	151.9	339.1
Tuff, ash-flow, light brown, dark-yellowish-brown to dark-yellowish-orange, moderately to densely welded, devitrified, but partially vitric, argillic and zeolitic(?), (altered vitrophyre in lower 7 m); pumice light brown, dusky-yellowish-brown, pale-yellowish-orange, dark-yellowish-orange, devitrified vitric (lower 7 m), commonly 8-50 mm; 1 percent phenocrysts of sanidine and plagioclase; sparse very-light-gray rhyolitic-lithic fragments, commonly range from 5 mm to as		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
large as 84 mm; two fault zones with moderate to intense alteration [smectite(?)] along nearly vertical fault planes at 400.5-400.9 m, and 401.8-402.3 m; 0.6 m or more of displacement along second fault zone, as indicated by core sample at 401.9 m.	62.2	401.3
Tuff, ash-flow, dark-gray to black, densely welded, vitrophyre; pumice, black, glassy, 1 to 2 percent phenocrysts (sanidine and plagioclase); sparse very-light-gray rhyolitic-lithic fragments, commonly 4 to 18 mm, occasionally as large as 30 mm; moderate-olive-brown with light-brown pumice fragments; moderately altered from 401.9 to 402.2 m; interval contains several near-vertical, silica-coated, fractures (conchoidal micro-fractures common) (lower contact gradational).	8.8	410.1
Tuff, ash-flow, light brown to black, vitric, nonwelded to moderately welded (welding decreases downward): pumice, light phenocrysts of sanidine and plagioclase; abundant black glass shards near top and base; rare very-light-gray, brownish-gray and pale-red rhyolitic-lithic fragments, commonly from less than 1.5 mm to as large as 60 mm.	9.8	419.9
Tuff, ash-flow, light-brown and grayish-orange-pink, partially welded, zeolitized; pumice, light-brownish and pale-yellowish-orange, zeolitic, commonly less than 10 mm in size; 1 percent phenocrysts of sanidine and plagioclase; abundant (3 to 30 percent of rock) brownish-gray, grayish-red, greenish-gray, rhyolitic- and vitrophyric-lithic fragments vary from 5 to 80 mm, many fragments greater than 20 mm in length (lower contact gradational).	3.1	423.0

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Paintbrush Tuff--Continued		
Topopah Spring Member--Continued		
Tuff, ash-flow, grayish-orange-pink, nonwelded, partly vitric and partly zeolitic (interval from 423.3-423.8 m) dominantly vitric; pumice, very-pink-orange, grayish-orange-pink, and moderate-yellow, mainly zeolitic, some vitric, commonly range in size from 3 to 20 mm, as large as 42 mm; sparse (2 to 3 percent) volcanic-lithic fragments, grayish-brown, brownish-gray, medium-light gray, rhyolitic and vitrophyric, commonly less than 10 mm in size, a few as large as 40 mm; fault plane cutting core from 428.5-428.6 m; fault about 20 mm thick; contains silicified breccia, inclined about 72° relative to core axis.	5.8	428.8
Bedded tuff, reworked, ash-fall, light-brown, pale-red and light-gray, moderately indurated, zeolitic; dominantly made up of pumice fragments, white to light-gray, and light-brownish-gray, zeolitic, subrounded, commonly less than 5 mm in size; beds are 430 and 370 mm thick.	0.8	429.6
Tuffaceous beds of Calico Hills (informal usage)		
Tuff, ash-flow, moderate-orange-pink, moderate-reddish-orange, and light brown, nonwelded, vitric (slightly zeolitic); pumice grayish-orange, very-pale-orange, yellowish-gray, and medium-light-gray, dominantly vitric; commonly range from 5 to 50 mm, as large as 110 mm (larger pumice fragments occur in upper 1.2 m of unit); 3 to 4 percent phenocrysts (quartz, sanidine, plagioclase, biotite); sparse grayish-red rhyolitic and grayish-black to medium gray, slightly altered, vitrophyre lithic fragments, commonly range in size from 3 to 35 mm; greater concentration of lithic fragments in lower 2.0 m of unit.	4.6	434.2

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Tuffaceous beds of Calico Hills--Continued		
Tuff, bedded, reworked, moderate-orange-pink, pale-red, and grayish-orange-pink, moderately to highly indurated, zeolitic; dominantly composed of pumice, grayish-orange-pink and grayish-orange, zeolitic, subrounded, commonly less than 5 mm; abundant grayish-red rhyolitic-lithic fragments, commonly less than 2 mm in size; individual beds range from 30-240 mm.	0.5	434.7
Tuff, ash-flow, grayish-orange, grayish-orange-pink, and moderate reddish-orange, nonwelded, zeolitic; pumice, very-pale-orange, grayish-orange-pink, moderate-orange-pink, and yellowish-gray zeolitic; commonly range from 3 to 35 mm, as large as 50 mm; 1 percent phenocrysts (quartz, sanidine, plagioclase); rare medium-dark-gray and brownish-gray rhyolitic-lithic fragments, commonly less than 5 mm, occasionally as large as 50 mm; larger fragments are commonly slightly altered vitrophyric fragments.	6.3	441.0
Tuff, reworked, ash-fall, bedded, light brown, pale-red, grayish-orange-pink, and moderate-orange-pink, moderately indurated, zeolitic, and, in places, silicified; dominantly composed of pumice fragments having similar colors as those listed above, pumice commonly less than 10 mm in size, zeolitic; subordinate amounts of brownish-gray and medium-gray rhyolitic-lithic fragments, less than 10 mm in size; individual beds less than 670 mm thick, where well-defined, bedding planes are inclined 5° to 6°.	2.9	443.9
Tuff, ash-flow, moderate-orange-pink, grayish-orange-pink, light brown, grayish-orange, and dusky-yellow, nonwelded zeolitic; pumice, very-pale-orange, pale-red, moderate pink, grayish-orange-pink, yellowish-gray, grayish-yellow, grayish-orange, zeolitic, commonly range from 20 to 45 mm; 1 percent phenocrysts (quartz, sanidine, plagioclase, biotite); rare-to-sparse		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Tuffaceous beds of Calico Hills--Continued		
moderate-brown and grayish-red rhyolitic-lithic fragments, commonly less than 20 mm in size; lower 3.4 m of unit indicates a slight increase in content of lithic fragments; fault plane with slickensides present from 474.4-474.6 m, inclined 77°.	31.8	475.7
Tuff, ash-fall and reworked, moderate-orange-pink and grayish-orange, moderately indurated, zeolitic; dominantly composed of pumice, grayish-yellow, grayish-orange-pink, dusky-yellow, and very-pale-orange, zeolitic, commonly less than 20 mm in size, subangular to sub-rounded, poorly sorted; subordinate quantities (10-20 percent) of volcanic lithic fragments, grayish-red, dark gray, and medium-light-gray, subangular to subrounded, poorly sorted, range in size from 1 to 23 mm; lower 0.5 m of unit contains some of lithic fragments; individual beds range in thickness from 60-300 mm.	1.0	476.7
Tuff, ash-flow, grayish-orange, light brown, and moderate-reddish-orange, and occasionally dark-yellowish-brown, nonwelded zeolitic; pumice, very-pale-orange, grayish-yellow, dusky-yellow, moderate-greenish-yellow, zeolitic, commonly range in size from 2 to 310 mm, as large as 570 mm; 1 to 2 percent phenocrysts (quartz, sanidine, plagioclase, biotite); sparse (1-2 percent) rhyolitic-lithic fragments, brownish-gray and brownish-black, commonly less than 5 mm in size; ash-fall parting, 10 mm thick, present at 489.8 m, inclined 7°; fault plane present from 497.2-497.3 m, slightly offset, inclined 77°; ash-fall parting, 63 mm thick present from 506.6-506.7 m; shear fractures with slickensides present from 498.0-498.1 m and 509.3-509.4 m; ash-fall tuff, 140 mm thick at 506.9 m.	43.1	519.8
Bedded tuff, ash-fall, reworked (tuffaceous sandstone) grayish-yellow, yellowish-gray, light brown, greenish-gray, moderate-reddish-		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Tuffaceous beds of Calico Hills--Continued		
brown, dusky-yellow, pale-yellowish-brown, grayish-yellow, zeolitic (in places, silicified) moderately to well indurated; pumice, moderate-orange-pink, grayish-pink, very-pale-orange, pale-greenish-yellow, and grayish-yellow, zeolitic, commonly less than 5 mm in size, sparse to abundant brownish-black, brownish-gray and medium-gray rhyolitic-lithic fragments, commonly less than 5 mm in size; individual beds as much as 1.5 m thick; numerous silicified beds are present from 519.8-520.6 m; basal part of unit from 536.1-536.9 m, consists of tuffaceous sandstone, pale-yellowish-brown to dark-yellowish-brown, well-sorted, abundant biotite; individual beds range from 5-85 mm.	17.1	536.9
Crater Flat Tuff of Tertiary age		
Prow Pass Member		
Tuff, ash-flow, generally light-brown and gray, nonwelded, argillic, zeolitic; 5 to 10 percent phenocrysts (sanidine, quartz, plagioclase, biotite, pyroxene pseudomorphs(?); rare volcanic and mudstone lithic fragments less than 5 mm in size; smectite altered zone 0.5 m thick at 537.2 m; possible shear fracture at 546.5 m.	10.6	547.5
Tuff, ash-flow, grayish-orange-pink in upper 3 m of unit, grading downward into light-gray, and medium-light-gray into light-brownish-gray partially welded, vapor phase; pumice, light-brown, moderate-brown, pale-yellowish-brown, light-gray and medium-light-gray, vapor-phase crystallization dominant (devitrified), commonly less than 10 mm in size; 7 percent phenocrysts [quartz, sanidine, plagioclase, bronze biotite, pyroxene(?)]; rare to sparse moderate-reddish-brown mudstone-lithic fragments and brownish-black rhyolitic-lithic fragments commonly less than 5 mm in size. Shear fracture with slickensides at 547.7 m, high-angle fractures		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
with pale-reddish-brown iron oxide(?) staining cut core from 564.5-565.9 m; below 565.8 m, opaque substances [iron oxides(?)] are concentrated in pumice fragments (lower contact gradational).	22.6	570.1
Tuff, ash-flow, light-brownish-gray grading downward into pale-yellowish-brown, partially welded (slight increase in welding) devitrified; pumice, very-pale-orange to grayish-orange-pink, devitrified (some vapor-phase crystallization), vapor-phase crystallization common in upper 7.3 m and decreases downward; black opaque substances [iron and (or) manganese oxides] concentrated in pumice fragments in upper 4.6 m of unit; pumice fragments noticeably larger than in previous unit, commonly range in size from 5 to 25 mm, as large as 65 mm; 10 to 15 percent phenocrysts (quartz, sanidine, plagioclase, biotite, hornblende or pyroxene pseudomorphs); sparse (1 to 2 percent) moderate-reddish-brown mudstone-lithic fragments, commonly less than 4 mm in size, as large as 20 mm; shear fractures present at 577.4-578.5 m, 582.3-582.7 m; fault plane indicated by abrupt termination of pumice fragments along plane, cuts core from 585.5-586.9 m; slickensides observed along fault.	17.7	587.8
Tuff, ash-flow, light-brownish-gray and light-olive-gray, stained light-red near fractures 593.4-594.2 m, and 594.7-595.6 m, partially welded, devitrified; [partially argillic(?)], increase in degree of alteration relative to unit above, alteration progressively increases downward to base of unit; pumice, very-light-gray light-olive-gray, devitrified (some vapor-phase crystallization) pumice in lower 1.1 m of unit extensively altered to clays and zeolites(?); 10-15 percent phenocrysts (quartz, sanidine, plagioclase, biotite); sparse (1 to 2 percent) moderate-reddish-brown mudstone-lithic fragments,		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
commonly less than 4 mm, as large as 15 mm; shear fractures present at 589.5 m, 591.3-595.6 m; abrupt contact with lower unit but no apparent ash-fall parting.	8.0	595.8
Tuff, ash-flow, grayish-orange-pink, moderate-orange-pink, light-olive-gray, non-to-partially welded, moderately to highly zeolitic; pumice, very-pale-orange, grayish-pink, moderate-pink, moderate-size from 2-20 mm, as large as 30 mm; 5 to 7 percent phenocrysts [quartz, sanidine, plagioclase, biotite, pyroxene pseudomorphs(?)]; 2 to 4 percent mudstone, minor grayish-red volcanic lithic fragments, commonly 2-20 mm, as large as 33 mm, very thin clay parting at 603.2 m; shear fracture at 596.2-596.5 m, possible fault with breccia along plane at 606.6-607.2 m; abrupt contact at base.	29.1	624.9
Tuff, ash-flow, yellowish-gray, pale-olive, moderate greenish-yellow, pale-yellowish-brown, grayish-orange, partially welded, devitrified, slightly to moderately zeolitic, slightly to moderately silicified; pumice, dominantly light-brown and grayish-orange, pale-yellow, zeolitic [slightly silicified(?)], commonly range in size from 5-35 mm, as large as 65 mm, 10-15 percent phenocrysts [quartz, sanidine, plagioclase, pyroxene pseudomorphs(?)]; rare (1-2 percent) lithic fragments, dominantly dark-reddish-brown and light-brown mudstone, subordinate grayish-red and light-brown rhyolitic, commonly range in size from 2-20 mm; moderately to well indurated [silicified(?)] from 630.5-640.5 m, 640.8-643.7 m, 646.6-649.2 m.	43.4	668.3
Tuff, ash-flow, moderate-greenish-yellow, moderate-orange-pink, nonwelded, slightly to highly zeolitic; pumice, moderate-greenish-yellow, grayish-yellow, and pale-greenish-yellow, zeolitic and argillic, commonly range in size from 3-35 mm, as		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Prow Pass Member--Continued		
large as 65 mm; noticeable increase in abundance of larger pumice fragments relative to unit above; lower 2.4 m contains numerous, very altered pumice fragments commonly ranging from 30-50 mm; 5-7 percent phenocrysts [quartz, sanidine, plagioclase, biotite, hematite and (or) magnetite]; sparse (2 to 3 percent) mudstone and rhyolitic-lithic fragments.	13.7	682.0
Bedded tuff, ash-fall, reworked, upper 0.5 m consists of tuffaceous siltstone and very-fine tuffaceous sandstone; lower 1.4 m consists of ash-fall and reworked tuff, grayish-orange, moderate-reddish-orange, grayish-yellow, moderate-greenish-yellow, and moderate-reddish-brown; slightly to moderately zeolitic; thickness of bedding ranges from about 30-980 mm; base of unit marked by fault.	2.0	684.0
Bullfrog Member		
Tuff, ash-flow, pale-red, light-gray grades downward into grayish-orange-pink to pale-yellowish-brown, light-brownish-gray to light-olive-gray, partially welded, devitrified (slightly altered); pumice, moderate-pink and pale-red in upper 1.8 m, grades downward into very-pale-orange, light-brown, pale-yellowish-brown, grayish-orange, light-brownish-gray, light-olive-gray, and yellowish-gray, devitrified (occasional vapor phase, slightly argillic), commonly 0.2-1.5 mm in size; 10-15 percent phenocrysts (sanidine, quartz, plagioclase, hornblende, biotite rich in upper part); very rare (less than 1 percent) rhyolitic-lithic fragments, occasional mudstone-lithic fragments; lithic fragments commonly range in size from 4-11 mm, as large as 60 mm; fault zone from 684.0-685.2 m, fractures indicate offset (truncation of pumice fragments along fracture), interval moderately altered, appears to contain		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Bullfrog Member--Continued		
fragments of reworked tuff; fault plane dips at 73° relative to axis of core; shear fractures at 685.8, 686.3, 694.4, and 694.7 m (lower contact gradational).	14.9	698.9
Tuff, ash-flow, grayish-orange-pink, pale-yellowish-brown, partially welded, vapor-phase crystallization; pumice, light-brownish-gray, pale-yellowish-brown, pale-red, and medium-gray, vapor-phase crystallization dominant, commonly less than 15 mm, as large as 70 mm; 10-15 percent phenocrysts (quartz, sanidine, plagioclase, hornblende pseudomorphs(?), bronze biotite) first unit where bronze biotite is dominant type of biotite; very rare (less than 1 percent) lithic fragments, commonly grayish-red, black, and brownish-gray rhyolite, subordinate moderate-reddish-brown mudstone, commonly range from 5 to 7 mm in size, conspicuous near vertical-shear fracture extending along core from 713.8-715.0 m, in places, aperture along fracture is as large as 5 mm in width (lower contact gradational).	23.5	722.4
Tuff, ash-flow, pale-yellowish-brown to pale-brown, moderately welded, devitrified (some vapor-phase crystallization); pumice, pale-brown, pale-red, and medium-gray, devitrified (subordinate vapor-phase crystallization), commonly range in size from 5 to 25 mm, as large as 75 mm; 15 percent phenocrysts [quartz, sanidine, plagioclase, biotite, hornblende pseudomorphs(?)]; very rare (less than 1 percent) blackish-red and light-brown lithic fragments silicic to intermediate; many are cognate (commonly range in size from 4-22 mm) (lower contact abruptly gradational).	8.5	730.9
Tuff, ash-flow, grayish-orange-pink, light-olive-gray, grades downward into very-light-gray, partially welded, vapor-phase crystallization;		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Bullfrog Member--Continued		
pumice, light-gray, medium-light-gray, medium-gray, grades downward into light-brownish-gray and brownish-gray, vapor-phase crystallization dominant, commonly ranges in size from 4-24 mm, as large as 65 mm; 12-15 percent phenocrysts (sanidine, quartz, plagioclase, biotite); very rare (less than 1 percent) lithic fragments, pale-yellowish-brown, brownish-gray, and pale-brown, silicic to intermediate, and mudstone, commonly range in size from 7 to 18 mm; near vertical-shear fractures occur from 743.2-744.5 m, and from 745.3-745.7 m; lower 1.7 m is tuff, ash-fall interbedded with ash-flow(?), very-light-gray, well-indurated, devitrified, with abundant medium-light-gray and light-brownish-gray pumice fragments; very thin (10-15 mm) ash-fall beds occur at 770.7 m and 770.8 m.	41.5	772.4
Tuff, ash-flow, light-brownish-gray and grayish-orange-pink, nonwelded, devitrified; pumice, medium-light-gray, yellowish-gray, light-brownish-gray to brownish-gray, devitrified, commonly range in size from 7-17 mm; 8 to 10 percent phenocrysts (quartz, sanidine, plagioclase, black biotite); rare (1 percent) lithic fragments, grayish-orange, brownish-gray, dominantly silicic to intermediate, minor mudstone-lithic fragments, commonly range in size from 5 to 18 mm (lower contact gradational).	7.6	780.0
Tuff, ash-flow, moderate-yellowish-brown, pale-yellowish-brown, pale- to moderate-brown, partially to densely welded, devitrified; pumice, light-brown, pale-yellowish-brown, pale-yellowish-orange, and grayish-orange, devitrified and zeolitic, commonly range in size from 2-30 mm, as large as 49 mm, eutaxitic structure, moderately developed; 9-15 percent phenocrysts (quartz, sanidine, plagioclase, black biotite, hornblende, pseudomorphs); 1-3 percent lithic fragments, dark-gray, grayish-brown, moderate-brown, dark-reddish-brown, dominantly		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Bullfrog Member--Continued		
rhyolitic, subordinate mudstone, commonly range in size from 2-18 mm, as large as 40 mm; shear fractures present from 781.2-783.8 m and 809.0-809.6 m; 2 low-angle, manganese-oxide coated fractures, with 3- to 11-mm separation marking base of interval.	37.0	817.0
Tuff, ash-flow, dark-yellowish-orange, light-brown, partially welded, slightly indurated, mostly argillic; pumice, dark-yellowish-brown, light-brown, altered to swelling clay, commonly 2-55 mm; 5-7 percent sparse (1-2 percent) lithic fragments, light-brownish-gray, dark-gray, light-brown, dominantly silicic, some mudstone, commonly range in size from 2-10 mm, as large as 17 mm (lower contact gradational).	4.6	821.6
Tuff, ash-flow, moderate-reddish-orange, light-brown, and pale-reddish-brown, partially welded, devitrified (well indurated); pumice, pale-reddish-brown, moderate-reddish-orange, light-brown, moderate-brown, moderate-yellowish-green, grayish-orange, devitrified, commonly range in size from 4-35 mm, as large as 60 mm; 8-10 percent phenocrysts (quartz, sanidine, plagioclase, biotite); rare (1 percent) lithic fragments, moderate-brown, grayish-red, dominantly rhyolitic, sparse mudstone, commonly range in size from 3-14 mm (lower contact gradational).	9.5	831.1
Tuff, ash-flow, light-brown, grayish-orange-pink, nonwelded, devitrified (slightly zeolitic); pumice, very-pale-orange, grayish-orange, grayish-yellow, light-brown, devitrified [slightly zeolitic(?)], commonly range in size from 2-40 mm; 7-8 percent phenocrysts (quartz, sanidine, plagioclase, black biotite); rare (1 percent) lithic fragments, grayish-red,		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Bullfrog Member--Continued		
blackish-red, pale-brown, dominantly rhyolitic, commonly range in size from 3-8 mm.	2.0	833.1
Bedded tuff, ash-fall, reworked, moderate-pink, moderate-reddish-brown, dusky-yellow, pale-yellowish-brown, light-brown, moderate-brown, moderately indurated, in places slightly argillic and slightly zeolitic, moderately sorted, most beds dominantly composed of pumice fragments, subangular to subrounded, commonly less than 6 mm in size; individual beds less than 0.6 m thick, most contacts gradational; thin clay parting occurs at 839.7 m, and at base of interval.	6.8	839.9
Tram Member		
Tuff, ash-flow, pale-reddish-brown, grades downward into pale-brown, lower 120 mm, pale-reddish-brown, nonwelded, devitrified; pumice, very-pale-orange, grayish-orange, pale-yellowish-orange, devitrified [slightly zeolitic(?) and argillic], noticeably narrow size range, ranges in size from 2-8 mm, as large as 45 mm; 10-12 percent phenocrysts (quartz, sanidine, plagioclase, black biotite); rare (1-2 percent) lithic fragments, grayish-red, light-gray, moderate-brown, and dusky-brown, dominantly rhyolitic, commonly 2-17 mm in size, as large as 45 mm.	1.6	841.5
Tuff, ash-flow, light-brown, non-to-partially welded, devitrified; pumice very-pale-orange, grayish-orange and light-brown, devitrified, commonly ranges in size from 1-8 mm, rarely as large as 13 mm; 7-9 percent phenocrysts of quartz, sanidine, plagioclase, black biotite; very rare (less than 1 percent) lithic fragments, grayish-red, moderate-brown, grayish-brown, and medium-light-gray, dominantly silicic, commonly range in size from		

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

Stratigraphy and lithologic description	Thickness of interval (meters)	Depth to bottom of interval (meters)[1]
Crater Flat Tuff--Continued		
Tram Member--Continued		
2-18 mm, rarely as large as 55 mm; ash-fall tuff, 30 mm thick at 841.9 m.	15.0	856.5
Tuff, ash-flow, grayish-orange-pink, light-brownish-gray, lower 460 mm, pale-red, non-to-partially welded, devitrified; pumice, very-pale-orange, moderate-yellowish-brown, grayish-orange, light-gray, very-light-gray, devitrified, commonly 2-25 mm, as large as 60 mm; 10-12 percent phenocrysts of quartz, sanidine, plagioclase, black biotite; sparse (1-3 percent) lithic fragments, light-brown, dark-gray, moderate-brown, silicic to intermediate, commonly 2-20 mm in size.	9.5	866.0
Tuff, ash-flow, light-brownish-gray, light-olive-gray, and grayish-orange-pink, upper 1.5 m; mottled pale-red, moderate-red, and light-brownish-gray, devitrified; pumice, grayish-orange, very-pale-orange, light-brownish-gray, very-light-gray, light-gray, yellowish-gray, dominantly vapor-phase crystallization, commonly range in size from 2-17 mm, as large as 40 mm; 12-14 percent phenocrysts (quartz, sanidine, plagioclase, black biotite); sparse (1-3 percent) lithic fragments, light-brownish-gray, brownish-gray, brownish-black, medium-dark-gray, moderate-red, light-brown, grayish-red silicic to intermediate, commonly range in size from 2-25 mm; prominent shear fractures occur at 885.3 m, 887.0 m, 889.9-891.3 m, 893.0-893.6 m, 894.0-894.4 m, 909.9-911.2 m and 914.4 m.	48.7	914.7
	Total depth[1]	914.7

[1]Depth to bottom of individual interval and total depth are accurate only to the nearest meter, but are reported to tenths of a meter to agree with thickness of individual units. Total depth probably is 915 meters ± 0.5 meter.

Geophysical Well Logs

Geophysical logs were run in test well USW G-4 to define lithology, correlate with logs of nearby wells, collect data on porosity and fractures, obtain fluid levels, and gage the diameter of the well. Geophysical logs also were used to help select intervals for hydraulic testing. A summary of geophysical logs made in this well for testing purposes, and the intervals logged are listed in table 2.

Geophysical logs that can be related directly to water-yielding zones include: (1) The self-potential curve on electric logs; (2) the optical television log that shows water seeps above the water table and low-angle fractures in the water-yielding zone; and (3) the temperature log where the thermal gradient changes opposite water-yielding zones.

Table 2.--*Summary of geophysical well logs*

Geophysical log	Depth interval (meters)	Geophysical log	Depth interval (meters)
Acoustic fracture	12-138	Spectralog	0-913
Caliper	0-603	Television, optical	0-137
	556-914		261-412
			411-472
			471-579
Density, borehole compensated	12-138		
	142-541		
	533-912		
		Temperature (static)	0-914
Electric	12-138	(pumping)	152-913
	143-541		
	457-603	3-D velocity	506-603
	600-911		588-912
Gamma Ray	3-138		
	143-541		
Geophone survey	30-136		
	143-546		
	564-907		
Gyroscopic	0-907		
Neutron, compensated	12-138		
	51-541		
	457-604		
	600-912		

Hydrologic Properties of Core Samples

More than 350 vertical core samples were taken between depths of 12 and 915 m (total depth) from test well USW G-4. Core samples from selected intervals have been sent to the U.S. Geological Survey laboratory, and Holmes and Narver Materials Testing Laboratory for determining porosity, density, pore saturation, and other physical properties. Results of these laboratory analyses are not yet available.

Water Levels

Water-level observations and measurements in test well USW G-4 were made during and after the drilling as part of hydraulic tests, for the purpose of: (1) Locating any perched-water zones above the water table; (2) identifying the depth at which ground-water saturation occurs; (3) determining the composite hydraulic head in the well; and (4) identifying hydraulic heads in various water-bearing zones. Water-level measurements are listed in table 3.

HYDROLOGIC TESTING AND WATER SAMPLING

Pumping Tests

Drawdown and recovery tests were made in conjunction with two pumping periods after test well USW G-4 had been drilled to its total depth, cased to 615 m, and perforated below 549 m. Pumping-test information is given in table 4. Data plots of these tests are shown in figures 4 through 7. Drawdown-test data were plotted using drawdown versus time after start of pumping as the coordinates. Recovery-test data were plotted with recovery against time after pumping stopped as the coordinates.

Table 3.--*Water levels*

[Altitude of land surface at well is 1,269.6 meters; water level in well accurate to ± 0.5 meter]

Date	Depth zone (meters)	Water level in well (meters)		Remarks
		Depth to water below land surface	Altitude water surface above sea level	
11-22-82	12-915	538.0	732.0	Hole reamed to 646 meters; hole below 646 meters filled with drill cuttings.
12-03-82	549-915	541.3	728.7	
12-05-82	549-915	541.1	728.9	
12-07-82	549-915	544.0	726.0	Pumping level; discharge = 15.5 liters per second.
12-09-82	549-915	543.9	726.1	
01-03-83	549-915	540.8	729.2	
01-03-83	549-915	541.4	728.6	
01-04-83	549-915	541.4	728.6	
01-05-83	549-915	541.2	728.8	
01-06-83	549-915	541.5	728.5	
01-07-83	615-915	541.4	728.8	
01-07-83	615-655	541.5	728.5	
01-07-83	655-701	541.4	728.8	
01-08-83	655-701	540.7	729.3	
01-08-83	702-747	541.6	728.4	
01-08-83	702-747	541.1	728.9	
01-08-83	747-792	541.6	728.4	
01-09-83	792-838	541.6	728.4	
01-09-83	826-850	541.6	728.4	
01-10-83	850-875	541.8	728.2	
01-10-83	875-899	541.8	728.2	
01-10-83	899-915	541.7	728.3	
01-11-83	722-747	542.0	728.0	
01-11-83	719-826	541.8	728.2	
01-11-83	719-826	541.6	728.4	
01-11-83	875-899	541.8	728.2	

NOTE: A correction of 1.53 meters should be subtracted from depths and added to altitudes above to correct for hole deviation from vertical.

Table 4.--*Summary of pumping tests for the interval from 549 to 915 meters in the Crater Flat Tuff of Tertiary age*

Type of test	Pumping rate (liters per second)	Pumping recovery period (minutes)
Drawdown	16	5,740
Recovery	±[1]16	120
Drawdown	13	1,660
Recovery	±[1]13	120

[1] ± Pumping rate prior to recovery.

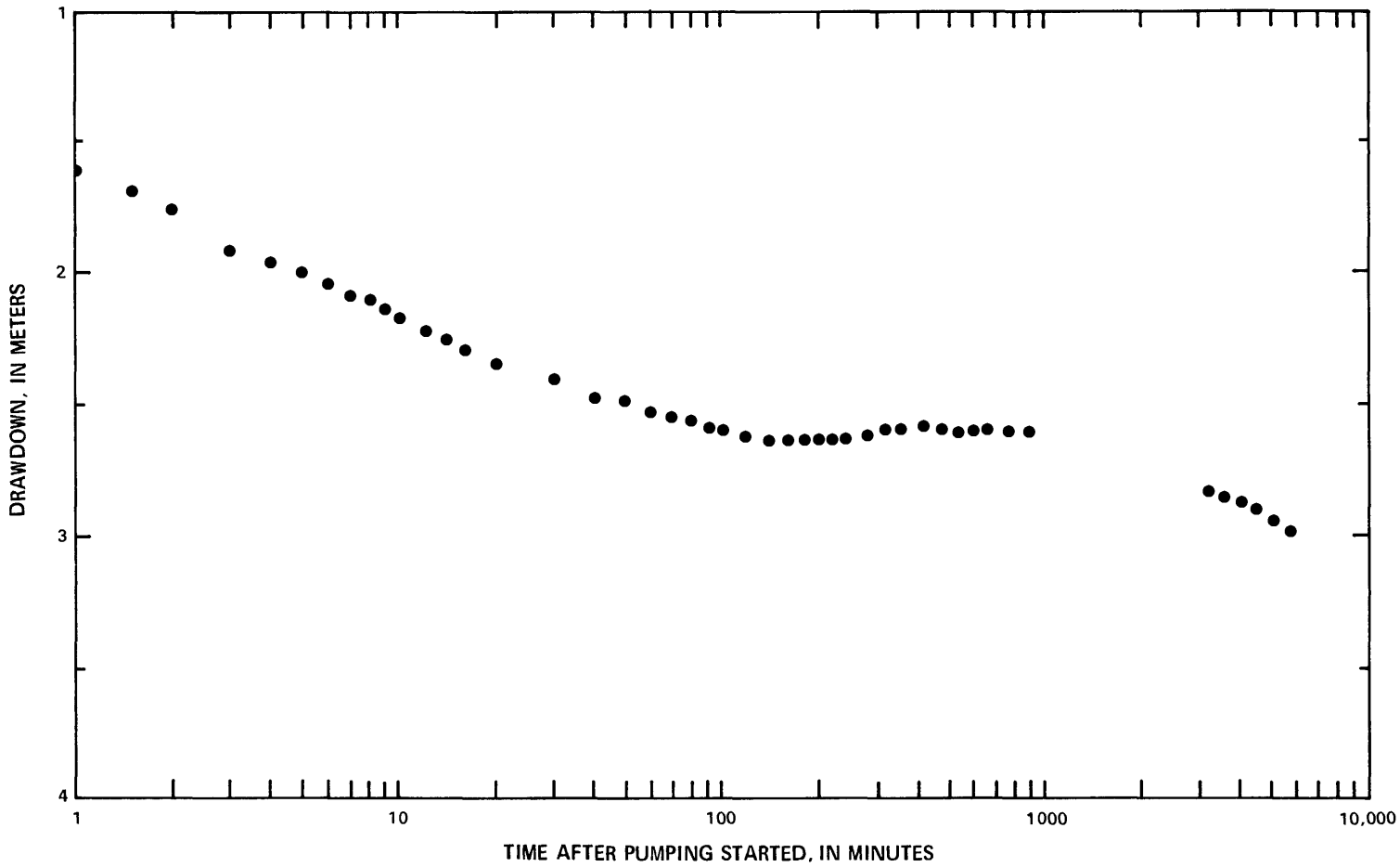

Figure 4.--Water-level drawndown, pumping test 1, depth interval from 549 to 915 meters.

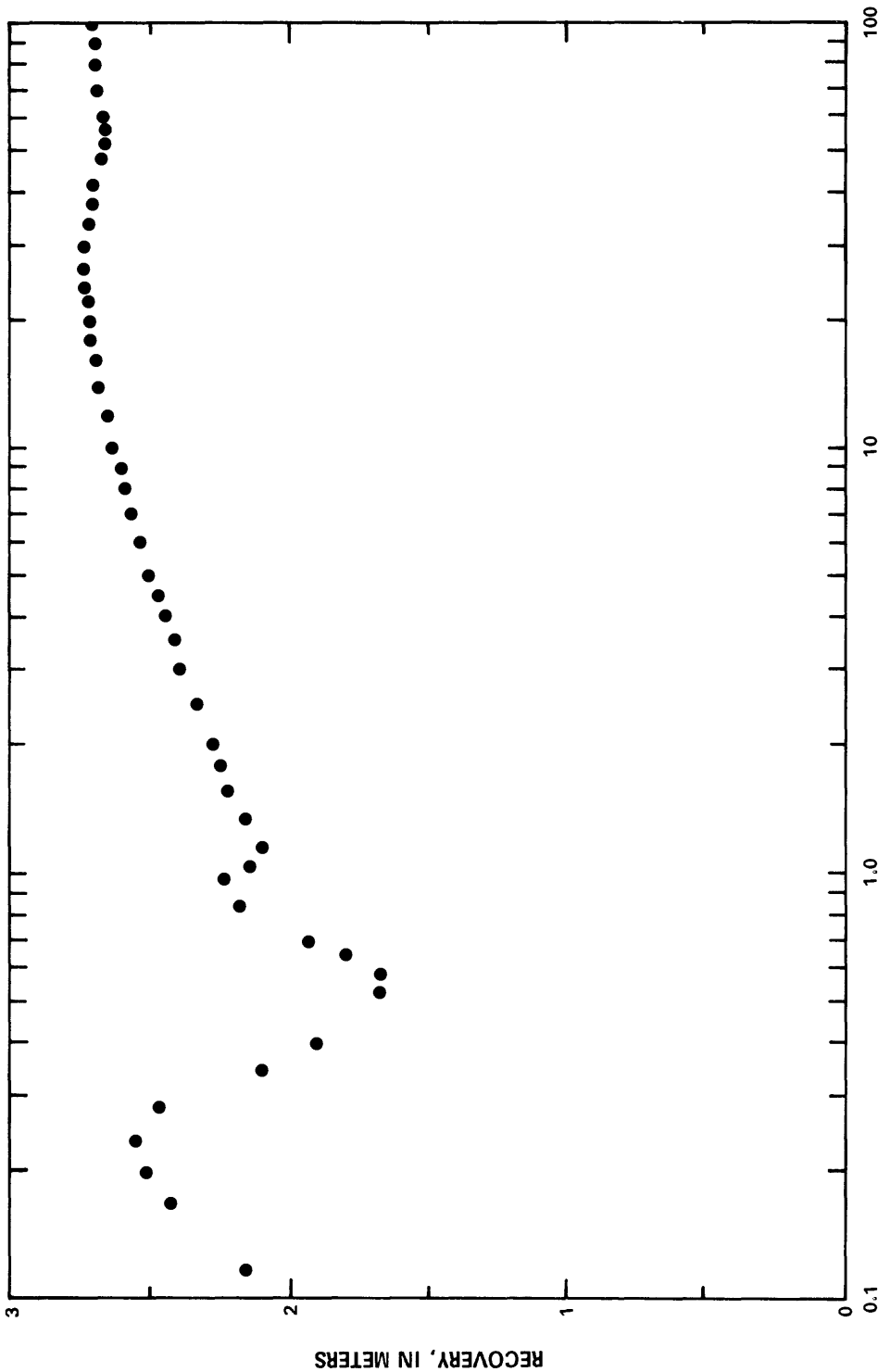

Figure 5.--Water-level recovery, pumping test 1, depth interval from 549 to 915 meters.

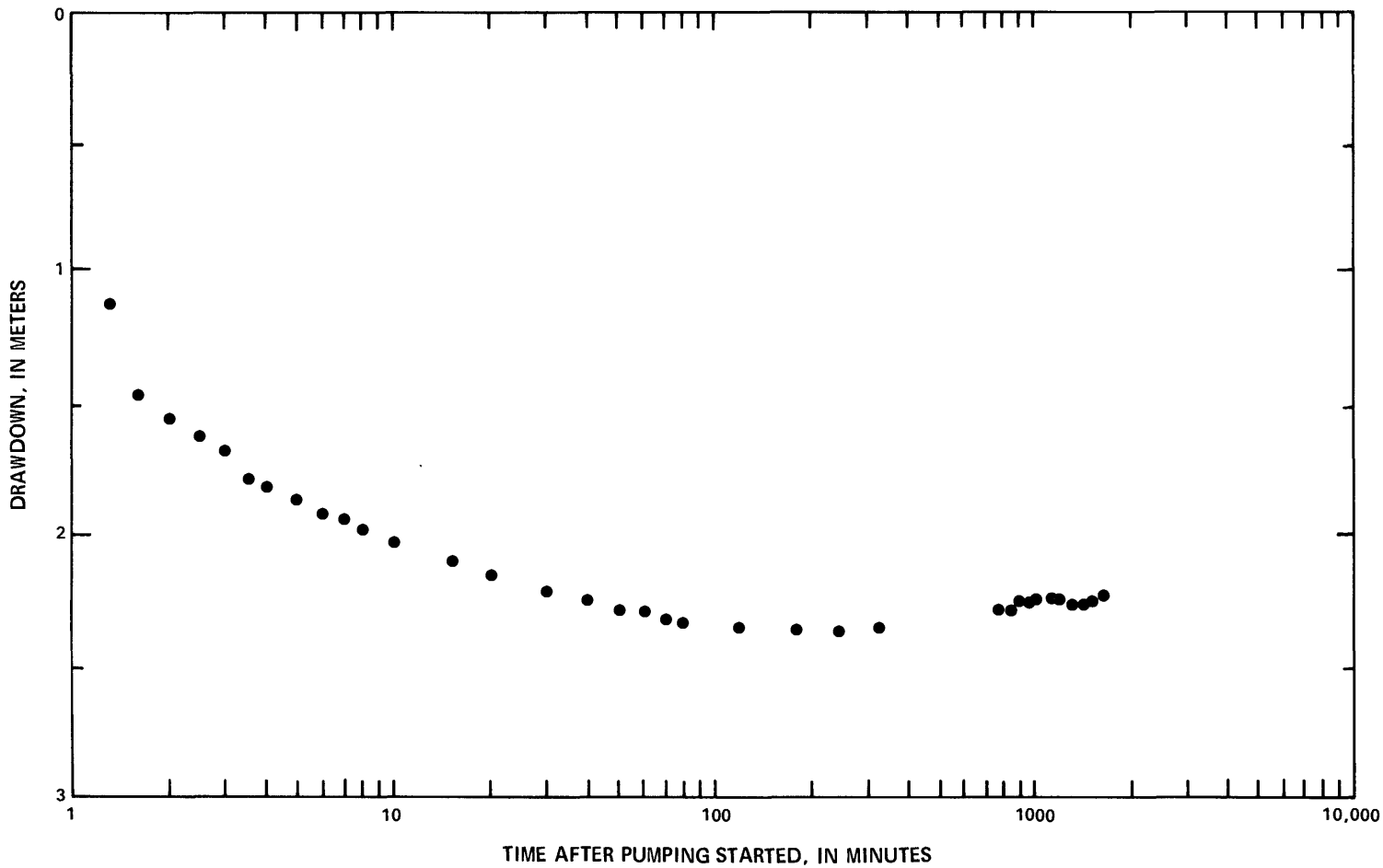

Figure 6.--Water-level drawdown, pumping test 2, depth interval from 549 to 915 meters.

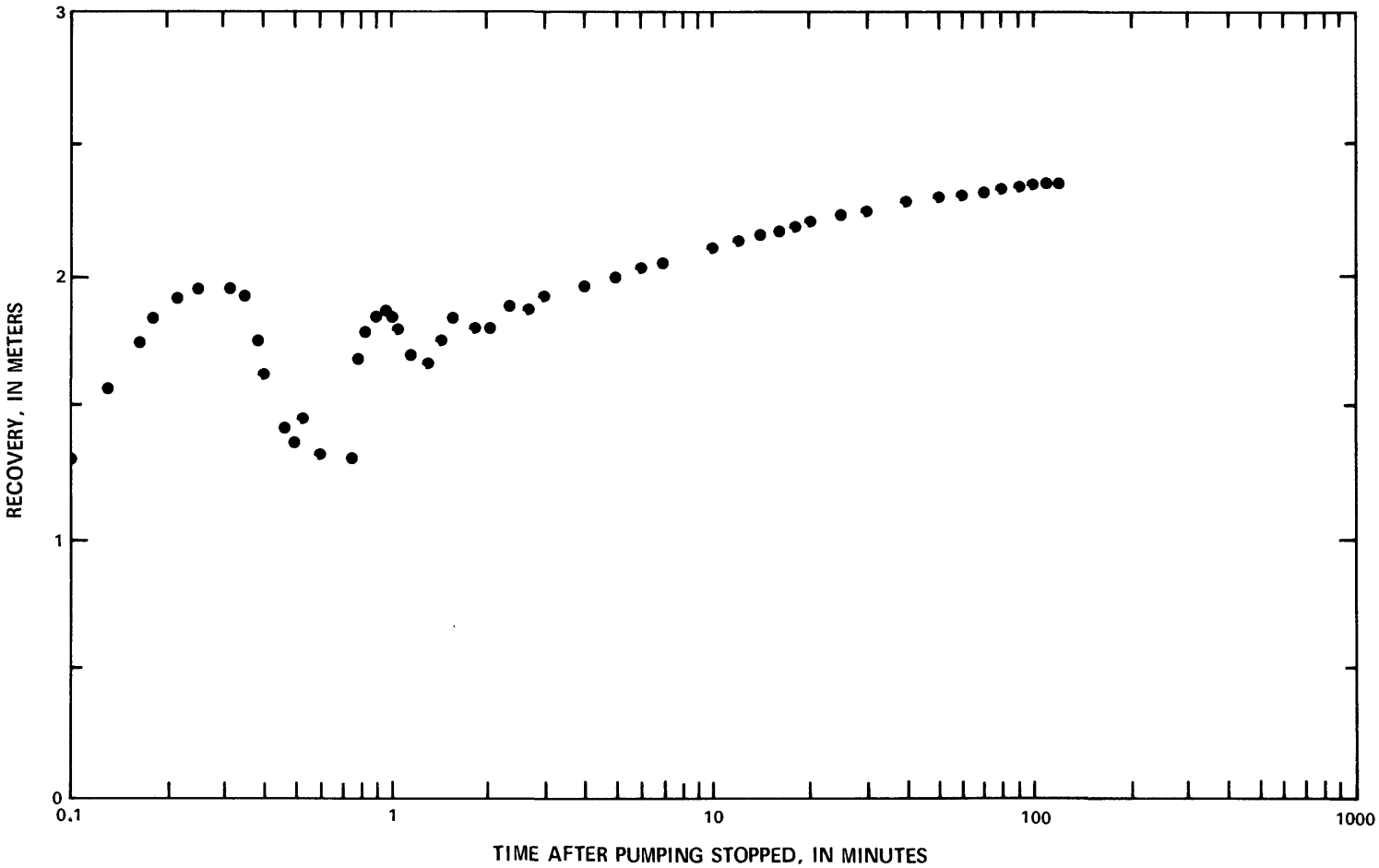

Figure 7.--Water-level recovery, pumping test 2, depth interval from 549 to 915 meters.

Borehole-Flow Survey

A borehole-flow survey with radioactive iodine-131 as a tracer was used to measure vertical flow of water in the well bore, while water was being pumped from the well. The tracer was released into the well at selected depths and tracked past two gamma detectors to determine velocity of the water. Velocity, multiplied by the cross-sectional area of the hole determined from caliper logs, defined the rate of flow in the well at a given depth. The borehole-flow survey in test well USW G-4 was made during the drawdown phase of pumping test 2. Results of the survey are shown in figure 8.

Packer-Injection Tests

Packer-injection tests were made, using inflatable packers to isolate test zones for intervals where hole-size and configuration allowed setting the packers. Intervals tested are listed in table 5. Water was injected into the interval between two packers, or between one packer and the bottom of the hole. The decline of hydraulic head with time was monitored in the isolated interval. Thirteen tests were made in test well USW G-4 for the intervals between 615 and 915 m (total depth). Injection curves are plotted in figures 9 through 21. The ratio of hydraulic head at time after injection started (H_t) to hydraulic head (H_o) at time of injection is plotted against time after injection started.

Chemical Analysis of Water

A composite water sample was collected for chemical analysis from test well USW G-4 near the end of the first pumping test; results of the analysis are shown in table 6.

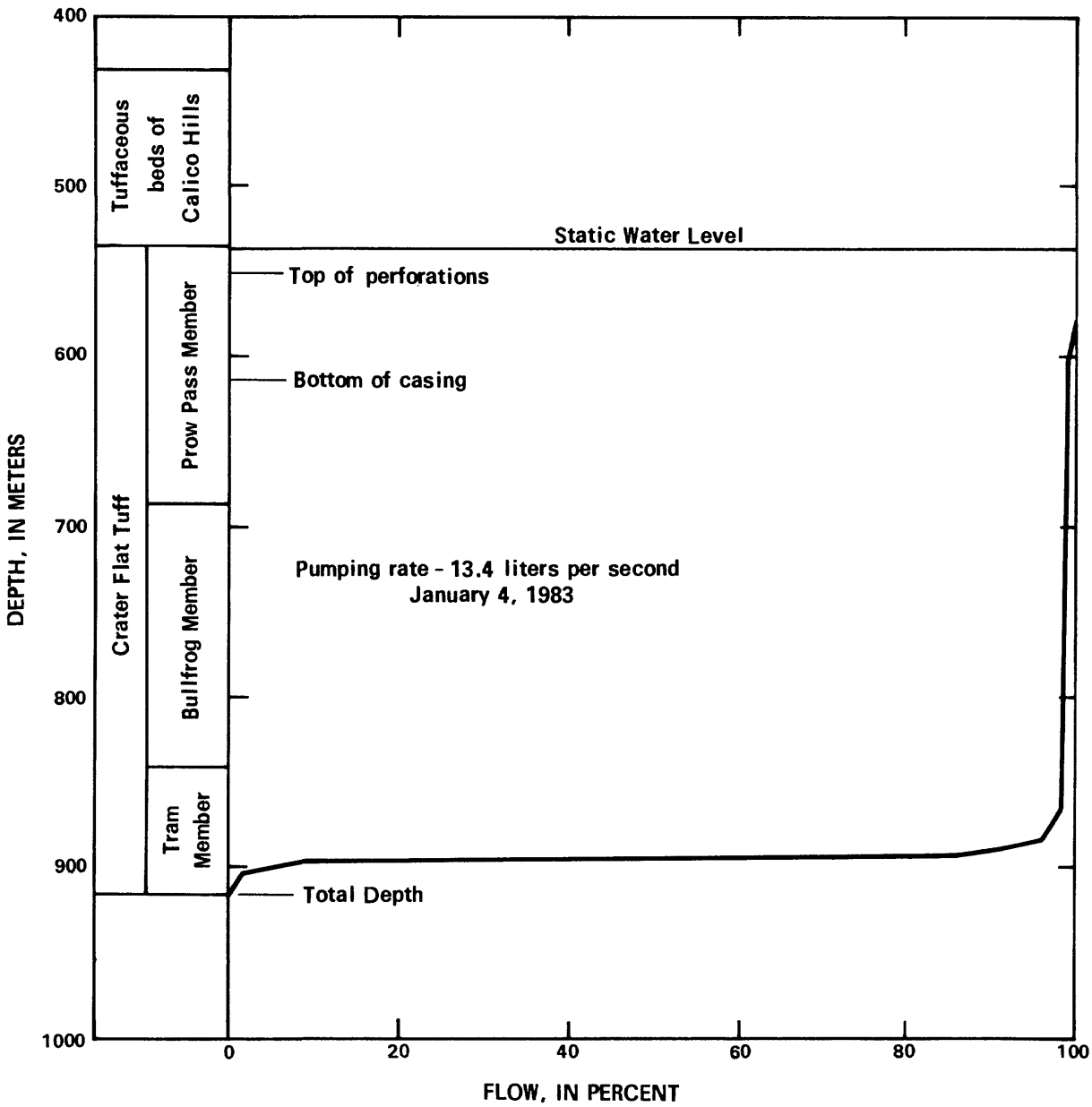

Figure 8.--Borehole-flow survey showing percent of total pumping rate produced by intervals.

Table 5.--*Summary of packer-injection tests*

Test interval (meters)	Stratigraphic unit(s) tested (Crater Flat Tuff)	Length of injection period (minutes)
615-655	Prow Pass Member	60
655-701	Prow Pass Member	140
	Bullfrog Member	
698-722	Bullfrog Member	180
702-747	do.	120
722-747	do.	71
747-792	do.	60
792-838	do.	60
802-826	do.	45
802-826	do.	60
826-850	Bullfrog Member	60
	Tram Member	
850-875	Tram Member	30
875-899	do.	15
902-915	do.	15

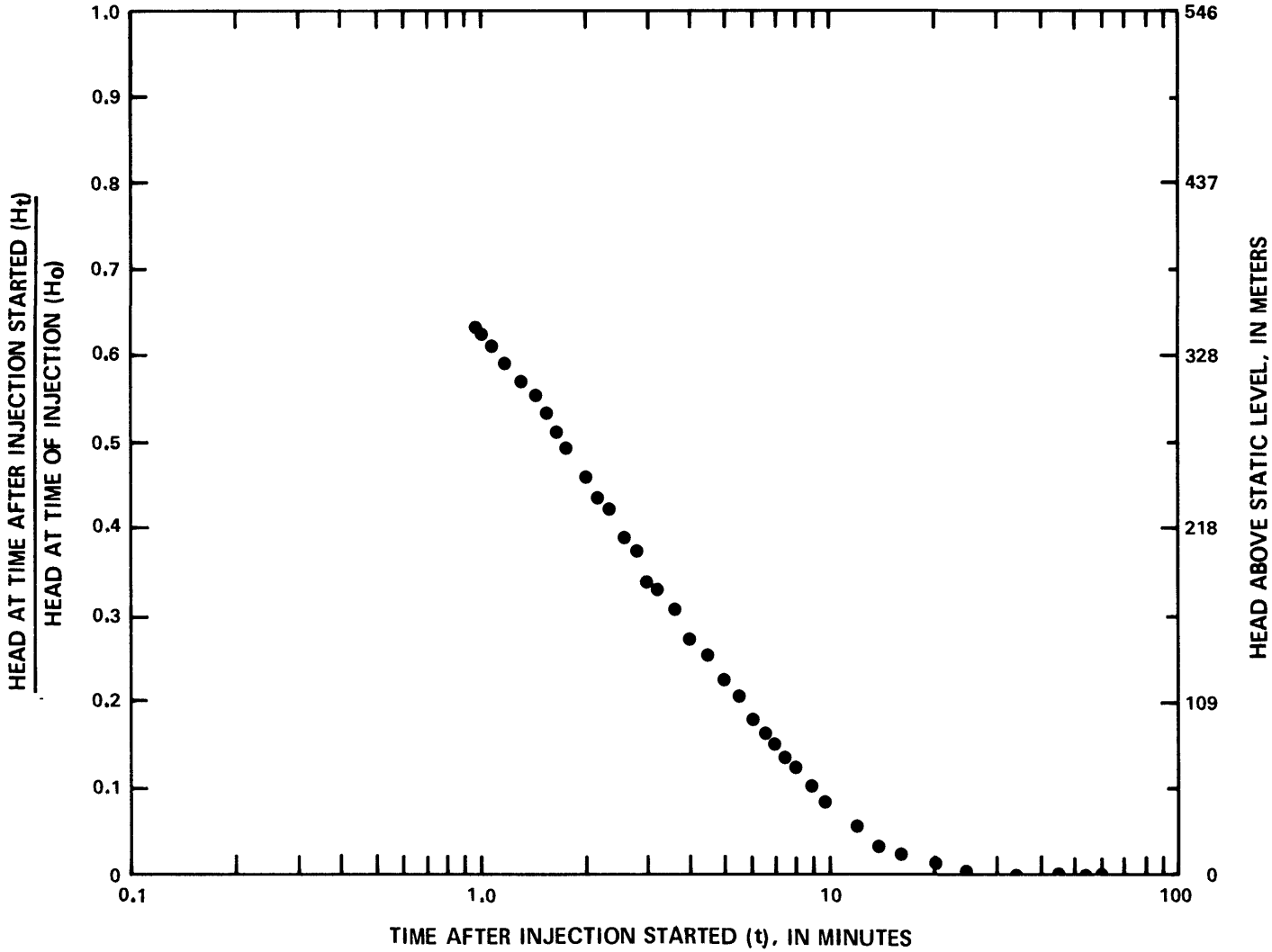

Figure 9.--Packer-injection test for depth interval from 615 to 655 meters.

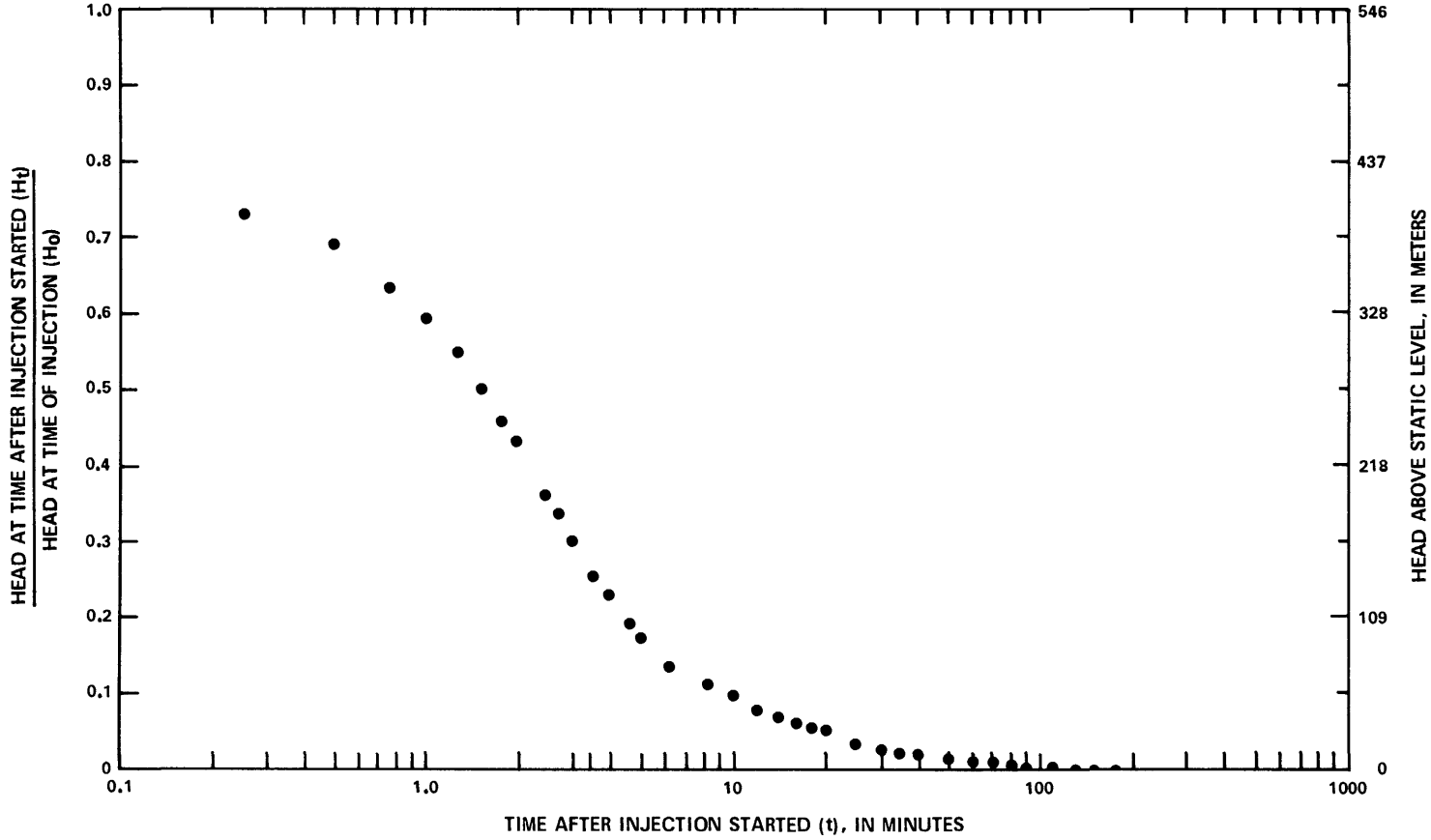

Figure 10.--Packer-injection test for depth interval from 655 to 701 meters.

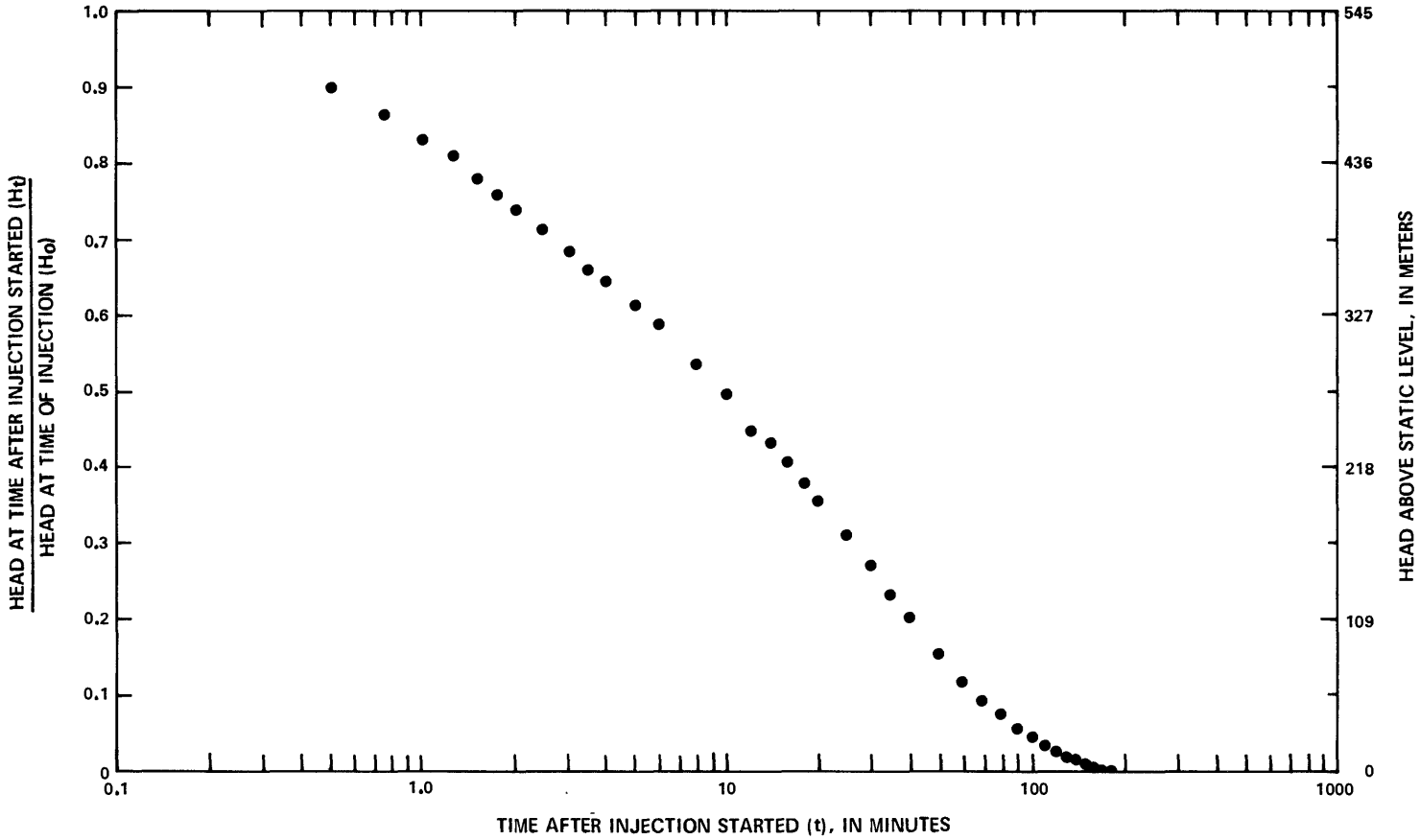

Figure 11.--Packer-injection test for depth interval from 698 to 722 meters.

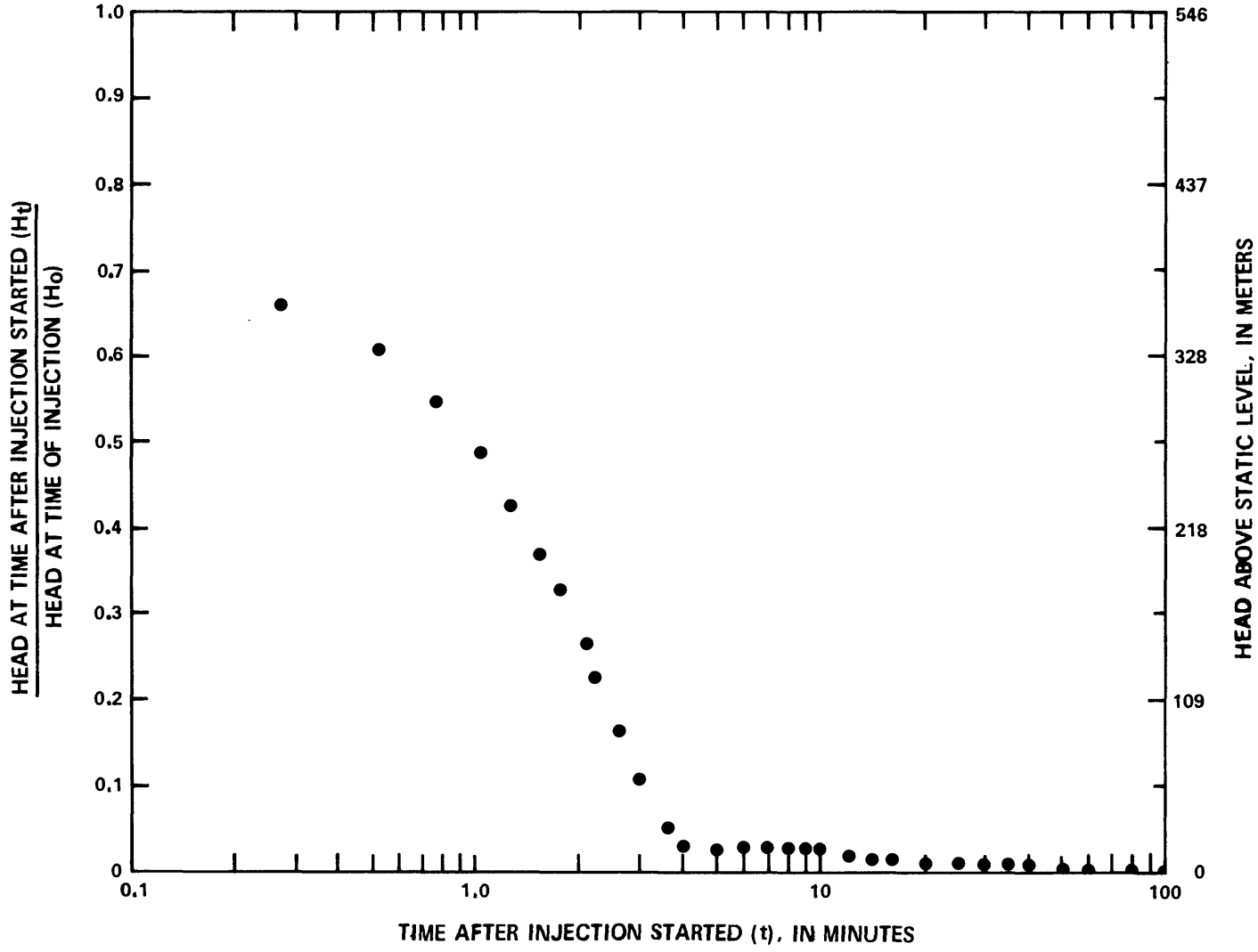

Figure 12.--Packer-injection test for depth interval from 702 to 747 meters.

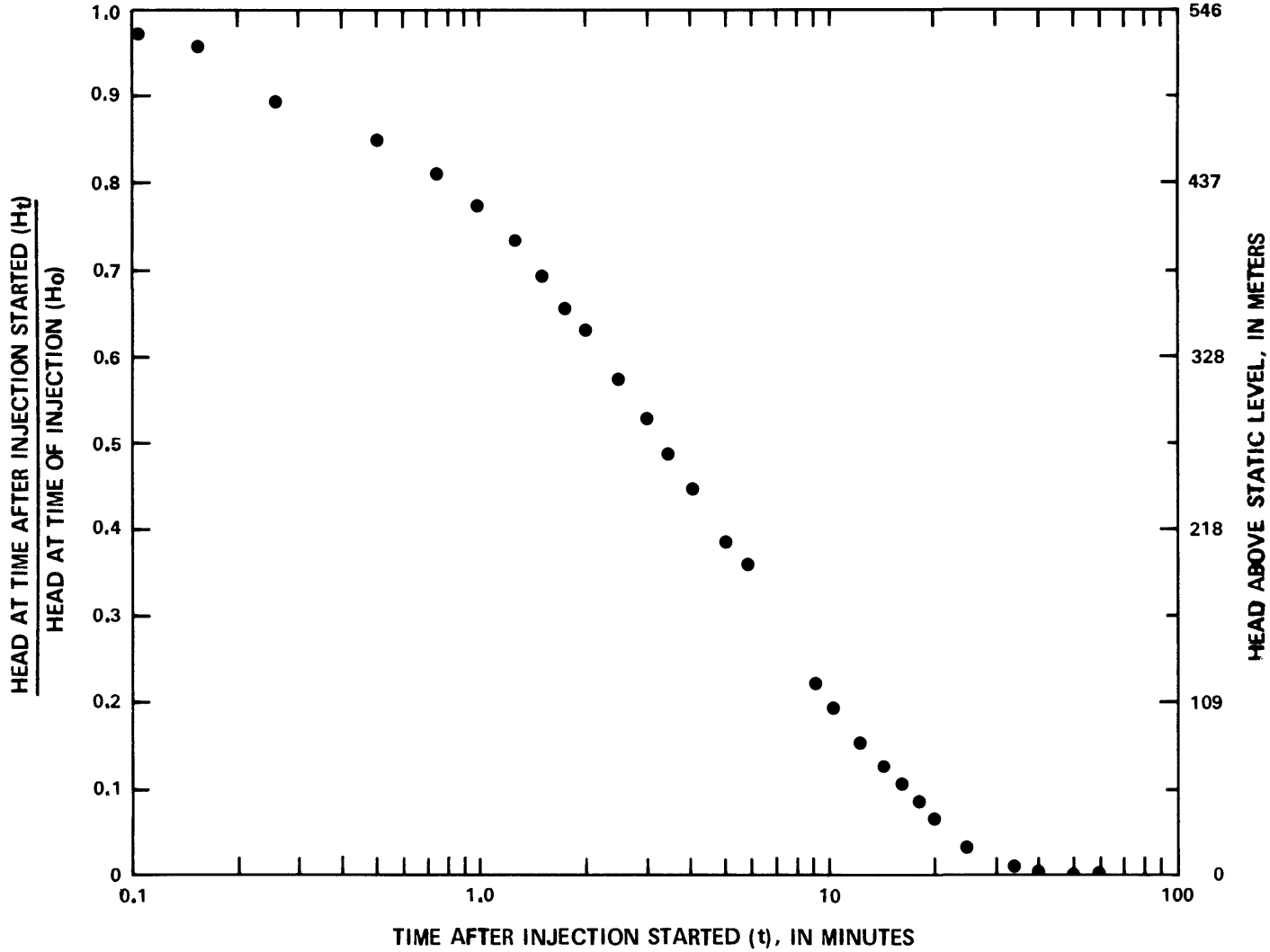

Figure 13.--Packer-injection test for depth interval from 722 to 747 meters.

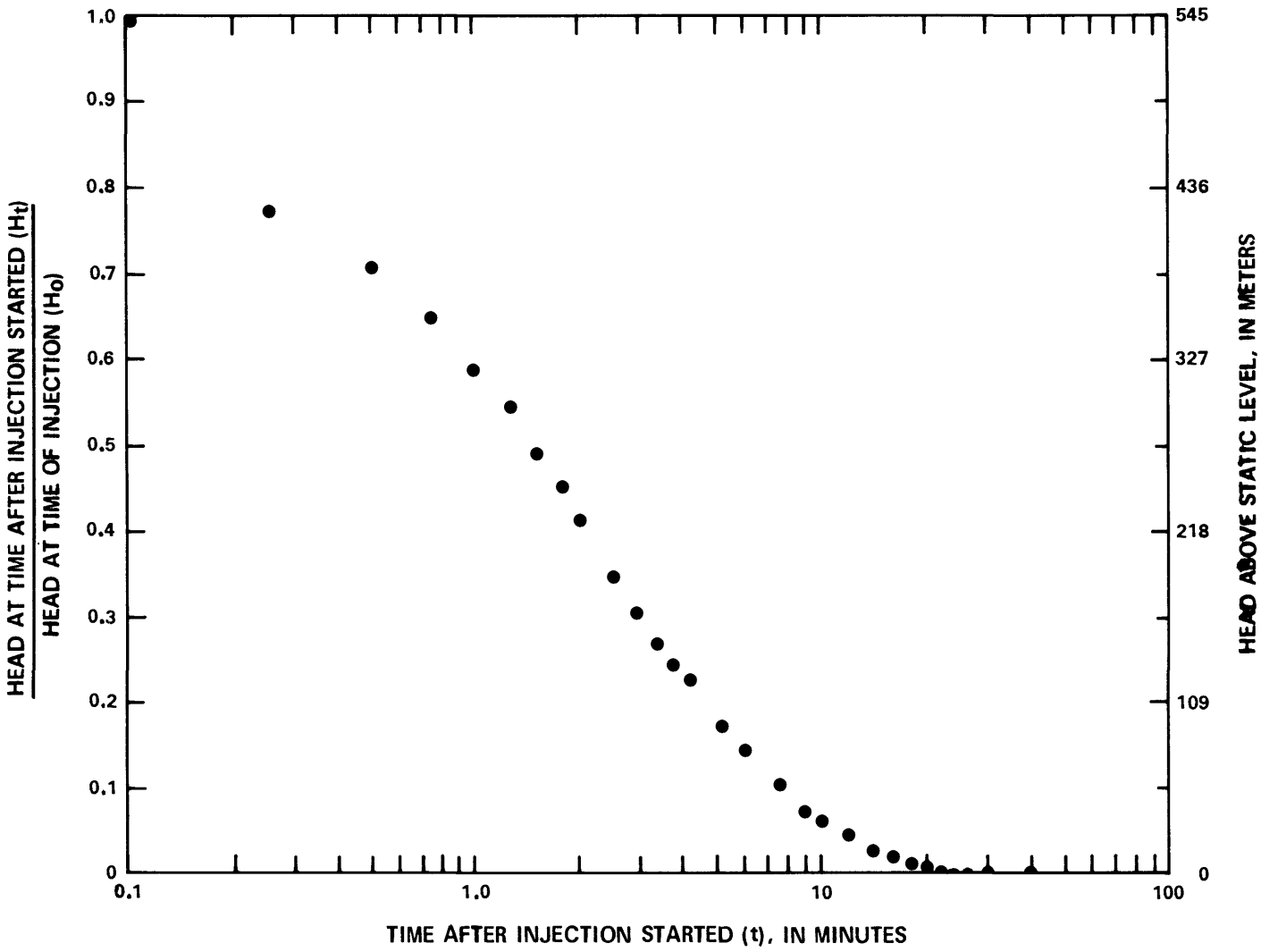

Figure 14.--Packer-injection test for depth interval from 747 to 792 meters.

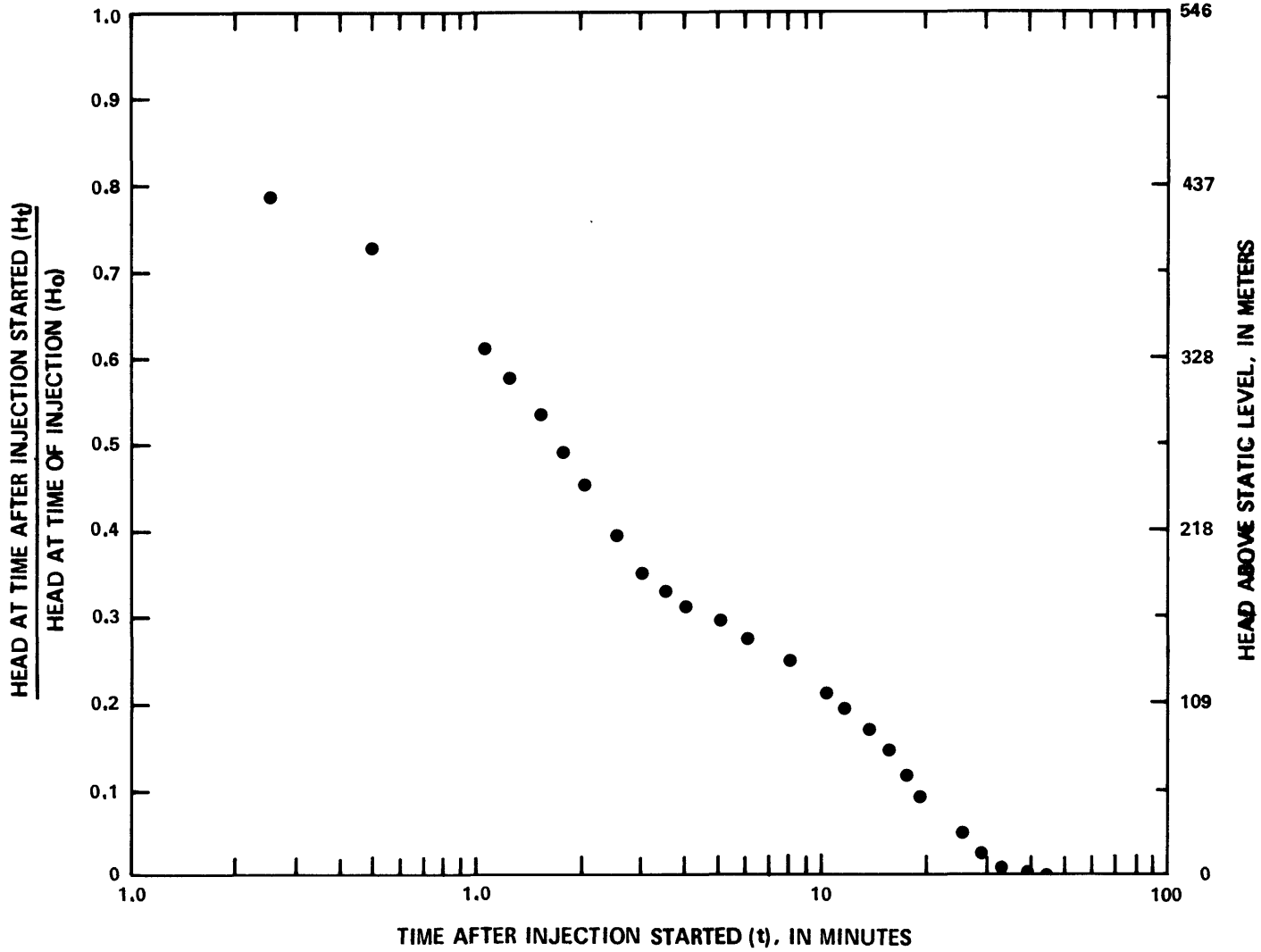

Figure 15.--Packer-injection test for depth interval from 792 to 838 meters.

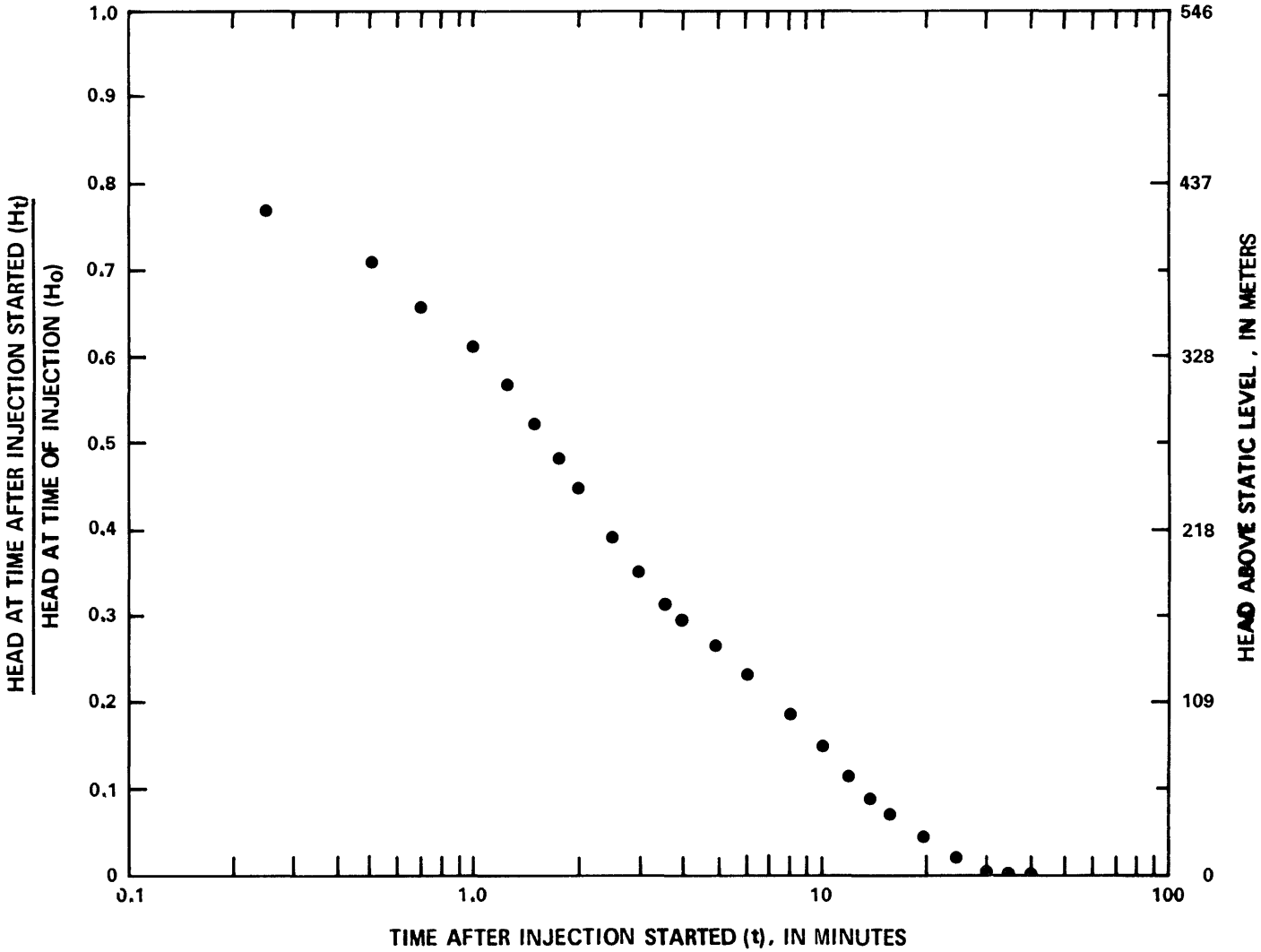

Figure 16.--Packer-injection test for depth interval from 802 to 826 meters (first test).

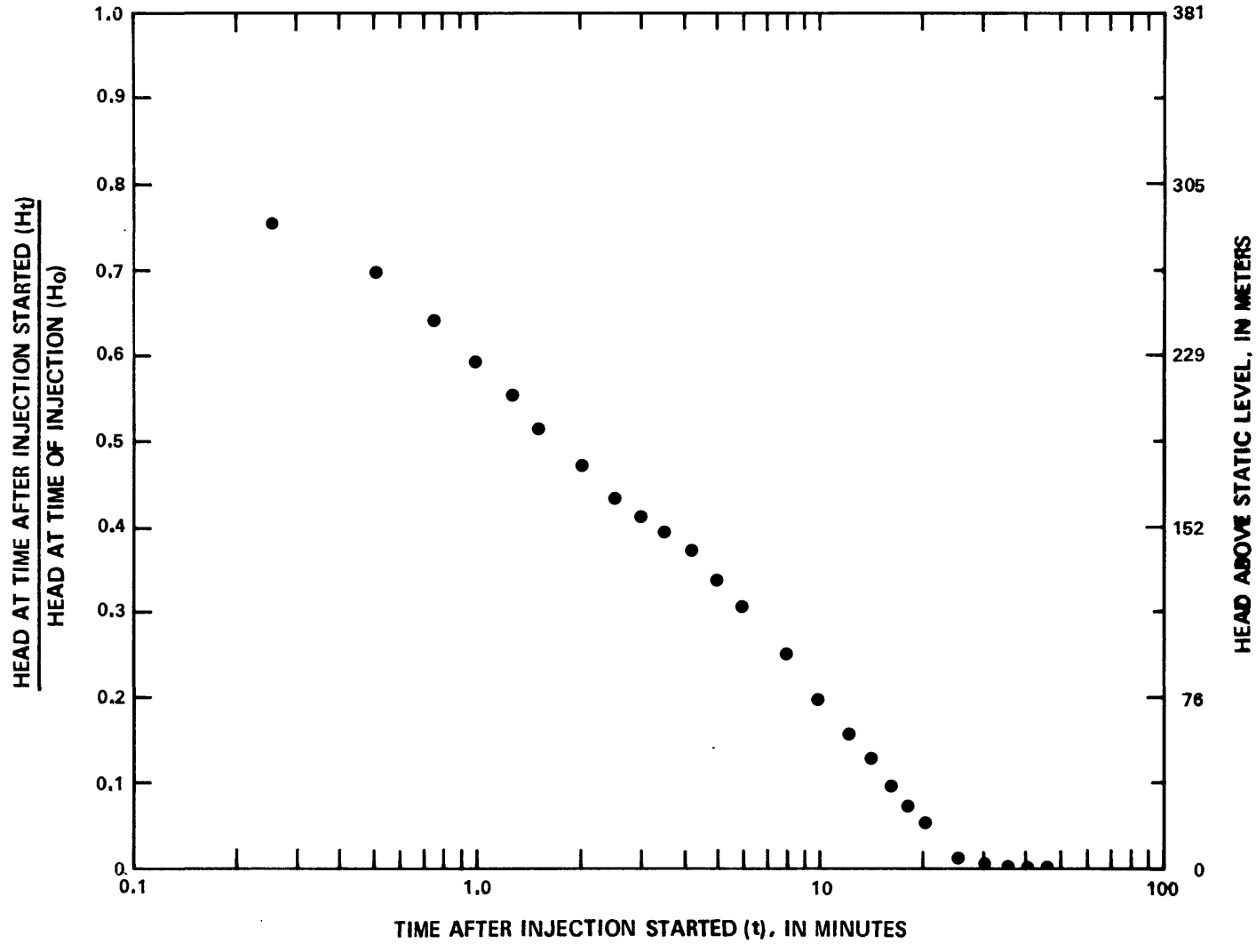

Figure 17.--Packer-injection test for depth interval from 802 to 826 meters (second test).

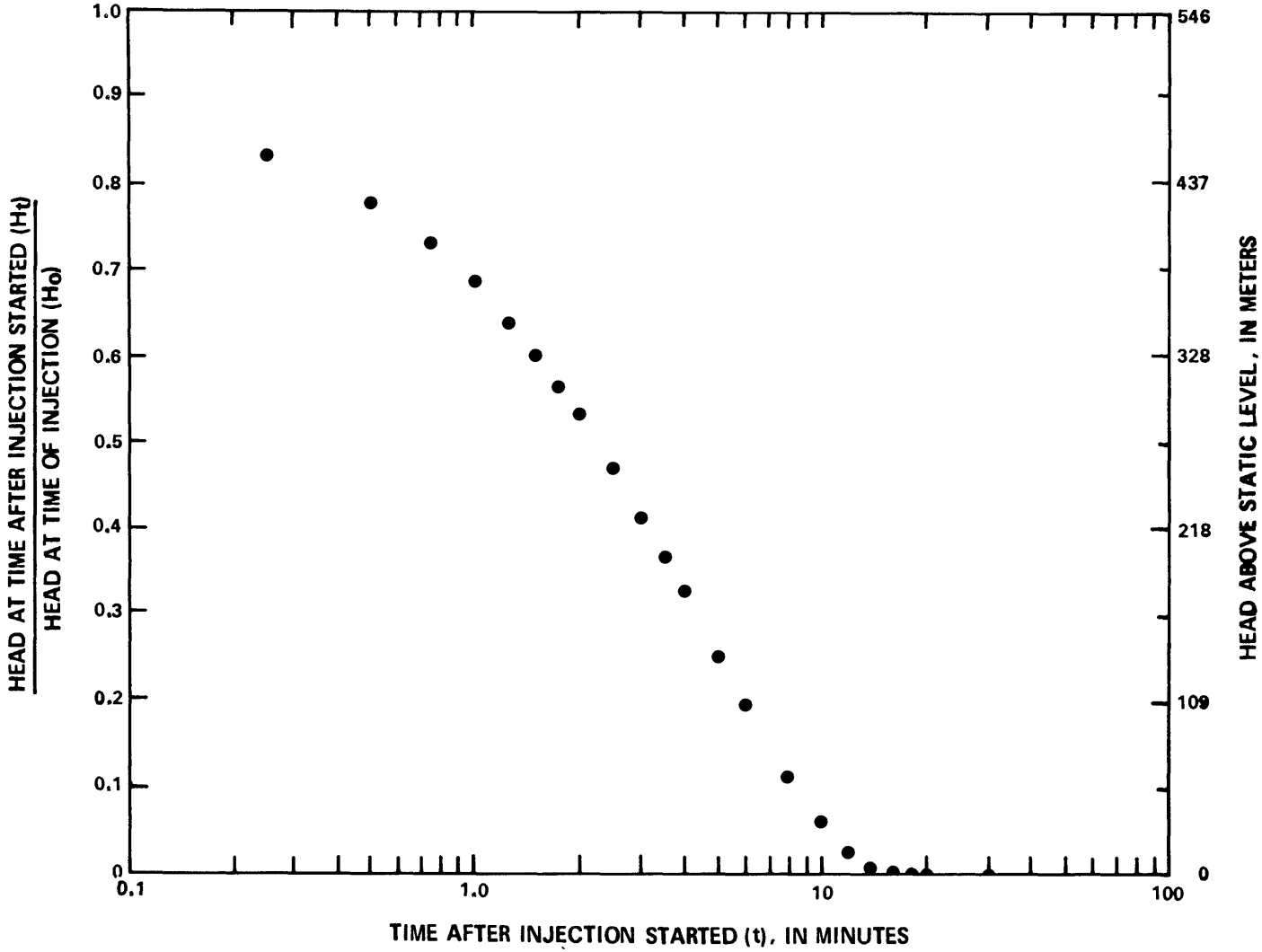

Figure 18.--Packer-injection test for depth interval from 826 to 850 meters.

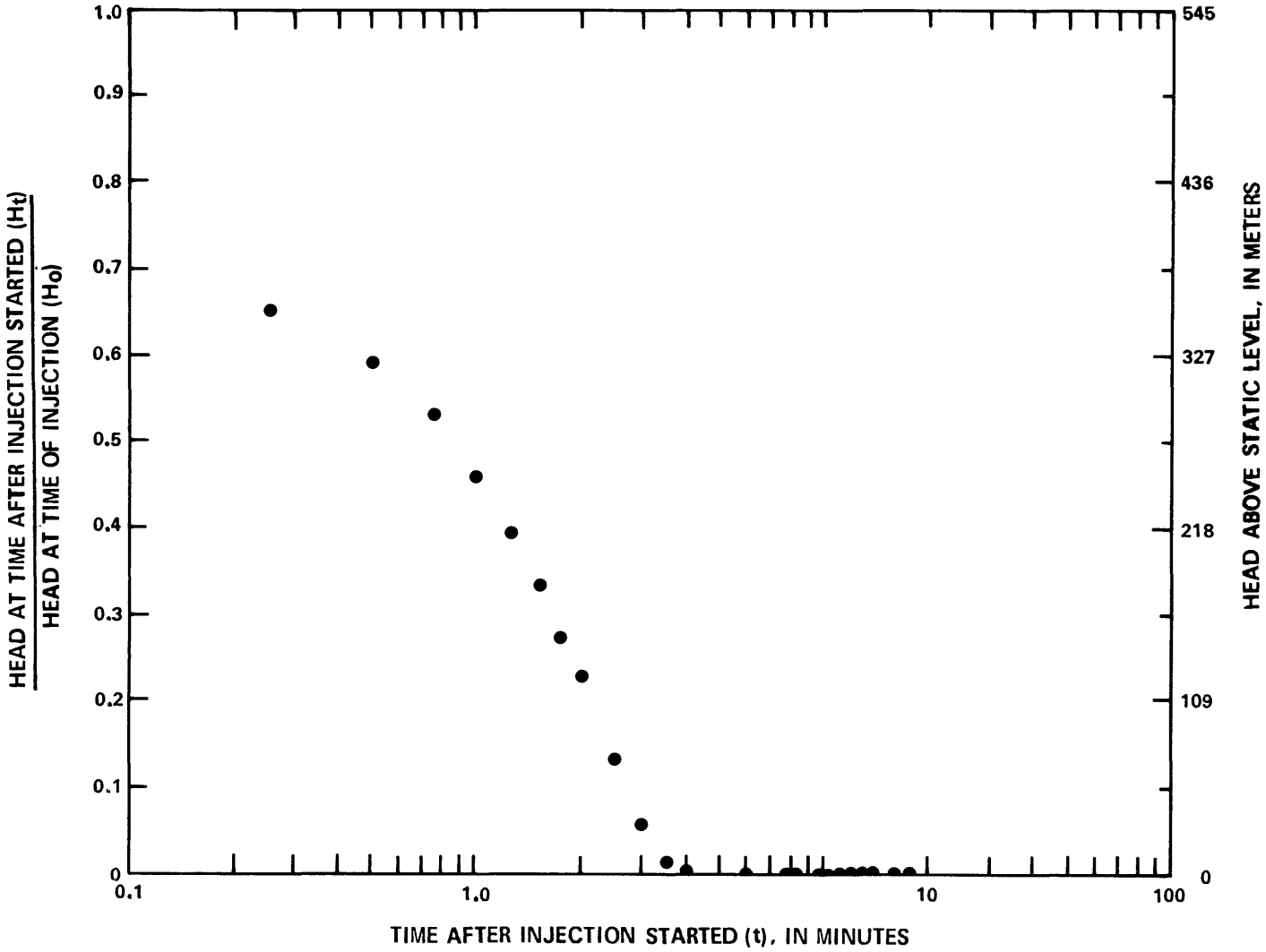

Figure 19.--Packer-injection test for depth interval from 850 to 875 meters.

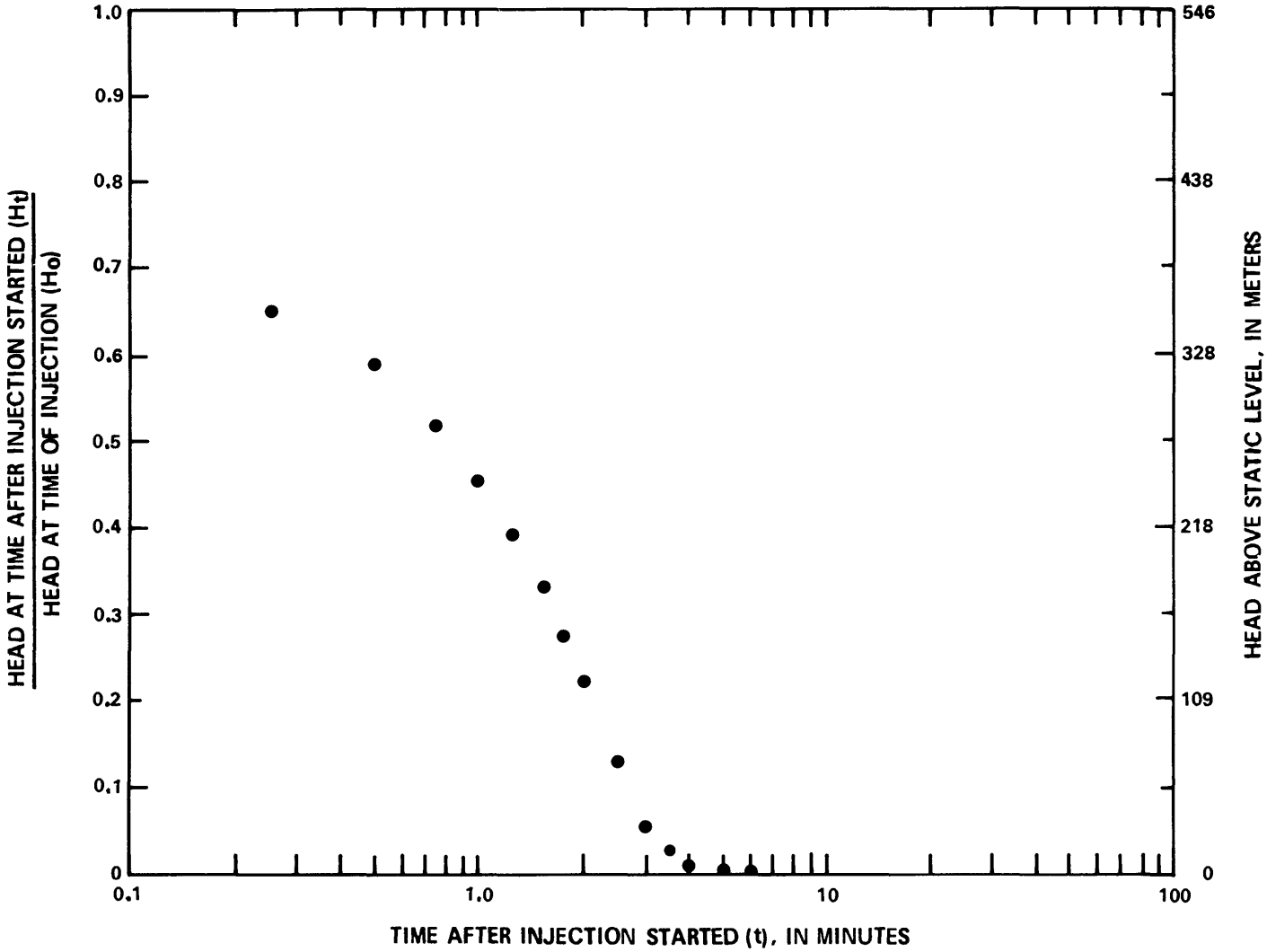

Figure 20.--Packer-injection test for depth interval from 875 to 899 meters.

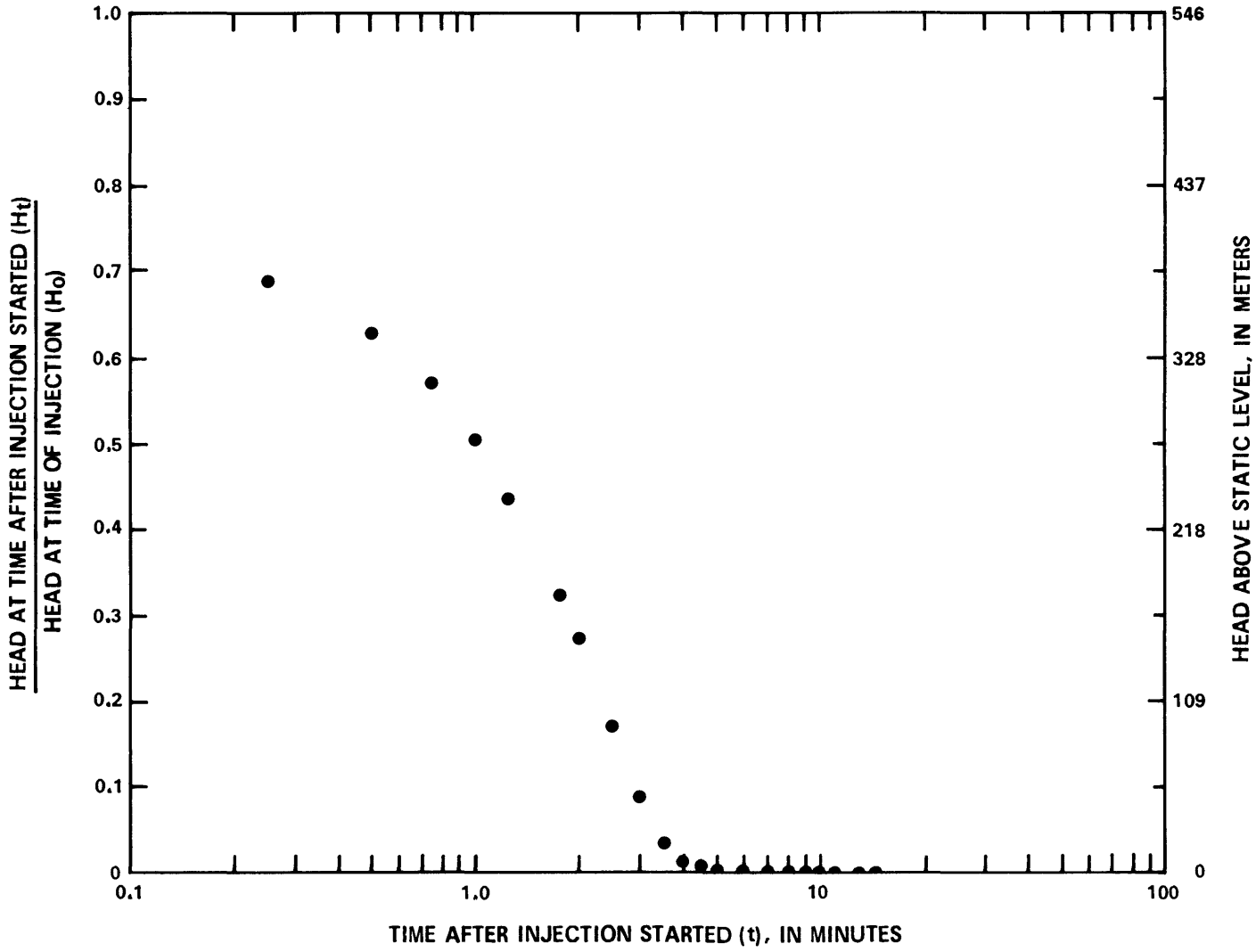

Figure 21.--Packer-injection test for depth interval from 899 to 915 meters.

Table 6.--*Results of chemical analysis of water sample from depth interval between 549 and 915 meters*

[Analysis by U.S. Geological Survey, Denver, Colorado. All dissolved constituents are in milligrams per liter unless otherwise indicated. Date of collection, 12-09-82]

Constituent or property	Concentration or value
Bicarbonate (HCO_3)	143
Bromide (Br)	0.04
Calcium (Ca)	13
Chloride (Cl)	5.9
Fluoride (F)	2.5
Lithium (Li), in micrograms per liter	67
Magnesium (Mg)	0.20
Potassium (K)	2.1
Silica (SiO_2)	45
Sodium (Na)	57
Strontium (Sr), in micrograms per liter	17
Sulfate (SO_4)	19
Dissolved solids (residue on evaporation)	216
Hardness	33
Temperature, in degrees Celsius	35.6
Specific conductance, onsite, in microsiemens per centimeter at 25° Celsius[1/]	312
Specific conductance, laboratory, in microsiemens per centimeter at 25° Celsius[1/]	307
pH, onsite, in standard units	7.7
pH, laboratory, in standard units	7.5
Sodium absorption ratio	4.3
Tritium, in picocuries per liter	Pending
Oxygen 18-16 ($\delta^{18}O$)[2/]	Pending
Deuterium/hydrogen ($\delta^{2}H$)[3/]	Pending
Carbon-13-12 ($\delta^{13}C$)[4/]	Pending
Carbon-14, percent of modern standard	Pending

[1/] Equivalent to micromhos per centimeter at 25° Celsius.

[2/] Deviation of oxygen-18/oxygen-16 ratio of sample from standard mean ocean water (SMOW) relative to SMOW, in parts per thousand.

[3/] Deviation of deuterium/hydrogen ratio of sample from standard mean ocean water (SMOW) relative to SMOW, in parts per thousand.

[4/] Deviation of carbon-13/carbon-12 ratio of sample from PeeDee Belemnite standard (PDB) relative to PDB, in parts per thousand.

SELECTED REFERENCES

Birdwell Division, 1973, Geophysical well log interpretation: Tulsa, Seismograph Service Corporation, Birdwell Division, 188 p.

Blankennagel, R. K., 1968, Geophysical logging and hydraulic testing, Pahute Mesa, Nevada Test Site: Ground Water, v. 6, no. 4, p. 24-31.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, 174 p.

Lohman, S. W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Papadopulos, S. S., Bredehoeft, J. D., and Cooper, H. H., 1973, The analysis of slug test data: Water Resources Research, v. 9, no. 4, p. 1087-1089.

Schlumberger Limited, 1972, Log interpretation, volume 1--Principles: New York, 113 p.

GPO 842-408