GEOHYDROLOGY OF ROCKS PENETRATED BY TEST WELL UE-25p#1, YUCCA MOUNTAIN AREA, NYE COUNTY, NEVADA

By R. W. Craig and J. H. Robison

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CONTENTS

ILLUSTRATIONS

CONTENTS

TABLES

CONVERSION TABLE

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

Multiply	*By*	*To obtain inch-pound*
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter squared per day (m^2/d)	10.76	foot squared per day (ft^2/d)
meter squared per second (m^2/s)	10.76	foot squared per second (ft^2/s)
liter (L)	0.2642	gallon (gal)
liter per second (L/s)	15.85	gallon per minute (gal/min)
meter per second (m/s)	3.281	foot per second (ft/s)
meter per second squared (m/s^2)	3.281	foot per second squared (ft/s^2)
degree Celsius (°C)	F = 9/5°C + 32	degree Fahrenheit (°F)
milligram per liter (mg/L)	1[1]	part per million
microgram per liter (μg/L)	1[1]	part per billion

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

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ABSTRACT

This report contains the results of hydraulic testing and hydrologic monitoring of test well UE-25p#1, one of several test wells drilled, in cooperation with the U.S. Department of Energy, in the southwestern part of the Nevada Test Site, for investigations related to the isolation of high-level nuclear wastes. This test well is the first in the area to penetrate rocks of Paleozoic age.

Test well UE-25p#1 was drilled to a total depth of 1,805 meters. To a depth of 1,244 meters, the rocks are predominantly ash-flow tuffs of Tertiary age. From 1,244 to 1,805 meters, the rock is dolomite of Paleozoic age. The composite static water level was approximately 381 meters below land surface for the Tertiary section and 361 meters for the Paleozoic section. The hydraulic-head difference indicates a major hydrologic barrier to vertical movement of fluid. The likely confining layer is a conglomerate (unnamed) near the bottom of the Tertiary section in the depth interval from 1,138 to 1,172 meters. Any vertical fluid movement between the Tertiary and Paleozoic sections would be small and would be from the Paleozoic rocks into the Tertiary rocks.

In the Tertiary section, an interval of less than 30 meters in the upper part of the Prow Pass Member of the Crater Flat Tuff has an apparent transmissivity of 14 meters squared per day. The saturated part of the tuffaceous beds of Calico Hills has an apparent transmissivity of about 0.5 meter squared per day. The Bullfrog Member of the Crater Flat Tuff has an apparent transmissivity of 1.5 meters squared per day. The lower part of the Prow Pass Member and the Tram Member of the Crater Flat Tuff, and most of the Lithic Ridge Tuff have no significant fracture permeability. The lower part of the Lithic Ridge Tuff, the underlying older tuffs, and the upper 97 meters of the Paleozoic section have an apparent transmissivity of about 10 meters squared per day.

In the Paleozoic section below 1,297 meters, an interval of less than 22 meters in the upper part of the Lone Mountain Dolomite has an apparent transmissivity of 69 meters squared per day. Below this permeable zone, the next 190 meters has an apparent transmissivity of 33 meters squared per day. Between 1,550 and 1,805 meters, the apparent transmissivity is 6 meters squared per day.

Composition of water from the Tertiary section was similar to water from other wells in the Yucca Mountain area. Water from the Paleozoic section was similar to but had greater concentrations of dissolved solids than waters from the regional carbonate aquifer of the Ash Meadows ground-water basin.

INTRODUCTION

The U.S. Geological Survey has been conducting investigations at Yucca Mountain, Nevada, to determine the hydrologic and geologic suitability of the site for storage of high-level nuclear waste in an underground mined repository. The investigations are part of the Nevada Nuclear Waste Storage Investigations being conducted by the U.S. Geological Survey and other agencies in cooperation with the U.S. Department of Energy, Nevada Operations Office, under Interagency Agreement DE-AI08-78ET44802. Test drilling has been a principal method of investigation.

The purpose of this report is to characterize the geohydrology of the saturated volcanic and dolomitic rocks penetrated in test well UE-25p#1. This report contains hydrologic interpretations based on data obtained from borehole tests conducted in the well and supported by geological and geophysical information, also obtained from the well.

Test well UE-25p#1 is in Nye County, Nevada, approximately 140 km northwest of Las Vegas in the southern part of the State (fig. 1). The site, located at N. 756,171 ft. and E. 571,485 ft. in the Nevada State Coordinate System Central Zone, is on the valley floor about 1.5 km east of Yucca Mountain. Altitude of the land surface at the well site is 1,113.9 m above sea level.

Hydraulic testing of test well UE-25p#1 occurred during two phases: (1) After the sequence of Tertiary rocks had been penetrated; and (2) when the hole was at a total depth of 1,805 m. The two phases are referred to as: (1) Test of the Tertiary section; and (2) test of the Paleozoic section. A complete sequence of water-level measurements, borehole-flow surveys, pumping and recovery tests, water sampling, and packer-injection tests were conducted in both the Tertiary and Paleozoic sections.

The test of the Tertiary section occurred after the test well had been drilled to a depth of 1,301 m. Because the hole had penetrated 97 m into Paleozoic rocks, and because of difficulties in keeping the hole open at about 1,203 m, a temporary cement plug was set in the well, with the top of the plug at 1,197 m. As discussed in the section on borehole-flow surveys, evidence indicated that major bypass occurred around the temporary plug. Further evidence from water-quality data indicated bypass of the plug (see section "Ground-Water Chemistry"). If bypass of the plug occurred, testing of the Tertiary section included 97 m of Paleozoic rocks. Where appropriate, depth intervals relative to the Tertiary testing are given to a depth of 1,301 m, rather than to the top of the temporary plug. The well construction at the time of testing of the Tertiary section is shown in figure 2. Testing of the Paleozoic section occurred after the hole was completed at a total depth of 1,805 m. Testing was within the depth interval from 1,297 to 1,805 m. Final well construction is shown in figure 3.

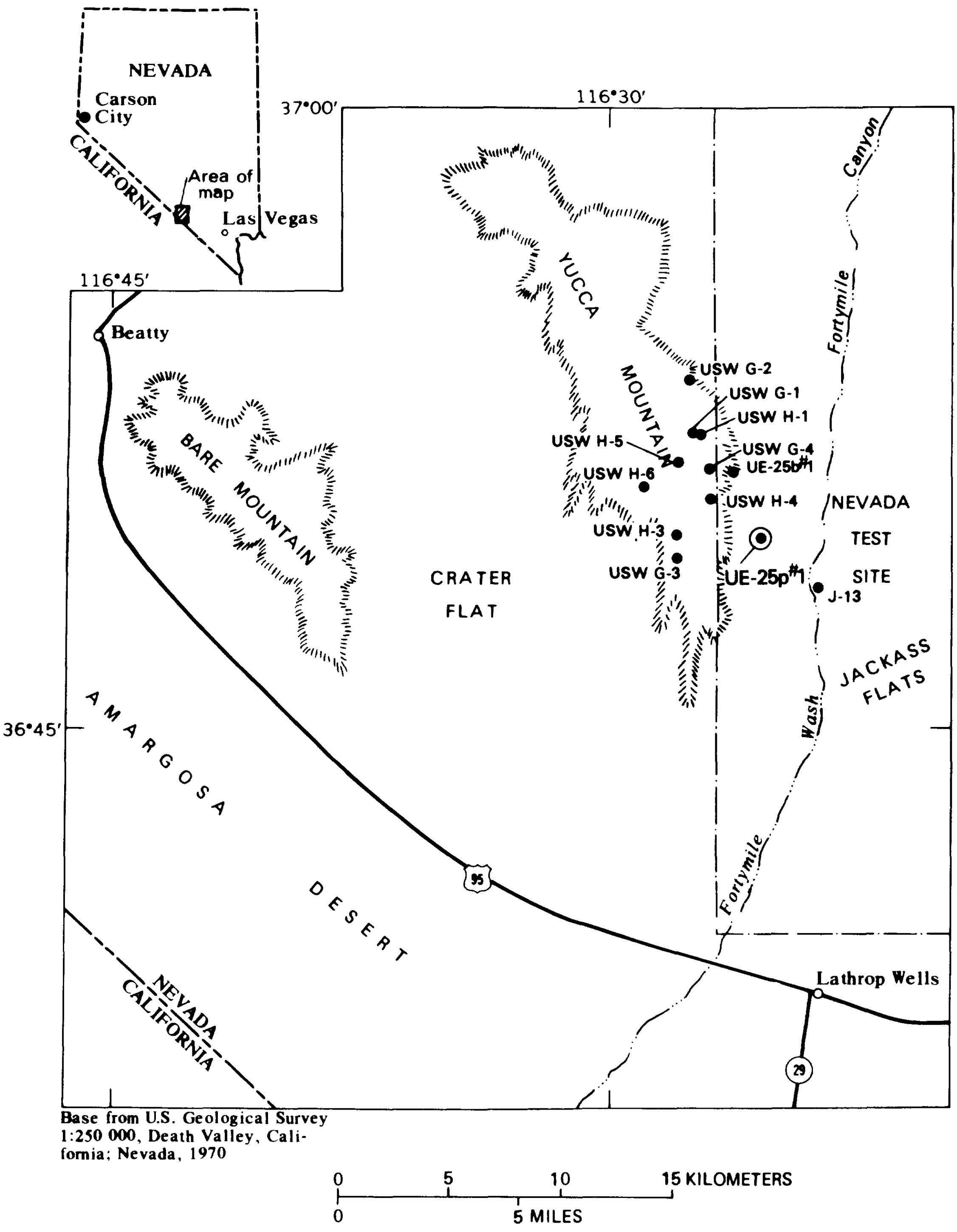

Figure 1.--Location of test well UE-25p#1 and other test wells in the vicinity.

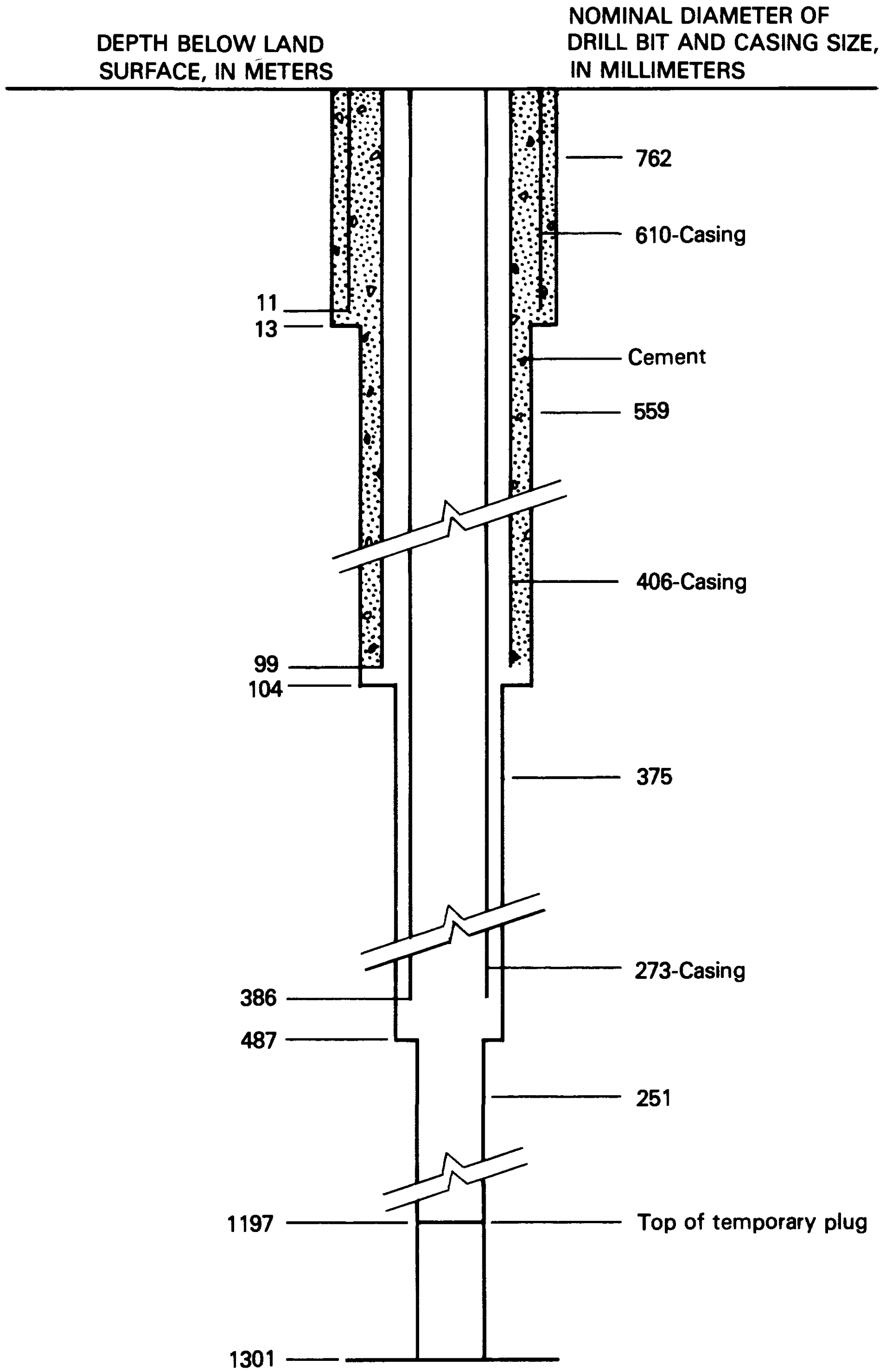

Figure 2.--Well construction during hydraulic testing of Tertiary section.

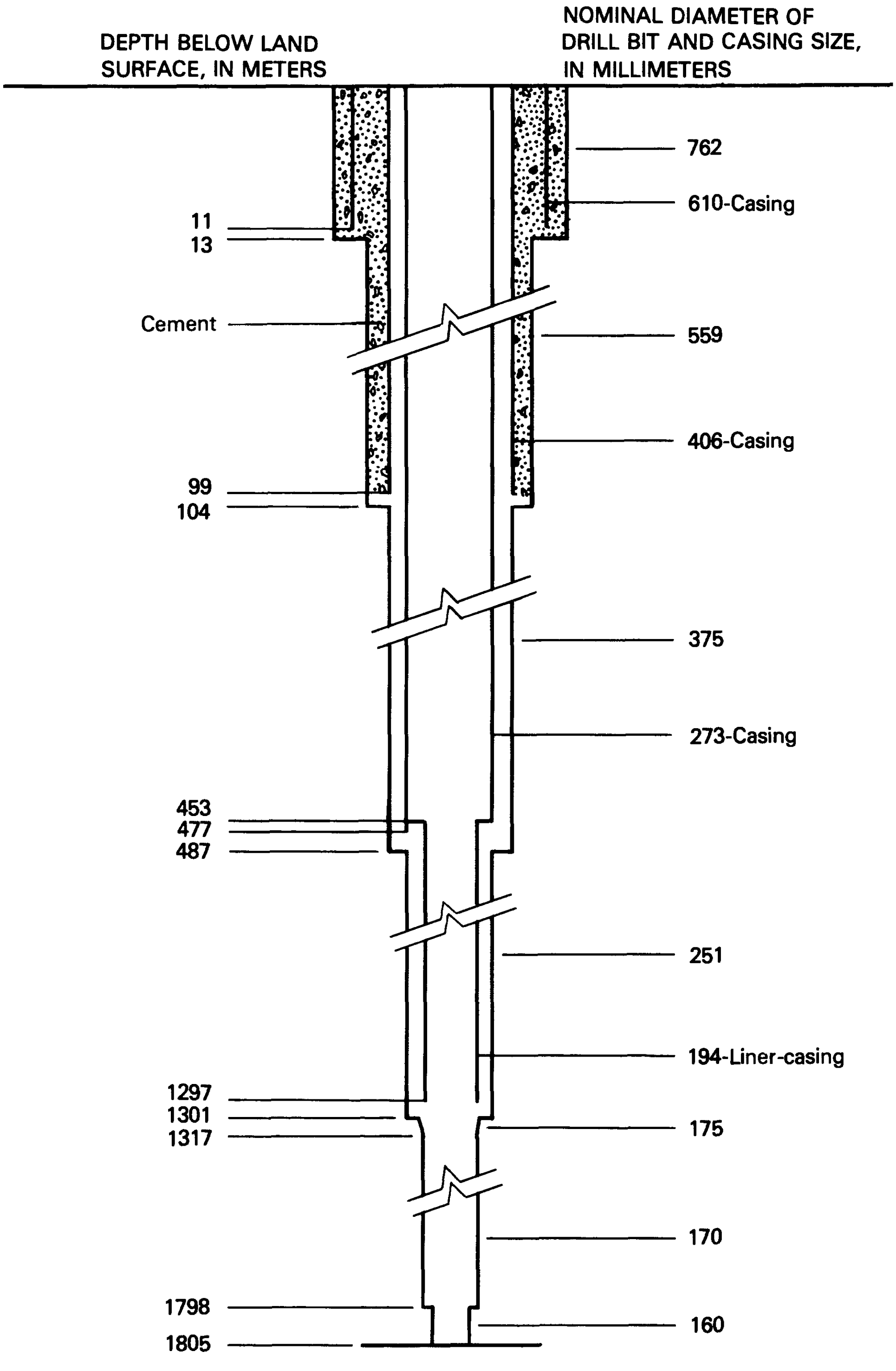

Figure 3.--Final well construction.

A summary of major lithostratigraphic units and contacts penetrated in the well is shown in table 1. The rocks penetrated are primarily Tertiary ash-flow tuffs to a depth of 1,244 m, and Paleozoic dolomite to a total depth of 1,805 m. A conglomerate, 34 m thick, is the major lithologic exception to the ash-flow tuffs. The Paleozoic dolomite includes the Roberts Mountains Formation, overlain by Lone Mountain Dolomite. The contact between the formations is gradational within the depth interval from 1,652 to 1,687 m (M. D. Carr, U.S. Geological Survey, written commun., 1984).

WATER LEVELS

Water levels measured prior to or after each packer-injection test are summarized in table 2; water levels also are illustrated in figure 4, showing variations in hydraulic head and water temperature with depth. Within Crater Flat Tuff, the measured hydraulic head ranged from 729.9 to 730.8 m above sea level, which was similar to levels in nearby wells. The hydraulic head was slightly higher in the Lithic Ridge Tuff and, at 752.2 m, was substantially higher in the older tuffs (unnamed) and conglomerate (unnamed).

Because of drilling difficulties, the zone between 1,197 and 1,297 m was not readily tested, and accurate hydraulic head measurements were not obtained; this section, as well as the entire upper section, was later sealed. Below the Paleozoic contact, the hydraulic head declined slightly, but still was about 20 m higher than in most of the Tertiary section. Adjustment of measured water levels to equivalent cold-water hydraulic heads at 20° C (to account for density variation with temperature) confirmed the slight decline in hydraulic head with depth below the contact.

Variation of water temperature with depth was similar to that of hydraulic head; maximum values for both occurred in the vicinity of the Tertiary-Paleozoic contact. This geologic contact may be an important hydrologic feature.

Although the reasons for the occurrence of a zone of higher hydraulic head overlying a zone of lower hydraulic head at the test well site are poorly understood, an increase of hydraulic head with depth is not unique in the area: In test well USW H-1 (6.5 km to the northwest), piezometers showed that, at a depth of 1,800 m in the Crater Flat Tuff, the head was as high as 784 m, whereas the water-table altitude was 730 m (Robison, 1984).

BOREHOLE-FLOW SURVEYS

Flow surveys were made to determine which intervals yielded water during pumping or to determine which intervals yielded or received water during static (non-pumping) conditions. The surveys were used to appraise relative magnitude of permeability of intervals and also to guide planning of additional work, such as packer-injection tests.

Table 1.--*Summary of major lithostratigraphic units and contacts penetrated by test well UE-25p#1 (M. D. Carr, U.S. Geological Survey, written commun., 1984)*

Unit	Depth of interval (meters)	Thickness of interval (meters)
Alluvium-------------------------	0-39	39
.... unconformity		
Timber Mountain Tuff		
Rainier Mesa Member-------------	39-52	13
.... unconformity		
Paintbrush Tuff		
Bedded tuff---------------------	52-55	3
Tiva Canyon Member--------------	55-81	26
.... fault		
Topopah Spring Member-----------	81-381	300
Tuffaceous beds of Calico Hills---	381-422	41
Bedded tuff-----------------------	422-436	14
Crater Flat Tuff		
Prow Pass Member----------------	436-546	99
Bedded tuff---------------------	546-558	12
Bullfrog Member-----------------	558-683	125
Bedded tuff---------------------	683-690	7
Tram Member---------------------	690-873	183
.... fault		
Lithic Ridge Tuff-----------------	873-1,063	190
Bedded tuff-----------------------	1,063-1,067	4
Older tuffs of test well USW G-1		
Unit A--------------------------	1,067-1,100	33
Unit C--------------------------	1,100-1,137	37
Conglomerate----------------------	1,138-1,172	34
Calcified ash-flow tuff-----------	1,172-1,204	31
Tuff of Yucca Flat (?)------------	1,204-1,244	40
.... fault		
Lone Mountain Dolomite and Roberts Mountains Formation-----	1,244-1,805	561

Table 2.--*Static water levels measured prior to, or after each packer-injection test*[1]

Tested interval (meters)	Depth to water (meters)	Altitude above sea level (meters)
Tertiary section		
Static-500	383.9	729.9
500-550	383.5	730.4
550-600	383.9	729.9
739-789	383.3	730.6
764-834	383.1	730.8
834-904	381.1	732.7
904-974	382.2	731.7
974-1,044	380.9	733.0
1,044-1,114	379.4	734.5
1,110-1,180	361.7	752.2
Paleozoic section		
1,297-1,308	362.0	751.9
1,297-1,338	362.3	751.6
1,341-1,381	362.3	751.6
1,381-1,420	362.4	751.5
1,423-1,463	362.5	751.4
1,463-1,509	362.4	751.5
1,509-1,554	362.6	751.3
1,554-1,585	362.5	751.4
1,597-1,643	362.7	751.2
1,643-1,689	363.0	750.9
1,689-1,734	362.9	751.0
1,734-1,780	363.1	750.8
1,780-1,805	363.0	750.9

[1]The depths and altitudes above include a correction of 0.02 meter due to hole deviation from vertical between land surface and the water table. Water-level altitudes are based on a land-surface altitude of 1,113.9 meters.

Spot or continuous measurements were made of the vertical velocity of the fluid, from the top of the saturated interval open to the hole to the bottom of the hole. In test well UE-25p#1, spot measurements were made, using a radioactive tracer (Blankennagel, 1967, p. 15-26). An aqueous solution of iodine-131 (7.5-day half-life) was ejected from a down-hole tool, and movement of the radioactive slug was monitored as it passed by two gamma detectors. Measured velocity was combined with the cross-sectional area determined from a caliper survey, and the rate of flow as a function of depth was obtained.

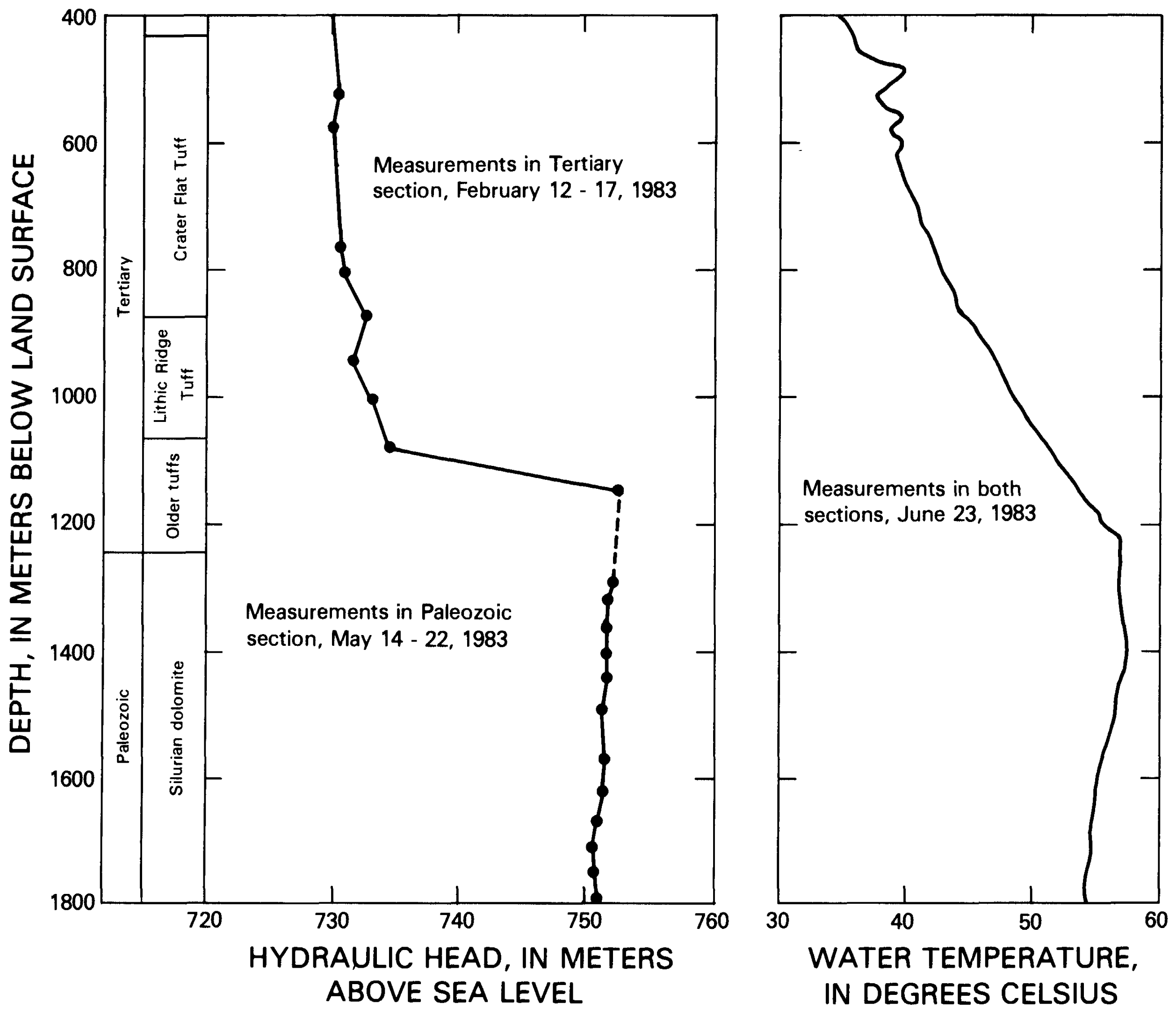

Figure 4.--Variation of hydraulic head and water temperature with depth.

Three flow surveys were made in test well UE-25p#1. The first survey of the Tertiary section (fig. 5), when the hole was 1,301 m deep, was made during an aquifer test pumping at a rate of 22.1 L/s. The second survey (fig. 6), also of the Tertiary section, was made during non-pumping conditions to determine water movement in the hole between lithologic units. The third survey (fig. 7), of the Paleozoic section after completion to total depth of 1,805 m, was made while pumping at a rate of 31.5 L/s.

The first survey of the Tertiary section (fig. 5) showed that about 28 percent of the total production was moving past the lowermost measurable station, which was 10 m above the top of the temporary cement plug at 1,197 m. This flow indicated that the plug was leaking and that about 6 L/s was being produced from the interval between the plug and the total depth of the hole at the time of the survey (1,301 m).

A small proportion of the production occurred from older tuffs (unnamed) and the Lithic Ridge Tuff; no measurable yield occurred from the Tram Member; and very little yield occurred from the Bullfrog Member. The lower part of the Prow Pass Member yielded no water, but an interval less than 30 m thick within the upper part of the Prow Pass Member yielded about 58 percent of the total. The tuffaceous beds of Calico Hills yielded less than 2 percent, although almost the entire unit was saturated. A water-temperature survey made during the flow survey showed deflections that correlated well with the water-yielding zones (fig. 5).

The static, or non-pumping, flow survey in the Tertiary section showed upward movement within the hole, beginning at the cement plug, where the rate was more than 0.4 L/s, to a maximum of 0.8 L/s. Virtually all the upward-moving water entered the thin interval in the Prow Pass Member that yielded 58 percent of the total during pumping. Upward flow was driven by the difference in hydraulic heads among the formations (see section titled "Water Levels").

The flow survey made while pumping the Paleozoic section showed that only 5 percent of the yield of the Paleozoic rocks came from below about 1,550 m. Thirty percent of the yield came from a 190-m interval in the middle part of the Lone Mountain Dolomite. More than 50 percent was derived from an interval in the upper part of the Lone Mountain Dolomite that is less than 10 m thick. Water temperature deflections corresponded with production zones, but the correlation was reversed from that of the Tertiary surveys.

CONCEPTUAL MODEL OF GROUND-WATER FLOW

The accuracy of determining hydraulic characteristics of an aquifer depends to a large degree on applying the correct, or most nearly correct, model to the system under study. Porous-media models are well known to hydrologists; less well known are systems in which heterogeneity exists. In a summary of methods for interpreting flow tests in fissured formations, Gringarten (1982, p. 237) stated that the understanding of fluid flow in heterogeneous formations still is the subject of much debate.

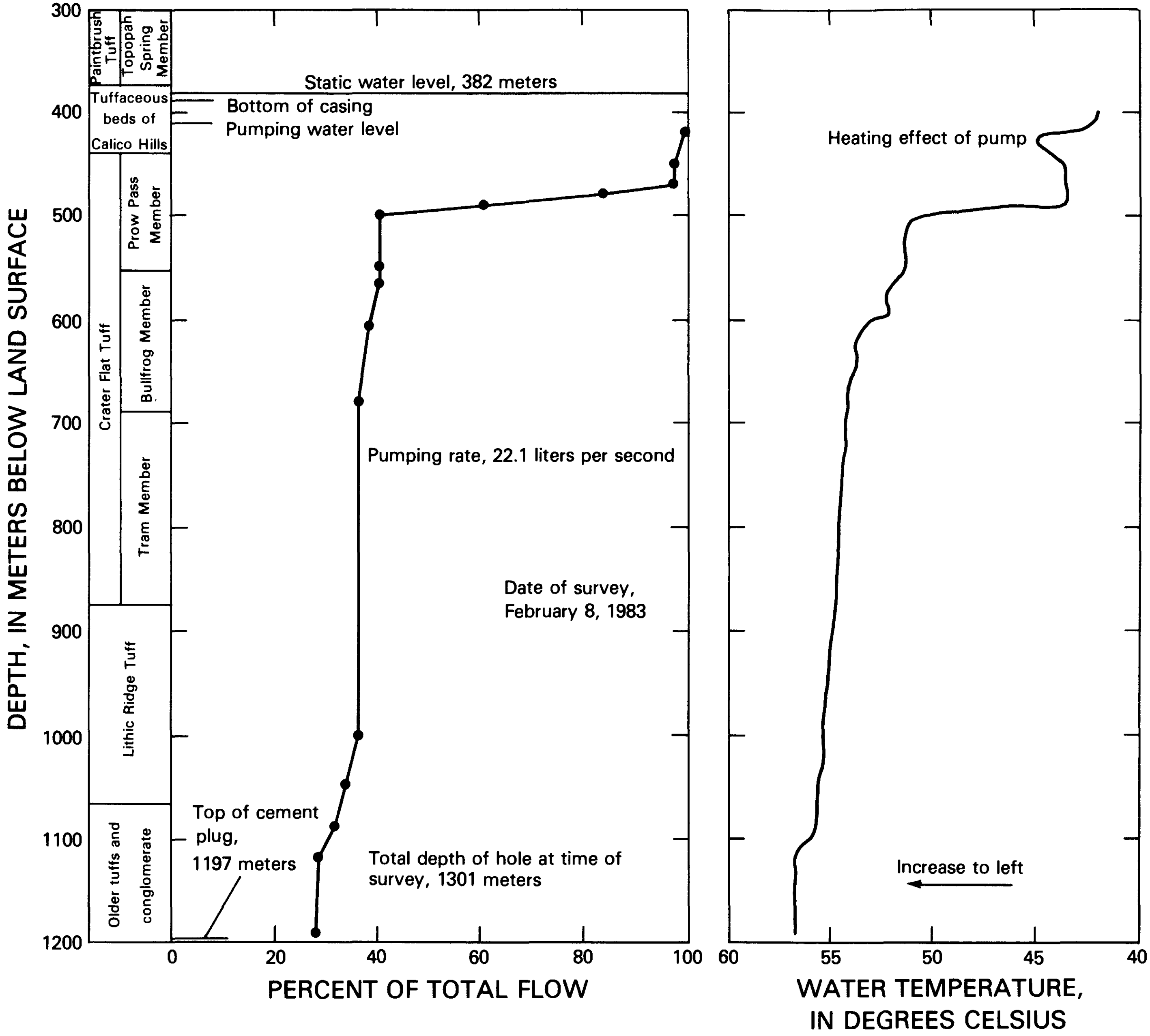

Figure 5.--Borehole-flow survey (pumping) of Tertiary section.

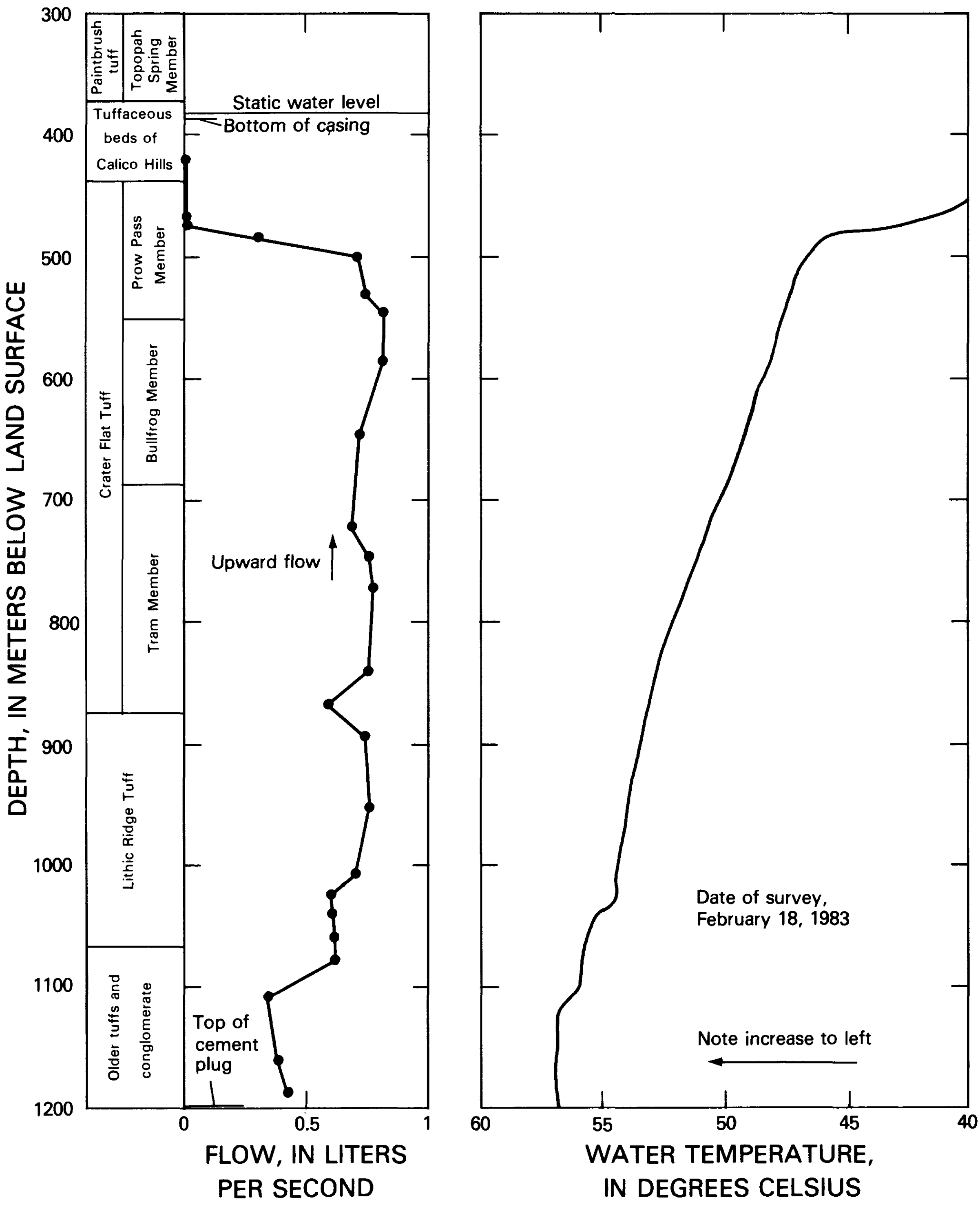

Figure 6.--Borehole-flow survey (non-pumping) of Tertiary section.

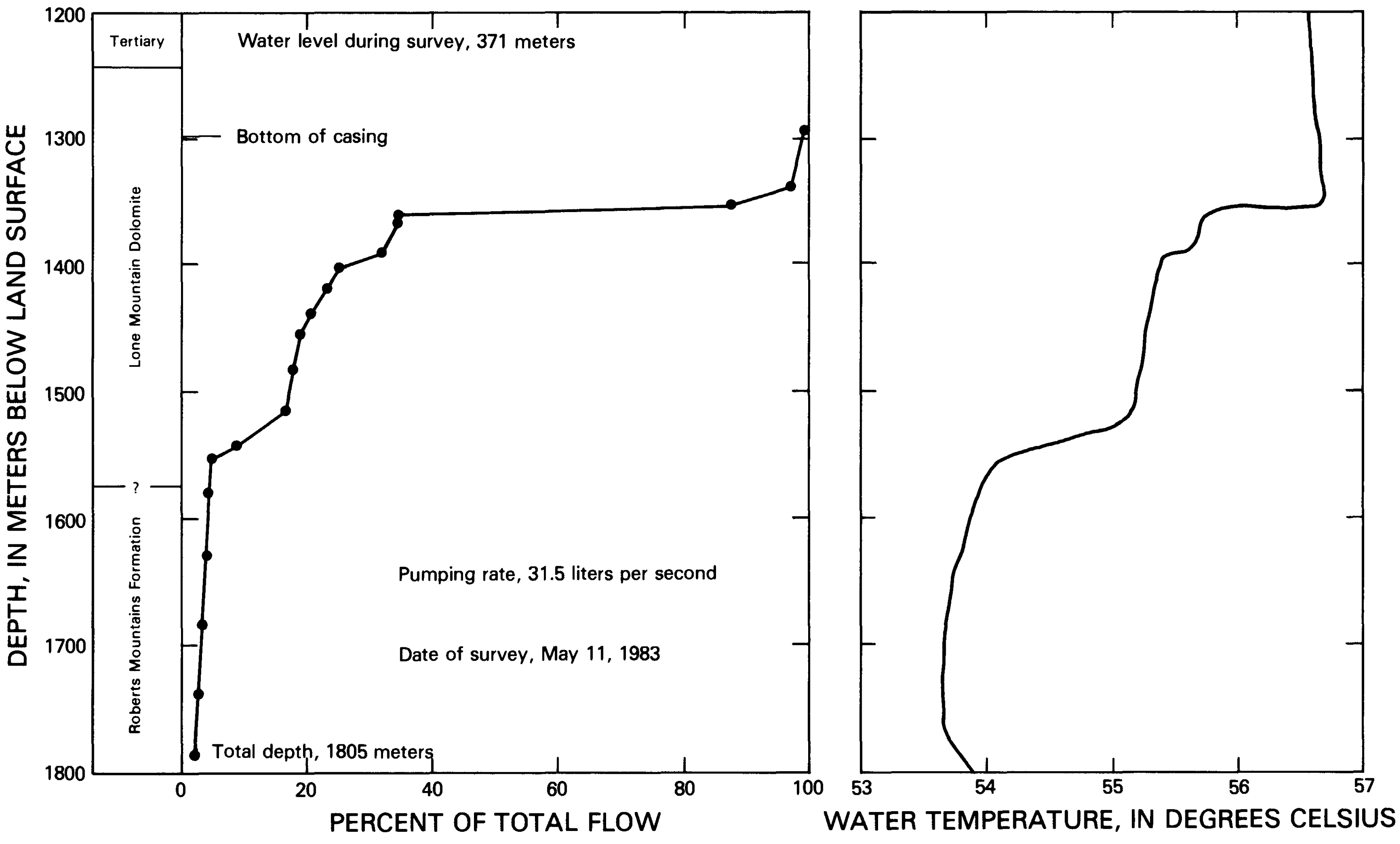

Figure 7.--Borehole-flow survey of Paleozoic section.

The conceptual model chosen for this study is a dual-porosity model. Barenblatt and others (1960) first introduced the concept of a dual-porosity medium to represent a fractured aquifer. Later studies (Warren and Root, 1963; Odeh, 1965; Kazemi and others, 1969; de Swaan, 1976) investigated variations of the dual-porosity model.

The conceptual model used in this study has the following elements:

1. Both primary and secondary porosity are present.
2. Primary porosity in the matrix is homogeneous and isotropic; secondary porosity is controlled by fractures, which generally are vertical or high angle.
3. Both primary and secondary porosity may be decreased by mineral deposition.
4. Flow to the well is through fractures only; flow occurs between the matrix and fractures. Mineral deposition at the matrix-fracture surface probably decreases such flow.
5. Hydraulic conductivity of fractures is several orders of magnitude greater than hydraulic conductivity of the matrix.
6. Volume of water stored in the fractures is small relative to the volume stored in the matrix.
7. Distances between fractures are small in comparison with dimensions of the ground-water system under study.
8. On a small scale, the fracture permeability is anisotropic; on a large scale, the orientation of fractures is assumed to be random, so the system appears isotropic.

On the basis of the dual-porosity model, homogeneous porous-medium solutions can be used to define general ground-water flow properties using late-time data (Odeh, 1965, p. 63; Kazemi, 1969, p. 458; Kazemi and others, 1969, p. 467; Najurieta, 1980, p. 1247; and Gringarten, 1982, p. 251). Gringarten (1982, p. 251) further stated that, at early time, pressure response is due to the fracture system, with flow from the matrix virtually being zero. The solution for the pressure response is the homogeneous equation for the fracture system. At intermediate times, a transition occurs from fracture flow to a combined flow from fractures and matrix. During intermediate time, the matrix-flow contribution affects aquifer response in a manner similar to that of delayed yield in an unconfined system. At late time, the transition is complete. Average values for hydraulic characteristics then can be determined for the combined system. It should be noted, as did Gringarten (1982, p. 252), that log-log curves of fissure pressure versus time in a dual-porosity fractured reservoir are identical to those corresponding to Boulton's (1963) drawdown versus time curves for delayed yield in an unconfined aquifer. Knowledge of whether the aquifer is confined or unconfined would prevent misinterpretation of the data. Also, as the time required to approach quasi-steady-state conditions in a heterogeneous reservoir is one or two orders of magnitude greater than in a homogeneous reservoir, a consideration of the time element might prevent an incorrect interpretation (Warren and Root, 1963, p. 251).

Selection of the conceptual model is supported by the following:

1. Production was associated with known fractures, although not all known fractures yielded water.

2. Borehole-flow surveys showed production was derived from limited intervals. Most intervals of borehole yielded little or no water during pumping. This supports the concept of small matrix hydraulic conductivity and large fracture hydraulic conductivity.

3. Laboratory measurements of horizontal and vertical matrix hydraulic conductivities of ash-flow tuffs from a nearby test well (USW H-1) were about 1×10^{-4} to 1×10^{-6} m/s (Rush and others, 1983). A pumping test of the Tertiary section showed that apparent transmissivity was much larger than could be accounted for by matrix hydraulic conductivity alone (see Pumping and Recovery Test 1 section).

The degree to which this model describes the actual system in the vicinity of test well UE-25p#1 is not entirely known. One measure of the reliability of the model is the fit of the test data to the response predicted by the model. A good fit does not entirely rule out other models, but it does indicate that the conceptual model may adequately describe the system being studied.

PUMPING AND RECOVERY AQUIFER TESTS

In the following sections, the pumping and recovery tests conducted in test well UE-25p#1 are evaluated in terms of the conceptual model and the following elements deriving from that model.

1. A logarithmic data plot should follow a Theis type curve at early time, should be below the Theis type curve at intermediate time, and should again follow a Theis type curve during late time.

2. A semi-logarithmic data plot should show a straight-line segment in both early and late time. Transition- or intermediate-time data also should plot on a straight line of lesser slope.

3. The above two elements are dependent on late time having been reached and early-time data not having been distorted by factors such as skin effect and wellbore storage.

According to the conceptual model, if a pumping test does not reach late time, a semi-logarithmic plot will have at most only two straight-line segments. The same type of drawdown-time response also could be the result of a hydraulic boundary with increased transmissivity that would appear the same as the transistional period of a dual-porosity model.

Pumping and Recovery Test 1

The pumping and recovery test of the Tertiary section was conducted when the well was at a depth of 1,301 m. A cement plug previously had been set from approximately 1,197 to 1,204 m. The plug apparently was not effective, as shown by a combination of borehole-flow surveys, temperature logs, and water-quality data. The effective interval of pumping probably was from static water level to a depth of 1,301 m. Composite static water level prior to pumping was 382 m below land surface. The well was pumped at 22.1 L/s for 3,150 minutes with the pump intake at 425 m. Drawdown at the end of pumping was 33.7 m. Recovery was monitored for 1,060 minutes.

An analysis of drawdown versus time is shown in logarithmic form in figure 8. In data analysis, the aquifer above a bedded tuff at a depth of 422 m was envisioned as an unconfined, fractured aquifer in which hydraulic conductivity was predominantly within interconnecting, high-angle fractures. Confined conditions probably occurred at greater depths within the tested zone. Early-time data appeared to have extended to about 80 minutes. During the time from about 1 to 5 minutes, drainage of the fracture system that extends to the water table was occurring. Between about 10 and 80 minutes, response was due to characteristics of the deeper, main fracture system. Drainage from the less permeable matrix was still insignificant at this time. At time greater than 80 minutes, the response probably was the transitional period of a dual-porosity system. Late time apparently was not reached. On the basis of early-time data to about 5 minutes, upper fractures may be more permeable than the main fracture system, or the data may indicate greater permeability close to the wellbore that was drilling-induced. In either case, if the preceding analysis is approximately correct, the apparent transmissivity of the main fracture system can be determined by matching the data from 10 to 80 minutes to a Theis type curve. The following equation modified from Ferris and others (1962, p. 94) was used to calculate transmissivity:

$$T = \frac{6.9\ Q\ w(u)}{s}\ , \qquad (1)$$

where T is transmissivity, in meters squared per day;
Q is discharge, in liters per second;
w(u) is the well function of u, dimensionless, a match point; and
s is drawdown, in meters, a match point.

Apparent transmissivity of the fracture network determined by the preceding interpretation is 24 m^2/d.

An analysis of drawdown versus time for pumping test 1 on a semi-logarithmic graph is shown in figure 9. The first straight-line segment analyzed started at about 10 minutes and continued until about 80 minutes. A second straight-line segment of lesser slope started at about 100 minutes. The last data point indicated a possible third segment of different slope. A detailed examination of data (most not shown) from 2,300 minutes to the end of pumping, especially the last 160 minutes, indicated that the last few data points probably were affected by water-sampling operations that varied the discharge rate. Based on the conceptual model, the first straight-line segment corresponded to early time, during which response was due to the main fracture system. The second straight-line segment was the transitional period between fracture flow and a combined fracture-matrix flow. A third straight-line segment representative of late time probably was not reliably observed.

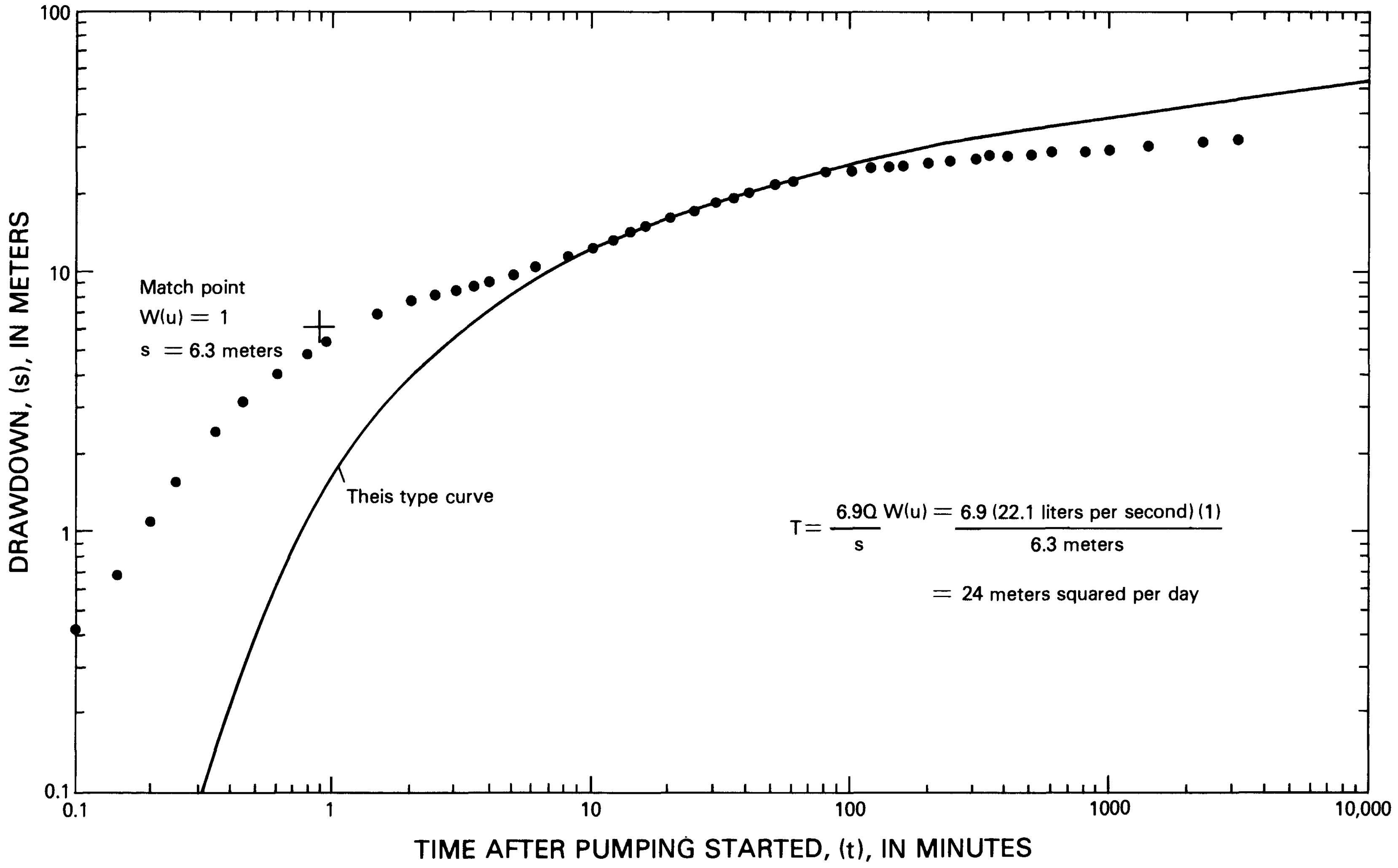

Figure 8.--Analysis of water-level drawdown, pumping test 1, depth interval 382 to 1,301 meters, Theis method.

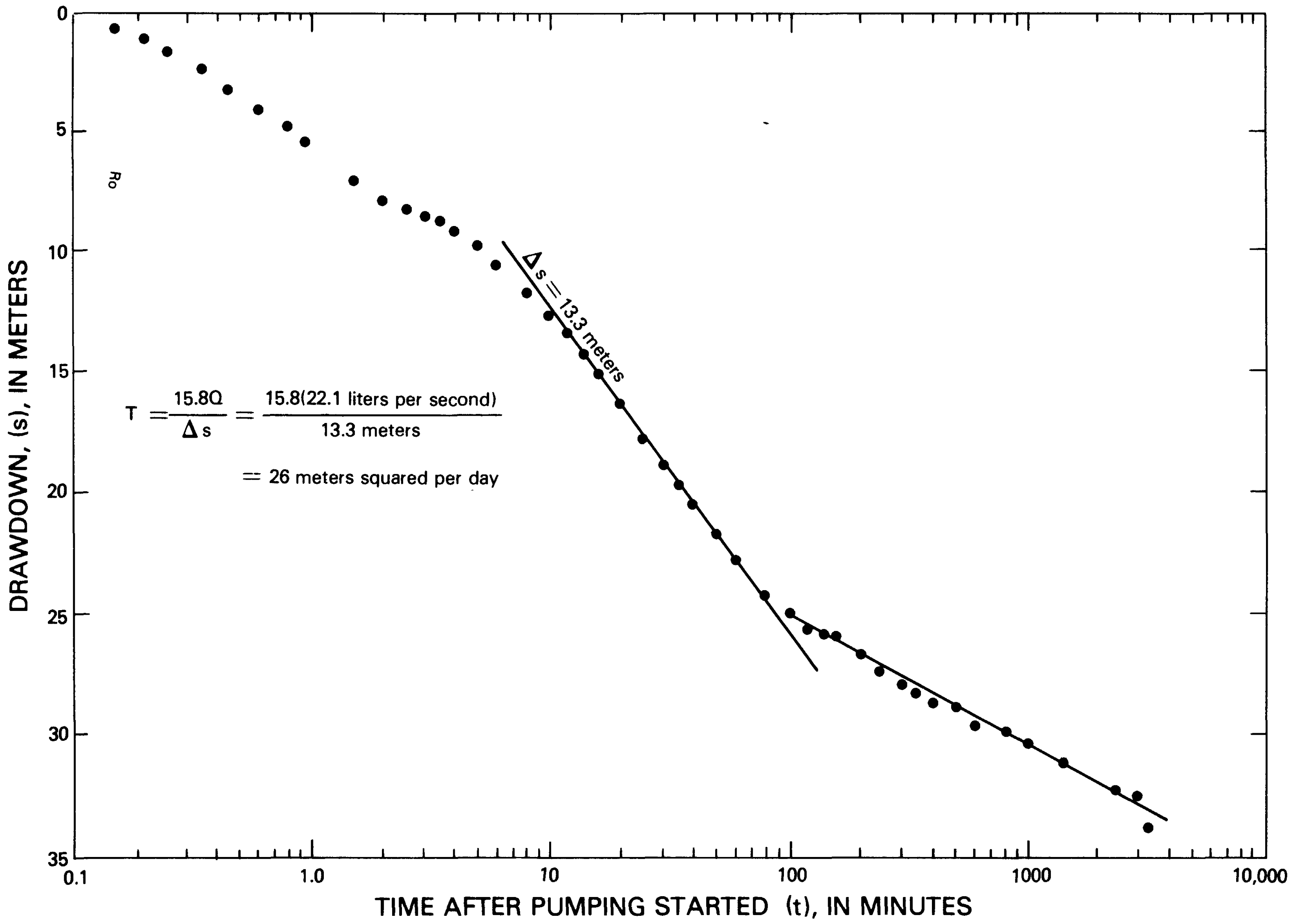

Figure 9.--Analysis of water-level drawdown, pumping test 1, depth interval 382 to 1,301 meters, straight-line method.

Apparent transmissivity of the fracture network was determined from the first straight-line segment, based on the straight-line method of Cooper and Jacob (1946); method assumptions are discussed in the cited reference. The equation for the straight-line method is:

$$T = \frac{15.8Q}{\Delta s} , \quad (2)$$

where T is transmissivity, in meters squared per day;
Q is discharge, in liters per second; and
Δs is change in drawdown over one log cycle of time, in meters.

Apparent transmissivity of the Tertiary section based on pumping test 1 was 26 m^2/d.

Analysis of recovery test 1 is shown in figure 10. Data are shown as residual drawdown versus time since pumping started, divided by time since pumping stopped. Static water level immediately prior to commencing pumping was used in residual drawdown calculations. It is unlikely that any change in static water level during testing would have been of sufficient magnitude to affect the analyses. These data can be analyzed by a straight-line method similar to a pumping-test analysis to determine transmissivity (Jacob, 1963). Apparent transmissivity of the fracture network determined from the recovery data was 18 m^2/d.

Although the data from pumping and recovery test 1 fit the response predicted by the dual-porosity conceptual model, they do not exclude other models. One model is that of a hydraulic boundary, with increased transmissivity, at some unknown distance from the well. If the second straight-line segment in figure 9 were due to such a boundary, the transmissivity would be about 60 m^2/d on the basis of a straight-line solution of the second straight-line segment. Although such a boundary probably is less likely than the dual-porosity system, transmissivity of 60 m^2/d can be considered a likely maximum. A more probable value is an apparent transmissivity of about 25 m^2/d for the fracture system.

Pumping and Recovery Test 2

Pumping and recovery test 2 was conducted during testing of the Paleozoic section. At the time of testing, the well was open to formation rock from 1,297 m to a total depth of 1,805 m. Static water level for the open interval was 362 m below land surface prior to pumping. The pump intake was at 417 m, and the pump was operated at 31.5 L/s for 6,080 minutes.

Drawdown versus time data for pumping test 2 in semi-logarithmic form in figure 11 shows an unusual response to pumping. Temperature changes in the water column during the initial 50 minutes of pumping explain a part of the response. Prior to pumping, a temperature survey showed that the temperature in the water column ranged from 33°C near the top of the water column to a

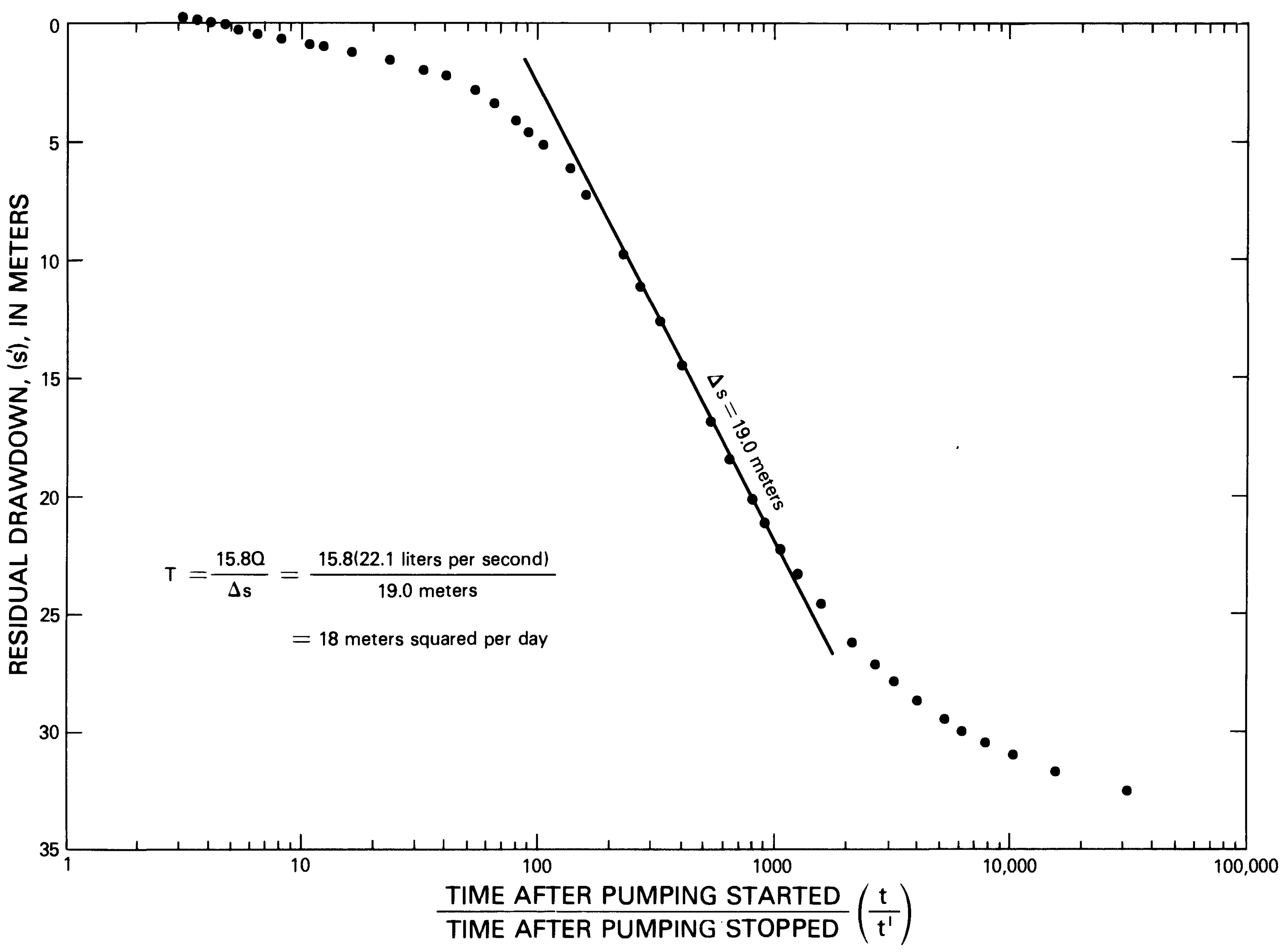

Figure 10.--Analysis of residual drawdown, recovery test 1, depth interval 382 to 1,301 meters, straight-line method.

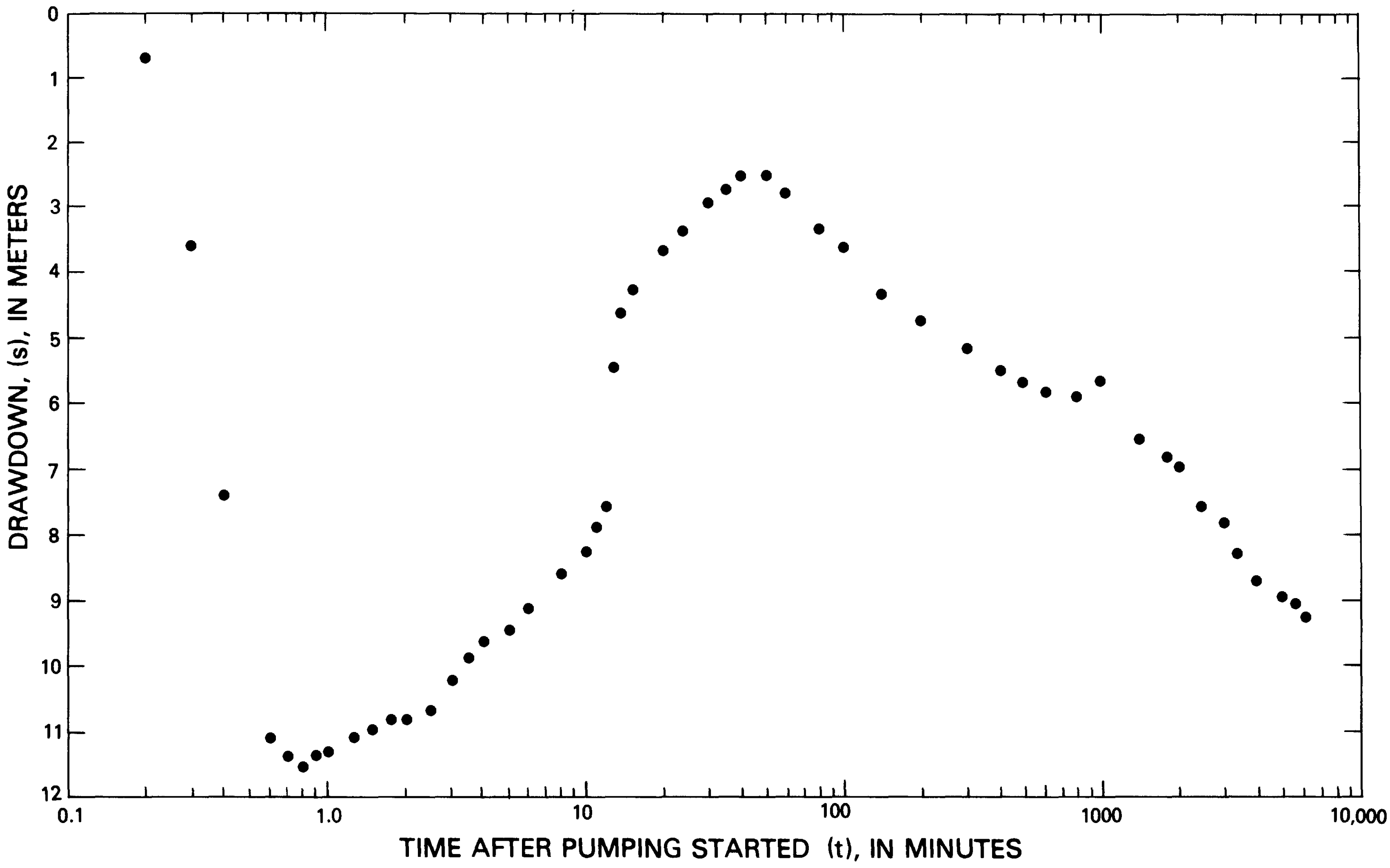

Figure 11.--Water-level drawdown, pumping test 2, depth interval 1,297 to 1,805 meters.

maximum of about 56°C near 1,370 m. Calculations based on the average specific volume (inverse of density) of the fluid column at temperatures measured prior to pumping, versus the average specific volume after the column reached a constant discharge temperature of 56.5°C, indicated an increase in the average specific volume of slightly more than 0.5 percent. Calculations were based on an assumed constant temperature of 56.5°C throughout the fluid column above 1,370 m during pumping, using temperature and specific volume data adjusted for hydrostatic pressure. Calculated expansion of the fluid column necessary to maintain an equivalent pressure head was 5.4 m.

In addition to changing temperature, inertia affected early drawdown. The effect of inertia can be explained best by examining the data for recovery test 2 shown in figure 12. Water level is shown as residual drawdown versus time on a semi-logarithmic graph. The recovery had the form of a damped sine wave. Bredehoeft and others (1966) modeled this type of response in an electrical-analog investigation of the effect of inertia in well-aquifer systems. Such a system can be described as overdamped, underdamped, and, at transition between the two, critically damped, depending on its force-free motion. In an overdamped system, inertia effects are negligible. No oscillation follows an initial change in water level, as water moves back to its original level. In an underdamped system, inertia effects are significant, and water level will oscillate following an initial change. The magnitude of inertial effects is dependant on a combination of aquifer transmissivity and effective length (mass) of the water column. During recovery test 2, the well-aquifer system was responding as an underdamped system. A simulated response in a well with underdamped conditions, immediately after turning on a pump, is shown in figure 13. The initial response was a very abrupt apparent drawdown, followed by a sine wave. At the beginning of pumping test 2 (fig. 11), the same type of response occurred, at least in the initial downward surge. Probably as the water level in the well started to rebound, the effect of the temperature change in the fluid column became significant, and a sine wave never developed.

Responses of pumping and recovery test 2 do not lend themselves easily to the same methods of analyses as those methods applied to pumping and recovery test 1. To analyze pumping test 2, the drawdown versus time data from 50 minutes to the end of the test were replotted in figure 14 after adding an additional 5.4 m of drawdown due to the expansion of the water column. In addition, the data points from 50 to 200 minutes were projected back to zero drawdown, which point was about 26 seconds after pumping started. The implication was that the data from 50 to 200 minutes represented a good approximation of the aquifer response minus temperature effects for the first 200 minutes of the test. Calculations by the straight-line method gave an apparent transmissivity of 131 m^2/d for the first 200 minutes. Based on the dual-porosity model, the response during this time was representative of the fracture network. A second straight-line segment of lesser slope corresponded to the transitional period; a third segment from 1,000 to 6,000 minutes represented late time. If late time was reached, as it appeared from the data, then average transmissivity for the combined system of fractures and matrix would be 111 m^2/d. Transmissivities calculated for the fracture system and the fracture-matrix system seemed inconsistent: It was expected that

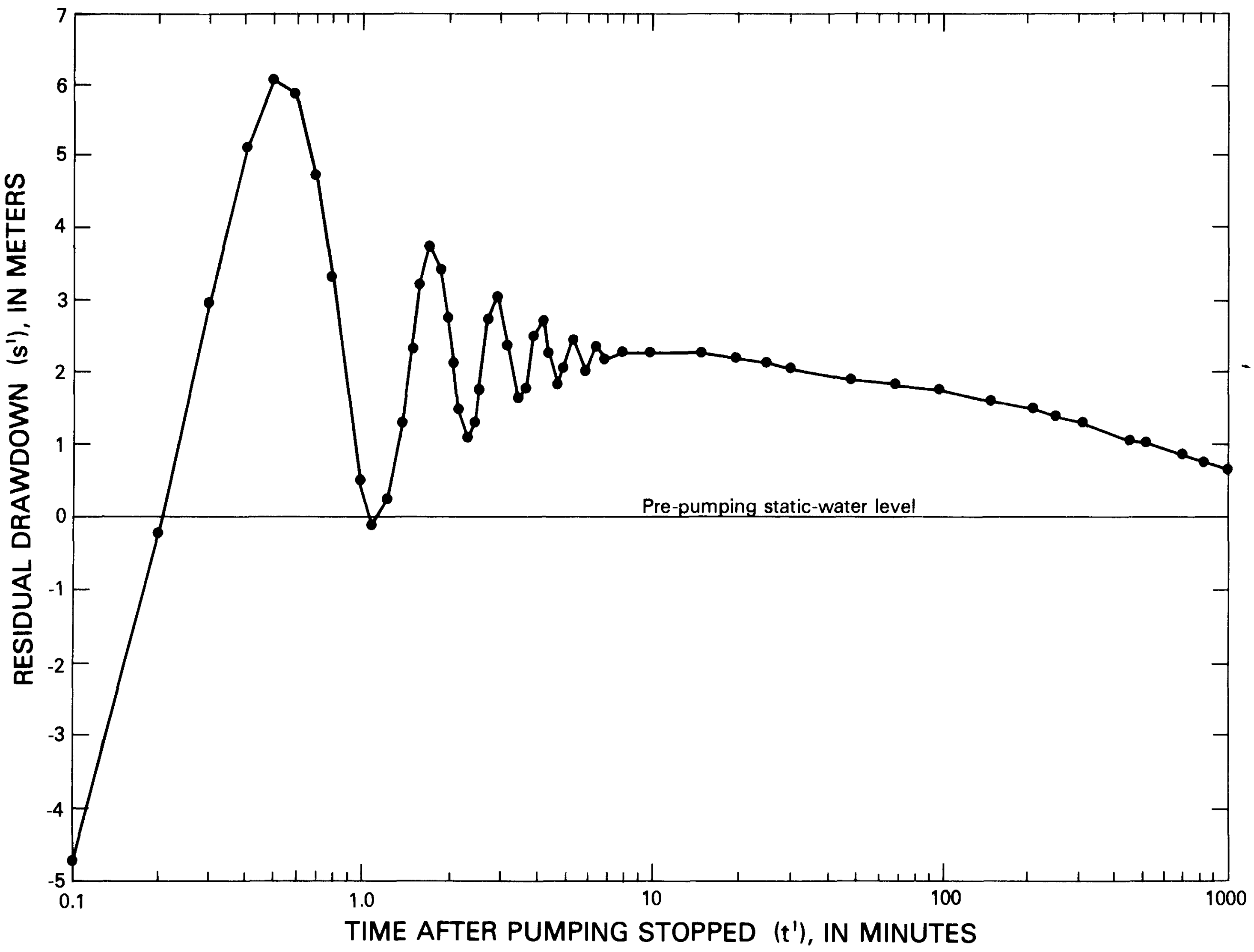

Figure 12.--Residual drawdown, recovery test 2, depth interval 1,297 to 1,805 meters.

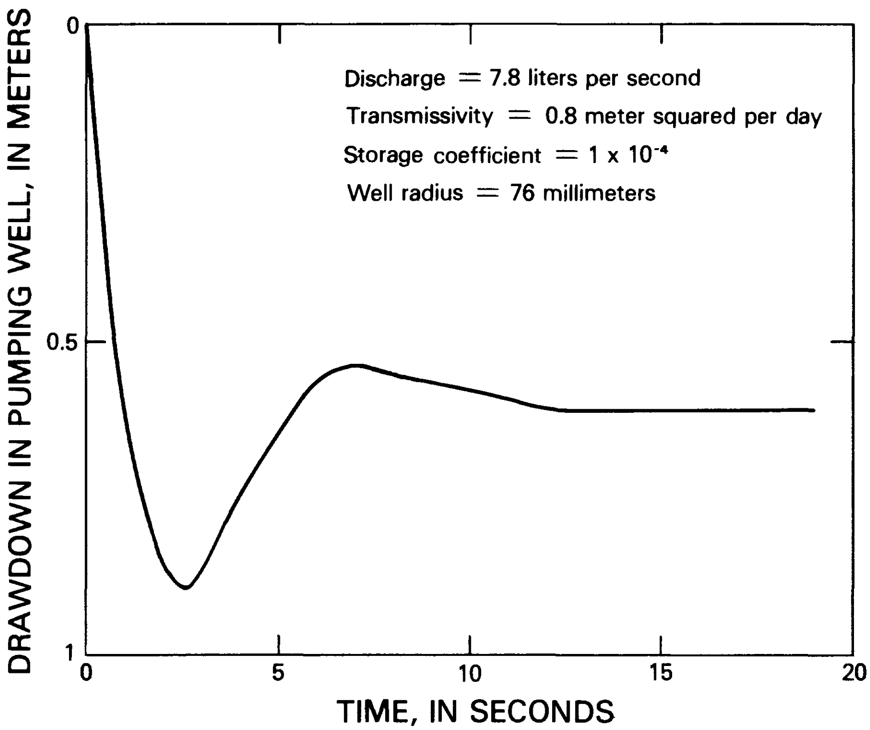

Figure 13.--Oscillograph illustrating the effect in a pumping well of commencing to pump from an underdamped well-aquifer system at a constant rate (modified from Bredehoeft and others, 1966, p. 706).

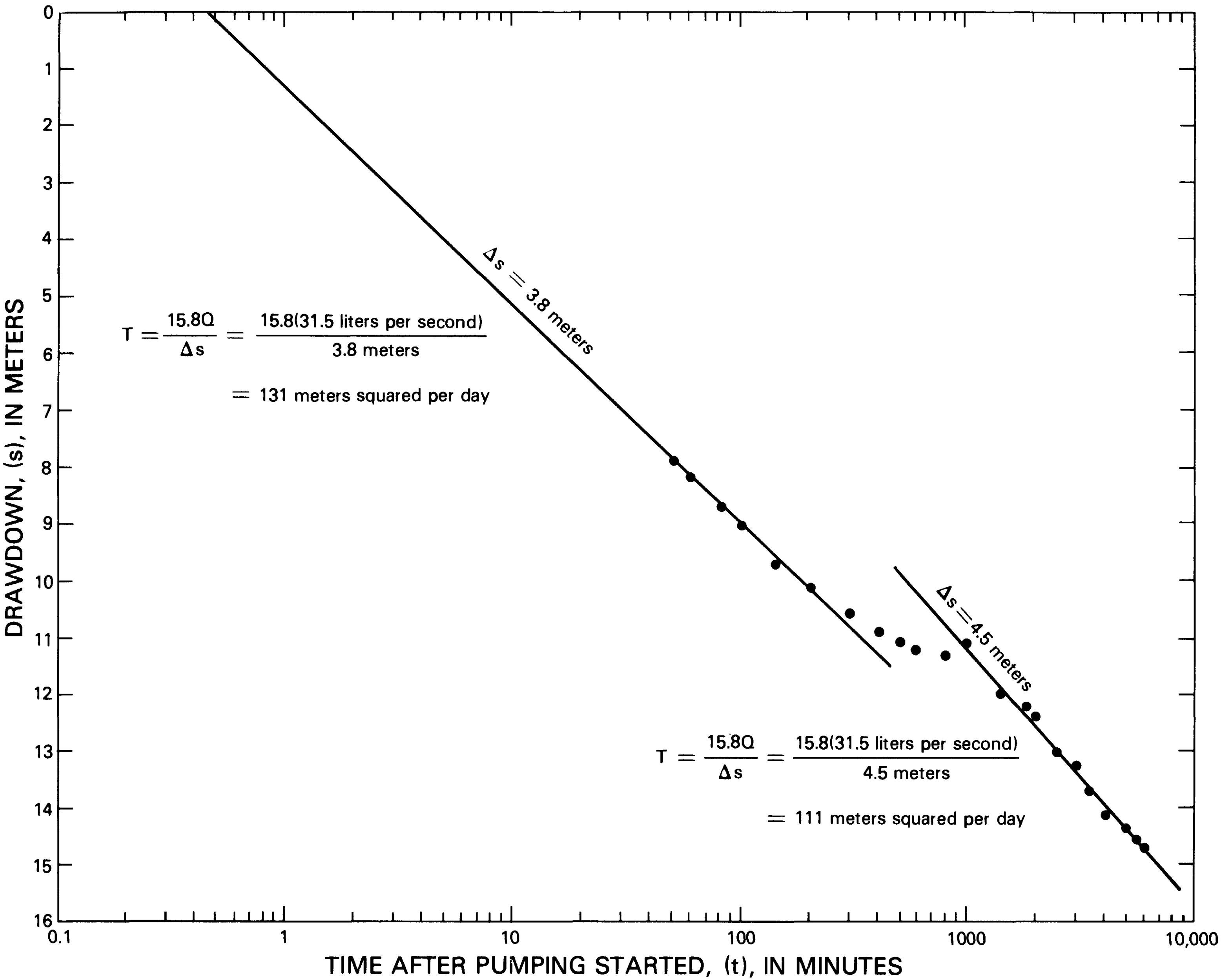

Figure 14.--Analysis of adjusted water-level drawdown, pumping test 2, depth interval 1,297 to 1,805 meters, straight-line method.

combined transmissivities of fractures and matrix would be slightly greater than transmissivity of the fracture system alone. Two possible explanations for the results are:

1. The first straight-line segment could still have been affected by inertia and, therefore, was not representative of fracture transmissivity.

2. The dual-porosity model did not apply, and the system was responding as a homogeneous porous medium with some deflection from ideal between about 200 and 1,000 minutes. In this case, the transmissivity would be about 170 m^2/d.

The response probably is consistent with a dual-porosity model, based on examination of pumping tests in Winograd and Thordarson (1975, p. C24-C30). These authors analyzed eight pumping tests in carbonate aquifers in or near the Nevada Test Site. Although they did not use a dual-porosity model, in each of the pumping tests, at least two straight-line segments of differing slopes were determined. In two of the tests, a third segment was evident. All the data fit a response curve consistent with a dual-porosity model. In addition, the flow survey of the Paleozoic section in test well UE-25p#1 indicated significant percentages of production from localized intervals, a characteristic of flow from fractured media. There were uncertainties in early-time data; however, late time apparently was reached, and a transmissivity of 111 m^2/d, determined from late-time data, probably was representative of the combined fracture-matrix flow.

The data in the logarithmic graph of drawdown versus time in figure 15 was adjusted in a manner similar to figure 14. The calculated 5.4 m of expansion in the fluid column was added to all drawdown data from 50 minutes to the end of pumping. Data shown prior to 50 minutes are artificial in the sense that they were obtained from the backward projection of data in figure 14. The shape of the data curve fits the response predicted by the conceptual model very well. All three time periods were present: The early-time or fracture-system response to about 200 minutes, a transitional period, and the late time representing the combined fracture-matrix flow. Matching the late data with a Theis type curve was tenuous, but the match chosen gave a transmissivity of 111 m^2/d.

Analysis of recovery test 2 could not be accomplished by using either the straight-line or Theis method. Although Bredehoeft and others (1966) described the response of a system in which inertial effects were significant, they did not derive solutions for hydraulic properties. Van der Kamp (1976) gave an approximate solution for determining the transmissivity of an interval tested by slug test in which inertial effects were significant.

Although recovery test 2 was not a slug test, an attempt was made to apply van der Kamp's slug-test solution to the data. The solution is based on the period of the damped sine wave after initial displacement of the water level and the crest-to-trough displacement of two succeeding waves. Unfortunately, most data for recovery test 2 occurred during turbulent flow in the wellbore. Normally, laminar flow is required to use the solution. Because of

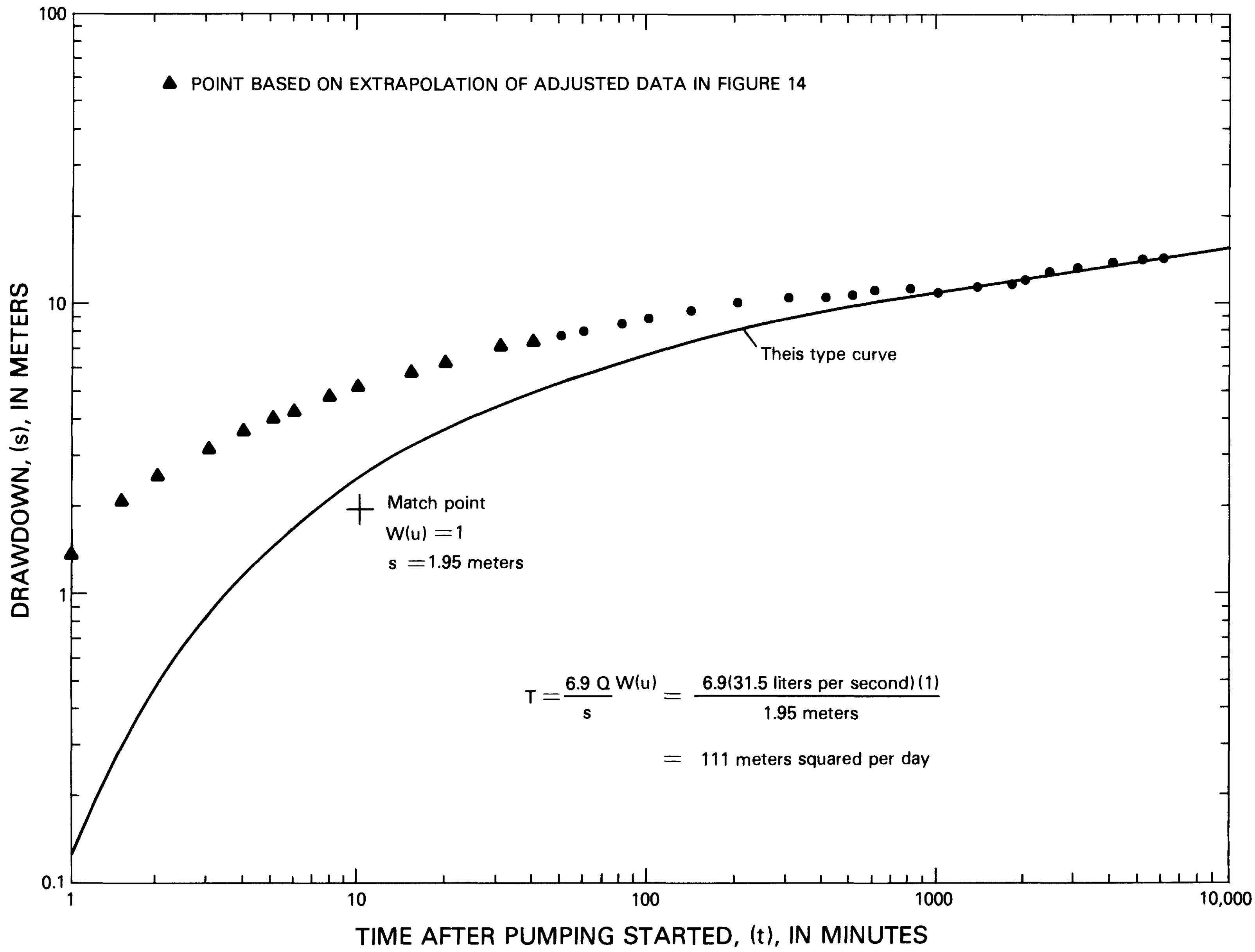

Figure 15.--Analysis of adjusted water-level drawdown, pumping test 2, depth interval 1,297 to 1,805 meters, Theis method.

large uncertainties in applying van der Kamp's solution to recovery test data, and the scarcity of data during laminar flow, the attempt was abandoned.

The plot in figure 12 indicates that, because of thermal expansion of the water column, the water level recovered to a higher level than the prepumping water level. As the water column cooled, the water level declined toward the original static level.

PACKER-INJECTION TESTS

Packer-injection (slug) tests were conducted in various intervals of the well to obtain data for determination of the distribution of hydraulic characteristics in the formations. Tests were conducted in intervals isolated between packers, or in the interval from the bottom packer to the bottom of the open hole. Water was injected by filling tubing that was connected to the packer tool, then opening the tool to the appropriate interval. Because the volume of fluid injected during each test was relatively small (about 2,000 L), the radius of investigation in the formations was small.

Although slug tests may be useful at transmissivities less than about 650 m^2/d (Lohman, 1972, p. 27), design of the packer-injection tool used during testing of well UE-25p#1 restricted determinations to transmissivities less than about 5 m^2/d (C. O. Stokley, TAM International, oral commun., 1983). Apparently, this restriction applied in two tests of the Tertiary section, and in all but two tests of the Paleozoic section. The criterion used to determine whether the decline in water level during testing was due to formation characteristics or tool restrictions was whether static water level was attained in about 5 minutes or less; if so, the response was considered to be due to tool limitations. The data for tests of the Paleozoic section, for which the response appeared to have been due to tool limitations, are not shown in this report, but are shown in another report for this well (Craig and Johnson, 1984).

Packers used for injection tests in test well UE-25p#1 were used later in another test well where it was observed that a tool malfunction was allowing the upper packer to deflate slowly, thereby allowing water to bypass the packer. This resulted in water-level changes occurring more quickly than the tested interval alone would have allowed and might have resulted in an erroneously large value of calculated permeability. At test well UE-25p#1, no tool malfunction was observed, and only indirect evidence was used to determine when the upper packer may have begun to deflate during testing. Based on rates of water-level changes during the tests and records of pressure obtained concurrently from beyond the tested intervals, those tests for which leakage could have occurred and for which the results are not necessarily valid are marked with a footnote in table 3 (page 31), beginning with test number 20.

Determination of transmissivity was by the method of Cooper and others (1967) and Papadopulos and others (1973) for those intervals for which data could be matched to a type curve. This method assumes a homogeneous, isotropic, confined aquifer that is fully penetrated by the tested well. In addition, the well is instantaneously charged with one slug of water. Inertia of the water column in the well is ignored. Although a dual-porosity system violates a strict assumption of homogeneity, during the relatively short duration of tests of intervals containing permeable fractures, flow was into fractures that were treated as homogeneous. Test intervals without permeable fractures probably are nearly homogeneous and isotropic. The greatest divergence from these assumptions probably occurred in intervals with minor fracture permeability.

The decline of water level during each test, shown as the ratio of hydraulic head above static water level at a given time (H), to hydraulic head above static water level at the time of injection (H_o), versus time since injection began, is shown in semi-logarithmic graphs in figures 16 through 29. The ratio H/H_o is along the vertical, or arithmetic, axis; time is along the horizontal, or logarithmic, axis. Hydraulic head above static water level at the time of injection for each test is shown as the value equal to H_o; hydraulic head at time of injection commonly was about 5 m above land surface. A family of type curves was used to determine a best fit with the data. A match line was selected on the logarithmic scale of the type-curve graph, with a value of 1.0. The corresponding match line of time, t, on the data curve then was determined. In general, a best fit corresponded well with the middle part of the data. The beginning and ending data of many of the tests were below the type curve chosen. The lack of a good fit at the beginning and end of many of the tests was attributed to an initial decline in water level, as the well-aquifer system became pressurized during the start of a test. The initial decline in water level probably resulted in a value of H_o being used that was actually greater than the true value. As a result, the true value of H/H_o probably was greater than shown. Such error would have had only a small effect on the steeper or middle part of the curve that is matched to calculate transmissivity. The beginning and ending data would be below a type curve. Results were thought not to have been significantly affected.

Transmissivities were calculated by use of the following equation (Cooper and others, 1967, p. 267):

$$T = \frac{1440\ r_c^2}{t}, \qquad (5)$$

where T is transmissivity, in meters squared per day;
r_c is radius of tubing in interval over which water level fluctuates, in meters; and
t is match line of time since injection began, in minutes.

Relevant data for the packer-injection tests, as well as apparent transmissivities, are listed in table 3. Storage coefficients can, in principle, be calculated by the method of Cooper and others (1967, p. 267); but, as they stated, a determination by their method has questionable reliability, because the shapes of the type curves for the different values of storage parameter, α, are so similar that it is not possible to select one that definitely gives a superior fit to the data. Determination of transmissivity is much less sensitive to curve matching. Therefore, values of the storage coefficient were not calculated.

Table 3.--*Results of packer-injection tests*

Test number	Test interval (meters)	Stratigraphic unit(s) tested (See table 1 for rank of unit tested)	Apparent transmissivity (meters squared per day)	Approximate time to attain static water level (minutes)
1	384-500	Tuffaceous beds of Calico Hills, bedded tuff, and Prow Pass Member.	1/	1/
2	500-550	Prow Pass Member and bedded tuff.	0.1	150
3	550-600	Bedded tuff and Bullfrog Member.	2.8	40
4	600-650	Bullfrog Member.	2/~3-5	30
5	640-690	Bullfrog Member and bedded tuff.	1.1	110
6	690-740	Tram Member.	.2	3/
7	739-789	Tram Member.	1.1	110
8	764-834	Tram Member.	.6	170
9	834-904	Tram Member and Lithic Ridge Tuff.	.8	150
10	904-974	Lithic Ridge Tuff.	.9	120
11	974-1,044	Lithic Ridge Tuff.	2/~3-5	30

Table 3.--*Results of packer-injection tests*--Continued

Test number	Test interval (meters)	Stratigraphic unit(s) tested (See table 1 for rank of unit tested)	Apparent transmissivity (meters squared per day)	Approximate time to attain static water level (minutes)
12	1,044-1,114	Lithic Ridge Tuff, bedded tuff, and older tuff (units A and C).	4/ >5	5
13	1,110-1,180	Older tuff (unit C), conglomerate, and calcified ash-flow tuff.	0.1	120
14	1,183-1,301	Calcified ash-flow tuff, tuff of Yucca Flat(?), and Lone Mountain Dolomite.	1/	1/
15	1,297-1,308	Lone Mountain Dolomite.	.7	150
16	1,297-1,337	Lone Mountain Dolomite.	2/ ~3-5	25
17	1,341-1,381	Lone Mountain Dolomite.	4/ >5	5
18	1,381-1,421	Lone Mountain Dolomite.	4/ >5	5
19	1,423-1,463	Lone Mountain Dolomite.	4/ >5	6
20 5/	1,463-1,509	Lone Mountain Dolomite.	4/ >5	5
21 5/	1,509-1,555	Lone Mountain Dolomite.	4/ >5	5
22	1,558-1,805	Lone Mountain Dolomite and Roberts Mountains Formation.	4/ >5	5
23 5/	1,554-1,600	Lone Mountain Dolomite.	4/ >5	5

Table 3.--*Results of packer-injection tests*--Continued

Test number	Test interval (meters)	Stratigraphic unit(s) tested (See table 1 for rank of unit tested)	Apparent transmissivity (meters squared per day)	Approximate time to attain static water level (minutes)
24[5/]	1,597-1,643	Lone Mountain Dolomite.	[4/]>5	5
25	1,646-1,805	Lone Mountain Dolomite and Roberts Mountains Formation.	[4/]>5	6
26[5/]	1,643-1,689	Lone Mountain Dolomite and Roberts Mountains Formation.	[4/]>5	5
27[5/]	1,689-1,735	Roberts Mountains Formation.	[4/]>5	5
28[5/]	1,735-1,781	Roberts Mountains Formation.	[4/]>5	5
29	1,783-1,805	Roberts Mountains Formation.	[2/]~3-5	20

1/Water-level measurement only. Based on flow survey, apparent transmissivity was greater than 5 meters squared per day.

2/Transmissivity in this interval estimated to be between about 3 and 5 meters squared per day, based on: (1) Data curve too steep to match type curve; and (2) duration of test longer than minimum time based on tool limitations (see text for discussion of estimate).

3/Test stopped after 120 minutes, with about 73 percent of the water column dissipated.

4/Transmissivity in this interval greater than about 5 meters squared per day on the basis of test duration less than minimum time based on tool limitation (see text for explanation of injection-tool limitations).

5/Determination of transmissivity not necessarily valid (see test for explanation).

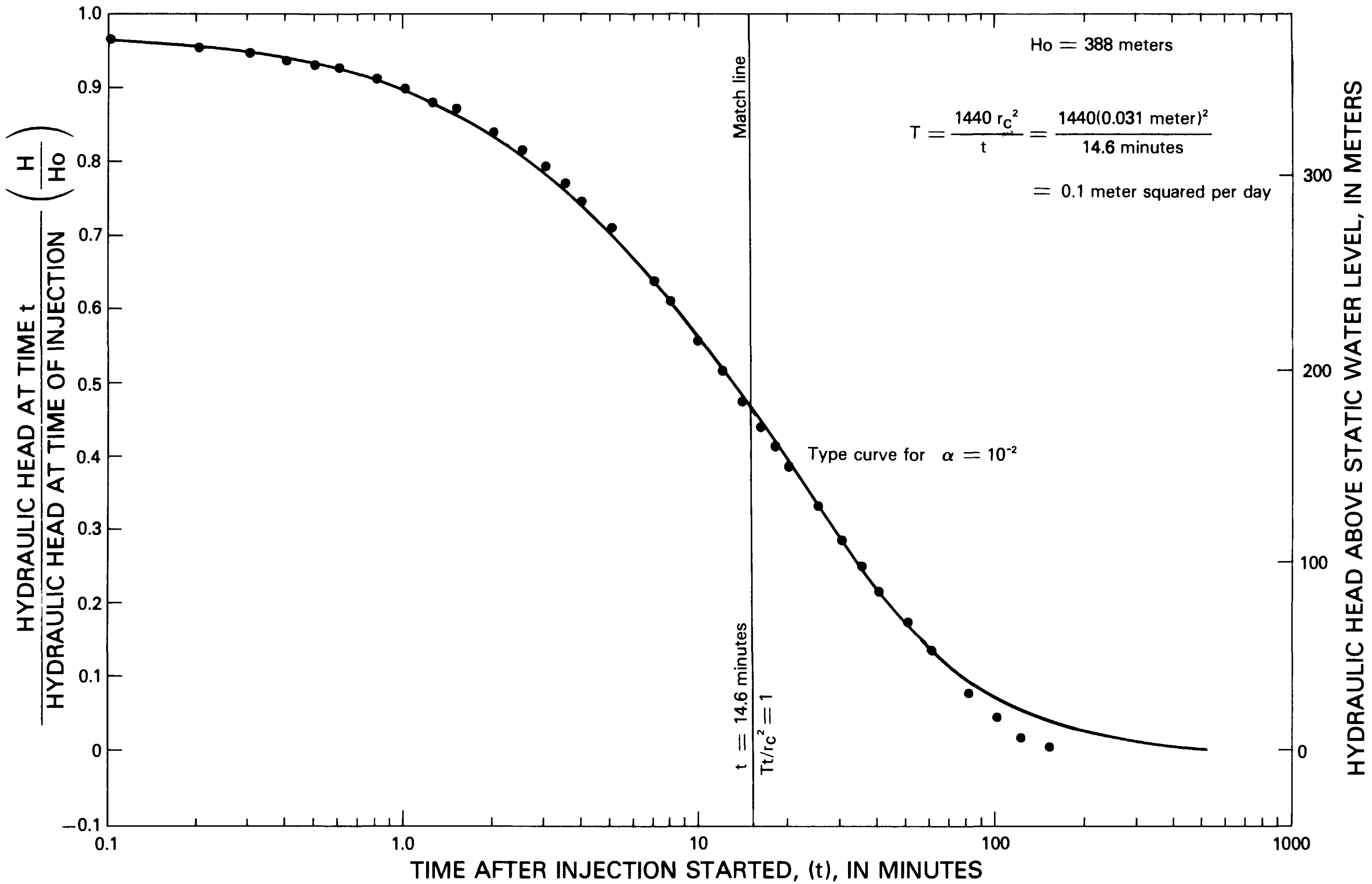

Figure 16.--Analysis of packer-injection test 2, depth interval from 500 to 550 meters.

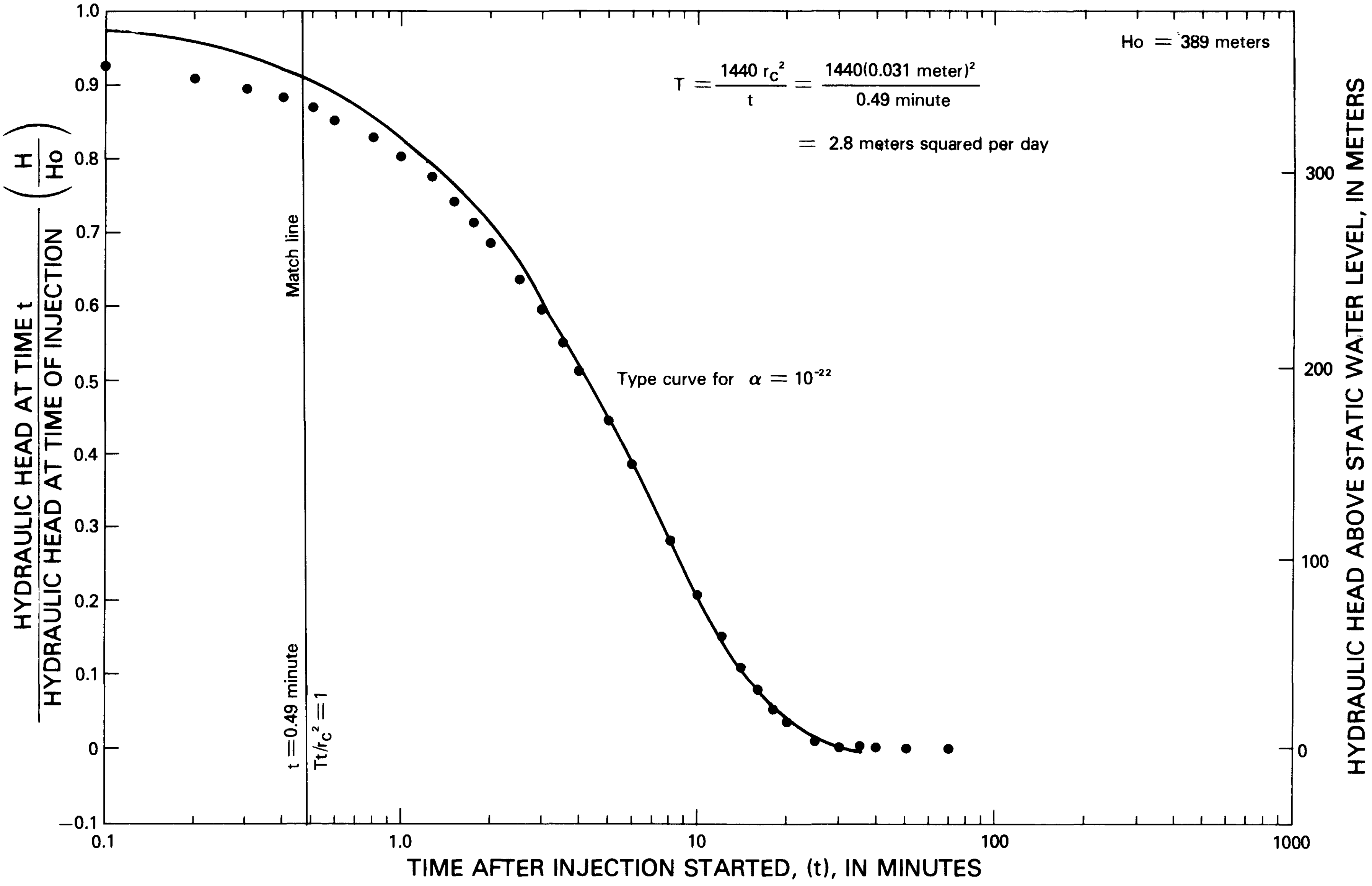

Figure 17.--Analysis of packer-injection test 3, depth interval from 550 to 600 meters.

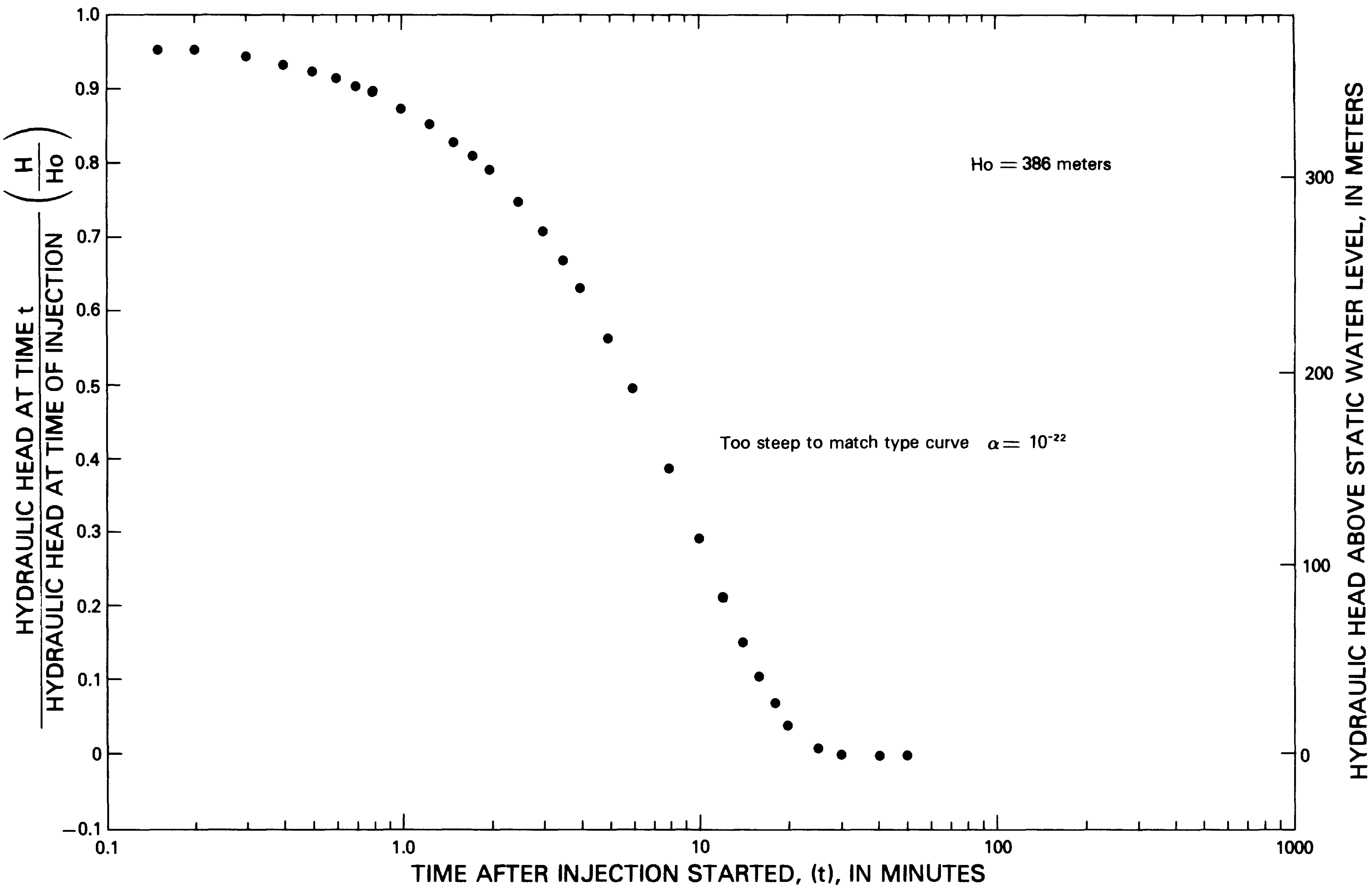

Figure 18.--Analysis of packer-injection test 4, depth interval from 600 to 650 meters.

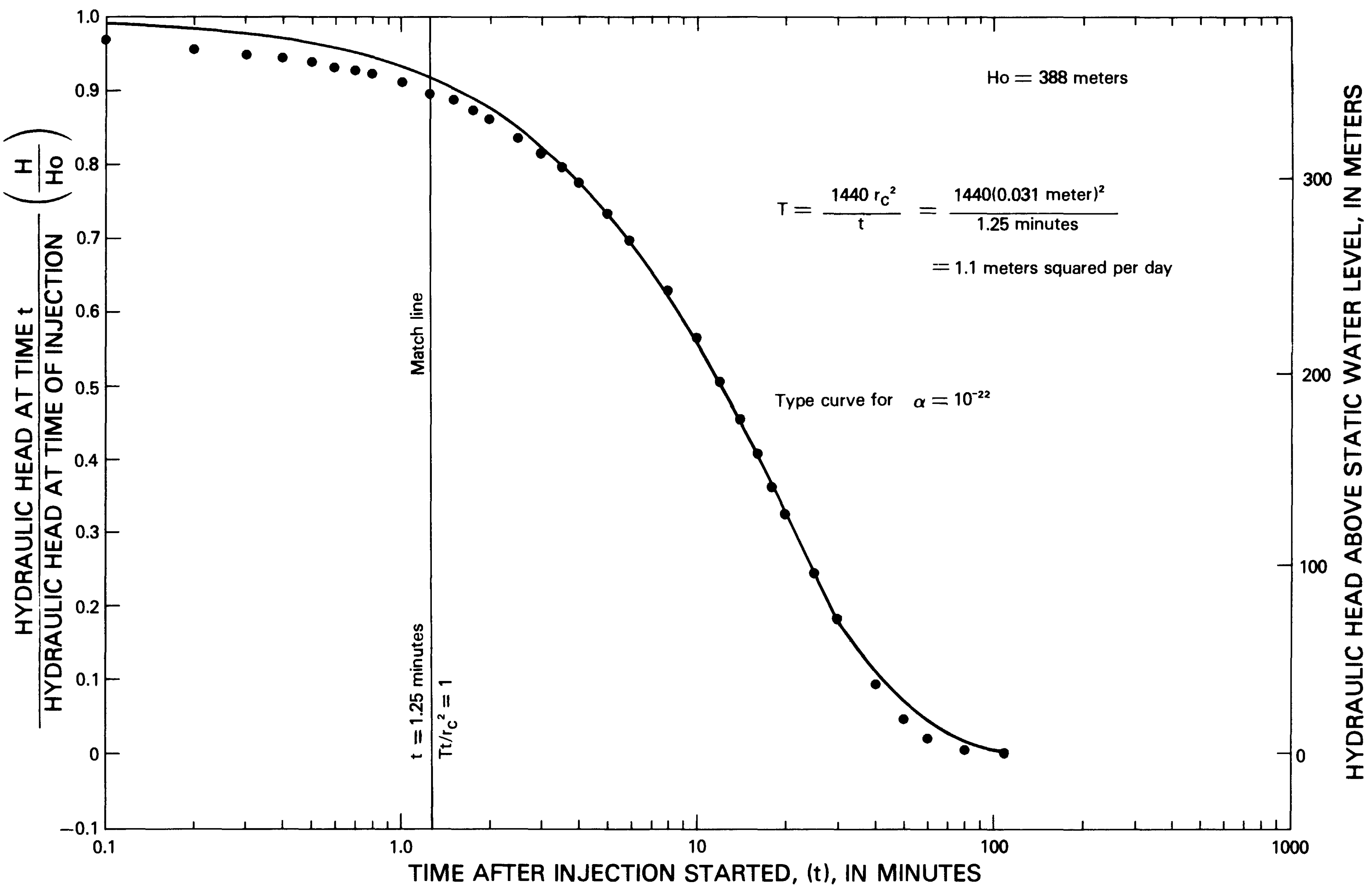

Figure 19.--Analysis of packer-injection test 5, depth interval from 640 to 690 meters.

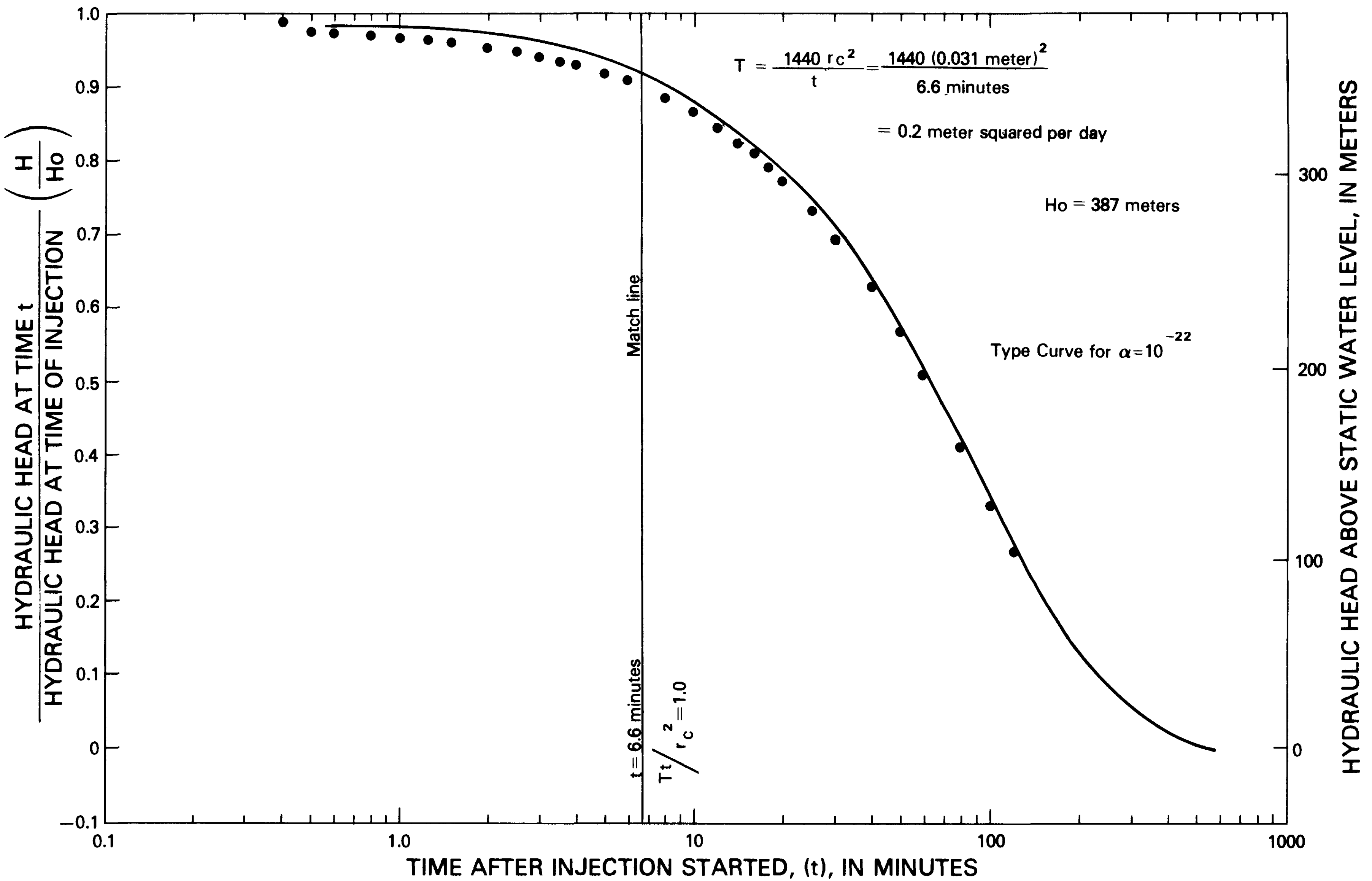

Figure 20.--Analysis of packer-injection test 6, depth interval from 690 to 740 meters.

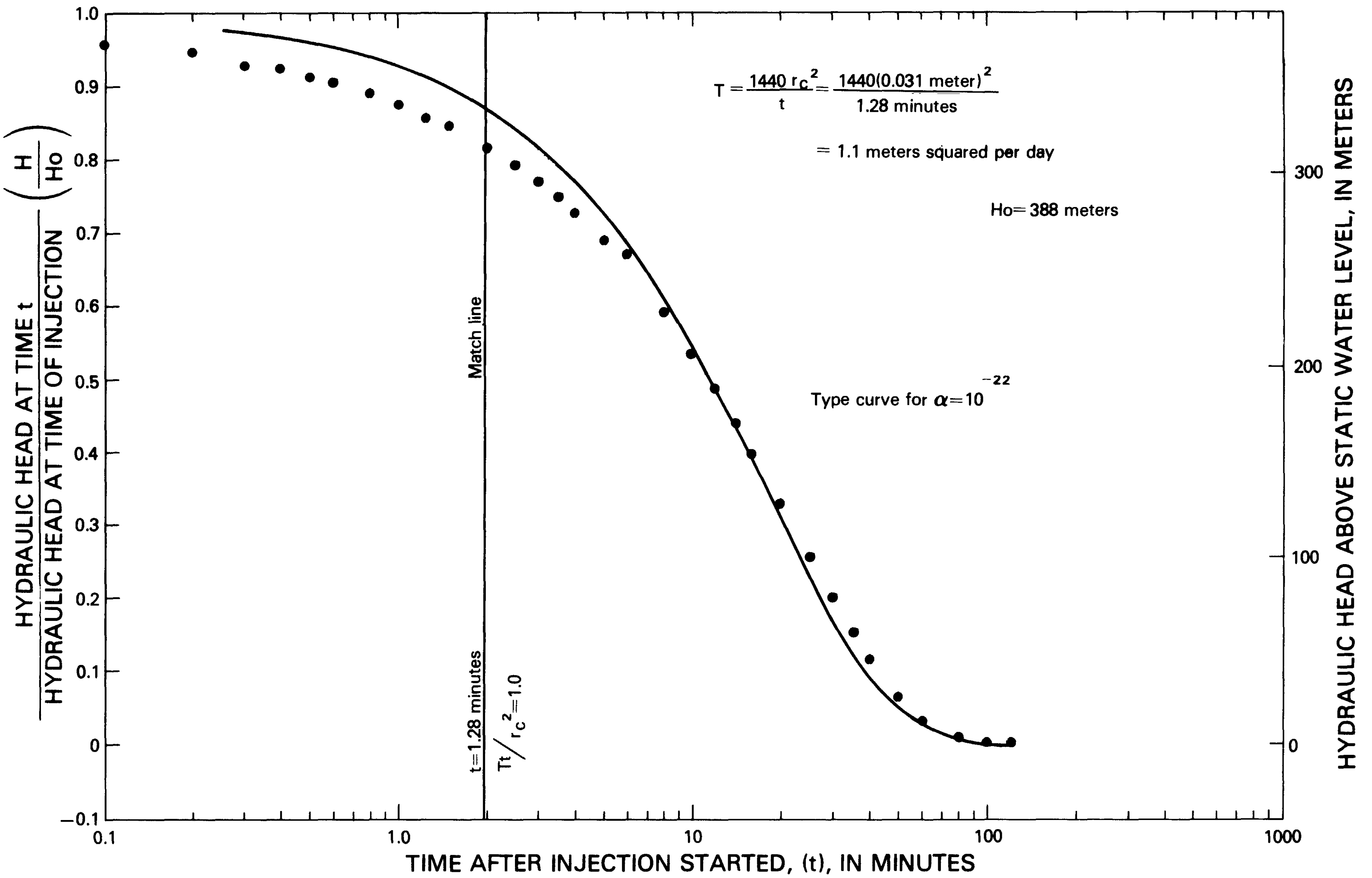

Figure 21.--Analysis of packer-injection test 7, depth interval from 739 to 789 meters.

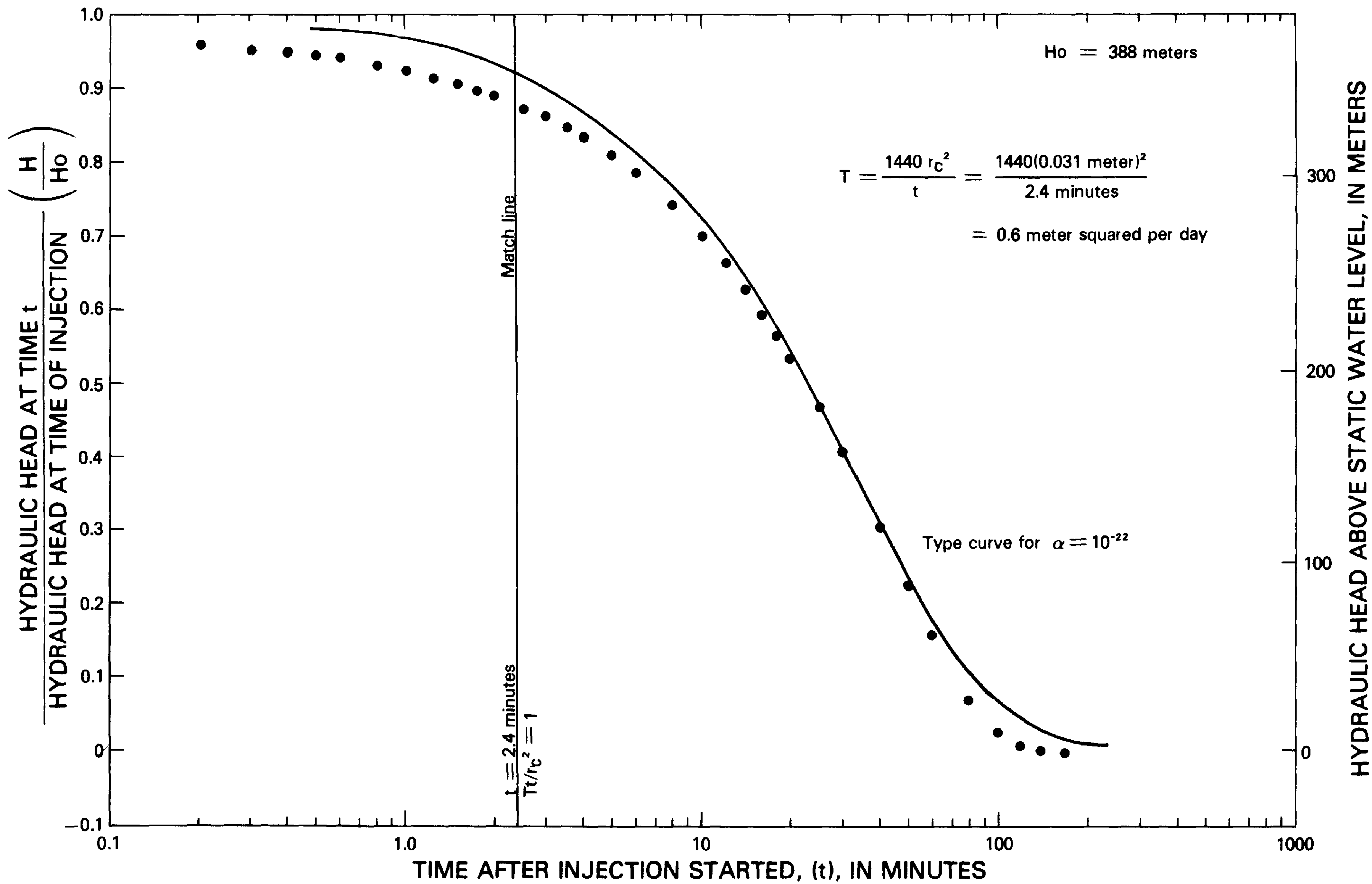

Figure 22.--Analysis of packer-injection test 8, depth interval from 764 to 834 meters.

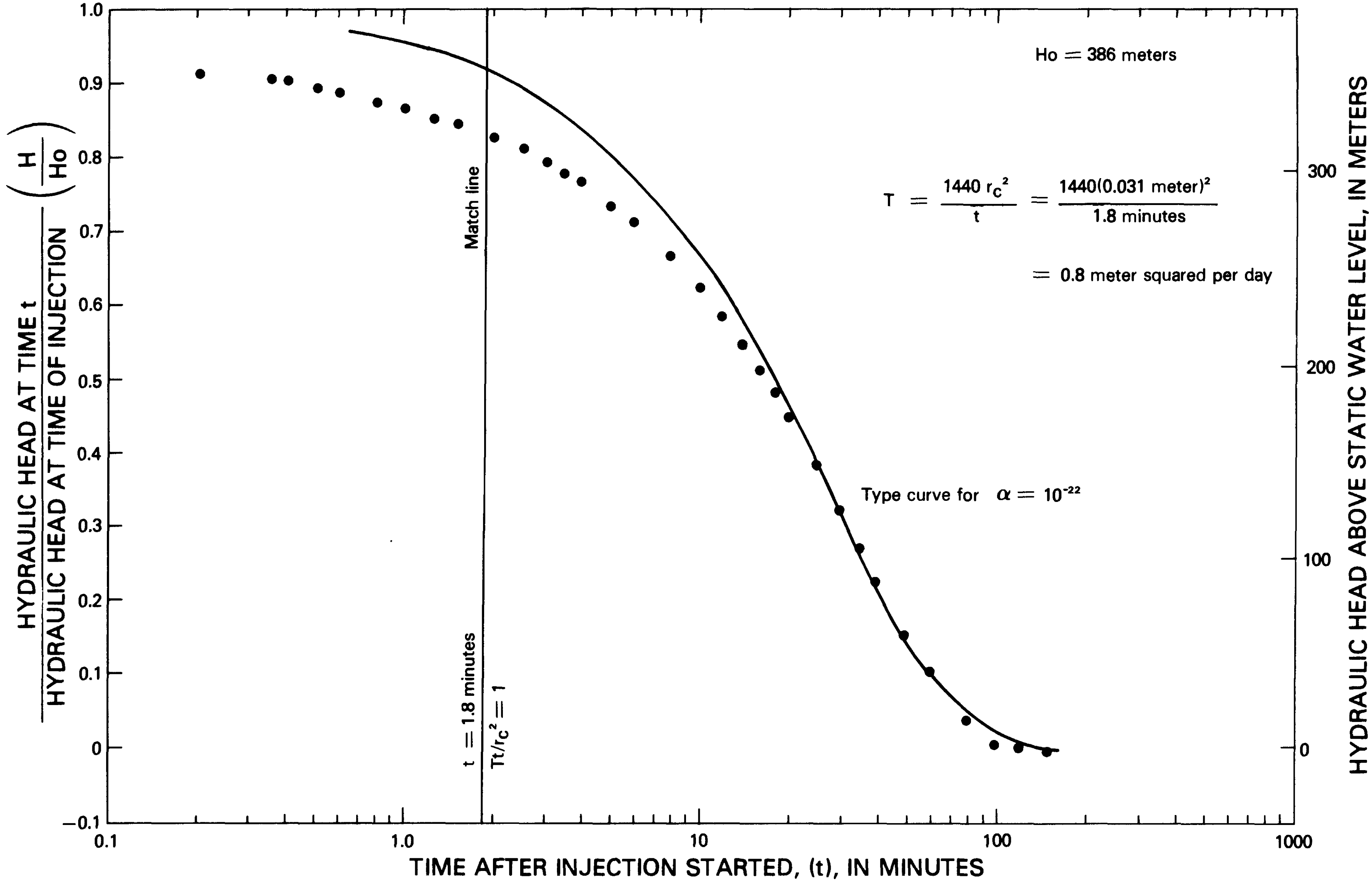

Figure 23.--Analysis of packer-injection test 9, depth interval from 834 to 904 meters.

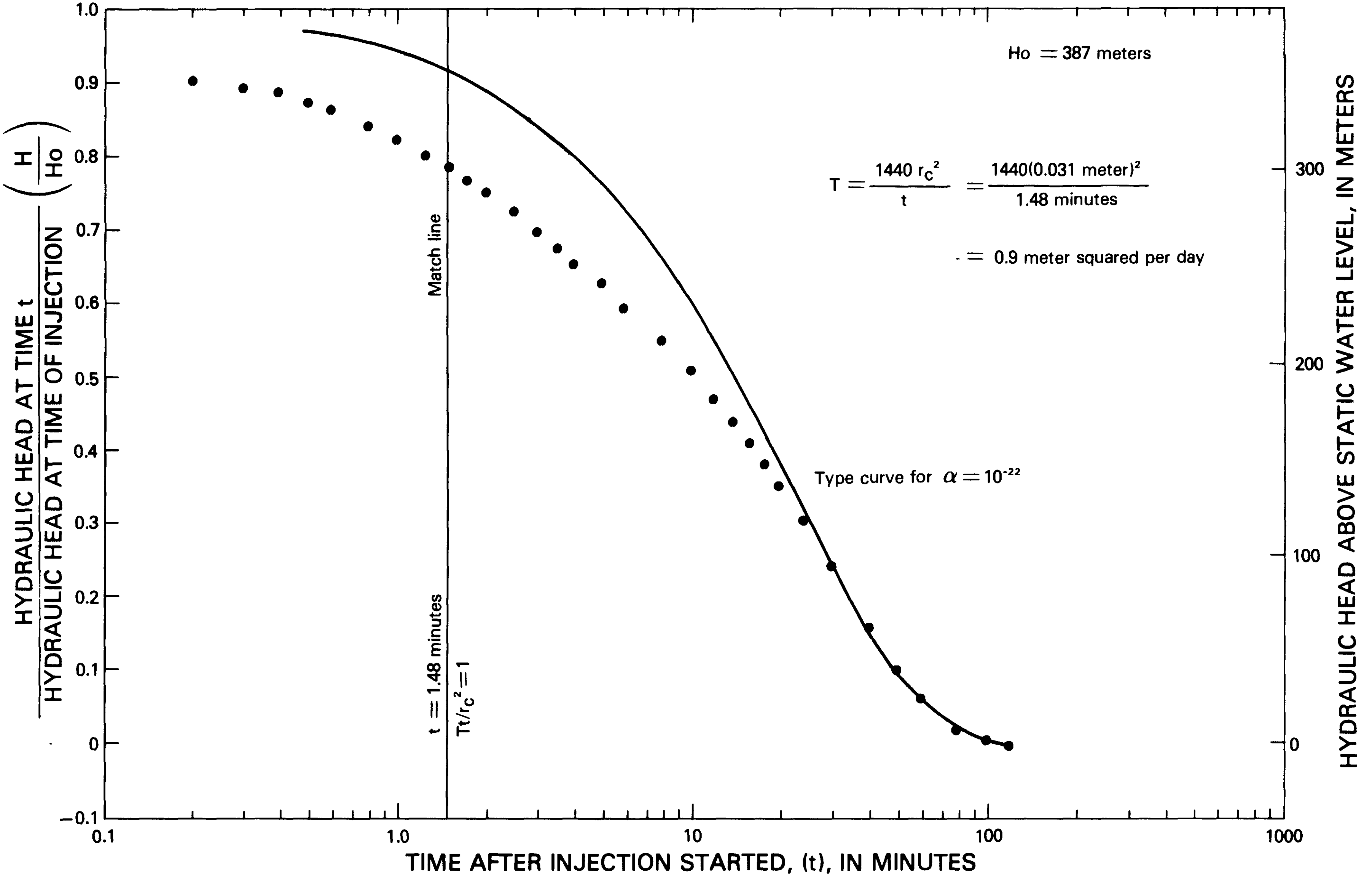

Figure 24.--Analysis of packer-injection test 10, depth interval from 904 to 974 meters.

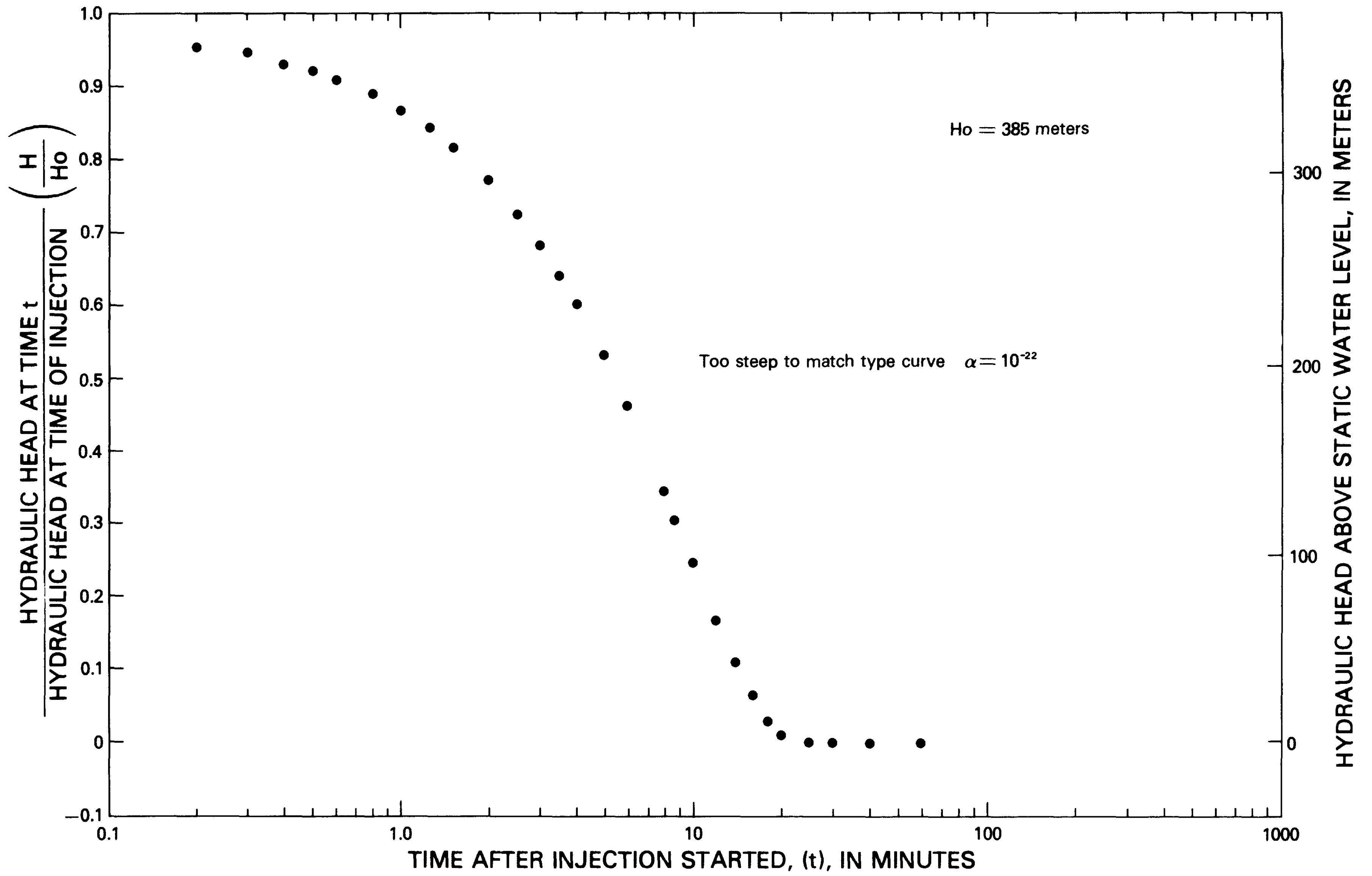

Figure 25.--Analysis of packer-injection test 11, depth interval from 974 to 1,044 meters.

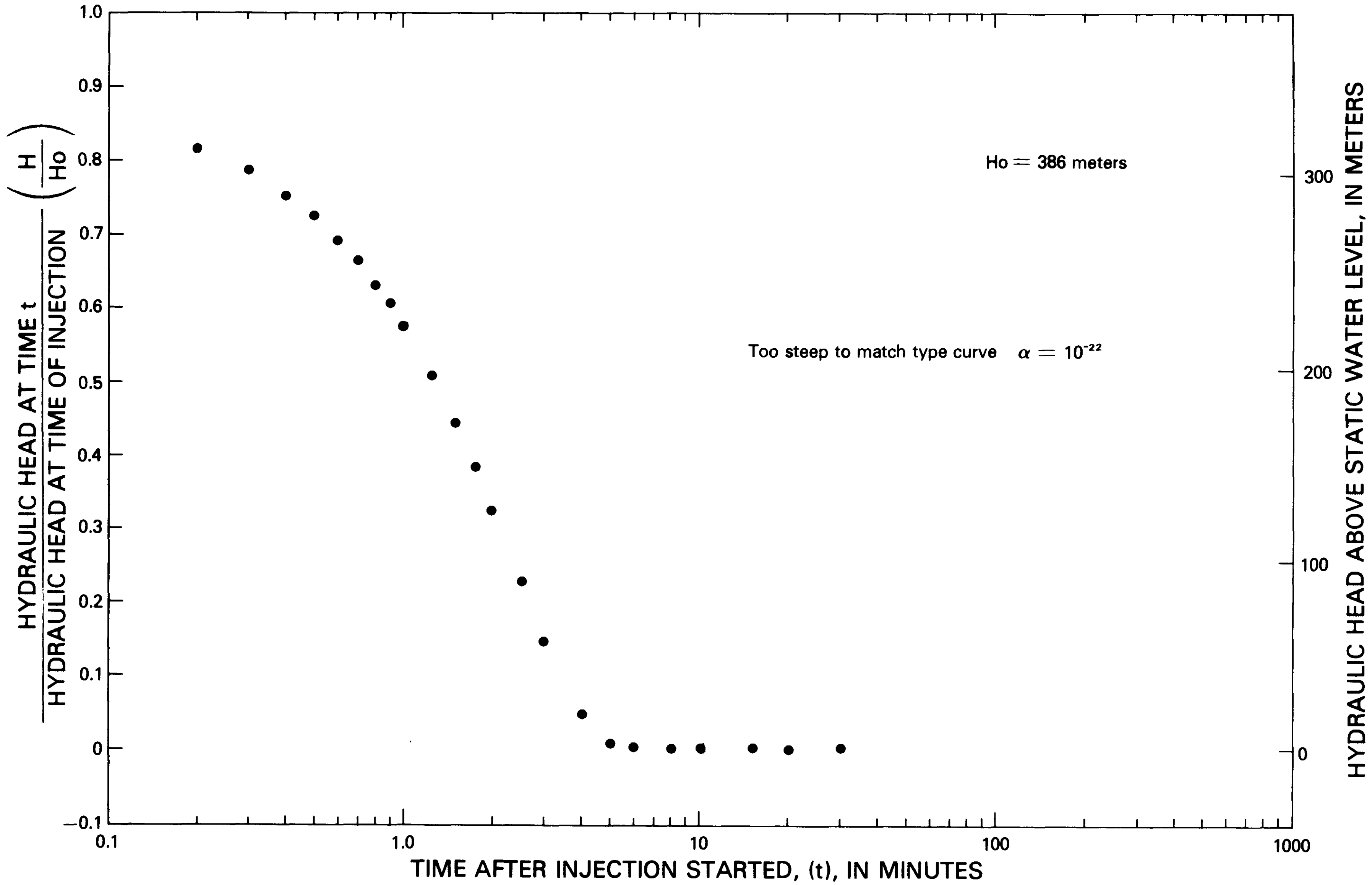

Figure 26.--Analysis of packer-injection test 12, depth interval from 1,044 to 1,114 meters.

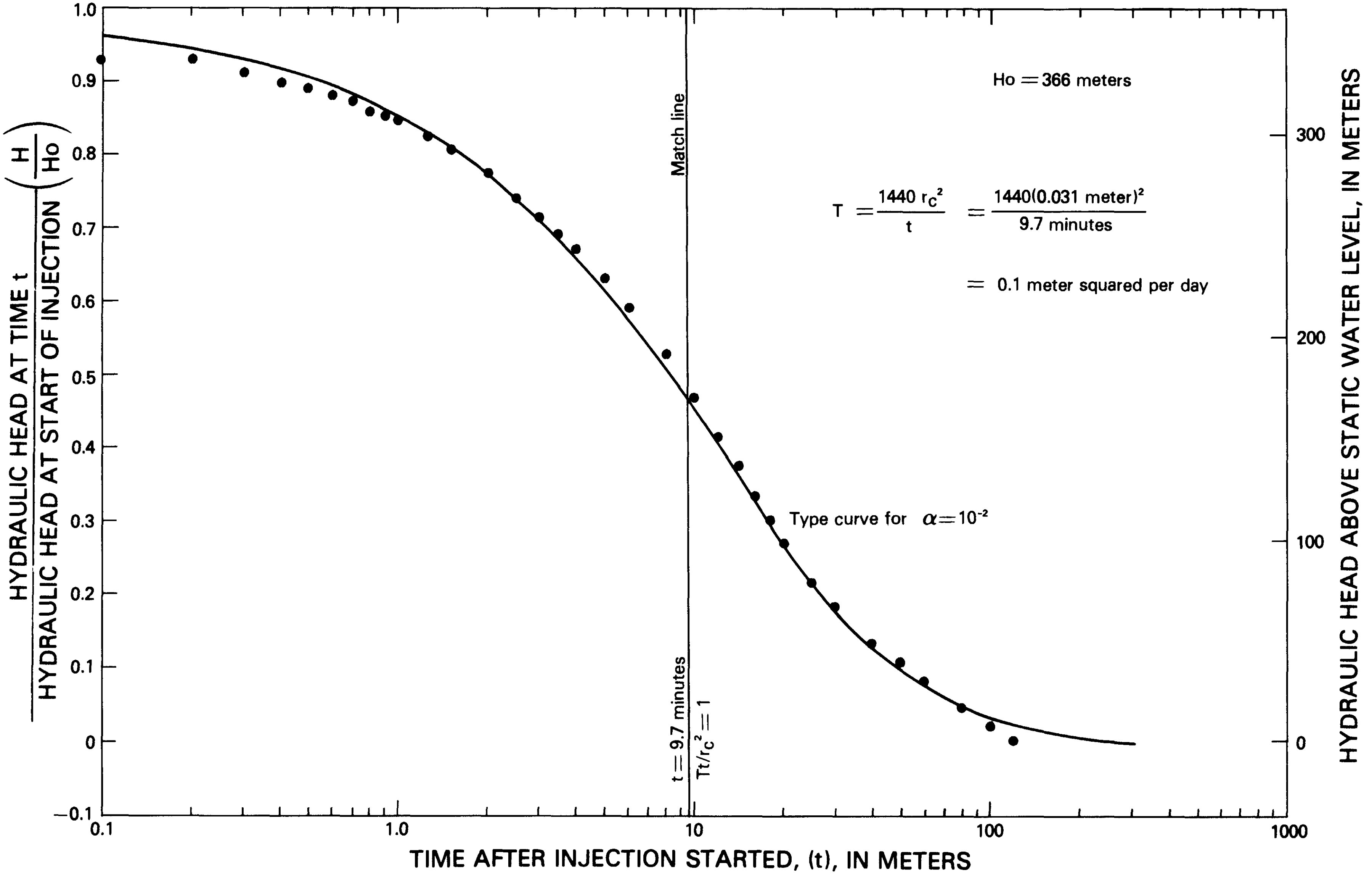

Figure 27.--Analysis of packer-injection test 13, depth interval from 1,110 to 1,180 meters.

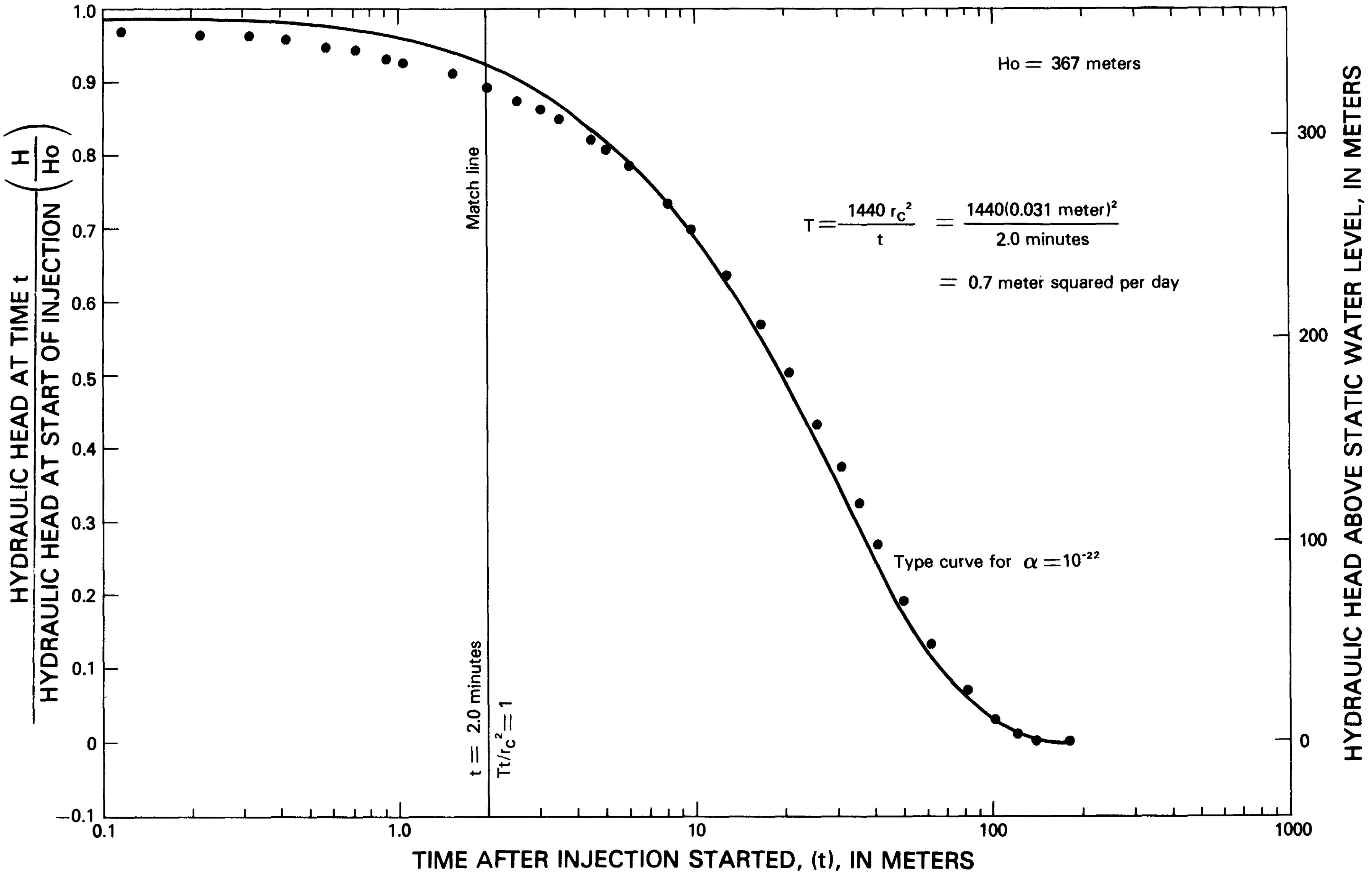

Figure 28.--Analysis of packer-injection test 15, depth interval from 1,297 to 1,308 meters.

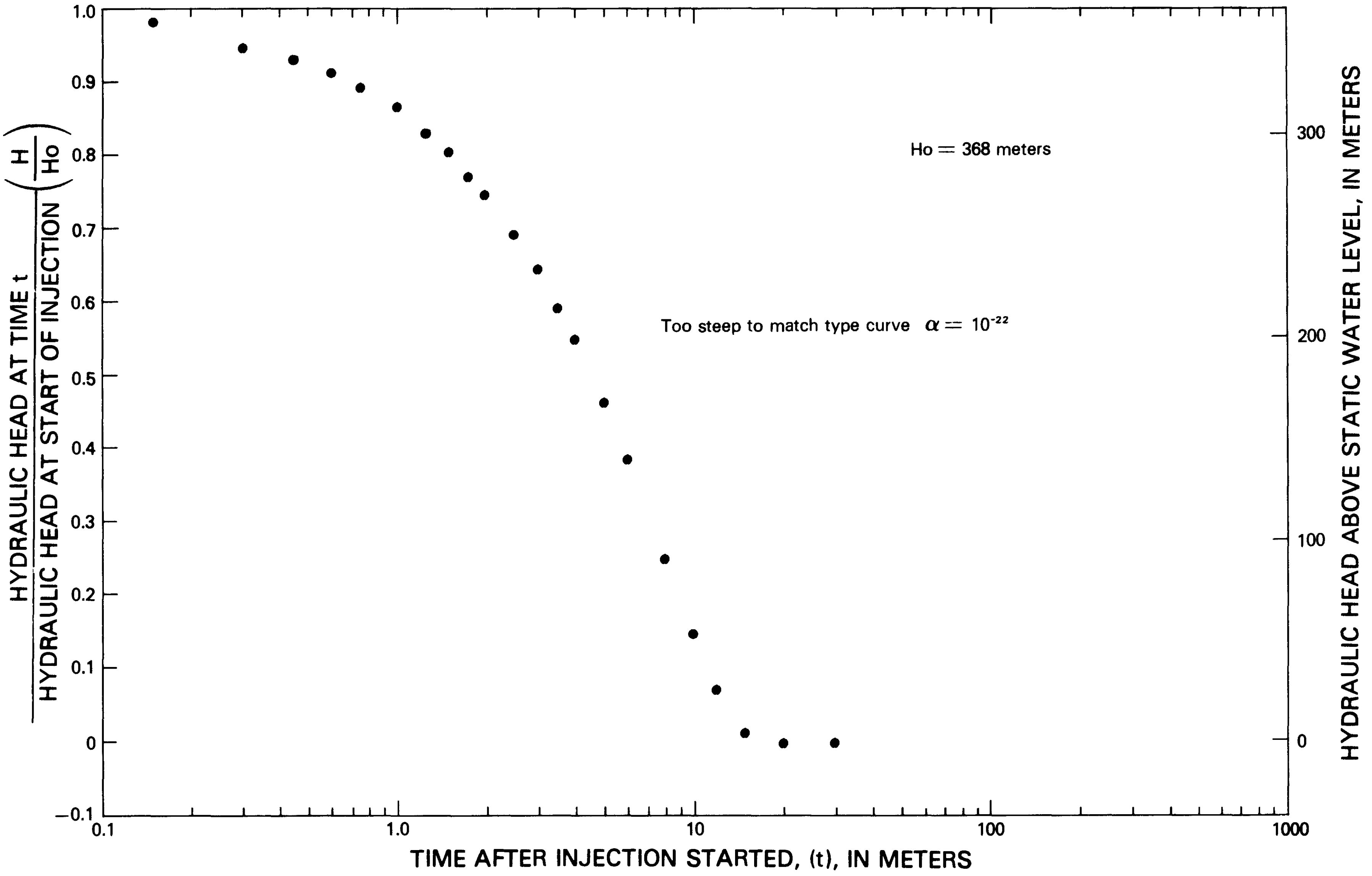

Figure 29.--Analysis of packer-injection test 29, depth interval from 1,783 to 1,805 meters.

Transmissivities of the intervals tested during the Tertiary phase of testing ranged from about 0.1 m^2/d to greater than 5 m^2/d. Two intervals, test 1 in the lower tuffaceous beds of Calico Hills and upper part of the Prow Pass Member of the Crater Flat Tuff and test 14 in older tuff (unnamed) and Lone Mountain Dolomite were isolated from the remainder of the hole for water-level measurements, but not tested by means of a packer-injection test. A borehole-flow survey during pumping indicated that both zones had transmissivities in excess of 5 m^2/d. In the remainder of the Tertiary section, only test interval 12, containing the lower part of the Lithic Ridge Tuff, a bedded tuff (unnamed), and older tuff (units A and C) had a transmissivity greater than 5 m^2/d. In two tests, test 4 in the Bullfrog Member and test 11 in the Lithic Ridge Tuff, data curves were too steep to match with available type curves. As a match was obtained in test 3 in the upper part of the Bullfrog Member of the Crater Flat Tuff with a transmissivity of 2.8 m^2/d, it was assumed that intervals penetrated by test well UE-25p#1 that have data curves that are too steep to match have a transmissivity greater than about 3 m^2/d. A maximum limit can be obtained by noting that the time to attain static water level in each test was about 20 to 25 minutes. As the time to attain static water level at transmissivities greater than about 5 m^2/d (the tool limitation) was about 5 minutes, transmissivities of the two intervals (tests 4 and 11) could be estimated as between 3 and 5 m^2/d. Based on the time to attain static water level, actual values probably are closer to 3 m^2/d than to 5 m^2/d.

The other test intervals in the Tertiary section, with three exceptions, were characterized as having apparent transmissivities of about 0.5 to 1 m^2/d. The three exceptions have apparent transmissivities of 0.1 to 0.2 m^2/d. These three intervals occur in the lower part of the Prow Pass Member (test 2), in the upper part of the Tram Member (test 6), and in a combination of older tuff (unnamed), and unnamed conglomerate (test 13). The combined apparent transmissivity of the intervals isolated within the Tertiary section probably is greater than 30 m^2/d.

Most packer-injection tests conducted in the Paleozoic formations were significantly affected by inertia. The three exceptions were the uppermost and lowermost tests (15, 16, and 29). In each of the remaining tests, an oscillation in the water level indicated that inertial effects were significant. As an example, the sine wave fluctuation during test 26 in the Lone Mountain Dolomite is shown in figure 30. The other tests affected by inertia are not shown here, but are shown in Craig and Johnson (1984). An attempt was made to apply van der Kamp's (1976) approximate solution, using data for the underdamped tests. As noted in the section on pumping and recovery test 2, the solution normally only applied during laminar flow. In most of the tests, available data did not define the sine-wave response in sufficient detail during laminar flow. Viscosity of water was assumed to have been 1×10^{-6} m^2/s. Most tests that can be analyzed by van der Kamp's (1976) solution gave values of transmissivities that seemed too large. The estimate of the transmissivity of test interval 26 (fig. 30) was 83 m^2/d. [See van der Kamp (1976) for appropriate equations and method of calculation.] This estimate seemed too high for the 46-m interval; based on the transmissivity determined by the pumping test (111 m^2/d) and on the small production of the interval during the borehole-flow survey, a transmissivity of about 1 m^2/d was expected for the interval. Alternatively, if the top packer was not seated

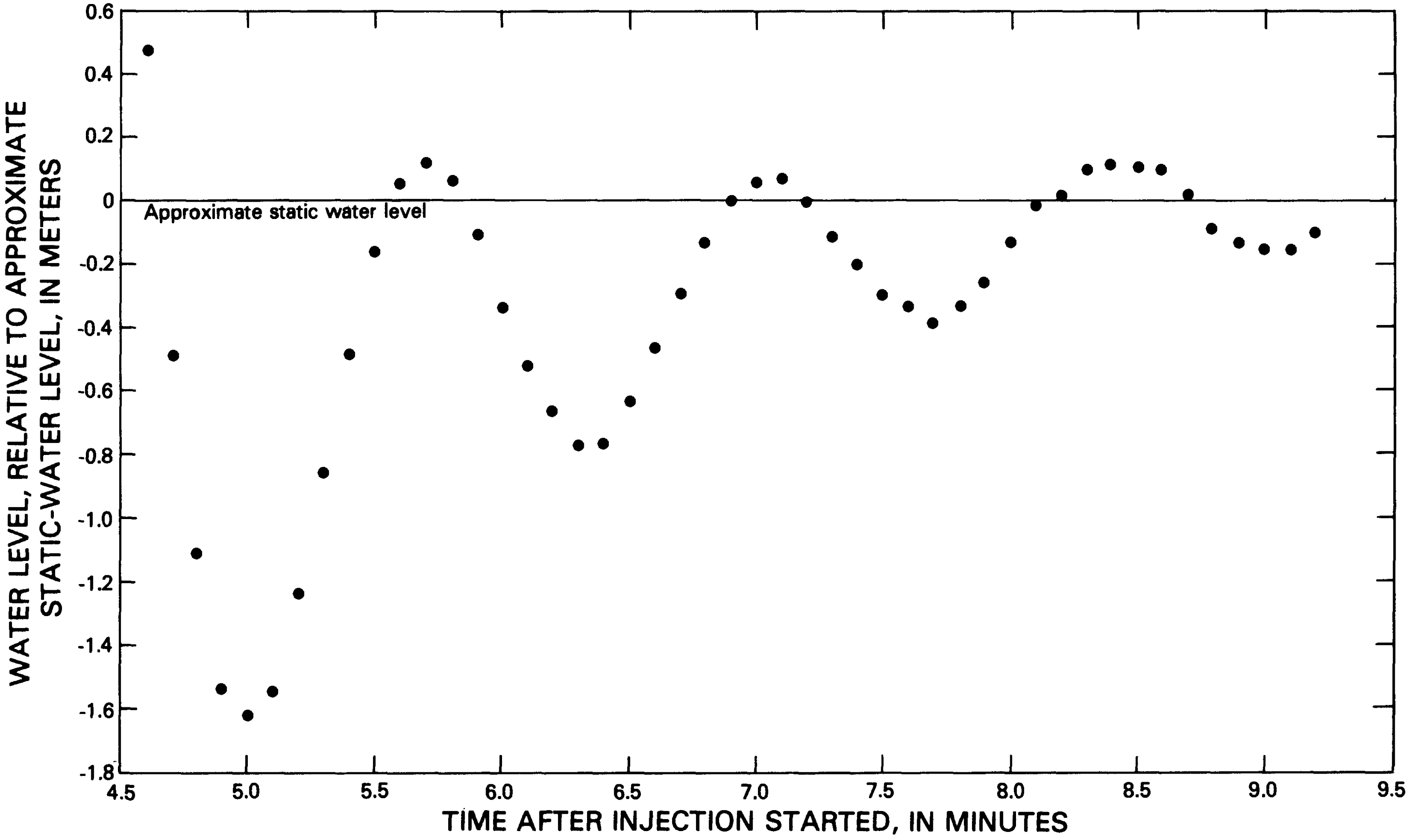

Figure 30.--Damped sine-wave response during packer-injection test 26, depth interval from 1,643 to 1,689 meters.

during test 26, calculated transmissivity would have applied to the depth interval from the bottom of casing at 1,297 m to the bottom packer at 1,689 m. In this case, the transmissivity would be in reasonable agreement with the pumping test results. Due to uncertainty about test results, further estimates of transmissivity based on van der Kamp's solution are not shown.

In summary, the packer-injection tests in the Paleozoic section, with three exceptions, indicated a transmissivity for each tested interval greater than about 5 m^2/d, based on the tool limitation. Test interval 15 had a transmissivity of 0.7 m^2/d, and test intervals 16 and 29 had data curves too steep to match to available type curves. On the basis of the same argument presented in the discussion of Tertiary-section tests 4 and 11, the transmissivity of test intervals 16 and 29 was estimated to range from 3 to 5 m^2/d. An estimate of the minimum transmissivity of the Paleozoic section based on packer-injection tests was about 60 m^2/d.

GROUND-WATER CHEMISTRY

Chemical compositions of three ground-water samples from test well UE-25p#1 are shown in table 4. Sample 3182060 was collected during non-pumping conditions using a thief sampler positioned just above the plug; a few days later a borehole-flow survey was made, also during non-pumping conditions; the survey showed upward movement of water above the plug. Therefore, it was concluded that the thief sample represented water that flowed from below the plug during pumping of the Tertiary interval. Sample 3182061 was collected while pumping the Paleozoic carbonate (lower test) interval, and sample 3182062 was collected while pumping the Tertiary (upper test) interval. A borehole-flow survey of the Tertiary interval (fig. 6) indicated that 28.6 percent of the total flow probably came from beneath a temporary plug at the base of the tested Tertiary interval.

The stable isotopes and concentrations of most constituents of the sample from the thief sample and the Paleozoic interval are nearly identical. The chemical character generally is similar (although constituents in the water from test well UE-25p#1 are more concentrated) to ground water from the regional carbonate (Paleozoic) aquifer of the Ash Meadows ground-water basin (Winograd and Pearson, 1976, tables 1 and 2). The $\delta^{13}C$ value for the sample from the Paleozoic aquifer, at -2.2 parts per thousand, is more concentrated than is typical of most ground water, including water from Ash Meadows. This difference indicates that a significant part of the aqueous carbon may have been derived from marine carbonate minerals.

Table 4.--*Chemical and isotopic composition of ground water*

[Values for chemical constituents are in milligrams per liter unless otherwise indicated. Analyses by U.S. Geological Survey, Denver, Colorado]

Name of sample (see text)	Test well UE-25p#1: Thief sample, Paleozoic aquifer	Test well UE-25p#1: Paleozoic aquifer	Test well UE-25p#1: "Contaminated" Tertiary aquifer	Test well UE-25p#1: Calculated, Tertiary aquifer	Well J-13, Tertiary[1]	Test well USW H-4, Tertiary[1]
Laboratory sample number	3182060	3182061	3182062	---------	-------	2145006
Depth interval (meters)	1,173	1,298-1,792	400-1,193	400-1,193	282-1,063	520-1,220
Date	2/11/83	5/12/83	2/09/83	2/09/83	3/26/71	5/17/82
Specific conductance, laboratory (microsiemens per centimeter at 25° Celsius	1,220	1,330	639	406±16	-----	381
pH, field (units)	6.7	6.6	6.8	6.6	7.2	7.4
pH, laboratory (units)	7.8	7.2	7.7	-------	-----	7.9
Temperature (° Celsius)[2]	57	56	44	39	31	35
Calcium	94	100	37	14±2	12	17
Magnesium	31	39	10	1.6±.6	2.1	.3
Sodium	150	150	92	69±2	42	73
Potassium	12	12	5.6	[3]3.0±.1	5.0	2.6
Total alkalinity, as HCO_3, field	730	710	330	-------	-----	------
Total alkalinity, as HCO_3, laboratory	753	694	344	179±11	124	171
Sulfate	78	160	38	22±1	17	26
Chloride	26	28	13	7.8±.3	7.1	6.9
Fluoride	4.9	4.7	3.4	2.8	2.4	4.6
Silica	44	41	49	51±1	57	46
Dissolved solids (sum)	812	878	418	260	252	261
Lithium (micrograms per liter)	310	590	230	198±2	40	130
Strontium (micrograms per liter)	490	450	180	56±9	20	27
Tritium	37±10	0±10	0±10	-------	------	<10
Oxygen-18/oxygen-16[4]	-13.7	-13.8	-13.5	-13.4	-13.0	-14.0
Deuterium/hydrogen[5]	-107.5	-106.0	-106.0	-105.5	-97.5	-104
Carbon-13/carbon-12[6]	-2.8	-2.2	-4.2	-4.8	-7.3	-7.4
Carbon-14 (percent modern)	-----	2.31	3.40	-------	29.1	11.8

[1]Composition of well J-13 and USW H-4 waters from Benson and others, 1983.

[2]Measured or calculated at collection point.

[3]Error estimates based on ±5 percent of the values obtained from the thief sample (see text).

[4]Oxygen-18/oxygen-16 ($\delta^{18}O$) ratio of sample relative to standard mean ocean water (SMOW), in parts per thousand.

[5]Deuterium/hydrogen (δD) ratio of sample relative to SMOW, in parts per thousand.

[6]Carbon-13/carbon-12 ($\delta^{13}C$) ratio of sample relative to Pee Dee Belemnite Standard (PDB), in parts per thousand.

The chemical composition of the Tertiary aquifer contribution (C_o) to sample 3182062 (C_1) was calculated using the composition of the thief sample (C_2) and the percent dilution (28.6 percent) determined from the borehole-flow survey:

$$C_o = \frac{C_1 - 0.286\ C_2}{1 - 0.286} \quad . \tag{6}$$

The calculated composition of water from the Tertiary aquifer penetrated by test well UE-25p#1 and the chemical composition of water from well J-13 (3.4 km to the southeast) and test well USW H-4 (3.0 km to the northwest) are very similar (table 4); the calculated $\delta^{13}C$ concentration for water from test well UE-25p#1, however, is larger.

The carbon-14 activity of the sample from the Paleozoic aquifer was 2.31 ± 0.23 percent of modern. The "contaminated" sample from the Tertiary aquifer yielded carbon-14 activity of 3.40 ± 0.24 percent of modern.

If the sample from the Tertiary aquifer is assumed to have been diluted with 28.6 percent of water containing carbon from the Paleozoic aquifer, the calculated activity for water from the Tertiary aquifer, accounting for the difference in alkalinities, would be 5.6 percent of modern, which would give an apparent age of about 24,000 years before present. Such an age is not consistent with apparent ages of other water from the Yucca Mountain area, most of which range from about 9,000 to 17,000 years before present (Benson and others, 1983).

SUMMARY AND CONCLUSIONS

Measurements of hydraulic head in various intervals of test well UE-25p#1 showed a distinct difference in hydraulic head between the Tertiary tuffaceous rocks in the upper part of the well and the Paleozoic dolomite in the lower part of the well. Hydraulic heads in the Paleozoic section were about 20 m higher than in most of the Tertiary section. Measurements made prior to, or after each packer-injection test indicated that the major change in hydraulic head occurred between 1,114 and 1,180 m below land surface. The depth-to-water in the interval 1,044 to 1,114 m was 379.4 m, whereas depth-to-water in the interval 1,110 to 1,180 m was 361.7 m. The abrupt change in hydraulic head indicates that a confining layer with minimal vertical hydraulic conductivity occurs between 1,114 and 1,180 m. Units in this interval were 23 m of unnamed older tuff (unit C), 34 m of an unnamed conglomerate, and 9 m of calcified ash-flow tuff, all of Tertiary age. The conglomerate has a claystone matrix and probably is the confining layer.

Within the Tertiary section, hydraulic head increases with depth. Below the general area of the Tertiary-Paleozoic contact, hydraulic head decreases slightly with depth. A temperature survey indicated that the increase of temperature with depth in the Tertiary section approximately parallels the increasing hydraulic-head measurements. The survey showed almost isothermal conditions from about 1,220 to 1,400 m, followed by a decrease in temperature to a point near the bottom of the hole. A slight increase in temperature occurred in the last few meters of the hole. Conversion of the water-level measurements in the Paleozoic section to equivalent cold-water hydraulic heads at 20°C indicated that the decline in hydraulic head with depth is caused by some factor other than the decrease in temperature.

Borehole-flow surveys in both the Tertiary and Paleozoic sections showed that production while pumping was not evenly distributed throughout the well. In the Tertiary section, an interval less than 30 m in the upper part of the Prow Pass Member of the Crater Flat Tuff yielded 58 percent of production during pumping test 1. Other intervals that produced significant yields were in the upper part of the Bullfrog Member of the Crater Flat Tuff, in the lower part of the Lithic Ridge Tuff, and in older tuff (unnamed). An additional 28 percent probably came from below a temporary plug at 1,197 m. In the Paleozoic section, more than 50 percent of production during pumping test 2 came from an interval of less than 10 m in the upper part of the Lone Mountain Dolomite. A 190-m section in the middle part of the Lone Mountain Dolomite yielded 30 percent of production. The remaining amount came from other parts of the section, with about 5 percent detected below 1,550 m.

Results of the pumping test of the Tertiary section were consistent with early and middle times of a dual-porosity model. Pumping did not continue long enough to reach late time. Although an average transmissivity for a combined fracture-matrix system could not be determined from the data, an apparent transmissivity for the fracture system was determined to be about 25 m^2/d. The average transmissivity of the total system in the Tertiary section tested probably is slightly greater.

The pumping test of the Paleozoic section from 1,297 to 1,805 m appeared to have reached late time, based on a dual-porosity model, but the transmissivity calculated for late-time data was slightly less than the value calculated for early time. According to a dual-porosity model, the reverse should be true. An alternative interpretation is that the Paleozoic section was responding in a manner more like a porous-media system. However, large uncertainties in the early-time data raise questions about the reliability of the calculated transmissivity for this period and indicate that the dual-porosity model is appropriate. If the response was due to a dual-porosity system, the transmissivity was 111 m^2/d. Recovery data were dominated by inertial effects. An attempt to analyze the data was not successful because of a scarcity of data during periods of laminar flow in the wellbore and uncertainty about the application of the method to recovery data.

Packer-injection tests of the Tertiary section generally confirmed the borehole-flow survey. Those intervals that showed significant production during the flow survey also have the largest values of transmissivity. Total transmissivity of the saturated Tertiary section to a depth of 1,180 m, based on packer-injection tests, is greater than 30 m^2/d.

In the Paleozoic section, packer-injection tests indicated transmissivities greater than about 5 m^2/d for all test intervals, except three intervals at the top and bottom of the section. Based on the packer-injection tests, transmissivity of the Paleozoic section is greater than 60 m^2/d.

A comparison of transmissivities based on pumping tests and borehole-flow surveys versus transmissivities based on packer-injection tests is shown in table 5. The intervals listed correspond to intervals of packer-injection tests. Transmissivities listed under pumping tests and borehole-flow surveys were determined by multiplying the percentage of production from the interval during pumping by the total transmissivity determined by the pumping test. Transmissivity used for the Tertiary section was 25 m^2/d, and transmissivity used for the Paleozoic section was 111 m^2/d. Where direct comparison was possible, the packer-injection tests consistently indicated a greater transmissivity, within a factor of about 5. The packer-injection testing results probably represent conditions in the rock close to the borehole, where drilling-induced fractures may have increased the permeability.

On the basis of the hydrologic data collected during testing of test well UE-25p#1, it is concluded that:

1. The hydraulic-head difference of approximately 20 m between the majority of the Tertiary section and the Paleozoic section indicates that a hydrologic barrier to vertical movement of water exists. The major change in hydraulic head occurs in the depth interval 1,114 to 1,180 m. The likely confining layer is a conglomerate with claystone matrix, between 1,138 and 1,172 m. Any vertical water movement between the Tertiary and Paleozoic sections would be small and would flow from the Paleozoic upward into the Tertiary.

2. Based on transmissivity derived from pumping tests and percentage of flow determined by a flow survey of the Tertiary section, an interval of less than 30 m in the upper part of the Prow Pass Member has significant permeability, with an apparent transmissivity of 14 m^2/d. The depth interval from 1,197 to 1,301 m, which includes the bottom of the Tertiary section and 97 m of Paleozoic Lone Mountain Dolomite, has a probable apparent transmissivity of at least 8 m^2/d. In the remainder of the Tertiary section, the tuffaceous beds of Calico Hills have an apparent transmissivity of about 0.5 m^2/d. The lower part of the Prow Pass Member has no significant fracture permeability. The Bullfrog Member has an apparent transmissivity of 1.5 m^2/d. The Tram Member and Lithic Ridge Tuff to a depth of 1,000 m have no significant fracture permeability. The lower part of the Lithic Ridge Tuff and units A and C of older tuff (unnamed) have a combined apparent transmissivity of about 2.5 m^2/d.

3. Based on a pumping test and flow survey of the Paleozoic section for the depth interval 1,297 to 1,805 m, an interval of less than 10 m in the upper part of the Lone Mountain Dolomite has an apparent transmissivity of 59 m^2/d. The 12-m interval immediately above has an apparent transmissivity of 10 m^2/d. Below this zone of significant permeability, the next 190 m has an apparent transmissivity of 33 m^2/d. Below 1,550 m, transmissivity is 6 m^2/d.

Table 5.--*Comparison of transmissivities based on pumping tests and borehole-flow surveys versus packer-injection tests*

Depth interval (meters)	Transmissivity (meters squared per day)		Stratigraphic unit(s) (see table 1 for rank of unit)
	Pumping test and borehole-flow survey	Packer-injection test	
384-500	14	Not tested[1]	Tuffaceous beds of Calico Hills, bedded tuff, and Prow Pass Member.
500-550	No flow detected.	0.1	Prow Pass Member and bedded tuff.
550-600	0.5	2.8	Bedded tuff and Bullfrog Member.
600-650	.5	3-5	Bullfrog Member.
640-690	.3	1.1	Bullfrog Member and bedded tuff.
690-740	No flow detected.	.2	Tram Member.
739-789	No flow detected.	1.1	Tram Member.
764-834	No flow detected.	.6	Tram Member.
834-904	No flow detected.	.8	Tram Member and Lithic Ridge Tuff.
904-974	No flow detected.	.9	Lithic Ridge Tuff.
974-1,044	.5	3-5	Lithic Ridge Tuff.
1,044-1,114	1.5	>5	Lithic Ridge Tuff, bedded tuff, and older tuff (units A and C).
1,110-1,180	No flow detected.	.1	Older tuff (unit C), conglomerate, and calcified ash-flow tuff.
1,180-1,301	7	Not tested[1]	Older tuff and Lone Mountain Dolomite.
1,297-1,337	3	>5	Lone Mountain Dolomite.
1,341-1,381	72	>5	Lone Mountain Dolomite.
1,381-1,421	10	>5	Lone Mountain Dolomite.
1,423-1,463	4	>5	Lone Mountain Dolomite.
1,463-1,509	2	>5	Lone Mountain Dolomite.

Table 5.--*Comparison of transmissivities based on pumping tests and borehole-flow surveys versus packer-injection tests*--Continued

Depth interval (meters)	Transmissivity (meters squared per day)		Stratigraphic unit(s) (see table 1 for rank of unit)
	Pumping test and borehole-flow survey	Packer-injection test	
1,509-1,555	13	>5	Lone Mountain Dolomite.
1,554-1,600	1	>5	Lone Mountain Dolomite.
1,597-1,643	1	>5	Lone Mountain Dolomite.
1,643-1,689	1	>5	Lone Mountain Dolomite and Roberts Mountains Formation.
1,689-1,735	1	>5	Roberts Mountains Formation.
1,735-1,781	1	>5	Roberts Mountains Formation.
1,783-1,805	2	3-5	Roberts Mountains Formation.

[1]Pumping test and borehole-flow survey indicated transmissivity greater than tool limitation of 5 meters squared per day.

4. The dual-porosity conceptual model adequately defines the aquifer systems of both the Tertiary and Paleozoic sections and is consistent with all present knowledge of the systems.

5. Chemistry of water from the Tertiary section is typical of water from Tertiary tuffs in the area. Water from the Paleozoic section is similar, but more concentrated than, water from the regional carbonate aquifer system of the Ash Meadows ground-water basin.

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