GLOVER, BROWN

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IN REPLY REFER TO

HYDROLOGY DOCUMENT NUMBER 615

April 30, 1986

Lee Brown
M.S. F665; ESS-5
Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87545

Dear Lee:

Enclosed is a summary of work that has been done at the C-holes near Yucca Mountain, Nevada. The summary is intended to give an overview of C-hole investigations and, although it provides a significant amount of detailed information, I would use the document only for planning purposes. Any quantitative interpretation of C-hole information should be done with the original data. Data shown in the figures are computerized. I also would caution you when using any results of interpretations given in the summary. Results such as hydraulic-conductivity estimates and intra-borehole flow rates should be viewed as very preliminary and probably will be revised in the future.

Most of the information contained in the summary has been presented in the form of conference papers and will be formally documented in reports now in preparation. A list of conference papers is included in the summary.

The summary briefly mentions plans for additional work at the C-holes but does not attempt to give comprehensive details. If you find it useful I could provide a thumbnail sketch of our plans or, if you are willing to wait until later in May, I could present a fairly detailed description of plans. Our short-term plans do not include field testing. Instead, our efforts are being directed towards producing reports of past testing, completing various planning documents, and implementing a reasonable QA program.

I would find it useful if you could provide me with an overview of investigations you have undertaken or planned. If this could be done before we set a meeting date, I suspect our progress during the meeting would be that much greater. In any event, I look forward to meeting you and others at LANL who will be involved in C-hole studies.

Very truly yours,

Kent Glover

Kent Glover

Enclosures (4)

March 17, 1986

Memorandum

To: The Record
From: Devin Galloway, NHP
Subject: Status of the C-hole investigations as they pertain to hydraulic characterization

Much information has been gleaned from the C-holes since drilling began on C1 in August 1983 and ended on C3 in April 1984. Lithologic, geophysical, hydrologic and hydraulic logs have been compiled for each of the three C-holes. The major objective has been and is to characterize the hydrogeologic features controlling ground-water flow at the study site, so that a firmly based calculation of ground-water travel time can be made. An understanding of the hydraulics of flow is an essential component of the calculation.

Information which has contributed most to formulating a conceptual model of ground-water flow at the study site has come from lithologic logs, borehole televiewer(bht) and television camera(tc) logs, temperature, tracejector and nonpumping intraborehole point-dilution and interval-dilution tracer logs, and single-well falling-head packer injection tests and multiple-well pumping test logs. The purpose of this memorandum is to provide an overview of the results from analyses of these logs, and to present a conceptual model of ground-water flow at the C-holes based on these findings. Areas where gaps occur in our understanding of the flow system are discussed , as well as planned and proposed testing/monitoring/analysis needs.

Lithologic Logs

Figure 1 shows the stratigraphic columns determined from the lithologic logs for each hole. Also shown is the physical property stratigraphy based on the degree of welding. Bedded units separate the Topopah Springs member, tuffaceous beds of Calico Hills, Prow Pass, Bull Frog and Tram members. The logs are presented here as reference to discussions below.

Fractures

Borehole televiewer (bht) logs were run in all three holes. Television camera (tc) logs were run in C1 and C2. Fracture strike and dip were determined for each fracture identified on bht log by fitting a sine curve to the acoustic trace of the fracture. Fracture strike and dip direction were also measured for fractures viewed on the video recording of the tc log. Fracture dip angle could not be reliably determined from the tc log. Figures 2 and 3 show fracture strike and dip histograms for bht and tc logs. Strike is defined in a 360^{o} azimuth and depends on dip direction such that 0^{o} corresponds to a N-S trending plane which dips to the east, and 270^{o} corresponds to any E-W trending plane which dips to the north.

More fractures were identified in C1 and C2 from tc log than from bht log. This discrepancy was also noted in the H4 fracture logs. The majority of fractures identified strike in a range $N30^{o}E$ to $N30^{o}W$, and are westerly dipping at angles greater than 60^{o}. This may indicate that NW trending fractures have smaller apertures than NE trending ones and therefore may go undetected by the less sensitive bht log. On the basis of regional stresses (the least principal horizontal stress direction measured in G1 and G2 is about $N60^{o}W$), the NW trending fractures should be under more closing stress than the NE trending ones.

The occurrence of fractures is sparse in several depth intervals: 1700-1750, 1900-2100, 2575-2650 feet, which correspond to the upper and lower zones of the Prow Pass, and the lower zone of the Bull Frog, respectively. Figure 4 shows the occurrence of fractures in depth profile versus strike. There is a higher occurrence of fractures evident between 1800-1900, 2250-2550, and 2700-2900 feet, which correspond to the middle zone of the Prow Pass, the upper and middle zones of the Bull Frog, and the Tram, respectively. Figure 5 shows the density of fractures compared to physical property stratigraphy expressed by differences in degree of welding for each hole, for fractures identified from bht and tc logs. Fracture density is highest for moderate and moderate-to-densely welded tuffs. Fracture densities calculated for the C-holes compare favorably to those published by Bob Scott for 6 surface traverses on Yucca Mountain over Paintbrush Tuffs, Tiva Canyon and Calico Hills; however, fracture densities calculated for G3 by Scott are significantly higher than those presented here. The difference may be due in part to the availability of core samples from G3, supplying visual evidence for fracture identification.

Analyses of fracture geometry have been made on the basis of fractures identified from bht logs. Each fracture was simulated as an infinite plane and fracture spacing statistics were determined. For each hole the distribution of spacing between fractures most closely fits a lognormal distribution. The relation holds regardless of the orientation of the sample line along which spacing between fractures was calculated. To gain some insight into the potential connectivity of fractures between boreholes, fracture plane - borehole intersects were simulated. Simulations of fracture projections from each borehole to each of the other two satellite holes were made for various cases. In one case the fractures were projected only between bedded units, such that a fracture identified in one borehole above a given bedded unit could not project below that unit or above an overlying bedded unit to intersect a satellite borehole. In another case fracture projections between boreholes were ~~was~~ restricted to the originating lithologic unit. In the final case, only fractures associated with flow producing intervals were projected under the stratigraphic restrictions of the previous two cases. The simulations represent an ideal overly-simplified model of the hole-to-hole fracture connectivity but are a useful starting point. The results of these simulations indicate that potentially many fracture-fracture intersections occur which interconnect the C-holes. Even for the most restrictive case of fracture projection, many fracture-fracture and fracture-borehole intersections occurred. The results of the simulations further indicate that the siting of the boreholes relative to each other was appropriate to maximize the liklihood of borehole-borehole fracture-hydraulic connection, given the orientation of the fractures observed in the C-holes.

<u>Tracejector Logs</u>

Results of C-hole production surveys are shown in Table 1.

Table 1. Results of production surveys in C1,C2,C3

Hole	Q	%Q	Depth	Strat. Unit
C1	223	64	2555	BF/N-PW
		25	2775	T/PW
		11	2890	T/PW
C2	268	80	2394	BF/M-DW
		12	2460	BF/M-DW
		8	*	*
C3	420	14	2370	BF/M-DW
		24	2425	BF/M-DW/ N-PW
		31	2445	BF/N-PW
		3	2530	BF/N-PW
		24	2840	T/PW
		4	*	*

* - this %Q distributed over several depths.
BF - Bull Frog; T - Tram; N - non; P - partially;
M - moderately; D - densely; W - welded.

Discrete major fluid producing zones were identified in the lower part of the Bull Frog moderate-to-densely welded zone and the upper part of the underlying non-to partially welded zone; and in the Tram partially welded zones. The fluid producing zones are coincident with the highly fractured zones (figure 4). The results show that while many fractures were identified in the C-holes, only a few contribute to borehole production. Because of the insensitivity of the production survey and the frequency of fracturation it was not possible to associate production with individual fractures, but a number of fractures could be associated with production zones. It is important to note that the production survey emphasizes the relative contribution of permeable fractures under pumping stress, and that the same fractures may exhibit a quite different relative contribution to borehole flow under nonpumping conditions.

Temperature Surveys

Analysis of open-hole temperature surveys, conducted under pumping and nonpumping conditions (figures 6,7, and 8) can give some indication of intraborehole flow. The pumping temperature profile in C1 indicates production occurred at about 2900, 2775, 2560, and 2480 feet. Except for the production at 2480 feet, these observations are in agreement with the tracejector survey. (The tracejector survey in C1 was of poor quality.) The nonpumping temperature survey in C1 indicates that fluid is produced from the lower depths and flows up-hole to about 2560 feet where borehole fluid is reentering the formation. Fluid appears to be entering the hole at 2480 feet and flowing down and out at 2560 feet. The C2 pumping temperature log (figure 7) shows fluid production at about 2800, 2490, 2460, and 2390 feet. The nonpumping temperature survey indicates fluid produced at 2490 feet may be moving down-hole and out at 2800 feet. Fluid produced at 2460 feet may be moving up-hole and out at 2394 feet. The C3 pumping temperature survey (figure 8) suggests fluid is produced at about 2830, 2530, 2440, and 2380 feet. The nonpumping survey shows that fluid is moving up-hole from 2830 to 2440 feet where fluid is reentering the formation. The pumping and nonpumping temperature surveys when used in conjuction, have proven to be sensitive indicators of intraborehole flow. Currently they can aid a qualitative interpretation of flow, but the more insensitive tracejector survey must be relied upon for a quantitative interpretation. We are attempting to apply coupled fluid-heat flow models of borehole flow to quantify fluid flow based on the temperature profiles. A first cut calculation of fluid flow based on the temperature profile for the nonpumping condition for C3, between 2830 and 2530 feet with the packers in place (figure 8: 10/23/85), gives a flow rate of 12 ft^3/hr. More information on the nonpumping intraborehole flow has been gained from point- and interval-dilution tracer tests.

Point- and Interval- Dilution Tracer Tests

Dual-element pip packers were positioned in C1 and C3, and a bridge plug was set in C2 in March and April 1985, and are in place today. Table 2 gives the positions of the packers and plugs.

Table 2. Positions of Packers and Plugs in C1,C2,C3

Hole	Top of Plug/Packer	Bottom
C1	2610	2620
C2	2482	2488
C3	2465	2475

The packers were positioned to isolate the permeability in the Bull Frog from that in the Tram in C1 and C3, and to separate non-producing intervals below from producing ones above in C2.

The tracer tests were conducted in late June and early August 1985 in each of the C-holes.

C1: Two intervals were conditioned with I^{131} for the interval-dilution tests: 2460-2588 and 2760-2920 feet. Both conditioned intervals straddled production zones identified from tracejector surveys. The lower conditioned interval showed fluid moving from below the packers up-hole around the packers from total depth (t.d.) to 2555 feet where fluid reentered the formation. The ready movement of tracer around the packers is evidence that the packers are not effectively seated against the bore wall. Two rates of fluid movement were inferred from the moving tracer below the packers: a slower rate occurred from t.d.-2775 feet; and a faster rate was observed from 2775-2555 feet. Two point-dilution tests conducted below the packers, however, showed no detectable movement, statistically, but, qualitatively fluid appeared to be moving upward at about 5 ft/hr. Results from an interval-dilution test conducted above the packers was less demonstrative, but indicated fluid was moving up-hole and out at 2555 feet. Above 2555 feet fluid was was moving more slowly down-hole and out at 2555 feet. A point-dilution test conducted at 2542 feet showed downward movement at 2.4 ft/hr.

The outflow zone at 2555 feet corresponds to the interval identified on the tracejector survey which contributed 64% of production; and on the nonpumping temperature surveys (figure 6) as an inflection point where cooler fluid from above and warmer fluid from below meet. The upward movement from below corresponds to two production zones on the tracejector survey; one, 11% at 2890 feet; and another, 25% at 2775 feet.

C2: One interval-dilution test and three point-dilution tests were run in C2, above the bridge plug. An interval from 2366-2478 feet was conditioned and monitored for two and three-quarter days. The results from the interval test are not clear cut. Cross-flow seems to be occurring in the interval 2390-2420 feet. A rough calculation based on point dilution and accounting for radioactive decay gives a flow rate of 9 ft^3/day; the actual flow rate is probably higher than this. Three fractures identified in this interval from bht logs strike in the range 168-174° and dip 68-80°. The lower boundary of this flow-thru interval is not obvious from temperature and tracejector surveys, which show fluid flowing between 2460 and 2394 feet. The interval-dilution test did not yield discernable evidence for significant flow occurring at 2460 feet. However, a point-dilution test at 2466 feet showed statistically significant down-hole movement of fluid at 0.5 ft^3/hr. Another test at 2425 feet showed statistically significant up-hole movement of fluid at about 1.4 ft^3/hr. And another test at 2386 feet showed no detectable movement. There was no indication from these tests that the plug was not well-seated.

It seems possible that by plugging off the lower zones in C2, we've changed the flow system above the plug. The production zone observed at 2460 feet on both the tracejector survey and the temperature surveys is not easily discernable from the dilution tracer tests. The tracejector survey and the pumping temperature survey indicate that the zone at 2460 feet is permeable; and the open-hole (unplugged) nonpumping temperature survey suggests that flow produced at 2460 feet moves down-hole to 2780 feet. The plug seems to have interrupted this gradient and changed the flow from 2460 feet. The nonpumping temperature survey run above the plug (figure 7) may reflect the change: when compared to the open-hole survey the plugged temperature survey shows a warming of the interval above the plug, and a straightening of the concave upward shape of the open-hole log below 2460.

A drift-pumpback tracer test in C2 is scheduled for August 1986. Currently we are planning to place the tracer in the "flow-through" interval to initiate the drift phase of the test. Prior to the drif-pumpback test, in June 1986 another nonpumping plugged temperature survey will be run to track temporal changes in the temperature profile since June 1985. Also in June the pump in C2 will be turned on for about one week, during which a more detailed tracejector survey will be run in the interval 2390-top of plug.

C3: Three interval-dilution tests and eight point-dilution tests were run in C3 in June and August 1985. Dilution tests conducted below the packers in the intervals, 2500-2570 feet and 2703-2940 feet indicate fluid is entering the borehole at about 2840 feet and moving up-hole and out at 2540 feet. A point-dilution test at 2699 feet showed statistically significant upward movement of fluid at 9.2 ft^3/hr. This compares well to the 12 ft^3/hr computed on the basis of the nonpumping temperature survey as discussed above. A point-dilution test at 2928 feet showed no detectable movement. Above the packers results from the interval-dilution test were inconclusive due primarily to the short time duration of the monitoring period (4 hrs). In comparison, fluid movement was inferred from the interval-dilution tests below the packers in only 90 minutes monitoring time. Relatively, for the interval above the packers, flow, if it occurs, occurs at a much slower rate. Point-dilution tests run above the packer at 2287 and 2353 feet showed statistically significant down-hole movement of fluid at 3.7 and 1.2 ft^3/hr, respectively. Several other tests conducted between 2287 and 2360 feet showed no statistically significant fluid flow. The tests suggest there may be fluid moving down-hole from 2287 to 2370 feet where an inflection occurs in the open-hole temperature profile, and a production zone was identified on the tracejector survey. A slope change occurs in the packer temperature profiles in this region, too. Unfortunately, point-dilution tests were not conducted in the interval, 2400-2440 where the packed temperature profile is nearly vertical. Fluid may be moving up-hole in this interval from the production zones, 2445 and 2425 feet, toward 2370 feet.

To support the C-hole tracer tests, we designed, implemented and tested a microcomputer-controlled geophysical logging and ground-water monitoring system that gives us the capability of running wire-line temperature, gamma and tracejector logs. The system is installed in a "logging truck" and was used to perform some of tracer dilution tests, and temperature surveys in the C-holes. The system has other capabilities some of which are discussed below. We plan to use the tracejector tool to deliver tracer to the test interval in C2 for the drift-pumpback test, and the gamma tools will be used to monitor tracer activity during the drift phase of the test.

Hydraulic Stress Testing

A pumping test was conducted in each hole immediately after drilling was completed on the hole. In September 1983 C1 was pumped at 245 GPM for about 10 minutes when the water-level in the well was drawn below the pump intake, following which, the well produced a steady 170 GPM with no significant further drawdown (figure 9). Since C1 was the first well to be drilled, there were no observation wells. The pressure-transients (p-t) in C1 exhibited an initial well-bore storage period lasting about 1 minute, followed by a 9 minute period where the drawdown was proportional to the fourth root of time, which has been associated with flow through low permeability fractures. Drawdown stablized at about 100 feet. A second pumping test was conducted in C2 in March 1984. For this test C1 was configured with a dual element straddle packer and fluid pressure was monitored in the between interval which bracketed the "most permeable zone". Table 3 shows the various packer configurations for each pumping test.

Table 3. Packer Configurations for C-hole Pumping Tests

		Packed-off Intervals		
Pumping Test	Hole	Above	Between	Below
C1	C1		(Open Hole)	
C2	C1	*	2523-2594	*
	C2		(Open Hole)	
C3	C1	WL-2514	2523-2594	2603-TD
	C2	WL-2355	2364-2475	2484-TD
	C3		(Open Hole)	

* - not monitored.

Figure 10 shows the p-t for the C2 pumping test. An instantaneous 4.5 feet of drawdown in the pumping well may be indicative of nondarcian flow occurring near the well bore. Eleven feet of total drawdown suggest that a permeable source of water is near the well. Transmissivities (T) of 3.25 ft^2/min. and 6.16 ft^2/min. were calculated from Jacob's straight-line method for the early-time and late-time data, respectively. A good match to the Theis solution was possible for the p-t in C1, the observation well. The match yielded a T of 11.8 ft^2/min.

C3 was pumped at 420 GPM for two weeks in November 1984. Fluid pressure was monitored in packed-off intervals in C2 and C1 (Table 3). Figure 11 shows the p-t for the pumping well and C2 observation intervals during recovery. Data from C2-below are not shown due to a malfunctioning pressure transducer. A poor match to the Theis curve for the early time recovery in the pumped well gives T = 0.13 ft^2/min.; a match to the Hantush leaky-artesian solution gives T = 0.08 ft^2/min. Sixty of the sixty-five feet of drawdown were recovered in the first minute of the recovery period, indicating that this well too, is connected to a nearby permeable source.

The p-t response for observation well C1 (figure 12) in the between interval gave a good match to the Theis curve, T = 13.5 ft^2/min. The response for C1-below could not be matched to the Theis curve. The middle-time data very nearly overlie the C1-between curve, and we can presume that the T for C1-below would be comparable to that computed for the between interval. The p-t for C1-above have not been analysed due to the erratic and unceratin performance of the pressure transducer. Analyses of the C2 p-t yielded a good match for the between interval data to the Theis curve, T = 13.5 ft^2/min. The response in C2-below is very similar to that observed for C1-below. Both exhibit a log-log slope of 5:4 for the early time period, which suggests a similar process controlling flow to these intervals during recovery.

Twenty-six drill-stem packer-injection tests were conducted in C1 in October 1983. Eighteen of the 26 tests were falling-head injection tests, 7 were pressurized injection tests and one was a packer compliance test. Four separate runs were made with straddle packers equipped with pressure/temperature transducers monitoring above, between, and below intervals. Packer straddles were configured for between interval lengths of 160, 40, 40, and 22 feet for the four runs, respectively. Due to a malfunction of the between gauge on Run 2 , data for five of the pressurized slug tests arè available only from a back-up Kuester gauge. Data for the remaining 2 pressurized tests suffer from lack of time and initial-head accounting. To date these 7 tests have not been fully analyzed. Data for the 18 falling-head injection tests have come from a USGS back-up transducer which was suspended in the riser pipe. Again, the contractor gauge data are poor in regards to time and intial-head accounting. Because the contractor gauges recorded pressures at 2 minute intervals, initial heads were often missed, and for some tests in permeable zones, the entire pressure decay went unrecorded.

The injection testing was conducted with a design 700-foot head above static level. Data from the suspended transducer reflect pipe-friction head losses occurring through the riser pipe and packers. Calculations of friction-head losses for a representative test conducted in a permeable zone indicate 35-40% of the initial head may be lost to friction-head during the initial period of gravity injection. Results of modeling these effects indicates that although the initial period of normalized recovery curves may be altered due to friction-head losses, the middle- and late-time recovery are generally unaffected. As a result attempts to analyse these tests focused on mid-to-late time data.

Figure 13 shows the normalized recovery curves for the 18 falling-head injection tests in C1. Attempts to match the test curves to Cooper's (et al.) solution for isotropic, homogeneous, radial flow were unsuccessful. The most apparent deviation from Cooper's solution is for the late-time region where the test curves have a sharper, more steeply sloping pressure-decay tail. The greatest divergence occurs for the test curves from "most permeable zones". Figure 14 shows the recovery curve for test #3 (1865-2025 feet), and the match to Cooper's solution for an alpha value of 10^{-1}. The T from this match is .0148 ft^2/min. Figure 15 shows the recovery curve for test #21 (2476-2498 feet) and Cooper's type curves for alpha values, 10^{-3}, and 10^{-10}. Although the match was poor, the computed T for alpha 10^{-10} is 0.21 ft^2/min. The most rapid pressure decay was observed for test #15 (figure 13), conducted in the "most permeable" interval (from tracejector survey). Recovery was complete in less than 3 minutes and a match to Cooper's solution was not possible.

Various conceptual models of flow have been invoked in an attempt to explain the divergence of observed pressure decay from that predicted by Cooper's conventional radial flow solution. A linear flow model which simulates flow in and perpendicular to fracture planes produced flatter tails (figure 16). A spherical flow model produced steeper tails than Cooper's , albeit not as steep as the observed tails (figure 17). Imposing a linear constant-head boundary at some variable distance from the test interval' resulted in some steepening of tails, but not as steep as observed tails. Results for a radial contant-head boundary were similar to those for the linear boundary. These models could produce steeper tails than Cooper's by moving the boundary far enough, but not too far from the well such that late-time recovery was affected by the boundary. Results from a skin-layer model which simulates radial flow through a finite-thickness borehole skin surrounded by an isotropic, homogeneous porous medium yielded steeper tails than Cooper's, but less steep than observed tails. A double-porosity model yielded type curve tails which were insignificantly steeper than Cooper's.

Several composite flow models were also applied to explain the observed responses. The models simulated flow through an inner flow region with the well at its center, surrounded by an outer flow region. One model simulated linear flow through the inner region and radial flow through the outer region. Tails produced by this model were no steeper than Cooper's. A second model simulated radial flow through the inner region and spherical flow through the outer region. Like the simpler spherical flow model, this model produced steeper tails than Cooper's but not as steep as the observed tails.

We were not able to explain the observed pressure-transients (p-t) from injection tests, especially those for permeable intervals by applying various models of flow geometry. Some of the ramificatons of these results are discussed below.

Our experience in conducting and analysing the falling-head injection test has led us to the following conclusions:

1. The falling-head boundary condition creates formidable mathematical problems for formulating analytical solutions to various conceptual models of flow.
2. Pipe-friction losses for straddle packer injection tests can be enormous; the initial head should be kept to a minimum.
3. Pressures should be measured in the tested interval to mitigate pipe-friction losses.
4. If possible, this test should be avoided in favor of constant flux tests.

A constant-head test was conducted in C2 - between in October 1984 just prior to the C3 pumping test. The injection flow rate immediately stablized at 167 GPM. During the 90 minute test, a buildup of about 1 foot was measured in C1-between, while little or no response was observed in the above or below interval (figure 18). A Theis match to the response in C1 -between gave T = 13.9 ft^2/min, while analysis of the p-t in the injection well gave T = .03 ft^2/min.

Although more work needs to be done in analysing these stress stests, a "conceptual model" of groung-water flow at the C-hole site is emerging. Perhaps the major feature of the model is that fractures are the principal conduits of ground-water flow. While no satisfactory quantitative analysis has been made for p-t in the stressed wells, it appears that T's computed from observation-well p-t are about 2 orders of magnitude larger than T's estimated from pumping-well p-t. This supports the concept of an inner and outer flow region centered around the well. Flow in the inner zone may be restricted due to relatively fewer fractures connecting the borehole with a more well connected network of fractures representing the outer flow region; or, may be due to the occurrence of turbulent flow in the fractures near the fracture-borehole interface. The effects of turbulent fracture flow near the well is being examined. The concept of a sparsely connected inner zone in communication with a more widely connected outer zone is a reasonable scenario for a vertical well in a population of sub-vertical fractures.

The Theis-like behavior of the p-t response for the permeable test zones in observation wells may indicate that an equivalent anisotropic porous-medium may suitably describe flow in these zones. However, the non-Theis behavior observed in the zones of "lesser permeability" suggest that an equivalent prorous-medium may not apply for flow through these zones at this scale. Since open-hole pumping tests were conducted little can be inferred from them about the hydraulic connection between permeable zones in the Tram and the Bull Frog; however, we can infer that the hydraulic connection between these zones is minimal on the basis of the C2 constant-head injection test conducted in the "most permeable interval in C2, in the Bull Frog, which did not elicit an observable response in the permeable Tram member in C1.

The highest T's reliably measured in the C-holes have come from analysis of observation well response to pumping stress. Transmissivities for both permeable zones, the Bull Frog moderate-to-densely welded, and the Tram partially-welded, appear to be about $13 ft^2/min$. In the Bull Frog, the tested interval thickness was about 100 feet, and in the Tram, about 300 feet. Since the permeability in both zones is from discrete fracture-borehole intersections, the effective thickness of each test interval is not known. If we assume 100 feet for the Bull Frog test interval, then K is 0.13 ft/min. (187 ft/day ; 57 m/day). This K is more than one order of magnitude larger than the "conservative" 1 m/day being used at this stage in the performance allocation process for the 1000-yr ground-water travel time requirement. The measured T's are in agreement with the T computed from Czarnecki and Waddells modelling results for the C-hole vicinity.

Future work on the stress tests will include additional attempts to analyse the non-Theis responses to pumping stress. Cross-hole interference testing is tentatively planned for January-February 1987. Our aim is to conduct constant flux tests for selected combinations of stressed interval - observed intervals, in order to determine directional permeability and to provide data from which the hydraulic connectivity in 3-D may be ascertained. These data are necessary to determine whether several unconnected aquifers exist or one variously connected aquifer exists. The results will have implications on the development of a ground-water flow model for analysis of the tracer tests.

An improved pressure/temperature monitoring capability was implemented in the logging truck in January 1986. Whereas before the fastest rate at which we could monitor a pressure/temperature pair from the GRC electronic pressure gauges was 20 seconds, now we can accomplish the same task in less than 2 seconds. This enhances our ability to define the p-t for stress tests in "permeable zones" and should increase the quality of the interference test results.

We have been monitoring barometric pressure at the surface, and water levels in each of the C-hole accessible zones since mid-December 1985. Currently we're attempting to calculate an effective porosity based on earth-tide stress analysis of the periodic water-level fluctuations.

Inferences about permeability and ground-water flux

Estimates of an equivalent porous-medium anisotropic permeability tensor were made for the tracer site based on the geometry of fractures observed in the C-holes. The method developed by Snow takes into account fracture frequency, orientation and aperture, and assumes the fractures are ideal nonintersecting infinite planes. As such, hydraulic conductivity (K) values computed by the Snow method are conservative in that they tend to represent an upper limit of K. Since fracture apertures are not known, the magnitude of K can only be computed for a "likely" range of apertures, but the orientation and eccentricity of the ellipsoidal representation of the the tensor can be examined. Table 4 lists some of the results from the Snow analyses. Fractures asscociated with permeable zones from the tracejector surveys were aperture-weighted to reflect their relative contribution to borehole flow under pumping stress. The results of these analyses are also shown in Table 4. Due to the relative homogeneous population of fracture orientation, the net effect on the permeability tensor is small. This analysis was not performed for C1 due to the poor quality of the tracejector survey.

An estimate of the ground-water specific discharge for the saturated zone in the vicinity of the C-holes was made from:

$$\bar{q} = \bar{\bar{K}}\,\bar{J},$$

where $\bar{q}$ is the specific discharge vector, $\bar{\bar{K}}$ is the second order hydraulic conductivity tensor, and $\bar{J}$ is the gradient vector. The direction of the gradient in the vicinity, S25°W was determined from Czarnecki and Waddell's model results. The magnitude can be taken

Table 4.

RELATIVE MAGNITUDES AND ORIENTATIONS OF UE25C-HOLES' HYDRAULIC CONDUCTIVITY ELLIPSES COMPUTED FROM SNOW'S FRACTURE SAMPLING METHOD

All Fractures Equal Aperture

	Relative Magnitudes of the Principal Semi-Axes to the Major Semi-Axis of the Permeability Ellipse			Orientation of Plane containing Two Largest Principal Axes	
	X1	X2	X3	Strike	Dip
C1	0.14	0.97	1.0	195	81
C2	0.10	0.96	1.0	185	76
C3	0.21	0.97	1.0	205	83

Selected Fractures Weighted Apertures

	X1	X2	X3	Strike	Dip
C1					
C2	0.07	0.95	1.0	179	76
C3	0.13	0.89	1.0	206	80

directly from the C1 - P1 head differential, 3.24×10^{-4} ft/ft. $\bar{\bar{K}}$ was determined from the Snow analysis for the C1 fracture sets identified from bht logs, for an arbitrary aperture of 1×10^{-4} m. Since the magnitude of the Snow-computed $\bar{\bar{K}}$ is arbitrary, we can use the computed direction matrix for $\bar{\bar{K}}$ along with K determined from the stress tests to compute $\bar{q}$ for the "most permeable zones". The resulting $\bar{q}$ is 4.21×10^{-5} ft/min., S5^{o}W. Since $\bar{\bar{K}}$ computed from Snow was two orders of magnitude less than that computed from stress tests, the estimated aperture of 10^{-4} m is most likely too small and the effective aperture is probably greater than 10^{-3} m.

Reports, Papers and Presentations

Waddell, R.K., Erickson, J.R. and Galloway D.L. , 1984. "Field permeability measurements in fractured tuffs at Yucca Mountain, Nevada Test Site", 29TH Annual Midwest Groundwater Conference, Lawrence, Kansas, October 1-3, 1984, Abstracts with Programs, (abstract).

Waddell, R.K., 1984. "Solute-transport characteristics of fractured tuffs at Yucca Mountain, Nevada Test Site -- A preliminary assessment: GSA, Abstracts with Programs, v. 16, no. 6, p471 (abstract).

Erickson,J.R., Galloway,D.L., and Karasaki,K., 1985. "Interpretations of falling-head injection test data for fractured volcanic tuffs, Yucca Mountain, Nevada Test Site", GSA, Orlando, Florida, October 28-31, 1985, (abstract, poster session).

Galloway,D.L., and Erickson,J.R., 1985. "Tracer test for evaluating nonpumping intraborehole flow in fractured media", American Nuclear Society, Transactions v.50, Nuclear Techniques for Hydrogeological Studies, p 192-193 (summary paper).

Anderson,B.A., Galloway, D.L., and Miller, G., 1985. "Microcomputer application in geophysical logging and ground-water monitoring", AGU: EOS, Transactions v. 66, no. 46, p. 911, Nov. 12, 1985 , Abstracts with Programs, (abstract).

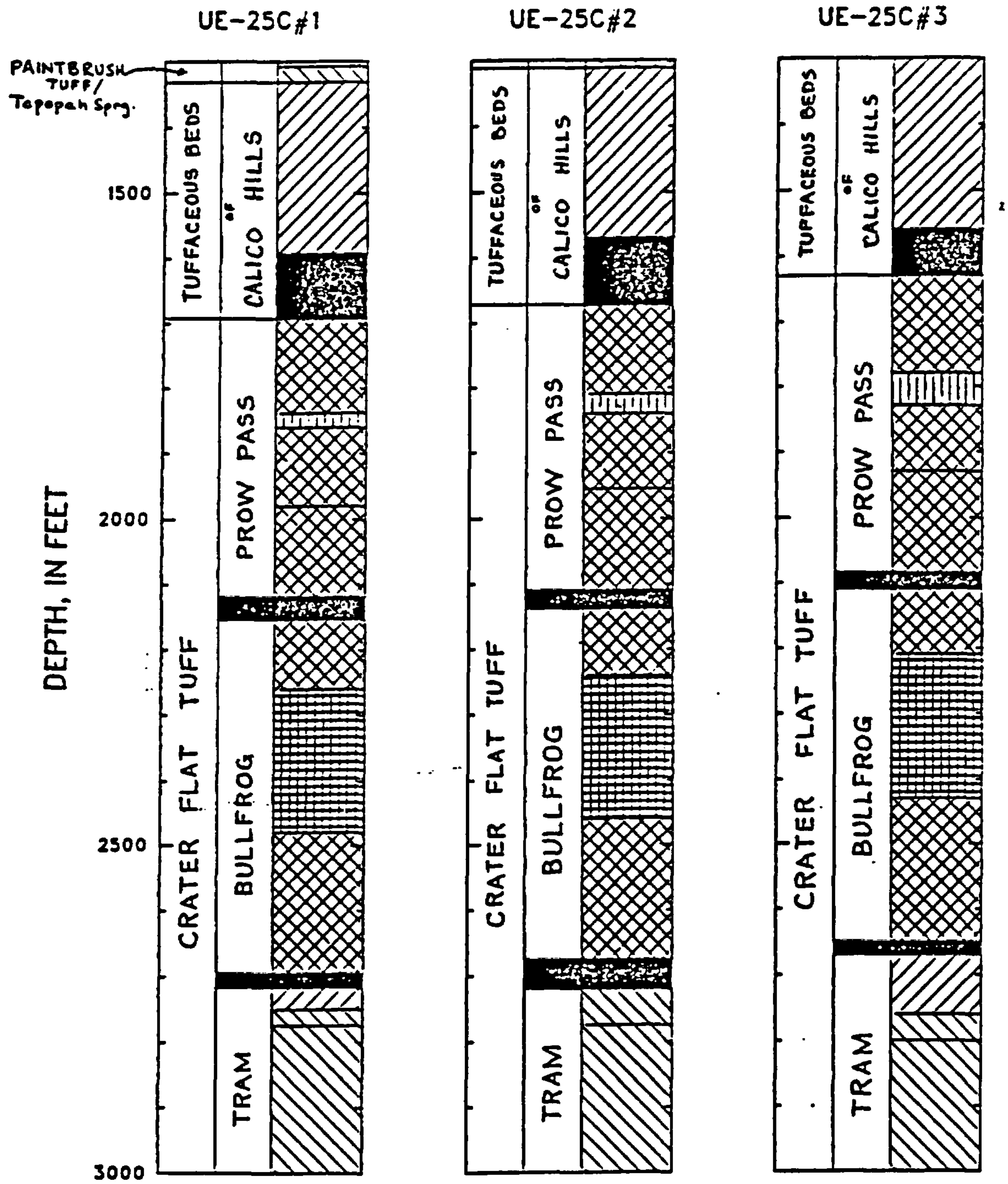
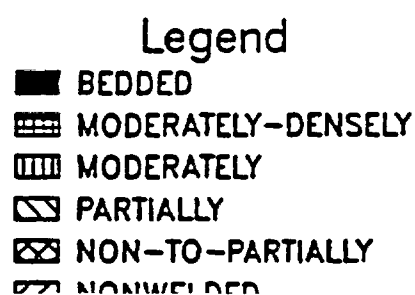


Figure 1.- PHYSICAL PROPERTY OF STRATIGRAPHY EXPRESSED BY DIFFERENCES IN DEGREE OF WELDING



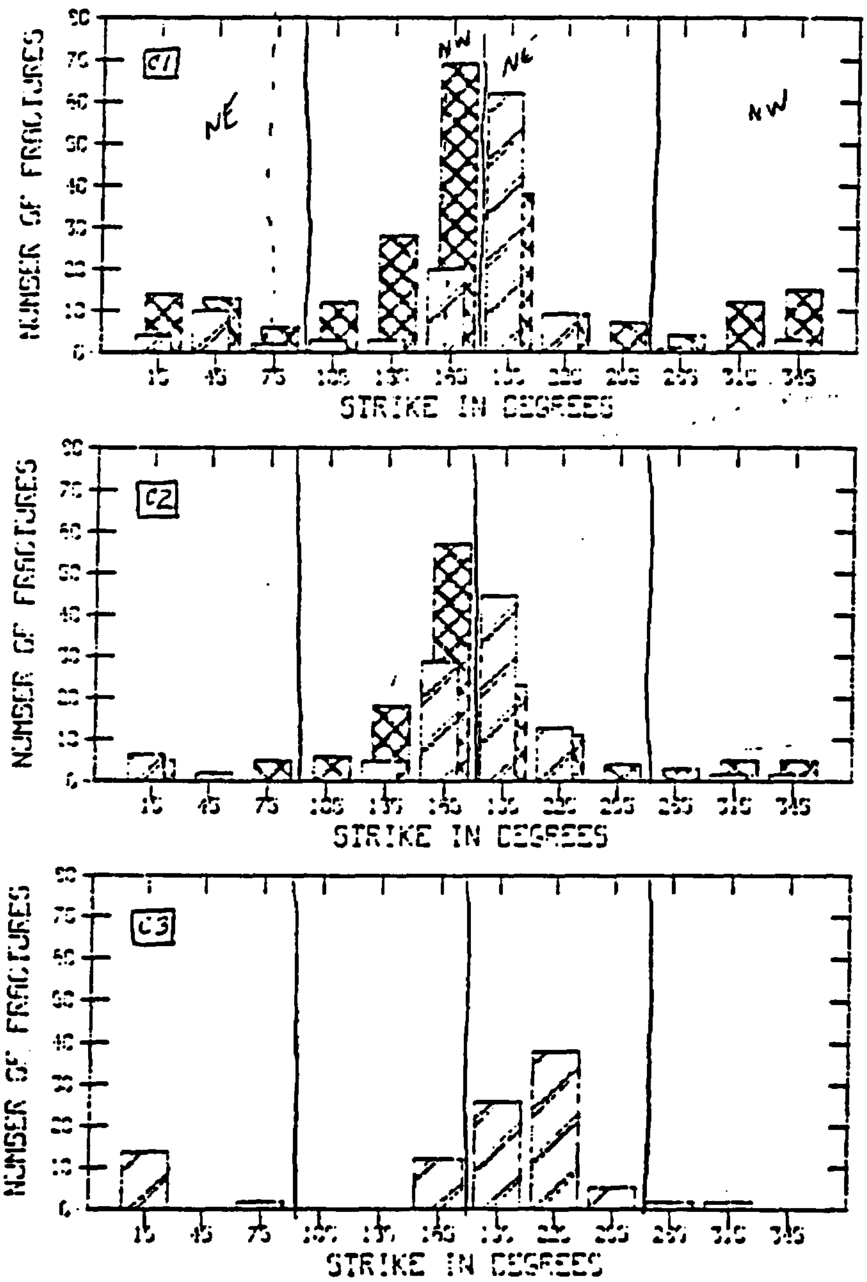


Figure 2. Number of fractures versus fracture strike angle as determined from seisviewer and television-camera logs for test wells UE-25c#1, and UE-25c#2, and as determined from seisviewer logs for UE-25c#3.

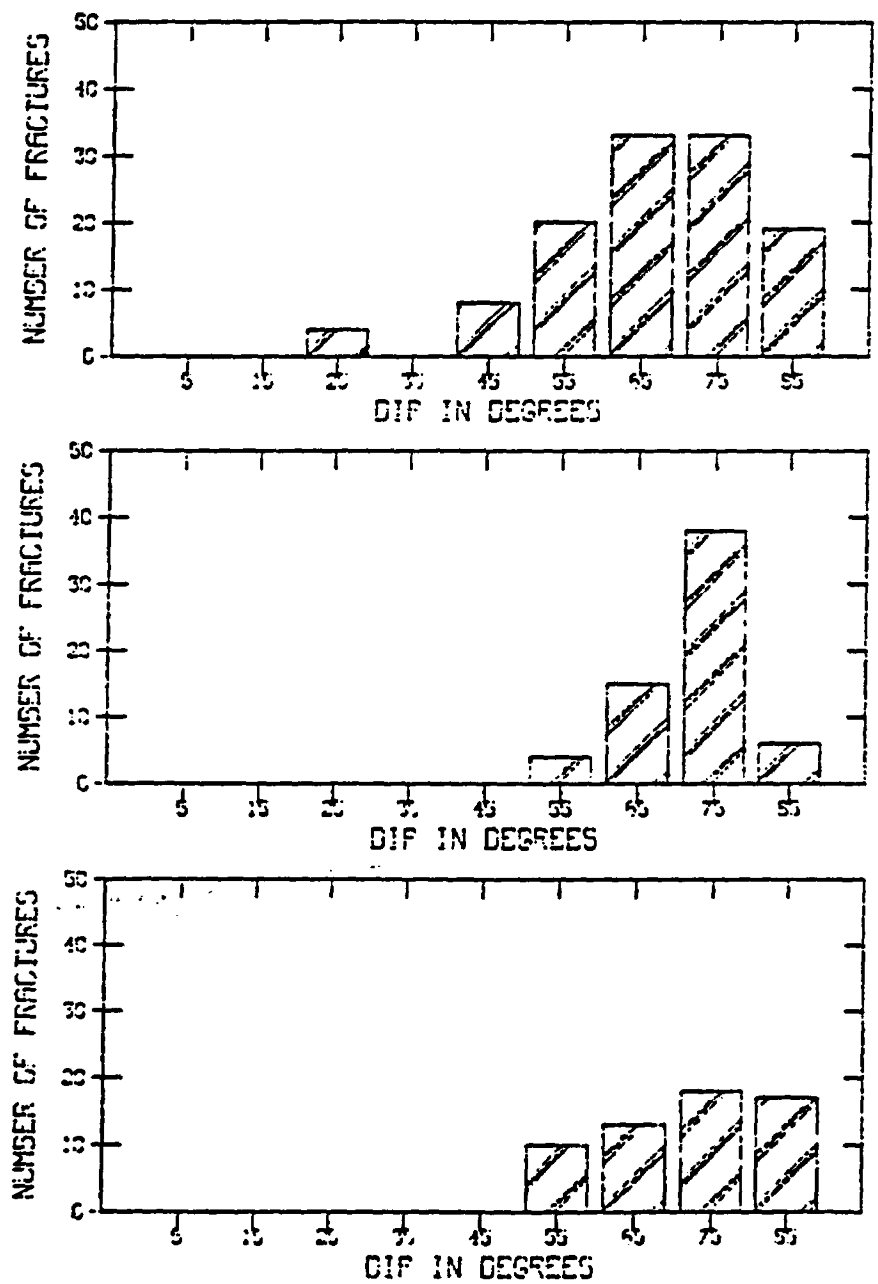


Figure 3. Number of fractures versus fracture dip angle as determined from seisviewer logs for test wells UE-25c#1, c#2, and c#3.

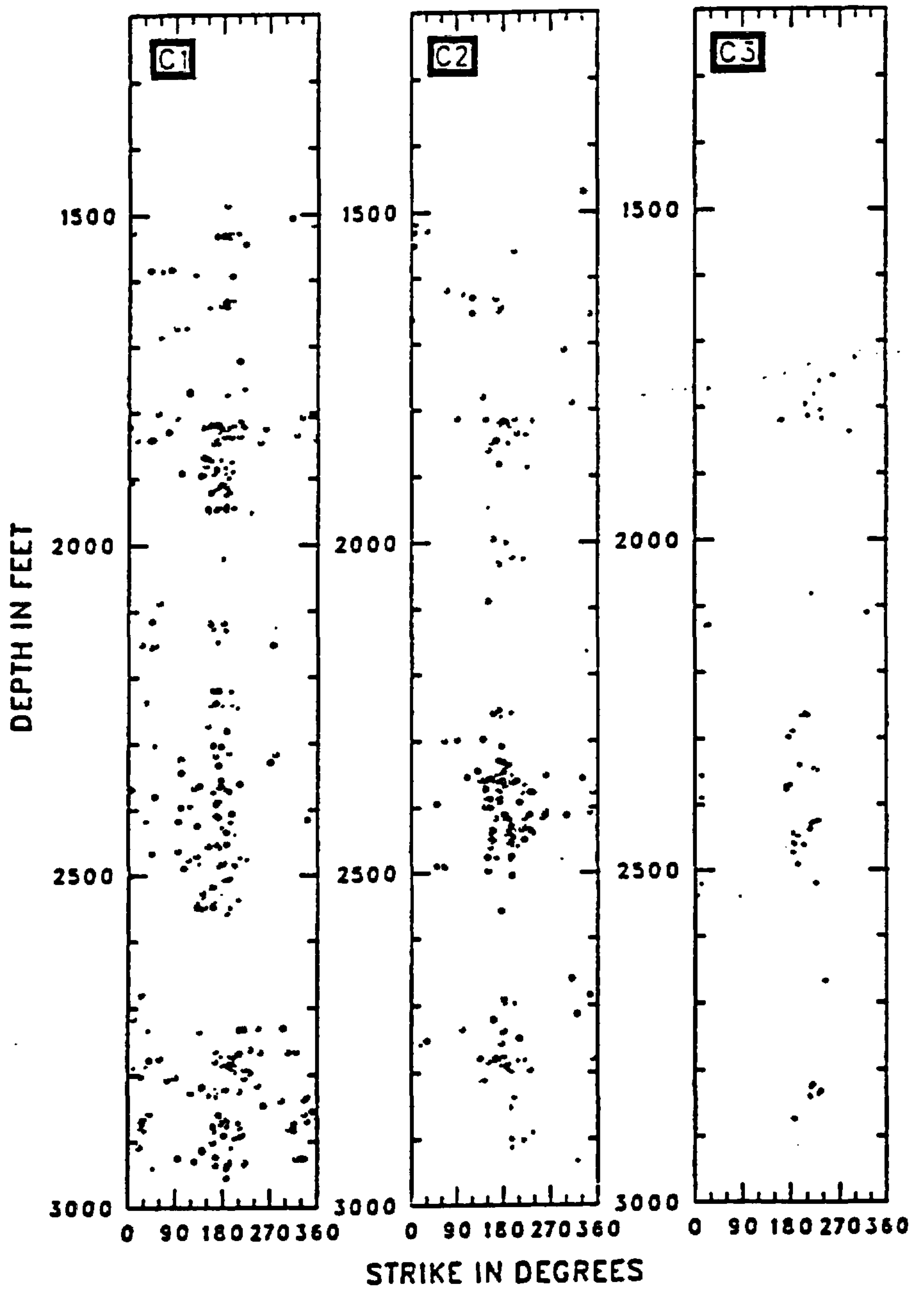


Figure 4. Fracture depth versus fracture strike angle as determined from seisviewer and television-camera logs for test wells UE-25c#1 and UE-25c#2 and as determined from seisviewer logs for UE-25c#3.

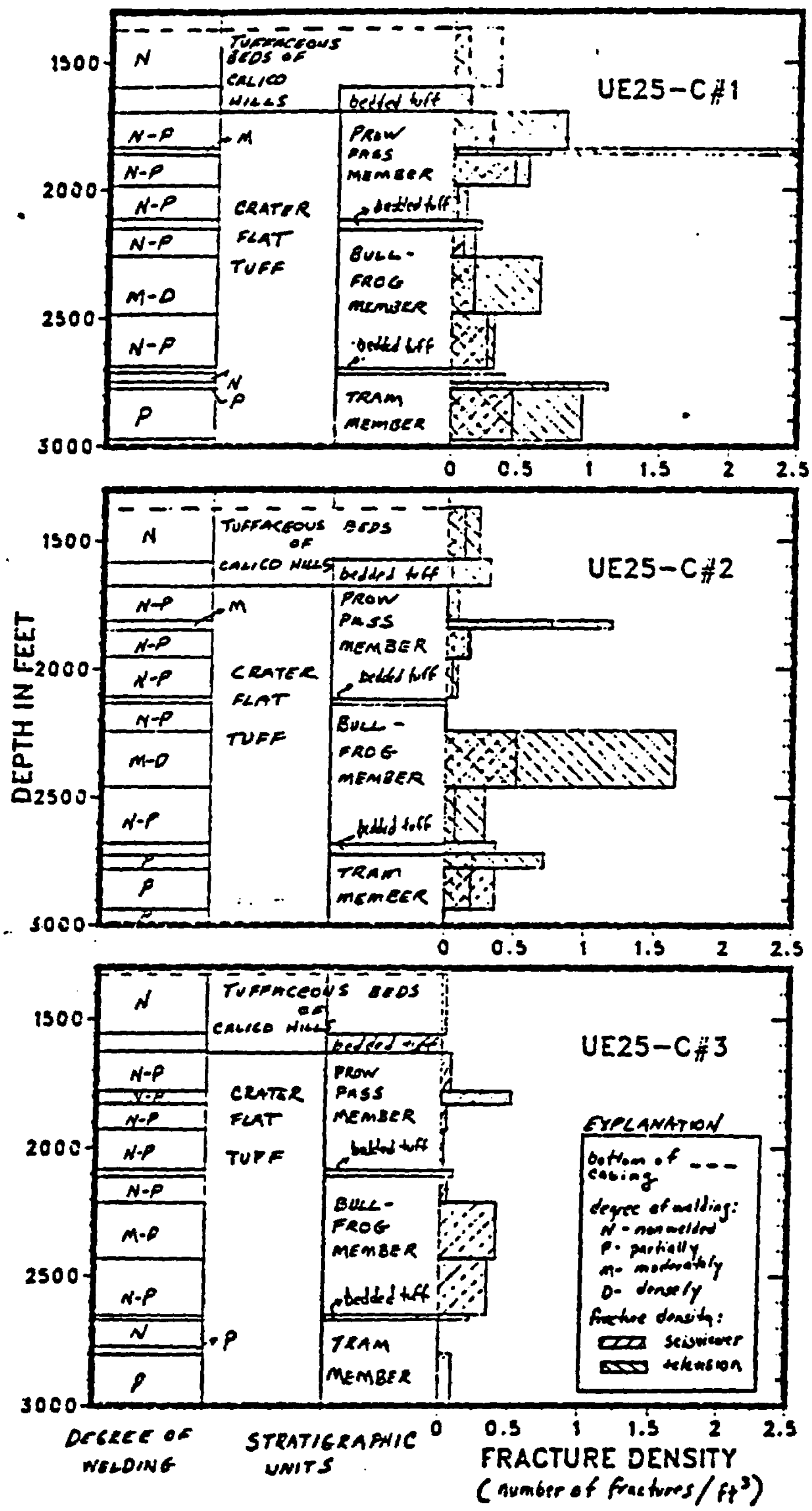


Figure 5. Density of fractures compared to physical property stratigraphy expressed by differences in degree of welding, UE25-C#1, C#2, C#3.

C#1 TEMPERATURE SURVEY

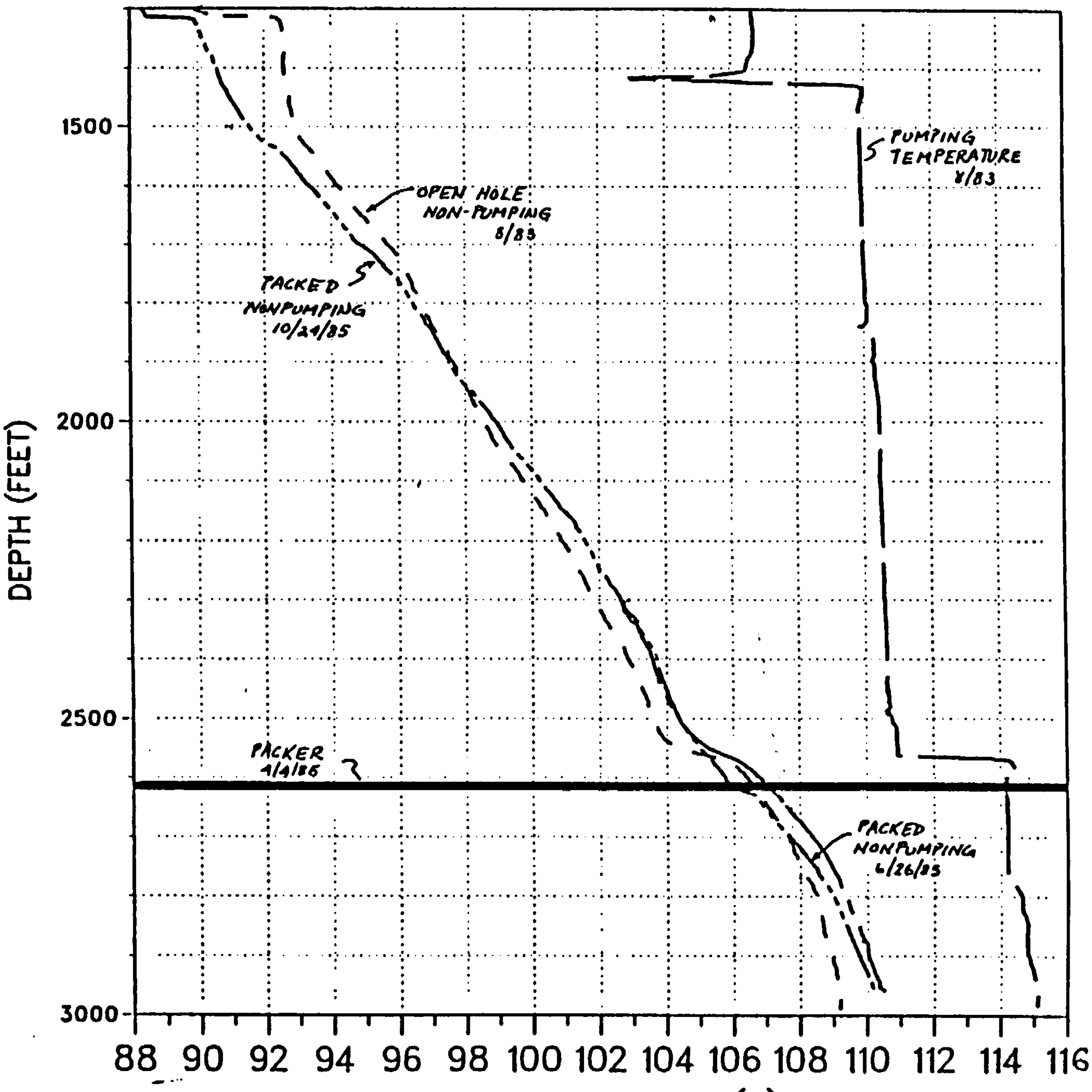


Figure 6.

Open-hole pumping and non-pumping temperature surveys

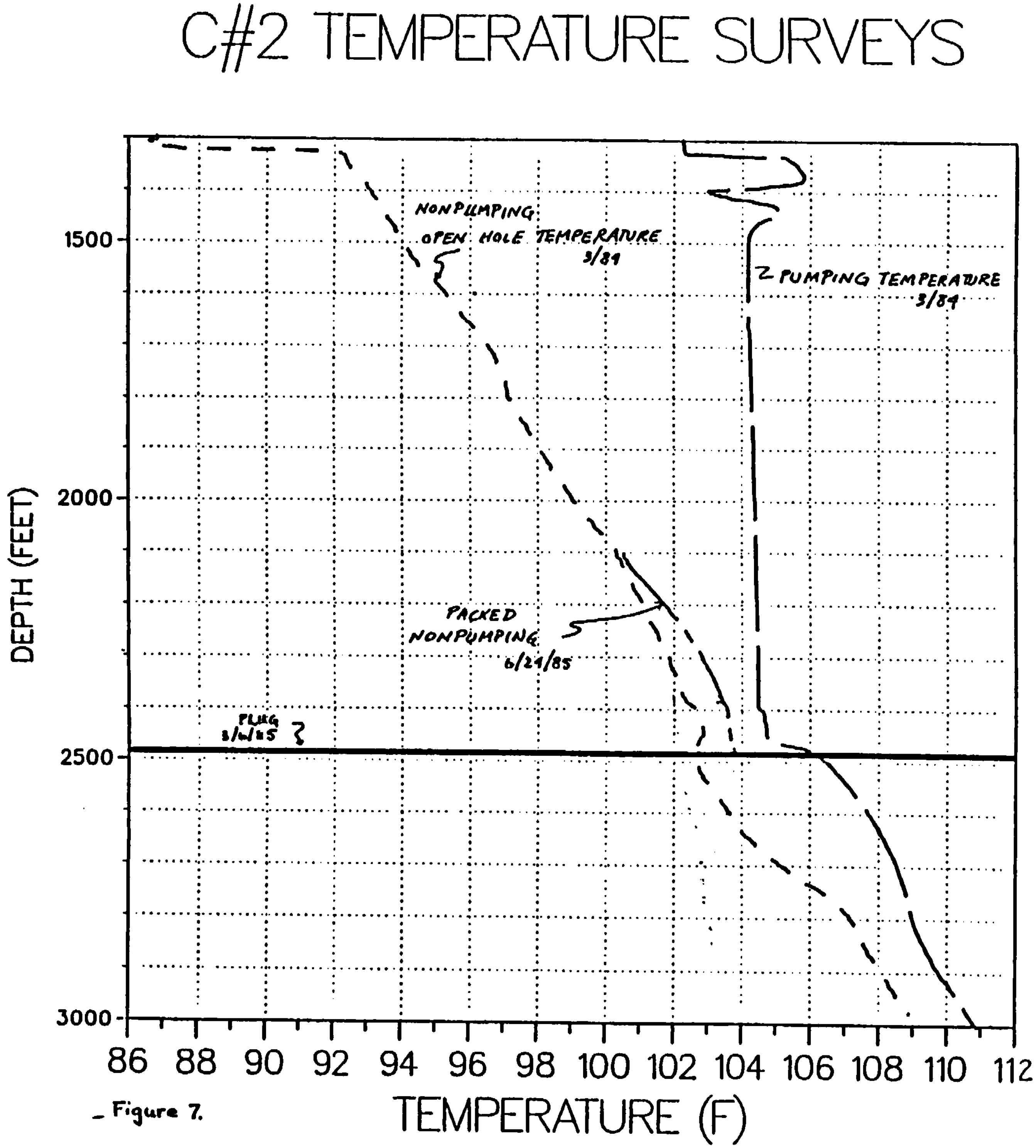
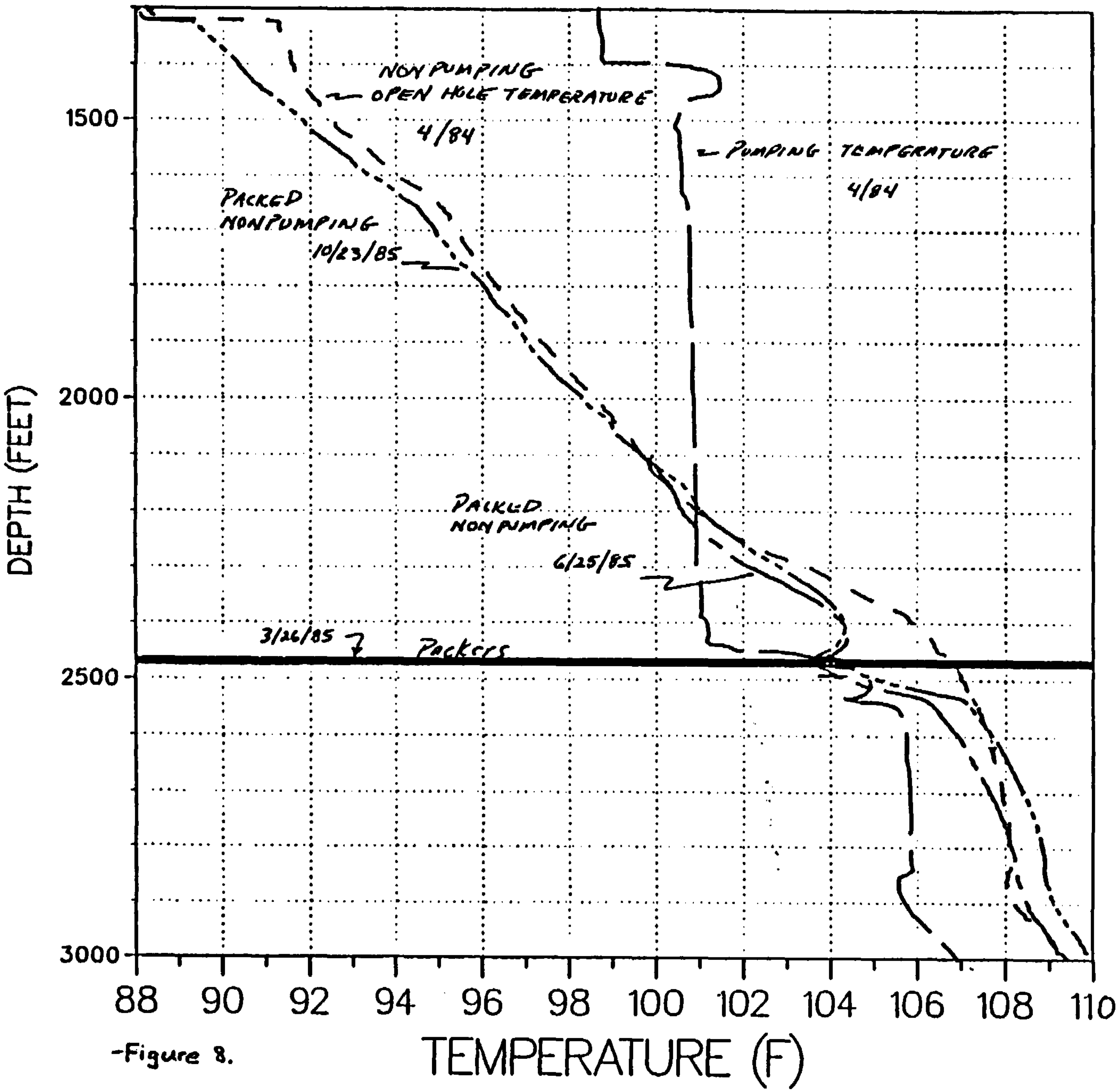


Figure 7.

Open-hole pumping and nonpumping temperature surveys



-Figure 8.

Open-hole pumping and nonpumping temperature surveys and packed-off temperature surveys in UE-25c#3.

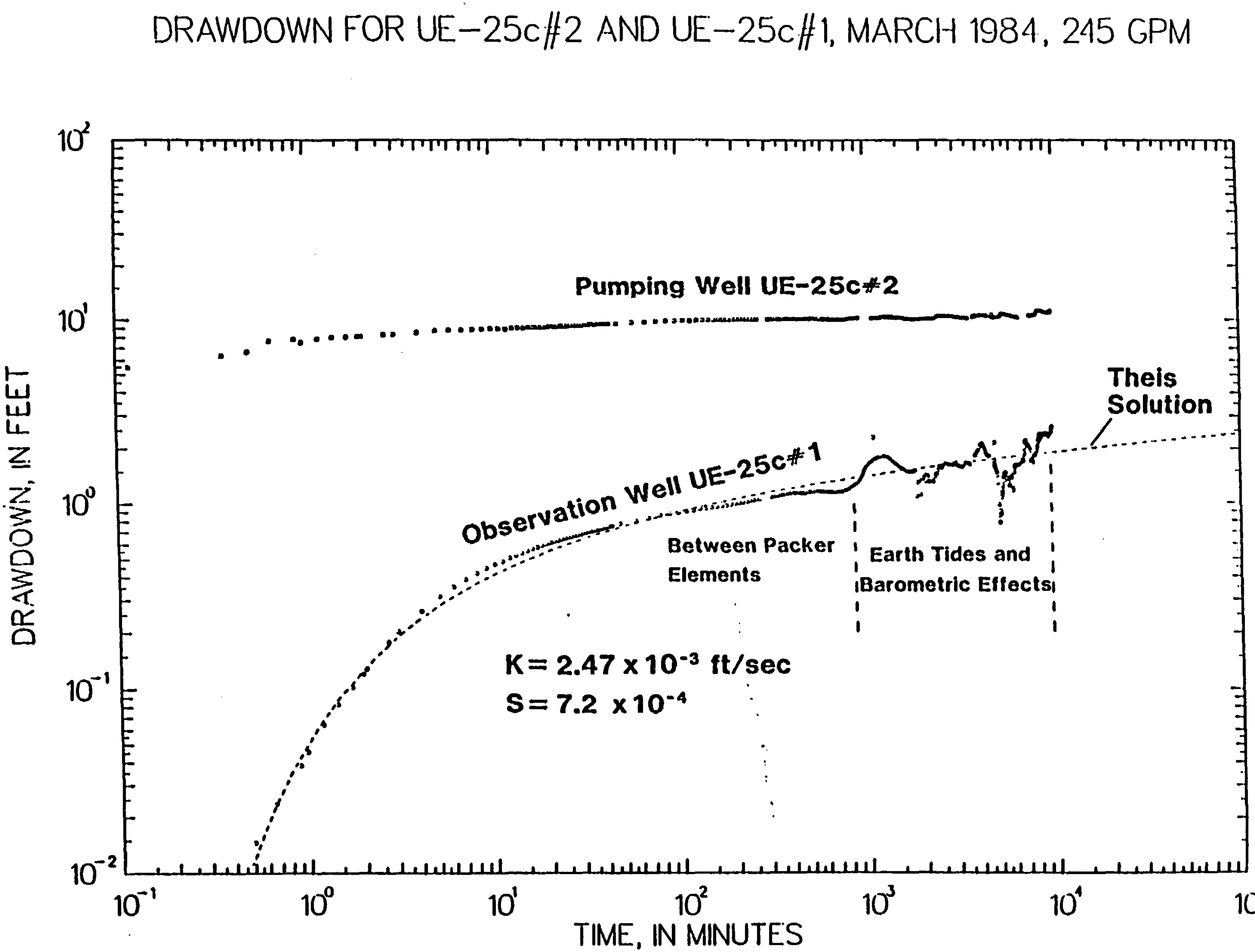


Figure 10. *Pressure-transients to c#2 pumping test.*

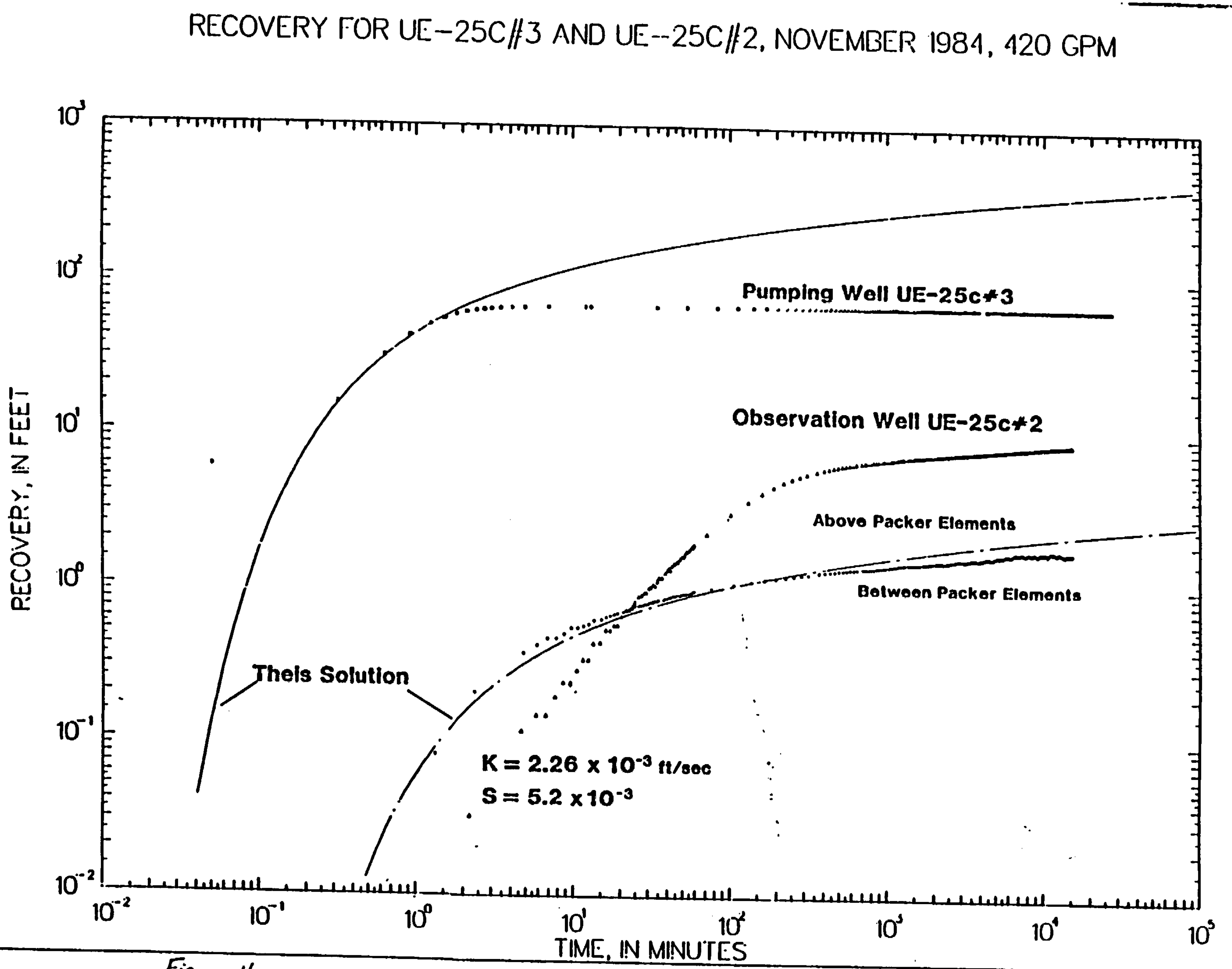


Figure 11.

Pressure transients to c#3 pumping test, observation well c#2.

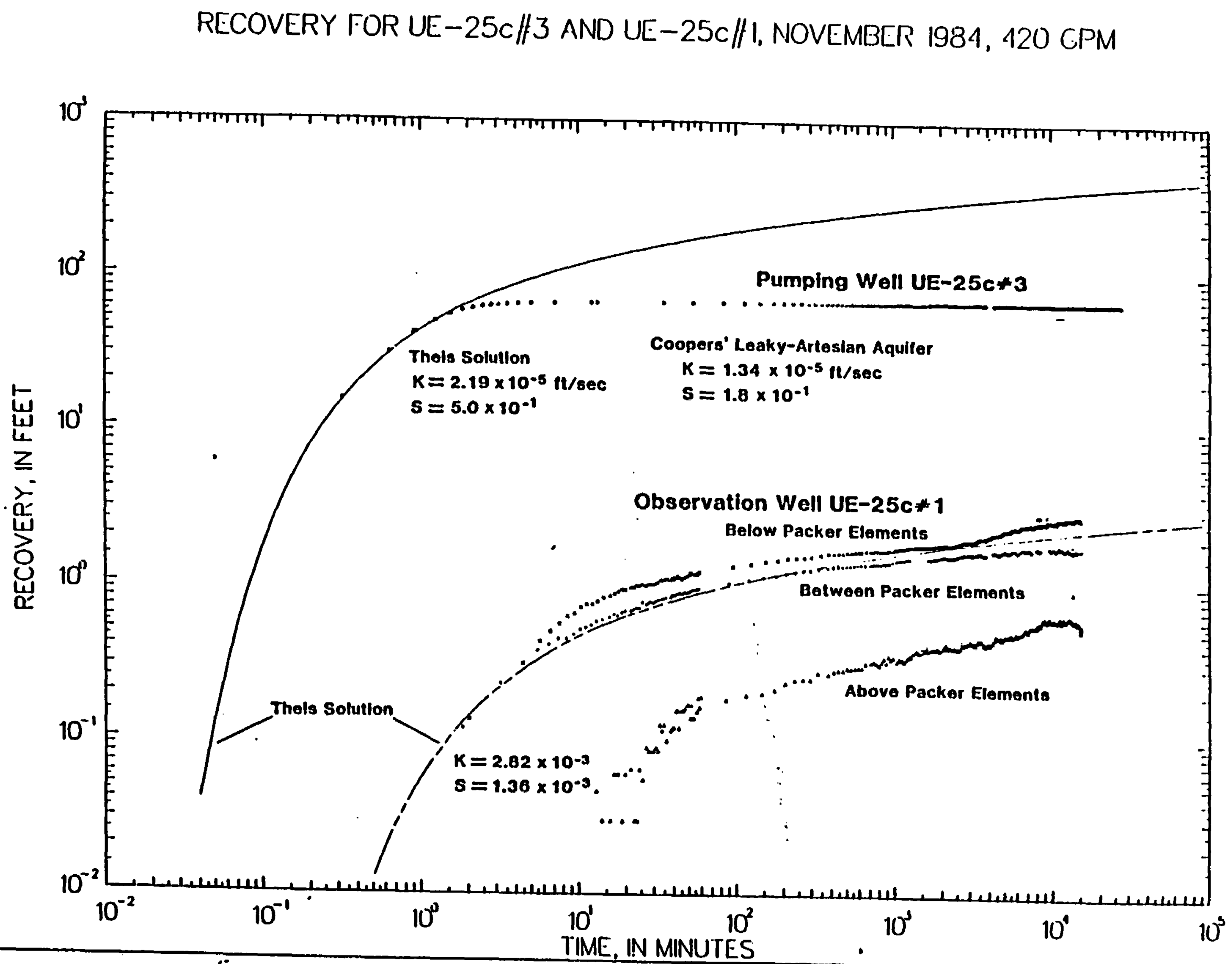


Figure 12. Pressure-transients to c#3 pumping test, observation well c#1.

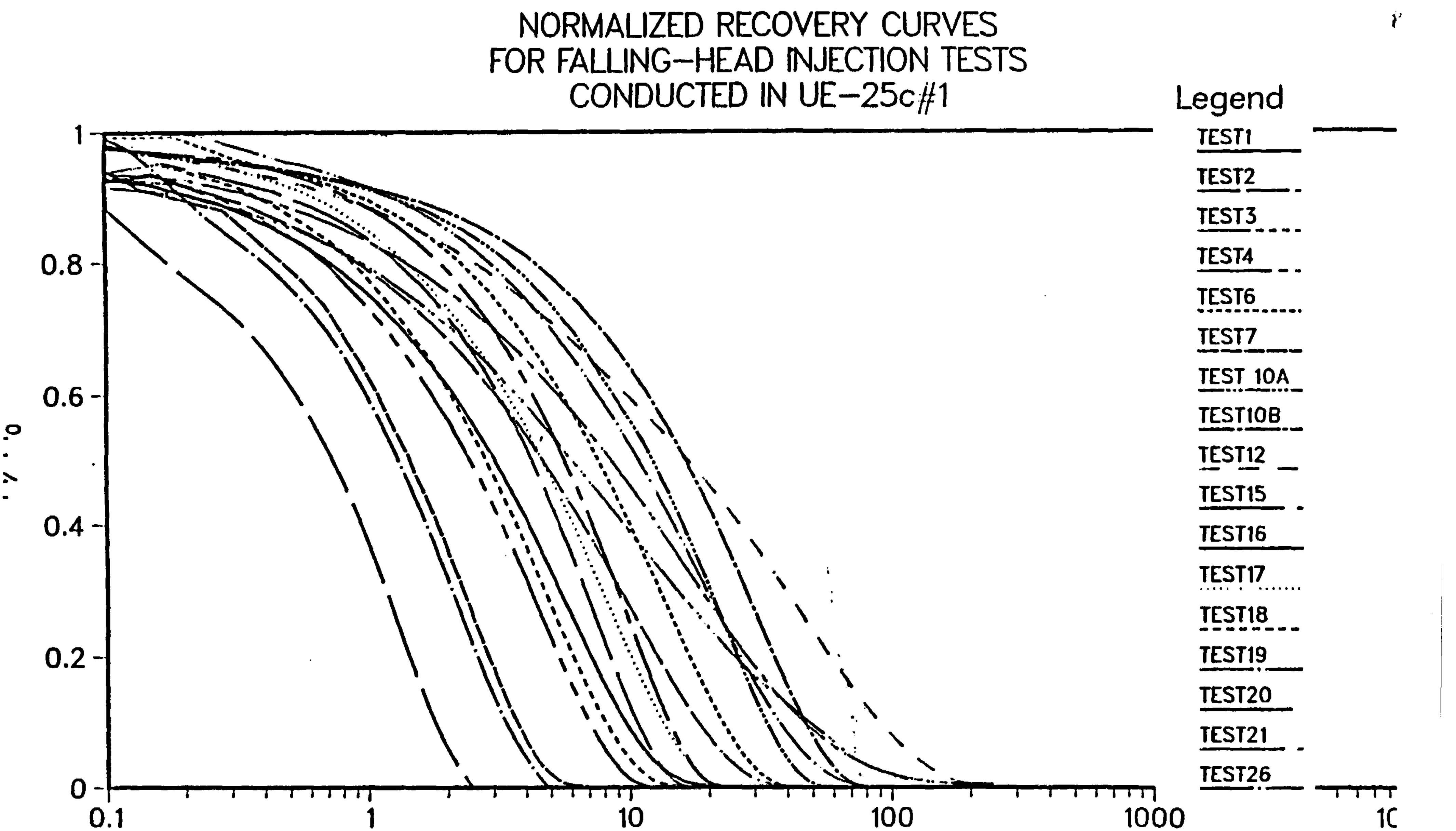


Figure 13.
Recovery curves for falling-head injection tests in C#1.

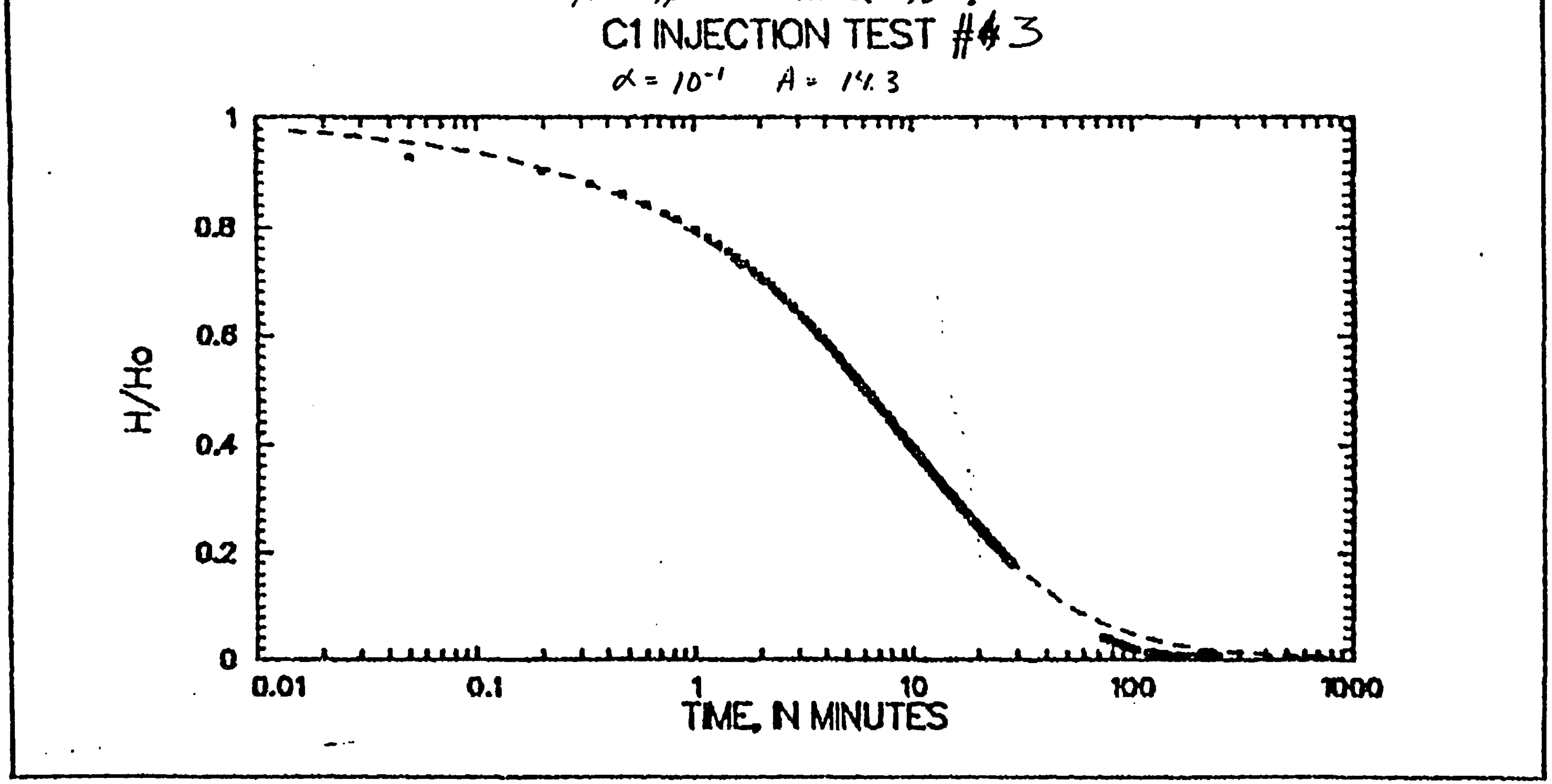
$\beta = 7.0 \times 10^{-3}$

$t = 0.1$

$T = 2.28 \times 10^{-5}$ m²/sec

$S = 4 \times 10^{-3}$

Figure 14. Recovery curve for falling-head injection test #3 in C#1, and Cooper's type curve for $\alpha = 10^{-1}$.



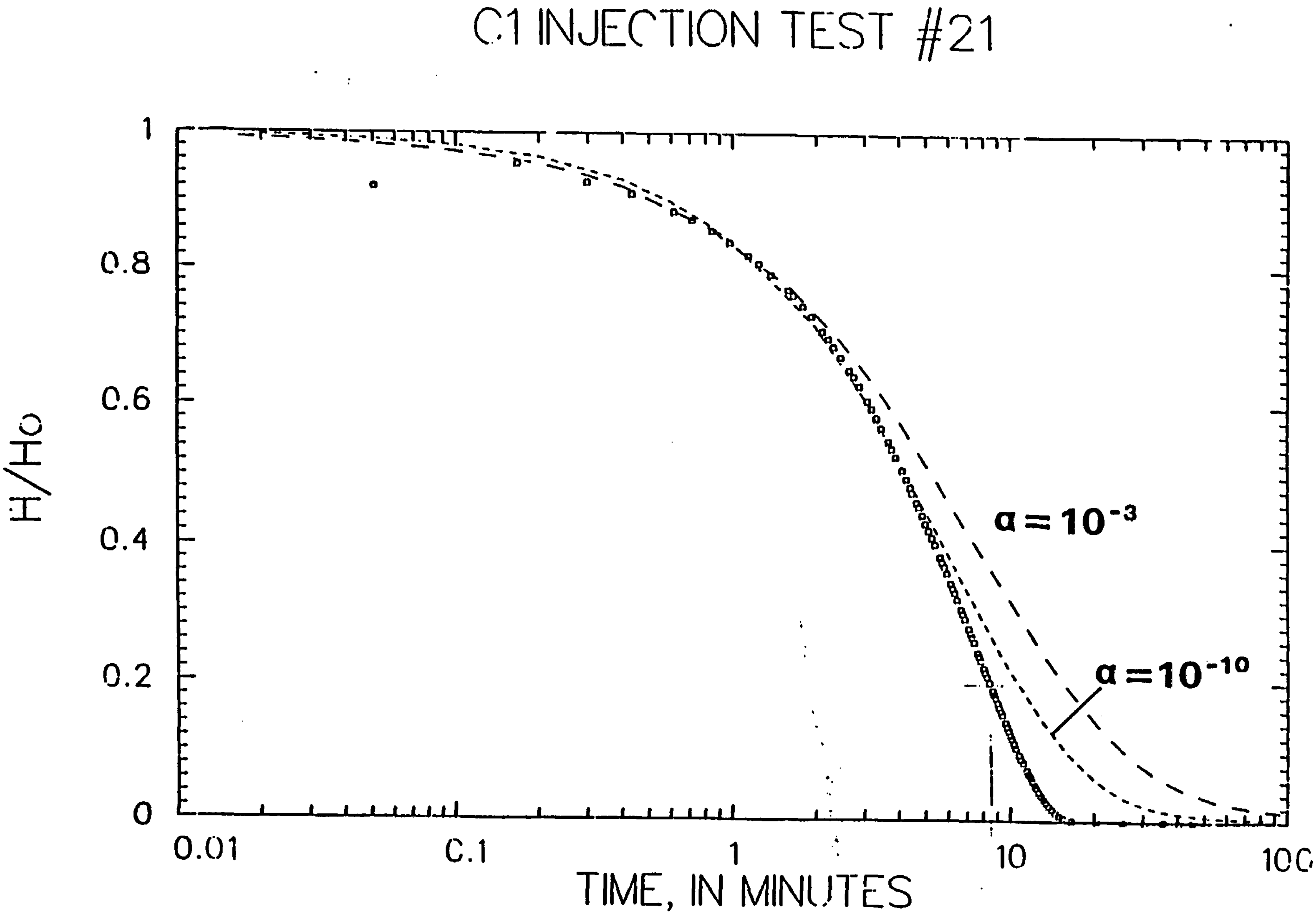


Figure 15. Recovery curve for falling-head injection test #21 in C#1, and Cooper's type curves for $\alpha = 10^{-3}$ and 10^{-10}.

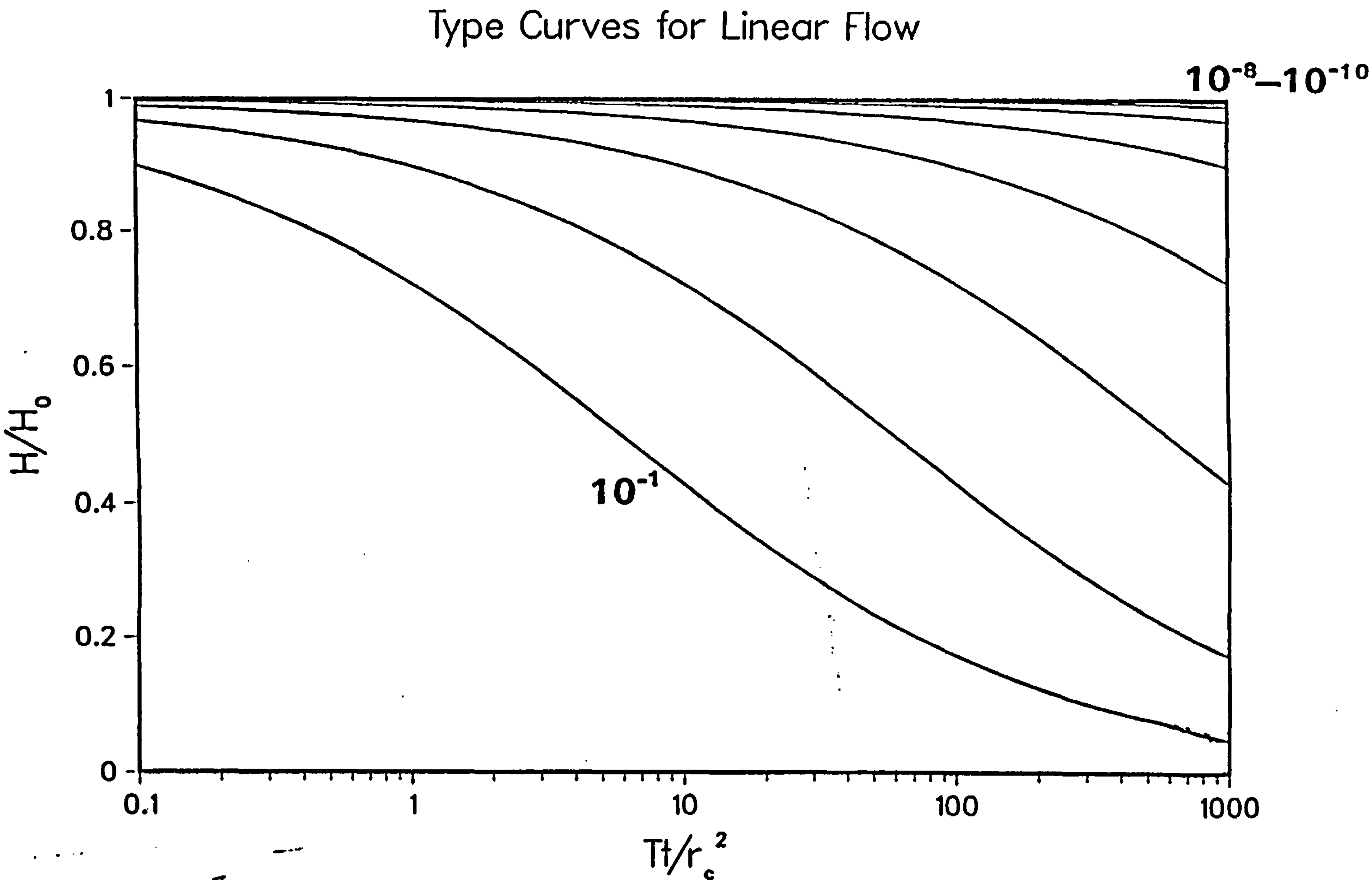


Figure 16. Type curves for linear flow with a

Type Curve for Spherical Flow

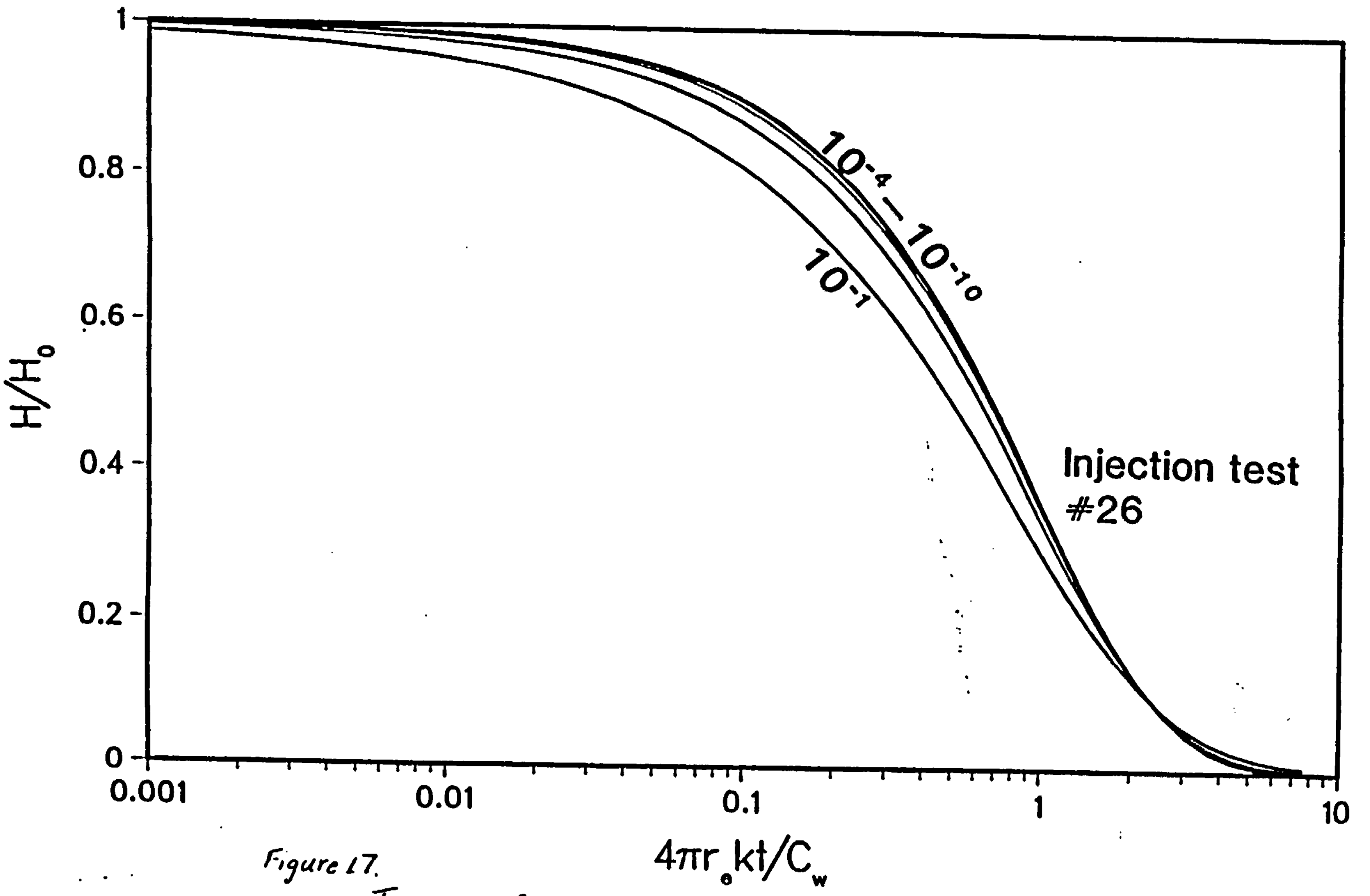


Figure 17.

Type curves for spherical flow with a falling-head boundary condition at the well

UE25-C#2 INJECTION TEST: 2365 - 2475 FT

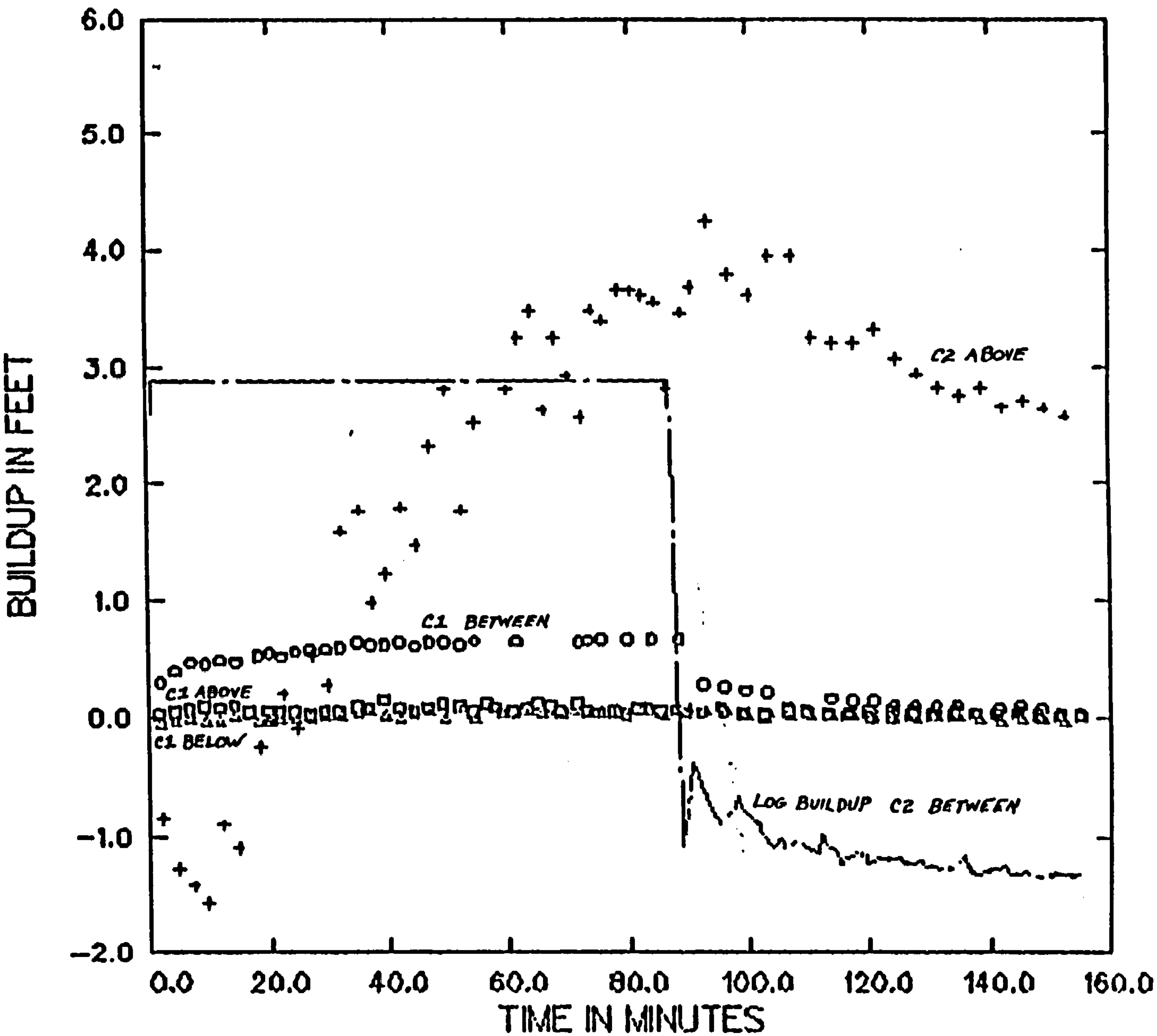


Figure 18. Pressure-transients for constant-head injection test in C#2, observation well C#1.