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RESULTS OF BOREHOLE PACKER TESTS AT THE VILLE MERCIER GROUNDWATER TREATMENT SITE

by

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ABSTRACT

The disposal of liquid waste into shallow lagoons in an abandoned gravel pit has led to the contamination of the groundwater resources near the town of Mercier, Quebec. In 1983, work aimed to control the contamination and restore the aquifer as a source of potable water began. Hydrogeological studies are currently being undertaken by Laval University and the University of Québec, Chicoutimi to assess the extent of the contamination in the bedrock and the effectiveness of aquifer reclamation efforts. As part of these studies, seven boreholes were drilled in the upper 14 metres of the bedrock at the Mercier groundwater treatment plant site. To determine the vertical distribution of hydraulic conductivity in the bedrock, the length of each borehole was tested using slug and constant head packer test techniques. The results of the packer tests show a range of hydraulic conductivities between $6x1010^{-5}$ m/s and $1x10^{-10}$ m/s.

RÉSUMÉ

Les effluents déversés dans des lagunes peu profondes situées dans une ballastière abandonnée ont contaminé les eaux souterraines à proximité de la ville de Mercier, au Québec. En 1983, des travaux ont été entrepris en vue de décontaminer l'aquifère et d'en restaurer la qualité afin d'obtenir de l'eau potable. Des études hydrogéologiques sont actuellement effectuées par l'université Laval et l'université du Québec à Chicoutimi pour évaluer le degré de contamination de la roche en place et l'efficacité des efforts de décontamination de l'aquifère. Dans le cadre de ces études, sept sondages ont été forés dans les 14 mètres supérieurs de la roche en place à l'usine de traitement des eaux souterraines de Mercier. Afin de déterminer la distribution verticale de la conductivité hydraulique dans la roche en place, des essais d'eau avec paliers de pression ont été effectués dans chaque sondage. Les résultats de ces essais montrent que la conductivité hydraulique varie entre $6x1010^{-5}$ m/s et $1x10^{-10}$ m/s.

MANAGEMENT PERSPECTIVE

This report presents the results of hydraulic testing, conducted by NWRI personnel, in boreholes at the Mercier groundwater treatment site in October 1988.

A plume of organic chemicals extending over an area of 30 km^2 from this site makes the Mercier plume the largest in Canada and the one requiring the most expensive clean-up effort.

NWRI's assistance was requested by the consortium of consultants lead by SNC, Montreal, who are under contract to DSS to assess the remedial measures presently being conducted at this site. NWRI is providing hydrogeological and geochemical advice to the Environment Canada/Environment Quebec review committee overseeing this UP.

The Mercier site provided a good opportunity to test and evaluate our field methods and equipment in contaminated fractured sedimentary rock. The packer tests provide basic hydrogeological data essential to the understanding of the movement of contaminated groundwater in the region.

PERSPECTIVES GESTION

Le présent rapport contient les résultats d'essais hydrauliques effectués par l'INRS dans des sondages forés à l'usine de traitement des eaux souterraines de Mercier, en octobre 1988.

Un panache de substances chimiques organiques s'étend sur 30 km^2 à partir du site, de sorte que des méthodes de nettoyage très coûteuses doivent être utilisées pour éliminer ce plus gros panache au Canada.

L'aide de l'INRS a été sollicitée par le groupe d'experts-conseils dirigé par la SCN (Montréal) qui, en vertu d'un contrat signé avec le MAS, évalue les mesures prises actuellement à cet endroit. L'INRS fournit des conseils en matière d'hydrogéologie et de géochimie au comité d'étude d'Environnement Canada et d'Environnement Québec.

L'usine de Mercier nous a donné l'occasion de tester et d'évaluer nos méthodes et notre équipement dans la roche sédimentaire fissurée et contaminée. Les essais d'eau fournissent les données hydrogéologiques de base essentielles à la compréhension du mouvement de l'eau souterraine contaminée dans la région.

INTRODUCTION

Between 1968 and 1972, 40,000 cubic metres of liquid waste were dumped into shallow lagoons in an abandoned gravel pit, near the town of Mercier, outside of Montreal, Quebec (Figure 1(a)). Seepage of organic material from the lagoons has contaminated the groundwater supply in both the surficial sand and gravel deposits and underlying fractured bedrock. In 1983, work aimed to control the contamination and restore the aquifer as a source for potable water began (Poulin, 1977; 1985). As part of the ongoing hydrogeological studies at the site, to assess the extent of the contamination in the bedrock and the effectiveness of aquifer reclamation efforts, seven boreholes were drilled in the upper 14 metres of the bedrock (Figure 1(b)). The length of each borehole was tested using slug and constant head packer test techniques and completed with multi-level casing. The results of the hydraulic tests only are presented in this report.

SITE DESCRIPTION

The bedrock underlying the study area is fractured dolomite, dolomitic sandstone and orthoquartzite. The bedrock is overlain by 30-40 metres of surficial glacial deposits. The surficial geology is described in detail by Poulin (1977). A total of seven 76 mm boreholes, completed in the bedrock, were tested in this portion of the study (1 to 7 in Figure 1(b), referred to as R1-R7 in the report).

METHODS

Each of the seven boreholes (Figure 1(b)) was hydraulically tested using the constant head method conducted sequentially from the bottom of the borehole to the top of the bedrock. Slug tests were carried out in selected intervals in three boreholes.

Constant head tests were carried out by injecting water at a constant flowrate (Q) into an isolated test interval and measuring the pressure increase (injection head) within the section. A schematic of the testing apparatus used to conduct the constant head tests is shown in Figure 2. A 1.75 m test interval was isolated using two pneumatic packers. Each packer consists of an expandable rubber gland with a reinforced kevlar cuff and a seal length of 0.6 m. At the surface, a series of five tanks of different diameters were pressurized with compressed nitrogen to ensure constant injection flowrate. Flowrate was measured using sight tubes on the side of the injection tanks. A pressure transducer was located above the packers and used to measure the pressure within the test interval. Generally, hydraulic conductivities within the range between 10^{-10} m/s to 10^{-4} m/s can be measured with this particular test apparatus. Imposed injection heads were for the most part between 2 and 35 m above equilibrium. Two or three different injection steps (i.e., different flowrates) were carried out in each test interval. The different steps were conducted by increasing the injection flowrate into a test interval by adjusting the compressed nitrogen pressurizing the tanks. The methodology and use of injection tests is discussed in detail in Zeigler (1976).

A total of 46 tests were conducted in the different boreholes. Each of the seven boreholes was tested systematically from the bottom of the hole upwards to the top of the bedrock using a 1.75 m packer spacing. It should be noted that due to the nature of the casing and grout completion of the boreholes the upper 1 to 1.5 m of rock in each borehole could not be tested. With a double packer system the bottom 1 to 1.5 m of rock is also not tested. Five to seven tests were completed in each borehole.

Slug tests were conducted by instantaneously adding a column of water to a packer isolated interval and measuring the subsequent decline in pressure. The double packer system used in constant head injection testing was modified to accommodate a 37 mm I.D. standpipe connected directly to the packers and extending to ground surface (Figure 3). After allowing the hydraulic head to reach equilibrium in the test interval, a slug test was conducted by inflating a small rubber packer (the mini-packer in Figure 3) in the standpipe, filling the standpipe with water and then deflating the small packer. A pressure transducer, located in the casing above the mini-packer, was used to measure the decline in hydraulic head after the addition of the water column. The measurement of hydraulic head was collected on a strip chart recorder.

A total of ten open-hole slug tests were conducted in selected intervals in 3 boreholes (R2, R3 and R6) to obtain hydraulic conductivities for comparison with the constant head injection tests. Each slug test was carried out to at least 80% of total recovery.

RESULTS

A total of 46 constant head injection tests were completed in the seven boreholes. From the ratio of injection flow rate to the resulting head difference over static conditions ($Q/\Delta H$), a modified version of the Theim equation for steady state radial flow was used to obtain the equivalent rock mass hydraulic conductivity (K) for each given isolated interval (Hvorslev, 1951; Zeigler, 1976). The expression used is as follows:

$$K = \frac{Q}{\Delta H 2\pi L} \cdot \ln (r_e/r_w)$$

where Q = steady state flowrate (m^3/s)

ΔH = steady state head difference (m)

L = length of influence (m)

r_e = radius of influence (m)

r_w = radius of well (m)

The radius of influence, or outer flow boundary, was assumed to be 10 m in all tests. While the radius of influence is unknown in most field situations, since it appears as a logarithmic term in the above equation, large errors in estimation of r_e will result in only small errors in the calculation of K (Zeigler, 1976). The results of the constant head tests are summarized in Table 1 and shown in Figures 4 to 10.

The slug tests were analyzed using standard type curve analyses (Cooper et al., 1967). The results of the slug test analyses are presented in Table 2. The quality of the type curve fits (Appendix A) range from good (over 90% of field data fits type curve) (e.g., R2, test #1) to poor (<30% of field data fits type curve) (e.g., R6, test #2). In most tests over 75% of the field data fits the type curve. The corresponding storativities are also presented in Table 2. Storativities obtained from this type of analysis are generally considered to be unreliable due to the insensitivity of the differing type curves matches (Cooper, 1967). The poor fits to some of the data may be indicative of the nature of radial flow in fractured rock. Other models which consider the effect of both the matrix and fracture permeability of the rock may be more appropriate for analysis of these tests.

The results of the borehole packer tests show a range of hydraulic conductivities for the bedrock at the site between 6×10^{-5} m/s and 1×10^{-10} m/s.

SUMMARY

As part of hydrogeological studies at the Ville Mercier groundwater treatment site, seven boreholes completed in the upper 14 metres of the bedrock were tested prior to the installation of permanent multi-level casing systems. Constant head and slug test techniques were used to obtain estimates of near well hydraulic conductivity.

The wide range of hydraulic conductivities observed suggests that groundwater flow is primarily through fractures or fracture zones and not through the bulk rock matrix. Examination of the bedrock lithology and the nature and continuity of the fractures is needed in conjunction with the hydraulic tests to better define the properties of the bedrock at the site. This report presents only the results of the constant head injection tests and slug tests and does not attempt to present any hydrogeological interpretation of the results.

REFERENCES

Cooper, H.H., Bredehoeft, J.E. and Papadopulos, I.S. Response of a finite diameter well to an instantaneous charge of water, Water Resources Research, 3(1), 263-269, 1967.

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Zeigler, T.W. Determination of Rock Mass Permeability, Waterways Experiment Station, Technical Report S-76-2, Vicksburg, Mississippi, 1976.

Table 1. Summary of constant head test results.

Borehole	Test #	Interval (m)[A]	Q/ΔH (m^2/s)	K[B] (m/s)
R1	2	56.72-54.97	1.2×10^{-8}	6.9×10^{-9}
	3	58.47-56.72	5.7×10^{-8}	2.9×10^{-8}
	4	60.47-58.72	—	$<10^{-10}$
	5	61.97-60.22	7.7×10^{-8}	3.9×10^{-8}
	6	63.72-61.97	9.3×10^{-8}	4.7×10^{-8}
	7	65.47-63.72	7.1×10^{-9}	3.6×10^{-9}
	8	65.97-64.22	8.1×10^{-9}	4.1×10^{-9}
R2	1	57.12-55.37	1.1×10^{-7}	5.4×10^{-8}
	2	58.71-56.96	8.5×10^{-7}	4.3×10^{-7}
	3	58.46-56.71	2.6×10^{-9}	1.3×10^{-9}
	4	60.46-58.71	3.2×10^{-5}	1.6×10^{-5}
	5	62.21-60.46	3.3×10^{-7}	1.7×10^{-7}
	6	63.96-62.21	1.1×10^{-8}	5.5×10^{-7}
	7	65.71-63.96	2.2×10^{-8}	1.1×10^{-8}
R3	1	57.33-55.58	3.7×10^{-9}	1.9×10^{-9}
	2	59.08-57.33	1.0×10^{-9}	5.2×10^{-10}
	3	60.83-59.08	8.3×10^{-10}	4.2×10^{-10}
	4	62.58-60.83	1.9×10^{-9}	9.5×10^{-10}
	5	64.33-62.58	2.8×10^{-9}	1.4×10^{-9}
	6	66.08-64.33	1.5×10^{-6}	7.5×10^{-7}
R4	1	55.16-53.41	8.1×10^{-9}	4.1×10^{-9}
	2	56.91-55.16	2.8×10^{-7}	1.4×10^{-7}
	3	58.66-56.91	2.8×10^{-7}	1.4×10^{-7}
	4	60.41-58.66	1.5×10^{-5}	7.7×10^{-6}
	5	62.16-60.41	2.8×10^{-9}	1.4×10^{-9}
	6	63.91-62.16	8.7×10^{-8}	4.4×10^{-8}
R5	1	59.44-57.69	2.8×10^{-9}	1.4×10^{-9}
	2	61.19-59.44	2.0×10^{-7}	1.0×10^{-7}
	3	62.94-61.19	6.7×10^{-9}	3.4×10^{-9}
	4	64.69-62.94	2.8×10^{-9}	1.4×10^{-9}
	5	66.44-64.69	1.2×10^{-9}	6.3×10^{-10}
	6	68.19-66.44	4.3×10^{-9}	2.2×10^{-9}
R6	1	58.45-56.70	1.1×10^{-4}	5.7×10^{-5}
	2	60.20-58.45	2.0×10^{-5}	1.0×10^{-5}
	3	61.95-60.20	2.2×10^{-5}	1.1×10^{-5}
	4	63.70-61.95	2.8×10^{-5}	1.4×10^{-5}
	5	65.45-63.70	1.5×10^{-9}	7.5×10^{-10}
	6	67.20-65.45	6.9×10^{-7}	3.5×10^{-7}
	7	67.95-66.20	1.9×10^{-7}	9.7×10^{-8}
R7	1	57.40-55.65	3.6×10^{-9}	1.8×10^{-9}
	2	59.15-57.40	1.4×10^{-9}	7.0×10^{-10}
	3	60.90-59.15	2.2×10^{-9}	1.1×10^{-9}
	4	62.65-60.90	3.5×10^{-9}	1.8×10^{-9}
	5	64.40-62.65	2.8×10^{-9}	1.4×10^{-9}
	6	66.15-64.40	3.0×10^{-9}	1.5×10^{-9}
	7	67.15-66.15	4.9×10^{-9}	2.5×10^{-9}

[A] metres relative to a fixed point on field site
[B] hydraulic conductivity

Table 2. Summary of slug test results.

Borehole	Test #	Interval (m)[A]	K^B (m/s)	S^B
R3	1	66.08-64.33	$2.3x10^{-7}$	$2.4x10^{-3}$
R2	1	60.41-58.66	$1.8x10^{-5}$	$2.4x10^{-5}$
R2	1R(repeat)	60.41-58.66	$2.1x10^{-5}$	$2.4x10^{-5}$
R2	2	62.16-60.41	$1.1x10^{-6}$	$2.4x10^{-4}$
R2	3	63.91-62.16	$8.0x10^{-7}$	$2.4x10^{-6}$
R6	1	58.45-56.70	$2.8x10^{-5}$	$2.4x10^{-5}$
R6	2	60.20-58.45	$7.8x10^{-6}$	$2.4x10^{-10}$
R6	3	61.95-60.20	$8.0x10^{-6}$	$2.4x10^{-3}$
R6	4	63.70-61.95	$1.1x10^{-6}$	$2.4x10^{-8}$
R6	5	67.20-65.45	$6.3x10^{-7}$	$2.4x10^{-8}$

[A] elevation in metres relative to a fixed point on field site
[B] hydraulic conductivity or storativity determined from type-curve matches (Cooper et al., 1967)

(a)

(b)

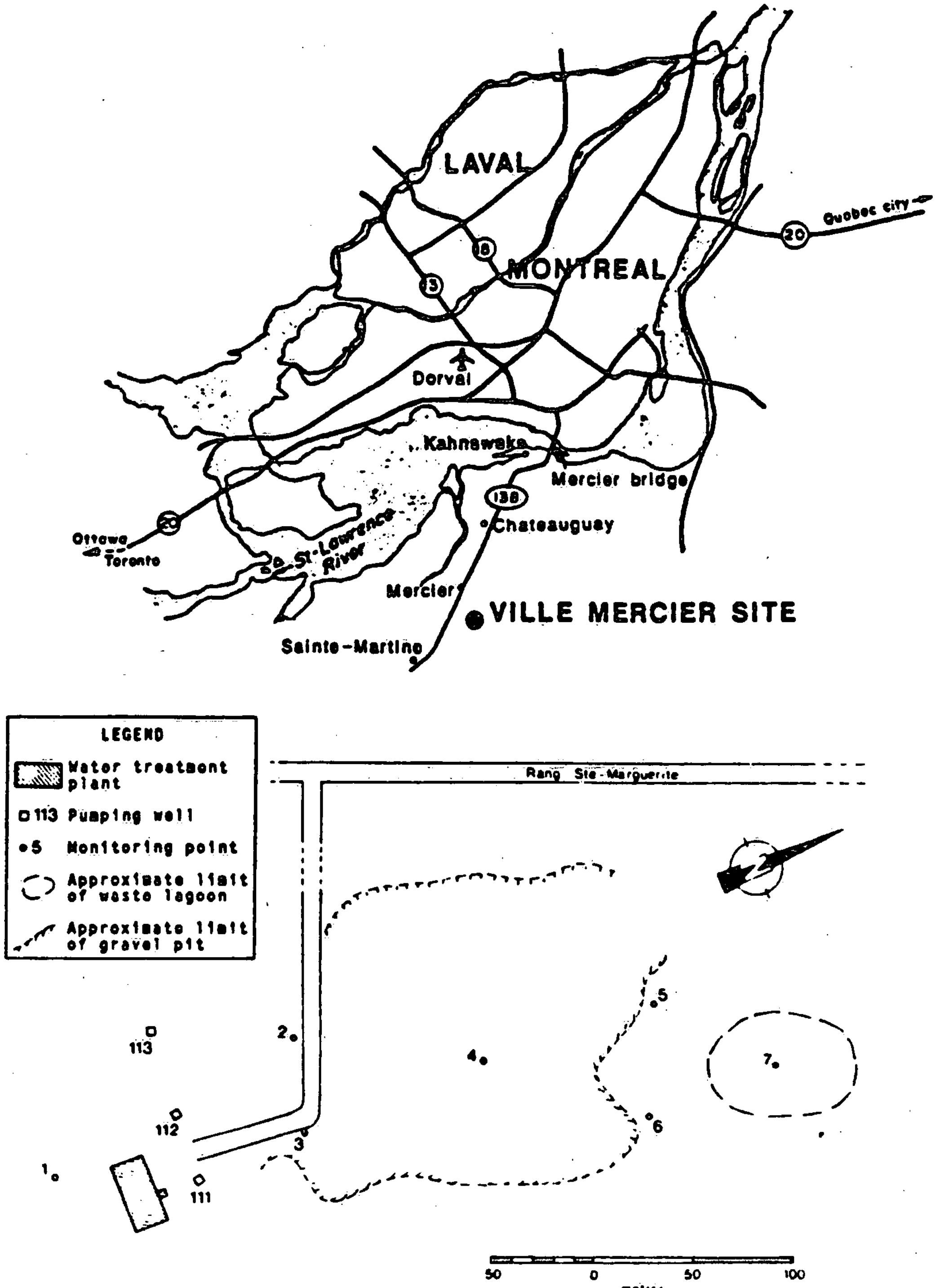


Figure 1: (a) Location of Ville Mercier Site
(b) Site Plan (courtesy of A. Masson, Laval University)

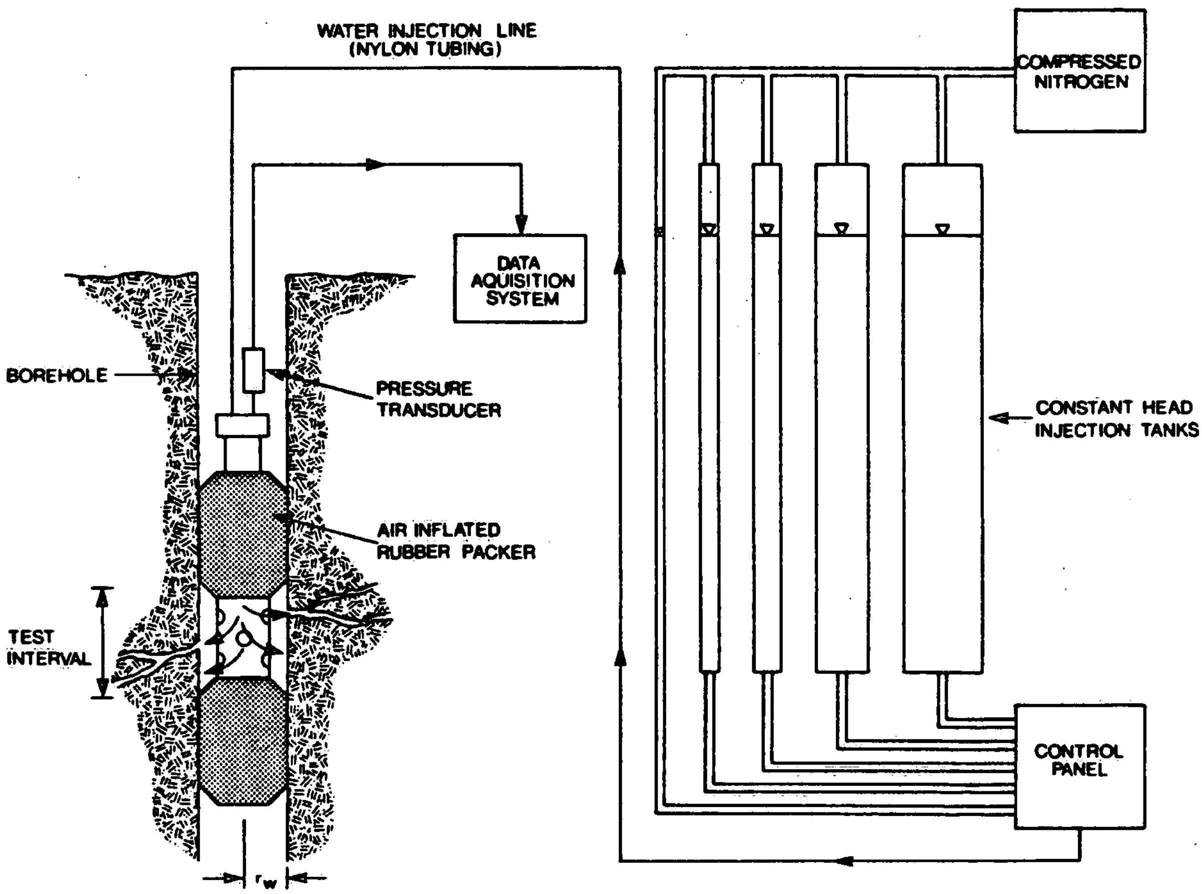


Figure 2. Schematic of constant head injection testing setup.

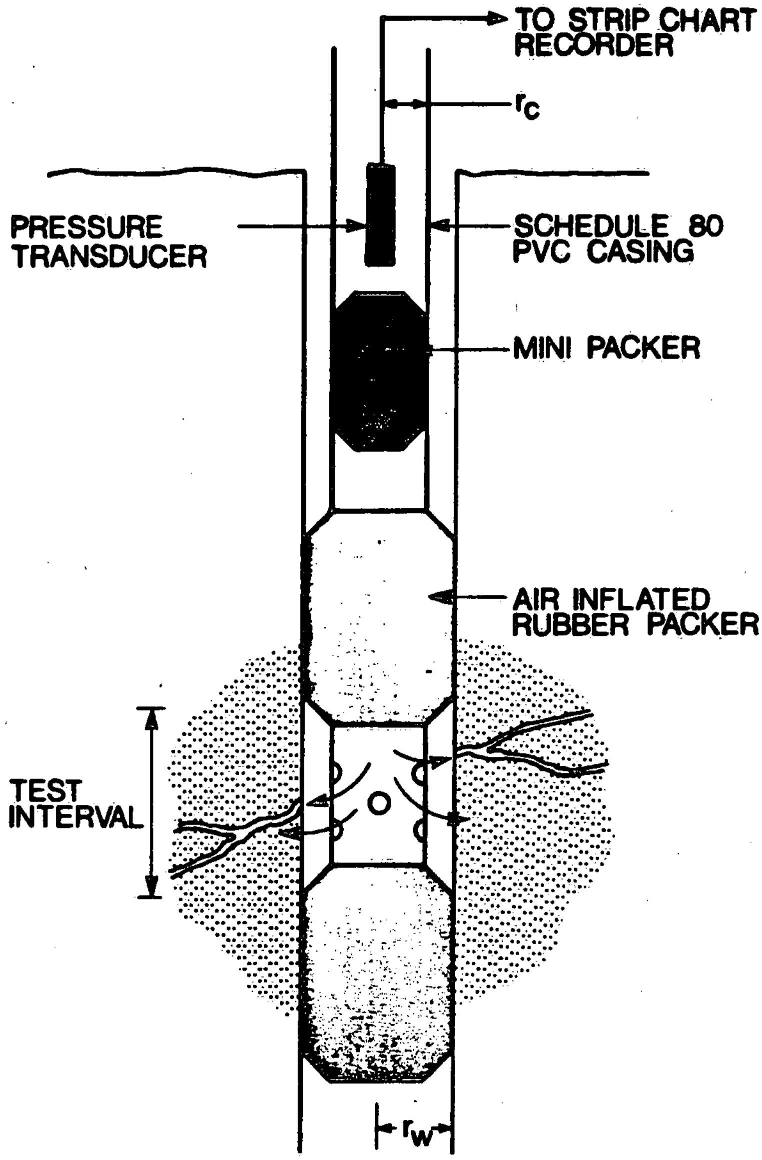


Figure 3. Schematic diagram of slug testing set-up.

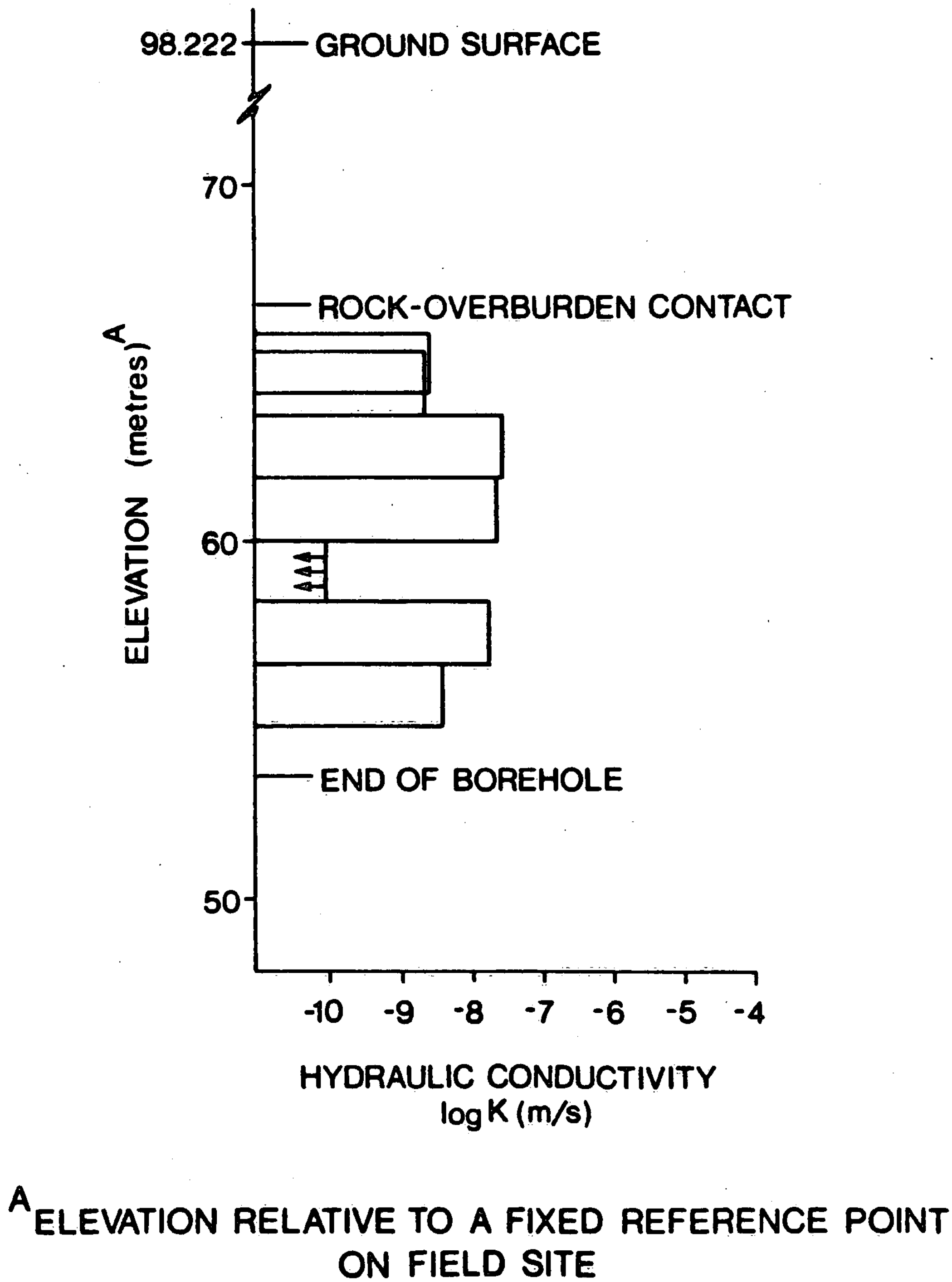
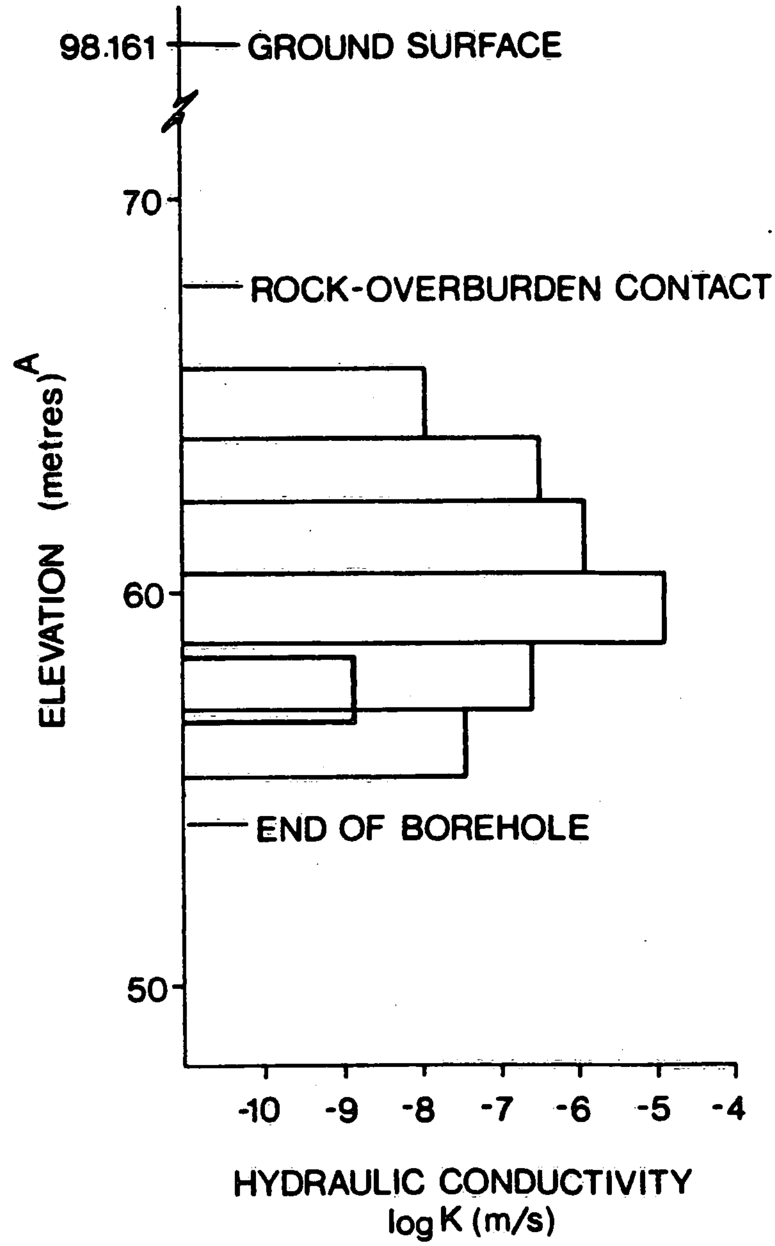


Figure 4. R1 hydraulic conductivity profile.



AELEVATION RELATIVE TO A FIXED REFERENCE POINT ON FIELD SITE

Figure 5. R2 hydraulic conductivity profile.

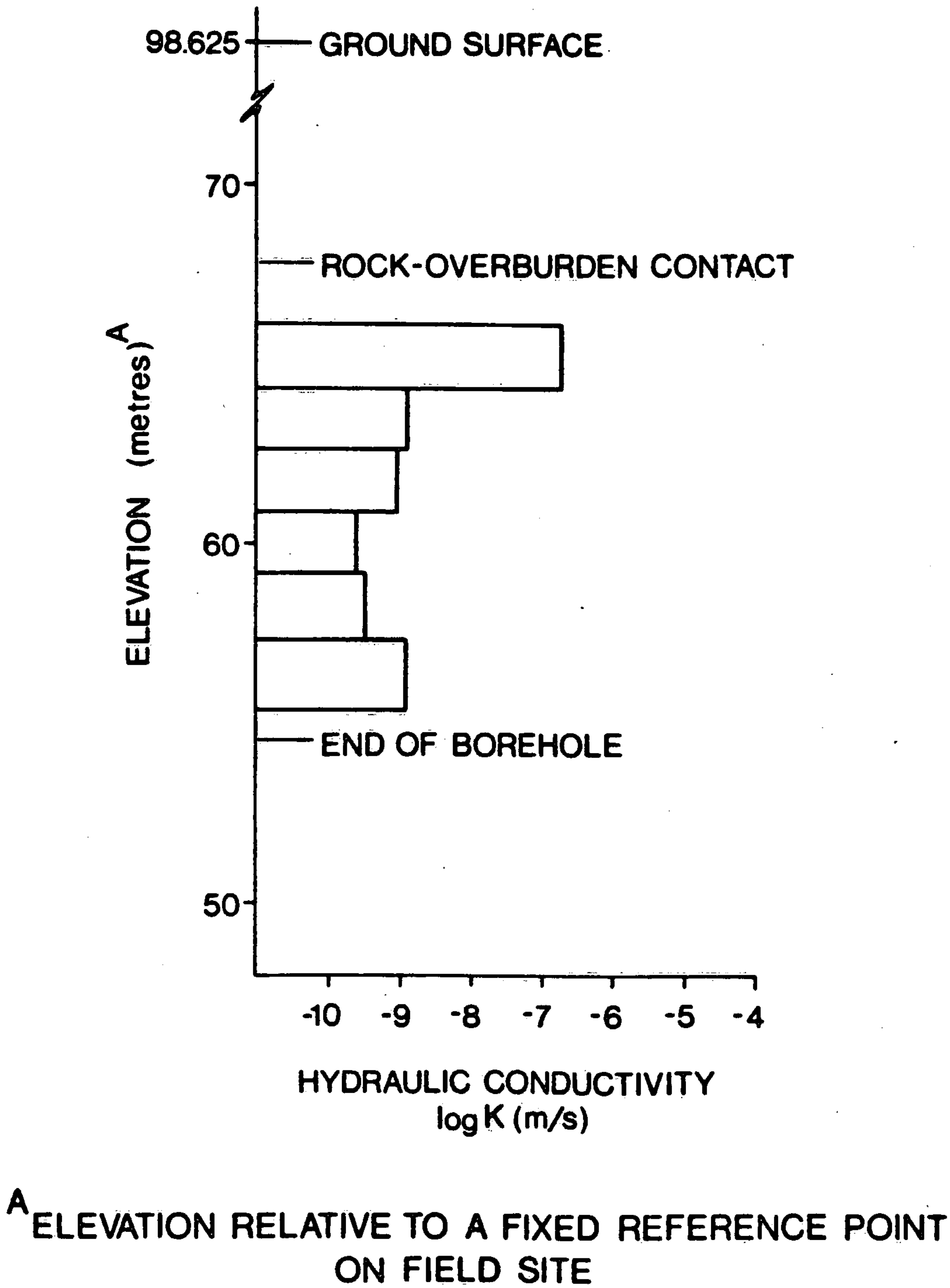
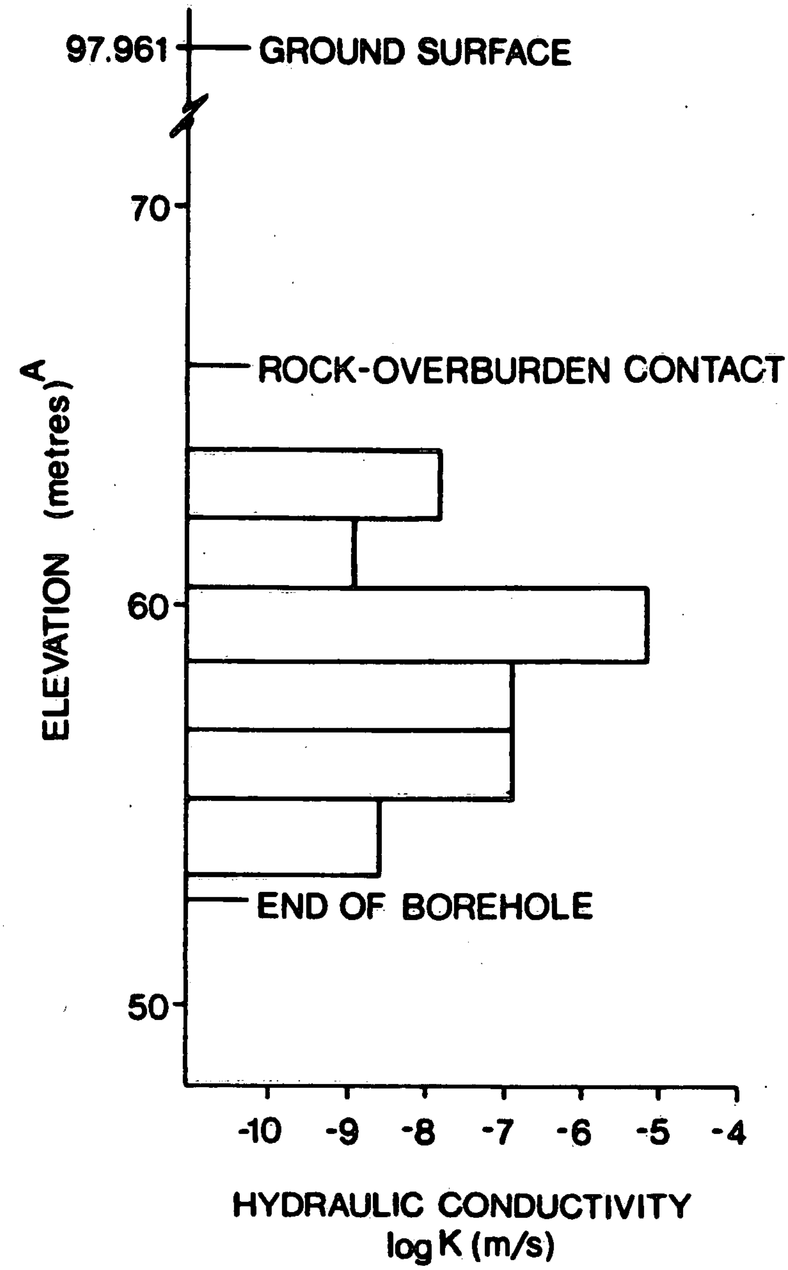


Figure 6. R3 hydraulic conductivity profile.



AELEVATION RELATIVE TO A FIXED REFERENCE POINT ON FIELD SITE

Figure 7. R4 hydraulic conductivity profile.

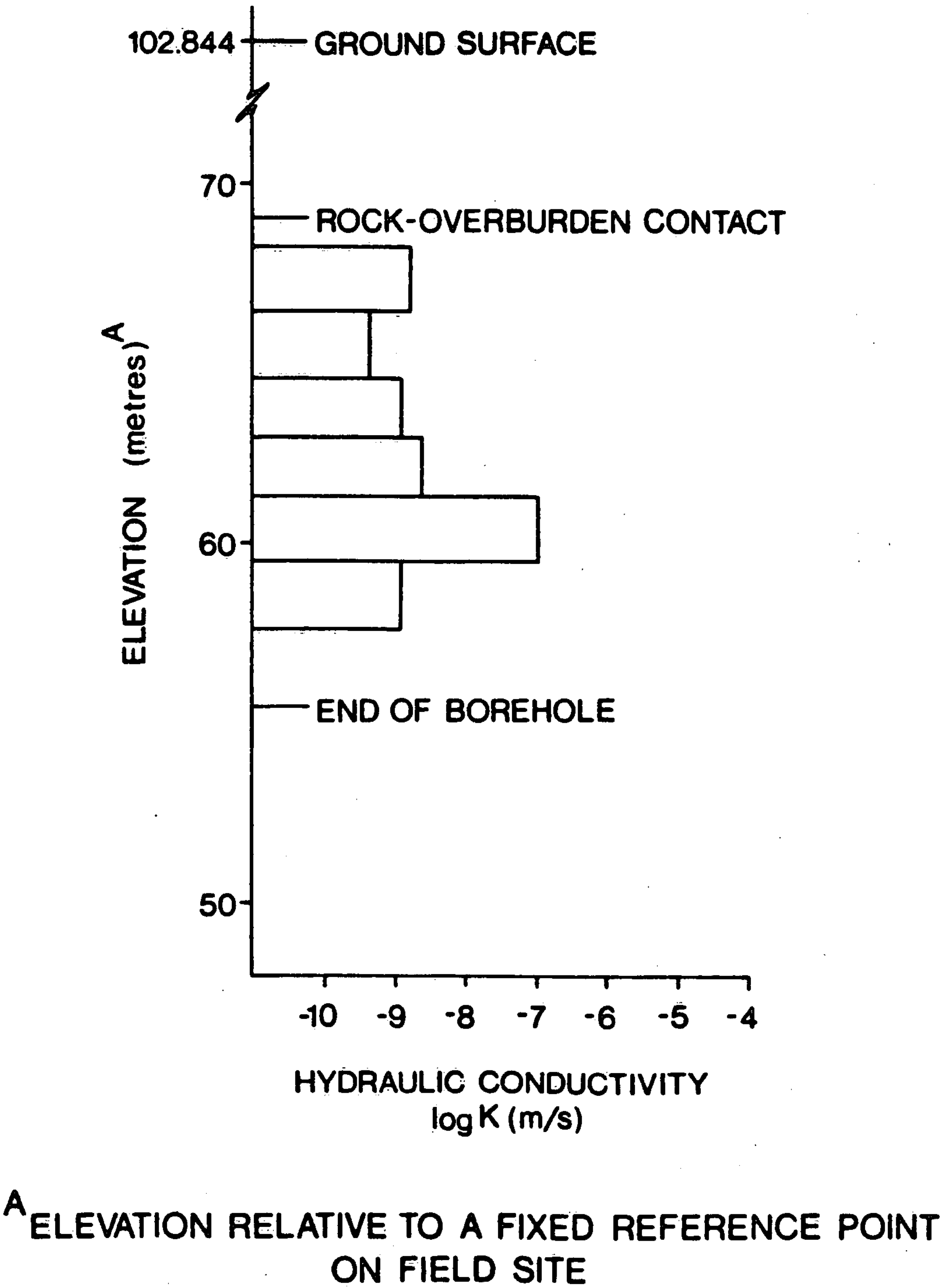


Figure 8. R5 hydraulic conductivity profile.

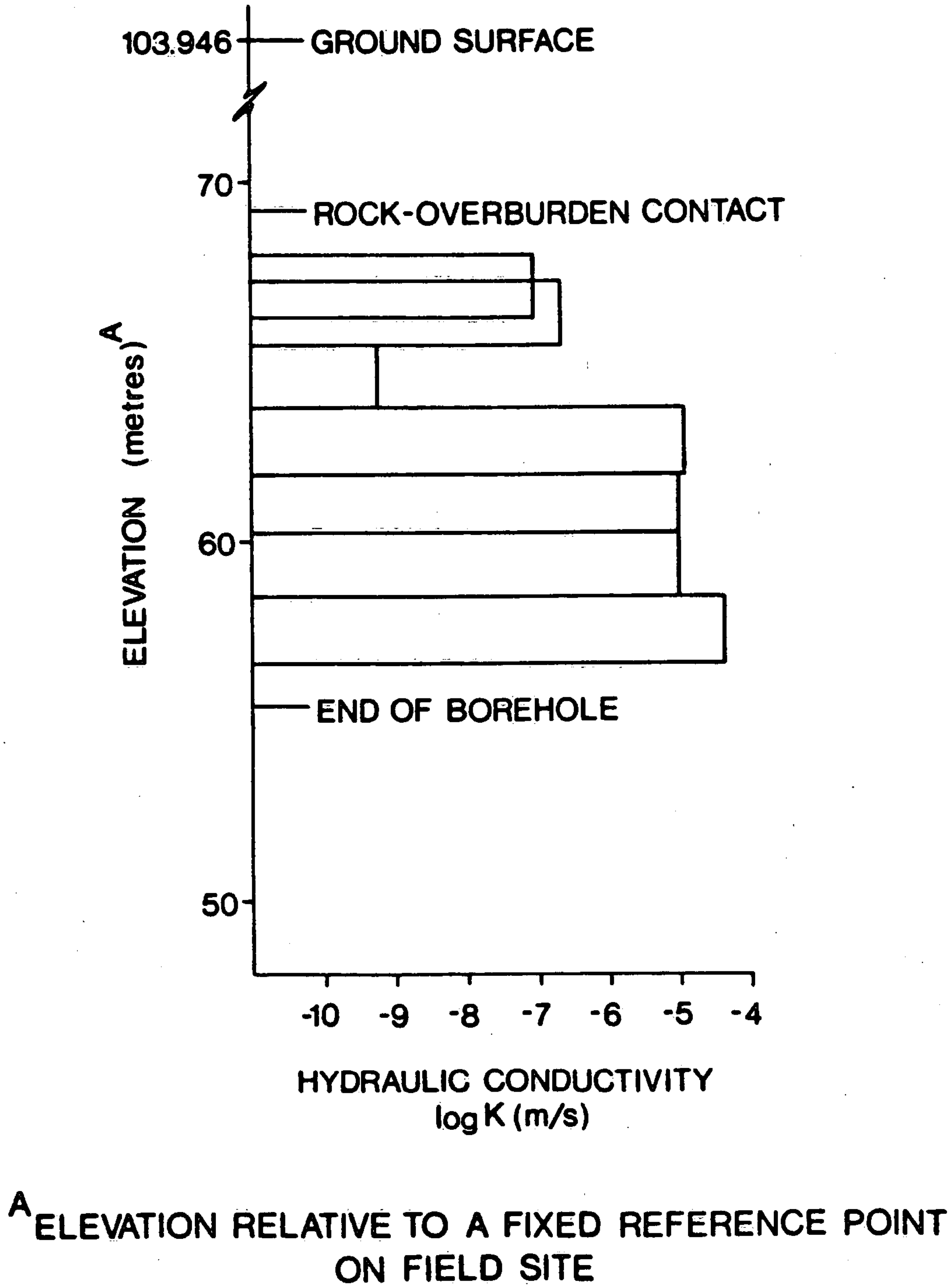
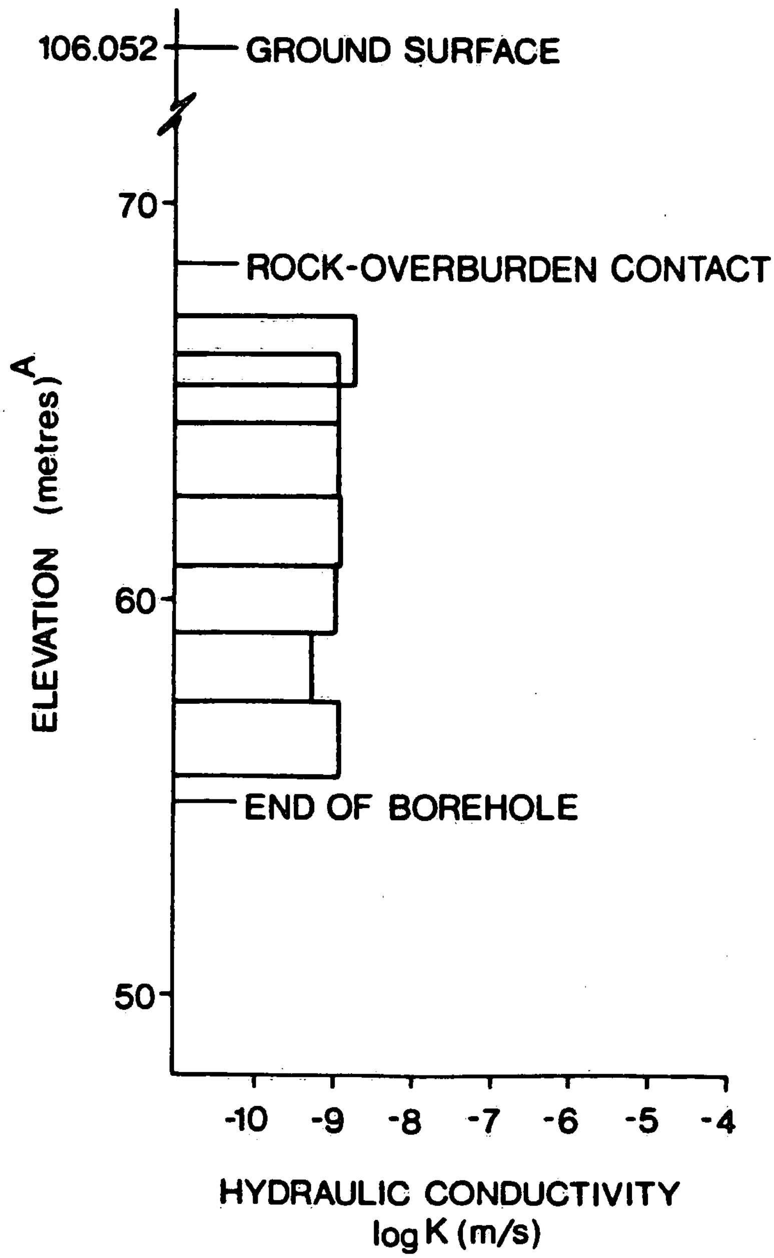


Figure 9. R6 hydraulic conductivity profile.



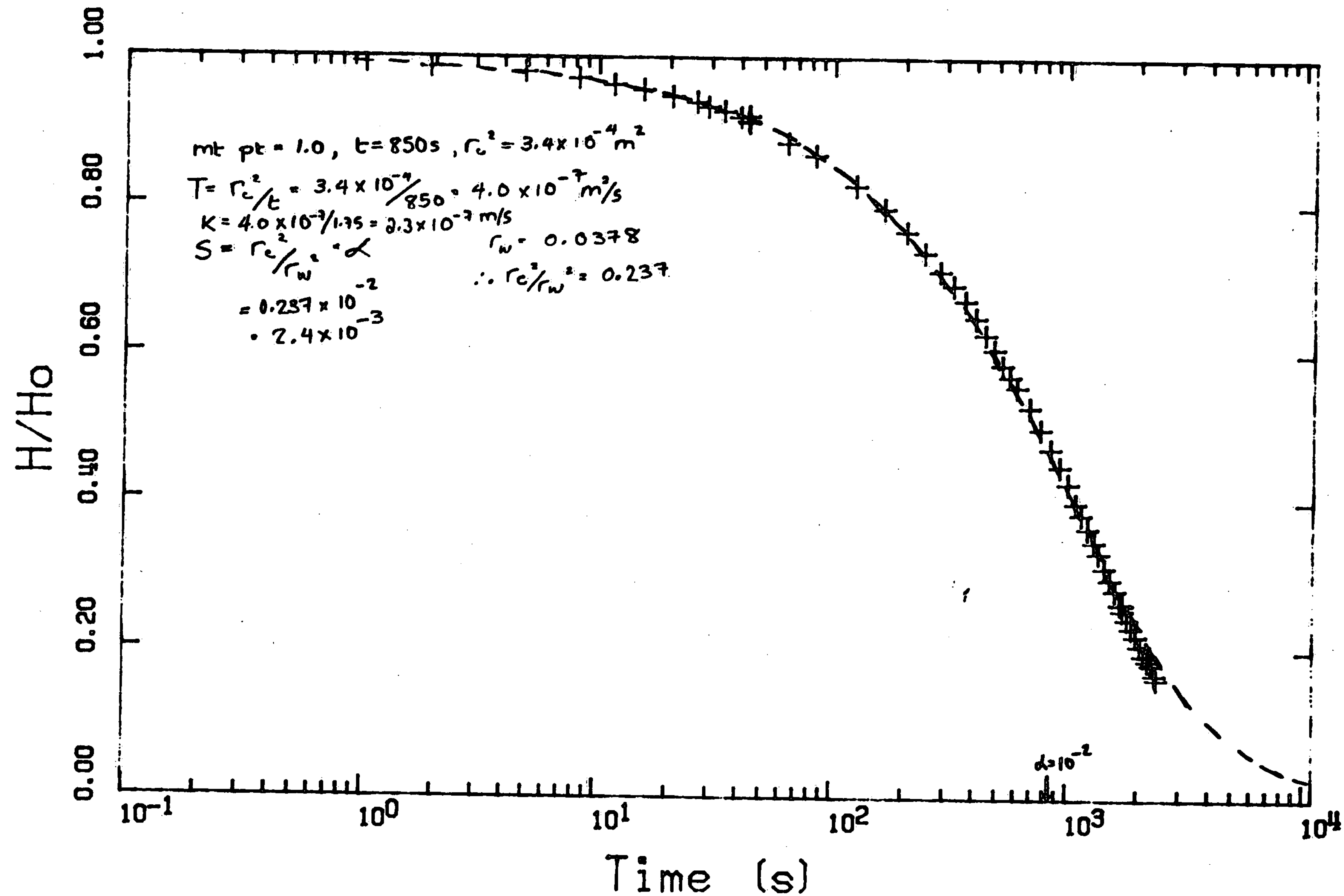
A ELEVATION RELATIVE TO A FIXED REFERENCE POINT ON FIELD SITE

Figure 10. R7 hydraulic conductivity profile.

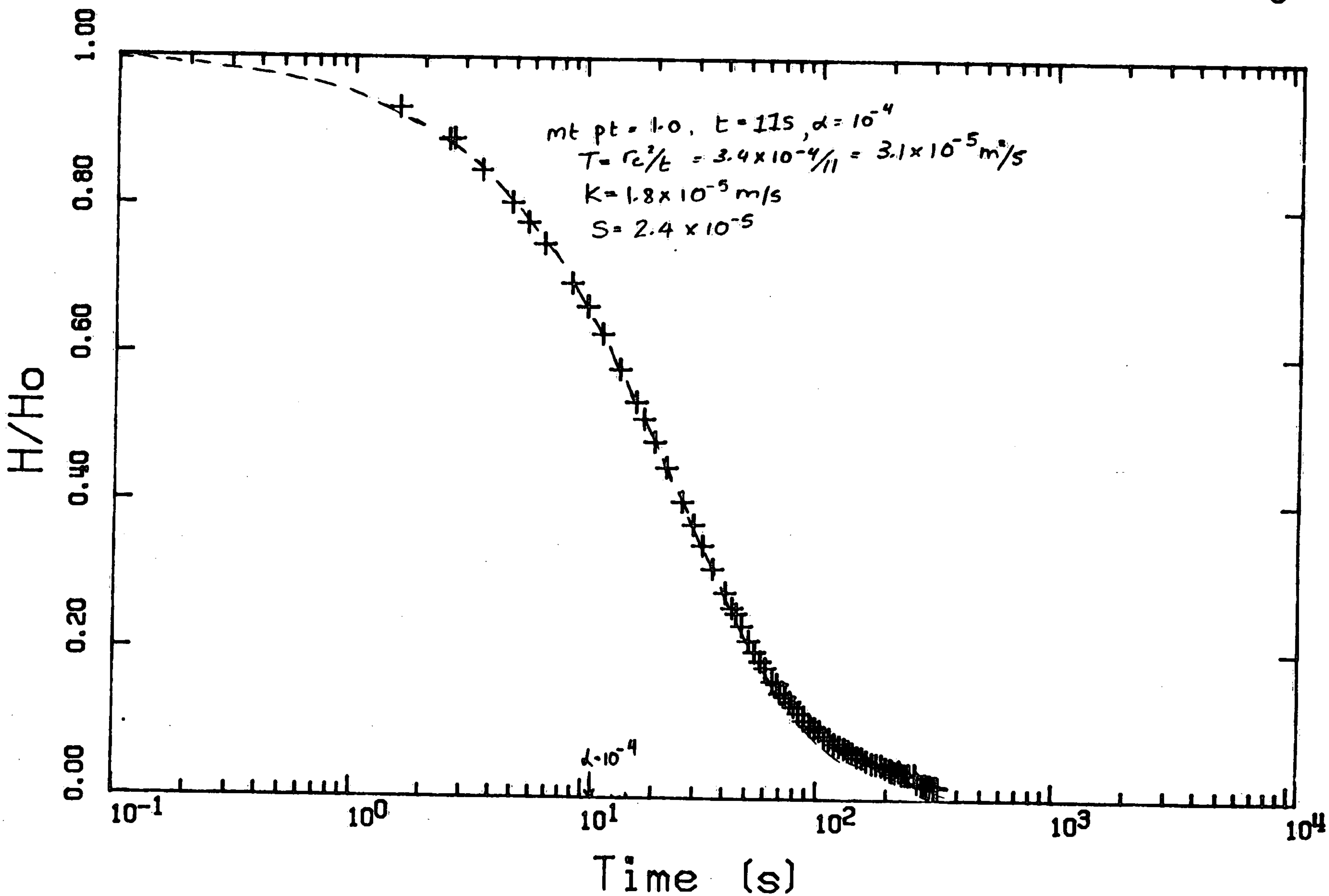
APPENDIX A

SLUG TEST TYPE CURVE MATCHES

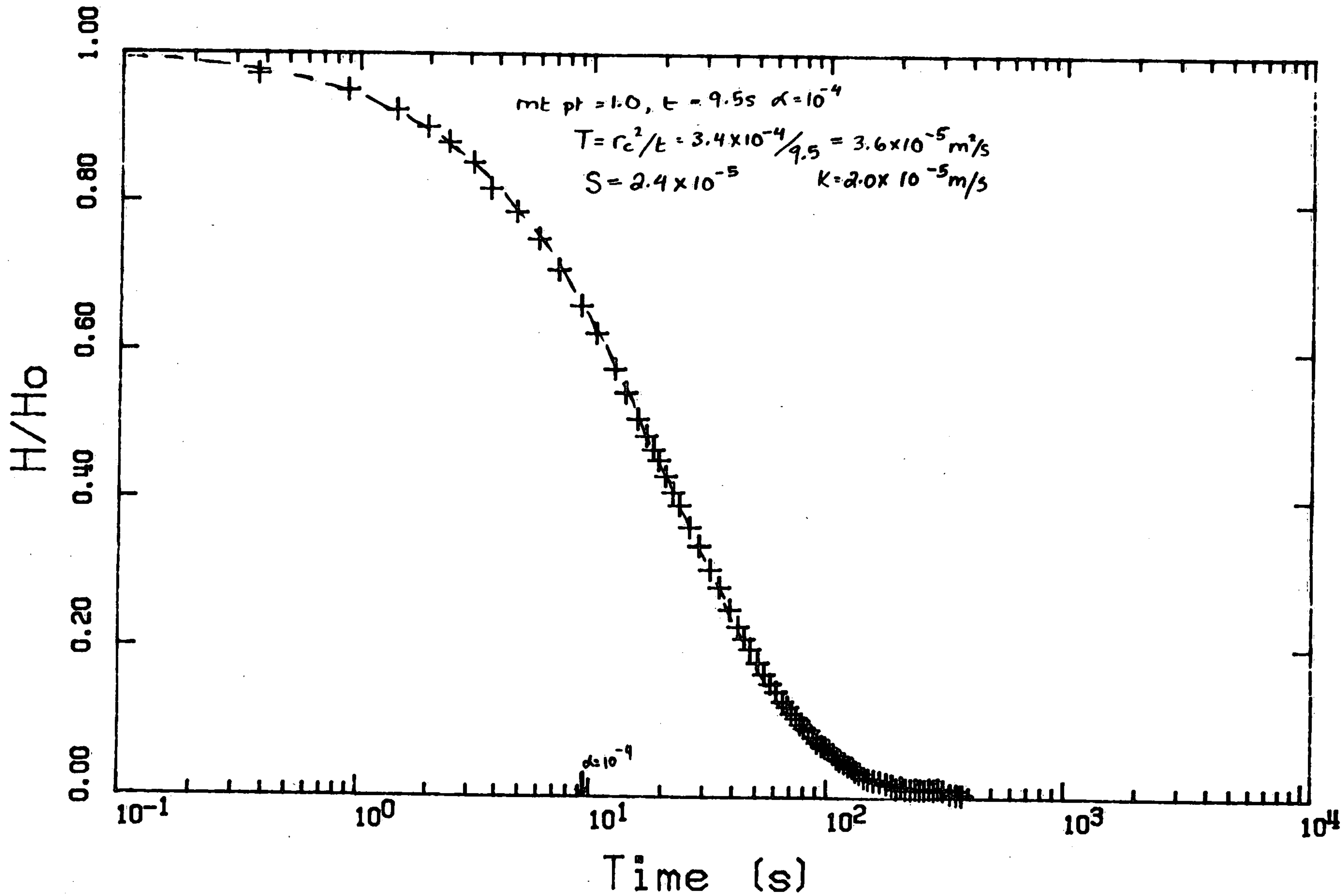
Ville Mercier slug tests: R3 test #1 32.55-34.30 mbgs



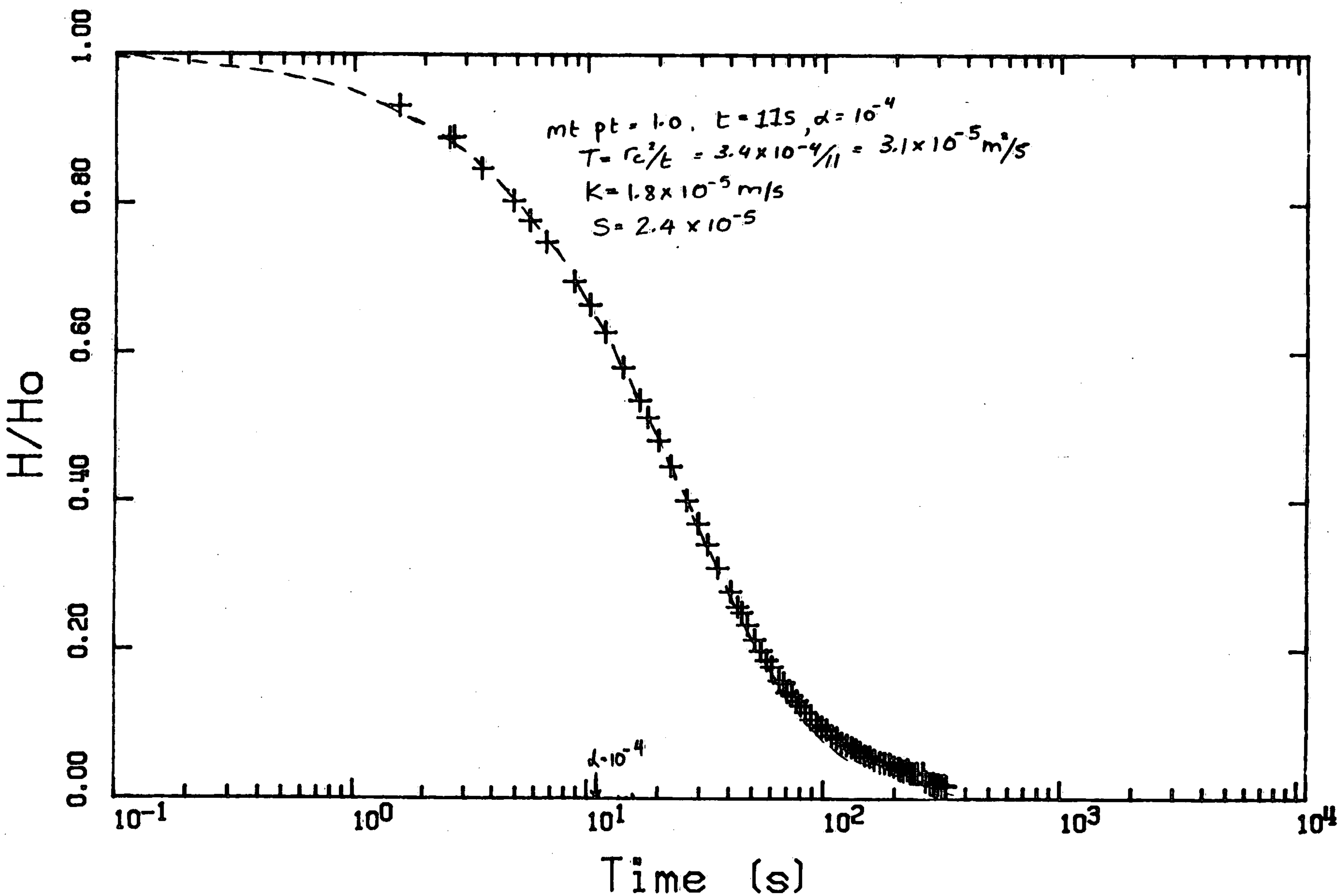
Ville Mercier slug tests: R2 test #1 (repeat) 37.75-39.50 mbgs

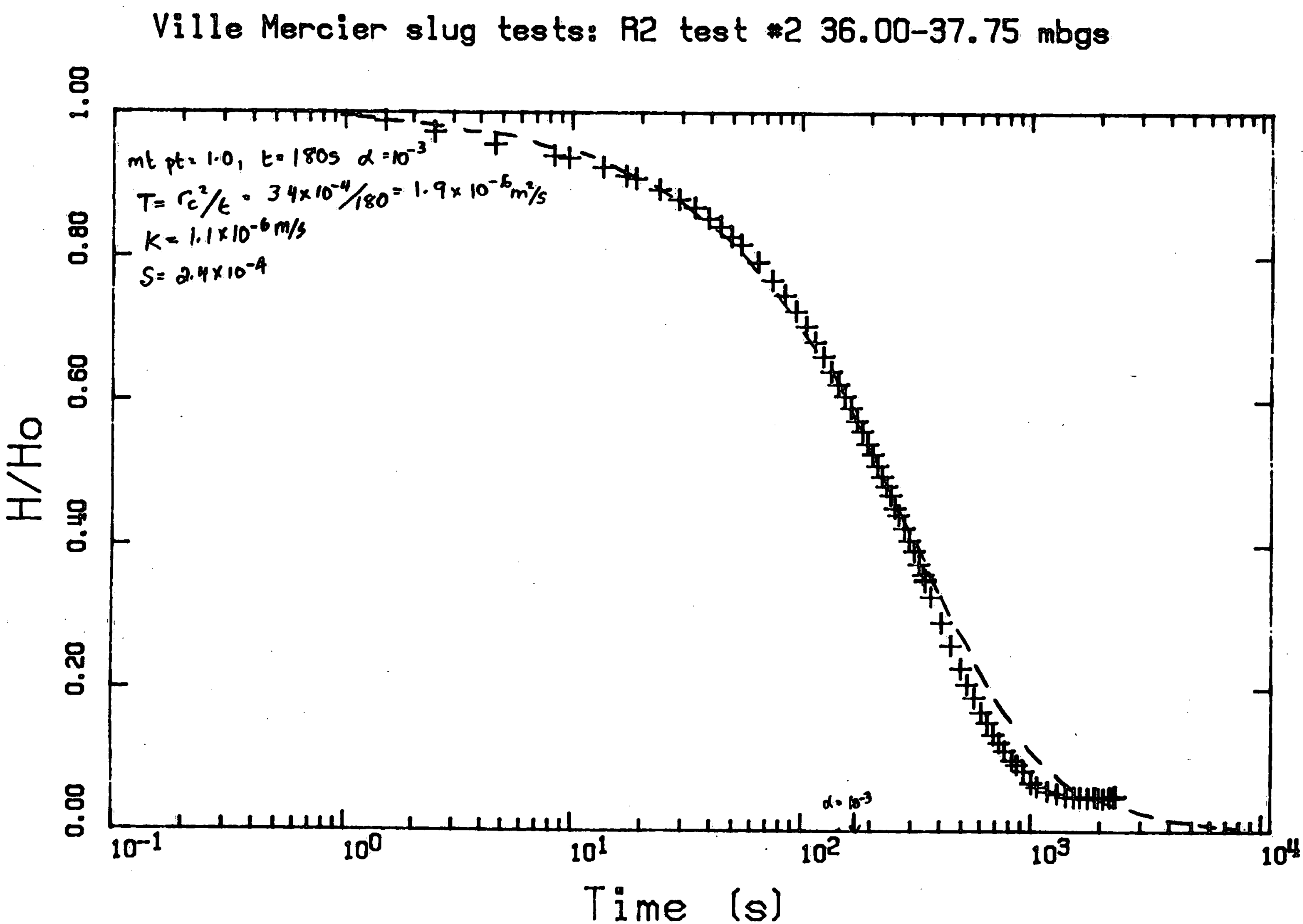


Ville Mercier slug tests: R2 test #1 37.75-39.50 mbgs

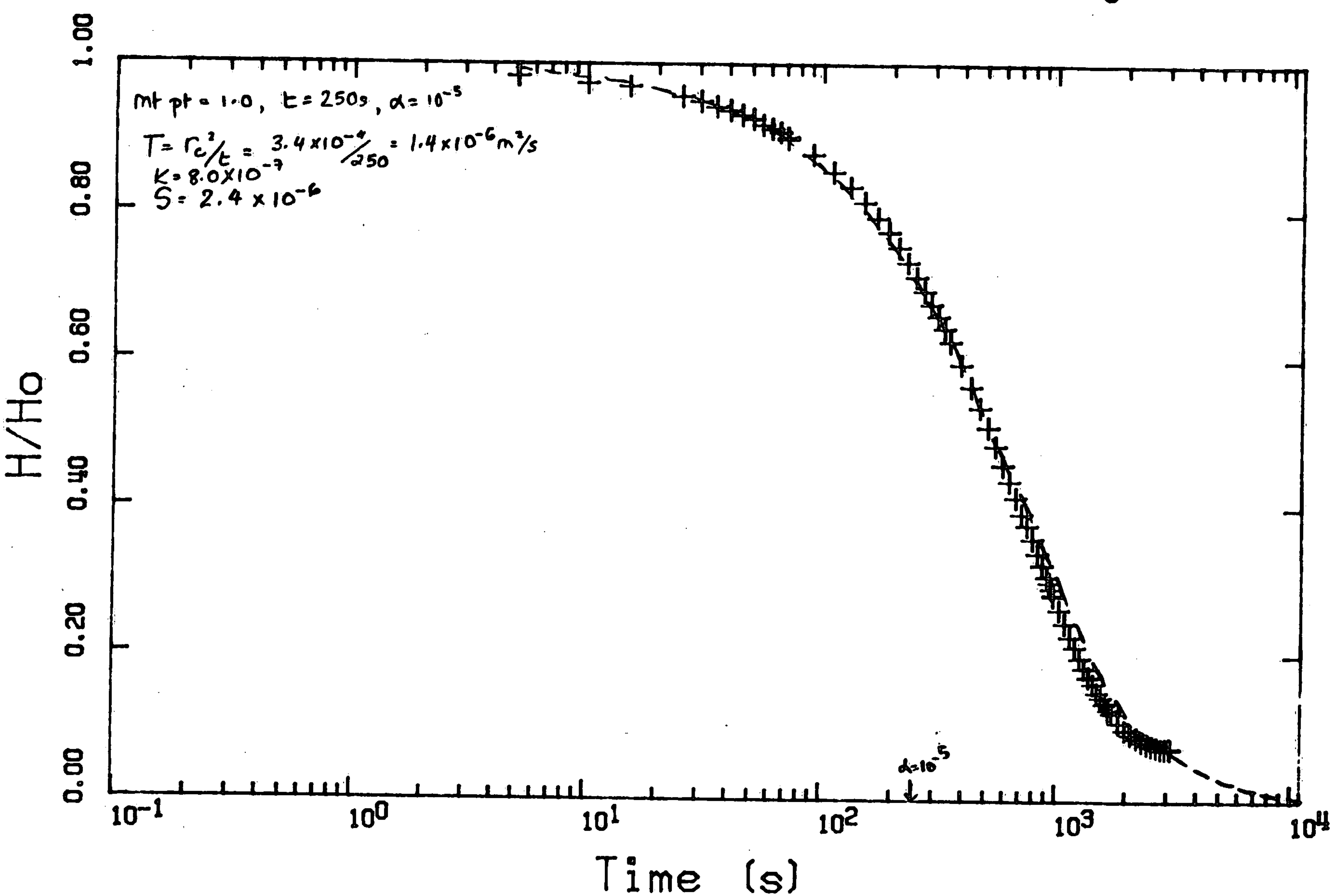


Ville Mercier slug tests: R2 test #1 (repeat) 37.75-39.50 mbgs

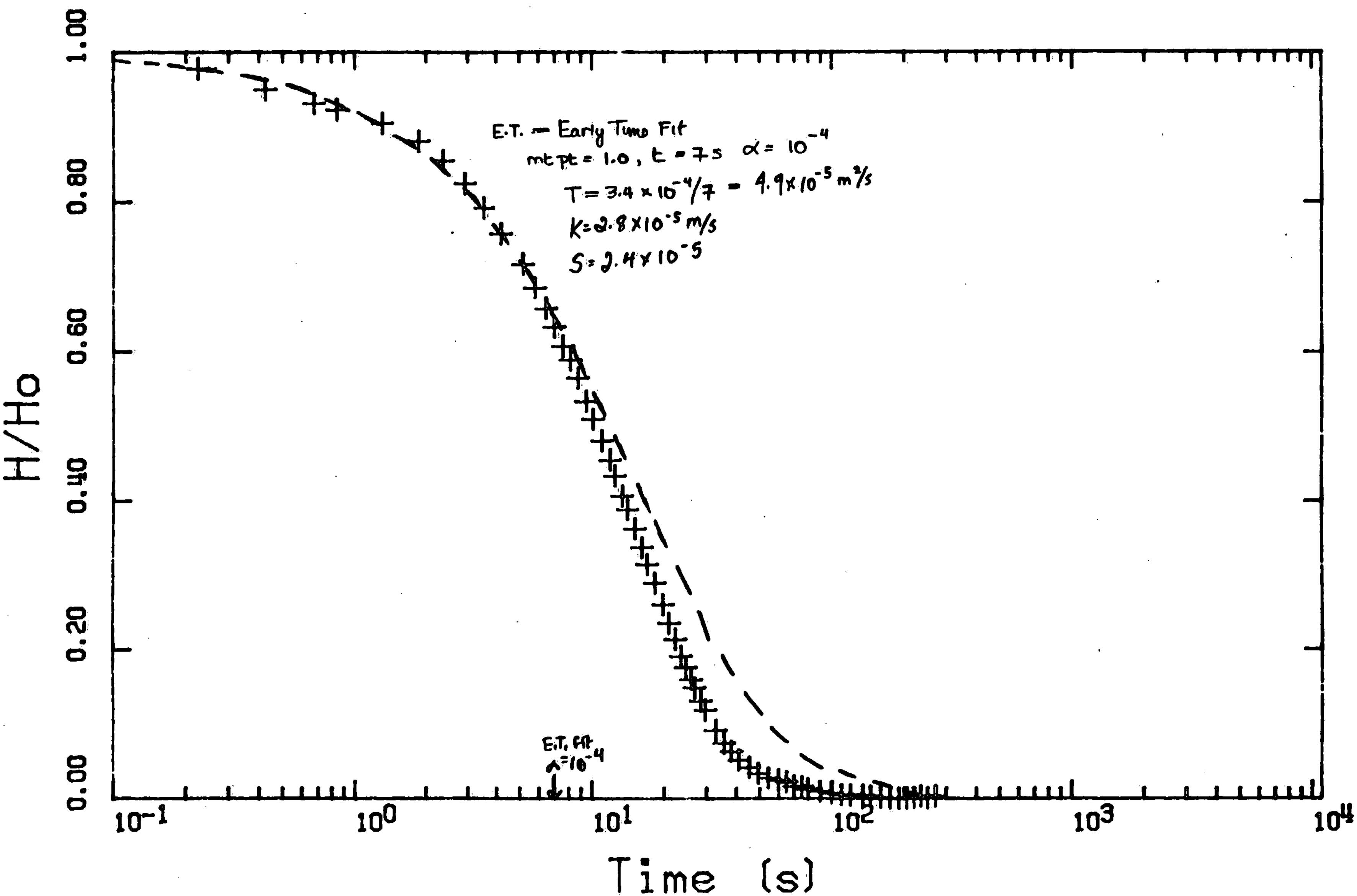


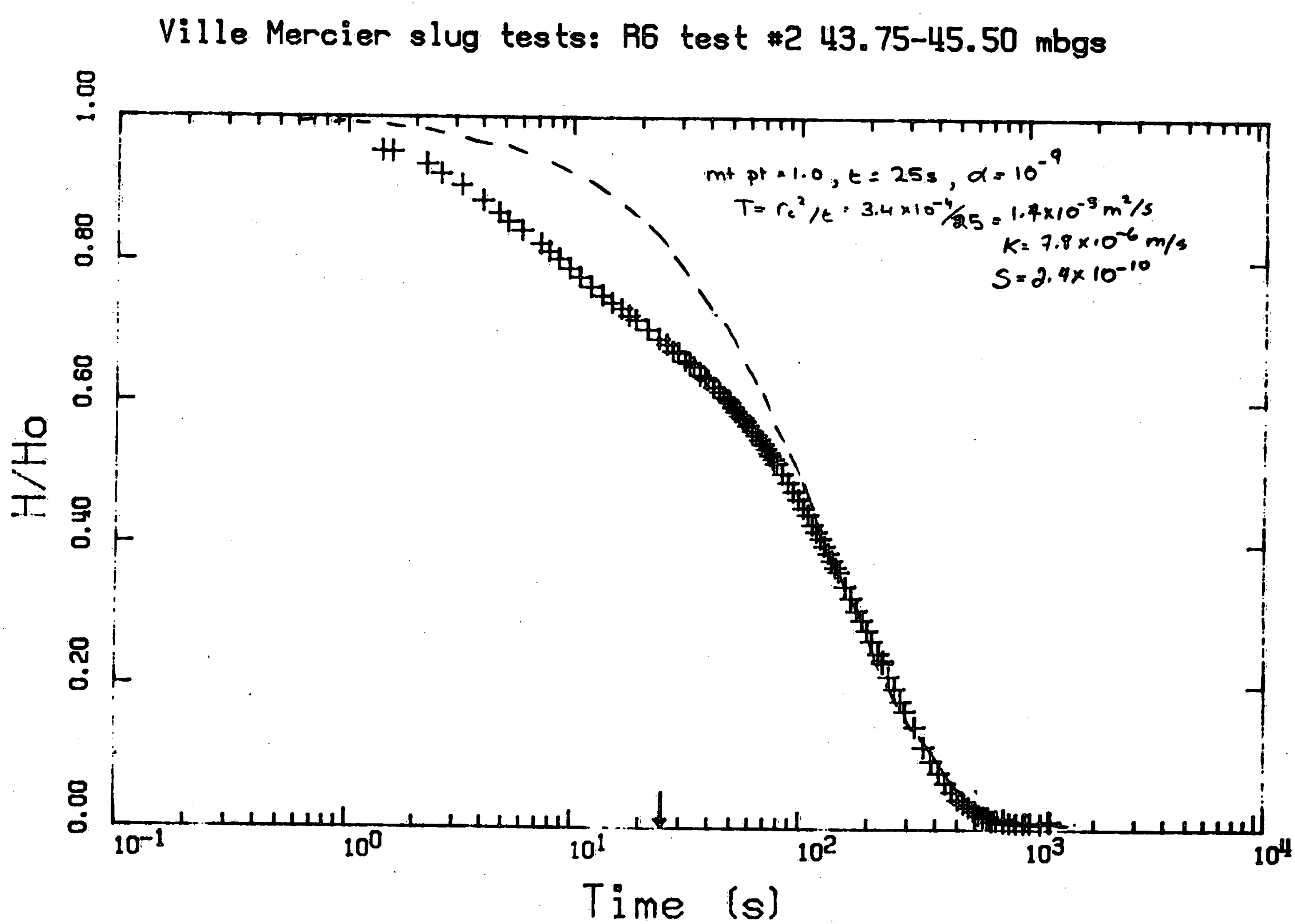

Ville Mercier slug tests: R2 test #2 36.00-37.75 mbgs
mt pt = 1.0, t = 180s α = 10^-3
T = rc²/t = 3.4x10^-4/180 = 1.9x10^-6 m²/s
K = 1.1x10^-6 m/s
S = 2.4x10^-4
α = 10^-3
H/Ho
1.00
0.80
0.60
0.40
0.20
0.00
10^-1
10^0
10^1
10^2
10^3
10^4
Time (s)

Ville Mercier slug tests: R2 test #3 34.25-36.00 mbgs

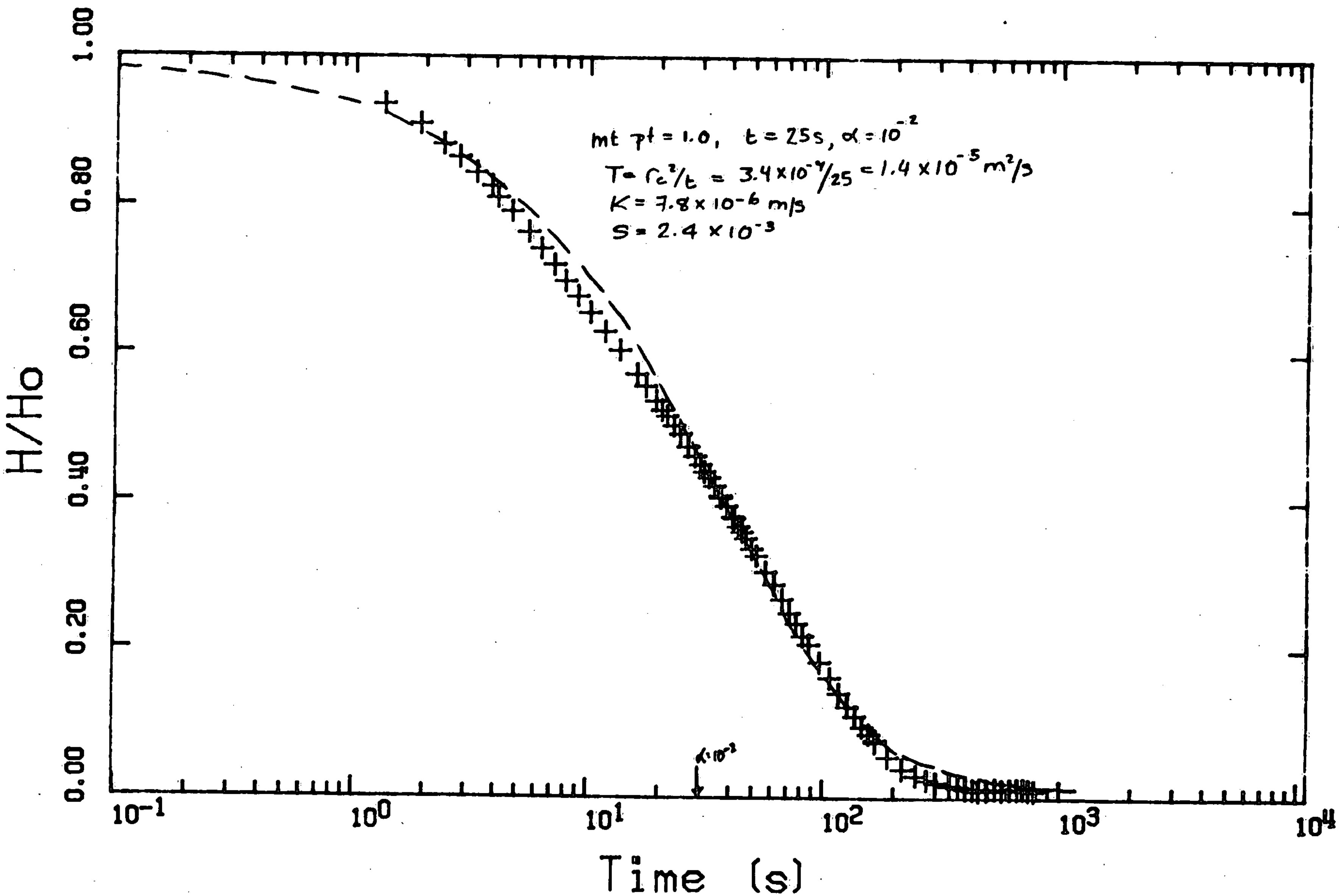


Ville Mercier slug tests: R6 test #1 45.50-47.25 mbgs

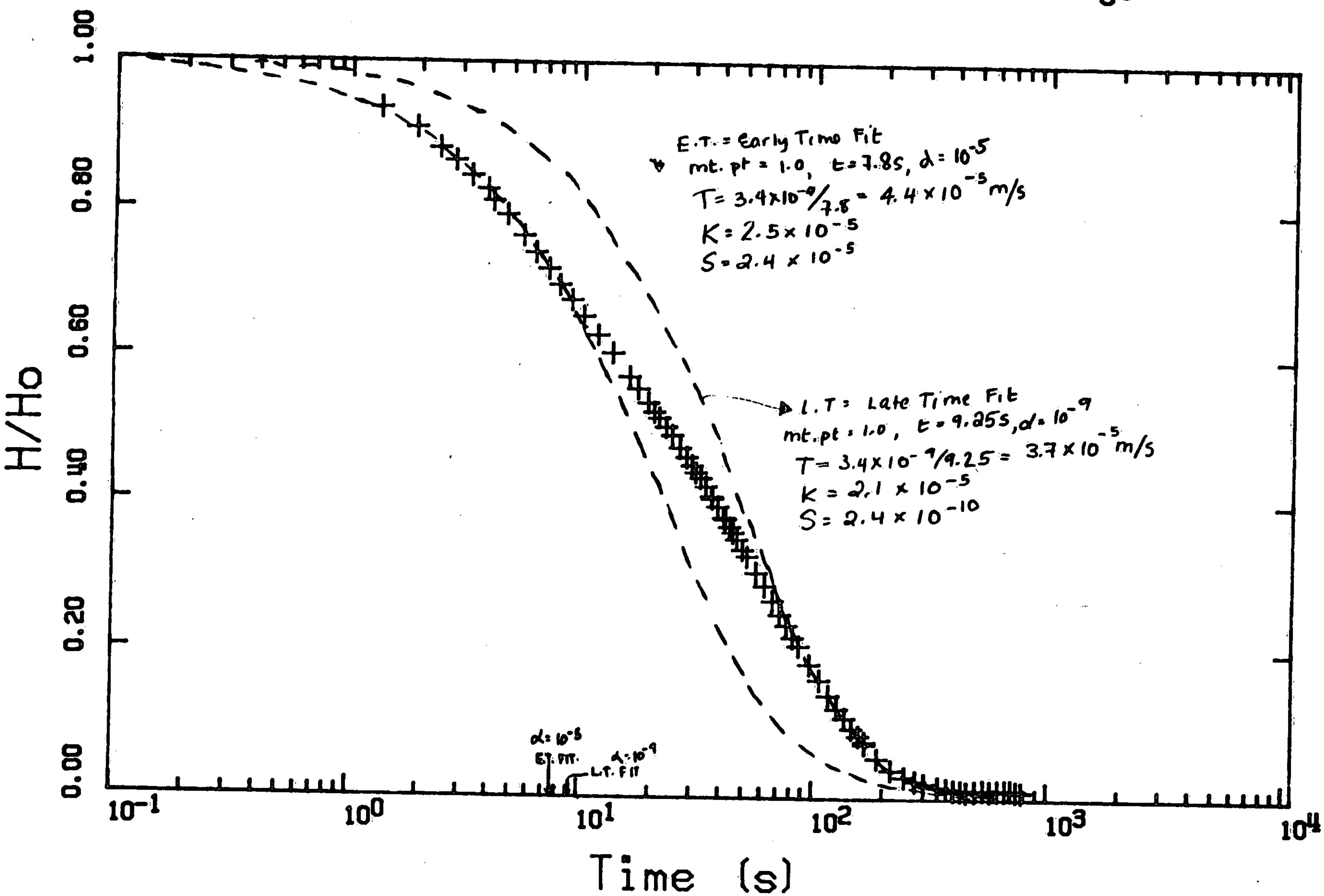



Ville Mercier slug tests: R6 test #2 43.75-45.50 mbgs
1.00
0.80
0.60
0.40
0.20
0.00
H/Ho
10-1
100
101
102
103
104
Time (s)
mt pt = 1.0, t = 25s, α = 10-9
T = rc2/t = 3.4x10-4/25 = 1.4x10-5 m2/s
K = 7.8x10-6 m/s
S = 2.4x10-10

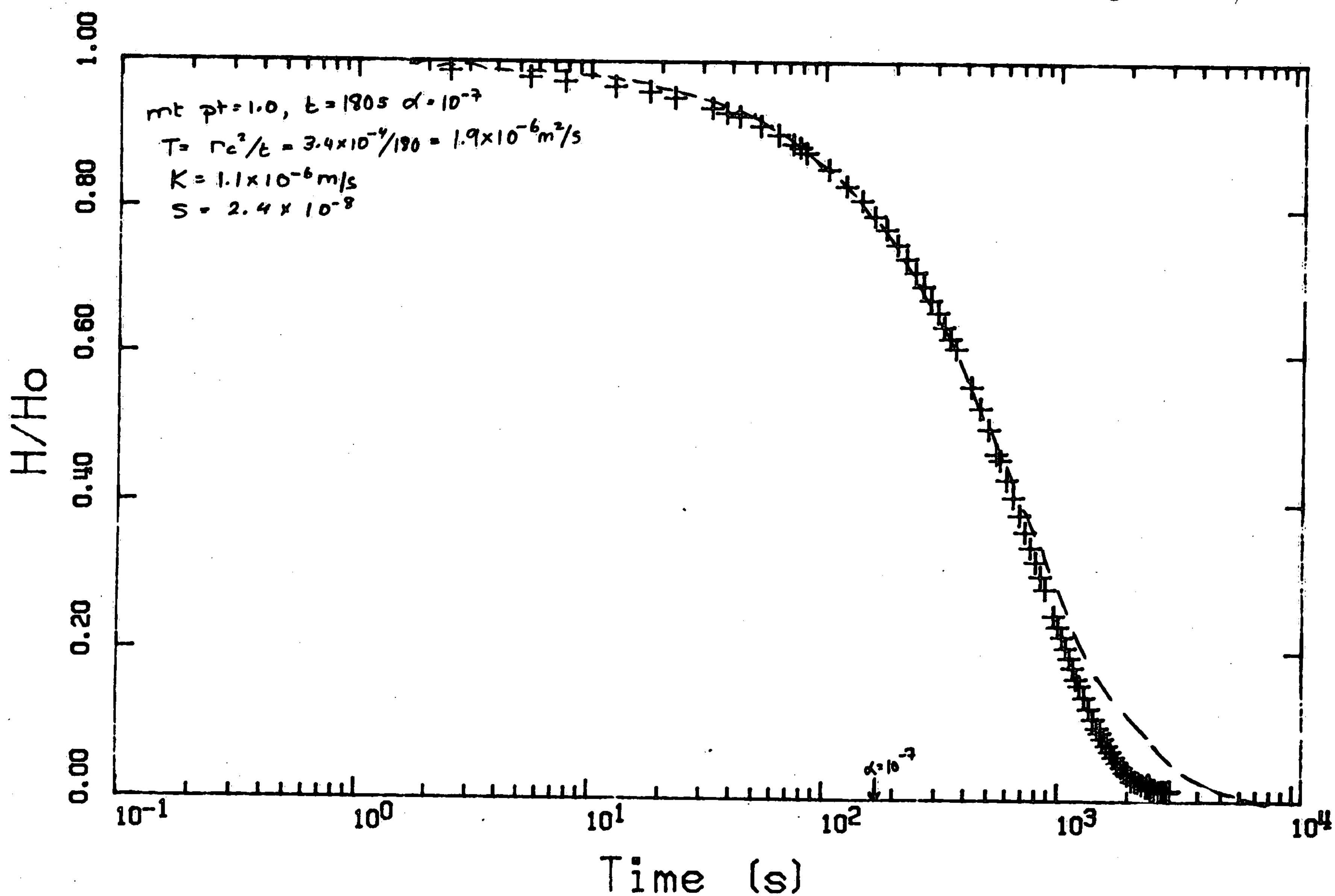
Ville Mercier slug tests: R6 test #3 42.00-43.75 mbgs



Ville Mercier slug tests: R6 test #3 42.00-43.75 mbgs



Ville Mercier slug tests: R6 test #4 40.25-42.00 mbgs



Ville Mercier slug tests: R6 test #5 36.75-38.50 mbgs