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Äspö Hard Rock Laboratory

TRUE Block Scale experiment

Detailed flow logging of core boreholes KA2511A, Kl0025F and KA3510A using a double packer system

Bengt Gentzschein

Geosigma AB

July 1997

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19

Äspö Hard Rock
Laboratory

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Gentzschein	
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1. BACKGROUND

During 1996 characterization work for the TRUE Block Scale Project commenced at Äspö with drilling of borehole KA2563A from the spiral tunnel. Characterization data from this borehole and data from boreholes KA2511A and KA3510A have been used to update the structural model of the southwestern part of the Äspö HRL (Hermanson and Follin, TN 97-19b).

On the basis of this updated model and the identified centre of gravity for further investigations, several alternative borehole positions were considered. Eventually, the borehole KI0025F located in the "I-drift/niche, and near south directed was drilled", cf. Figure 1.1.

The boreholes have been characterized with acoustic flow logging (UCM), borehole radar (RAMAC), borehole TV (RAAX-BIPS) and detailed double packer flow logging.

The detailed flow logging of borehole KA2563A was performed during november 1996 (Gentzschein 1997, SKB TN 97-07b). This technical note describes the detailed flow logging with double-packer technique, which was carried out in the boreholes KA2511A, KI0025F and KA3510A between May 21th and June 3rd 1997. Data of the three boreholes are summarized in Table 1.1

Table 1.1 Data of the three core boreholes KA2511A, KI0025F and KA3510A.

Borehole	Length (m)	Diameter (m)	Inclination (°)	Drilling period
KA2511A	293	0.056	33.71	Aug.-Sept. 1993
KA3510A	150.06	0.076	c. 30	Aug.-Sept. 1996
KI0025A	193.66	0.076	c. 20	April 1997

2. OBJECTIVES

The objective of the flow logging of KA2511A, KA3510A and KI0025F was to:

- achieve a detailed mapping of the inflow into the boreholes along selected segments.

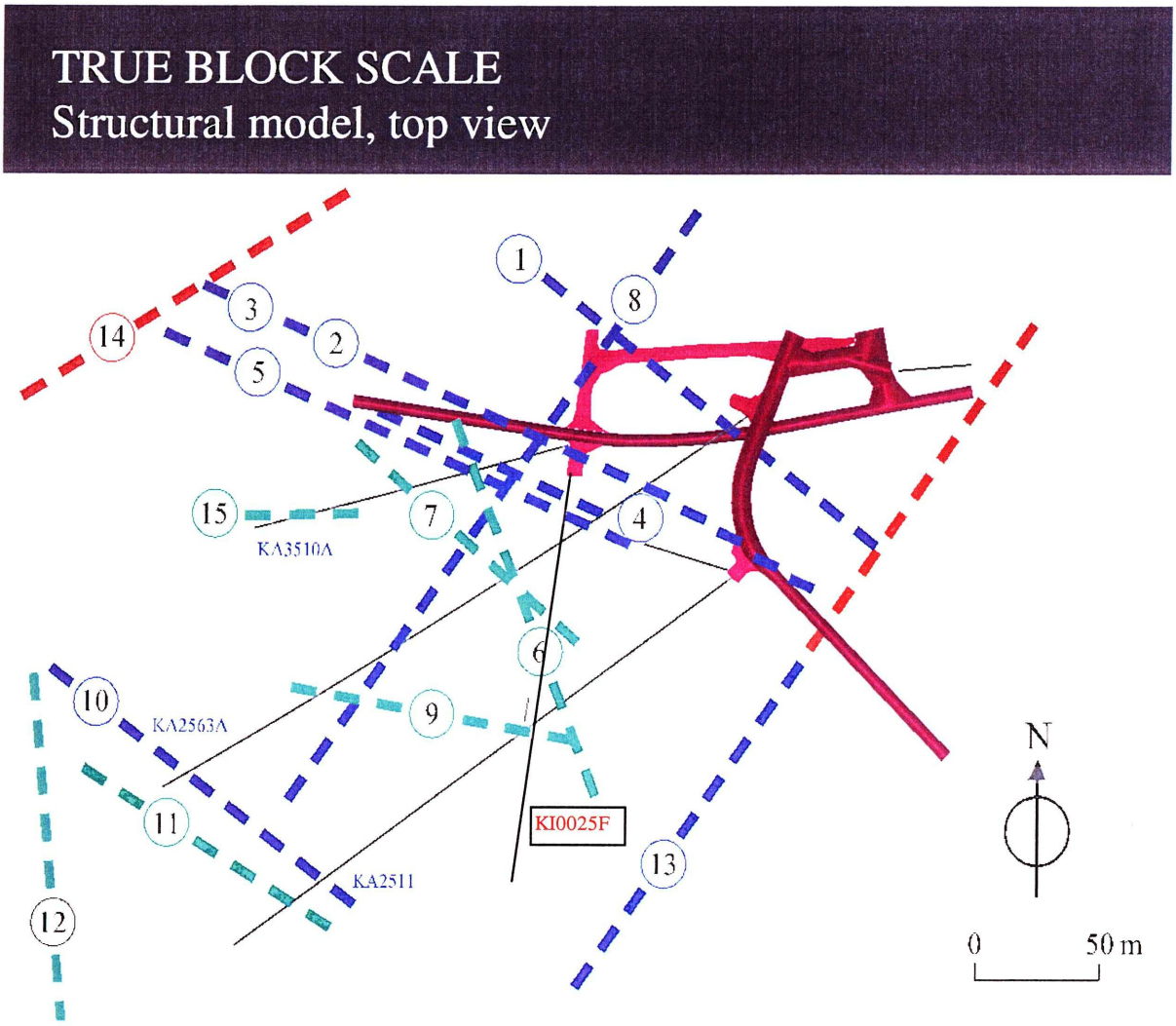


Figure 1-1 Updated structural model of the TRUE Block Scale Volume. Planar section at Z=-450 masl (Hermanson and Follin, in press). Horizontal projection of tentative geometry of borehole KI0025F (tentative borehole label).

3. SCOPE

The flow logging was performed in selected intervals of the three boreholes KA2511A, KA3510A and KI0025F. A double-packer system with the packer spacing 5 m was used .

The measurements in KA2511A complement performed flow and pressure build-up tests in 3m sections in the interval L= 172 - 265 m (Olsson et al 1994, SKB PR 25-94-14). Measurements in KA3510A and KI0025F are focused on a rock volume assumed non-affected by cement grouting

After the double-packer measurements the flows of the entire boreholes were measured. Table 3.1 summarizes the flow logging of the three boreholes.

Table 3.1 Number of flow measurements, detailed flow logging of core boreholes KA2511A, KA3510A and KI0025F.

Borehole	Length of measurement section (m)	Number of measurements	Borehole interval (m)
KA2511A	5	25	50 - 175
"	293	1	0 - 293
KA3510A	5	19	50 - 145
"	150	1	0 - 150
KI0025F	5	25	42 - 167
"	193	1	0 - 193

Data on inflow to each test section has been determined and is presented in tables and diagrams, see Chapter 6.

With the help of the flow logging data the transmissivity of each test interval has been estimated, see Chapter 6.

4. EQUIPMENT USED

The flow logging equipment used in the three boreholes is illustrated in Figure 4.1. The measurement sections were shut in by a double-packer system. The packers, which have a sealing length of 1 m, were inflated by water pressurized by nitrogen gas in a stainless steel pressure vessel. A plastic hose, type Tecalan ⌀ 6/4 mm, connect the pressure between the pressure vessel and the double-packer. A second Tecalan hose connected the measurement section with a pressure transducer, located outside the borehole. The transducer is manufactured by Druck, type PTX 510, abs., pressure range 0 - 5 Mpa.

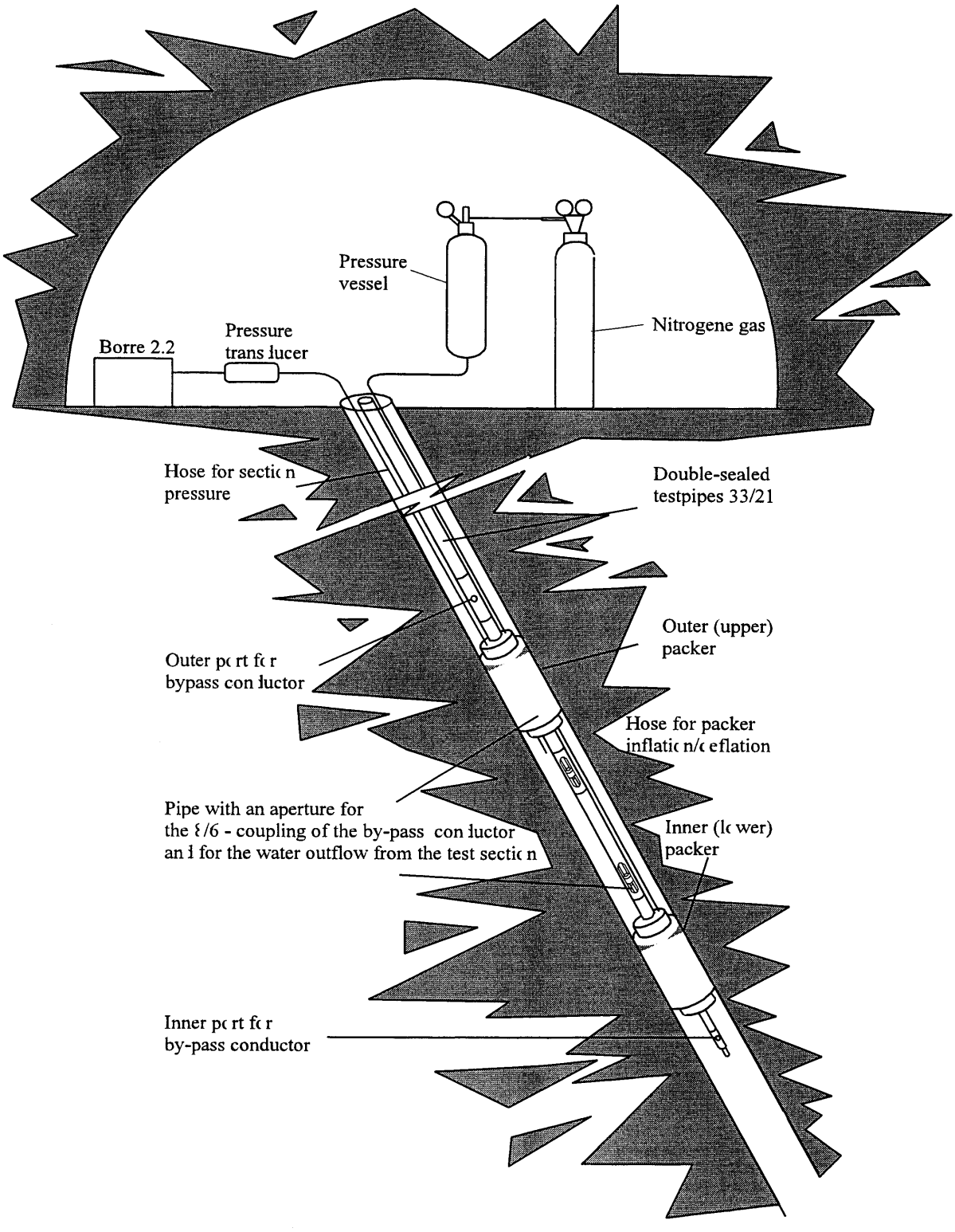
Pressure data were stored using the data logger BORRE MDL ver. 2.2, manufactured by IPA-konsult AB. The software of the logger is very flexible concerning sampling intervals etc. A measurement sequence can be started either by a temporarily connected computer or by using the key pad at the front of the data logger. Pressure values are shown on the computer screen during the measurements. The key pad enables three measurement options. The option "SLOW" initiates one hour interval measurement and "FAST" a 5 minutes interval. The "SEQ"-option is usually used during hydraulic testing. This option has stepwise increase in measurement intervals starting with 2 seconds (if one channel is used). After 30 minutes and onwards the measurement interval is three minutes.

The flow into the measurement section was conducted to the borehole outlet by aluminium pipes, ⌀ 33/21 mm, double sealed with O-ring gaskets.

The flow emerging from the borehole interval beyond the lower packer was, during each measurement (with the packers inflated), drained by the by-pass conductor, see Figure 4.1. The conductor penetrates the centre of both packers as well as the test section. By this arrangement the water from the borehole part beyond the lower packer is added to the flow of the upper part of the borehole. The added flow was then conducted by the borehole itself (outside the aluminium pipes) to the borehole outlet.

The flow rates of the measurement sections as well as the added flows were determined by means of calibrated vessels and a stop watch.

The down-hole equipment was lowered and hoisted up using a manually operated winch.



Figur 4-1. Schematic drawing of the equipment used for flow logging

5. DATA ACQUISITION

The flow logging test cycle was perfomed as follows:

- start of the data logger (one minute measurement interval was selected)
- packer inflation: 10 minutes
- the logaritmic scanning option of the logger was initiated
- flow measurements during 10 minutes
- the logaritmic scanning option of the logger was disconnected
- packer deflation: 5 minutes
- transfer to next section: 5 minutes

The flow rates of the test sections and of the remaining parts of the borehole respectively, were measured separately and noted on field protocols.

After 10 min of packer inflation, the assumed inflow to the section created by packer creeping is approximately 0.2 ml/min in KA2511A (c. 0.8 ml/min in KA3510A and KI0025F). At the end of the flow measurement period, this value decreased to about 0.14 ml/min (c. 0.6 ml/min). The flow measurements are affected by an error due to this effect. The relative error is larger in low-conductive sections. Therefore, the flow rate in sections with an approximate flow $Q \geq 10$ ml/min was measured during the whole flow period, whereas in sections with lower flow rate the measurements were limited to the last three minutes of the flow phase.

Hydraulic head values in packed-off sections of borehole KA2511A were taken from the Hydro Monitoring System (HMS). The shut-in pressures of the entire boreholes KI0025F and KA3510A respectively, were measured after the flow logging measurements with the help of a pressure transducer and a Borre data logger.

The pressure data recorded by the transducer and the logger were processed as described by Nyberg (1994).

6. RESULTS

6.1 Flow logging results

The results of the flow logging are shown in Tables 6.1 - 6.3 and in Figures 6.1 - 6.3.

Table 6.1 True Block Scale Experiment. Detailed double packer flow logging in KA2511A
Test section length = 5 m. packer length = 1 m.
Test period: 97-05-21 15:45 - 97-05-23 10:56

Test section (m)	Time #1 (min.)	Volume #1 (l)	Flow #1 (l/min)	P (bar)	Time #2 (sec.)	Volume #2 (l)	Flow #2 (l/min)
50- 55	0.59	30.2	51.19	2.3	37.7	27.5	43.8
55- 60	10	7.66	0.766	0.11	18.9	30	95.2
60- 65	10	0.126	0.0126	0.11	19.5	30.5	93.8
65- 70	10	0.346	0.0346	0.11	17.9	28.5	95.5
70- 75	10	2.39	0.2390	0.1	19.3	30	93.3
75- 80	10	0.641	0.0641	0.11	18.8	29	92.6
80- 85	10	18.035	1.804	0.11	19.5	30	92.3
85- 90	10	0.2215	0.0222	0.11	18.9	29.5	93.7
90- 95	3	0.0147	0.0049	0.11	19.1	30	94.2
95-100	10	92.5	9.25	0.35	20.1	29	86.6
100-105	10	110.7	11.07	0.44	19.9	29	87.4
105-110	10	1.1195	0.112	0.12	18.9	30	95.2
110-115	10	0.13	0.0130	0.12	19.3	30.5	95.1
115-120	3	0.012	0.0040	0.11	18.1	28.5	94.5
120-125	10	0.246	0.0246	0.12	18.1	29	96.1
125-130	3	0.0018	0.0006	0.12	18.9	31	98.4
130-135	3	0.0011	0.0004	0.12	17.6	27.9	95.2
135-140	3	0.0109	0.0036	0.12	18.5	30	97.3
140-145	10	37.7	3.77	0.17	19.8	31	93.9
145-150	10	1.85	0.185	0.12	19.4	30	92.8
150-155	10	5.19	0.519	0.12	19.3	29	90.2
155-160	10	0.914	0.0914	0.12	19.3	28.5	88.6
160-165	10	1.011	0.1011	0.12	19.6	29.5	90.3
165-170	10	0.924	0.0924	0.12	18.8	27.5	87.8
170-175	10	0.035	0.0035	0.12	19.5	28.5	87.7
0-293	0.29	28.1	95.80				

Flow #1 = Flow from test section
Flow #2 = Flow from remaining part of borehole (excluding the test section)
P = Pressure in the test section (transducer at the borehole collar)
Volume #1 = Measured water volume from the test section
Volume #2 = Measured water volume from remaining part of borehole (excluding the test section)
Time # = Time during which flow measurement is made.

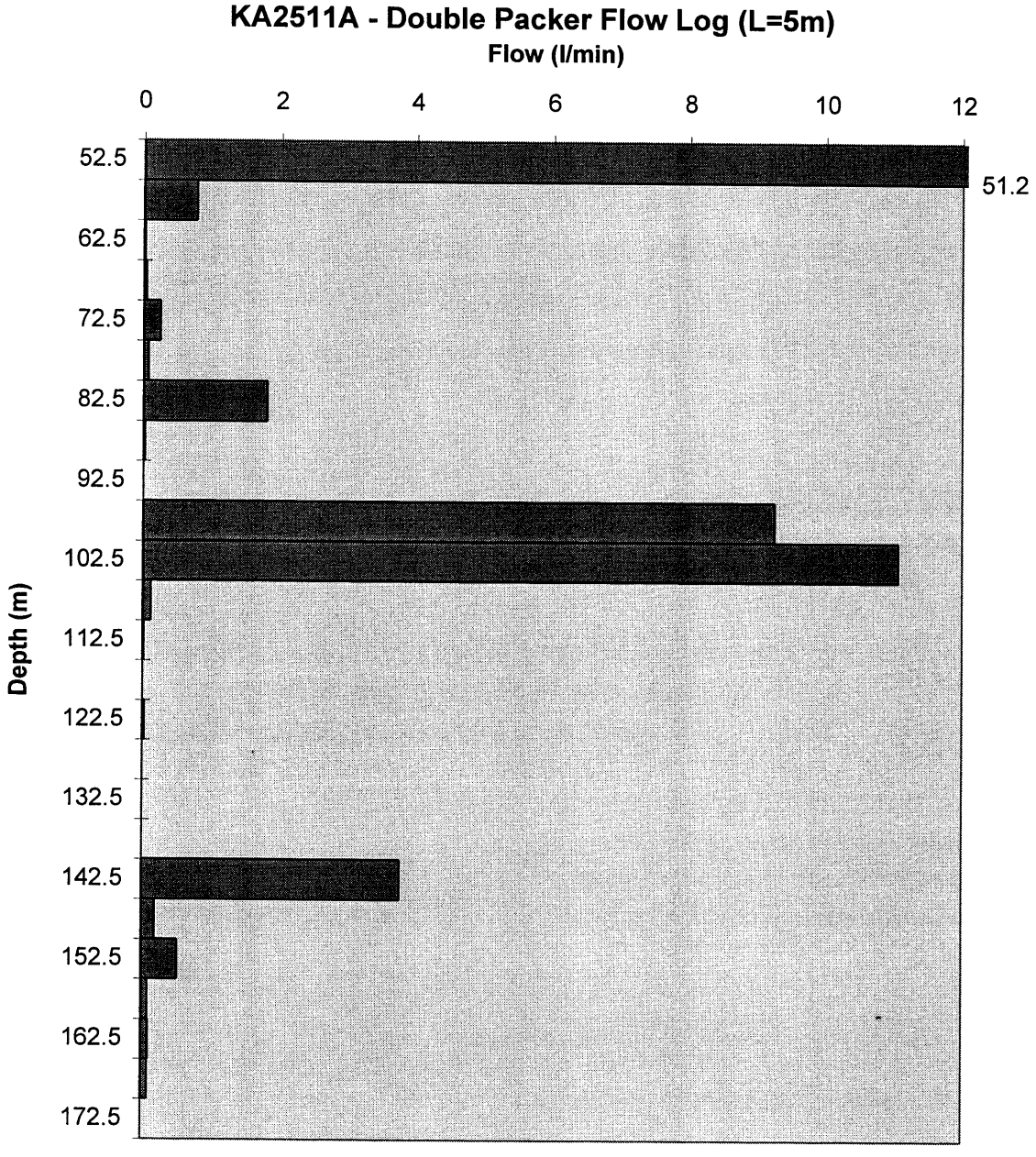


Figure 6.1 Detailed double packer flow logging in KA2511, section length 5 m

Table 6.2 True Block Scale Experiment. Detailed double packer flow logging in KI0025F
Test section length = 5 m. packer length = 1 m.
Test period: 97-05-29 12:41 - 97-06-02 17:41

Test section (m)	Time #1 (min.)	Volume #1 (l)	Flow #1 (l/min)	P (bar)	Time #2 (seconds)	Volume #2 (l)	Flow #2 (l/min)
42-47	10	15.2	1.52	0.14	20.7	23.1	67.0
47-52	3	0.0034	0.0011	0.14	22.3	25.5	68.6
52-57	3	0.0022	0.0007	0.14	22.9	26.3	68.9
57-62	3	0.0038	0.0013	0.14	22.1	25.1	68.1
62-67	3	0.002	0.0007	0.14	22.6	25.5	67.7
67-72	3	0.003	0.0010	0.14	19.2	21.4	66.9
72-77	3	0.003	0.0010	0.14	15.1	16.6	66.0
77-82	3	0.001	0.0003	0.14	21.6	24.1	66.9
82-87	3	0.0108	0.0036	0.14	21.9	24.9	68.2
87-92	10	10.8	1.08	0.15	20.7	23.5	68.1
92-97	3	0.003	0.0010	0.14	23.5	26.5	67.7
97-102	3	0.0045	0.0015	0.14	20.5	23.0	67.3
102-107	3	0.0015	0.0005	0.14	19.9	22.5	67.8
107-112	3	0.0075	0.0025	0.14	19.6	22.5	68.9
112-117	3	0.004	0.0013	0.14	20.2	22.7	67.4
117-122	3	0.0082	0.0027	0.14	21.6	24.5	68.1
122-127	3	0.003	0.0010	0.14	21.0	23.8	68.2
127-132	3	0.0025	0.0008	0.14	21.7	24.2	66.9
132-137	3	0.004	0.0013	0.14	19.8	22.7	68.8
137-142	3	0.003	0.0010	0.14	21.2	24.0	67.9
142-147	3	0.002	0.0007	0.14	21.1	24.0	68.2
147-152	3	0.003	0.0010	0.14	23.4	26.4	67.7
152-157	10	1.25	0.1250	0.14	19.1	21.9	68.8
157-162	10	0.067	0.0067	0.14	21.3	24.3	68.5
162-167	2.28	50	21.9	0.54	30.4	23.5	46.4
0-193.8	0.388	28.5	73.30				

Flow #1 = Flow from test section
Flow #2 = Flow from remaining part of borehole (excluding the test section)
P = Pressure in the test section (transducer at the borehole collar)
Volume #1 = Measured water volume from the test section
Volume #2 = Measured water volume from remaining part of borehole (excluding the test section)
Time # = Time during which flow measurement is made.

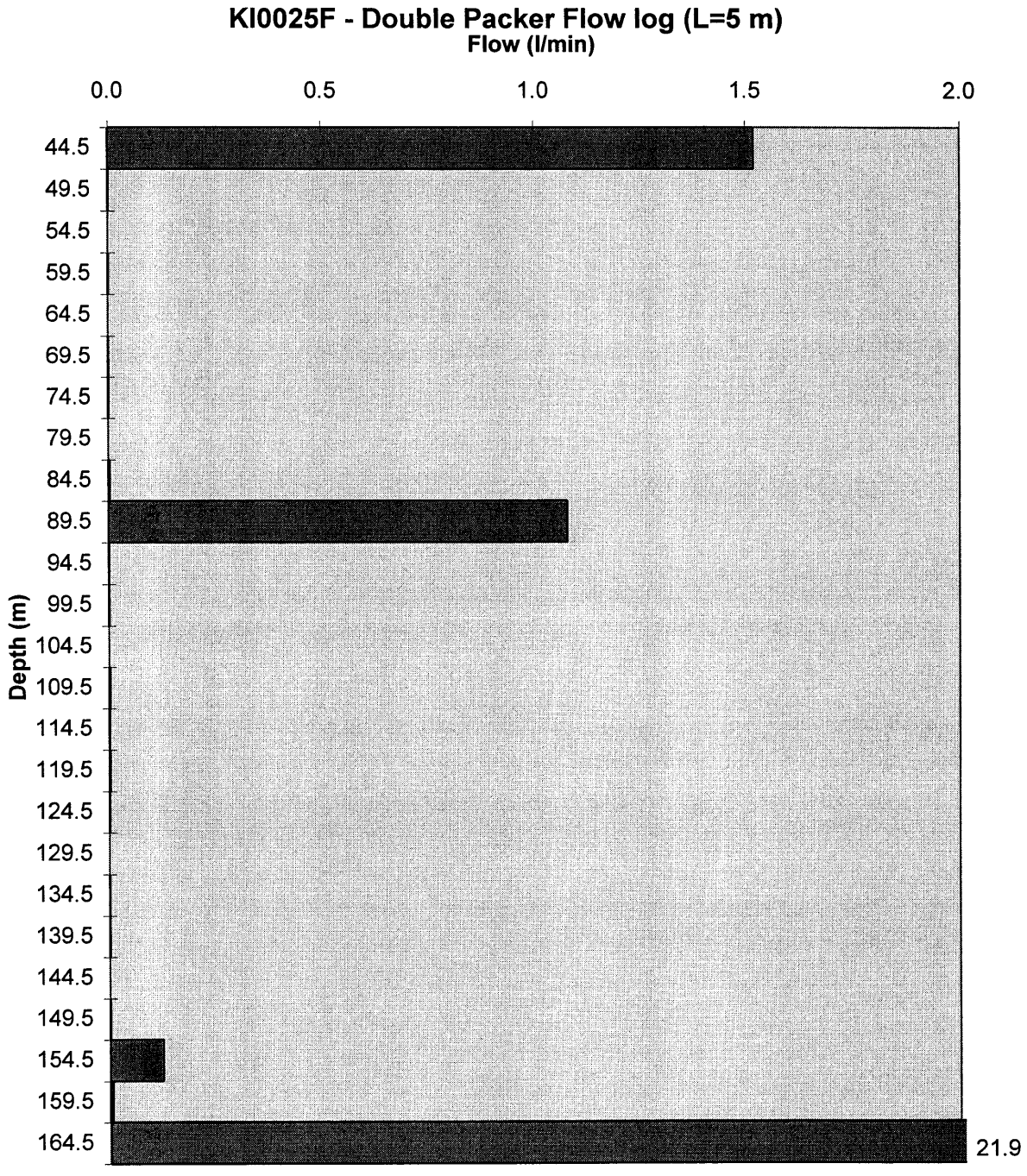


Figure 6.2 Detailed double packer flow logging in KI0025F, section length 5 m

Table 6.3 True Block Scale Experiment. Detailed double packer flow logging in KA3510A. Test section length = 5 m. packer length = 1 m. Test period: 97-05-03 10:37 - 97-06-03 20:12

Section #1 (m)	Time #1 (min)	Volume #1 (l)	Flow #1 (l/min)	P (bar)	Time #2 (seconds)	Volume #2 (l)	Flow #2 (l/min)
50-55	10	0.230	0.0230	0.07	23.8	11.0	27.8
55-60	3	0.0095	0.0032	0.17	24.9	11.8	28.4
60-65	3	0.004	0.0013	0.05	22.2	10.3	27.9
65-70	3	0	0	0.09	25.8	12.1	28.1
70-75	3	0	0	0.2	29.7	14.0	28.3
75-80	10	1.66	0.166	0.23	30.5	14.5	28.6
80-85	3	0.001	0.0003	0.13	29.9	14.2	28.5
85-90	3	0.0015	0.0005	0.22	31.4	14.5	27.7
90-95	3	0	0	0.19	32.0	15.0	28.1
95-100	5	0.080	0.0160	0.18	32.8	15.1	27.6
100-105	3	0.0012	0.0004	0.16	32.0	15.0	28.1
105-110	3	0	0	0.17	31.6	14.5	27.5
110-115	3	0.0012	0.0004	0.15	32.3	15.0	27.8
115-120	1.87	50	26.8	0.15	56.7	2.0	2.1
120-125	10	0.235	0.0235	0.11	31.7	15.0	28.4
125-130	3	0.001	0.0003	0.12	34.5	15.5	26.9
130-135	3	0	0	0.15	32.3	15.2	28.2
135-140	3	0.003	0.0010	0.15	31.7	15.0	28.4
140-145	3	0.004	0.0013	0.16	31.0	14.5	28.0
0-150.06	0.49	14.5	29.6				

Flow #1 = Flow from test section
Flow #2 = Flow from remaining part of borehole (excluding the test section)
P = Pressure in the test section (transducer at the borehole collar)
Volume #1 = Measured water volume from the test section
Volume #2 = Measured water volume from remaining part of borehole (excluding the test section)
Time # = Time during which flow measurement is made.

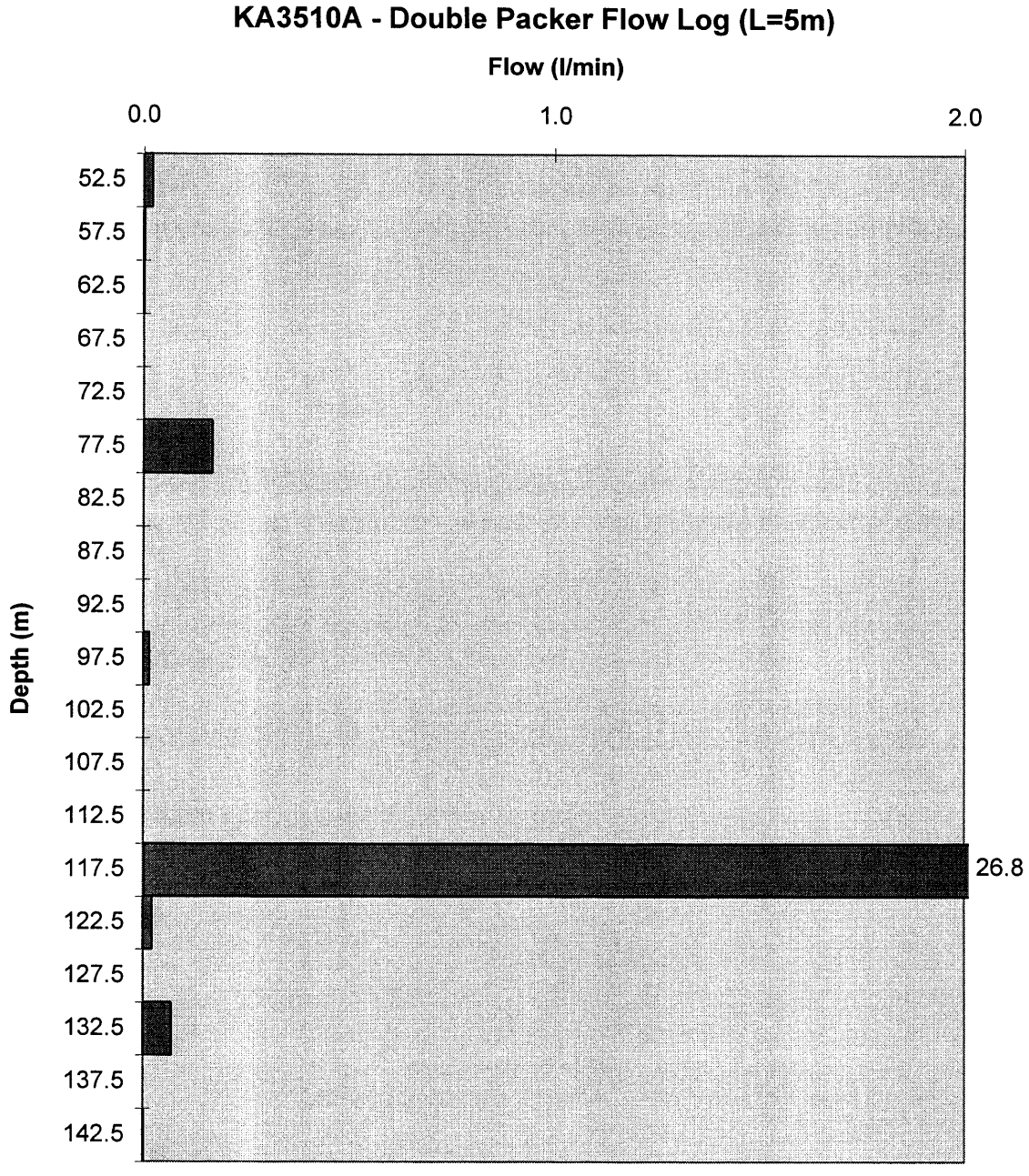


Figure 6.3 Detailed double packer flow logging in KA3510A, section length 5 m

6.2 Transmissivity

The transmissivity of the measured sections have been calculated using Moye's formula:

$$T = \frac{Q}{Dp} \cdot C$$

where

Q = measured flow rate of the test section (m^3/s)

Dp = H - P (m)

H = hydraulic head of the test section when the borehole is closed, determined with the help of long term pressure registration in packed-off sections (KA2511A), or by pressure measurements of the entire borehole (KI0025F and KA3510A), see Chapter 5.

P = section pressure during the flow measurements (from Tables 6.1 - 6.3).

$C = [1 + \ln(L/2r_w)]/ 2\pi$

L = Length of the test section (m)

r_w = borehole radius (m)

If the length of the measurement section (L) is 5 metres and the borehole diameter (ø) is 0.056 m the constant C is equal to 0.8741 (KA2511A)
If L=5 m and ø= 0.076 m, C = 0.8255 (KI0025F and KA3510A).

Calculated transmissivities of 5 m-sections are shown in tables 6.4 - 6.6 and in Figures 6.4 - 6.6.

The evaluation of the transmissivities can be improved when and if more accurate and distributed values of hydraulic pressure/head will become available after the multipacker installations.

Considering the creeping effects of the packers (Chapter 5) and the uncertainties of the flow- and pressure measurements the lower limit of the transmissivities could be estimated to $1.0 * 10^{-10}$ m^2 /s.

Table 6.4 True Block Scale Experiment.
Calculated transmissivities from flow logging data of KA2511A.
Test section length = 5 m. packer length = 1 m.
Test period: 97-05-21 15:45 - 97-05-23 10:56

Test section (m)	Flow #1 (l/min)	P (bar)	H (m)	Dp (m)	T (m2/s)
50-55	51.19	2.3	305.5	282.5	2.6E-06
55-60	0.766	0.11	305.5	304.4	3.7E-08
60-65	0.0126	0.11	305.5	304.4	6.0E-10
65-70	0.0346	0.11	305.5	304.4	1.7E-09
70-75	0.2390	0.1	305.5	304.5	1.1E-08
75-80	0.0641	0.11	305.5	304.4	3.1E-09
80-85	1.804	0.11	309.0	307.9	8.5E-08
85-90	0.0222	0.11	309.0	307.9	1.0E-09
90-95	0.0049	0.11	309.0	307.9	2.3E-10
95-100	9.25	0.35	309.0	305.5	4.4E-07
100-105	11.07	0.44	309.0	304.6	5.3E-07
105-110	0.112	0.12	309.0	307.8	5.3E-09
110-115	0.0130	0.12	309.0	307.8	6.2E-10
115-120	0.0040	0.11	309.0	307.9	1.9E-10
120-125	0.0246	0.12	309.0	307.8	1.2E-09
125-130	0.0006	0.12	309.0	307.8	2.8E-11
130-135	0.0004	0.12	309.0	307.8	1.7E-11
135-140	0.0036	0.12	309.0	307.8	1.7E-10
140-145	3.77	0.17	309.0	307.3	1.8E-07
145-150	0.185	0.12	309.0	307.8	8.8E-09
150-155	0.519	0.12	309.0	307.8	2.5E-08
155-160	0.0914	0.12	309.0	307.8	4.3E-09
160-165	0.1011	0.12	309.0	307.8	4.8E-09
165-170	0.0924	0.12	309.0	307.8	4.4E-09
170-175	0.0035	0.12	309.0	307.8	1.7E-10
0-293	95.80		304	304.0	4.6E-06

Flow #1 = Flow from test section
P = Pressure in the test section (transducer at the borehole collar)
H = Hydraulic head of the the test section, determined with the help of long term registration(HMS)
Dp = H - P

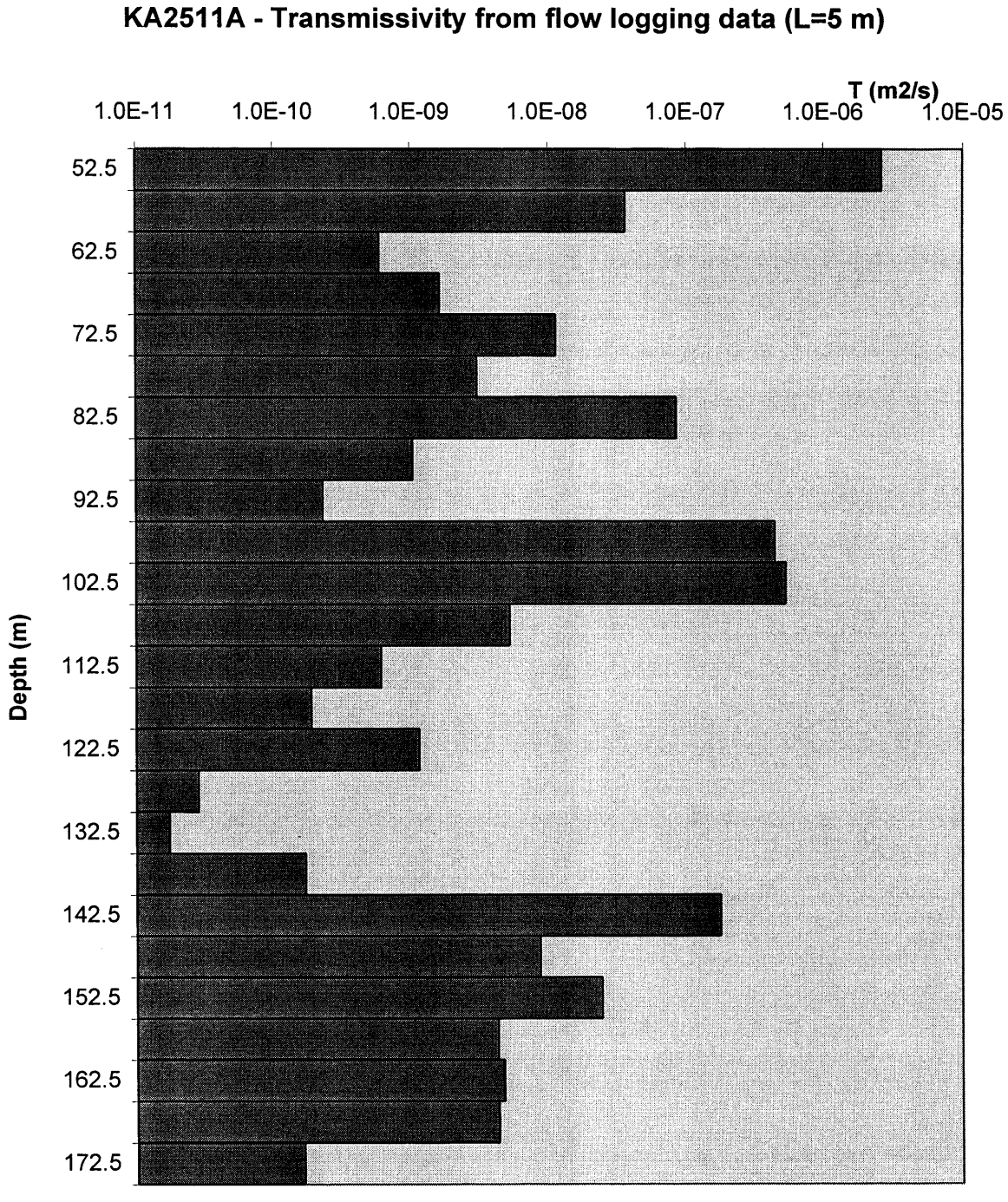


Figure 6.4 Calculated transmissivities of borehole KA2511A. Data from detailed flow logging, section length = 5 m.

Table 6.5 True Block Scale Experiment.
Calculated transmissivities from flow logging data of KI0025F.
Test section length = 5 m. packer length = 1 m.
Test period: 97-05-29 12:41 - 97-06-02 17:41

Test section (m)	Flow #1 (l/min)	P (bar)	H (m)	Dp (m)	T (m2/s)
42-47	1.52	0.14	420.6	419.2	5.0E-08
47-52	0.0011	0.14	420.6	419.2	3.7E-11
52-57	0.0007	0.14	420.6	419.2	2.4E-11
57-62	0.0013	0.14	420.6	419.2	4.2E-11
62-67	0.0007	0.14	420.6	419.2	2.2E-11
67-72	0.0010	0.14	420.6	419.2	3.3E-11
72-77	0.0010	0.14	420.6	419.2	3.3E-11
77-82	0.0003	0.14	420.6	419.2	1.1E-11
82-87	0.0036	0.14	420.6	419.2	1.2E-10
87-92	1.08	0.15	420.6	419.1	3.6E-08
92-97	0.0010	0.14	420.6	419.2	3.3E-11
97-102	0.0015	0.14	420.6	419.2	4.9E-11
102-107	0.0005	0.14	420.6	419.2	1.6E-11
107-112	0.0025	0.14	420.6	419.2	8.2E-11
112-117	0.0013	0.14	420.6	419.2	4.4E-11
117-122	0.0027	0.14	420.6	419.2	9.0E-11
122-127	0.0010	0.14	420.6	419.2	3.3E-11
127-132	0.0008	0.14	420.6	419.2	2.7E-11
132-137	0.0013	0.14	420.6	419.2	4.4E-11
137-142	0.0010	0.14	420.6	419.2	3.3E-11
142-147	0.0007	0.14	420.6	419.2	2.2E-11
147-152	0.0010	0.14	420.6	419.2	3.3E-11
152-157	0.1250	0.14	420.6	419.2	4.1E-09
157-162	0.0067	0.14	420.6	419.2	2.2E-10
162-167	21.9	0.54	420.6	415.2	7.3E-07
0-193.8	73.30		420.6	420.6	2.4E-06

Flow #1 = Flow from test section
P = Pressure in the test section (transducer at the borehole collar)
H = Hydraulic head of the the entire borehole, measured June 1997
Dp = H - P

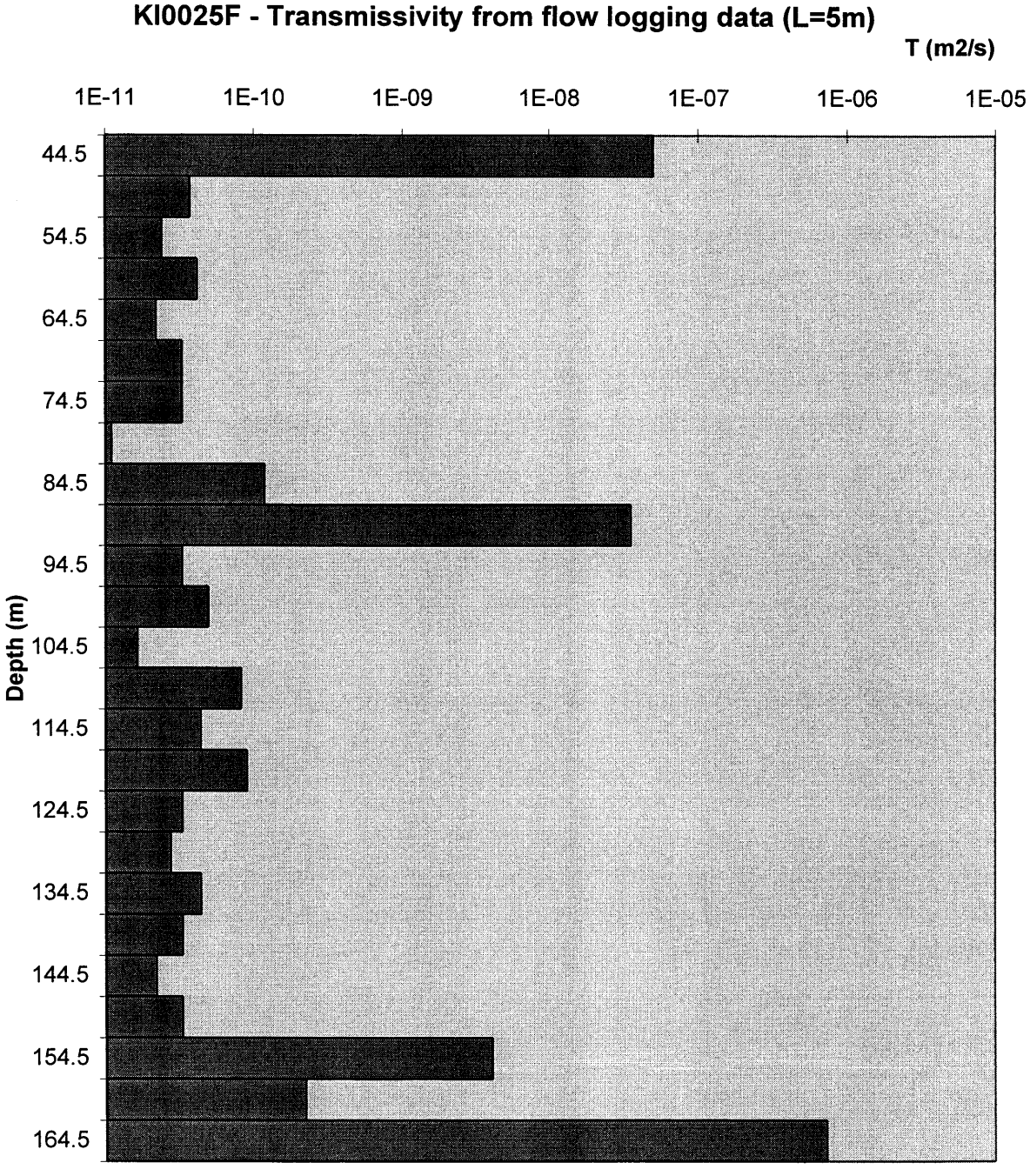


Figure 6.5 Calculated transmissivities of borehole KI0025F. Data from detailed flow logging, section length = 5 m.

Table 6.6 True Block Scale Experiment.
Calculated transmissivities from flow logging data of KA3510A.
Test secti on length = 5 m. packer length = 1 m.
Test period: 97-06-03 10:37 - 97-06-03 20:12

Test section (m)	Flow #1 (l/min)	P (bar)	H (m)	Dp (m)	T (m2/s)
50-55	0.0230	0.07	416.5	415.8	7.6E-10
55-60	0.0032	0.17	416.5	414.8	1.1E-10
60-65	0.0013	0.05	416.5	416	4.4E-11
65-70	0	0.09	416.5	415.6	0
70-75	0	0.2	416.5	414.5	0
75-80	0.166	0.23	416.5	414.2	5.5E-09
80-85	0.0003	0.13	416.5	415.2	1.1E-11
85-90	0.0005	0.22	416.5	414.3	1.7E-11
90-95	0	0.19	416.5	414.6	0
95-100	0.0160	0.18	416.5	414.7	5.3E-10
100-105	0.0004	0.16	416.5	414.9	1.3E-11
105-110	0	0.17	416.5	414.8	0
110-115	0.0004	0.15	416.5	415	1.3E-11
115-120	26.8	0.15	416.5	415	8.9E-07
120-125	0.0235	0.11	416.5	415.4	7.8E-10
125-130	0.0003	0.12	416.5	415.3	1.1E-11
130-135	0	0.15	416.5	415	0
135-140	0.0010	0.15	416.5	415	3.3E-11
140-145	0.0013	0.16	416.5	414.9	4.4E-11
0-150.06	29.6		416.5	416.5	9.8E-07

Flow #1 = Flow from test section
P = Pressure in the test section (transducer at the borehole collar)
H = Hydraulic head of the the entire borehole, measured June 1997
Dp = H - P

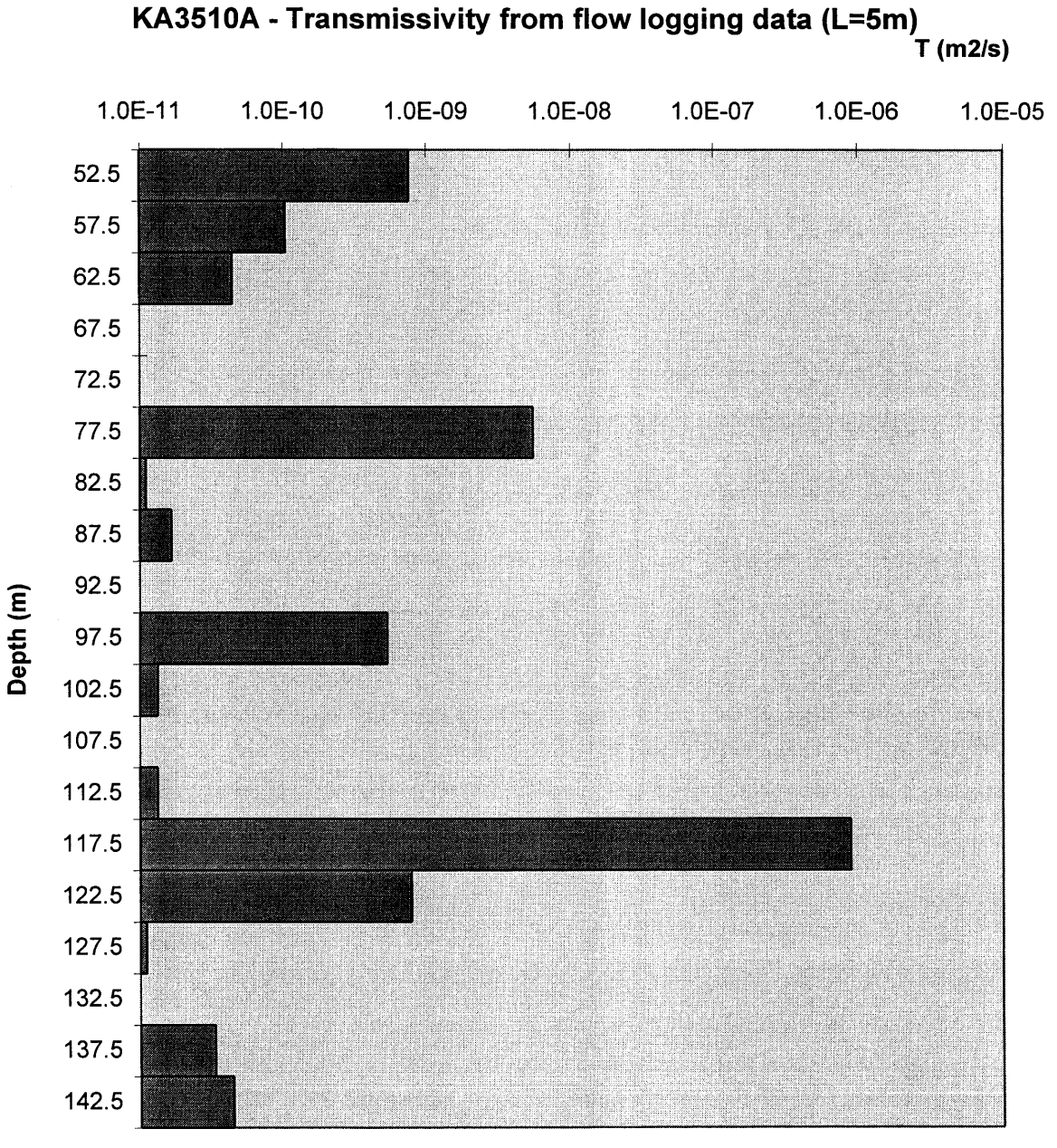


Figure 6.6 Calculated transmissivities of borehole KA3510A. Data from detailed flow logging, section length = 5 m.

7. REFERENCES

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