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Äspö Hard Rock Laboratory

Äspö Pillar Stability Experiment

Core boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01: Hydrogeological characterization and pressure responses during drilling and testing

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March 2003

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Abstract

The hydrogeological investigations of core boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01 presented in this report aim at:

- Describing the four boreholes, which are drilled in three alternative areas suggested for a future tunnel for Äspö Pillar Stability Experiment (APSE).
- Evaluating the influence of the four boreholes on the surroundings during drilling and hydraulic tests and effects related to test blasting by compiling and comparing pressure responses in a number of selected boreholes.

Obtained data should be used to make a more informed choice concerning location of a tunnel and a future grouting strategy. Due to high hydraulic heads, estimated fracture apertures are often small even though inflows are significant. Consequently, future grouting is likely to demand several boreholes to be able to penetrate and seal these fractures. Based on investigations, one may expect a future tunnel in connection to boreholes KA3386A01 or KA3376B01 (Alternatives 2 or 3) to have a larger influence on ongoing experiments than Alternative 1 (KF0066A01 and KF0069A01). KA3376B01 influences the Long Term Diffusion Experiment (LTDE) area. It is of importance that those responsible for neighbouring experiments evaluate whether the pressure responses presented herein are acceptable considering their future work. It should be taken into consideration that inflows into a future tunnel might be larger and found at other locations along the borehole than indicated by this study (e.g. if the investigated borehole has intersected a fracture at a locally small aperture). To decrease the risk of influencing other experiments, the tunnel work should be organised so that as stable conditions as possible are continually kept, particularly if more sensitive work is performed such as monitoring of pressure changes during, and soon after, back-filling of the Prototype Repository etc.

Sammanfattning

De hydrogeologiska undersökningarna av kärnborrhålen KF0066A01, KF0069A01, KA3386A01 och KA3376B01 som presenteras i rapporten syftar till att:

- Beskriva de fyra borrhålen, borrade i tre alternativa områden föreslagna för en framtida tunnel för Äspö Pillar Stability Experiment (APSE).
- Utvärdera påverkan ifrån de fyra borrhålen på omgivningen under borrning, hydrauliska tester samt påverkan som en effekt av testsprängning. Detta görs genom att sammanställa och jämföra tryckresponser i ett antal utvalda borrhål.

Data skall användas som underlag för att bättre kunna välja plats för tunneln och lämplig injekteringsstrategi. Det höga grundvattentrycket gör att de skattade sprickvidderna ofta är små även om inflödet är betydande. En konsekvens av detta är att framtida injektering troligen kommer att kräva ett tätt borrhålsmönster för att kunna tränga in i och täta dessa sprickor. Utifrån genomförda undersökningar kan man förvänta att en framtida tunnel i anslutning till KA3386A01 eller KA3376B01 (Alternativ 2 eller 3) kommer att ha större påverkan på pågående experiment än Alternativ 1 (KF0066A01 och KF0069A01). KA3376B01 påverkar området för LTDE (Long Term Diffusion Experiment). Det är av vikt att ansvariga för omgivande experiment värderar om de tryckresponser som presenteras i denna rapport är acceptabla med hänsyn till deras framtida arbete. Hänsyn bör även tas till att inflödet till en tunnel kan vara större och finnas vid andra lägen längs borrhålet än vad studien visar (t ex om borrhålet har korsat en spricka vid en lokalt mindre sprickvidd). För att minska risken för att andra experiment påverkas, måste tunnelarbetet organiseras så att så stabila förhållanden som möjligt upprätthålls, framför allt under tiden för mer känsliga moment såsom uppföljning av tryckförändringar under tiden för och strax efter uppfyllnad av Prototypförvaret etc.

Contents

1 Introduction

The Äspö Pillar Stability Experiment (APSE) aims at demonstrating the possibility to predict spalling in a fractured rock mass. Further, it is of interest to investigate the effect of the backfill on the development of micro fractures in rock close to a deposition borehole. For this study, a new tunnel will be excavated and two vertical deposition boreholes will be drilled in the floor of this tunnel. Between the two boreholes, a pillar will remain and the effect of increased pressure and heat will be investigated.

The hydrogeological investigations of core boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01 presented in this report aims at:

- Describing the four boreholes, which are drilled in three alternative areas suggested for a future tunnel (Figure 1.1).
- Investigating the influence of the four boreholes on the surroundings during drilling and hydraulic tests and effects related to test blasting by compiling and comparing pressure responses in a number of selected boreholes.

Obtained data should be used to make a more informed choice concerning location of a tunnel and a future grouting strategy. The results will briefly be commented from a grouting point of view. Selected boreholes when investigating pressure response are located at the Tracer Retention Understanding Experiment (TRUE) Block scale and Prototype experiment sites and since experiments sensitive to pressure changes will also be performed at the Long Term Diffusion Experiment (LTDE) site and in the TASF-tunnel (Matrix Fluid Chemistry experiment), boreholes at these locations are also included (see Figure 2.2). Pressure data compiled should be used by those involved in the experiments to evaluate whether pressure responses are acceptable when considering their future work. During blasting, investigating that the hydro monitoring system is not damaged is of importance.

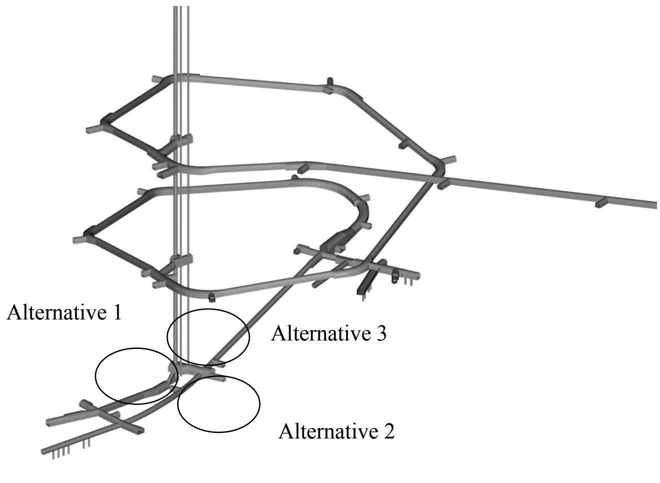

Figure 1.1 *Overview of the Äspö tunnel. The vertical lines show the elevator and ventilation shafts from the ground surface. The two first suggested areas for a new tunnel are found north (Alternative 1) and south (Alternative 2) of the access tunnel. Alternative 3 was added as a new alternative during the study.*

2 Site description

The main rock type within the Äspö area is a medium- to coarse-grained, porphyritic, more or less isotropic granite to granodiorite. Texturally it is relatively inhomogeneous, and locally a foliation is developed. There are also a few larger bodies of diorite to gabbro, traditionally called "greenstone" together with unspecified mafic rocks. Xenolites to enclaves and minor bodies of diorite to gabbro, as well as narrow dykes and minor massifs of fine-grained granite are rather common in the predominating granite to granodiorite.

The area suggested for the Äspö Pillar Stability Experiment (APSE) is situated at a level of approximately –450 m and the three different alternatives for a new tunnel are shown in Figure 1.1.

According to Andersson et al. (2002) the area for TRUE Block Scale (south of the access tunnel, TASA) has a conductive geometry that is made up of steeply dipping NW and NNW structures. Investigations in the area of the Prototype Repository test in the end of the TASA-tunnel and north of the TRUE Block Scale area show a pattern of a hydraulically dominant response direction running WNW (see Forsmark et al., 2001). Water bearing structures with a NW trend intersect the tunnels TASA and TASF (Maersk Hansen and Hermansson, 2002). A stereonet contour plot presented shows that the major part of fractures are sub horizontal beside two almost sub-vertical sets with N-S and NW-SE trends (based on TASA-, 2/625-2/700 m, TASF-, TASG-, TASI-, TASJ-tunnels and hoist shaft below –350 m down to –450 m) see Figure 2.1.

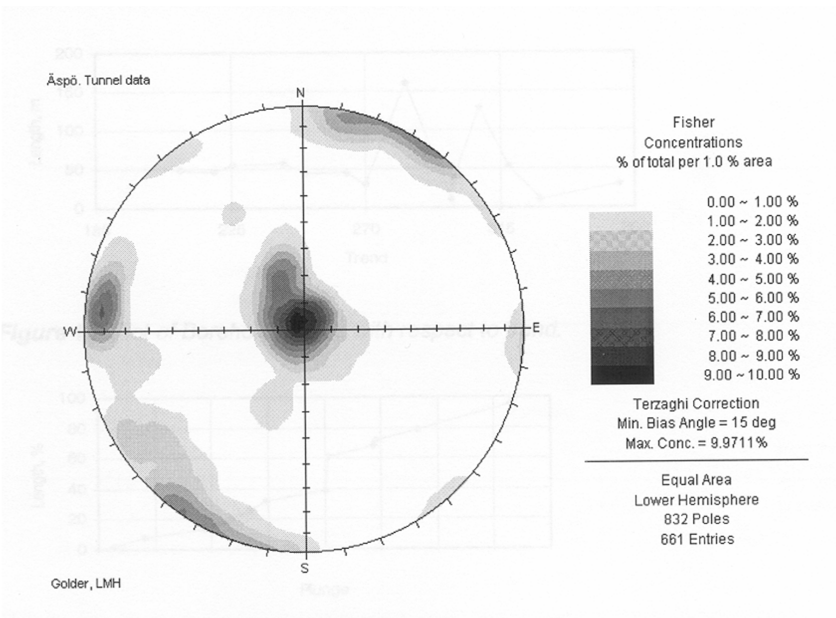

Figure 2.1 *Stereonet contour plot of joints (in tunnels TASA, 2/625-2/700 m, TASF, TASG, TASI, TASJ and hoist shaft below –350 m, from Maersk Hansen and Hermansson, 2002).*

The new core boreholes KF0066A01 and KF0069A01 (see Figure 2.2) were drilled on the northern side of the access tunnel from the F-tunnel using wire-line technique (TASF, Alternative 1). The borehole KF0066A01 has an upward direction, which resulted in some difficulties to de-air the borehole for the hydraulic tests. The borehole KA3386A01 was drilled to investigate Alternative 2 and borehole KA3376B01 was drilled to investigate Alternative 3. The other boreholes shown in the figure were used to look at pressure responses during drilling, blasting and pressure build-up tests to get indications of magnitudes and connections between boreholes. The boreholes were mainly selected to identify responses for the TRUE Block Scale and the Prototype repository areas. The boreholes KI0025F and KI0023B (together with KA2563A, not included) were according to Andersson et al. (2002) sufficient to develop a basic model of the network of major structures in the TRUE Block Scale area and KA2511A is interesting since a hydraulic discontinuity is indicated between the core of the TRUE Block scale rock and this overlying borehole. The boreholes KG0048A01, KG0021A01 and KA3600F give possibilities to look at the influences on the Prototype repository. Further, tests sensitive to pressure responses are to be performed at the LTDE-site and in the TASF-tunnel (Matrix Fluid Chemistry), which is the reason for selecting KA3010A, KA3067A, KF0051A and KXTT4 (TRUE-1). Table 2.1 compiles the dates for the different activities related to the three boreholes KF0066A01, KF0069A01 and KA3386A01 (correct time for HMS system, protocols may refer to + 1 hour due to summer time) and Table 2.2 refers to activities for borehole KA3376B01 which was added during the study.

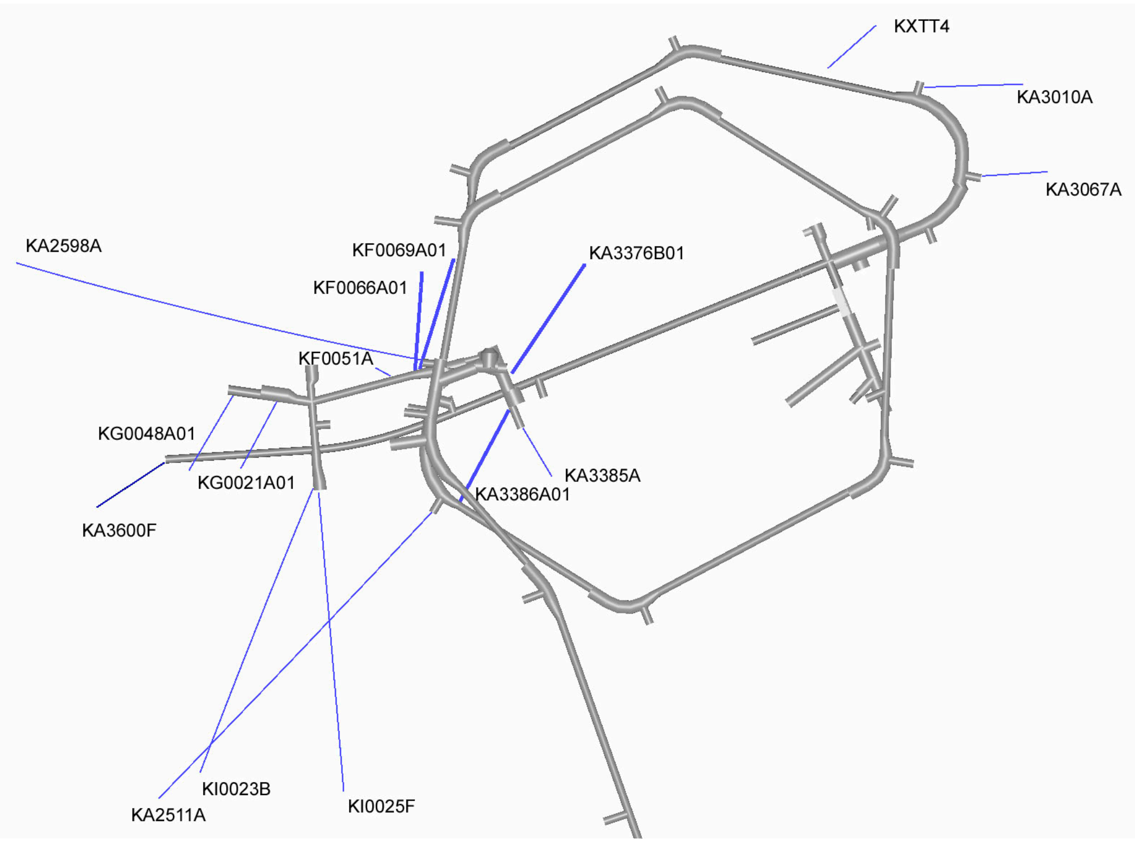

Figure 2.2 *The new boreholes KF0066A01, KF0069A01, KA3386A01and KA3376B01, and boreholes for which the pressure responses were investigated.*

Table 2.1 Activities related to boreholes KF0066A01, KF0069A01 and KA3386A01 (drilling, Posiva Flowlogging, blasting and pressure build-up tests).

Activity	Location/borehole	Date
Drilling	KF0069A01	2002-05-15, 09:37:00 - 2002-05-21, 11:04:00
	KF0066A01	2002-05-28, 15:31:00 - 2002-06-01, 15:29:00
	KA3386A01	2002-06-04, 08:53:00 - 2002-06-15, 09:18:00
Posiva Flowlogging	KF0069A01	2002-08-06, 15:26 - 2002-08-07, 08:50
	KF0066A01	2002-08-07, 08:52 - 2002-08-07, 12:55
	KA3386A01	2002-08-07, 13:26 - 2002-08-07, 17:58
Blasting	1, TASA, (see Figure 3.18)	2002-08-14, 06:45, 07:03, 08:41, 08:55, 09:18
	2, TASF, (see Figure 3.18)	2002-08-14, 12:01, 12:21, 12:46
Pressure build-up tests	KA3386A01	2002-08-29, 9:26
	KF0066A01	2002-09-03, 9:24
	KF0069A01	2002-09-09, 9:00

Table 2.2 Activities related to borehole KA3376B01 (drilling, Posiva Flowlogging, and pressure build-up tests).

Activity	Location/borehole	Date
Drilling	KA3376B01	2002-11-08, 15:22:00 - 2002-11-26, 15:39:00
Pressure build-up test	KA3376B01	2002-12-11, 13:50
Posiva Flowlogging	KA3376B01	2003-01-14, 15:15 – 2003-01-15, 8:15
Flowing of borehole (PBT 2, due to disturbances during drilling and Pressure build-up test)	KA3376B01	2003-01-16, 09:59

Due to other activities disturbing the first pressure build-up test in borehole KA3376B01 (Table 2.2), it was decided to perform a second test for studies of pressure responses in other boreholes (PBT 2).

3 Compilation of hydrogeological data

3.1 Inflow during drilling

Drilling of the three boreholes KF0066A01, KF0069A01 and KA3386A01 was performed between 2002-05-15 and 2002-06-15 (see Table 2.1). For borehole KA3376B01 drilling was made 2002-11-08, 15:22:00 - 2002-11-26 (see Table 2.2). The accumulated inflow during drilling of the core boreholes is shown in Figure 3.5, Figure 3.6, Figure 3.7 and Figure 3.8. Based on these figures, the accumulated inflows are approximately 8-9 L/min for KF0066A01, 13 L/min for KF0069A01, 40-60 L/min for KA3386A01 and 80 L/min for KA3376B01. Inflow for the first three boreholes was measured at the same time as the uptake of the core, which took place approximately every 3 meters (Andersson, 2002). For KA3376B01 these measurements were made with an increased accuracy at approximately every 1.5 meters.

3.2 BIPS / Core logging

BIPS-based (Borehole Image Processing System) BOREMAP corelog was performed and Table 3.1, Table 3.2, Table 3.3 and Table 3.4 show the dominant rock types. Further, Figure 3.1, Figure 3.2, Figure 3.3 and

Figure 3.4 present the number of natural fractures along the four boreholes.

3.2.1 KF0066A01

For borehole KF0066A01 the dominant rock type is Diorite. Minor occurrences of Fine-grained granite and Hybride rock are also found, see Table 3.1. Based on fracture frequency, a crush zone is found at approximately 43.0 – 44.0 m. According to the rock type mapping this is identified as hybride rock. According to documentation from core mapping a fracture that is almost parallel to the borehole intersects the core along the interval 51.2 – 55.6 m. An inspection of the core proved this to be wrong (Andersson, 2002).

Table 3.1 Dominant rock types for KF0066A01

Borehole	Interval (m)		Rock type
KF0066A01	0.0	2.4	Casing
	2.4	10.3	Diorite
	10.3	11.4	Fine-grained granite
	11.4	23.2	Diorite
	23.2	24.7	Fine-grained granite
	24.7	42.7	Diorite
	42.7	44.2	Hybride rock
	44.2	51.4	Diorite
	51.4	52.7	Fine-grained granite
	52.7	60.0	Diorite

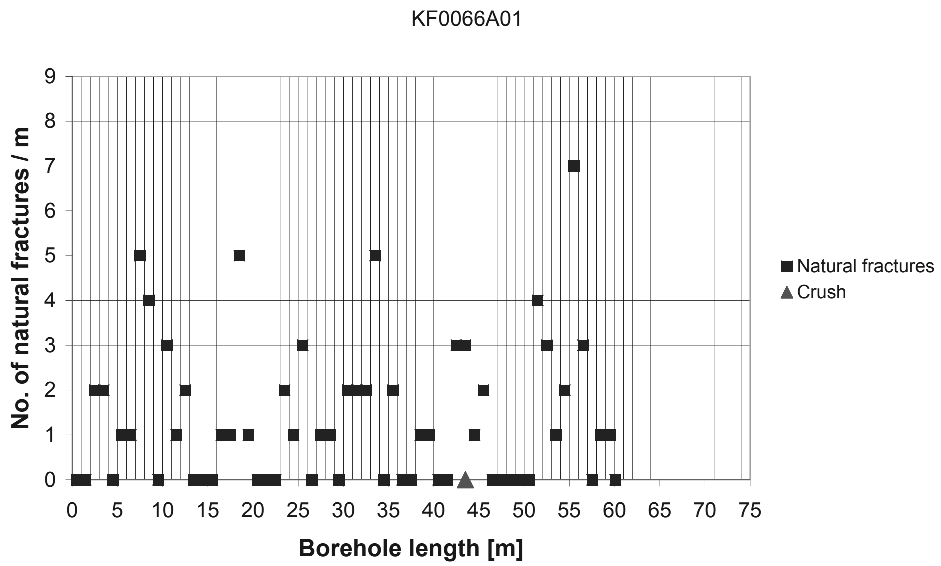

Figure 3.1 *Fracture frequency (natural) along borehole, KF0066A01. Crush described as 150 fractures / m.*

3.2.2 KF0069A01

For borehole KF0069A01 the dominant rock type is Diorite beside minor occurrences of Fine-grained granite and Hybride rock, see Table 3.2.

Table 3.2 Dominant rock types for KF0069A01

Borehole	Interval (m)		Rock type
KF0069A01	0.0	2.5	Casing
	2.5	3.9	Diorite
	3.9	5.1	Hybride rock
	5.1	32.3	Diorite
	32.3	35.0	Fine-grained granite
	35.0	59.0	Diorite
	59.0	61.9	Hybride rock
	61.9	66.3	Diorite
	66.3	67.3	Hybride rock
	67.3	69.8	Diorite

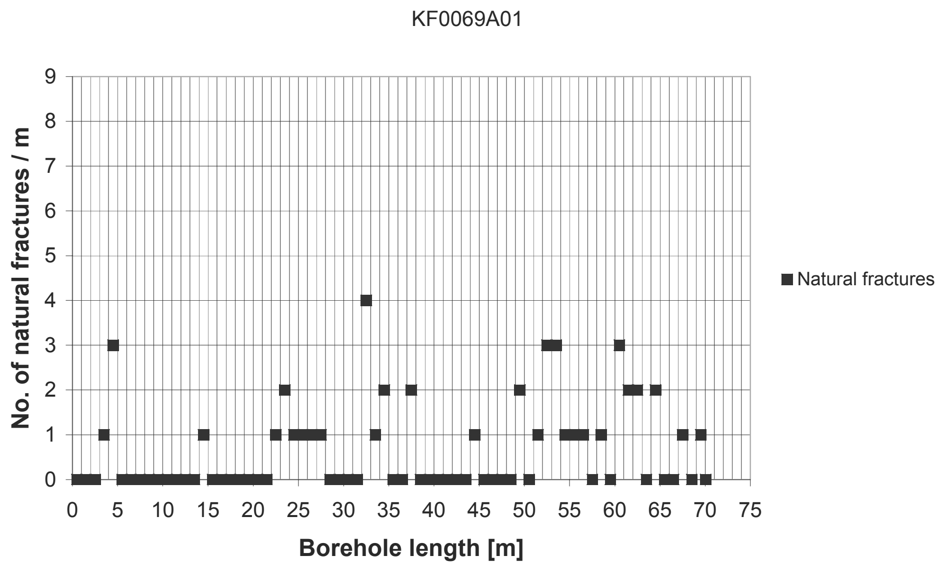

Figure 3.2 *Fracture frequency (natural) along borehole, KF0069A01.*

3.2.3 KA3386A01

For borehole KA3386A01 the dominant rock type is Diorite. Fine-grained granite is found along a larger interval than for the other three boreholes, see Table 3.3, this is also where the largest frequencies of fractures are found Figure 3.3. Amphibole was identified at two locations.

Table 3.3 Dominant rock types for KA3386A01

Borehole	Interval (m)		Rock type
KA3386A01	0.0	2.2	Casing
	2.2	3.6	Amphibole
	3.6	14.3	Diorite
	14.3	15.7	Amphibole
	15.7	35.5	Diorite
	35.5	46.4	Fine-grained granite
	46.4	65.0	Diorite

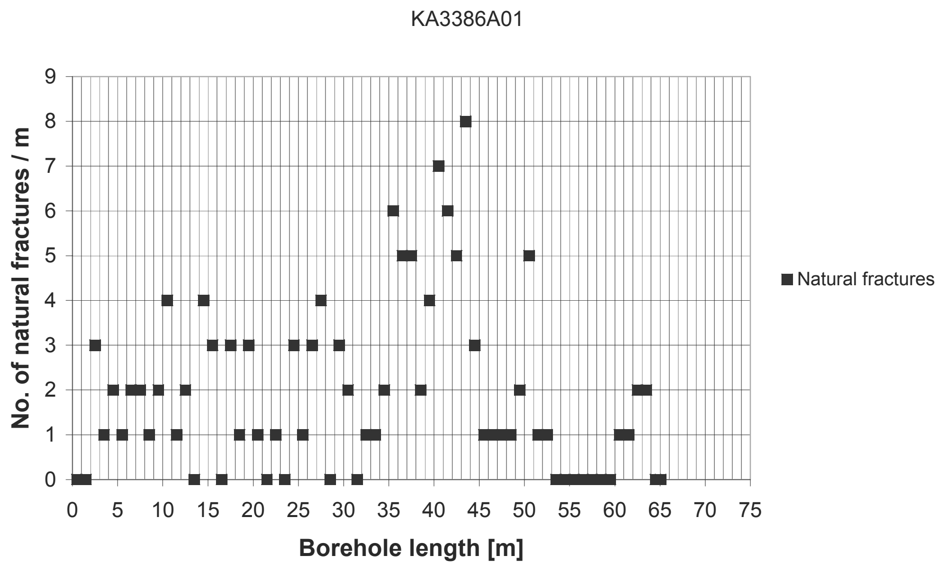

Figure 3.3 *Fracture frequency (natural) along borehole, KA3386A01.*

3.2.4 KA3376B01

For borehole KA3376B01 the dominant rock type is Diorite, see Table 3.4. ***Figure 3.4*** presents the fracture frequency for the borehole.

Table 3.4 Dominant rock types for KA3376B01

Borehole	Interval (m)		Rock type
KA3376B01	0.0	2.4	Casing
	2.4	23.8	Diorite
	23.8	26.2	Hybride rock
	26.2	76.4	Diorite
	76.4	79.9	Diorite

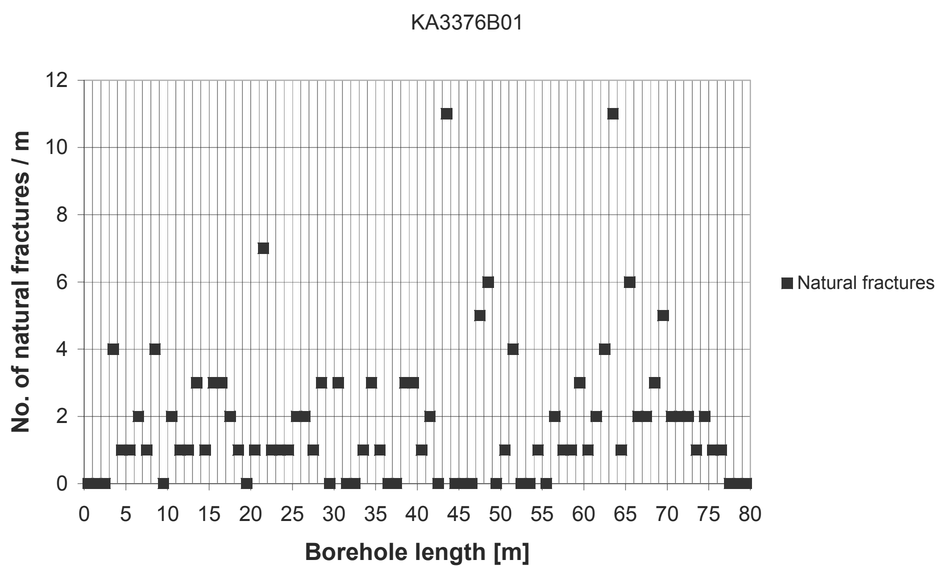

Figure 3.4 *Fracture frequency (natural) along borehole, KA3376B01.*

3.3 Hydraulic tests

3.3.1 Posiva Flowlogging

Posiva Flowlogging (PFL, Rouhiainen, 2000 and Pöllänen and Rouhiainen, 2002 and 2003), aimed at identifying location and inflows for conductive features and was performed between 2002-08-06 - 2002-08-07 and 2003-01-14 – 2003-01-15 (see Table 2.1, Table 2.2 and Table 3.5). Flowlogging was performed for 1 m test sections where the measurement device was moved with 0.1 m steps. Rubber disks instead of inflatable packers are used to isolate the tested section and the inflow in that section is the only flow that passes through the flow sensor. This difference flow method is based on pulse transit time of a thermal pulse for small flows (0.1-10 mL/min) and thermal dilution rate for high flows (2-5000 mL/min). Beside inflow, single point resistance (SPR), electrical conductivity (EC) and temperature are also measured to help locate the inflow along the borehole. The single point resistance electrode is located between the rubber discs at the upper end of the test section.

Table 3.5 Hydraulic tests: Posiva Flowlogging

Borehole	Borehole length (m)	Type of tests performed	Test scale (L) (m)	Step length for moving measured section (dL) (m)	Total test section, Secup (m)	Total test section, Seclow (m)
KF0066A01	60.11	Flowlogging –Posiva FlowLogg	1	0.1	~2	~58
KF0069A01	70.09	“	“	“	~2	~68
KA3386A01	65.11	“	“	“	~2	~63
KA3376B01	80.19	“	“	“	~2	~78

The total measured inflows during Posiva flowlogging were 6.0 L/min for KF0066A01, 10.7 L/min for KF0069A01, 53 L/min for KA3386A01 and 95 L/min for KA3376B01. When adding individual measured inflows during Posiva flowlogging inflows were 7.3 L/min for KF0066A01, 9.0 L/min for KF0069A01, 35.4 L/min for KA3386A01 and 45.9 L/min for KA3376B01. Figure 3.5, Figure 3.6, Figure 3.7 and Figure 3.8 present accumulated inflow during drilling and the calculated accumulated inflow for Posiva Flowlogg for the four boreholes. The difference in measured inflow seen in these figures is likely to be due to difficulties for Posiva Flowlogg to measure inflows exceeding 5 L/min. This is particularly seen for boreholes KA3386A01 and KA3376B01. The accumulated inflows during drilling are approximately 8-9 L/min for KF0066A01, 13 L/min for KF0069A01, 40-60 L/min for KA3386A01 and 80 L/min for KA3376B01. Since inflow during drilling was only measured when doing uptakes of the cores, this may explain the difference in borehole depth for changes in flow. Due to KF0066A01 being drilled slightly upwards gas is most likely found in the borehole, resulting in values of EC and temperature that are not correct in most cases. The depth of flowing fractures was measured for this borehole even though it was difficult because of gas.

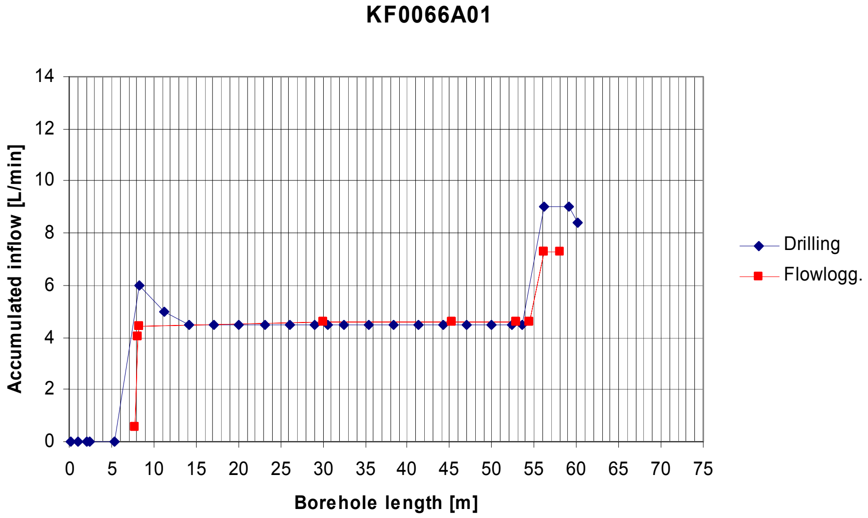

Figure 3.5 *Inflow during drilling and for Posiva Flowlogg, KF0066A01. Borehole length: 60.11 m. Last "Flowlogg-point" shows the lowest section of measurements (~58 m).*

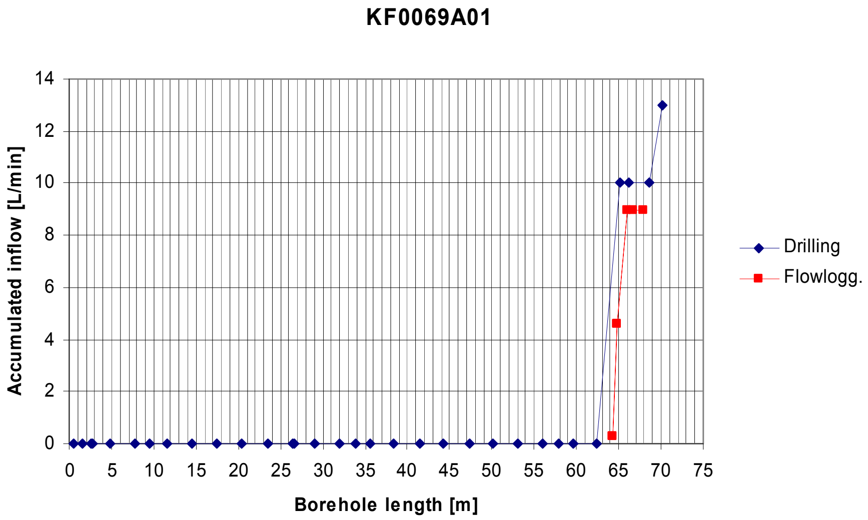

Figure 3.6 *Inflow during drilling and for Posiva Flowlogg, KF0069A01. Borehole length: 70.09 m. Last "Flowlogg-point" shows the lowest section of measurements (~68 m).*

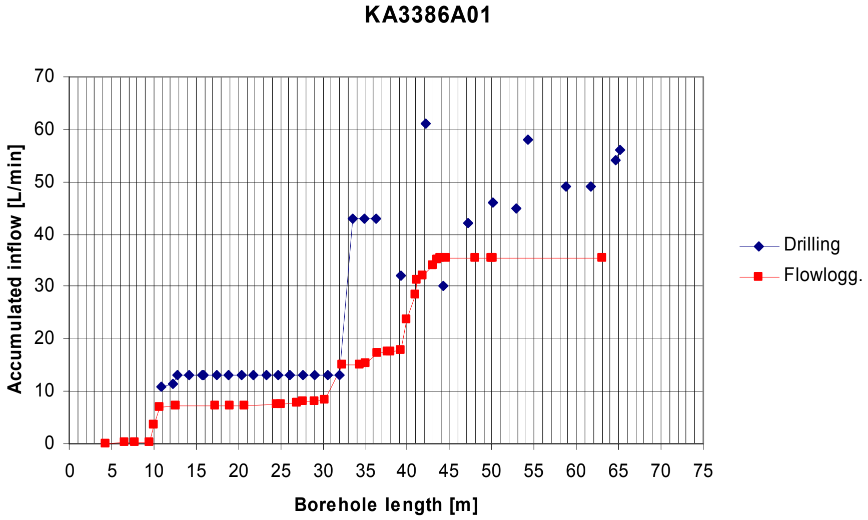

Figure 3.7 *Inflow during drilling and for Posiva Flowlogg, KA3386A01. Borehole length: 65.11 m. Last "Flowlogg-point" shows the lowest section of measurements (~63 m). Difference in total inflow due to the measurement limit for the Posiva Flowlogg.*

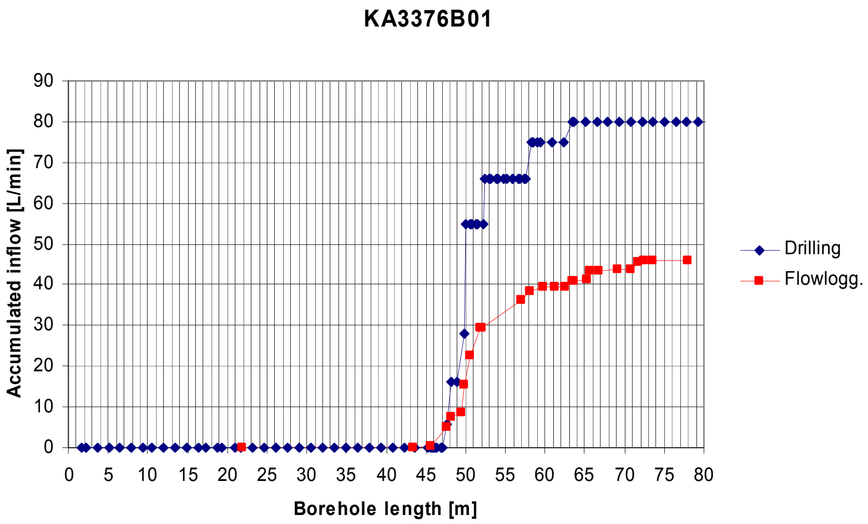

Figure 3.8 *Inflow during drilling and for Posiva Flowlogg, KA3376B01. Borehole length: 80.19 m. Last "Flowlogg-point" shows the lowest section of measurements (~78 m). Difference in total inflow due to the measurement limit for the Posiva Flowlogg.*

Data from the Posiva flowlogging are presented in Appendix B. These are depth of borehole (~450 m), flow, elevation and estimated transmissivities (for evaluation see Pöllänen and Rouhiainen, 2002 and Pöllänen and Rouhiainen, 2003). The transmissivities and apertures that are estimated from these data assume steady state conditions and the values of hydraulic heads being the same as the elevation of the fracture in the borehole. More certain values of transmissivities and apertures would demand knowledge concerning the hydraulic head or transient tests.

Table 3.6 shows univariate statistics for the estimated transmissivities of fractures identified along the boreholes (see Appendix B). The mean Log10(T) for boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01 are – 8.3, - 7.7, – 8.3 and -7.7 m^2/s or approximately 5.0E-9, 2.0E-8, 5.0E-9 and 2.0E-8 m^2/s. Corresponding normal probability plots are shown in Figure 3.9, Figure 3.10, Figure 3.11 and Figure 3.12. The measurement limit is clearly identified in Figure 3.12.

Table 3.6 Univariate statistics for transmissivities identified and estimated from Posiva Flowlogg data along boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01 (dh~450 m), see Appendix B.

Borehole	Sec up	Sec low	Test scale	Measurement limit (lower –upper)	Sample size	Transmissivity (T) Log10(T)		
	(m)	(m)	(m)	Q: (mL/h) T: (m^2/s)		Mean (m^2/s)	Std (m^2/s)	Max (m^2/s)
KF0066A01	~2	~58	1	Q: 12 000 - 300 000 T: 7.3E-9 - 1.8E-7	8	-8.3	1.1	-6.9
KF0069A01	~2	~68	1	Q: 240 - 300 000 T: 1.5E-10 - 1.8E-7	4	-7.7	1.1	-6.8
KA3386A01	~2	~63	1	Q: 120 - 300 000 T: 7.3E-11 - 1.8E-7	34	-8.3	1.0	-6.6*
KA3376B01	~2	~78	1	Q: 1000-300 000 T: 6.1E-10 - 1.8E-7	25	-7.7	0.9	-6.6*

* "Max" is the measurement limit and not the maximum value.

The lower measurement limits (Table 3.6) are different for the four boreholes. KA3386A01 is looked upon as "normal" whereas KF0066A01 probably contained gas during testing. For KF0069A01 the "flow noise" is slightly increased because of the high flow from the bottom of the borehole, see Figure 3.6. For the normal probability plots, two transmissivity values are higher and one lower than the measurement limits for borehole KA3386A01 and for KF0066A01 four transmissivity values are lower. Borehole KA3376B01 has one value that is lower and four values that exceed the measurement limit. These data do not seem to change the distributions to any large degree when included, see figures below.

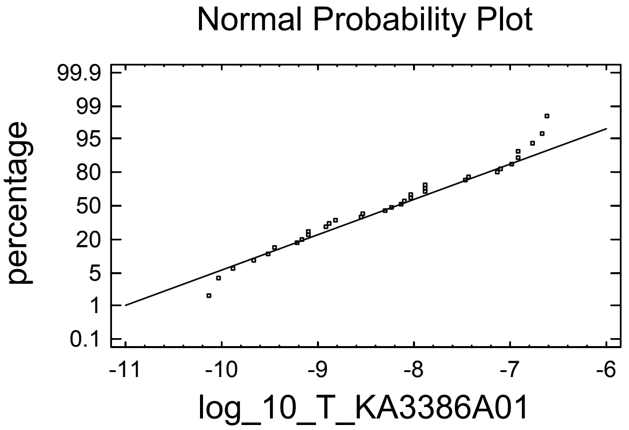

Figure 3.9 *Normal probability plot of transmissivities along borehole KA3386A01 identified and estimated from Posiva Flowlogg data. Included in the figure are two of the transmissivity values that are higher and one that is lower than the measurement limits, Table 3.6.*

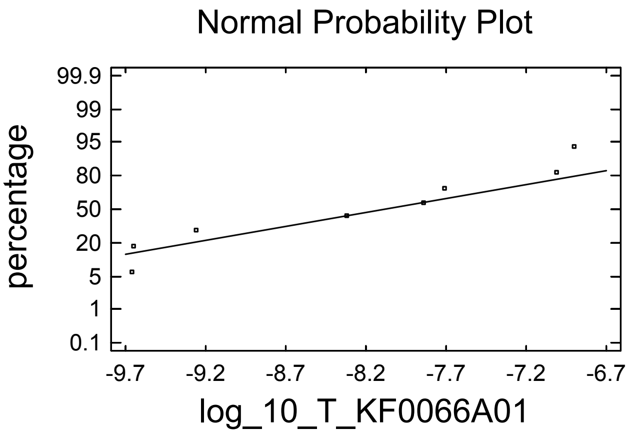

Figure 3.10 *Normal probability plot of transmissivities along borehole KF0066A01 identified and estimated from Posiva Flowlogg data. Four of the transmissivity values included in the figure are lower than the lower measurement limit, Table 3.6.*

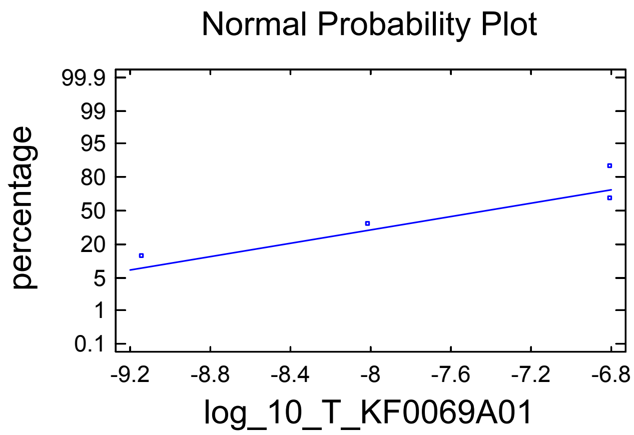

Figure 3.11 *Normal probability plot of transmissivities along borehole KF0069A01 identified and estimated from Posiva Flowlogg data.*

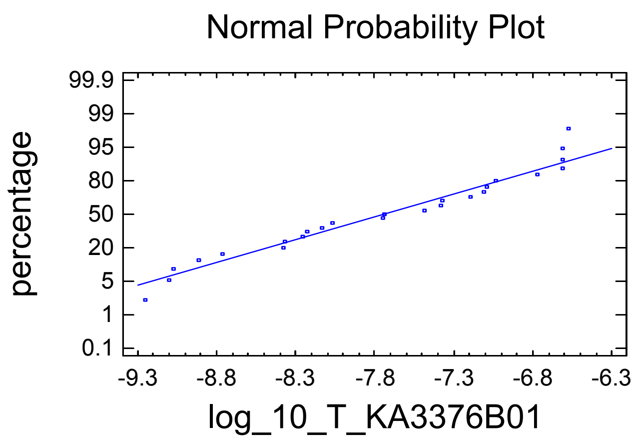

Figure 3.12 *Normal probability plot of transmissivities along borehole KA3376B01 identified and estimated from Posiva Flowlogg data. Included in the figure are four of the transmissivity values that are higher and one that is lower than the measurement limits, Table 3.6.*

The cubic-law (e.g. de Marsily, 1986):

$$T = \frac{\rho g b^3}{12\mu} \qquad (1)$$

describes how the hydraulic aperture, b, between two plane-parallel plates are related to the transmissivity, T. Besides the aperture, the transmissivity is influenced by the density and viscosity of the fluid, ρ and μ, and the acceleration due to gravity, g. Assuming that the transmissivities presented in Table 3.6 originate from individual fractures, the estimated mean (Log10) apertures would be approximately 20, 30, 20 and 30 μm for KF0066A01, KF0069A01, KA3386A01 and KA3376B01. The maximum apertures for KF0066A01 and KF0069A01 would be 55 and 60 μm. For these calculations, the density and viscosity of the fluid, ρ and μ, where assumed to be 1000 kg/m^3 and 1.3E-3 kg/(m·s) and the acceleration due to gravity 9.81 m/s^2. Apertures of 50 and 100 μm would in this case correspond to 7.9E-8 m^2/s (Log(10)= –7.1) and 6.3E-7 m^2/s (Log(10)= –6.2) respectively. Since these apertures are often referred to as the lower limits for what is groutable with cement grout, only few of the fractures are expected to be groutable.

3.3.2 Pressure build-up tests

The main aim of the full length pressure build up tests was to investigate the pressure response to assess if grouting for the future tunnel is likely to influence ongoing experiments. Below, the performance and evaluation of the pressure build-up tests are presented. Beside the transmissivities, T, the specific capacities (flow divided by difference in hydraulic head, Q/dh) of the boreholes were also evaluated.

For the full-length test, a mechanical packer was mounted in the top of the borehole. Subsequently, both borehole and pipe were filled with water before the valve was closed and the data logger was started. Initially, the pressure should stabilise and testing was initiated by a 24-hour flow period followed by 24 hours of pressure build-up. Manual readings of the flow rate were made for one hour after having opened the valve and for one hour before closing.

The transmissivity (T) was estimated from the recovery phase of the pressure build-up test using Jacob's method (Cooper and Jacob, 1946). The recovery (s") is expressed as given below:

$$s'' = \frac{Q}{2\pi T}\frac{1}{2}\left(0.8091 + \ln\frac{T}{r^2 S}\cdot\left(\frac{t_{PB}\cdot t_P}{t_{PB}+t_P}\right)\right) = \frac{Q}{4\pi T}\left(0.8091 + \ln\frac{Tt_e}{r^2 S}\right) \tag{2}$$

where r=radial distance, S=storage coefficient and Q=flow (e.g., Gustafson 1986). The adjusted time (t_e) is estimated from the time of injection or flow time, t_P , and the time since recovery started or the Pressure build-up time, t_{PB}. Initially, log-log plots of the recovery (s") and the adjusted time (t_e) are used to evaluate the flow dimension of tests. A slope of 1:1 indicates an effect of wellbore storage. The shape of curves also indicates if there is one-dimensional (1D) flow, radial or two-dimensional (2D) flow, or three-dimensional (3D) flow, (e.g., Carlsson and Gustafson 1991). Doe and Geier (1990) further describe the spatial dimension for flow in hydraulic tests.

Jacob's method consists of plotting the recovery (s") and the adjusted time (t_e) on a semi-logarithmic plot. The transmissivity is evaluated using the following equation:

$$T = \frac{0.183Q}{\Delta s''} \tag{3}$$

where, Δs" is the slope of the recovery line on the plot of s" against t_e.

Test data for the pressure build-up tests are shown in Table 3.7 and the estimated specific capacity, Q/dh, and transmissivity are presented in Table 3.8.

Table 3.7 Test data for pressure-build up tests performed in KF0066A01, KF0069A01, KA3386A01 and KA3376B01.

Borehole	Test section, Secup (m)	Test section, Seclow (m)	Type of tests performed	Pressure/ Draw down (m)	Flow rate (L/min)	Flow period (hours)	Recovery period (hours)
KF0066A01	~2	60.11	Pressure build-up test	~252	6.3	~24	~24
KF0069A01	~2	70.09	"	~400	8.5	~24	~24
KA3386A01	~2	65.11	"	~219	44.1	~24	~24
KA3376B01	~2.5	80.19	"	~343	96.3	~24	~24

Graphs (log-log and lin-log plots) for the pressure build-up tests are presented in Appendix C. The log-log plots for the boreholes KF0066A01 and KF0069A01 follow a slope greater than unity before starting to stabilise (as mentioned above, a slope of 1:1 indicates an effect of wellbore storage). One possible explanation for this is a change in wellbore storage, which occurs when the compressibility of the fluid in the wellbore is not constant (Bourdet, 2002). In this case gas is most likely found in the two boreholes, with a faster change in pressure when the gas is dissolved in the water. For borehole KF0069A01 a larger conductive feature is possibly found at a distance from the borehole (T~1.7E-6 m^2/s, see Appendix C). For borehole KA3386A01 the transmissivity is equal to the specific capacity and for KA3376B01 the transmissivity is larger than the specific capacity.

Table 3.8 Estimated specific capacity and transmissivity for KF0066A01, KF0069A01, KA3386A01 and KA3376B01.

Borehole	Test section, Secup (m)	Test section, Seclow (m)	Type of tests performed	Specific capacity (m^2/s)	Transmissivity (m^2/s)
KF0066A01	~2	60.11	Pressure build-up test	4.2E-7	- gas in borehole
KF0069A01	~2	70.09	"	3.5E-7	- gas in borehole (1.7E-6, see Appendix C)
KA3386A01	~2	65.11	"	3.4E-6	3.4E-6
KA3376B01	~2-2.5	80.19	"	4.7E-6	1.5E-5

3.4 Pressure response (KF0066A01, KF0069A01, KA3386A01)

In order to enable assessment of what influence future blasting and grouting in the area may have on other experiments (mainly the Prototype Repository Test and TRUE Block Scale), the pressure responses in a number of boreholes were measured. This study includes compilation and analyses of pressure responses caused by drilling, blasting and hydraulic tests. Blasting was performed in the TASF-tunnel and in niche NASA3384A, which are the locations for the two first tunnel alternatives.

At Äspö Hard Rock Laboratory (Äspö HRL) several boreholes are connected to a hydro monitoring system, HMS, that continually measure ground water pressure. Normally, this system registers the pressure once every second hour and a detailed scanning starts when the measured pressure change exceeds 2 kPa. During drilling and pressure build-up tests this normal mode was used and when blasting detailed scanning of a number of boreholes was also added. The different activities (drilling, blasting and pressure build-up tests), location/borehole and dates are presented in Table 2.1.

During drilling and pressure build-up tests, 12 different boreholes were investigated see Figure 2.2. The eventual responses in the LTDE- and TRUE-1 areas were studied using boreholes KXTT4, KA3010A and KA3067A. For the area north of the access tunnel boreholes KF0051A, KA2598A, KG0021A01 and KG0048A01 (Matrix Fluid Chemistry and Prototype repository experiment) were used and finally, boreholes KA3385A, KA2511A, KI0023B, KI0025F and KA3600F investigated the responses in the area south of the access tunnel (Prototype repository and the TRUE Block Scale experiments). During blasting a larger number of boreholes were investigated to see that the monitoring systems do not risk to be damaged, see Table 3.10. Observe the amounts of explosive since they are fairly small.

3.4.1 Drilling

Drilling was performed between 2002-05-15 and 2002-06-15 (see Table 2.1) and the boreholes presented above were investigated. Based on the inflow during drilling (see Figure 3.5, Figure 3.6 and Figure 3.7) larger inflows were obtained at the following approximate times, see Table 3.9. This is helpful information for analysing responses and connections between boreholes. Some of the variations in pressure seen in the figures are due to the boreholes being closed a number of times.

Table 3.9 Time for larger inflows, borehole depth and increase in accumulated inflow when drilling boreholes KF0069A01, KF0066A01 and KA3386A01.

Borehole	Time for larger flow anomaly when drilling	Borehole depth	Increase in accumulated inflow
KF0069A01	2002-05-21, ~10:00	~65 m	0 to 10L/min
KF0066A01	2002-05-30, ~13:30	~8 m	0 to 6 L/min
	2002-06-01, ~14:00	~56 m	5 to 9 L/min
KA3386A01	2002-06-11, ~08:00	~11 m	0 to 11 L/min
	2002-06-12, ~10:30	>33 m	13 to 43 L/min

Observed responses in the area for TRUE-1 and LTDE (see borehole KXTT4, Figure 3.13) the 2002-05-28 and 2002-06-10 are likely to be due to pressure build-up tests in KA2865A01 and packer release in the LTDE area respectively (SICADA Activity logs). The decrease at 2002-05-28 seems to occur before drilling of KF0066A01 has started and the decrease at 2002-06-10 starts earlier than the occurrence of larger inflow in KA3386A01. However, one cannot exclude that the responses are a result of a combination of these activities and drilling of KF0069A01, KF0066A01 and KA3386A01 (represented by (D) and coloured lines in the figure). This is concluded when comparing the times for pressure responses in borehole KXTT4 and the approximate times of larger inflow above (Table 3.9).

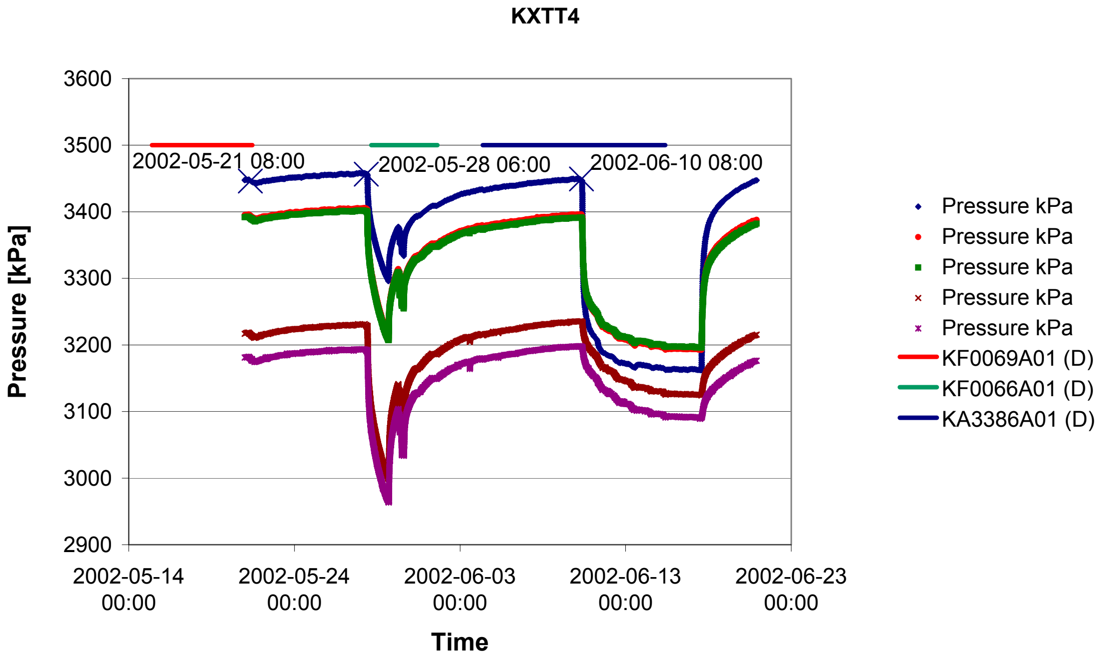

Figure 3.13 *Pressure response in borehole KXTT4. (D) and coloured lines represent drilling of KF0069A01, KF0066A01 and KA3386A01. Time for responses 2002-05-28 and 2002-06-10 (identified by X) do not agree with time for larger inflow, Table 3.9. Possible agreement 2002-05-21.*

In the area north of the access tunnel, however, the pressure of KA2598A changes when drilling all three boreholes (only slightly for KF0069A01), see Figure 3.14.

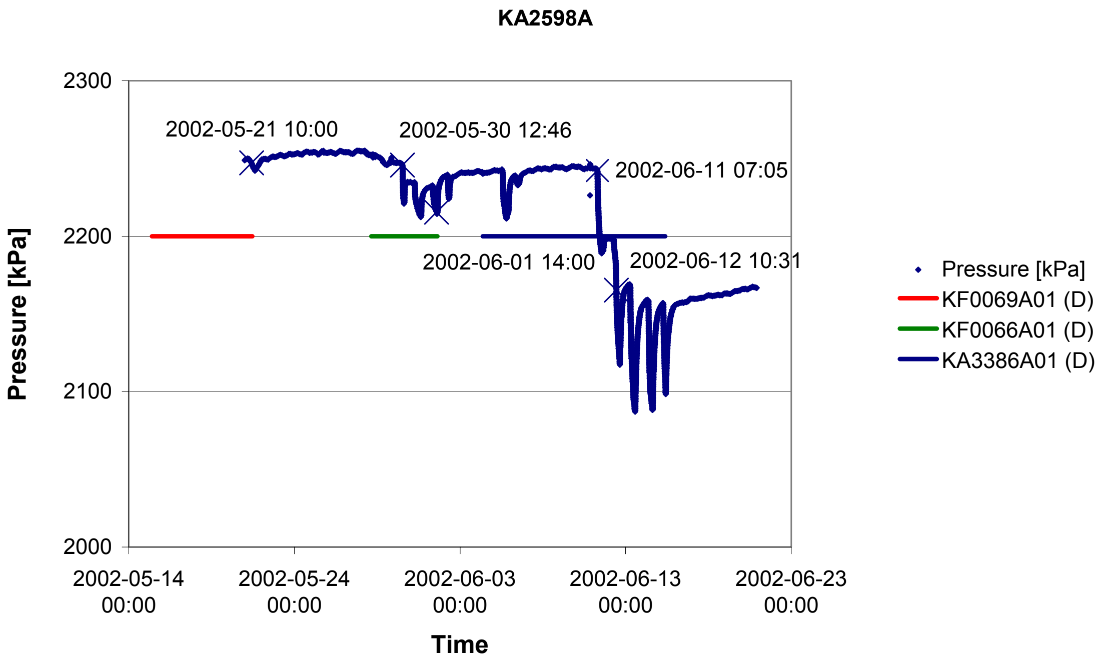

Figure 3.14 *Pressure response in borehole KA2598A during drilling. (D) and coloured lines represent drilling of KF0069A01, KF0066A01 and KA3386A01. Agreement between responses (identified by X) and time for larger inflow, Table 3.9.*

Larger inflows that may correspond to these pressure responses occurred in KF0069A01 at 2002-05-21, 10h00 in KF0066A01 at 2002-05-30, 13h30 and in KA3386A01 at 2002-06-11, 08h00 (Table 3.9). For KF0051A (Matrix Fluid Chemistry experiment) variations in pressure are very small. Responses in boreholes south of the access tunnel are mainly seen when drilling KA3386A01. The pressure of KA3385A changed when drilling all three boreholes (only slightly for KF0069A01, Figure 3.15).

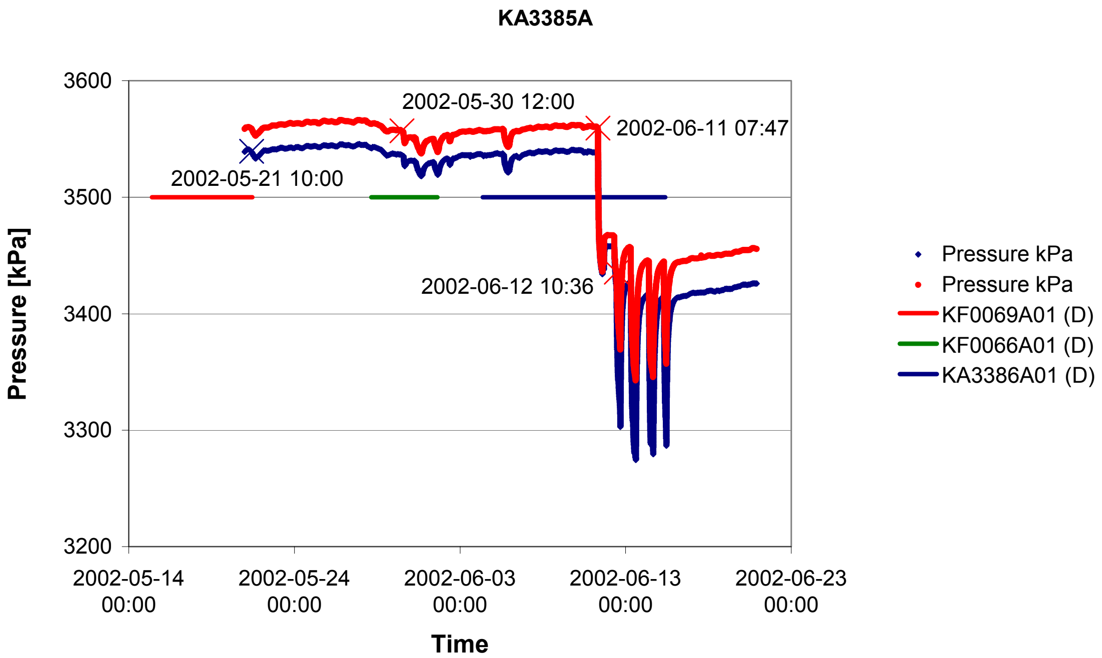

Figure 3.15 *Pressure response in borehole KA3385A during drilling. (D) and coloured lines represent drilling of KF0069A01, KF0066A01 and KA3386A01. Agreement between responses (identified by X) and time for larger inflow, Table 3.9***.**

When drilling KA3386A01, both KA2598A and KA3385A show responses the 2002-06-11 at approximately 8h00. This is likely to represent the increase in inflow from 0 to 11 L/min, which should have occurred after drilling approximately 10 or 11 meters, see Table 3.9. In Figure 3.16, which describes the pressure response in KG0021A01, the increase is seen the 2002-06-12 at approximately 10h30, which indicate that two different structures have been intersected. A similar result was seen for borehole KG0048A01, see Figure 3.17.

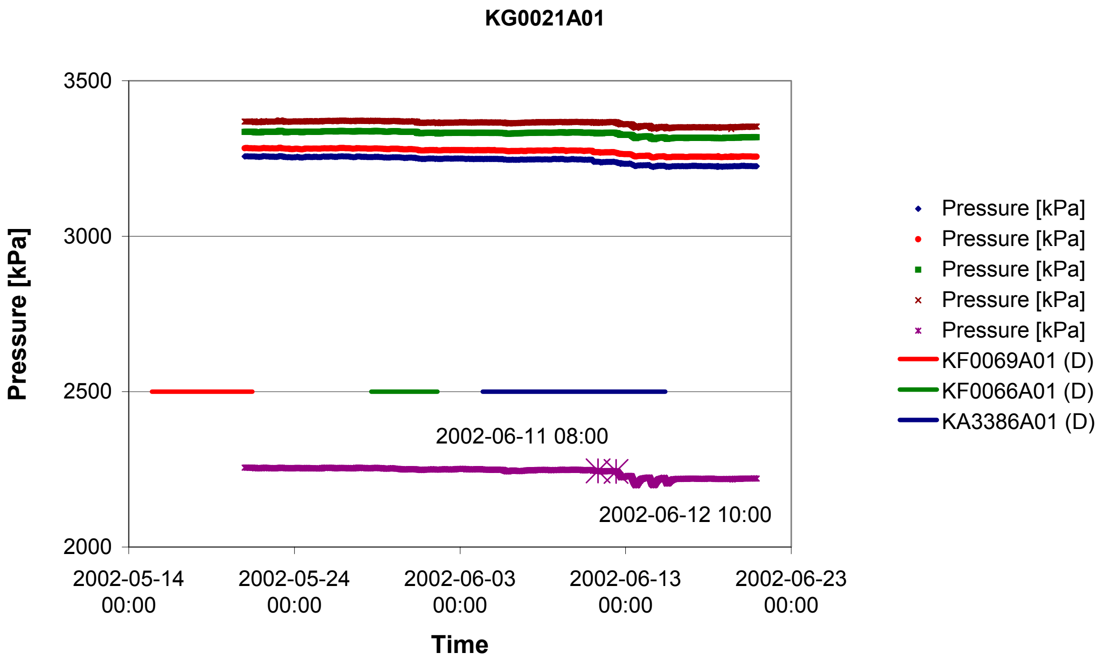

Figure 3.16 *Pressure response in borehole KG0021A01 during drilling. (D) and coloured lines represent drilling of KF0069A01, KF0066A01 and KA3386A01. Agreement between responses (identified by X) and time for larger inflow, Table 3.9*.

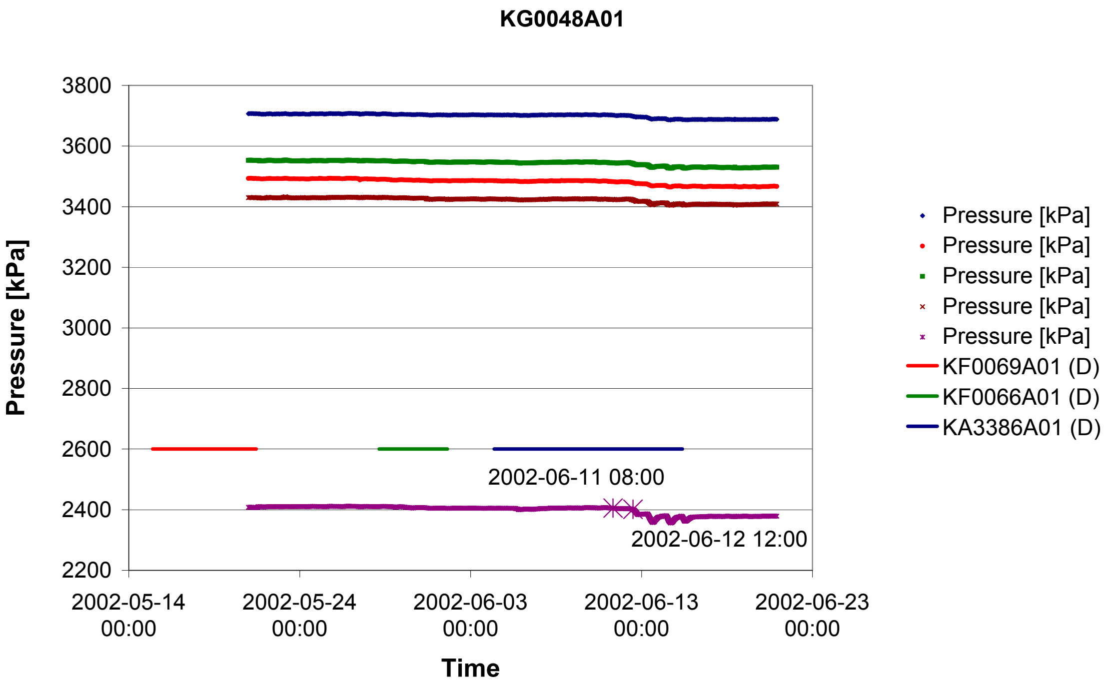

Figure 3.17 *Pressure response in borehole KG0048A01 during drilling. (D) and coloured lines represent drilling of KF0069A01, KF0066A01 and KA3386A01. Agreement between responses (identified by X) and time for larger inflow, Table 3.9.*

3.4.2 Posiva Flowlogging

Possible response data due to the boreholes being open during Posiva Flowlogging were not thoroughly investigated since similar data and for a longer period were obtained during the pressure build-up tests.

3.4.3 Blasting

In order to enable a study of even smaller variations the boreholes presented in Table 3.10 and Appendix D were investigated using detailed scanning (approximately 20-50 measurements per second, without an asterisk). Here, as well as during drilling, detailed scanning for other boreholes should be initiated when the measured pressure change exceeds 2 kPa. Boreholes only connected to the HMS-system are identified by an asterisk (measurement every 1-2 seconds).

Test blasting was performed 2002-08-14 at two different locations, 1 and 2, see Table 3.11 and Figure 3.18. *Figure 3.18* also shows locations where vibration measurements were performed (not further reported here). For location 1 at 06h45, 07h03, 08h41, 08h55, 09h18 and for location 2 at 12h01, 12h21 and 12h46 (HMS-time). Location of blasting and amount and type of explosives are shown in Table 3.12. Detailed scanning started just before and was stopped just after blasting for most of the boreholes.

Table 3.10 Boreholes for measurement of pressure response during blasting and location/comment (with asterisk: HMS data, without asterisk: detailed scanning).

Borehole	Location/Comment
HA1960A*	For general study
KA1755A*	Rock volume above Alternative 1
KA2162B*	For general study / Alternative 2
KA2511A	TRUE Block Scale / Alternative 2
KA2563A	TRUE Block Scale/ Alternative 2
KA2598A	Rock volume above Alternative 1
KA3010A	Between TRUE-1 & LTDE (NW-2?)
KA3067A*	LTDE
KA3385A	Niche Alternative 2
KA3510A	Prototype / TRUE Block Scale
KA3566G01-KA3600F see Appendix D	Prototype, 25 boreholes
KF0051A01	Rock volume Alternative 1 / Matrix Fluid Chemistry
KG0021A01	Prototype from G-tunnel
KG0048A01	Prototype from G-tunnel
KI0023B	TRUE Block Scale
KI0025F	TRUE Block Scale
KI0025F02	TRUE Block Scale
KI0025F03	TRUE Block Scale
KXTT4	TRUE-1

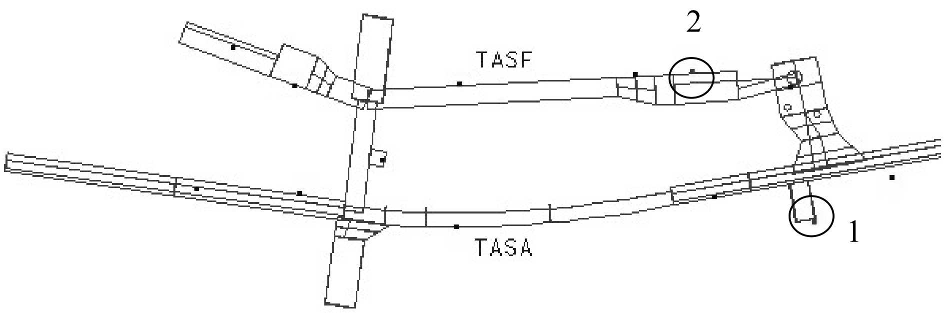

Figure 3.18 *Locations of blasting (circles) and locations where vibration measurements were performed.*

Table 3.11 Locations of blasting (coordinates in Äspö96).

Location	Northing	Easting	Z
1 NASA3384A	7261,114	2079,883	-446,389
2 (TASF)	7300,863	2047,953	-457,183

Table 3.12 Location of blasting and amount and type of explosives.

Location	Time (HMS-time)	Amount and type of explosives
TASA (1)	06:45 (1)	50 g Detonex
”	07:03 (2)	100 g Detonex
”	08:41 (3)	50 g Detonex
”	08:55 (4)	100 g Detonex
”	09:18 (5)	50 g / borehole Detonex
TASF (2)	12:01 (6)	100 g Detonex
”	12:21 (7)	200 g Detonex
”	12:46 (8)	100 g / borehole Detonex

During blasting, none of the boreholes connected to the HMS system automatically initiated a detailed scanning. Based on this, the measured change in pressure did not exceed 2 kPa. Observe the amounts of explosive since they are fairly small.

In general no or possibly small responses are visually identified and to analyse data, the maximum and minimum values and the arithmetic mean were used. Based on this the largest increase (max-mean) or decrease (mean-min) were less than 0.01 Bar or 0.1 m, which is also small enough to be defined as noise.

3.4.4 Pressure build-up tests

The same boreholes were investigated during drilling and pressure build-up tests , see Figure 2.2. During drilling, changes in pressure were identified at the LTDE/TRUE-1 sites (KXTT4). Since hardly any changes in pressure is seen during the Posiva Flowlogging and pressure build-up tests, see Figure 3.19, the responses during drilling is likely to be due to pressure build-up tests in KA2865A01 and packer release in the LTDE area (SICADA Activity logs). The lowering of the pressure between 2002-08-09 and 2002-08-12 could not be explained based on information from SICADA Activity logs. For the area north of the access tunnel, the largest response during pressure build-up tests is seen for borehole KA2598A, Figure 3.20. For the southern area borehole KA3385A is most influenced,

Figure ***3.21***. This is in agreement with the results obtained during drilling. (PFL), (PBT) and coloured lines in the figures show when the three boreholes were tested with Posiva Flowlogging or pressure build-up tests.

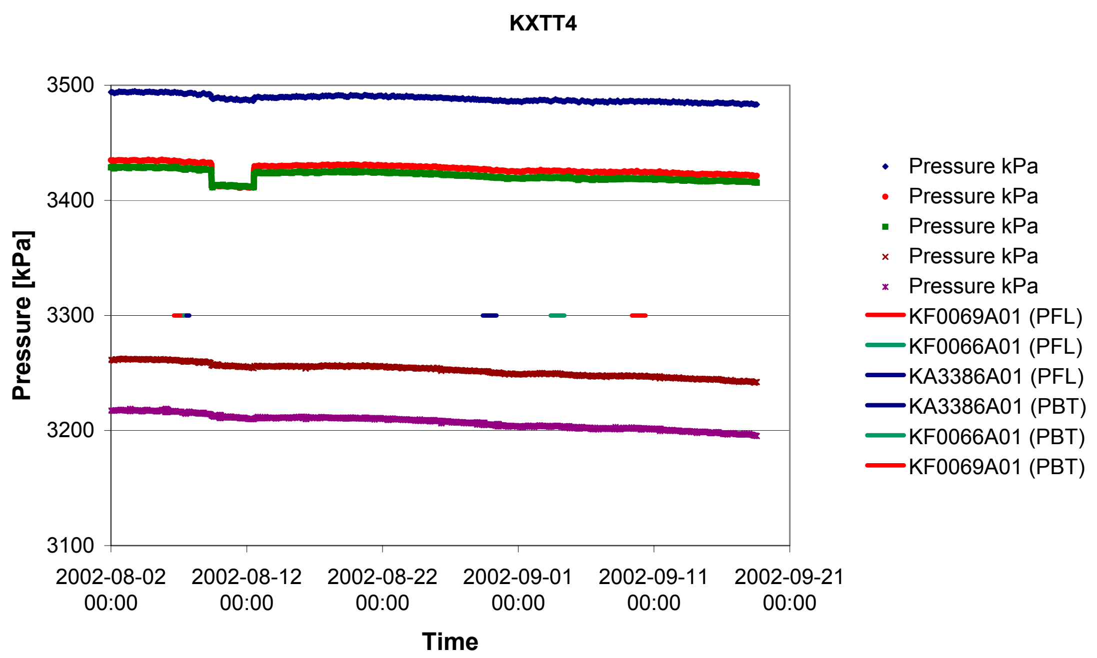

Figure 3.19 *Pressure response in borehole KXTT4 during hydraulic tests. (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KF0069A01, KF0066A01 and KA3386A01 (order of tests shown in the legend).*

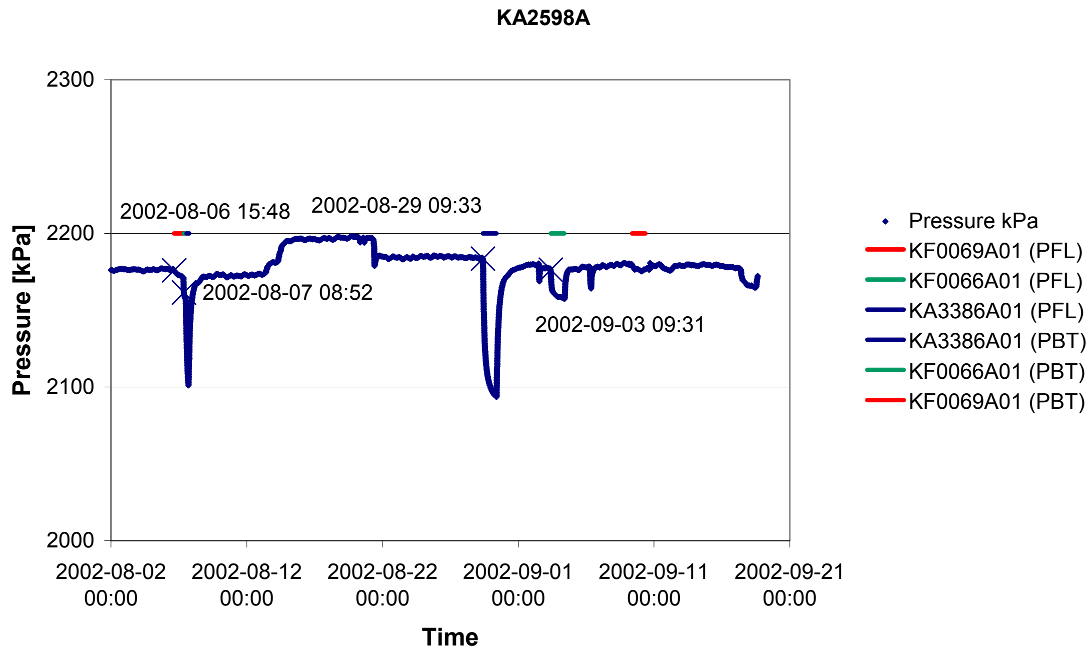

Figure 3.20 *Pressure response in borehole KA2598A during hydraulic tests. (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KF0069A01, KF0066A01 and KA3386A01 (order of tests shown in the legend). Agreement between responses (identified by X and time) and time for hydraulic tests, Table 2.1.*

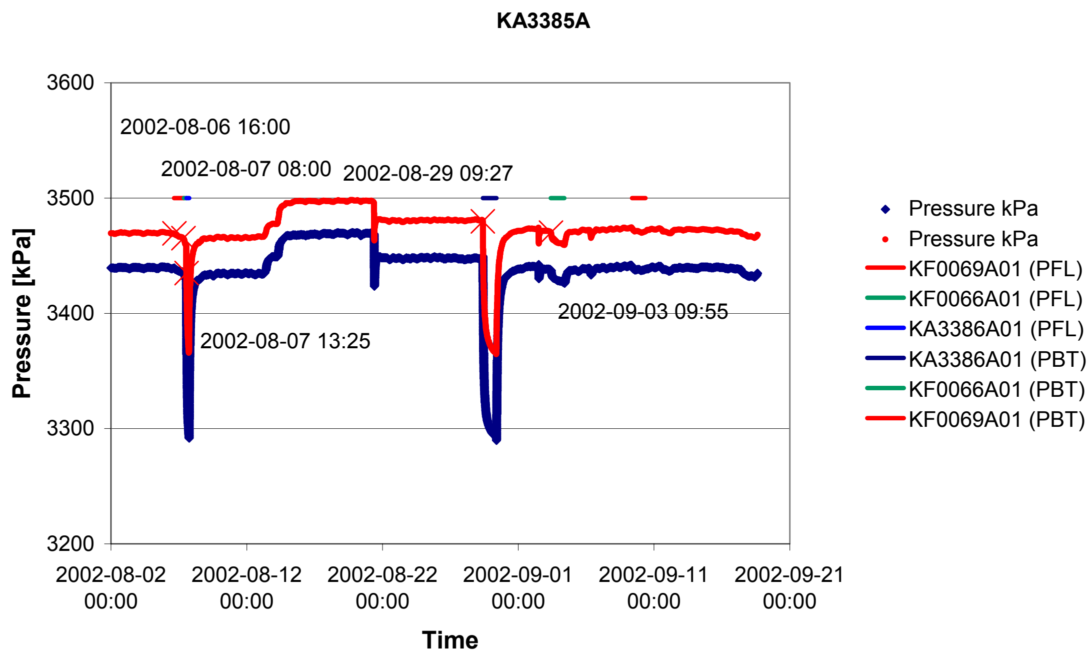

Figure 3.21 *Pressure response in borehole KA3385A during pressure build-up tests. (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KF0069A01, KF0066A01 and KA3386A01 (order of tests shown in the legend). Agreement between responses (identified by X and time) and time for hydraulic tests, Table 2.1.*

3.5 Pressure response (KA3376B01)

3.5.1 Drilling

Drilling was performed between 2002-11-08 and 2002-11-26 and time for larger inflows are shown in Table 3.13. For boreholes KA2598A and KA3385A connection to borehole KA3376B01 is clearly identified, see e.g. Figure 3.22 but the different inflows are difficult to separate. “Other activity” refers in this case to a loss in pressure due to problems with a packer. Some of the variations in pressure seen in the figures are due to the boreholes being closed a number of times.

Table 3.13 Time for larger inflows, borehole depth and increase in accumulated inflow when drilling borehole KA3376B01.

Borehole	Time for larger flow anomaly when drilling	Borehole depth	Increase in accumulated inflow	Inflow
KA3376B01	2002-11-20, 09:38 - 09:48	~47.5 m	0 to 5.8 L/min	~5.8 L/min
	2002-11-20, 10:53 - 11:01	~48 m	5.8 to 16.0 L/min	~10.2 L/min
	2002-11-20, 13:14 - 13:22	~49.5 m	16.0 to 28.0 L/min	~12 L/min
	2002-11-20, 14:44 - 14:48	~50 m	28.0 to 55.0 L/min	~27 L/min
	2002-11-22, 13:17 - 13:28	~52.3 m	55.0 to 66.0 L/min	~11 L/min
	2002-11-24, 13:39 - 13:53	~58 m	66.0 to 75.0 L/min	~9 L/min
	2002-11-25, 14:51 - 15:29	~63 m	75.0 to 80.0 L/min	~5 L/min

Figure 3.23 shows the responses in borehole KF0066A01 and KF0069A01 during drilling of KA3376B01. Pressure responses were measured in two sections of borehole KF0066A01 and a larger response is seen for the section closest to the tunnel (KF0066A01:2) than for the inner section (KF0066A01:1). For KF0069A01 identification of a response is difficult.

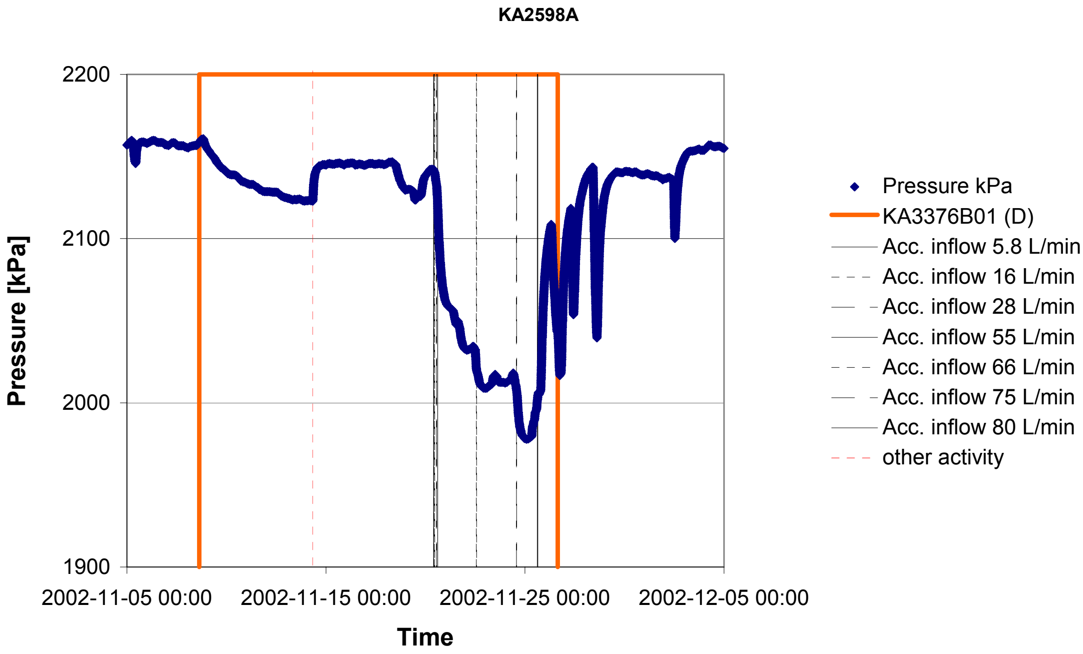

Figure 3.22 *Pressure response in borehole KA2598A during drilling (D) of borehole KA3376B01.*

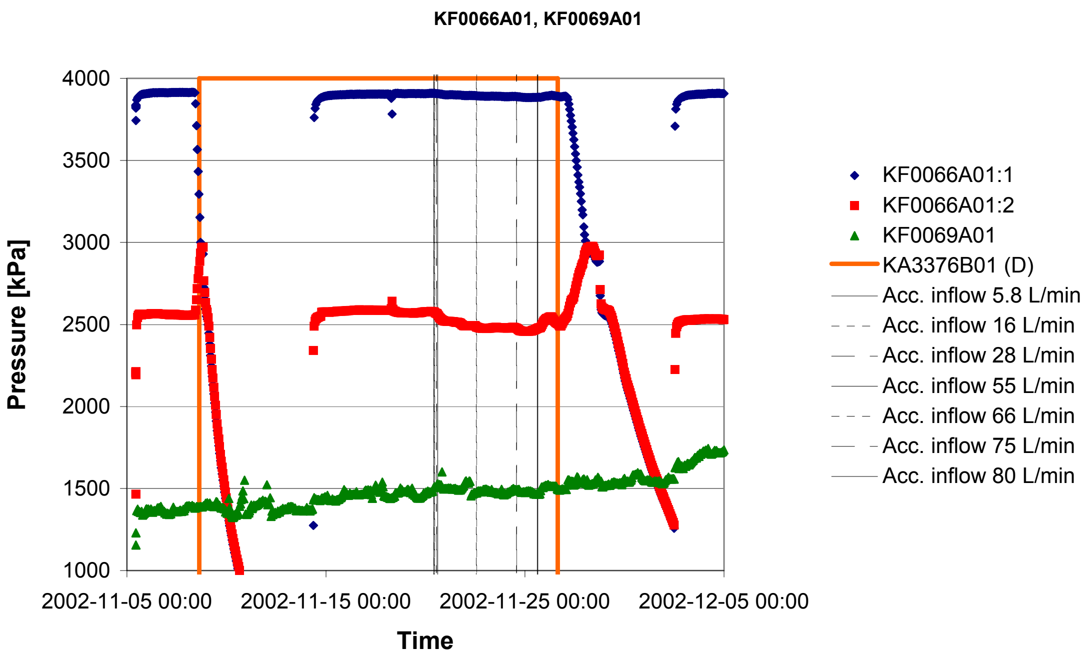

Figure 3.23 *Pressure responses in borehole KF0066A01 and KF0069A01 during drilling (D) of borehole KA3376B01.*

3.5.2 Posiva Flowlogging and Pressure build-up test

Response data due to the boreholes being open during Posiva Flowlogging were not thoroughly investigated since similar data and for a longer period were obtained during the pressure build-up tests. PBT2 in figures below refers to the second 24 hour flowing of borehole KA3376B01 since responses were influenced by other activities such as water sampling during the first pressure build-up test. Figure 3.24 to Figure 3.28 show responses due to Posiva Flowlogging (PFL) and the second flowing of the borehole (PBT2). Responses for all investigated boreholes are presented in Appendix E. Here as well, KA2598A and KA3385A are clearly connected to borehole KA3376B01. Boreholes KXTT4 and KG0021A01 are only slightly influenced and the response may partly be due to other activities since the pressure decreases before the Posiva flowlogging has been started, see detail in Figure 3.28.

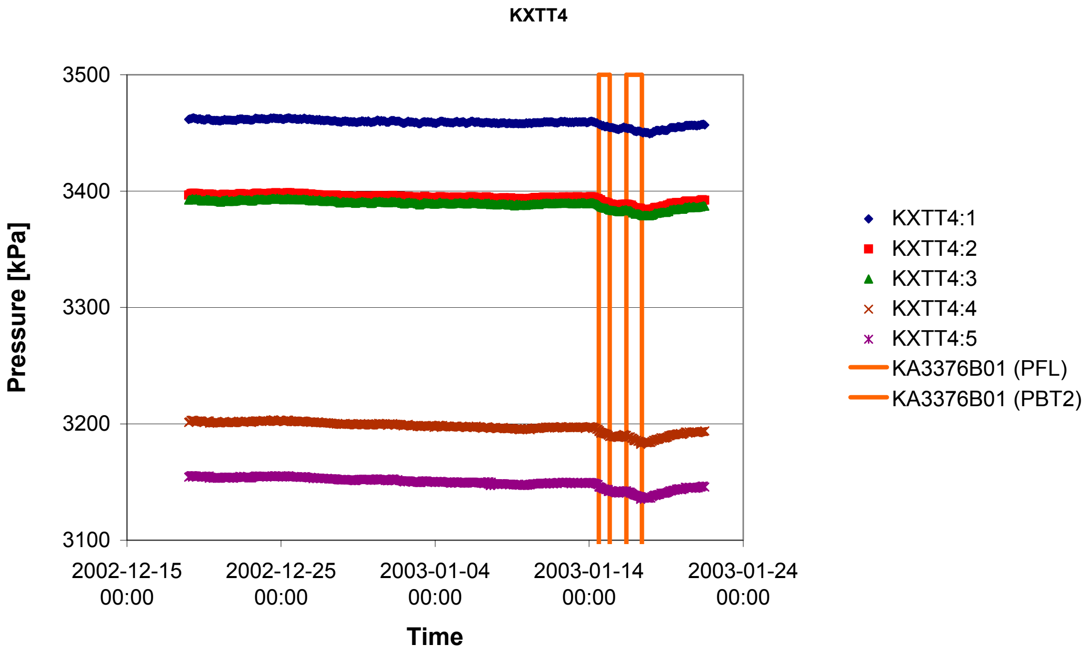

Figure 3.24 *Pressure response in borehole KXTT4 during hydraulic tests (see detail in Figure 3.28). (PFL), (PBT2) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KA3376B01 (order of tests shown in the legend).*

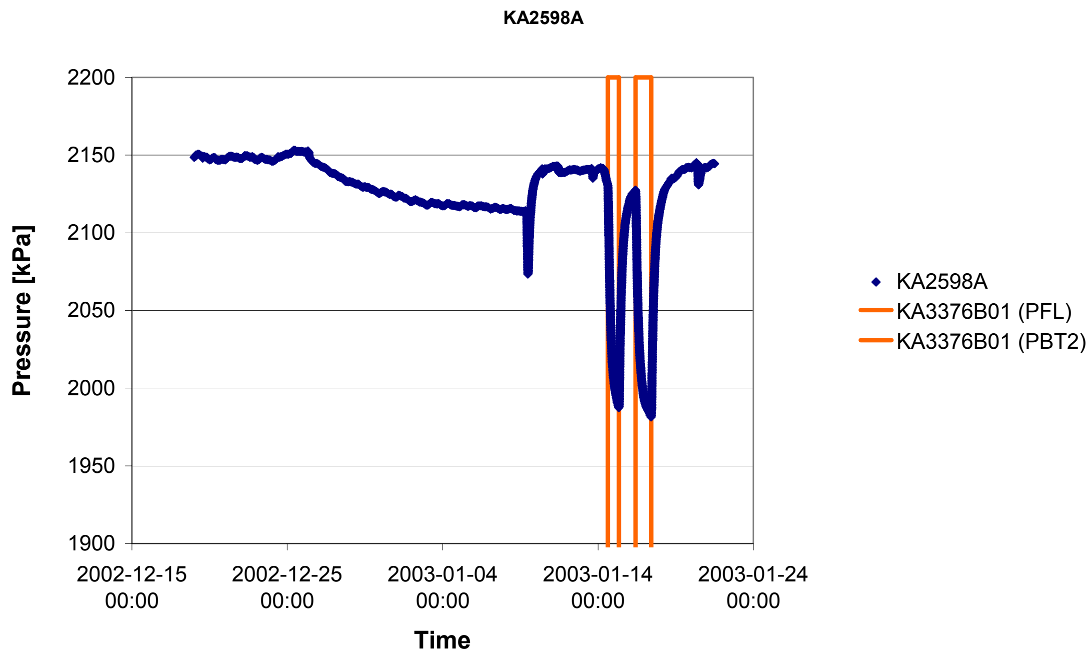

Figure 3.25 *Pressure response in borehole KA2598A during hydraulic tests. (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KA3376B01 (order of tests shown in the legend).*

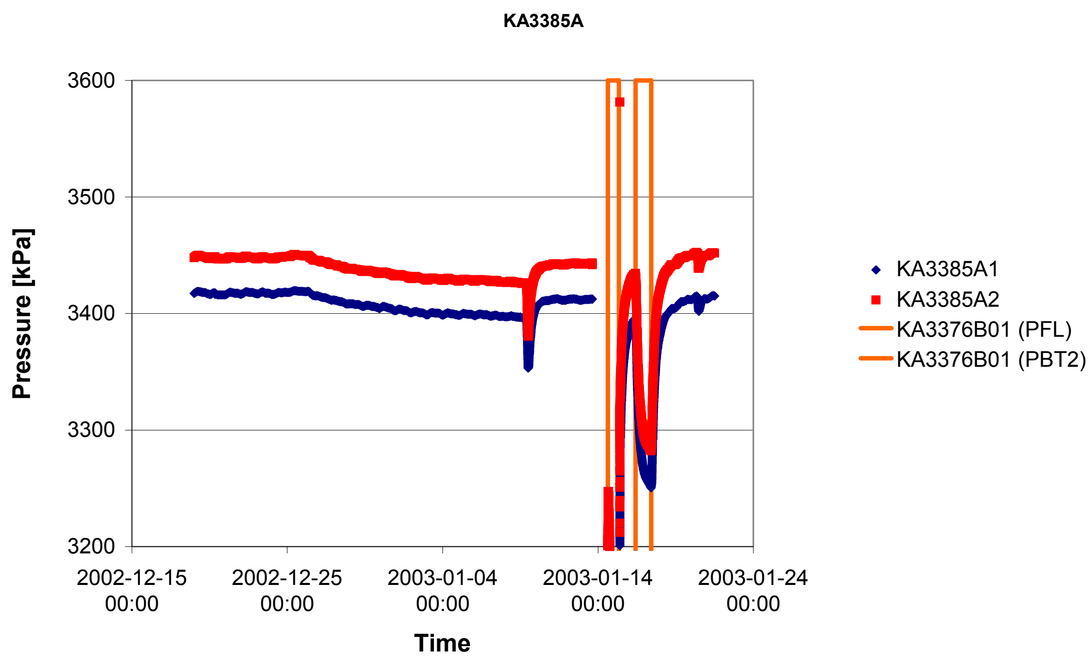

Figure 3.26 *Pressure response in borehole KA3385A during hydraulic tests. (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KA3376B01 (order of tests shown in the legend).*

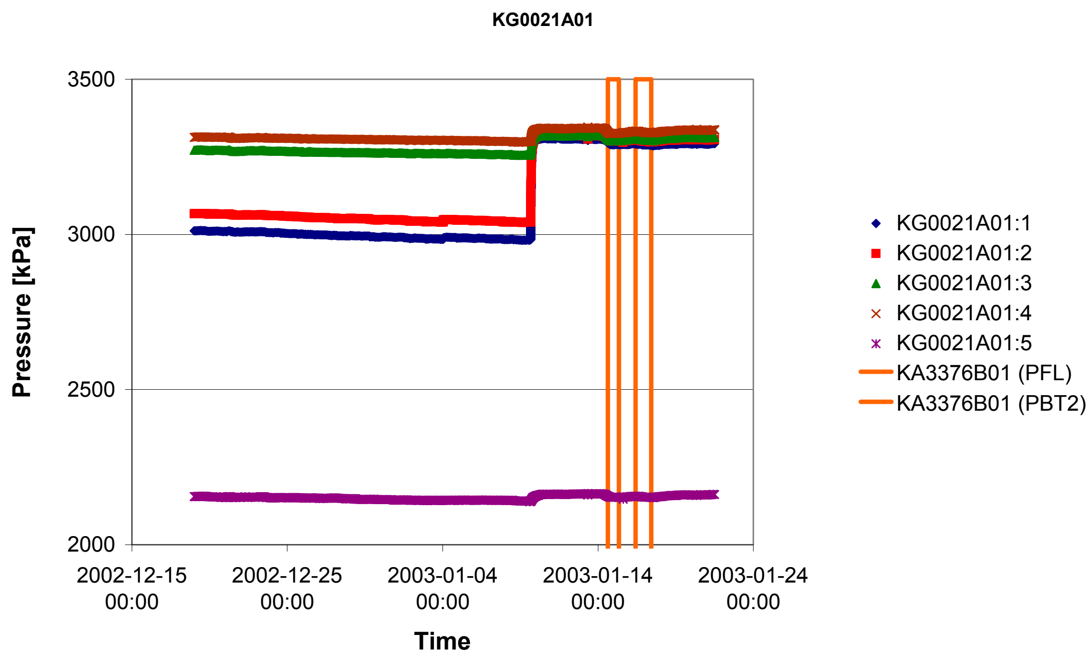

Figure 3.27 *Pressure response in borehole KG0021A01 during hydraulic tests. (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KA3376B01 (order of tests shown in the legend).*

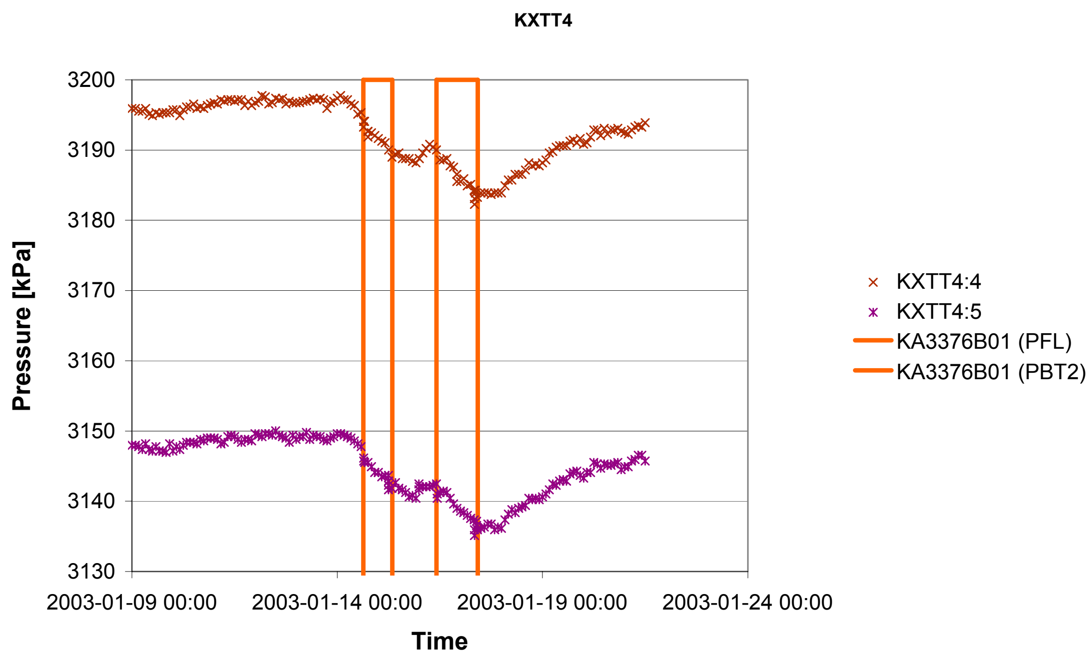

Figure 3.28 *Pressure response in borehole KXTT4 during hydraulic tests (detail). (PFL), (PBT) and coloured lines represent duration of Posiva Flowlogging and Pressure build-up tests for KA3376B01 (order of tests shown in the legend).*

4 Discussion

4.1 Hydrogeological characterization of boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01

The hydrogeological investigations of core boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01 aim at describing the boreholes, which are drilled in three alternative areas suggested for a future tunnel (Alternatives 1-3, Figure 1.1). Obtained data should be used to make a more informed choice concerning location of a tunnel and future grouting strategy. The results will be briefly commented from a grouting point of view.

Based on Posiva Flowlogg, few inflow points were identified along KF0066A01 and KF0069A01 (8 and 4 respectively), whereas 34 and 25 inflow points respectively were found along boreholes KA3386A01 and KA3376B01. For Posiva flowlogg data the borehole depth (~450 m) where used to estimate transmissivities. Probability distributions for these data are presented in Figure 3.9 to Figure 3.12. The agreement between accumulated inflow measured during drilling and calculated accumulated inflow using Posiva Flowlogging is fairly good for boreholes KF0066A01 and KF0069A01 (see Figure 3.5 and Figure 3.6). The difference in inflow for KA3386A01 and KA3376B01 (Figure 3.7 and Figure 3.8) is mainly due to difficulties for Posiva Flowlogg to measure inflows exceeding 5 L/min. Table 4.1 presents data for inflows exceeding 5 L/min, which are compared to the approximate inflows identified during drilling. The inflow during drilling is difficult to assess for the inner part of borehole KA3386A01 (see Figure 3.7). Hydraulic apertures estimated using the inflow and the measured water pressure (from Pressure build-up tests) are generally 10 –20 % larger than the aperture based on the borehole depth (~450 m).

Table 4.1 Inflows exceeding 5 L/min based on Posiva Flowlogg (PFL) compared to approximate inflows during drilling for boreholes KA3376B01 and KA3386A01. Estimates of specific capacity and hydraulic aperture.

Borehole	Borehole depth, PFL (m)	Inflow, PFL (L/min)	Borehole depth, drilling (m)	Inflow during drilling (L/min)	Q/dh, (m^2/s)	b(Q/dh) (µm)	Q/dh (m^2/s)	b(Q/dh) (µm)
KA3386A01					dh: ~450 m		dh: 219 m	
	32.4	6.7	32.0-33.5	43-13=30	1.1E-6	~121	2.3E-06	~154
	40.0	5.8	*	*	*		*	
KA3376B01					dh: ~450m		dh: 343 m	
	49.8	6.7	48.9-49.9	28-16=12	4.4E-7	~89	5.8E-07	~98
	50.5	7.3	49.9-50.0	55-28=27	1.0E-6	~117	1.3E-06	~128
	51.8	6.7	52.2-52.3	66-55=11	4.1E-7	~87	5.3E-07	~95
	57.0	6.7	57.6-58.3	75-66=9	3.3E-7	~81	4.4E-07	~89
Σ		27.4		59	2.2E-6			

*Inflow difficult to assess

In Figure 4.1, Figure 4.2,
Figure 4.3 and Figure 4.4, inflow number of natural fractures and rock type are compiled for the four boreholes. For KA3386A01 the highest, fracture frequencies are seen where Fine-grained granite is present, this is also the case for borehole KF0069A01. For KA3386A01 more than half of the total inflow occurs in the Fine-grained granite. Observe that inflows larger than 5 L/min are underestimated see Table 4.1.

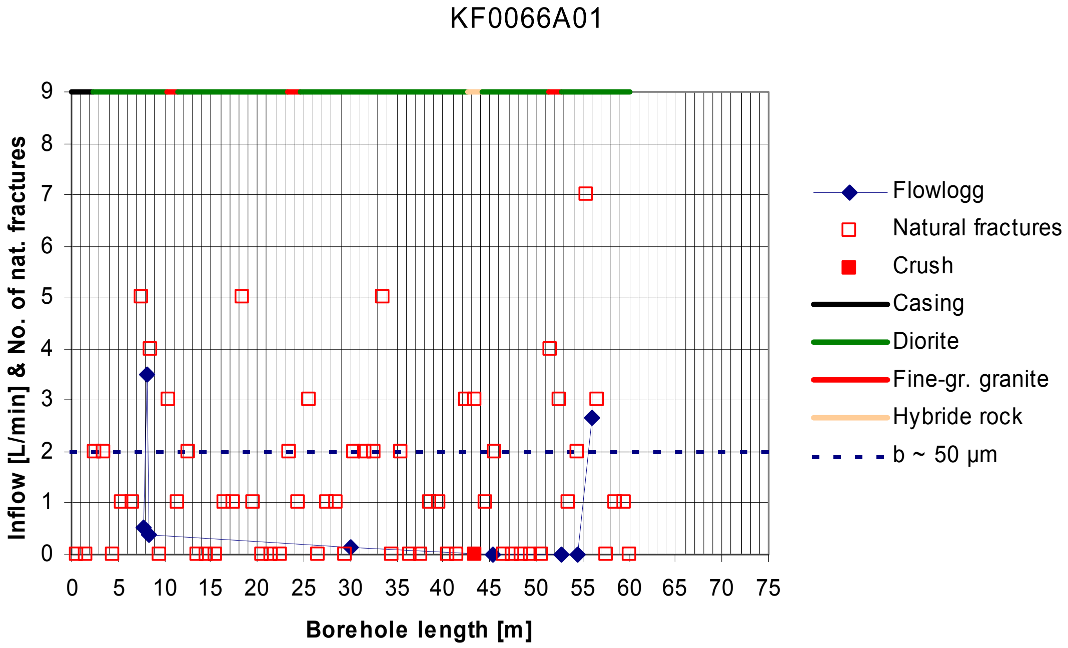

Figure 4.1 *Inflow (Posiva Flowlogg), number of natural fractures and rock type for KF0066A01. Borehole length: 60.11 m and lowest section of measurements (Posiva Flowlogg) ~58 m. Observe crushed rock at 43-44 m. An inflow of 2 L/min and a hydraulic head of 450 m give a hydraulic aperture of approximately 50 µm.*

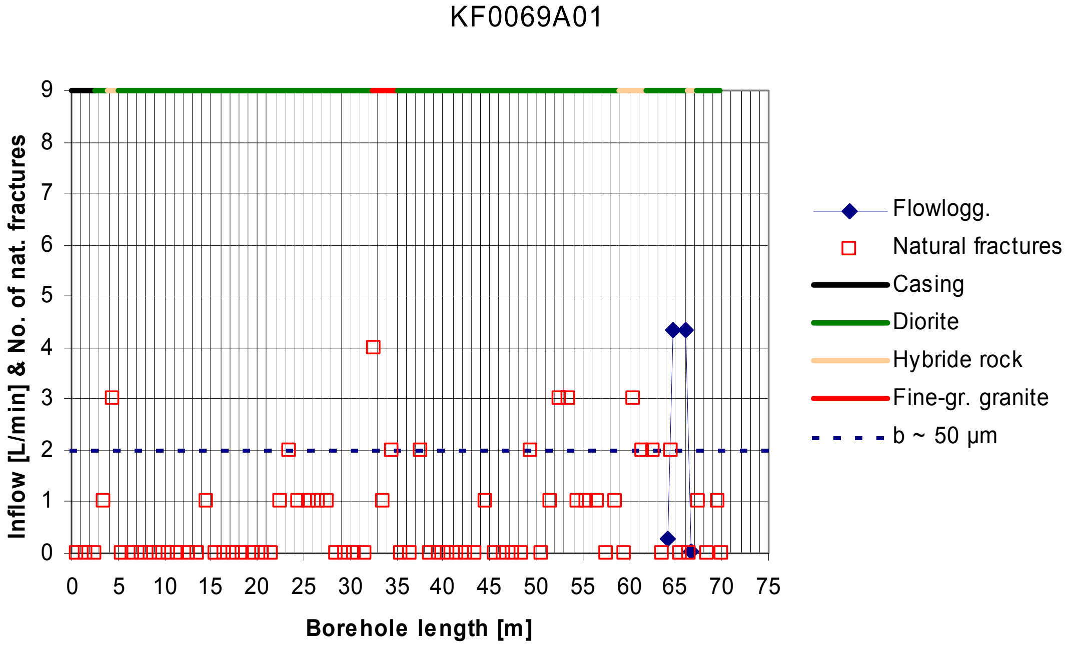

Figure 4.2 *Inflow (Posiva Flowlogg), number of natural fractures and rock type for KF0069A01. Borehole length: 70.09 m and lowest section of measurements (Posiva Flowlogg) ~68 m. An inflow of 2 L/min and a hydraulic head of 450 m give a hydraulic aperture of approximately 50 µm.*

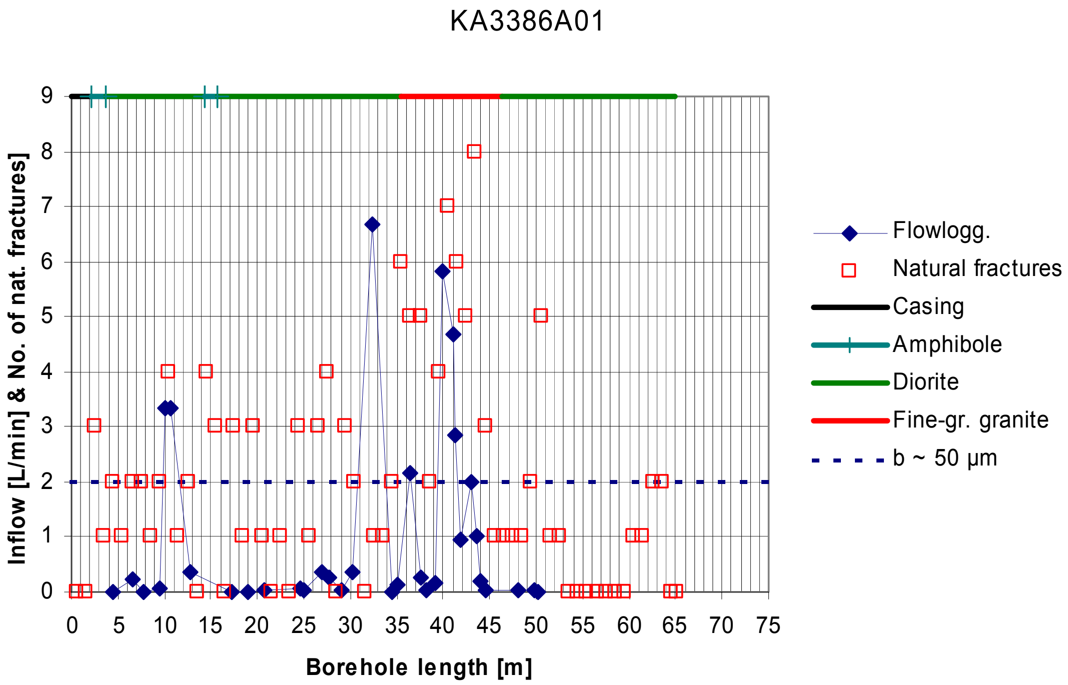

Figure 4.3 *Inflow (Posiva Flowlogg), number of natural fractures and rock type for KA3386A01. Borehole length: 65.11 m and lowest section of measurements (Posiva Flowlogg) ~63 m. The inflow exceeds 5 L/min at one or two locations see Table 4.1. An inflow of 2 L/min and a hydraulic head of 450 m give a hydraulic aperture of approximately 50 µm.*

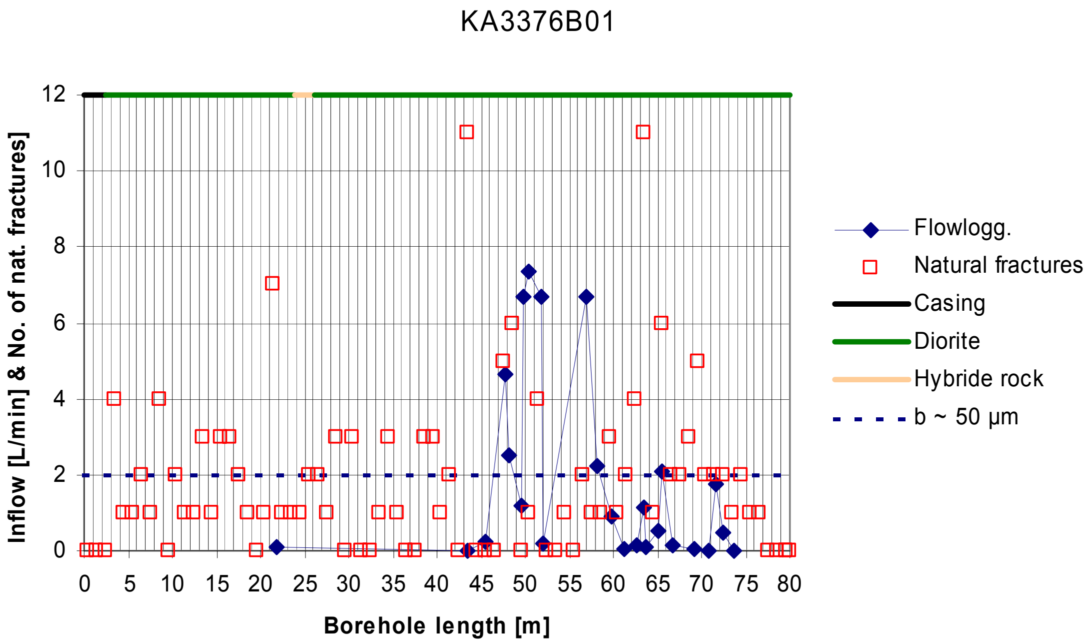

Figure 4.4 *Inflow (Posiva Flowlogg), number of natural fractures and rock type for KA3376B01. Borehole length: 80.19 m and lowest section of measurements (Posiva Flowlogg) ~78 m. The inflow exceeds 5 L/min at four locations see Table 4.1. An inflow of 2 L/min and a hydraulic head of 450 m give a hydraulic aperture of approximately 50 µm.*

One of the advantages related to the area investigated by KF0066A01 and KF0069A01 (referred to as Alternative 1) was that other boreholes in the area have indicated only few water conductive features. For Alternative 2, here investigated by borehole KA3386A01, the area was described as wet with a lot of water bearing features. These results were confirmed both by the accumulated inflow during drilling of the core boreholes and measurements performed using Posiva Flowlogg. Borehole KA3376B01 was found to have the largest total inflow.

When sealing of fractures is considered, fracture apertures of 50 to 100 µm are often referred to as the lower limit for what is groutable with cement grout. For a plane parallel fracture this would correspond to transmissivities of 7.9E-8 m^2/s and 6.3E-7 m^2/s respectively (cubic law, Equation 1). Based on the lower of these transmissivities and the inflow and transmissivities presented in Appendix B only few of the fractures can possibly be groutable (as an approximation the ones having an inflow exceeding 120 L/h or 2 L/min, see dashed line in figures above). As presented in the figures, these fractures transmit the major part of the inflow. Figures above and the aperture 50 µm and the inflow of 2 L/min should be looked upon as guidance and not definite limits. It is particularly important to remember that the inflow depends upon both aperture and hydraulic head or pressure. The transmissivities and apertures used are estimated from Posiva Flowlogg data assuming steady state conditions and values for the hydraulic head (~450 m). Table 4.2 presents the summary of transmissivities obtained by Posiva Flowlogging (Appendix B) and, specific capacity and transmissivity evaluated from pressure build-up tests. Graphs (log-log and lin-log plots) for the pressure build-up tests are presented in Appendix C. The log-log plots for the boreholes KF0066A01 and KF0069A01 follow a slope greater than unity before the pressure starts to stabilise (a slope of 1:1 indicates an effect of wellbore storage). One possible explanation for this is a change in wellbore storage, which may occur when the compressibility of the fluid in the wellbore is not constant (Bourdet, 2002). In this case gas is most likely found in the two boreholes, with a faster change in pressure when the gas is dissolved in water. For borehole KF0069A01 a larger conductive feature is possibly found at a distance from the borehole (T~1.7E-6 m^2/s, see Appendix C). For borehole KA3386A01 the transmissivity based on the pressure build-up test was found to be equal to the specific capacity. One explanation when the specific capacity and the transmissivity deviate can be that the borehole intersects a high permeable fracture where the aperture is locally small. For KA3386A01 and KA3376B01, the small transmissivities when summing up individual values from Posiva Flowlogging is most likely due to the method not measuring inflows above 5 L/min correctly. The largest values presented in the normal probability plots of transmissivities along KA3386A01 and KA3376B01, which are identified and estimated from Posiva Flowlogg data (Figure 3.9 and Figure 3.12) are therefore likely to be underestimated. This would also give a better agreement between inflow during drilling and inflow measured by Posiva Flowlogg (Figure 3.7 and Figure 3.8). The summation of transmissivities when using specific capacities based on inflow when drilling for flows exceeding 5 L/min (Table 4.1) instead of the values obtained using Posiva flowlogg are presented within parentheses in Table 4.2. Inflow for KA3376B01 when considering the difference between Posiva flowlogg (Qacc: 45.9 L/min) and inflow during drilling (80 L/min) would be 77.5 L/min (45.9-27.4+59=77.5 L/min, Table 4.1), which is close to the 80 L/min measured during drilling. For KA3386A01 (Qacc: 35.4 L/min) a similar calculation would give approximately 59 L/min (35.4-6.7+30=58.7 L/min), which is within the 40-60 L/min measured during drilling.

Table 4.2 Summation of transmissivities from Posiva Flowlogging (PFL) and specific capacity and transmissivity evaluated from pressure build-up tests (PBT, Table 3.7 and Table 3.8). Qacc is the estimated accumulated inflow using PFL (each inflow <5 L/min) and Qtot is the total inflow measured from the borehole when performing the PFL.

Borehole	Test section, Secup (m)	Test section, Seclow (m)	Sum. Transmissivity (PFL) dh:~450 m (m^2/s)	Specific capacity (PBT) (m^2/s)	Transmissivity (PBT) (m^2/s)
KF0066A01	~2	60.11	2.6E-7 *PFL* *Qacc: 7.3 L/min** *(Qtot: 6.0 L/min)** *Drilling* *Q: 8-9 L/min*	4.2E-7 *Q: 6.3 L/min* *dh: 252 m*	- gas in borehole
KF0069A01	~2	70.09	3.2E-7 *PFL* *Qacc: 9.0 L/min* *(Qtot: 10.7 L/min)* *Drilling* *Q: 13 L/min*	3.5E-7 *Q: 8.5 L/min* *dh: 400 m*	- gas in borehole (1.7E-6, see Appendix C)
KA3386A01	~2	65.11	1.3E-6 (2.2E-6)** *PFL* *Qacc: 35.4 L/min* *(Qtot: 53 L/min tot)* *Drilling* *Q: 40-60 L/min*	3.4E-6 *Q: 44.1 L/min* *dh: 219 m*	3.4E-6
KA3376B01	~2-2.5	80.19	1.7E-6 (2.9E-6)** *PFL* *Qacc: 45.9 L/min* *(Qtot: 95 L/min)* *Drilling* *Q: 80 L/min*	4.7E-6 *Q: 96.3 L/min* *dh: 343 m*	1.5E-5

*Qacc larger than Qtot could be due to difficulties during flow measurement, small values uncertain. Borehole inclined upwards.

**Including inflows larger than 5 L/min based on inflow during drilling (Table 4.1).

4.2 Pressure response during drilling, blasting and hydraulic tests

The influence of the four boreholes on the surroundings during drilling and hydraulic tests and effects related to test blasting are investigated by compiling and comparing pressure responses in a number of selected boreholes. Selected boreholes are located at the Prototype and TRUE Block scale experiment sites and since experiments sensitive to pressure changes will also be performed at the LTDE-site and in the TASF-tunnel (Matrix Fluid Chemistry), boreholes at these locations are also included. Compiled data should be used by those involved in other experiments to evaluate whether pressure responses are acceptable when considering their future work. During blasting, investigating that the hydro monitoring system is not damaged is of main importance.

Pressure responses during drilling, pressure build-up tests and blasting were investigated and approximate magnitude of responses during drilling and pressure build-up tests are presented in Table 4.3 and Table 4.4. During drilling and the pressure build-up test in borehole KA3376B01 other activities such as e.g. water sampling disturbed the pressure responses. For this reason, flowing of the borehole for 24 hours was performed a second time (PBT2).

Table 4.3 includes three columns representing boreholes KF0069A01, KF0066A01 and KA3386A01 and 12 rows showing the boreholes where responses were investigated. Responses exceeding 10 kPa are written in bold. For these boreholes responses where seen both when drilling (D) and during pressure build-up tests (PBT). During drilling, important inflows are referred to by numbers (1) to (5) indicating inflow and depth for KF0069A01, KF0066A01 and KA3386A01 at the time when a response was seen see Table 4.3 and Figure 4.5. Observed responses due to pressure build-up tests are referred to by (R). It should be kept in mind that the duration of drilling and the inflow differ for the three boreholes and that the boreholes were also closed a number of times. Therefore the magnitude of the response during drilling should be looked upon as qualitative and not quantitative guidance. Pressure build-up tests were all performed for 24 hours, which makes a comparison more valuable. During blasting, none of the boreholes connected to the HMS system automatically initiated a detailed scanning. Based on this, the measured change in pressure did not exceed 2 kPa. Observe the amounts of explosive (Table 3.12) since they are fairly small.

During drilling of KF0066A01, KF0069A01 and KA3386A01, changes in pressure were identified at the LTDE/TRUE-1 sites. This is likely to be due to other activities (pressure build-up tests in KA2865A01 and packer release in the LTDE area) since hardly any changes in pressure were seen during the pressure build-up tests (see, Figure 3.13 and Figure 3.19).

Based on Table 4.3, only minor responses were seen when drilling and performing pressure build-up tests in borehole KF0069A01. For borehole KF0066A01 responses are identified in KA2598A when drilling, this is likely to be the result of the intersection of some kind of water-bearing feature at approximately 8 m (2). Difficulties in separating the response due to inflow at approximately 8 m (2) and 56 m are the reason why (3)? was used in the table. Smaller responses when drilling are also seen for KA3385A and KA2511A. Responses are seen when drilling and testing borehole KF0066A01 therefore indicates a NW trending water-bearing feature (A? in Figure 4.5). KF0051A, which is the site of the Matrix Fluid Chemistry experiment and located close to boreholes KF0066A01 and KF0069A01 have only small (if any) changes in pressure.

Table 4.3 Pressure response during drilling (D) and pressure build-up test (PBT) for boreholes KF0069A01, KF0066A01 and KA3386A01. During drilling, pressure response is related to possible inflow and its location along the boreholes (1) – (5). (R) describes identified responses during pressure build-up tests. Boreholes are shown in Figure 4.5.

	KF0069A01 *Drilling* *(1) Q~0-10 L/min (~65 m)* *Pressure build-up test* *(R) Q~8.5 L/min*	KF0066A01 *Drilling* *(2) Q~0-6 L/min (~8 m)* *(3) Q~5-9 L/min (~56 m)* *Pressure build-up test* *(R) Q~6.3 L/min*	KA3386A01 *Drilling* *(4) Q~0-11 L/min (~11 m)* *(5) Q~13-43 L/min (>33 m)* *Pressure build-up test* *(R) Q~44.1 L/min*
LTDE/TRUE-1			
KXTT4	D: other activities* PBT: < 2 kPa	D: other activities* PBT: < 2 kPa	D: other activities* PBT: < 2 kPa
KA3067A	D: other activities* PBT: < 2 kPa	D: other activities* PBT: < 2 kPa	D: other activities* PBT: < 2 kPa
KA3010A	D: other activities* PBT: < 2 kPa	D: other activities* PBT: < 2 kPa	D: other activities* PBT: < 2 kPa
North of access tunnel			
KA2598A	D: ~7 kPa, *(1)* PBT: ~3 kPa *(R?)*	**D: ~34 kPa, *(2) & (3)?*** **PBT: ~19 kPa *(R)***	**D: ~155 kPa, *(4) & (5)?*** **PBT: ~90 kPa *(R)***
KF0051A	D: ~1 kPa PBT: ~1 kPa	D: ~1 kPa PBT: ~1 kPa	D: ~1 kPa PBT: ~1 kPa
KG0021A01	D: ~2 kPa PBT: ~2 kPa	D: ~7 kPa *(2)? & (3)?* PBT: ~3 kPa	**D: ~45 kPa, *(5)*** **PBT: ~41 kPa *(R)***
KG0048A01	D: ~3 kPa PBT: ~2 kPa	D: ~7 kPa *(2)? & (3)?* PBT: ~4 kPa	**D: ~48 kPa, *(5)*** **PBT: ~44 kPa *(R)***
South of access tunnel			
KA2511A	D: ~5 kPa, *(1)* PBT: ~4 kPa	**D: ~8 kPa, *(2) & (3)?*** **PBT: ~12 kPa *(R)***	**D: ~60 kPa, *(4) & (5)?*** **PBT: ~31 kPa *(R)***
KA3385A	D: ~7 kPa, *(1)* PBT: ~4 kPa *(R?)*	**D: ~18 kPa, *(2) & (3)?*** **PBT: ~11 kPa *(R)***	**D: ~262 kPa, *(4) & (5)?*** **PBT: ~158 kPa *(R)***
KI0023B	D: ~3 kPa PBT: ~3 kPa	D: ~10 kPa PBT: ~2 kPa	**D: ~21 kPa, *(4) & (5)?*** **PBT: ~6 kPa *(R)***
KI0025F	D: ~2 kPa *(1)?* PBT: ~2 kPa	D: ~9 kPa *(2)? & (3)?* PBT: ~2 kPa	**D: ~25 kPa, *(4) & (5)?*** **PBT: ~9 kPa *(R)***
KA3600F	D: ~2 kPa *(1)?* PBT: ~2 kPa	D: ~4 kPa *(2)? & (3)?* PBT: ~2 kPa	**D: ~16 kPa, *(4) & (5)?*** **PBT: ~8 kPa *(R)***

*LTDE/TRUE-1 have been influenced by other activities than those investigated in this report.

The largest response during drilling and pressure build-up tests for borehole KA3386A01 is seen south of the access tunnel for KA3385A, which is found east of KA3386A01. The response during drilling is seen when intersecting a feature at approximately 11 m. Simultaneously a response is seen north of the access tunnel in KA2598A. Both responses indicate a NW trending water-bearing feature (A?). Responses are also seen in the TRUE Block Scale and Prototype area (boreholes KA2511A, KI0023B, KI0025F and KA3600F). The same boreholes that were influenced by drilling show responses during the pressure build-up tests. The pressure response in KA3385A as a result of the inflow of 44 L/min in KA3386A01 was approximately 260 kPa and for KA2598A approximately 90 kPa. The response in KA3600F, west of the access tunnel, was approximately 8 kPa. Boreholes KG0021A01 and KG0048A01 seem to be influenced when drilling the inner part of KA3386A01 (>33 m), see Figure 3.16 and

Figure ***3.17***. This could possibly be the result of another NW trending feature (B?). More definite orientations of these features are not known at this stage.

For pressure build-up tests in borehole KA3376B01 as well as in KA3386A01, the largest responses are seen in boreholes KA2598A and KA3385A. This confirms a connection such as A? (Figure 4.5) between the two boreholes. The inflow in borehole KA3376B01 is however twice the inflow in KA3386A01 and Table 4.5 shows the specific drawdown (dh/Q) estimated from the values presented in Table 4.4 to be used for comparisons.

Table 4.4 Pressure response due to pressure build-up tests (PBT) for boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01. Flow period: 24 hours.

	KF0069A01 *Q~8.5 L/min* [kPa]	KF0066A01 *Q~6.3 L/min* [kPa]	KA3386A01 *Q~44.1 L/min* [kPa]	KA3376B01 *Q~92 L/min* [kPa]
LTDE/TRUE-1				
KXTT4	< 2	< 2	< 2	~8
KA3067A	< 2	< 2	< 2	~3
KA3010A	< 2	< 2	< 2	~3
North of access tunnel				
KA2598A	~3	~19	~90	~146
KF0051A	< 2	< 2	< 2	< 2
KG0021A01	~2	~3	~41	~10
KG0048A01	~2	~4	~44	~5
South of access tunnel				
KA2511A	~4	~12	~31	~4
KA3385A	~4	~11	~158	~152
KI0023B	~3	~2	~6	~5
KI0025F	~2	~2	~9	~14
KA3600F	~2	~2	~8	~3

Table 4.5 Specific drawdown due to pressure build-up tests (PBT) for boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01.

	KF0069A01 dh/Q [s/m^2]	KF0066A01 dh/Q [s/m^2]	KA3386A01 dh/Q [s/m^2]	KA3376B01 dh/Q [s/m^2]
LTDE/TRUE-1				
KXTT4	-	-	-	532
KA3067A	-	-	-	199
KA3010A	-	-	-	199
North of access tunnel				
KA2598A	2159	18446	12482	9706
KF0051A	-	-	-	-
KG0021A01	1439	2912	5686	665
KG0048A01	1439	3883	6102	332
South of access tunnel				
KA2511A	2878	11650	4299	266
KA3385A	2878	10679	21913	10105
KI0023B	2159	1942	832	332
KI0025F	1439	1942	1248	931
KA3600F	1439	1942	1110	199

A comparison of specific drawdowns shows that the influence of borehole KA3386A01 is the largest when considering boreholes both north and south of the access tunnel. The LTDE/TRUE-1 area is influenced by KA3376B01 but this may be a combination of disturbances from the test in KA3376B01 and other activities (see Figure 3.28 and Appendix E). Based on this, one may expect a future tunnel in the areas of KA3376B01 and KA3386A01 to have a larger influence on ongoing experiments than Alternative 1 (KF0066A01 and KF0069A01). Further, Alternative 3 (KA3376B01) have less influence on the Prototype and TRUE Block scale sites than Alternative 2 (KA3386A01), which is in accordance with the most conductive features trending NW.

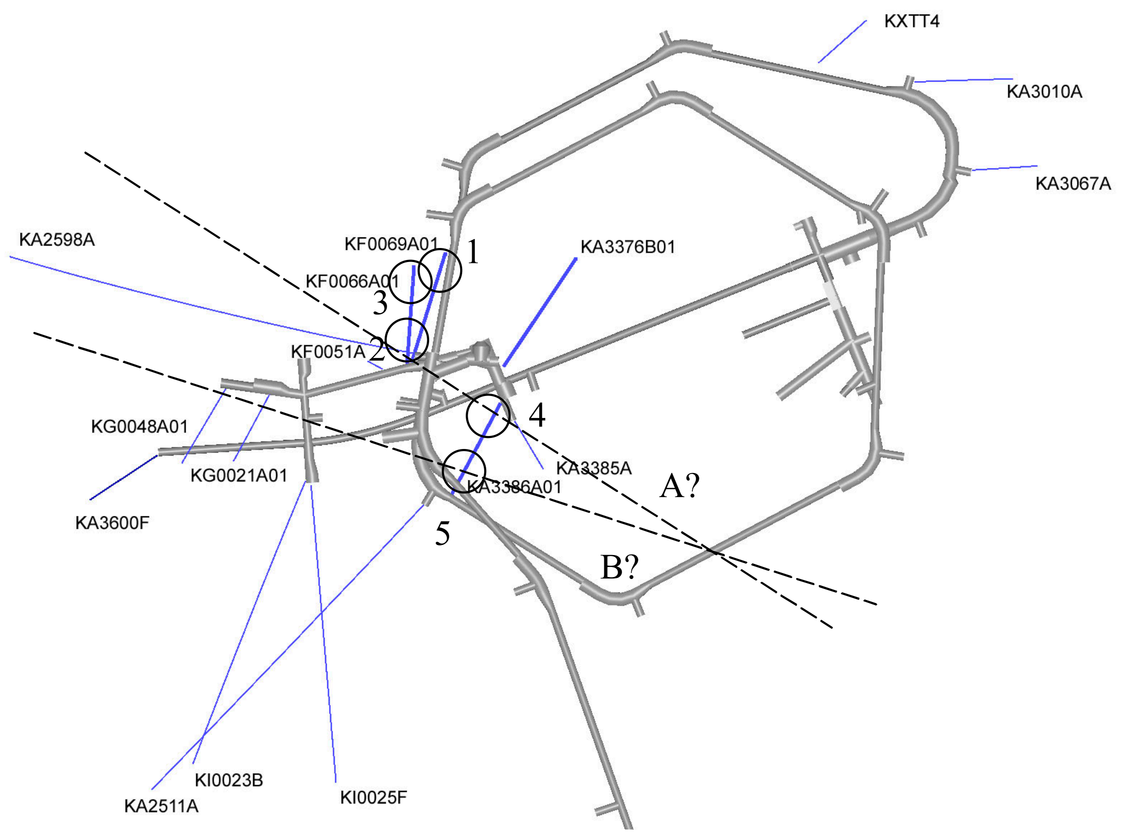

Figure 4.5 *Investigated boreholes and the approximate locations of larger inflows (1)-(5) along boreholes KF0069A01, KF0066A01 and KA3386A01. A? and B? represent possible NW trending water-bearing features based on pressure responses.*

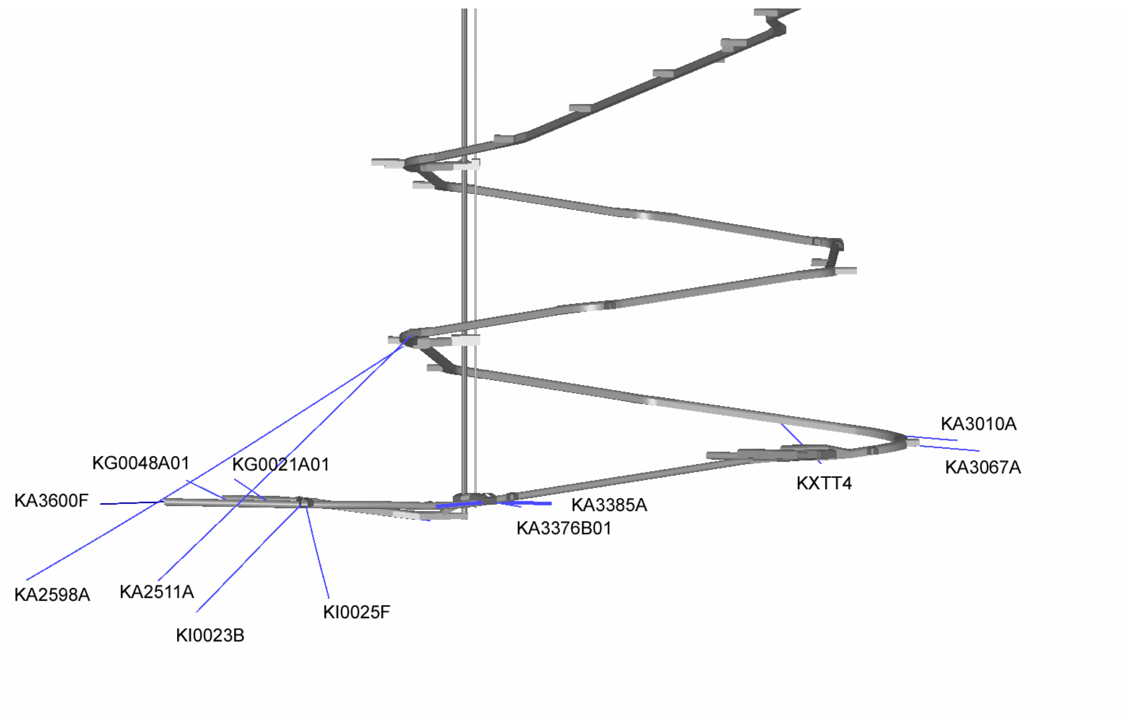

Figure 4.6 *Investigated boreholes (front, direction north).*

5 Conclusions

The hydrogeological investigations of core boreholes KF0066A01, KF0069A01, KA3386A01 and KA3376B01 aim at describing the boreholes to enable a more informed choice concerning the location of a new tunnel and a future grouting strategy. The influence of the boreholes on the surroundings during drilling, hydraulic tests and blasting was investigated by compiling and comparing pressure responses in 12 boreholes within the Prototype Repository, TRUE Block Scale and LTDE areas (during blasting more extensive investigations where made). Compiled data should be used by those involved in the experiments to evaluate whether pressure responses are acceptable when considering their future work. During blasting, investigating that the hydro monitoring system was not damaged was of importance.

Earlier investigations indicate that the area north of the access tunnel where KF0066A01 and KF0069A01 were drilled has only few water conductive features (the maximum estimated hydraulic aperture based on Posiva flowlogg for the two boreholes is here ~55-60 µm), whereas the area intersected by borehole KA3386A01 was described as wet with a lot of water bearing features. This was confirmed by this study. Assuming that the transmissivities obtained by Posiva flowlogging originate from individual fractures, the estimated mean (Log10) apertures would be approximately 20, 30, 20 and 30 µm for KF0066A01, KF0069A01, KA3386A01 and KA3376B01 respectively. The largest measurable inflow using Posiva flowlogg is 5 L/min which for one fracture at this depth would correspond to a hydraulic aperture of ~65 µm. The most conductive features of KA3386A01 are found between approximately 30 and 45 m depth (two flow anomalies >5 L/min, where the maximum estimated hydraulic aperture based on actual inflow during drilling would be ~120 µm assuming a hydraulic head of 450 m, see Table 4.1). Borehole KA3376B01 drilled in the same orientation as KA3386B01 but north of the access tunnel had the largest total inflow. The most conductive features of KA3376B01 are found between 49-50 m and at 57 m (four flow anomalies >5 L/min, maximum estimated hydraulic aperture based on actual inflow during drilling would be ~120 µm assuming a hydraulic head of 450 m, see Table 4.1). Due to the high hydraulic head, estimated fracture apertures are generally small even though inflows are significant. Consequently, future grouting is likely to demand several boreholes to be able to penetrate and seal these fractures, which as indicated by these investigations, have small apertures. Here, all apertures estimated from Posiva flowlogg assume a hydraulic head approximately equal to the depth of the boreholes (dh~450 m). Using the hydraulic head obtained from pressure build up tests would here generally result in an increase in aperture of approximately 10-20 %.

Comparatively small pressure responses were seen during drilling and pressure build-up tests for KF0066A01 and KF0069A01 (20 kPa in KA2598A during pressure build-up test in KF0066A01, inflow ~6 L/min and flow-period ~24 hours). Borehole KA3386A01 seem to be hydraulically connected to water bearing features which are possibly NW trending and which would therefore intersect the access tunnel (TASA), the F-tunnel (TASF) and possibly also the G-tunnel (TASG) (pressure response during pressure build-up test in KA3386A01 approximately 90 kPa for KA2598A and 160 kPa for KA3385A, inflow ~44 L/min). Due to other activities influencing the responses when drilling KA3376B01 and performing pressure build-up test, the borehole was left to flow a second time for 24 hours (PBT2). A possible feature connecting KA2598A and KA3385A is confirmed by investigations related to KA3376B01 (PBT2: inflow ~92 L/min) and responses in the two sections of KF0066A01 during drilling of this borehole show a better connection to the section closest to the tunnel. This is in agreement with the feature A? presented in Figure 4.5. The orientations of the features are indicated by the pressure responses and are therefore not certain. The LTDE/TRUE-1 sites do not seem to be influenced by drilling and pressure build-up tests for boreholes KF0066A01, KF0069A01 and KA3386A01. During blasting, none of the boreholes connected to the HMS system automatically initiated a detailed scanning, observe amounts of explosives in Table 3.12. Based on this, the measured change in pressure did not exceed 2 kPa. For KA3376B01 small pressure responses are seen in the LTDE/TRUE-1 area (3-8 kPa) during the second pressure build-up test.

Considering the above, one may expect a future tunnel south of the access tunnel (Alternative 2, KA3386A01) to have a larger influence on ongoing experiments than Alternative 1 (KF0066A01 and KF0069A01). Further, Alternative 3 (KA3376B01) have less influence on the Prototype and TRUE Block scale sites than Alternative 2 which is in agreement with the most conductive features trending NW. It is of importance that those responsible for experiments evaluate whether the pressure responses presented herein are acceptable. These responses are likely to increase slightly for a borehole open for a longer duration since the change in pressure commonly is faster in the initial stage of a test to become slower later on. It should be taken into consideration that inflows into a future tunnel might be larger and found at other locations along the borehole than indicated by this study (e.g. if the investigated borehole intersects a fracture at a locally small aperture). To decrease the risk of influencing other experiments, the tunnel work should be organised so that as stable conditions as possible are continually kept, particularly if more sensitive work is performed such as monitoring of pressure changes during, and soon after, back-filling of the Prototype repository etc.

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Appendices

Appendix A Core boreholes

KF0066A01, 2002-05-30 10:00:00 (drilling)

Length (m)	Bearing (degrees)	Inclination (degrees)	Bearing Err (degrees)	Inclination Err (degrees)
0.00	15.9764	0.5089	0.2000	0.2000

KF0069A01, 2002-05-17 10:15:00 (drilling)

Length (m)	Bearing (degrees)	Inclination (degrees)	Bearing Err (degrees)	Inclination Err (degrees)
0.00	28.8710	-1.7559	0.2000	0.2000

KA3386A01, 2002-06-10 14:20:00 (drilling)

Length (m)	Bearing (degrees)	Inclination (degrees)	Bearing Err (degrees)	Inclination Err (degrees)
0.00	219.9344	-1.9507	0.2000	0.2000

KA3376B01, 2002-11-27 08:30:00 (drilling)

Length (m)	Bearing (degrees)	Inclination (degrees)	Bearing Err (degrees)	Inclination Err (degrees)
0.00	45.5362	-0.8962	0.0200	0.0200

Appendix B Results from Posiva Flowlogg

KA3386A01

Depth(m)	Flow(ml/h)	Elevation(m)	Transmissivity (m2/s)	
50.2	120	-448	7.36E-11	*
49.9	2100	-448	1.29E-09	
48	2000	-448	1.23E-09	
44.6	1300	-448	7.97E-10	
43.9	12000	-448	7.36E-09	*
43.6	60000	-448	3.68E-08	
43.1	120000	-448	7.36E-08	
41.9	56000	-448	3.43E-08	
41.2	170000	-448	1.04E-07	*
41	280000	-448	1.72E-07	
40	350000	-448	2.15E-07	*
39.2	9500	-448	5.83E-09	
38.1	2500	-448	1.53E-09	*
37.6	15000	-447	9.22E-09	
36.4	130000	-447	7.99E-08	
35.1	8100	-447	4.98E-09	
34.4	500	-447	3.07E-10	*
32.4	400000	-447	2.46E-07	*
30.3	21000	-447	1.29E-08	
29	1300	-447	7.99E-10	*
27.7	15000	-447	9.22E-09	
27	21000	-447	1.29E-08	
25	1100	-447	6.76E-10	
24.6	4700	-447	2.89E-09	
20.7	1000	-447	6.15E-10	
19	570	-447	3.50E-10	
17.2	150	-447	9.22E-11	*
12.7	21000	-446	1.29E-08	
10.7	200000	-446	1.23E-07	
10.1	200000	-446	1.23E-07	
9.5	4500	-446	2.77E-09	
7.7	210	-446	1.29E-10	*
6.6	13000	-446	8.01E-09	
4.4	350	-446	2.16E-10	

* Flow rate uncertain

KF0066A01

Depth(m)	Flow(ml/h)	Elevation(m)	Transmissivity (m2/s)	
56.1	160000	-454	9.68E-08	
54.4	900	-454	5.45E-10	*
52.8	370	-454	2.24E-10	*
45.3	360	-454	2.18E-10	*
30.1	7900	-454	4.78E-09	
8.3	24000	-454	1.45E-08	*
8.1	210000	-454	1.27E-07	
7.7	32000	-454	1.94E-08	*

* Flow rate uncertain

KF0069A01

Depth(m)	Flow(ml/h)	Elevation(m)	Transmissivity (m2/s)	
66.70	1200	-457	7.21E-10	*
66.10	260000	-457	1.56E-07	
64.80	260000	-457	1.56E-07	
64.20	16000	-457	9.62E-09	

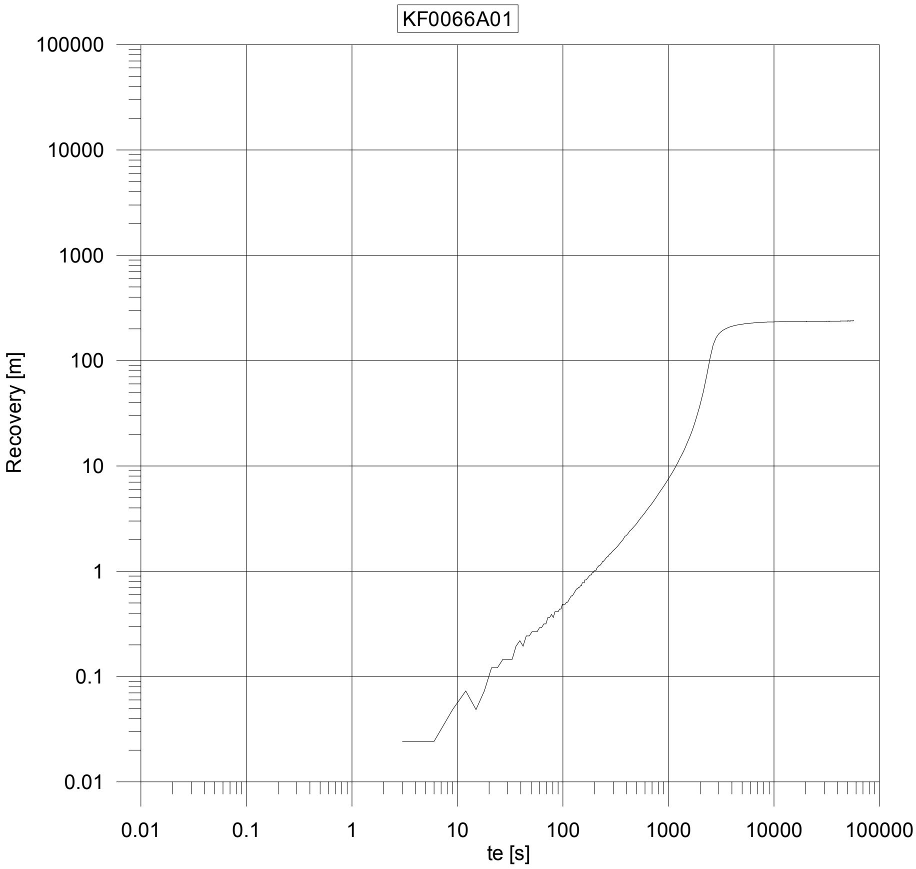
* Flow rate uncertain

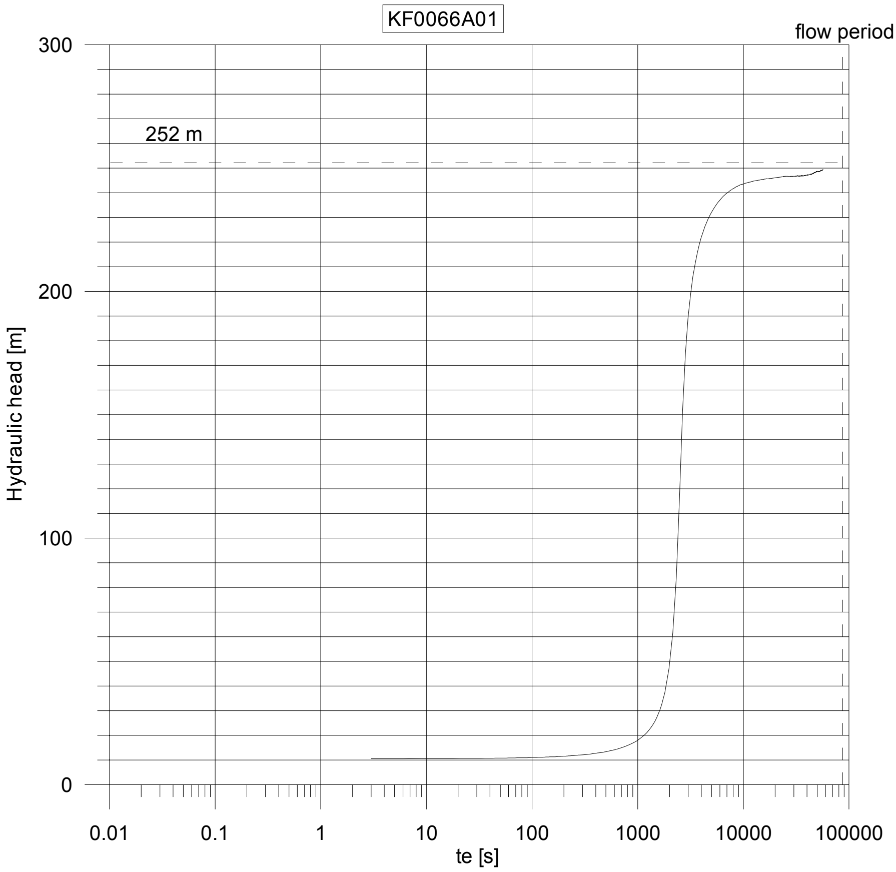
KA3376B01

Depth(m)	Flow(ml/h)	Elevation(m)	Transmissivity (m2/s)	
73.6	920	-450	5.6E-10	
72.4	29000	-450	1.8E-08	
71.7	105000	-450	6.4E-08	
70.8	1400	-450	8.5E-10	*
69.2	2800	-450	1.7E-09	
66.8	9000	-450	5.5E-09	
65.6	126000	-450	7.7E-08	
65.2	30000	-450	1.8E-08	
63.7	7000	-450	4.3E-09	*
63.4	68000	-450	4.2E-08	
62.6	9800	-450	6.0E-09	
61.2	2000	-450	1.2E-09	
59.8	54000	-450	3.3E-08	
58.2	134000	-450	8.2E-08	
57	400000	-450	2.4E-07	**
52.1	12000	-450	7.3E-09	*
51.8	400000	-450	2.4E-07	**
50.5	440000	-450	2.7E-07	**
49.8	400000	-450	2.4E-07	**
49.5	70000	-450	4.3E-08	*
48.2	150000	-450	9.2E-08	
47.7	280000	-450	1.7E-07	
45.6	14000	-450	8.5E-09	
43.4	1300	-450	7.9E-10	*
21.8	6800	-450	4.2E-09	

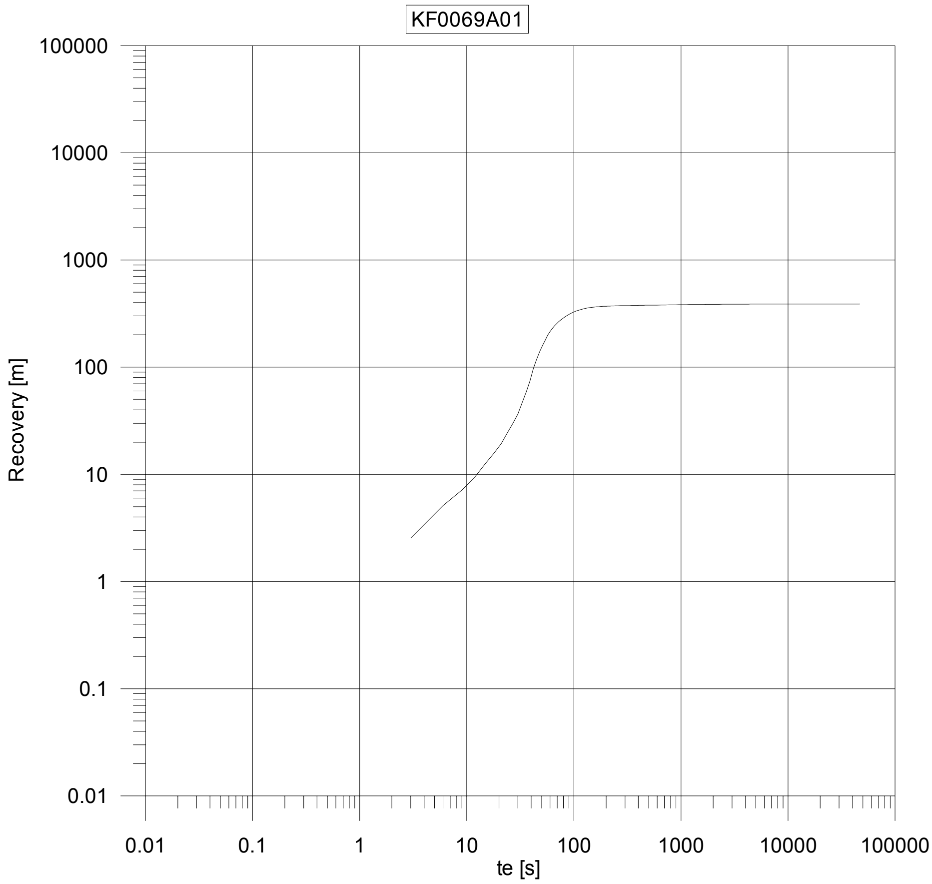
* Flow rate uncertain
** Upper limit of measurement exceeded, flow rate and transmissivity probably larger than specified value

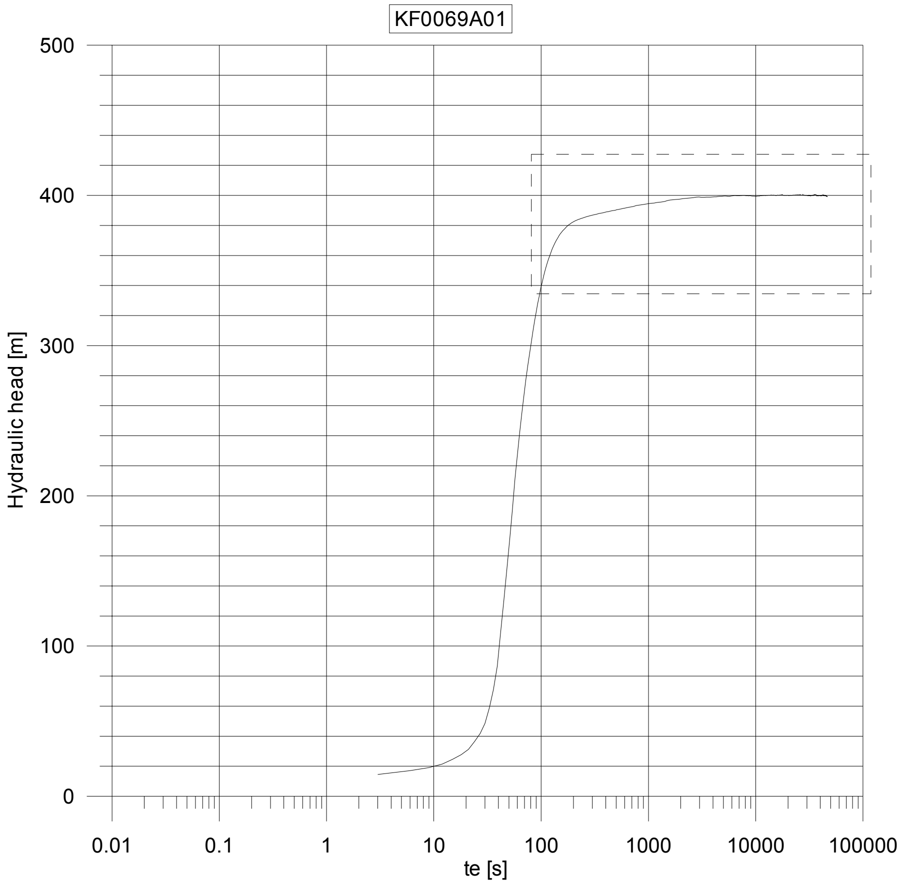
Appendix C Graphs: hydraulic tests

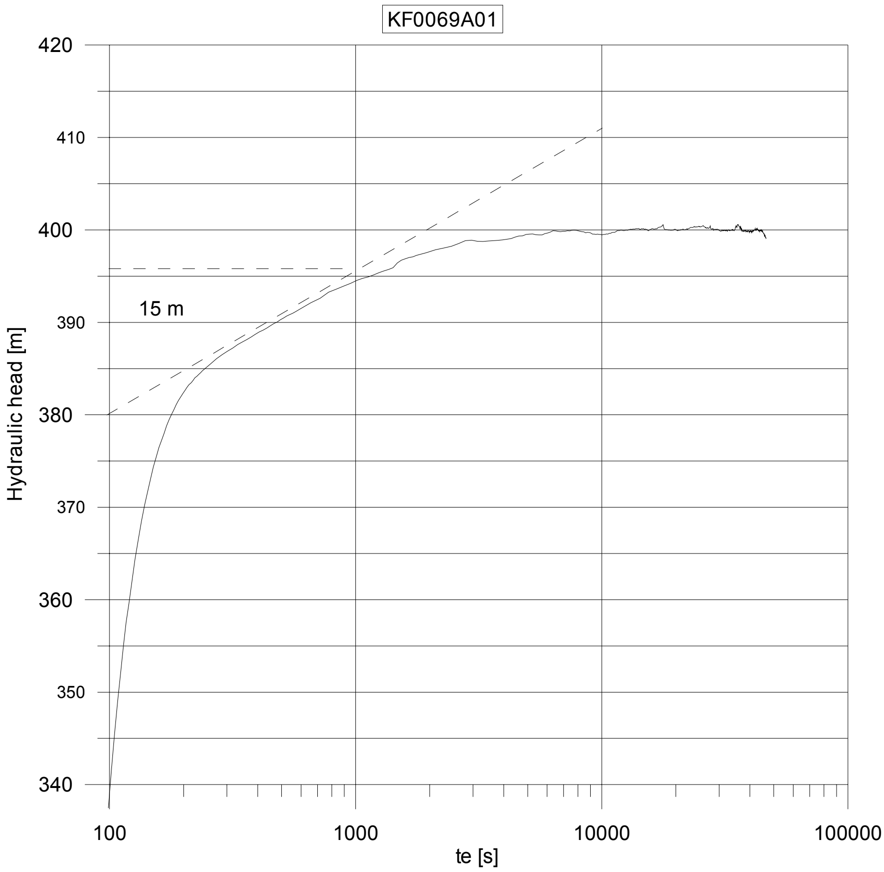




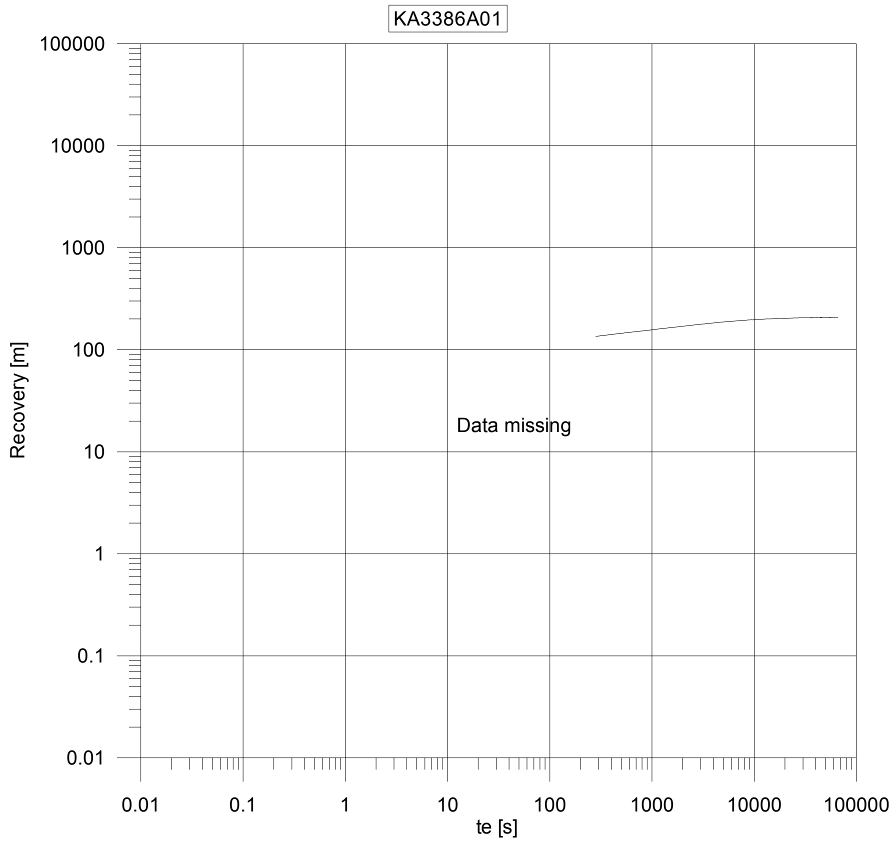
h(te = 86845 s) = 252 m

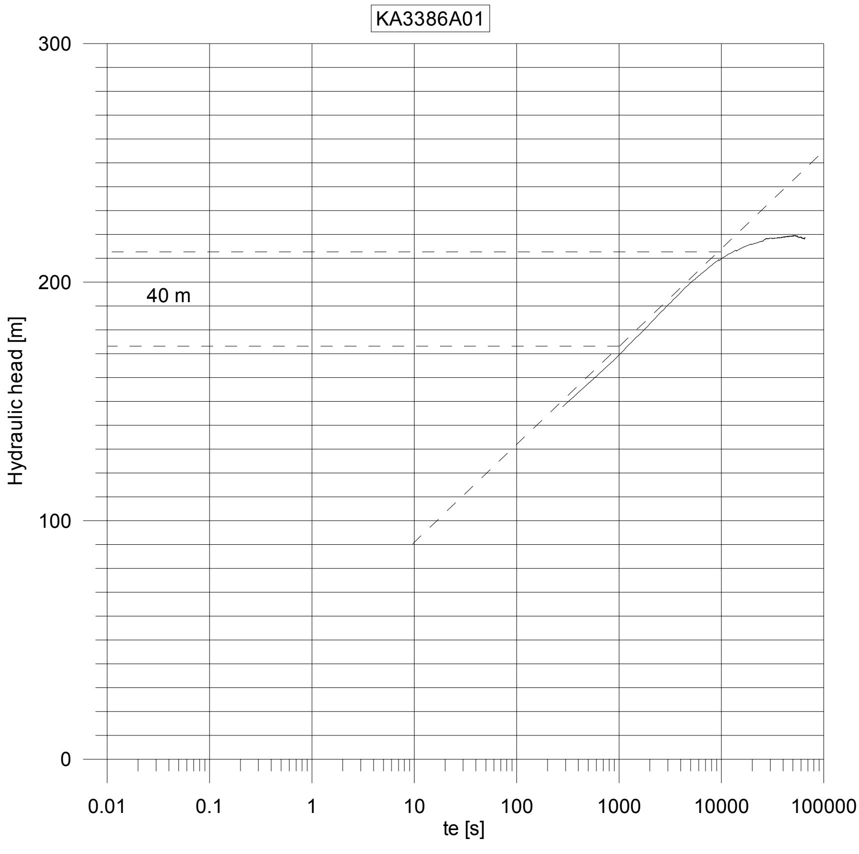

KF0069A01
Recovery [m]
100000
10000
1000
100
10
1
0.1
0.01
0.01
0.1
1
10
100
1000
10000
100000
te [s]


KF0069A01
Hydraulic head [m]
500
400
300
200
100
0
0.01
0.1
1
10
100
1000
10000
100000
te [s]

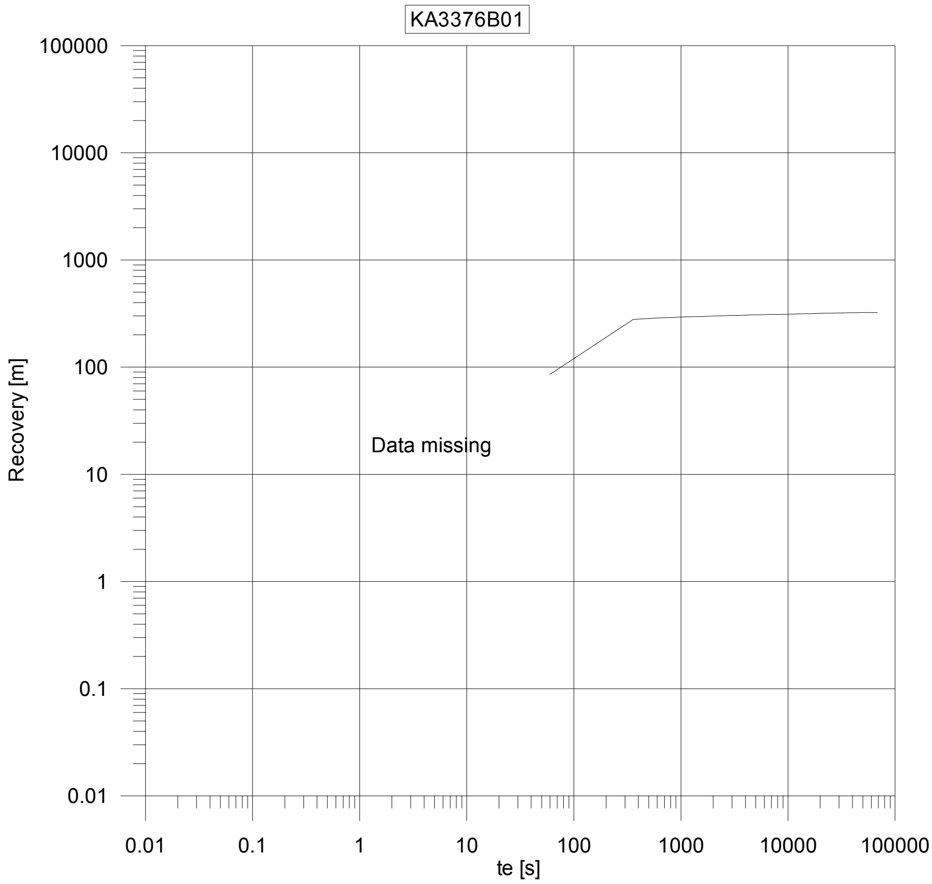


Q = 8.5 L/min = 1.42E-4 m^3/s
ds’’ = 15 m
T = 0.183*Q/ ds’’ = 1.7E-6 m^2/s
h(te = 86530 s) = 400 m

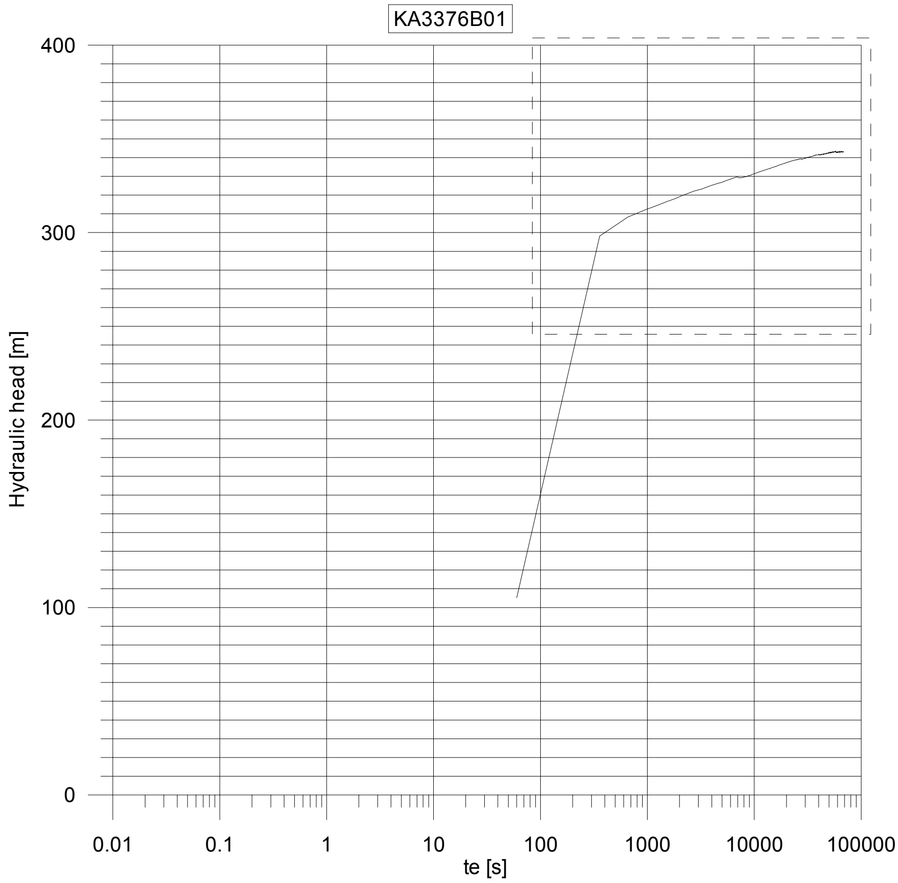




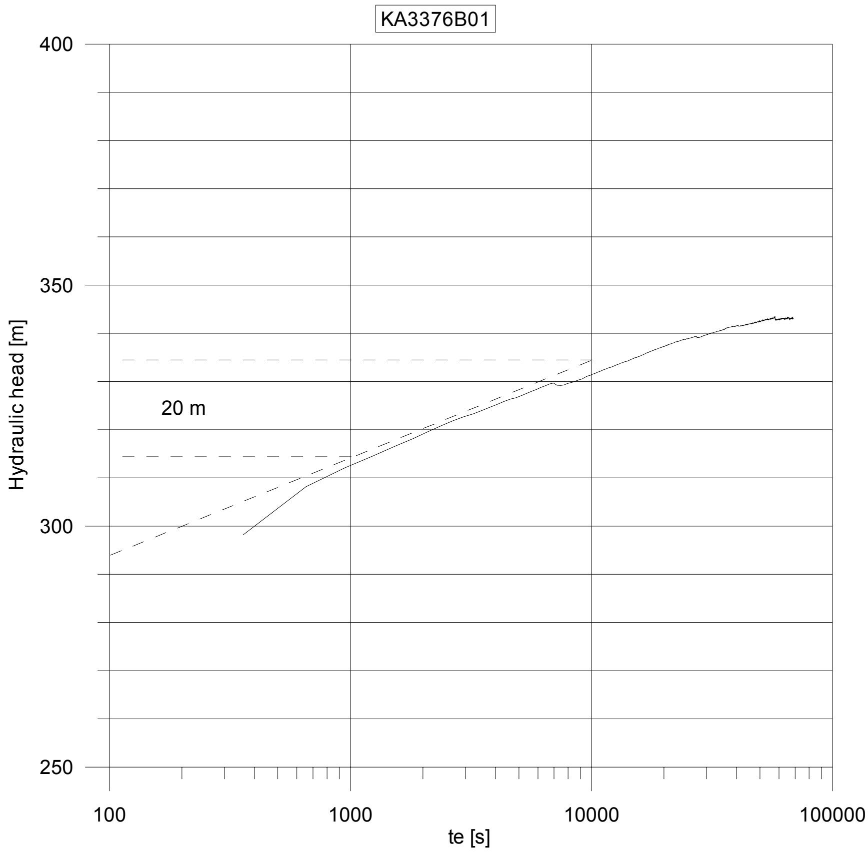
Q = 44.1 L/min = 7.35E-4 m^3/s
ds'' = 40 m
T = 0.183*Q/ ds'' = 3.4E-6 m^2/s
h(te = 86830 s) = 219 m



KA3376B01
100000
10000
1000
100
10
1
0.1
0.01
Recovery [m]
Data missing
0.01
0.1
1
10
100
1000
10000
100000
te [s]



KA3376B01
400
300
200
100
0
Hydraulic head [m]
0.01
0.1
1
10
100
1000
10000
100000
te [s]



Q = 96.3 L/min = 1.60E-3 m3/s
ds'' = 20 m
T = 0.183*Q/ ds'' = 1.47E-5 m2/s
h(te = 86221 s) = 343 m

Appendix D Additional boreholes for detailed scanning during blasting

KA3566G01
KA3566G02
KA3568D01
KA3572G01
KA3573A
KA3573C01
KA3574D01
KA3574G01
KA3576G01
KA3578C01
KA3578G01
KA3578H01
KA3579D01
KA3579G
KA3584G01
KA3588C01
KA3588D01
KA3588I01
KA3590G01
KA3590G02
KA3592C01
KA3593G
KA3597D01
KA3597H01
KA3600F

Appendix E Pressure responses during Posiva Flowlogging and Pressure build-up test (PBT2) in borehole KA3376B01