P-05-167

Oskarshamn site investigation

Drilling of cored borehole KLX03

Henrik Ask, H Ask Geokonsult AB

Mansueto Morosini, Lars-Erik Samuelsson
Svensk Kärnbränslehantering AB

Liselotte Ekström, Studsvik RadWaste AB

Nils Håkanson, HCC- Håkanson Coring Consultants

July 2005

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

Abstract

Borehole KLX03 is located in the Laxemar subarea. Drilling was made between May and September 2004 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden.

The hole was core drilled to a depth of 1,000.42 m with 76 mm equipment. The uppermost section, to a depth of 100.35 m, was constructed as a telescopic section with an inner diameter of 200 mm.

A water inflow of 47 litres per minute was estimated over the whole length of the telescopic section during percussion drilling.

Pumping tests were performed with wireline equipment, typically with one hundred metres intervals. The resulting transmissivities (T_M) varied between 2.7×10^{-7} and 1.3×10^{-5} m^2/s. The most transmissive section was between 103 and 218 m.

Continuous monitoring of drilling parameters and flushing water parameters with the drilling monitoring system was conducted throughout the core drilling phase.

Water sampling for chemical analysis were collected during drilling. Four samples were collected from the core drilling phase. One of the four samples had a too high drilling water content to ensure accurate results.

An airlift pumping test in the telescopic section performed when the cored hole was drilled to its full length gave a transmissivity (T_M) of 2.8×10^{-5} m^2/s.

The upper 620 m were dominated by Ävrö granite with minor sections of diorite/gabbro. Below 620 m the core consists mainly of quartz monzodiorite with intercalations of fine-grained diorite-gabbro, fine-grained granite and fine-grained dioritoide.

Oxidation occurs sporadically in the core, other types of alterations have also been noted. Saussuritization ie alteration of calcic plagioglase feldspar, with faint to medium intensity is common between 650 and 830 m.

The distribution of total fractures in the core is rather homogeneous with a frequency of 0–10 (fractures/m) in the Ävrö granite and slightly higher, ca 5–15, in the quartz monzodiorite.

Sammanfattning

Borrhål KLX03 ligger inom delområde Laxemar. Borrningen utfördes mellan maj och september 2004 som ett led i platsundersökningen för ett möjligt djupförvar för utbränt kärnbränsle i Oskarshamns kommun.

Hålet kärnborrades med 76 mm utrustning till 1 000,42 m borrad längd. Den övre delen av hålet, från markytan till 100,35 m, utfördes som en teleskopdel med ca 200 mm inre diameter.

Ett vatteninflöde på 47 liter per minut uppskattades över hela teleskopdelen vid hammarborrningen.

Pumptester med wireline-baserad mätutrustning utfördes normalt var hundrade meter. Uppmätta transmissiviteter (T_M) varierade mellan $2{,}7\times10^{-7}$ och $1{,}3\times10^{-5}$ m^2/s. Den mest transmissiva sektionen var mellan 103 och 218 m.

Kontinuerliga mätningar av borrningsparametrar och spolvattenparametrar via DMS (drilling monitoring system) gjordes under hela kärnborrningsfasen.

Vattenprovtagning för kemisk analysering genomfördes i samband med borrning, där fyra prov togs under kärnborrningsfasen. Ett prov, av de fyra tagna, hade ett för högt spolvatteninnehåll för att ge tillförlitliga resultat.

En mammutpumpning i teleskopdelen som gjordes när kärnborrningen utförts till full längd gav en transmissivitet (T_M) på $2{,}8\times10^{-5}$ m^2/s.

De övre 620 metrarna domineras av Ävrögranit med mindre inslag av diorit/gabbro. Under 620 m består kärnan huvudsakligen av kvartsmonzodiorit med inslag av finkornig diorit-gabbro, finkornig granit och finkornig dioritoid.

Oxidering förekommer sporadiskt längs borrhålet och andra typer av omvandling har också noterats. Saussuritisering, dvs omvandling av kalcium-rik plagioklasfältspat, med obetydlig till medelhög intensitet är vanlig mellan 650 och 830 m.

Fördelningen av totala sprickor är ganska homogen i kärnan med en frekvens på 0–10 (sprickor/m) i Ävrögraniten och något högre, ca 5–15 i kvartsmonzodioriten.

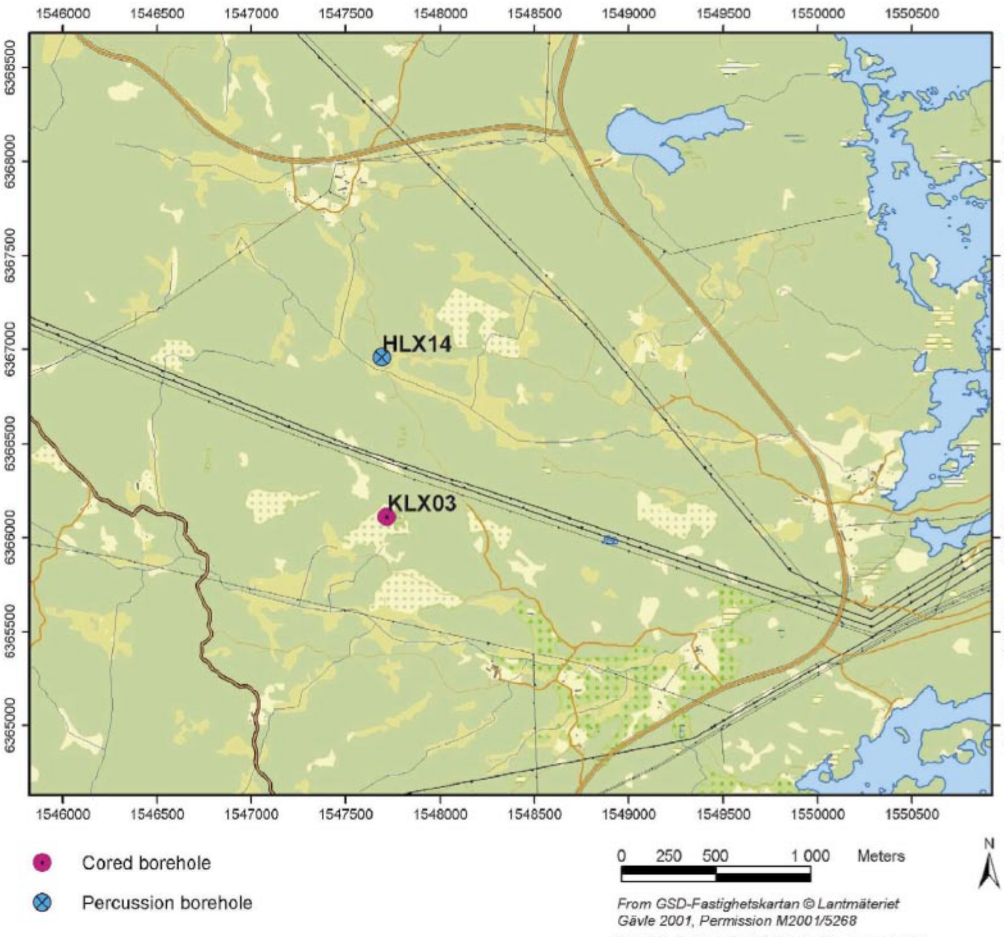
Contents

1 Introduction

SKB, the Swedish Nuclear Fuel & Waste Management Company, performs site investigations in order to evaluate the feasibility of locating a deep repository for spent nuclear fuel /1/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. Borehole KLX03 is located in the Laxemar subarea of the investigation area in Oskarshamn.

Drilling and investigations in boreholes are fundamental activities in order to facilitate characterisation of rock and groundwater properties at depth. KLX03 was the sixth deep cored borehole within the Oskarshamn site investigation. The location of the core drilled borehole, KLX03 and the water source, HLX14 in the Laxemar subarea is shown in Figure 1-1.

The drilling of KLX03 and all related on-site operations were performed according to a specific Activity Plan, which in turn refers to a number of method descriptions, see Table 1-1.



From GSD-Fastighetskartan © Lantmäteriet Gävle 2001, Permission M2001/5268

Swedish Nuclear Fuel & Waste Management Co
2005-06-22, 12:36

Figure 1-1. *Location of the cored borehole KLX03 the Laxemar subarea and percussion borehole HLX14.*

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	**Number**	**Version**
Kärnborrning KLX03	AP PS 400-04-008	1.0
Amendment for environmental wells SSM000017, SSM000019 and SSM000021	AP PS 400-04-008	
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	1.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	1.0
Metodbeskrivning för genomförande av hydrauliska enhålstrester	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning	SKB MD 640.001	1.0
Metodbeskrivning för pumptest, tryckmätning och vattenprovtagning i samband med wireline-borrning	SKB MD321.002	1.0
Mätsystembeskrivning för längdmarkering (spårfräsning)	SKB MD620.009	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruktion för användning av kemiska produkter och material vid borrning och undersökningar	SKB MD 600.006	1.0
Instruktion för borrplatsanläggning	SKB MD 600.005	1.0
Instruktion för spolvattenhantering	SKB MD 620.007	1.0
Instruktion för utsättning och inmätning av borrhål	SKB MD 600.002	1.0

The activity plans and method descriptions are SKB internal documents.

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of KLX03. A number of related activities, such as wireline hydraulic tests, water sampling and monitoring of drilling parameters that were performed in conjunction with drilling will also be reported here.

The main reasons for drilling borehole KLX03 was to gain geological information at depth of the central part of the Laxemar subarea and to facilitate further investigation at depth in the borehole. The decision to drill KLX03 is given in SKB id no 1020796.

The hole was constructed as a "telescope hole", which means that the upper, normally, 100 m section of the hole has a wider diameter than the deeper core drilled part of the hole.

A notification in accordance with the Environmental Code was issued to the regional authorities on 2003-05-21, SKB id no 1014488. Detailed information with borehole coordinates and specifications on return water handling was sent to the Regional Authorities on 2004-01-20, SKB id no 1021628.

3 Overview of the drilling method

3.1 The SKB telescope drilling method

In brief, the telescope drilling method is based on the construction of a larger diameter hole (200 mm diameter) to a length of normally 100 m followed by a cored section to full length. The larger diameter section can either be percussion drilled or reamed with a percussion bit after core drilling of a pilot hole.

The main purpose of the upper large diameter section is to improve the removal of water from the hole by air-lift pumping in order to minimize the intrusion of foreign substances (flushing water and cuttings) to the surrounding bedrock. It also enables the use of submersible pumps for tests and to facilitate the installation of multi-packer systems for ground water pressure recordings.

After drilling 0–100 m, equipment for air lift pumping is installed in the borehole. The air-lift pumping will create a pressure drawdown and help remove water and cuttings while core drilling between 100 m and 1,000 m, see Figure 3-1. The effect of drawdown is dependent on the depth and capacity of major groundwater conductors.

During the core drilling phase several measurements and sampling exercises are performed through the drilling monitoring system (DMS), wireline tests for hydraulic purposes and sampling for water chemistry.

After the core drilling is completed to full length, depth reference slots are reamed in the borehole wall and a conical guide of stainless steel is installed between the telescope part and the deeper core drilled part, see Figure 3-2.

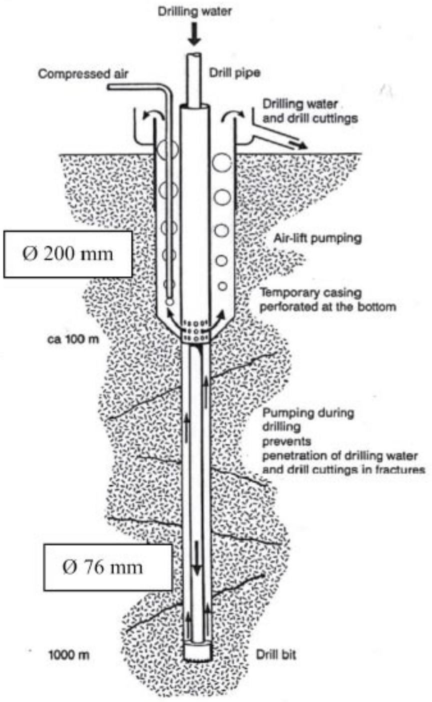


Figure 3-1. *A sketch of the telescopic drilling method with air-lift pumping for retrieval of drilling water and cuttings.*

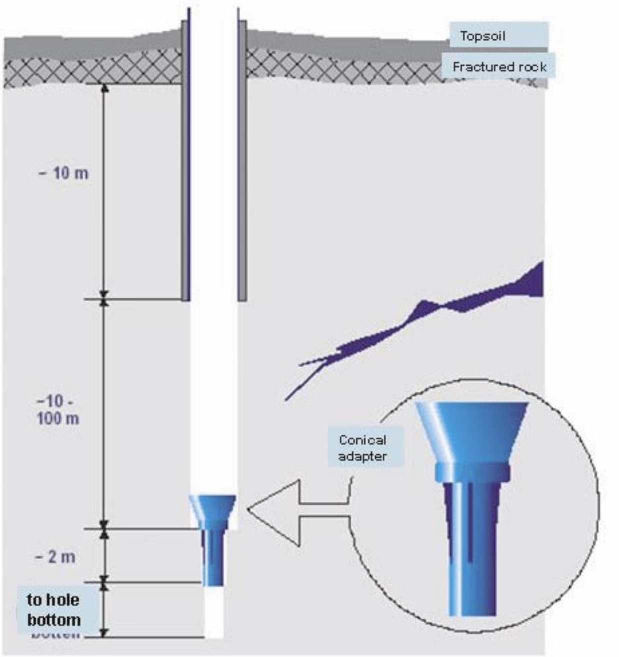


Figure 3-2. Installation of the conical guide.

3.1.1 The flushing water system

The handling of flushing water includes a source of water with a submersible pump, tanks and air-lift pumps for raising the water from the bottom of the telescope part to surface. The return water is led to settling containers before discharge, see Figure 3-3.

Nitrogen gas is bubbled through the drilling water to remove dissolved oxygen. This is done to avoid introduction of oxygen to the formation water and thereby disturbing the virgin chemical properties.

In order to monitor possible mixing of formation and drilling water, a tracer dye (uranine) is added to the drilling water to a fixed concentration, see Figure 3-4.

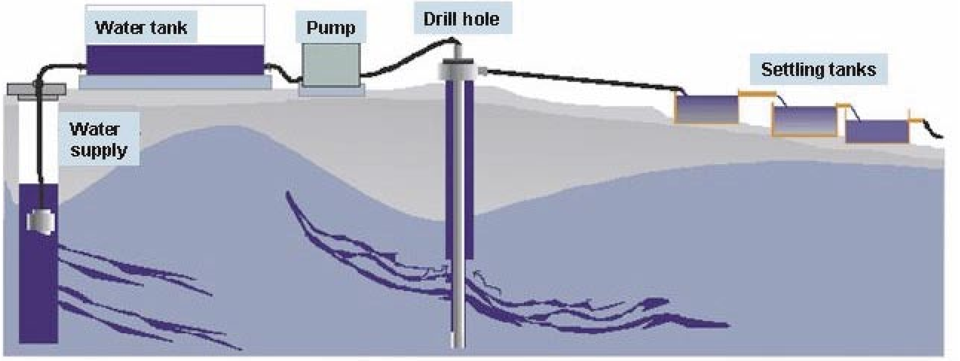


Figure 3-3. The flushing water system from source to discharge point.

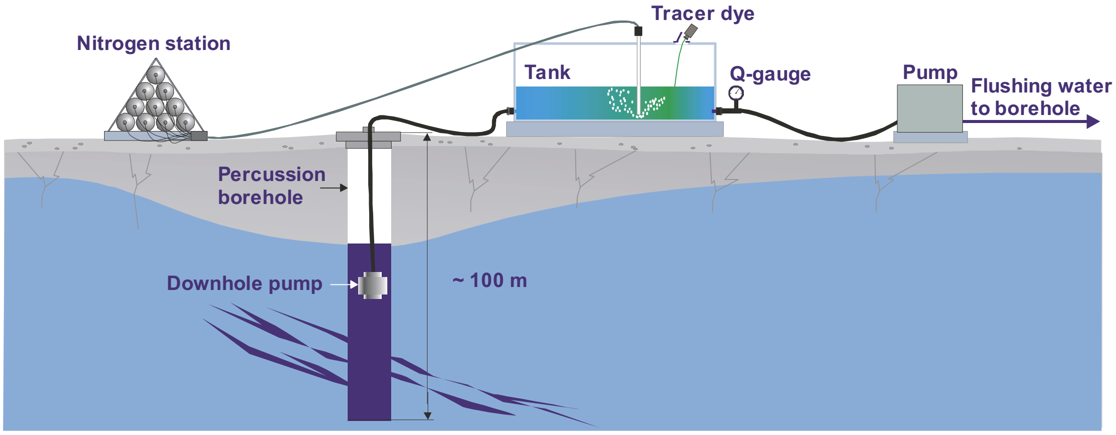


Figure 3-4. *Preparation of flushing water. Uranine is added to the water in the tank as a tracer dye. Nitrogen is bubbled through the water to remove dissolved oxygen.*

3.2 Measurements and sampling during drilling

3.2.1 Percussion drilling

Drill cuttings are collected manually during percussion drilling. The return water flow is measured and a sample is taken when noticeable changes in flow occur. The water colour is noted at the same time. The drill penetration rate is logged manually.

At the end of the percussion drilling phase, a recovery test is made by blowing compressed air to remove the water in the hole. The recovery of the water table is then measured manually.

3.2.2 Core drilling

The sampling and measurements during the core drilling phase of KLX03 consisted of:

- Wireline measurements.
- Air lift pumping and recovery tests.
- Water sampling at the surface.
- The drilling monitoring system.

Wireline measurements and water sampling

The measurements and the sampling are made in the borehole with a wire-line based equipment. The measurements for hydrogeological purposes include pumping tests and measurements of absolute pressure and are normally performed for every 100 m of drilled length. Sampling of water for chemical analysis is done in conjunction with the hydrogeological measurement where feasible. The wireline tests are done in accordance with SKB Method Description MB 321.002, SKB internal document.

Air lift pumping with evaluation of drawdown and/or recovery

Air lift pumpings with evaluation of drawdown and/or recovery are done with 300 m intervals, nominally at 400, 700 and 1,000 m length. The actual levels are adapted to when changes of drill bit, or some other reason to raise the drill stem, occur. The test cycle can include both the drawdown phase and the recovery phase, however normally the recovery phase would be used for evaluation.

- The test cycle is started with air-lift pumping in the telescopic section.
- Drilling or other related activities such as rinsing of drill cuttings can occur prior to lifting the stem. This means that an inflow of water through the drill stem can occur during the initial stages of the test cycle.
- After the stem has been removed the air lift pumping continues between 30 minutes and one hour to achieve stable conditions.
- The air lift pumping is stopped.
- The recovery of the water table in the telescopic section is monitored.

Water sampling at the surface

Water samples of flushing and return water, ie the water entering and returning from the borehole at the surface, are taken at 10 to 20 m intervals of drilled length for analysis of drilling water content (percentage of water with uranine tracer content) and electrical conductivity.

Drilling monitoring system (DMS)

Drilling is monitored on-line by continuous registration of drill rig parameters (logged every centimetre of bit penetration) and flushing water parameters (logged every 10 seconds). The data is compiled into a database called drilling monitoring system (DMS).

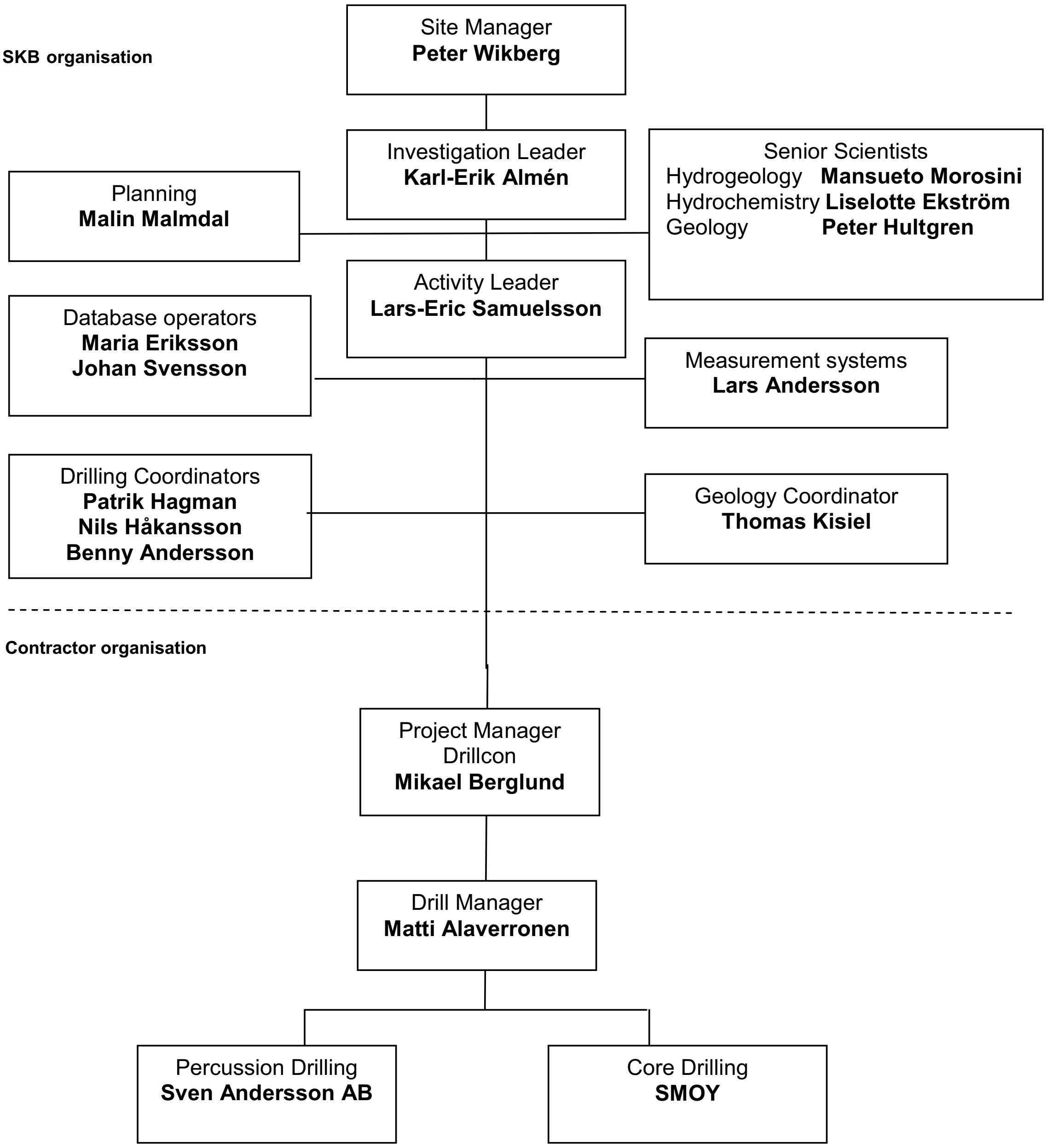
4 Contractors and equipment

4.1 Contractors

The main contractor for drilling was Drillcon Core AB, with subcontractor for core-drilling Suomen Malmi OY (SMOY) and subcontractor for percussion drilling Sven Andersson AB.

An overview of the organisation for the drilling activity is given in Table 4-1.

Table 4-1. Drill activity organisation.



4.2 Percussion drilling equipment

The equipment used was a Puntel MX1000 percussion drill rig with an Atlas Copco XRVS 455 Md air compressor. The down-the-hole hammer was a Secoroc 8" or 6" and the drill rods were Driqoneq 114 mm. The casing utilized was SS 2343 208×4 mm and 324×7 mm. The casing dimensions are presented as outer diameter and thickness.

4.3 Core drilling equipment

Core drilling in KLX03 was made with a B 20 P Atlas Copco fully hydraulic machine fitted with a modern and environmentally adapted diesel engine. The rods were of the type Corac N3/50 NT with a 76 mm wireline triple tube core barrel system which gives a core diameter of 50.1 mm.

Directional drilling was made with the Liwinstone tool for 76 mm boreholes. The tool consists of a set of rods that can create an angle between the bit and the drill stem and is entered into the borehole by the conventional method, ie not by wireline. The obtainable deviation varies between 0.1 to 0.3 degrees per drilled metre. The core barrel allows for up to 3 m of recovery. The recovered core has a diameter of 45 mm.

The working procedure for the directional tool is as follows:

- The Liwinstone tool is lowered into the borehole.
- The direction of the tool is adjusted by measurements with a Maxibor equipment.
- The directional rod surrounding the core barrel is fixed to the borehole wall by water pressure (20 bar).
- The rotation of the drill stem, core barrel and drill bit is started and a feed force applied. The outer directional rod does not rotate during drilling.

Figure 4-1. *The KLX03 drill site.*

4.3.1 Wireline measurements equipment

The wireline probe equipment has been developed by SKB. With this equipment water sampling, pump tests and measurements of absolute pressure in a borehole section can be made without having to lift the drill stem.

Measurements are made with a wireline probe as specified in method description SKB MD 321.002, SKB internal document.

The principal components are:

- an inflatable packer,
- a probe fitted with pressure gauges for the test section and for the packer,
- a water sampler,
- a submersible pump (placed in the upper part of the drill stem),
- a flow meter (placed at the ground surface).

The probe and packer are lowered through the drill stem into position at the drill bit. The test section is between the lower end of the packer and the bottom of the borehole, see Figure 4-2.

Before the pumping tests are made, measurements for absolute pressure and a leakage test of the drill string is done.

Hydraulic tests performed during drilling are generally affected to some degree by disturbances caused by the drilling operations. Transients from changes in pressure, temperature and salinity might affect the hydraulic response curves.

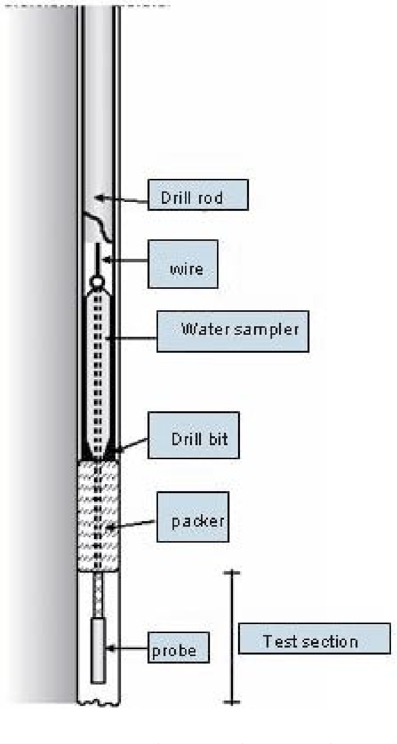


Figure 4-2. *The wireline probe and its emplacement in the hole.*

Pumping tests

The wireline probe is emplaced at the bottom of the drill stem. A submersible pump is lowered into the upper part of the drill stem at a length of about 40 m. The test section is hydraulically connected to the drill stem by opening a valve in the probe at a predetermined pressure. This creates a passage between the test section and the water column in the drill stem. The packer remains expanded during the entire test. Water is pumped from the drill stem and the pressure in the test section and packer are recorded in a data logger in the probe. The pumped surface flow rate is recorded to a data logger on the ground surface. The pressure transducer is situated 1.10 m below the lower end of the packer. The test consists of a pressure drawdown phase and a recovery phase. Typically the pumping time is three hours with a recovery phase of the same duration. However, the duration is sometimes adapted to the hydraulic situation of the tested section. The tests are normally carried out in sections of about 100 m length.

Water sampling

The equipment for water sampling is the same as for the pumping tests. The water volume in the section is removed at least three times by pumping water out of the drill stem. The water in the test section is then replaced by formation water and a sample is collected. The wireline probe, with a maximum sample volume of 5 litres, is subsequently brought to the surface.

Pumping tests and water sampling are normally performed as an integrated activity. The aim is to characterize the hydrochemistry as well as the hydrology in the bedrock when the conditions are least affected by hydraulic short circuiting in the borehole.

Absolute pressure measurement

The wireline probe is placed in position at the drill bit. The packer is inflated and the pressure build-up in the test section is recorded for a period of at least eight hours, typically this is done overnight. The measuring range for the pressure gauge is 0–20 MPa (± 0.05% FSD). The absolute pressure measurement is conducted if the flowrate during the pumping test exceeds 1 litre per minute.

4.3.2 Drilling monitoring system

During the core drilling phase continual monitoring was made of several measurement-while-drilling (MWD) parameters and flushing water parameters. The data is compiled into the DMS database.

The results presented in this report have been checked in accordance with a working routine for quality assurance of DMS data that have been in use since October 2003.

The drill rig (MWD) parameters include:

- Rotational pressure (bar).
- Bit force (kN).
- Flush water flow in (l/min).
- Water pressure at bit (kPa).
- Rotation (rpm).
- Penetration rate (cm/min).

The flushing water parameters include:

- Water level in the telescope part of the borehole (kPa).
- Oxygen level of flushing water (mg/l).
- Flow of flushing (ingoing) and return (outgoing) water (l/min).
- Electrical conductivity of flushing and return water (mS/m).
- Air pressure (kPa).

Data from on-line monitoring of flushing water parameters were stored on two different logging units (CR10 and CR23). A separate logging unit was used for the measurement-while-drilling (MWD) dataset. The data from the loggers was downloaded either continuously (CR10 and CR23) or by diskette or CD-ROM to the DMS database.

4.3.3 Equipment for deviation measurements

Deviation measurements were performed in the borehole using a Reflex MAXIBOR™ (non-magnetic) optical equipment and a Flexit (magnetometer/accelerometer) equipment.

Figure 4-3. *The CR23 logging unit for parameters "air-pressure" and "electrical conductivity".*

4.3.4 Equipment for reaming reference slots

In order to establish accurate and similar depth references for the various measurements that will be performed in the borehole, reference slots are reamed in the borehole wall.

The equipment has been developed by SKB and consists of a reaming tool that can be fitted to conventional drilling rods for 56 and 76 mm drilling equipment. The reaming tool is operated hydraulically from the surface, so that when the water pressure is increased the cutters expand.

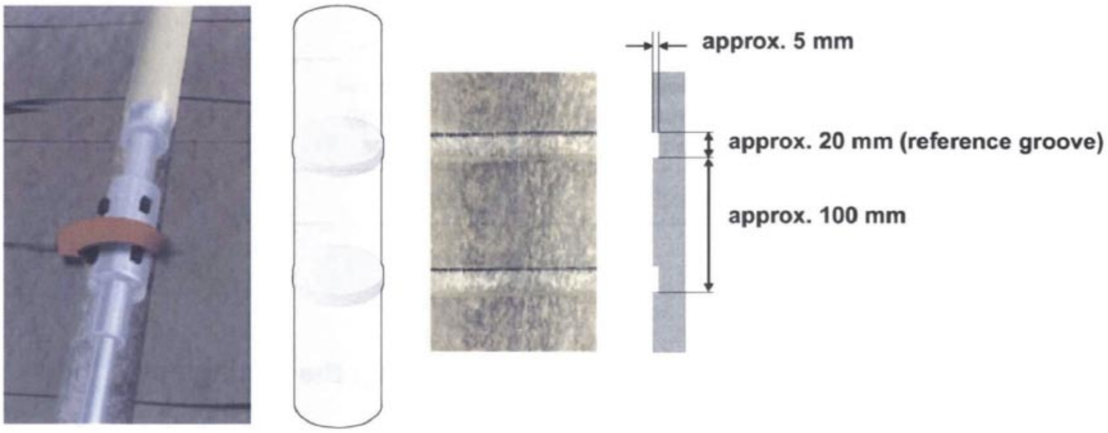


Figure 4-4. *The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.*

5 Execution and results

5.1 Summary of KLX03 drilling

A technical summary of the drilling of KLX03 and the borehole design after completion is given in Table 5-1 and Figure 5-1. A summary of drilling progress and borehole measurements is given in Table 5-2 and chronological summary is presented in Table 5-3. Drilling progress over time is further reported in Section 5.5 "Drilling monitoring results".

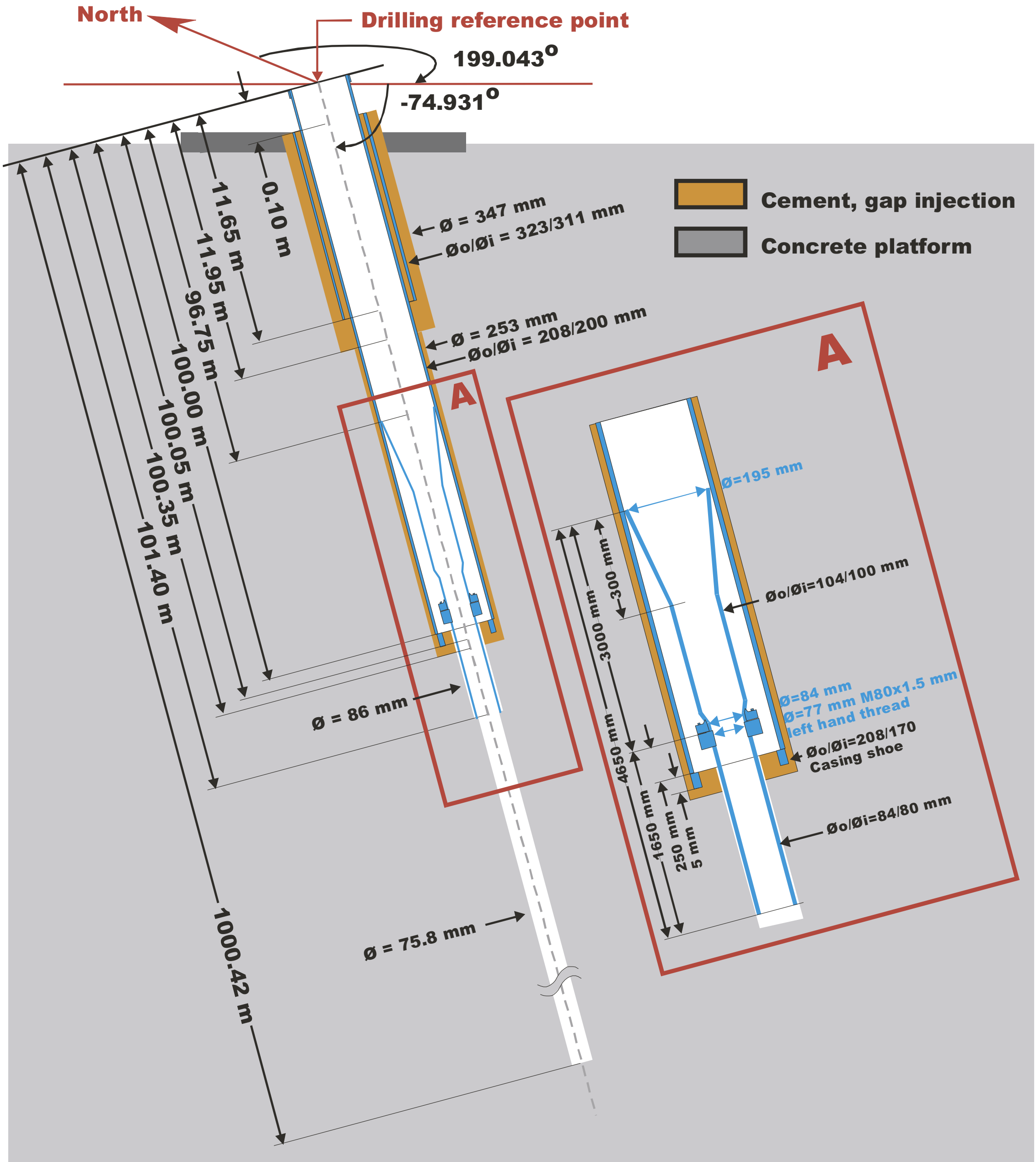
Further descriptions of the two main drilling steps, the telescope section 0–100.35 m and the core drilling section 100.35–1,000.42 m are given in Sections 5.2 and 5.3 respectively.

Table 5-1. KLX03 Technical summary.

General	Technical
Name of hole: KLX03	*Percussion drill rig* Puntel MX 1000
Location: Laxemar, Oskarshamn Municipality, Sweden	*Percussion hole length* 100.35 m
Contractor for drilling	*Core drill rig* B 20 P Atlas Copco *Core drill dimension* 76 mm
Drillcon AB	*Cored interval* 100.35–1,000.42 m
Subcontractor percussion drilling	*Average core length retrieved in one run* 2.85 m
Sven Andersson AB	*Number of runs* 316
Subcontractor core drilling	*Diamond bits used* 8
Suomen Malmi OY (SMOY)	*Average bit life* 112 m
Drill start date May 03, 2004 *Completion date* September 7, 2004	*Position KLX03 (RT90 RH70) at top of casing:* N 6366112.59, E 1547718.93, Z 18.49 (m a s l) *Azimuth (0–360)/Dip (0–90)* 199.0/–74.9
	Position KLX03 (RT90 RH70) at 993 m length: N 6365922.13, E 1547580.95, Z –944.89 (m a s l) *Azimuth (0–360)/Dip (0–90)* 245.2/–76.8

Technical data

Borehole KLX03



Drilling reference point

Northing: 6366112.59 (m), RT90 2,5 gon V 0:-15
Easting: 1547718.93 (m), RT90 2,5 gon V 0:-15
Elevation: 18.49 (m), RHB 70

Drilling period

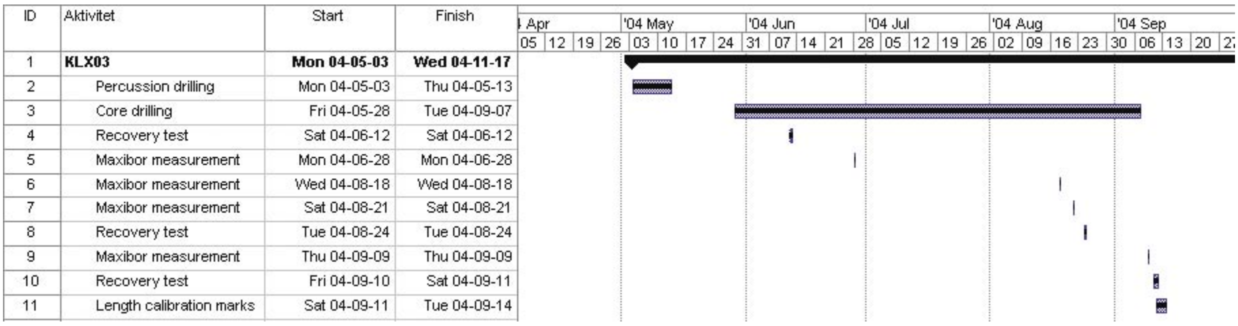
Drilling start date: 2004-05-03
Drilling stop date: 2004-09-07

Figure 5-1. Technical data from KLX03.

Table 5-2. Summary of drilling progress and borehole measurements.

	Drilled length, pumping tests and water sampling	Measurements of absolute pressure	Airlift pumping with evaluation of drawdown and/or recovery	Deviation measurement	Miscellaneous
0 m				040531. Maxibor measurement 0 - 111 m 0.86 m right	
	040604. Drilled length 218.02 m. Pumping test, 103.00-218.02 m, without WL-probe. Ca 5,5 L/min, 10 m drawdown. Water sample.			040611. Maxibor 0 - 381 m 11.33 m right 1.47 m down	
	040608. Drilled length 314.02 m. Pumping test, 215.72-314.02 m, without water sampler. Yield 0.9 L/min at 16 m drawdown. No water sample.				
	040613. Drilled length 408.02 m. Pumping test, 312.00-408.02 m, without water sampler. Yield 0.7 L/min at 20 m drawdown. No water sampling.		040612. Airlift pumping 101.40 - 399.47 m. No drill stem in borehole.	040628. 0 - 465 m 16.40 m right 3.36 m down	040629. Forecast for deviation at 1000 m was: 66 m right 33 m down.
	040804. Drilled length 500.03 m. Pumping test , 407.00-500.03 m, without water sampler. Yield 0.9 L/min at 20 m drawdown.			040805. Decision to direct the borehole to the left Deviated drilling to direct the borehole to the left was made between 500.00 m (040805) and 531.01 m	
	040813. Drilled length 599.89 m. Pumping test 497.02 - 599.89 m. Yield 2.4 L/min at 16 m drawdown. The new water sampler was used and worked well.	040814. Measurement of absolute pressure. 497.02 - 623.02 m.		040813. 465 - 594 m. 22. 01 right 6.28 down	040813. Forecast for deviation at 1000 m was: 46. 6 m right. 16 m down.
	040817. Drilled length 695.24 m. Pumping test 600.00 - 695.24 m. Yield 0.8 L/min at 25 m drawdown. Water samling with the new sampler.			040821 594 - 729 m 30.66 m right 10.99 m down	040821. Forecast for deviation at 1000 m was: 61 m right 40 m down.
	040823. Drilled length 761.11m Pumping test 692.86 - 761.11m. Yield 4.5 L/min at 13 m drawdown. Water sample OK.	040824. Measurement of absolute pressure	040824. Airlift pumping 101.40 - 764.09 m.		
	040831. Drilled length 869.07 m. Pumping test 758.86 - 869.07 m. Yield 0.4 L/min at 24 m drawdown.				
1,000 m	040907. Drilled length 1000.42 m. Pumping test 867.02 - 1000.42 m. Yield 0.4 L/min at 24 m drawdown. No water sample taken.		040910. Airlift pumping 101.40- 1000.47 m. No drill stem in borehole	040909. Final measurement 0 - 993 m. 68.29 m right 33.17 m down	

Table 5-3. Chronological summary of main drilling events.



ID	Aktivitet	Start	Finish
1	**KLX03**	**Mon 04-05-03**	**Wed 04-11-17**
2	Percussion drilling	Mon 04-05-03	Thu 04-05-13
3	Core drilling	Fri 04-05-28	Tue 04-09-07
4	Recovery test	Sat 04-06-12	Sat 04-06-12
5	Maxibor measurement	Mon 04-06-28	Mon 04-06-28
6	Maxibor measurement	Wed 04-08-18	Wed 04-08-18
7	Maxibor measurement	Sat 04-08-21	Sat 04-08-21
8	Recovery test	Tue 04-08-24	Tue 04-08-24
9	Maxibor measurement	Thu 04-09-09	Thu 04-09-09
10	Recovery test	Fri 04-09-10	Sat 04-09-11
11	Length calibration marks	Sat 04-09-11	Tue 04-09-14

5.2 Drilling, measurements and results in the telescopic section 0–100.35 m

Drilling, reaming and gap injection were made from May 3 to 13, 2004.

5.2.1 Preparations

A cement pad for emplacement of drill rig, fuel container and compressor was built.

Cleaning of all DTH (down-the-hole) equipment was done with a high-capacity steam cleaner.

5.2.2 Drilling and casing installation

The construction of the upper telescope section (0–100.35 m) of KLX03 was made in steps as described below:

Drilling was done by Sven Andersson AB and consisted of the following items:

- Drilling was made to 11.95 m length with NO-X 280 mm equipment. This gave a hole diameter of 347 mm and left a casing (324×7 mm diameter) to a depth of 11.65 m. The soil depth was 1.0 m.
- Inner supportive casing for guidance for the drill string was mounted and a cement plug was emplaced at bottom of the borehole as shown in Figure 5-2.
- A pilot percussion hole of 163.5 mm was drilled to a depth of 100.35 m. The initial diameter of the bit was 164 mm.

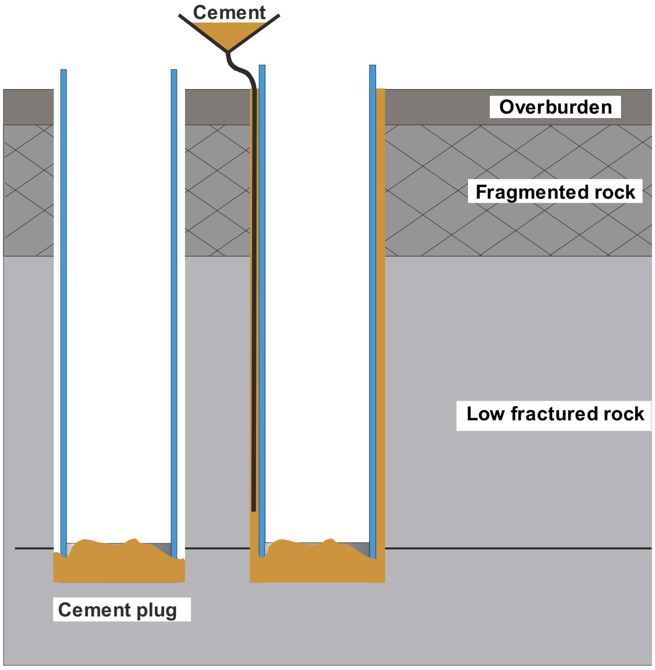


***Figure 5-2.** Gap injection technique 1. A cement plug is emplaced at the bottom and allowed to harden. The gap filling cement is introduced between the casing and the rock wall.*

- The hole was reamed to diameter 253 mm between 11.95 and 100.35 m.

- Stainless casing of 208×4 mm was installed from 0 to 100.35 m and gap injection with low alkali cement based concrete (1,928 kg or 2,080 litres) was made as described in Figure 5-3.

- After hardening the hole was rinsed and flushed to remove concrete and water. The tightness of the concrete gap filling was tested by manual groundwater measurements which confirmed that the water inflow was less than the required 0.5 litres per minute.

5.2.3 Measurements and sampling in the telescopic section

Sampling and measurements done during drilling of the telescopic section included:

- Drill cuttings were collected by taking three grab samples over a length of three metres resulting in one composite sample per three metres. The samples were stored for preliminary logging.
- Penetration rate (expressed as seconds per 20 cm) was recorded manually and observation of changes in water flow was noted.

The preliminary geological results and penetration rate is presented in Figure 5-4.

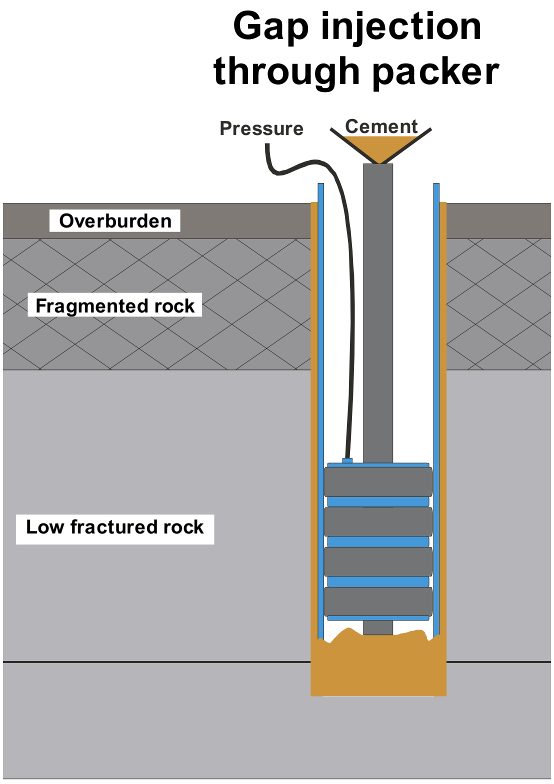


Figure 5-3. Gap injection technique 2. A packer is emplaced at the bottom of the borehole. The concrete is introduced through the packer and forced up between the casing and the rock wall.

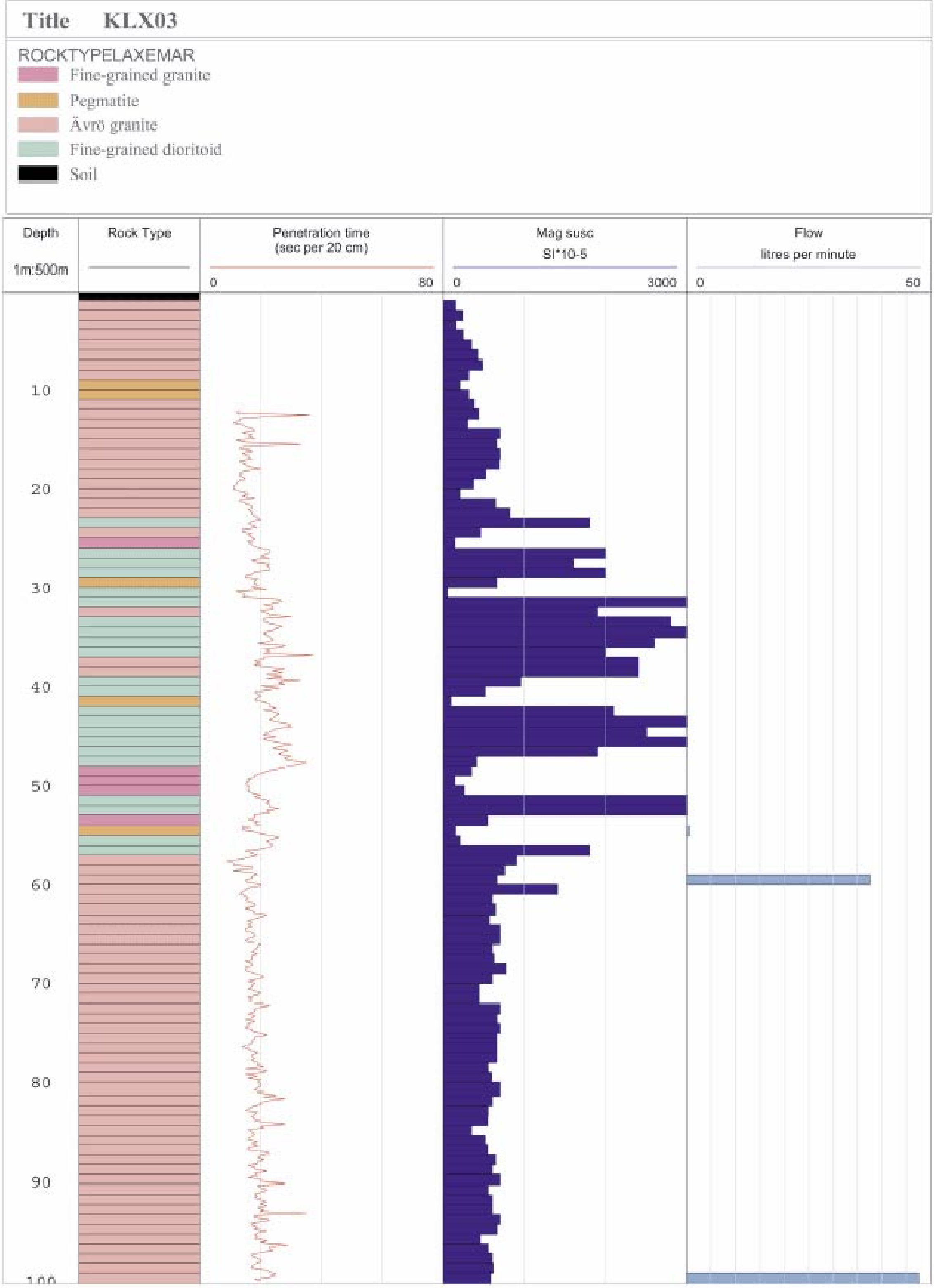


Figure 5-4. *Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KLX03.*

Hydrogeology

The total water yield at full length was 47.5 L/min. The observations of water yield during percussion drilling of the pilot hole are summarized in Table 5-4.

Table 5-4. Water yield during percussion drilling.

From (m)	To (m)	Observed water flow (L/min)
11.95	54.0	0.5
11.95	60.0	37.5
11.95	100.3	47.5

Hydrochemistry

Two water samples were collected from telescopic section in KLX03. Sampling and analysis of the samples 7340 and 7341 were performed according to SKB class 3, see Table 5-5. The analytical results are given in Table 5-6.

Table 5-5. Sample dates and length during percussion drilling in KLX03.

SKB number	Date	Test section, length (m)	SKB chemistry class
7340	2004-05-04	11.95–60.00	3 (not analysed for main components and isotopes)
7341	2004-05-04	11.95–100.30	3 (not analysed for main components and isotopes)

Table 5-6. Analytical results from water samples 7340 and 7341.

Parameter	Sample 7340	Sample 7341
pH	8.58	8.46
El Conductivity (mS/m)	62.0	61.5
Cl (mg/L)	33.4	21.0
HCO_3 (mg/L)	341.0	352.0
SO_4 (mg/L)	13.0	10.2
F (mg/L)	2.80	2.49
Br (mg/L)	< 0.2	< 0.2

5.3 Core drilling 100.35–1,000.42 m

Core drilling in KLX03 was conducted between May 21, 2004 and September 7, 2004.

The main work in KLX03 after drilling the telescopic section consisted of the following steps:

- preparations for core drilling,
- core drilling including directional drilling,
- deviation measurements,
- borehole completion.

Measurements and results from wireline tests and drill monitoring are given in Sections 5.4 and 5.5.

5.3.1 Preparations

The preparations for the core drilling consisted of installation of air-lift pumping equipment and supportive casing for alignment of the core drill rods, see Figure 5-5.

The installation of supportive casing was done in two steps:

- An outer casing with a diameter of 98/89 mm, fitted with fins to align with the diameter of the percussion drilled borehole was installed.
- Equipment for air-lift pumping was installed and a discharge header was fitted to collect the return water.
- Drilling was made between 100.05 and 101.40 m with T-86 equipment. An inner supportive casing with diameter 84/77 mm was installed to 101.40 m.

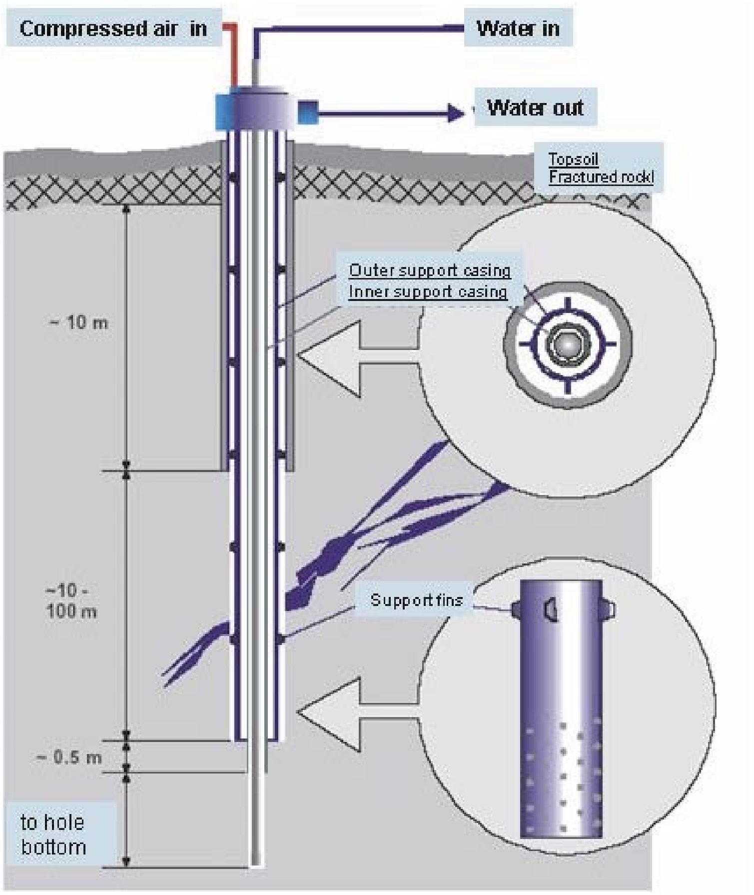


Figure 5-5. In the telescopic part of the drill hole a temporary installation is made with casing tubes for support and alignment and equipment for air-lift pumping. In the uppermost part the return water discharge header is mounted. The water discharge is led to the settling containers.

The supportive casings have a perforated section between 99.20 and 99.60 m length so that water from the borehole can be lead to the air-lift pumping system outside the supportive casings. A pressure meter for monitoring of the water level was emplaced at a length of 90 m.

The flushing water source was percussion borehole HLX14, see Figure 1-1. Treatment of the flushing water before introduction into borehole KLX03 consisted of removal of oxygen by nitrogen flushing and addition of the fluorescent tracer uranine. The water is also treated with ultraviolet light in order to reduce the microbial content. The flushing and return water handling and the emplacement of related monitoring equipment in KLX03 is shown in Figure 5-6.

The targeted content for uranine in the flushing water is 0.20 mg/L and the average uranine content was indeed 0.20 mg/L, see also Figure 5-13 and Section 5.5.2.

The return water from drilling was led to a series of sedimentation containers in order to collect sludge before infiltration to the ground, see also Section 5.8.

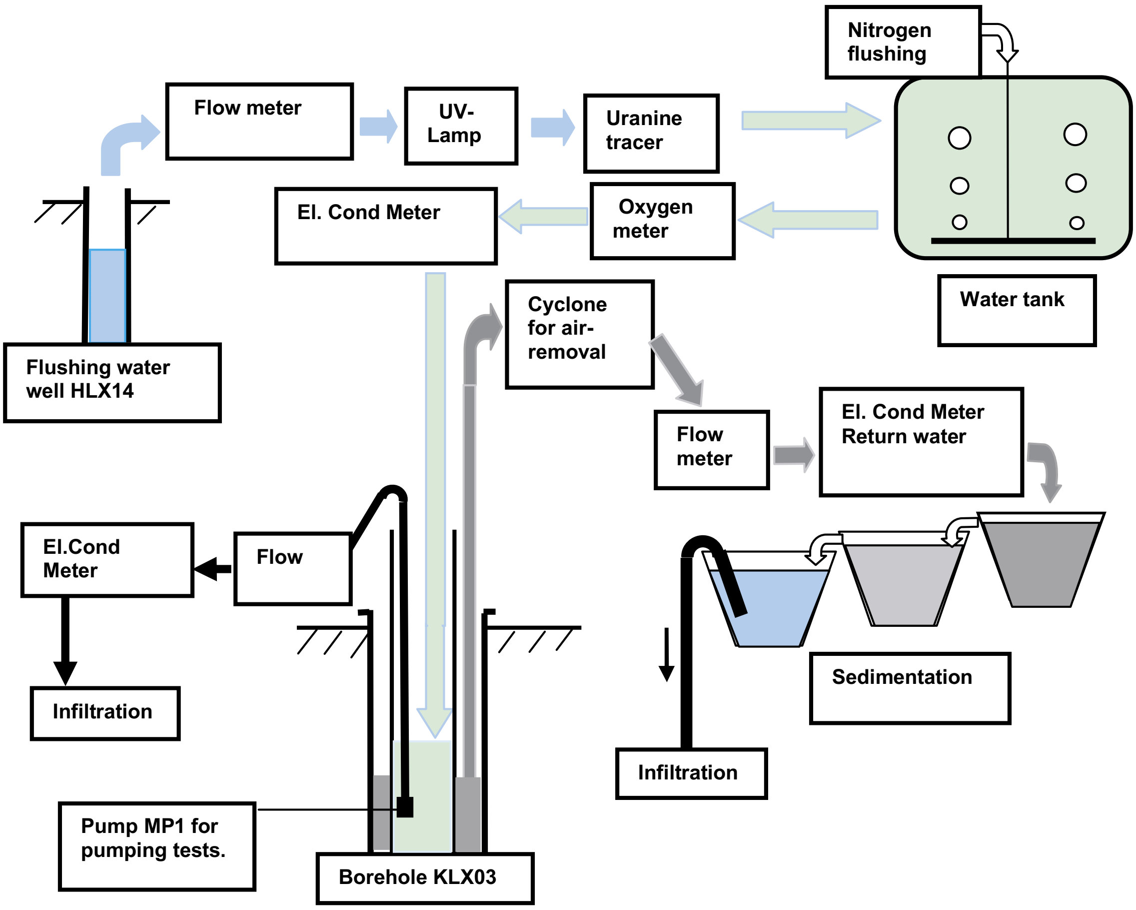


Figure 5-6. The flushing and return water handling and the emplacement of related monitoring equipment in KLX03.

5.3.2 Drilling

Core drilling with 76 mm triple-tube, wireline equipment was conducted from 101.40 m to the final length of 1,000.42 m which gave a core of 50.1 mm diameter.

Directional drilling was made in five intervals between 500.00 and 531.01 m length. The core diameter in these sections is reduced to 45 mm, see also Section 4.3.

A total of eight drill bits were used for KLX03, see Figure 5-8.

Figure 5-7. *Core drilling in KLX03.*

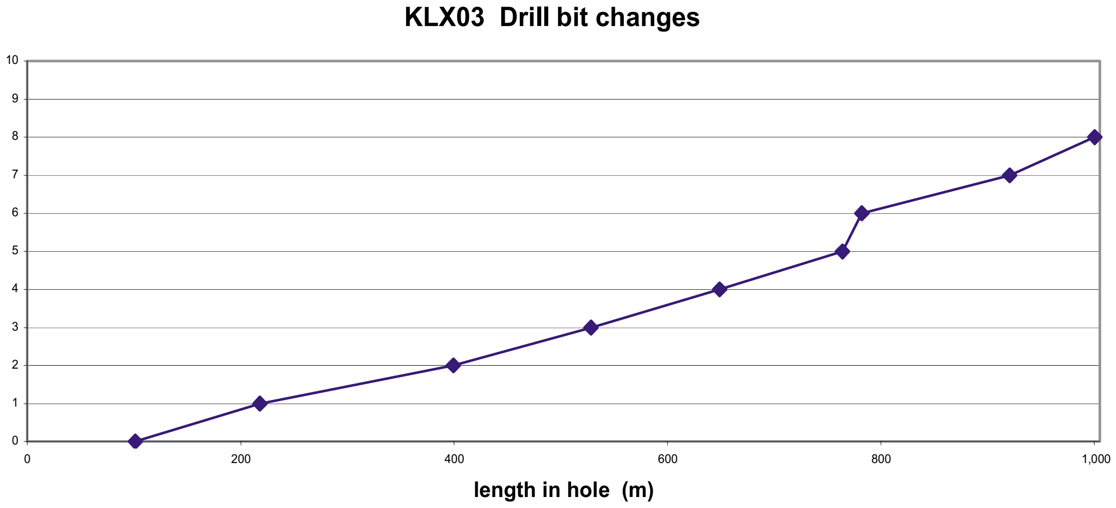


Figure 5-8. *Changes of drill bit during core drilling in KLX03.*

The elasticity of the drill stem was not measured during the drilling of KLX03.

Further results from drill monitoring ie drill penetration rate and various measurements will be presented in Chapter 5.5 "Drilling monitoring results" and in Appendix 1. The drilling progress over time is shown in Section 5.5, see Figure 5-17.

5.3.3 Deviation measurements

Two plots of the results of the final run with the Maxibor method covering the entire length of borehole KLX03 is given in Appendix 4. Borehole KLX03 was also measured with the Flexit method after borehole completion (April 28, 2005). Both sets of data are stored in the Sicada database, however, in accordance with method description MD 620.003, the Maxibor data should be used as deviation data and the Flexit data should be seen as a check-up measurement only.

A comparison of the results obtained by the two different methods is given in Appendix 8.

5.3.4 Borehole completion

Reaming of depth reference slots was done at intervals as shown in Table 5-7. The depth reference slots are used for depth calibration of down-hole equipment for subsequent investigations in the hole.

Table 5-7. Depth reference slots (m).

110.00	m	550.00	m
150.00	m	600.00	m
200.00	m	650.00	m
250.00	m	700.00	m
300.00	m	750.00	m
350.00	m	800.00	m
399.00	m	850.00	m
400.00	m	900.00	m
450.00	m	950.00	m
500.00	m		

The presence of the depth reference slots have been confirmed by caliper log measurements.

After core drilling was concluded, the air lift pumping equipment and the inner supportive casing in the telescopic section was removed.

A steel conical guide was installed between 96.75 m and 99.75 m depth together with a 86/80 mm casing between 99.75 and 101.40 m. The conical guide tapers from an inner diameter of 195 mm to 77 mm.

The length of the hole was rinsed by flushing with nitrogen gas. A total of 10 m^3 of water was flushed out of the hole. A dummy probe was run through the length of the hole to ensure that the hole was unobstructed.

The borehole was secured by mounting a lockable steel cap fastened to the concrete pad. All equipment was removed, the site cleaned and inspected by representatives from SKB and the contractor to ensure that the site had been satisfactorily restored.

5.4 Hydrogeological and hydrochemical measurements and results 100.35–1,000.42 m.

The performed measurements, as already outlined in Tables 5-2 and 5-3, can be summarized as follows:

Wireline measurements:

- Nine pumping tests at various intervals, all gave useful results, see Section 5.4.1.
- Two tests for absolute pressure, see Section 5.4.1.
- Four water samples were successfully collected from the nine pumping tests, see Section 5.4.2.

Analytical results from sampling of flushing and return water at the surface are given in Section 5.4.2.

Three air lift pumping and recovery tests were made, see Section 5.4.3.

5.4.1 Hydrogeological results from wireline measurements

Results from the wireline tests in KLX03 are presented in Table 5-8 and Figure 5-9.

The pumping tests are evaluated with steady-state assumption in accordance with /2/. The flow rate, Q, in L/min, and the drawdown, s, in kPa, at the end of the drawdown phase are used for calculating the specific capacity, Q/s, and the transmissivity, T_M.

A total of nine pumping tests were performed, and all of them achieved sufficiently stable conditions for calculating pseudo steady-state transmissivity. The plots from the pumping tests are given in Appendix 5.

Table 5-8. Pumping test with wireline probe in KLX03.

Tested section (m)	Q/s (m²/s)	T_M (m²/s)	Comments
103.00–218.02	1.0×10^{-5}	1.3×10^{-5}	Values of the pressure are taken from the upper part of the drill stem. Pseudo steady state.
215.72–314.02	9.0×10^{-7}	1.2×10^{-6}	Test functionally OK. No water sample.
312.00–408.02	4.1×10^{-7}	5.3×10^{-7}	Test functionally OK. No water sample.
407.00–500.03	3.9×10^{-7}	5.0×10^{-7}	Test functionally OK. No water sample.
497.02–599.89	2.4×10^{-6}	3.1×10^{-6}	Test functionally OK.
600.00–695.24	5.7×10^{-7}	7.4×10^{-7}	Test functionally OK.
692.86–761.11	8.2×10^{-6}	1.0×10^{-5}	Test functionally OK.
758.86–869.07	2.0×10^{-7}	2.7×10^{-7}	Test functionally OK. Pseudo steady state. No water sample.
867.02–1,000.42	2.0×10^{-7}	2.7×10^{-7}	Test functionally OK. Pseudo steady state. No water sample.

The start and stop times for the interval used for evaluation of the pumping tests are given i Table 5-9.

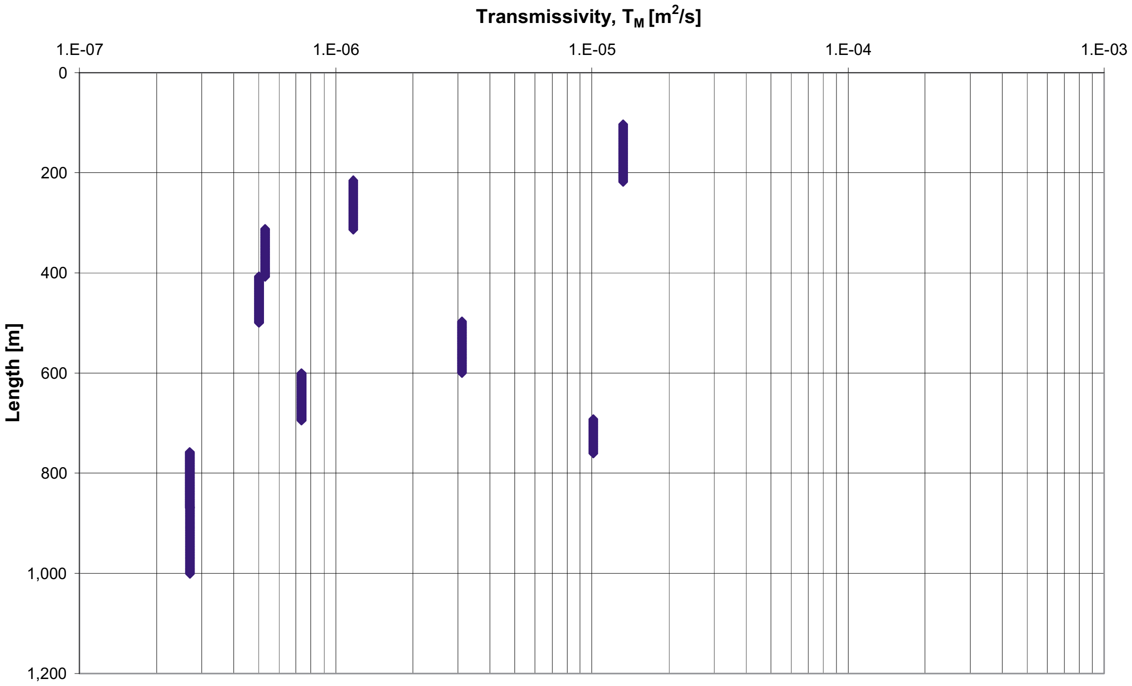


Figure 5-9. Transmissivity from wireline pumping tests in KLX03 versus borehole length.

Table 5-9. Start and stop times for the interval used for evaluation of the pumping tests.

Tested section (m)	Start (YY-MM-DD HH:MM)	Stop (YY-MM-DD HH:MM)
103.00–218.02	2004-06-04 02:05	2004-06-04 14:16
215.72–314.02	2004-06-08 11:06	2004-06-08 14:08
312.00–408.02	2004-06-13 16:52	2004-06-13 20:34
407.00–500.03	2004-08-04 16:28	2004-08-04 21:53
497.02–599.89	2004-08-13 16:58	2004-08-14 06:23
600.00–695.24	2004-08-17 09:24	2004-08-18 12:30
692.86–761.11	2004-08-22 17:25	2004-08-23 06:28
758.86–869.07	2004-08-30 15:39	2004-08-30 20:35
867.02–1,000.42	2004-09-07 17:45	2004-09-08 20.45

Measurements of the absolute pressure were conducted in two sections, as specified in Table 5-10 and Figure 5-10.

Table 5-10. Absolute pressure measurements in KLX03.

Tested section	Last pressure reading during build-up (kPa)	Duration of pressure build-up (h)	Borehole length to pressure gauge (m)
497.02–623.02	4,780	6	499.12
620.86–764.09	5,955	12	621.96

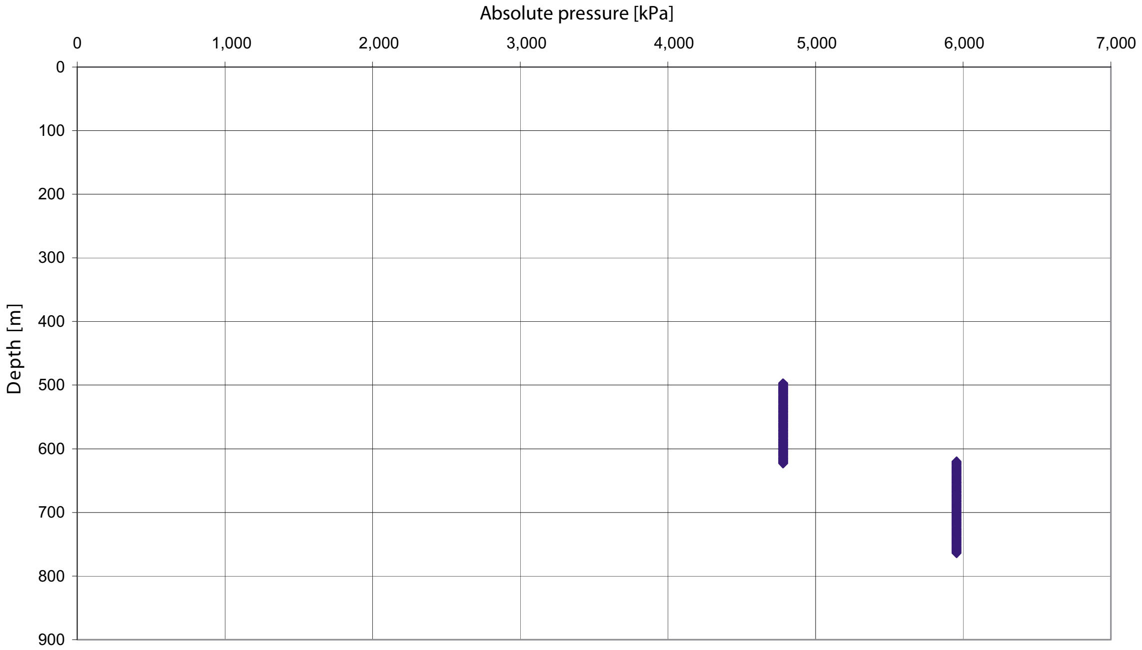


Figure 5-10. Absolute pressure measurements from wireline tests in KLX03 versus borehole length.

After packer inflation the pressure stabilization phase often displays different types of transient effects, both of increasing and decreasing pressure. The reason for these transients is not known, though they might be attributable to previous disturbances in the borehole caused by the drilling operations.

5.4.2 Hydrochemistry

In total, four water samples were collected in connection with core drilling in KLX03. The dates, test sections and chemistry classes for the samples are given in Table 5-11.

Sample 7673 had a very high drill water content (calculated from uranine tracer content) and was therefore not analyzed for other parameters. The drill water content is a reflection of how successful the sampling is. A low drill water content implies that the amount of pristine formation water is high.

Selected analytical results from KLX03 and the water source, HLX14, are given in Table 5-12. A complete record of analytical results is given in Appendix 2 and a further account on analytical method and quality is given Appendix 3.

The percussion drilled borehole HLX14 was the source for flushing water during drilling. Four water samples from HLX14 were taken in connection with drilling in KLX03.

Sample 7346 is a check sample for sample 7345 and is stored at the Äspö laboratory.

Table 5-11. Sample dates and length during core drilling in KLX03.

SKB number	Date	Test section, length (m)	SKB chemistry class
7441	2004-06-04	103.00–218.02	3 and all option isotopes
7669	2004-08-14	497.02–599.89	3 and all option isotopes
7673	2004-08-17	600.00–695.24	3 (only analysed for drill water percentage)
7675	2004-08-23	692.86–761.11	3 and all option isotopes

Table 5-12. Analytical results from water chemistry sampling.

Borehole	Sample no	Date	From m	To m	Drill water %	TOC mg/L	pH	Conductivity mS/m	Cl mg/L
KLX03	7441	2004-06-04	103.00	218.02	1.02	–	8.18	182.0	507.0
KLX03	7669	2004-08-14	497.02	599.89	5.15	–	8.27	171.0	381.0
KLX03	7673	2004-08-17	600.00	695.24	100.00*	–	–	–	–
KLX03	7675	2004-08-23	692.86	761.11	30.3	–	6.89	1,070.0	3,550.0
HLX14	7345	2004-05-07	11.90	115.90	–	7.8	8.11	87.9	69.7
HLX14	7346	2004-05-07	11.90	115.90	–	–	8.19	73.2	70.3
HLX14	7433	2004-06-01	11.90	115.90	–	3.0	–	–	–
HLX14	7434	2004-06-01	11.90	115.90	–	3.0	–	–	–

*In the Sicada database, and in Appendix 2 in this report, the drilling water percentage is given at 102%. This value is not realistic and it is here reported as 100%.

Organic content and microorganisms

Three samples for establishing the total organic carbon (TOC) were taken in HLX14. The initial sample, 7345, showed a concentration of 7.8 mg TOC/L. After renewed pumping of the well two more samples, 7433 and 7434, were taken. The concentration of TOC in the latter samples was 3.0 mg/L which was considered an acceptable level for the water in HLX14 to be used as flushing water for the core drilling in KLX03 without further filtration measures to lower the organic carbon content.

A total of 6 samples were taken in order to determine the microorganism content within the flushing water system. They were all sampled on June 3 after the whole system had been cleaned. The samples were taken from three different locations within the flushing water system. The results will be reported separately.

Monitoring of uranine tracer content

A total of 189 samples for laboratory testing of uranine content in flushing and returning water were taken along the borehole. The analytical results are shown in Figure 5-13. A calculation of the uranine balance is given in section 5.5.2, Table 5-14.

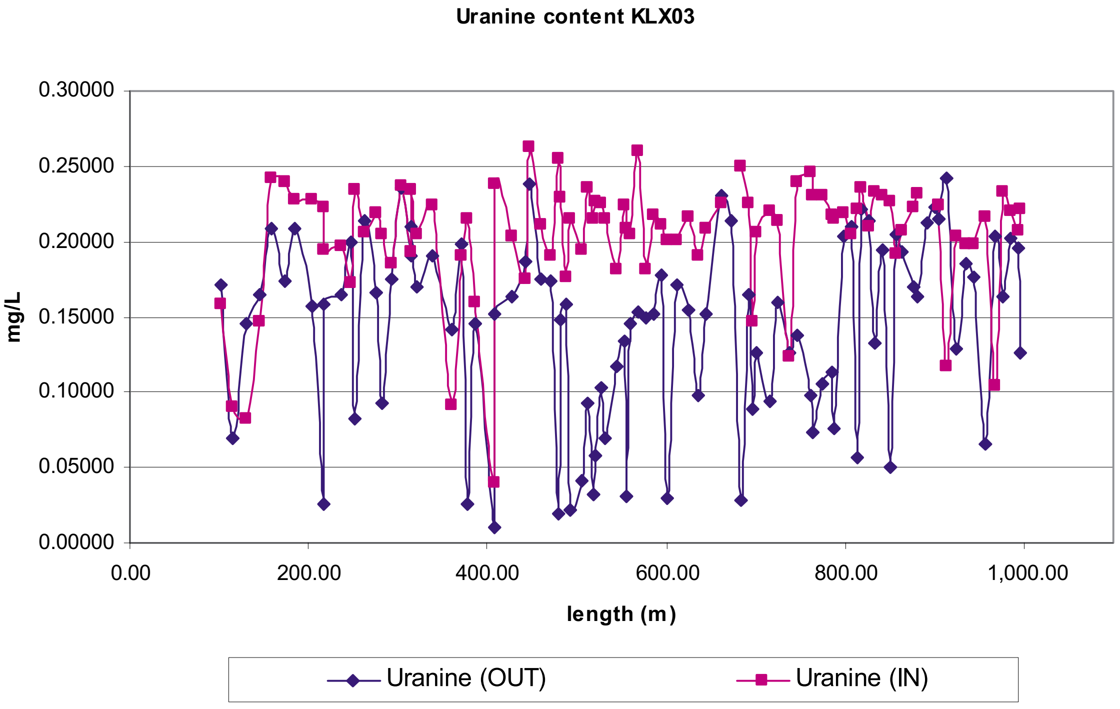


Figure 5-13. *The uranine concentration of flushing water (IN) and returning water (OUT) in KLX03 during drilling.*

5.4.3 Results from air lift pumping with evaluation of drawdown and/or recovery

Two airlift pumping tests were conducted during drilling, and one additional test was conducted after the borehole was drilled to full depth. The execution of the tests can vary in detail as drilling or other related activities such as cleaning and flushing of drill cuttings can occur prior to lifting the stem. The inflow of water in the test made between 101.4 and 764.09 m is related to rinsing of cuttings after drilling.

The steady state transmissivity, T_M, was calculated according to /2/, as well as the specific capacity, *Q/s*. The results are shown in Table 5-13.

The plots from the drawdown and recovery tests are given in Figures 5-14 through 5-16.

Table 5-13. Results from airlift pumping in KLX03.

Tested section (m)	Flow rate (L/min)	Drawdown (m)	Q/s (m^2/s)	T_M (m^2/s)	Comments
101.40–399.47	22	58	6.3×10^{-6}	9.3×10^{-6}	Test functionally OK.
101.40–764.09	28	47.5	9.8×10^{-6}	1.6×10^{-5}	Increased flow and groundwater level at 09.00 due to lifting of drill stem.
101.40–1,000.42	34	34	1.7×10^{-5}	2.8×10^{-5}	Test functionally OK.

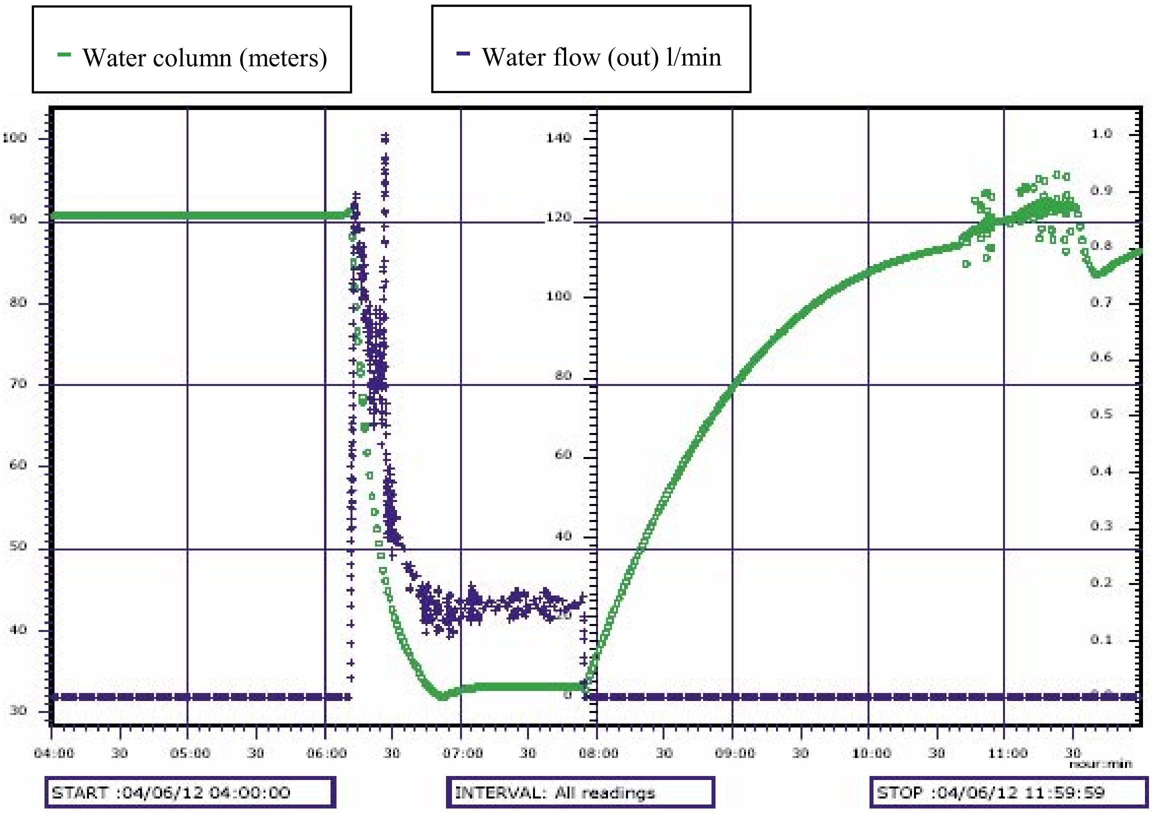


Figure 5-14. *Air lift pumping test in KLX03 101.4–399.47 m showing the pumped flow- rate (blue) and the height of the water column (green) in the telescopic part of the borehole. The pressure transducer was positioned 90 m below top of casing and the flow rate was measured at the ground surface.*

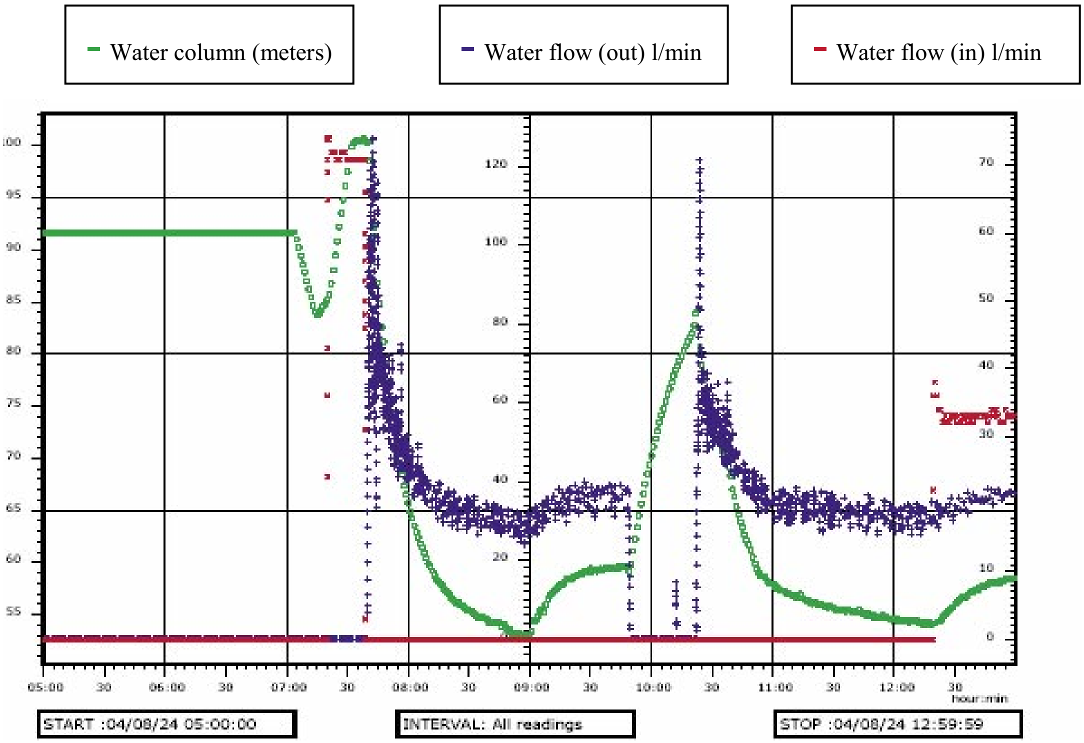


***Figure 5-15.** Air lift pumping in KLX03 101.4 m–764.09 m showing the inflow rate(red), the net outflow rate (blue) and the height of the water column (green) in the telescopic part of the borehole. The pressure transducer was positioned 90 m below top of casing and the flow rate was measured at the ground surface. During the drawdown stage of the test, rinsing of cuttings was made which explains why there was an inflow of water in the borehole.*

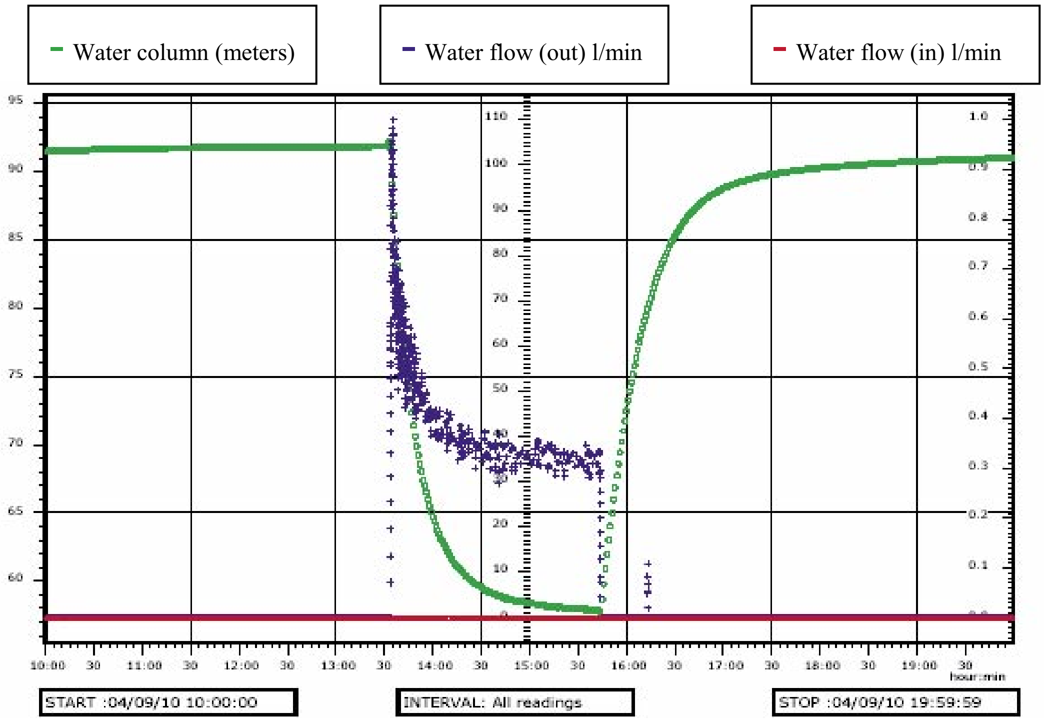


***Figure 5-16.** Air lift pumping in KLX03 101.4 m–1,000.42 m showing the outflow rate (blue) and the height of the water column (green) in the telescopic part of the borehole. There was no inflowing water during the test, as shown by the red line. The pressure transducer was positioned 90 m below top of casing and the flow rate was measured at the ground surface.*

5.5 Drilling monitoring results

5.5.1 Drill monitoring system DMS

The DMS database contains substantial amounts of drilling monitoring data. A selection of results primarily from the monitoring of the flushing water parameters are presented in Figures 5-17 through 5-19 below.

Selected parameters from the drill rig (MWD parameters) are presented in Appendix 1. The MWD parameters require some explanation:

- Drillability ratio- this parameter is defined as penetration rate divided by feed force.
- Flushing water ratio- this is defined as flushing water flow divided by flushing water pressure.
- Water pressure (of the water entering the drill stem).
- Flushing water flow (flow of ingoing water).
- Penetration rate (rate of drill bit penetration as measured on the surface on the drill stem).
- Hydraulic indication- this parameter is defined as penetration rate divided by flushing water flow.

In order to maintain reasonable size data files, a reduction in the number of points incorporated in the pictures has been done in Figures 5-17 through 5-19. Since DMS data are related to time (ie not strictly to borehole length) periods were drilling is not performed are also registered.

Figure 5-17 depicts the drill bit position (green) over time and the water level (red) in the telescope part of the drill hole. The water level, given as pressure of the overlying water column reflects the air-lift pumping activity in the hole. The break in drilling between June 16 and 30 corresponds to a period when drilling of cored borehole KLX04 was prioritized and the personnel normally working on KLX03 were transferred to that borehole. The break in drilling between July 3 and August 4 corresponds to the summer holiday when drilling was discontinued.

Figure 5-18 shows the flushing water flow (green) entering the hole and the return water flow (red).

Figure 5-19 shows the conductivity of the ingoing flushing water, conductivity of the return water and the oxygen content of the flushing water. The oxygen content of the flushing water is low, typically 1–3 mg/L.

5.5.2 Measurements of flushing water and drill cuttings

A calculation of accumulated water flow based on water flow measurements from the DMS system (continuous readings) is given in Figure 5-20.

The amount of flushing water consumed during drilling was 1,000 m^3, giving an average consumption of ca 1.1 m^3 per metre drilled. The amount of effluent return water from drilling in KLX03 was 1,200 m^3, giving an average discharge of ca 1.3 m^3 per metre drilled.

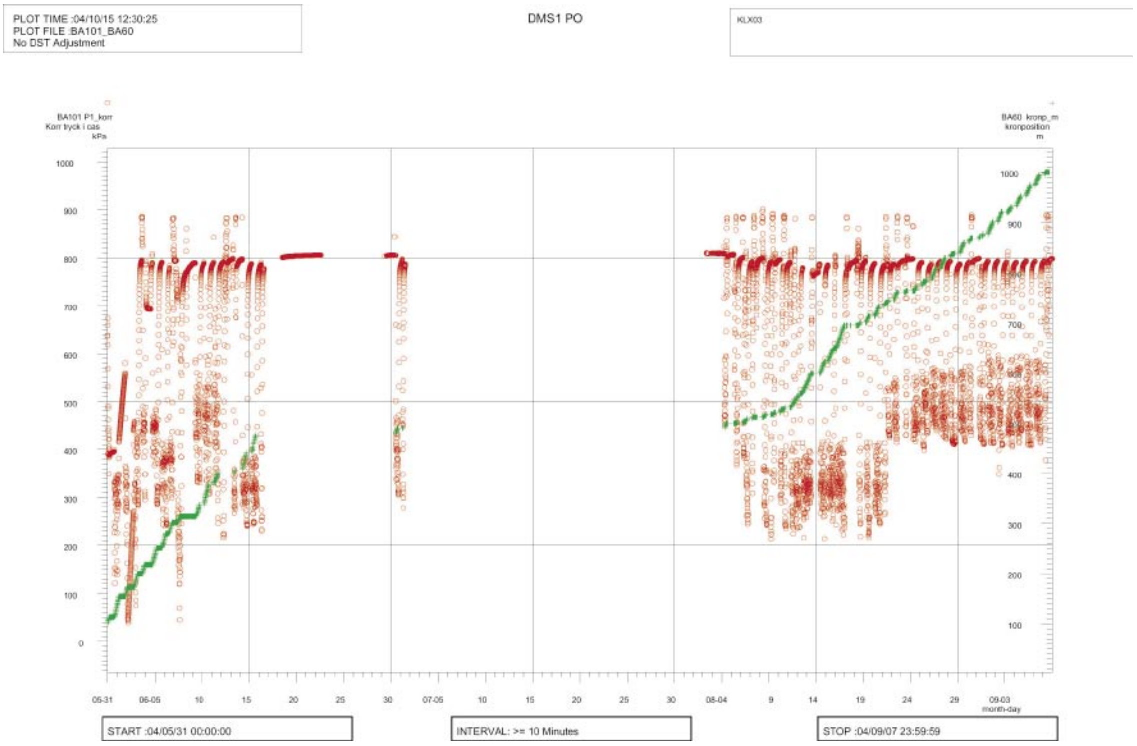


Figure 5-17. *Drill bit position (green) and water level from air-lift pumping (red). The water level is expressed as the pressure in kPa of the water column overlying the pressure gauge ie the ambient air-pressure has been subtracted. The pressure gauge is emplaced at 90 m borehole length. The drill bit position is given in cm x 10*^{3}*.*

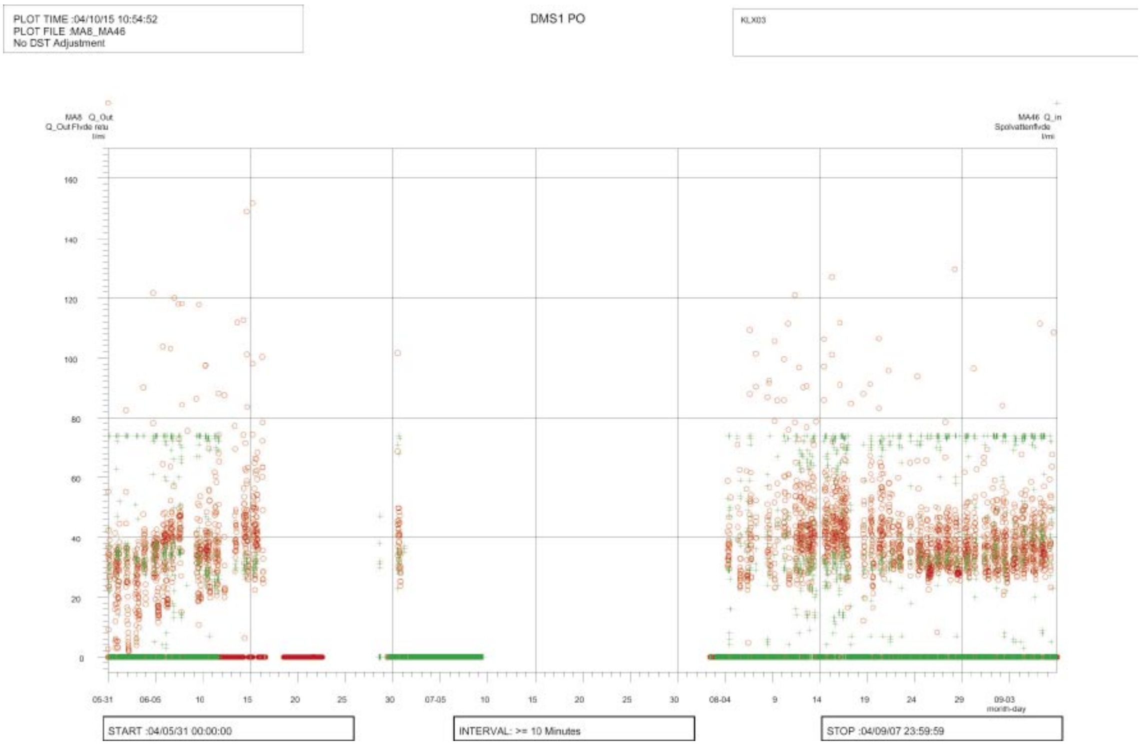


Figure 5-18. *Flushing water flow (green) and return water flow (red) in litres per minute.*

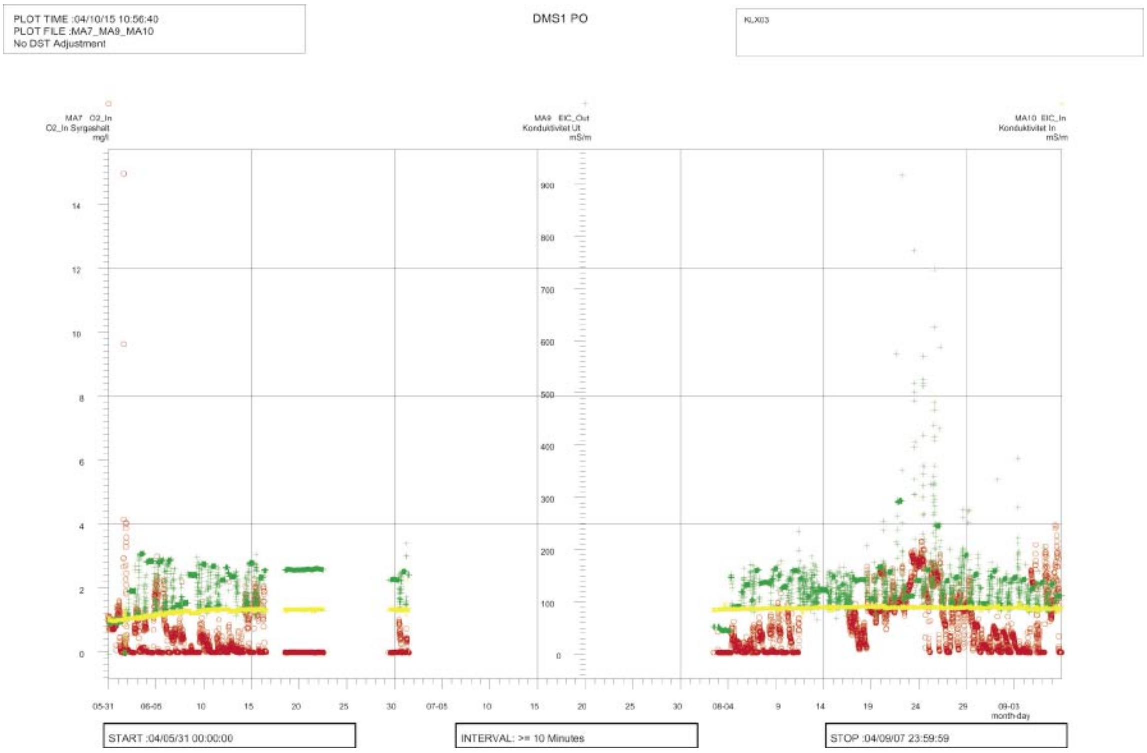


Figure 5-19. *Conductivity of flushing water (yellow) and return water (green). The oxygen content in mg/l of the flushing water (red) is also shown. The oxygen content of the flushing water is normally below 4 mg/l.*

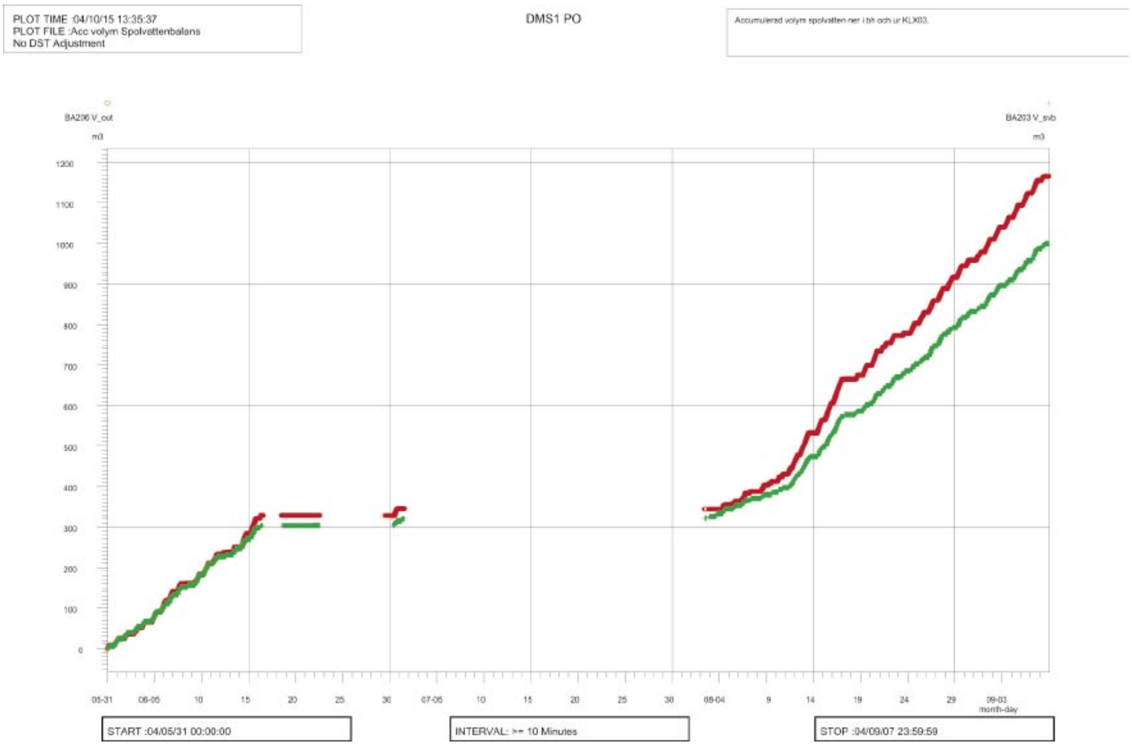


Figure 5-20. *Flushing water balance from KLX03 as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.*

Drill cutting balance

The weight of cuttings in the settling containers amounted to 3,000 kg. The content of suspended material in the return water was not analysed in borehole KLX03, however previous sampling has shown the content to be 400 mg/L /5/. The amount of material in suspension carried with the return water would amount to 500 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing over a length of 900 m is 6,000 kg assuming a density of 2.65 kg/dm^3. This means that about 60% of the material liberated by drilling is removed from the formation.

The recovered drill cuttings were collected in steel containers. After completion of drilling, the containers were removed from the site and emptied at an approved site.

Uranine tracer balance

The amount of introduced and recovered uranine is presented in Table 5-14. The results show that 85% of the introduced uranine was retrieved during drilling.

Table 5-14. Balance calculation of uranine tracer in KLX03.

Average uranine content IN (mg/L)	0.20
Volume IN (m^3)	1,000
Amount uranine introduced (g)	200
Average uranine content OUT (mg/L)	0.14
Volume OUT (m^3)	1,200
Amount uranine recovered (g)	170

5.6 Geology

The geological results based on the Boremap logging, /3/, are shown in Appendix 1.

The upper 620 m were dominated by Ävrö granite with minor sections of diorite/gabbro. Below 620 m the core consists mainly of quartz monzodiorite with intercalations of fine-grained diorite-gabbro, fine-grained granite and fine-grained dioritoide.

Oxidation occurs sporadically in the core, other types of alterations have also been noted. Saussuritization ie alteration of calcic plagioclase feldspar, with faint to medium intensity is common between 650 and 830 m.

The distribution of total fractures in the core is rather homogeneous with a frequency of 0–10 (fractures/m) in the Ävrö granite and slightly higher, ca 5–15, in the quartz monzodiorite.

5.7 Data handling

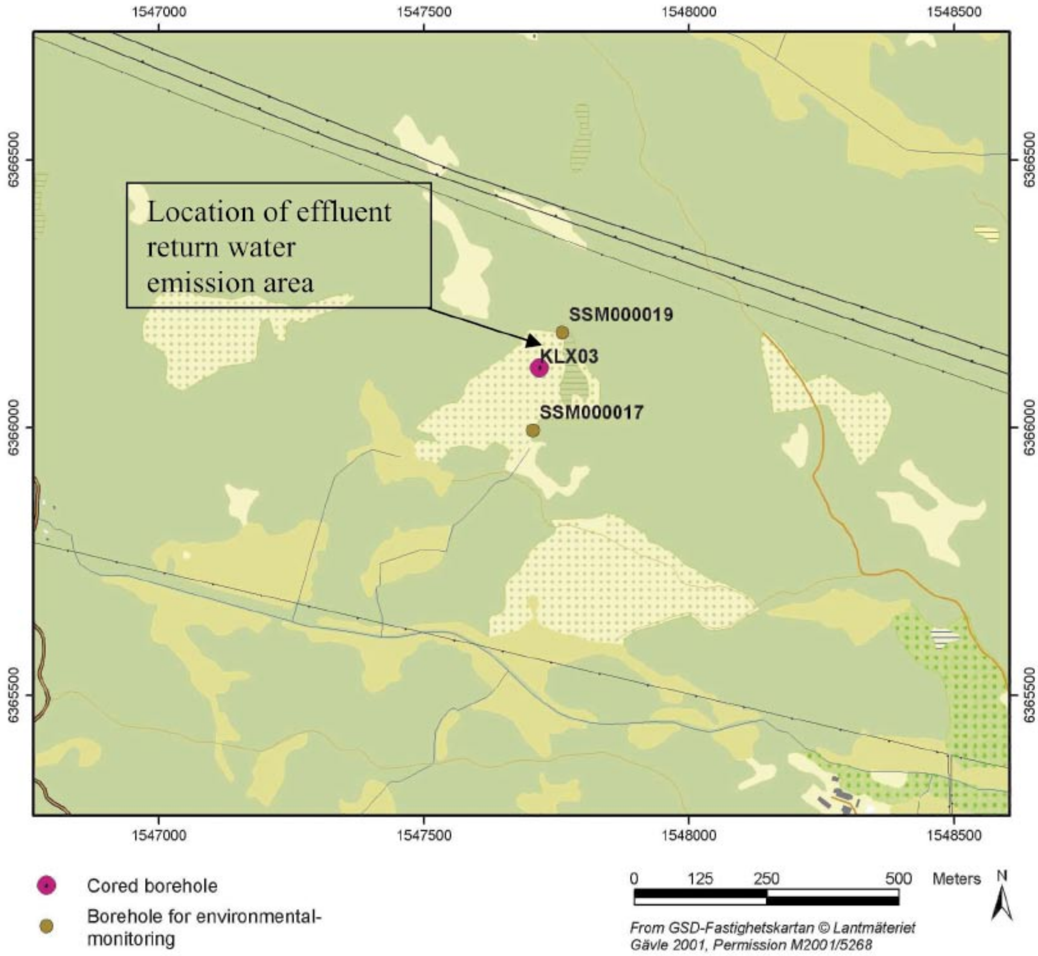
Data collected by the drilling contractor and the SKB drill coordinators were reported in daily logs and other protocols and delivered to the Activity Leader. The information was entered to SICADA (SKB database) by database operators.

5.8 Environmental control

The SKB routine for environmental control (SDP-301, SKB internal document) was followed throughout the activity. A checklist was filled in and signed by the Activity Leader and filed in the SKB archive.

All waste generated during the establishment, drilling and completion phases have been removed and disposed of properly. Water effluent from drilling was allowed to infiltrate to the ground in accordance with an agreement with the environmental authorities. The location of the water emission area is shown in Figure 5-21. Precautionary guidelines values for effluent return water emission to the ground were prescribed by the Regional Authorities for the following parameters:

- Salinity, 2,000 mg/l (monitored as electrical conductivity, with the limit 300 mS/m).
- Uranine content, 0.3 mg/l.
- Suspended material, 600 mg/l.



From GSD-Fastighetskartan © Lantmäteriet Gävle 2001, Permission M2001/5268

Swedish Nuclear Fuel & Waste Management Co
2005-07-01, 15:04

Figure 5-21. *Location of environmental monitoring wells SSM000017 and SSM000019 in relation to the core drill site for KLX03. The effluent return water was infiltrated to the ground some 30 m north of KLX03.*

Drilling of environmental monitoring wells

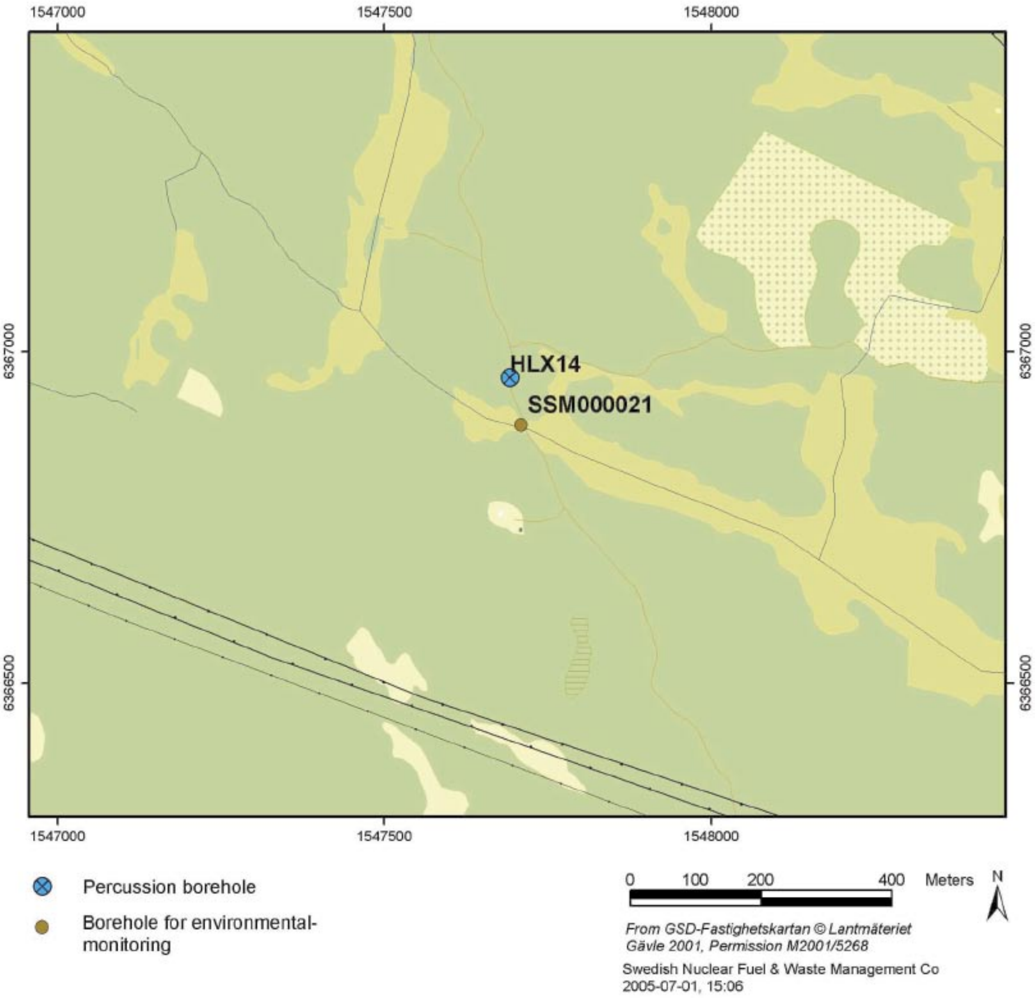
Three environmental monitoring wells SSM000017, SSM000019 and SSM000021 were drilled. Wells SSM000017 and SSM000019 are located around borehole KLX03. SSM000021 is located by the percussion borehole HLX14 which served as a source of water for the core drilling of KLX03. The locations of the wells are given in Figures 5-21 and 5-22.

Drilling of the environmental monitoring wells was made on 040505 and 040506. The technical specifications of the wells are given in Appendix 7.

Reference sampling

A reference sample of surface soil from the core drill site was taken on 2004-04-14. The sample ID is SKB PO 09004.

Reference samples of ground water from the environmental wells and manual ground water measurements were taken as shown in Table 5-15. Pressure loggers (transducers) for measuring the ground water table were not installed until 2004-08-26 due to late delivery of logging units.



From GSD-Fastighetskartan © Lantmäteriet
Gävle 2001, Permission M2001/5268
Swedish Nuclear Fuel & Waste Management Co
2005-07-01, 15:06

Figure 5-22. *Location of environmental monitoring wells SSM000021 in relation to percussion borehole HLX14, which was the water source during core drilling of KLX03. No water emission to the ground took place at this location.*

Table 5-15. Measurements in environmental monitoring wells.

Monitoring well	Measurement	Date
SSM000017	Ground water table – manual	040505
SSM000017	Water sample 7343	040506
SSM000017	Transducer installation	040826–041209
SSM000019	Ground water table – manual	040505
SSM000019	Water sample 7342	040506
SSM000019	Transducer installation	040826–041209
SSM000021	Ground water table – manual	040506
SSM000021	Water sample 7344	040506
SSM000021	Transducer installation	040826–

Monitoring of effluent water

The effluent water, ie discharge to the ground, from the core drilling of KLX03 never exceeded the guideline value of 300 mS/m as a daily average /4/.

The uranine content was below 0.25 mg/l, see Figure 5-13.

The concentration of suspended material was not analysed in this borehole, however previous sampling has shown that the concentration was well below the prescribed guideline value /5/.

To sum up, the monitored parameters in the emitted water complied with the prescribed guideline values.

Monitoring of ground and surface water recipients

To monitor the possible effects in the ground and surface water a monitoring programme was set up with focus on salinity and the effects of salinity. No indication of an increase in salinity in the surface water could be seen during the period of core drilling /4/.

5.8.1 Consumption of oil and chemicals

No significant amounts of oils or lubricants were consumed during the drilling.

The concrete consumption was 1,928 kg in total. The concrete was based on white silica, low alkali cement.

5.9 Nonconformities

No formal nonconformities are reported for the activity.

The pressure transducers for logging the water table in environmental monitoring wells SSM000017 and SSM000019 were not installed at the beginning of core drilling due to late delivery of logging units.

6 References

/1/ **SKB, 2001.** Platsundersökningar, Undersökningsmetoder och generellt genomförandeprogram. SKB R-01-10, Svensk Kärnbränslehantering AB.

/2/ **Moye D G, 1967.** Diamond drilling for foundation exploration, Civil Eng. Trans. Inst. Eng, Australia.

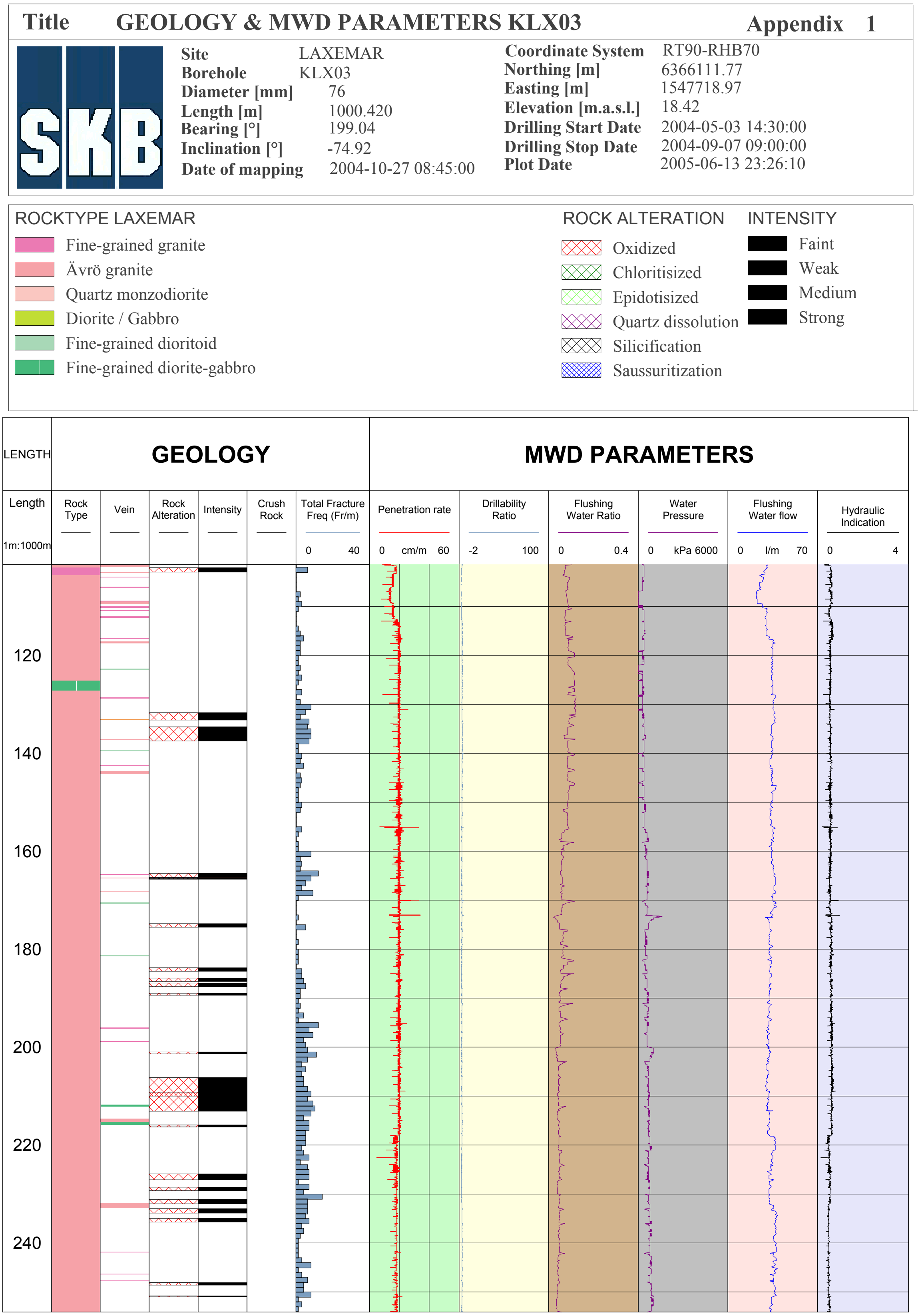
/3/ **SKB, 2005.** Boremap mapping of core drilled boreholes KLX03. SKB P-05-24 (in prep), Svensk Kärnbränslehantering AB.

/4/ **Aquilonius and Wijnbladh, 2005.** Compilation and evaluation of data from monitoring of flushing water from KLX03 and KLX04. SKB P-05-41, Svensk Kärnbränslehantering AB.

/5/ **Ask et al. 2004.** Core drilling of KSH03. SKB P-04-233, Svensk Kärnbränslehantering AB.

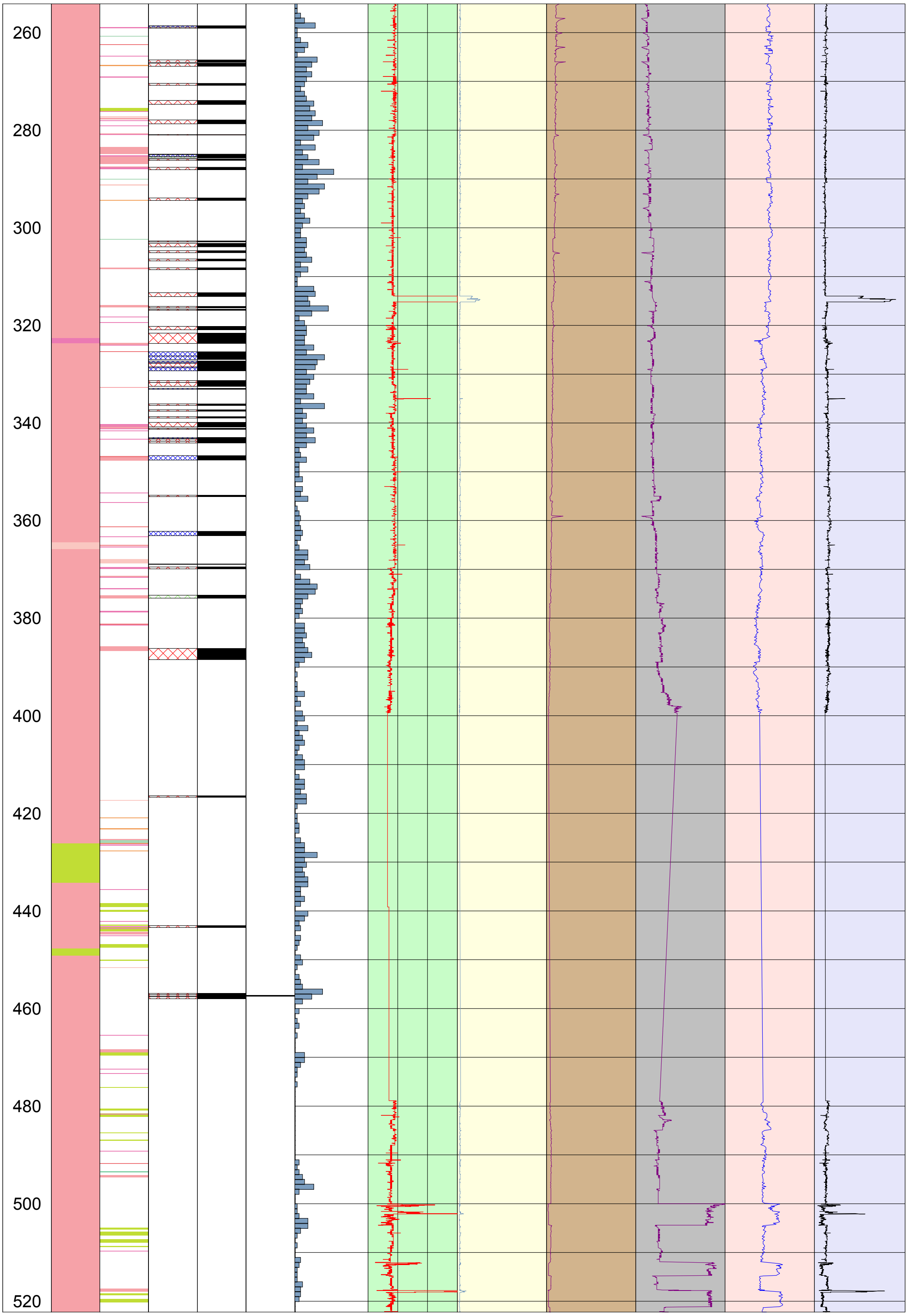
Appendix 1

Geology and MWD parameters KLX04

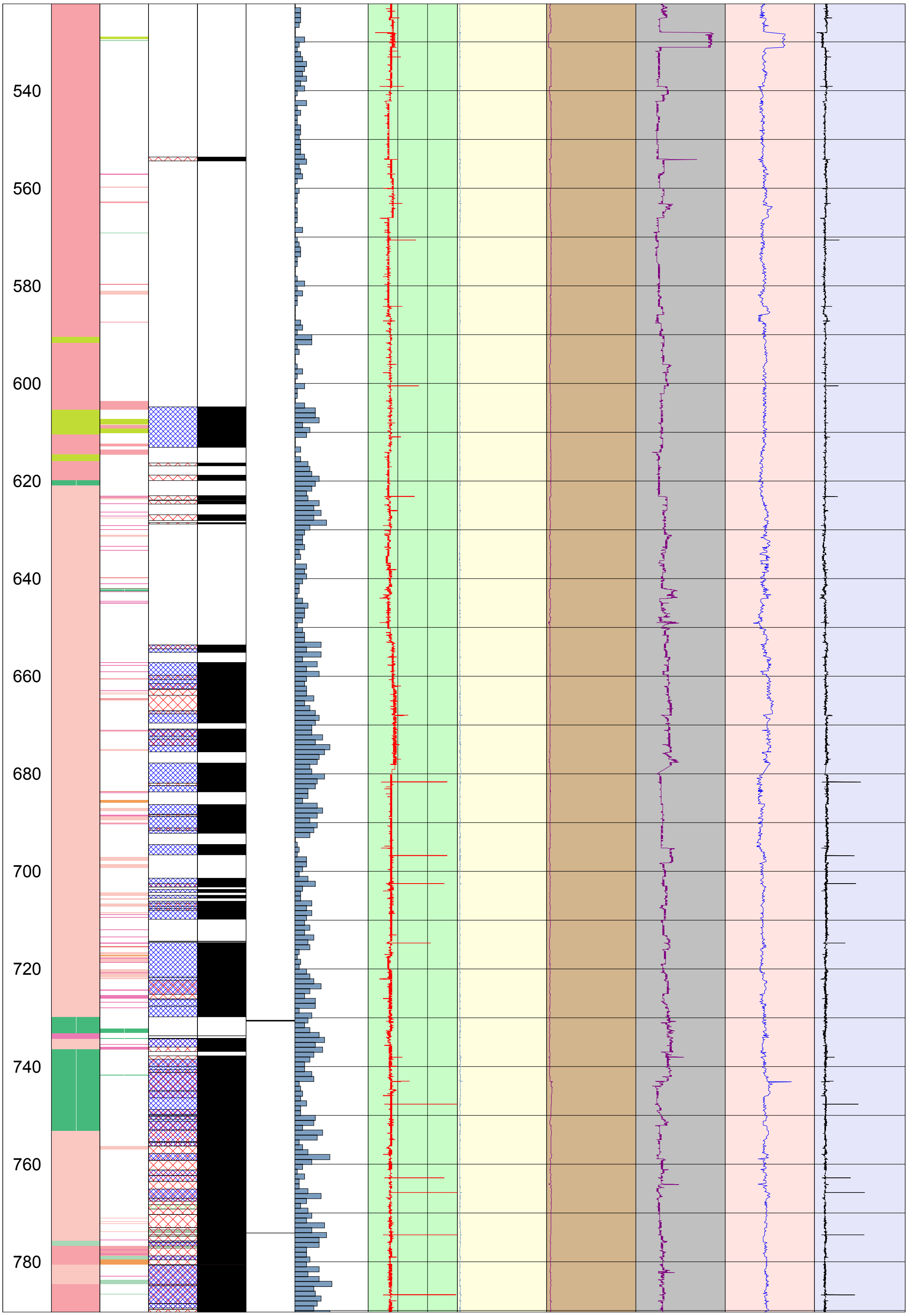


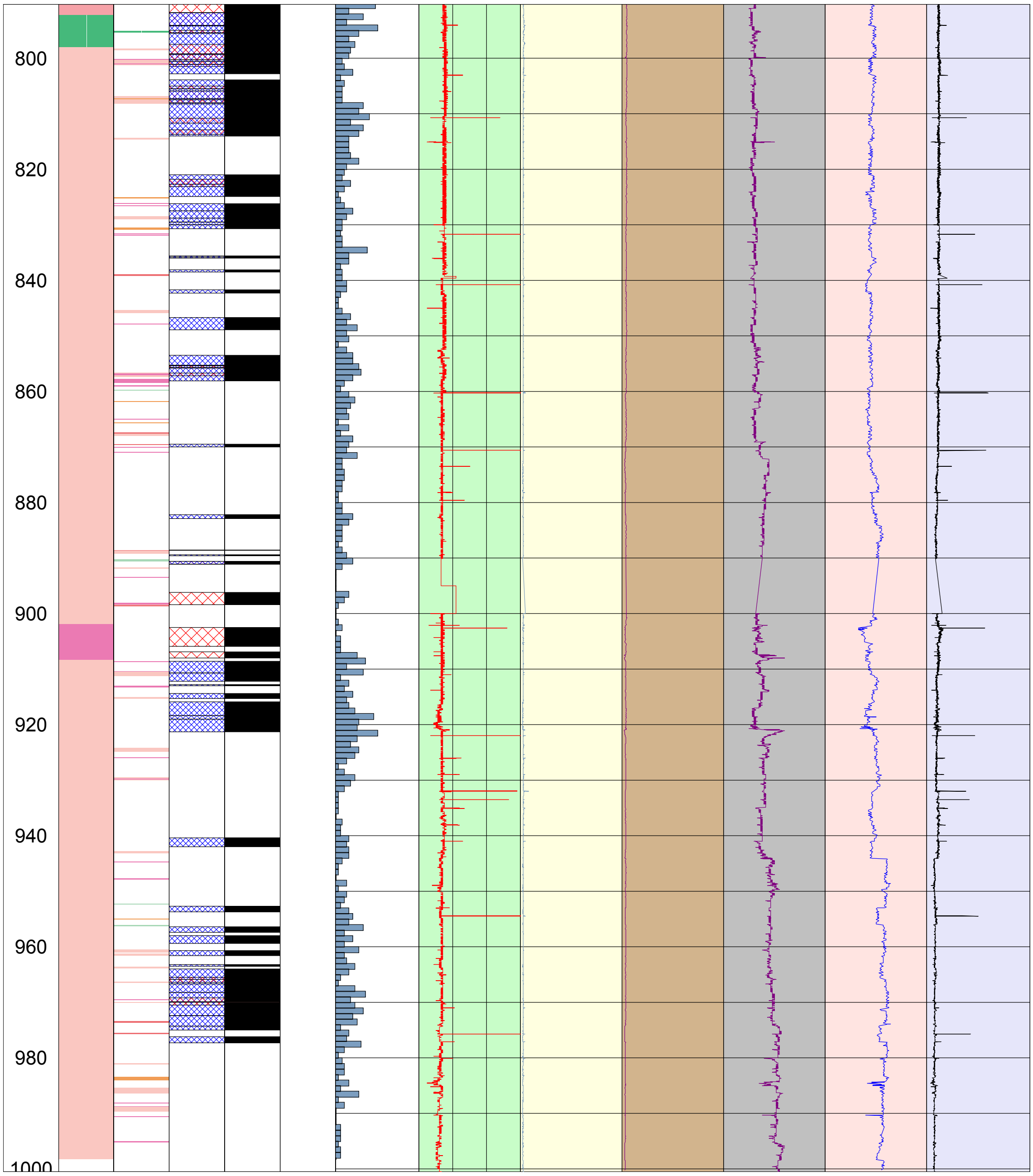
Title **GEOLOGY & MWD PARAMETERS KLX03** **Appendix 1**

Site	LAXEMAR	**Coordinate System**	RT90-RHB70
Borehole	KLX03	**Northing [m]**	6366111.77
Diameter [mm]	76	**Easting [m]**	1547718.97
Length [m]	1000.420	**Elevation [m.a.s.l.]**	18.42
Bearing [°]	199.04	**Drilling Start Date**	2004-05-03 14:30:00
Inclination [°]	-74.92	**Drilling Stop Date**	2004-09-07 09:00:00
Date of mapping	2004-10-27 08:45:00	**Plot Date**	2005-06-13 23:26:10



260
280
300
320
340
360
380
400
420
440
460
480
500
520


540
560
580
600
620
640
660
680
700
720
740
760
780


800
820
840
860
880
900
920
940
960
980
1000

Appendix 2

Chemical results

Borehole	KLX03	KLX03	KLX03	KLX03	KLX03	KLX03	HLX14	HLX14	HLX14	HLX14
Date of measurement	5/4/04	5/4/04	6/4/04	8/14/04	8/17/04	8/23/04	5/7/04	5/7/04	6/1/04	6/1/04
Upper section limit	11.95	11.95	103.00	497.02	600.00	692.86	11.90	11.90	11.90	11.90
Lower section limit	60.00	100.30	218.02	599.89	695.24	761.11	115.90	115.90	115.90	115.90
Sample_no	7340	7341	7441	7669	7673	7675	7345	7346	7433	7434
Groundwater Chemistry Class	3	3	3	3	3	3	5	5	5	5
pH	8.58	8.46	8.18	8.27		6.89	8.11	8.19		
Conductivity mS/m	62.0	61.5	182.0	171.0		1,070.0	87.9	73.2		
TOC mg/l							7.8		3.0	3.0
Drill water %			1.02	5.15	102.00	30.3				
Densitet g/cm³						1.0008	0.9970	0.9967		
Na mg/l			330	288		1,260	138			
K mg/l			3.34	3.49		8.12	3.08			
Ca mg/l			46.8	43.1		924.0	18.8			
Mg mg/l			7.2	5.9		12.3	4.7			
HCO3 mg/l Alkalinity	341.0	352.0	271.0	300.0		41.1	302.0	305.0		
Cl mg/l	33.4	21.0	507.0	381.0		3,550.0	69.7	70.3		
SO4 mg/l	13.0	10.2	30.2	42.9		392.0	31.3	31.5		
SO4_S mg/l Total Sulphur			9.73	13.60		122.00	9.44			
Br mg/l	< 0.2	< 0.2	2.50	1.78		24.30	0.415	0.405		
F mg/l	2.80	2.49	2.90	2.90		1.65	3.77	3.80		
Si mg/l			5.62	5.07		5.94	6.69			
Fe mg/l Total Iron			0.247	4.830		11.000	0.269			

Borehole	KLX03	KLX03	KLX03	KLX03	KLX03	KLX03	HLX14	HLX14	HLX14	HLX14
Mn mg/l			0.080	0.234		0.500	0.0773			
Li mg/l			0.040	0.034		0.188	0.015			
Sr mg/l			0.875	0.804		16.400	0.32			
PMC % Modern Carbon			42.7				54.7			
C-13 dev PDB			–17.18	–16.32			–18.5			
AGE_BP Groundwater age			6,785				4,795			
AGE_BP_CORR			60				45			
D dev SMOW			–89.7	–85.2		–96.5	–78.6			
Tr TU			–0.8	–0.8		1.5	3.8			
O-18 dev SMOW			–12.7	–11.7		–13.1	–11.2			
B-10 B-10/B-11			0.2443	0.2309		0.2348	0.2371			
S-34 dev SMOW			48.2	37.2		4.3	32.1			
Cl-37 dev SMOC			0.16	–0.25		0.43				
Sr-87 Sr-87/Sr86			0.715190	0.715213		0.715808	0.715656			

Appendix 3

Chemistry – analytical method and quality

Analysis	Sample bottle	Preparation	SKB label	Laboratory
pH, conduktivity, alkalinity	250 ml		Green	Äspö/field
Anions (F^-, Br^-, Cl^-, SO_4^{2-})	250 ml		Green	Äspö/field
Uranine	100 ml brown glass		Green	Äspö/field
Main components (except Fe, Mn)	Analytica's 100 ml acid washed	1 ml HNO_3 suprapur, filtering membrane filter	Red	Analytica
Archive samples	2 ea 250 ml	Filtering Pallfilter	Green	

Option				
Deuterium, O–18	100 ml square		green	IFE
Tritium	500 ml dried	Flooded at least once	green	Waterloo
Sr-87	100 ml square		green	IFE
Cl-37	500 ml		green	Waterloo
B-10	Same as for main components	Filtering membrane filter	red	Analytica
C-13, PMC	2 st 100 ml brown glass		green	Waterloo
S-34	1,000 ml		green	IFE

Quality of the analyses

The charge balance errors give an indication of the quality and uncertainty of the analyses of the major components. The relative charge balance error is calculated for the selected set of data from the borehole KLX03. The errors do not exceed ± 5% in the samples (7669 and 7675) which is fully satisfactory. In sample 7441 the charge balance error is –5.80%.

The charge balance error in sample 7345 from the borehole HLX14 is –1.91% which is also fully satisfactory.

The charge balance error is not calculated for the sample 7673 collected in KLX03 due to the high drilling water percentage.

Figures A3-1 and A3-2 illustrate the consistency of the analyses. The figures are based on the data presented in Appendix 2. Electric conductivity values are plotted versus chloride concentrations in Figure A3-1.

The bromide and chloride concentrations are plotted in Figure A3-2. A plot of bromide versus chloride serves as a rough quality control of the bromide analyses.

The following routines for quality control and data management are generally applied for hydrogeochemical analysis data, independent of sampling method or sampling object.

- Several components are determined by more than one method and/or laboratory. Control analyses by an independent laboratory are normally performed as a standard procedure on every five or ten collected samples. Control analyses were not done in this case because of the small number of samples taken.
- All analytical results were stored in the SICADA database. The chemistry part of the database contains two types of tables, raw data tables and primary data tables (final data tables).

- Data on basic water analyses are inserted into raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample. These data sets are compiled in a primary data table named "water composition". The evaluation is based on:
- Comparison of the results from different laboratories and/or methods. The analyses are repeated if a large disparity is noted (generally more than 10%).
- Calculation of charge balance errors. Relative errors within ± 5% are considered acceptable. For surface waters errors of ± 10%.
- Rel. Error (%) = $100 \times \frac{(\sum \text{cations(equivalents)} - \sum \text{anions(equivalents)})}{(\sum \text{cations(equivalents)} + \sum \text{anions(equivalents)})}$
- General expert judgement of plausibility based on earlier results and experiences.

All results from "biochemical" components and special analyses of trace metals and isotopes are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a "best choice" notation will indicate those results which are considered most reliable.

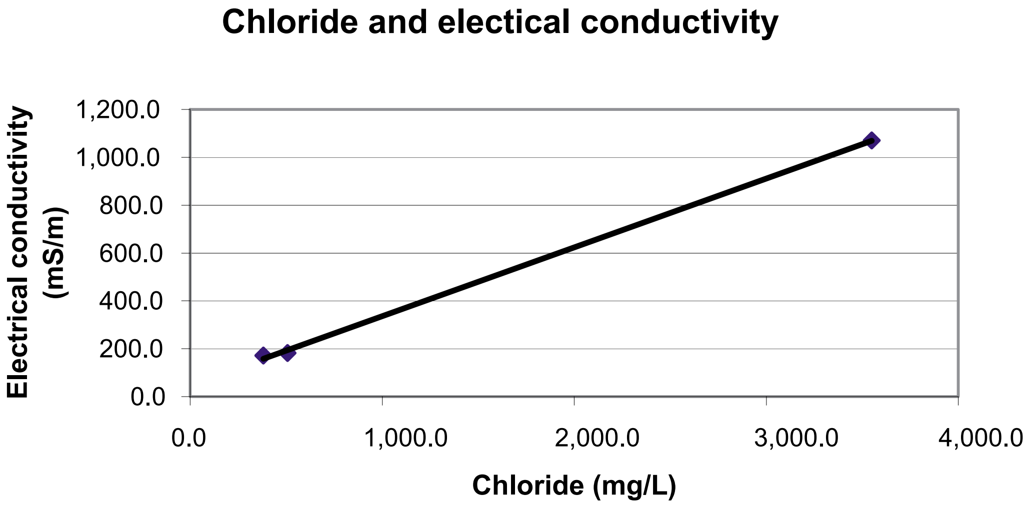


Figure A3-1. Plot of electrical conductivity versus chloride concentration.

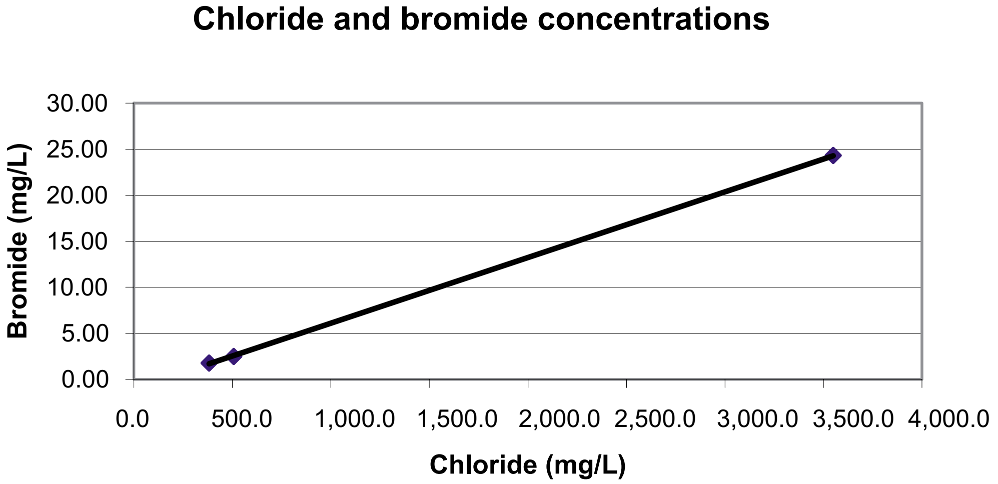
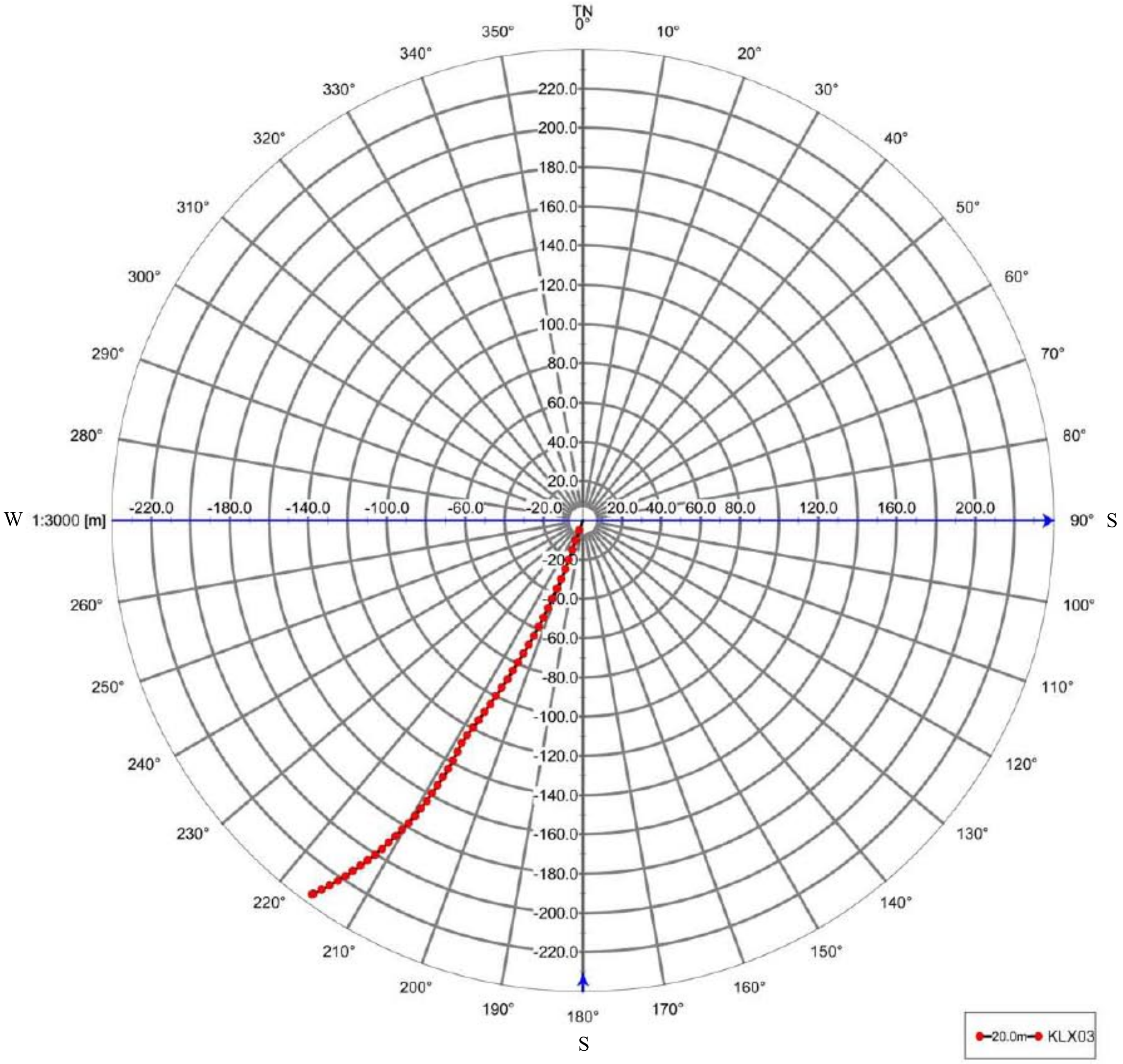


Figure A3-2. Plot of bromide concentrations versus chloride concentrations.

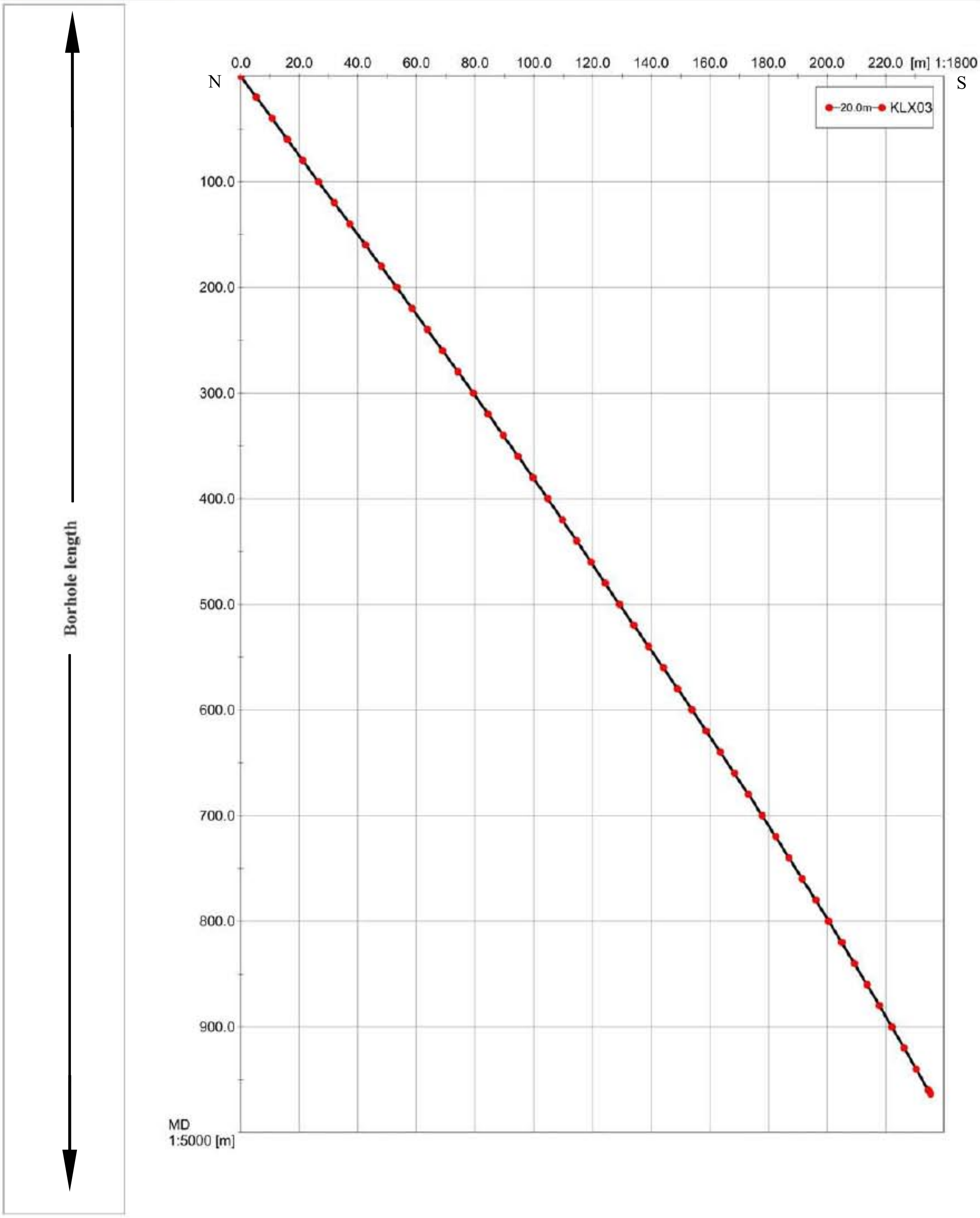
Appendix 4

Deviation measurements

Deviation measurement		Appendix: 4
Site	LAXEMAR	
Borehole	KLX03	
View from above		

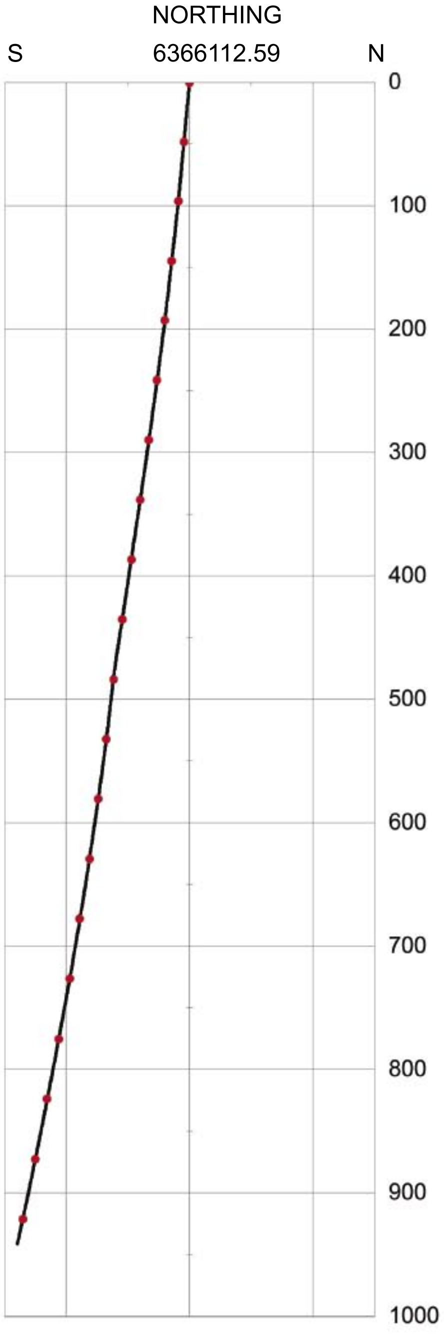


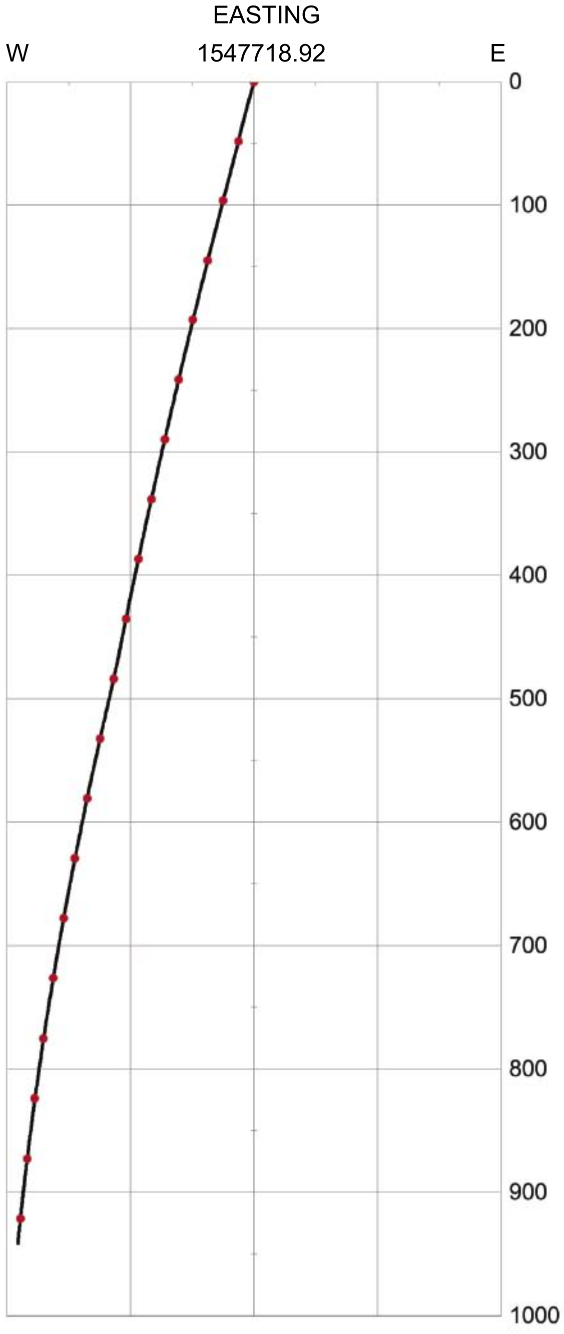
Site LAXEMAR
Borehole KLX03
Vertical Section



Appendix 4

Borehole KLX03
Site Laxemar
Coordinate system RT90-RHB70
Length 1000.42m
Bearing 199.04
Inclination -74.92
● Interval 50m





Appendix 5

Wireline pumping tests

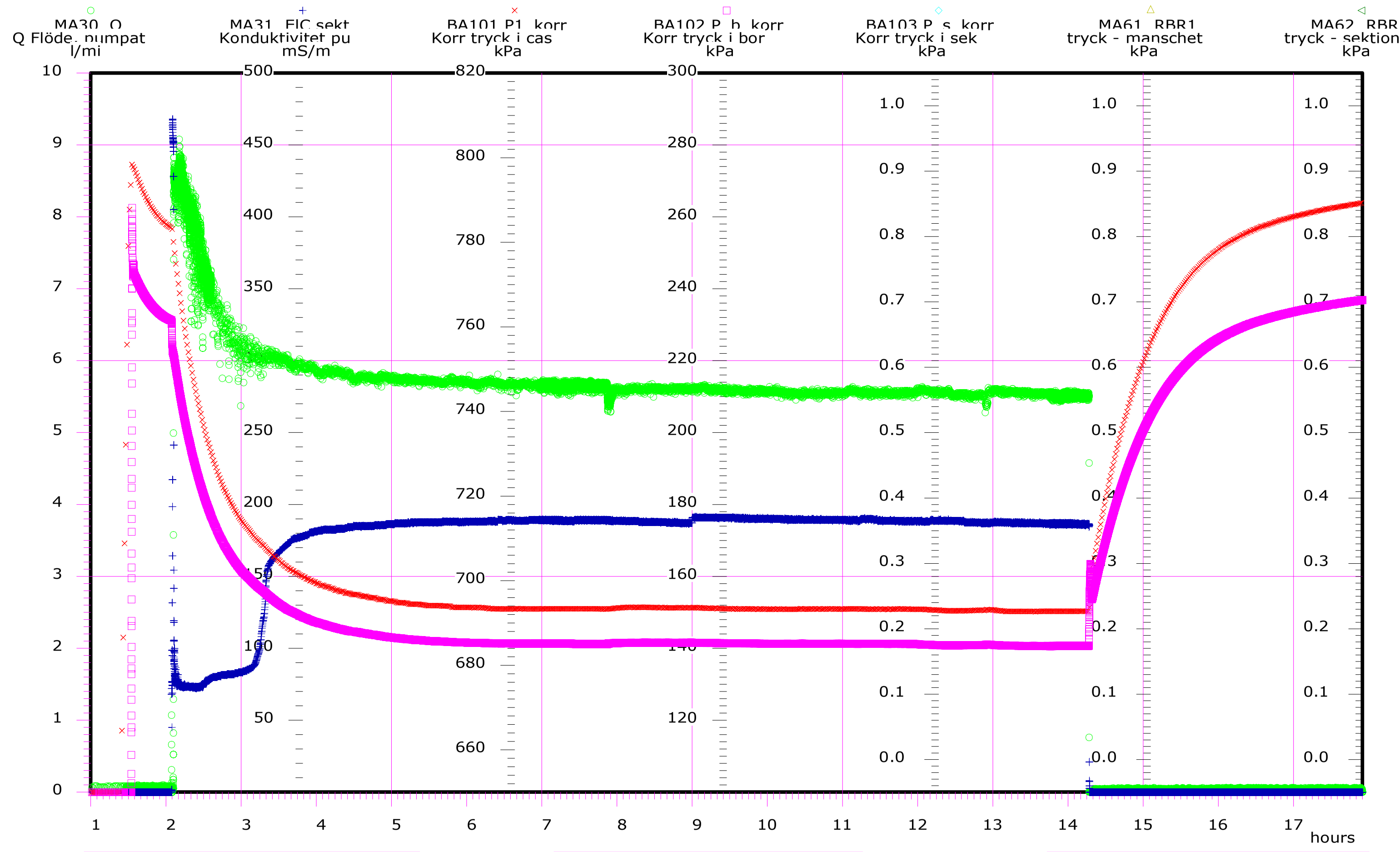
Description of the parameters in the enclosed plots.

Channel	Parameter	Unit	Description
MA30	Water flow	Litre/minute	Flow of water pumped up from the borehole during the test.
MA31	Electrical conductivity	mS/m	Electrical conductivity in the pumped out water
BA101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
BA102	Pressure	kPa	Pressure of the water column in the test section ie at depth in the borehole, subtracted with the ambient air pressure.
BA103	Pressure – section	kPa	Pressure of the water column in the test section ie at depth in the borehole, subtracted with the ambient air pressure.
MA61	Pressure – packer	kPa	Inflation pressure in packer
MA62	Pressure – section	kPa	Pressure of the water column in the test section ie at depth in the borehole. Not corrected for ambient air pressure

PLOT TIME :04/10/19 09:31:20
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test
KLX03 103.00-218.02m
Wireline sond



START :04/06/04 01:00:00

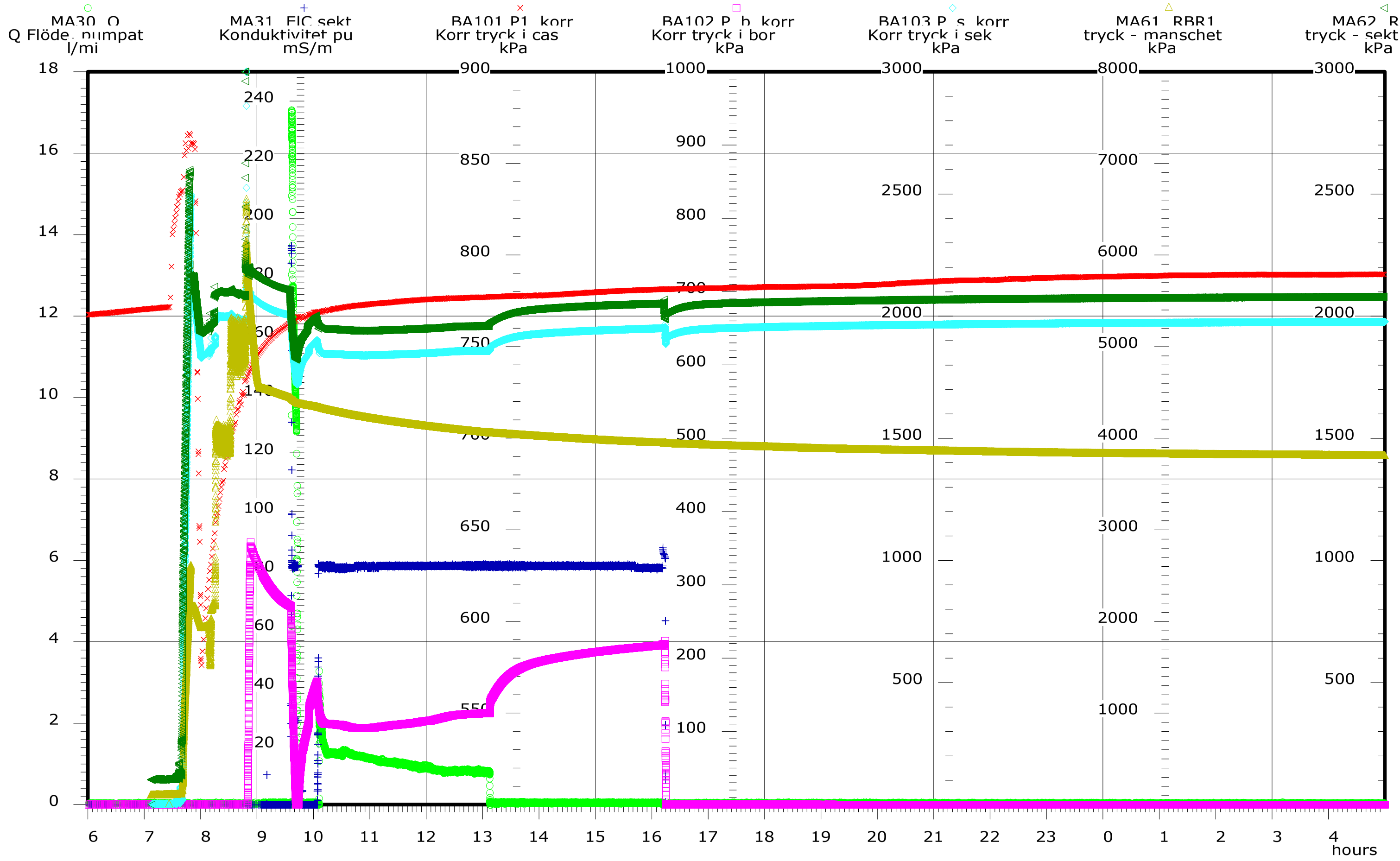
INTERVAL: All readings

STOP :04/06/04 17:54:59

PLOT TIME :04/09/23 15:31:00
PLOT FILE :P_pumptest
No DST Adjustment

DMS1 PO

Pumping test
KLX03 215.72-314.02m
Wireline sond



START :04/06/08 06:00:00

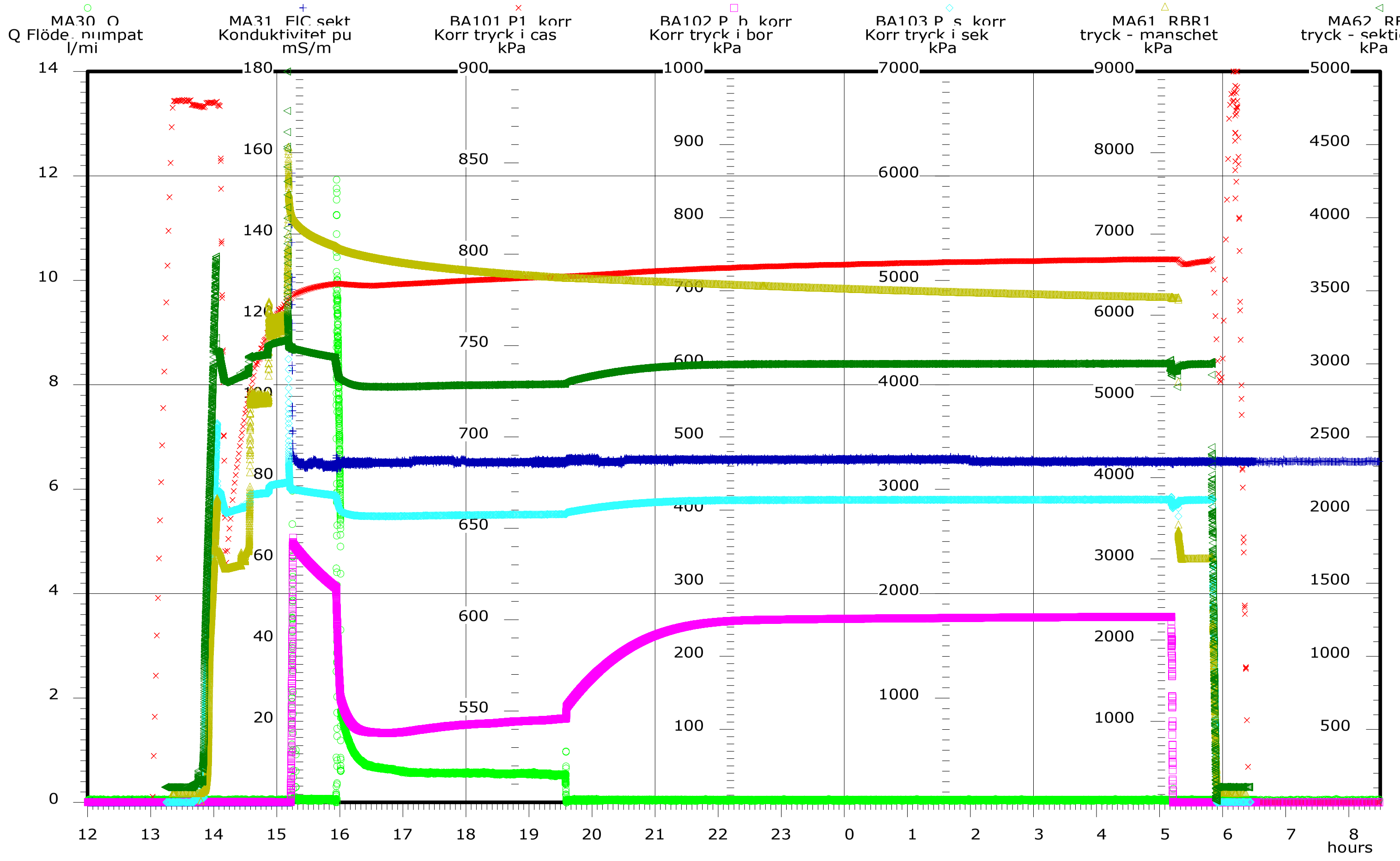
INTERVAL: All readings

STOP :04/06/09 04:59:59

PLOT TIME :04/09/23 16:05:33
PLOT FILE :P pumptest
No DST Adjustment

DMS1 PO

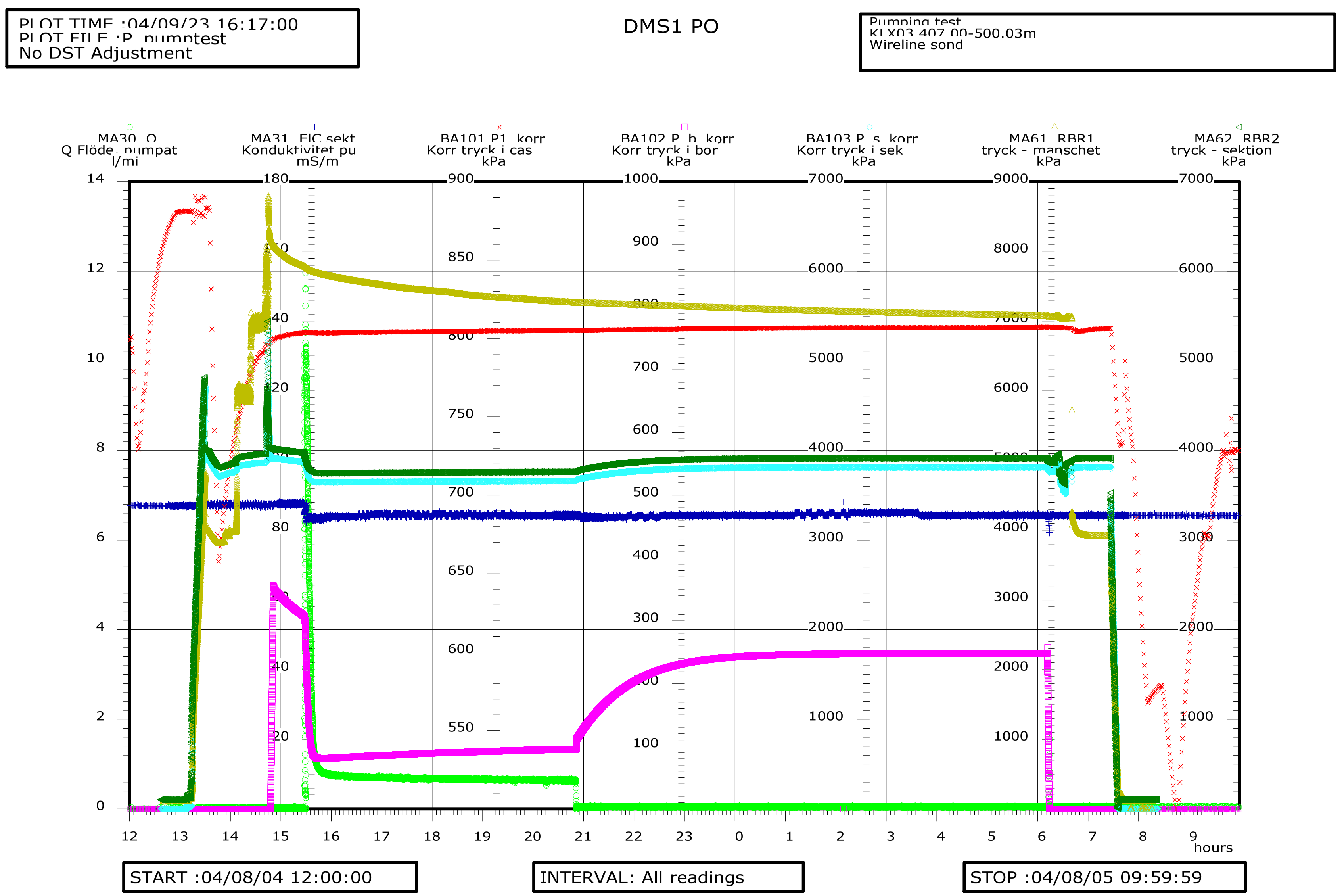
Pumping test
KLX03 312.00-408.02m
Wireline sond

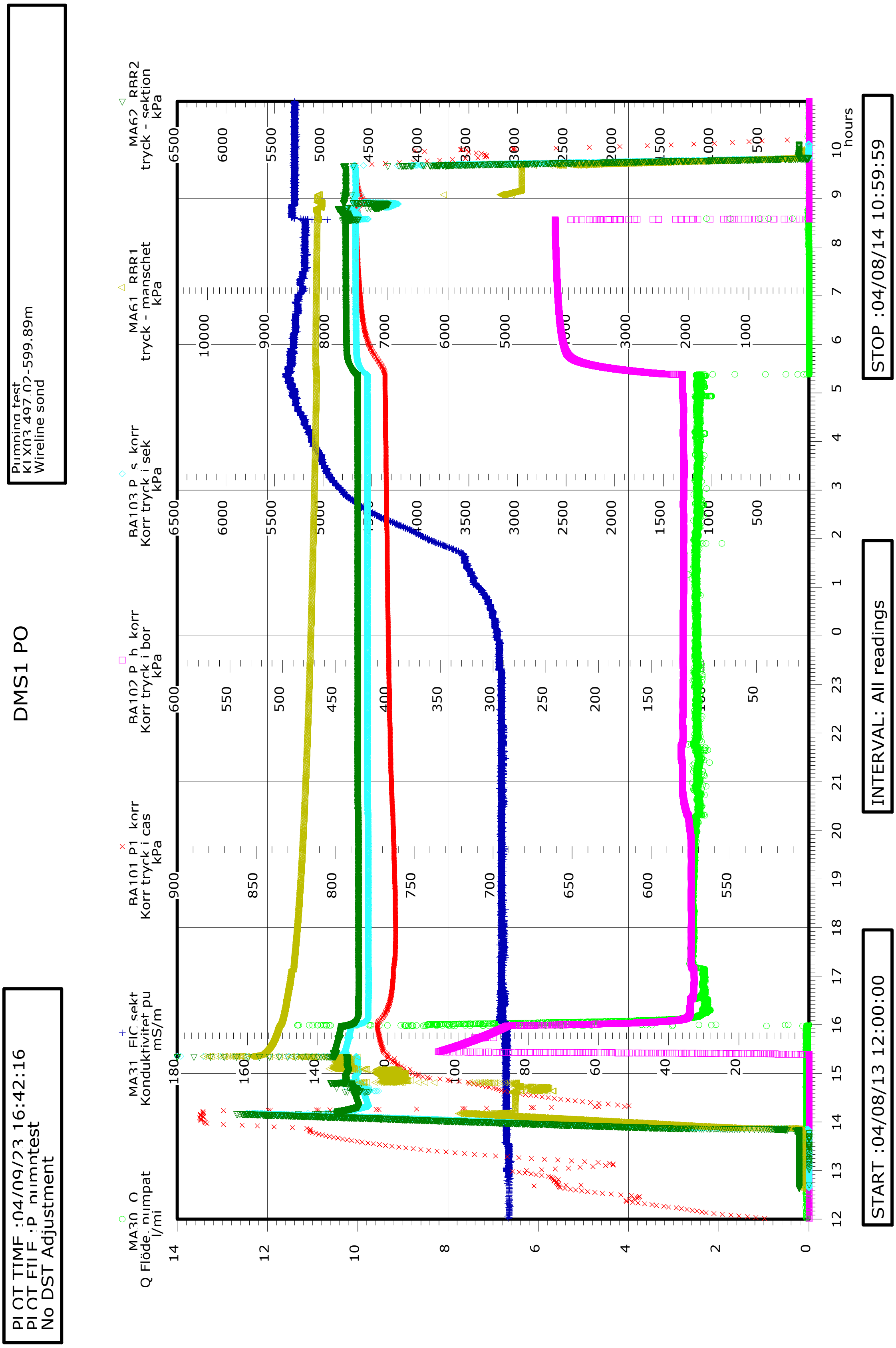


START :04/06/13 12:00:00

INTERVAL: All readings

STOP :04/06/14 08:29:59

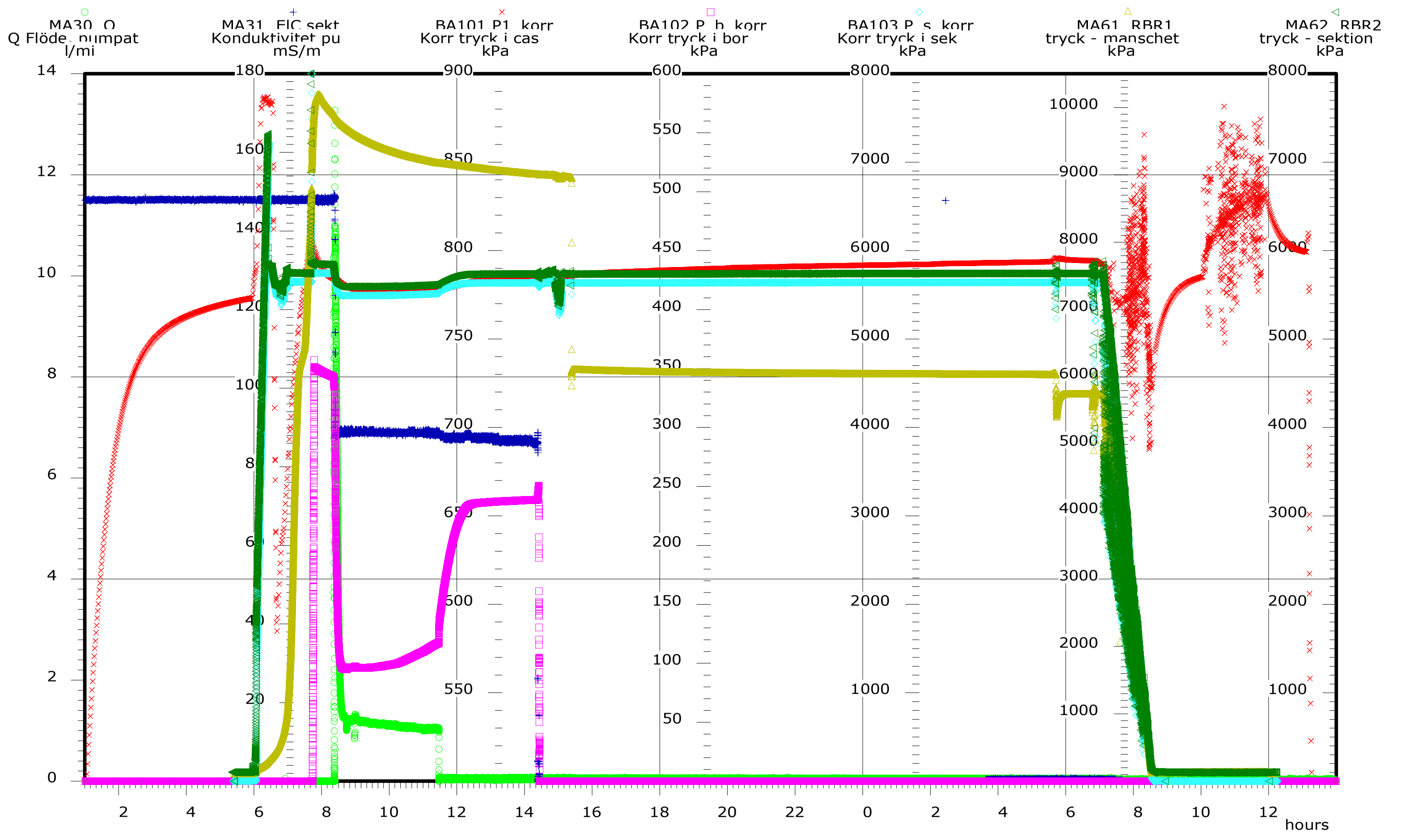

PLOT TIME :04/09/23 16:17:00
PLOT FILE :P_pumptest
No DST Adjustment
DMS1 PO
Pumping test
KLX03 407.00-500.03m
Wireline sond
MA30_Q
Q Flöde, pumpat
l/mi
MA31_EC sekt
Konduktivitet pu
mS/m
BA101_P1_korr
Korr tryck i cas
kPa
BA102_P_b_korr
Korr tryck i bor
kPa
BA103_P_s_korr
Korr tryck i sek
kPa
MA61_RBR1
tryck - manschet
kPa
MA62_RBR2
tryck - sektion
kPa
14
12
10
8
6
4
2
0
180
160
140
120
100
80
60
40
20
900
850
800
750
700
650
600
550
1000
900
800
700
600
500
400
300
200
100
7000
6000
5000
4000
3000
2000
1000
9000
8000
7000
6000
5000
4000
3000
2000
1000
7000
6000
5000
4000
3000
2000
1000
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6
7
8
9
hours
START :04/08/04 12:00:00
INTERVAL: All readings
STOP :04/08/05 09:59:59

PLOT TIME :04/09/23 16:42:16
PLOT FILE :P_pumptest
No DST Adjustment
DMS1 PO
Pumping test
KLX03 497.02-599.89m
Wireline sond
MA30 Q
Q Flöde pumpat
l/mi
MA31 FIC sekt
Konduktivitet pu
mS/m
RA101 P1 korr
Korr tryck i cas
kPa
RA102 P h korr
Korr tryck i bor
kPa
RA103 P s korr
Korr tryck i sek
kPa
MA61 RRR1
tryck - manschet
kPa
MA62 RRR2
tryck - sektion
kPa
0
2
4
6
8
10
12
14
20
40
60
80
100
120
140
160
180
550
600
650
700
750
800
850
900
50
100
150
200
250
300
350
400
450
500
550
600
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
12
13
14
15
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6
7
8
9
10
hours
START :04/08/13 12:00:00
INTERVAL: All readings
STOP :04/08/14 10:59:59

PLOT TIME :04/09/23 17:09:28
PLOT FILE :P_pumptest
No DST Adjustment

DMS1 PO

Pumping test
KLX03 600.00-695.24m
Wireline sond



START :04/08/17 01:00:00

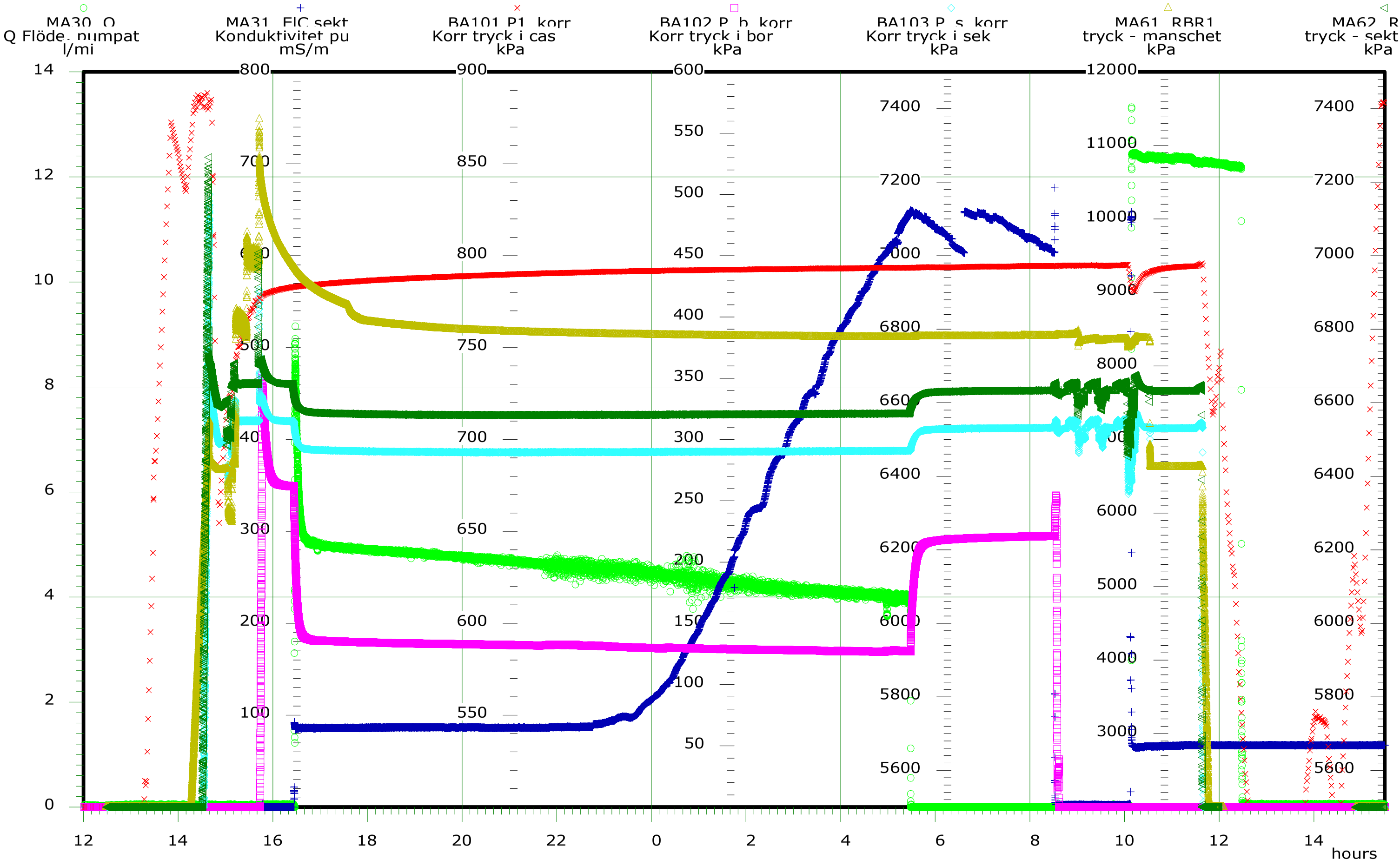
INTERVAL: All readings

STOP :04/08/18 13:59:59

PLOT TIME :04/09/24 08:19:23
PLOT FILE :P_pumptest
No DST Adjustment

DMS1 PO

Pumping test
KLX03 692.86-761.11m
Wireline sond



START :04/08/22 12:00:00

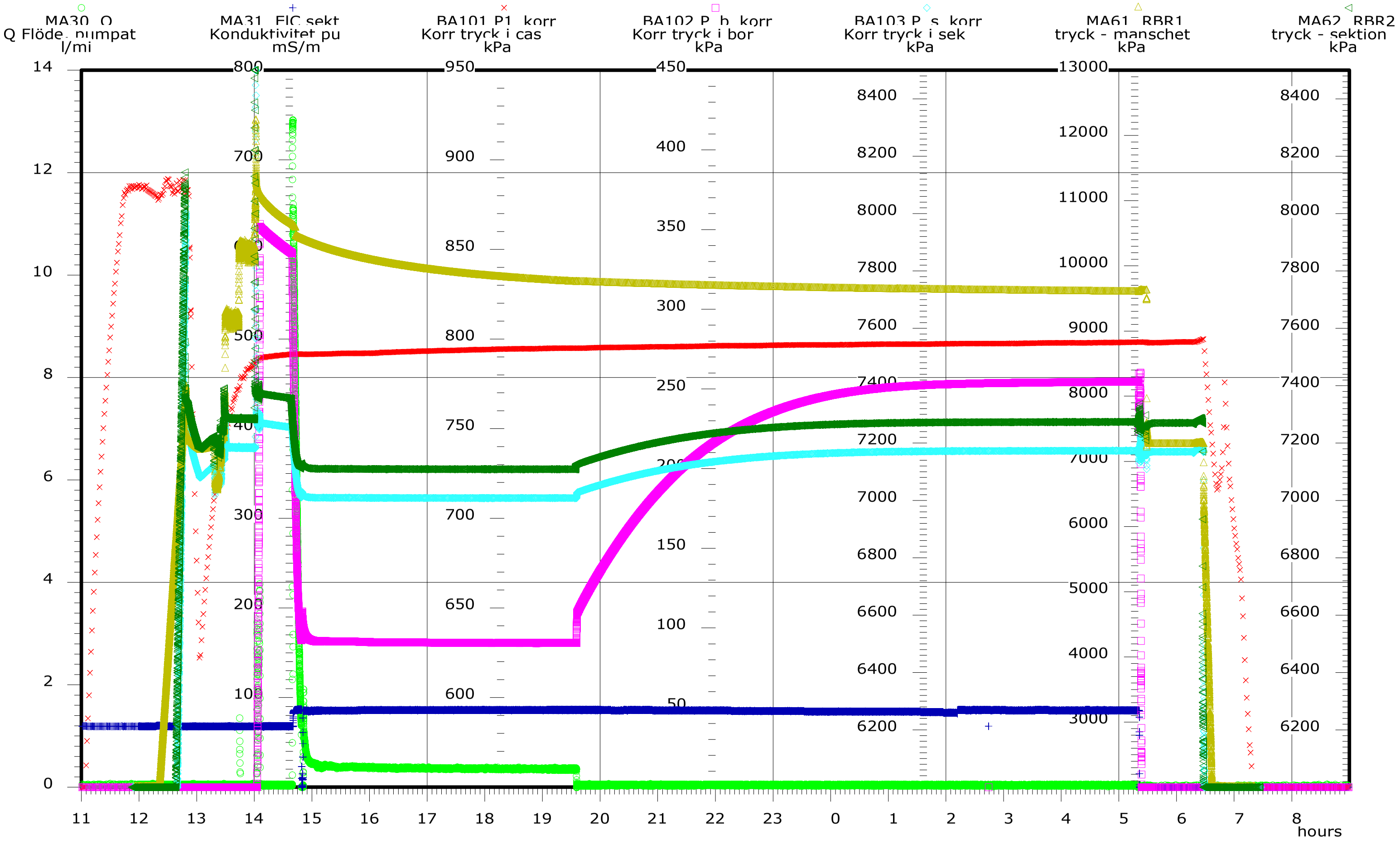
INTERVAL: All readings

STOP :04/08/23 15:29:59

PLOT TIME :04/09/24 08:40:28
PLOT FILE :P_pumptest
No DST Adjustment

DMS1 PO

Pumping test
KLX03 758.86-869.07m
Wireline sond



START :04/08/30 11:00:00

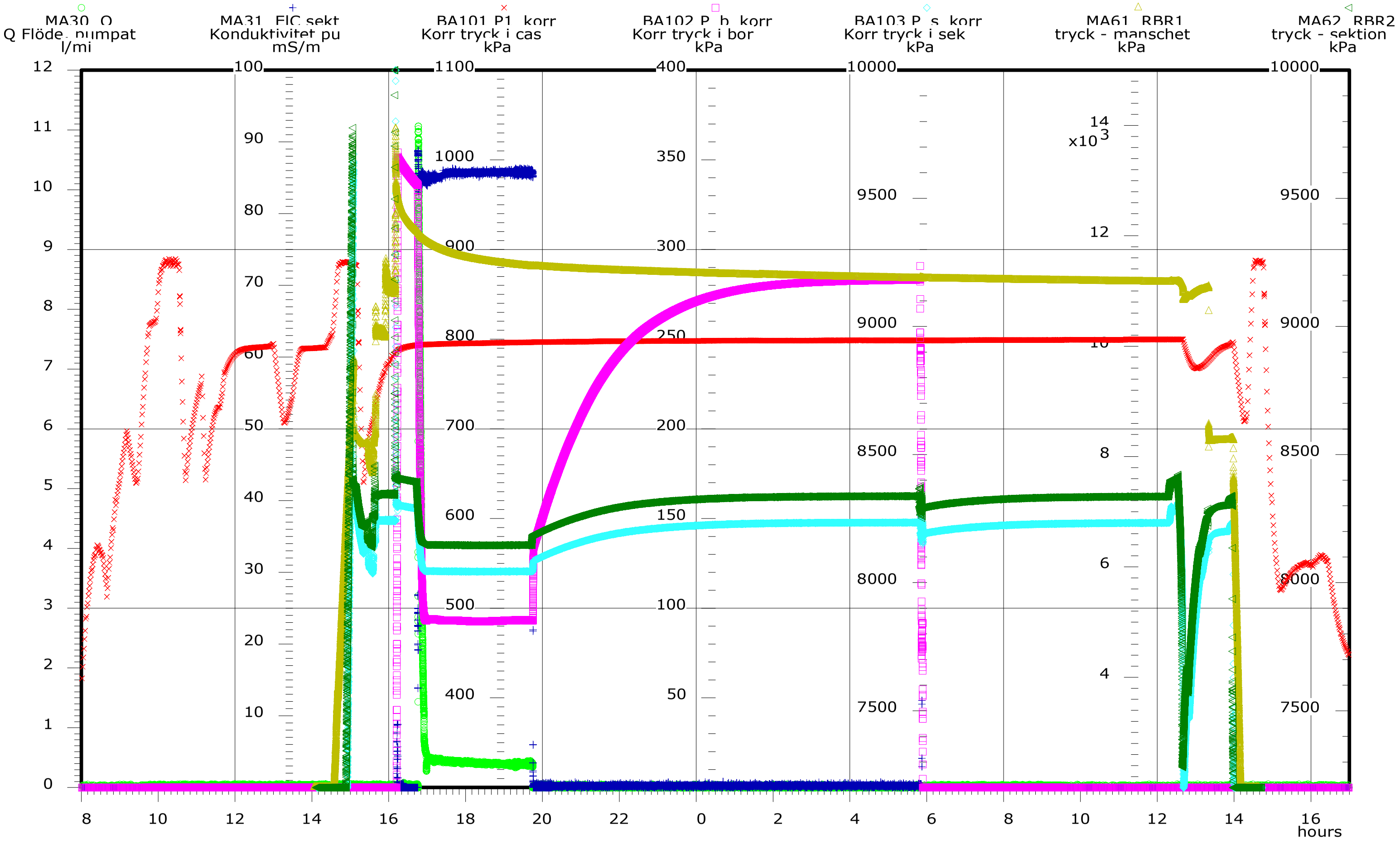
INTERVAL: All readings

STOP :04/08/31 08:59:59

PLOT TIME :04/09/24 09:35:06
PLOT FILE :P_pumptest
No DST Adjustment

DMS1 PO

Pumping test
KLX03 867.02-1000.42m
Wireline sond



START :04/09/07 08:00:00

INTERVAL: All readings

STOP :04/09/08 16:59:59

Appendix 6

Time series of absolute pressure measurements

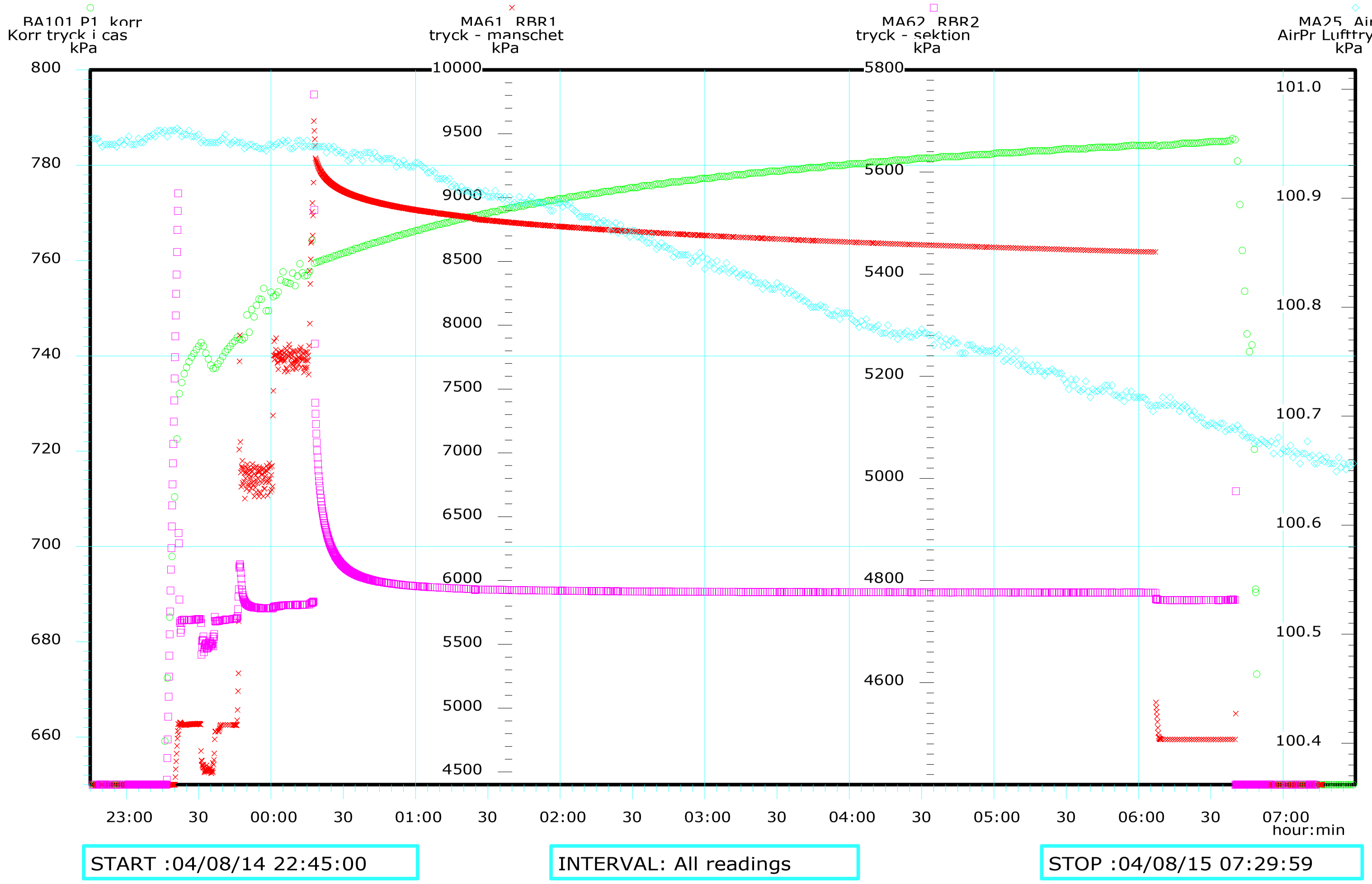
Description of the parameters in the enclosed plots.

Channel	Parameter	Unit	Description
BA101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
MA61	Pressure – packer	kPa	Inflation pressure in packer
MA62	Pressure – section	kPa	Pressure of the water column in the test section ie at depth in the borehole. Not corrected for ambient air pressure
MA25	Air pressure	kPa	

PLOT TIME :04/10/06 13:24:18
PLOT FILE :P_tryck_i _sektion
Adjusted for DST

DMS1 PO

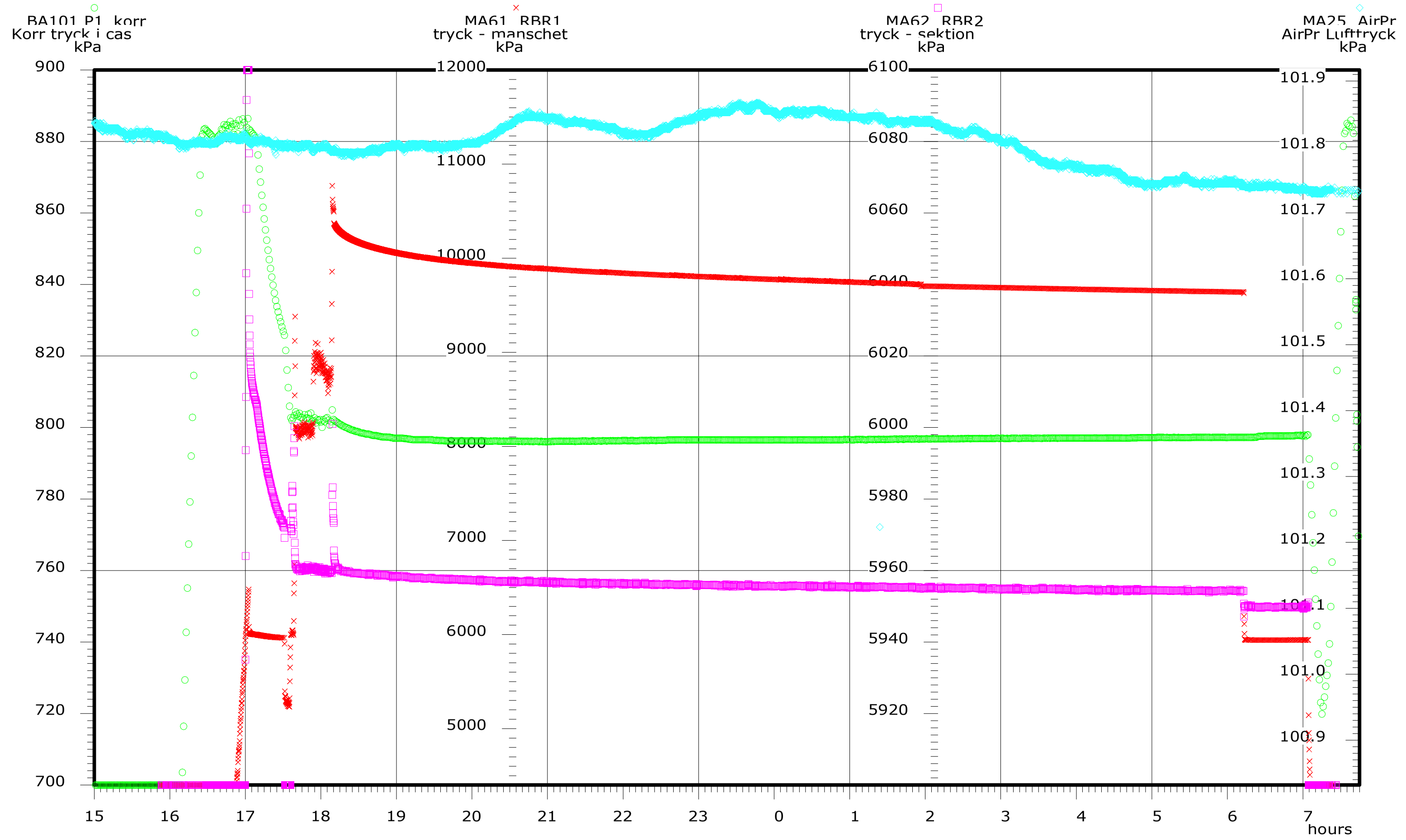
Absolute pressure measurement
KLX03 497.02-623.02m
Wireline sond



PLOT TIME :04/10/06 13:54:04
PLOT FILE :P_tryck_i _sektion
Adjusted for DST

DMS1 PO

Absolute pressure measurement
KLX03 620.86-764.09m
Wireline sond



START :04/08/23 15:00:00

INTERVAL: All readings

STOP :04/08/24 07:44:59

Appendix 7

Technical specifications of environmental monitoring wells SSM000017, SSM000019 and SSM000021

WSP

SIMPEVARP BOREHOLE SSM000017

Company rep.
Lennart Adestam and Torbjörn Johansson

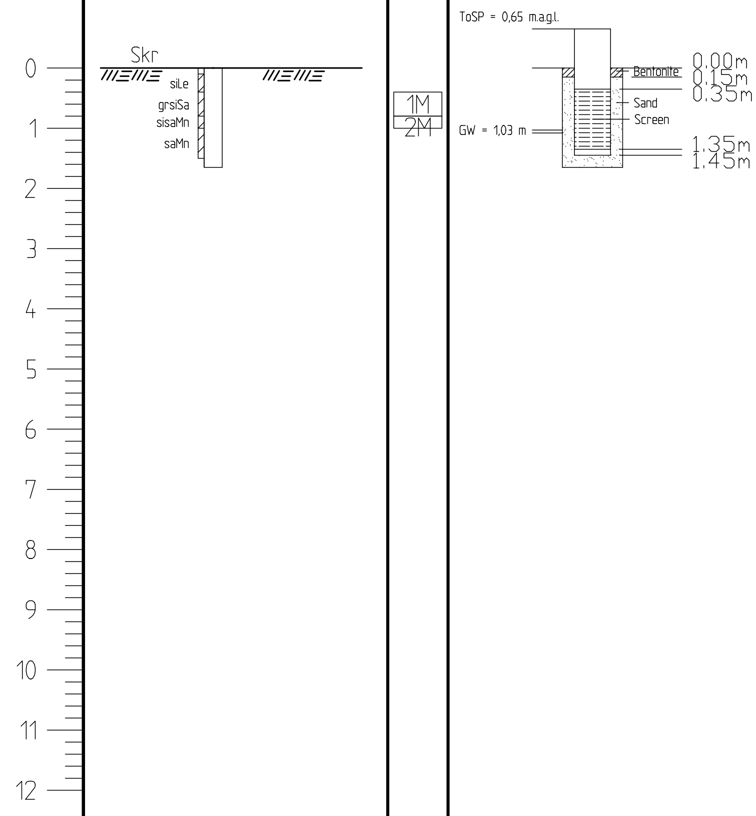
Client: Svensk Kärnbränslehantering AB

Northing :6365995.395
Easting :1547706.594

Coordinate system : RT90-RHB70

Top of stand pipe : 0,65 m.a.g.l.
Total pipe length : 2,10 m
Groundwater level : 1,03 m.b.g.l.
Date of completion : 2004-05-04

Depth (m) | Description | Samples | Groundwater monitoring well description | Borehole Construction Information



Drilling method : AUGER
Borehole diameter : 90 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 0,15 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,50 m

DRILLING EQUIPMENT
Drilling rig : Geotech 604
Drill hammer : Furukawa HB2G
Drill rod : Geostång Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG

0-0,1m	Top soil
0,1-0,4m	silty clay
0,4-0,8m	gravelly silty sand
0,8-1,0m	silty sandy till
1,0-1,5m	sandy till

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

SIMPEVARP BOREHOLE SSM000019

Company rep.
Lennart Adestam and Torbjörn Johansson

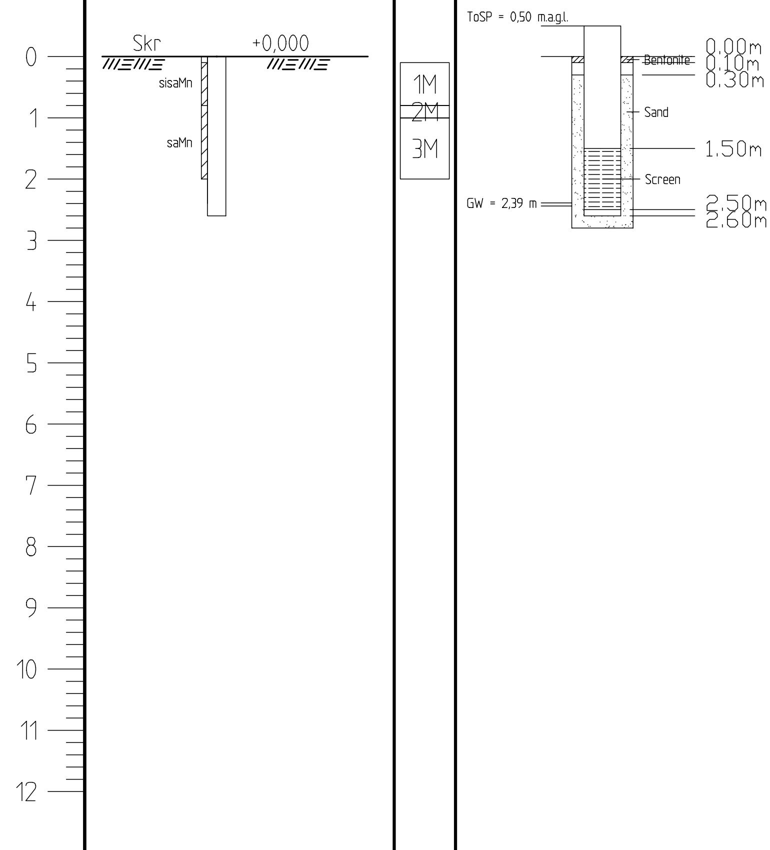
Client: Svensk Kärnbränslehantering AB

Northing :6366177.502
Easting :1547762.047

Coordinate system : RT90-RHB70

Top of stand pipe : 0,50 m.a.g.l.
Total pipe length : 3,10 m
Groundwater level : 2,39 m.b.g.l.
Date of completion : 2004-05-04

Depth (m) | Description | Samples | Groundwater monitoring well description | Borehole Construction Information



Drilling method : AUGER
Borehole diameter : 90 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 2,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 0,10 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 2,50 m

DRILLING EQUIPMENT
Drilling rig : Geotech 604
Drill hammer : Furukawa HB2G
Drill rod : Geostång Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG

0-0,1m	Top soil
0,1-0,8m	silty sandy till
0,8-2,0m	sandy till

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

SIMPEVARP BOREHOLE SSM000021

Company rep.
Lennart Adestam and Torbjörn Johansson

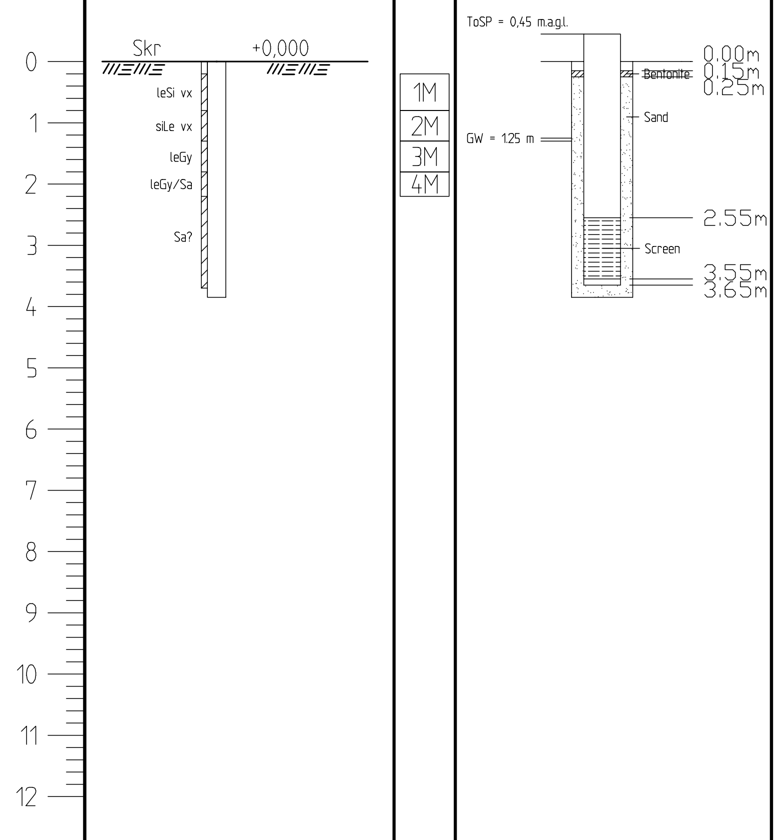
Client: Svensk Kärnbränslehantering AB

Northing	:6366889.706
Easting	:1547709.616

Coordinate system : RT90-RHB70

Top of stand pipe	:0,45 m.a.g.l.
Total pipe length	:4,10 m
Groundwater level	:1,25 m.b.g.l.
Date of completion	:2004-05-04

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method	: AUGER
Borehole diameter	: 90 mm
sampling method	: Auger

CASING

Material	: PEH
Outer diameter	: 63 mm
Inner diameter	: 50 mm
Total length	: 3,00 m

SCREEN

Material	: PEH
Outer diameter	: 63 mm
Inner diameter	: 50 mm
Total length	: 1,00 m
Slot	: 0,3 mm

ANNULUS SEAL

Material	: Bentonite clay
Total length	: 0,10 m

SAND PACK

Grain size	: 0,4-0,8 mm
Total length	: 3,60 m

DRILLING EQUIPMENT

Drilling rig	: Geotech 604
Drill hammer	: Furukawa HB2G
Drill rod	: Geostång Φ44
Drill bit	: Stift Φ54

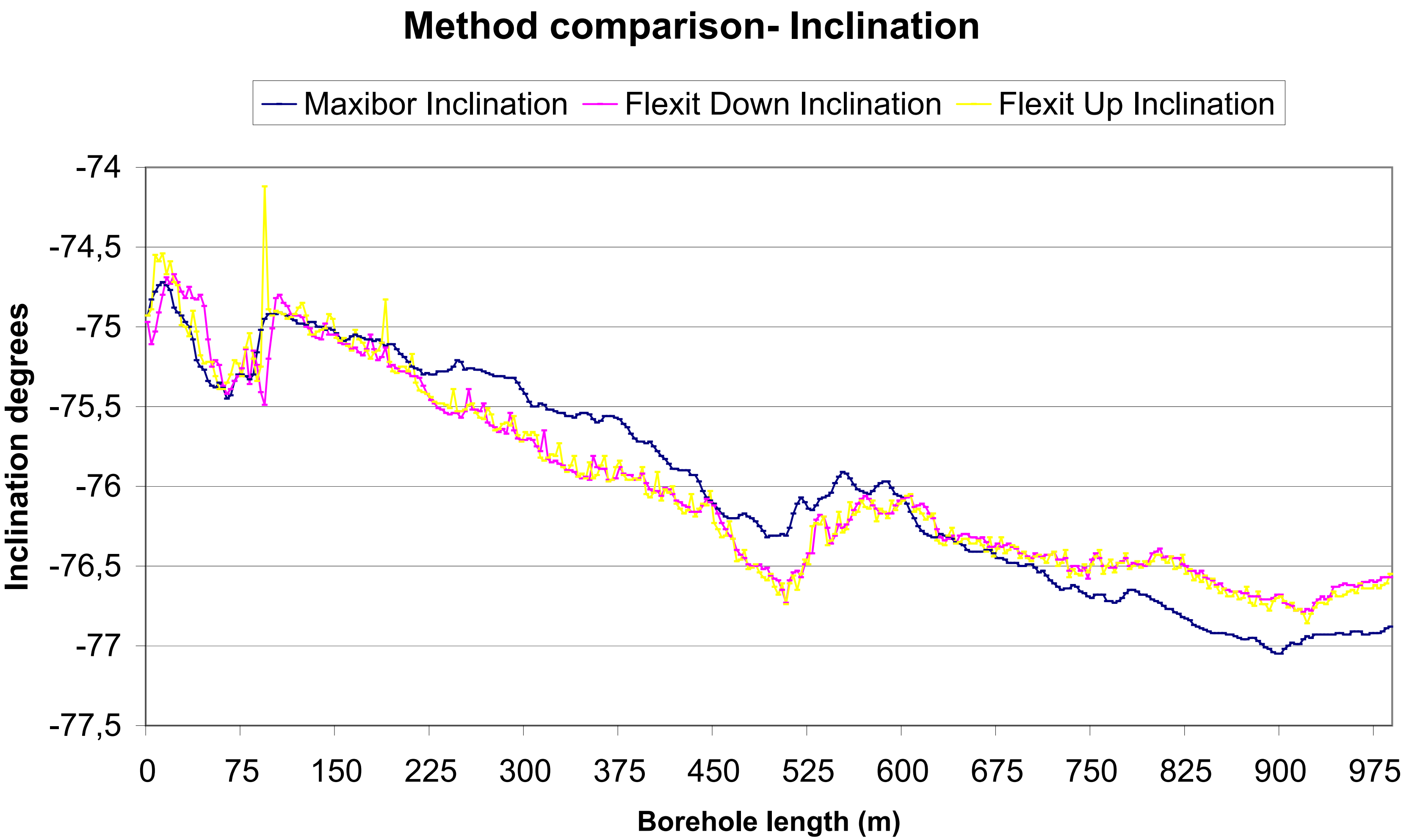
GEOLOGICAL LOG

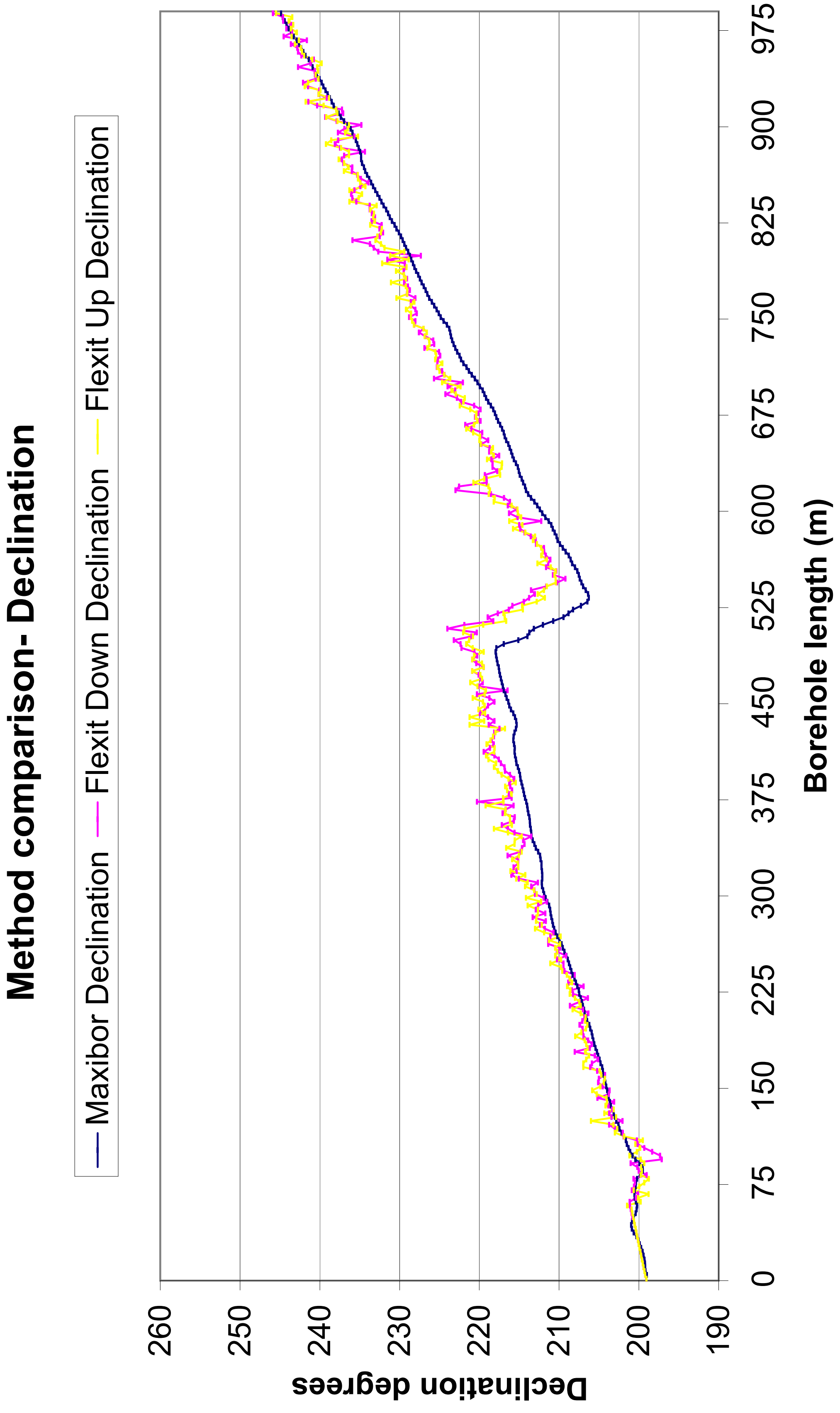
0-0,2m	Top soil
0,2-0,8m	clayey silt containing plant remains
0,8-1,3m	silty clay containing plant remains
1,3-1,8m	clayey gyttja
1,8-2,2m	clayey gyttja/sand
2,2-3,7m	frictional material (Sand?)

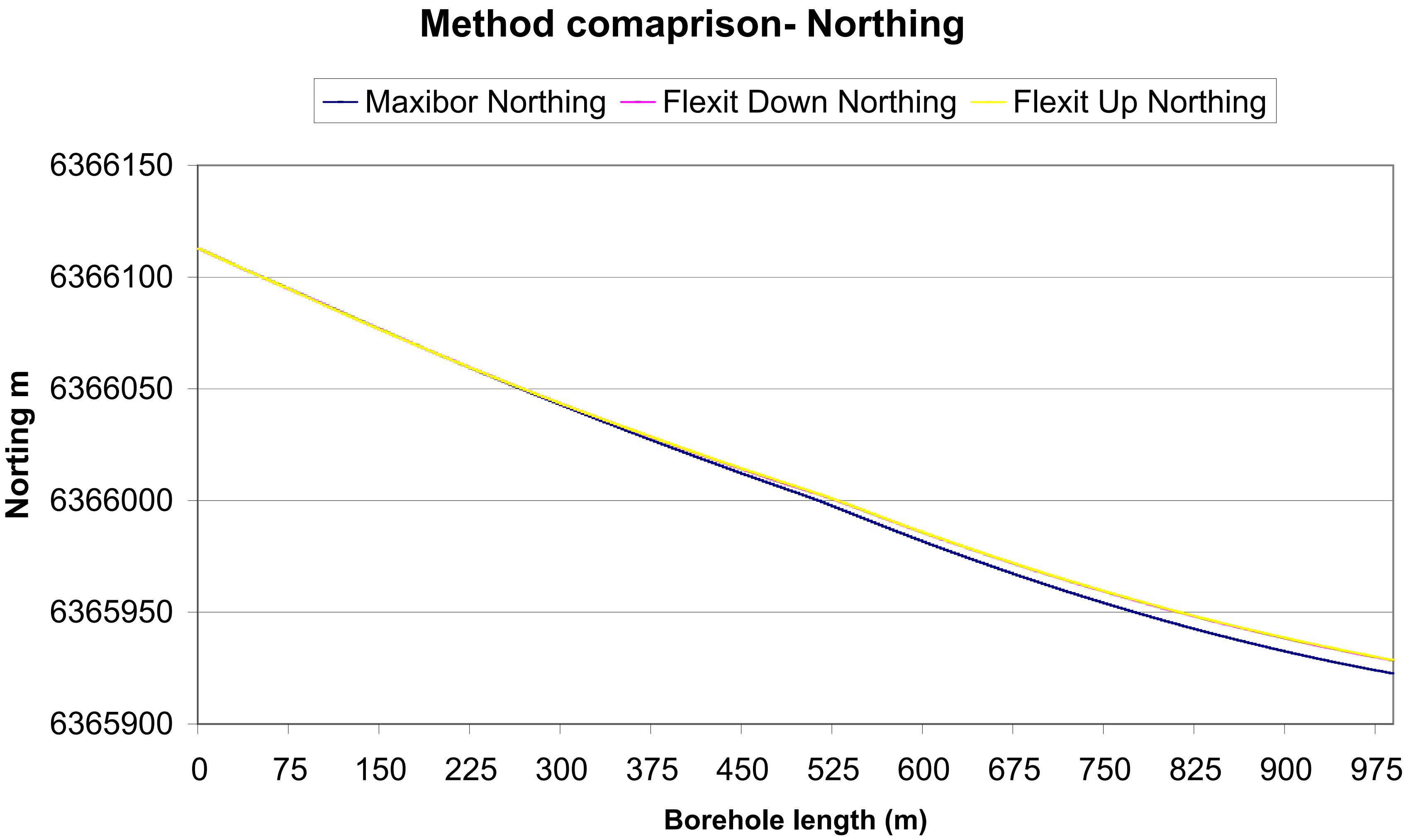
ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Appendix 8

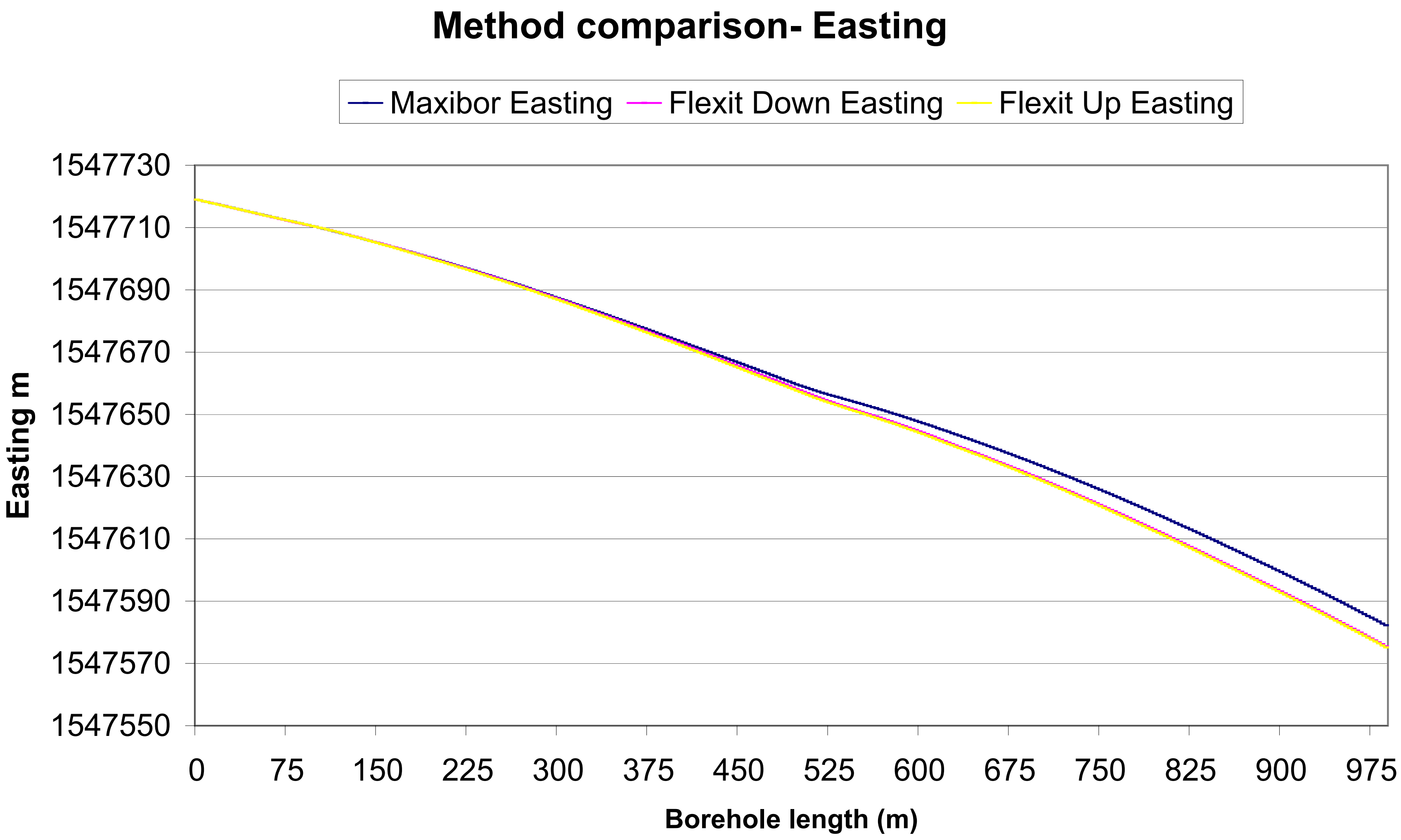
Method comparison between Maxibor and Flexit data for borehole deviation measurements

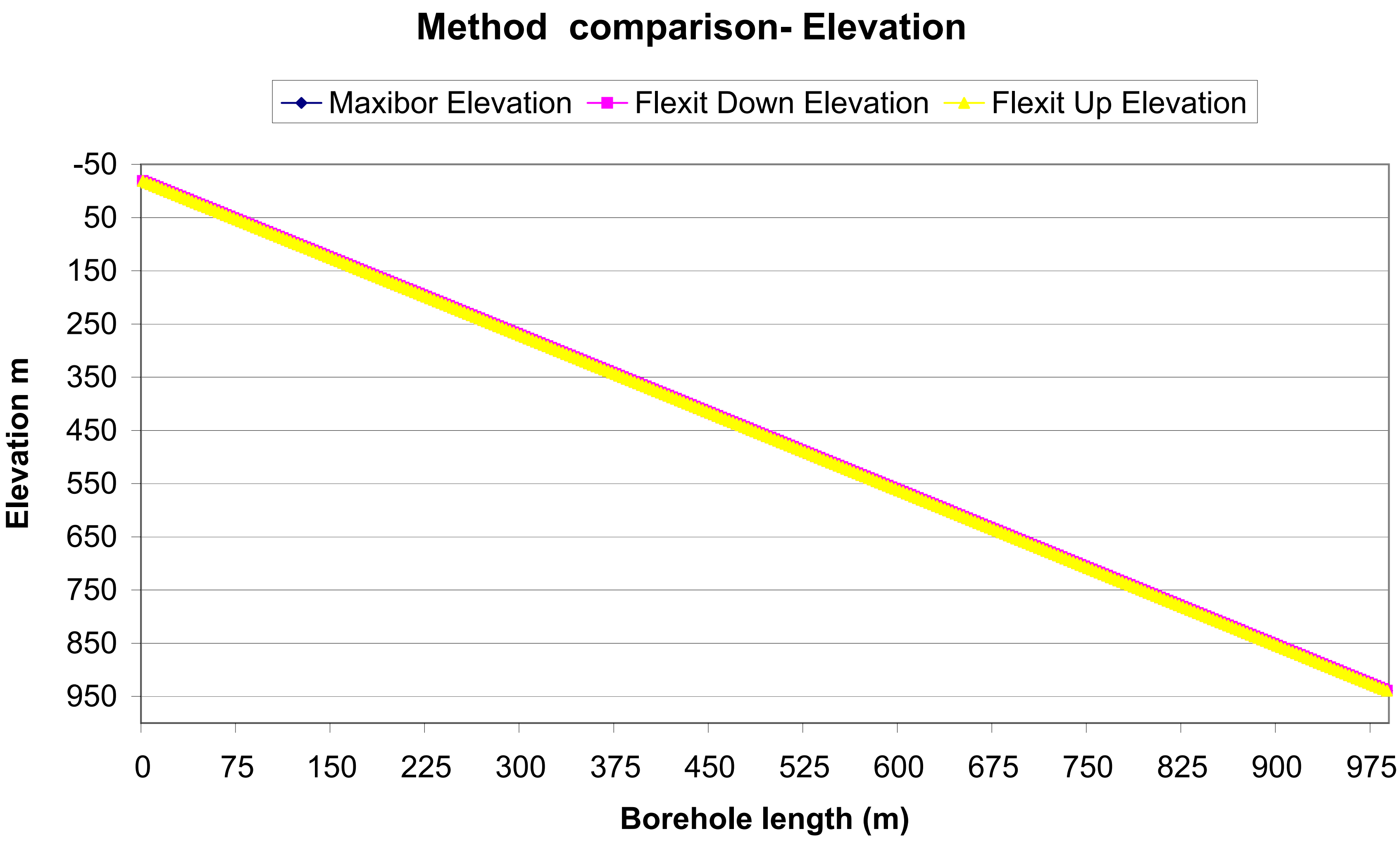



Method comparison- Declination
Maxibor Declination
Flexit Down Declination
Flexit Up Declination
Declination degrees
260
250
240
230
220
210
200
190
Borehole length (m)
0
75
150
225
300
375
450
525
600
675
750
825
900
975



Method comaprison- Northing


Method comparison- Easting
Maxibor Easting
Flexit Down Easting
Flexit Up Easting
Easting m
1547730
1547710
1547690
1547670
1547650
1547630
1547610
1547590
1547570
1547550
0
75
150
225
300
375
450
525
600
675
750
825
900
975
Borehole length (m)


Method comparison- Elevation
Maxibor Elevation
Flexit Down Elevation
Flexit Up Elevation
Elevation m
-50
50
150
250
350
450
550
650
750
850
950
0
75
150
225
300
375
450
525
600
675
750
825
900
975
Borehole length (m)