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December 2006

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Abstract

Borehole KLX10 is located in the Laxemar subarea. Drilling was made between May and October 2005 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden.

KLX10 was core drilled to a length of 1,001.20 metres with N-size (76 mm) equipment. The uppermost section, to the length of 100.6 metres, was constructed as a telescopic section with an inner nominal diameter of 200 mm.

A water inflow of 45 litres per minute was measured over the entire length of the telescopic section during percussion drilling.

Ten pumping tests were performed in KLX10 with wireline equipment, typically with one hundred metre intervals. The resulting transmissivities (T_M) varied between $1.0 \cdot 10^{-8}$ and $1.0 \cdot 10^{-4}$ m^2/s. The most transmissive section was between 298 and 407 metres.

Continuous monitoring of drilling parameters and flushing water parameters with the drilling monitoring system was conducted throughout the core drilling phase in KLX10.

Five water samples for chemical analysis were collected during the core drilling of KLX10. One of the samples had too high drill water content to warrant any further analysis.

An air-lift pumping test in the telescopic section performed when borehole KLX10 was core drilled to its full length gave a transmissivity (T_M) of $2.6 \cdot 10^{-4}$ m^2/s.

Lithologically the core is dominated by Ävrö granite. Minor sections of fine-grained diorite-gabbro, fine grained granite, fine-grained dioritoid and diorite-gabbro occur. The borehole ends in quartz monzodiorite from 980 to 1,000 m.

Oxidation (red-staining) with weak to medium intensity is common to 340 m. Below 340 m length the amount of oxidation is gradually reduced.

The distribution of total fractures in the core is typically in the range of 0–40 fractures/metre to a length of 460 m. Below 460 m the fracture frequency is significantly reduced, minor sections with elevated fracture frequencies do however occur.

The average fracture frequency over the entire core drilled section expressed as open fractures is 2.6 (fractures/metre).

Sammanfattning

Borrhål KLX10 ligger inom delområde Laxemar. Borrningen utfördes mellan maj och oktober 2005 som ett led i platsundersökningen för ett möjligt djupförvar för använt kärnbränsle i Oskarshamns kommun.

KLX10 kärnborrades med borrstorlek N (76 mm) till 1 001,20 meters borrad längd. Den övre delen av hålet, från markytan till 100,60 meter, utfördes som en teleskopdel med ca 200 mm inre diameter.

Ett vatteninflöde på 45 liter per minut kunde uppmätas över hela teleskopdelen vid hammarborrningen.

Tio pumptester med wireline-baserad mätutrustning utfördes över ca hundra meters intervaller. Uppmätta transmissiviteter (T_M) varierade mellan $1,0 \cdot 10^{-8}$ och $1,0 \cdot 10^{-4}$ m^2/s. Den mest transmissiva sektionen var mellan 298 och 407 meter.

Kontinuerliga mätningar av borrningsparametrar och spolvattenparametrar via DMS (drilling monitoring system) gjordes under hela kärnborrningsfasen i KLX10.

Fem vattenprover för kemisk analysering togs i samband med borrning i KLX10. Ett av proverna hade ett för högt spolvatteninnehåll för att medge ytterligare analysering.

En mammutpumpning i teleskopdelen som gjordes när kärnborrningen i KLX10 utförts till full längd gav en transmissivitet (T_M) på $2,6 \cdot 10^{-4}$ m^2/s.

Litologiskt domineras kärnan av Ävrögranit. Mindre inslag av finkornig diorit-gabbro, finkornig granit, finkornig dioritoid och diorit-gabbro förekommer. Borrhålet avlutas med kvartsmonzodiorit från 980 till 1 000 m.

Oxidation (rödfärgning) med svag till måttlig intensitet är vanlig ner till borrad längd 340 m. Nedanför 340 m borrad längd avtar oxidationsgraden gradvis.

Fördelningen av den totala mängden sprickor i kärnan är typiskt i intervallet 0–40 sprickor/meter ner till 460 m. Nedanför 460 m är sprickfrekvensen betydligt lägre, dock förekommer mindre partier med förhöjd sprickfrekvens.

Den genomsnittliga sprickfrekvensen över hela borrkärnan uttryckt som öppna sprickor är 2,6 (sprickor/meter).

Contents

1 Introduction

SKB, the Swedish Nuclear Fuel and 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 KLX10 is located in the central part of 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. KLX10 was the twelfth deep cored borehole within the Oskarshamn site investigation. The location of the core drilled borehole and the water sources, HLX27 and HLX10 in the Laxemar subarea is shown in Figure 1-1.

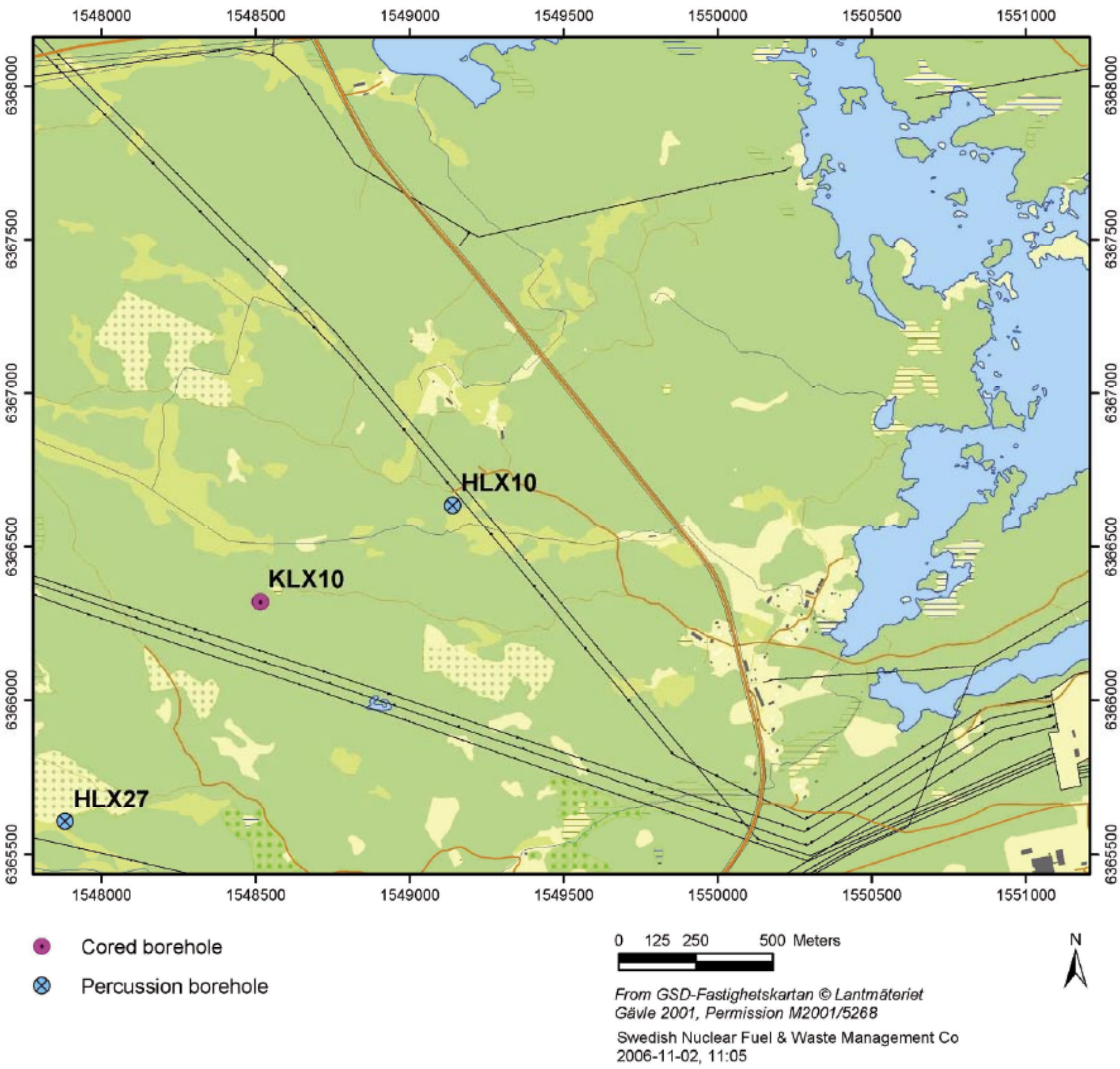


Figure 1-1. *Location of the cored borehole KLX10 and the water sources, percussion boreholes HLX27 and HLX10 in the Laxemar subarea.*

The drilling of KLX10 and all related on-site operations were performed according to a specific activity plan (AP PS 400-05-021), which in turn refers to a number of method descriptions, see Table 1-1.

The activity plans and method descriptions are SKB internal documents.

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

Activity plan	Number	Version
Kärnborrning KLX10	AP PS 400-05-021	1.0*
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 kvalitetssäkring av DMS data, Oskarshamn	SKB MD 640.008**	1.0
Instruktion för utsättning och inmätning av borrhål	SKB MD 600.002	1.0

* One amendment to AP PS 400-05-021 exists.

** The method description was formally approved on 2005-11-17.

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of borehole KLX10. 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 reason for drilling the borehole was to gain geological information and facilitate further investigation at depth in the central part of the Laxemar subarea. The decision for the location of KLX10 is given in SKB id no 1038385, dated 2005-04-19. An additional decision with the azimuth and dip of borehole KLX10 is given in SKB id no 1039775, dated 2005-05-19.

The hole was constructed as a "telescope hole", which means that the upper, normally, 100 metre 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 sent to the Regional Authorities 2005-03-03, SKB id no 1036192. Information of the final coordinates and details regarding the return water handling was submitted to the Regional Authorities on 2005-04-11, SKB id no 1037864.

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 metres followed by a N-size (76 mm diameter) 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 metres and 1,000 metres, 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.

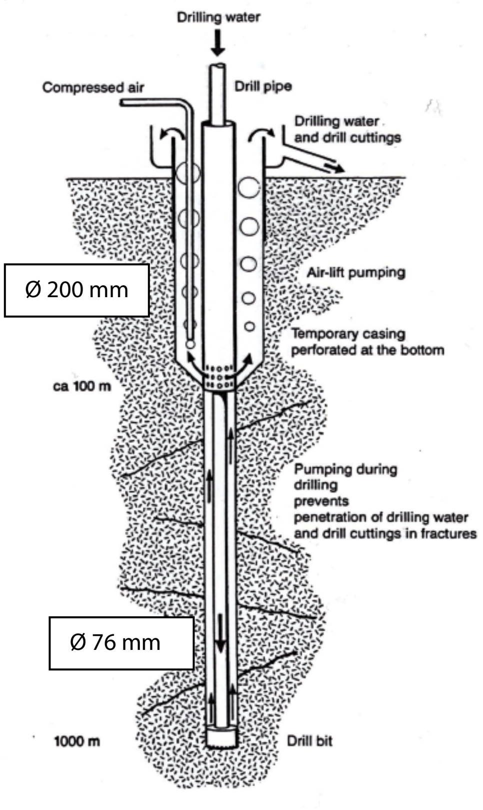


Figure 3-1. *A sketch of the telescopic drilling method with air-lift pumping for retrieval of drilling water and cuttings.*

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.

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.

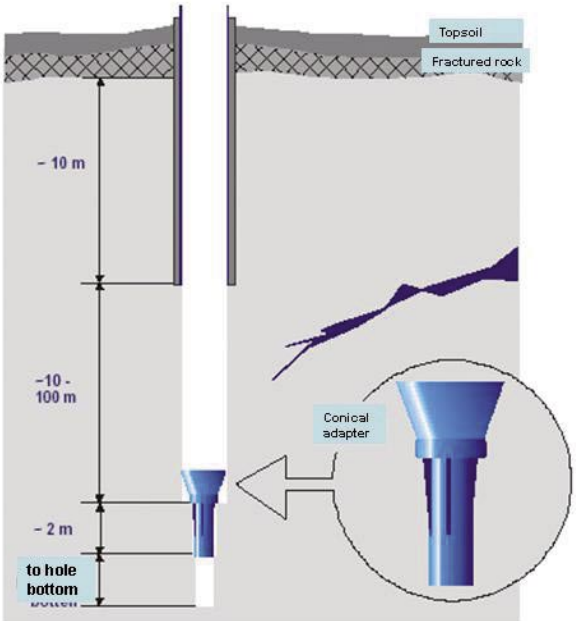


Figure 3-2. *Installation of the conical guide.*

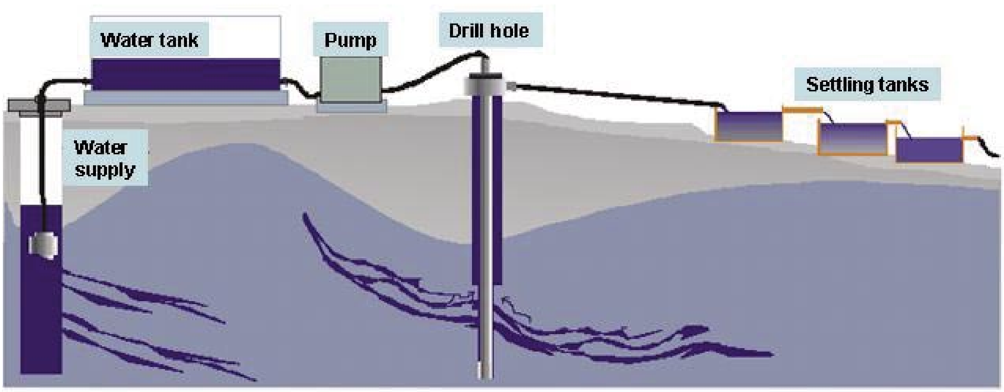


Figure 3-3. *The flushing water system from source to discharge point.*

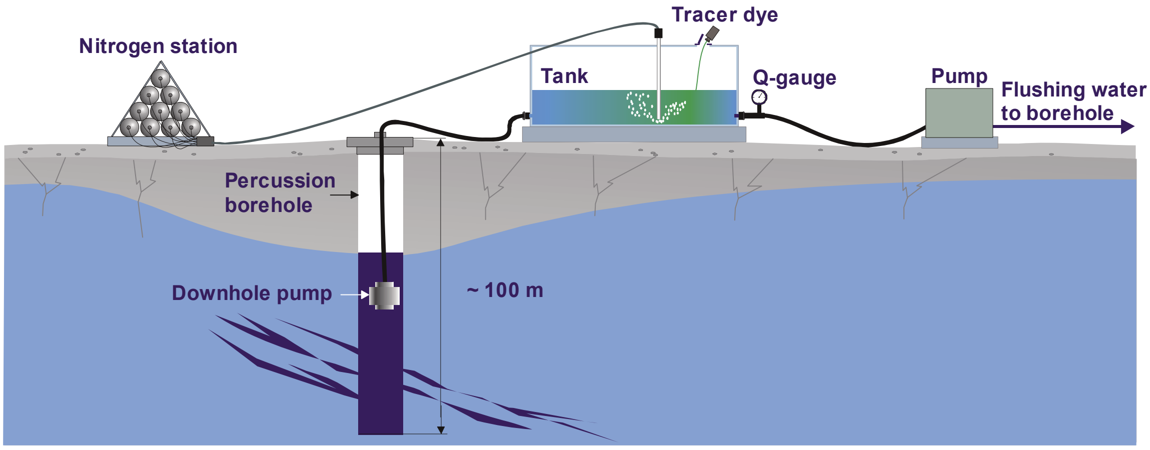


Figure 3-4. *Preparation of flushing water. Uranine is added to the water as a tracer dye. Nitrogen is bubbled through the water to remove dissolved oxygen.*

3.2 Measurements and sampling during drilling

3.2.1 Percussion drilling

Drill cuttings are collected for every metre during the percussion drilling. A preliminary geological logging of the cuttings is done on site. During the preliminary logging notes are made on the dominating lithology, size and shape of the cutting or any other noticeable geological feature. The magnetic susceptibility of the cuttings samples are measured with hand held equipment. Small cups of return water are taken systematically of the return water. The water colour and intensity are noted as indications on degree of rock oxidation and clay content. The return water flow (i.e. the amount of water driven up by compressed air) is measured when noticeable changes in flow occur. The drill penetration rate during percussion drilling is either logged automatically (most common) or manually.

3.2.2 Core drilling

The sampling and measurements during the core drilling phase of KLX10 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 wireline based equipment. The measurements for hydrogeological purposes include pumping tests and measurements of absolute pressure and are normally performed for every 100 metres 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 pumping with evaluation of drawdown and/or recovery is done with 300 metre intervals, nominally at 400, 700 and 1,000 metres length. The actual levels are adapted to when changes of drill bit, or some other reason to raise the drill stem, occur. The test is normally based on the drawdown phase.

- 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 two hours 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, i.e. the water entering and returning from the borehole at the surface, are taken at 10 to 20 metre 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).

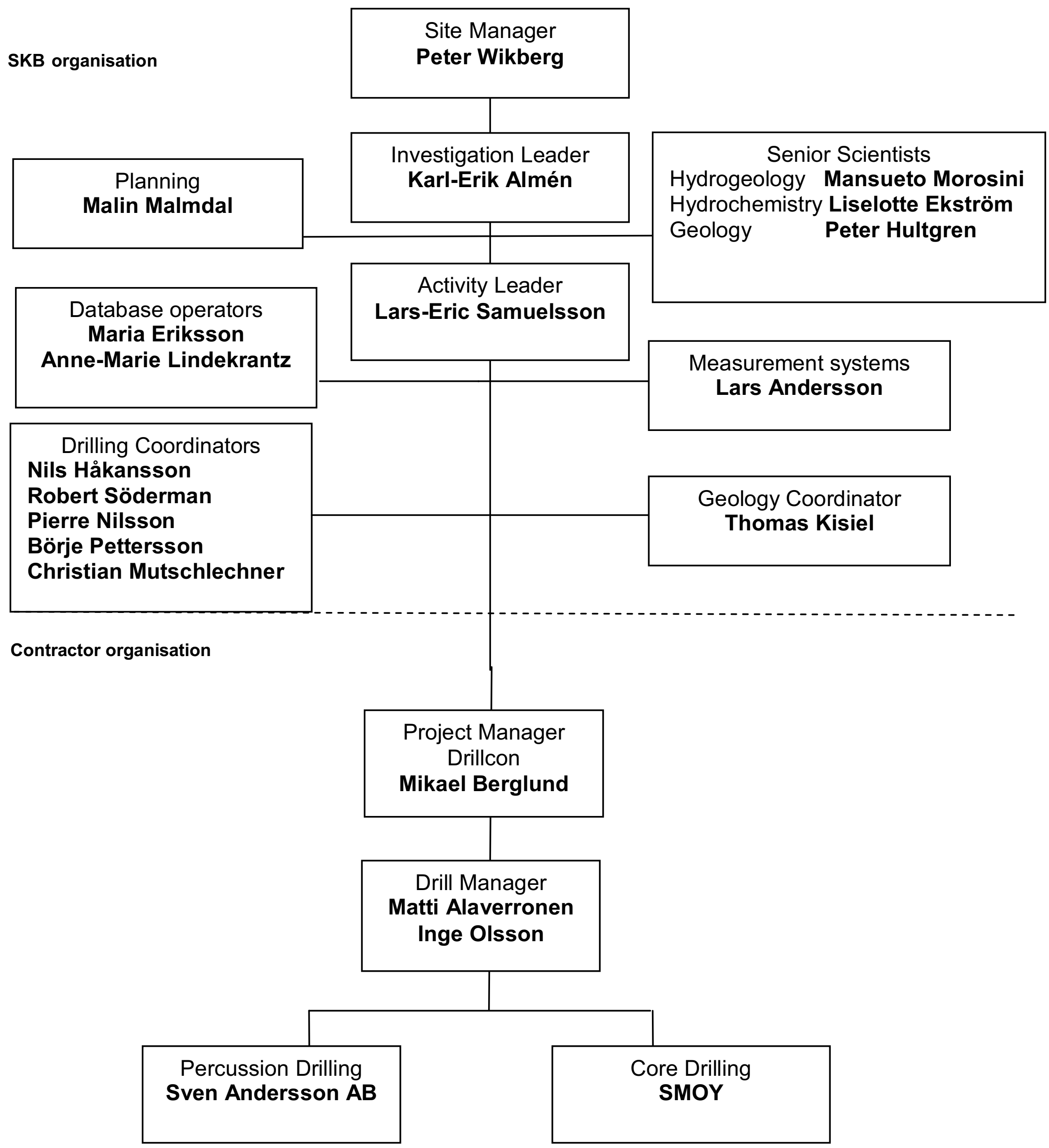
4 Contractors and equipment

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 in KLX10 was a Comacchio MC1500 percussion drill rig with an Atlas Copco XRVS 455 Md air compressor. Overburden drilling was made with NO-X 280 mm equipment. The down-the-hole hammer was a Secoroc 165 mm for the pilot borehole and the drill rods were Driqoneq 114 mm. Reamings were done with Secoroc DTH-hammers for 200 or 250 mm diameter. The casings utilized were 208×4 mm (SS 2343, stainless) and 311×15 mm (non stainless). The casing dimensions are presented here as outer diameter×thickness. The drill rig is shown in Figure 4-1.

4.3 Core drilling equipment

Core drilling in KLX10 was made with a Diamec U8 APC Atlas Copco fully hydraulic machine fitted with a modern and environmentally adapted diesel engine. The drilling was done with N-size, i.e. giving a borehole of 76 mm diameter. The core barrel was of the type AC Corac N3/50, a triple-tube wireline equipment which gives a core diameter of 50.2 mm. The rods were of type NT.

The drill rig was fitted with a diesel power generator of 175 kW which would give a capacity for drilling to a depth of ca 1,500 m with N-size drilling.

4.3.1 Equipment for directional drilling

Directional drilling, i.e. intentional guiding or changing of the drilling direction, was made with a Liwinstone tool for N-size (76 mm) boreholes.

The Liwinstone 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 conventional methods, i.e. 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 metres of recovery. The resulting core has a diameter of 45 mm.

Figure 4-1. *The Comacchio MC1500 percussion drill rig at KLX10.*

Figure 4-2. *The drill site and core drilling equipment at KLX10.*

The working procedure for the Liwinstone directional tool is as follows:

- The Liwinstone tool is lowered into the borehole.
- The direction of the tool is adjusted by measurements with the Maxibor equipment, see Section 4.3.4.
- 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.

4.3.2 Measurements with wireline probe

The wireline probe 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 as specified in method description SKB MD 321.002, SKB internal document.

The principal components are:

- an inflatable packer,
- 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 is 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 4-3.

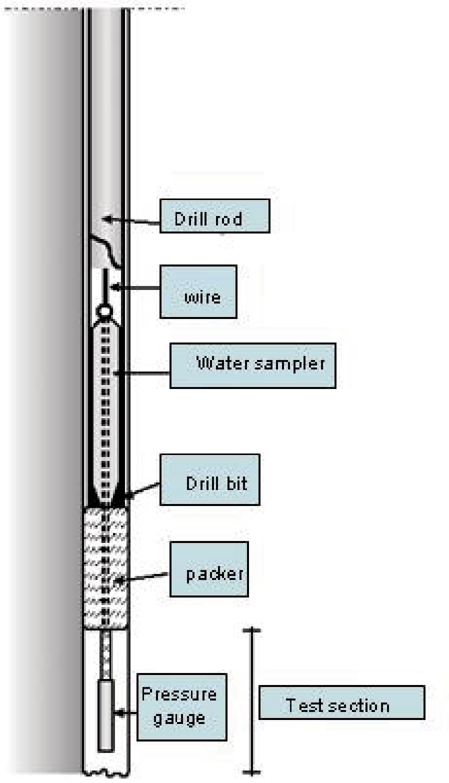


Figure 4-3. The wireline probe and its emplacement in the hole.

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

Pumping tests

The wireline probe is emplaced at the bottom of the drill stem. A submersible pump (Grundfoss MP1 or equivalent) 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 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. The pumped surface flow rate is recorded in a data logger on the ground surface. The pressure gauge (or 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 the sampling unit containing a maximum 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 flow rate during the pumping test exceeds 1 litre per minute.

4.3.3 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 procedure for data handling and quality assurance is given in method description SKB MD 640.008 (SKB internal document).

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).

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

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).
- Barometric 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.

4.3.4 Deviation measurements

Two types of deviation measurements were made:

- Measurements to keep track on the borehole direction and dip in order to make decisions on whether directional drilling was needed or not were made at 100 metre intervals with the magnetometer/accelerometer method Reflex EZ-AQ/EMS, also called "Easy-shot".
- Final measurements, along the entire length of the borehole after the drilling was completed, were made with two methods, Flexit and Maxibor. The Maxibor (Reflex MAXIBOR™) is a non-magnetic, optical method. The Flexit instrument (Flexit SmartTool) is based on magnetometer/accelerometer measurements. The Maxibor tool was run both up and down the borehole and upwards measurements were made with the Flexit tool. In all, three individual deviation measurements were done along the entire length of borehole KLX10.

4.3.5 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 the cutters expand when the water pressure is increased.

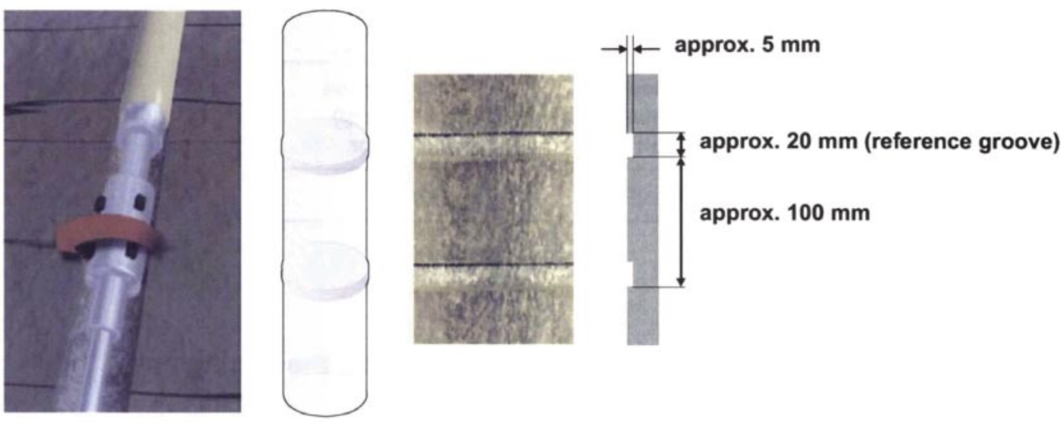


Figure 4-5. The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.

5 Execution and results

5.1 Summary of KLX10 drilling

A technical summary of the drilling of KLX10 is given in Table 5-1. A graphical presentation of the borehole after completion is given in 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.

Further descriptions of the percussion drilling of the telescopic section 0–100.60 metres and the measurements performed during this phase are given in Section 5.2. The core drilling between 100.60–1,001.20 metres is further described in Section 5.3. Results from hydrogeological and hydrogeochemical measurements during core drilling are presented in Section 5.4. Drilling progress over time is further reported in Section 5.5 "Drilling monitoring results".

Table 5-1. KLX10 Technical summary.

General	Technical
Name of hole: KLX10	Percussion drill rig Comacchio MC1500
Location: Laxemar, Oskarshamn Municipality, Sweden	Percussion hole length 100.50 m (diam 197.3 mm) 100.60 m (diam 162.8 mm)
Contractor for drilling: Drillcon AB	Core drill rig U8 APC Atlas Copco
Subcontractor percussion drilling: Sven Andersson AB	Core drill dimension N-size (76 mm)
	Cored interval 100.60–1,001.20 m
Subcontractor core drilling: Suomen Malmi OY (SMOY)	Average core length retrieved in one run 2.54 m
	Number of runs 354
Drill start date May 24, 2005	Diamond bits used 13
Completion date October 15, 2005	Average bit life 69 metres
	Position KLX10 (RT90 RH70) at top of casing:
	N 6366319.38 E 1548515.23 Z 18.28 (masl)
	Azimuth (0–360)/Dip (0–90)
	250.81/–85.19
	Position KLX10 (RT90 RH70) at 996 m length:
	N 6366312.48 E 1548410.17 Z –972.05 (m.a.s.l.)
	Azimuth (0–360)/Dip (0–90)
	274.5/–84.0

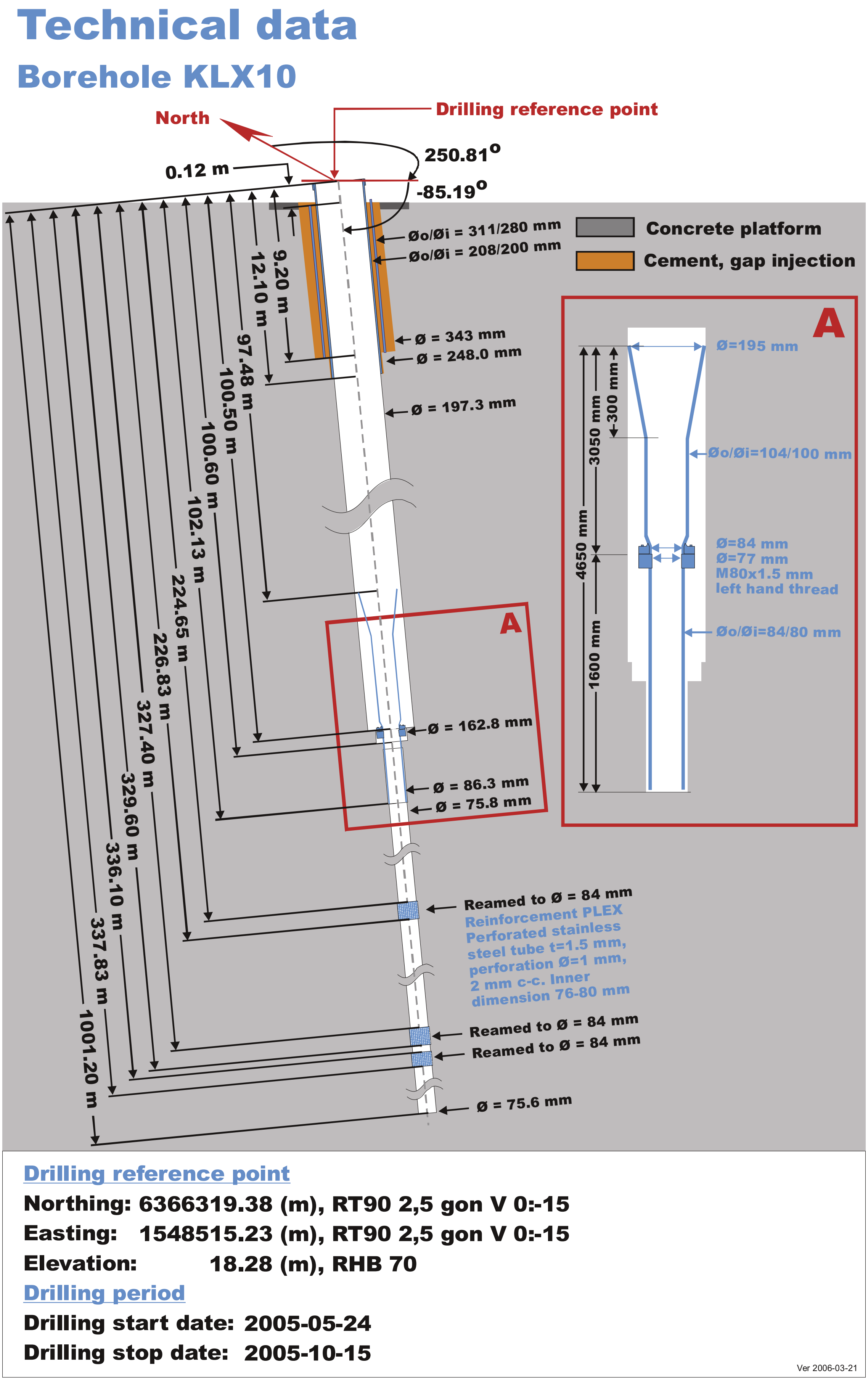


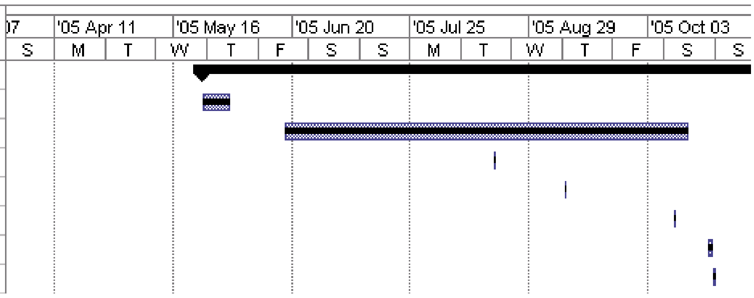
Figure 5-1. Technical data from KLX10.

Table 5-2. Summary of core drilling progress and borehole measurements in KLX10.

bh metres	Drilled length, pumping tests and water sampling	Measurements of absolute pressure	Airlift pumping with evaluation of drawdown and/or recovery	Deviation measurement	Miscellaneous
100	050603 Open hole pumping test in the telescopic section 12.10–100.60 m. 37 L/min at 16 m drawdown.			050526 Easy-shot at 95 m. Azimuth 259.3 Dip –81.9.	
				050622 Easy-shot at 138 m. Azimuth 260.8 Dip –81.5.	Guided drilling 155.10–156.35 168.50-169.50
200	050702 Pumping test 102.90–198.21 m. 16.5 L/min at 29 m drawdown. Water sample with 1.7%. Drill Water Content (DWC).	050703 Measurement of absolute pressure 102.9–200.2 m.		050701 Easy-shot at 177 m. Azimuth 262.7 Dip –81.7.	Guided drilling 188.00–192.05 198.21-200.20
				050705 Easy-shot at 204 m. Azimuth 277.7 Dip –83.0.	
300	050809 Pumping test 197.50–299.10 m. 11.4 L/min at 15 m drawdown. Water sample.	050810 Measurement of absolute pressure 197.5–311.1 m.		050709 Easy-shot at 294 m. Azimuth 273.2 Dip –83.1.	
	050812 Pumping test 319.30–334.65 m. 15 L/min with 18 m drawdown. Water sample.				Loss of water pressure at 322 m.
400	050816 Pumping test 298.20–407.05 m. 17 L/min with 22 m drawdown. Water sample.	050817 Measurement of absolute pressure 310.9–421.94 m.		050819 Easy-shot at 400 m. Azimuth 261.9 Dip –83.4.	
			050818 Airlift pumping 12.10–433.92 m. No drillstem in borehole.		
500	050824 Pumping test 405.97–514.92 m. 9 L/min with 222 m drawdown. Water sample.	050825 Measurement of absolute pressure 405.97–527.00 m.			
					Deviation measurement at 530 m failed due to rock fall-out at 420 m.
600	050902 Pumping test 514.10–598.83 m. 0.07 L/min with 20 m drawdown. No water sample.			050904 Easy-shot at 582 m. Azimuth 273.0 Dip –83.2.	
700	050915 Pumping test 598.80–709.98 m. 0.5 L/min with 14 m drawdown. No water sample.		050908 Airlift pumping 12.10–692.04 m. No drillstem in borehole.		
800	050922 Pumping test 709.00–797.00 m. 0 L/min with 20 m drawdown. No water sample.				Deviation measurement planned at 816 m could only reach 320 m.
900	050930 Pumping test 796.10–908.00 m. 0.2 L/min with 17 m drawdown. No water sample.				
				051022 Final Maxibor to 996 m. Azimuth 274.59 Dip –84.00.	
1,000	051009 Pumping test 906.85–1,000.90 m. 0 L/min with 20 m drawdown. No water sample.		051010 Airlift pumping 12.10–1,000.90 m. No drillstem in borehole.	051023 Flexit to 987 m. Azimuth 279.18 Dip –3.41.	051113 Flushing with nitrogen gas.

Table 5-3. Chronological summary of main drilling events in KLX10.

ID	Aktivitet	Start
1	**First activity starts**	**Tue 05-05-24**
2	Percussion drilling	Tue 05-05-24
3	Core drilling	Sat 05-06-18
4	Recovery test	Thu 05-08-18
5	Recovery test	Thu 05-09-08
6	Recovery test	Mon 05-10-10
7	Length calibration marks	Fri 05-10-21
8	Maxibor measurement	Sat 05-10-22



5.2 Drilling, measurements and results in the telescopic section 0–100.60 m

Drilling, reaming and grouting (gap injection) were made from May 24 to June 1, 2005.

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 (0–100.60 metres) of KLX10 was made in steps as shown in Figure 5-2 and described below:

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

- Drilling was made to 9.20 metres length with NO-X 280 mm equipment. This gave a hole diameter of 343 mm and left a casing (311×15 mm diameter) to a length of 9.20 m.
- Inner supportive casing for guidance for the drill string was mounted.
- A pilot percussion hole was drilled to a depth of 100.60 metres. The diameter at full length was 162.8 mm.
- Deviation measurement was made with Easy-shot to 95 metres length. A reduction in the dip could be noted.
- Reaming to diameter 248.0 mm was done from 9.20 to 12.20 m
- Stainless casing of 208·4 mm was installed from 0 to 12.20 m.
- Gap injection with low alkali cement based concrete (225 kg/360 litres) was made for both sets of casing.
- After the concrete had hardened, the hole was reamed from 12.20 to 100.50 m. The reaming diameter at 12.20 m was 197.7 mm and the diameter at full length was 197.3 mm. The bore-hole was rinsed and flushed to remove concrete and water. No test of the tightness of the concrete seal (gap injection) was made, see Section 5.9.

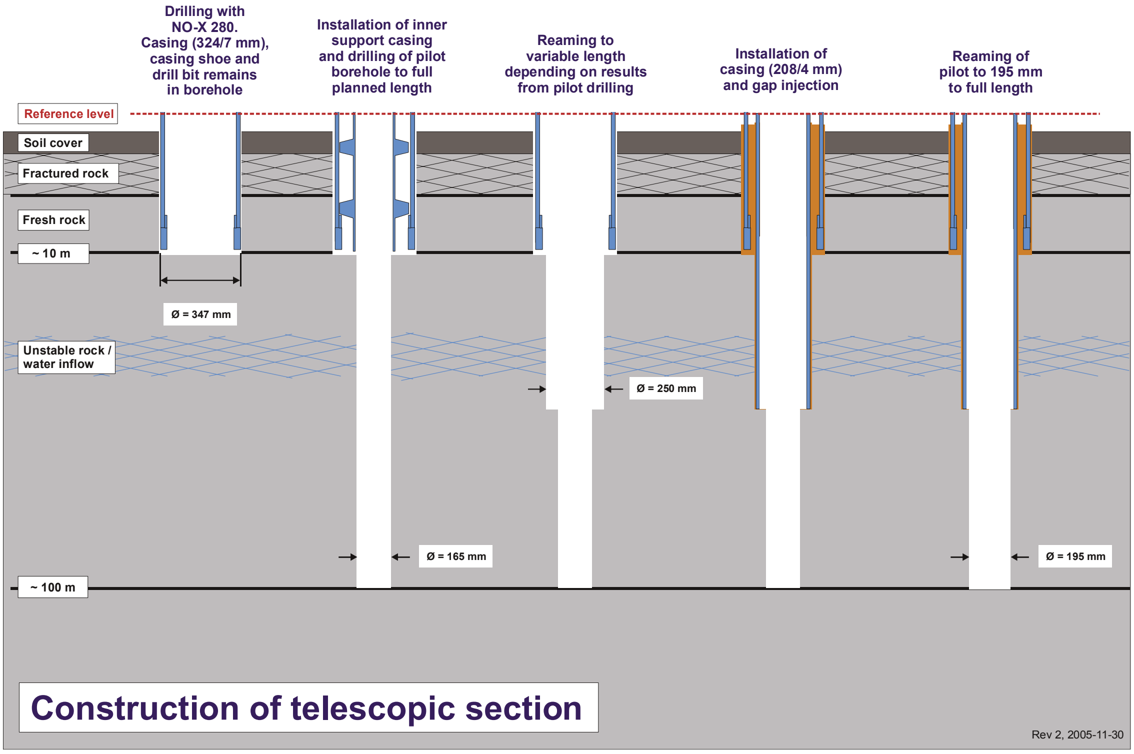


Figure 5-2. *Construction of the telescopic section. The gap filling cement is introduced between the casing and the rock wall. The drill bit acts as a barrier so that cement does not enter the pilot hole.*

5.2.3 Measurements and sampling during drilling of the telescopic section

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

- The percussion drilling progress was monitored by the geology coordinator (or contracted geologist). Drill cuttings samples were collected every metre and a preliminary geological logging including measurement of magnetic susceptibility was made.
- Penetration rate (expressed as seconds per 20 cm) was recorded manually and observation of changes in water flow was noted.

The preliminary geological results with penetration rate and magnetic susceptibility as measured on the cuttings are presented in Figure 5-3.

The depth to bedrock from top of casing was 0.1 m, i.e. drilling was performed directly in bedrock.

Hydrogeological observations during percussion drilling

A water inflow of nearly 25 litres per minute was measured at 80 m. An inflow of 45 litres per minute was measured over the entire length of the telescopic section.

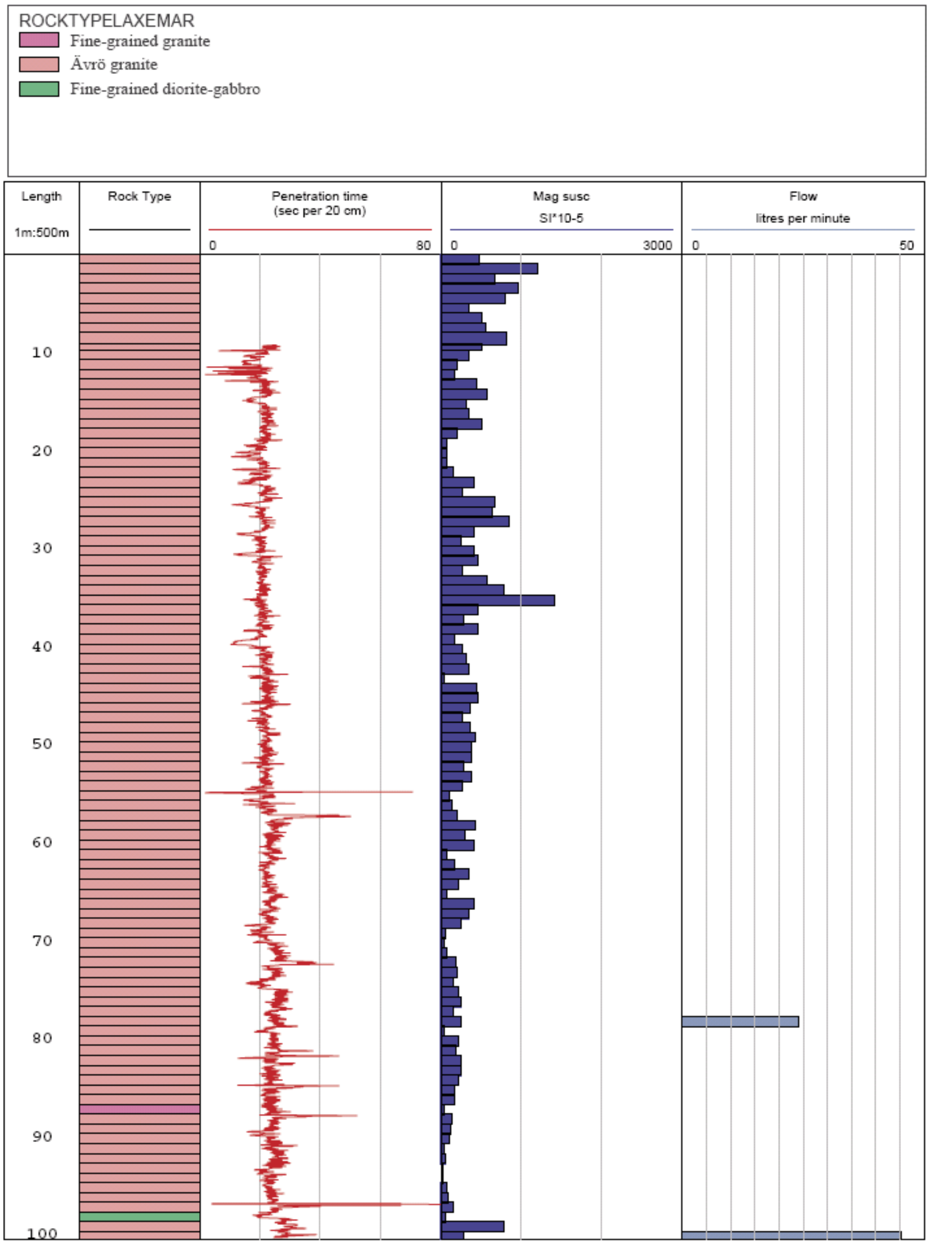


Figure 5-3. *Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KLX10.*

5.2.4 Hydrogeological and hydrochemical measurements in the telescopic section

In the telescopic section, 12.10–100.60 m a pumping and interference test was conducted. A pump was emplaced at 80 m and a pressure logger at 85 m. Pumping was made with a flow of 37 L/min for approximately four days. The pumping caused a 16 m drawdown in KLX10. The test was made after reaming of the telescopic section, i.e. when the borehole diameter was 197.3 mm. The pumping curve is shown in Figure 5-4 and the results from evaluation are given in Table 5-4. The pumping test was evaluated with steady-state assumption in accordance with Moye /2/.

MiniTroll loggers were installed in the surrounding observation boreholes HLX23, HLX24, HLX25, HLX30, HLX31, and HLX33 in order to see if any hydraulic response could be noted from the pumping in KLX10. The location of the boreholes is given in Figure 5-19. No hydraulic responses from the pumping in KLX10 could be seen in any of the observation boreholes.

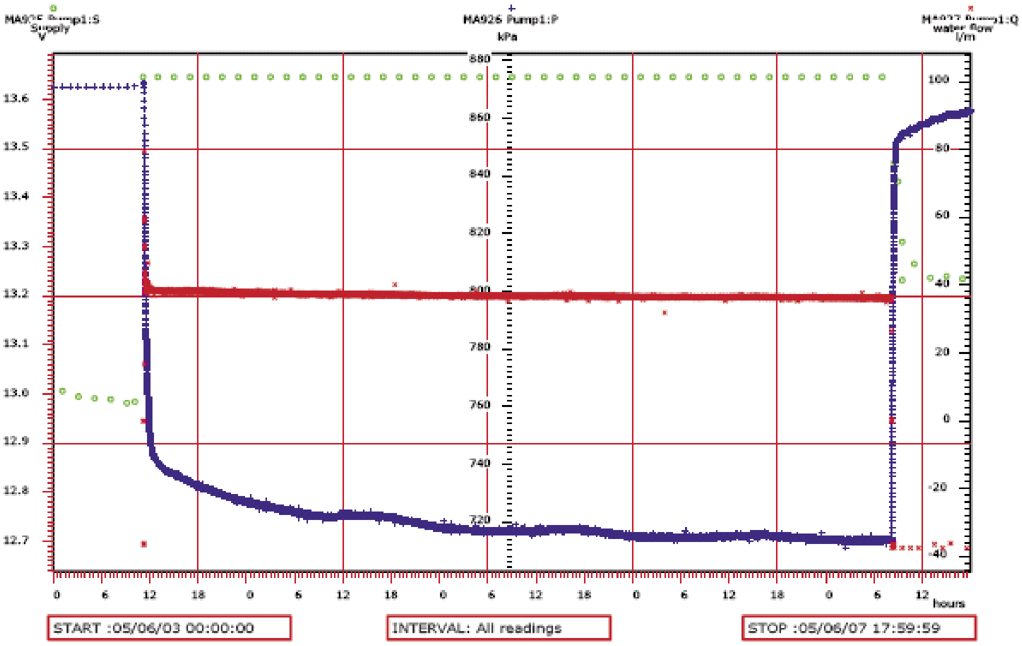


Figure 5-4. *Pumping and interference test June 3 to 7 in the telescopic section of KLX10. The drawdown (blue) is given in pressure unit (kPa) uncorrected for ambient air pressure. The flow rate (red) is given in litres per minute. The green symbols indicate the voltage of the power supply.*

Table 5-4. Pumping test 12.10–100.60 m in KLX10.

Tested section [m]	Flow rate [L/min]	Drawdown [m]	Q/s [m²/s]	TM [m²/s]
12.10–100.60	37	16	$3.9 \cdot 10^{-5}$	$4.4 \cdot 10^{-5}$

Two water samples were collected in the telescopic section in KLX10 during the pumping. Sampling and analysis of the samples 10326 and 10327 were performed according to SKB class 3, see Table 5-5.

Selected results are reported in Table 5-6 and a complete account is given in Appendix 2.

The samples were not analysed for isotopes. However, bottles intended for these analyses are stored in freezer and refrigerator at the Äspö laboratory.

Table 5-5. Sample dates and section lengths during percussion drilling in KLX10.

SKB number	Borehole	Date	Test section, length (m)	SKB chemistry class
10326	KLX10	2005-06-03	0.00–100.60	3 (not analysed for isotopes)
10327	KLX10	2005-06-07	0.00–100.60	3 (not analysed for isotopes)

Table 5-6. Selected analytical results from samples 10326 and 10327.

SKB number	pH	Conductivity (mS/m)	Chloride (mg/L)
10326	8.35	62.6	7.6
10327	8.26	58.6	8.2

5.3 Core drilling KLX10 100.60–1,001.20 m

Core drilling in KLX10 was conducted between June 18 and October 15, 2005.

The main work in KLX10 after drilling the telescopic section consisted of the following steps:

- preparations for core drilling,
- flushing and return water handling,
- core drilling including directional drilling and deviation measurements,
- borehole completion including risk assessment of the bore wall stability.

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

5.3.1 Preparations

The preparations for core drilling started on June 9, 2005 and 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 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 100.50 and 101.13 m with T-86 equipment. An inner supportive casing with diameter 84/77 mm was installed to 101.13 m.

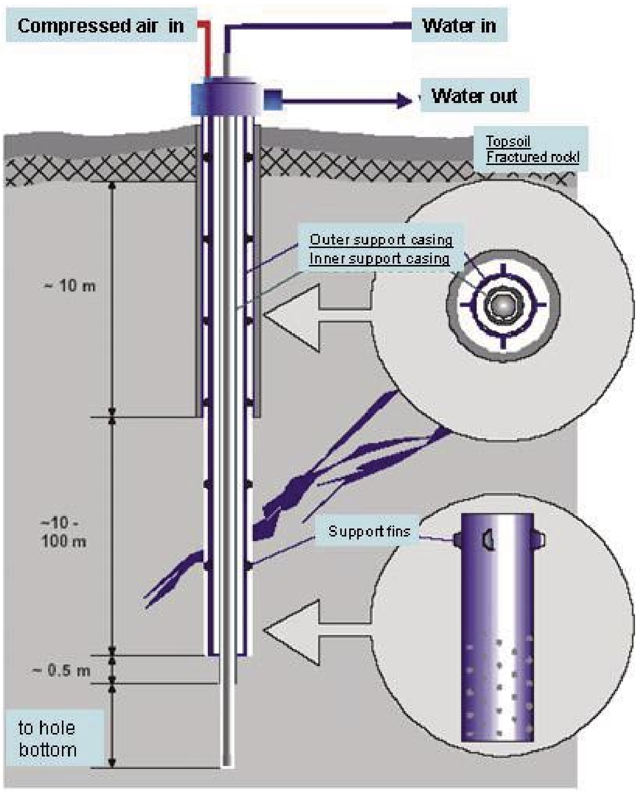


Figure 5-5. *In the telescopic part of the drill hole a temporary installation is made with casing tubes for support and alignment and equipment for air-lift pumping. In the uppermost part the return water discharge header is mounted. The water discharge is led to the settling containers.*

The supportive casings have a perforated section between 99.20 and 99.60 metres 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 metres.

5.3.2 Flushing and return water handling

The flushing water source was percussion borehole HLX27 initially. HLX10 was however used as a water source for the bulk part of the drilling, see also Sections 5.4.2 and 5.5. The locations of the water sources, boreholes HLX27 and HLX10 are given in Figure 1-1.

Treatment of the flushing water before introduction into the boreholes 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 KLX10 is shown in Figure 5-6.

The targeted content for uranine in the flushing water is 0.20 mg/L and the actual average uranine content was 0.206 mg/L, see also Figure 5-12 and Section 5.4.2.

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

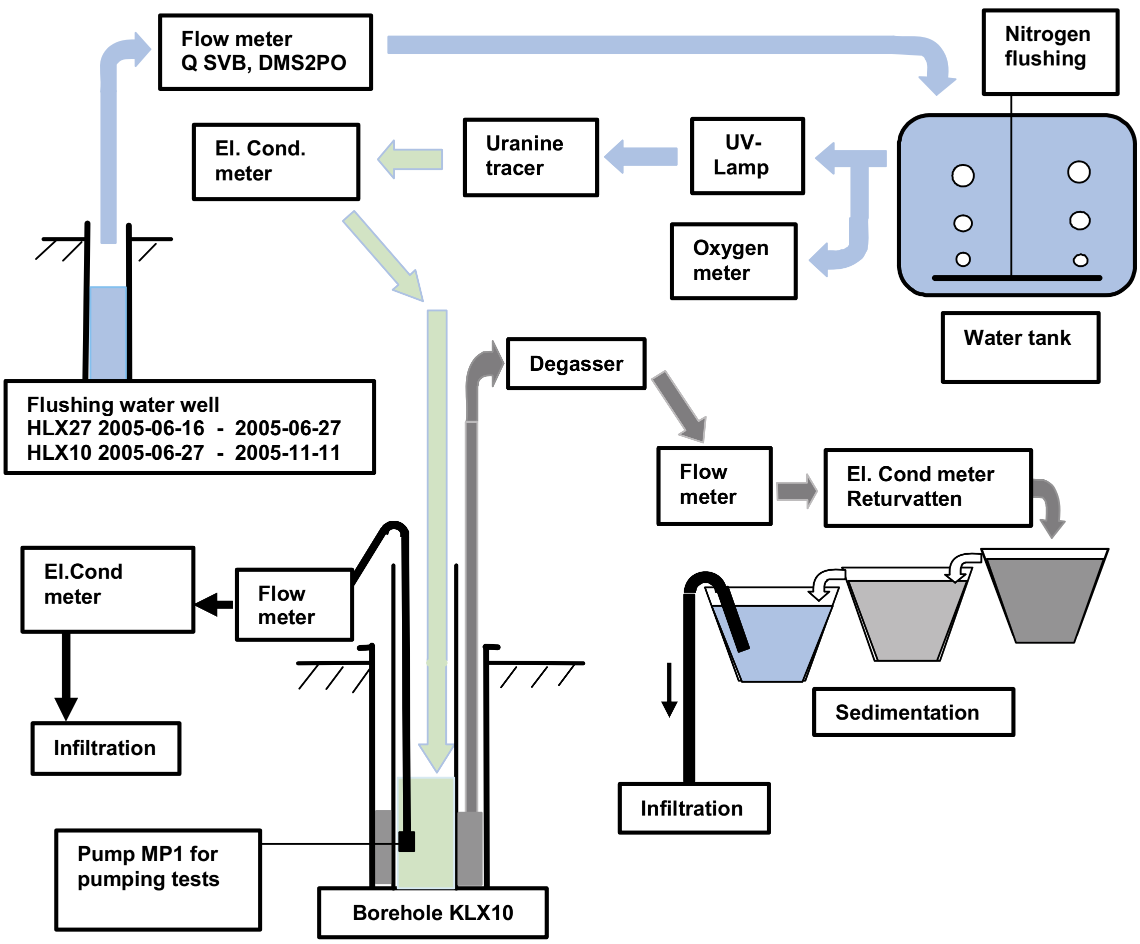


Figure 5-6. The flushing and return water handling and the emplacement of related monitoring equipment in KLX10.

5.3.3 Drilling and deviation measurements KLX10

Core drilling with N-size (76 mm) triple-tube, wireline equipment was conducted from 101.13 m to the final length of 1,001.20 m in KLX10.

A reduction in dip of three degrees was noted after the percussion drilling. In order to prevent further reduction in the dip in KLX10 and to try to restore the planned dip, a decision was taken to core drill ca 50 metres before starting the directional drilling.

Directional drilling was employed in intervals between 155.10 and 200.20 metres with the Liwinstone method. The directional drilling was monitored carefully with deviation measurements with both the Maxibor and magnetometer/accelerometer methods.

The core diameters and intervals for different drilling dimensions or method of directional drilling are given in Table 5-7.

The core drilling progress was routinely followed by deviation measurements with the Easy-Shot method, normally with 100 metre intervals, see Table 5-2. The results from these measurements are not stored in the Sicada database.

Three individual deviation measurements were done for the final evaluation of the borehole deviation. The Maxibor tool was run both up and down the borehole and upwards measurements were made with the Flexit tool. All three final measurements are stored in the Sicada database but only the downward Maxibor measurement is used for further evaluation of orientation of borehole features. At present (December 2006) an audit of all borehole deviation data within the Site Investigation is being performed. This could lead to changes in which set of data that will be used for further analysis of orientation of borehole features.

Selected results from deviation measurements are summarized for comparison in Table 5-8.

Horizontal and vertical plots of the results of the final downward run with the Maxibor method covering the entire length of borehole KLX10 are given in Appendix 4.

Core losses were noted in the Boremap mapping (see Section 5.6) at the intervals given in Table 5-9.

A total of thirteen drill bits were used for KLX10, see Figure 5-7.

Further results from drill monitoring, i.e. drill penetration rate and various measurements will be presented in Section 5.5 “Drilling monitoring results” and in Appendix 1. The drilling progress over time is shown in Section 5.5, see Figure 5-20.

Table 5-7. Core diameters, borehole diameters and drilling dimensions during core drilling.

Core diameter (mm)	Borehole diameter (mm)	Interval (m)	Drilling dimension or directional drilling method	Comment
72.0	86	100.60–102.13*	T-86	
50.2	76	102.13*–155.10	N	
45.0	76	155.10–156.35	Liwinstone N	directional
50.2	76	156.35–168.90	N	
45.0	76	168.90–169.50	Liwinstone N	directional
50.2	76	169.50–188.00	N	
45.0	76	188.00–192.05	Liwinstone N	directional
50.2	76	192.05–198.24	N	
45.0	76	198.24–200.20	Liwinstone N	directional
50.2	76	200.20–1,001.20	N	

* Reamed from 101.13 to 102.13 m after core drilling to full drilled length, see also Section 5.3.4. “Borehole completion”.

Table 5-8. Selected results from the deviation measurements in KLX10.

Date	Method	Borehole length (m)	Dip	Azimuth	Comment
Measurements performed as drilling progressed					
–	Survey	0	–85.19	250.81	Top of casing
2005-05-28	Easy-shot	95	–81.9	259.3	At the end of the telescopic section (i.e. before directional drilling)
2005-07-05	Easy-shot	204	–83.0	277.7	After directional drilling
Final measurements (i.e. after drilling was completed)					
2005-10-22	Maxibor	996	–84.00°	274.50°	Final Maxibor (down)*
2005-10-23	Flexit	987	–83.41°	279.18°	Final Flexit (up)*

* At present (December 2006) an audit of all borehole deviation data within the Site Investigation is being performed. This could lead to changes in which set of data that will be used for further analysis of orientation of borehole features.

Table 5-9. Core losses noted in KLX10.

From (m)	To (m)	Length (m)	Comment
351.76	351.79	0.03	missing core piece
438.61	438.70	0.09	mechanical
568.94	568.98	0.04	missing core piece

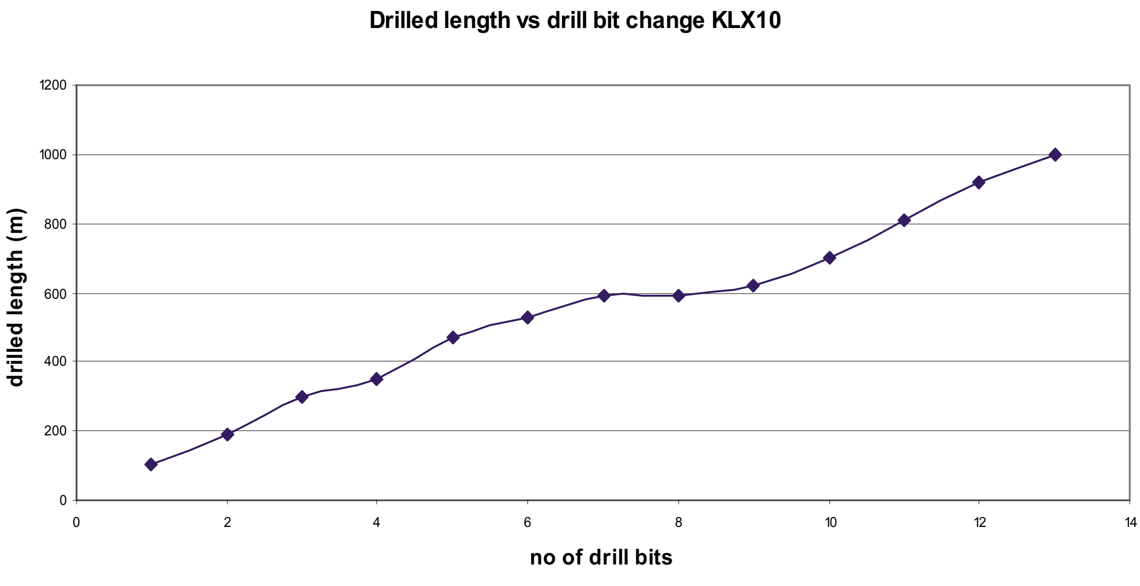


Figure 5-7. Changes of drill bits during core drilling in KLX10.

5.3.4 Borehole wall risk assessment, stabilisation and completion

Borehole wall risk assessment and stabilisation

A borehole wall assessment was prepared on November 15, 2005, SKB id no 10446532, SKB internal document.

The assessment is summarized as follows:

- A distinct drop in water pressure was noted on August 11 at about 322 m.
- Fall-out of rock fragments were collected from the borehole bottom on August 23.
- When performing deviation measurements on September 24, the Easy-shot tool stopped at 320 m due to an obstruction in the borehole.
- A dummy probe was run through the length of the hole on October 17, to ensure that the hole was straight and unobstructed.
- A BIPS-logging (borehole image processing system, i.e. a down-hole digital camera) of the interval 0–980 m was done on October 18.
- The indicator (caliper log) for detecting the reference slots was run through the length of the borehole without any problems on October 21.
- A deviation survey with the Flexit method was made on October 23.

Based on the results from dummy probing, BIPS images and evaluation of the drill core a decision was taken to rinse certain problematic section mechanically, see Table 5-10. The flush and brush tool is shown in Figure 5-8.

Three of the mechanically rinsed sections were reinforced with perforated stabilising steel tubes (PLEX) in order to minimise the risk of rock fall-out from the borehole wall. The selection of which intersections to stabilise was based on expert judgement from the drilling technical staff in collaboration with the geology coordinator.

Perforated reinforcement plates, PLEX, where emplaced between October 26 and 30 at the borehole intervals given in Table 5-11.

Table 5-10. Borehole section that were mechanically rinsed by water flushing and rotating steel brush.

From (bh length m)	To (bh length m)
103	208
222	234
245	250
258	260
318	346
361	366
399	401
412	416
418	420
436	438
698	705
835	837

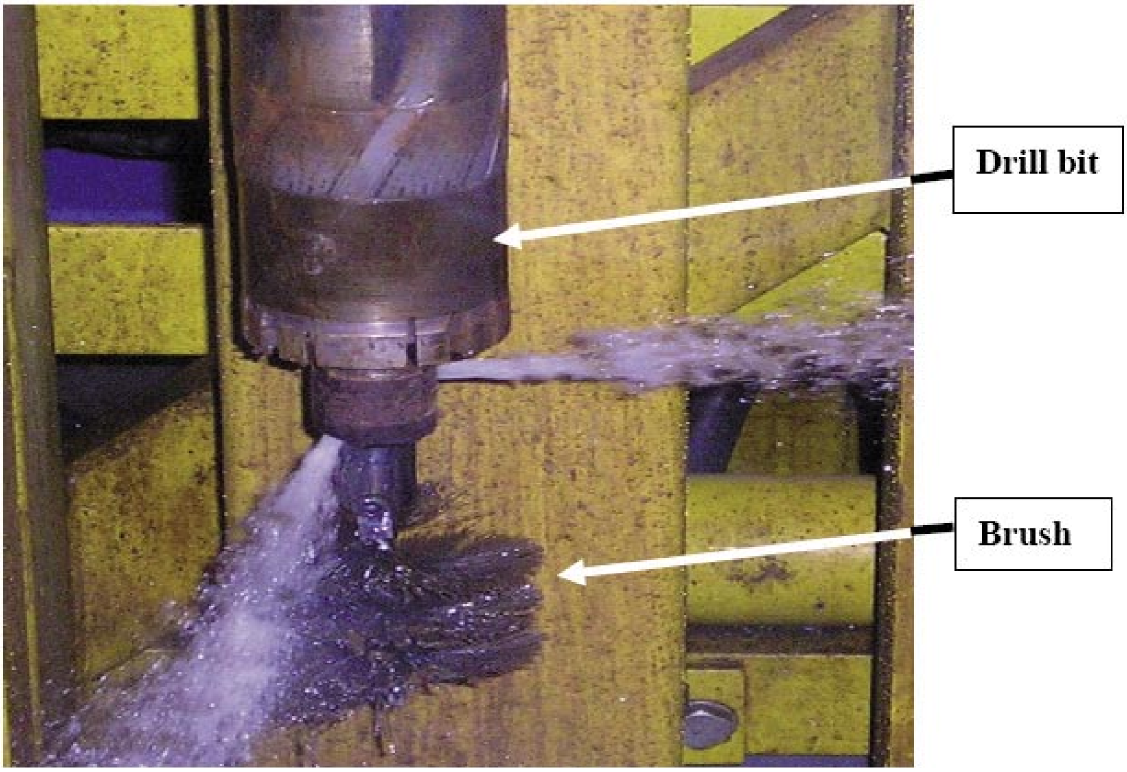


Figure 5-8. *The water flushing and rotating steel brush tool. The tool is lowered into the drill stem and can be seen in place just below the drill bit. During operating the drill string is moved up and down to remove loose rock fragments from the borehole wall.*

Table 5-11. Borehole length intervals for emplacement of PLEX stabilising steel tube.

From bh length (m)	To bh length (m)
224.7	225.7
327.4	329.6
336.1	337.8

The PLEX method is schematically described in Figure 5-9 and consists of:

- Lowering of the PLEX tool to the section to be stabilised.
- Extruding the reaming cutters with water pressure and gently reaming the problematic section.
- Expanding the rubber packer with water pressure and thereby forcing the perforated roll of steel plate into contact with the borehole wall.
- When the water pressure is removed the PLEX tool can be retracted.

The borehole wall is stabilised but retains a permeability for water flow (and hence it is possible to do hydrogeological tests).

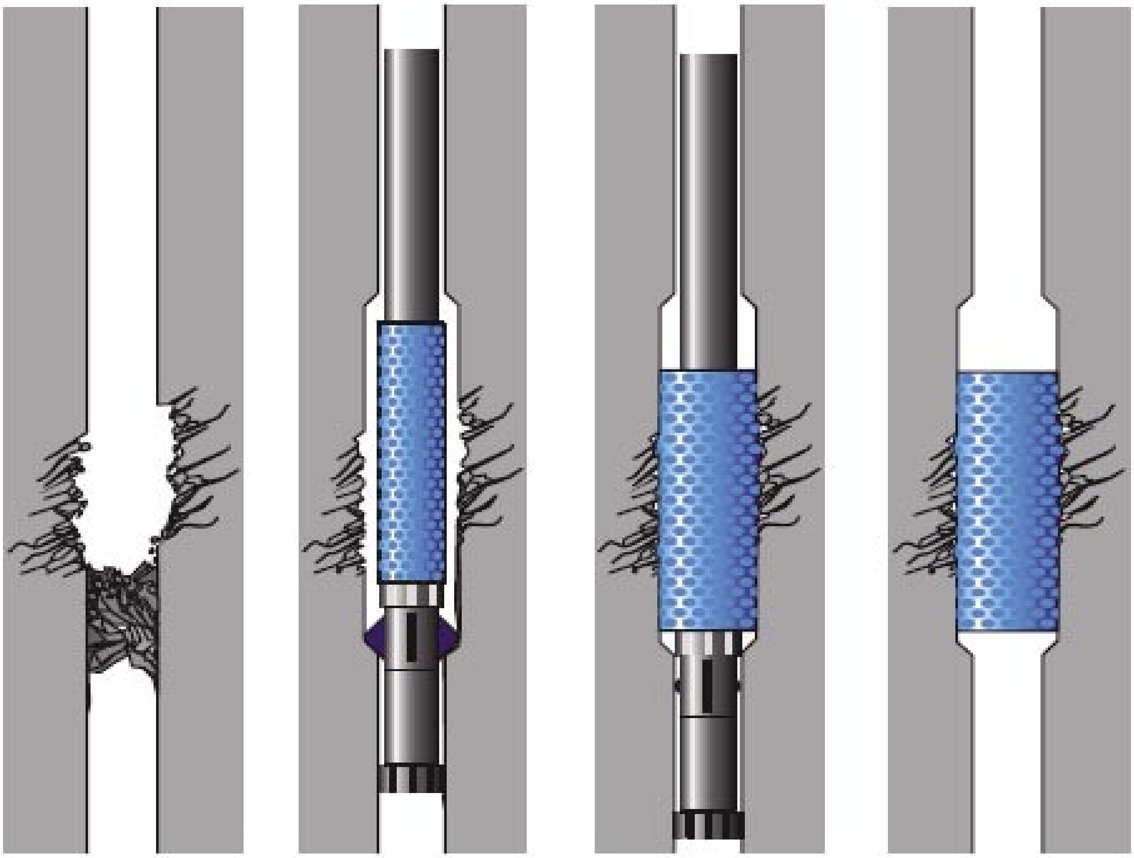


Figure 5-9. Schematic description of the PLEX method.

Borehole completion

Reaming of depth reference slots was done at the intervals shown in Table 5-12. The depth reference slots are used for depth calibration of down-hole equipment for subsequent investigations in the hole.

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

The air lift pumping equipment and the inner supportive casing in the telescopic section was removed.

The borehole was reamed from 101.13 to 102.13 with T-86 equipment. A steel conical guide was installed in KLX10 between 97.48 m and 100.50 m together with a 84/80 mm casing between 100.50 and 102.13 m. The conical guide tapers from an inner diameter of 195 mm to 77 mm.

The length of the holes was rinsed by flushing with nitrogen gas on November 13, 2005, see Table 5-13.

The boreholes were secured by mounting of lockable steel caps 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.

Table 5-12. Depth reference slots (m) in KLX10.

110.00	600.00
150.00	651.00
204.00	698.00
251.00	750.00
300.00	799.00
350.00	850.00
402.00	900.00
450.00	950.00
500.00	980.00
550.00	

Table 5-13. Dates for nitrogen gas flushing in KLX10.

Date	Time	Interval (m)	Water lifted (m^3)
051113	7:00–11:00	0–986	12.5
051113	12:00–14:45	0–983	20

5.4 Hydrogeological and hydrochemical measurements and results 100.60–1,000.90 m

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

Measurements and sampling with wireline equipment consisted of:

- Ten pumping tests were conducted at various intervals, see Section 5.4.1.
- Four measurements for absolute pressure were made, see Section 5.4.1.
- Five water samples were taken, see Section 5.4.2.

Three air-lift pumping tests with evaluation of the drawdown and/or recovery phase were made, for results see Section 5.4.3.

Hydraulic responses in near-by boreholes from drilling in KLX10 are commented in Section 5.4.4.

5.4.1 Hydrogeological results from wireline measurements

Results from the wireline tests in KLX10 are presented in Table 5-14 and Figure 5-10.

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

A total of ten tests were performed in KLX10. The measured flow in the tests in the sections below 500 m result in very low values of the transmissivity; the flow in section 806.85–1,000.90 was even lower than the measurement limit. Despite this, steady state was reached in all of the tests.

The plots from the pumping tests are given in Appendix 5.

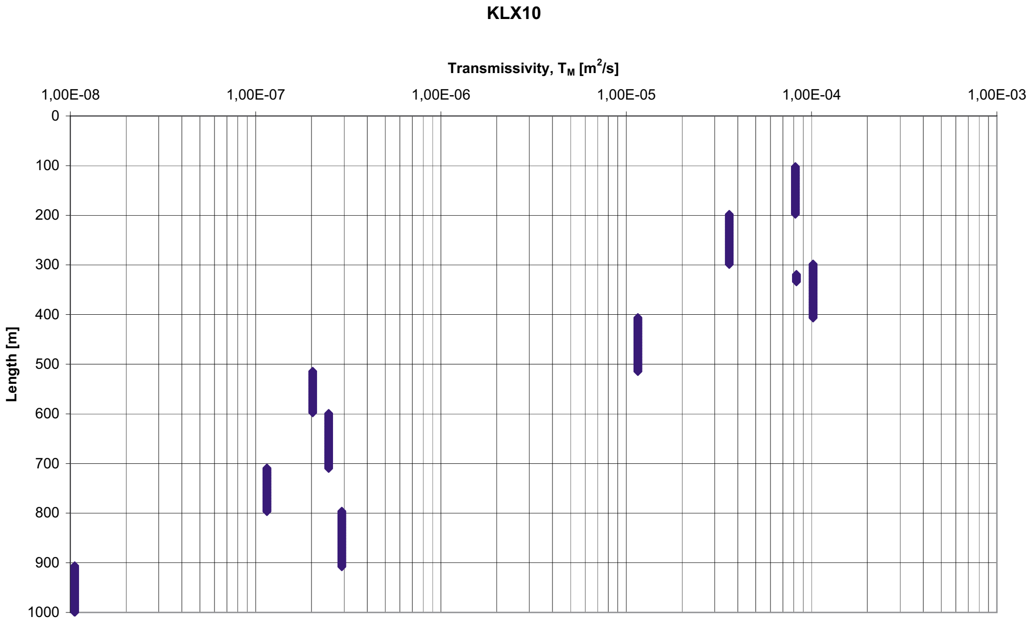


Figure 5-10. *Transmissivity from wireline pumping tests in KLX10 versus borehole length.*

Table 5-14. Pumping tests with wireline probe in KLX10.

Tested section [m]	Q/s [m²/s]	TM [m²/s]	Comments
102.90–198.21	$6.3 \cdot 10^{-5}$	$8.2 \cdot 10^{-5}$	Test functionally OK, good data.
197.50–299.10	$2.8 \cdot 10^{-5}$	$3.6 \cdot 10^{-5}$	Test functionally ok, good data.
319.30–334.65	$8.3 \cdot 10^{-5}$	$8.3 \cdot 10^{-5}$	Test functionally ok, good data.
298.20–407.05	$7.8 \cdot 10^{-5}$	$1.0 \cdot 10^{-4}$	Packer pressure only 100 kPa above hydrostatic pressure at the end of test, but data from tested section ok.
405.97–514.92	$8.8 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$	Test functionally OK, good data.
514.10–598.83	$1.6 \cdot 10^{-7}$	$2.0 \cdot 10^{-7}$	Evaluated test period: 16:31–17:30, due to very low flow. Mean flow used instead of Qp.
			Pressure in casing in transient recovery phase unaffected of pumping test.
598.80–709.98	$1.9 \cdot 10^{-7}$	$2.5 \cdot 10^{-7}$	Low flow, but test functionally OK, good data.
709.00–797.00	$9.0 \cdot 10^{-8}$	$1.2 \cdot 10^{-7}$	Very low flow, but test functionally OK.
796.10–908.00	$2.2 \cdot 10^{-7}$	$2.9 \cdot 10^{-7}$	Varying flow during the first test hour. Water was added manually between 18:37–18:43. Thereafter very low flow, but steady state.
906.85–1,000.90	$8.2 \cdot 10^{-9}$	$1.0 \cdot 10^{-8}$	Stable pressure even though the flow was very low (Q<0.01 L/min, below measurement limit).

The start and stop times for the interval used for evaluation of the pumping tests are given in Table 5-15.

Measurements of the absolute pressure were conducted in four sections, as specified in Table 5-16 and Figure 5-11.

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, such as pressure, salinity, and temperature.

Table 5-15. Evaluated test periods.

Tested section	Start (YYYY-MM-DD HH:MM)	Stop (YYYY-MM-DD HH:MM)
102.90–198.21	2005-07-02 17:00	2005-07-03 02:49
197.50–299.10	2005-08-09 17:32	2005-08-10 03:03
319.30–334.65	2005-08-12 15:31	2005-08-13 02:48
298.20–407.05	2005-08-16 16:02	2005-08-17 02:53
405.97–514.92	2005-08-24 16:39	2005-08-25 02:49
514.10–598.83	2005-09-02 16:31	2005-09-02 17:30
598.80–709.98	2005-09-15 17:22	2005-09-15 20:22
709.00–797.00	2005-09-22 16:38	2005-09-22 19:20
796.10–908.00	2005-09-30 17:44	2005-09-30 21:50
906.85–1,000.90	2005-10-09 17:07	2005-10-09 19:53

Table 5-16. Absolute pressure measurements in KLX10.

Tested section	Last pressure reading during build-up [kPa]	Duration of pressure build-up [hours]	Borehole length to pressure gauge [m]
102.90–200.20	1,055	11.3	105.00
197.50–311.10	1,975	12.9	198.60
310.90–421.94	3,090	12.5	312.00
405.97–527.00	4,010	13.4	407.07

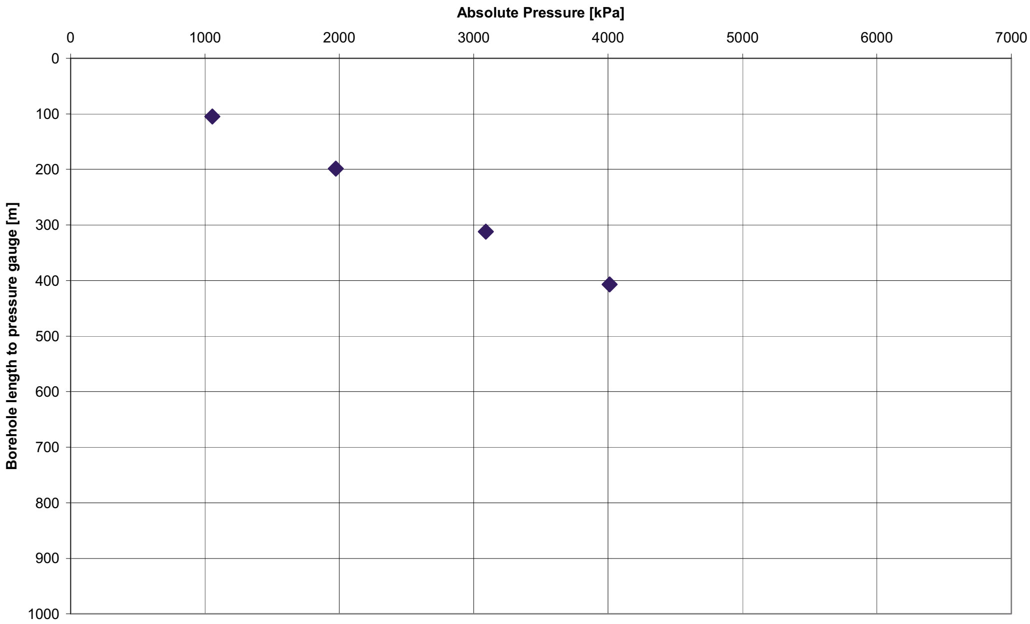


***Figure 5-11.** Absolute pressure measurements from wireline tests in KLX10 versus borehole length.*

5.4.2 Hydrochemistry

Five water samples were collected with wireline equipment in connection with core drilling in KLX10. The times and lengths for the samples are given in Table 5-17 together with specifications on sampling and analysis according to the SKB chemistry classes. A further account on analytical method and quality together with an explanation of SKB chemistry class 3 is given in Appendix 3.

All samples were collected at the drill site as soon as possible after the sampling occasion and were prepared and conserved at the Äspö laboratory. The samples were stored cold, in a refrigerator, until the drilling of the borehole was completed. At that time it was decided which samples should be sent to external laboratories for analyses.

All five samples were intended for analysis according to SKB chemistry class 3. Based on the analysis of drill water content a selection of the samples suited for further analysis was made. The drilling water content is a measure of the amount of uranine tracer in the return water. A low percentage of drilling water implies that the amount of pristine formation water is high in the sample, i.e. low amount of the uranine-spiked flushing water.

Sample 10452 was not used for further analysis due to high drill water content in the sample.

Sample 10445 was not analysed for isotopes due to relatively high drill water content. A sufficient amount of water from this sample is stored, part frozen and part refrigerated, at the Äspö laboratory for possible future isotope analysis.

Archive samples have been collected for all class 3 samples in Table 5-17, except for sample 10452.

Selected analytical results from KLX10 are given in Table 5-18. A complete record of analytical results is given in Appendix 2.

Table 5-17. Sample dates and length during core drilling in KLX10.

Sample number	Date	Test section, length (m)	SKB chemistry class
10403	2005-07-03	102.90–198.21	3 and all option isotopes
10445	2005-08-10	197.50–299.10	3 (not analysed for isotopes)
10450*	2005-08-13	319.30–334.60	3 and all option isotopes
10452	2005-08-17	298.20–407.05	3 (only analysed for drill water percentage)
10475*	2005-08-25	405.97–514.92	3 and all option isotopes

* Br not analysed at the Äspö laboratory due to analytical problems. This only affects samples with < 0,2 mg/l Br and < 100 mg/l Cl, i.e. samples 10450 and 10475.

Table 5-18. Analytical results from water chemistry sampling.

Sample Number	Date	From (m)	To (m)	Drill water (%)	pH	Electrical Conductivity (mS/m)	Cl^- (mg/L)
10403	2005-07-03	102.90	198.21	1.73	8.42	65.7	11.1
10445	2005-08-10	197.50	299.10	28.10	8.58	97.4	32.6
10450	2005-08-13	319.30	334.60	15.50	8.28	345.0	805.0
10452	2005-08-17	298.20	407.05	47.10	–	–	–
10475	2005-08-25	405.97	514.92	26.60	7.58	765.0	2,380.0

The percussion drilled boreholes HLX27 and HLX10 were used as water sources during the drilling of KLX10. However, HLX27 was only used until June 27. After that date HLX10 was used as the water source for the remainder of the drilling of KLX10. Samples of total organic content, TOC, has been collected from the water source HLX10 at earlier occasions and results from these samples are reported in previous reports /3 and 4/.

Water sampling and analysis of uranine tracer content and electrical conductivity

From KLX10, a total of 132 samples for uranine content and electrical conductivity in flushing and returning water were taken along the borehole.

The results are shown graphically in Figure 5-12. All the samples were analysed at the Äspö laboratory.

The calculated average uranine content for the whole borehole is 0.206 mg/l. This value has also been used for further calculations of the drill water content in the samples collected after drilling. However, for the samples collected during drilling (i.e the samples in this report), the drill water content for each sample is based on the average uranine content in the flushing water samples up to the time of sampling.

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

Two air-lift 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 varies in detail as drilling or other related activities such as cleaning and flushing of drill cuttings may occur prior to lifting the drill stem.

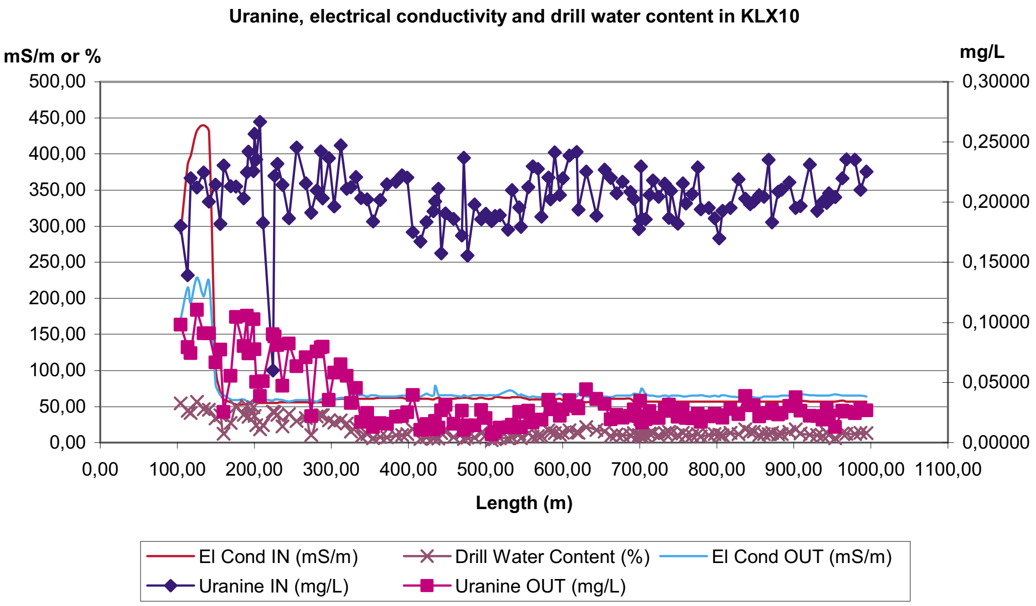


Figure 5-12. The uranine concentration and electrical conductivity of flushing water (IN) and returning water (OUT) in KLX10. The drill water content in the returning water is also shown.

The steady state transmissivity, T_M, was calculated according to Moye /2/, as well as the specific capacity, *Q/s*. The results are shown in Table 5-19 and stored in the SICADA database as "recovery tests" (code HY050). The tested section is here defined as the section between the lower end of the grouted casing and the borehole bottom.

The plots from the drawdown and recovery tests are given in Figures 5-13, 5-14, and 5-15. It should be emphasized that each plot shows a full day of drilling. The air-lift pumping in the telescopic section starts in the morning and continues throughout most part of the day. Drilling is indicated by water being pumped into the borehole (flow in). Towards the end of the day drilling is stopped and the drill stem is removed from the borehole. The "flow in" is reduced to zero when drilling stops. Air-lift pumping in the telescopic section however continues for a period of 30 minutes to two hours. This period of undisturbed air-lift pumping without the drill stem in the borehole constitutes the drawdown period on which the test evaluation is based.

Table 5-19. Results from air-lift pumping in KLX10.

Tested section [m]	Flow rate [L/min]	Drawdown [m]	Q/s [m²/s]	TM [m²/s]	Comments
12.10–433.92	36.6	7.3	$8.4 \cdot 10^{-5}$	$1.3 \cdot 10^{-4}$	Q derives from accumulated volumes of water in and out.* Q = ΣV/dt
12.10–692.04	63.5	8.2	$1.3 \cdot 10^{-4}$	$2.1 \cdot 10^{-4}$	Q derives from accumulated volumes of water in and out.* Q = ΣV/dt
12.10–1,000.90	37.9	4.0	$1.6 \cdot 10^{-4}$	$2.6 \cdot 10^{-4}$	Q derives from accumulated volumes of water in and out.* Q = ΣV/dt

* During the drawdown phase on which the test evaluation is based, there is no inflow of water, i.e. the accumulated volume of water is zero.

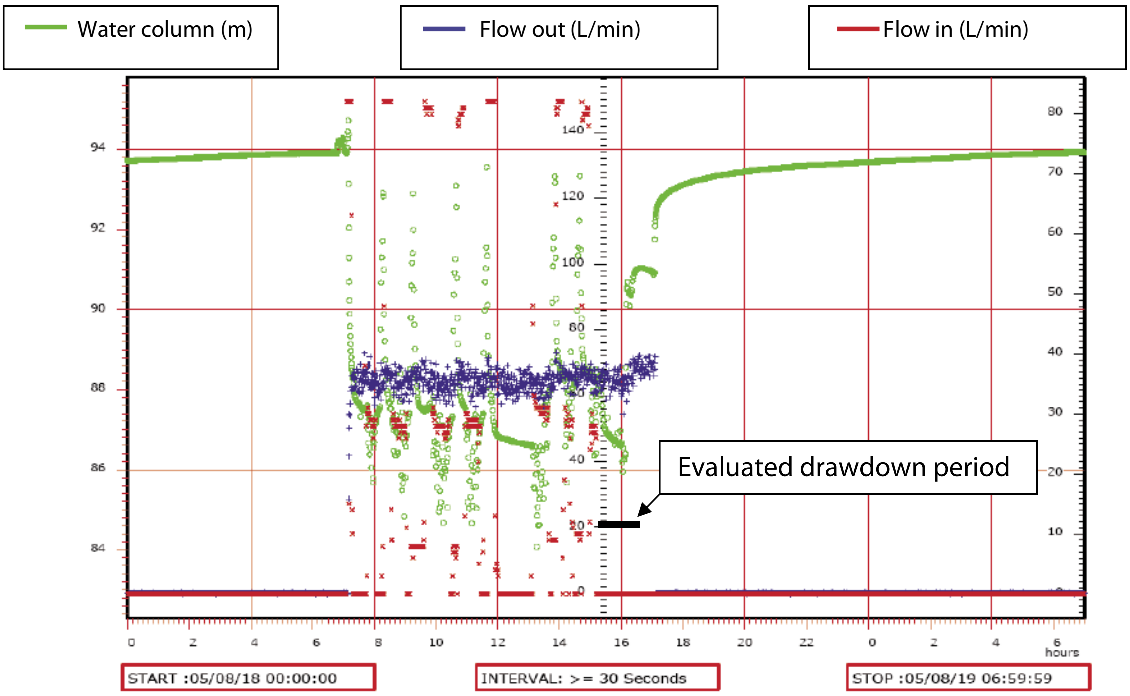


Figure 5-13. *Air-lift pumping in KLX10 12.10–433.92 m. The green line represents the height of the water column in the borehole, the flow out (i.e. pumped flow from air-lift pumping in the telescopic section) is shown as the blue dotted line. Inflow of water (red line) is related to drilling. The drawdown period on which the test results are derived is given with a black bar.*

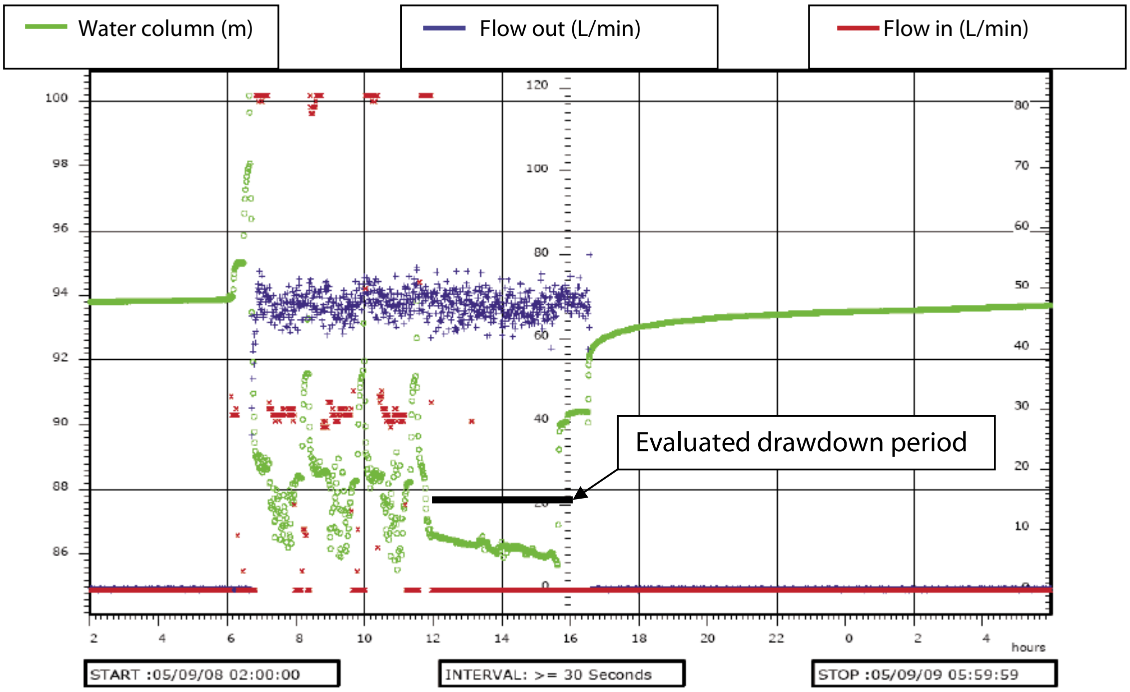


Figure 5-14. *Air-lift pumping in KLX10 12.10–692.04 m. The green line represents the height of the water column in the borehole, the flow out (i.e. pumped flow from air-lift pumping in the telescopic section) is shown as the blue dotted line. Inflow of water (red line) is related to drilling. The drawdown period on which the test results are derived is given with a black bar.*

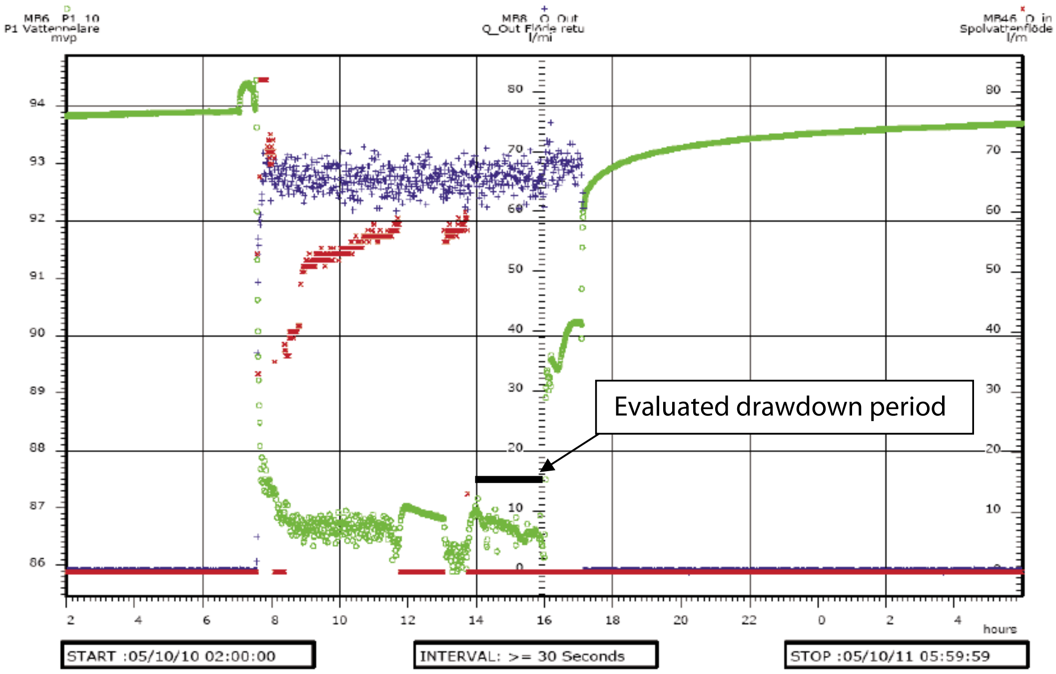


Figure 5-15. *Air-lift pumping in KLX10 12.10–1,000.90 m. The green line represents the height of the water column in the borehole, the flow out (i.e. pumped flow from air-lift pumping in the telescopic section) is shown as the blue dotted line. Inflow of water (red line) is related to drilling. The drawdown period on which the test results are derived is given with a black bar.*

5.4.4 Hydraulic responses in near-by boreholes

Hydraulic responses from activities in a borehole can be created by the drawdown from air-lift pumping and from flushing the borehole with nitrogen gas.

Hydraulic responses in near-by boreholes from air-lift pumping in KLX10

No correlation between air-lift pumping in KLX10 and hydraulic responses in the closest near-by boreholes (HLX24 and 33) can be seen. Figure 5-16 gives an overview of the entire period of core drilling in KLX10. Figure 5-17 shows water level fluctuations in the same near-by boreholes over the time period 050915 to 050919. The fluctuations in water levels in percussion boreholes HLX24 and HLX33 can not be related to drilling activities in KLX10 but should be attributed to diurnal variations.

The location of the mentioned boreholes is given in Figure 5-19.

The dates for the pump tests indicated in Figure 5-16 are summarised in Table 5-20.

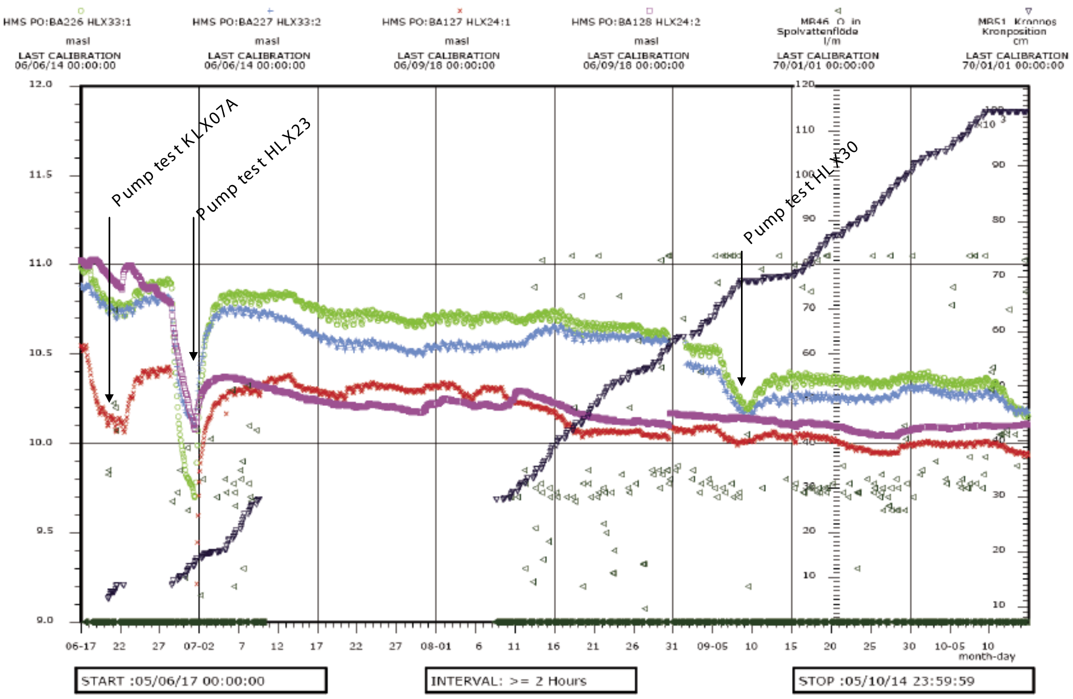


Figure 5-16. Overview of groundwater levels in HLX24 and HLX33 (the boreholes closest to KLX10) during the time period of drilling in KLX10 (050617–051014). No hydraulic responses from drilling activities in KLX10 can be seen in boreholes HLX24 or HLX33. The water levels in HLX33 are given in green (section 1) or blue (section 2) and the levels in HLX24 are given in red (section 1) or purple (section 2). The drilling progress from 100 to 1,000 m length is shown as a increasing line of black triangles. The flushing water flow into borehole KLX10 is given as dark green triangles. The draw-downs that can be seen in the figure are shown with arrows and are here interpreted as resulting from pump tests in other boreholes, see also Table 5-19.

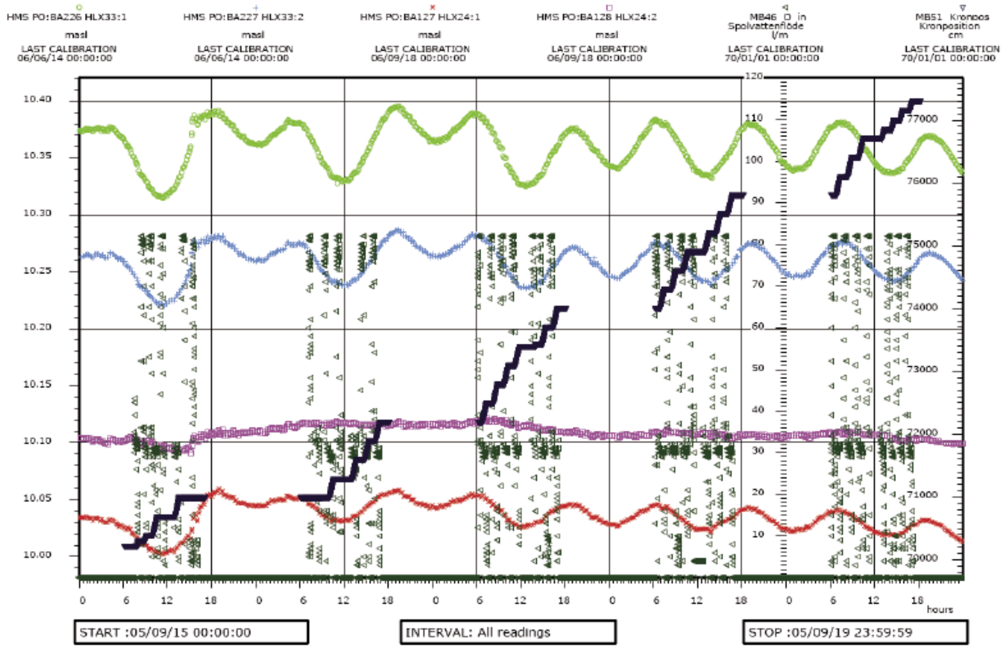


Figure 5-17. Groundwater levels in HLX24 and HLX33 during the time period of 050915–050919. No hydraulic responses from drilling activities in KLX10 can be seen in boreholes HLX24 or HLX33. The water levels in HLX24 and HLX33 only show diurnal variations. The water levels in HLX33 are given in green (section 1) or blue (section 2) and the levels in HLX24 are given in red (section 1) or purple (section 2). The drilling progress is shown as a increasing line of black triangles. The flushing water flow into borehole KLX10 is given as dark green triangles.

Table 5-20. Summary of pump tests that probably give hydraulic responses in HLX24 and HLX33.

Pump hole	Pump start	Pump stop
KLX07A	050617	050622
HLX23	050628	050628
HLX30	050905	050909

Hydraulic responses in near-by boreholes from nitrogen gas flushing in KLX10

Nitrogen gas flushing covering the entire length of the borehole was done in twice on 051113, also see Table 5-13.

Percussion boreholes HLX24 and HLX33 were checked for possible hydraulic responses from nitrogen gas flushing in KLX10, see Table 5-21. The locations of mentioned boreholes are given in Figure 5-19. No hydraulic draw-down from nitrogen gas flushing could be seen, see Figure 5-18.

Table 5-21. Hydraulic responses from nitrogen gas flushing in KLX10.

Borehole (section*)	Nitrogen flushing in KLX10 051113 7:00–11:00	Nitrogen flushing in KLX10 051113 12:00–14:45
HLX24 (1)	No	No
HLX33 (1)	No	No

* Installation for monitoring in boreholes are often made in a series of sections divided by packers along the length of the borehole. Section 1 is the lowest (i.e. deepest in the hole).

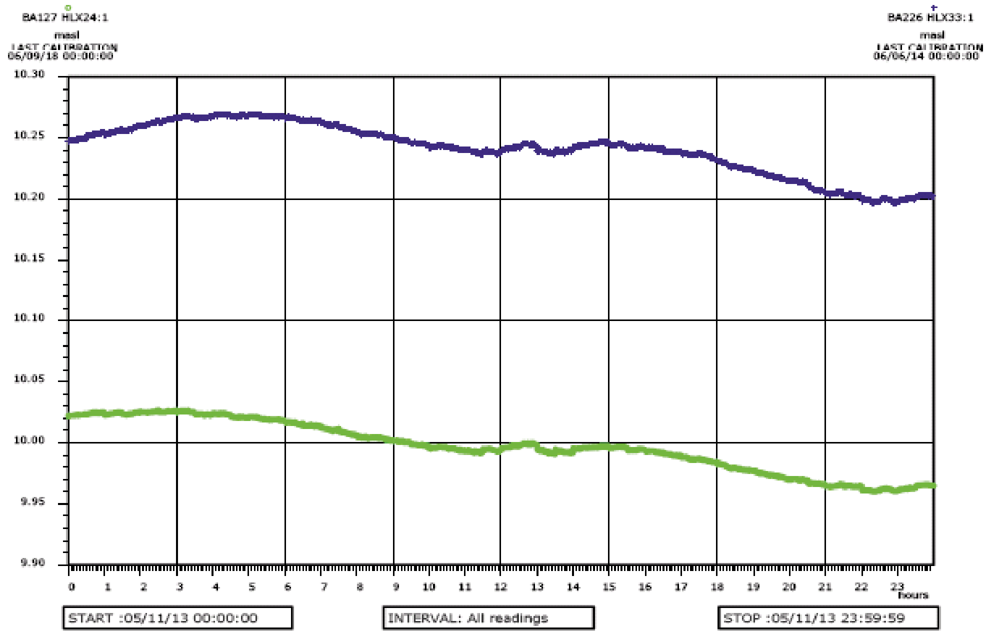


Figure 5-18. *Water levels in HLX24 green) and HLX33 (blue) during 051113. Nitrogen gas flushing was made twice during the day, between 7–11 and 12–14:45. No clear hydraulic response from nitrogen gas flushing in KLX10 could be seen in HLX24 or HLX33. A slightly anomalous change in the water levels that is probably not related to diurnal variations can be seen at ca 12:50.*

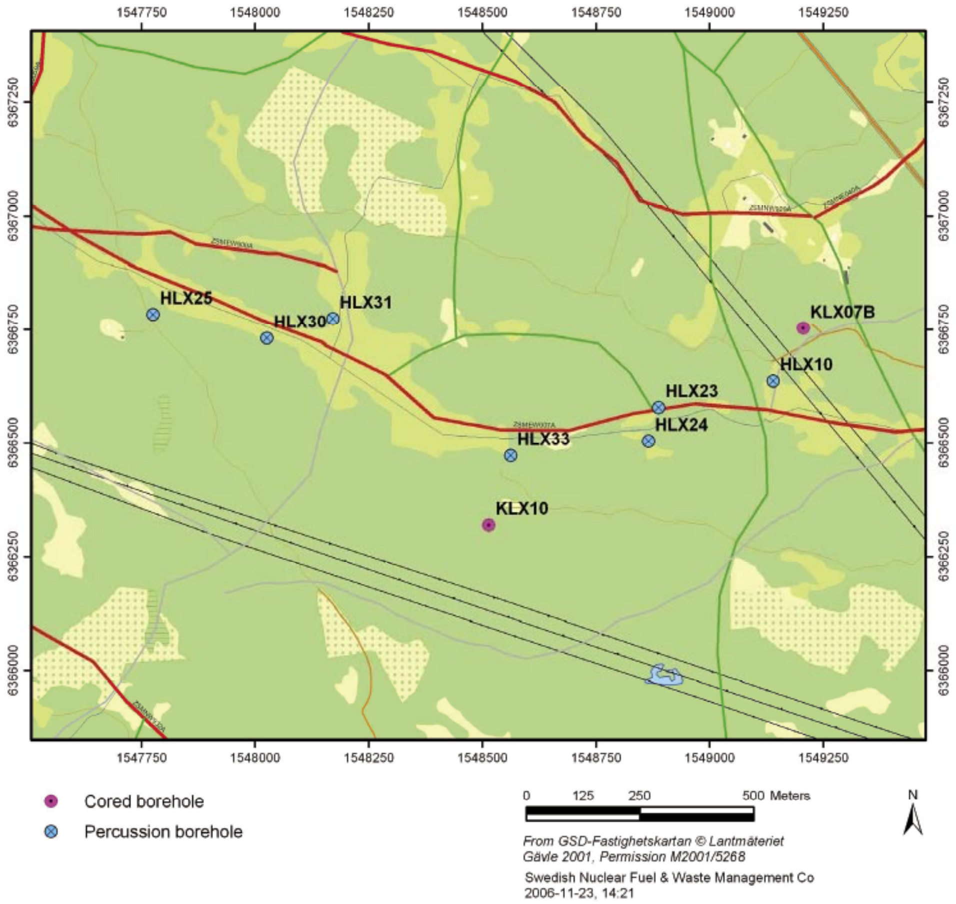


Figure 5-19. *Map showing the location of cored boreholes KLX10 and KLX07A and the percussion boreholes HLX10, HLX23, HLX24, HLX25, HLX30, HLX31 and HLX33.*

5.5 Drilling monitoring results

This section presents the results from drill monitoring, i.e. continuous data series of water parameters or technical drilling parameters. The two main drilling steps, the telescope section 0–100.33 metres and the core drilling section 100.33–1,000.41 metres are described in Sections 5.2 and 5.3 respectively.

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 5-20 through 5-22 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 5-20 through 5-22. Since DMS data are related to time (i.e. not strictly to borehole length) periods were drilling is not performed are also registered.

Figure 5-20 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.

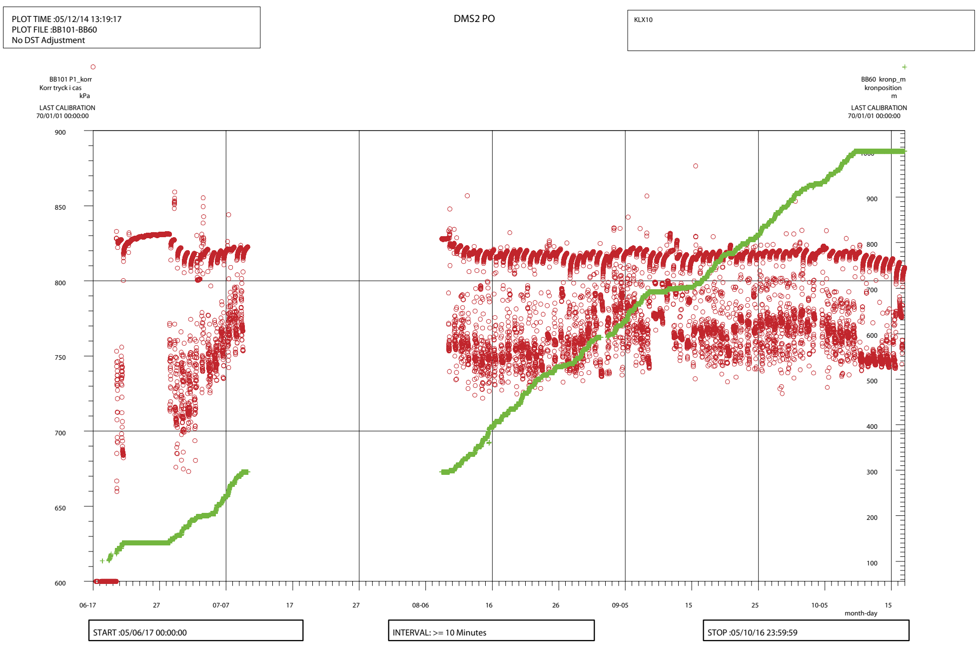


Figure 5-20. *Drill bit position (green) and water level from air-lift pumping (red). The water level is expressed as the pressure in kPa of the water column overlying the pressure gauge, i.e. the ambient air-pressure has been subtracted. The pressure gauge is emplaced at 89 metres borehole length. The drill bit position is given in cm·10³.*

Figure 5-21 shows the flushing water flow (green) entering the hole and the return water flow (red). The flushing water flows (green) show three distinct levels of flow:

- A flow of 30–40 litres/minute corresponding to pumped flow during drilling.
- A flow of ca 80 litres/minute corresponding to the flow while pumping down the core-barrel.
- No flow (zero litres/minute) when no drilling is performed.

Figure 5-22 shows the conductivity of the ingoing flushing water, conductivity of the return water and the oxygen content of the flushing water. The oxygen content was initially low (< 4 mg/L) when the flushing water was taken from HLX27 (050618–050627). After switching to HLX10 as a water source on June 27 the oxygen levels recorded by the DMS system increased to readings peaking at 15 mg/L. A series of measures were taken to explain and reduce the elevated oxygen readings. Repeated cleaning of hoses, water tanks and the oxygen meter, as well as calibrating the oxygen meter, where performed between June 29 and August 31. In August tests were made to increase the flow of nitrogen gas used for stripping oxygen. The improvements from these actions were limited and short-lived. The water tank and all hosing from the water supply well HLX10 to the cored borehole site, KLX10 were replaced on September 1. A significant reduction in oxygen could be noted after this. The overall judgement by SKB drilling and technical personnel is that the elevated oxygen readings during June and August do not really reflect the true oxygen content of the flushing water entering KLX10, but should be attributed to technical problems with the measuring system.

The electrical conductivity of the flushing water was high at ca 400 mS/m during the period June 18 to 30. The high conductivity in the flushing water was due to high conductivity in the flushing water well, HLX27. The use of HLX27 as a water supply for the core drilling of KLX10 was discontinued on June 27. A distinct reduction in electrical conductivity to a level of 60 mS/m in the flushing water can be seen after the switch in water source from HLX27 to HLX10.

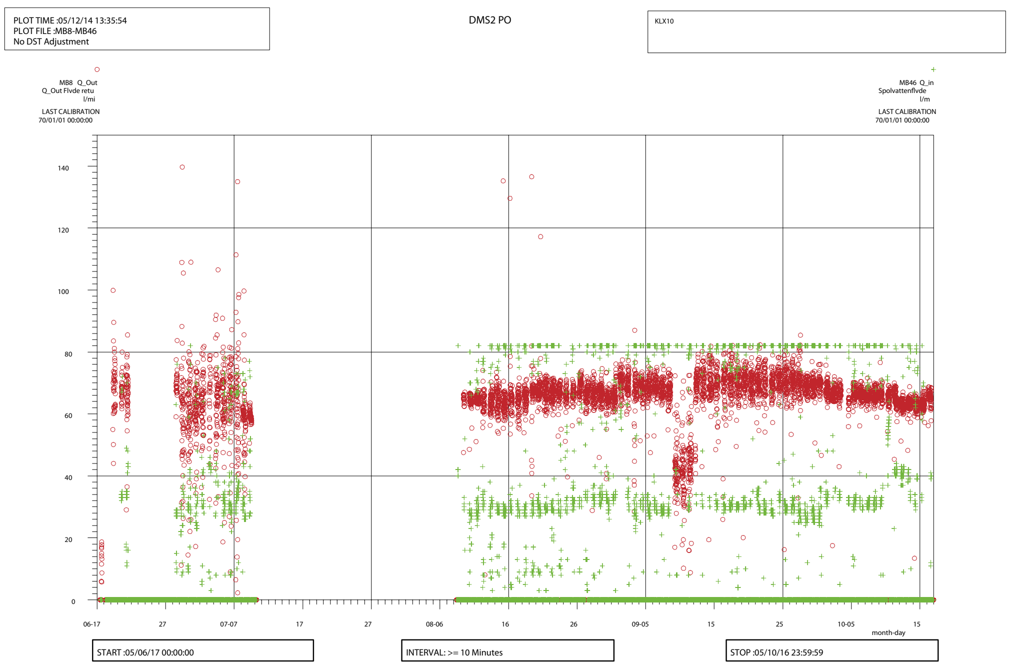


***Figure 5-21.** Flushing water flow (green) and return water flow (red) in litres per minute.*

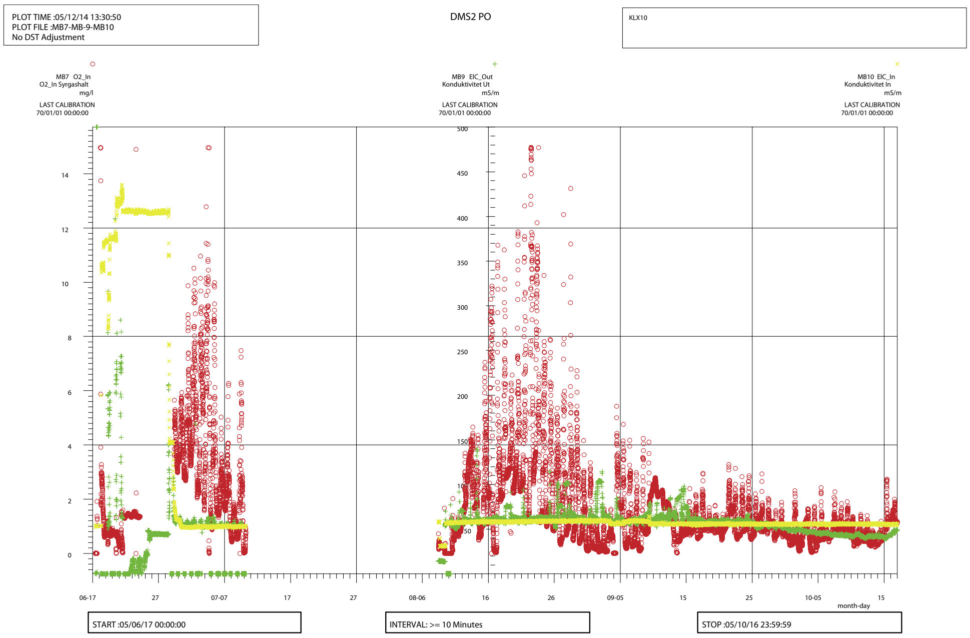


Figure 5-22. Conductivity of flushing water (yellow) and return water (green). The oxygen content in mg/l of the flushing water (red) is also shown. The oxygen content of the flushing water was low (< 4 mg/l) initially and in September an onwards. The elevated oxygen readings during June and August do not really reflect the true oxygen content of the flushing water entering KLX10, but should be attributed to technical problems with the measuring system.

5.5.2 Measurements of flushing water and drill cuttings

A calculation of accumulated amounts of water flowing in and out of the borehole based on water flow measurements from the DMS system (continuous readings) is given in Figure 5-23.

The amount of flushing water consumed during drilling was 1,100 m^3, giving an average consumption of ca 1.2 m^3 per metre drilled. The amount of effluent return water from drilling in KLX10 was 3,300 m^3, giving an average of ca 3.7 m^3 per metre drilled.

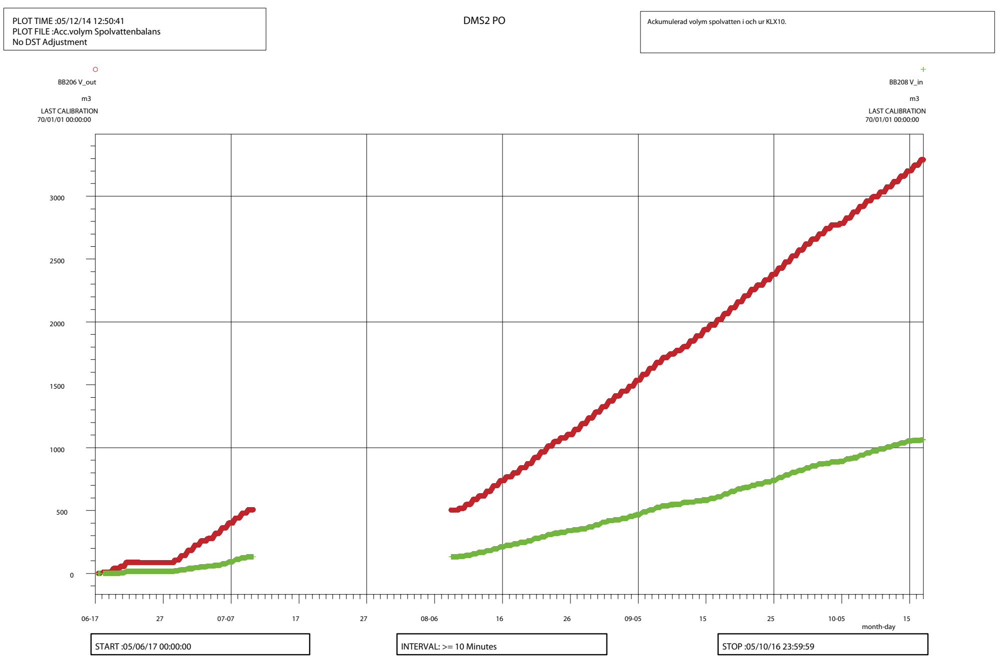


Figure 5-23. Flushing water balance from KLX10 as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.

Drill cutting balance

The weight of cuttings in the settling containers amounted to 1,406 kg. The content of suspended material in the return water was not analysed in borehole KLX10, 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 1,320 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing over a length of 900 metres is 6,000 kg assuming a density of 2.65 kg/dm^3. This means that about 45% of the material liberated by drilling is accountable as removed from the borehole or 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 5-22. The results show that 52% of the introduced uranine was retrieved during drilling of KLX10.

5.6 Geology

A preliminary geological mapping of the core is done as drilling progresses as part of the drilling activity. This mapping phase includes a first pass mapping of major geological features as well as RQD-logging and photodocumentation of the core.

A more detailed mapping with the Boremap method is made after measurements have been made in the borehole that can provide orientation of geological features. Boremap mapping and the related measurements are not part of the drilling activity. The results from the Boremap logging are included in this report as it represents a more complete geological record than the preliminary geological mapping.

The geological results based on the Boremap logging are shown in Appendix 1. It should be stressed that the geological description given in this report is a brief summary only. A more complete account is given in /5/.

Lithologically the core is dominated by Ävrö granite (87% of the core expressed as Boremap "Rock type"). Minor sections of fine-grained diorite-gabbro, fine grained granite, fine-grained dioritoid and diorite-gabbro occur. The borehole ends in quartz monzodiorite from 980 to 1,000 m.

Red staining with weak to medium intensity is common to 340 m. Below 340 m length the amount of red staining is gradually reduced. There is, however, a correlation between red staining, both occurrence and intensity, and fracture frequency. Sections with red staining are indicated as "oxidized" in Appendix 1.

The distribution of total fractures in the core is typically in the range of 0–40 fractures/metre to a length of 460 m. Below 460 m the fracture frequency is significantly reduced, minor sections with elevated fracture frequencies do however occur.

Table 5-22. Balance calculation of uranine tracer in KLX10.

Average uranine content IN (mg/L)	0.206
Flushing water volume IN (m^3)	1,100
Amount uranine introduced (g)	227
Average uranine content OUT (mg/L)	0.036
Return water volume OUT (m^3)	3,300
Amount uranine recovered (g)	119

The average fracture frequency over the entire core drilled section expressed as open fractures is 2.6 (fractures/metre). NB The fracture frequency given in Appendix 1 shows the total fracture frequency (i.e. open fractures, sealed fractures and fractures in crushed sections).

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 5-24. Precautionary guideline 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.

Monitoring of effluent water

The effluent water, i.e. discharge to the ground, from the core drilling of KLX10 exceeded the guideline value for electrical conductivity of 300 mS/m on two occasions, see Figure 5-22. Simultaneous analytical results from return water samples however show that the conductivity was around 200–250 mS/m, see Figure 5-12. The flushing water source with high conductivity (HLX27) was nevertheless discontinued early on in the drilling progress and the electrical conductivity of the effluent water was significantly reduced. Typical conductivity values were in the range of 50–100 mS/m for the most of the core drilling phase, see Figures 5-12 and 5-22.

The uranine content was well below 0.3 mg/l, see Figure 5-12.

The concentration of suspended material was not analysed in the boreholes, however previous sampling has shown that the concentration was well below 600 mg/L /6/.

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

Drilling of environmental monitoring wells

Drilling of environmental monitoring wells SSM000220 and SSM000221 was done on May 30 and 31, 2005. The technical data for the environmental wells are given in Appendix 7. The location of the environmental monitoring wells SSM000220 and SSM000221 is shown in Figure 5-24.

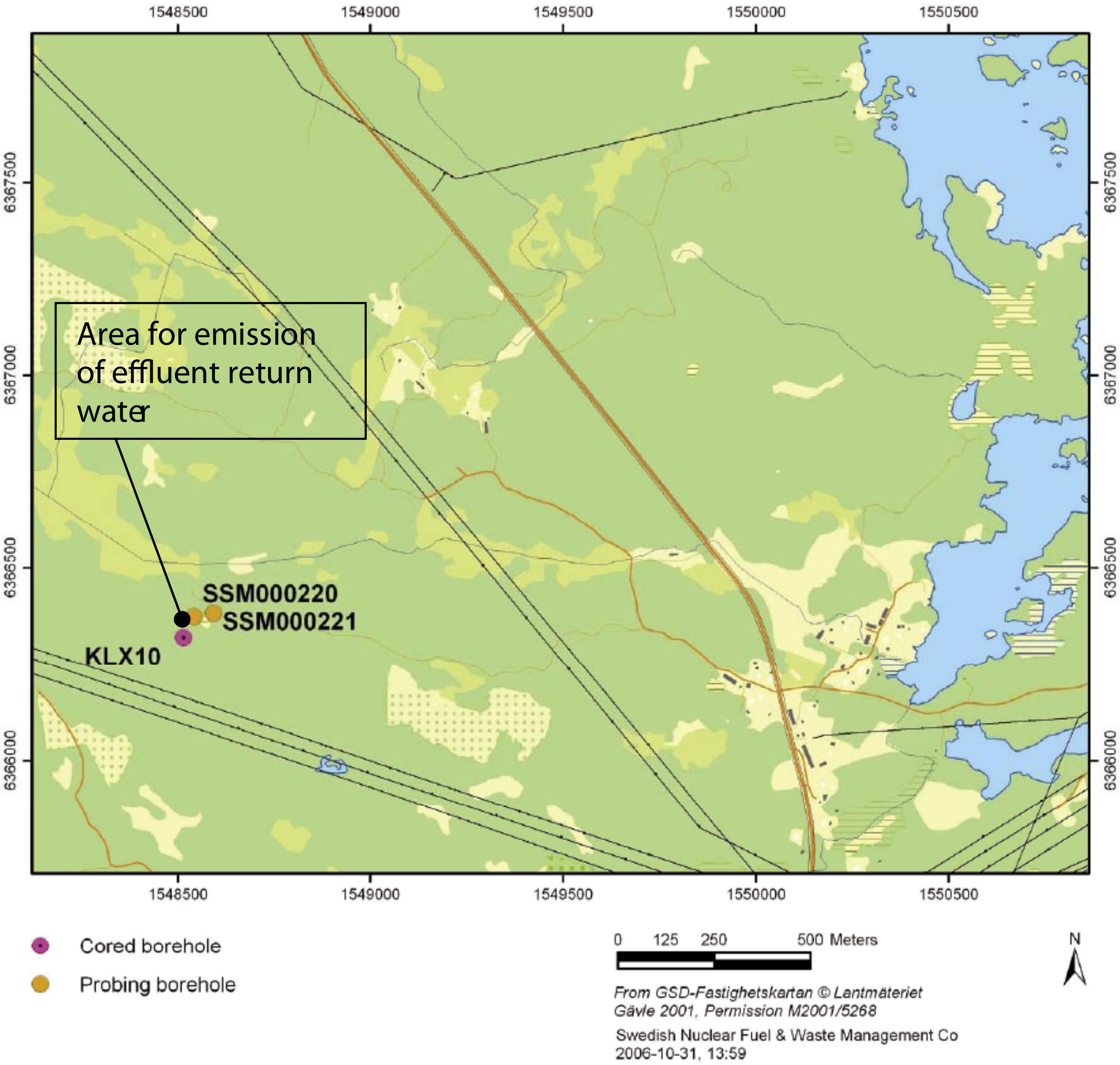


***Figure 5-24.** Location of environmental monitoring wells SSM000220 and SSM000221 in relation to the core drill site for KLX10.*

Reference sampling

A reference sample of surface soil from the drill site of KLX10 was taken on May 5, 2005. The SKB sample number is 9008.

Water samples for reference of the ground water in environmental monitoring wells SSM000220 and SSM000221 were taken according to Table 5-23.

Table 5-23. Reference water samples.

Monitoring well	Sample id number	Date
SSM000220	10477	2005-05-25
SSM000221	10360	2005-06-16

Monitoring of soil ground water levels

A pressure logger (transducer) for measuring the ground water table was installed in SSM000220 and SSM000221 during the core drilling of KLX10. The water levels are given graphically in Figures 5-25 and 5-26.

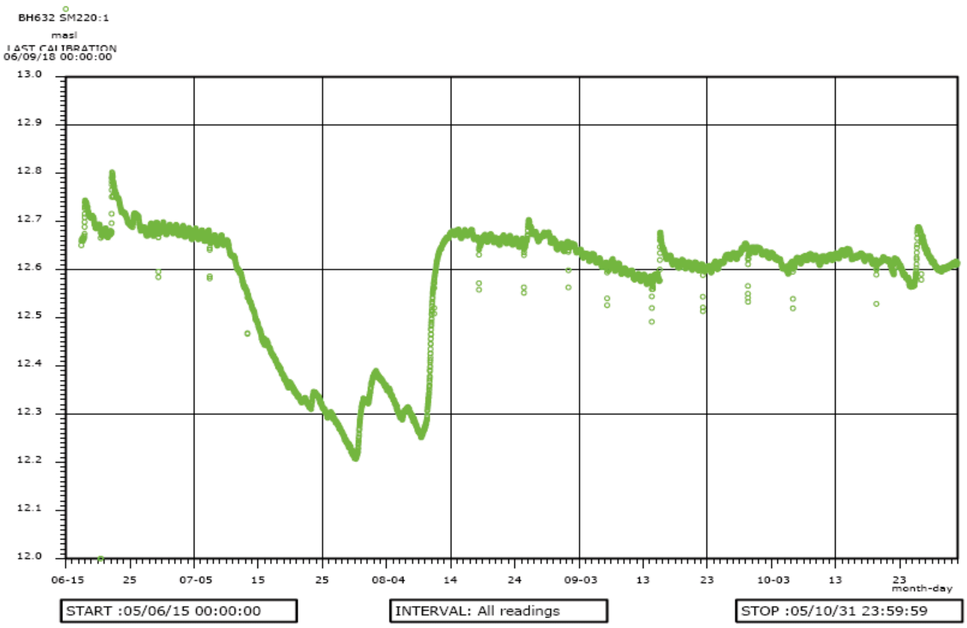


Figure 5-25. *Ground water level in well SSM000220.*

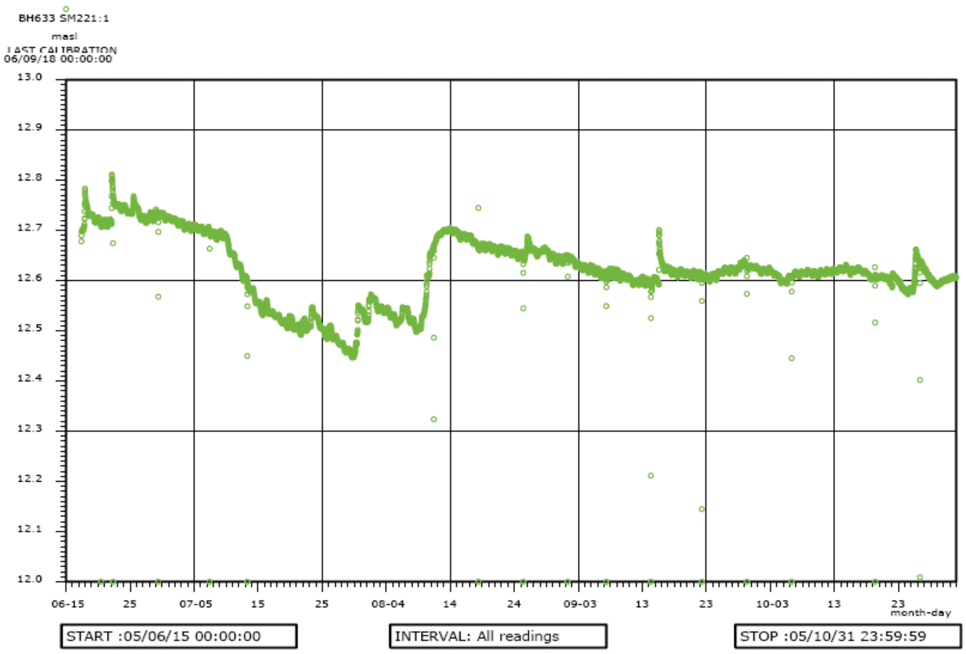


Figure 5-26. *Ground water level in well SSM000221.*

Monitoring of electrical conductivity and pH in ground water samples

Water samples were collected with a one to two week interval for monitoring of the electrical conductivity and pH in the ground water in the environmental monitoring wells SSM000220 and SSM000221. The results show very steady values for pH and an increasing trend for the electrical conductivity, see Figures 5-27 and 5-28. The increase in electrical conductivity is modest and the levels do not reach in any way alarming levels.

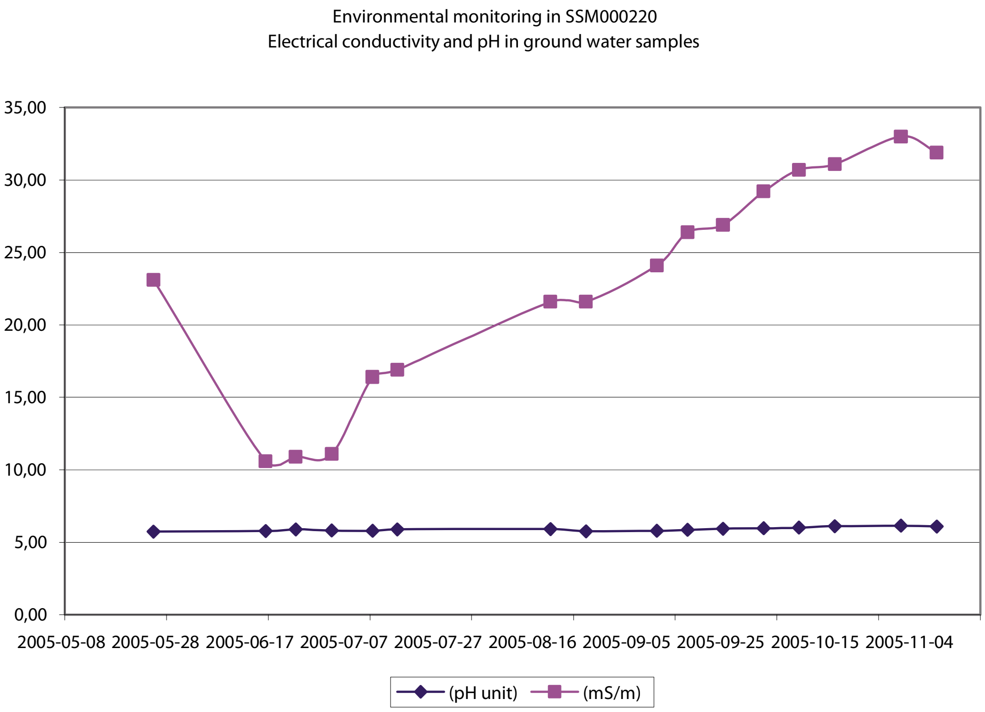


***Figure 5-27.** Electrical conductivity and pH in ground water samples from SSM000220.*

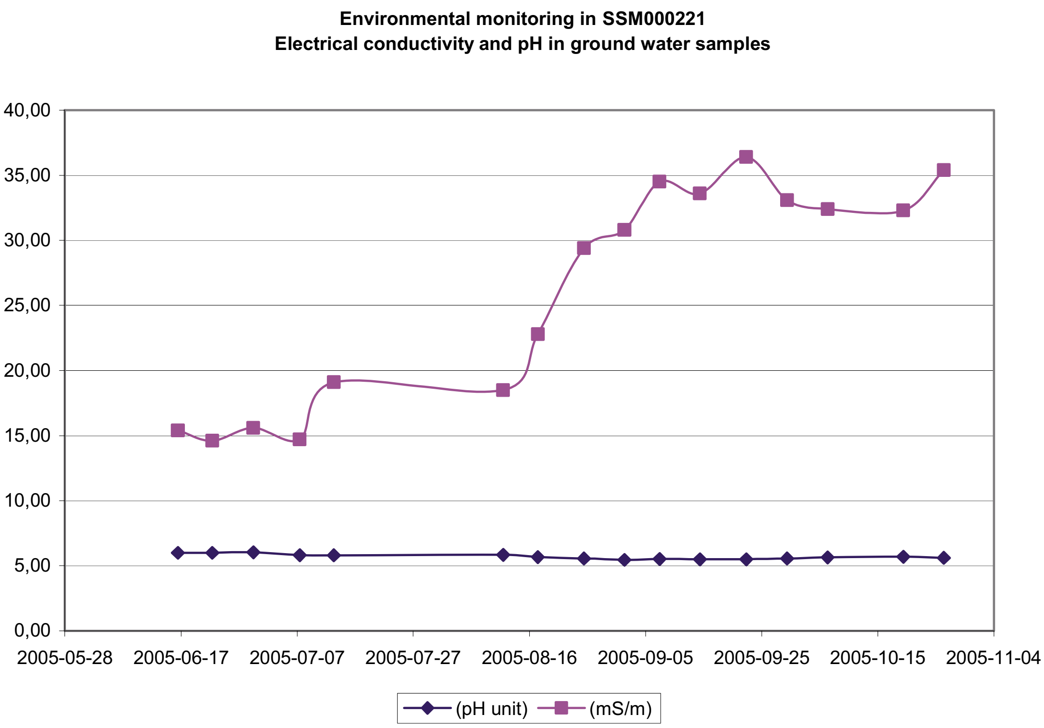


***Figure 5-28.** Electrical conductivity and pH in ground water samples from SSM000221.*

5.8.1 Consumption of oil and chemicals

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

The concrete consumption was 520 litres in total. The concrete was based on white silica, low alkali cement.

5.9 Nonconformities

The tightness of the concrete gap injection of the casing in the upper part of the telescopic section was not tested due to a slight modification of drilling procedure. Previous drillings and related testing show that the gap injections fulfil the requirements stated in the method description (SKB MD 620.003 v1.0, internal document) for core drilling.

No pumping test was performed after the pilot drilling with 165 mm diameter in the telescopic section. Instead a four day pumping test was made in the telescopic section after reaming to 197.3 mm diameter, se Section 5.2.4.

6 References

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

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

/3/ **Ask, Morosini, Samuelsson, Ekström, 2004.**Drilling of cored borehole KSH02, SKB P-04-151, Svensk Kärnbränslehantering AB.

/4/ **Ask, Morosini, Samuelsson, Ekström, Håkanson, 2005.**Drilling of cored borehole KLX05, SKB P-05-233, Svensk Kärnbränslehantering AB.

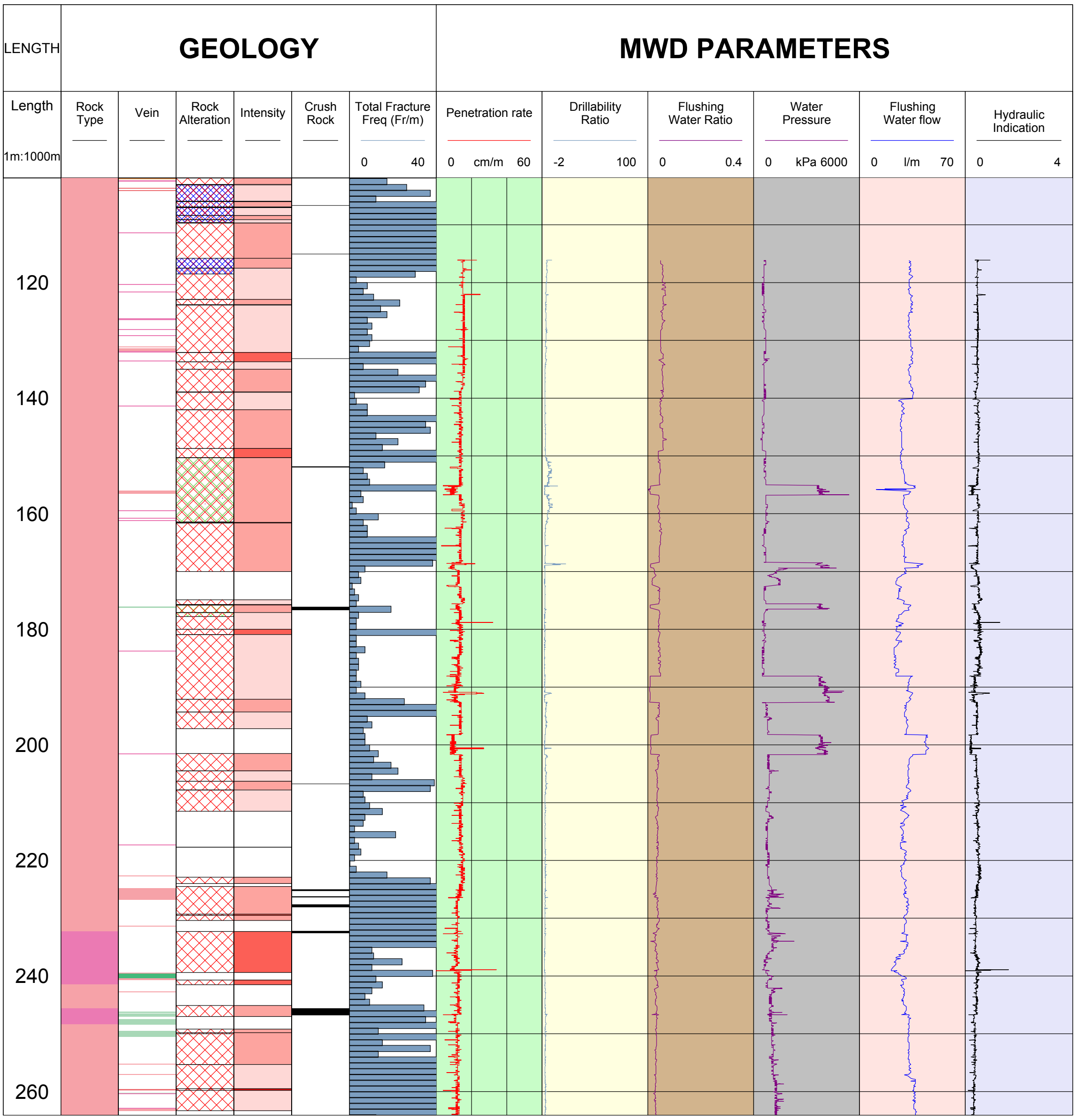
/5/ **Dahlin, Mattsson, Ehrenborg, 2006.**Boremap mapping of core drilled borehole KLX10, SKB P-06-51, Svensk Kärnbränslehantering AB.

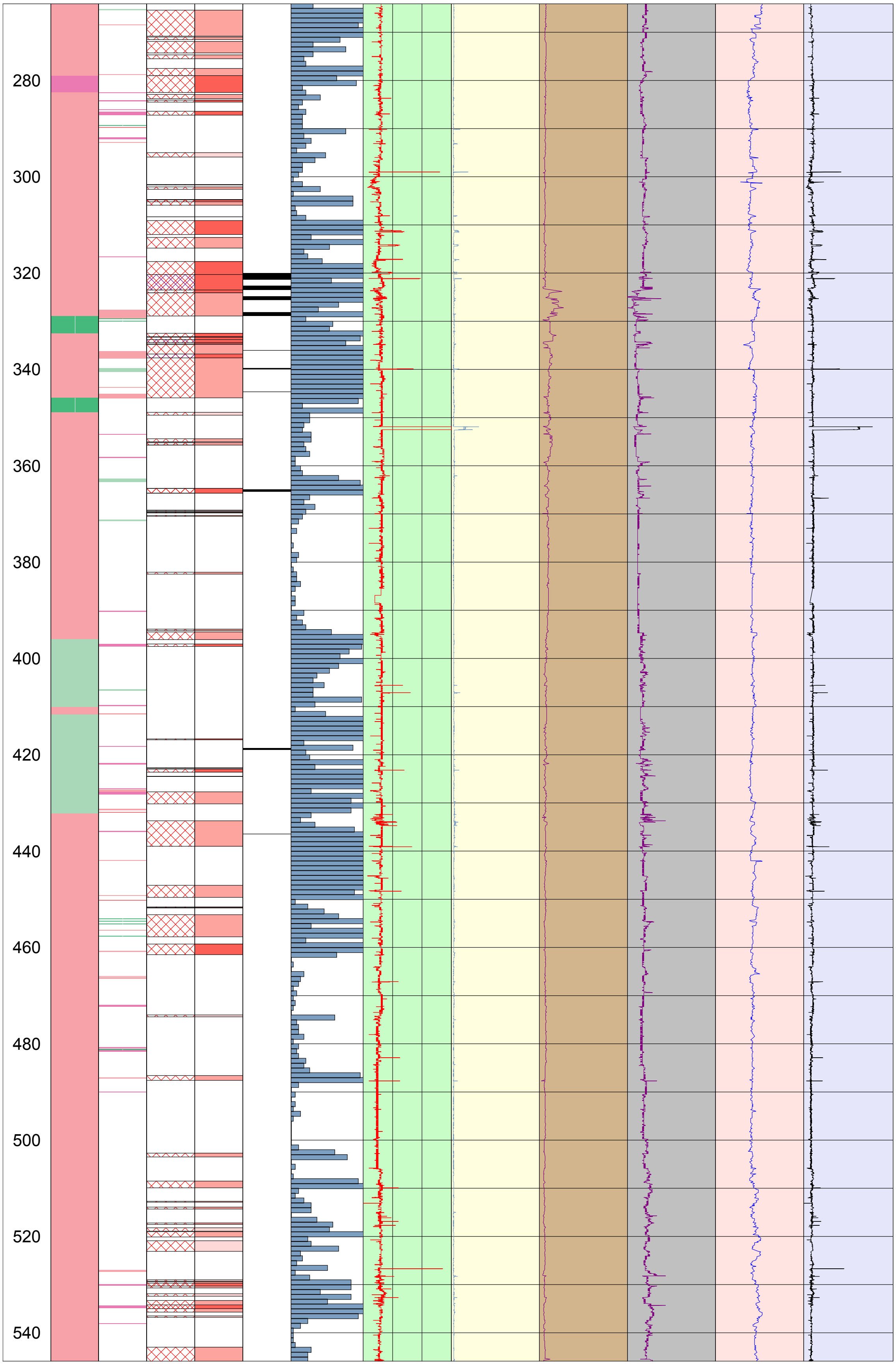
/6/ **Ask, Morosini, Samuelsson, Ekström, Håkanson, 2004.**Core drilling of KSH03, SKB P-04-233, Svensk Kärnbränslehantering AB.

Geology and MWD parameters KLX10

Title	GEOLOGY & MWD PARAMETERS KLX10		Appendix 1
Site	LAXEMAR	Coordinate System	RT90-RHB70
Borehole	KLX10	Northing [m]	6366319.38
Diameter [mm]	76	Easting [m]	1548515.23
Length [m]	1001.200	Elevation [m.a.s.l.]	18.28
Bearing [°]	250.80	Drilling Start Date	2005-05-24 12:30:00
Inclination [°]	-85.19	Drilling Stop Date	2005-10-15 07:40:00
Date of mapping	2005-11-29 09:18:00	Plot Date	2007-01-16 22:15:47

ROCKTYPE LAXEMAR	ROCK ALTERATION	INTENSITY
Fine-grained granite	Oxidized	Faint
Ävrö granite	Chloritisized	Weak
Quartz monzodiorite	Epidotisized	Medium
Diorite / Gabbro	Sericitisized	Strong
Fine-grained dioritoid	Quartz dissolution	
Fine-grained diorite-gabbro	Argillization	
	Albitization	
	Saussuritization	

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520
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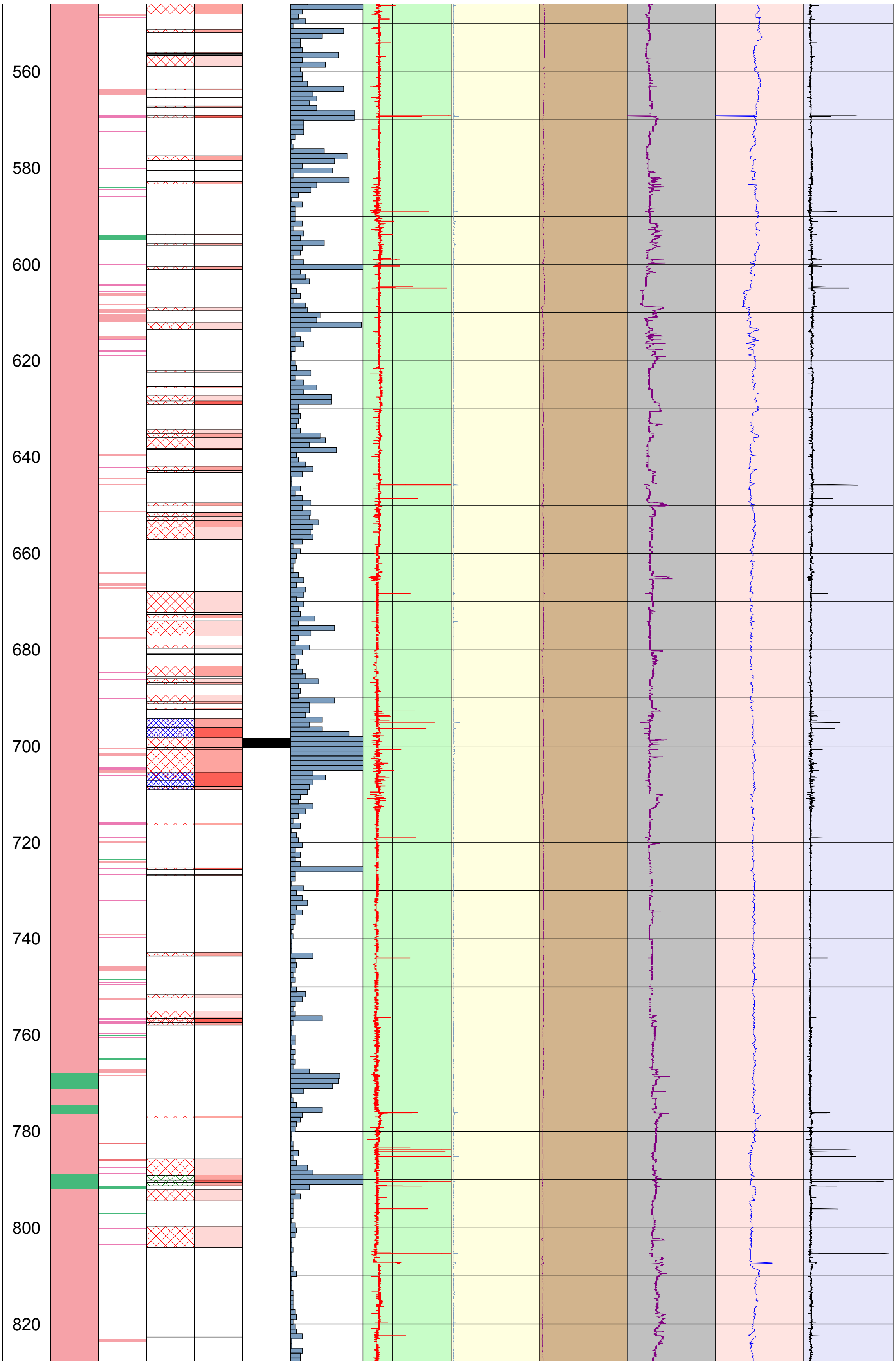
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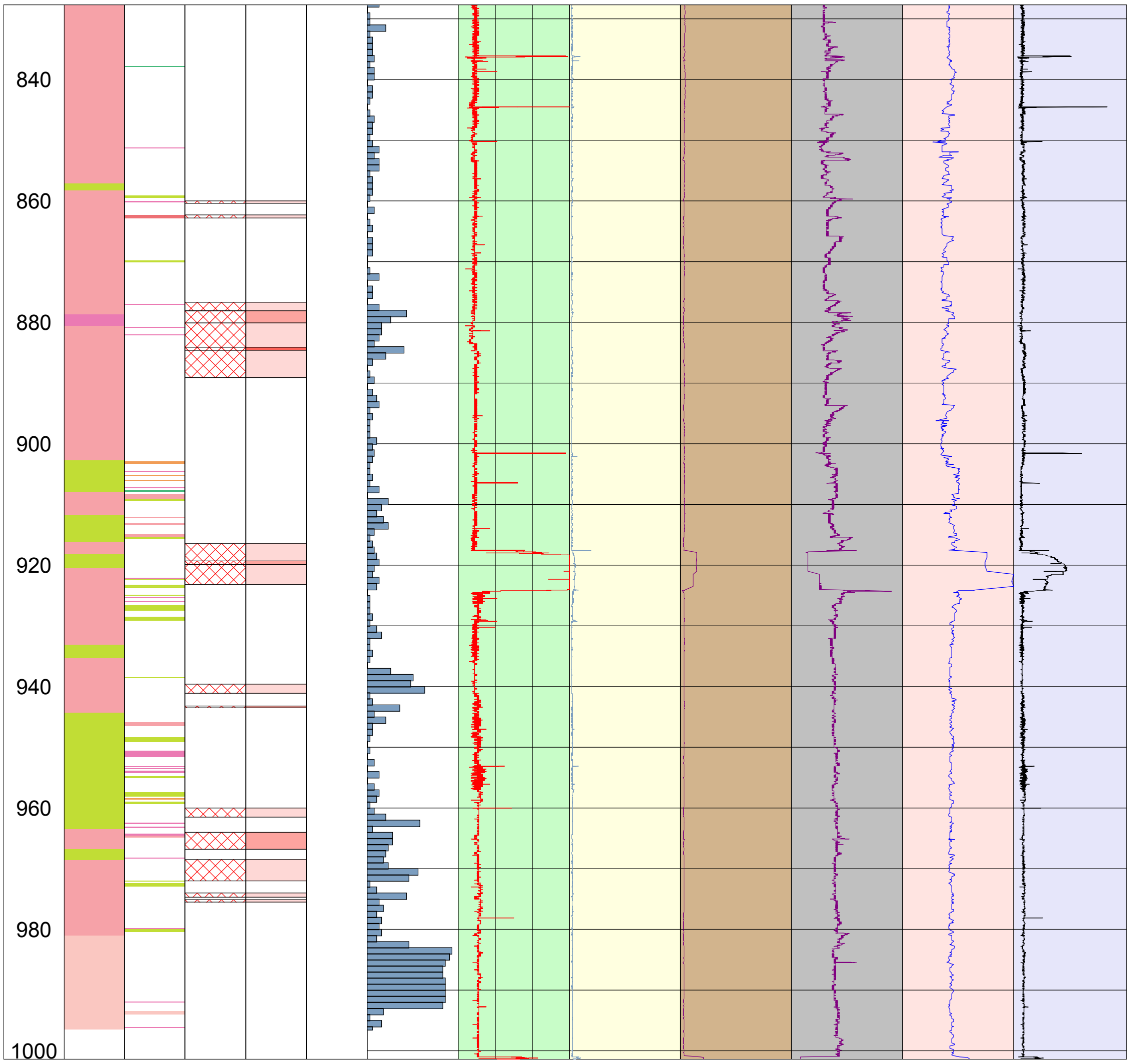
760
780
800
820


840
860
880
900
920
940
960
980
1000

Appendix 2

Chemical results

Borehole	KLX10	KLX10	KLX10	KLX10	KLX10	KLX10	KLX10
Date of measurement	2005-06-03	2005-06-07	2005-07-03	2005-08-10	2005-08-13	2005-08-17	2005-08-25
Upper section limit (m)	0.00	0.00	102.90	197.50	319.30	298.20	405.97
Lower section limit (m)	100.60	100.60	198.21	299.10	334.60	407.05	514.92
Sample_no	10326	10327	10403	10445	10450	10452	10475
Groundwater Chemistry Class	3	3	3	3	3	3	3
pH	8.35	8.26	8.42	8.58	8.28		7.58
Conductivity mS/m	62.6	58.6	65.7	97.4	345.0		765.0
Drill water %			1.73	28.10	15.50	47.10	26.60
Density g/ml	0.9963	0.9964	0.9963	0.9964	0.9974		0.9990
Charge balance %	–0.62	0.14	6.20	1.26	–2.16		–5.81
Na mg/l	121.0	128.0	157.0	180.0	555.0		939.0
K mg/l	3.20	3.34	3.94	5.13	6.18		9.87
Ca mg/l	6.4	7.5	9.3	11.3	104.0		374.0
Mg mg/l	2.0	2.2	2.6	3.0	17.8		52.4
HCO3 mg/l Alkalinity	301	311	307	302	106		84.1
Cl mg/l	7.6	8.2	11.1	32.6	805.0		2,380.0
SO4 mg/l	24.2	29.0	47.4	104.0	345.0		153.0
SO4_S mg/l Total Sulphur	8.54	10.30	18.00	38.40	124.00		56.70
Br mg/l	<0.2	<0.2	<0.2	<0.2			
F mg/l	4.28	4.39	4.86	5.54	3.44		2.40
Si mg/l	6.76	6.00	7.53	9.40	3.80		6.58
Fe mg/l Total Iron	0.4960	0.0637	3.0700	2.8200	1.4800		4.1700
Mn mg/l	0.0375	0.0360	0.0781	0.0703	0.1220		0.3780
Li mg/l	0.010	0.010	0.015	0.021	0.069		0.126
Sr mg/l	0.094	0.115	0.148	0.153	1.680		6.710
PMC % Modern Carbon			54.72		35.91		46.70
C-13 dev PDB			–16.45		–9.79		–13.39
AGE_BP Groundwater age			4,789		8,173		6,063
AGE_BP_CORR			35		35		35
D dev SMOW			–75.7		–75.6		–75.8
Tr TU			1.90		–0.80		1.10
O-18 dev SMOW			–10.6		–10.20		–9.90
B-10 B-10/B-11			0.2390		0.2387		0.2393
S-34 dev SMOW			25.0		25.9		21.4
Cl-37 dev SMOC			0.34		–0.14		–0.28
Sr-87 Sr-87/Sr86			0.715928		0.715364		0.715600

Appendix 3

Chemistry – analytical method

SKB Chemistry class 3.

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	1 ml HNO_3 suprapur, filtering membrane filter	red	Analytica
C-13, PMC	2 ea 100 ml brown glass		green	Waterloo
S-34	1,000 ml		green	IFE

Quality of the analyses

The charge balance errors (see Appendix 2) give an indication of the quality and uncertainty of the analyses of the major components. The relative charge balance errors are calculated for the selected set of data from the borehole KLX10. The errors do not exceed ± 5% in any of the samples except for 10403 and 10475 which have charge balance errors of 6.20 and –5.81 respectively.

The charge balance error is not calculated for the sample 10452 collected in KLX10.

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. No control analyses were performed on the water samples from KLX10.
- 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 (%) = $100 \cdot \dfrac{(\sum \text{cations(equivalents)} - \sum \text{anions(equivalents)}}{(\sum \text{cations(equivalents)} + \sum \text{anions(equivalents)}}$
- General expert judgement of plausibility based on earlier results and experiences.

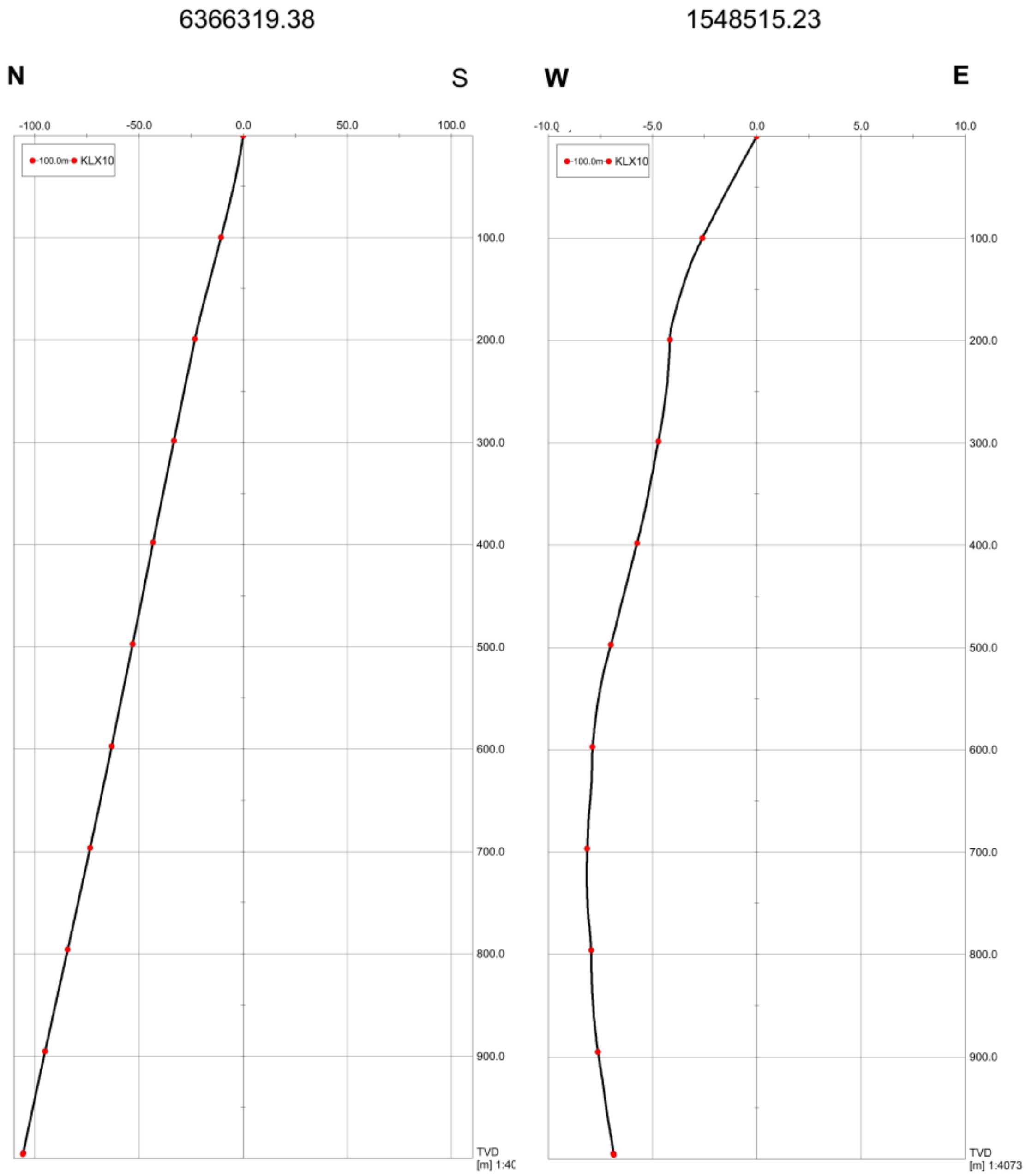
All results from "biochemical" components and special analyses of trace metals and isotopes are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a "best choice" notation will indicate those results which are considered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

Appendix 4

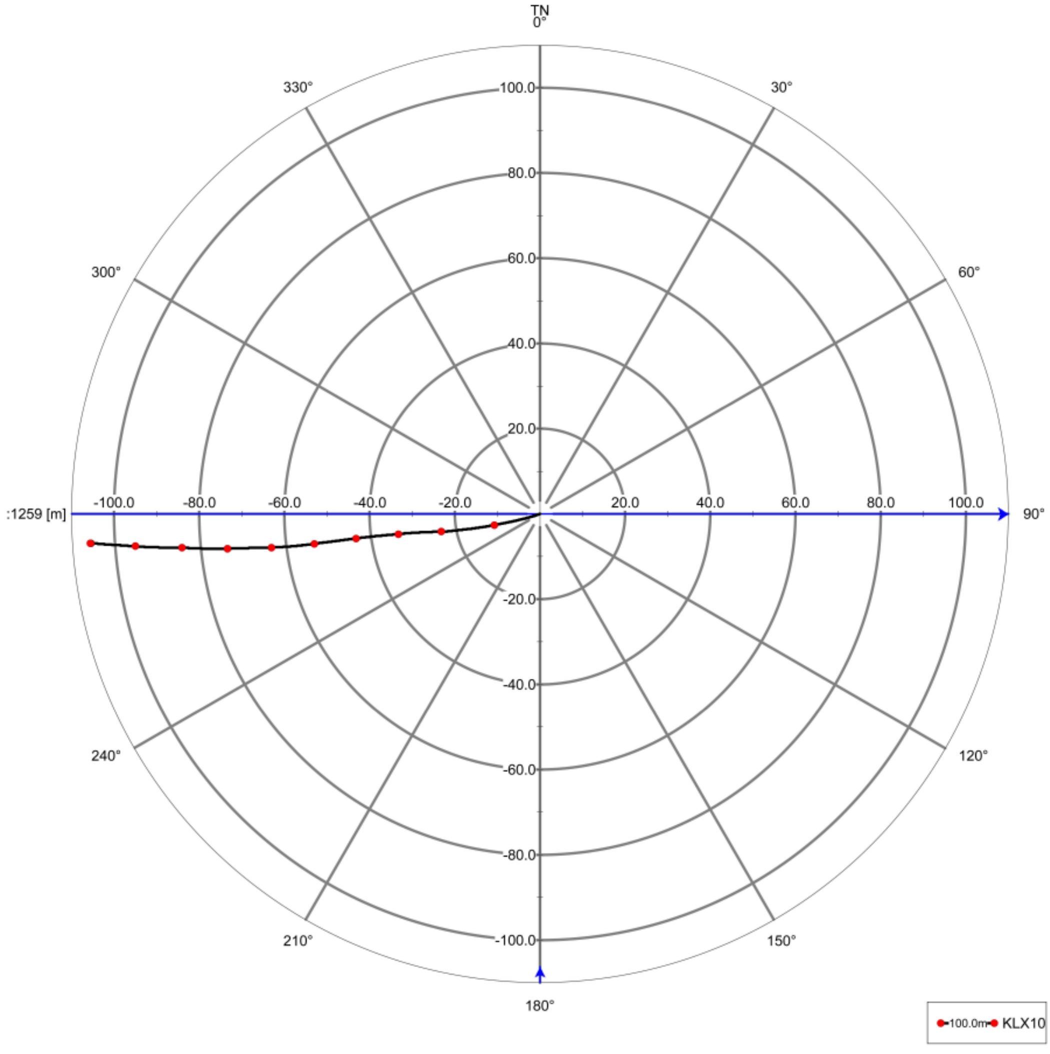
Deviation measurements

Vertical section / Orthogonal projection **Appendix: 4**

Borehole	KLX10
Site	Laxemar
Coordinate system	RT90-RHB70
Length	1001.80
Bearing	174.33
Inclination	-85.19
● Interval	



Deviation measurement		Appendix: 4
Site	Laxemar	
Borehole	KLX10	
View from above		

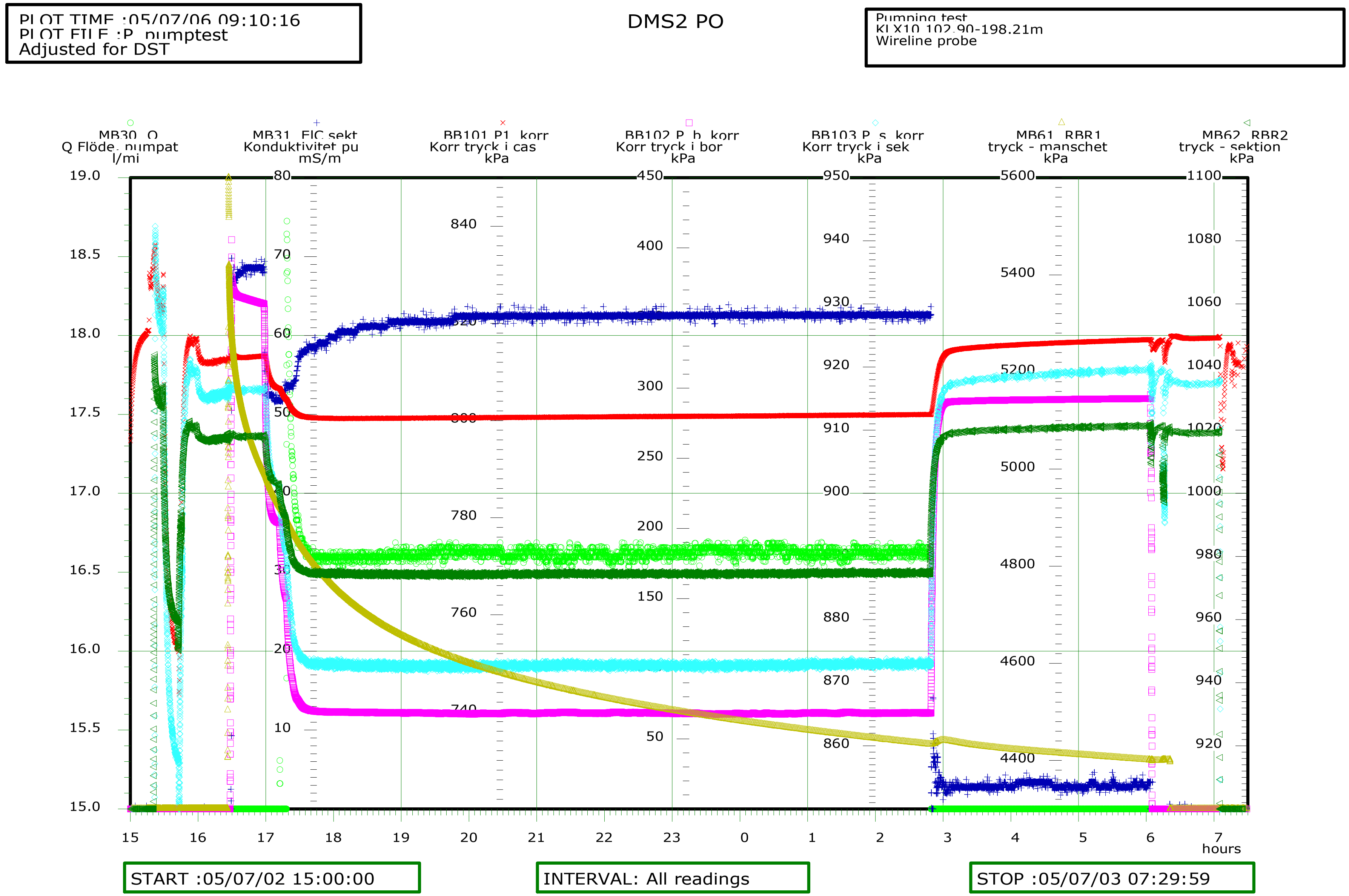


Appendix 5

Wireline pumping tests

Description of the parameters in the enclosed plots.

Channel	Parameter	Unit	Description
MB30	Water flow	Litre/minute	Flow of water pumped up from the borehole during the test.
MB31	Electrical conductivity	mS/m	Electrical conductivity in the pumped out water.
BB101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
BB102	Pressure	kPa	Pressure of the water column in the test section, i.e. at depth in the borehole, subtracted with the ambient air pressure.
BB103	Pressure – section	kPa	Pressure of the water column in the test section, i.e. at depth in the borehole, subtracted with the ambient air pressure.
MB61	Pressure – packer	kPa	Inflation pressure in packer.
MB62	Pressure – section	kPa	Pressure of the water column in the test section, i.e. at depth in the borehole. Not corrected for ambient air pressure.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PLOT FILE :P_pumptest
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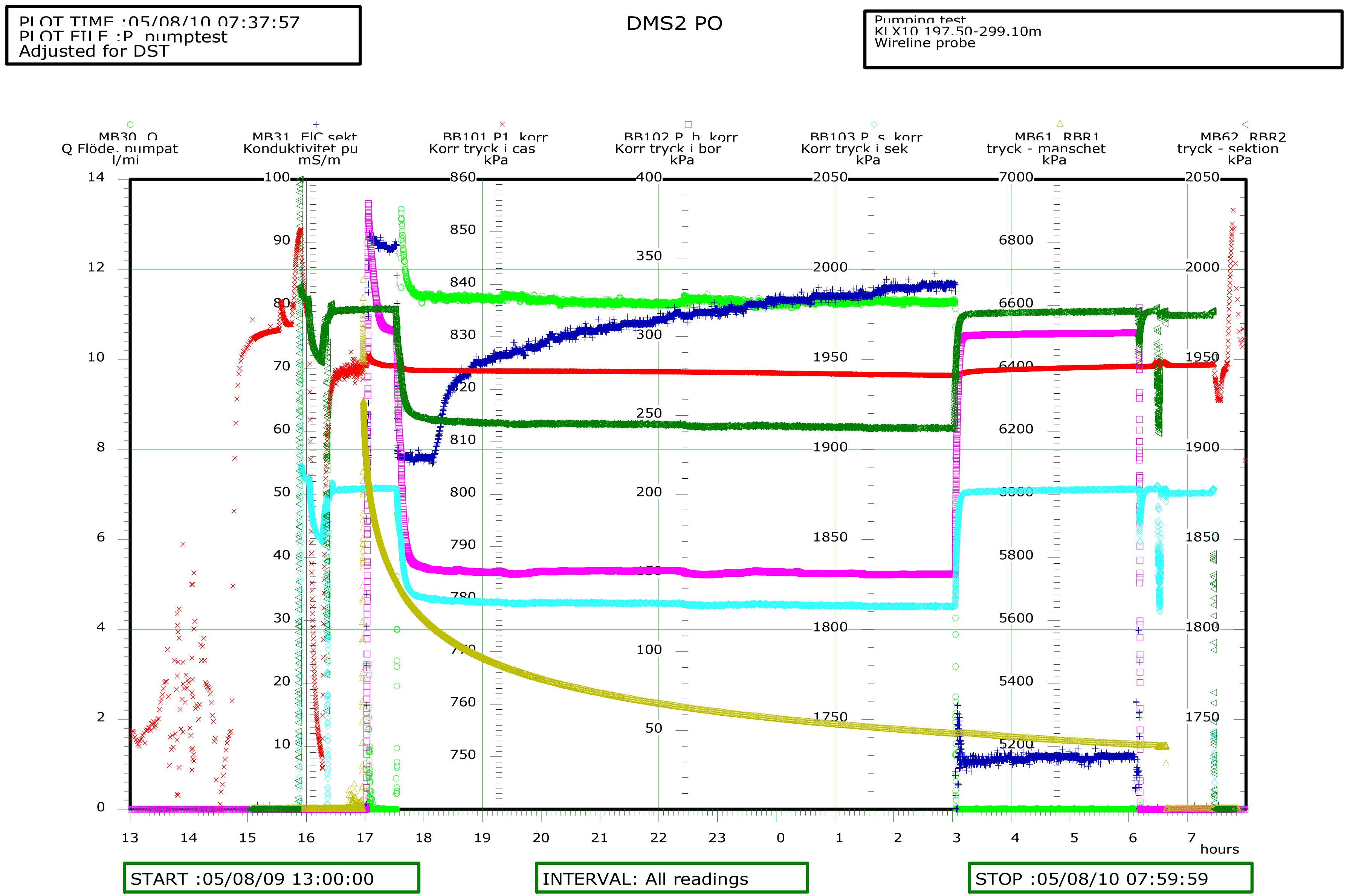
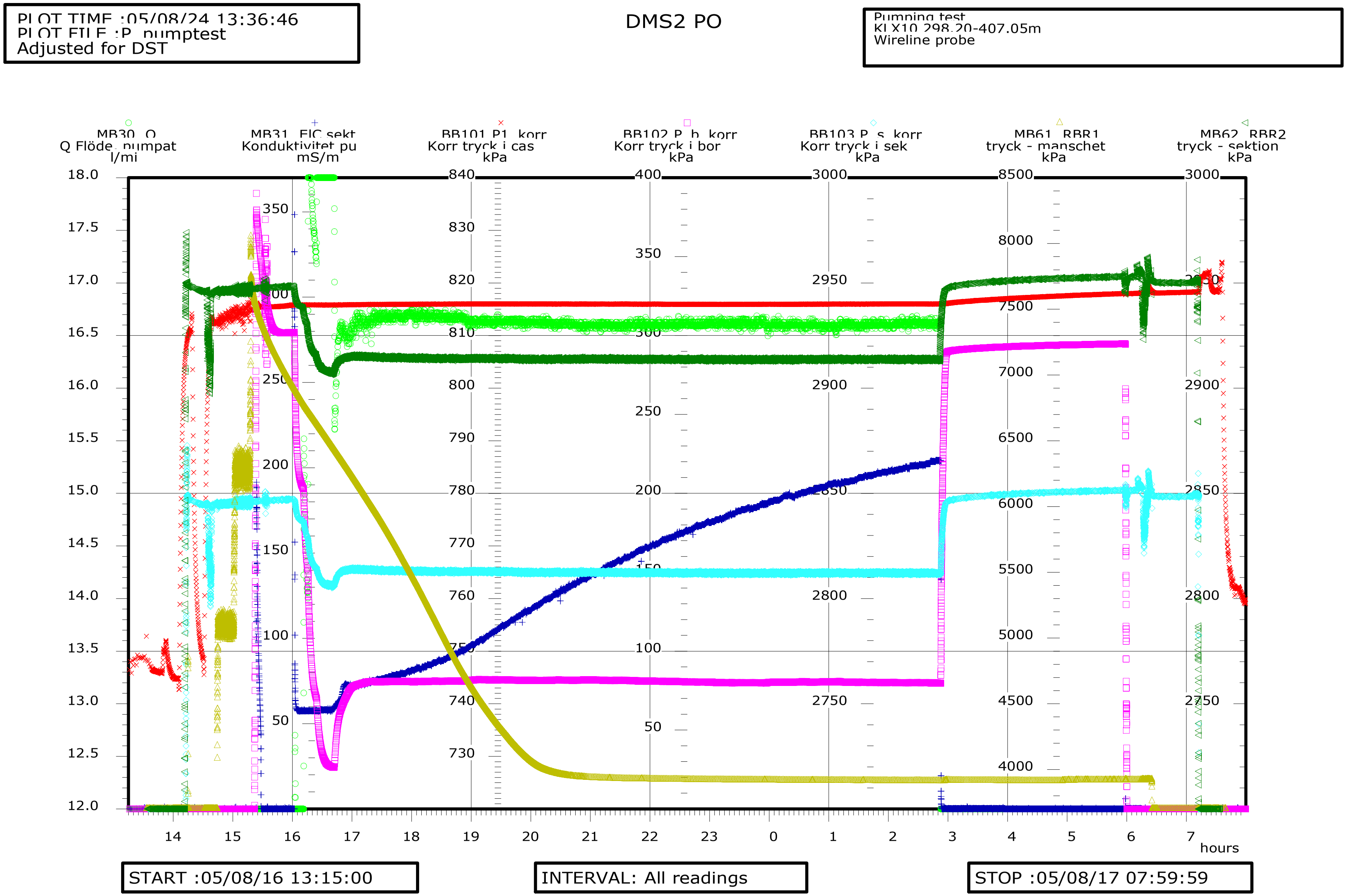
DMS2 PO
Pumping test
KLX10 102.90-198.21m
Wireline probe
MB30_Q
Q Flöde, pumpat
l/mi
MB31_EIC sekt
Konduktivitet pu
mS/m
BB101_P1_korr
Korr tryck i cas
kPa
BB102_P_b_korr
Korr tryck i bor
kPa
BB103_P_s_korr
Korr tryck i sek
kPa
MB61_RBR1
tryck - manschet
kPa
MB62_RBR2
tryck - sektion
kPa
hours
START :05/07/02 15:00:00
INTERVAL: All readings
STOP :05/07/03 07:29:59


PLOT TIME :05/08/10 07:37:57
PLOT FILE :P_pumptest
Adjusted for DST
DMS2 PO
Pumping test
KLX10 197.50-299.10m
Wireline probe
MB30 Q
Q Flöde, pumpat
l/mi
MB31 EC sekt
Konduktivitet pu
mS/m
BB101 P1 korr
Korr tryck i cas
kPa
BB102 P_h korr
Korr tryck i bor
kPa
BB103 P_s korr
Korr tryck i sek
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
hours
START :05/08/09 13:00:00
INTERVAL: All readings
STOP :05/08/10 07:59:59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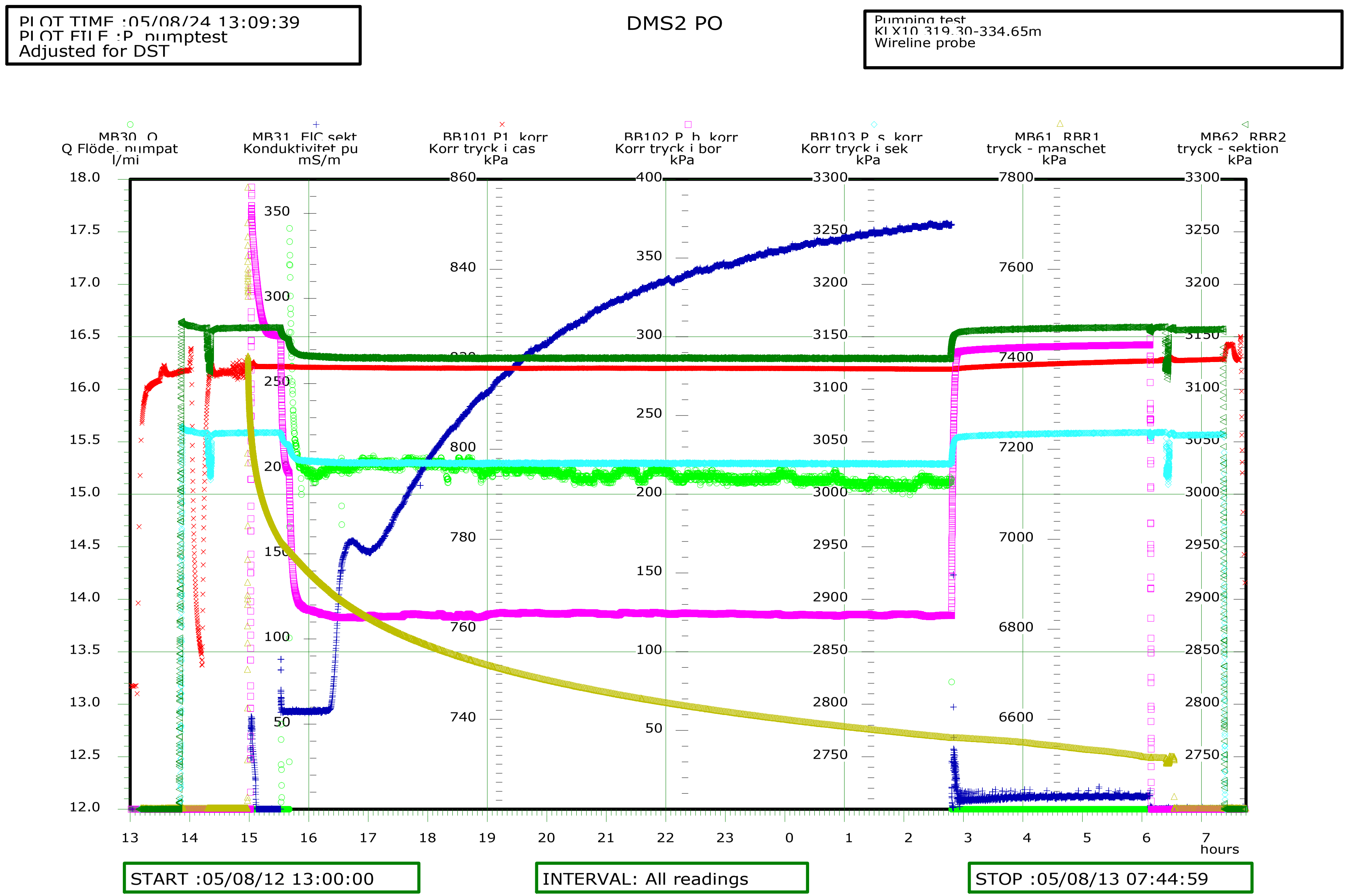
Adjusted for DST
DMS2 PO
Pumping test
KLX10 298.20-407.05m
Wireline probe
MB30 Q
Q Flöde, pumpat
l/mi
MB31 EC sekt
Konduktivitet pu
mS/m
BB101 P1 korr
Korr tryck i cas
kPa
BB102 P h korr
Korr tryck i bor
kPa
BB103 P s korr
Korr tryck i sek
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
hours
START :05/08/16 13:15:00
INTERVAL: All readings
STOP :05/08/17 07:59:59



PLOT TIME :05/08/24 13:09:39
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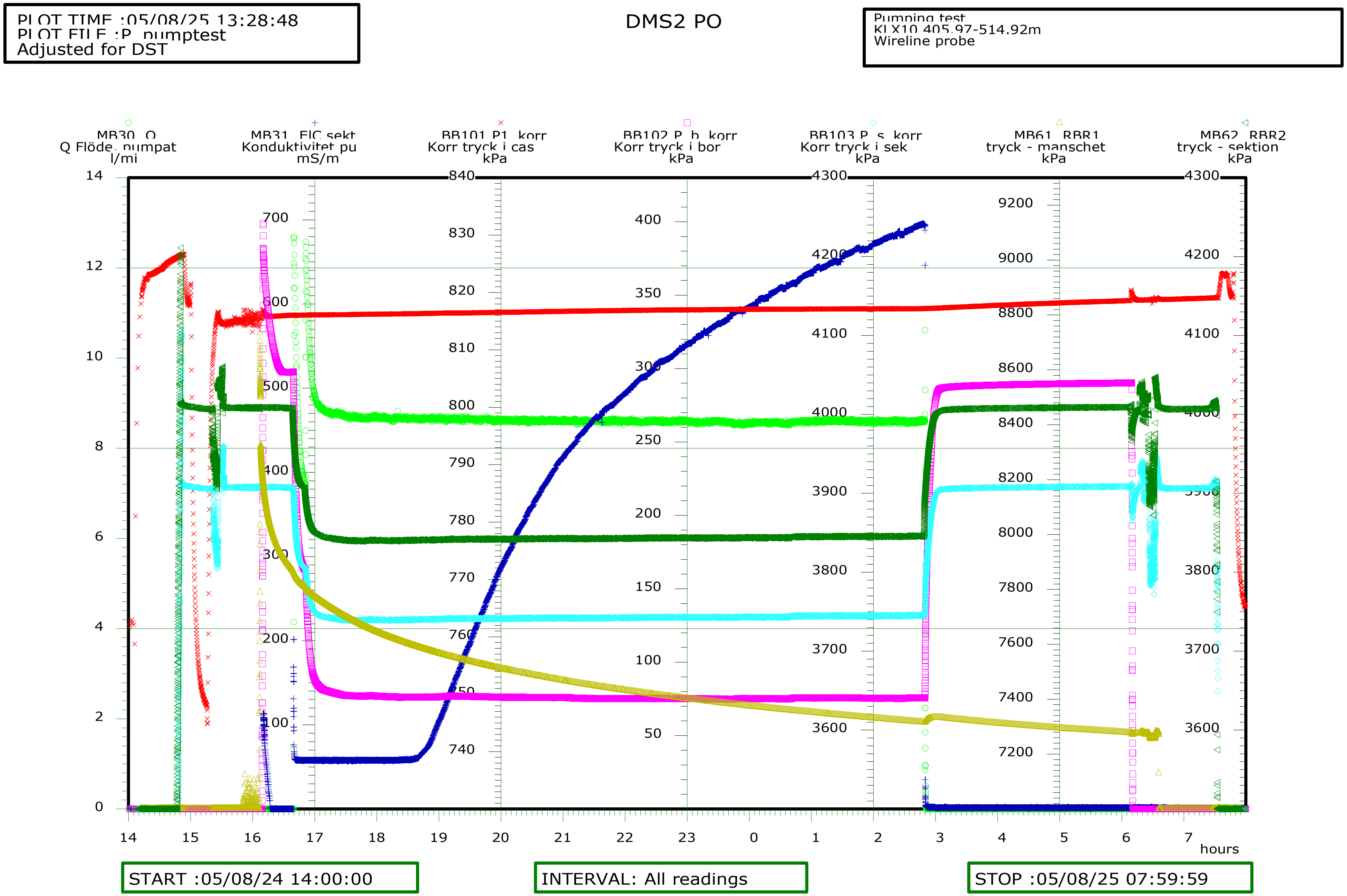
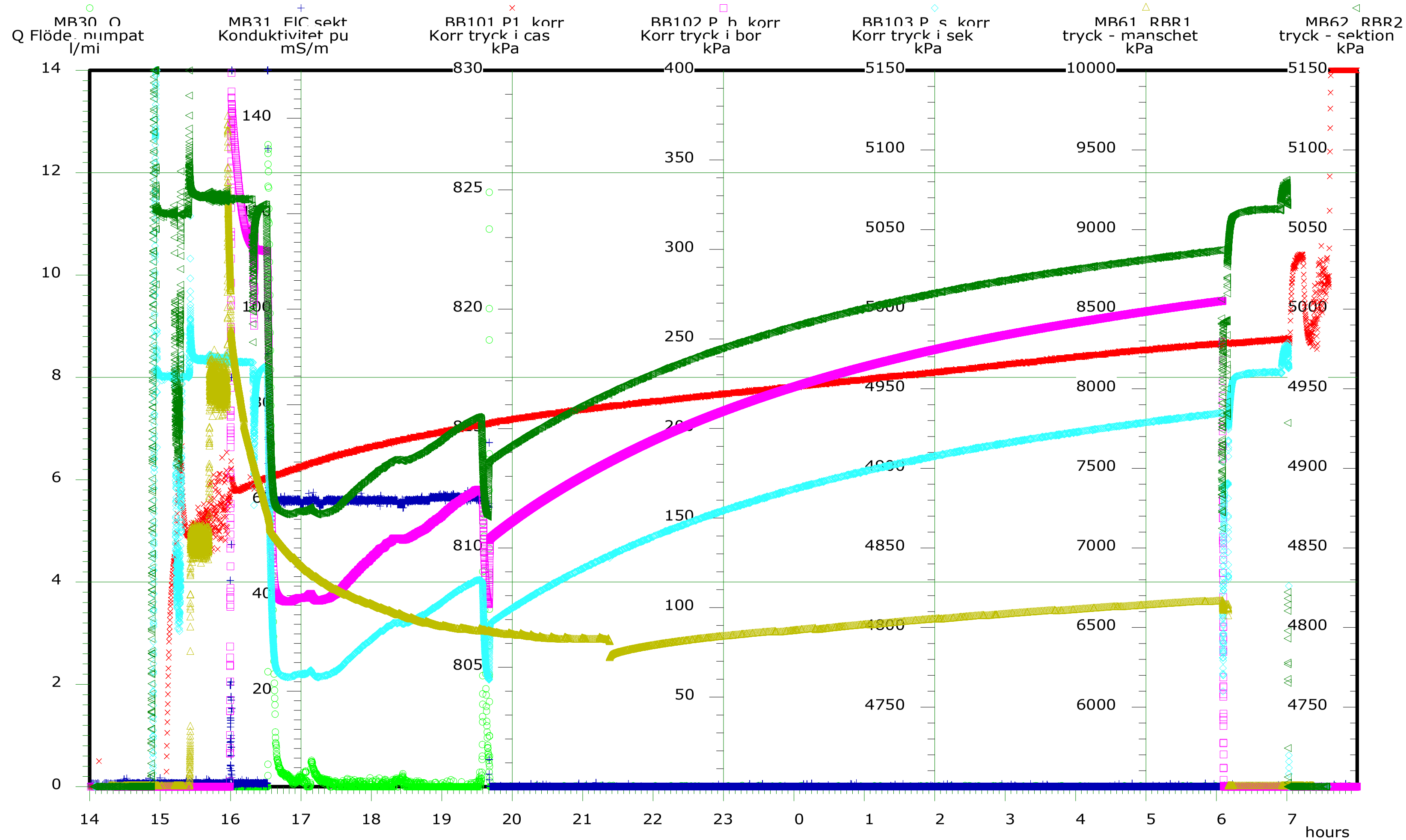
Adjusted for DST
DMS2 PO
Pumping test
KLX10 319.30-334.65m
Wireline probe
MB30 Q
Q Flöde, pumpat
l/mi
MB31 EC sekt
Konduktivitet pu
mS/m
BB101 P1 korr
Korr tryck i cas
kPa
BB102 P_b korr
Korr tryck i bor
kPa
BB103 P_s korr
Korr tryck i sek
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
hours
START :05/08/12 13:00:00
INTERVAL: All readings
STOP :05/08/13 07:44:59


PLOT TIME :05/08/25 13:28:48
PLOT FILE :P_pumptest
Adjusted for DST
DMS2 PO
Pumping test
KLX10 405.97-514.92m
Wireline probe
MB30_Q
Q Flöde, pumpat
l/mi
MB31_EC sekt
Konduktivitet pu
mS/m
BB101_P1_korr
Korr tryck i cas
kPa
BB102_P_b_korr
Korr tryck i bor
kPa
BB103_P_s_korr
Korr tryck i sek
kPa
MB61_RBR1
tryck - manschet
kPa
MB62_RBR2
tryck - sektion
kPa
hours
START :05/08/24 14:00:00
INTERVAL: All readings
STOP :05/08/25 07:59:59

PLOT TIME :05/09/06 12:10:22
PLOT FILE :P_pumptest
Adjusted for DST

DMS2 PO

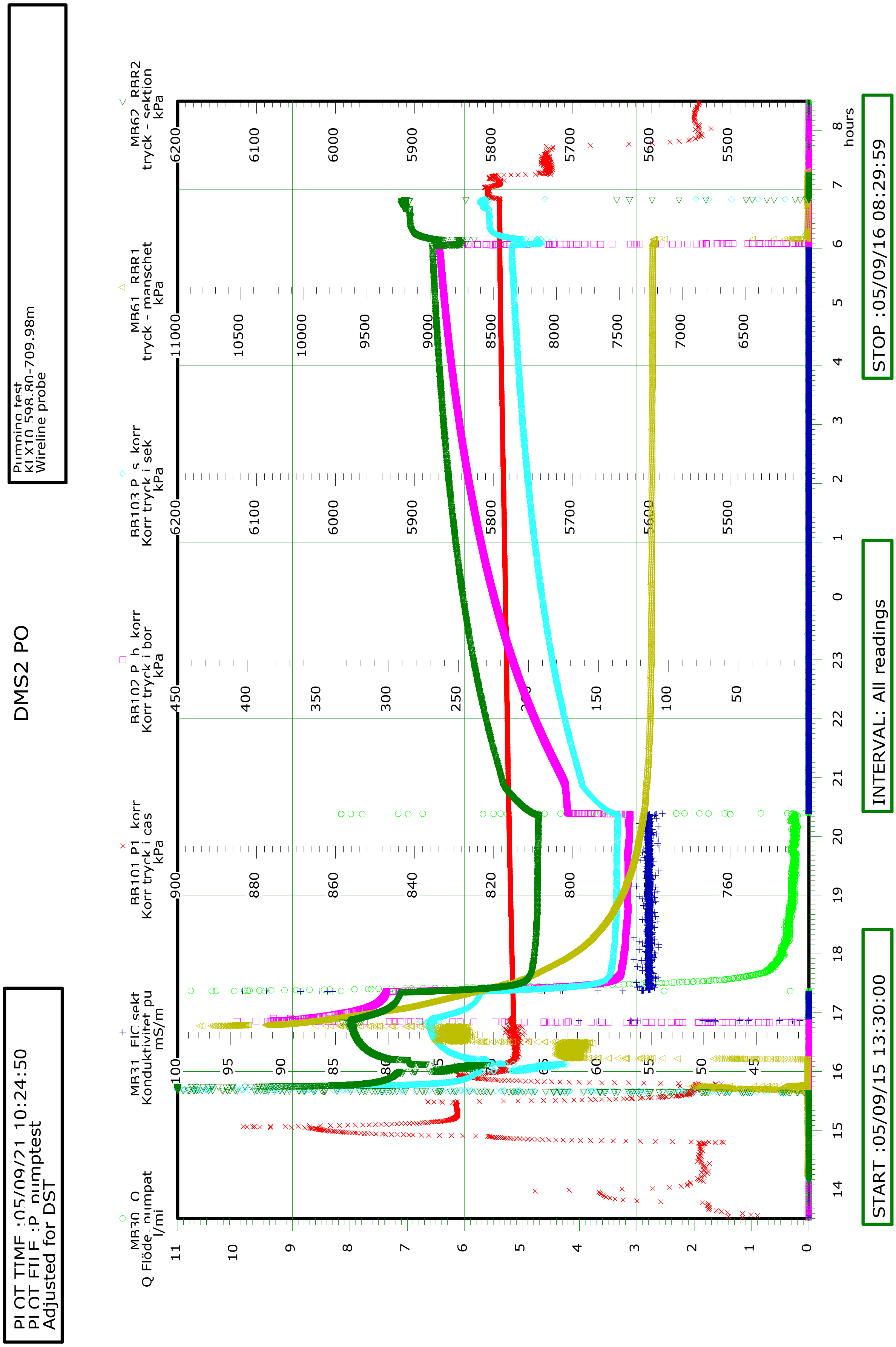
Pumping test
KLX10 514.10-598.83m
Wireline probe



START :05/09/02 14:00:00

INTERVAL: All readings

STOP :05/09/03 07:59:59



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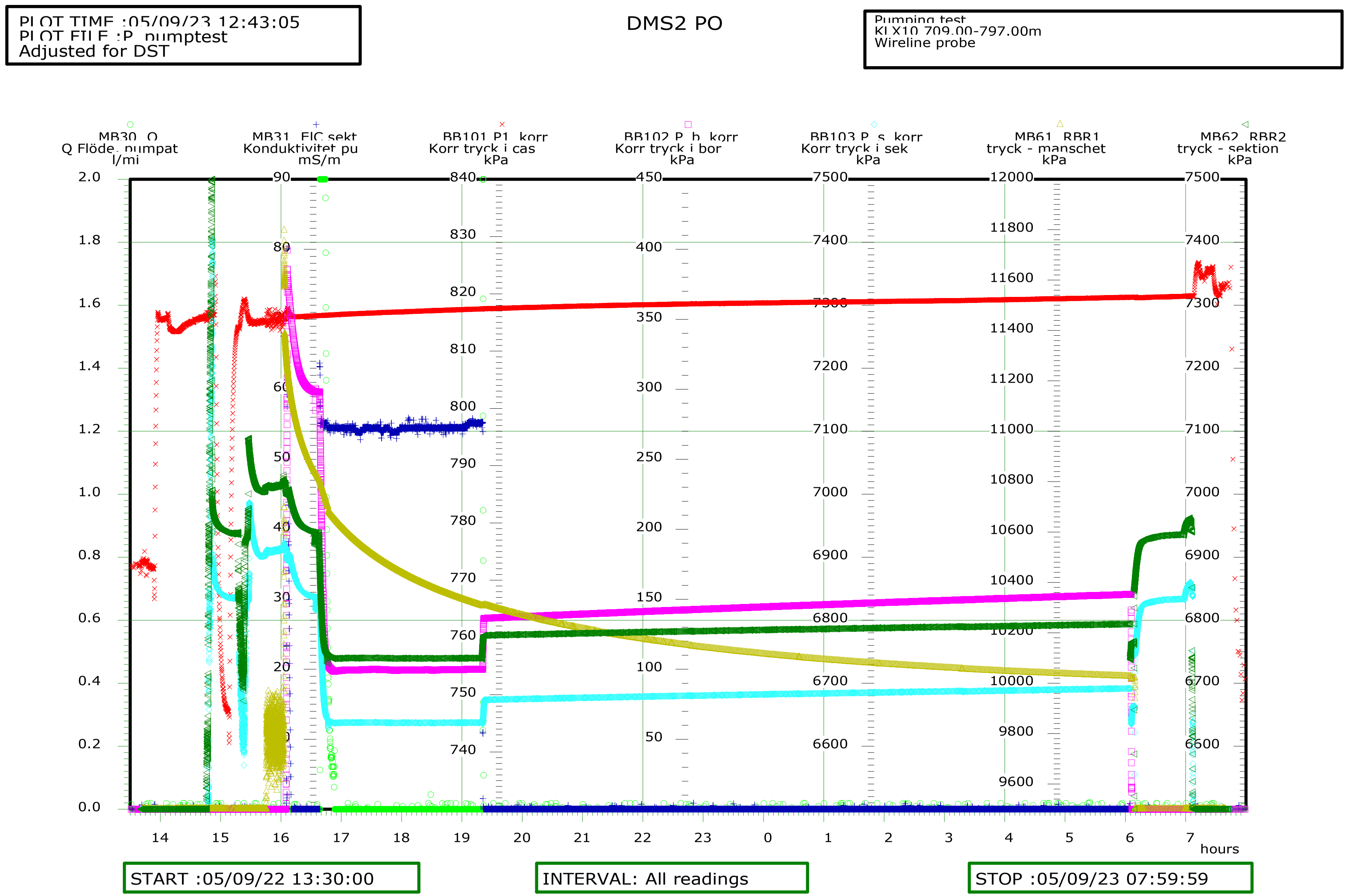
PLOT FILE :P_pumptest
Adjusted for DST
DMS2 PO
Pumping test
KLX10 598.80-709.98m
Wireline probe
MR30_Q
Q Flöde, pumpat
l/mi
MR31_FIC_sekt
Konduktivitet pu
mS/m
BR101_P1_korr
Korr tryck i cas
kPa
BR102_P_b_korr
Korr tryck i bor
kPa
BR103_P_s_korr
Korr tryck i sek
kPa
MR61_RBR1
tryck - manschet
kPa
MR62_RBR2
tryck - sektion
kPa
hours
START :05/09/15 13:30:00
INTERVAL: All readings
STOP :05/09/16 08:29:59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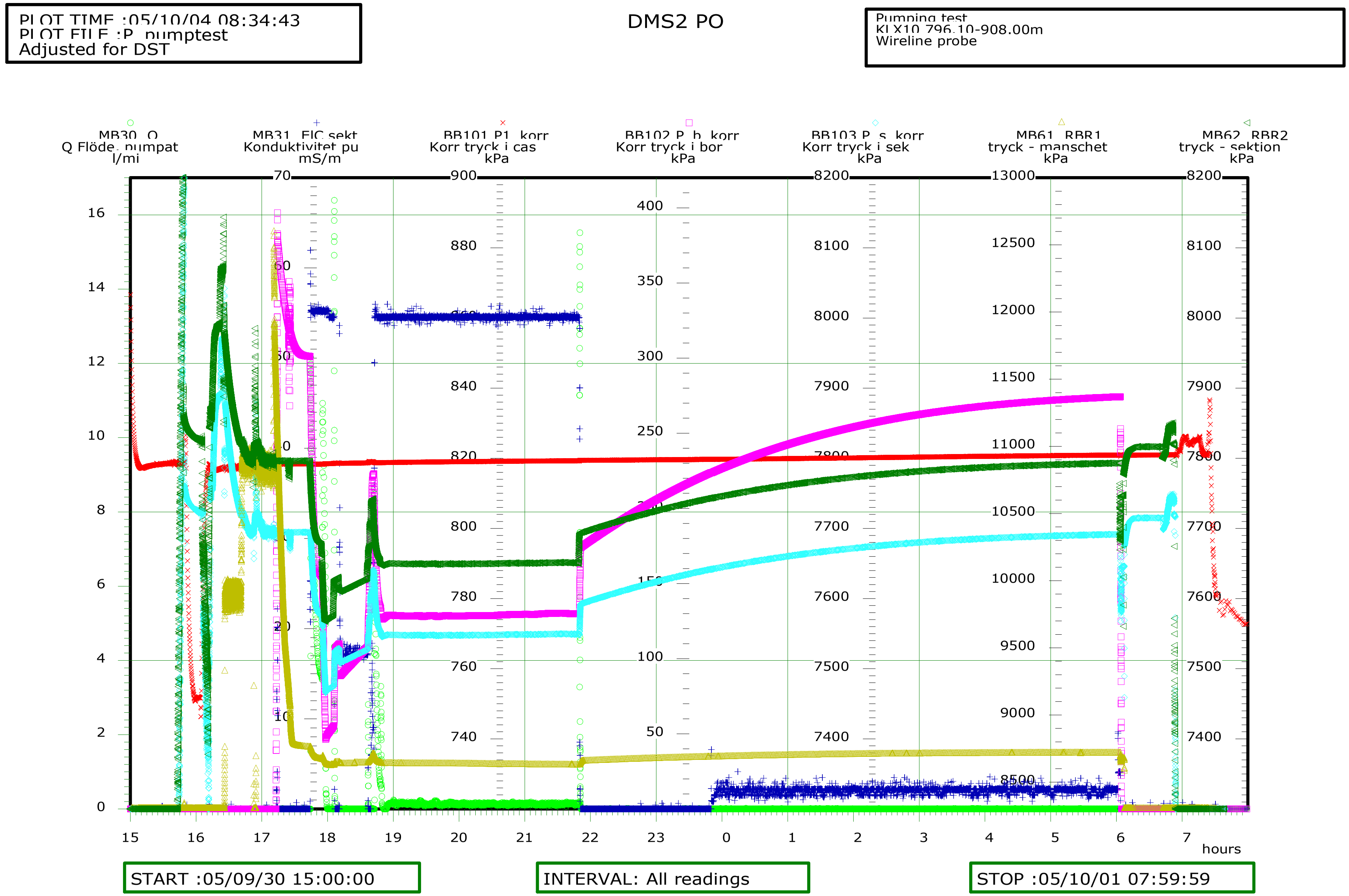
Adjusted for DST
DMS2 PO
Pumping test
KLX10 709.00-797.00m
Wireline probe
MB30 Q
Q Flöde, pumpat
l/mi
MB31 EC sekt
Konduktivitet pu
mS/m
BB101 P1 korr
Korr tryck i cas
kPa
BB102 P_b korr
Korr tryck i bor
kPa
BB103 P_s korr
Korr tryck i sek
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
hours
START :05/09/22 13:30:00
INTERVAL: All readings
STOP :05/09/23 07:59:59


PLOT TIME :05/10/04 08:34:43
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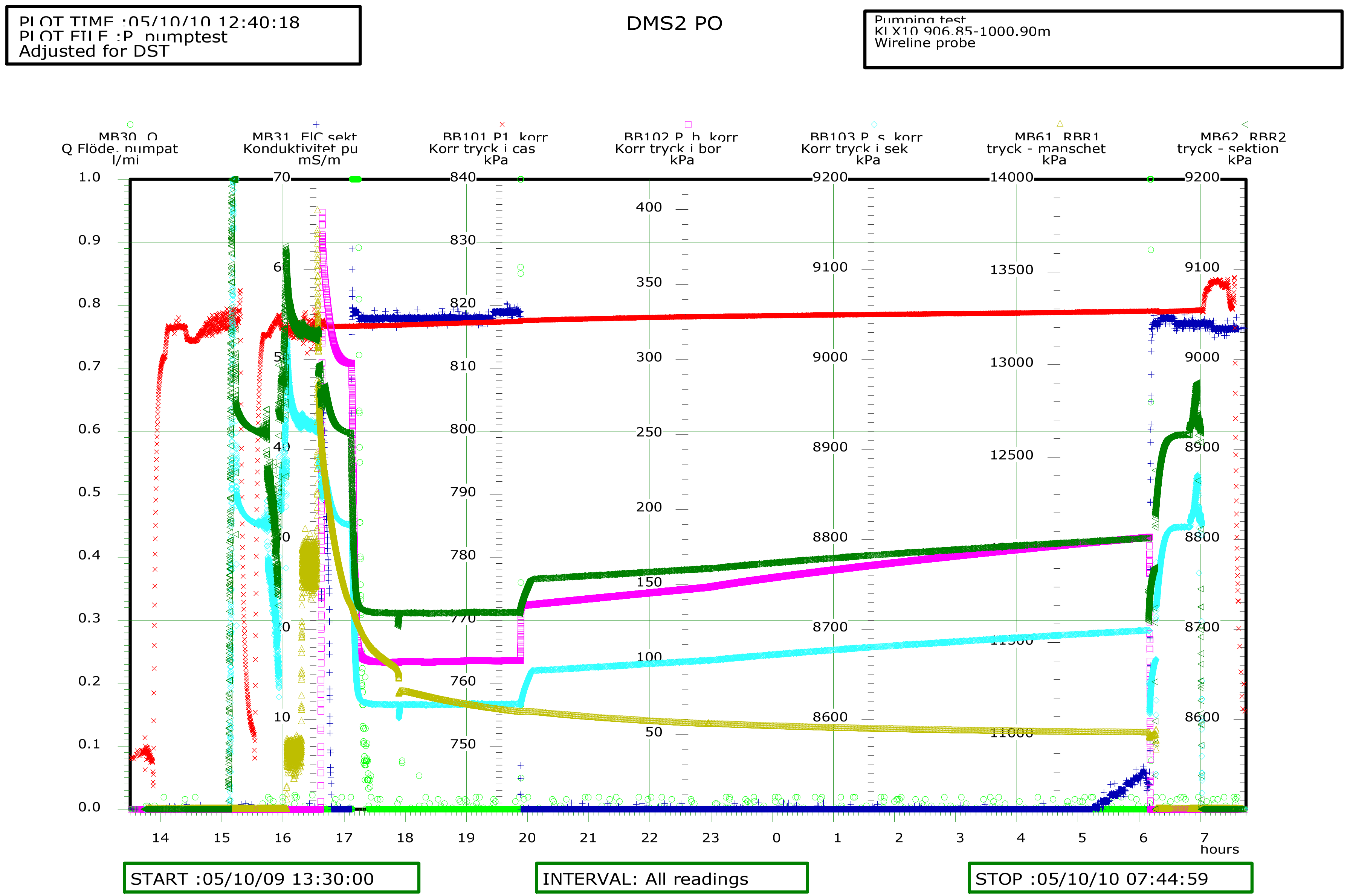
Adjusted for DST
DMS2 PO
Pumping test
KLX10 796.10-908.00m
Wireline probe
MB30_Q
Q Flöde, pumpat
l/mi
MB31_EC sekt
Konduktivitet pu
mS/m
BB101_P1_korr
Korr tryck i cas
kPa
BB102_P_b_korr
Korr tryck i bor
kPa
BB103_P_s_korr
Korr tryck i sek
kPa
MB61_RBR1
tryck - manschet
kPa
MB62_RBR2
tryck - sektion
kPa
hours
START :05/09/30 15:00:00
INTERVAL: All readings
STOP :05/10/01 07:59:59

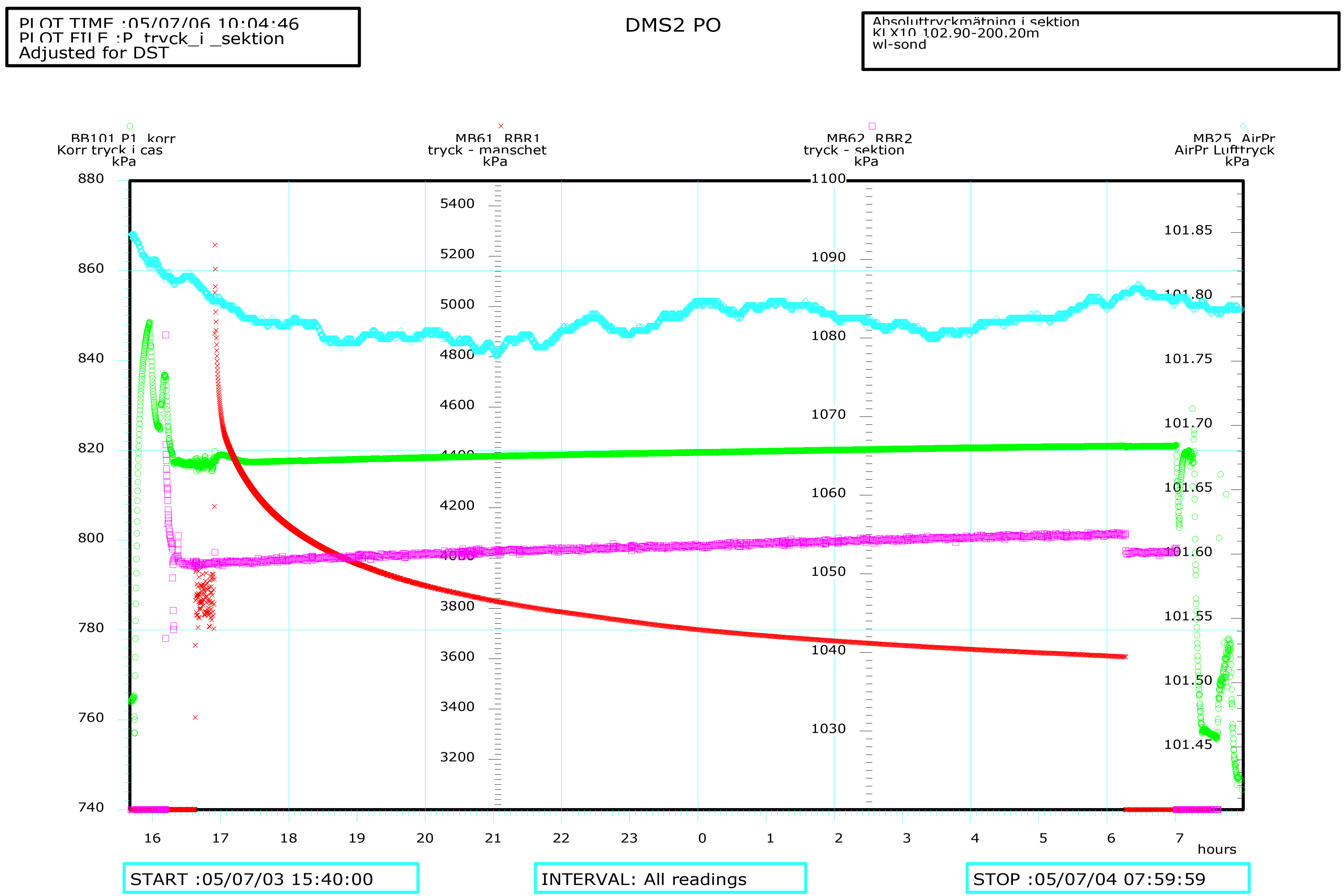

PLOT TIME :05/10/10 12:40:18
PLOT FILE :P_pumptest
Adjusted for DST
DMS2 PO
Pumping test
KLX10 906.85-1000.90m
Wireline probe
MB30_Q
Q Flöde, pumpat
l/mi
MB31_EC sekt
Konduktivitet pu
mS/m
BB101_P1_korr
Korr tryck i cas
kPa
BB102_P_b_korr
Korr tryck i bor
kPa
BB103_P_s_korr
Korr tryck i sek
kPa
MB61_RBB1
tryck - manschet
kPa
MB62_RBB2
tryck - sektion
kPa
hours
START :05/10/09 13:30:00
INTERVAL: All readings
STOP :05/10/10 07:44:59

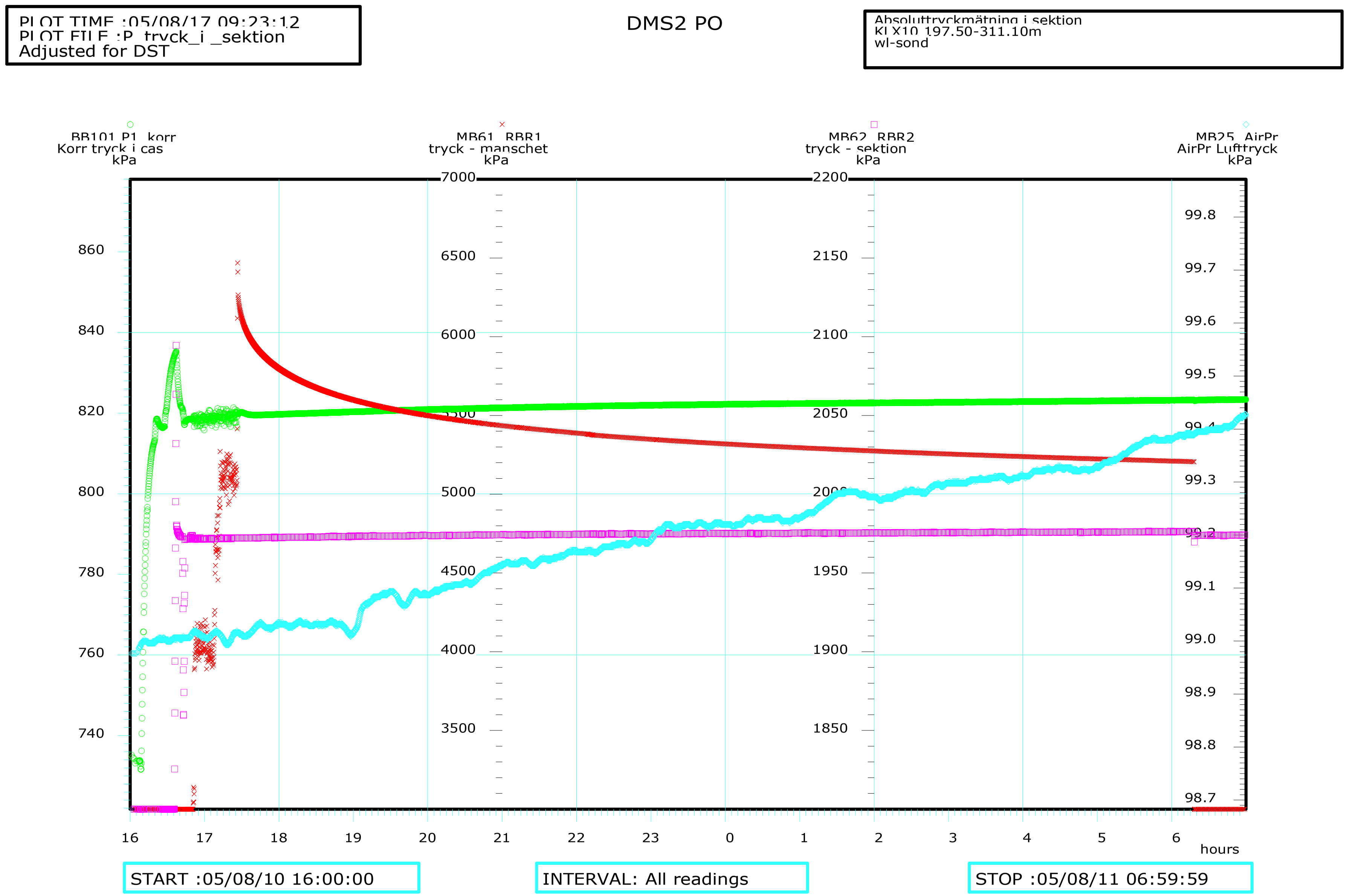
Appendix 6

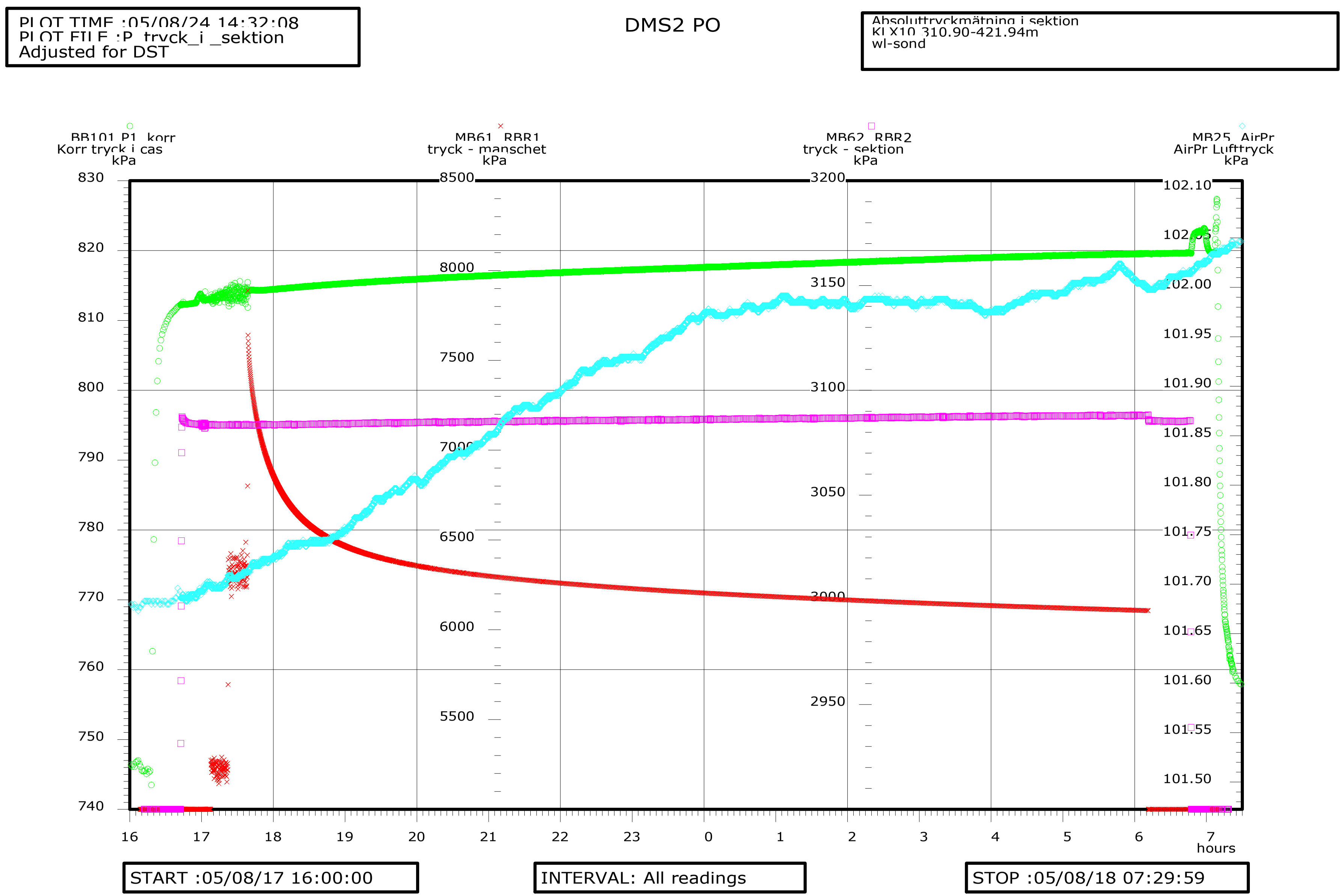
Absolute pressure measurement

Description of the parameters in the enclosed plots.

Channel	Parameter	Unit	Description
BB101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
MB61	Pressure – packer	kPa	Inflation pressure in packer.
MB62	Pressure – section	kPa	Pressure of the water column in the test section, i.e. at depth in the borehole. Not corrected for ambient air pressure.
MB25	Air pressure	kPa	


PLOT TIME :05/07/06 10:04:46
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS2 PO
Absoluttryckmätning i sektion
KLX10 102.90-200.20m
wl-sond
BB101 P1 korr
Korr tryck i cas
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
MB25 AirPr
AirPr Lufttryck
kPa
880
860
840
820
800
780
760
740
5400
5200
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
1100
1090
1080
1070
1060
1050
1040
1030
101.85
101.80
101.75
101.70
101.65
101.60
101.55
101.50
101.45
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6
7
hours
START :05/07/03 15:40:00
INTERVAL: All readings
STOP :05/07/04 07:59:59


PLOT TIME :05/08/17 09:23:12
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS2 PO
Absoluttryckmätning i sektion
KLX10 197.50-311.10m
wl-sond
BB101_P1_korr
Korr tryck i cas
kPa
MB61_ RBB1
tryck - manschet
kPa
MB62_ RBB2
tryck - sektion
kPa
MB25_ AirPr
AirPr Lufttryck
kPa
860
840
820
800
780
760
740
7000
6500
6000
5000
4500
4000
3500
2200
2150
2100
2050
1950
1900
1850
99.8
99.7
99.6
99.5
99.3
99.1
99.0
98.9
98.8
98.7
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6
hours
START :05/08/10 16:00:00
INTERVAL: All readings
STOP :05/08/11 06:59:59

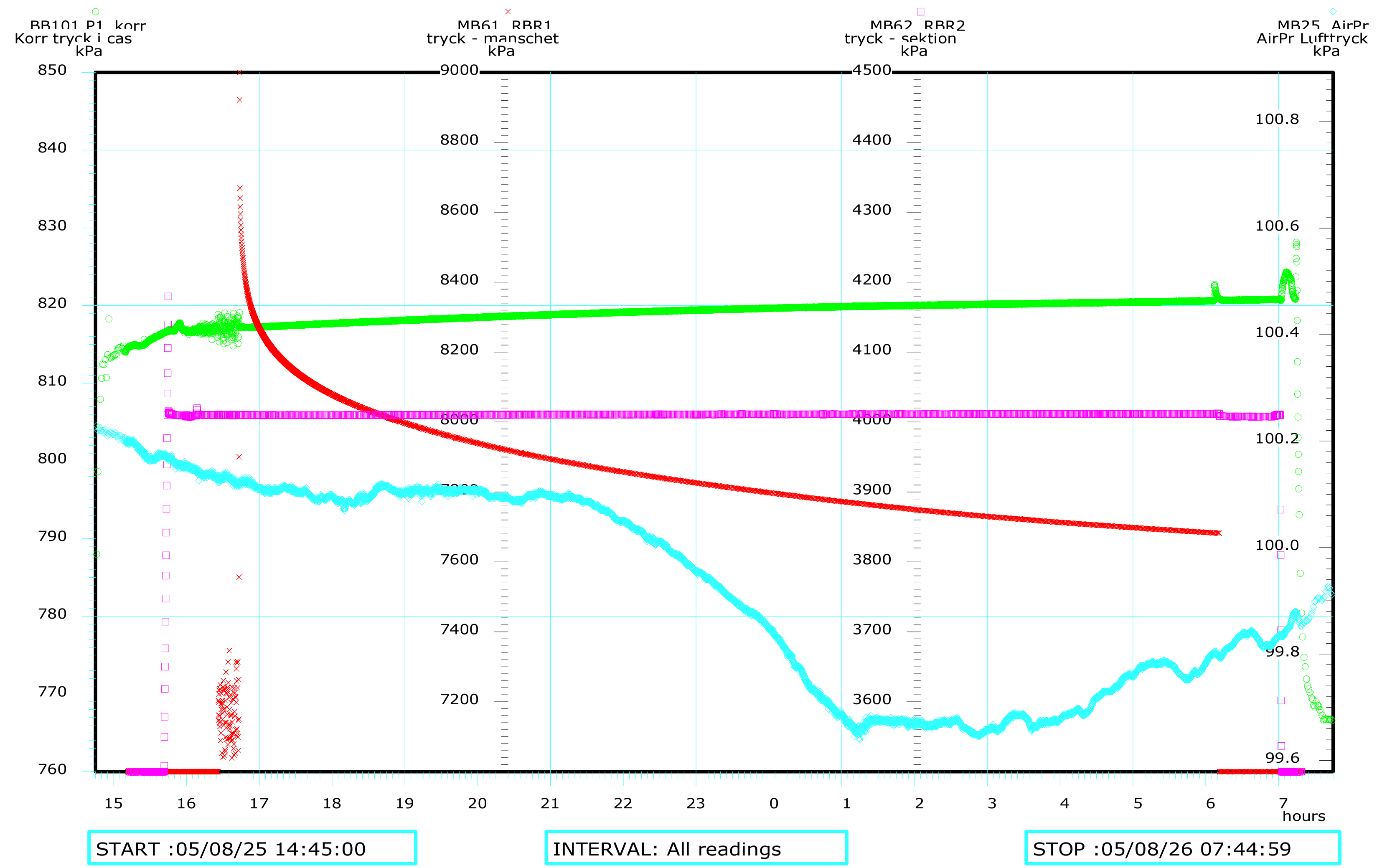


PLOT TIME :05/08/24 14:32:08
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS2 PO
Absoluttryckmätning i sektion
KLX10 310.90-421.94m
wl-sond
BB101 P1 korr
Korr tryck i cas
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
MB25 AirPr
AirPr Lufttryck
kPa
830
820
810
800
790
780
770
760
750
740
8500
8000
7500
7000
6500
6000
5500
3200
3150
3100
3050
3000
2950
102.10
102.05
102.00
101.95
101.90
101.85
101.80
101.75
101.70
101.65
101.60
101.55
101.50
16
17
18
19
20
21
22
23
0
1
2
3
4
5
6
7
hours
START :05/08/17 16:00:00
INTERVAL: All readings
STOP :05/08/18 07:29:59

PLOT TIME :05/08/29 08:17:42
PLOT FILE :P_tryck_i _sektion
Adjusted for DST

DMS2 PO

Absoluttryckmätning i sektion
KLX10 405.97-527.00m
wl-sond



Appendix 7

Technical data from environmental monitoring wells SSM000220 and SSM000221

LAXEMAR BOREHOLE SSM000220

Company rep.
Lennart Adestam and Torbjörn Johansson

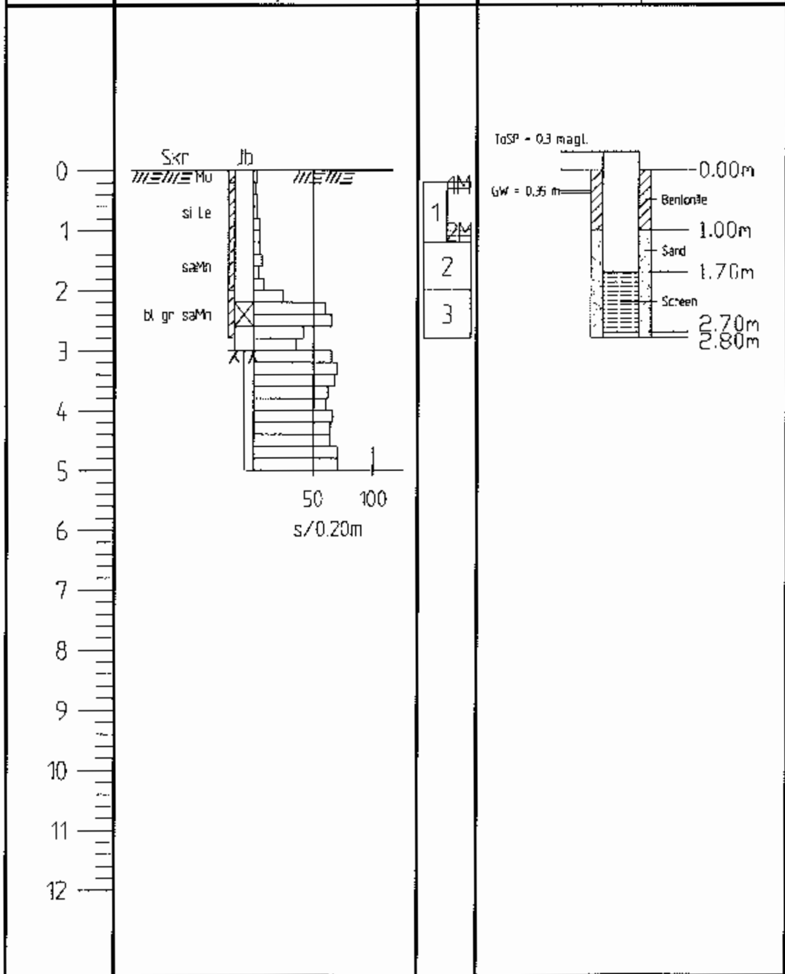
Client: Svensk Kärnbränslehantering AB

Northing : 6366375
Easting : 1548543

Coordinate system : RT90-RHB70

Top of stand pipe : 0,3 m.a.g.l.
Total pipe length : 3,10 m
Groundwater level : 0,35 mbgl
Date of completion : 2005-05-31

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



Drilling method : NCEK
Borehole diameter : 120 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 : 1,00 m

SAND PACK
Grain size : 0,4-0.8 mm
Total length : 1.80 m

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

GEOLOGICAL LOG
0-0,2m Topsoil
0,2-1,2m silty clay
1,2-2,0m sand fill
2,0-2,8m boulder-bearing gravelly sand fill

ToSP : Top of Stand Pipe
magl. : meters above ground level
mbgl : meters below ground level

LAXEMAR BOREHOLE SSM000221

Company rep
Lennart Adestam and Torbjörn Johansson

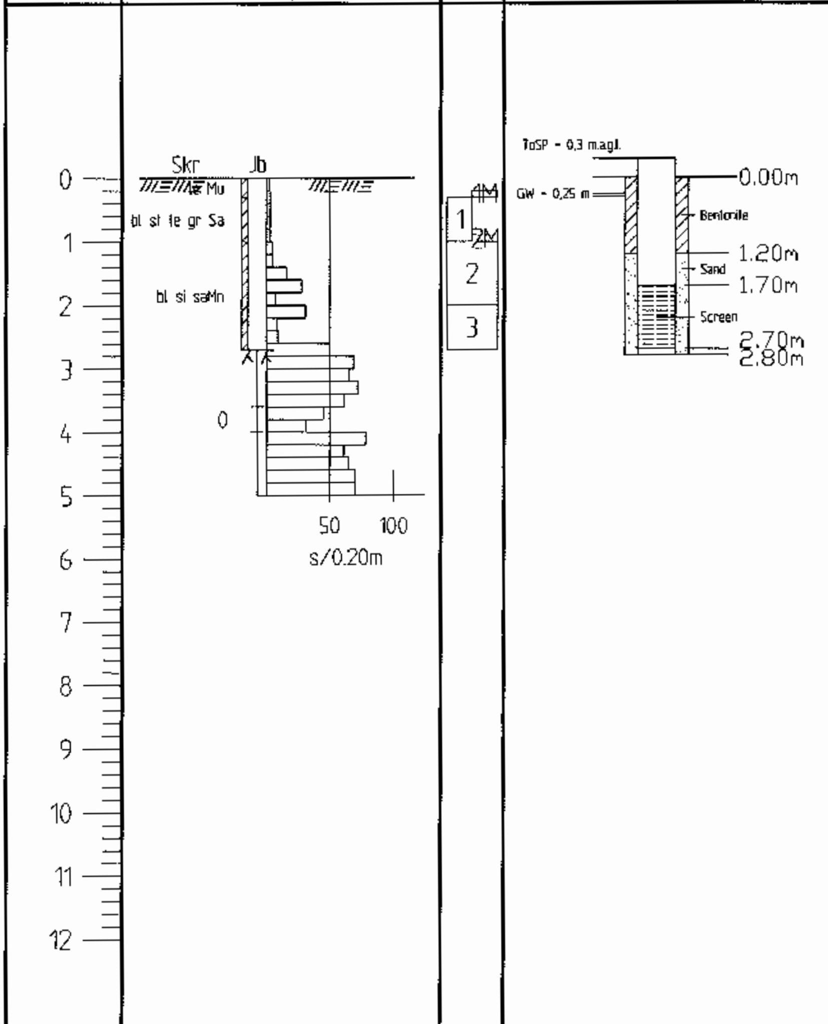
Client: Svensk Kärnbränslehantering AB

Northing .6366384
Easting .1548594

Coordinate system . RT90-RHB70

Top of stand pipe : 0,3 m.a.g.l.
Total pipe length : 3,10 m
Groundwater level : 0,25 m.b.g.l.
Date of completion : 2005-05-30

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



Drilling method : NOEK
Borehole diameter : 120 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 : 1,20 m

SAND PACK
Grain size . 0,4-0,8 mm
Total length : 1,60 m

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

GEOLOGICAL LOG
0-0,3m Clayey topsoil
0.3-1,0m boulder- and cobble-bearing clayey gravelly sand
1,0-2,7m boulder-bearing silty sand till
2,7m rock surface

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