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Oskarshamn site investigation

Drilling of cored borehole KLX20A

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September 2007

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Keywords: Core drilling, Bedrock, Measurement while drilling, Flushing water monitoring, Water sampling, Wireline measurements, Air-lift pumping, Telescope hole.

Abstract

Borehole KLX20A is located in the Laxemar subarea. Drilling was made between February and April 2006 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden. KLX20A was the sixteenth deep cored borehole within the site investigation in Oskarshamn.

KLX20A was core drilled to a length of 457.92 metres with N-size (76 mm) equipment. The uppermost section, to the length of 99.91 metres, was constructed as a telescopic section with an inner nominal diameter of 200 mm.

No water inflow could be measured over the entire length of the telescopic section during percussion drilling.

In total five pumping tests were performed with wireline equipment in KLX20A. Two of the tests failed completely due to leakages in the equipment. The results from the three pumping tests are given in this report and the resulting transmissivities (T_M) varied between 1.1×10^{-7} and 2.6×10^{-5} m^2/s. The most transmissive section was between 102 and 195 metres.

Continuous monitoring of drilling parameters and flushing water parameters with the drilling monitoring system was conducted throughout the core drilling phase in KLX20A.

Two water samples for chemical analysis were collected during the core drilling of KLX20A.

The air-lift pumping test in the telescopic section performed when borehole KLX20A was core drilled to its full length gave a transmissivity (T_M) of 9.5×10^{-6} m^2/s.

Lithologically the core is dominated by Quartz monzodiorite. Dolerite was encountered between 180 and 230 m. Minor intercalations of fine-grained diorite-gabbro and fine grained granite were noted in the borehole.

Red staining with weak intensity occurs frequently to ca 300 m. The red staining is often associated with saussuritization i.e. alteration of calcic plagioclase to epidote/zoisite. Below 300 m length the presence of red staining is less common. Sections with red staining are indicated as "oxidized" in Appendix 1.

The average fracture frequency over the entire core drilled section expressed as open fractures is 2.58 (fractures/metre).

Sammanfattning

Borrhål KLX20A ligger inom delområde Laxemar. Borrningen utfördes mellan februari och april 2006 som ett led i platsundersökningen för ett möjligt djupförvar för använt kärnbränsle i Oskarshamns kommun. KLX20A var det sextonde djupa kärnborrhålet inom platsundersökningen i Oskarshamn.

KLX20A kärnborrades med borrstorlek N (76 mm) till 457,92 meters borrad längd. Den övre delen av hålet, från markytan till 99,91 meter, utfördes som en teleskopdel med ca 200 mm inre diameter.

Inget vatteninflöde kunde uppmätas över hela teleskopdelen vid hammarborrningen.

Fem pumptester med wireline-baserad mätutrustning utfördes. Två av testerna misslyckades dock fullständigt på grund av läckage i utrustningen. I denna rapport presenteras resultat från tre pumptester och de uppmätta transmissiviteterna (T_M) varierade mellan $1{,}1 \times 10^{-7}$ och $2{,}6 \times 10^{-5}$ m^2/s. Den mest transmissiva sektionen var mellan 102 och 195 meter.

Kontinuerliga mätningar av borrningsparametrar och spolvattenparametrar via DMS (drilling monitoring system) gjordes under hela kärnborrningsfasen i KLX20A.

Två vattenprover för kemisk analysering togs i samband med borrning i KLX20A.

Mammutpumpningen i teleskopdelen som gjordes när kärnborrningen i KLX20A utförts till full längd gav en transmissivitet (T_M) på $9{,}5 \times 10^{-6}$ m^2/s.

Litologiskt domineras kärnan av kvartsmonzodiorit. Diabas påträffades mellan 180 och 230 m. Mindre inslag av finkornig diorit/gabbro och finkornig granit har noterats i borrhålet.

Rödfärgning med svag intensitet förekommer sporadiskt ner till borrad längd 300 m. Rödfärgningen är ofta associerad med saussuritisering dvs omvandling av kalcium-rik plagioklas till epidot/zoisit. Nedanför 300 m är förekomsten av rödfärgning mindre vanlig. Sektioner med rödfärgning är angivna som ”oxiderade” i bilaga 1.

Den genomsnittliga sprickfrekvensen över hela borrkärnan uttryckt som öppna sprickor är 2,58 (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, 2/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. Borehole KLX20A is located in the western 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. KLX20A was the sixteenth deep cored borehole within the Oskarshamn site investigation. The location of the core drilled borehole and the water source, HLX28 in the Laxemar subarea is shown in Figure 1-1.

The drilling of KLX20A and all related on-site operations were performed according to a specific Activity Plan (AP PS 400-06-026), which in turn refers to a number of Method Descriptions, see Table 1-1.

The Activity Plan and Method Descriptions are SKB internal documents.

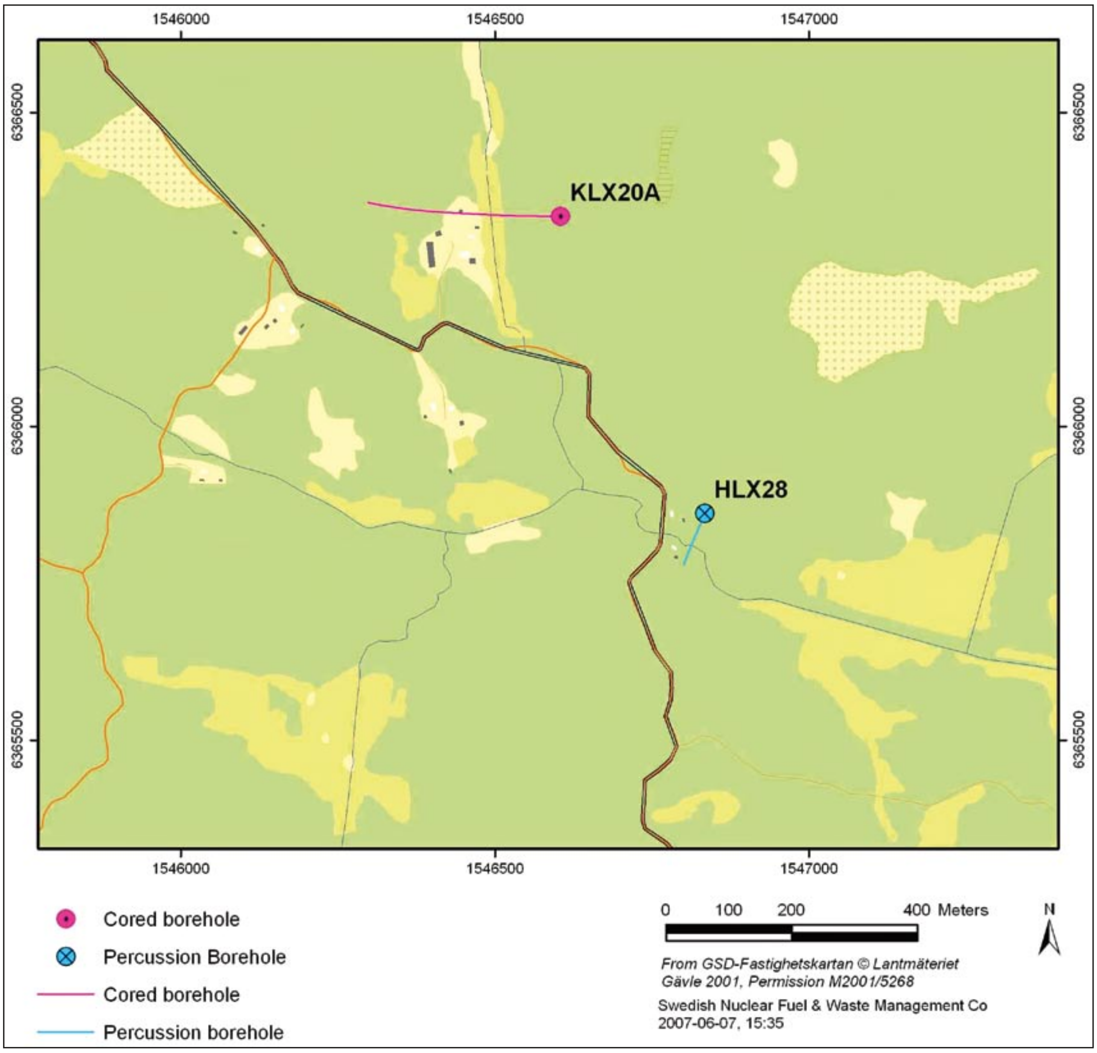


Figure 1-1. *Location of the cored borehole KLX20A and the water source, percussion borehole HLX28 in the Laxemar subarea.*

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

Activity Plan	Number	Version
Kärnborrning KLX20A	AP PS 400-06-026	1.0
Method Descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	1.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0
Metodbeskrivning för 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 vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning	SKB MD 321.002	1.0
Mätsystembeskrivning för längdmarkering (spårfräsning)	SKB MD 620.009	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 ansättning av hammar och kärnborrhål	SKB MD 600.002	1.0
Instruktion för längdkalibrering vid undersökningar i kärnborrhål	SKB MD 620.010	2.0
Instruktion för hantering och provtagning av borrkärna	SKB MD 143.007	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål	SKB MD 224.001	1.0
Instruktion för miljökontroll av ytvatten, ytnära grundvatten och mark vid borrning och pumpning i berg	SKB MD 300.003	2.0

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of borehole KLX20A. 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 objective for the borehole was to drill through and characterize the deformation zone NS001. The borehole should also provide further information of the rock properties in the Quartz monzodiorite which is the dominating rock type in the southwestern part of the Laxemar subarea. The decision to drill KLX20A is given in SKB id no 1050875, dated 2006-02-21.

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.

Borehole KLX20A was drilled from the same drill site as KLX11A i.e. from an already established drill site. No notification to the Regional Authorities was sent specifically for KLX20A. Information of the final coordinates and details regarding the return water handling was however sent to the Regional Authorities on 2006-02-16, SKB id no 1050723.

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 full planned length, see Figure 3-1. The effect of drawdown is dependent on the depth and capacity of major groundwater conductors.

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

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

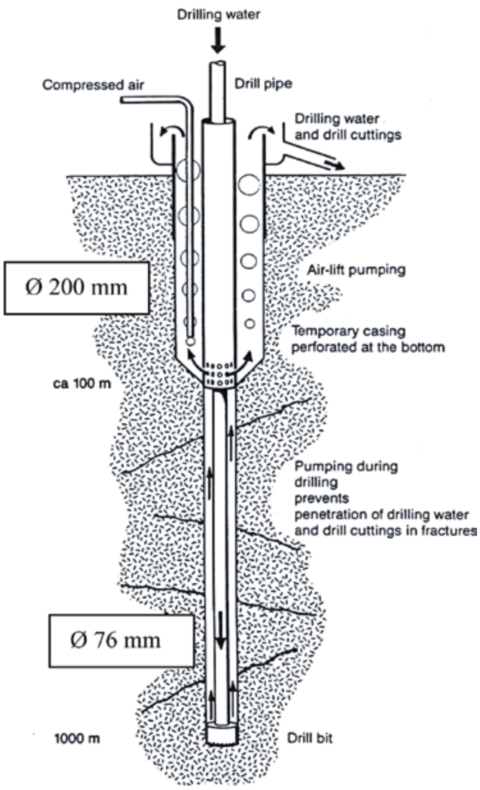


Figure 3-1. *A sketch of the telescopic drilling method with air-lift pumping for retrieval of drilling water and cuttings.*

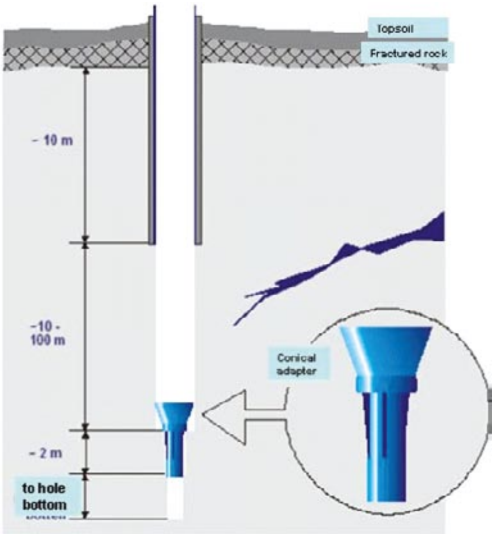


Figure 3-2. *Installation of the conical guide.*

3.1.1 The flushing water system

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

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

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

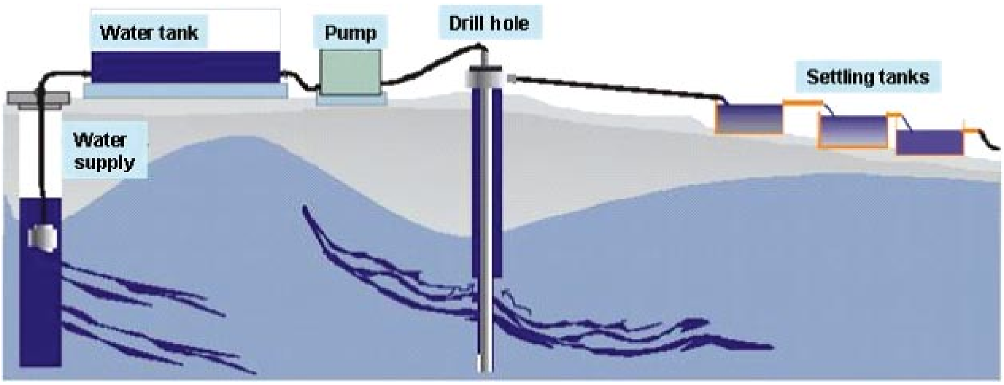


Figure 3-3. *The flushing water system from source to discharge point.*

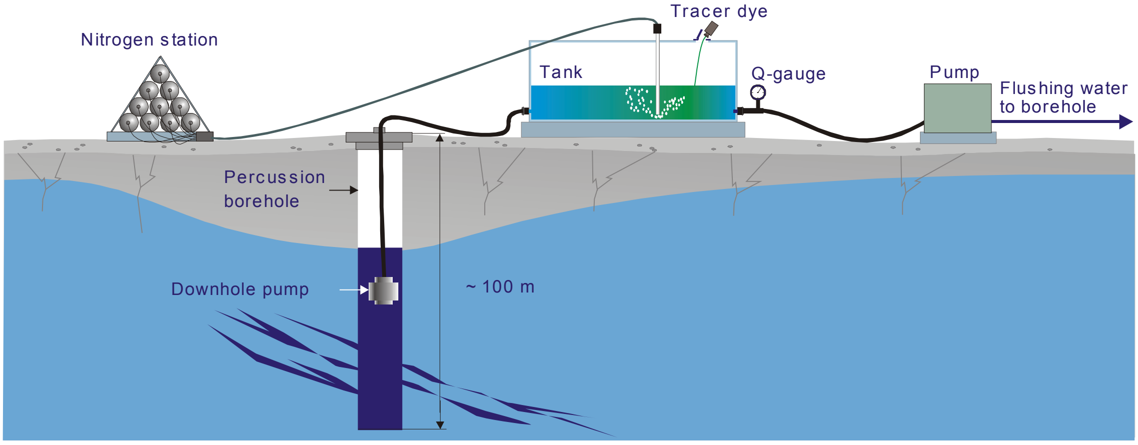


Figure 3-4. *Schematic drawing of the preparation of flushing water. Uranine is added to the water as a tracer dye and nitrogen is bubbled through the water to remove dissolved oxygen.*

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 KLX20A 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. Pumping tests are evaluated according to Moye /3/ and are normally performed for every 100 metres of drilled length. Sampling of water for chemical analysis is done in conjunction with the pumping tests where feasible. The wireline tests are done in accordance with SKB Method Description MB 321.002, SKB internal document.

NB Measurement of absolute pressure were not done in KLX20A following an internal decision, (SKB id 1044856, internal document).

Air-lift pumping with evaluation of drawdown

Air-lift pumping with evaluation of drawdown is done with 300 metres intervals, nominally at 400 and full drilled 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 metres 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).

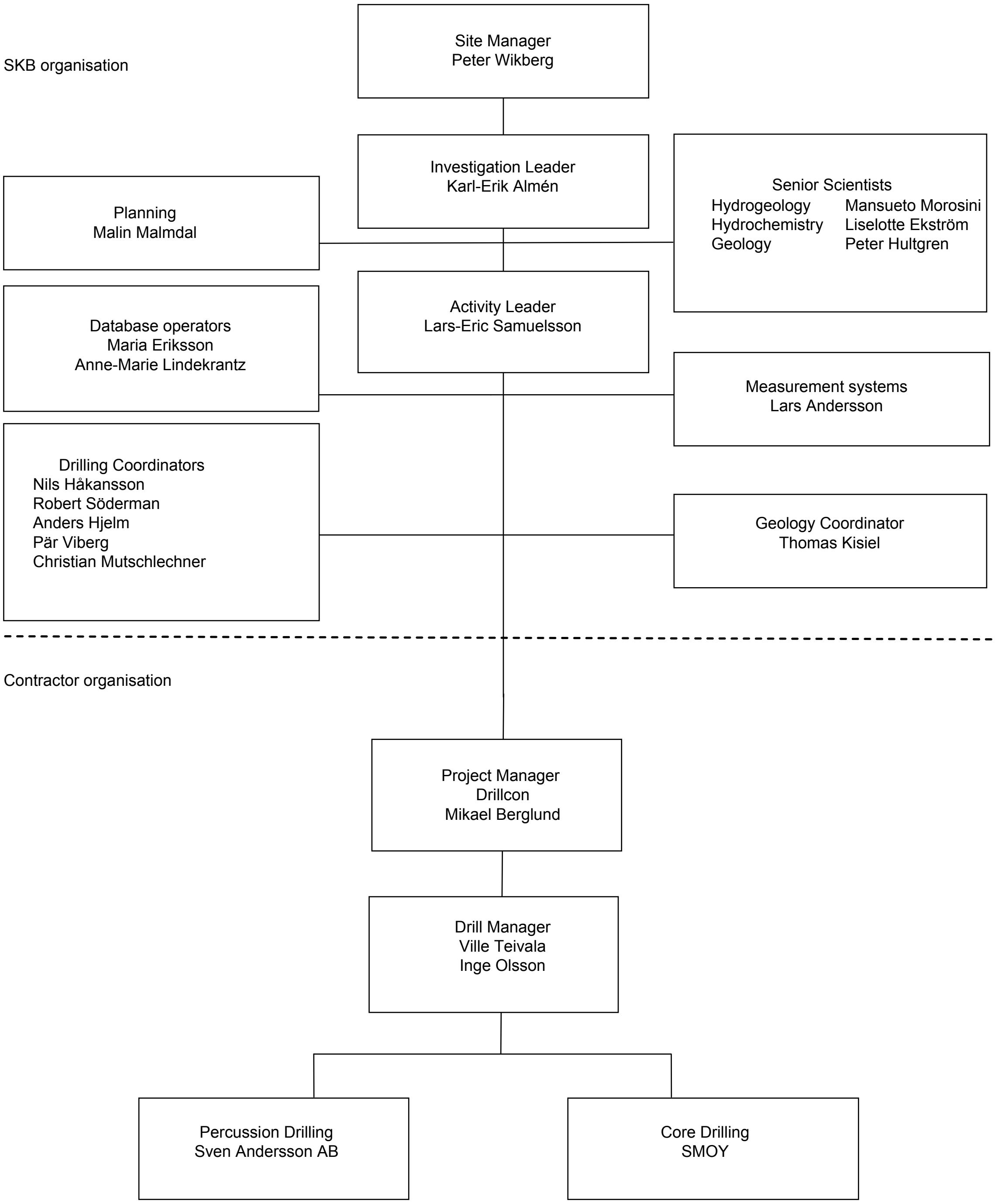
4 Contractors and equipment

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 KLX20A 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 323×11 mm (non stainless). The casing dimensions are presented here as outer diameter × thickness.

4.3 Core drilling equipment

Core drilling in KLX20A 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. Directional drilling was not made in KLX20A.

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 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 4-1.

Before the pumping tests are made leakage tests 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

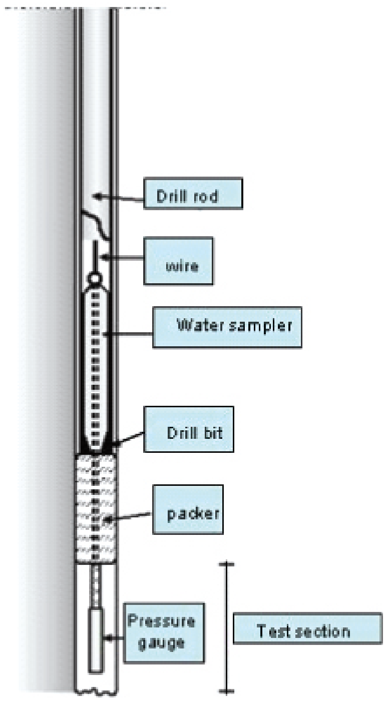


Figure 4-1. *The wireline probe and its emplacement in the hole.*

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

No measurements of absolute pressure were done in KLX20A.

4.3.2 Drilling monitoring system

During the core drilling phase continuous 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).

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 disk to the DMS database.

4.3.3 Deviation measurements

Two types of deviation measurements were made:

- Measurements to keep track on the borehole orientation were made with the magnetometer/accelerometer method Reflex EZ-AQ/EMS (or Easy-Shot) and Flexit, see also Table 5-2 and Section 5.3.3.
- Final measurements, along the entire length of the borehole after the drilling was completed, was 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. Both final deviation measurements, i.e. both Maxibor and Flexit, were made up and down the borehole in KLX20A.

4.3.4 Equipment for reaming reference slots

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

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

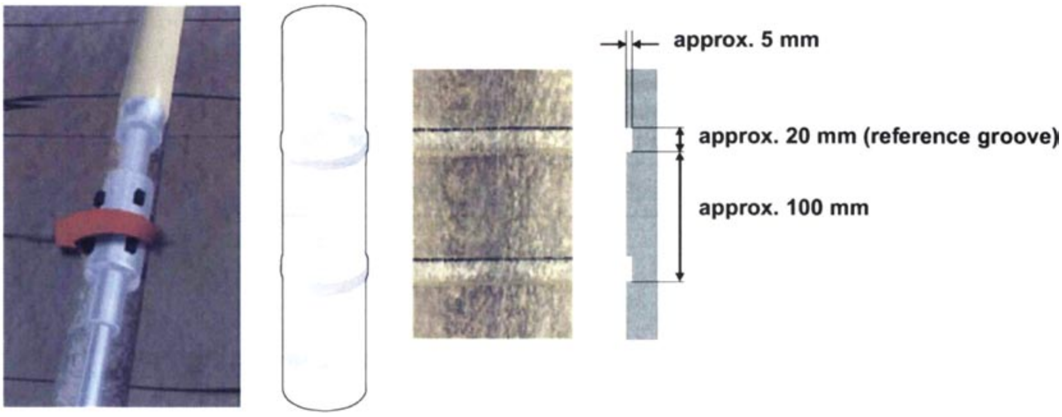


Figure 4-2. *The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.*

5 Execution and results

The original data and results are stored in the SICADA database. Only the datasets in the database will be used for further interpretation and modelling. The data is traceable in SICADA by the Activity Plan number, AP PS 400-06-026.

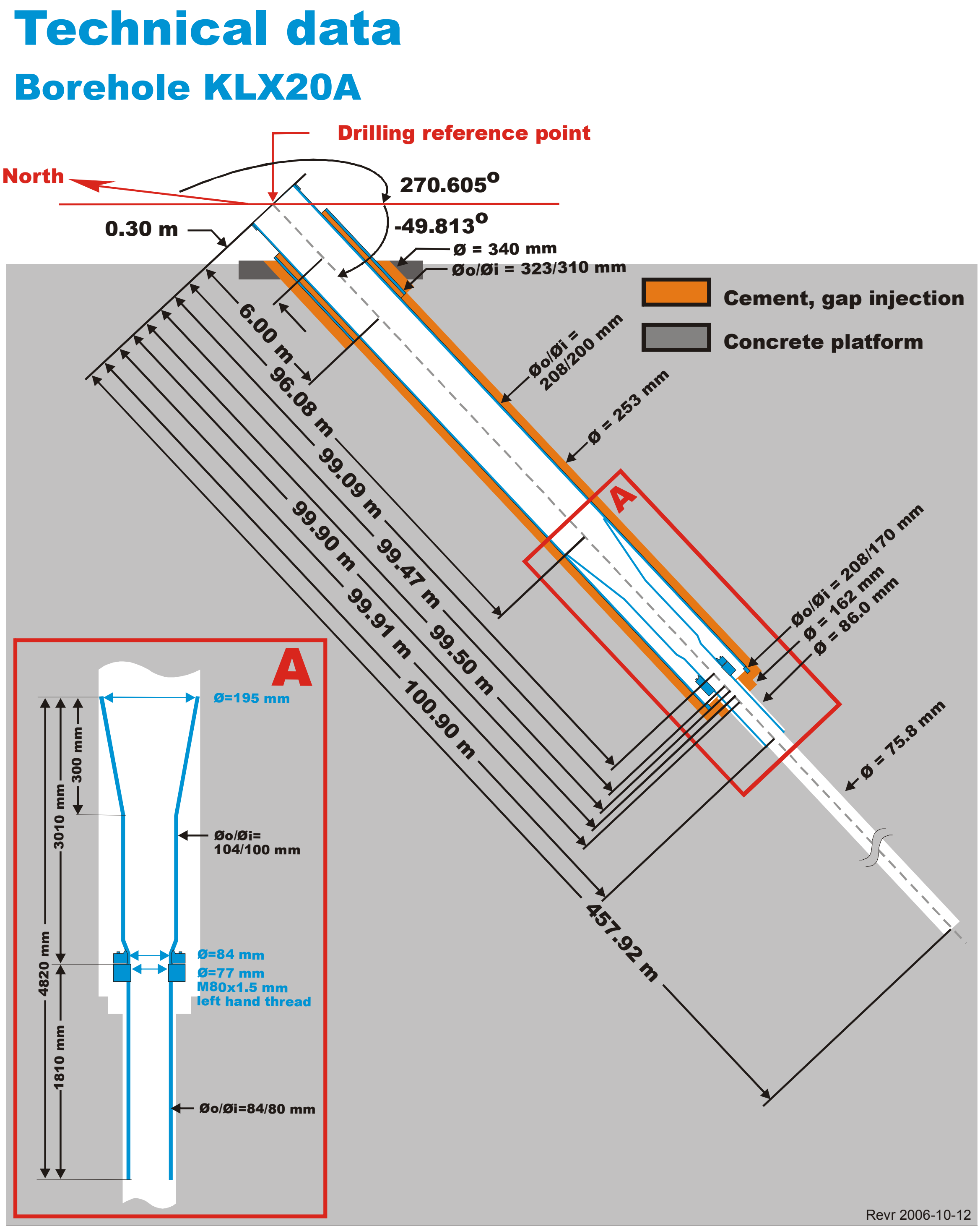
5.1 Summary of KLX20A drilling

A technical summary of the drilling of KLX20A 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 a chronological summary is presented in Table 5-3.

Further descriptions of the percussion drilling of the telescopic section 0–99.91 metres and the measurements performed during this phase are given in Section 5.2. The core drilling between 99.91–457.92 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. KLX20A Technical summary.

General	Technical
Name of hole: KLX20A	*Percussion drill rig* Comacchio MC1500
Location: Laxemar, Oskarshamn Municipality, Sweden	*Percussion hole length* 99.90 m (diam 253.0 mm) 99.91 m (diam 162.0 mm)
Contractor for drilling	
Drillcon AB	*Core drill rig* U8 APC Atlas Copco
Subcontractor percussion drilling	*Core drill dimension* N-size (76 mm)
Sven Andersson AB	*Cored interval* 99.91–457.92 m
Percussion drill start date February 22, 2006	*Diamond bits used* 5
Completion date March 8, 2006	*Average bit life* 72 metres
	Position KLX20A (RT90 RH70) at top of casing:
	N 6366334.57 E 1546604.89 Z 27.24 (m.a.s.l.)
Subcontractor core drilling	*Azimuth (0–360)/ Dip (0–90)*
Suomen Malmi OY (SMOY)	270.605 / –49.813
Core drill start date March 25, 2006	*Position KLX20A (RT90 RH70) at 457.92 m length:*
	N 6366356.60 E 1546298.59 Z –311.34 (m.a.s.l.)
Completion date April 24, 2006	*Azimuth (0–360)/ Dip (0–90)*
	281.69 / –41.04



Drilling reference point

Northing: 6366334.57 (m), RT90 2,5 gon V 0:-15

Easting: 1546604.89 (m), RT90 2,5 gon V 0:-15

Elevation: 27.24 (m), RHB 70

Drilling period

Drilling start date: 2006-02-22

Drilling stop date: 2006-04-24

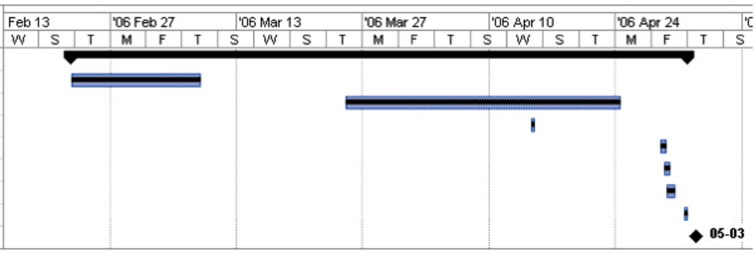
Figure 5-1. *Technical data from KLX20A.*

Table 5-2. Summary of core drilling progress and borehole measurements in KLX20A.

bh metres	Pumping tests and water sampling	Airlift pumping with evaluation of draw-down and/or recovery	Deviation measurement	Miscellaneous
	No pumping test. No detectable water table in the telescopic section after three days.		Performed at 50 and 100 m in the telescopic section.	
100				
	060402 Pumping test 101.60–194.65 m. Water flow 14 L/min at 10 m drawdown. Water sample with < 1% Drill Water Content.		060404 Flexit at 180 m Azimuth 273.8 Dip –48.9.	
200				
		060414 Airlift pumping 99.50–268.50 m. No drillstem in borehole.		
300				
	060419 Pumping test 189.65–331.80 m. Water flow 1 L/min at 8 m drawdown. No water sample.			
400				
	060425 Pumping test 331.00–457.92 m. Water flow approximate 0.05 L/min at 10 m drawdown. No water sample.	060501 Airlift pumping 99.50–457.92 m. No drillstem in borehole.		Borehole finished on 060424 at drilled length 457.92 m. 060501 Nitrogen gas flushing with drill stem at 457 m. Pumped up volume was 400 litres.

Table 5-3. Chronological summary of main drilling events in KLX20A.

Aktivitet	Start	Finish
First activity starts	**Wed 06-02-22**	**Tue 06-05-02**
Percussion drilling	Wed 06-02-22	Wed 06-03-08
Core drilling	Sat 06-03-25	Mon 06-04-24
Recovery test	Fri 06-04-14	Sat 06-04-15
Maxibor measurement	Sat 06-04-29	Sat 06-04-29
Maxibor measurement	Sat 06-04-29	Sat 06-04-29
Length calibration marks	Sat 06-04-29	Sun 06-04-30
Recovery test	Mon 06-05-01	Tue 06-05-02
Last activity ends	Wed 06-05-03	Wed 06-05-03



5.2 Drilling, measurements and results in the telescopic section 0–99.91 m

Drilling, reaming and grouting (gap injection) were made from February 22 to March 8, 2006.

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 (0–99.91 metres) of KLX20A 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 6.00 m length with NO-X 280 mm equipment. This gave a hole diameter of 340 mm and left a casing (323/310 mm diameter) to a length of 6.00 m.
- Inner supportive casing for guidance for the drill string was mounted.
- A pilot percussion hole was drilled to a depth of 99.91 m. The diameter at full length was 161.9 mm.
- Deviation measurements were done at 50 m and after full drilled length.
- Reaming to diameter 254 mm was done from 6.00 to 99.90 m. The final diameter at 99.81 m drilled length was 253.4 mm.
- Stainless casing of 208×4 mm was installed from 0 to 99.50 m, i.e. over the entire length of the telescopic section.
- Casing grouting (gap injection) with low alkali cement based concrete (1,700 litres) was made for both sets of casing. The outer casing was cut along the ground surface.
- After the concrete had hardened the borehole was rinsed and flushed to remove loose concrete and water. The tightness of the concrete seal (casing grouting) was made by measuring the water table recovery. No inflow of water could be noted over a period of three days.

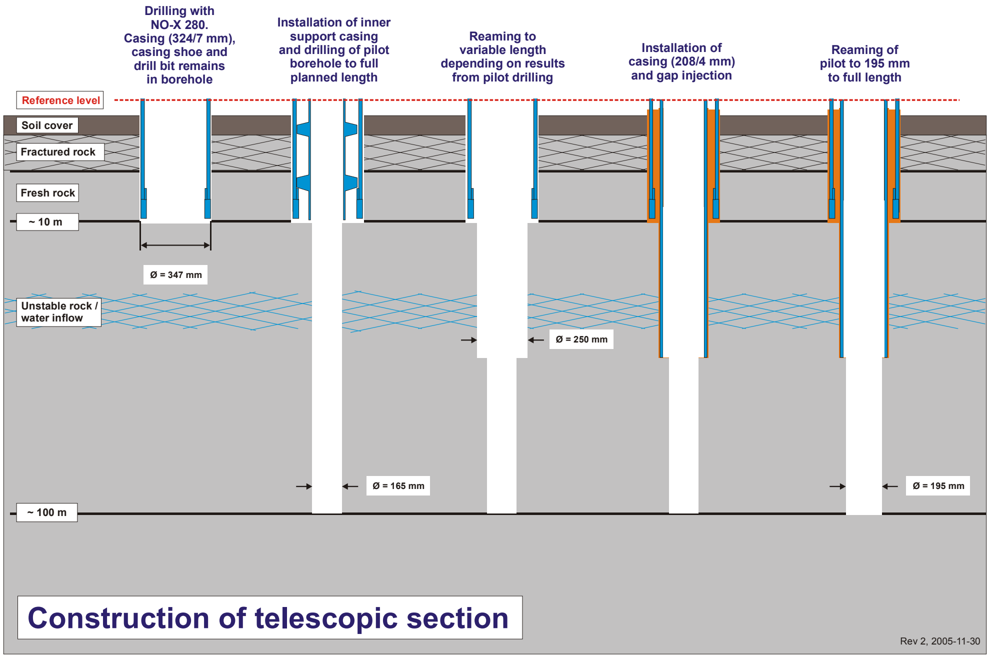


Figure 5-2. *Construction of the telescopic section. The cement for casing grouting is introduced between the casing and the rock wall. The drill bit acts as a barrier so that cement does not enter the pilot hole. In KLX20A the inner casing (208/200 mm diameter) was emplaced from surface to full drilled length in the telescopic section i.e. the final reaming as indicated in the figure was not done in KLX20A.*

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 a 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 automatically 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 1.0 m. The soil depth (ground surface to rock) was 0.7 metres.

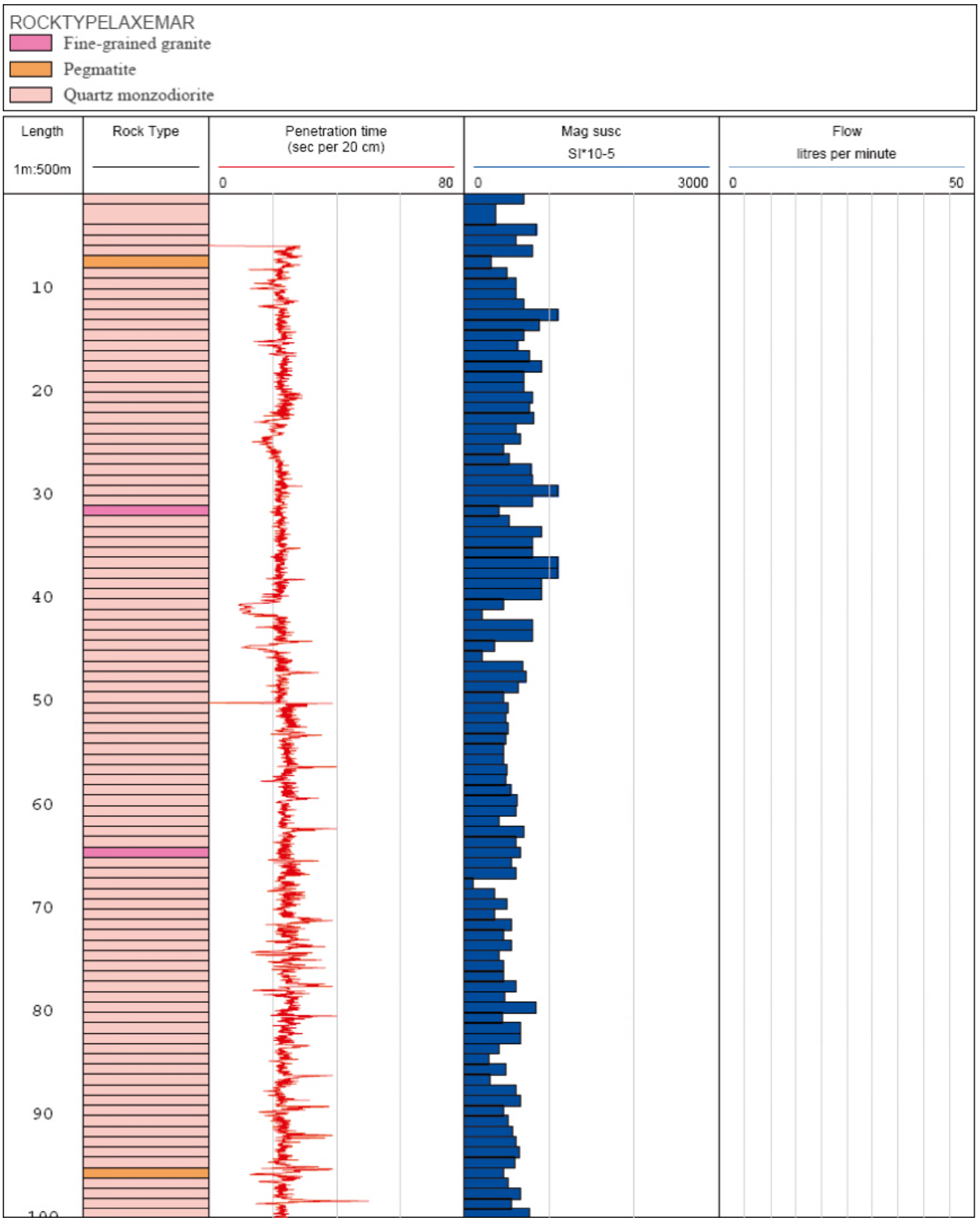


Figure 5-3. *Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KLX20A.*

Hydrogeological observations during percussion drilling

No water inflow could be measured over the entire length of the telescopic section.
No hydrogeological testing or water sampling was done in the telescopic section.

5.3 Core drilling KLX20A 99.91–457.92 m

Core drilling in KLX20A was conducted between March 25 and April 24, 2006.

The main work in KLX20A 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 borehole wall stability.

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

5.3.1 Preparations

The preparations for core drilling started on March 21, 2006 and consisted of installation of air-lift pumping equipment and supportive casing for alignment of the core drill rods, see Figure 5-4.

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 99.91 and 100.40 m with T-86 equipment. An inner supportive casing with diameter 84/77 mm was installed to 100.40 m.

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 HLX28, see also Sections 5.4.2 and 5.5. The location of the water source, borehole HLX28 is shown in Figure 1-1.

Treatment of the flushing water before introduction into the boreholes consisted of stripping of oxygen with nitrogen gas 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 KLX20A is shown in Figure 5-5.

The targeted content for uranine in the flushing water was 0.20 mg/L and the actual average uranine content was 0.237 mg/L, see also Figure 5-9 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.

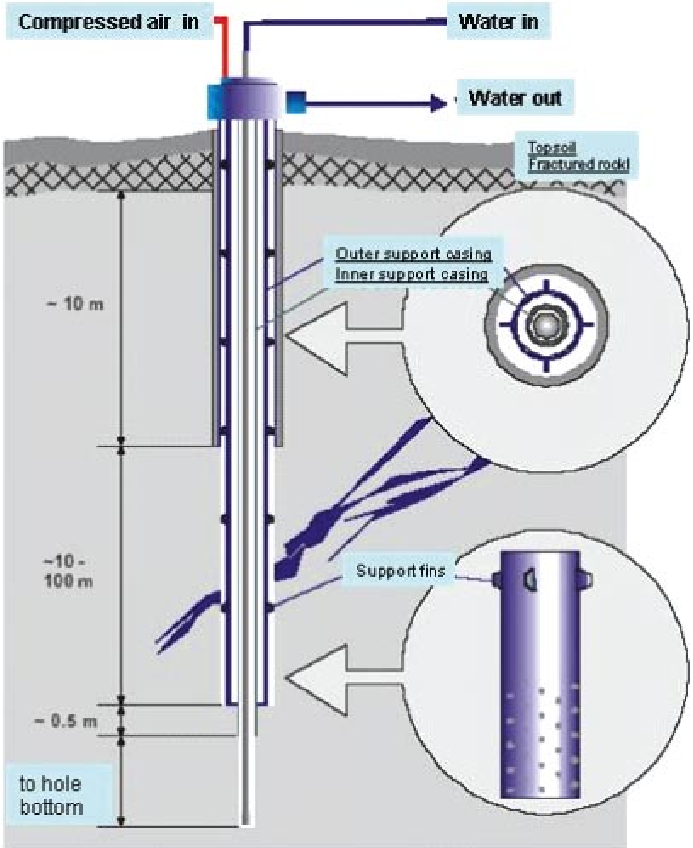


Figure 5-4. *In the telescopic part of the drill hole a temporary installation is made with casing tubes for support and alignment and equipment for air-lift pumping. In the uppermost part the return water discharge header is mounted. The water discharge is led to the settling containers.*

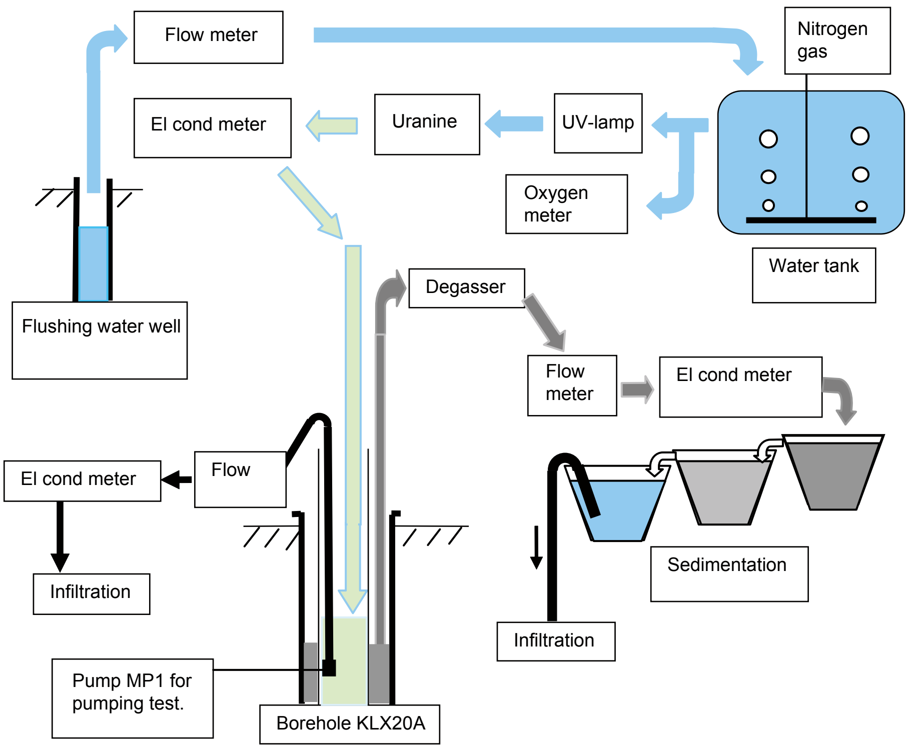


Figure 5-5. *The flushing and return water handling and the emplacement of related monitoring equipment in KLX20A.*

5.3.3 Drilling and deviation measurements KLX20A

Core drilling with T-86 equipment giving an 86 mm diameter hole was done from 99.91 to 100.40 m in KLX20A.

Core drilling with N-size (76 mm) triple-tube, wireline equipment was conducted from 100.40 m to the final length of 457.92 m in KLX20A.

The core diameters and intervals for different drilling dimensions or method of directional drilling are given in Table 5-4.

Measurements of borehole deviation are made for two purposes:

- Monitoring of drilling progress.
- Measurements at full drilled length for final calculation of borehole deviation.

The core drilling progress was followed by deviation measurements with the Flexit method once along the borehole. The results from this measurement are not stored in the Sicada database but are given in a summary fashion in Table 5-2.

Measurements were done with the Flexit and Maxibor methods for the final evaluation of the borehole deviation in KLX20A. The Flexit tool was run both up and down the borehole from 0 to 456 metres. In addition measurements with the Maxibor instrument were performed both up and down the hole between 0 and 456 metres. The final deviation file in KLX20A is calculated based on the measurements given in Table 5-5 together with the surveyed bearing and inclination of the top-of-casing. The calculations are made according to routines specified in the SICADA database and general expert judgement. Further comment on the method for calculation of final borehole deviation is given in /4/.

Horizontal and vertical plots of the results of the calculated deviation covering the entire length of borehole KLX20A are given in Appendix 4.

Core losses were noted in the Boremap mapping, see Section 5.6, at the intervals given in Table 5-6.

A total of five drill bits were used for KLX20A, see Figure 5-6.

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.

Table 5-4. Core diameters, borehole diameters and drilling dimensions during core drilling in KLX20A.

Core diameter (mm)	Borehole diameter (mm)	Interval (m drilled length)	Drilling dimension or directional drilling method	Comment
72.0	86	99.91–100.40	T-86	
50.2	86	100.40–100.90	N and T-86	Reamed to 86 mm diameter
50.2	76	100.90–457.92	N	

Table 5-5. Measurements used for borehole deviation calculation in KLX20A.

Deviation measurement method	Used for calculation of bearing/ inclination	Interval from (m)	Interval to (m)	Measuring direction	Date	Sicada database activity ID
Maxibor	bearing	3.00	456.00	in/down	2006-04-29	13114898
Flexit	bearing	117.00	456.00	in/down	2006-05-08	13120027
Flexit	inclination	3.00	456.00	in/down	2006-05-08	13120027
Flexit	bearing	117.00	456.00	out/up	2006-05-08	13141380
Flexit	inclination	3.00	456.00	out/up	2006-05-08	13141380
Maxibor	bearing	3.00	456.00	out/up	2006-04-29	13141381

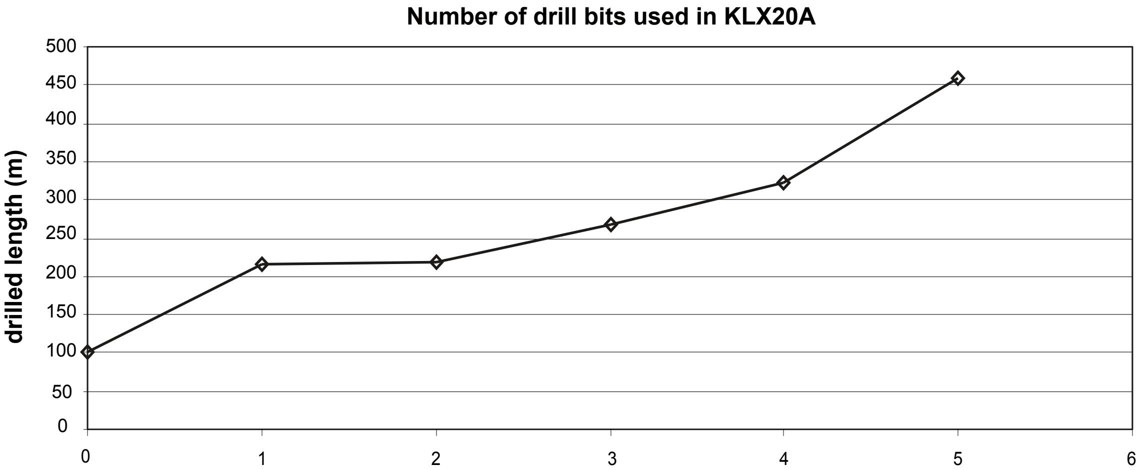


Figure 5-6. Drill bit changes during core drilling in KLX20A.

Table 5-6. Core losses noted in KLX20A.

From (m)	To (m)	core loss length (m)	Comment
215.73	215.88	0.15	Missing Core Piece
277.01	277.07	0.06	Missing Core Piece
277.76	277.90	0.14	Missing Core Piece
307.48	307.58	0.10	Missing Core Piece

5.3.4 Borehole wall risk assessment, stabilisation and completion

Borehole wall risk assessment and stabilisation

A borehole wall assessment was prepared on May 29, 2006, SKB id no 1055391, SKB internal document.

The main drilling events that have influence on the risk assessment are summarized as follows:

- Diamond drilling completed at 457.92 m. Two rock fall-outs occurred during drilling. The loose rocks came from the section 181.50–231.00 m i.e. the diabase (dolerite).
- Flushing and brushing with high water pressure on the borehole wall was done along intervals as given in Table 5-7. Some rock fall-out was noted in conjunction with the brushing operation. The selection of the intervals to rinse was based mainly on study of the drill core. The flush and brush tool is shown in Figure 5-7.
- The steel dummy was lowered without any problems along the entire length of the borehole (to 457.92 metres). The probe is designed so that it will run smoothly along the borehole if the curvature does not exceed 0.1°/ metre.
- Downhole operations consisting of deviation measurements, milling of reference grooves and flushing of the borehole with nitrogen gas were made without stability problems.
- Minor problems with moving the dummy probe through the cone (steel conical guide, shown in Figure 5-1) between the telescopic section and the core drilled part. It was judged that the problems are due to the relatively shallow dip of the borehole.
- BIPS logging for final risk assessment was done to full drilled length.

The overall assessment was that the probability for rock fallout was medium in the borehole.

Table 5-7. Borehole sections that were mechanically rinsed by water flushing and rotating steel brush.

From (bh length m)	To (bh length m)
136	138
172	177
181	186
188	189
192	194
197	234
265	266
268	269
275	278
289	290
308	309
312	313

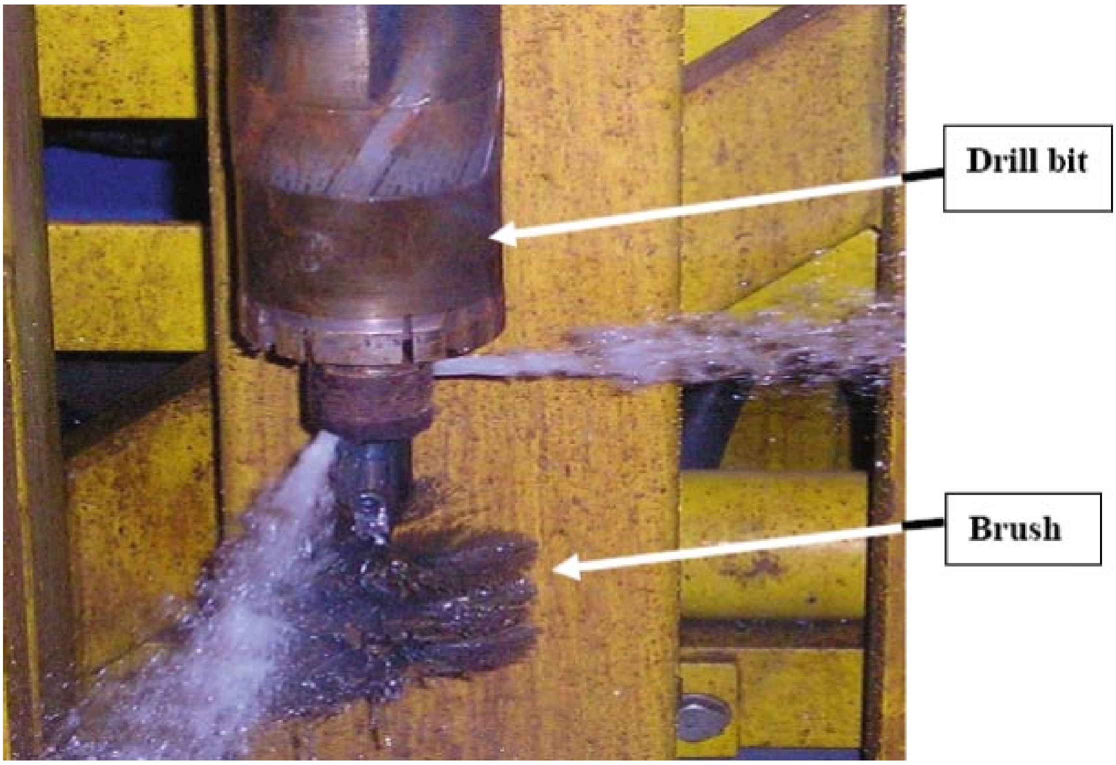


Figure 5-7. *The water flushing and rotating steel brush tool. The tool is lowered into the drill stem and can be seen in place just below the drill bit. During operating the drill string is moved up and down to remove loose rock fragments from the borehole wall.*

Borehole completion

Reaming of depth reference slots was done at the drilled lengths shown in Table 5-8. 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 were removed.

The borehole was reamed from 100.40 to 100.90 with T-86 equipment. A steel conical guide was installed in KLX20A between 96.08 m and 100.90 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 at times given in Table 5-9.

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.

5.4 Hydrogeological and hydrochemical measurements and results 99.91–457.92 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:

- Three successful pumping tests were conducted at various intervals, see Section 5.4.1.
- Two water samples were taken, see Section 5.4.2.

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

Hydraulic responses in near-by boreholes from drilling in KLX20A are commented in Section 5.4.4.

Table 5-8. Depth reference slots (m) in KLX20A.

110.00	300.00
150.00	350.00
200.00	400.00
250.00	430.00

Table 5-9. Nitrogen gas flushing in KLX20A. (time is given in local time including daylight saving time i.e. GMT+2).

Date	Time	Interval (m)
060501	06.00	99.50–457.92
060508	10.53	99.50–457.92
060508	12.37	99.50–457.92
060508	13.25	99.50–457.92

5.4.1 Hydrogeological results from wireline measurements

Results from the wireline tests in KLX20A are presented in Table 5-10 and Figure 5-8.

The pumping tests were evaluated with steady-state assumption in accordance with Moye /3/. 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 and s is the drawdown.

A total of five tests were performed in KLX20A, and two achieved sufficiently stable conditions for calculating pseudo steady-state transmissivity and hydraulic conductivity. The reason behind the failed tests is mainly leakage between the casing and the tested section, due to a malfunction check valve. The results from the test in section 101.60–194.65 are only a rough evaluation of the hydraulic parameters, and are not reported to the SICADA data base, as the estimation is based on an assumption of maximum flow, due to leakage between casing and tested section.

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

The start and stop times (Swedish Normal Time GMT+1) for the intervals used for evaluation of the pumping tests are given in Table 5-11.

Table 5-10 Pumping tests with wireline probe in KLX20A.

Tested section [m]	Q/s [m²/s]	T_M [m²/s]	Comments
101.60–194.65	$2.3 \cdot 10^{-5}$	$2.6 \cdot 10^{-5}$	Pressure in casing in transient recovery phase, affected of pumping test. The leakage flow from casing to tested section is not considered to affect the pumped flow in any significant way. However, the hydraulic parameters are estimated based on a maximum flow, i.e. true T < estimated T.
189.65–331.80	$2.4 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$	Pseudo steady state not fully reached, decreasing flow and increasing pressure in test section. Pressure in casing in transient recovery phase, unaffected of pumping test.
331.00–457.92	$8.2 \cdot 10^{-8}$	$1.1 \cdot 10^{-7}$	Pressure in drawdown phase, unaffected of pumping test. Very low flow (Q ≈ 0.05 L/min).

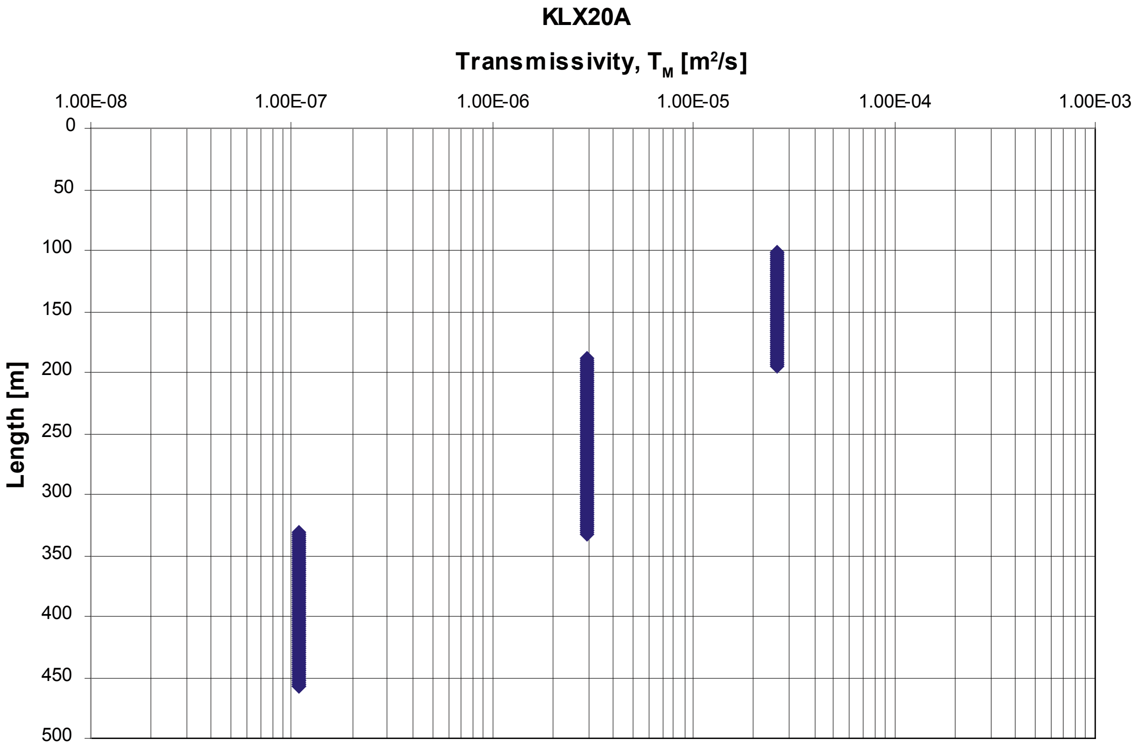


Figure 5-8. Transmissivity from wireline pumping tests in KLX20A versus borehole length. Note that the result from the test in section 101.60 – 194.65 only is an approximate value.

Table 5-11. Evaluated test periods.

Tested section	Start (YYYY-MM-DD HH:MM)	Stop (YYYY-MM-DD HH:MM)
101.60–194.65	2006-04-02 16:56	2006-04-03 03:01
189.65–331.80	2006-04-19 16:22	2006-04-20 19:31
331.00–457.92	2006-04-25 18:16	2006-04-26 21:18

5.4.2 Hydrochemistry

Two water samples were collected in connection with core drilling in KLX20A. Time and lengths for the samples are given in Table 5-12.

Sampling and analysis were performed according to the SKB classes specified in Table 5-12. The samples were collected at the drill site as soon as possible after the sampling occasion and prepared and conserved at the Äspö laboratory. The samples were stored in a refrigerator until the drilling of the borehole was completed.

Sample 10983 was discarded due to a probable leakage in the wire line probe during sampling and it was decided not to analyse this sample for isotopes. Collected isotope bottles from the sample are stored in freezer at the Äspö laboratory. Water for tritium and carbon isotopes analysis are stored in a refrigerator.

The drilling water content was low in sample 10949 and it was therefore analysed for isotopes.

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.

Archive samples (two 250 ml bottles with filtered water) have been collected for the samples 10949, 10983 and 10872. The samples are stored in a freezer at the Äspö laboratory.

Selected analytical results from KLX20A and the water source HLX28 are given in Table 5-13. A complete record of analytical results is given in Appendix 2.

Table 5-12. Sample dates and length during core drilling in KLX20A.

Sample number	Borehole	Date	Test section, length (m)	SKB chemistry class
10949	KLX20A	2006-04-03	101.60–194.65	3 (and all option isotopes)
10983	KLX20A	2006-04-17	193.00–291.17	3 (isotope options not included)

Table 5-13. Analytical results from water chemistry sampling.

Borehole	Sample no	Date	From m	To m	Drill water %	pH	Conductivity mS/m	Cl mg/l
KLX20A	10949	2006-04-03	101.60	194.65	0.98	8.50	41.9	11.5
KLX20A	10983	2006-04-17	193.00	291.17	2.94	8.11	123.0	281.0

Borehole	Sample no	Date	From m	To m	TOC mg/l	pH	Conductivity mS/m	Cl mg/l
HLX28	10872	2006-03-10	6.03	154.20	5.5	8.10	64.4	39.3

The percussion drilled borehole HLX28 was used as water source during the drilling of KLX20A.

One water sample (10872) was collected from HLX28 in connection with the drilling of KLX20A. The concentration of total organic carbon (TOC) in this sample was 5.5 mg/l. This value was considered acceptable for the groundwater to be used as flushing water for the core drilled part of KLX20A without further filtration measures to lower the organic carbon content.

Sample 10872 was not analysed for isotopes since there has been other samples collected from HLX28 at earlier occasions. Results from these samples are given in drilling report for borehole KLX11A /5/. Bottles intended for isotope determinations are nevertheless stored in a freezer (tritium and carbon isotopes in refrigerator) at the Äspö laboratory.

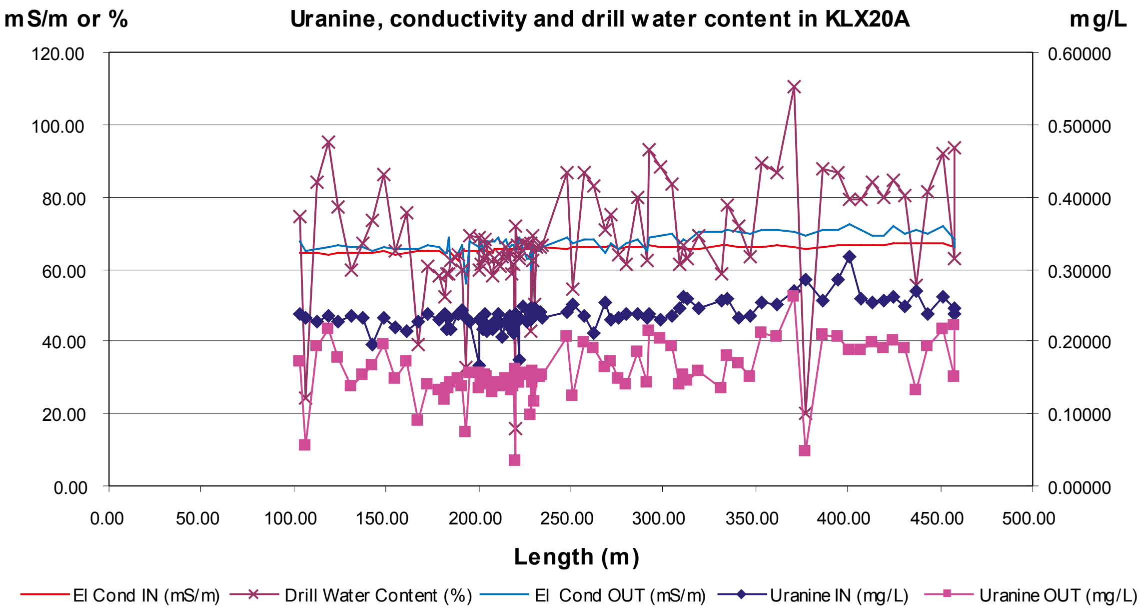
A further account on analytical method, chemistry class 3 and quality is given in Appendix 3.

Sampling for uranine tracer content and electrical conductivity

From KLX20A, a total of 84 samples for uranine content and electrical conductivity in flushing and returning water were taken along the borehole.

The results are shown graphically in Figure 5-9. All the samples were analysed at the Äspö laboratory.

The calculated average uranine content for the whole borehole is 0.237 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.



Figur 5-9. *The uranine concentration, electrical conductivity of flushing water (IN) and return water (OUT) and drill water percentage in KLX20A during drilling.*

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

One air-lift pumping test was 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 stem.

The steady state transmissivity, T_M, was calculated according to Moye /3/, as well as the specific capacity, Q / s. The results are shown in Table 5-14 and are 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 5-10 and 5-11.

Table 5-14. Results from airlift pumping in KLX20A.

Tested section [m]	Flow rate [L/min]	Drawdown [m]	Q/s [m²/s]	T_M [m/s]	Comments
99.50–268.50	16.7	34	$8.2 \cdot 10^{-6}$	$1.1 \cdot 10^{-5}$	Q derives from accumulated volumes of water in and out 13:50–15:50. Q = ΣV/dt
99.50–457.92	11	29	$6.3 \cdot 10^{-6}$	$9.5 \cdot 10^{-6}$	Q = Qnet 10:00–15:14

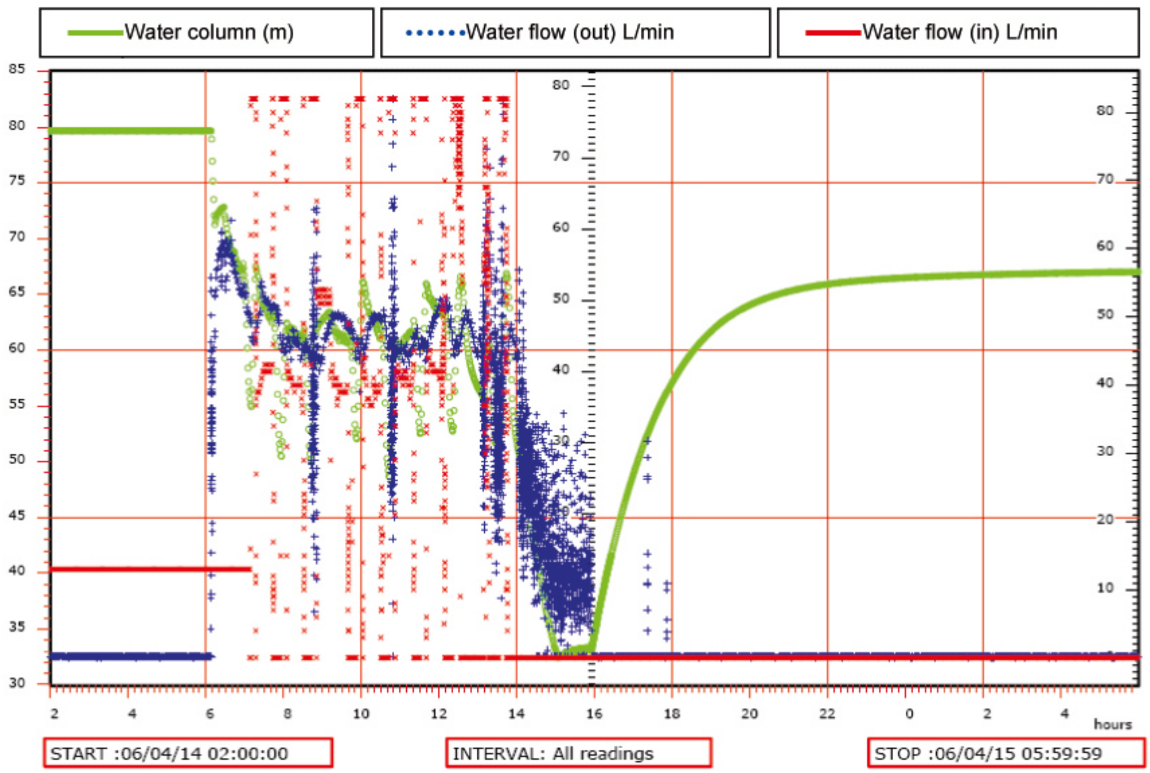


Figure 5-10. *Airlift pumping in KLX20A 99.50–268.50 m. The green line represents the height of the water column in the borehole. The water flow out is shown as the blue dotted line and the inflow rate as the red line. Times are in Swedish Normal Time. The period for test evaluation is shown with a black bar.*

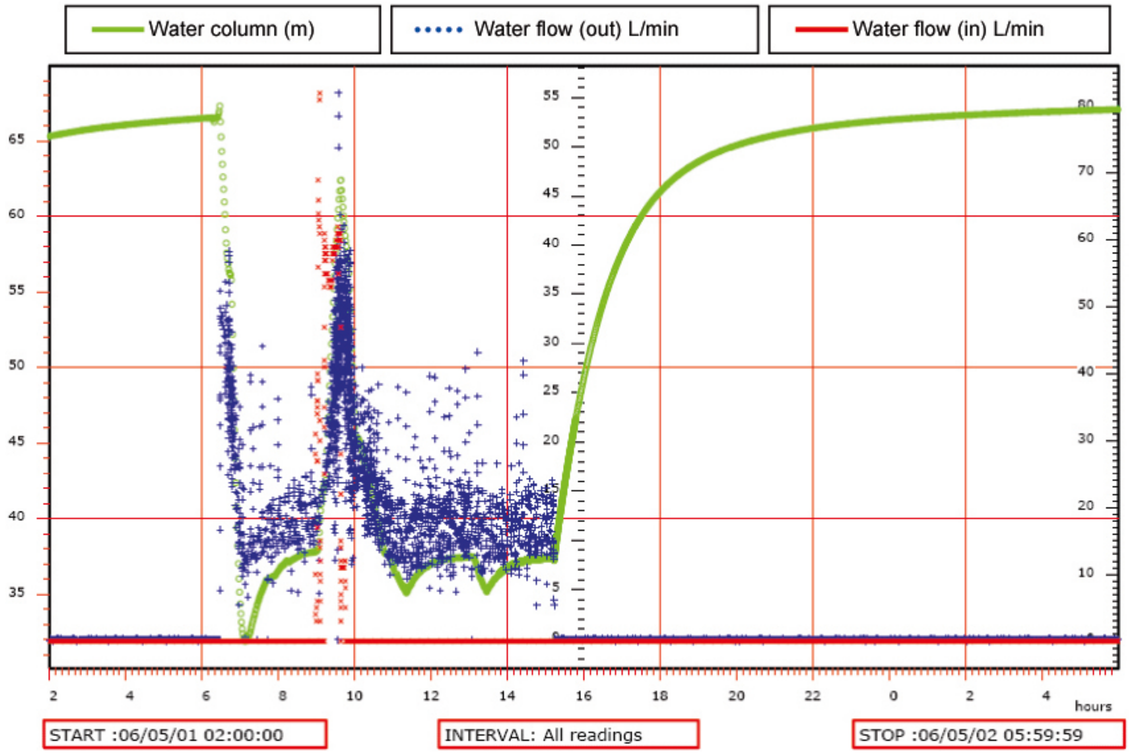


Figure 5-11. *Airlift pumping in KLX20A 99.50–457.92 m. The green line represents the height of the water column in the borehole. The water flow out is shown as the blue dotted line and the inflow rate as the red line. The inflow rate was 0 L/min during the whole test period. Times are in Swedish Normal Time. The period for test evaluation is shown with a black bar.*

5.4.4 Hydraulic responses in near-by boreholes

Hydraulic responses from drilling activities in a borehole are created by the drawdown from air-lift pumping during core drilling and from flushing or rinsing the borehole with nitrogen gas (i.e. lifting the water with nitrogen gas). Percussion drilling of the telescopic section also constitutes an air-lift pumping from a hydrogeological point of view.

Hydraulic responses in near-by boreholes from percussion of the telescopic section in KLX20A

No hydraulic responses from percussion drilling in KLX20A could be seen in the observation boreholes KLX11A, HLX28, HLX36 or HLX37.

A plot showing the water table in observation boreholes KLX11A (logger in open borehole), HLX28, HLX36 and HLX37 during percussion drilling of the telescopic section in KLX20A is given in Figure 5-12. No response from percussion drilling in KLX20A could be seen in the observation boreholes. The water table measurements in HLX36 and HLX37 were discontinued because of geophysical logging. Possible hydraulic responses in KLX03 from drilling in KLX20A were not evaluated as part of this report.

Hydraulic responses in near-by boreholes from air-lift pumping during drilling in KLX20A

Groundwater level in boreholes KLX20A, HLX28, HLX36 and HLX37 during the core drilling in borehole KLX20A are shown in Figure 5-13. No responses from air-lift pumping or other drilling related activities can be seen in HLX36. The crenulations in the water table for HLX37 could be an effect of air-lift pumping in KLX20A, see also Figure 5-14. The water table variations in KLX20A and HLX28 are dominated by pumping (air-lift pumping in KLX20A and flushing water pumping in HLX28) and any hydraulic response between the two boreholes is therefore obscured. Possible hydraulic responses in KLX03 from drilling in KLX20A were not evaluated as part of this report.

Hydraulic responses in near-by boreholes from nitrogen gas flushing in KLX20A

Nitrogen gas flushing covering the entire length of the borehole was done once on May 1 and three times on May 8. No hydraulic responses could be seen in observation boreholes HLX28 and HLX36. A weak response can possibly be seen in HLX37 from the nitrogen gas flushing on May 8. A plot of the water table in KLX20A and the observation boreholes during the first half of May 2006 is given in Figure 5-14. Possible hydraulic responses in KLX03 from drilling in KLX20A were not evaluated as part of this report.

The location of the mentioned boreholes is given in Figure 5-15.

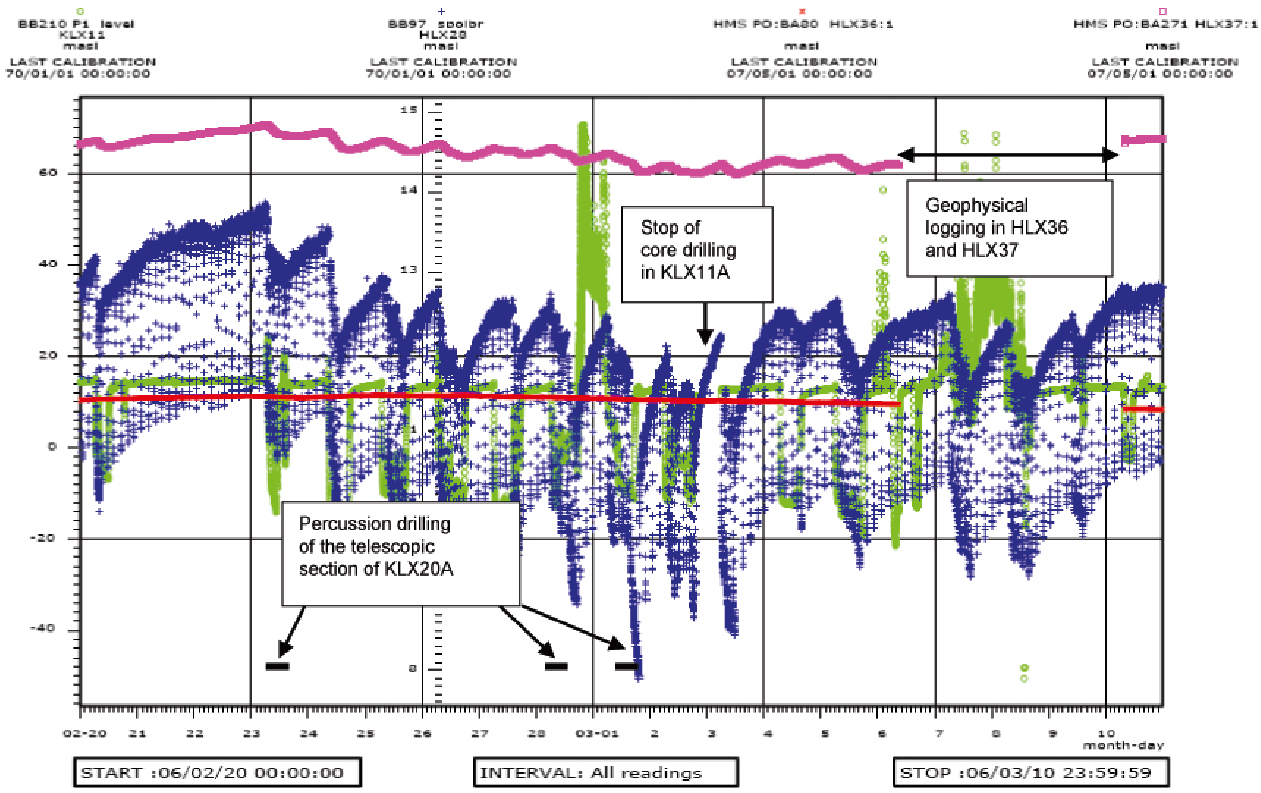


Figure 5-12. *Water table in observation boreholes KLX11A (logger in open borehole), HLX28, HLX36 and HLX37 during percussion drilling of the telescopic section in KLX20A. The scale for the water level is the same in HLX36 (red crosses) and HLX37 (red squares) as it is for HLX28 (blue crosses). No response from percussion drilling in KLX20A could be seen in the observation boreholes. The water table measurements in HLX36 and HLX37 were discontinued because of geophysical logging. The water table fluctuations in HLX28 are caused by pumping (air-lift pumping in KLX20A and flushing water pumping in HLX28). Times are given in SNT (GMT+1).*

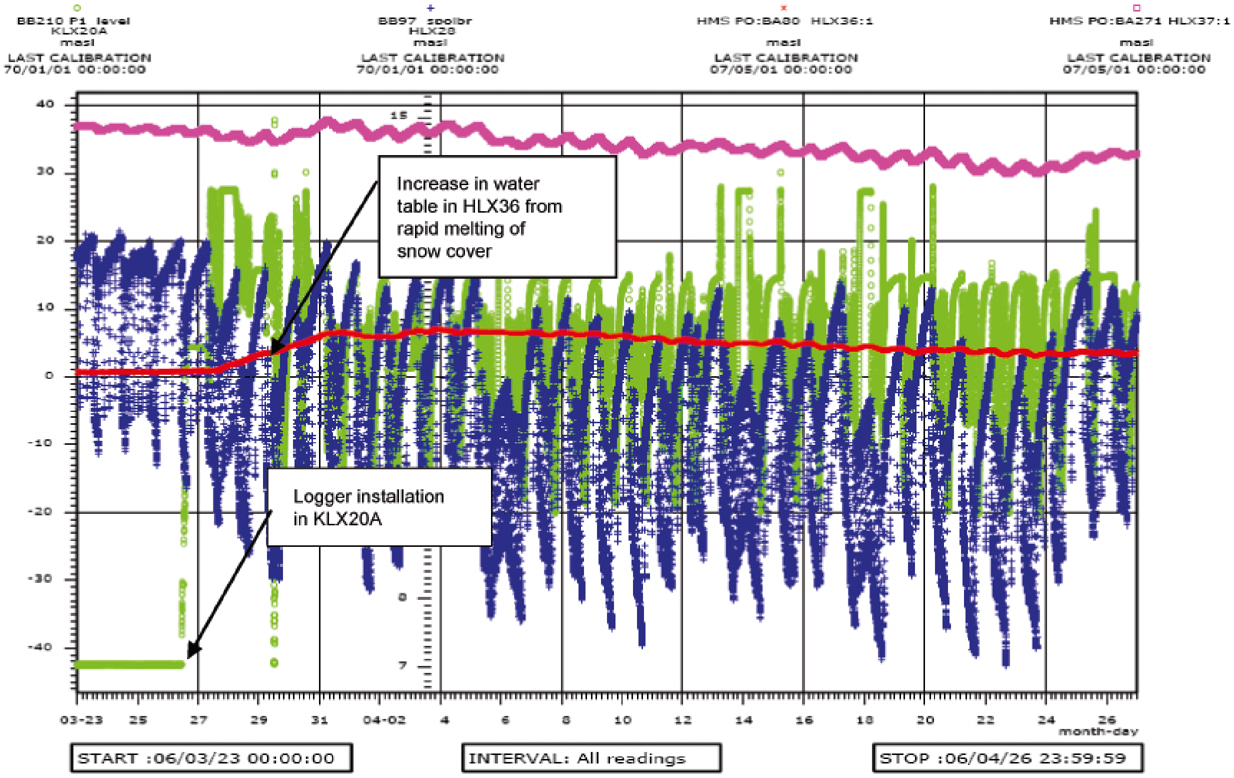


Figure 5-13. *Groundwater level in boreholes KLX20A, HLX28, HLX36 and HLX37 during the core drilling in borehole KLX20A. The scale for the water level is the same in HLX36 (red crosses) and HLX37 (red squares) as it is for HLX28 (blue crosses). No responses from air-lift pumping or other drilling related activities can be seen in HLX36. The crenulations in the water table for HLX37 could be an effect of air-lift pumping in KLX20A, see also Figure 5-14. The water table variations in KLX20A and HLX28 are dominated by pumping (air-lift pumping in KLX20A and flushing water pumping in HLX28) and any hydraulic response between the two boreholes is therefore obscured. Times are given in SNT (GMT+1).*

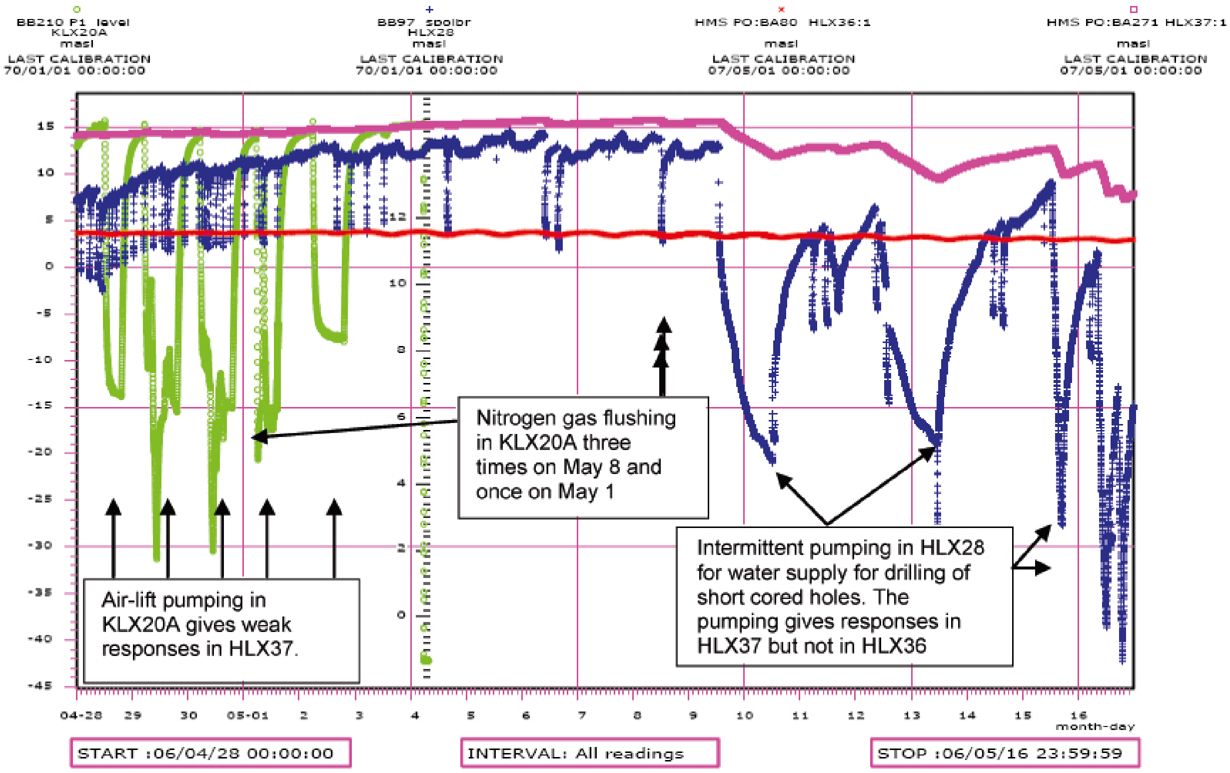


Figure 5-14. *Water levels in KLX20A, HLX28, HLX36 and HLX37 during nitrogen gas flushing in KLX20A. The scale for the water level is the same in HLX36 (red crosses) and HLX37 (red squares) as it is for HLX28 (blue crosses). No hydraulic response could be seen in observation boreholes HLX28 and HLX36. Possibly a weak response can be seen in HLX37 from the nitrogen gas flushing on May 8. Registration of drilling monitoring parameters in DMS2PO was discontinued on May 4. The times are given in Swedish Normal Time (GMT+1).*

Figure 5-15. *Map showing the location of cored boreholes KLX20A and KLX11A together with the percussion boreholes HLX28, HLX36 and HLX37.*

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 0–99.91 metres and the core drilling section 99.91–457.92 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 5-16 through 5-18 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 5-16 through 5-18. Since DMS data are related to time (i.e. not strictly to borehole length) periods where drilling is not performed are also registered.

Figure 5-16 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 5-17 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 60–80 litres/minute corresponding to the flow while pumping down the core barrel.
- No flow (zero litres/minute) when no drilling is performed.

Figure 5-18 shows the conductivity of the ingoing flushing water, conductivity of the return water and the oxygen content of the flushing water. The oxygen content of the flushing water was low (< 4 mg/L).

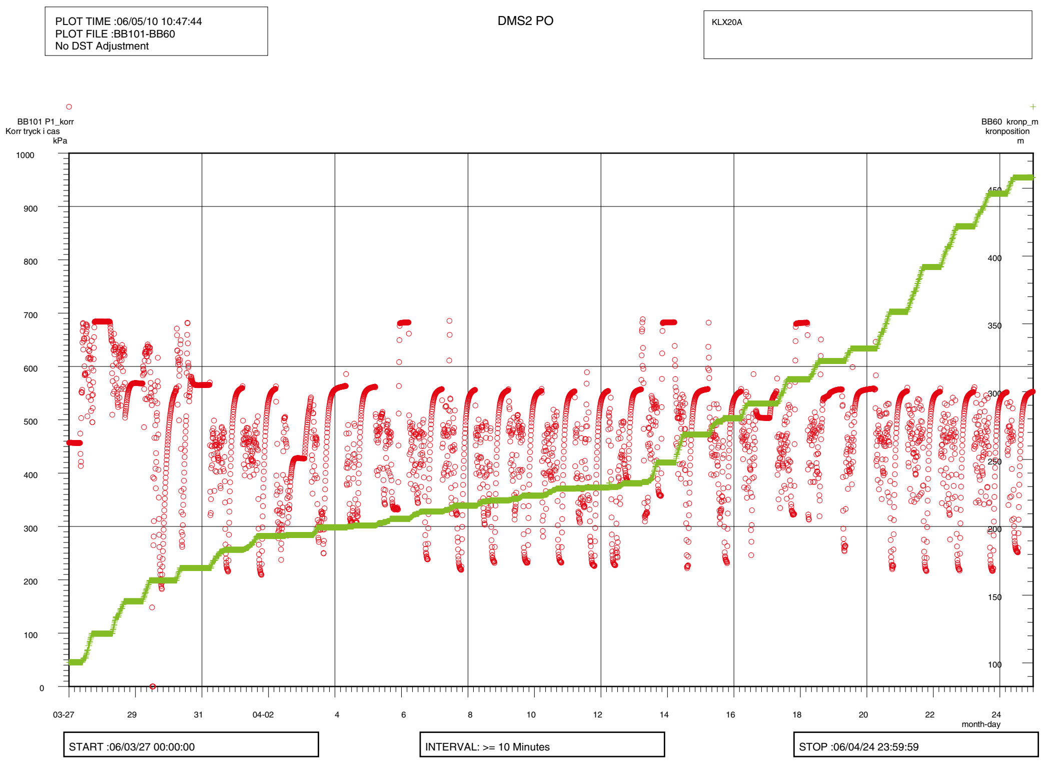


__Figure 5-16.__ Drill bit position (green) and water level from air-lift pumping (red). The water level is expressed as the pressure in kPa of the water column overlying the pressure gauge i.e. the ambient air-pressure has been subtracted. The pressure gauge is emplaced at 90 metres borehole length.

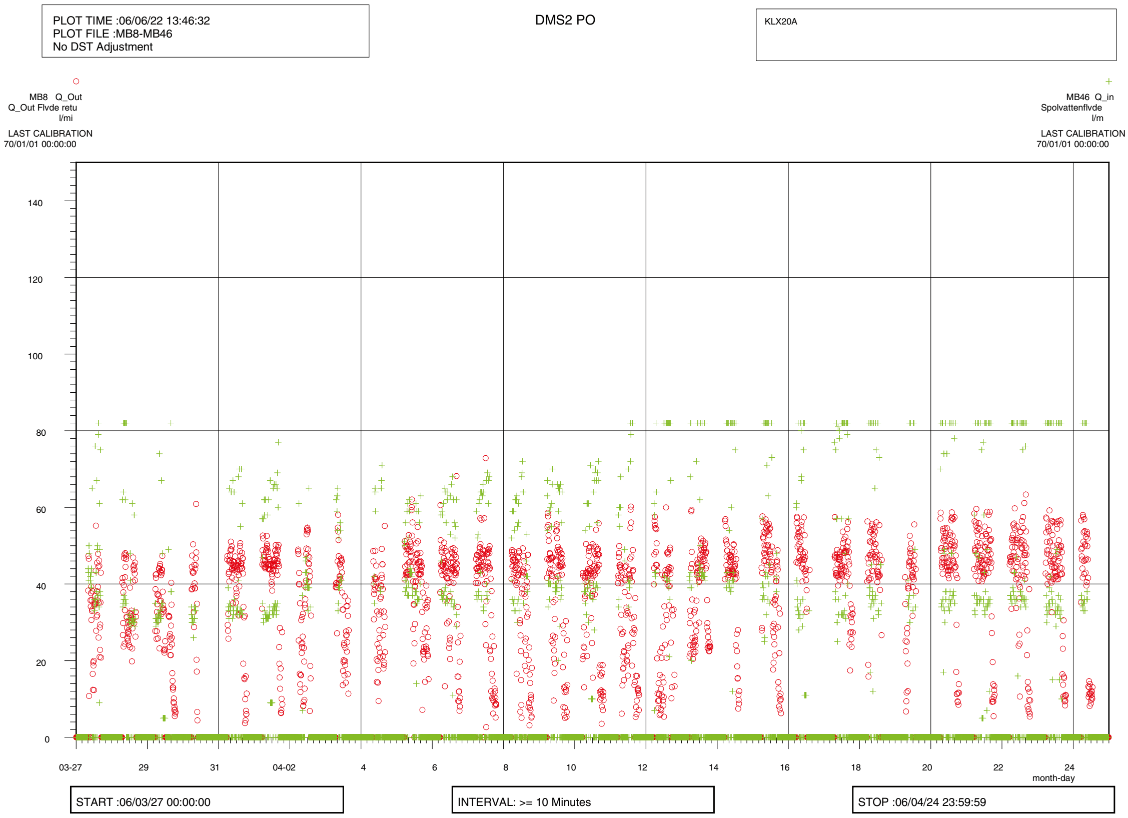


Figure 5-17. *Flushing water flow (green) and return water flow (red) in litres per minute.*

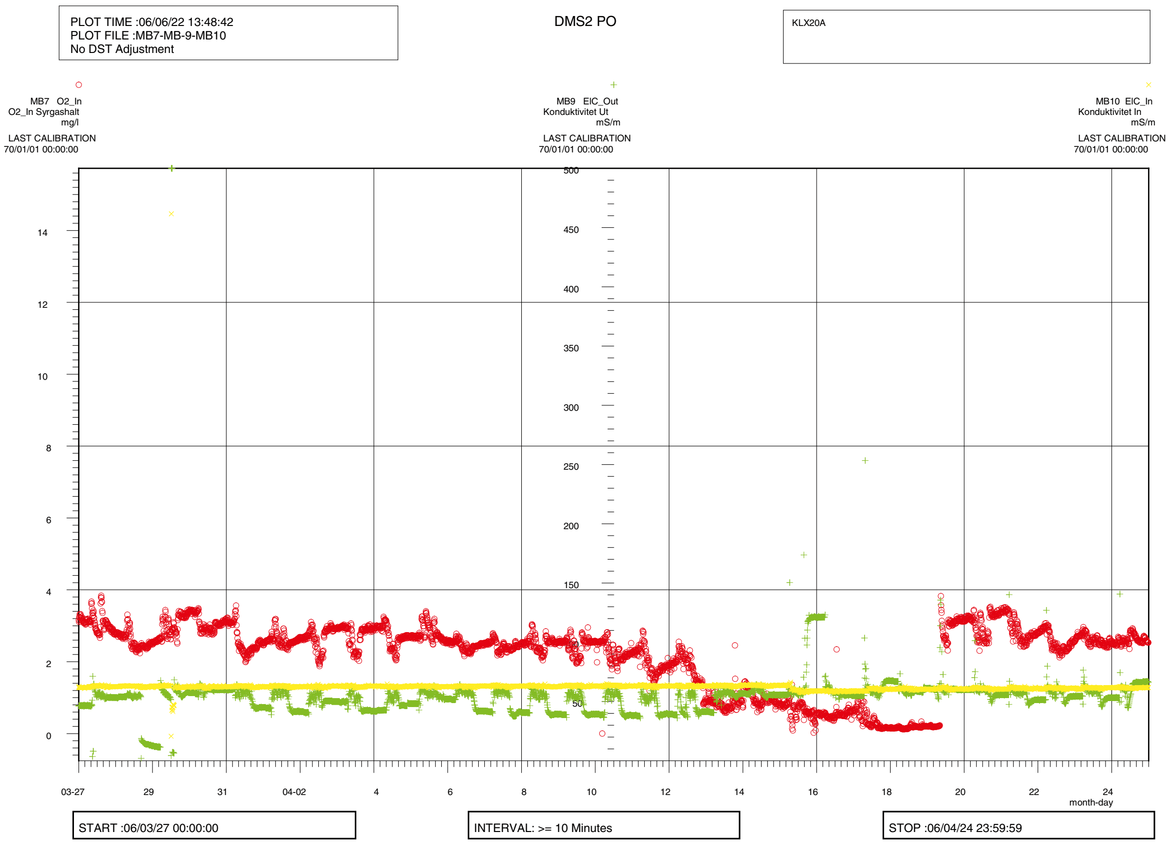


Figure 5-18. *Conductivity of flushing water (yellow) and return water (green). The oxygen content in mg/L of the flushing water (red) is also shown. The oxygen content of the flushing water is typically low (< 4 mg/L) with only scattered slightly elevated readings.*

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 5-19.

The amount of flushing water consumed during drilling was 430 m^3, giving an average consumption of ca 1.2 m^3 per metre core drilled. The amount of effluent return water from drilling in KLX20A was 750 m^3, giving an average of ca 2.1 m^3 per metre core drilled.

Drill cutting balance

The weight of cuttings in the settling containers amounted to 664 kg. The content of suspended material in the return water was not analysed in borehole KLX20A, however previous sampling has shown the content to be 400 mg/L /6/. The amount of material in suspension carried with the return water would amount to 300 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing (with core barrel N3/50) over a length of 360 metres is 2,430 kg assuming a density of 2.7 kg/dm^3. This means that 40% 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 5-15. The results show that all (> 100% according to balance calculation!) of the introduced uranine was retrieved during drilling of KLX20A.

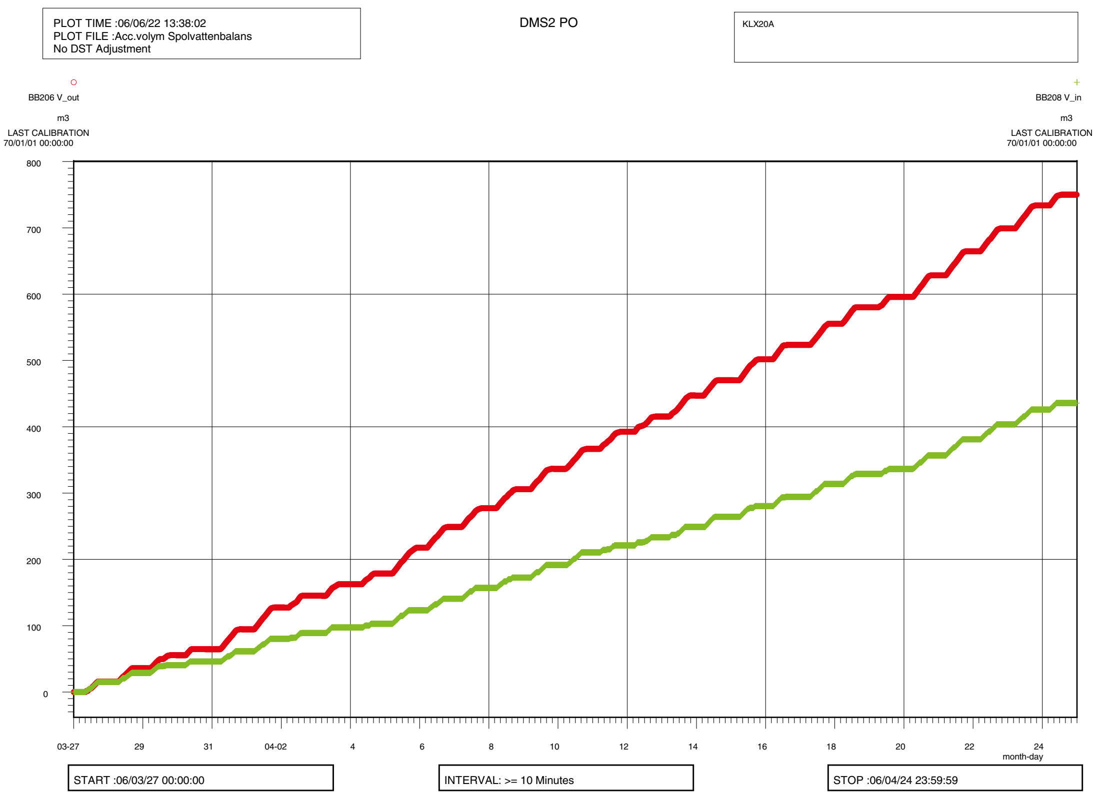


Figure 5-19. *The flushing water balance in KLX20A as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.*

Table 5-15. Balance calculation of uranine tracer in KLX20A.

Average uranine content IN (mg/L)	0.237
Flushing water volume IN (m^3)	430
Amount uranine introduced (g)	102
Average uranine content OUT (mg/L)	0.156
Return water volume OUT (m^3)	750
Amount uranine recovered (g)	117

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 /6/.

Lithologically the core is dominated by Quartz monzodiorite. Dolerite was encountered between 180 and 230 m. Minor intercalations of fine-grained diorite-gabbro and fine grained granite have been noted in the borehole.

Red staining with weak intensity occurs frequently to ca 300 m. The red staining is often associated with saussuritization i.e. alteration of calcic plagioclase to epidote/zoisite. Below 300 m length the presence of red staining is less common. Sections with red staining are indicated as "oxidized" in Appendix 1.

The average fracture frequency over the entire core drilled section expressed as open fractures is 2.58 (fractures/metre). NB The fracture frequency given in Appendix 1 shows the total fracture frequency (i.e. open fractures, sealed fractures, sealed network 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 and the environmental monitoring wells SSM000236 and SSM000237 is shown in Figure 5-20. 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.

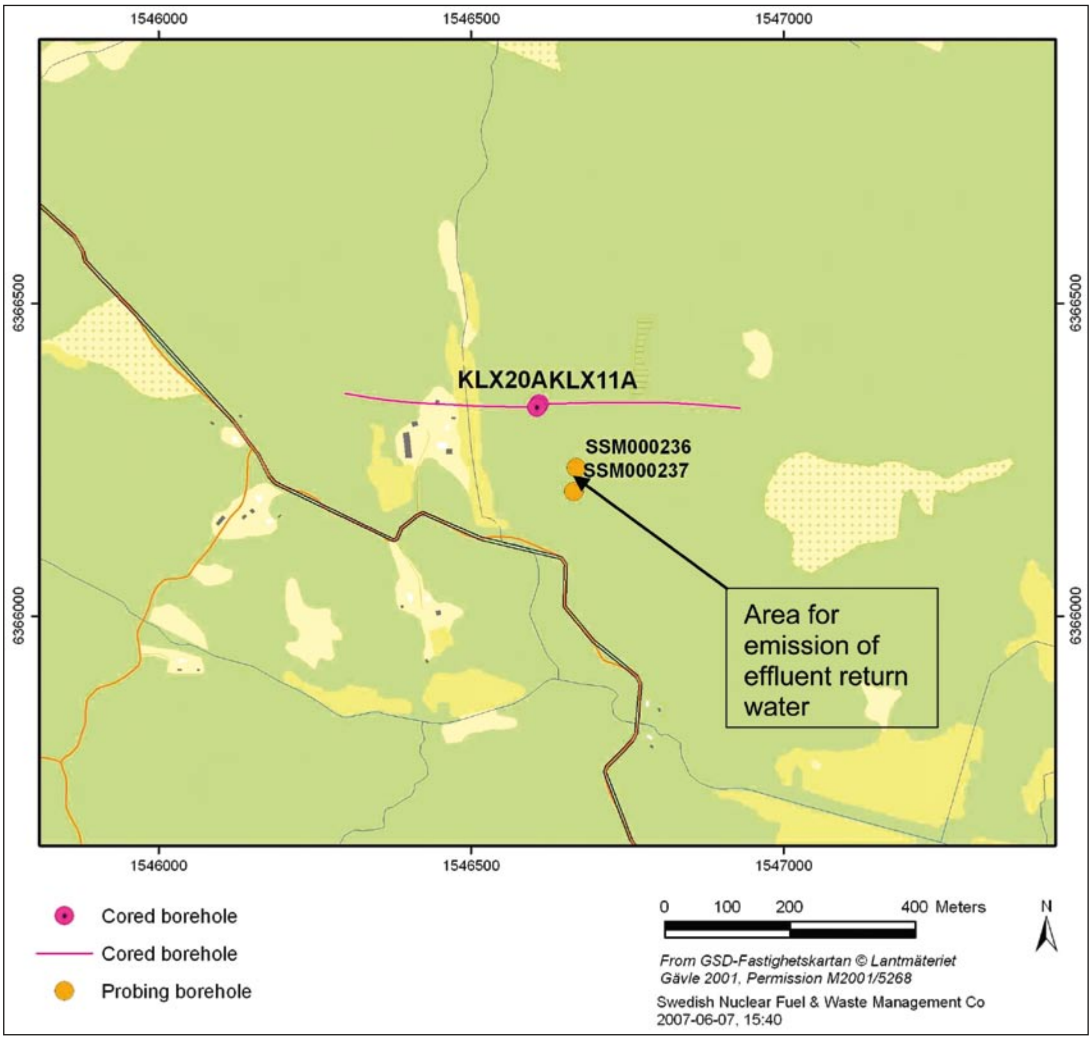


Figure 5-20. *The location of the site for return water emission and the environmental monitoring wells SSM000236 and SSM000237 in relation to the core drill site for KLX20A.*

Monitoring of effluent water

The electrical conductivity, as measured by the DMS system, of the return water from the core drilling of KLX20A was typically below 100 mS/m, see Figure 5-18. Samples of the return water that were analysed for electrical conductivity were all below 80 mS/m, see Figure 5-9.

The uranine content was well below 0.3 mg/L, see Figure 5-9.

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 /7/.

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

Environmental monitoring wells and reference sampling

Core drilling of KLX20A was done from a previously established drill site. The environmental monitoring wells were drilled as part of the core drilling activity of KLX11A. The technical specifications are given in /5/.

Reference samples of the surface soil and ground water, before drill start and establishment of the drill site was taken in conjunction with the drilling of KLX11A. The reference samples are reported in /5/.

Monitoring of soil ground water levels

A pressure logger (transducer) for measuring the ground water table was installed in SSM000237 during the core drilling of KLX20A. The water levels are given graphically in Figure 5-21.

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 SSM000236 and SSM000237. The results show steady and low values for pH and electrical conductivity, see Figures 5-22 and 5-23. No significant influence can be seen on the shallow ground water in the environmental monitoring wells from the drilling activity in KLX20A.

5.8.1 Consumption of oil and chemicals

The consumption of hammer oil (Hydra 46) was 15 litres for the percussion drilling of the telescopic section. No other significant amounts of oils or lubricants were consumed during the drilling.

The concrete consumption was 1,700 litres in total. The concrete was based on white silica, low alkali cement.

5.9 Nonconformities

No formal nonconformities are noted for borehole KLX20A.

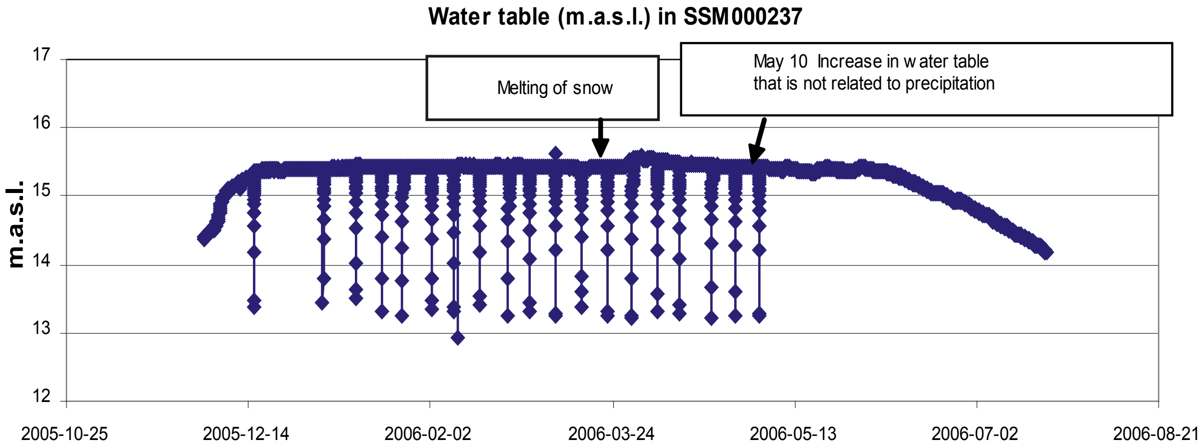


Figure 5-21. *The ground water level in well SSM000237. The dips in water levels are related to water sampling. The percussion drilling of the telescopic section did not influence the water level in the monitoring well SSM000237. The water level in the monitoring well was not affected by the core drilling activity in KLX20A.*

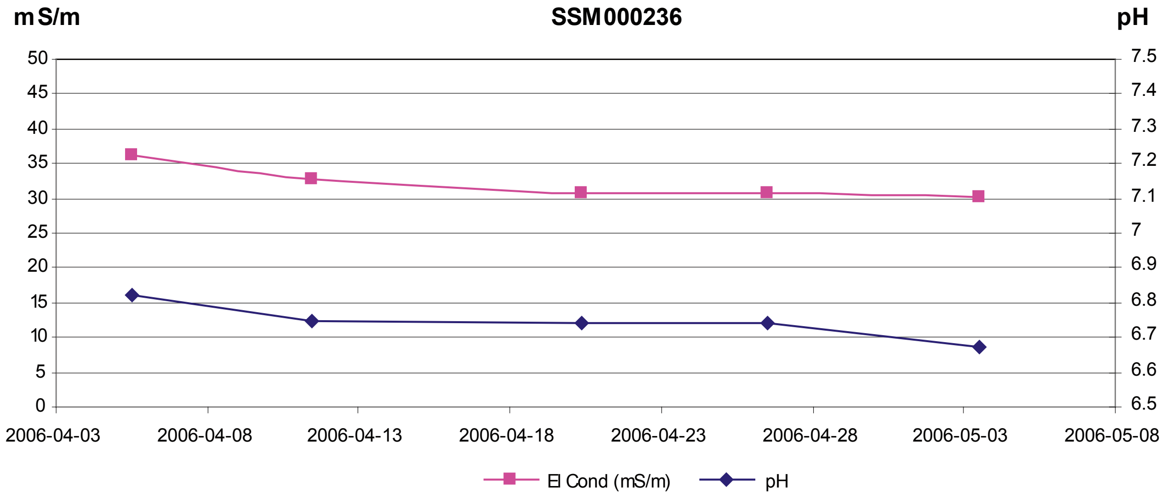


Figure 5-22. *Electrical conductivity and pH in ground water samples from SSM000236.*

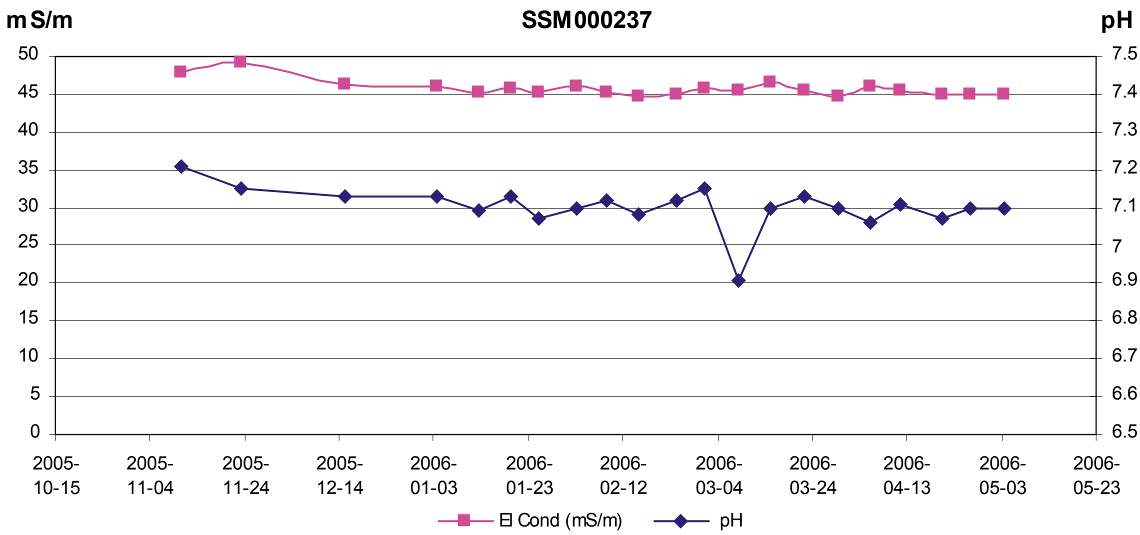


Figure 5-23. *Electrical conductivity and pH in ground water samples from SSM000237.*

6 References

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

/2/ **SKB, 2005.** Platsundersökning Oskarshamn, program för fortsatta undersökningar i mark, vatten och miljö inom delområde Laxemar. SKB R-05-37, Svensk Kärnbränslehantering AB.

/3/ **Moye D G, 1967.** Diamond drilling for foundation exploration, Civil Eng. Trans. Inst. Eng, Australia.

/4/ **Stenberg, Håkanson, 2007.** Revision of borehole deviation measurements in Oskarshamn. SKB P-07-55, Svensk Kärnbränslehantering AB.

/5/ **Ask, Morosini, Samuelsson, Ekström, Håkanson, 2007.** Drilling of cored borehole KLX11A. SKB P-06-306, Svensk Kärnbränslehantering AB.

/6/ **Rauséus, Ehrenborg, 2006.** Boremap mapping of core drilled borehole KLX20A. SKB P-06-241, Svensk Kärnbränslehantering AB.

/7/ **Ask, Morosini, Samuelsson, Ekström, Håkanson, 2004.** Core drilling of KSH03. SKB P-04-233, Svensk Kärnbränslehantering AB.

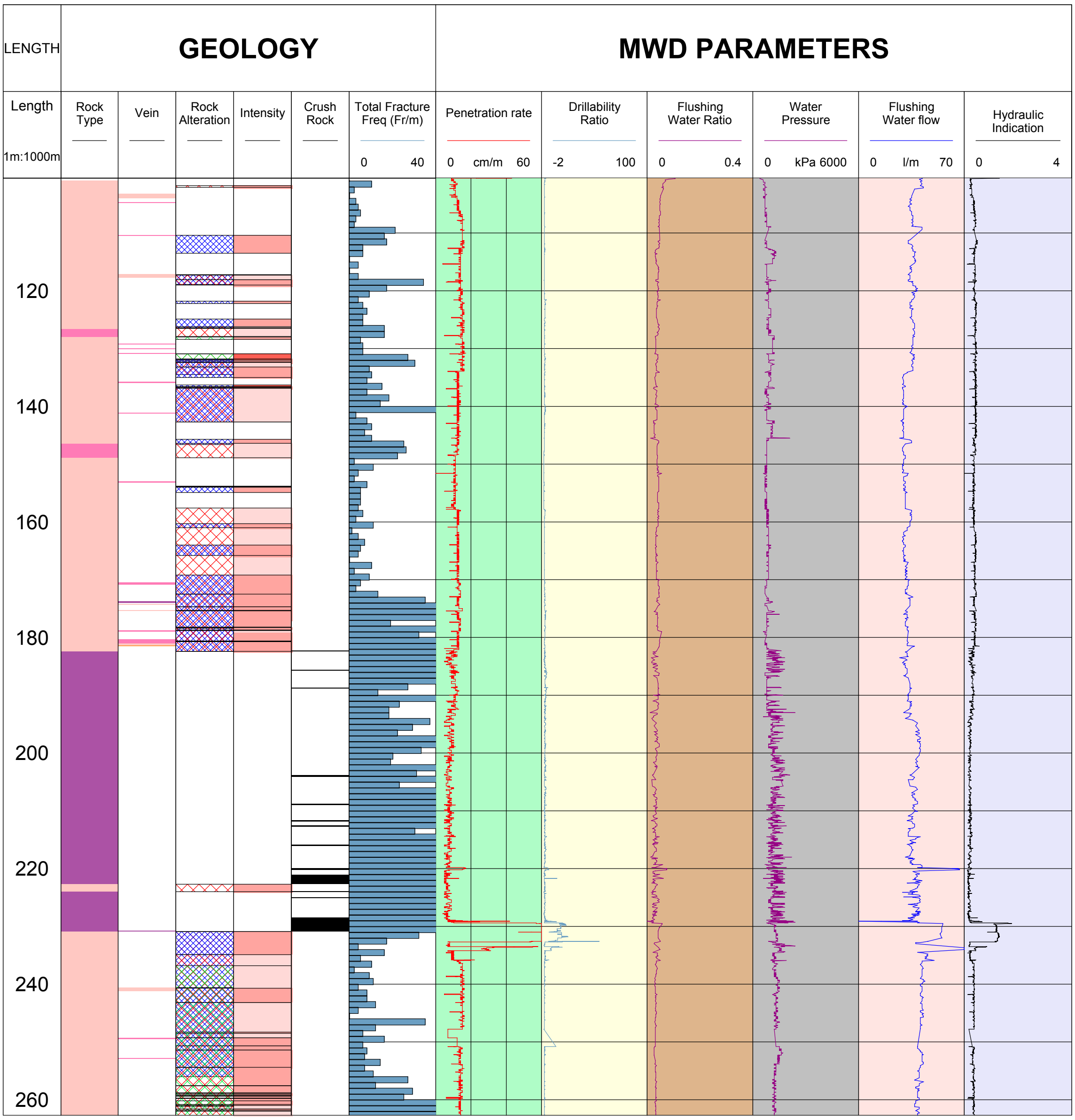
Title **GEOLOGY & MWD PARAMETERS KLX20A** Appendix 1

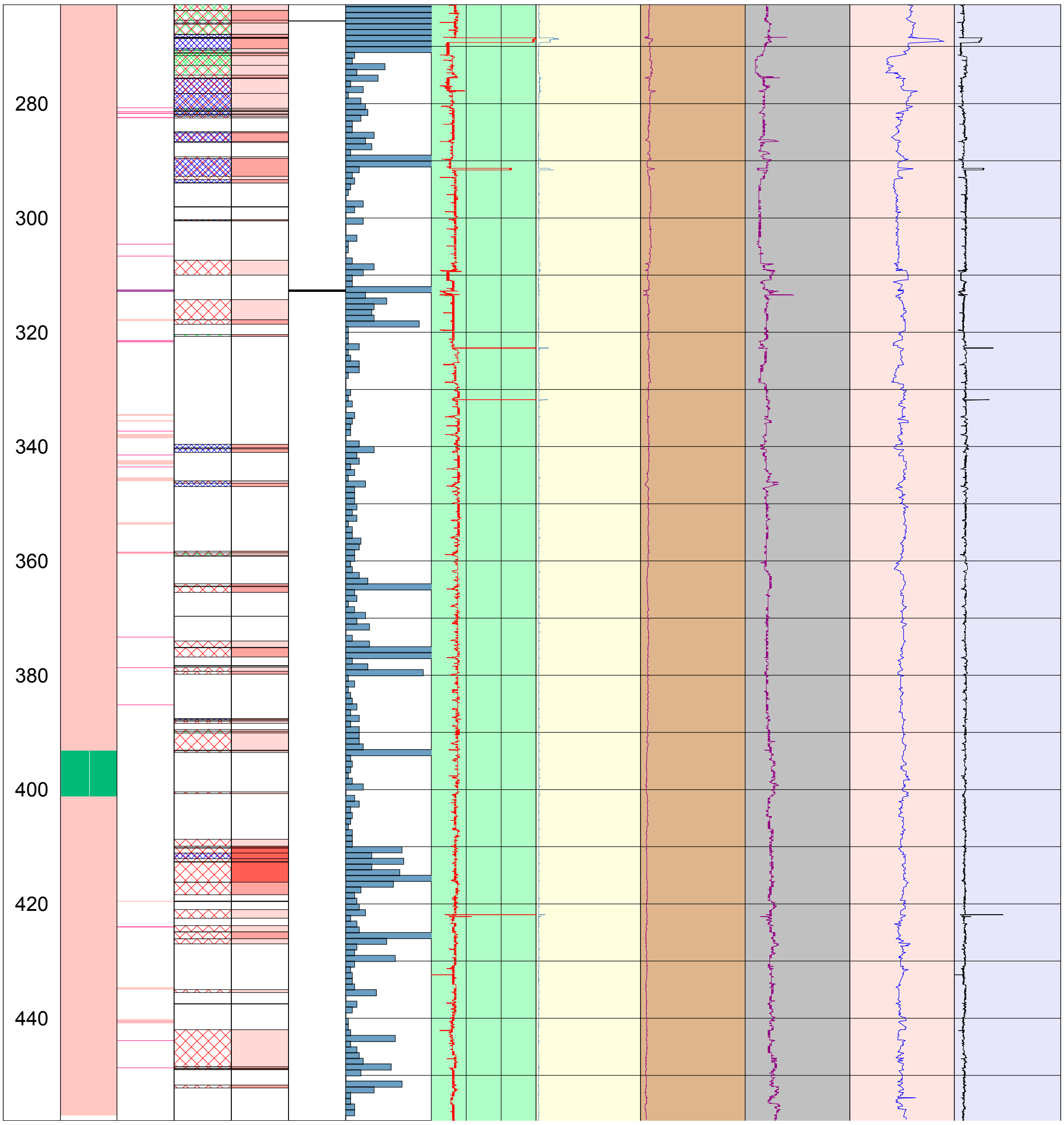
Site	LAXEMAR	**Coordinate System**	RT90-RHB70
Borehole	KLX20A	**Northing [m]**	6366334.57
Diameter [mm]	76	**Easting [m]**	1546604.89
Length [m]	457.920	**Elevation [m.a.s.l.]**	27.24
Bearing [°]	270.60	**Drilling Start Date**	2006-02-22 13:30:00
Inclination [°]	-50.02	**Drilling Stop Date**	2006-04-24 13:20:00
Date of mapping	2006-05-29 08:59:00	**Plot Date**	2007-06-03 23:15:13

ROCKTYPE LAXEMAR
- Dolerite
- Fine-grained granite
- Quartz monzodiorite
- Fine-grained diorite-gabbro

ROCK ALTERATION
- Oxidized
- Epidotisized
- Quartz dissolution
- Silicification
- Albitization
- Saussuritization

INTENSITY
- Faint
- Weak
- Medium




280
300
320
340
360
380
400
420
440

Appendix 2

Chemical results

Borehole	KLX20A	KLX20A	HLX28
Date of measurement	2006-04-03	2006-04-17	2006-03-10
Upper section limit (m)	101.60	193.00	6.03
Lower section limit (m)	194.65	291.17	154.20
Sample_no	10949	10983	10872
Groundwater Chemistry Class	3	3	5
pH	8.50	8.11	8.10
Conductivity mS/m	41.9	123.0	64.4
Drill water %	0.98	2.94	xx
Density g/ml	0.9975	0.9976	0.9968
Charge balance %	–2.85	–2.61	–2,23
Na mg/l	79.2	214.0	115.0
K mg/l	2.47	3.27	3.35
Ca mg/l	8.1	22.6	15.1
Mg mg/l	2.1	3.6	4.8
HCO3 mg/l Alkalinity	218	169	248
Cl mg/l	11.5	281.0	39.3
SO4 mg/l	8.95	22.30	51.90
SO4_S mg/l Total Sulphur	3.21	7.81	18.50
Br mg/l	< 0.2	1.280	< 0.2
F mg/l	4.39	4.11	3.72
Si mg/l	6.38	5.86	7.10
Fe mg/l Total Iron	5.8500	4.2500	0.0892
Mn mg/l	0.0917	0.1470	0.0780
Li mg/l	0.009	0.022	0.012
Sr mg/l	0.109	0.371	0.180
TOC mg/l	xx	xx	5.5
PMC % Modern Carbon	45.45	xx	xx
C-13 dev PDB	–16.96	xx	xx
AGE_BP Groundwater age	6,279	xx	xx
AGE_BP_CORR	35	xx	xx
D dev SMOW	–77.3	xx	xx
Tr TU	–0.80	xx	xx
O-18 dev SMOW	–10.80	xx	xx
B-10 B-10/B-11	0.2383	xx	xx
S-34 dev SMOW	28.4	xx	xx
Cl-37 dev SMOC	0.21	xx	xx
Sr-87 Sr-87/Sr86	0.716224	xx	xx

xx=not analysed

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 st 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 set of data from borehole KLX20A and the water source HLX28. The errors do not exceed ± 5 % in any of the samples.

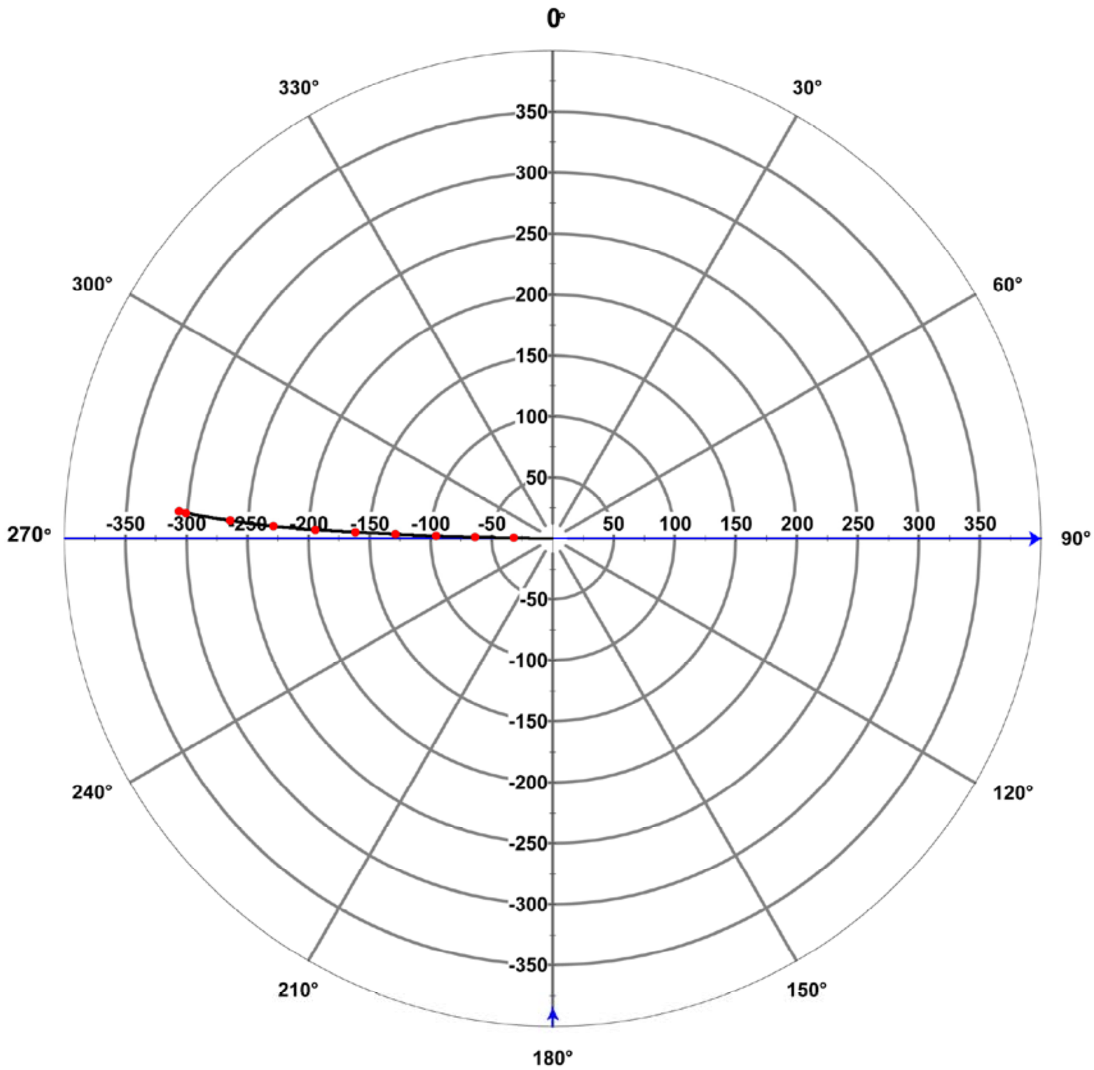
The following routines for quality control and data management are generally applied for hydrogeochemical analysis data, independent of sampling method or sampling object.

- 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 KLX20A and HLX28.
- All analytical results were stored in the SICADA database. The chemistry part of the database contains two types of tables, raw data tables and primary data tables (final data tables).
- Data on basic water analyses are inserted into raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample. These data sets are compiled in a primary data table named "water composition". The evaluation is based on:
  - Comparison of the results from different laboratories and/or methods. The analyses are repeated if a large disparity is noted (generally more than 10 %).
  - Calculation of charge balance errors. Relative errors within ± 5 % are considered acceptable. For surface waters errors of ± 10 %.
  - Rel. Error (%) = $100 \times \frac{(\sum \text{cations(equivalents)} - \sum \text{anions(equivalents)})}{(\sum \text{cations(equivalents)} + \sum \text{anions(equivalents)})}$
  - General expert judgement of plausibility based on earlier results and experiences.

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

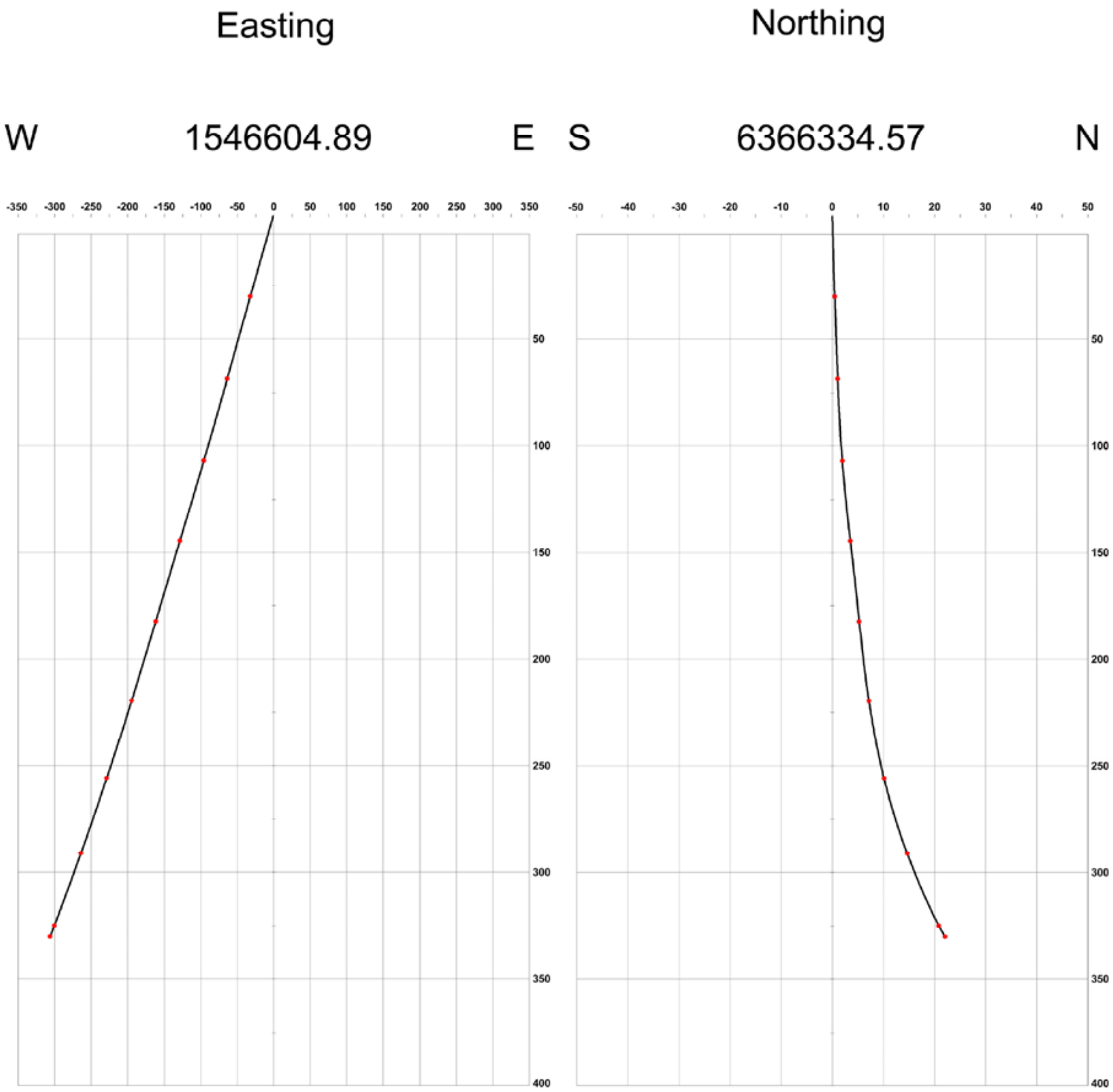
Appendix 4

Deviation measurement KLX20A		Appendix: 4
SKB	Site LAXEMAR Borehole KLX20A View from above	



Deviation measurement KLX20A	Appendix: 4

Site LAXEMAR
Borehole KLX20A
Vertical Section

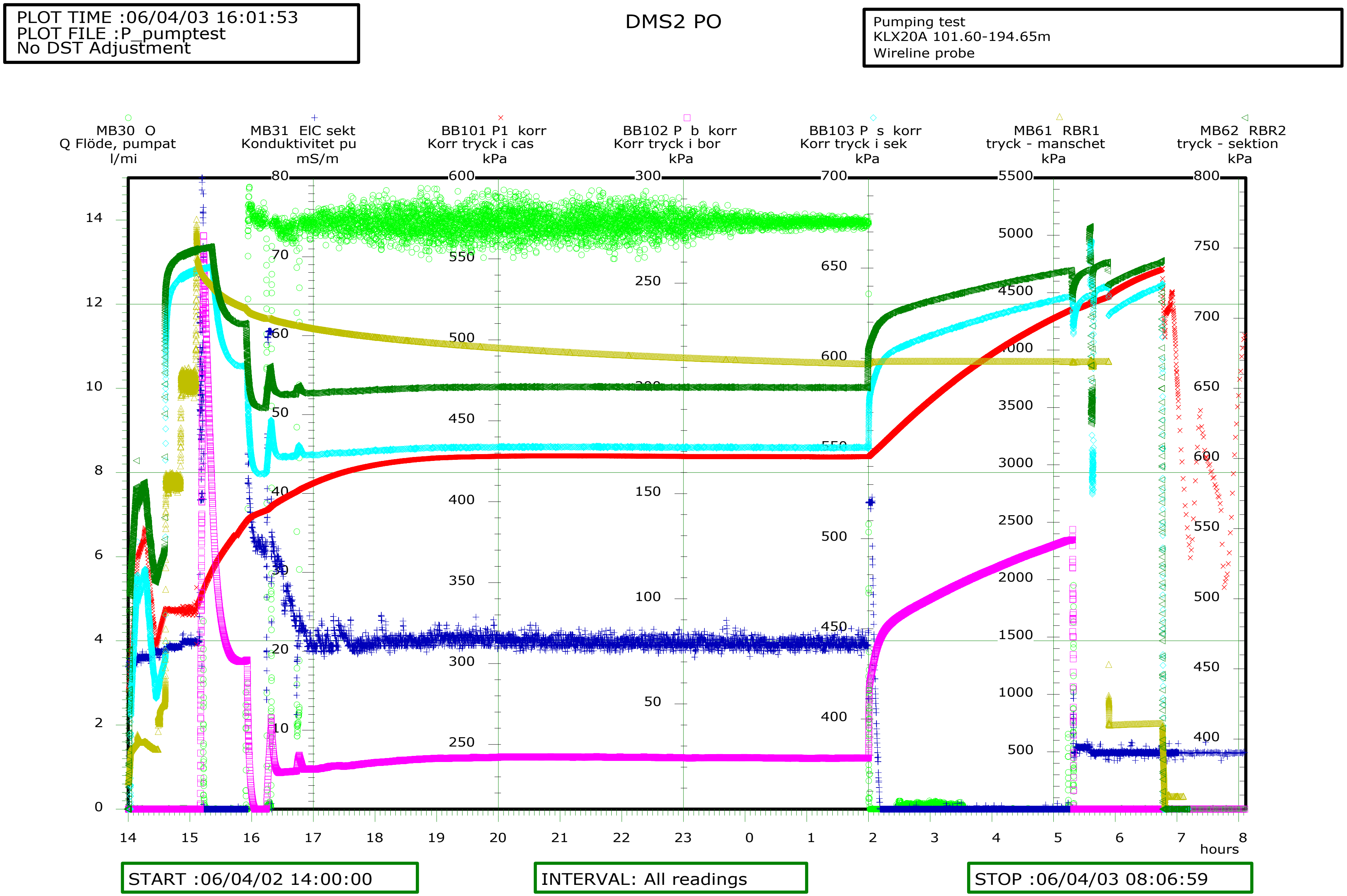


Appendix 5

Wireline pumping tests

Description of the parameters in the enclosed plots

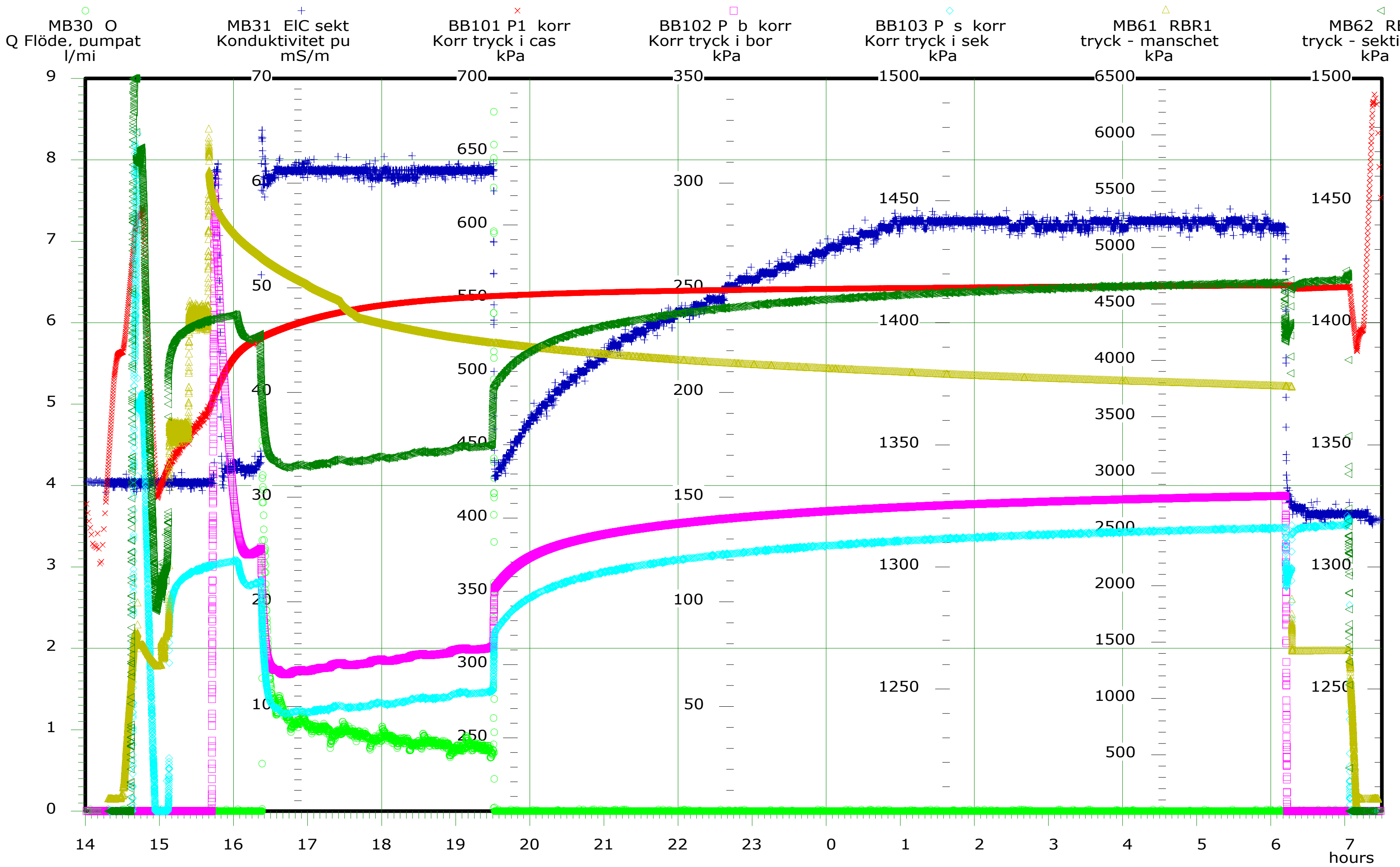
Channel	Parameter	Unit	Description
MB30	Water flow	Litre/minute	Flow of water pumped up from the borehole during the test.
MB31	Electrical conductivity	mS/m	Electrical conductivity in the pumped out water
BB101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient 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


PLOT TIME :06/04/03 16:01:53
PLOT FILE :P_pumptest
No DST Adjustment
DMS2 PO
Pumping test
KLX20A 101.60-194.65m
Wireline probe
MB30 O
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
0 2 4 6 8 10 12 14
10 20 30 40 50 60 70 80
250 300 350 400 450 500 550 600
50 100 150 200 250 300
400 450 500 550 600 650 700
500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500
400 450 500 550 600 650 700 750 800
14 15 16 17 18 19 20 21 22 23 0 1 2 3 4 5 6 7 8
hours
START :06/04/02 14:00:00
INTERVAL: All readings
STOP :06/04/03 08:06:59

PLOT TIME :06/04/26 09:51:55
PLOT FILE :P_pumptest
Adjusted for DST

DMS2 PO

Pumping test
KLX20A 189.65-331.80m
Wireline probe



START :06/04/19 14:00:00

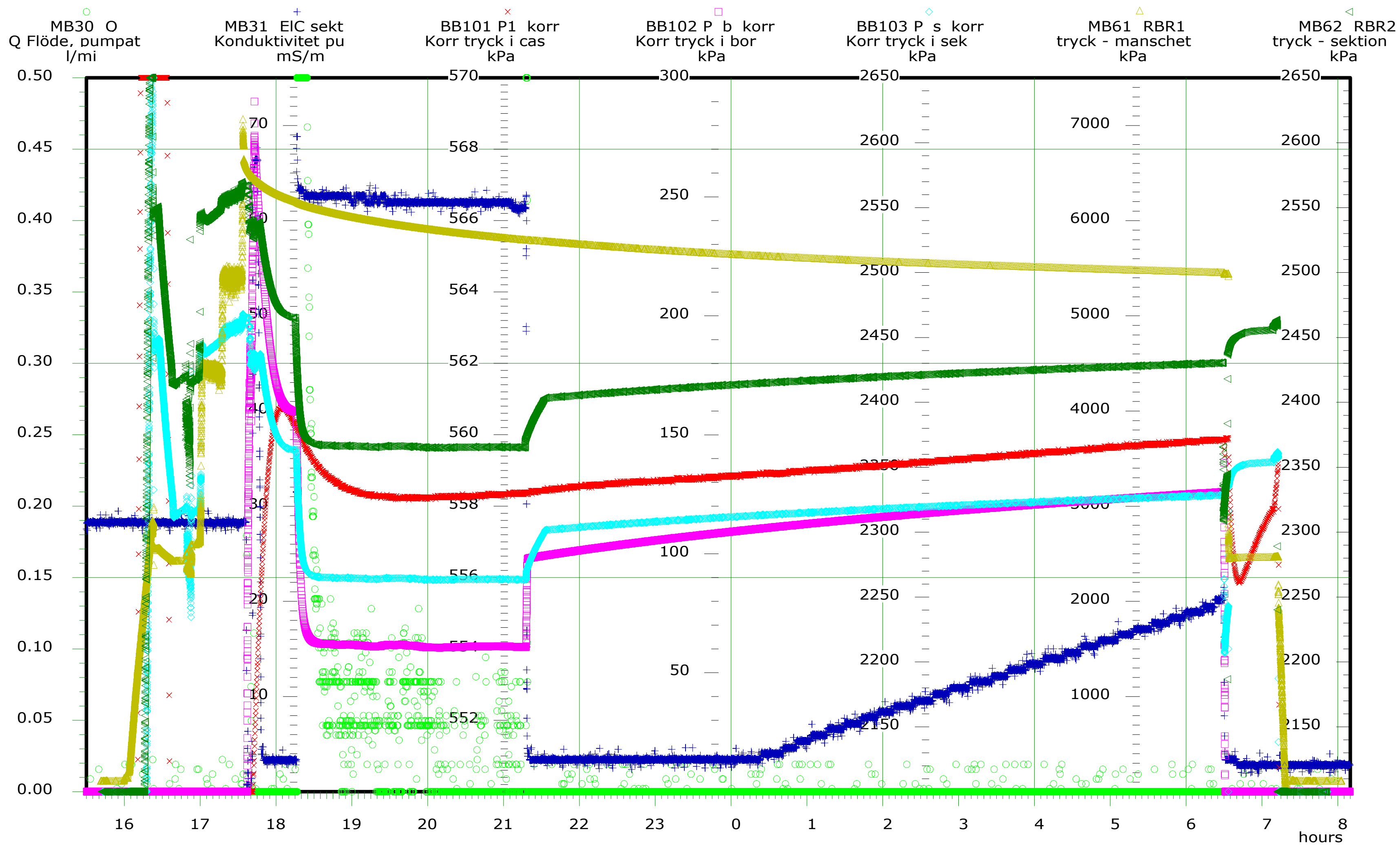
INTERVAL: All readings

STOP :06/04/20 07:29:59

PLOT TIME :06/04/26 13:13:13
PLOT FILE :P_pumptest
Adjusted for DST

DMS2 PO

Pumping test
KLX20A 331.00-457.92m
Wireline probe



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INTERVAL: All readings

STOP :06/04/26 08:09:59