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Oskarshamn site investigation

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May 2007

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Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

Abstract

Borehole KLX12A is located in the Laxemar subarea. Drilling was made between October, 2005 and March 2006 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden.

KLX12A was core drilled to a length of 602.29 metres with N-size (76 mm) equipment. The uppermost section, to the length of 100.57 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.

Three pumping tests were performed in KLX12A with wireline equipment. The resulting transmissivities (T_M) varied between $2.6 \cdot 10^{-7}$ and $1.5 \cdot 10^{-6}$ m^2/s. The most transmissive section was between 198 and 302 metres.

Continuous monitoring of drilling parameters and flushing water parameters with the drilling monitoring system was conducted throughout the core drilling phase in KLX12A.

Rock stress measurements with the overcoring method were done in three intervals. The stress state in borehole KLX12A was characterized by low to medium horizontal stress at the first interval of measurement (ca 225 m). The stress level was medium in the second interval (ca 350 m). The direction of the principal stress in the first and second measurement intervals were ENE to WSW. The third measurement interval showed medium to high stress with a slight shift of the horizontal stress direction compared to the first two intervals.

One water sample for chemical analysis was collected during the core drilling of KLX12A.

An air-lift pumping test in the telescopic section performed when borehole KLX12A was core drilled to its full length gave a transmissivity (T_M) of $8.4 \cdot 10^{-6}$ m^2/s.

Lithologically the core is dominated by Ävrö granite to ca 420 m. From 420 m to ca 525 m the core consists almost entirely of diorite-gabbro. Beneath 525 m the dominant rock type is quartz monzodiorite.

Red staining with weak to medium intensity occurs sporadically to ca 400 m. Below 400 m length the presence of red staining is very rare. 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 2.4 (fractures/metre).

Sammanfattning

Borrhål KLX12A ligger inom delområde Laxemar. Borrningen utfördes mellan oktober 2005 och mars 2006 som ett led i platsundersökningen för ett möjligt djupförvar för använt kärnbränsle i Oskarshamns kommun.

KLX12A kärnborrades med borrstorlek N (76 mm) till 602,29 meters borrad längd. Den övre delen av hålet, från markytan till 100,57 meter, utfördes som en teleskopdel med ca 200 mm inre diameter.

Inget vatteninflöde kunde uppmätas över hela teleskopdelen vid hammarborrningen.

Tre pumptester med wireline-baserad mätutrustning utfördes. De uppmätta transmissiviteterna (T_M) varierade mellan $2{,}6 \cdot 10^{-7}$ och $1{,}5 \cdot 10^{-6}$ m^2/s. Den mest transmissiva sektionen var mellan 198 och 302 meter.

Kontinuerliga mätningar av borrningsparametrar och spolvattenparametrar via DMS (**d**rilling **m**onitoring **s**ystem) gjordes under hela kärnborrningsfasen i KLX12A.

Bergspänningsmätningar med överborrningsmetoden gjordes i tre intervall. Spänningsförhållandena i borrhål KLX12A kännetecknas av låga till måttliga horisontella spänningar i det första mätintervallet (ca 225 m). Spänningarna var måttliga i det andra mätintervallet (ca 350 m). Riktningen på huvudspänningen i det första och andra mätintervallet var ÖNÖ till VSV. Det tredje mätintervallet uppvisade måttliga till höga spänningar med en vridning av uppmätta horisontalspänningar i förhållande till de första två mätintervallen.

Ett vattenprov för kemisk analysering togs i samband med borrning i KLX12A.

En mammutpumpning i teleskopdelen som gjordes när kärnborrningen i KLX12A utförts till full längd gav en transmissivitet (T_M) på $8{,}4 \cdot 10^{-6}$ m^2/s.

Litologiskt domineras kärnan av Ävrögranit till ca 420 m. Från 420 m till ca 525 m består kärnan nästan helt av diorit-gabbro. Under 525 m är kvartsmonzodiorit den dominerande bergarten.

Rödfärgning med svag till måttlig intensitet förekommer sporadiskt ner till borrad längd 400 m. Nedanför 400 m är förekomsten av rödfärgning mycket sällsynt. Sektioner med rödfärgning är angivna som ”oxiderade” i Bilaga 1.

Den genomsnittliga sprickfrekvensen över hela borrkärnan uttryckt som öppna sprickor är 2,4 (sprickor/meter).

Contents

1 Introduction

SKB, the Swedish Nuclear Fuel & Waste Management Company, performs site investigations in order to evaluate the feasibility of locating a deep repository for spent nuclear fuel /1/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. Borehole KLX12A 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. KLX12A was the fourteenth deep cored borehole within the Oskarshamn site investigation. The location of the core drilled borehole and the water source, HLX10 in the Laxemar subarea is shown in Figure 1-1.

The drilling of KLX12A and all related on-site operations were performed according to a specific activity plan (AP PS 400-05-070), which in turn refers to a number of method descriptions, see Table 1-1.

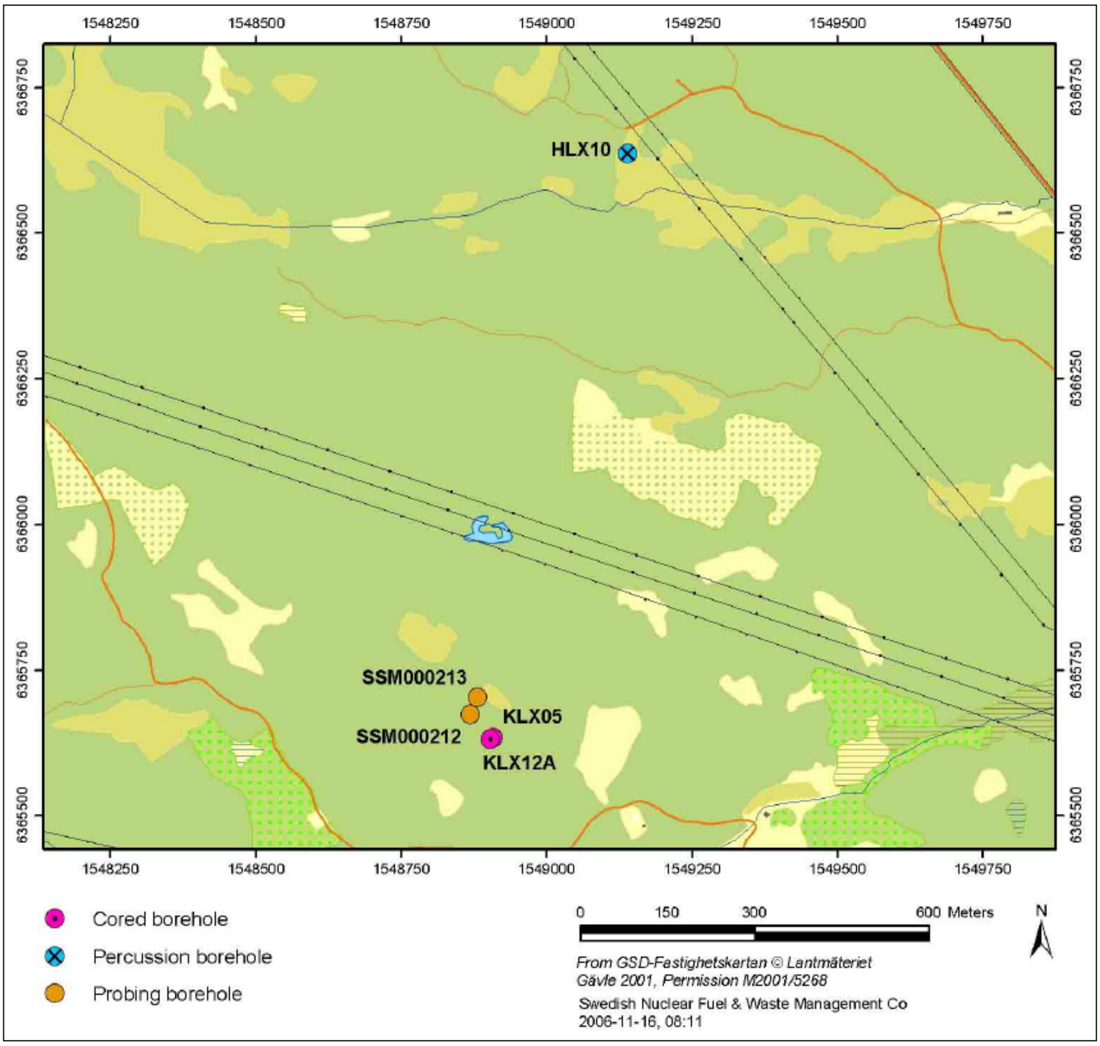


Figure 1-1. *Location of the cored borehole KLX12A and the water source, percussion borehole HLX10 in the Laxemar subarea is shown together with the two environmental monitoring wells SSM000212 and SSM000213. Borehole KLX12A was drilled from the same site as KLX05.*

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

Activity plan	Number	Version
Kärnborrning KLX12A	AP PS 400-05-070	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 pumptest, tryckmätning och vattenprovtagning 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 krökningsmätnign av hammar- och kärnborrhål	SKB MD 224.001	1.0
Instruktion för miljökontroll av ytvattten, ytnära grundvatten och mark vid borrning och pumpning i berg	SKB MD 300.003	2.0
Method description for rock stress measurement with the overcoring method	SKB MD 181.001	1.0

The activity plans and method descriptions are SKB internal documents.

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of borehole KLX12A. A number of related activities, such as wireline hydraulic tests, water sampling and monitoring of drilling parameters that were performed in conjunction with the 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 KLX12A is given in SKB id no 1044814, dated 2005-10-04.

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 KLX12A was drilled from an existing drill site (KLX05), hence no notification to the Regional Authorities was required. Information of the final coordinates and details regarding the return water handling was submitted to the Regional Authorities on 2005-10-04, SKB id no 1044759.

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.

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

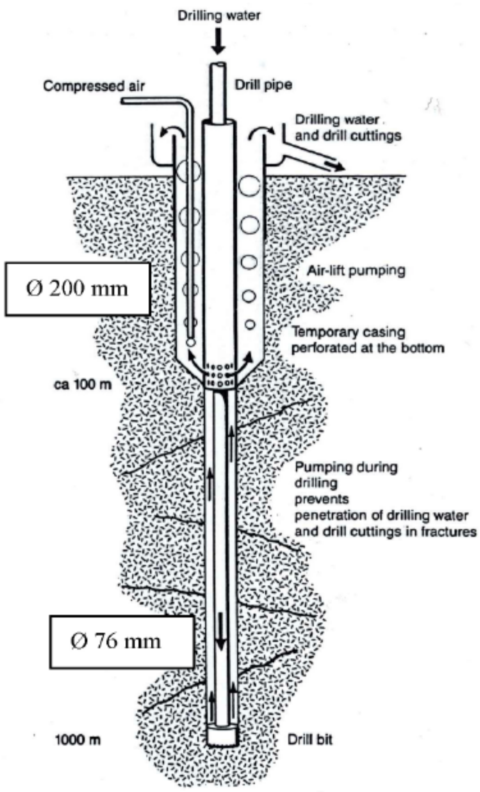


Figure 3-1. A sketch of the telescopic drilling method with air-lift pumping for retrieval of drilling water and cuttings.

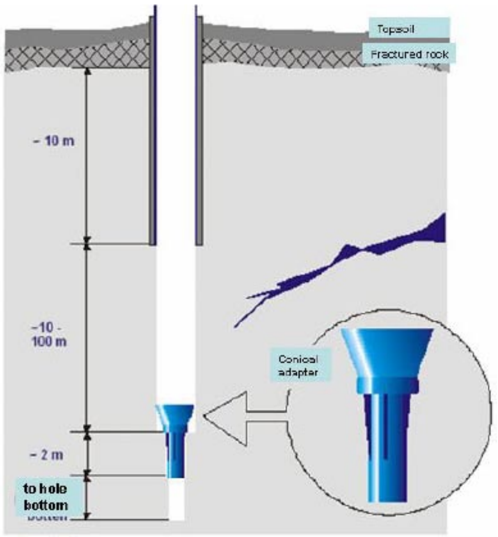


Figure 3-2. *Installation of the conical guide.*

3.1.1 The flushing water system

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

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

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

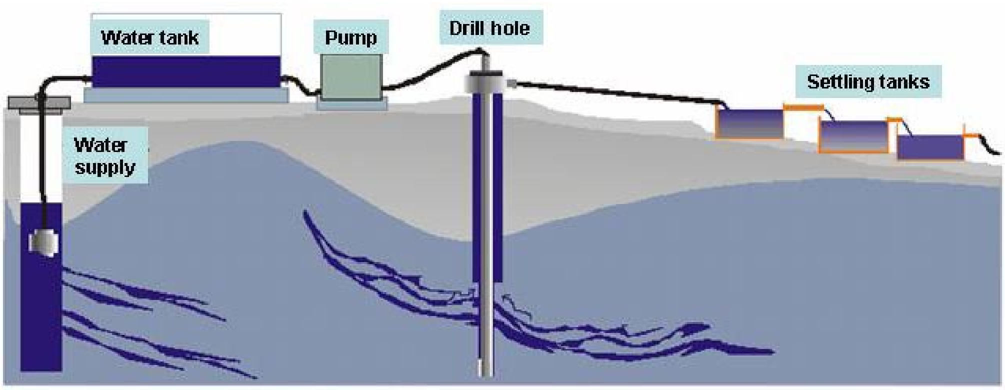


Figure 3-3. *The flushing water system from source to discharge point.*

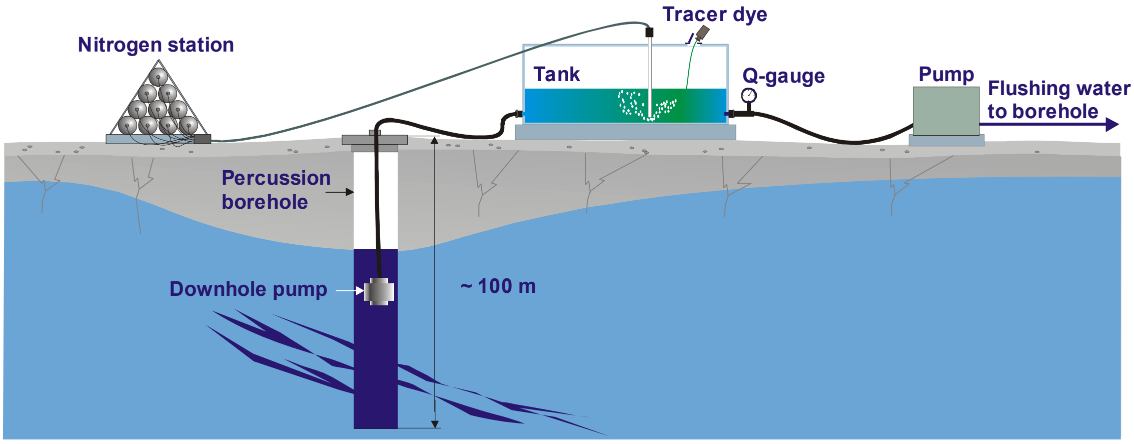


Figure 3-4. *Preparation of flushing water. Uranine is added to the water as a tracer dye. Nitrogen is bubbled through the water to remove dissolved oxygen.*

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 KLX12A consisted of:

- Wireline measurements.
- Rock stress measurements with the overcoring method.
- 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 /2/ 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 discontinued on 2005-10-06 following an internal decision, (SKB id 1044856, internal document).

Overcoring rock stress measurements

Three-dimensional overcoring rock stress measurements are based on measuring strains when a sample of rock is released from the rock mass and the stresses acting upon it. The in situ stresses can be calculated from the measured strains and with knowledge of the elastic properties of the rock. Only a brief account of the methods employed and results obtained will be included in this report as a complete account will be given in a separate report.

Air-lift pumping with evaluation of drawdown

Air-lift pumping with evaluation of drawdown is done with 300 metres 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 **d**rilling **m**onitoring **s**ystem (DMS).

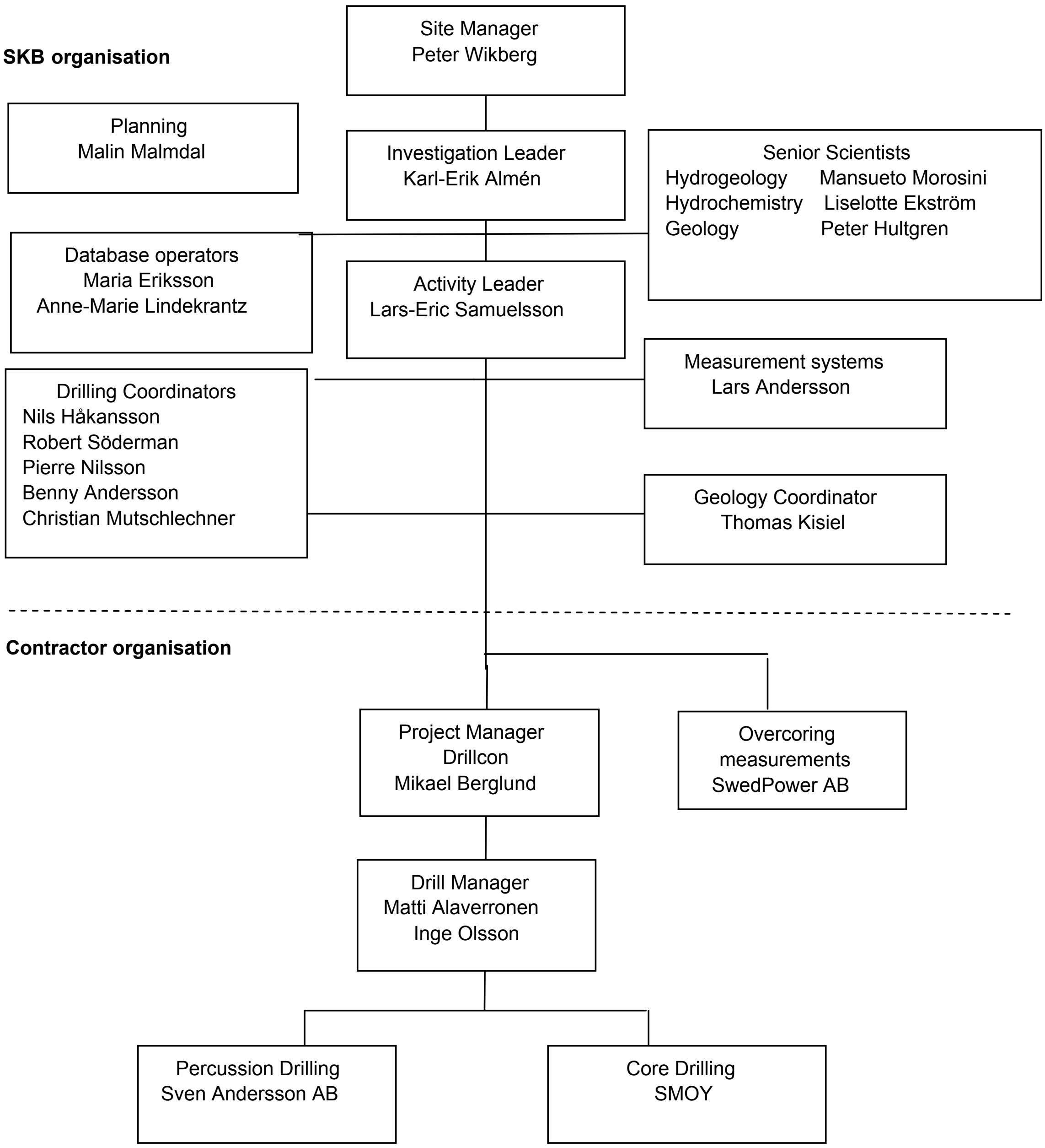
4 Contractors and equipment

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 KLX12A 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 x thickness.

4.3 Core drilling equipment

Core drilling in KLX12A was made with a Diamec B20 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 (75.8 mm) boreholes. Drilling of the directional sections are made with a NQ-size bit giving a core diameter of 48 (47.6) mm.

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 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 deviation measurements.
- 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 Equipment for the Rock Stress measurements

The *Borre* probe is owned and used by Swedpower AB for stress measurements in deep, water-filled boreholes. The equipment for overcoring rock stress measurements using the *Borre* probe comprises:

- pilot hole drilling equipment for wireline core drilling, including a grinding tool for levelling the borehole bottom surface,
- inspection tool (test probe) with built-in borehole cleaning brush,
- *Borre* probe with built-in data logger,
- set of strain gauges (to be mounted on the *Borre* probe),
- glue (for bonding strain gauges to the borehole wall),
- cell adapter (installation tool),
- biaxial test equipment including load cell, pressure gauge, hydraulic pump and strain indicator, and
- portable computer.

Execution of measurements

Overcoring stress measurement using the *Borre* probe involves:

1. Pilot hole drilling and examination.
2. Preparation and installation of the *Borre* probe.
3. Overcoring and recovery of the probe.
4. Biaxial testing of the overcore sample.

The overcoring drilling is done with T-76, i.e. 76 mm diameter, double tube, non-wireline equipment. The resulting over-cored cylinder of rock core has an outer diameter of 62 mm. The procedure for stress measurement using the Borre probe is briefly summarized in Figure 4-1.

4.3.3 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.

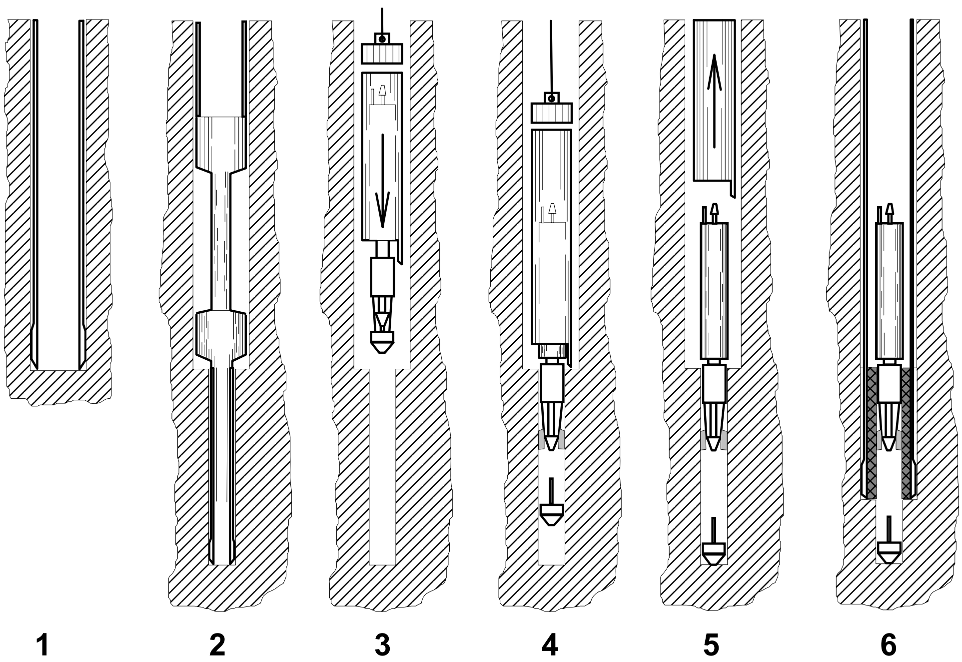


Figure 4-1. *Installation and measurement procedure with the Borre probe:*
1. *Advance 76 mm-diameter main borehole to measurement depth. Levelling the hole bottom using the grinding tool.*
2. *Drill 36 mm-diameter pilot hole and recover core for appraisal. Flush the borehole to remove drill cuttings.*
3. *Prepare the Borre probe for measurement and apply glue to strain gauges. Insert the probe in installation tool into hole.*
4. *Tip of probe with strain gauges enters the pilot hole. Probe releases from installation tool through a latch, which also fixes the compass, thus recording the installed probe orientation. Gauges bonded to pilot hole wall under pressure from the nose cone.*
5. *Allow glue to harden (usually overnight). Pull out installation tool and retrieve to surface. The probe is bonded in place.*
6. *Overcore the Borre probe and record strain data using the built-in data logger. Break the core after completed overcoring and recover in core barrel to surface.*

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 4-2.

Before a pumping test, a leakage test of the drill string is performed.

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 lower end of the drill stem, which is raised from the borehole bottom. 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.

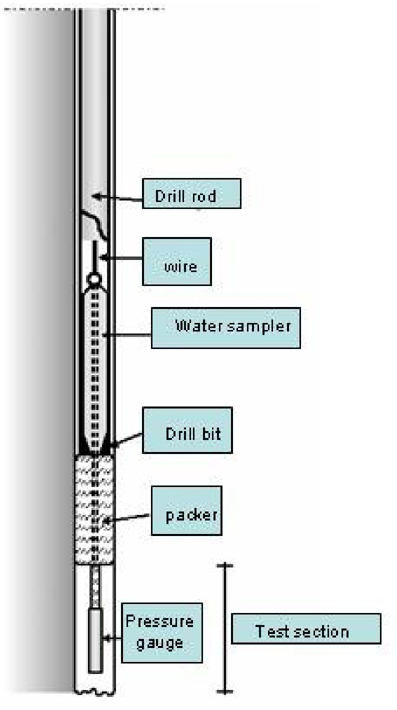


Figure 4-2. *The wireline probe and its emplacement in the hole.*

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 KLX12A.

4.3.4 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).

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.

4.3.5 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 the Flexit method. The Flexit instrument (Flexit SmartTool) is based on magnetometer/accelerometer measurements. Measurements with the Flexit tool were made both up and down the borehole in KLX12A.

4.3.6 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.

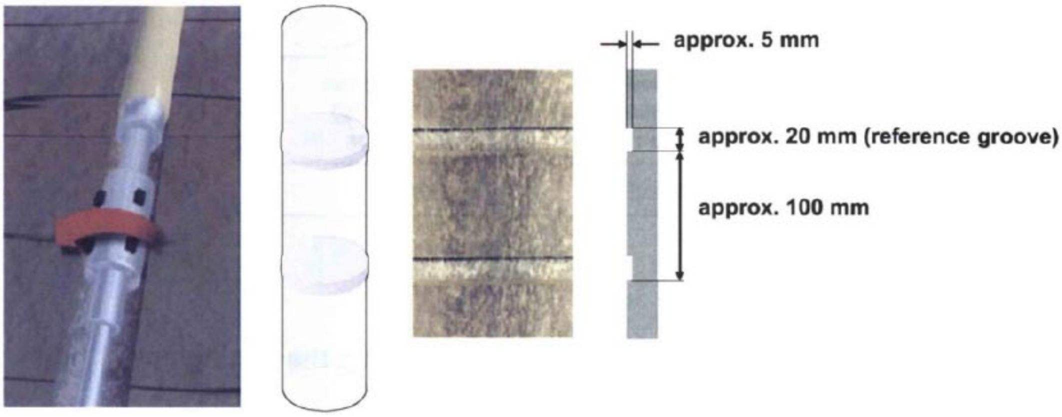


Figure 4-3. *The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.*

5 Execution and results

5.1 Summary of KLX12A drilling

A technical summary of the drilling of KLX12A 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.

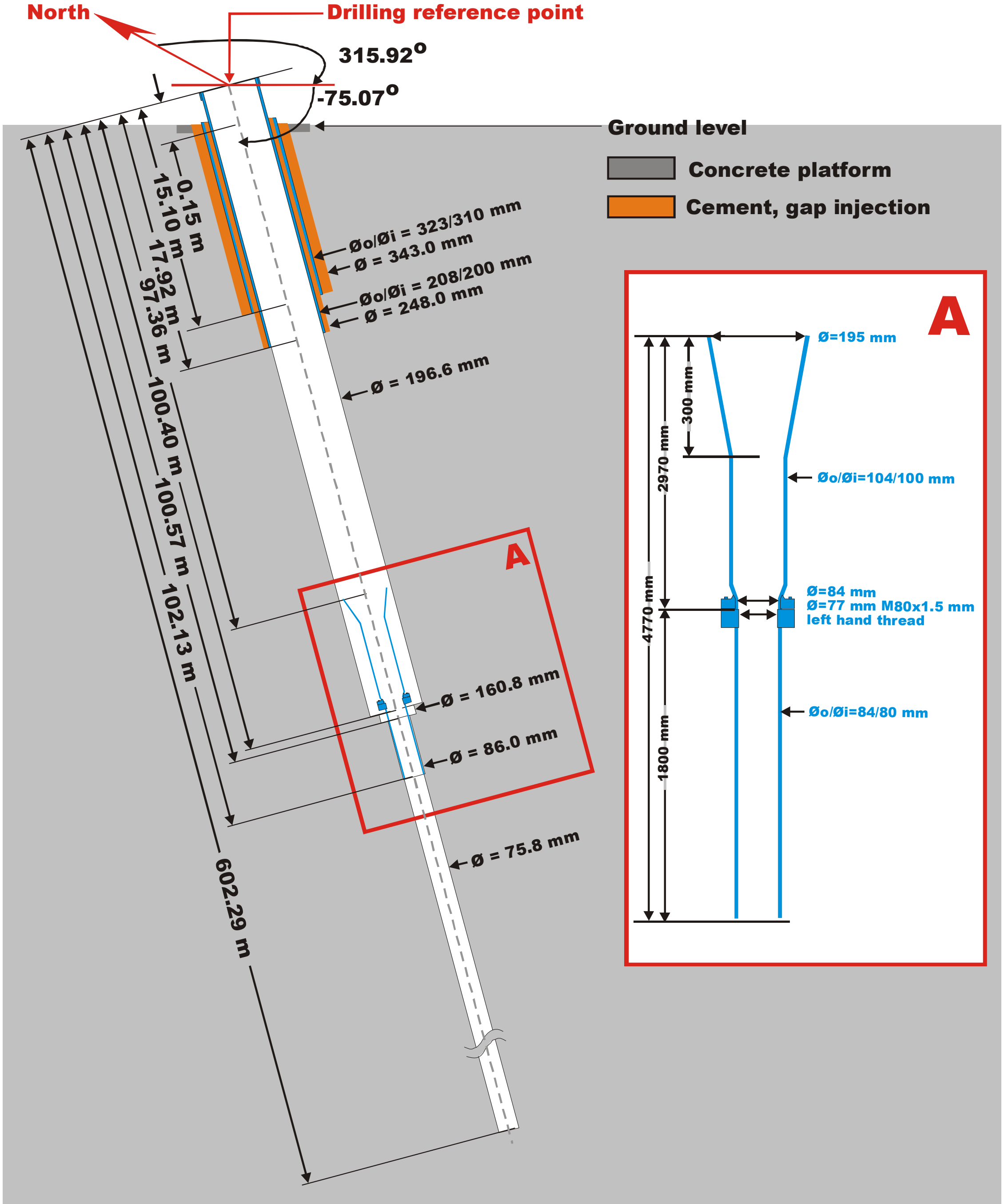
Further descriptions of the percussion drilling of the telescopic section 0–100.57 metres and the measurements performed during this phase are given in section 5.2. The core drilling between 100.57–602.29 metres is further described in section 5.3. Results from hydrogeological and hydrogeochemical measurements 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. KLX12A Technical summary.

General	Technical
Name of hole: KLX12A	*Percussion drill rig* Comacchio MC1500
Location: Laxemar, Oskarshamn Municipality, Sweden	*Percussion hole length* 100.40 m (diam 196.6 mm) 100.57 m (diam 160.8 mm)
Contractor for drilling	
Drillcon AB	*Core drill rig* B20 APC Atlas Copco
Subcontractor percussion drilling	*Core drill dimension* N-size (76 mm)
Sven Andersson AB	*Cored interval* 100.57–602.29 m
Percussion drill start date October 19, 2005	*Diamond bits used* 3
Completion date October 27, 2005	*Average bit life* 167 m
Subcontractor core drilling	*Position KLX12A (RT90 RH70) at top of casing:* N 6365630.78 E 1548904.44 Z 17.74 (m.a.s.l.)
Suomen Malmi OY (SMOY)	*Azimuth (0–360)/Dip (0–90)* 315.92/–75.07
Core drill start date November 10, 2005	*Position KLX12A (RT90 RH70) at 602.29 m length:* N 6365737.27 E 1548778.82 Z –561.39 (m.a.s.l.)
Completion date March 4, 2006	*Azimuth (0–360)/ Dip (0–90)* 307.3/–75.4

Technical data

Borehole KLX12A



Drilling reference point

Northing: 6365630.78 (m), RT90 2,5 gon V 0:-15

Easting: 1548904.44 (m), RT90 2,5 gon V 0:-15

Elevation: 17.74 (m), RHB 70

Drilling period

Drilling start date: 2005-10-19

Drilling stop date: 2006-03-04

Ver 2007-02-15

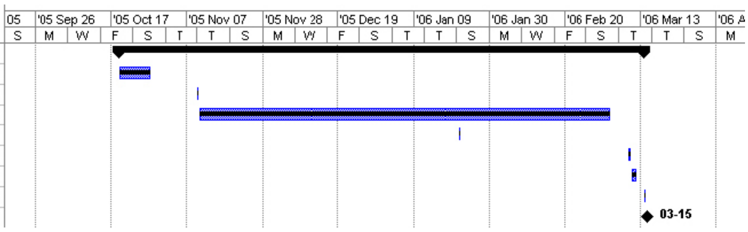
Figure 5-1. Technical data from KLX12A.

Table 5-2. Summary of core drilling progress and borehole measurements in KLX12A.

Bh metres	Drilled length, pumping tests and water sampling	Airlift pumping with valuation of drawdown and/or recoverye	Overcoring	Deviation measurement	Miscellaneous
100				051020 Easy-shot at 97 m Azimuth 306.7 Dip –73.1.	051111 The electrical conductivity (ElC) of the return water was rather high at 150 mS/m.The ElC of the flushing water was 55 mS/m. The pH of the return water was 8.78 on 051112 and 8.33 on 051113.
200	051115 Open hole pumping test 17.92–200.15 m. 5.5 L/min at 19 m drawdown.		Overcoring was made between 224.03–241.95 m	051118 Easy-shot at 210 m Azimuth 305.6 Dip –72.4.	A pumptest failed on 051114. A new test was therefore made on 051115 without the WL-probe, i.e. open hole test. 051207 High values of ElC on the return water were noted. Measurements in lat return water container showed however that the salinity was well below the guideline values for emission to the ground.
300	051206 Pumping test 197.70–302.17 m. 0 L/min at 22 m drawdown. No water sample.			051207 Easy-shot at 290 m Azimuth 301.3 Dip –72.3. 051210 Easy-shot at 318 m Azimuth 303.1 Dip –73.7.	051208 Directional drilling was initiated at 302.17 m. The reason was to increase the dip from 72 to 75 degrees for the forthcoming overcoring.
				051213 Easy-shot at 334 m Azimuth 303.5 Dip –75.5.	051213 Directional drilling was discontinued at 334.81 m.
400			Overcoring was made between 349.94–368.26 m	060121 Easy-shot at 410 m Azimuth 300.9 Dip –75.4.	
	060120 Pumping test 300.00–437.07 m. 0.4 L/min at 15 m drawdown. No water sample.	060121 Airlift pumping 17.92–440.12 m. No drillstem in borehole.			
500			Overcoring was made between 467.14–483.73 m		
600	060306 Pumping test 435.39–602.29 m. 0.3 L/min at 22 m drawdown. No water sample.	060309 Airlift pumping 17.92– 602.29 m. No drillstem in borehole.		060312–14 Final deviation measurements with the Flexit and Maxibor methods were made. These measurements were however not used for calculation the borehole deviation, see section 5.3.3.	060304 KLX12A completed. Length 602.29 m.

Table 5-3. Chronological summary of main drilling events in KLX12A.

ID	Aktivitet	Start
1	**First activity starts**	**Wed 05-10-19**
2	Percussion drilling	Wed 05-10-19
3	Recovery test	Wed 05-11-09
4	Core drilling	Thu 05-11-10
5	Recovery test	Sat 06-01-21
6	Recovery test	Thu 06-03-09
7	Length calibration marks	Fri 06-03-10
8	Maxibor measurement	Tue 06-03-14
9	Last activity ends	Wed 06-03-15



5.2 Drilling, measurements and results in the telescopic section 0–100.57 m

Drilling, reaming and grouting (gap injection) were made from October 19 to 27, 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 (0–100.57 metres) of KLX12A 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 15.10 m length with NO-X 280 mm equipment. This gave a hole diameter of 343 mm and left a casing (323/310 mm diameter) to a length of 15.10 m.
- Inner supportive casing for guidance for the drill string was mounted.
- A pilot percussion hole was drilled to a depth of 100.57 m. The diameter at full length was 160.8 mm.
- Deviation measurement was made with the Easy-shot equipment to 97 m length. A reduction in the dip could be noted.
- Reaming to diameter 248.0 mm was done from 15.10 to 17.92 m.
- Stainless casing of 208·4 mm was installed from 0 to 17.92 m.
- Casing grouting (gap injection) with low alkali cement based concrete (665 litres) was made for both sets of casing. The outer casing was cut along the ground surface.
- After the concrete had hardened, the hole was reamed from 17.92 to 100.40 m. The diameter at full length was 196.6 mm. The borehole 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.

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.

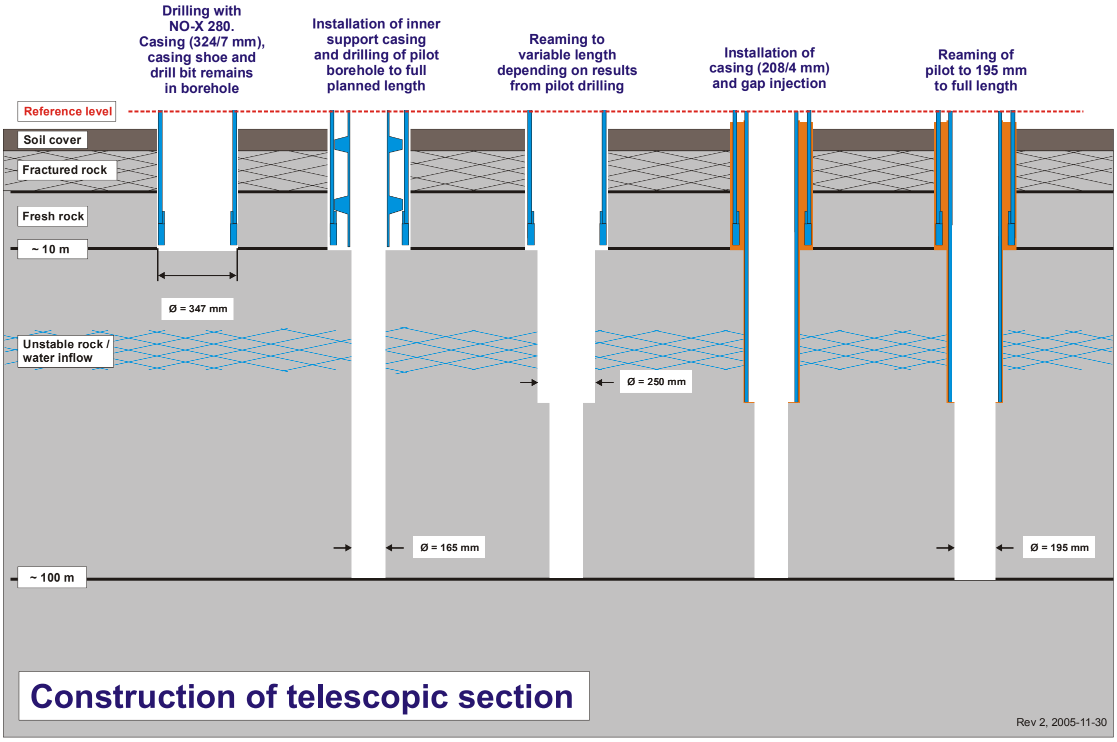


Figure 5-2. *Construction of the telescopic section. The cement for casing grouting is introduced between the casing and the rock wall. The pilot drill bit is placed at the lower level of the casing and acts as a barrier so that cement does not enter the pilot hole.*

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 1.55 m. The soil depth (ground surface to rock) was 1.4 metres.

Hydrogeological observations during percussion drilling

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

5.2.4 Hydrogeological measurements and results in the telescopic section

After percussion drilling of KLX12A, the groundwater table in the borehole was to low for a pumping test to be performed. However, the first pumping test with the wireline probe affected the pressure in casing above the packer. Therefore a pumping test in open borehole without wireline probe was performed in section 17.92–200.15 m. The pumping test was evaluated according to Moye /2/. The results are presented in Table 5-4.

Table 5-4. Results from single-hole pumping test in KLX12A, 17.72–200.15 m.

Tested section [m]	Q/s [m²/s]	T_M [m²/s]	Comments
17.92–200.15	$4.7 \cdot 10^{-6}$	$6.0 \cdot 10^{-6}$	Pumping test without wireline probe

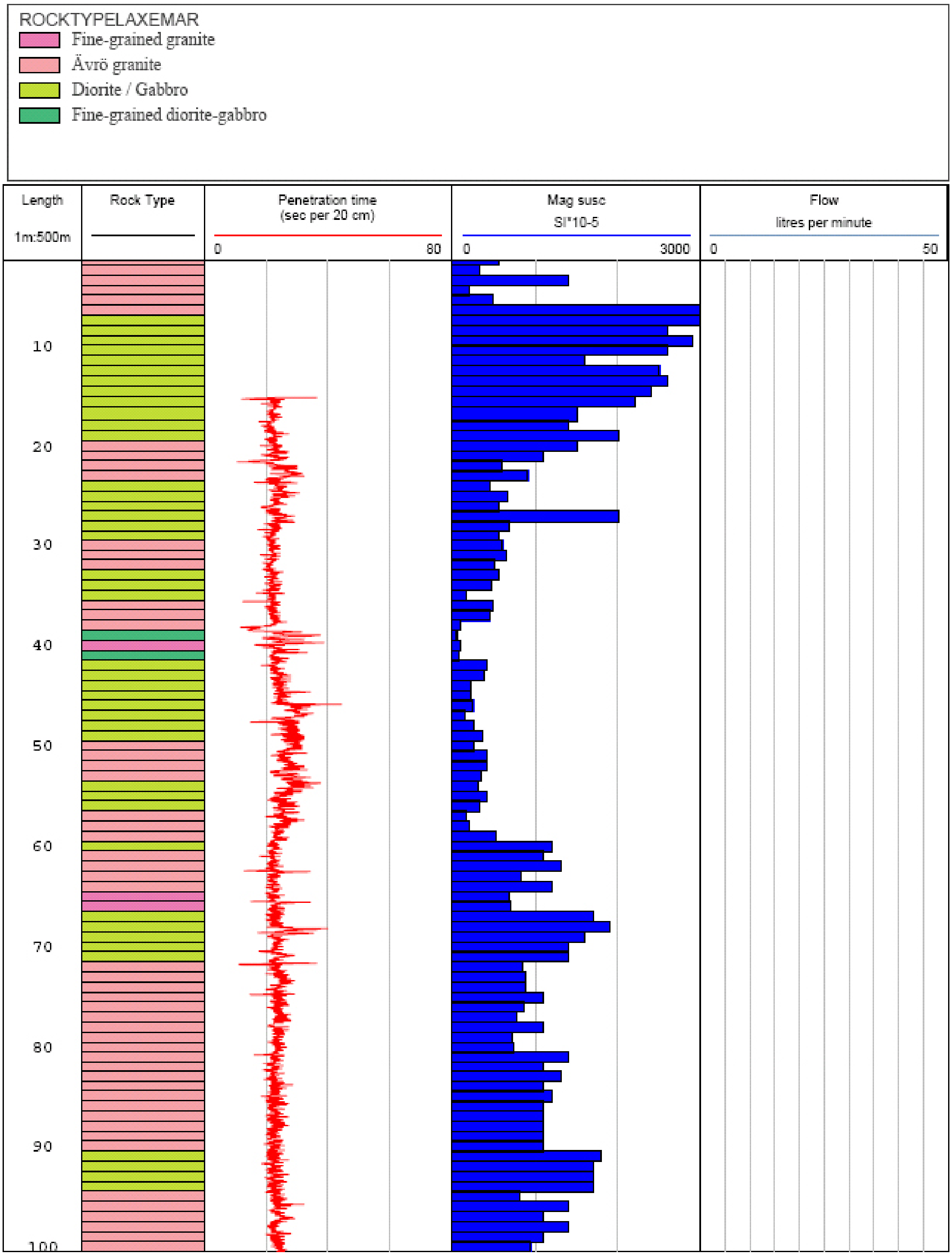


***Figure 5-3.** Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KLX12A.*

5.3 Core drilling KLX12A 100.57–602.29 m

Core drilling in KLX12A was conducted between November 10, 2005 and March 4, 2006.

The main work in KLX12A after drilling the telescopic section consisted of the following steps:

- preparations for core drilling,
- flushing and return water handling,
- core drilling including overcoring for rock stress measurements, 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 sections 5.4 and 5.5.

5.3.1 Preparations

The preparations for core drilling started on November 4, 2005 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 supports 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 100.57 and 101.12 m with T-86 equipment. An inner supportive casing with diameter 84/77 mm was installed to 101.12 m.

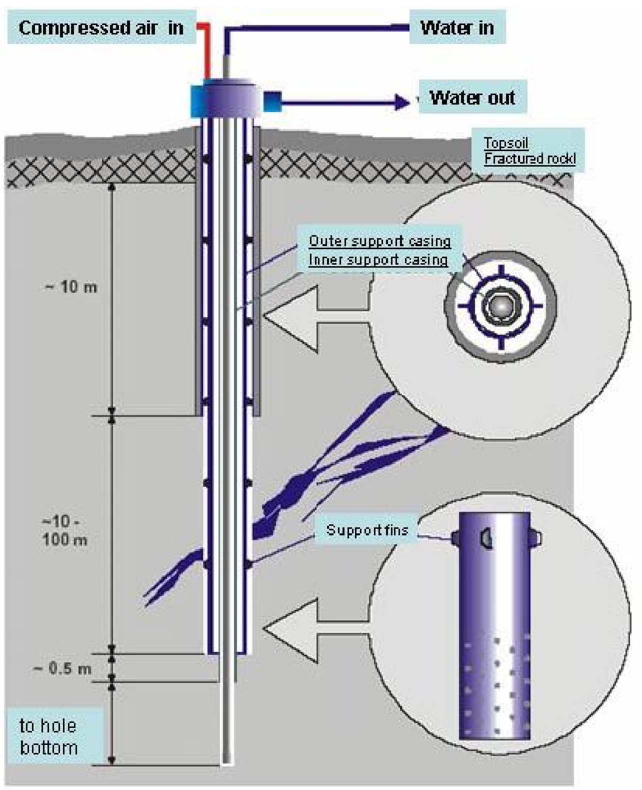


Figure 5-4. *In the telescopic part of the drill hole a temporary installation is made with casing tubes for support and alignment and equipment for air-lift pumping. In the uppermost part the return water discharge header is mounted. The water discharge is led to the settling containers.*

The supportive casings have a perforated section between 99.20 and 99.60 metres length for the return water from the borehole, 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 HLX10, see also sections 5.4.2 and 5.5. The location of the water source, borehole HLX10 is shown 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 KLX12A is shown in Figure 5-5.

The targeted content for uranine in the flushing water is 0.20 mg/L and the actual average uranine content was 0.196 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.

5.3.3 Drilling, directional drilling and deviation measurements KLX12A

Core drilling with N-size (76 mm) triple-tube, wireline equipment was conducted from 101.12 m to the final length of 602.29 m in KLX12A. The Rock Stress measurements were done along three intervals as given in Table 5-5.

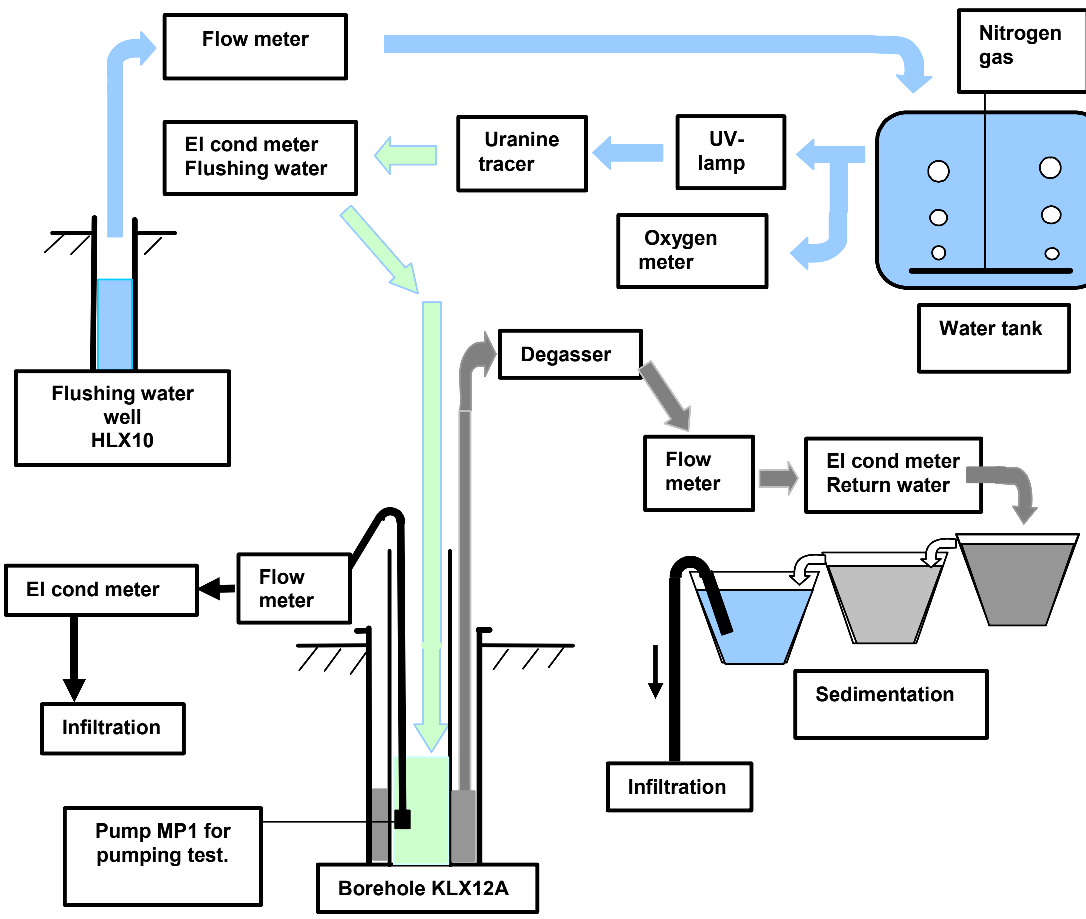


Figure 5-5. The flushing and return water handling and the emplacement of related monitoring equipment in KLX12A.

Directional drilling in KLX12A was done between 302.17 and 334.81 metres in order to increase the dip of the borehole for forthcoming rock stress measurements with the overcoring method at deeper levels. When directional drilling was started the dip of the borehole was 72°. At the end of the directional drilling the dip of the borehole was 75°, see Table 5-2.

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

Measurements of borehole deviation are made for two purposes:

- Monitoring of drilling progress, typically every hundred metres of drilled length.
- Measurements at full drilled length for final calculation of borehole deviation.

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

Two individual measurements were done with the Flexit method for the final evaluation of the borehole deviation in KLX12A. The Flexit tool was run both up and down the borehole from 0 to 597 metres. In KLX12A the final deviation file is calculated based on the measurements given in Table 5-6 together with the surveyed bearing and inclination of the top-of-casing. Further comment on how method and calculation of deviation measurements are given in /3/.

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

Core diameter (mm)	Borehole diameter (mm)	Interval (m drilled length)	Drilling dimension or directional drilling method	Comment
72.0	86	100.57–102.13	T-86	
50.2	86	101.12–102.13	N and T-86	The interval was reamed from 101.12 to 102.13 m after core drilling to full drilled length, see also section 5.3.5. ”Borehole wall risk assessment, stabilisation and completion”.
50.2	76	102.13–224.03	N	
50.2 and 62	76	224.03–241.95	N and T-76	Interval with overcoring measurements. Several minor core losses incurred by the overcoring measurements exist.
50.2	76	241.95–302.17	N	
50.2 and 47.6	76	302.17–334.81	N and Liwinstone N	Directional drilling was made in six intervals.
50.2	76	334.81–349.94	N	
50.2 and 62	76	349.94–386.26	N and T-76	Interval with overcoring measurements. Several minor core losses incurred by the overcoring measurements exist.
50.2	76	368.26–467.14	N	
50.2 and 62	76	467.14–483.73	N and T-76	Interval with overcoring measurements. Several minor core losses incurred by the overcoring measurements exist.
50.2	76	483.73–602.29	N	

Table 5-6 Measurements used for borehole deviation calculation in KLX12A.

Deviation measurement method	Used for calculation of bearing/inclination	Interval from (m)	Interval to (m)	Sicada database activity ID
Flexit	bearing	33	81	13141778
Flexit	bearing	33	81	13141808
Flexit	bearing	117	597	13141778
Flexit	bearing	117	597	13141808
Flexit	inclination	3	597	13141778
Flexit	inclination	6	597	13141808

Horizontal and vertical plots of the results of the calculated deviation covering the entire length of borehole KLX12A are given in Appendix 4.

Core losses were noted in the Boremap mapping, see section 5.6, at the intervals given in Table 5-7. All core losses are related to grinding in conjunction with overcoring for rock stress measurements.

Table 5-7. Core losses noted in KLX12A.

From (m)	To (m)	Missing piece length (m)	Overcoring level
225.34	225.42	0.09	1
226.29	226.33	0.04	1
226.63	226.74	0.11	1
226.74	226.87	0.13	1
228.78	228.84	0.06	1
229.84	229.89	0.05	1
230.99	231.15	0.16	1
232.00	232.18	0.18	1
233.17	233.24	0.07	1
235.70	235.96	0.26	1
235.96	236.08	0.12	1
236.99	237.11	0.12	1
238.84	238.87	0.03	1
239.10	239.16	0.06	1
241.84	241.89	0.05	1
343.95	344.02	0.07	2
346.62	346.66	0.04	2
346.66	346.70	0.04	2
348.23	348.34	0.11	2
349.82	349.90	0.08	2
350.89	351.04	0.15	2
352.03	352.13	0.10	2
353.63	353.86	0.23	2
354.86	355.01	0.16	2
356.01	356.09	0.08	2
357.13	357.17	0.04	2
358.14	358.17	0.03	2
359.31	359.38	0.07	2
361.23	361.29	0.06	2

From (m)	To (m)	Missing piece length (m)	Overcoring level
361.98	362.17	0.18	2
363.16	363.19	0.03	2
364.87	365.17	0.30	2
366.13	366.15	0.02	2
367.11	367.16	0.05	2
467.14	467.23	0.09	3
468.25	468.29	0.04	3
468.29	468.35	0.06	3
469.35	469.50	0.15	3
470.52	470.59	0.07	3
470.59	470.64	0.05	3
471.65	471.73	0.08	3
471.73	471.78	0.05	3
472.79	473.14	0.35	3
473.14	473.18	0.04	3
474.15	474.26	0.11	3
475.12	475.27	0.15	3
477.33	477.37	0.04	3
477.37	477.46	0.09	3
478.29	478.38	0.09	3
479.11	479.14	0.03	3
479.14	479.18	0.04	3
480.48	480.50	0.02	3
481.46	481.67	0.21	3
482.63	482.71	0.08	3
483.51	483.63	0.12	3

A total of three drill bits were used for KLX12A, 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.

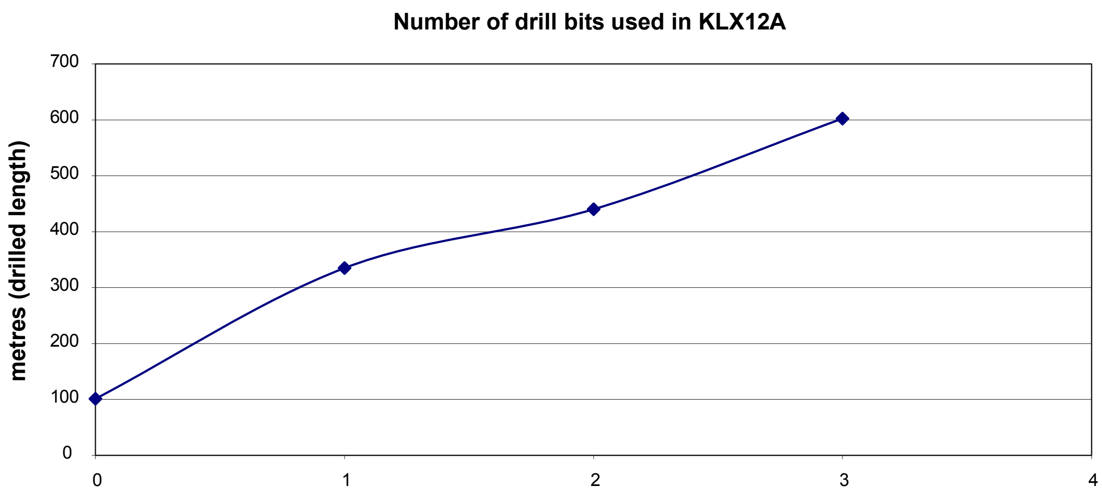


Figure 5-6. *Changes of drill bits during core drilling in KLX12A.*

5.3.4 Overcoring measurements

Measurements were made in three length intervals; 224–242, 350–368 and 467–484 metres. Several attempts at measuring with the overcoring method had to be made in each of the three intervals in order to obtain a complete record. The individual attempts were disturbed by fractures, variations in lithology and occasionally by instabilities in the borehole wall.

The stress state in borehole KLX12A was characterized by low to medium horizontal stress at the first interval of measurement. The stress level was medium in the second interval. The direction of the principal stress in the first and second measurement intervals were ENE to WSW. The third measurement interval showed medium to high stress with a slight shift of the horizontal stress direction compared to the first two intervals.

The overcoring rock stress measurements will be reported separately and the results are not commented further here.

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

- The dummy probe was lowered into the borehole to test the curvature of the borehole wall after directional drilling. The dummy was obstructed at 302 m i.e. at the starting point of the directional drilling.
- Diamond drilling completed at 602.29 m.
- Flushing and brushing with high water pressure on the borehole wall was done along intervals as given in Table 5-8. 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.
- Milling of the borehole wall was done at 302–335 m to improve the smoothness of the curvature.
- The steel dummy was lowered without any problems along the entire length of the borehole. The probe is designed so that it will run smoothly along the borehole if the curvature does not exceed 0.1°/ m.
- BIPS logging for final risk assessment was done to full drilled length.

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

Table 5-8. Borehole sections that were mechanically rinsed by water flushing and rotating steel brush.

From (bh length m)	To (bh length m)
102	104
105	107
118	119
201.5	202.5
315	317.5
329	330.5
372.5	374.5
398	399.5
419.5	420.5
434.5	435.5
523	524

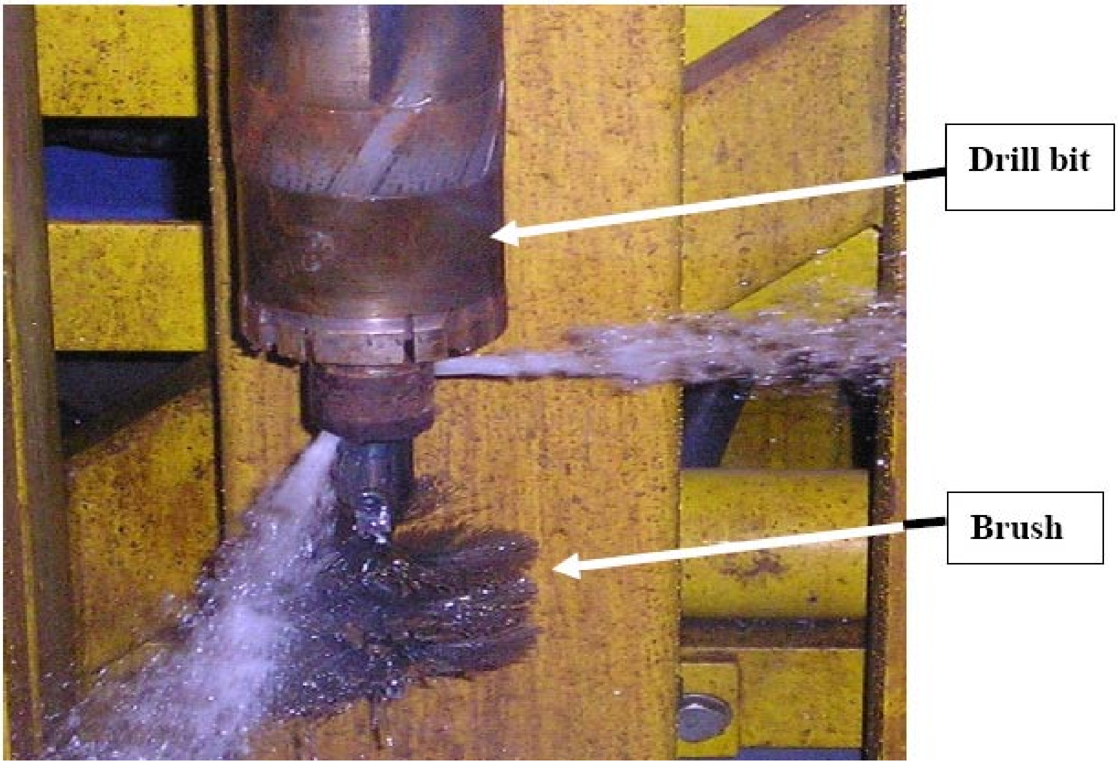


Figure 5-7. The water flushing and rotating steel brush tool. The tool is lowered into the drill stem and can be seen in place just below the drill bit. During operating the drill string is moved up and down to remove loose rock fragments from the borehole wall.

Borehole completion

Reaming of depth reference slots was done at the drilled lengths shown in Table 5-9. 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 101.12 to 102.13 with T-86 equipment. A steel conical guide was installed in KLX12A between 97.36 m and 102.13. 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 March 21, 2006, see Table 5-10.

Table 5-9. Depth reference slots (m) in KLX12A.

110.00	400.00
150.00	450.00
200.00	500.00
250.00	550.00
300.00	580.00
350.00	

Table 5-10. Dates for nitrogen gas flushing in KLX12A.

Date	Time	Interval (m)	Water lifted (m^3)
060321	6.00–11.00	17.92–602.29	6
060321	6.00–11.00	17.92–602.29	3
060321	6.00–11.00	17.92–602.29	5
060321	6.00–11.00	17.92–602.29	4

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 100.57–602.29 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:

- Three successful pumping tests were conducted, see section 5.4.1.
- One water sample was taken, see section 5.4.2.

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

Hydraulic responses in near-by boreholes from drilling in KLX12A are commented in section 5.4.4.

5.4.1 Hydrogeological results from wireline measurements

Results from the wireline tests in KLX12A are presented in Table 5-11 and Figure 5-8. The plots from the pumping tests are given in Appendix 5.

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 and s is the drawdown.

Only three pumping tests out of a total of eleven tests that were performed in KLX12A achieved sufficiently stable conditions for calculating pseudo steady-state transmissivity and hydraulic conductivity. The failed tests were reported to SICADA as activities, but without hydrogeological results.

The main reason behind the failed tests was leakage between the tested section and the casing section. The leakages were generally derived from malfunctioning packers, check valves or problems with the drill stem. Further comments on the individual quality and evaluation of the pumping tests are given in Table 5-11.

The start and stop times for the interval used for evaluation of the pumping tests are given in Table 5-12.

Table 5-11. Evaluated pumping tests with wireline probe in KLX12A.

Tested section [m]	Q/s [m²/s]	T_M [m²/s]	Comments
197.70–302.17	$1.1 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	Pressure did not reach pseudo steady-state conditions. Only a maximum value of the transmissivity is calculated, due to drop in pressure from 1.3 L/min to approx. 0–0.2 L/min. The lower flow does not lead to a constant pressure in the tested section; the real flow should be between 0.2–1.3 L/min.
300.00–437.07	$5.5 \cdot 10^{-7}$	$7.4 \cdot 10^{-7}$	Pseudo steady state was not achieved, the pressure in test section increased during the pumping period. The calculated hydraulic parameters are minimum values, assuming continuous low constant flow, and given that the pressure in test section did not continue to increase significantly. Pressure in casing during the transient recovery phase was unaffected by pumping test.
435.39–602.29	$1.9 \cdot 10^{-7}$	$2.6 \cdot 10^{-7}$	Steady state, good data. Pressure in casing during transient recovery phase was unaffected by pumping test.

Table 5-12. Evaluated test periods.

Tested section	Start (YYYY-MM-DD HH:MM)	Stop (YYYY-MM-DD HH:MM)
197.70–302.17	2005-12-06 16:55	2005-12-07 17:06
300.00–437.07	2006-01-20 15:30	2006-01-21 19:40
435.39–602.29	2006-03-06 15:45	2006-03-07 19:44

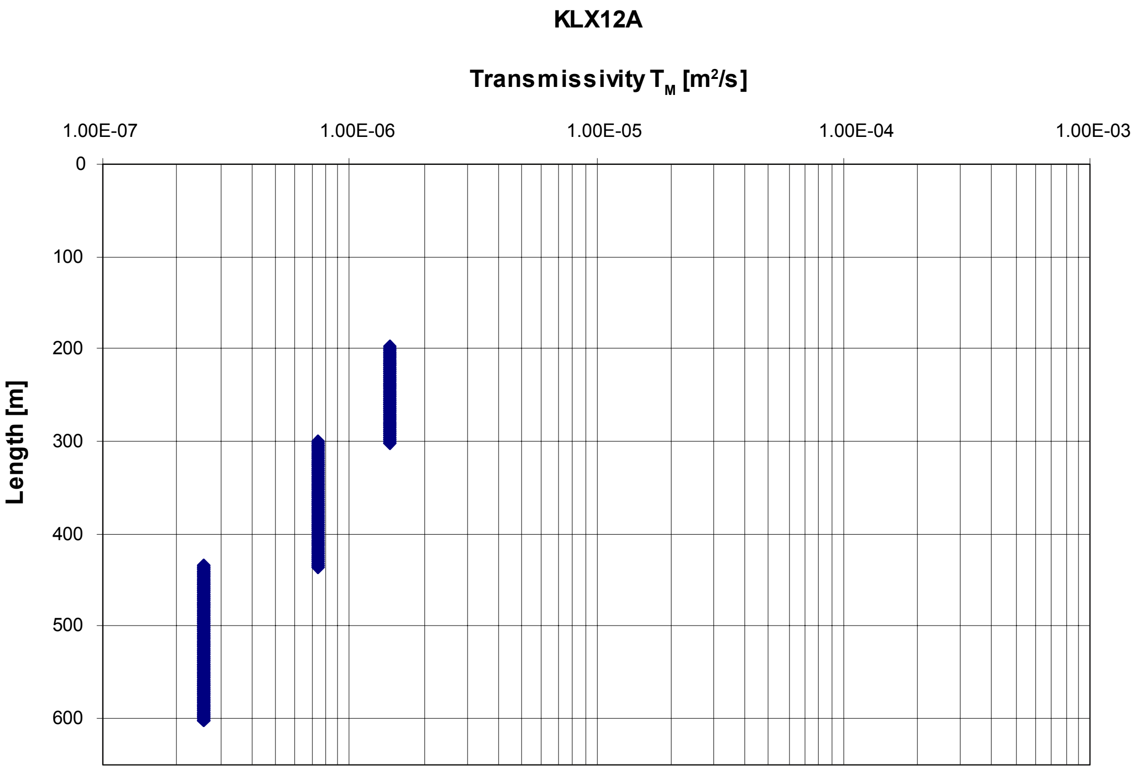


Figure 5-8. Transmissivity from wireline pumping tests in KLX12A versus borehole length.

5.4.2 Hydrochemistry

One water sample was collected in connection with core drilling in KLX12A. Sampling date and down-hole length interval for the sample is given in Table 5-13.

Sampling and analysis was performed according to the SKB class specified in Table 5-13.

The sample from KLX12A was collected at the drill site and prepared and conserved at the Äspö laboratory as soon as possible after the sampling occasion. The sample was stored in a refrigerator until the drilling of the borehole was completed.

Sample 10609 had a relatively high amount of drilling water but since this was the only sample collected from KLX12A it was decided to analyse all SKB class 3 parameters. 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.

Water from sample 10609 is archived in a freezer at the Äspö laboratory for future reference.

Selected analytical results from sample 10609 and from sampling of the water source HLX10, are given in Table 5-14. A complete record of analytical results is given in Appendix 2.

The percussion drilled borehole HLX10 was used as water source during the drilling of KLX12A. One water sample, 10579, was taken from HLX10 in connection with the drilling of KLX12A. The concentration of total organic carbon, TOC, in sample 10579 was 5.8 mg/L. This value was considered acceptable for the water in HLX10 to be used as flushing water for the core drilled part of KLX12A without further filtration measures to lower the organic carbon content.

Water samples have also been collected from HLX10 at earlier occasions and results from those analyses are reported in /4/ and references therein.

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 KLX12A, a total of 86 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 for uranine content and electrical conductivity at the Äspö laboratory.

The calculated average uranine content for the whole borehole is 0.196 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.

Monitoring of the electrical conductivity in the flushing and return water is also made via the drilling monitoring system, see section 5.5.

Table 5-13. Sample dates and length during core drilling in KLX12A.

Sample number	Borehole	Date	Test section, length (m)	SKB chemistry class
10609	KLX12A	2005-11-15	102.47–200.15	3 (and all option isotopes)

Table 5-14. Analytical results from water chemistry sampling.

Borehole	Sample no	Date	From m	To m	Drill water %	TOC mg/L	pH	El Cond mS/m	Cl mg/L
KLX12A	10609	2005-11-15	102.47	200.15	25.10		8.23	94.6	113.0
HLX10	10579	2005-10-28	3.00	85.00		5.8	7.03	57.0	23.9

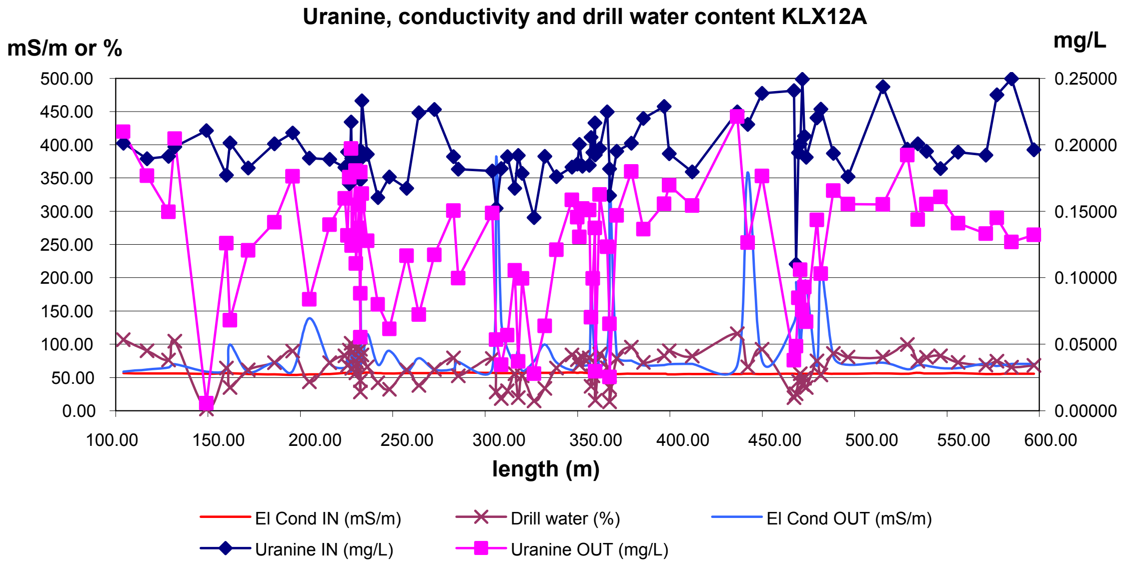


Figure 5-9. *The uranine concentration and electrical conductivity of flushing water (IN) and returning water (OUT) in KLX12A. The drill water content in the returning water is also shown.*

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 /2/, as well as the specific capacity, *Q/s*. The results are shown in Table 5-15, 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 5-10 and 5-11. 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 minimum 30 minutes to several hours after the core drilling has stopped. This period constitutes the drawdown phase.

The drawdown phases are shown graphically in Figures 5-10 and 5-11. Within the drawdown phase a period with as stable flow conditions as possible is selected for test evaluation.

The plots from the drawdown and recovery tests are given in Figures 5-10 and 5-11.

Table 5-15. Results from air-lift pumping in KLX12A.

Tested section [m]	Flow rate [L/min]	Drawdown [m]	Q/s [m²/s]	T_M [m²/s]	Comments
17.92–440.12	18	42	$7.1 \cdot 10^{-6}$	$1.1 \cdot 10^{-5}$	Q derives from Qout–Qin
17.92–602.29	16	50	$5.3 \cdot 10^{-6}$	$8.4 \cdot 10^{-6}$	Q derives from Qout–Qin

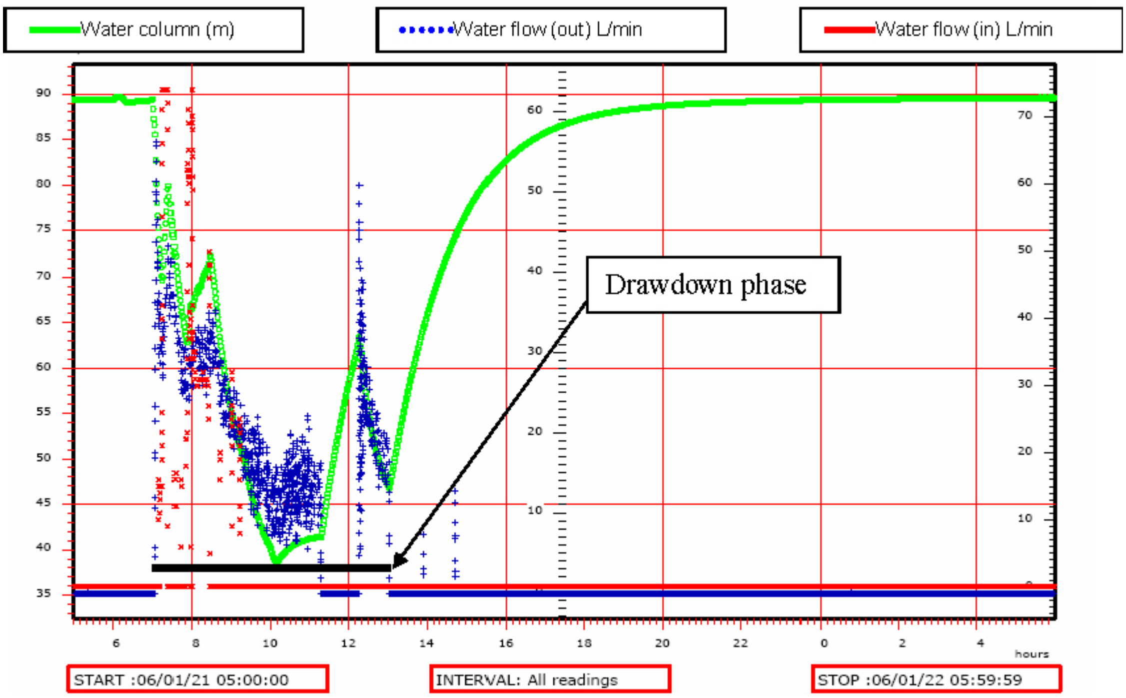


Figure 5-10. *Air-lift pumping in KLX12A 17.92–440.12 m. The green line represents the height of the water column in the borehole, the flow out (i.e. pumped flow from air-lift pumping in the telescopic section) is shown as the blue dotted line. Inflow of water (red line) is related to drilling. The drawdown period which includes the period for test evaluation is shown with a black bar.*

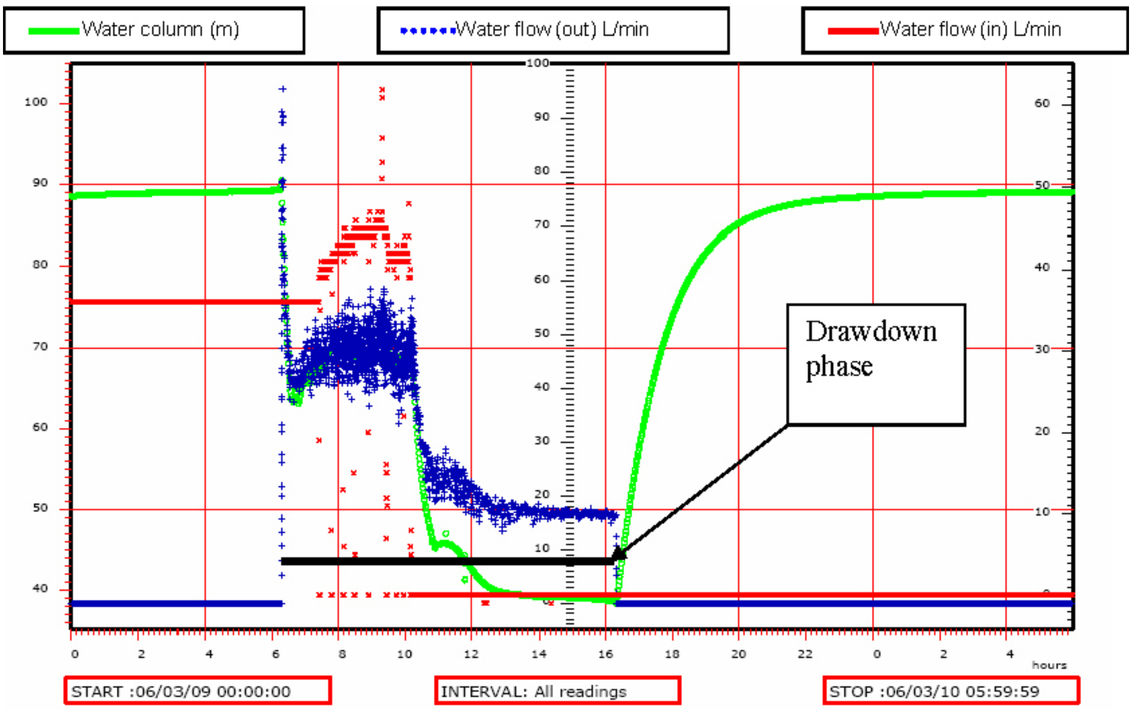


Figure 5-11. *Air-lift pumping in KLX12A 17.92–602.29 m. The green line represents the height of the water column in the borehole, the flow out (i.e. pumped flow from air-lift pumping in the telescopic section) is shown as the blue dotted line. Inflow of water (red line) is related to drilling. The test evaluation was done on the latter part of the drawdown phase ie when the pumped flow (blue) was stable around 18 L/min.*

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 KLX12A

No hydraulic response could be seen in surrounding percussion boreholes, HLX24, HLX26 or HLX27, from the percussion drilling of the telescopic section in KLX12A. A graphic example from observation borehole HLX26 is given in Figure 5-12.

Hydraulic responses from air-lift pumping and drilling activities could be seen in many sections in borehole KLX05, see Table 5-16 and Figures 5-13 and 5-14.

Table 5-16. Hydraulic responses in KLX05 from air-lift pumping in KLX12A 060102–060105.

Observation borehole (section*)	Hydraulic response
KLX05 (section 1) 721–1,000 m	No
KLX05 (section 2) 634–720 m	Yes
KLX05 (section 3) 625–633 m	No
KLX05 (section 4) 501–624 m	No
KLX05 (section 5) 361–500 m	Yes
KLX05 (section 6) 256–360 m	Yes
KLX05 (section 7) 241–255 m	Yes
KLX05 (section 8) 220–240 m	Yes
KLX05 (section 9) 128–219 m	Yes
KLX05 (section 10) 0–127 m	Yes

* Installation for long term monitoring in cored boreholes is made with a series of sections divided by packers along the length of the borehole.

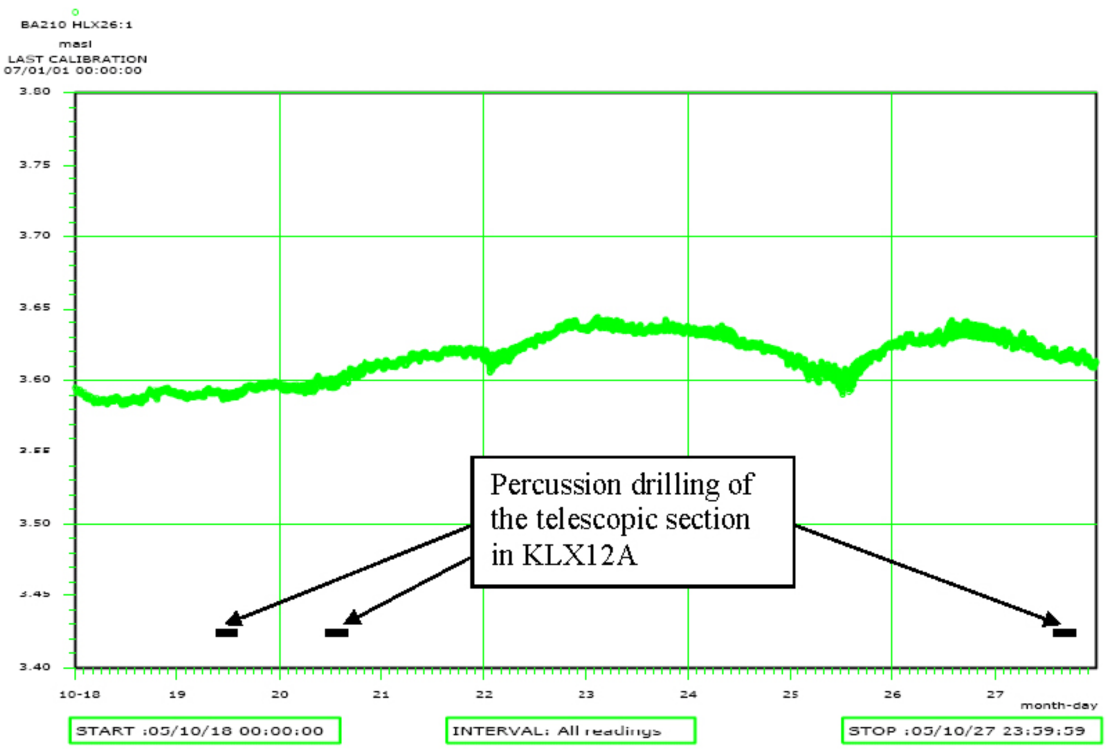


Figure 5-12. Water table in observation borehole HLX26 during percussion drilling of the telescopic section in KLX12A.

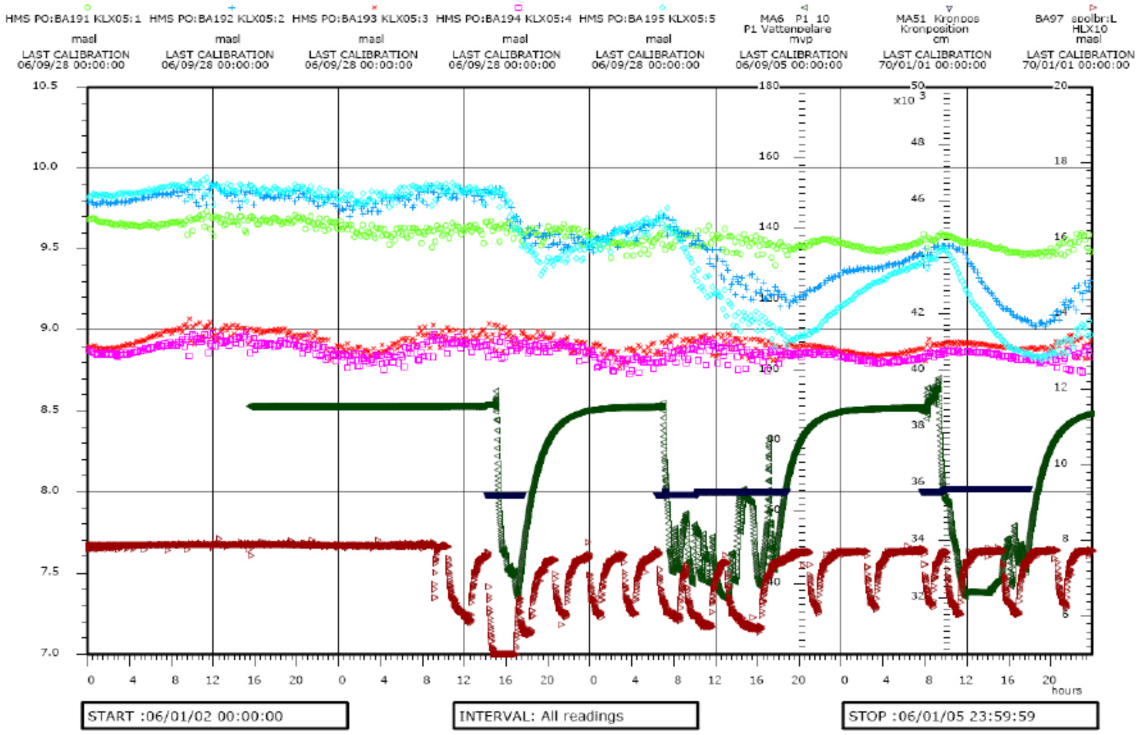


Figure 5-13. *Water table in observation borehole KLX05, sections 1 through 5. The water table in KLX12A and the drill water supply well, HLX10, is also shown. There is a clear correlation between drawdown in KLX12A and sections 2 (dark blue) and 5 (light blue) in KLX05. No hydraulic responses can be seen from airlift pumping in HLX10.*

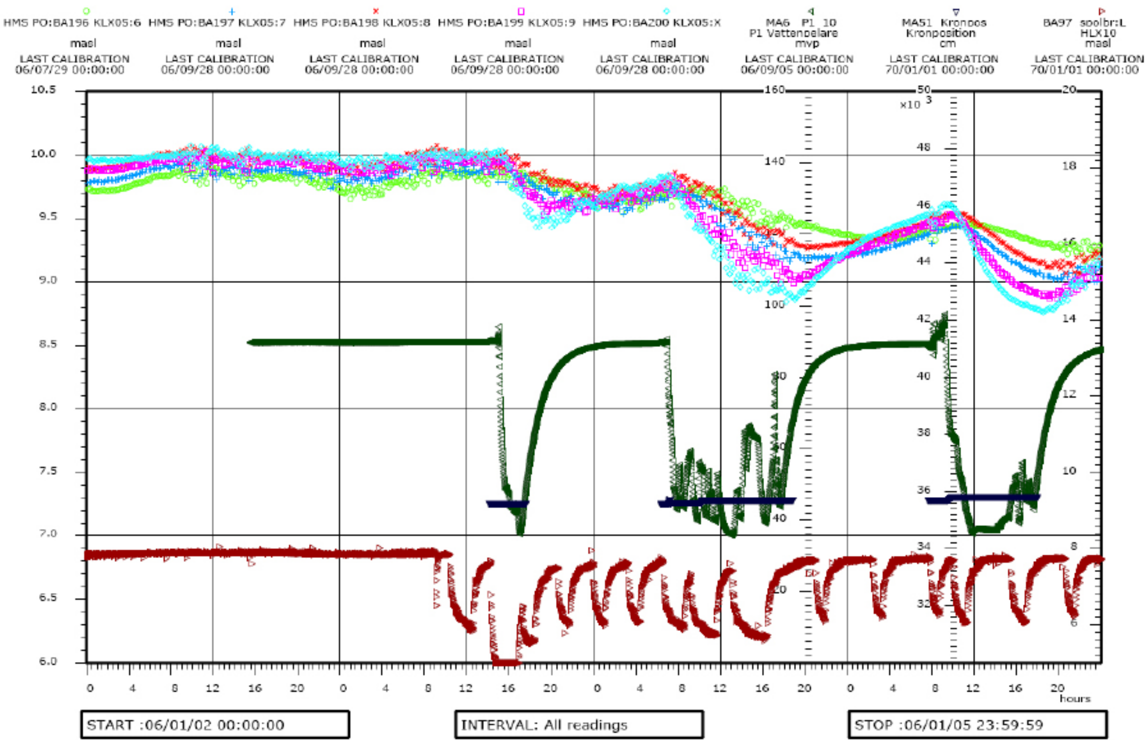


Figure 5-14. *Water table in observation borehole KLX05, sections 6 through 10. The water table in KLX12A and the drill water supply well, HLX10, is also shown. There is a clear correlation between drawdown in KLX12A and sections 6 through 10 in KLX05. No hydraulic responses can be seen from airlift pumping in HLX10.*

No hydraulic response could however be seen in HLX15, 24, 26 or HLX27 from air-lift pumping or related drilling activities in KLX12A, see Table 5-17. A graphical example of the water table in HLX15 during the drilling of KLX12A is shown in Figure 5-15.

Hydraulic responses in near-by boreholes from nitrogen gas flushing in KLX12A

Nitrogen gas flushing covering the entire length of the borehole was done four times on 060321. No hydraulic response could be seen in observation boreholes HLX24, 26 and HLX27. A plot of the water table during 060321 in HLX27 is given in Figure 5-16.

The location of the mentioned boreholes is given in Figure 5-17.

Table 5-17. Hydraulic responses in surrounding percussion boreholes from air-lift pumping in KLX12A.

HLX15	No
HLX24	No
HLX26	No
HLX27	No

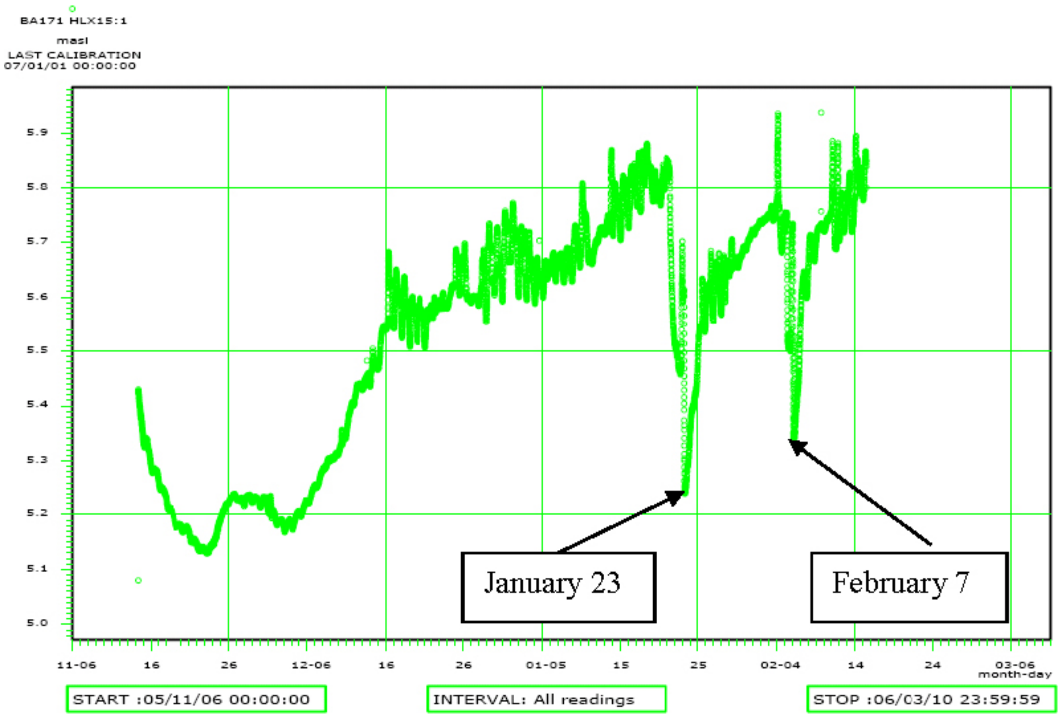


Figure 5-15. *The water table in observation borehole HLX15 during the drilling period of KLX12A. The two dips of the water table on January 23 and February 7 coincides with very cold weather (below minus 20° C). Borehole HLX15 is artesian and the ground water table reaches up into a standing pipe above the ground level. The likely explanation for the water table drawdown from strong cold is that the water in the standing pipe is frozen and thereby removed as weight on the pressure logger.*

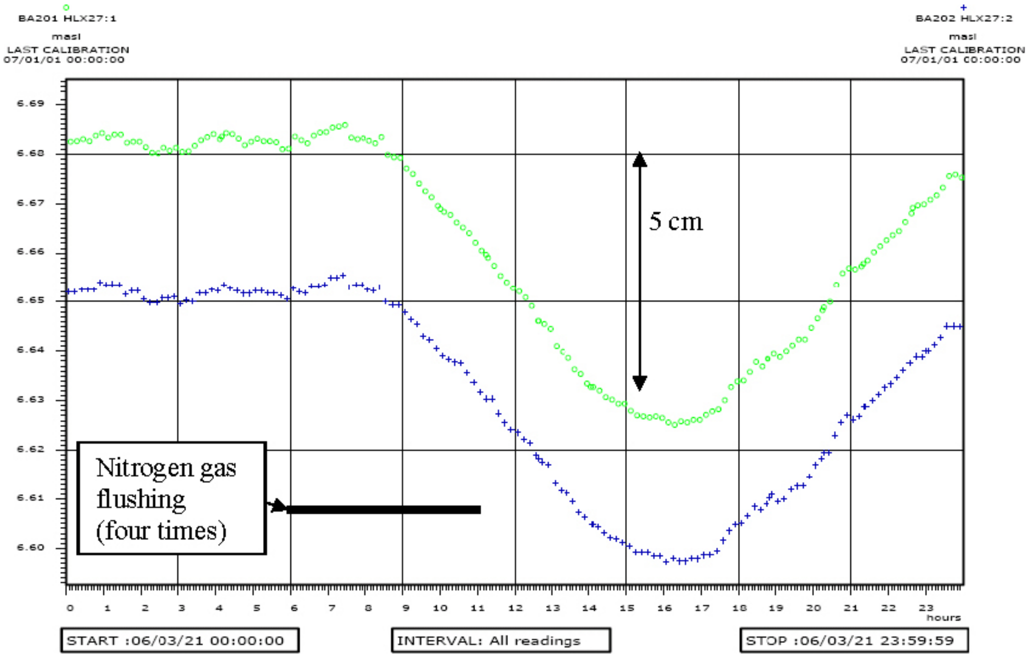


Figure 5-16. *Water levels in HLX27 during nitrogen gas flushing in KLX12A. No hydraulic response could be seen in observation borehole HLX27.*

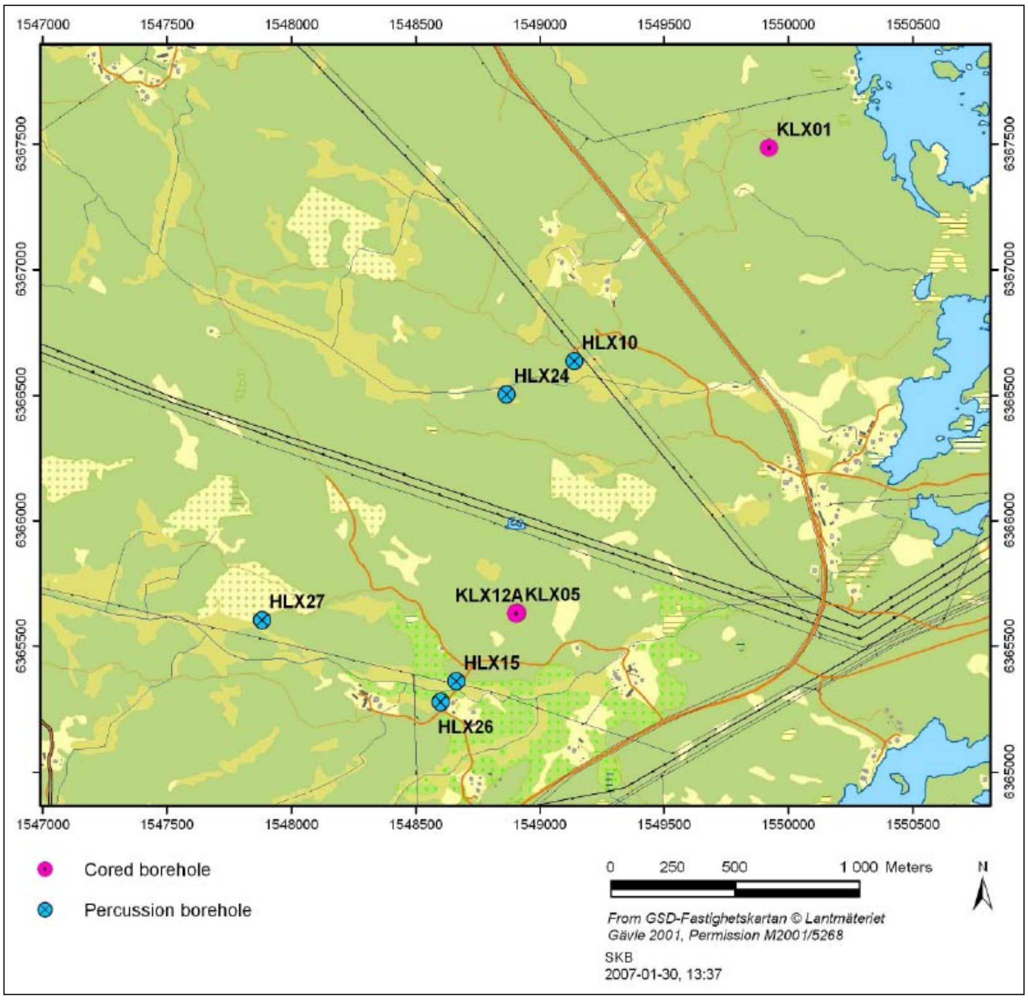


Figure 5-17. *Map showing the location of cored boreholes KLX12A and the percussion boreholes HLX10, HLX15, HLX24, HLX26 and HLX27.*

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 0–100.57 metres and the core drilling section 100.57–602.29 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 5-18 through 5-20 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 5-18 through 5-20. Since DMS data are related to time (i.e. not strictly to borehole length) periods were drilling is not performed are also registered.

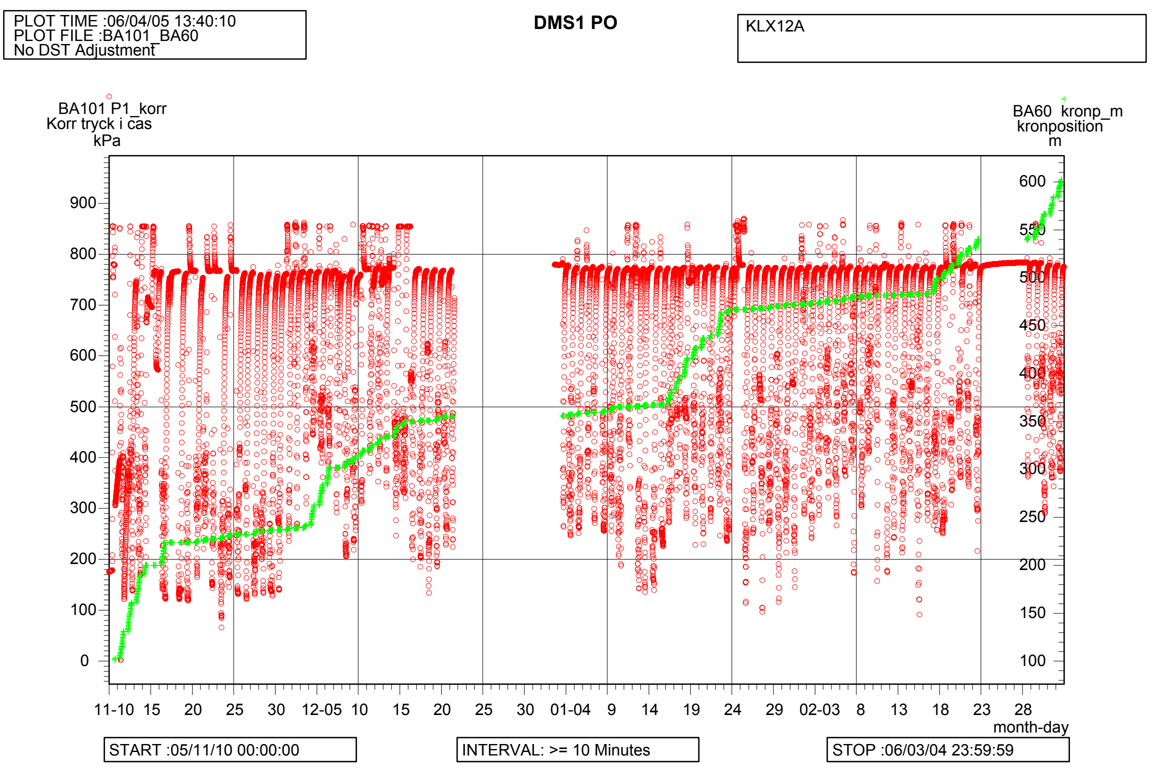


Figure 5-18. *Drill bit position (green) and water level from air-lift pumping (red). The water level is expressed as the pressure in kPa of the water column overlying the pressure gauge ie the ambient air-pressure has been subtracted. The pressure gauge is emplaced at 90 metres borehole length.*

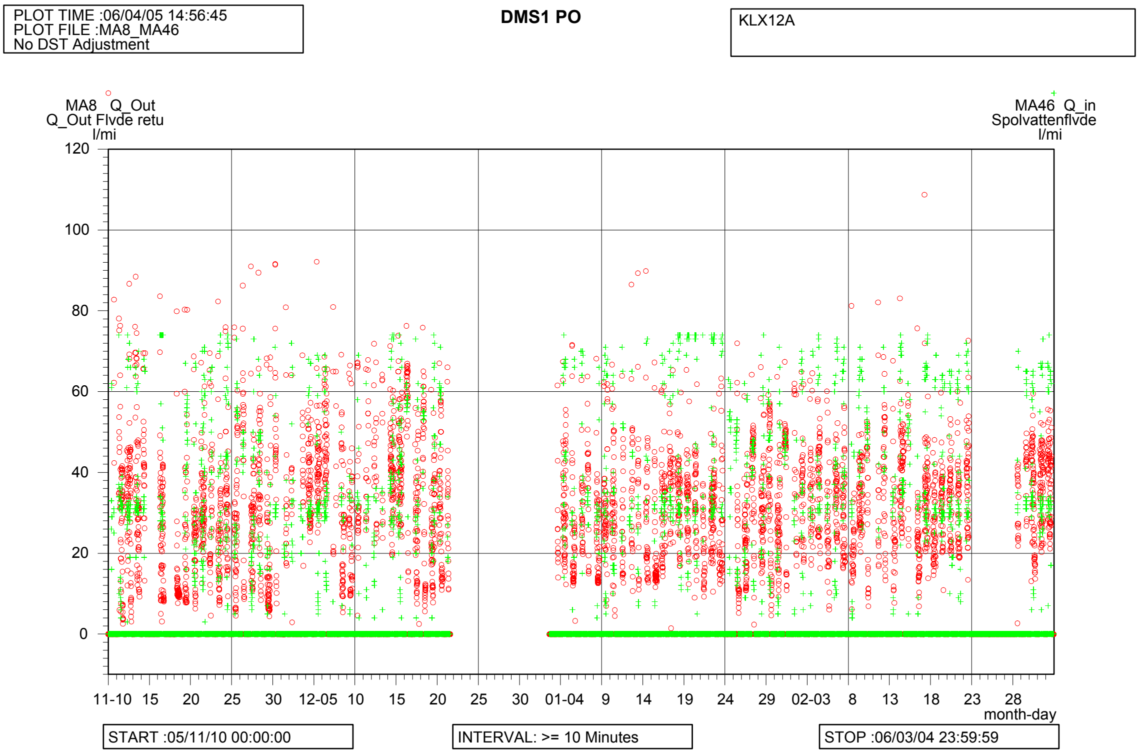


Figure 5-19. *Flushing water flow (green) and return water flow (red) in litres per minute.*

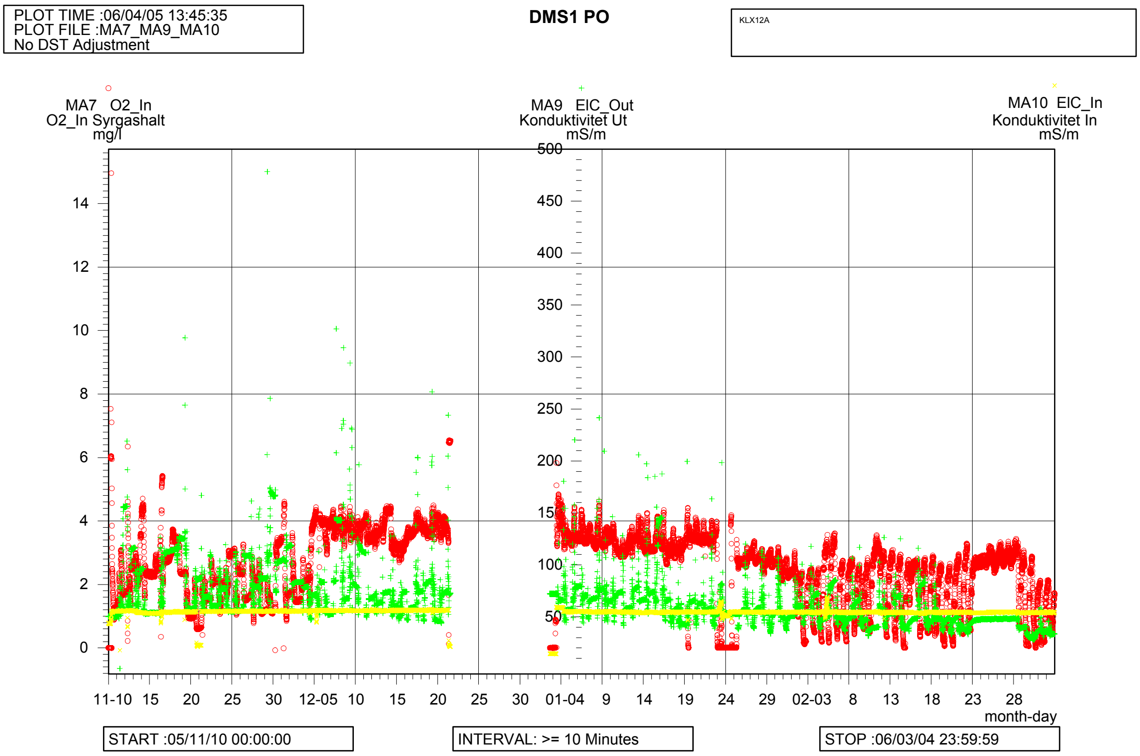


Figure 5-20. *Conductivity of flushing water (yellow) and return water (green). The oxygen content in mg/L of the flushing water (red) is also shown. The oxygen content of the flushing water is typically low (< 4 mg/L) with only scattered slightly elevated readings.*

Figure 5-18 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 5-19 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 ca 30 litres/minute corresponding to pumped flow during drilling.
- A flow of 60–75 litres/minute corresponding to the flow while pumping down the core barrel.
- No flow (zero litres/minute) when no drilling is performed.

Figure 5-20 shows the conductivity of the ingoing flushing water, conductivity of the return water and the oxygen content of the flushing water. The oxygen content of the flushing water is 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 5-21.

The amount of flushing water consumed during drilling was 820 m^3, giving an average consumption of ca 1.6 m^3 per metre drilled. The amount of effluent return water from drilling in KLX12A was 1,300 m^3, giving an average of ca 2.6 m^3 per metre drilled.

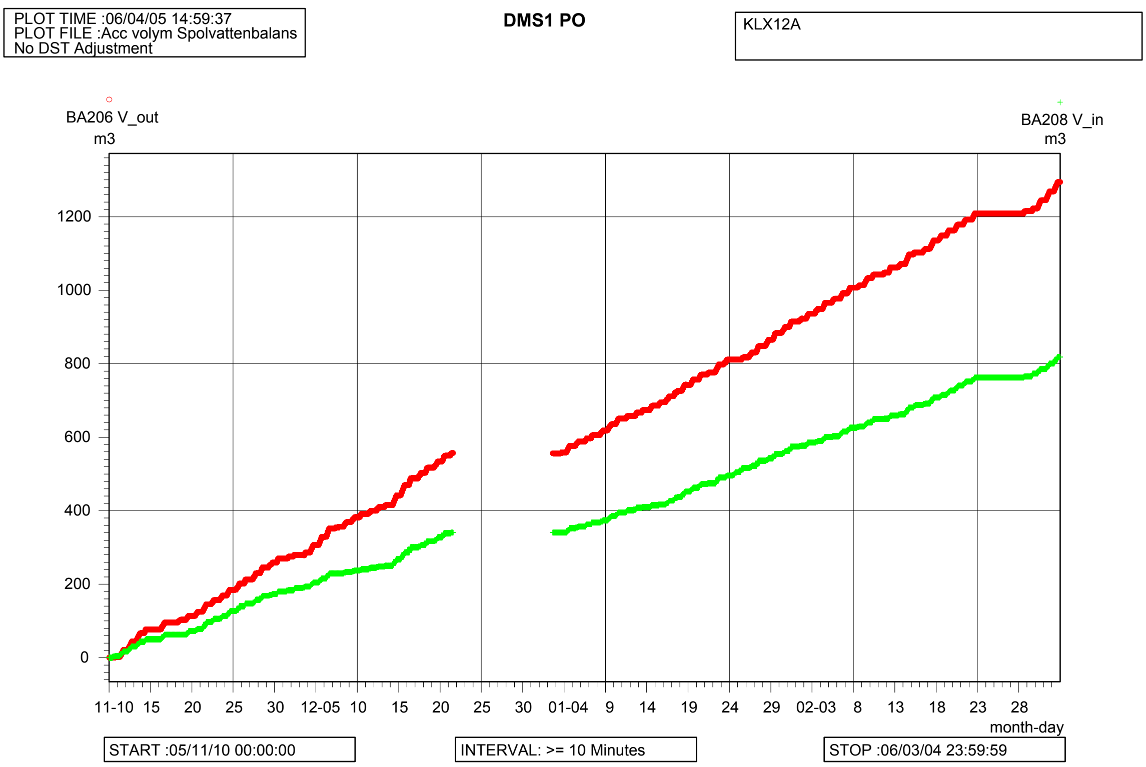


Figure 5-21. *Flushing water balance from KLX12A as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.*

Drill cutting balance

The weight of cuttings in the settling containers amounted to 1,310 kg. The content of suspended material in the return water was not analysed in borehole KLX12A, 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 520 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing (N3/50) over a length of 500 metres is 3,375 kg assuming a density of 2.7 kg/dm^3. This means that about 54% 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 5-18. The results show that almost all (99%) of the introduced uranine was retrieved during drilling of KLX12A.

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 can be described as being dominated by Ävrö granite to ca 420 m. From 420 m to ca 525 m the core consists almost entirely of diorite-gabbro. Beneath 525 m the dominant rock type is quartz monzodiorite. Minor portions of fine-grained diorite-gabbro, fine grained granite and fine-grained dioritoid do however occur along the borehole.

Red staining with weak to medium intensity occurs sporadically to ca 400 m. Below 400 m length the presence of red staining is very rare. 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 2.4 (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).

Table 5-18. Balance calculation of uranine tracer in KLX12A.

Average uranine content IN (mg/L)	0.196
Flushing water volume IN (m^3)	820
Amount uranine introduced (g)	161
Average uranine content OUT (mg/L)	0.122
Return water volume OUT (m^3)	1,300
Amount uranine recovered (g)	159

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 SSM000212 and SSM000213 is shown in Figure 5-22. 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.

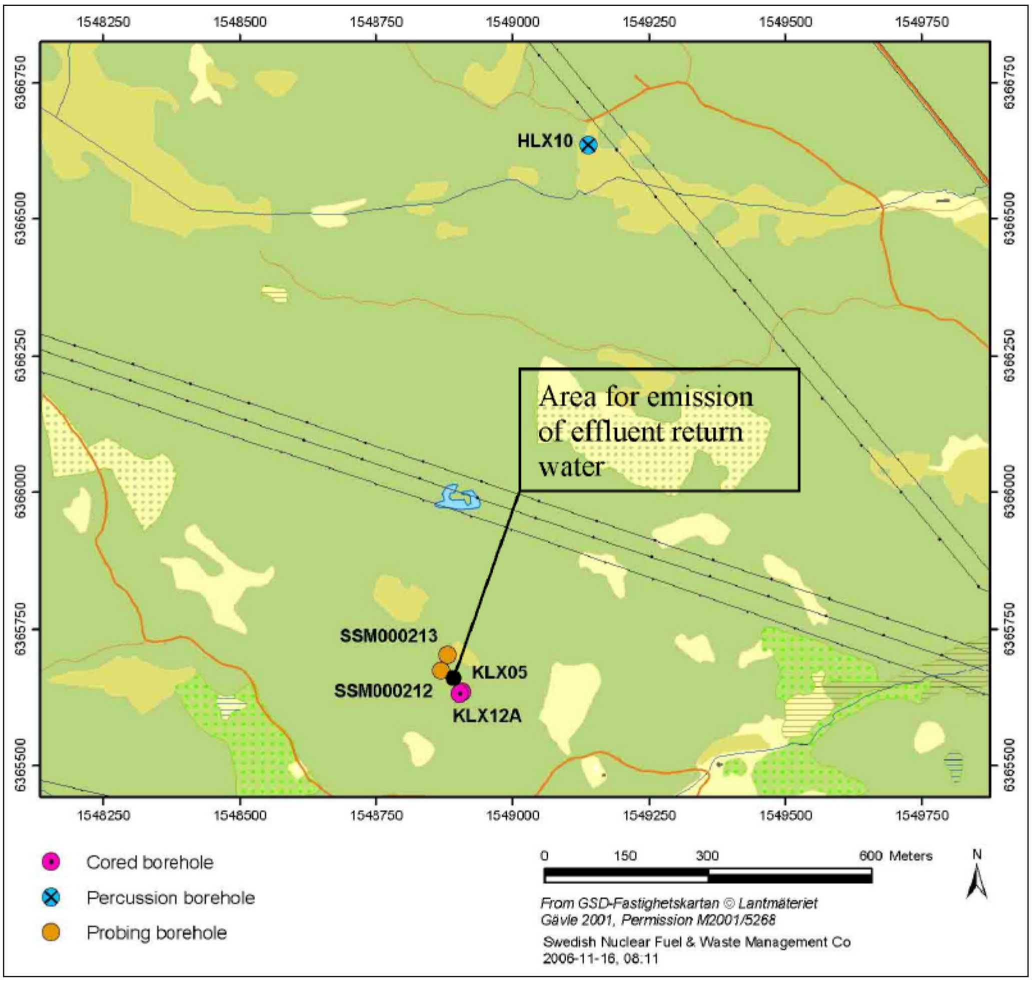


Figure 5-22. *Location of environmental monitoring wells SSM000212 and SSM000213 in relation to the core drill site for KLX12A.*

Monitoring of effluent water

The electrical conductivity, as measured by the DMS system, of the return water from the core drilling of KLX12A exceeded 300 mS/m on four occasions in late November and early December 2005, see Figure 5-20. Samples of the return water that were analysed for electrical conductivity showed values over 300 mS/m three times, see Figure 5-9. The value of electrical conductivity recorded by the DMS system or from a small water sample is not necessarily the same as the conductivity of the water released to the ground. When high electrical conductivities were noted by the DMS system, follow up sampling of the water was done to ensure that the prescribed guideline values were not exceeded. Sampling was therefore done immediately before the point of release to the ground i.e. in the third sedimentation container. The large volume of water in the sedimentation container clearly acts as a buffer and the electrical conductivity of the water released to the ground did not exceed the prescribed level of 300 mS/m. A schematic illustration of the difference in sampling location is shown in Figure 5-5.

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 /5/.

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

Reference sampling

No reference sample of surface soil was taken as borehole KLX12A was drilled from an existing drill site.

A reference water sample of ground water in environmental monitoring well SSM000213 was taken according to Table 5-19.

Monitoring of soil ground water levels

A pressure logger (transducer) for measuring the ground water table was installed in SSM000213 during the core drilling of KLX12A. The water levels are given graphically in Figure 5-23.

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 SSM000213. The results show steady and low values for pH and an overall decreasing trend for the electrical conductivity, see Figure 5-24. No significant influence can be seen on the shallow ground water in SSM000213 from the drilling activity in KLX12A.

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.

Table 5-19. Reference water samples.

Monitoring well	Sample id number	Date
SSM000213	10692	2005-12-15

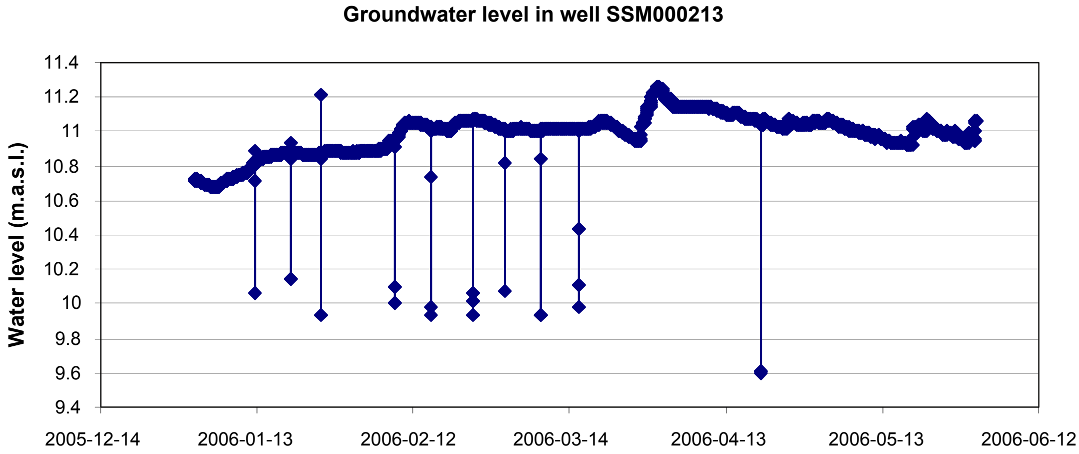


Figure 5-23. *Ground water level in well SSM000213. The dips in water levels are related to water sampling.*

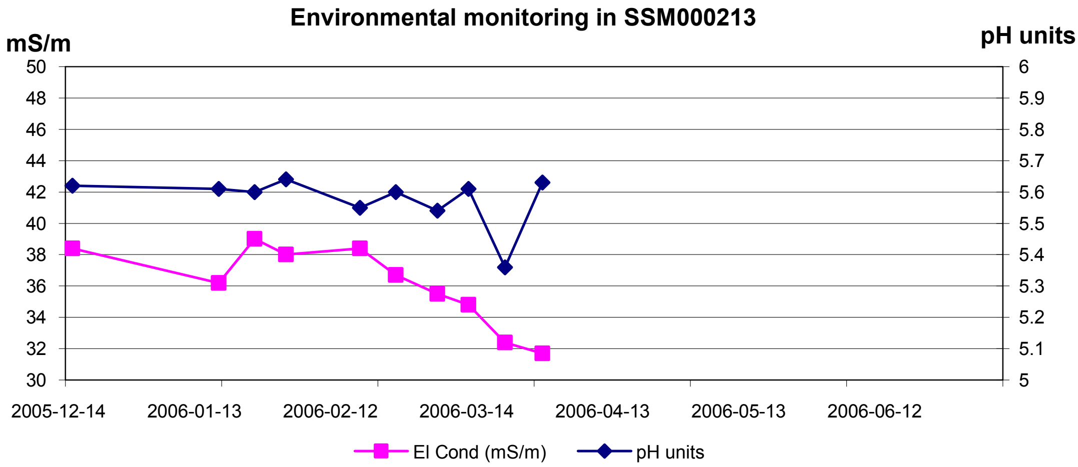


Figure 5-24. *Electrical conductivity and pH in ground water samples from SSM000213.*

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.

6 References

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

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

/3/ **Stenberg, Håkanson, 2007.** Revision of borehole deviation measurements in Oskarshamn. SKB P-07-55 (in prep), Svensk Kärnbränslehantering AB.

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

/5/ **Ask, Morosini, Samuelsson, Ekström, Håkanson, 2004.** Core drilling of KSH03. SKB P-04-233, Svensk Kärnbränslehantering AB.

/6/ **Raséus, Ehrenborg, 2006.** Boremap mapping of core drilled borehole KLX12A. SKB P-06-242, Svensk Kärnbränslehantering AB.

Geology and MWD parameters KLX12A

Title GEOLOGY & MWD PARAMETERS KLX12A — Appendix 1

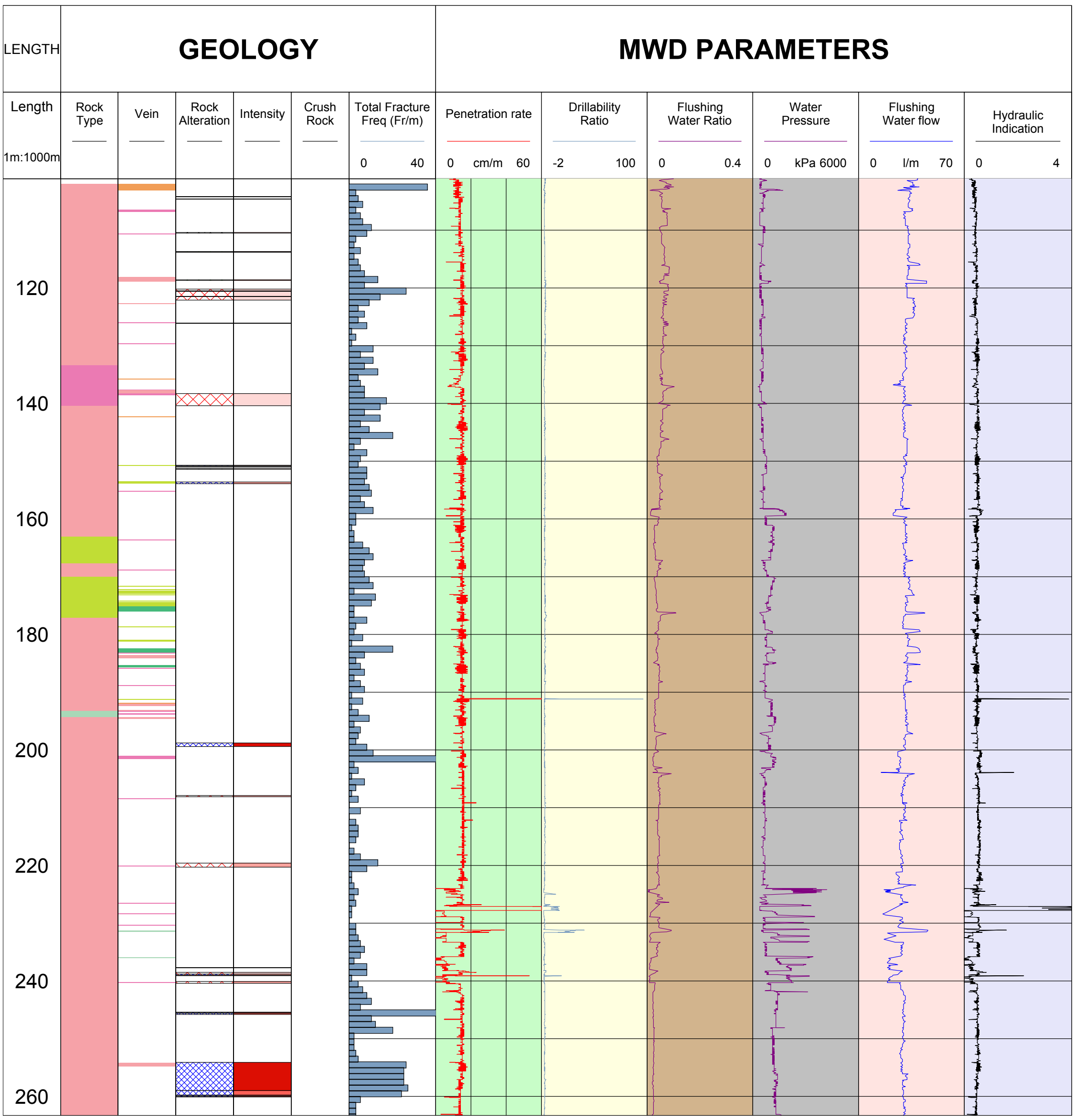
SKB

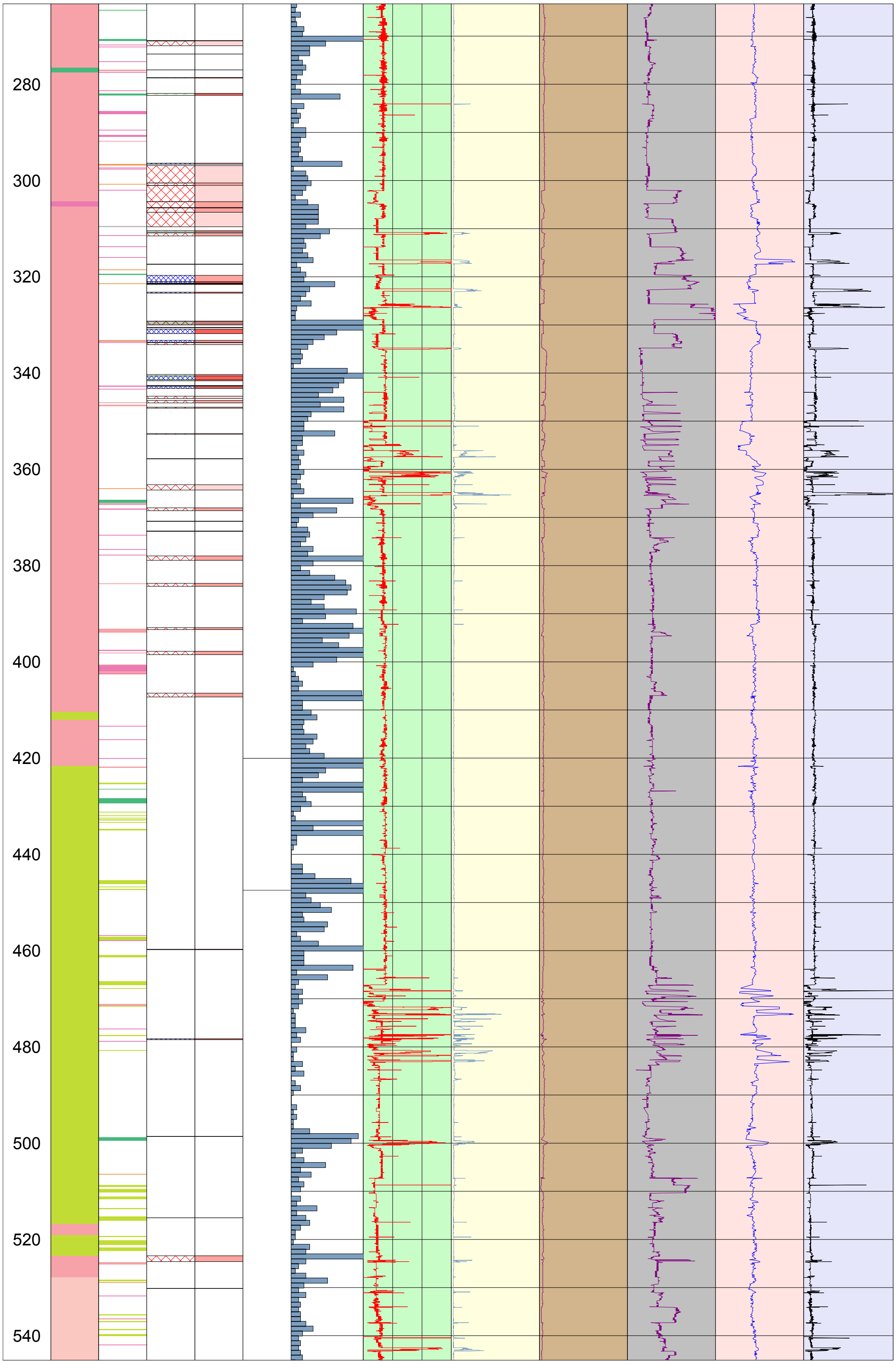
Site	LAXEMAR	**Coordinate System**	RT90-RHB70
Borehole	KLX12A	**Northing [m]**	6365630.78
Diameter [mm]	76	**Easting [m]**	1548904.44
Length [m]	602.290	**Elevation [m.a.s.l.]**	17.74
Bearing [°]	315.92	**Drilling Start Date**	2005-10-19 07:00:00
Inclination [°]	-75.06	**Drilling Stop Date**	2006-03-04 14:48:00
Date of mapping	2006-04-03 10:15:00	**Plot Date**	2007-01-16 22:15:47

ROCKTYPE LAXEMAR
- Fine-grained granite
- Ävrö granite
- Quartz monzodiorite
- Diorite / Gabbro
- Fine-grained dioritoid
- Fine-grained diorite-gabbro

ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Silicification
- Saussuritization

INTENSITY
- Faint
- Weak
- Medium
- Strong

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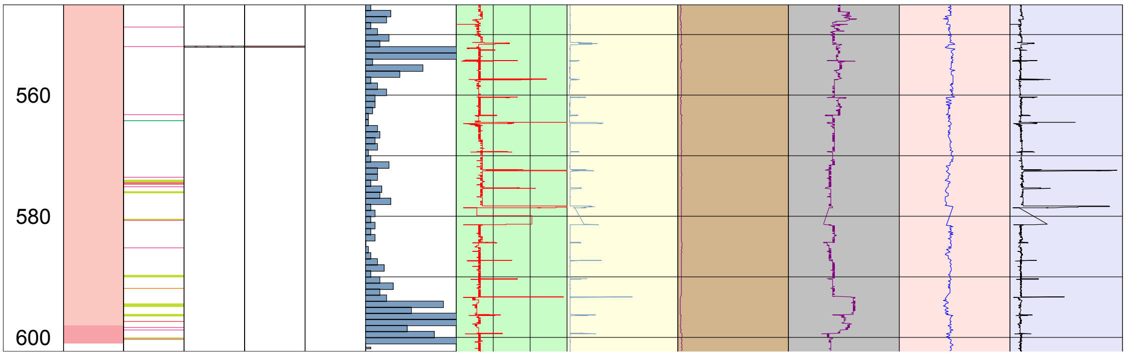

560
580
600

Appendix 2

Chemical results

Borehole	KLX12A	HLX10
Date of measurement	11/15/2005	10/28/2005
Upper section limit (m)	102.47	3.00
Lower section limit (m)	200.15	85.00
Sample_no	10609	10579
Groundwater Chemistry Class	3	5
pH	8.23	7.03
Conductivity mS/m	94.6	57.0
Drill water %	25.10	
Density g/ml	0.997	0.996
Charge balance %	3.59	–1.57
Na mg/l	180.0	104.0
K mg/l	7.24	3.19
Ca mg/l	24.9	11.9
Mg mg/l	9.6	4.1
HCO_3 mg/l Alkalinity	260	219
Cl mg/l	113.0	31.9
SO_4 mg/l	76.9	49.2
SO_4_S mg/l Total Sulphur	27.10	16.40
Br mg/l	0.375	0.313
F mg/l	4.29	3.81
Si mg/l	29.30	5.87
Fe mg/l Total Iron	24.100	0.100
Mn mg/l	0.309	0.064
Li mg/l	0.023	0.011
Sr mg/l	0.379	0.101
TOC mg/l		5.8
PMC % Modern Carbon	50.33	52.73
C-13 dev PDB	–15.71	–16.12
AGE_BP Groundwater age	5,460	5,087
AGE_BP_CORR	30	30
D dev SMOW	–80.4	–76.9
Tr TU	2.80	5.70
O-18 dev SMOW	–10.90	–10.80
B-10 B-10/B-11	0.239	0.239
S-34 dev SMOW	23.7	16.4
Cl-37 dev SMOC	0.08	0.09
Sr-87 Sr-87/Sr-86	0.716	0.716

Appendix 3

Chemistry – analytical method and quality

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 the boreholes KLX12A and HLX10. The errors do not exceed ± 5% in any of the samples.

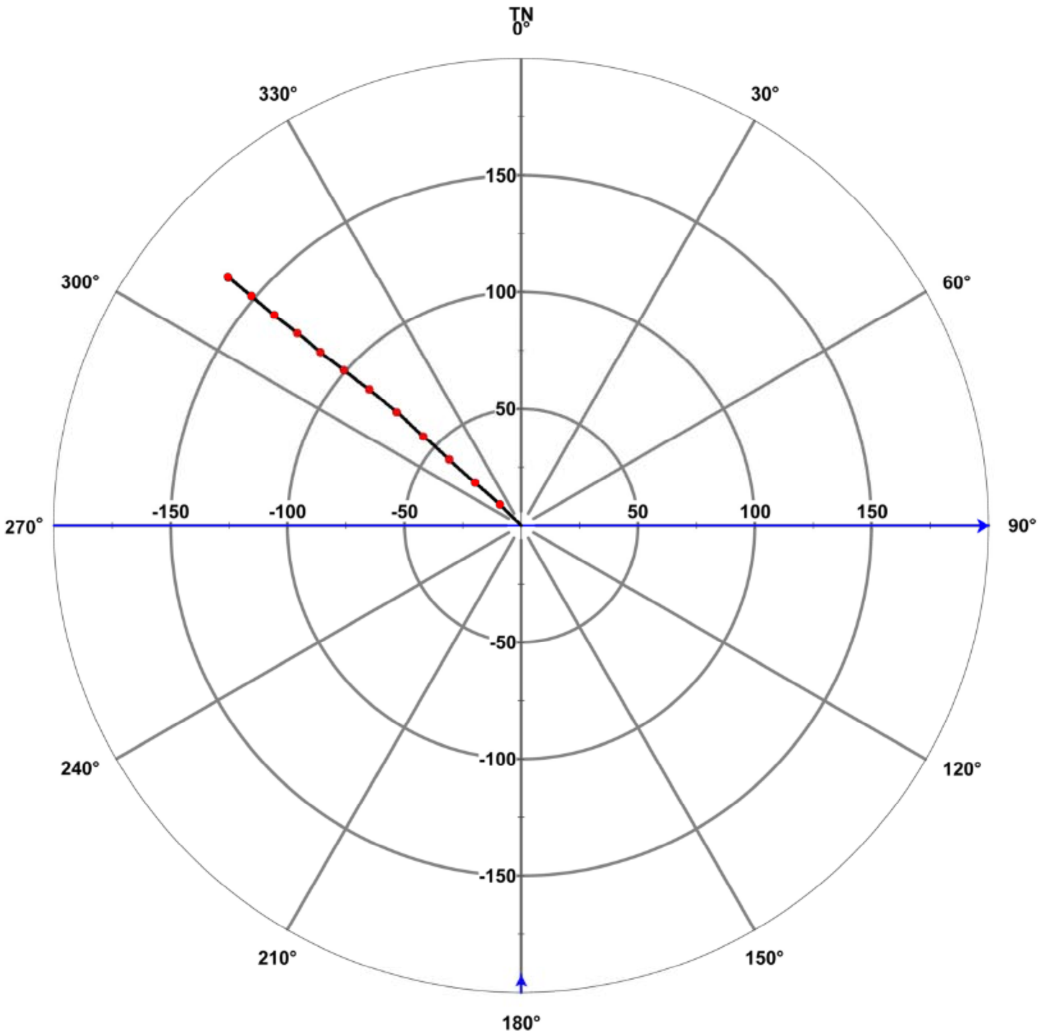
The following routines for quality control and data management are generally applied for hydrogeochemical analysis data, independent of sampling method or sampling object.

- 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 KLX12A and HLX10.
- 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%.
- $$\text{Rel. Error (\%)} = 100 \times \frac{(\sum \text{cations(equivalents)} - \sum \text{anions(equivalents)})}{(\sum \text{cations(equivalents)} + \sum \text{anions(equivalents)})}$$
- General expert judgement of plausibility based on earlier results and experiences.

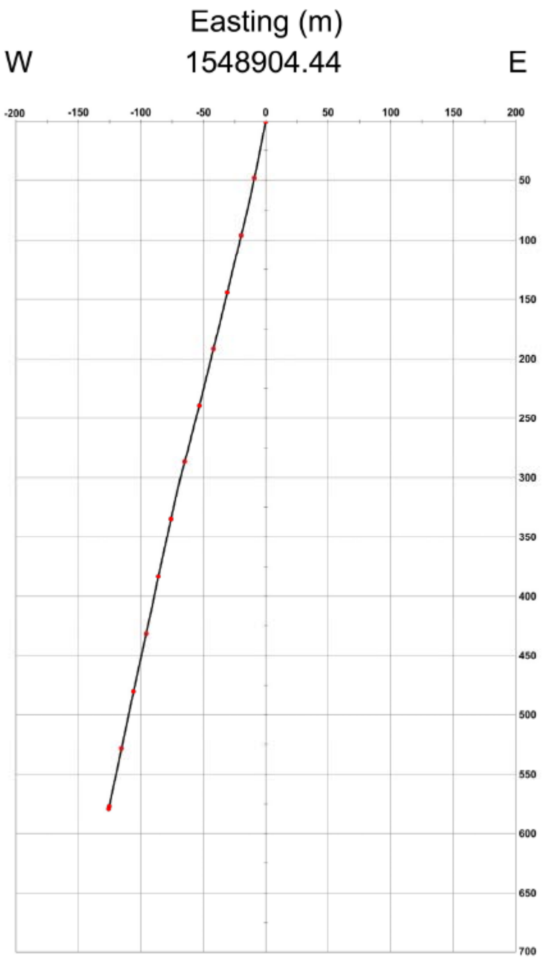
All results from "biochemical" components and special analyses of trace metals and isotopes are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a "best choice" notation will indicate those results which are considered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

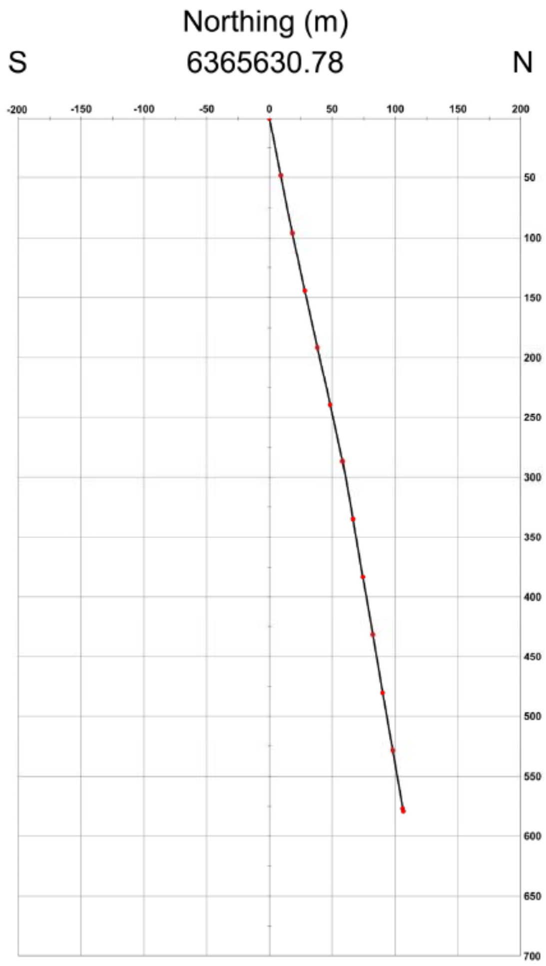
Deviation measurements

Deviation measurement KLX12A		Appendix: 4
Site	LAXEMAR	
Borehole	KLX12A	
View from above		



Deviation measurement KLX12A		Appendix: 4
Site	LAXEMAR	
Borehole	KLX12A	
Vertical Section		





Appendix 5

Wireline pumping tests in KLX12A

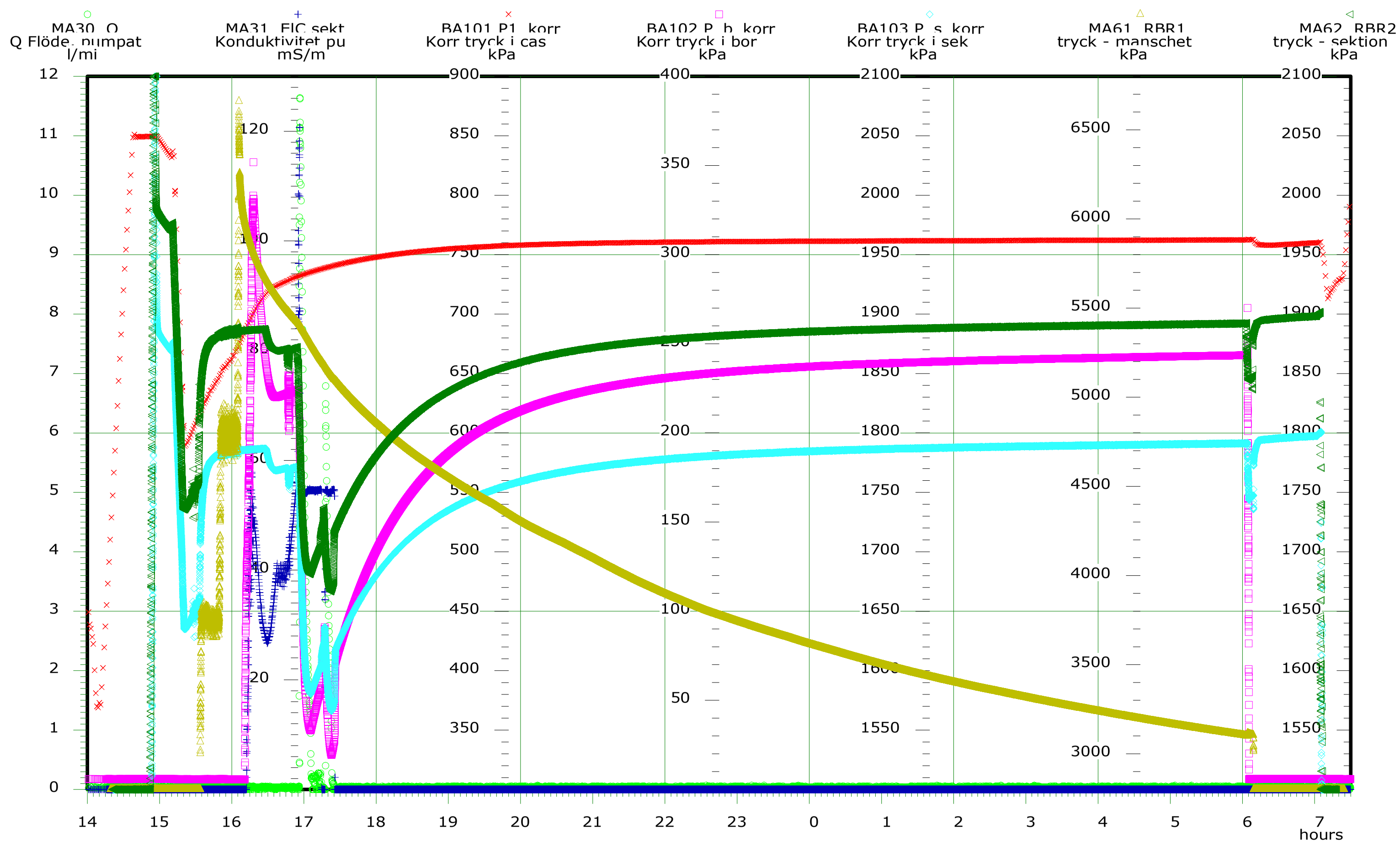
Description of the parameters in the enclosed plots.

Channel	Parameter	Unit	Description
MA30	Water flow	Litre/minute	Flow of water pumped up from the borehole during the test.
MA31	Electrical conductivity	mS/m	Electrical conductivity in the pumped out water.
BA101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
BA102	Pressure	kPa	Pressure of the water column in the test section i.e. at depth in the borehole, subtracted with the ambient air pressure.
BA103	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.
MA61	Pressure - packer	kPa	Inflation pressure in packer.
MA62	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 :05/12/13 11:44:54
PLOT FILE :P_Pumptest
No DST Adjustment

DMS1 PO

Pumping test wireline probe
KLX12A, 197.70-302.17 m



START :05/12/06 14:00:00

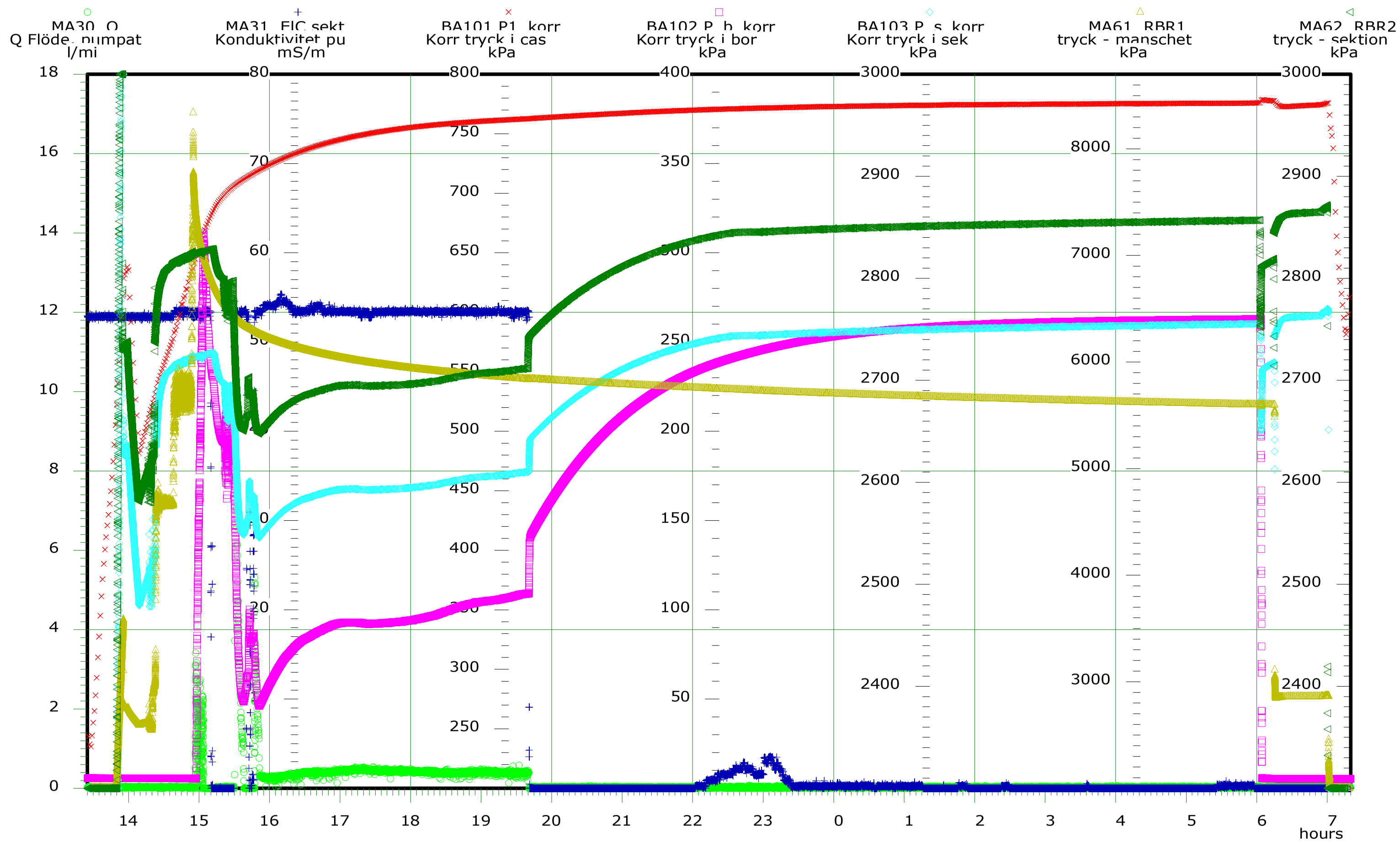
INTERVAL: All readings

STOP :05/12/07 07:29:59

PLOT TIME :06/01/23 08:56:02
PLOT FILE :P_Pumptest
No DST Adjustment

DMS1 PO

Pumping test wireline probe
KLX12A, 300.00-437.07 m



START :06/01/20 13:25:00

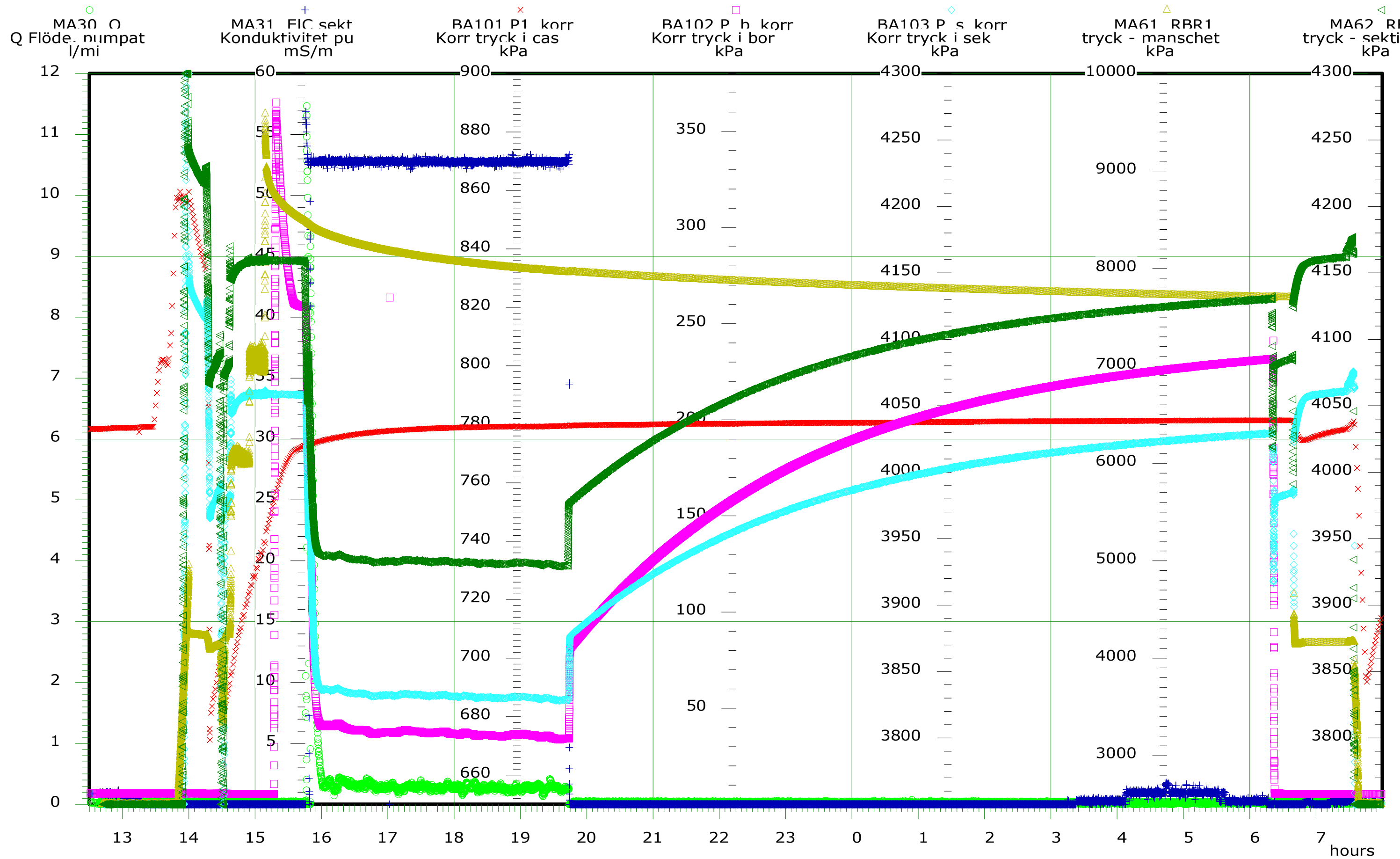
INTERVAL: All readings

STOP :06/01/21 07:19:59

PLOT TIME :06/03/07 15:22:35
PLOT FILE :P_Pumptest
No DST Adjustment

DMS1 PO

Pumping test wireline probe
KLX12A, 435.39-602.29 m



START :06/03/06 12:30:00

INTERVAL: All readings

STOP :06/03/07 07:59:59