P-05-25

Oskarshamn site investigation

Drilling of cored borehole KAV04

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January 2005

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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 KAV04 is located on the island of Ävrö. Drilling was made between October 2003 and May 2004 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden.

The hole was core drilled to a depth of 1,004.0 metres with 76 mm equipment, this hole was called KAV04A. The uppermost section, to a depth of 100.2 metres, was constructed as a telescopic section with an inner diameter of 200 mm. In order to retrieve core from surface to full depth a separate cored hole was drilled close to the telescopic section from the surface to 101.03 metres, this hole was called KAV04B.

A water inflow of 120 litres per minute at 49 metres length was estimated during the percussion drilling of the telescopic section.

Pumping tests were performed with a wireline equipment, typically with one hundred metres intervals. The resulting transmissivities (T_M) varied between 9×10^{-8} and 2×10^{-3} m^2/s. The most transmissive section was between 710 and 730 metres.

An airlift pumping test in the telescopic section performed when the cored hole was drilled to its full length gave a transmissivity (T_M) of 6×10^{-5} m^2/s.

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

Water sampling for chemical analysis were collected during drilling. Three samples were collected during the percussion drilling and nine samples were collected from the core drilling phase. Only two of the nine samples had a sufficiently low drilling water content to ensure accurate results.

The core is dominated by Ävrö granite with intercalations of quartz monzodiorite, fine-grained dioritoide and fine-grained granite. Minor segments of pegmatite and diorite/gabbro occur. Between 860 and 950 metres the core consists of fine-grained dioritoide.

Oxidation with faint to weak intensity occurs in sections of 5 to 30 metres width along the core in the upper 500 metres of the hole. At greater depth both the extent and intensity of oxidation increases.

The total fracture frequency is normally less than 20 per metre to ca 200 metres. Between 200 and 700 metres the fracture frequency is somewhat higher with a range of ca 5–30 fractures per metre. Below 700 metres several zones with crushed rock (i.e. total fracture frequency > 40 per metre) have been noted.

Sammanfattning

Borrhål KAV04 ligger på Ävrö. Borrningen utfördes mellan oktober 2003 och maj 2004 som ett led i platsundersökningen för ett möjligt djupförvar för utbränt kärnbränsle i Oskarshamns kommun.

Hålet kärnborrades med 76 mm utrustning till 1 004,0 meters djup. Detta hål kallades KAV04A. Den övre delen av hålet, från markytan till 100,2 meter, utfördes som en teleskopdel med 200 mm inre diameter. För att erhålla borrkärna från ytan till fullt djup borrades ett andra kärnborrhål från ytan till 101,03 meter, detta hål kallades KAV04B.

Ett vatteninflöde på 120 liter per minut vid 49 meters borrlängd uppskattades under hammarborrning av teleskopdelen.

Pumptester med wireline-baserad mätutrustning utfördes normalt var hundrade meter. Uppmätta transmissiviteter (T_M) varierade mellan 9×10^{-8} och 2×10^{-3} m^2/s. Den mest transmissiva sektionen var mellan 710 och 730 meter.

Ett pumptest med mammutpumpning i teleskopdelen som gjordes när kärnborrning utförts till full längd gav en transmissivitet (T_M) på 6×10^{-5} m^2/s.

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

Vattenprovtagning för kemisk analysering genomfördes i samband med borrning. Tre prov togs under borrning av teleskopdelen och nio prov togs under kärnborrningsfasen. Endast två prov, av nio tagna, från kärnborrningsfasen hade ett tillräckligt lågt spolvatteninnehåll för att ge tillförlitliga resultat.

Kärnan domineras av Ävrö granit med inslag av kvartsmonzodiorit, finkornig dioritoid och finkornig granit. Mindre inslag av pegmatit och diorit/gabbro förekommer. Ett större parti av finkornig diorit/gabbro finns mellan 860 och 950 meter.

Oxidation med obetydlig till svag intensitet förekommer i sektioner på mellan 5 och 30 meters bredd i kärnan i de övre 500 metrarna av kärnan. På större djup ökar både intensitet och utbredning av oxidation.

Den totala sprickfrekvensen är normalt mindre än 20 per meter till ca 200 meter. Mellan 200 och 700 meter är sprickfrekvensen något högre med ett spann på ca 5–30 per meter. Under 700 meter har flera krosszoner (dvs total sprickfrekvens > 40 per meter) noterats.

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. The island of Ävrö is situated in the northern part of the Simpevarp subarea of the investigation area in Oskarshamn /2/.

Drilling and investigations in boreholes are fundamental activities in order to facilitate characterisation of rock and groundwater properties at depth. KAV04 was the fourth deep cored borehole within the Oskarshamn site investigation. The location of the hole on Ävrö is shown in Figure 1-1.

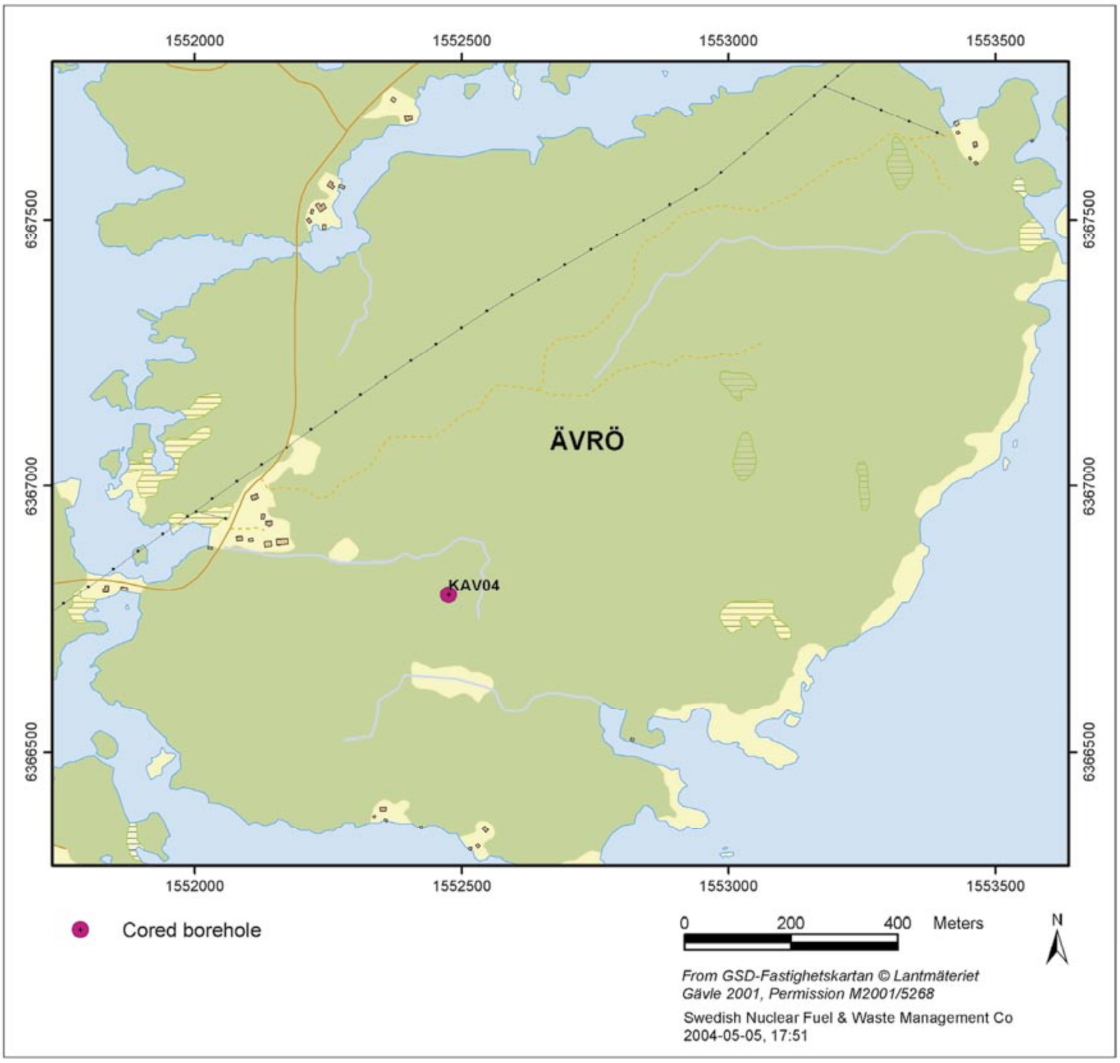


Figure 1-1. *Locations of the drillholes KAV04 on the island of Ävrö in the Simpevarp subarea.*

The drilling of KAV04 and all related on-site operations were performed according to a specific Activity Plan, which in turn refers to a number of method descriptions, see Table 1-1.

The activity plans and method descriptions are SKB internal documents.

Data collected during the drilling of KAV04 was entered into the Sicada database under field notes 143 and 341, see Table 1-2.

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

Activity plan	Number	Version
Kärnborrning KAV04	AP PS 400-03-050	1.0*
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	1.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	1.0
Metodbeskrivning för genomförande av hydrauliska enhålstrester	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning	SKB MD 640.001	1.0
Metodbeskrivning för pumptest, tryckmätning och vattenprovtagning i samband med wireline-borrning	SKB MD321.002	1.0
Mätsystembeskrivning för längdmarkering (spårfräsning)	SKB MD620.009	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruktion för användning av kemiska produkter och material vid borrning och undersökningar	SKB MD 600.006	1.0
Instruktion för borrplatsanläggning	SKB MD 600.005	1.0
Instruktion för spolvattenhantering	SKB MD 620.007	1.0
Instruktion för utsättning och inmätning av borrhål	SKB MD 600.002	1.0
Method description for in-situ stress measurements by means of overcoring using the Borre probe	SKB MD 181.001	1.0

* Two amendments dated 2003-10-17 exist.

Table 1-2. Data references.

Subactivity	Database	Identity number
Drilling KAV04A	SICADA	Field note 143
Drilling KAV04B	SICADA	Field note 341
Overcoring rock stress measurements	SICADA	Field note 143

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of KAV04. 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. Results from the the overcoring measurements will only be reported here in a summary fashion as a separate report, SKB P-04-84, has been compiled /3/.

The main reasons for drilling borehole KAV04 was to gain geological information at depth of the northern part of the Simpevarp subarea and to facilitate further investigation at depth in the borehole. The decision to drill KAV04 is included in SKB id no 1020713 (SKB internal document).

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

A notification in accordance with the Environmental Code was issued to the regional authorities on 2003-05-21, SKB id no 1014488 (SKB internal document). A reply, without objections, was received on 2003-06-13, SKB id no 1015298 (Regional Authority registration no 525-6832-03).

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 cored section to full length. The larger diameter section can either be percussion drilled or reamed with a percussion bit after core drilling of a pilot hole.

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

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

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

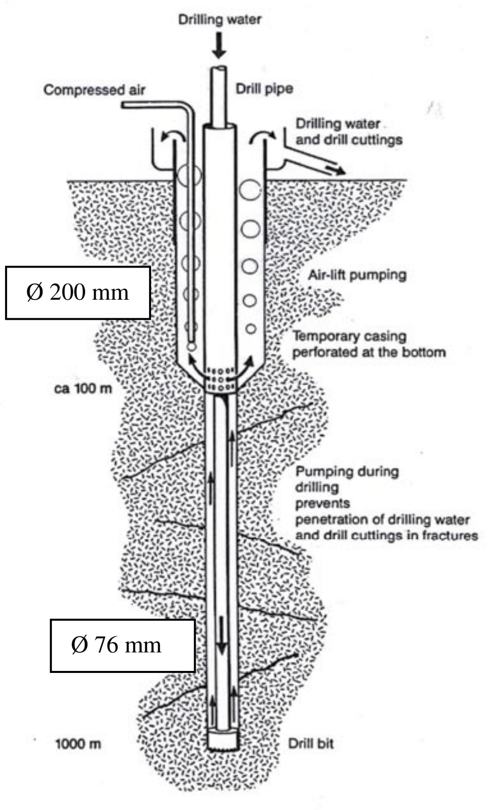


Figure 3-1. *A sketch of the telescopic drilling method with air-lift pumping for retrieval of drilling water and cuttings.*

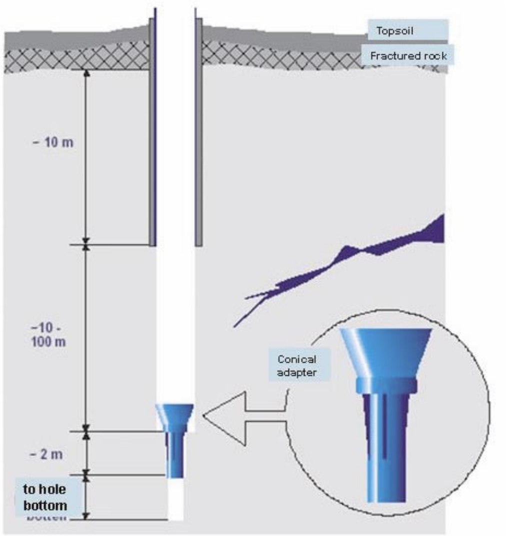


Figure 3-2. Installation of the conical guide.

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

3.1.1 The flushing water system

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

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

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

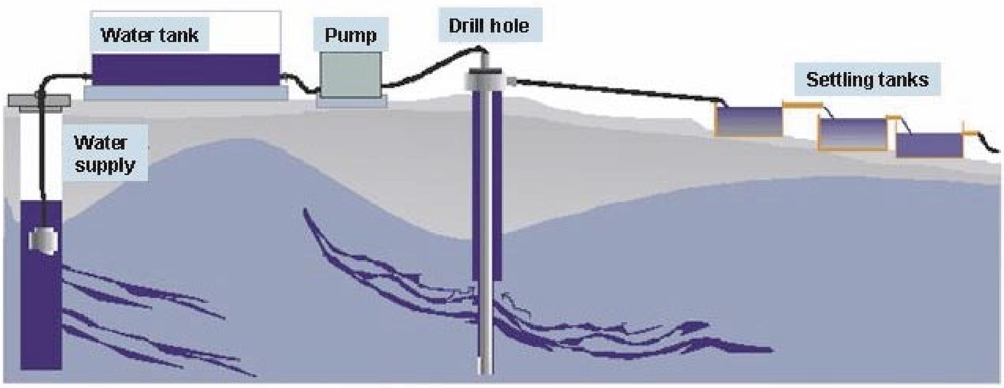


Figure 3-3. The flushing water system from source to discharge point.

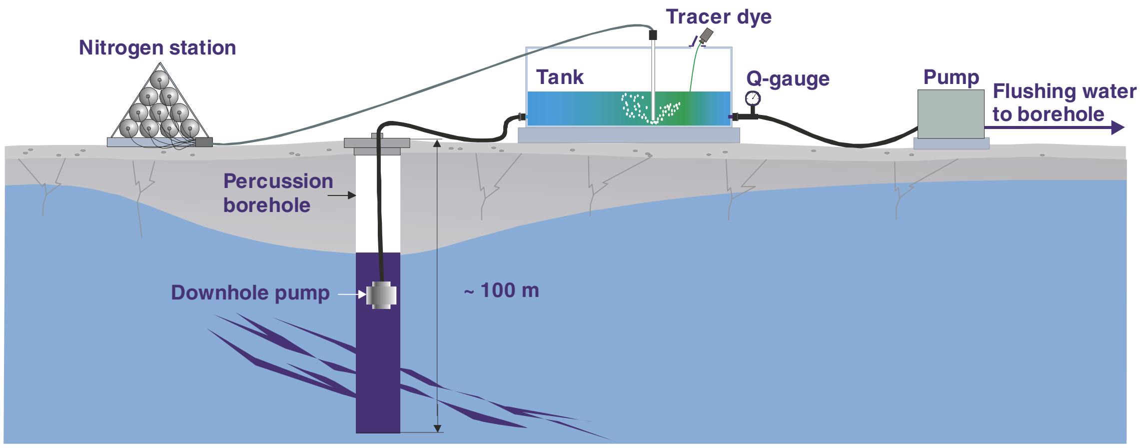


Figure 3-4. *Preparation of flushing water. Uranine is added to the water in the tank as a tracer dye. Nitrogen is bubbled through the water to remove dissolved oxygen.*

3.2 Measurements and sampling during drilling

3.2.1 Percussion drilling

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

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

3.2.2 Core drilling

The sampling and measurements during the core drilling phase of KAV04A consisted of:

- Rock stress measurements with the overcoring method.
- Wireline measurements.
- Air lift pumping and recovery tests.
- Water sampling at the surface.
- The drilling monitoring system.

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 is given in SKB report P-04-84 /3/.

Wireline measurements and water sampling

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

Air lift pumping and recovery tests

Air lift pumping and recovery tests are 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. After drilling has ceased and the stem removed, the flow of ingoing water is normally stopped. The air lift pumping, however, continues for a period of about one hour. After the air lift pumping has been discontinued the recovery of the water table in the telescopic section is measured.

Water sampling at the surface

Water samples of flushing and return water, ie the water entering and returning from the borehole at the surface, are taken at 10 to 20 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).

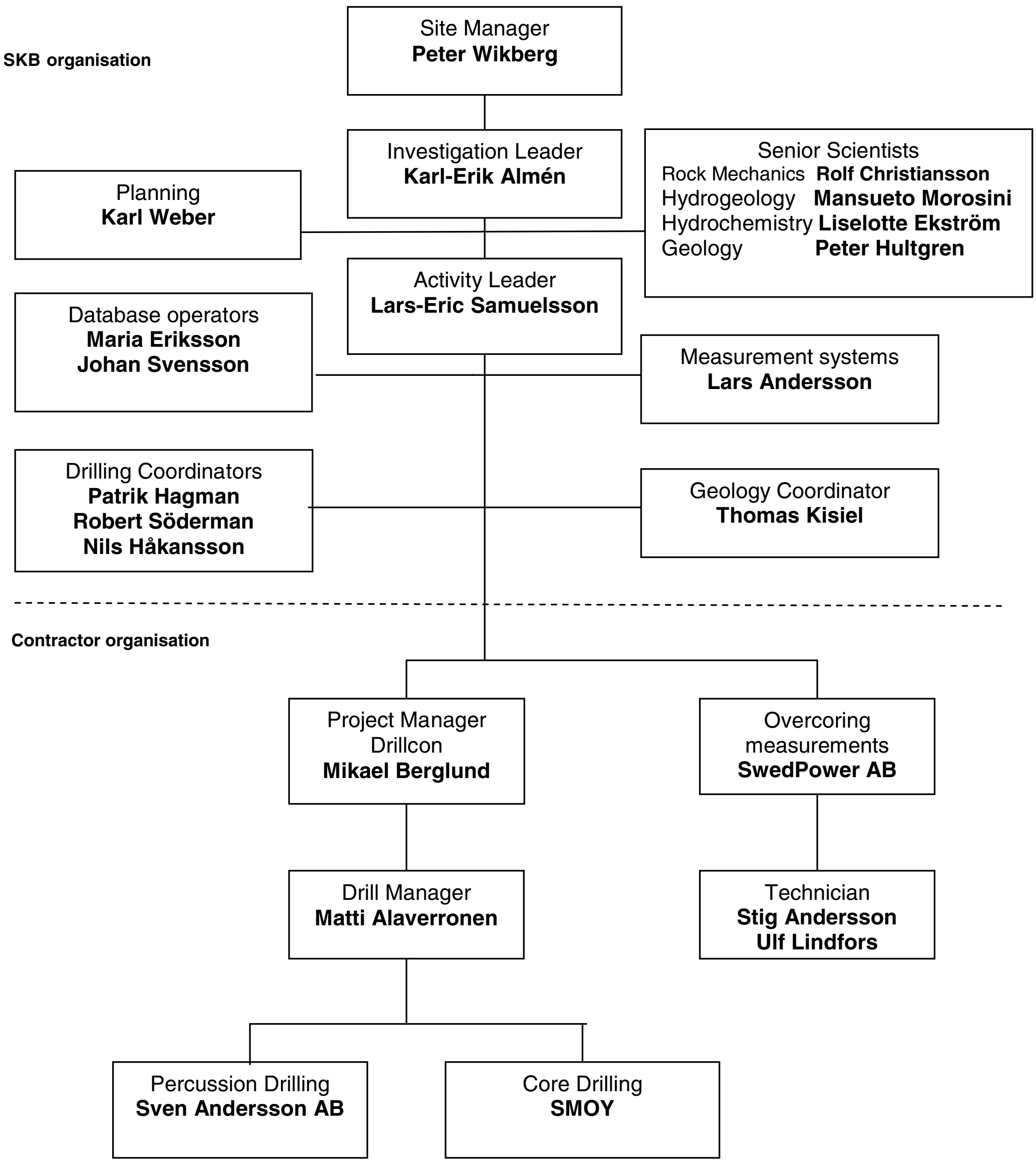
4 Contractors and equipment

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 was a Puntel MX1000 percussion drill rig with an Atlas Copco XRVS 455 Md air compressor. The down-the-hole hammer was a Secoroc 8" or 6" and the drill rods were Driqoneq 114 mm. The casing utilized was St 37 406.5 mm, SS 2343 208×4 mm and 273×4 mm. The casing dimensions are presented as outer diameter and thickness.

4.3 Core drilling equipment

Core drilling in KAV04 was made with a B 20 P Atlas Copco fully hydraulic machine fitted with a modern and environmentally adapted diesel engine. The rods were of the type Corac N3/50 NT with a 76 mm wireline triple tube core barrel system which gives a core diameter of 50.2 mm.

Figure 4-1. *Establishing the drill rig at the KAV04 drill site.*

4.3.1 Equipment for overcoring 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 planing tool,
- 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 procedure for stress measurement using the Borre probe is briefly summarized in Figure 4-2. Further description of equipment and procedure is given in /3/.

4.3.2 Wireline measurements equipment

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

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

The principal components are:

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

The probe and packer are lowered through the drill stem into position at the drill bit. The test section is between the lower end of the packer and the bottom of the borehole, see Figure 4-3.

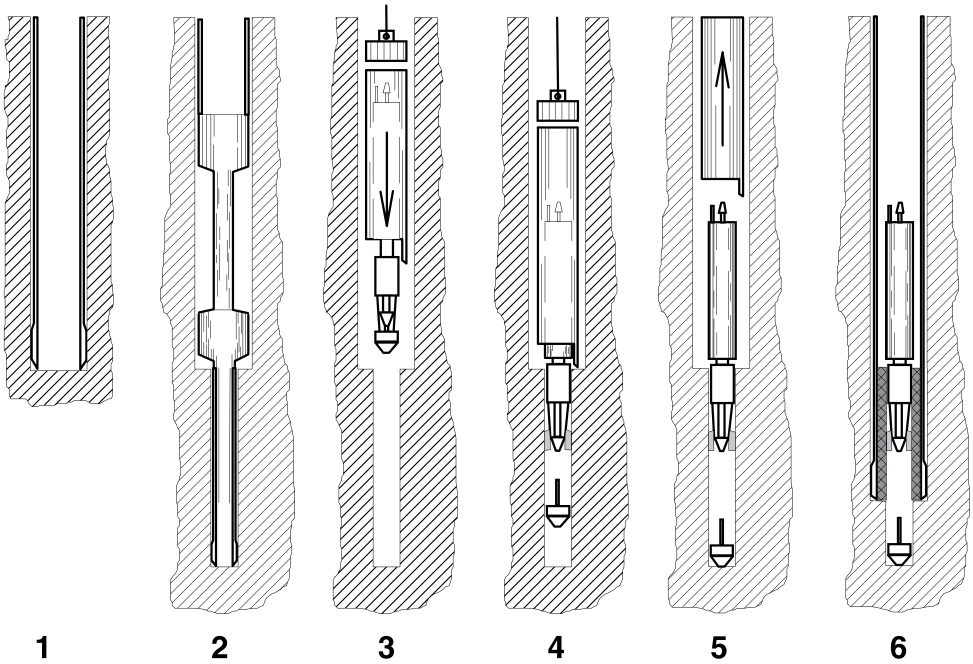


Figure 4-2. *Installation and measurement procedure with the Borre probe:*

1. *Advance 76 mm-diameter main borehole to measurement depth. Grind the hole bottom using the planing 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.*

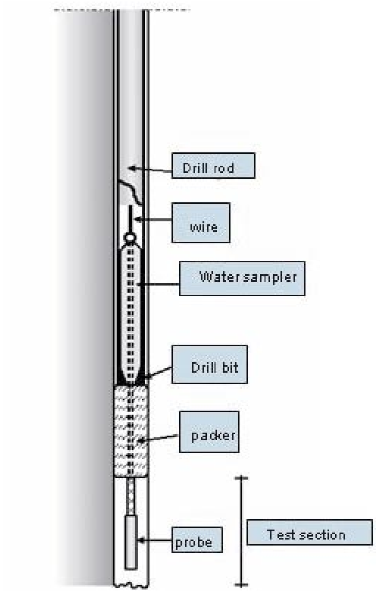


Figure 4-3. *The wireline probe and its emplacement in the hole.*

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

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

Pumping tests

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

Water sampling

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

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

Absolute pressure measurement

The wireline probe is placed in position at the drill bit. The packer is inflated and the pressure build-up in the test section is recorded for a period of at least eight hours, typically this is done overnight. The measuring range for the pressure gauge is 0–20 MPa (± 0.05% FSD).

4.3.3 Drilling monitoring system

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

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

The drill rig (MWD) parameters include:

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

The flushing water parameters include:

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

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

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

4.3.4 Equipment for deviation measurements

Deviation measurements were performed in the boreholes using a Reflex MAXIBOR™ (non-magnetic) optical equipment.

4.3.5 Equipment for reaming reference slots

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

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

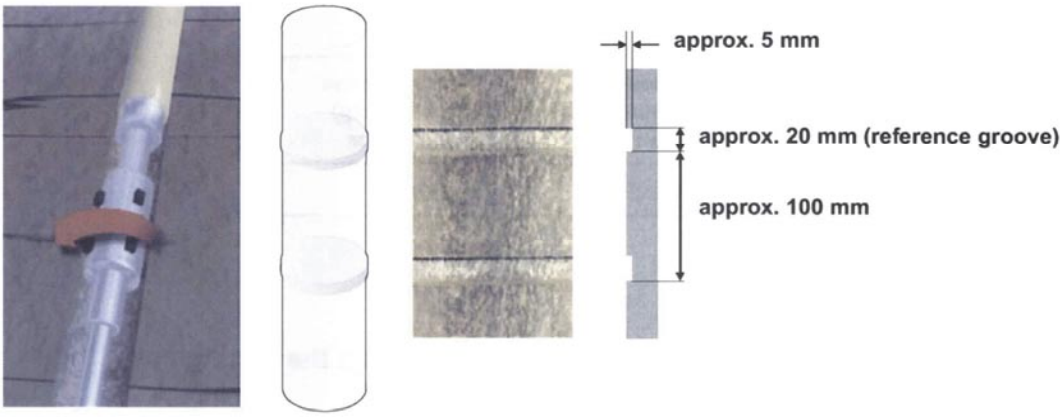


Figure 4-5. *The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.*

5 Execution and results

5.1 Summary of KAV04 drilling

A technical summary of the drilling of KAV04A and the borehole design after completion is given in Table 5-1 and Figure 5-1.

A technical summary of borehole KAV04B is given in Table 5-2 and Figure 5-2.

Further descriptions of the two main drilling steps, the telescope section 0–100.2 metres and the core drilling section 100.0–1,004.0 metres are given in sections 5.2 and 5.3 respectively.

Table 5-1. KAV04A summary.

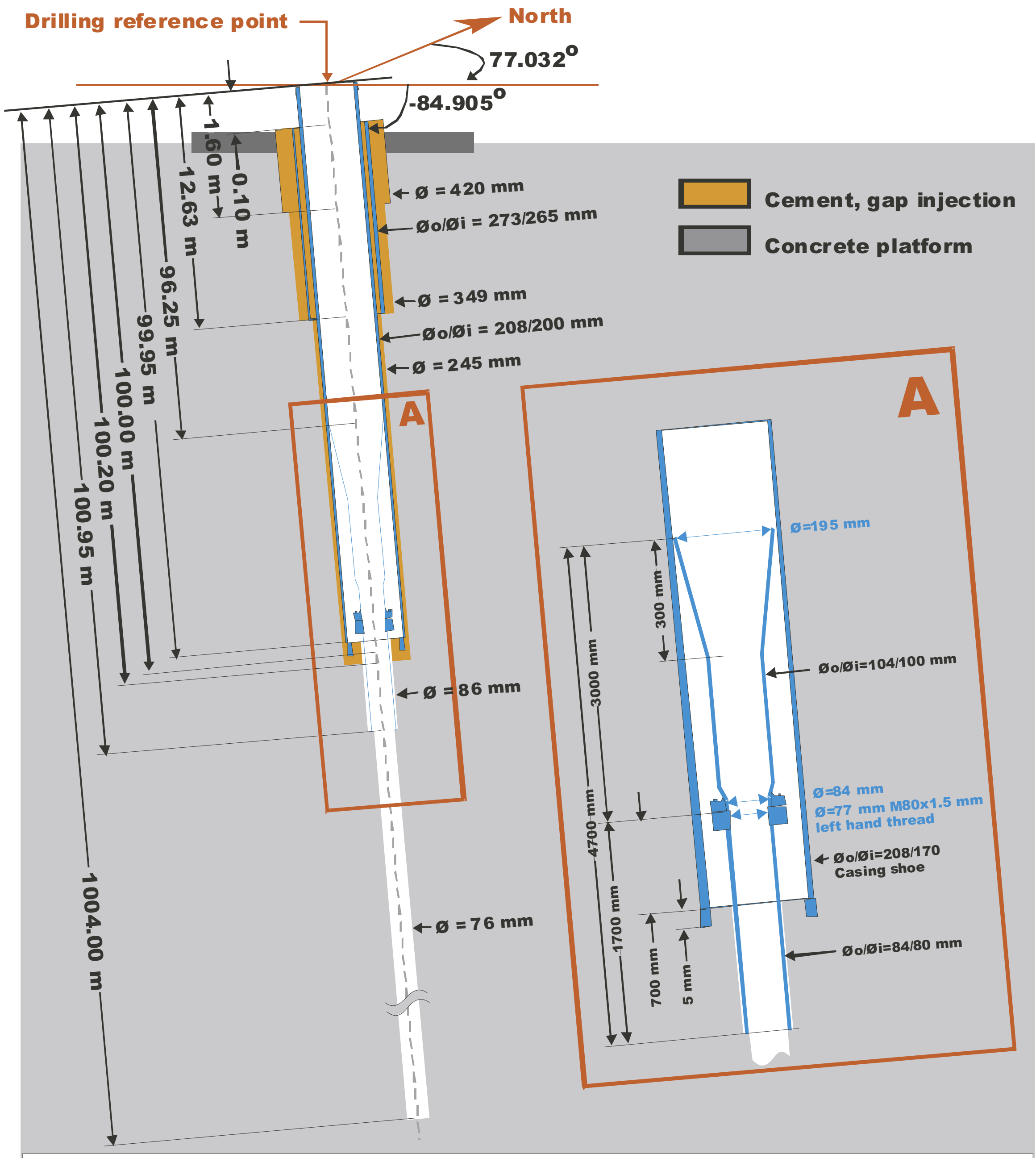
General	Technical
Name of holes: KAV04A	Percussion drill rig: Puntel MX 1000
Location: Simpevarp, Oskarshamn Municipality, Sweden	Percussion drill hole diameter: 245 mm
Contractor for drilling: Drillcon AB	Casing diameter (inner): 200 mm
Subcontractor percussion drilling: Sven Andersson AB	Percussion hole length: 100.2 m
Subcontractor core drilling: Suomen Malmi OY (SMOY)	Core drill rig: B 20 P Atlas Copco
Drill start date: October 10, 2003	Core drill dimension: 76 mm
Completion date: May 3, 2004	Cored interval: 100.0–1,004.0 m
	Average core length retrieved in one run: 2.06 m
	Number of runs: 439
	Diamond bits used: 12
	Average bit life: 75 metres
	Position KAV04A (RT90 RH70) at top of casing: N 6366795.76 E 1552475.00 Z 10.35 (masl)
	Azimuth (0–360) / Dip (0–90): 77.0 / –84.9
	Position KAV04A (RT90 RH70) at 996 m length: N 6366817.11 E 1552550.58 Z –982.46 (masl)
	Azimuth (0–360) / Dip (0–90): 87.2 / –85.5

Table 5-2. KAV04B summary.

General	Technical
Name of holes: KAV04B	Core drill rig: B 20 P Atlas Copco
Location: Simpevarp, Oskarshamn Municipality, Sweden	Core drill dimension: 76 mm
Contractor for drilling: Drillcon AB	Cored interval: 0–101.03 m
Subcontractor core drilling: Suomen Malmi OY (SMOY)	Position KSH03B (RT90 RH70) at top of casing: N 6366795.64 E 1552474.47 Z 10.35 (masl)
Drill start date: May 12, 2004	Azimuth (0–360) / Dip (0–90): 134.3 / –89.8
Completion date: May 18, 2004	

Technical data

Borehole KAV04A



Drilling reference point

Northing: 6366795.76 (m), RT90 2,5 gon V 0:-15

Easting: 1552475.00 (m), RT90 2,5 gon V 0:-15

Elevation: 10.35 (m), RHB 70

Drilling period

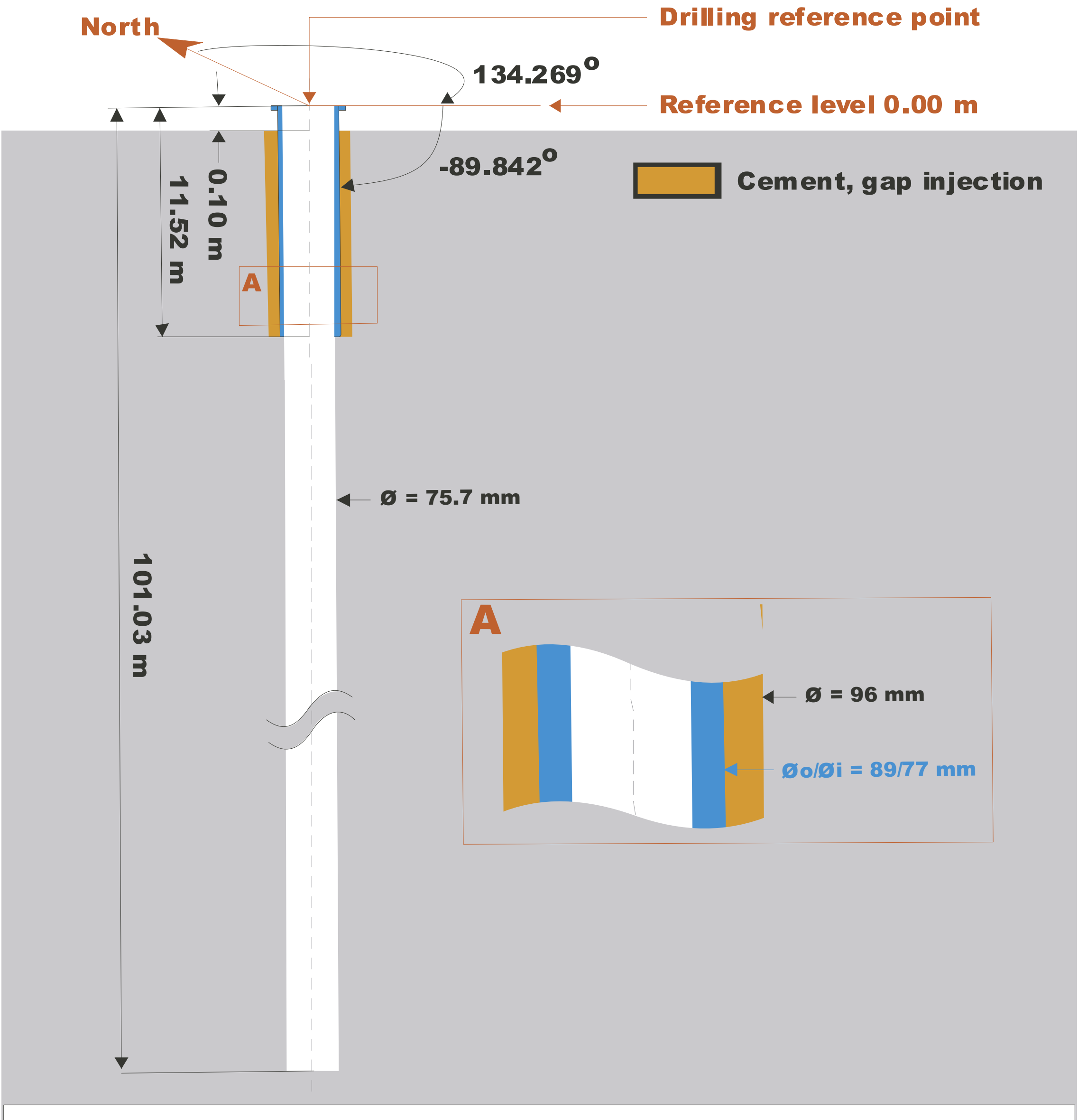
Drilling start date: 2004-10-06

Drilling stop date: 2004-05-03

Figure 5-1. *Technical data from borehole KAV04A.*

Technical data

Borehole KAV04B



Drilling reference point

Northing: 6366795.641 (m), RT90 2,5 gon V 0:-15

Easting: 1552474.469 (m), RT90 2,5 gon V 0:-15

Elevation: 10.352 (m), RHB 70

Drilling period

Drilling start date: 2004-05-12

Drilling stop date: 2004-05-18

Figure 5-2. *Technical data from borehole KAV04B.*

In order to retrieve a complete core from surface to full depth an additional drilling was made to 101.03 metres about one metre from the percussion drill hole. The core and the borehole are called KAV04B.

Drilling was made from the surface level with 76 mm core drilling equipment to a length of 11.5 metres. The hole was subsequently reamed to 96 mm diameter and a casing (89/77 mm) was installed and gap injected. The tightness of the gap injection was tested by manual measurements of water level recovery. No inflow of water could be established.

Drilling with 76 mm diameter was continued to 101.03 m. The geology of KAV04B is presented in Appendix 1.

N.B. Unless otherwise stated the rest of this report will deal with results from KAV04A.

5.2 Drilling, measurements and results in the telescopic section 0–100.2 m

Drilling, reaming and gap injection were made from October 6 to 9 and October 27 to November 1, 2003.

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 (0–100.2 metres) of KAV04A was made in steps as described below and shown in Figure 5-3:

Drilling was done by Sven Andersson AB between October 6–9 and consisted of the following items:

- Drilling was made to 1.6 metres depth with NO-X 400 mm equipment. This gave a hole diameter of 420 mm.
- Inner supportive casing for guidance for the drill string was mounted and a pilot percussion hole of 162 mm was drilled to a depth of 12.7 metres (to fresh rock). The inner casing was removed and the pilot hole was reamed in two steps to 246 mm and then to 350 mm diameter.
- The casing (273×4 mm diameter) through fractured rock was installed to a depth of 12.63 m. Gap injection with low alkali cement based concrete (357 kg or 400 litres) was made as described in Figure 5-4.
- A pilot hole with diameter 159 mm was drilled to a length of 100.2 m.

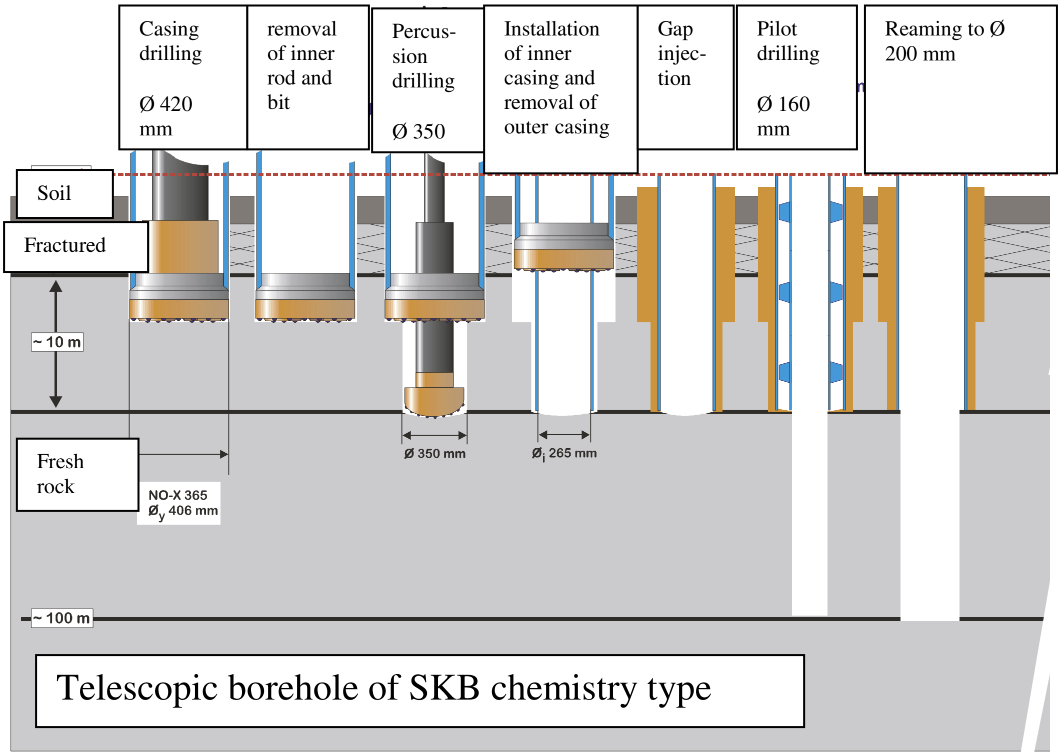


Figure 5-3. *Method for drilling and installation of the first 100 metres. In addition to the steps shown in the figure an extra set of casing (208/200 mm) was emplaced in KAV04A.*

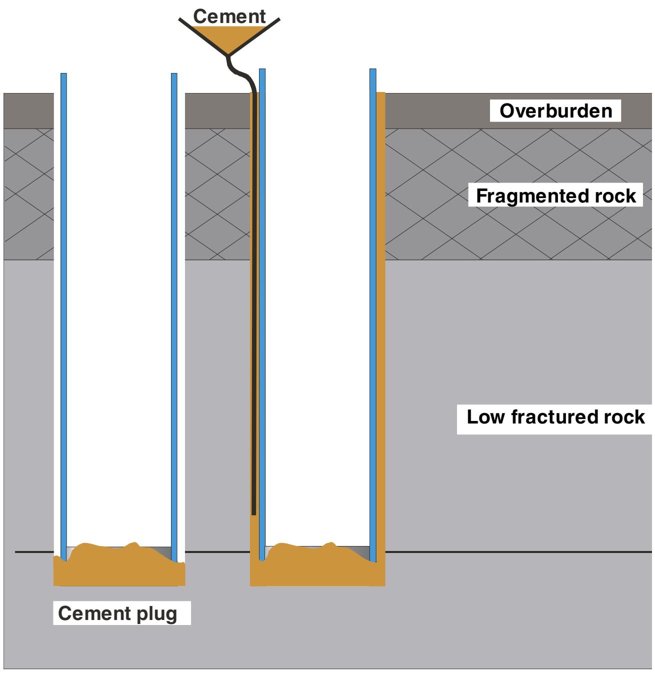


Figure 5-4. *Gap injection technique 1. A cement plug is emplaced at the bottom and allowed to harden. The gap filling cement is introduced between the casing and the rock wall.*

Drilling was resumed in KAV04 on October 27 after working on nearby holes HAV09 and HAV10.

- The hole was reamed to diameter 247 mm to a length of 100.2 m.
- Stainless casing of 208×4 mm was installed from 0 to 100.00 m and gap injection with low alkali cement based concrete (2,784 kg or 3,120 litres) was made as described in Figure 5-5. After hardening the hole was rinsed and flushed to remove concrete and water. The tightness of the concrete gap filling was tested by manual groundwater measurements which confirmed that the water inflow was less than the required 0.5 litres per minute.

5.2.3 Measurements and sampling in the telescopic section

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

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

The preliminary geological results and penetration rate is presented in Figure 5-6.

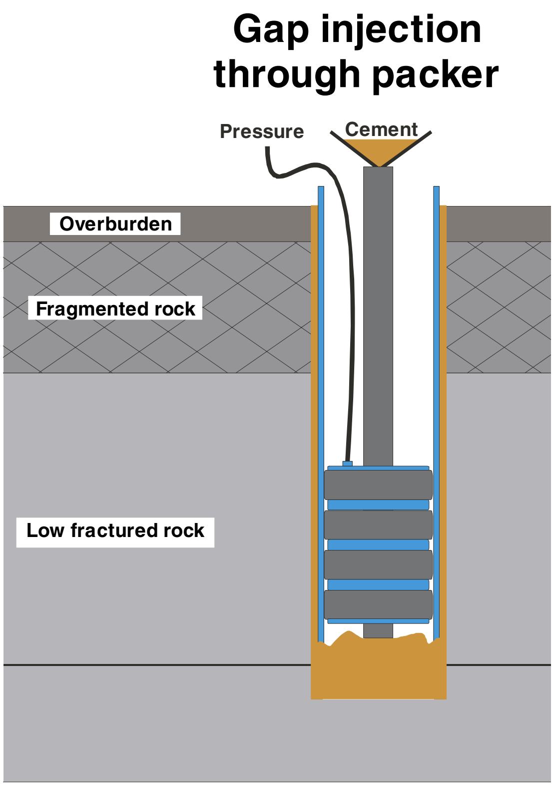


Figure 5-5. Gap injection technique 2. A packer is emplaced at the bottom of the hole and the concrete is introduced through the packer and forced up between the casing and the rock wall.

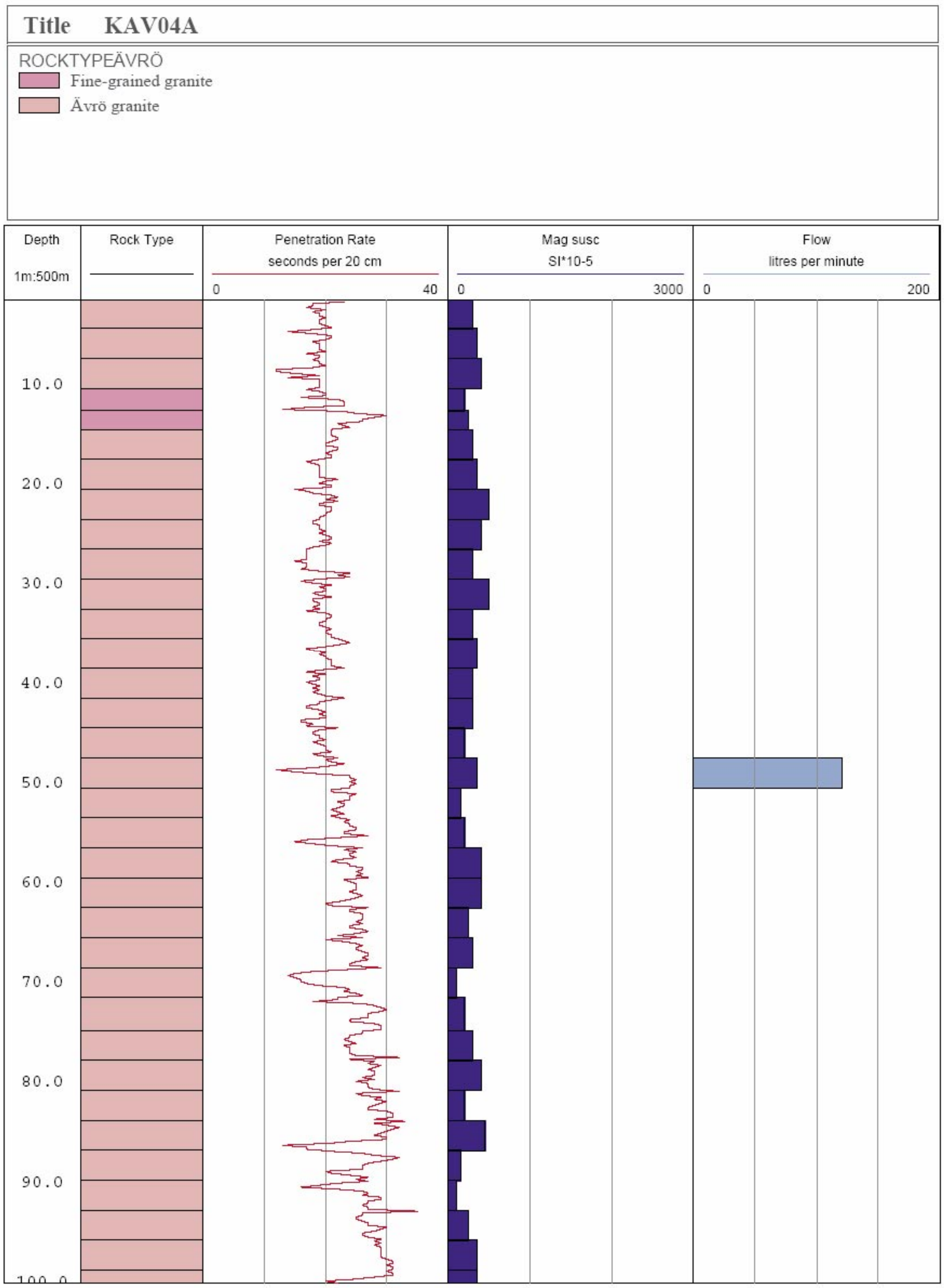


Figure 5-6. *Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KAV04A.*

Hydrogeology

A distinct inflow of water with a flow of 120 l/min was noted at 49 metres during the percussion drilling of the 159 mm hole.

A pumping test of the percussion drilled pilot hole (159 mm diameter) of KAV04A was made by SKB on October 21 ie before the hole was reamed to 247 mm. The pump was emplaced at 50 metres length.

The hole was pumped for about three hours with flow of $2.0 \cdot 10^{-3}$ m^3/s (120 litres per minute) resulted in a total drawdown of 17.2 m. The drawdown and recovery are shown in Figure 5-7.

The test was evaluated with Cooper-Jacob's method following the methodology in SKB MD 320.004 (SKB internal document). The results are presented in Table 5-3.

Table 5-3. Results from pumping test in section 12.63–100.00 m of KAV04A.

Tested section (m)	Pumping rate (m^3/s)	Total drawdown (m)	Q/s (m^2/s)	T_M (m^2/s)	T_{Sf} (m^2/s)	T_{Ss} (m^2/s)
12.63–100.00	$2 \cdot 10^{-3}$	17.2	$1.2 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$9 \cdot 10^{-5}$

T_{Sf} : Transmissivity from transient semi-log evaluation of drawdown phase.
T_{Ss} : Transmissivity from transient semi-log evaluation of recovery phase.

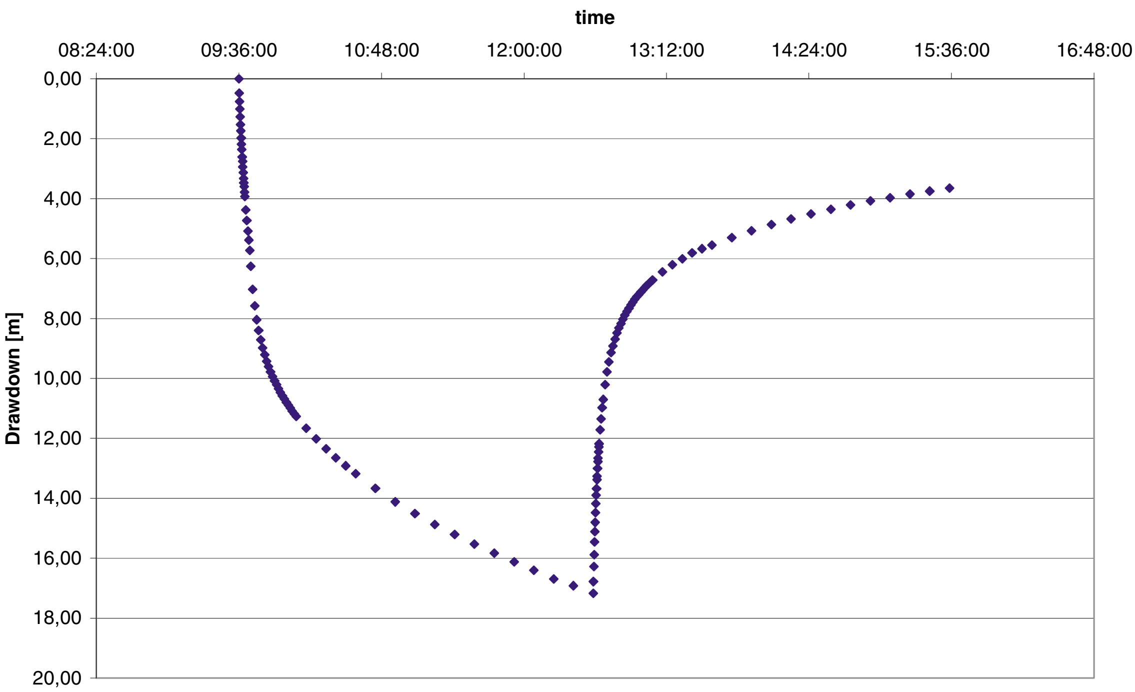


Figure 5-7. Drawdown and recovery from the pumping test in the percussion drilled section (12.63–100.0 m) of KAV04.

Hydrochemistry

Three water samples were collected. Sampling and analysis of the samples 5905 and 5904 were performed according to SKB class 3, see Table 5-4.

Table 5-4. Sample dates and length during percussion drilling in KAV04.

SKB number	Date	Test section, length (m)	SKB chemistry class
5905	2003-10-09	47.60–50.60	3
5904	2003-10-09	0.00–100.20	3
5909	2003-10-21	0.00–100.20	5, se comments below (3 and all isotope options)

Sample 5909 is analysed for DOC (dissolved organic carbon) and this analysis is an option in chemistry class 5. Apart from that the sample is analysed as a class 3 sample with all isotope options.

The sample 5909 is analysed for the stable isotope ^{37}Cl but the result has not yet been reported to SICADA. The ^{37}Cl result is therefore not included in this report and will only be reported in SICADA.

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

Table 5-5. Selected analytical results from samples 5905, 5904 and 5909.

Sample no	pH	Conductivity mS/m	Cl mg/l
5905	8.39	64.2	22.6
5904	8.18	69.0	37.4
5909	8.38	67.8	25.7

5.3 Core drilling 100.0–1,004.0 m

Core drilling in KAV04A was conducted between October 6, 2003 and May 3, 2004.

The main work in KAV04A after pre-drilling of the telescopic section consisted of the following steps:

- preparations for core drilling,
- drilling,
- overcoring rock stress measurements,
- deviation measurements,
- borehole completion.

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

5.3.1 Preparations

The preparations for the core drilling consisted of installation of air-lift pumping equipment and supportive casing for alignment of the core drill rods, see Figure 5-8.

The installation of supportive casing was done in two steps:

- An outer casing with a diameter of 98/89 mm, fitted with fins to align with the diameter of the stainless 200 mm (inner diameter) casing, was installed to a length of 99.58 m.
- Equipment for air-lift pumping was installed and a discharge header, see Figure 5-9, was fitted to collect the return water.
- Drilling was made between 99.55 and 100.95 m with T-86 equipment. An inner supportive casing with diameter 84/77 mm was installed to 100.95 m.

The supportive casings have a perforated section between 99.0 and 99.2 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.

The return water from drilling was led to a series of sedimentation containers in order to collect sludge before discharge to the Baltic Sea.

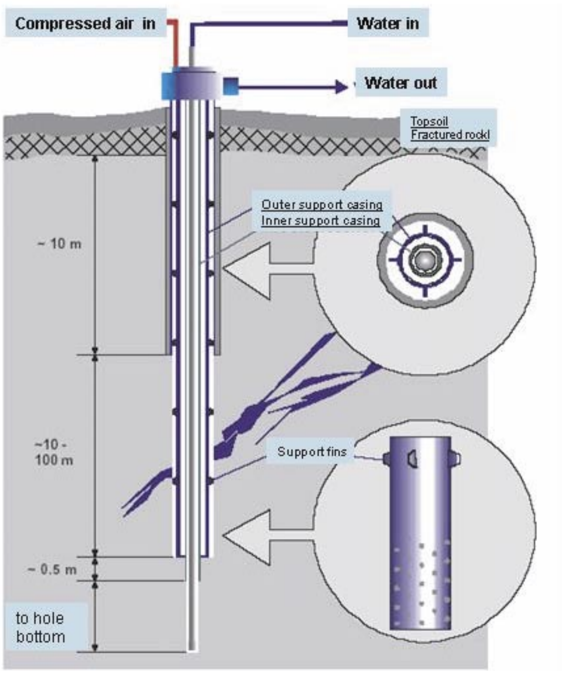


__Figure 5-8.__ In the telescopic part of the drill hole a temporary installation is made with casing tubes for support and alignment and equipment for air-lift pumping. In the uppermost part the return water discharge header is mounted. The water discharge is led to the settling containers.

Figure 5-9. *The water discharge header and hoses for air-lift pumping.*

5.3.2 Drilling

Core drilling with 76 mm triple-tube, wireline equipment commenced on December 11 and was conducted from 100.95 m to the final length of 1,004.0 m which gave a core of 50.2 mm diameter.

A total of twelve drill bits were used for KAV04A, see Figure 5-10.

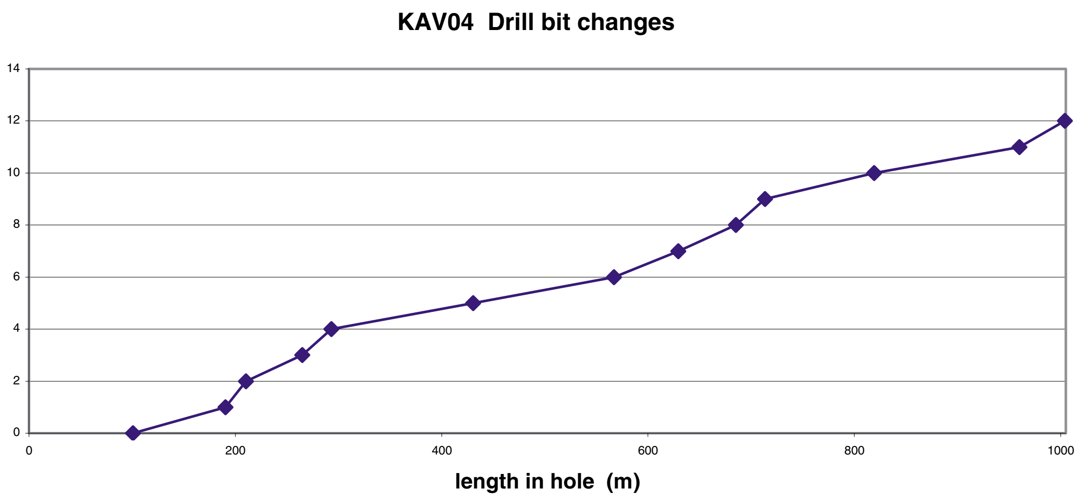


Figure 5-10. *Changes of drill bit during core drilling in KAV04A.*

The elasticity of the drill stem was not measured during the drilling of KAV04A.

Further results from drill monitoring ie drill penetration rate and various measurements will be presented in chapter 5.5 "Drilling monitoring results" and in Appendix 1. The drilling progress over time is shown in section 5.5, see Figure 5-16.

5.3.3 Overcoring measurements

Measurements were attempted along three length intervals, 249–273 metres, 429–456 metres and at 447–463 metres.

The stress state in borehole KAV04A was characterized by low to moderate stresses, reaching at the most 20 MPa at 640 metres. The maximum horizontal stress were in most cases oriented E-W to WNW-ESE.

The overcoring rock stress measurements are reported separately /3/ and will not be commented further here.

5.3.4 Deviation measurements

Two plots of the results of the final run with the Maxibor method covering the entire length of borehole KAV04A is given in Appendix 4. Deviation measurement of KAV04B was not made as part of the drilling activity.

5.3.5 Borehole completion

Reaming of depth reference slots was done at intervals as shown in Table 5-6. The depth reference slots are used for depth calibration of down-hole equipment for subsequent investigations in the hole.

Table 5-6. Depth reference slots (m).

110.00	550.00
150.00	600.00
200.00	650.00
250.00	700.00
300.00	750.00
350.00	800.00
400.00	846.00
451.00	900.00
500.00	950.00

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

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

A steel conical guide was installed between 96.25 m and 99.25 m depth together with a 84/80 mm casing between 99.25 and 100.95 m. The conical guide tapers from an inner diameter of 195 mm to 77 mm.

The length of the hole was rinsed by flushing nitrogen gas four times. A total of 42 m^3 of water was flushed out of the hole. A dummy probe was run through the length of the hole to ensure that the hole was unobstructed.

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

5.4 Hydrogeological and hydrochemical measurements and results 100.0–1,004.0 m.

The performed measurements can be summarised as follows:

Wireline measurements:

- Fourteen pumping tests resulting in ten completely successful tests were conducted, see section 5.4.1
- Five measurements of absolute pressure, see section 5.4.1
- Water samples were successfully collected from nine of the fourteen pumping tests, see section 5.4.2

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

Two air lift pumping and recovery test were made, see section 5.4.3.

5.4.1 Hydrogeological results from wireline measurements

Results from the pumping tests in KAV04 are presented in Table 5-7 and Figure 5-11.

The pumping tests are evaluated with steady-state assumption in accordance with Moye /4/. The flow rate at the end of the drawdown phase is used for calculating the specific capacity (Q/s) and transmissivity (T_M), where “Q” is the flow rate in litres/min, “s” is the drawdown in kPa and “T_M” is the transmissivity according to /4/.

A total of fourteen pumping tests were performed, and ten of them achieved sufficiently stable conditions for calculating pseudo steady-state transmissivity. The other four tests failed due to problems with the flow, the instruments or the electricity. The plots from the pumping tests are given in Appendix 5.

Table 5-7. Pumping tests with the wireline probe in KAV04A.

Tested section	Q/s (m^2/s)	T_M	Comments
100.00–202.82	$6.8 \cdot 10^{-8}$	$8.9 \cdot 10^{-8}$	Pumping test without wireline probe. Values of the pressure are taken from the drill stem.
245.85–273.74	–	–	The pumping test was discontinued due to a too low flow.
245.85–280.96	–	–	Test failed due to problems in communication with the instruments in the test section.
245.85–293.05	$2.0 \cdot 10^{-5}$	$2.4 \cdot 10^{-5}$	Highly variable flow during the test.
291.15–408.49	$2.1 \cdot 10^{-6}$	$2.8 \cdot 10^{-6}$	Highly variable flow at the end of the test period.
408.00–517.98	$8.9 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$	Test OK in section.
516.15–603.42	$5.4 \cdot 10^{-6}$	$7.0 \cdot 10^{-6}$	Test functionally OK.
602.90–713.58	$2.0 \cdot 10^{-6}$	$2.7 \cdot 10^{-6}$	Test functionally OK.
710.90–730.08	–	–	Test failed due to problems with logger battery.
710.90–730.08	$2.0 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	Test OK in section.
729.00–805.52	($5.7 \cdot 10^{-5}$)	($7.2 \cdot 10^{-5}$)	Large difference in drawdown between test section and surface part of the borehole indicate that there is probably no direct hydraulic connection to the test section. Calculated values(Q/s and T_M) are not considered representative for the formation.
729.00–819.01	$7.2 \cdot 10^{-6}$	$9.2 \cdot 10^{-6}$	Slowly increasing level in test section, in spite of continued pumping.
819.00–913.27	–	–	Test failed due to power cut.
911.93–1,001.2	$3.0 \cdot 10^{-7}$	$3.8 \cdot 10^{-7}$	Very low flow. Test OK in section.

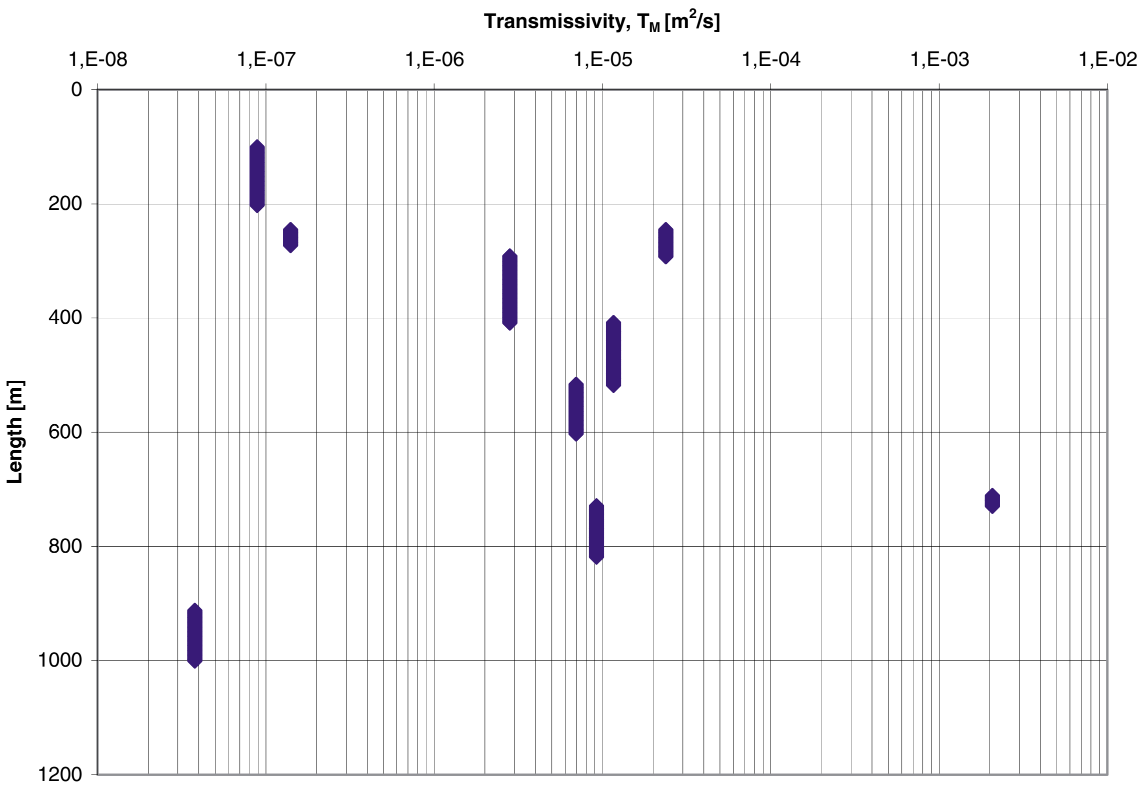


Figure 5-11. *Transmissivity from wireline pumping tests in KAV04 versus borehole length.*

Measurements of the absolute pressure were conducted in five sections, see Table 5-8. Graphical results from the tests are shown in Figure 5-12 and in full in Appendix 6.

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

Table 5-8. Absolute pressure measurements in KAV04A.

Tested section	Last pressure reading during build-up (kPa)	Duration of pressure build-up (hours)	Borehole length to pressure gauge (m)
201.00–293.05	2,005	13	202.10
290.15–417.45	2,848	12.5	291.25
602.90–713.58	5,920	12	604.00
710.90–739.10	7,022	13	712.00
729.00–819.01	7,198	12	731.10

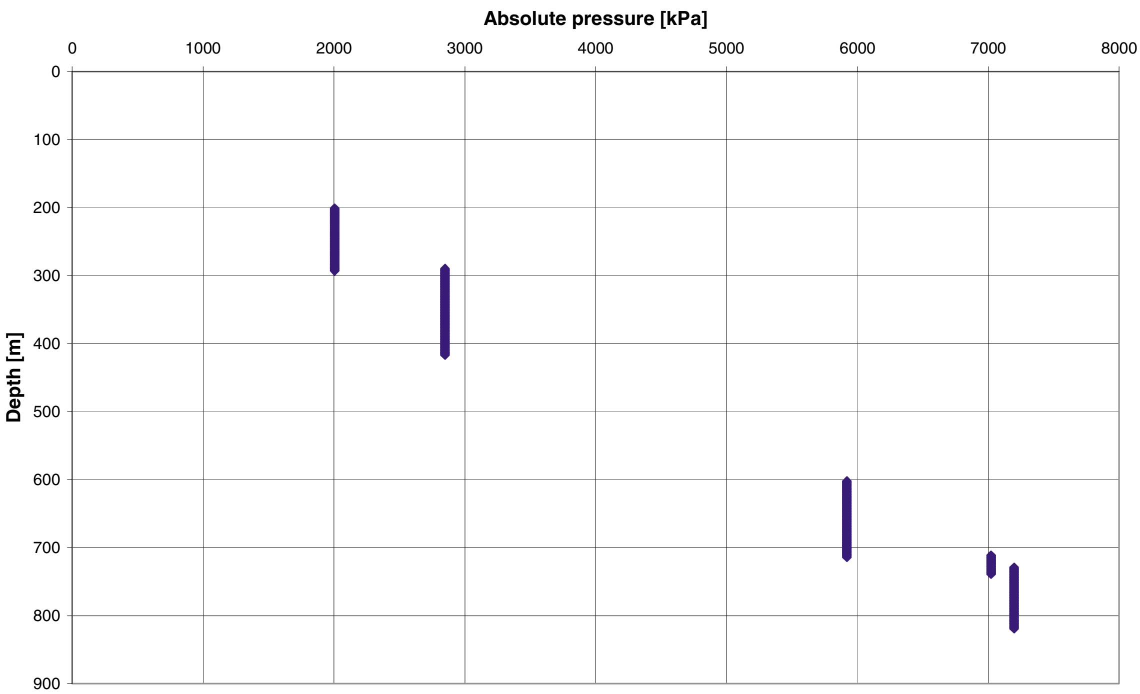


Figure 5-12. *Absolute pressure measurements from wireline tests in KAV04 versus borehole length.*

5.4.2 Hydrochemistry

In total, nine water samples were collected in connection with core drilling in KAV04A. Most of the samples were taken with the wireline probe but one sample, 7106, was taken by pumping water up to the surface.

Table 5-9. Sample dates and length during core drilling in KAV04.

SKB number	Date	Test section, length (m)	SKB chemistry class
7106	2004-01-29	245.85–293.05	3 and all option isotopes except Cl-37
7109	2004-02-08	291.15–408.49	1
7151	2004-02-21	408.00–517.98	3
7153	2004-02-26	516.15–603.42	1
7254	2004-03-26	513.58–602.90	3
7256	2004-03-30	710.90–730.08	1
7257	2004-03-31	710.90–730.08	1
7262	2004-04-14	729.00–805.52	1
7299	2004-04-16	729.00–819.01	3 and all option isotopes except Cl-37

Five samples were analysed according to SKB class 1. The only parameter analysed in these samples was drill water percentage.

Four samples were analysed according to SKB class 3. However, only pH and drill water percentage were analysed in sample 7151 due to the very high concentration of drilling water. For the same reason, cations and isotopes were not analysed in sample 7254.

Selected analytical results from KAV04 and the water source, HSH03, are given in Table 5-10. A complete record of analytical results is given in Appendix 2.

Sample 7299 is analysed for ^{13}C and PMC (percent modern carbon) but the results from these analyses have not yet been reported to SICADA. The carbon isotope results are therefore not included in this report and will only be reported in SICADA.

Table 5-10. Analytical results from water chemistry sampling.

Borehole	Sample no	Date	From m	To m	Drilling water %	pH	Conductivity mS/m	Cl mg/l
KAV04	7106	2004-01-29	245.85	293.05	12.30	7.16	961.0	3,220.0
KAV04	7109	2004-02-08	291.15	408.49	85.20			
KAV04	7151	2004-02-21	408.00	517.98	87.90	7.62		
KAV04	7153	2004-02-26	516.15	603.42	78.60			
KAV04	7254	2004-03-26	513.58	602.90	87.60	7.48	546.0	1,750.0
KAV04	7256	2004-03-30	710.90	730.08	94.20			
KAV04	7257	2004-03-31	710.90	730.08	73.70			
KAV04	7262	2004-04-14	729.00	805.52	63.50			
KAV04	7299	2004-04-16	729.00	819.01	29.20	6.46	2,240.0	8,240.0
HSH03	7108	2004-02-03	0.00	200.00		7.76	340.0	949.0

Two water sources were used during the drilling of KAV04. Initially the percussion drilled borehole HLX10 was used and the water was brought in by truck. In the period between January 18 and 28, corresponding to between 260 and 280 metres, water was intermittently used from both HLX10 and HSH03 because the hoses from HSH03 were frequently frozen. After January 28, ie below 280 metres drilled length, water was taken from HSH03.

One water sample, 7108, was taken from HSH03 in connection with the core drilling of KAV04. The concentration of TOC (total organic carbon) of 3.9 mg/l was considered acceptable for the groundwater to be used as flushing water for the core drilled part of KAV04A.

Previous analyses of the TOC content of the water sources HLX10 and HSH03 are given in earlier drilling reports /5, 6, 7/.

A total of 12 samples were taken in order to determine the microorganism content within the flushing water system. Six of the samples were taken on March 15 (before cleaning the system) and six samples were taken on March 16 (after cleaning). The results will be reported separately.

A total of 179 samples for laboratory testing of uranine content and electrical conductivity in flushing and returning water were taken along the borehole. The results are shown in Figure 5-13.

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

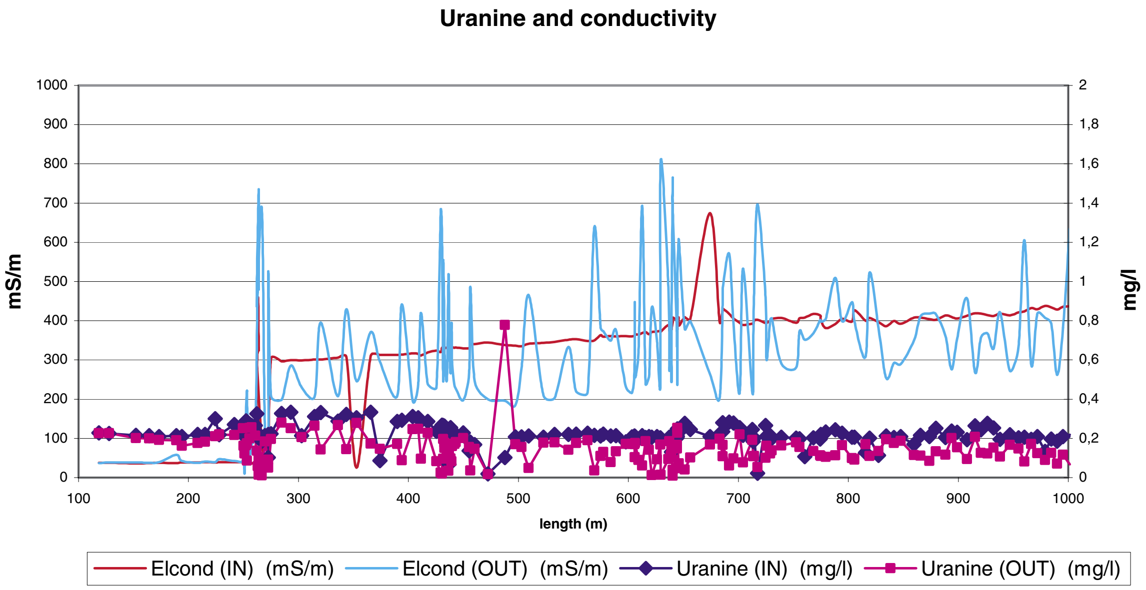


Figure 5-13. *The uranine concentration and electric conductivity of flushing water (IN) and returning water (OUT) in KAV04A during drilling. The increase in conductivity around 260 to 280 metres reflects the change in water source from HLX10 to HSH03. The high peak value in uranine content at 490 metres is probably erroneous, and should be disregarded. The same applies to the two unmotivated anomalies in electrical conductivity (IN) at 350 and 680 metres.*

5.4.3 Air lift pumping results

Air lift pumping tests were performed in the uppermost part of the cored borehole and when the hole was drilled to full depth. Transmissivities according to Moye, /4/, were calculated on the drawdown phase. The results are given in Table 5-11 and in Figures 5-14 and 5-15. The tested section is defined here as being between the lower end of the installed casing in the telescopic section and the hole bottom.

Table 5-11. Specific capacity and transmissivity derived from air lift pumping tests conducted in borehole KAV04A.

Tested section	Flow rate (L/min)	Drawdown (m)	Q/s (m^2/s)	T_M (m^2/s)	Comments
100.00–343.63	6	22	$4.6 \cdot 10^{-6}$	$6.6 \cdot 10^{-6}$	Highly variable flow results in variable groundwater head. The flow is given as an average of the accumulated total net outflow over the time period.
100.00–1,001.20*	67	26.5	$4.1 \cdot 10^{-5}$	$6.8 \cdot 10^{-5}$	Test functionally OK. The flow is given as an average of the accumulated total net outflow over the time period.

* NB the test was made at 1,001.2 m length before the final drilling to 1,004 m was made.

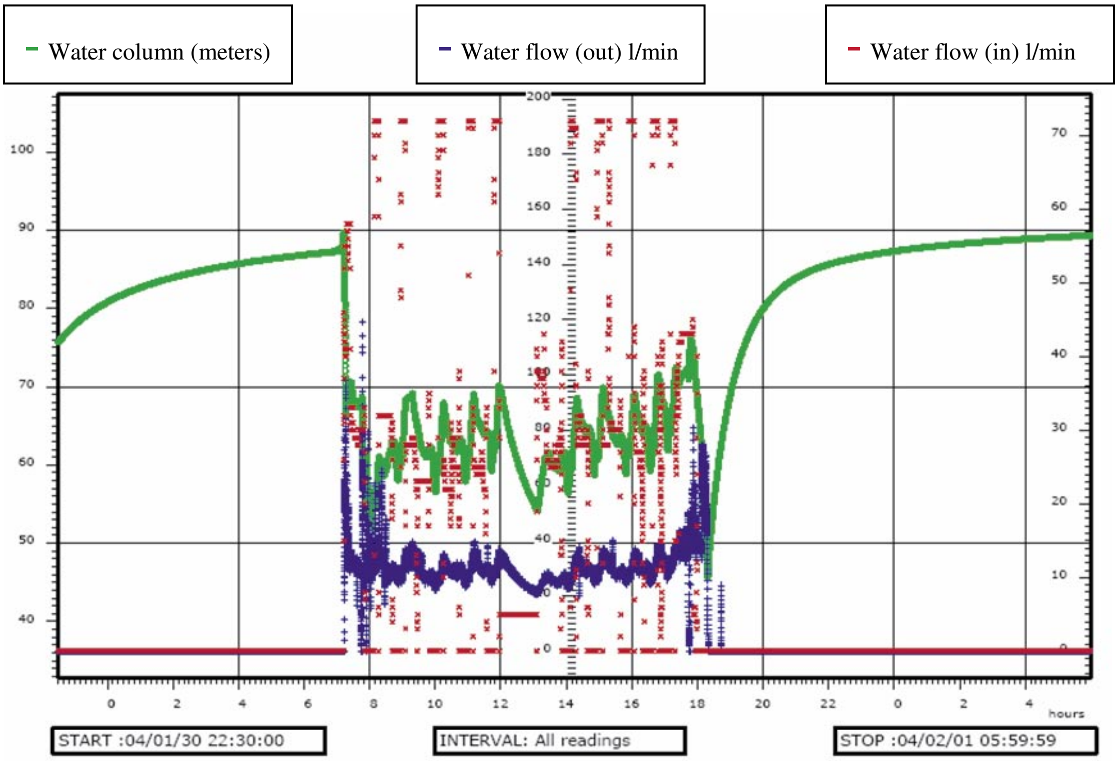


Figure 5-14. *Air lift pumping in KAV04A 100.00 m–343.63 m. showing the inflow rate (red), the net outflow rate (blue) and the height of the water column (green) in the telescopic part of the borehole. The pressure transducer was positioned 90 metres below top of casing and the flow rate was measured at the ground surface. The inflow is the flushing water pumped into the borehole ie not inflowing formation water.*

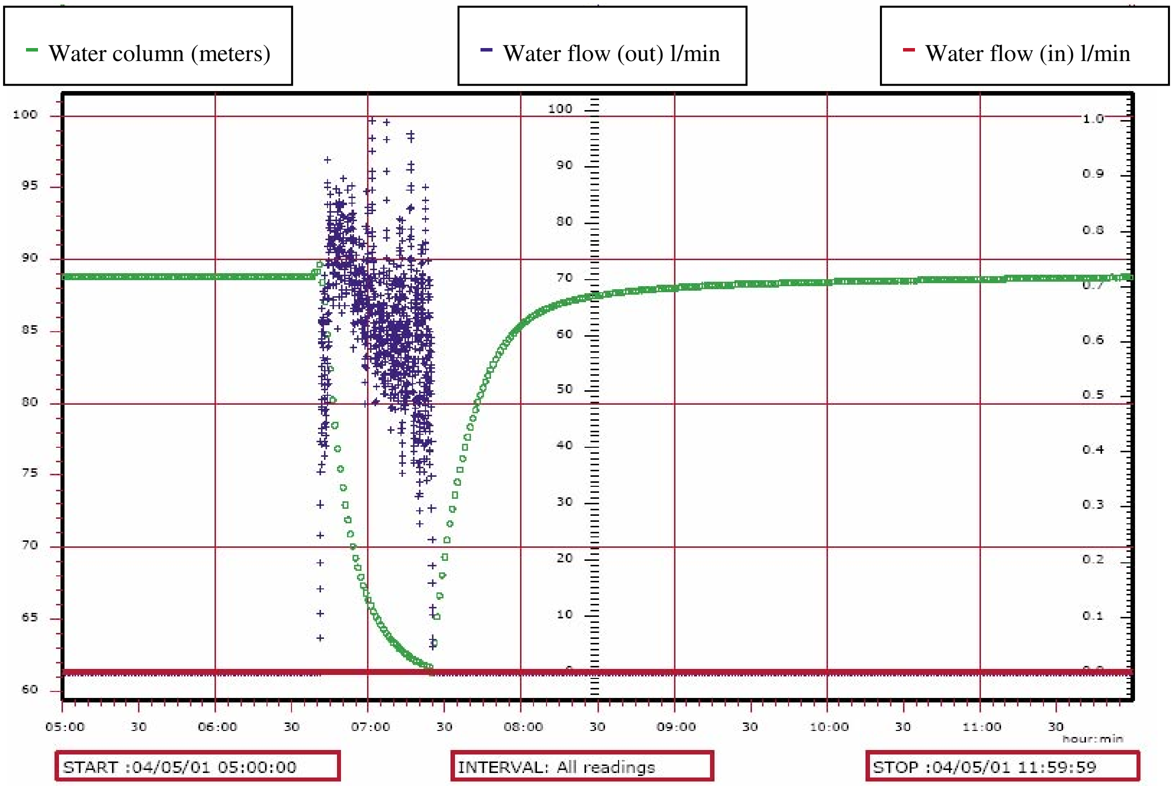


Figure 5-15. *Air lift pumping in KAV04A 100.00 m–1,004.0 m showing the outflow rate (blue) and the height of the water column (green) in the telescopic part of the borehole. There was no inflowing water during the test, as shown by the red line. The pressure transducer was positioned 90 metres below top of casing and the flow rate was measured at the ground surface.*

5.5 Drilling monitoring results

5.5.1 Drill monitoring system DMS

The DMS database contains substantial amounts of drilling monitoring data. A selection of results primarily from the monitoring of the flushing water parameters are presented in Figures 5-16 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 drillstem).
- 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 (ie not strictly to borehole length) periods were 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).

Figure 5-18 shows the conductivity of the ingoing flushing water (yellow). The increase in conductivity of the ingoing water between January 18 and 28 reflects the change in water source from HLX10 to HSH03. The conductivity of the return water (green) shows high peak values that should, in theory, correspond to the presence of saline formation water at depth. The oxygen content of the flushing water (red) is normally low below 3 mg/l. During the initial weeks the malfunctioning oxygen meter showed higher values of up to 15 mg/l. The meter was serviced and calibrated on January 27. After this date the oxygen levels were low.

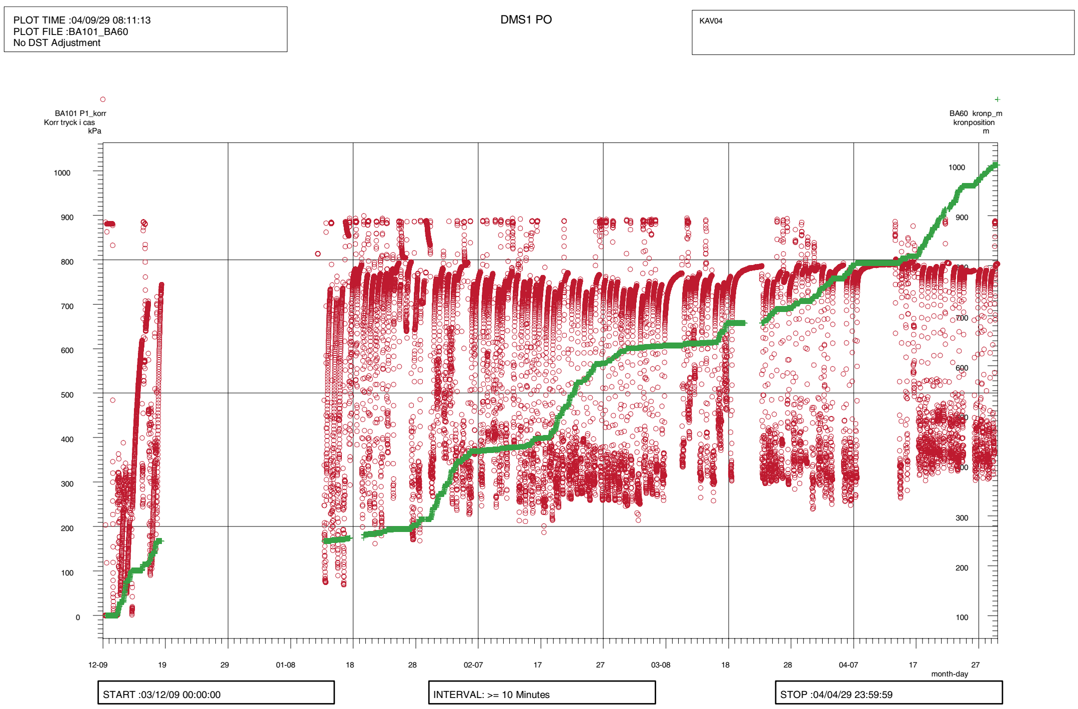


Figure 5-16. *Drill bit position (green) and water level from air-lift pumping (red). The water level is expressed as the pressure in kPa of the water column overlying the pressure gauge ie the ambient air-pressure has been subtracted. The pressure gauge is emplaced at 90.0 metres borehole length. The drill bit position is given in cm × 10^3.*

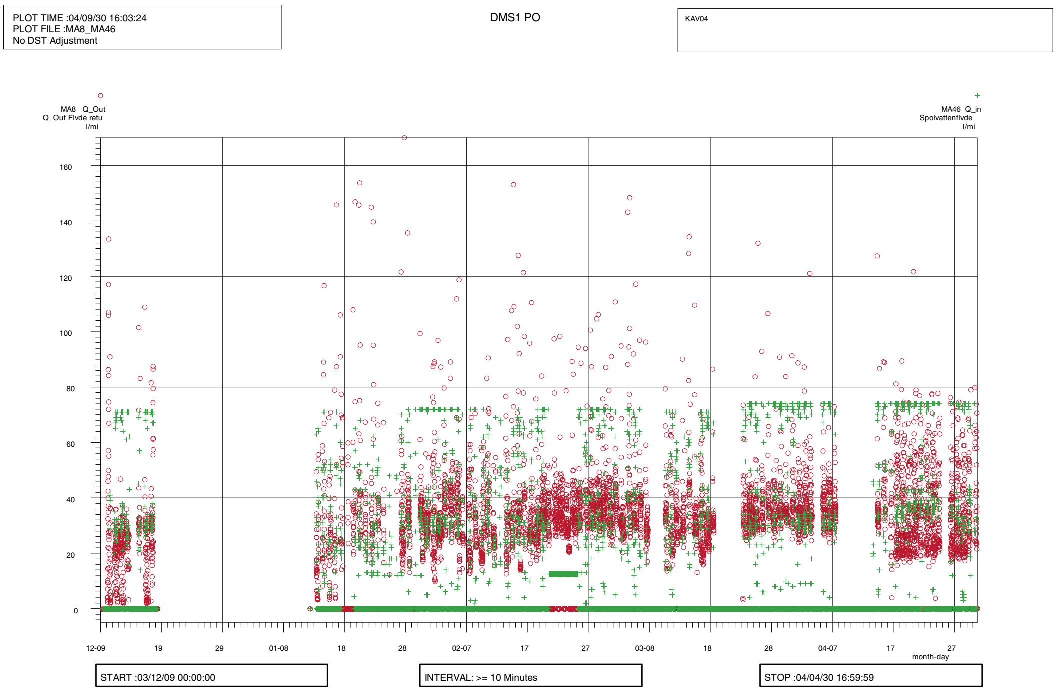


Figure 5-17. *Flushing water flow (green) and return water flow (red) in litres per minute.*

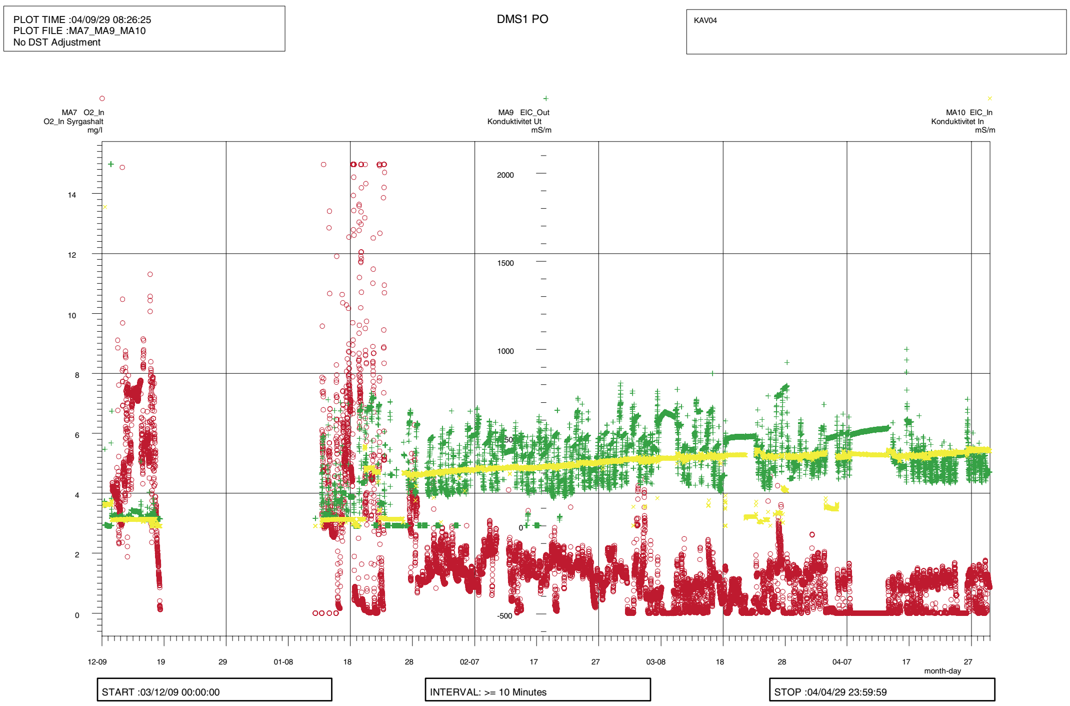


Figure 5-18. *Conductivity of flushing water in mS/m (yellow) and return water (green). The oxygen content in mg/l of the flushing water (red) is also shown. The oxygen content of the flushing water is normally low below 3 mg/l. During the initial weeks the malfunctioning oxygen meter showed higher values of up to 15 mg/l.*

5.5.2 Measurements of flushing water and drill cuttings

A calculation of accumulated water flow based on water flow measurements from the DMS system (continuous readings) is given in Figure 5-19.

The amount of effluent return water from drilling in KAV04A was 1,800 m^3, giving an average consumption of 2 m^3 per metre drilled.

The weight of cuttings in the settling containers amounted to 3,025 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing over a length of 900 metres is 5,700 kg assuming a density of 2.65 kg/dm^3.

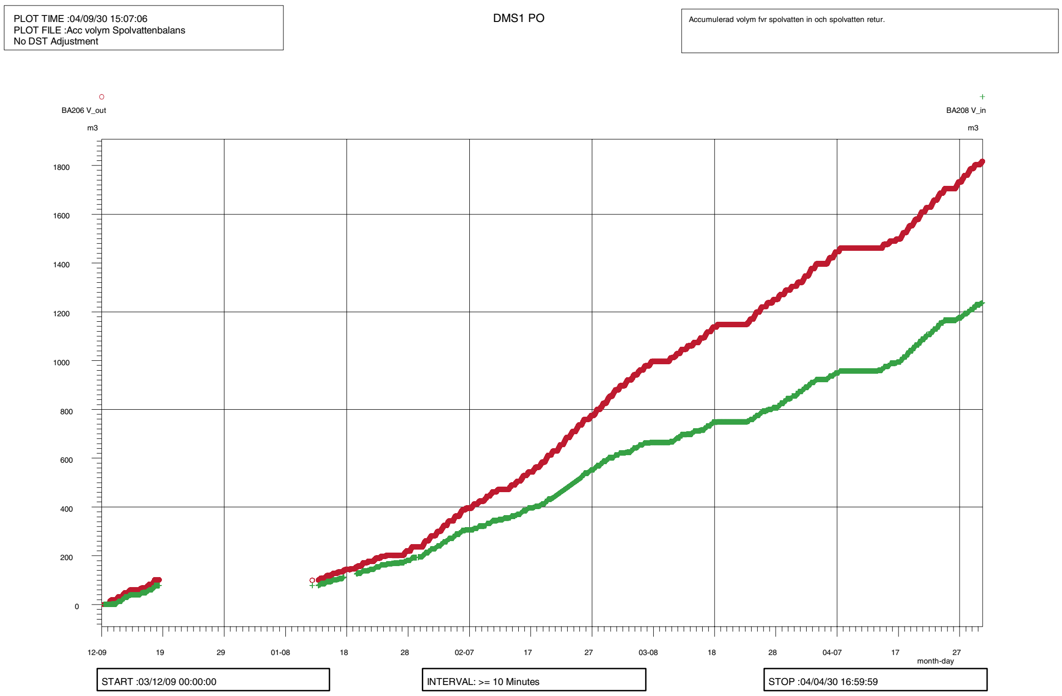


Figure 5-19. *Flushing water balance from KAV04A as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.*

5.6 Geology

The geological results based on the Boremap logging, /8/, are shown in Appendix 1.

The core is dominated by Ävrö Granite with intercalations of Quartz monzodiorite, fine-grained dioritoide and fine-grained granite. Minor segments of pegmatite and diorite/gabbro occur. Between 860 and 950 metres the core consists of fine-grained dioritoide.

Oxidation with faint to weak intensity occurs in sections of between 5 and 30 metres width along the core in the upper 500 metres of the hole. At greater depth both the extent and intensity of oxidation increases.

The total fracture frequency is normally less than 20 per metre to ca 200 metres. Between 200 and 700 metres the fracture frequency is somewhat higher with a range of ca 5–30 fractures per metre. Below 700 metres several zones with crushed rock (ie total fracture frequency > 40 per metre) have been noted.

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. The field note number for entry into SICADA is:

- KAV04A Field note Simpevarp 143
- KAV04B Field note Simpevarp 341

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 led to the Baltic Sea in accordance with an agreement with the environmental authorities.

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.

5.8.1 Consumption of oil and chemicals

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

The concrete consumption was 3,140 kg in total. The concrete was based on white silica, low alkali cement.

5.9 Nonconformities

Date	Reported by	Nonconformity
2004-01-29	Jonny Sjöberg, SwedPower	Several unsuccessful installation of the Borre cell resulted in modification of the protective cone, amendments and improvements of the quality routines and control of the wear on the adaptors.
2004-02-19	Matti Alaverronen, SMOY	Logging was discontinued due to low feed force during drilling in a zone of weak rock.

6 References

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

/2/ **SKB, 2001.** Geovetenskapligt program för platsundersökning vid Simpevarp, SKB R-01-44, Svensk Kärnbränslehantering AB.

/3/ **SKB, 2004.** Overcoring rock stress measurements in borehole KAV04, SKB P-04-84, Svensk Kärnbränslehantering AB.

/4/ **Moye D G, 1967.** Diamond drilling for foundation exploration, Civil Eng. Trans. Inst. Eng, Australia.

/5/ **SKB, 2004.** Drilling of cored borehole KSH01, SKB P-03-113, Svensk Kärnbränslehantering AB.

/6/ **SKB, 2004.** Drilling of cored borehole KSH02, SKB P-04-151, Svensk Kärnbränslehantering AB.

/7/ **SKB, 2004.** Drilling of cored borehole KSH03, SKB P-04-233, Svensk Kärnbränslehantering AB.

/8/ **SKB, 2004.** Boremap mapping of core drilled boreholes KAV04A and KAV04B, SKB P-05-22 (in prep), Svensk Kärnbränslehantering AB.

Appendix 1

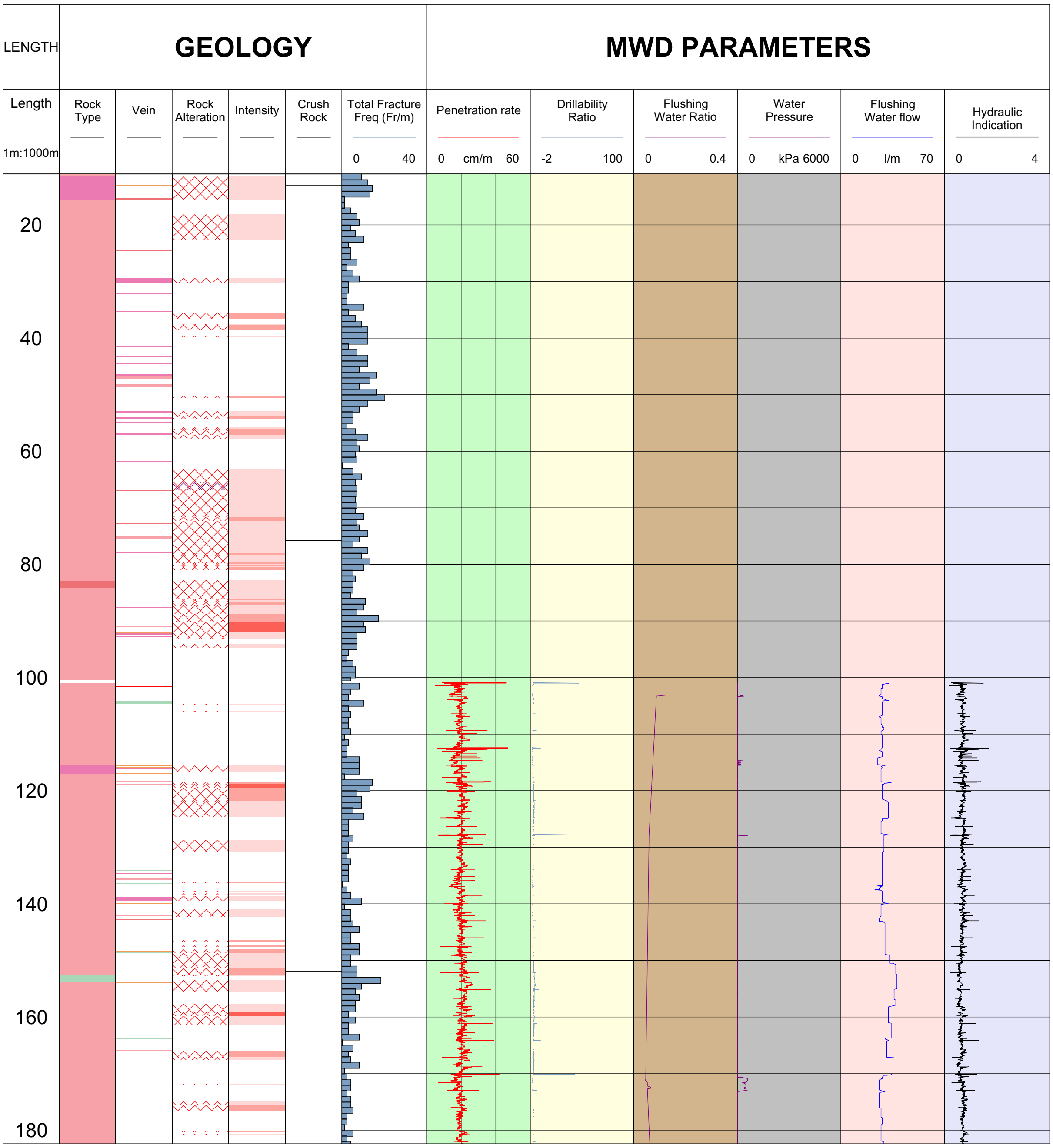
Geology and MWD parameters KAV04A and KAV04B

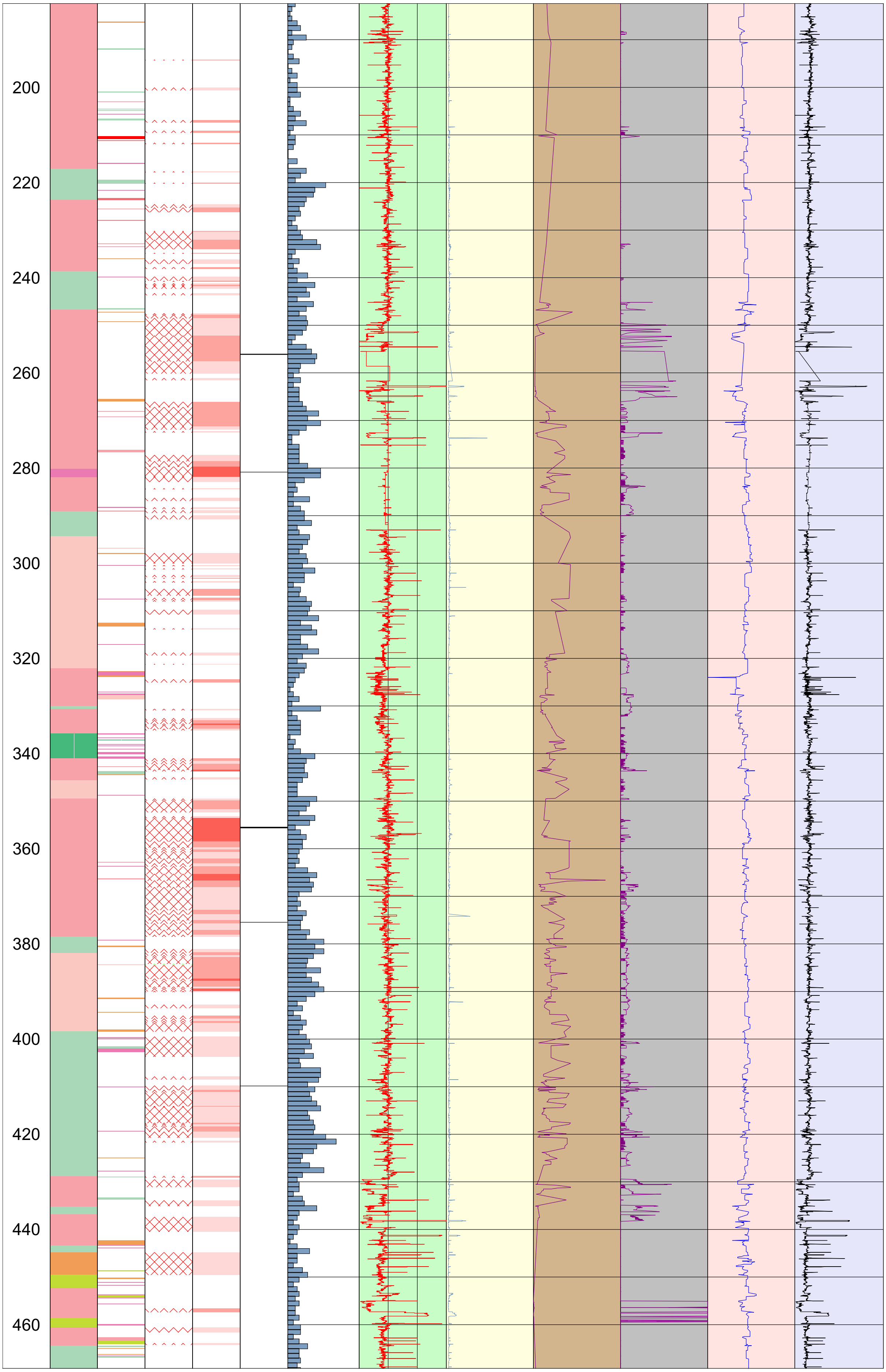
Site	ÄVRÖ	**Coordinate System**	RT90-RHB70
Borehole	KAV04A + KAV04B	**Northing [m]**	6366795.76
Diameter [mm]	76	**Easting [m]**	1552475.00
Length [m]	1004.000	**Elevation [m.a.s.l.]**	10.35
Bearing [°]	77.03	**Drilling Start Date**	2003-10-06 09:00:00
Inclination [°]	-84.90	**Drilling Stop Date**	2004-05-03 14:53:00
Date of mapping	2004-06-01 08:47:00	**Plot Date**	2004-12-27 21:03:07

ROCKTYPE ÄVRÖ
- Fine-grained granite
- Pegmatite
- Granite
- Ävrö granite
- Quartz monzodiorite
- Diorite / Gabbro
- Fine-grained dioritoid
- Fine-grained diorite-gabbro

ROCK ALTERATION
- Oxidized
- Epidotisized
- Albitization

INTENSITY
- Faint
- Weak
- Medium

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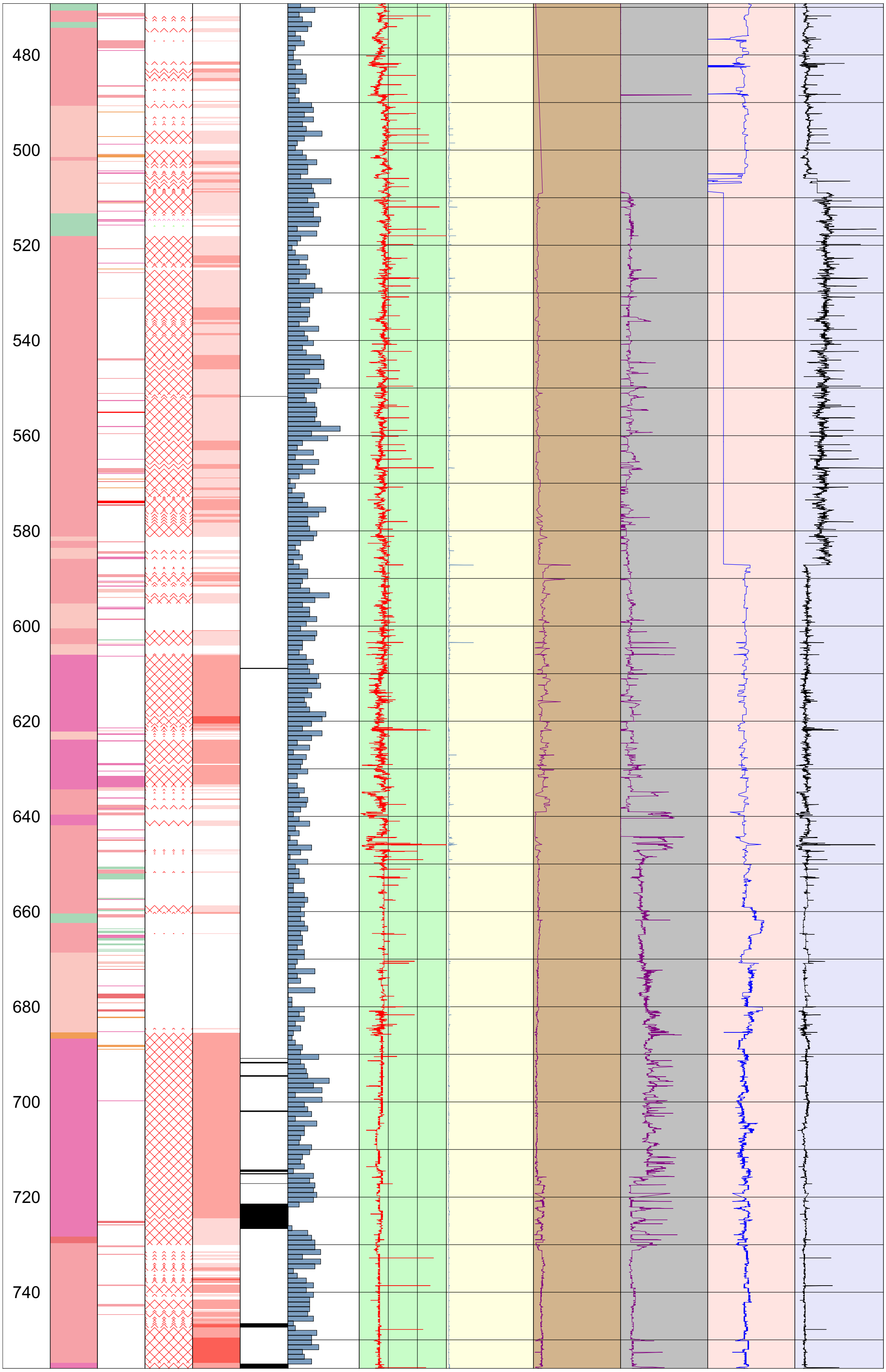
420
440
460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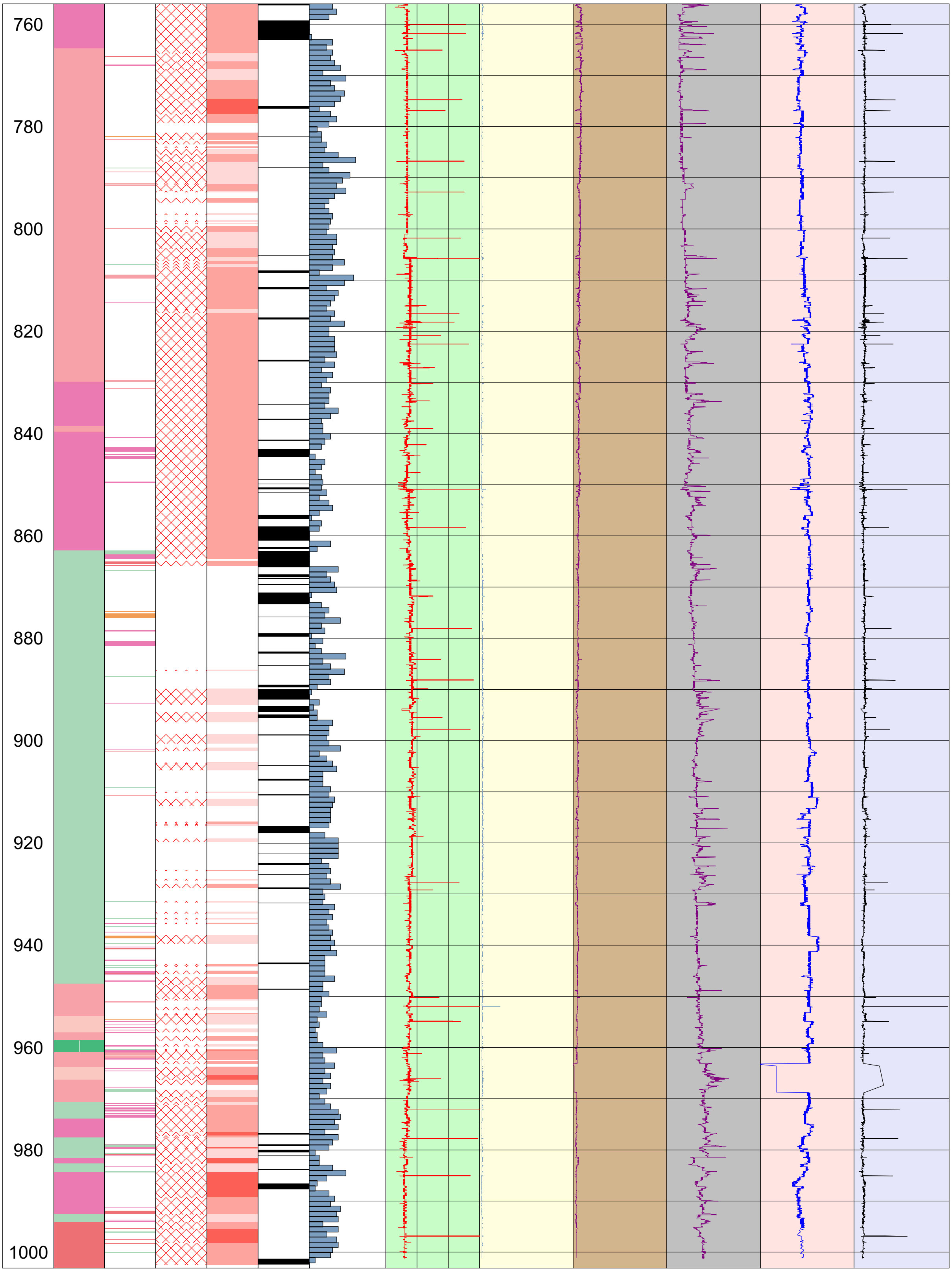
520
540
560
580
600
620
640
660
680
700
720
740


760
780
800
820
840
860
880
900
920
940
960
980
1000

Appendix 2

Chemical results

Borehole	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A	KAV04A		HSH03
Date of measurement	2003-10-09	2003-10-09	2003-10-21	2004-01-29	2004-02-08	2004-02-21	2004-02-26	2004-03-26	2004-03-30	2004-03-31	2004-04-14	2004-04-16		2004-02-03
Upper section limit	47,60	0,00	0,00	245,85	291,15	408,00	516,15	513,58	710,90	710,90	729,00	729,00		0,00
Lower section limit	50,60	100,20	100,20	293,05	408,49	517,98	603,42	602,90	730,08	730,08	805,52	819,01		200,00
Sample_no	5905	5904	5909	7106	7109	7151	7153	7254	7256	7257	7262	7299		7108
Groundwater Chemistry Class	3	3	5	3	1	3	1	3	1	1	1	3		3
pH	8,39	8,18	8,38	7,16		7,62		7,48				6,46		7,76
Conductivity mS/m	64,2	69,0	67,8	961,0				546,0				2240,0		340,0
TOC mg/l														3,9
DOC mg/l			4,8											
Drill water %	0,54	0,13	0,06	12,30	85,20	87,90	78,60	87,60	94,20	73,70	63,50	29,20		
Na mg/l	112,0	130,0	140,0	1210,0								2480,0		462,0
K mg/l	1,88	2,71	2,00	6,75								12,70		8,47
Ca mg/l	6,8	9,2	8,7	675,0								2490,0		130,0
Mg mg/l	1,1	2,8	1,6	61,8								45,7		31,7
HCO3 mg/l Alkalinity	261	271	247	45				141				28		174
Cl mg/l	22,6	37,4	25,7	3220,0				1750,0				8240,0		949,0
SO4 mg/l	70,39	71,21	76,03	134,00				156,00				368,00		122,00
SO4_S mg/l Total Sulphur	18,00	23,40	23,30	45,40								116,00		41,20
Br mg/l	<0,2	<0,2	<0,2	15,00				11,10				71,70		4,33
F mg/l	5,24	4,89	4,78	1,20				1,90						1,14
Si mg/l	4,1	10,2	5,7	4,2								3,8		5,3
Fe mg/l Total Iron	0,103	5,150	1,100	3,450								14,200		0,121
Mn mg/l	0,01	0,12	0,03	0,62								0,81		0,33
Li mg/l	0,024	0,032	-0,050	0,356								1,550		0,045
Sr mg/l	0,12	0,14	0,14	11,10								45,00		1,91
PMC % Modern Carbon			46,25	29,70										59,30
C-13 dev PDB			-16,5	-18,7										-16,9
AGE_BP Groundwater age			6141	9690										4140
AGE_BP_CORR			40	260										50
D dev SMOW			-75,7	-94,6								-85,7		-74,1
Tr TU			2,80	1,10								1,80		8,20
O-18 dev SMOW			-10,90	-13,10								-12,30		-10,40
B-10 B-10/B-11			0,2386	0,2368								0,2353		0,2385
S-34 dev SMOW			21,7	21,8								16,8		20,5
Cl-37 dev SMOC														
Sr-87 Sr-87/Sr86			0,716511	0,716148								0,716850		0,715462

Appendix 3

Chemistry – analytical method

Analysis	Sample bottle	Preparation	SKB label	Laboratory
pH, conduktivity, alkalinity	250 ml	Filtering Pallfilter	green	Äspö/field
Anions (F^-, Br^-, Cl^-, SO_4^{2-})	250 ml	Filtering Pallfilter	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	1,000 ml dried	Flooded at least once	green	Waterloo
Sr-87	100 ml square		green	IFE
Cl-37	Same as for Tritium		green	Waterloo
B-10	Same as for main components	Filtering membrane filter	red	Analytica
C-13, PMC	2*2 st 100 ml brown glass		green	Waterloo och Uppsala
S-34	1,000 ml		green	IFE

Quality of the analyses

The charge balance errors give an indication of the quality and uncertainty of the analyses of the major components. The relative charge balance errors are calculated for the selected sets of data from the borehole. The errors do not exceed ± 5% in samples 5909, 7106, and 7299 which is fully satisfactory. Sample 7299 was not analysed for F^- so the charge balance error for this particular sample is more uncertain.

The relative charge balance error in the samples 5905 and 5904 is –8, 26% and –5, 82% respectively.

The samples 7151 and 7254 were not analysed for main components due to the high concentration of flushing water. The relative charge balance errors could not be calculated for these samples.

Figures A1 and A2 illustrate the consistency of the analyses. The figures are based on the data from KAV04A presented in Appendix 2. Electric conductivity values are plotted versus chloride concentrations in Figure A1.

For the samples 5905, 5904 and 5909 the chloride concentration and electrical conductivity values were too low to be included in Figure A1. However, the charge balance errors for these samples are presented above.

The bromide and chloride concentrations are plotted in Figure A2. A plot of bromide versus chloride serves as a rough quality control of the bromide analyses.

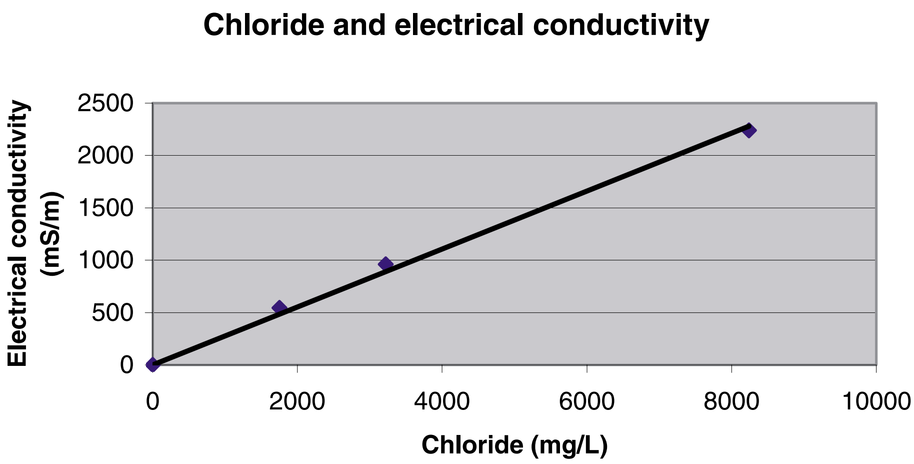


Figure A1. Plot of electric conductivity versus chloride concentration.

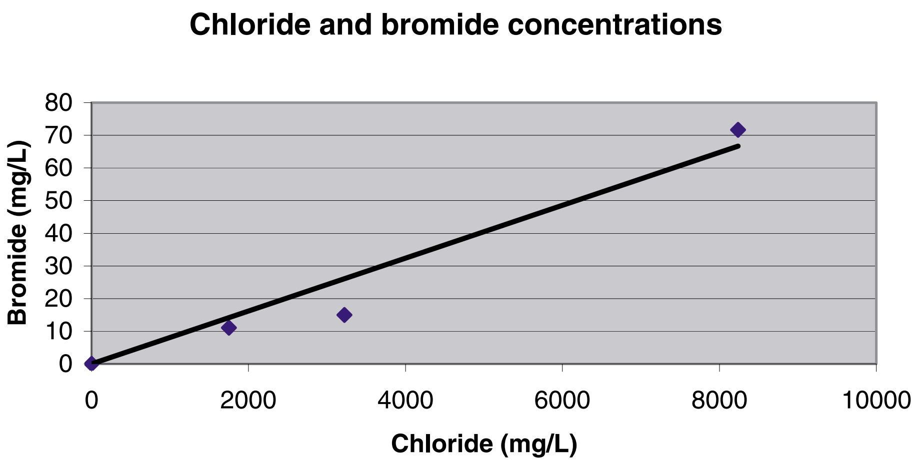


Figure A2. Plot of bromide concentrations versus chloride concentrations.

The bromide concentration in sample 7106 may, according to Figure A2, be a bit too low. On the other hand, the charge balance error for this particular sample is –1, 48% which is fully satisfactory.

The bromide concentration in the samples 5905, 5904 and 5909 was below the detection limit (see Appendix 2) so a plot of bromide concentrations versus chloride concentrations could not be made for these samples.

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

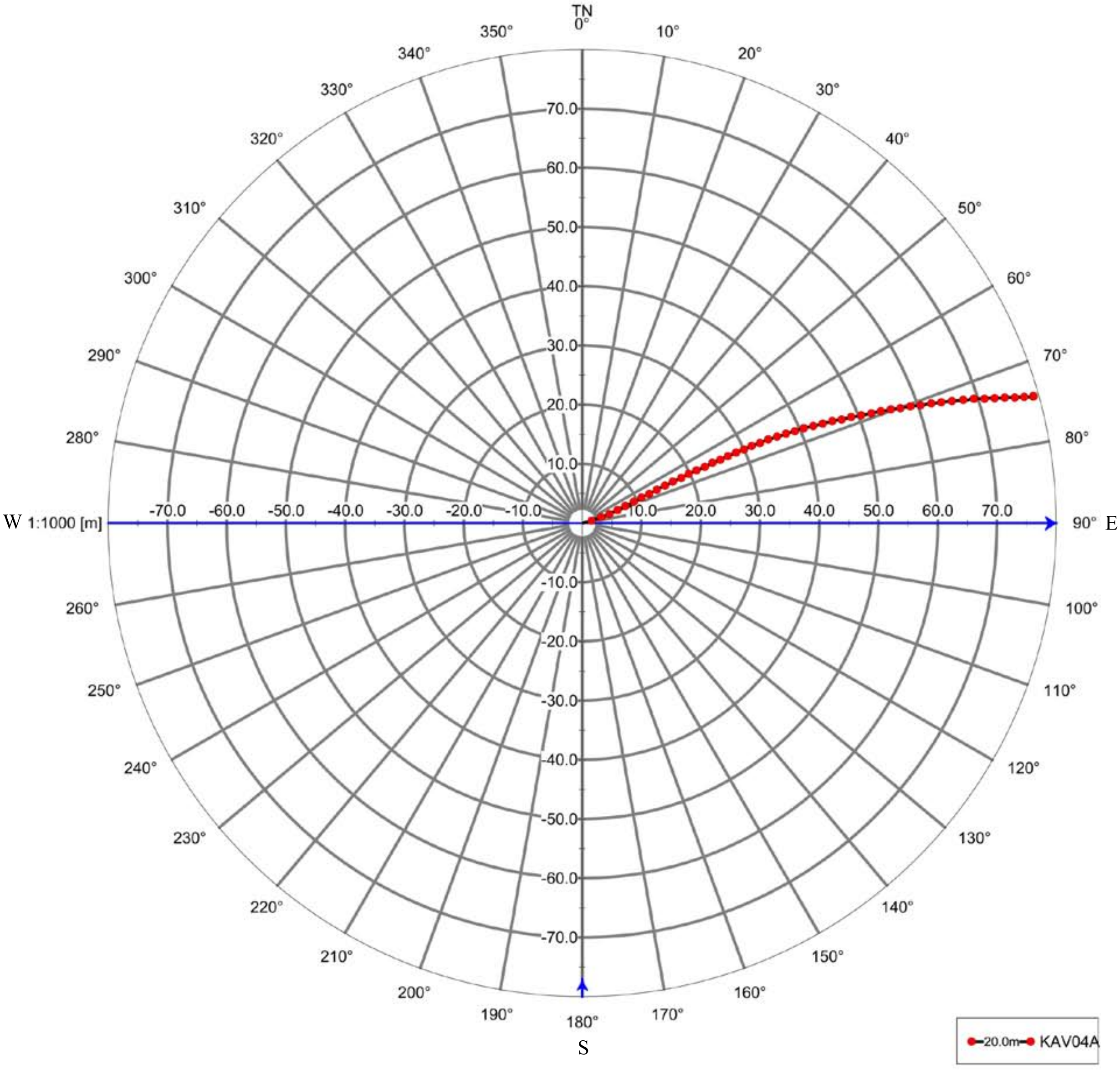
- Several components are determined by more than one method and/or laboratory. Control analyses by an independent laboratory are normally performed as a standard procedure on every five or ten collected samples. Control analyses were not done in this case because of the small number of samples taken.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

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

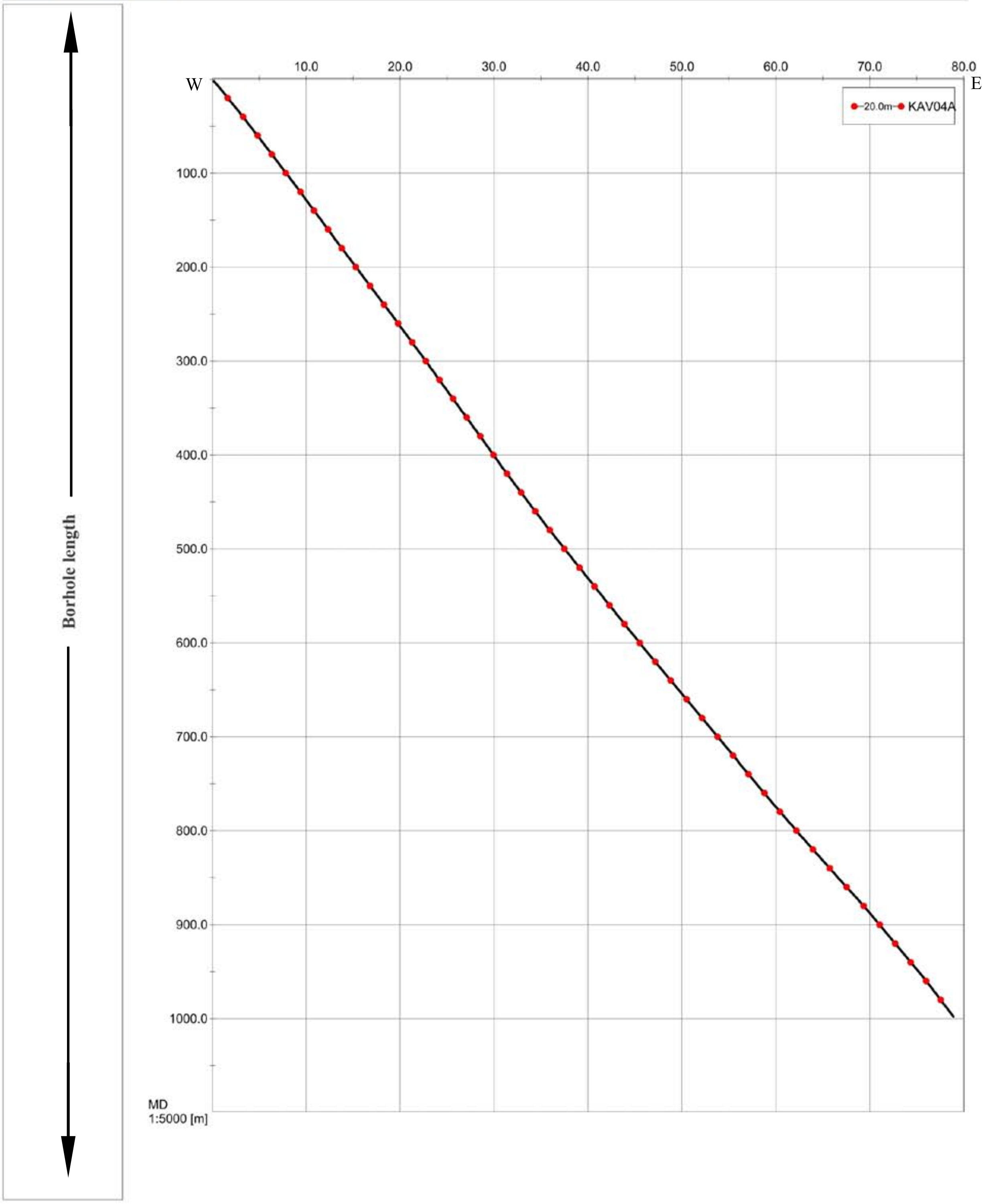
All results from "biochemical" components and special analyses of trace metals and isotopes are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a "best choice" notation will indicate those results which are considered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

Deviation measurements

SKB	Site	ÄVRÖ
	Borehole	KAV04A
	View from above	



Site ÄVRÖ
Borehole KAV04A
Vertical Section

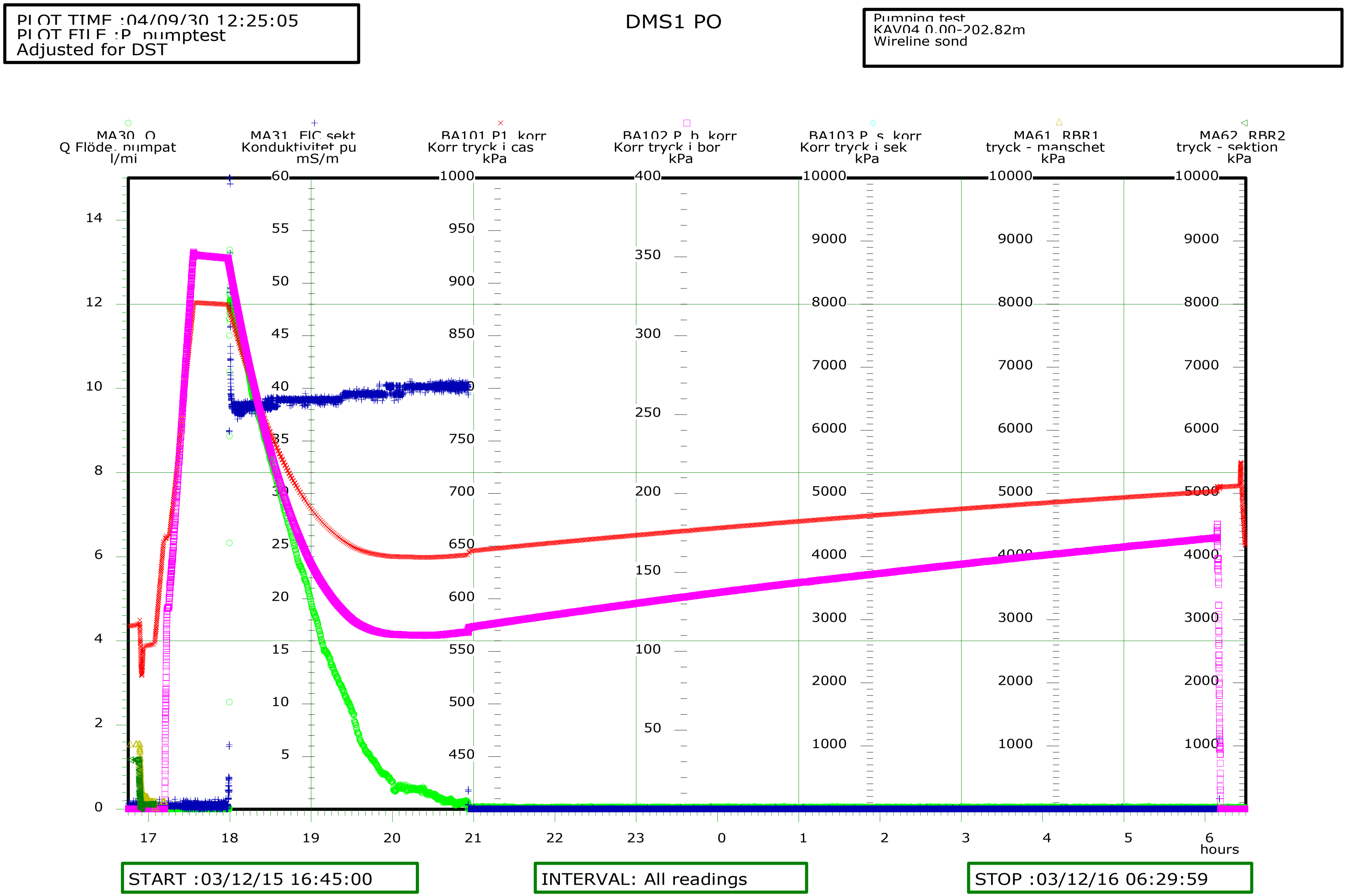


Appendix 5

Wireline pumping tests

Description of the parameters in the enclosed plots.

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



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DMS1 PO
Pumping test
KAV04 0.00-202.82m
Wireline sond
MA30_Q
Q Flöde, pumpat
l/mi
MA31_FIC sekt
Konduktivitet pu
mS/m
BA101 P1_korr
Korr tryck i cas
kPa
BA102 P_b_korr
Korr tryck i bor
kPa
BA103 P_s_korr
Korr tryck i sek
kPa
MA61_RBR1
tryck - manschet
kPa
MA62_RBR2
tryck - sektion
kPa
hours
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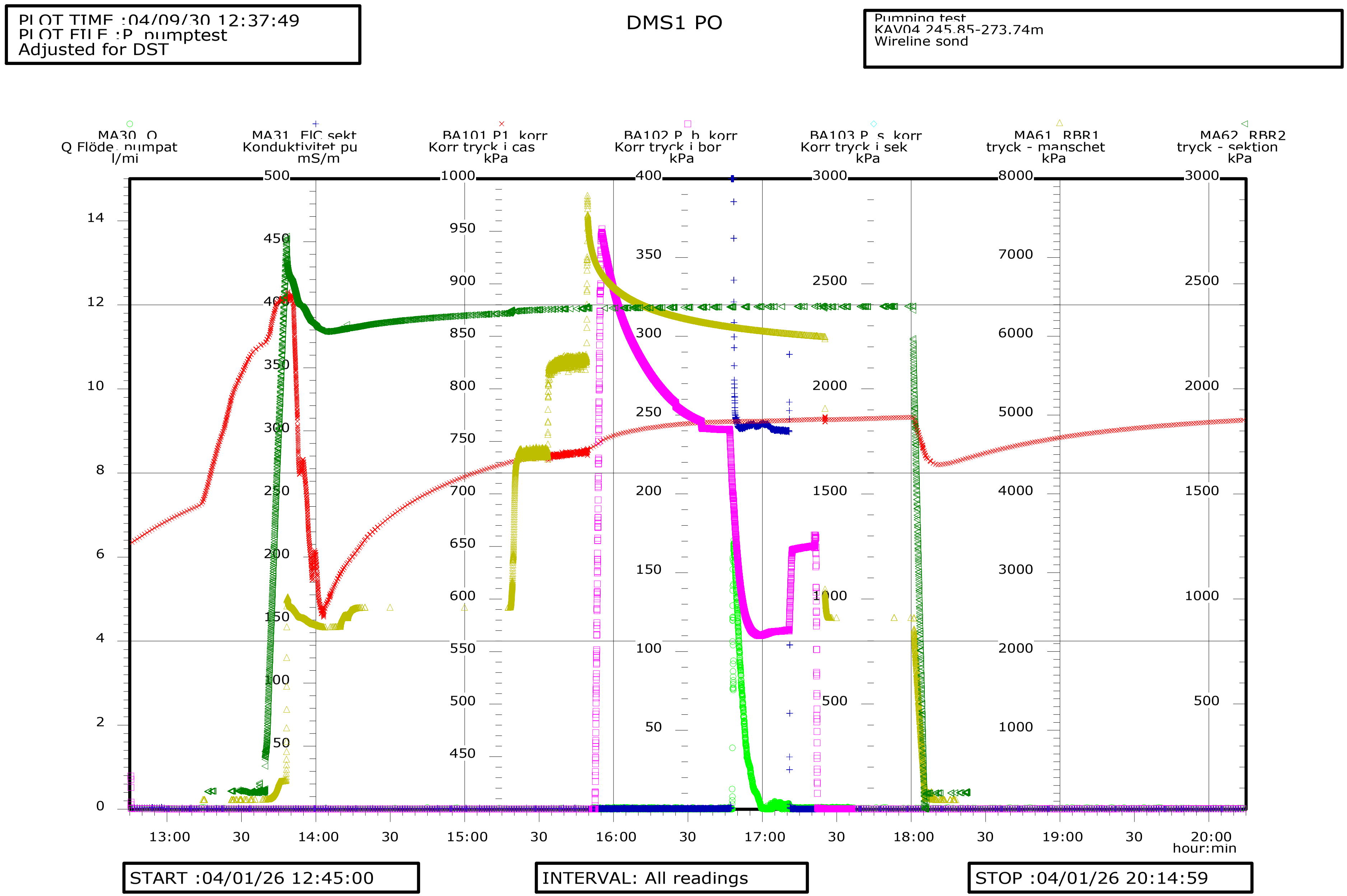
INTERVAL: All readings
STOP :03/12/16 06:29:59



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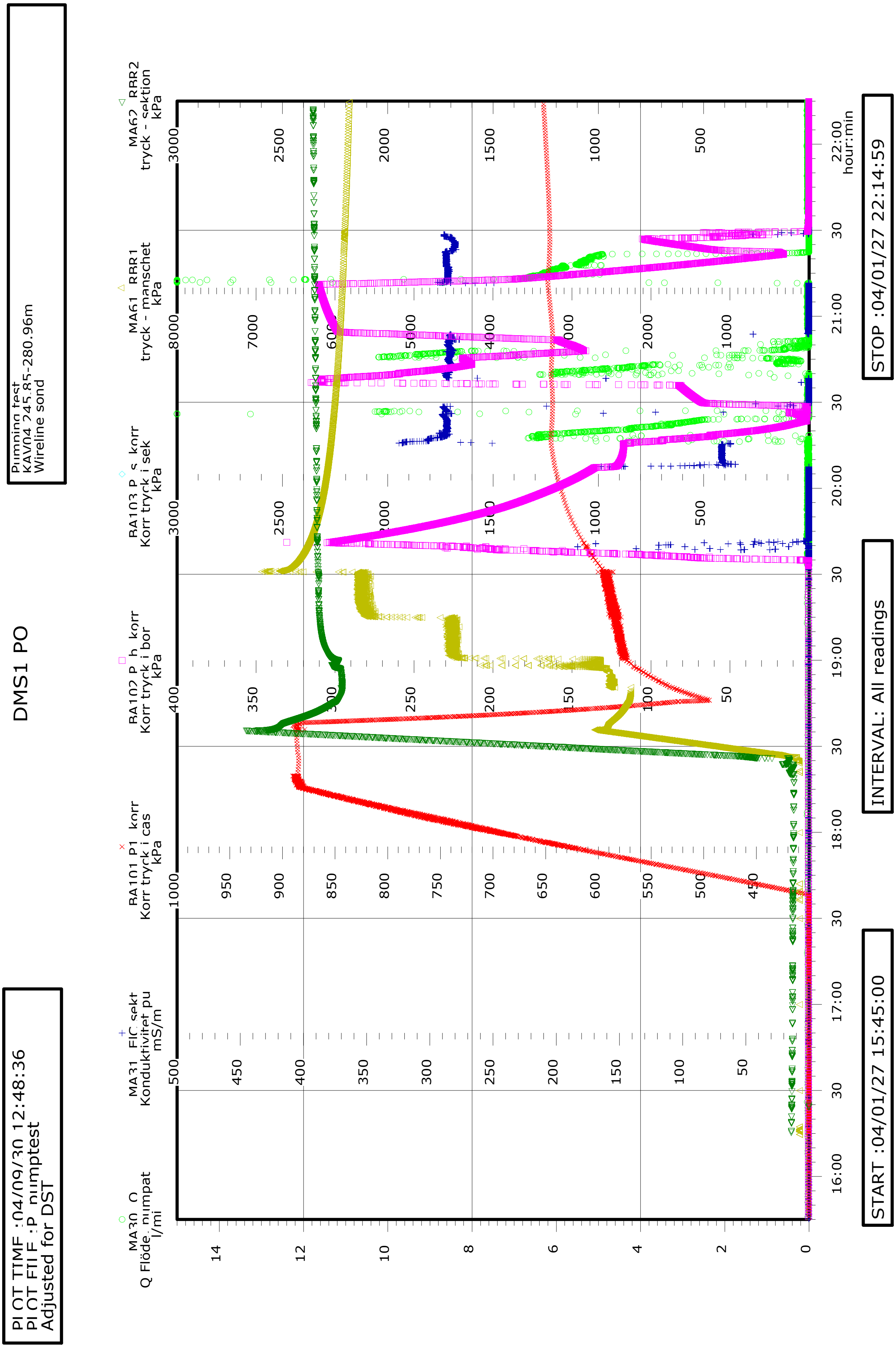
Pumping test
KAV04 245.85-273.74m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EIC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_b korr
Korr tryck i bor
kPa
BA103 P_s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hour:min
START :04/01/26 12:45:00
INTERVAL: All readings
STOP :04/01/26 20:14:59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DMS1 PO
Pumping test
KAV04 245.85-280.96m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EIC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P h korr
Korr tryck i bor
kPa
BA103 P s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hour:min
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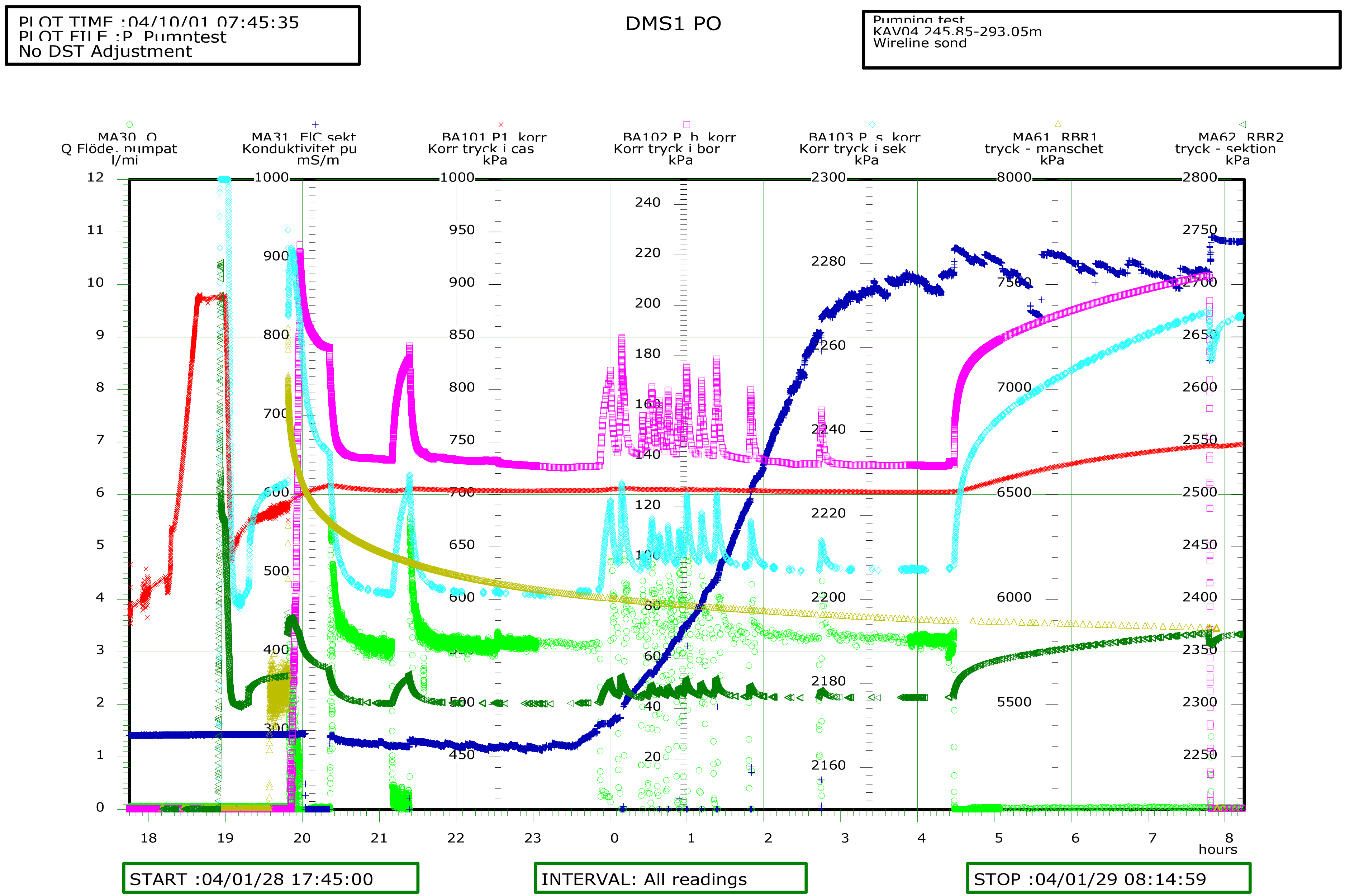
INTERVAL: All readings
STOP :04/01/27 22:14:59



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Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P b korr
Korr tryck i bor
kPa
BA103 P s korr
Korr tryck i sek
kPa
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tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hours
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INTERVAL: All readings
STOP :04/01/29 08:14:59

PLOT TIME :04/10/05 15:01:59
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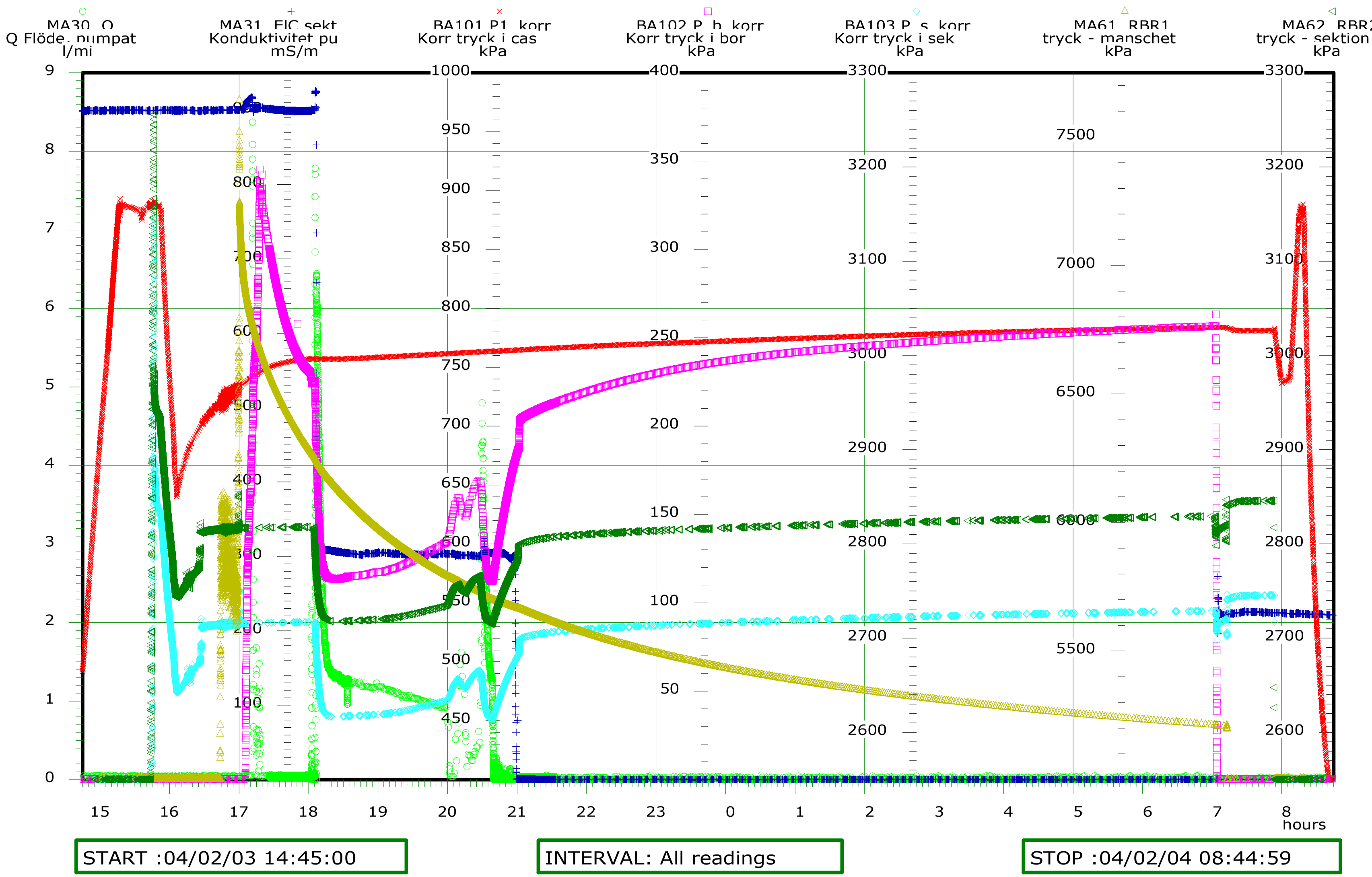
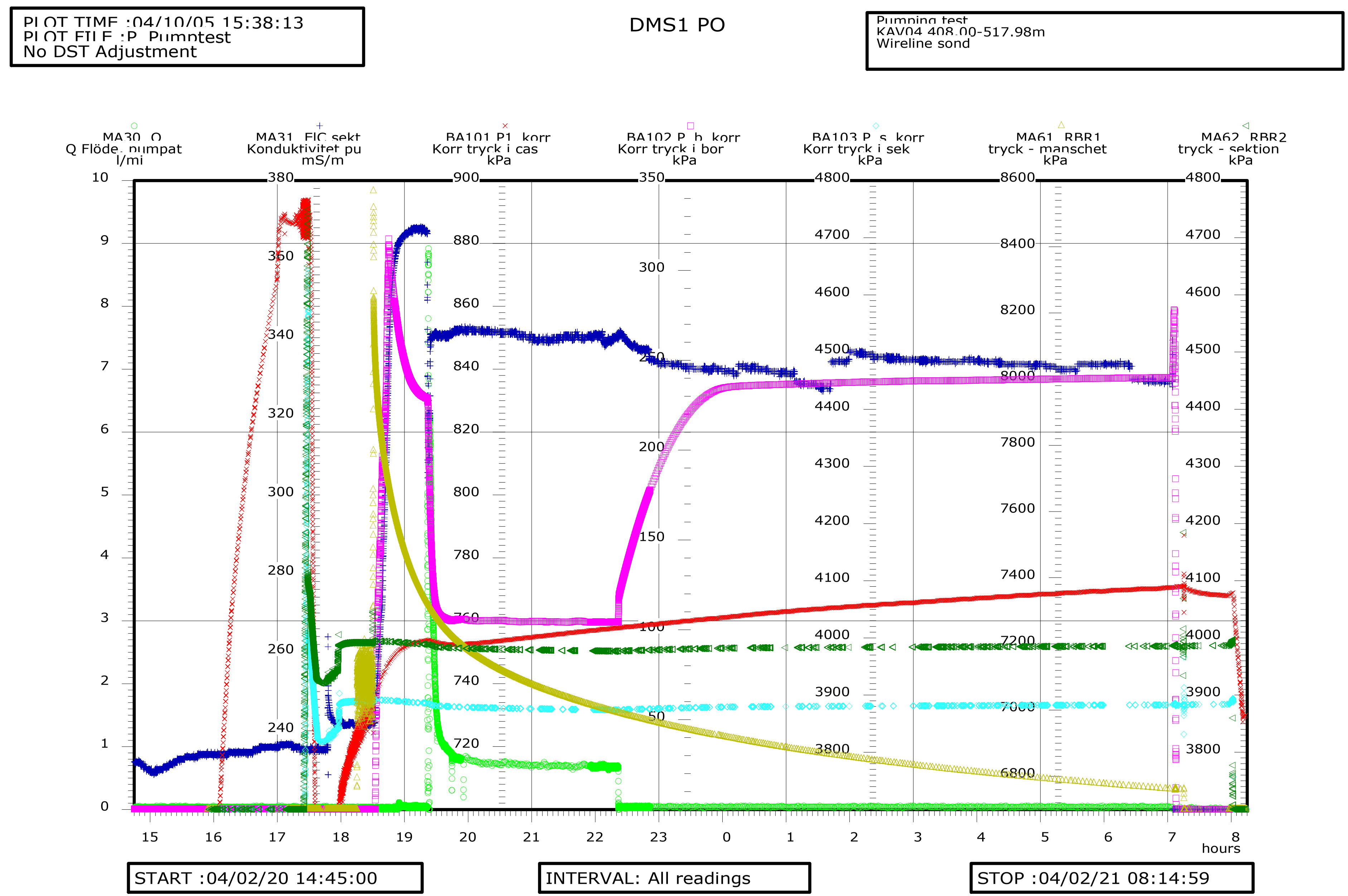
Adjusted for DST

DMS1 PO

Pumping test
KAV04 291.15-408.49m
Wireline sond

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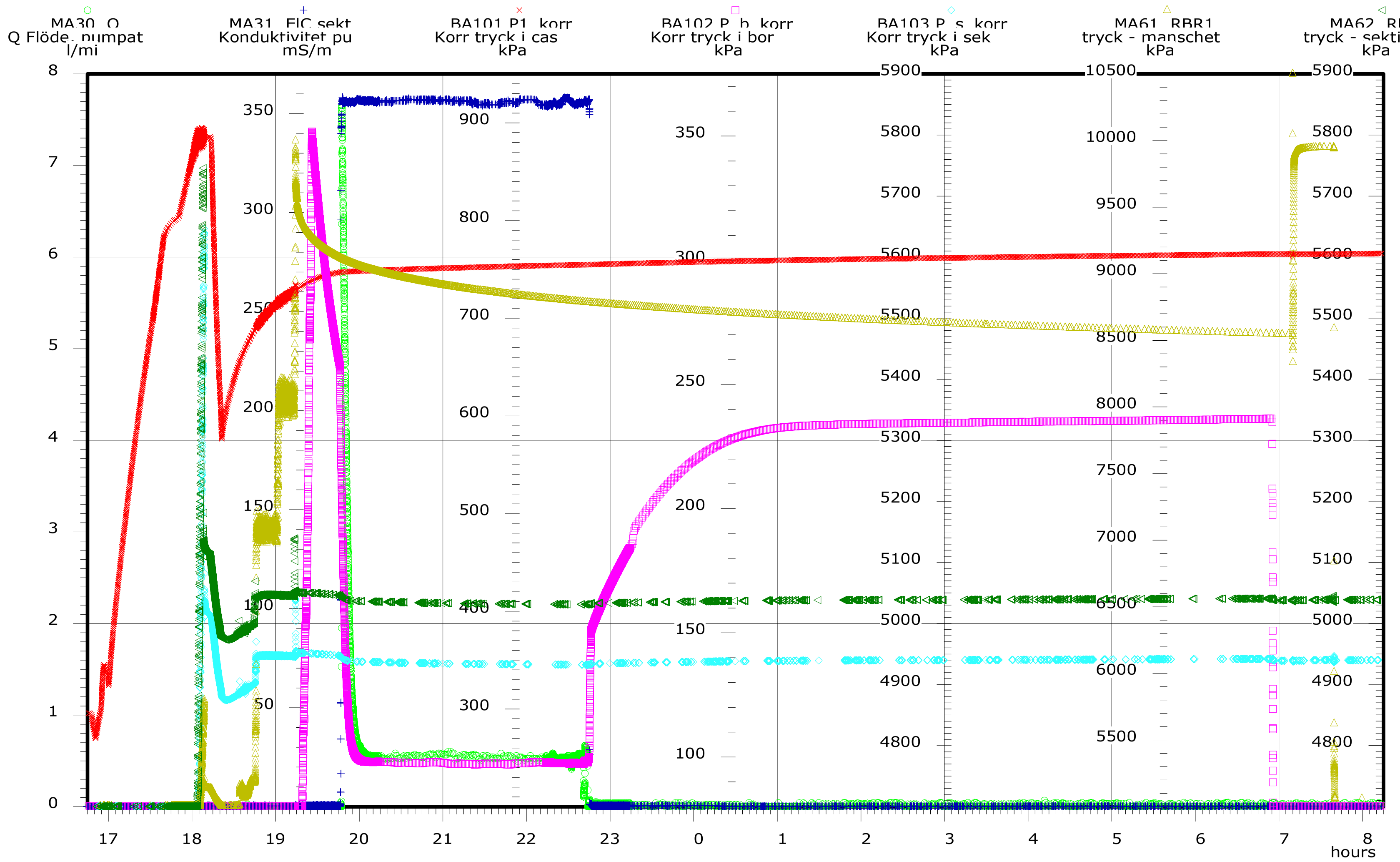
Pumping test
KAV04 408.00-517.98m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_b korr
Korr tryck i bor
kPa
BA103 P_s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hours
START :04/02/20 14:45:00
INTERVAL: All readings
STOP :04/02/21 08:14:59

PLOT TIME :04/10/05 16:20:08
PLOT FILE :P Pumptest
No DST Adjustment

DMS1 PO

Pumping test
KAV04 516.15-603.42m
Wireline sond



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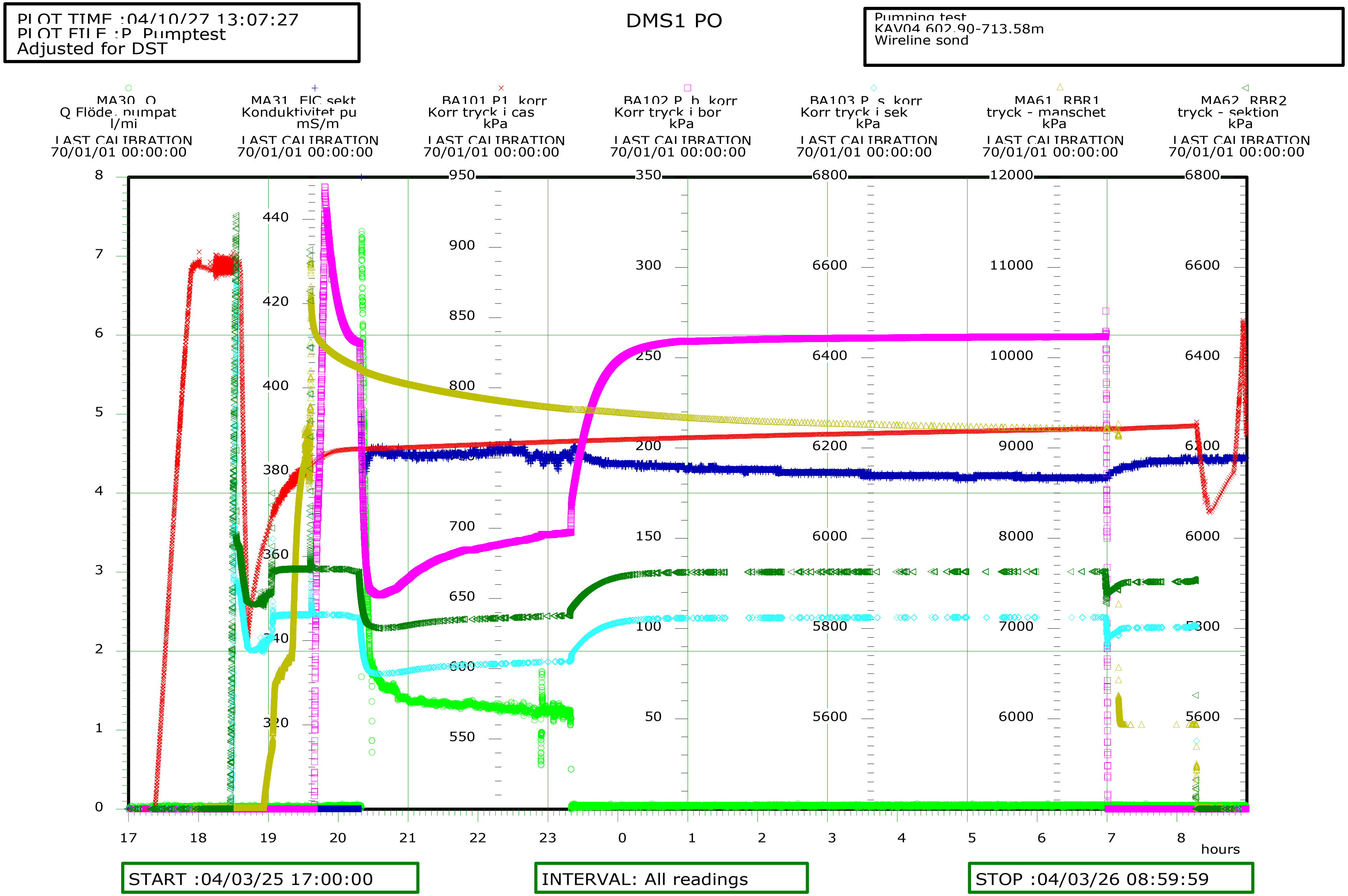
INTERVAL: All readings

STOP :04/02/26 08:14:59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Pumping test
KAV04 602.90-713.58m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
LAST CALIBRATION
70/01/01 00:00:00
MA31 EIC sekt
Konduktivitet pu
mS/m
LAST CALIBRATION
70/01/01 00:00:00
BA101 P1 korr
Korr tryck i cas
kPa
LAST CALIBRATION
70/01/01 00:00:00
BA102 P_b korr
Korr tryck i bor
kPa
LAST CALIBRATION
70/01/01 00:00:00
BA103 P_s korr
Korr tryck i sek
kPa
LAST CALIBRATION
70/01/01 00:00:00
MA61 RBR1
tryck - manschet
kPa
LAST CALIBRATION
70/01/01 00:00:00
MA62 RBR2
tryck - sektion
kPa
LAST CALIBRATION
70/01/01 00:00:00
hours
START :04/03/25 17:00:00
INTERVAL: All readings
STOP :04/03/26 08:59:59

PLOT TIME :04/10/06 08:17:40
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test
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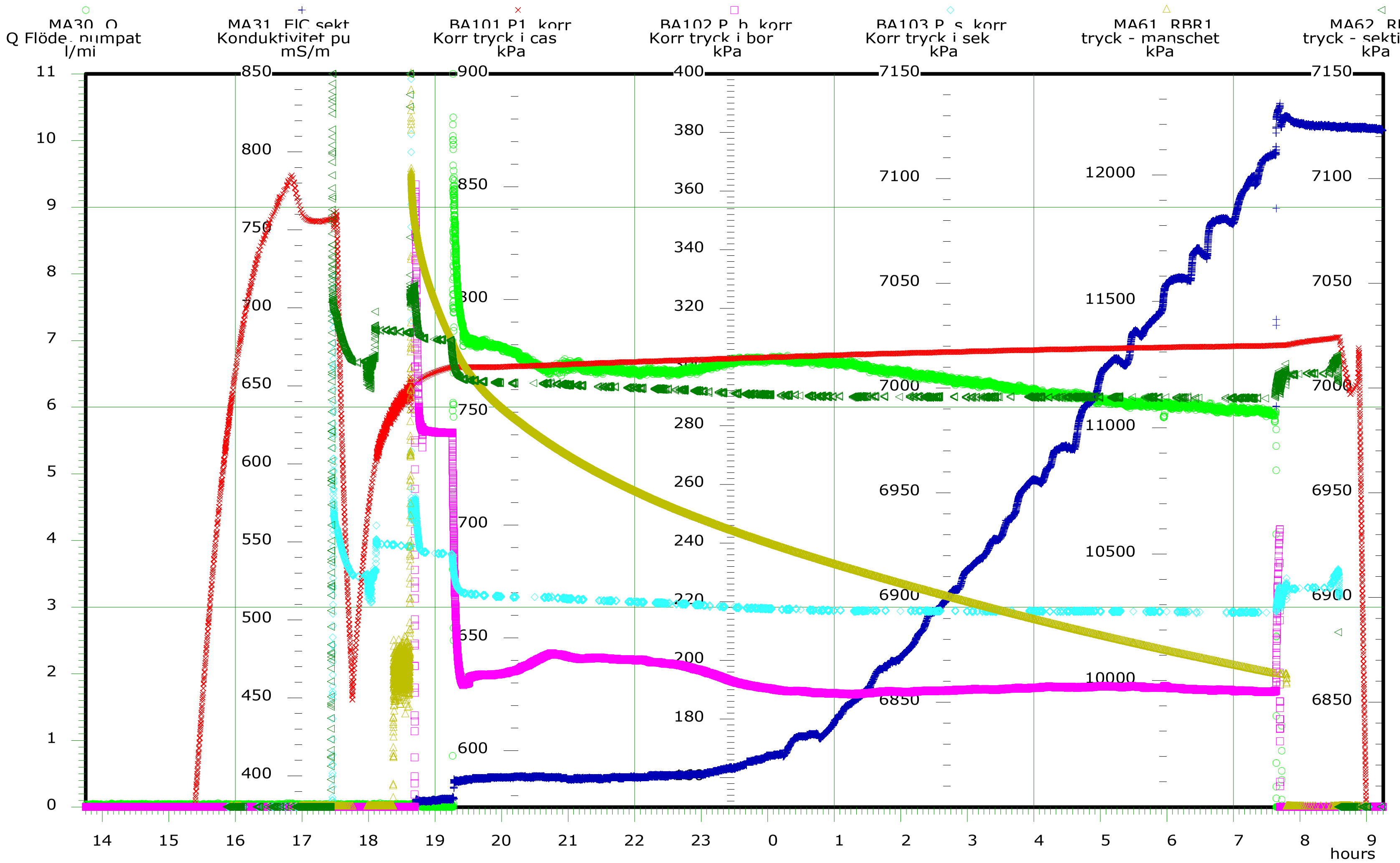
Wireline sond



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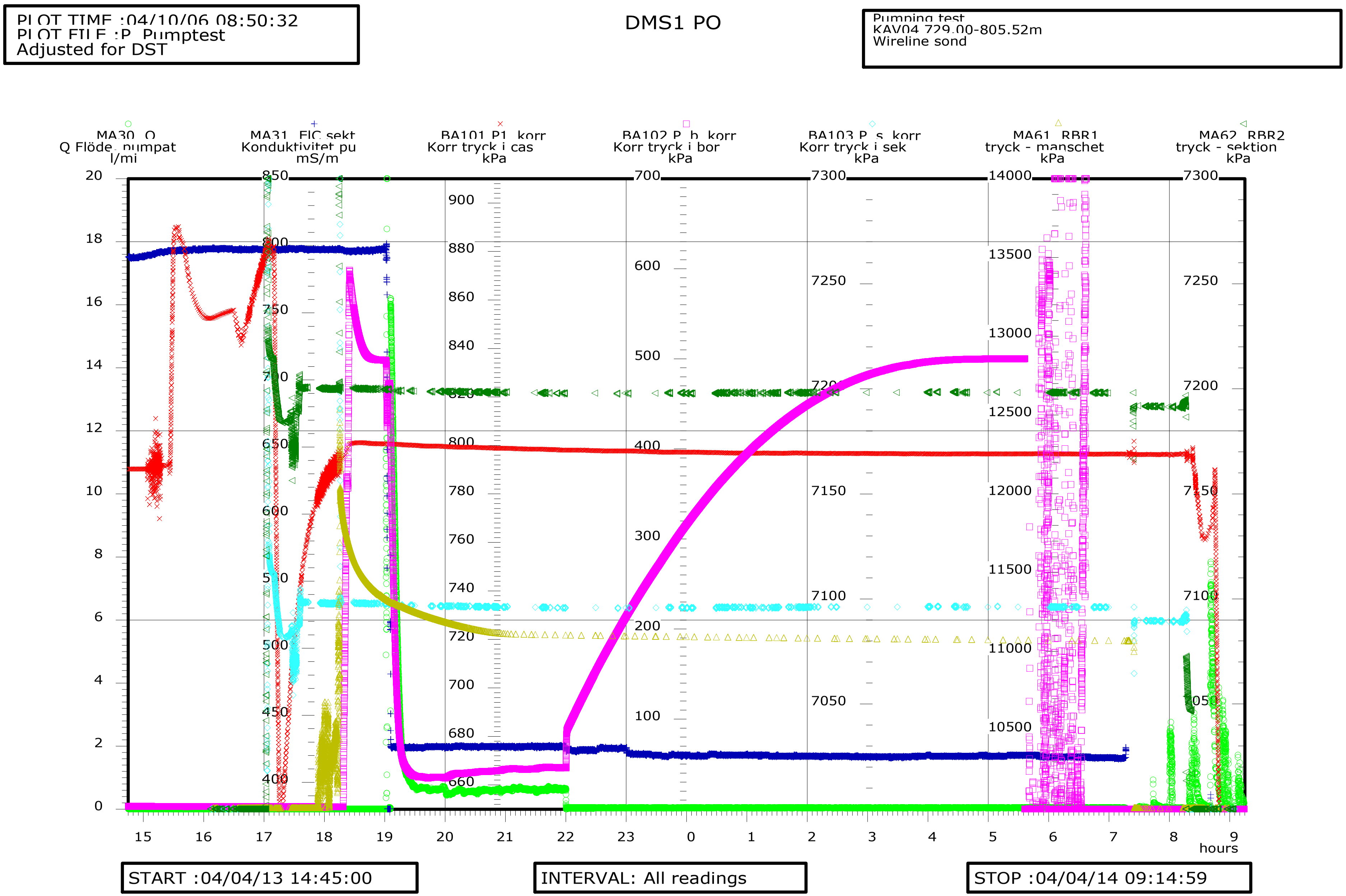
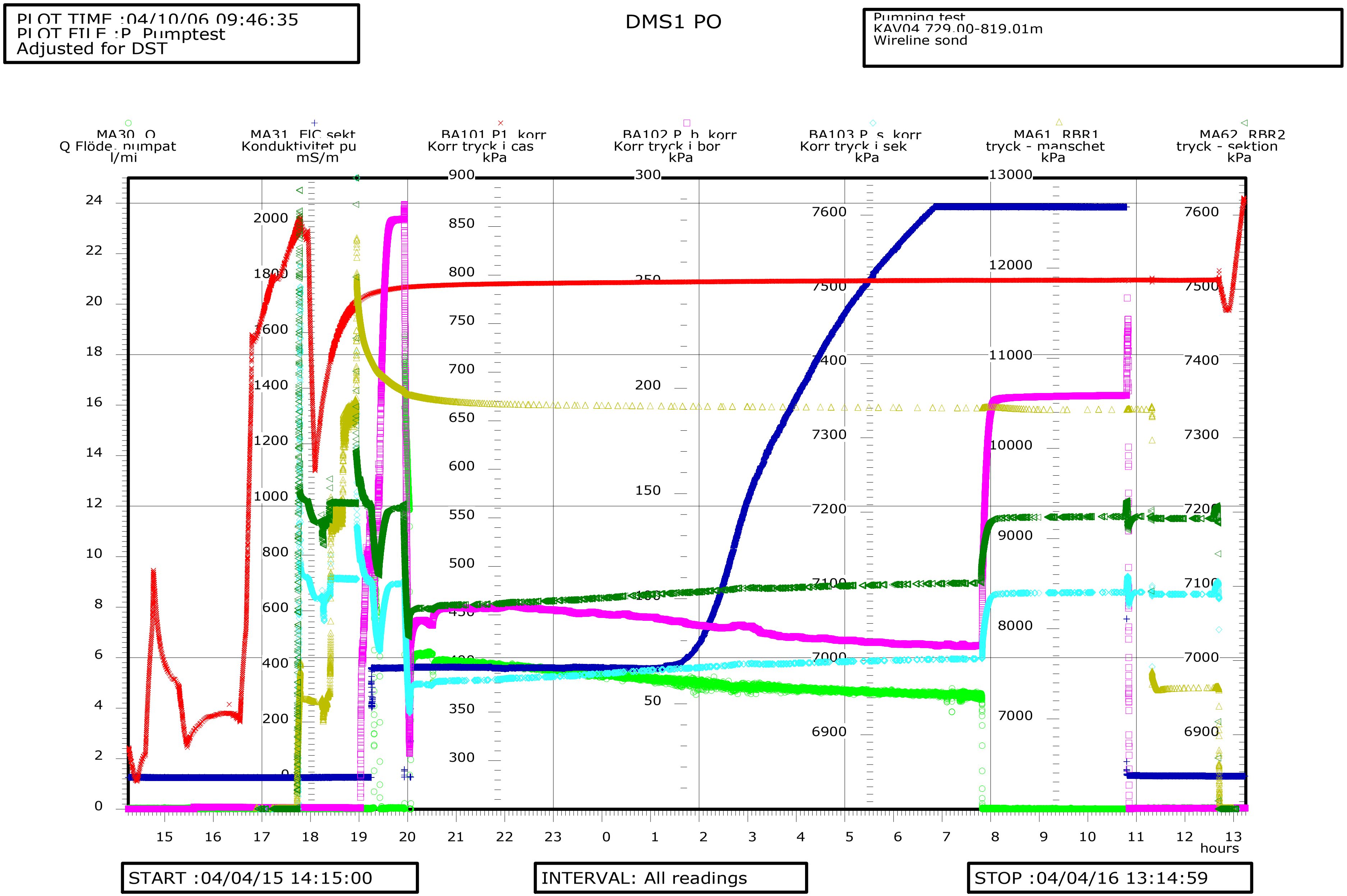
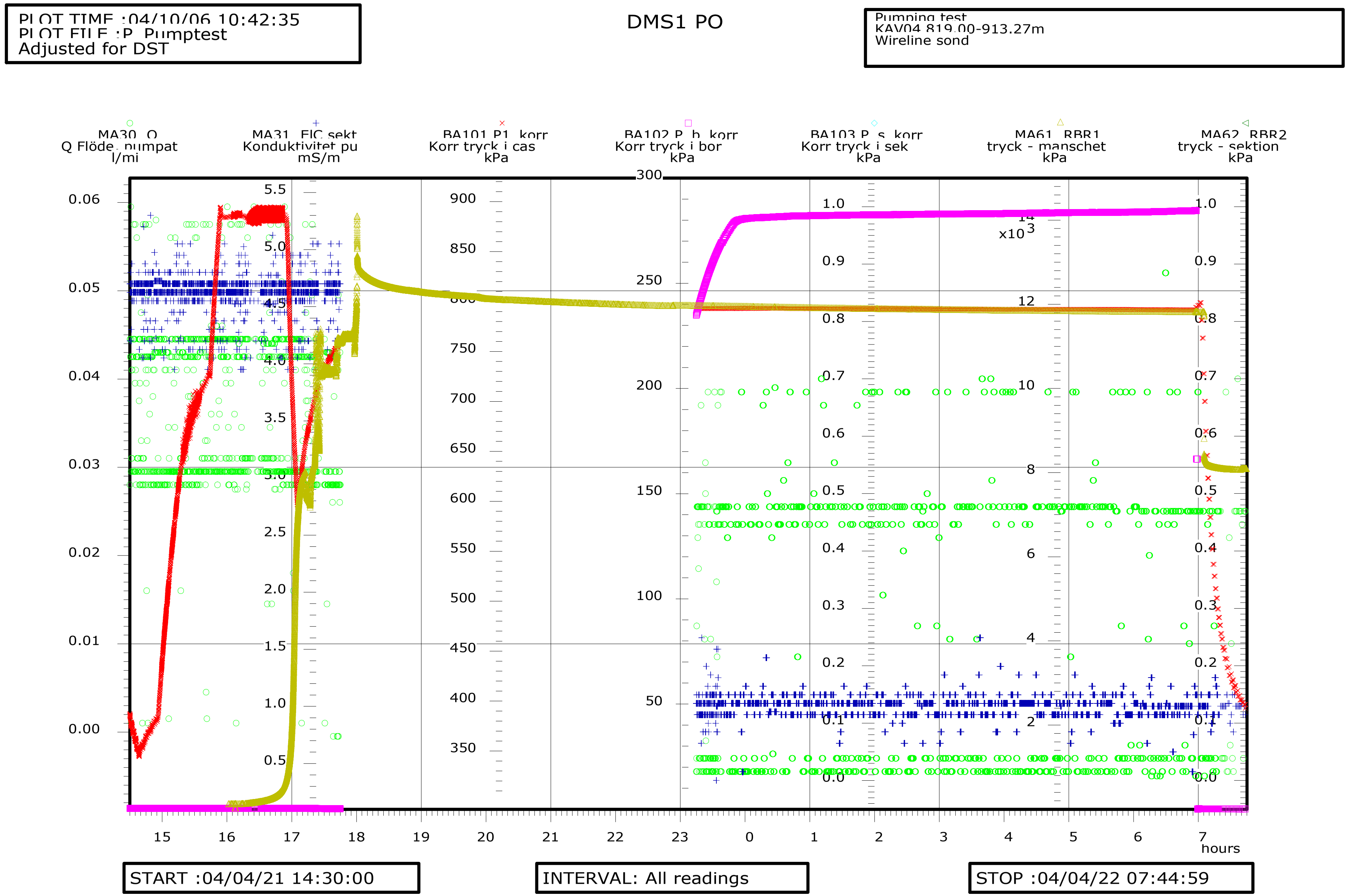
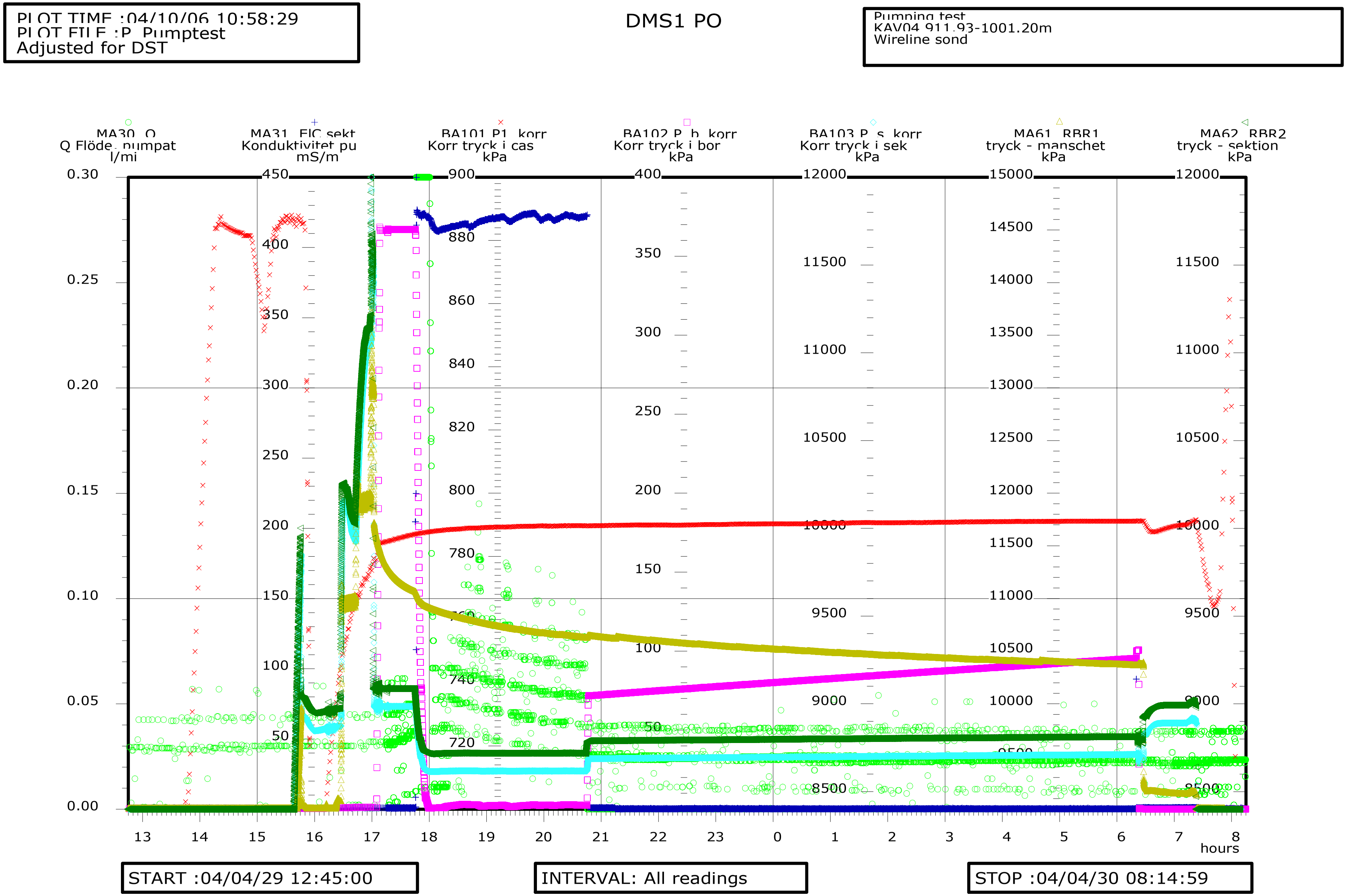
INTERVAL: All readings

STOP :04/03/31 09:14:59


PLOT TIME :04/10/06 08:50:32
PLOT FILE :P_Pumptest
Adjusted for DST
DMS1 PO
Pumping test
KAV04 729.00-805.52m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EIC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_b korr
Korr tryck i bor
kPa
BA103 P_s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hours
START :04/04/13 14:45:00
INTERVAL: All readings
STOP :04/04/14 09:14:59


PLOT TIME :04/10/06 09:46:35
PLOT FILE :P Pumptest
Adjusted for DST
DMS1 PO
Pumping test
KAV04 729.00-819.01m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P b korr
Korr tryck i bor
kPa
BA103 P s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
0 2 4 6 8 10 12 14 16 18 20 22 24
0 200 400 600 800 1000 1200 1400 1600 1800 2000
300 350 400 450 500 550 600 650 700 750 800 850 900
50 100 150 200 250 300
6900 7000 7100 7200 7300 7400 7500 7600
7000 8000 9000 10000 11000 12000 13000
6900 7000 7100 7200 7300 7400 7500 7600
15 16 17 18 19 20 21 22 23 0 1 2 3 4 5 6 7 8 9 10 11 12 13
hours
START :04/04/15 14:15:00
INTERVAL: All readings
STOP :04/04/16 13:14:59


PLOT TIME :04/10/06 10:42:35
PLOT FILE :P_Pumptest
Adjusted for DST
DMS1 PO
Pumping test
KAV04 819.00-913.27m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_b korr
Korr tryck i bor
kPa
BA103 P_s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
x10 3
hours
START :04/04/21 14:30:00
INTERVAL: All readings
STOP :04/04/22 07:44:59



PLOT TIME :04/10/06 10:58:29
PLOT FILE :P_Pumptest
Adjusted for DST
DMS1 PO
Pumping test
KAV04 911.93-1001.20m
Wireline sond
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EIC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_b_korr
Korr tryck i bor
kPa
BA103 P_s_korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hours
START :04/04/29 12:45:00
INTERVAL: All readings
STOP :04/04/30 08:14:59

Appendix 6

Time series of absolute pressure measurements

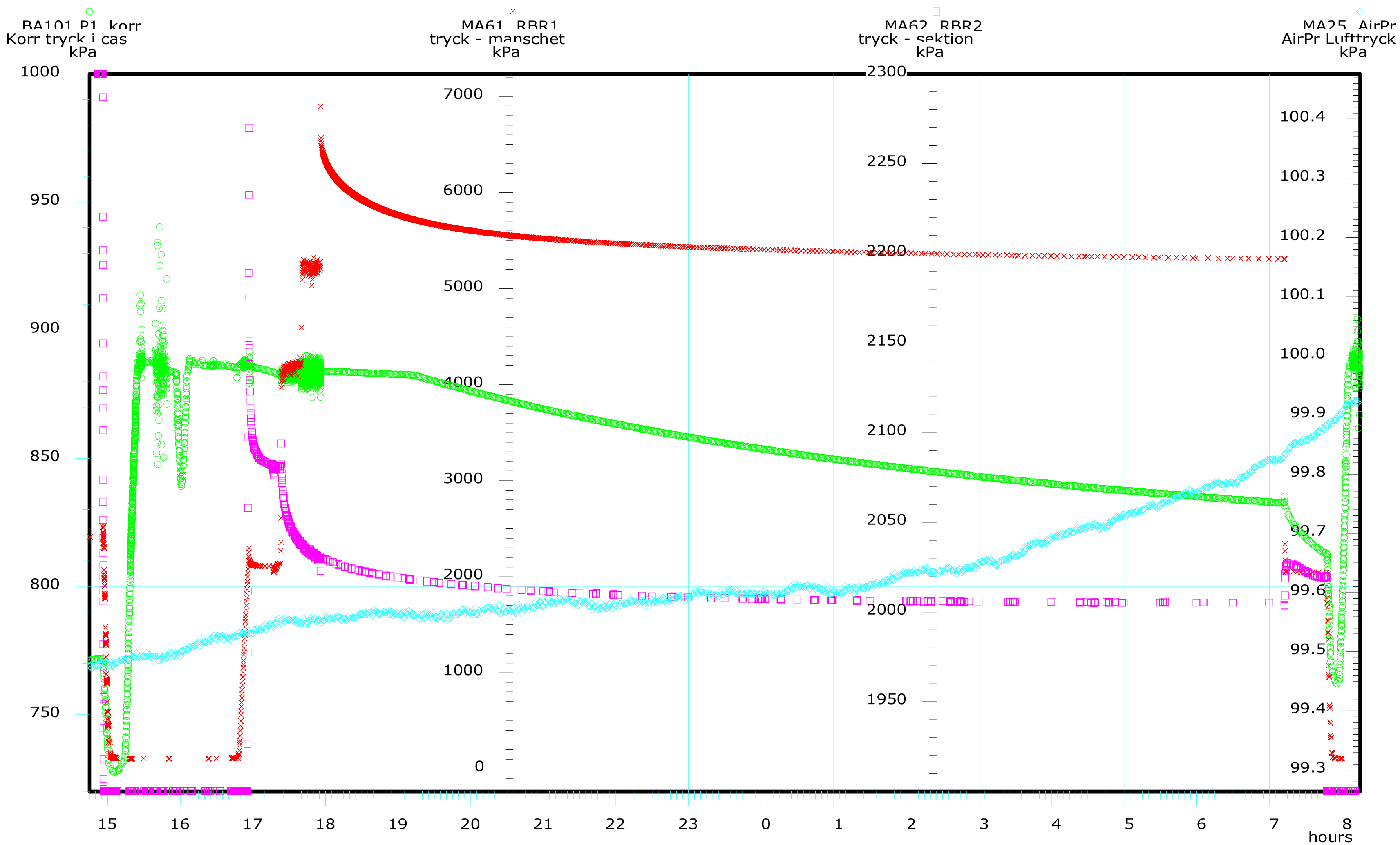
Description of the parameters in the enclosed plots.

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

PLOT TIME :04/10/06 12:33:11
PLOT FILE :P_tryck_i _sektion
Adjusted for DST

DMS1 PO

Absolute pressure measurement
KAV04 201.00-293.05m
Wireline sond



START :04/01/29 14:45:00

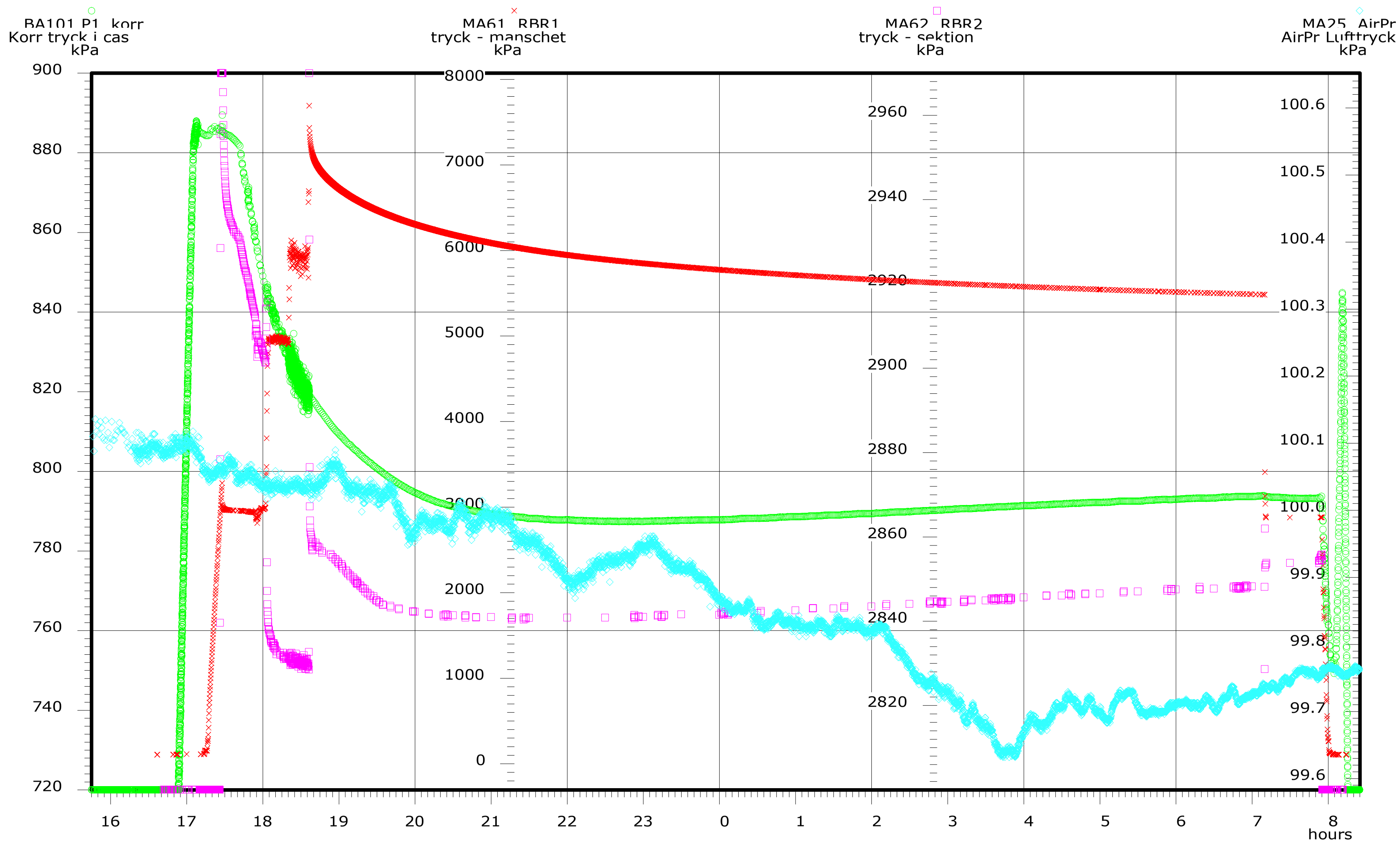
INTERVAL: All readings

STOP :04/01/30 08:14:59

PLOT TIME :04/10/06 12:42:58
PLOT FILE :P_tryck_i _sektion
Adjusted for DST

DMS1 PO

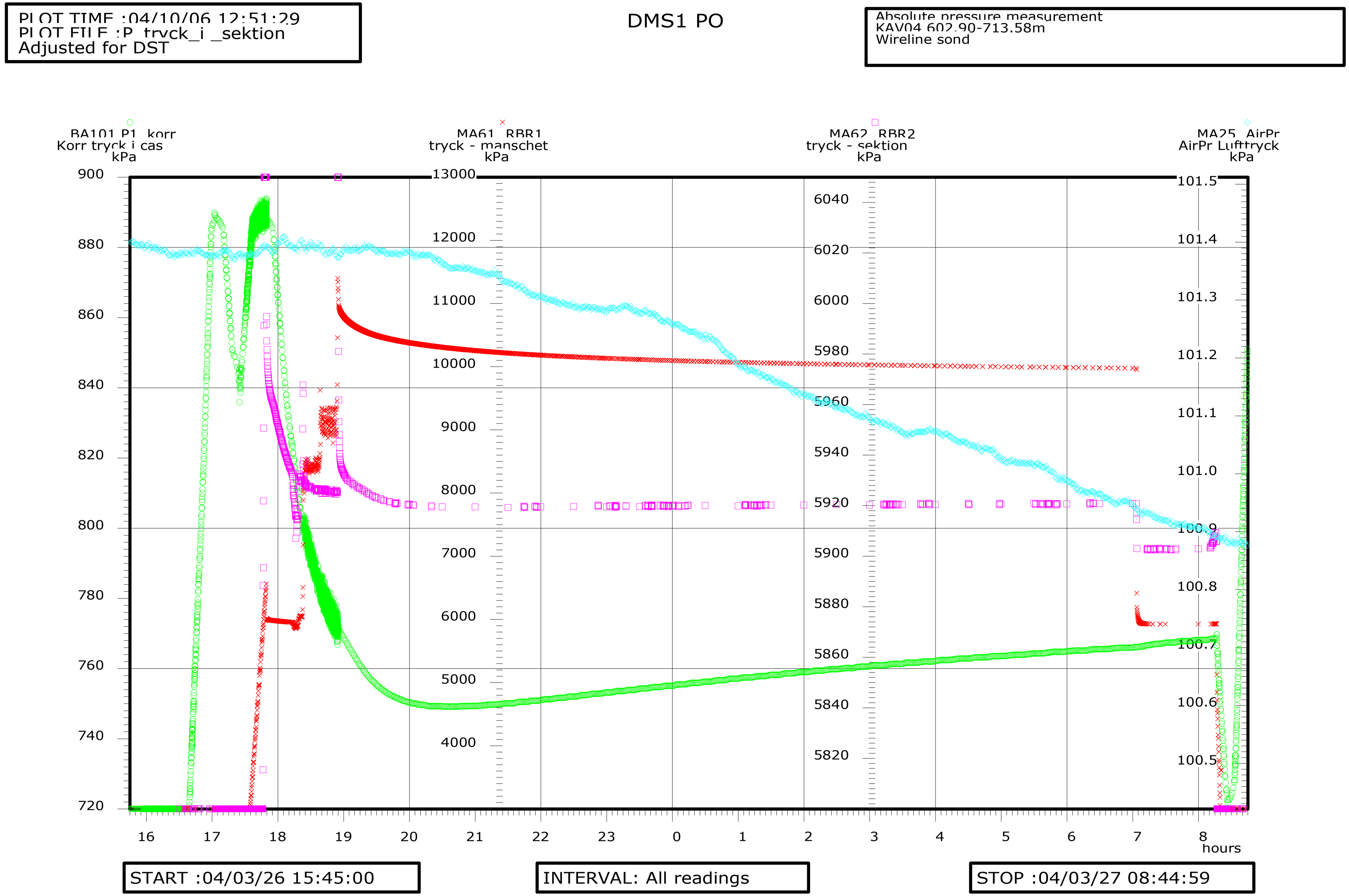
Absolute pressure measurement
KAV04 290.15-417.45m
Wireline sond

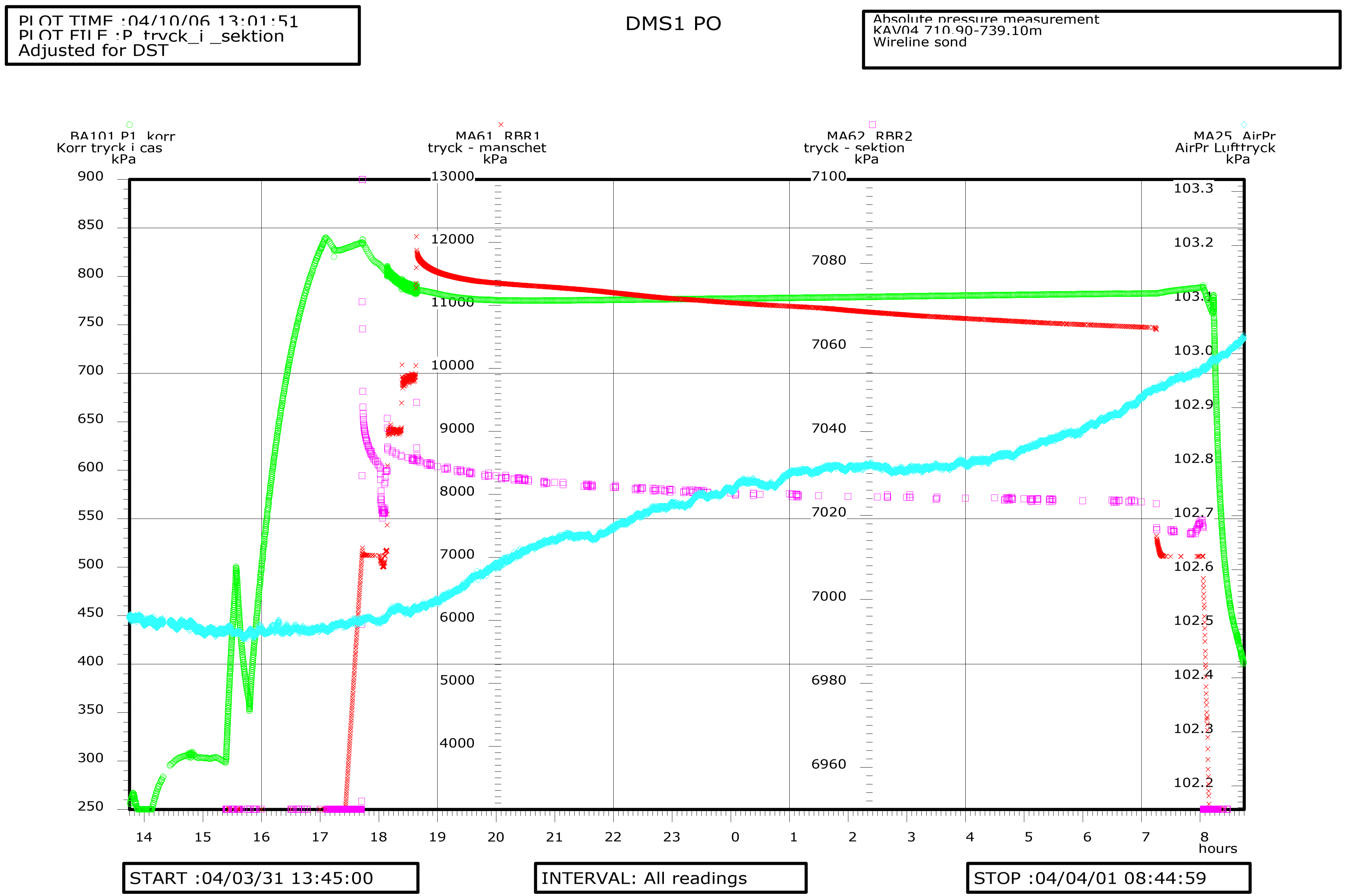


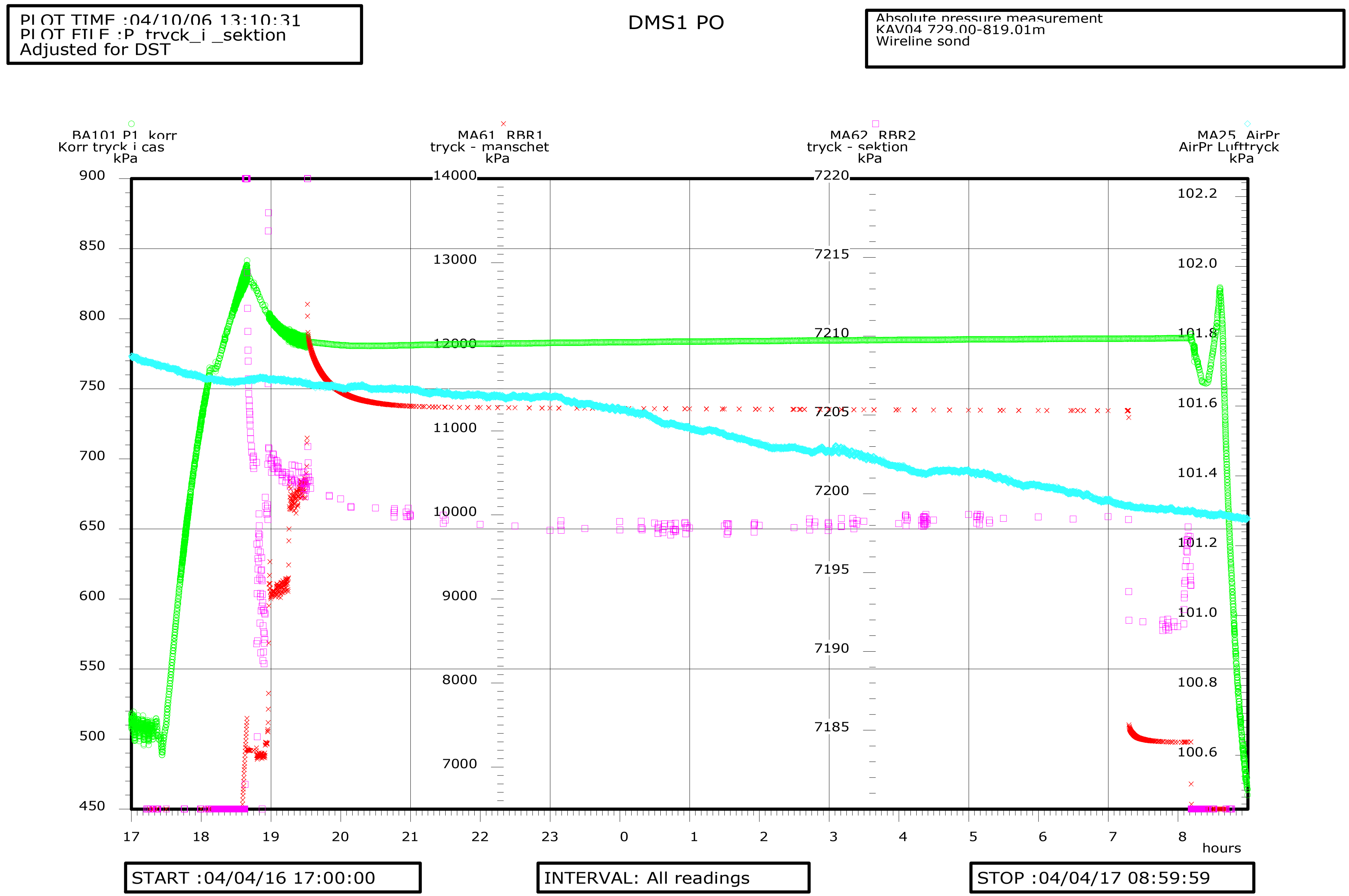
START :04/02/04 15:45:00

INTERVAL: All readings

STOP :04/02/05 08:24:59


PLOT TIME :04/10/06 12:51:29
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PO
Absolute pressure measurement
KAV04 602.90-713.58m
Wireline sond
RA101_P1_korr
Korr tryck i cas
kPa
MA61_RBR1
tryck - manschet
kPa
MA62_RBR2
tryck - sektion
kPa
MA25_AirPr
AirPr Lufttryck
kPa
hours
START :04/03/26 15:45:00
INTERVAL: All readings
STOP :04/03/27 08:44:59


PLOT TIME :04/10/06 13:01:51
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PO
Absolute pressure measurement
KAV04 710.90-739.10m
Wireline sond
BA101 P1 korr
Korr tryck i cas
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
MA25 AirPr
AirPr Lufttryck
kPa
hours
START :04/03/31 13:45:00
INTERVAL: All readings
STOP :04/04/01 08:44:59


PLOT TIME :04/10/06 13:10:31
PLOT FILE :P_tryck_i _sektion
Adjusted for DST
DMS1 PO
Absolute pressure measurement
KAV04 729.00-819.01m
Wireline sond
BA101 P1 korr
Korr tryck i cas
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
MA25 AirPr
AirPr Lufttryck
kPa
900
850
800
750
700
650
600
550
500
450
14000
13000
12000
11000
10000
9000
8000
7000
7220
7215
7210
7205
7200
7195
7190
7185
102.2
102.0
101.8
101.6
101.4
101.2
101.0
100.8
100.6
17
18
19
20
21
22
23
0
1
2
3
4
5
6
7
8
hours
START :04/04/16 17:00:00
INTERVAL: All readings
STOP :04/04/17 08:59:59