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Forsmark site investigation

Some corrosion observations and electrical measurements at drill sites DS4, DS7 and DS8

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December 2005

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Keywords: SP, Self Potential, Logging, Ground measurements, Corrosion, Clamp ampere meter, Gradient probe, Forsmark, AP PF 400-04-68.

Abstract

- Corrosion was observed on the chemical analyzing equipment at two occasions in borehole KFM04A.
- SP (Self Potential) measurements have been conducted during two days in KFM04A. The logging indicates correlation with the direct current in the Fennoskan HVDC cable.
- The SP measurements did not show any correlation with magnetic data from the Uppsala Magnetic Observatory.
- An SP-profile was conducted from DS4 to DS1. The profile indicates a strong anomaly at DS4.
- SP-measurements carried out on the ground surface around DS4 indicate a strong anomaly around the electric transformer and displayed increased values along the road to the drill site.
- SP gradient logging in the boreholes KFM04A, KFM07A and KFM08A with the new developed gradient probe indicated correlations with the power in the Fennoskan cable.
- Current measurements in the electrical grounding wires in the Forsmark area and potential measurements with the gradient probe in boreholes show a strong correlation with the current in the Fennoskan cable.

Sammanfattning

- Korrosion har observerats vid två tillfällen i borrhål KFM04A på den kemiska analysutrustningen.
- SP (själv-potential) mätningar har utförts i KFM04A under två dygn. Moniteringen visar att det finns signifikant korrelation med strömmen i Fennoskan HVDC kabeln. Ingen korrelation förekommer däremot med jordmagnetfältet, mätt vid Uppsala Magnetiska Observatorium.
- En SP-profil har utförts mellan BP4 och BP1. Profilen visar en mycket kraftig anomali vid BP4.
- SP-mätningarna i området runt BP4 visar på en kraftig anomali runt transformatorstationen och förhöjda värden längs vägen till borrplatsen.
- Gradientloggning i borrhålen KFM04A, KFM07A och KFM08A med en nyutvecklad mätsond visade korrelation med strömmen i HVDC kabeln.
- Strömmätningar i jordlinenätet i Forsmark och potentialmätningar i borrhål med gradientsonden visar stark korrelation med strömmen i Fennoskan-kabeln.

Contents

1 Introduction

This document reports the results gained by the Self Potential (SP) measurements at drill site 4 (DS4), which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-04-68. A complementary investigation with SP measurements was also carried out in and around DS4, as well as measurements in other boreholes, not included in the activity plan. Measurements of current in the electrical grounding wires and development of a new gradient probe for logging the potential gradient every minute were included in the activity as well.

In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

The measurements presented in this report include SP loggings in the c 1,000 m long inclined telescopic borehole KFM04A at a length of 225 to 240 m, SP measurements between drill sites DS4 and DS1, and SP measurements around DS4, see Figure 1-1. Measurements with the gradient probe were conducted in KFM04A, KFM07A and KFM08A. Geophysical data from KFM04A /1/ are presented in Appendix 1 for comparison.

The measurements were conducted by:

- Rolf Sandström (gradient probe measurements).
- Björne Fredriksson (electrical grounding wire measurements).
- Jaana Gustafsson, Johan Nissen (surface potential measurements, borehole logging).
- Ramböll (Self Potential geophysical logging).

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

Activity plan	Number	Version
SP (SjälvPotential) mätningar vid borrplats 4.	AP PF 400-04-68	1.0
Method descriptions.	**Number**	**Version**
Instruktion för rengöring av borrhålsutrustning och viss markbaserd utrustning.	SKB MD 600.004	1.0
Instruktioner för inmätning och avvägning av objekt.	SKB MD 110.001	1.0

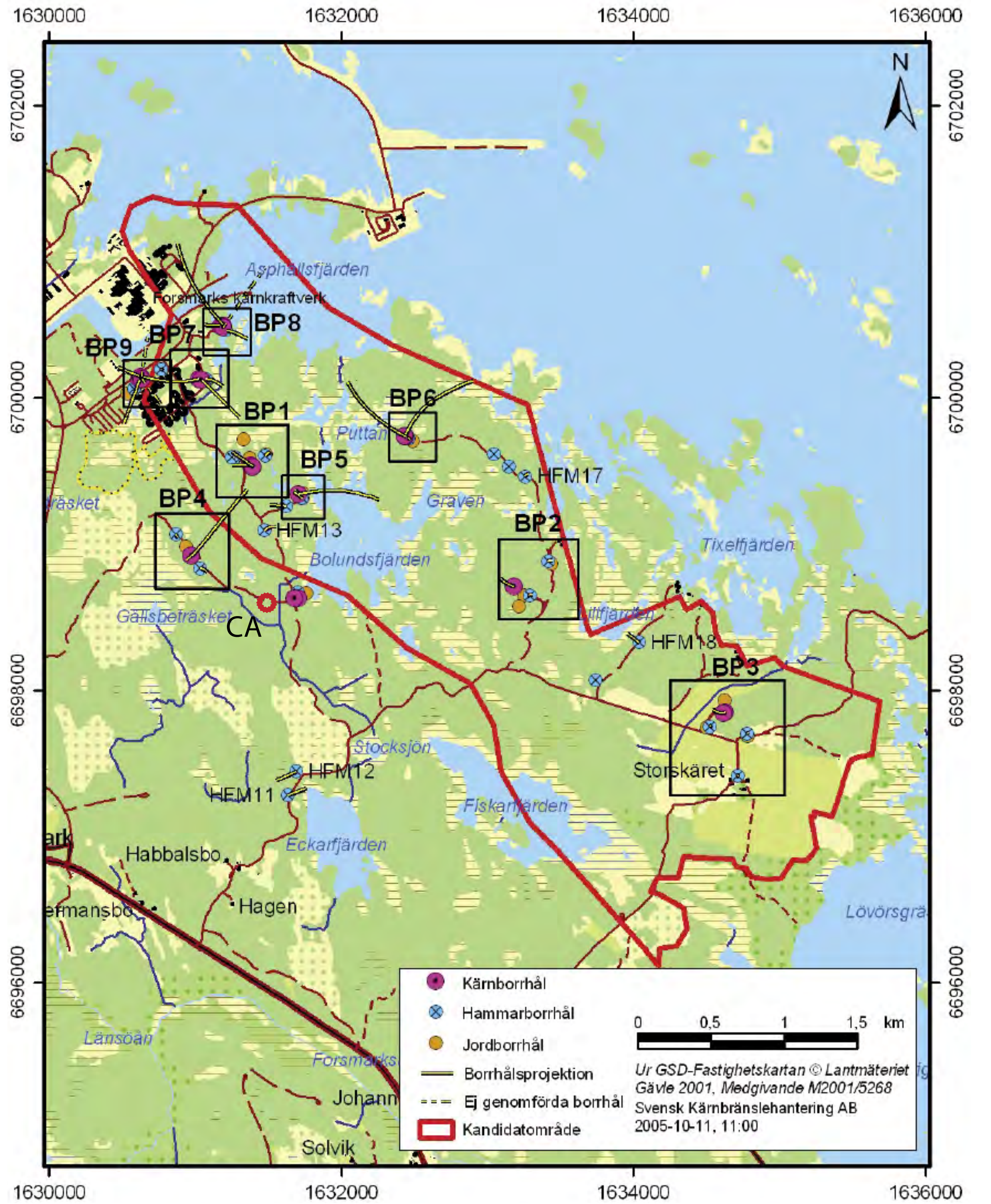


Figure 1-1. *General overview of the Forsmark site investigation area, showing the location of the drill sites DS1, DS4, DS7 and DS8 with the boreholes and their projection on the ground surface. The logging with the clamp ampere meter was conducted close to the red symbol CA.*

1.1 Description of Fennoskan HVDC sea cable to Finland

A connection for transferring High Voltage Direct Current exists between Finland and Sweden. The power rating for this system is 500 MW and the power can be transferred in both directions. The connection is designed according to the chart diagram in Figure 1-2. The location of the sea cable in the vicinity of Forsmark is shown in Figure 1-3. The Swedish electrode (anode) is placed at the vicinity of lighthouse Björn, approximately 30 km north of the site investigation area in Forsmark, see Figure 1-4. The Finnish electrode (cathode) is placed in Rauma. The anode consists of a titanium net and the cathode of a copper net.

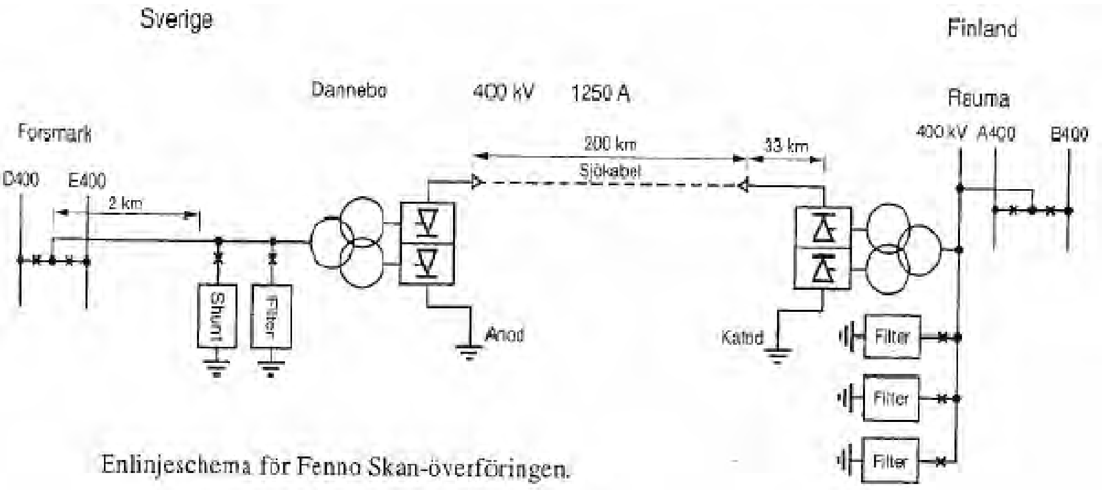


__Figure 1-2.__ Wiring chart showing the High Voltage DC cable between Sweden and Finland with anode and cathode.

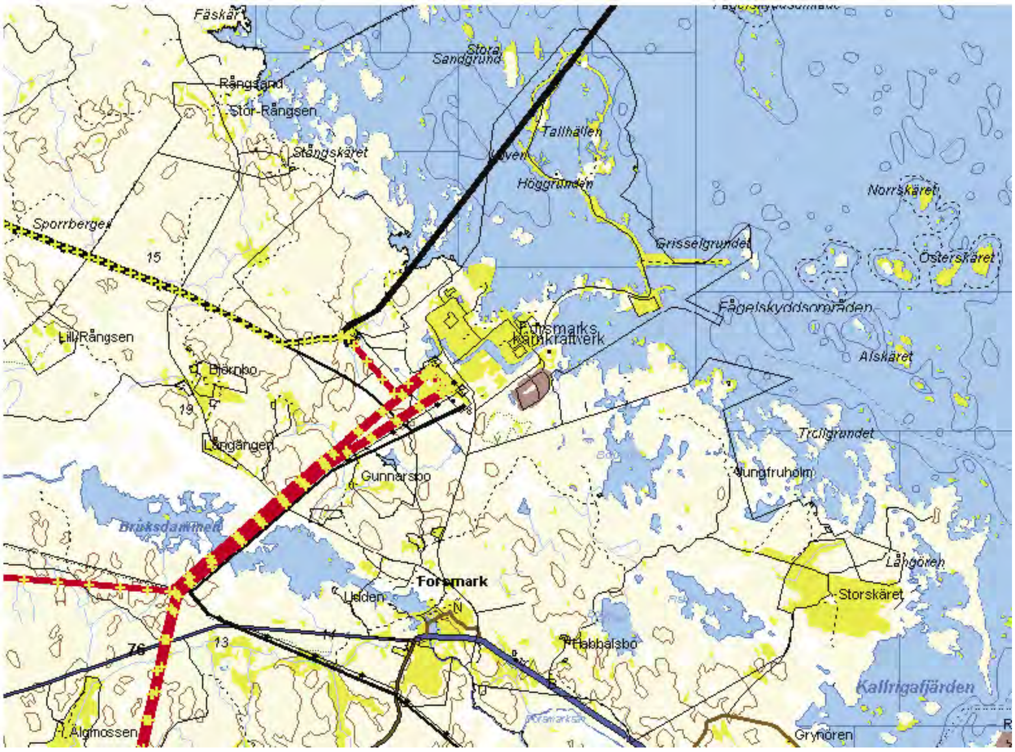


__Figure 1-3.__ General overview of Forsmark Power station, showing the location of Fennoskan (the High Voltage DC cable to Finland, black line on the map).

Figure 1-4. General overview of Fågelsundet, showing the location of the anode (black line in the map). The cathode is located in Finland.

In normal operation of the system, a DC current of up to 1,250 A is running between the anode and the cathode. The current can follow different paths between the electrodes, not necessarily the shortest way through the seawater. The actual path depends upon resistance in the earth, water, infrastructures etc. Metal structures with low resistance like pipes, pumps etc will make an easy path for the current and will cause corrosion to occur on those. This is a well-known problem in the neighbourhood of the electrodes were the current is high. In the surrounding of Forsmark, the voltage drop is believed to be around 300 mV/km.

An increasing need for exchange of power between Finland and Sweden ground the plans for Svenska Kraftnät to increase the power rating for the HVDC-system. An extension of the system is made by establishing a second sea cable with reversed polarity parallel to the existing, in order to create a bipolar connection. In normal operation the current in the extended system will pass through these two cables instead of the electrodes. Only in abnormal cases like malfunctioning, service and testing, the current will pass the electrodes. As a consequence, the current in the electrodes is estimated to be decreased with about 90%.

A preliminary decision for the investment has been taken in February 2005, but the final decision will be taken in 2008. The system will then be taken into operation in 2010.

2 Objective and scope

The objective of the surveys was to achieve information that could explain the high amount of corrosion observed on the chemical analysing equipment and the strange measurements observed for other systems when used in borehole KFM04A.

2.1 Background

Severe corrosion was observed on chemical analysing equipment at three occasions. The first sign of corrosion was noticed after only ten days of use in the borehole. After replacing borehole equipment, the system was used for another fourteen days. In the meantime, the corroded equipment was analysed by an external laboratory. The analysis indicated crevice corrosion and some spots of pitting corrosion. The process had been very fast and can not take place without an external driving force. The material in the equipment was confirmed to be stainless steel SS2343. This type of corrosion was unexpected in the oxygen-free environment. In terms of corrosion current, 1 cm^3 steel (Fe) corrosion in 10 days would correspond to a current of 32 mA, which follows from:

$$I = \frac{q}{t} = \frac{2 \cdot F \cdot \rho}{M_w \cdot t} \; (A)$$

where

F = Faradays constant = 9,6487 As/mol e^-

ρ = density for steel = 8 g/cm^3

M_w = molar weight for steel (Fe = 55.8 g/mol)

At examination of the second equipment it was observed that the same type of corrosion had occurred. The chemical environment in the borehole was similar to previously investigated boreholes in the Forsmark area, and nothing unusual has been found previously. The chemical analysing equipment was also checked for electrical malfunctions.

The down-hole umbilical hose, originally containing a steel wire, was replaced with a design with aramid braiding instead of the steel wire. The purpose was to isolate galvanically the borehole equipment from the surface.

After the modifications, the borehole equipment was used at a new section at 360 m borehole length, and it was observed that the problems still existed. Severe crevice corrosion was observed. A special device for measuring the corrosion potential in the borehole was therefore constructed. The idea with the device was to simulate the chemical analysing equipment, but in a smaller scale.

2.1.1 Corrosion of stainless steel SS2343

SS2343 is a stainless steel of intermediate quality from a corrosion point of view. It is not suitable for use in aerated seawater because of the high chloride concentration in combination with the high electrochemical potential imposed by the dissolved oxygen. Corrosion has been known to occur also in brackish water. The form of corrosion observed on SS2343 under these conditions is mainly crevice corrosion. Pitting corrosion can also be observed although crevice corrosion usually sets in at milder conditions than required for pitting corrosion.

Factors known to be detrimental for stainless steels are high chloride concentrations, high sulphide concentrations, high electrochemical potentials and high temperatures. High sulphide concentrations and high electrochemical potentials are usually mutually exclusive; a sulphide rich environment is reducing and not oxidising. For a construction in water, partially immersed in mud, sulphide in the mud may still contribute to the corrosivity of the environment because the electrochemical potential of the whole construction may be controlled by the part exposed to oxygen rich water.

SS2343 is suitable for use in ground water under anoxic conditions. Corrosion under such circumstances usually requires a metallic connection to surfaces exposed to an oxidising environment. Other factors that can cause corrosion are electric malfunction of electronic circuitry and strong external electric fields. The paths for the electric current for these two latter situations are indicated in Figures 2-1 and 2-2, respectively.

Common to both these latter factors is that one part of the construction must behave as an anode while the other behaves as a cathode.

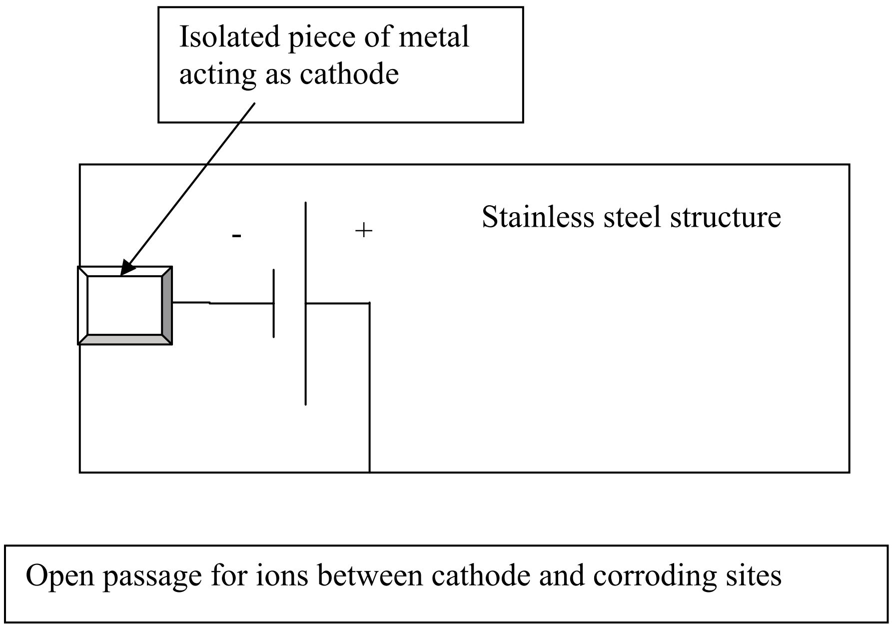


Figure 2-1. *Schematic illustration of electronic malfunction of internal circuitry as a cause for corrosion. The pieces of metal acting as a cathode need to be isolated from the stainless steel structure for corrosion to occur. Otherwise the battery would just be short circuited without causing corrosion.*

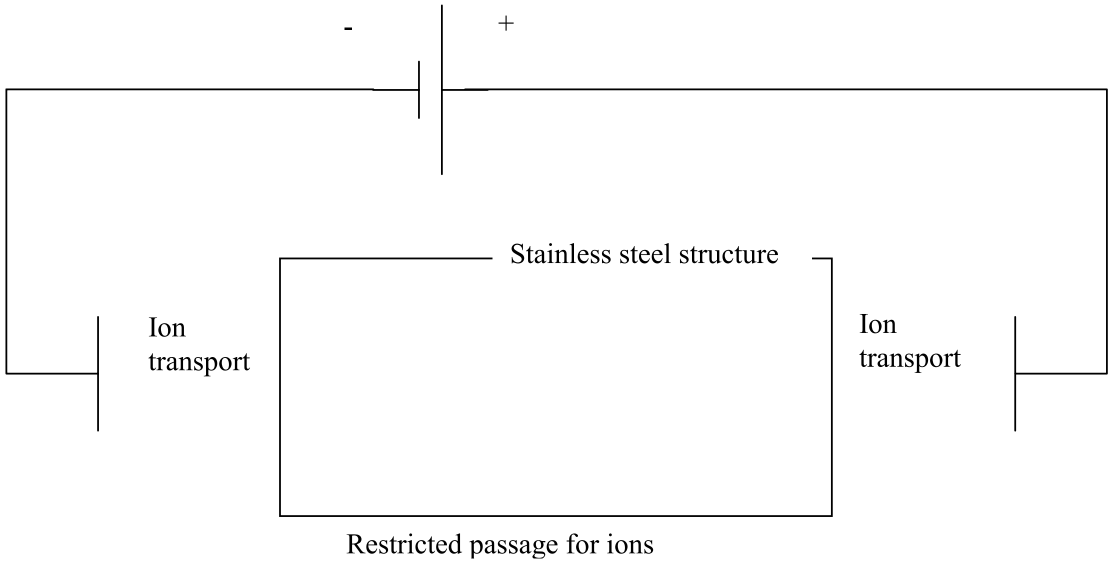


Figure 2-2. *Schematic illustration of an external electric field as a cause for corrosion. Ion transport to and from the ends of the structure must be facile while the ion transport along the structure must be restricted.*

The main anodic reaction is the electrochemical dissolution of the steel:

$Fe(steel) \rightarrow Fe^{2+} + 2e^-$

with similar contributions from nickel and chromium in the steel. The main cathodic reaction in the absence of dissolved oxygen is usually the cleavage of water to hydrogen.

$H_2O + e^- \rightarrow OH^- + 1/2\ H_2$

The molecular hydrogen formed does not necessarily form gas bubbles. Hydrogen gas has a significant solubility in water.

From a thermodynamic point of view, it might be possible for these two reactions to take place in the same piece of metal. However, the stability of stainless steels does not rely on thermodynamics but on passivity and all experience indicates that the reactions do not take place without an external driving force. The electrochemical dissolution of the steel requires a high electrochemical potential and the cleavage of water requires a low electrochemical potential. It is not easy to set an exact limit to the necessary voltage, reasonable estimates are in the range of 0.5 to 1.0 Volts.

For an internal electric malfunction to be a cause of corrosion, as indicated in Figure 2-1, one isolated piece of metal must be coupled to a battery and at least 0.5 Volts lower than the stainless steel. A closed circuit, which is a further prerequisite, requires electrolytic contact between the negative piece of metal and the stainless steel so that the voltage drop in the ground water is not prohibitive.

For a strong external electric field to be a cause of corrosion, as indicated in Figure 2-2, the voltage drop in the water must be relatively high. The required 0.5–1.0 V voltage drop must be located in the ground water along the structure, between the surface behaving as a cathode and the surface behaving as an anode.

2.1.2 Some pictures from inside and outside of the chemical analysing equipment.

The Figures 2-3 to 2-9 illustrate both pitting and crevice corrosion which was observed on the equipment.

Figure 2-3. *Pitting corrosion on the outside of the chemical analysing equipment.*

Figure 2-4. *Corroded thread and nut on a valve inside the chemical analysing equipment.*

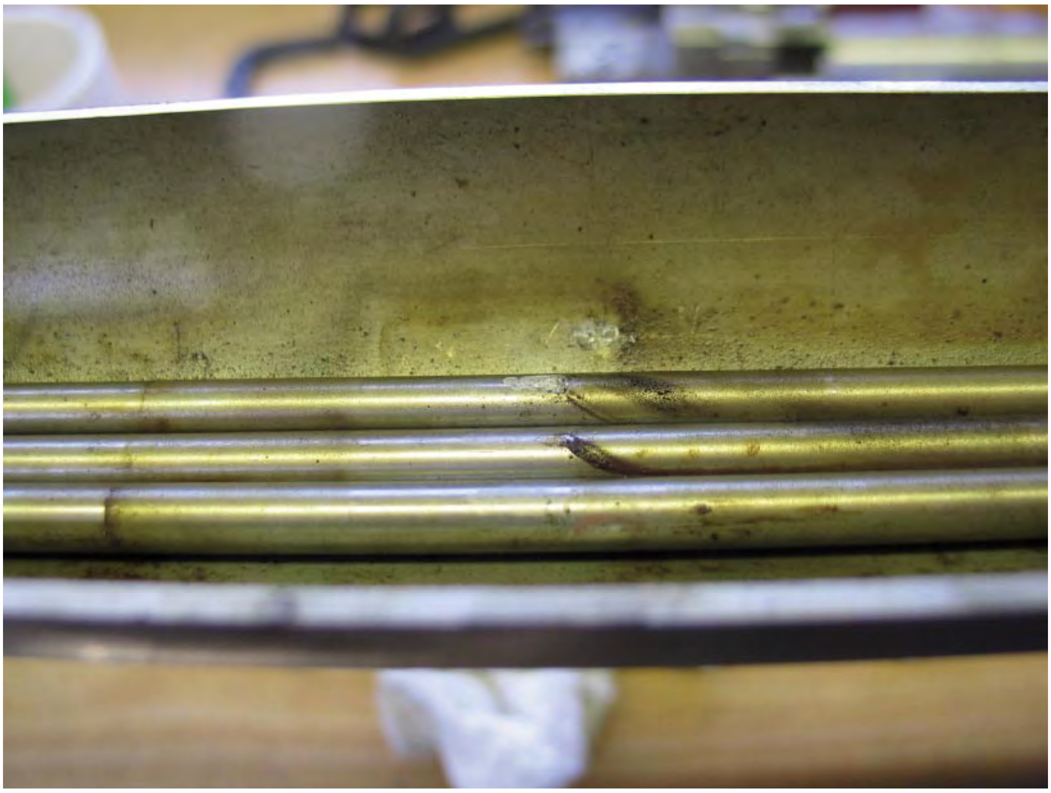


Figure 2-5. *Pipes with crevice corrosion inside the chemical analysing equipment.*

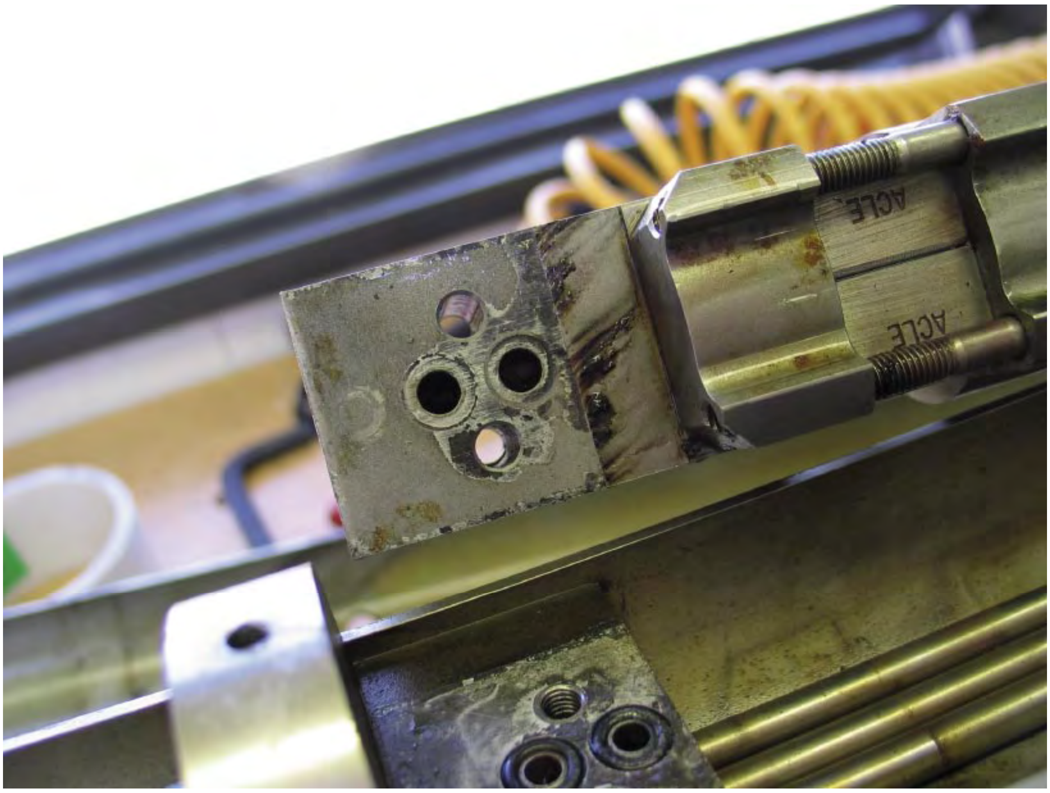


Figure 2-6. *Details with crevice corrosion inside the chemical analysing equipment.*

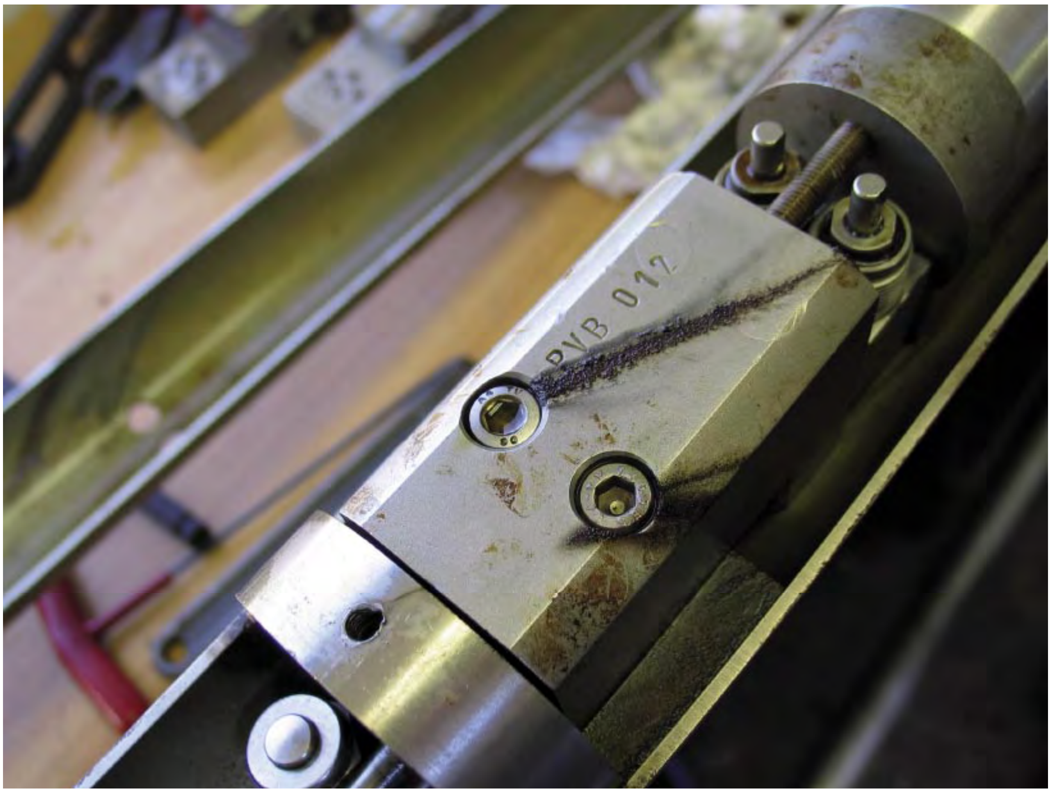


Figure 2-7. *Details with crevice corrosion inside the chemical analysing equipment.*

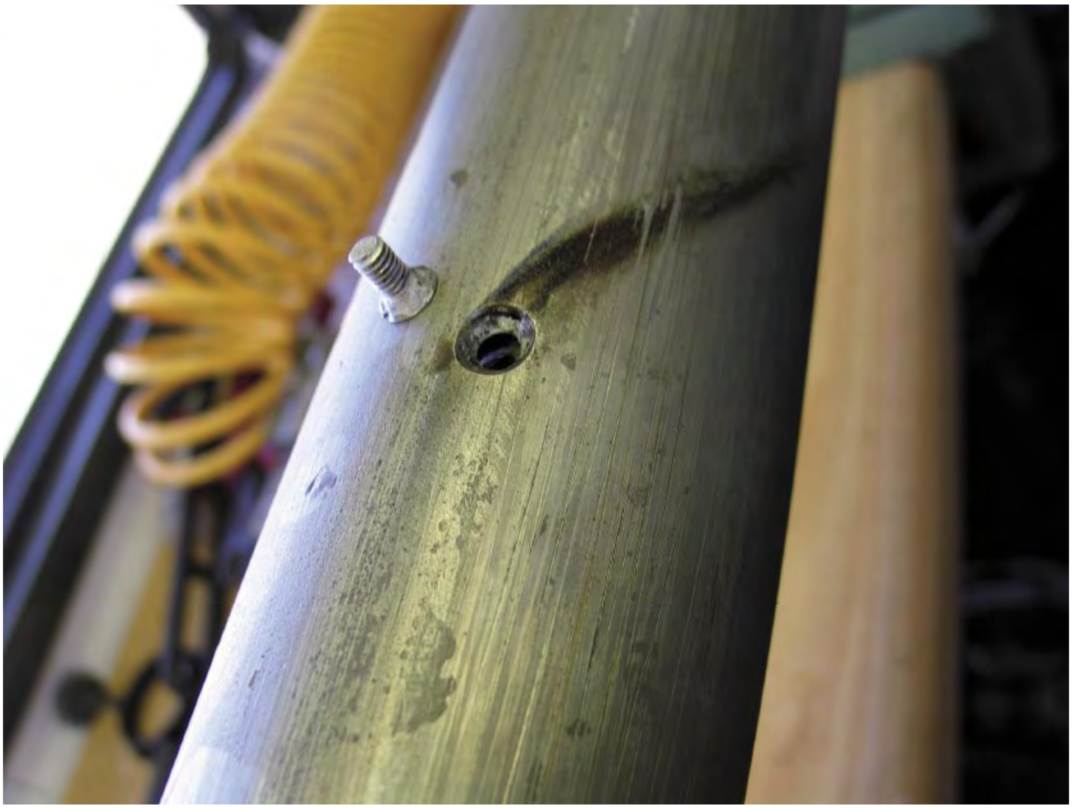


Figure 2-8. *Details with crevice corrosion inside the chemical analysing equipment. The black traces are metallic material flooding out from the points of corrosion.*

Figure 2-9. *Details with crevice corrosion inside the chemical analysing equipment.*

3 Equipment

Three different types of equipment were used for measuring the potential:

- For ground measurements and for logging in the borehole, relative to a surface reference point, a Terrameter SAS1000 was used.
- For gradient voltage measurements in the borehole, a gradient probe with a built-in data-logger was constructed by SKB.
- The current in the electrical grounding wires was measured using a clamp ampere meter with a connected logger.

3.1 Description of the Terrameter SAS1000

The equipment used for SP measurements, both for logging and for ground investigation, was a Terrameter SAS1000 (Serial Number 2041601), manufactured by ABEM. See Figure 3-1.

The SAS1000 was employed for resistivity, induced polarization and SP measurements. This equipment has a very high input impedance (> 10 Mohm), which is important when detecting voltage differences in a resistive environment. For technical specifications, see Table 3-1.

The SAS1000 was also used together with non-polarizable electrodes, manufactured by ABEM. These electrodes consist of a rough tube, containing a matrix of gypsum with lead-chloride, see Figure 3-1.

Figure 3-1. *Picture of the Terrameter SAS1000 and a non-polarizable electrode.*

Table 3-1. Technical specifications of the ABEM Terrameter SAS1000.

Receiver:	
Number of input channels	Single channel
Input impedance	10 MOhm
Resolution	30 nV
IP chargeability	Measured in 1–10 time intervals, e.g. 10–30 ms, 30–50 ms etc. Apparent chargeability given in [mV sec/V] = (msec).
IP integration interval	20 ms/16.66 ms depending on power line frequency (50 HZ/60 Hz).
Dynamic range	Up to 140 dB plus 64 dB automatic gain .
Transmitter	
Output current	1, 2, 5, 10, 20, 50, 100, 200, 500, 1,000 mA. Accuracy better than 0.5%.
Maximum output voltage	400 V
Maximum output effect	100 W
General	
Computer	PC compatible.
Memory	Capacity for more than 120,000 readings.
Display	LCD, 200×64 pixels.
Serial interface	RS 232
Support for external devices	LUND Imaging System SAS LOG 200/300, MULTIMAC.
Power	Internal or 12 V through SAS–EBA (External Battery Adapter).
Storage temp.	–15°C to +55°C
Operating temp.	–5°C to +50°C
Weight	4.9 kg with SAS–EBA

3.2 Description of the gradient probe with built-in logger

To simulate the chemical analysing equipment, a voltage gradient probe was constructed. The probe consists of a stainless steel structure and a packer. Electrodes of zinc were fitted in both ends, se Figures 3-2 and 3-3. The electrodes were galvanically isolated from the structure and connected to a four-channel data-logger type TXF11 v2. The logger was housed and electrically grounded to the lower end of the probe. Voltage difference between the upper zinc-electrode (channel 3) and the structure (channel 1) and the lower zinc-electrode (channel 2) and structure (channel 4) was monitored.

To avoid galvanic connection between the surface and the gradient probe it was lowered in the borehole by means of a rope. To expand and pressurise the packer a polyamide tube was used. The packer was pressurised to 20 bars during measurements.

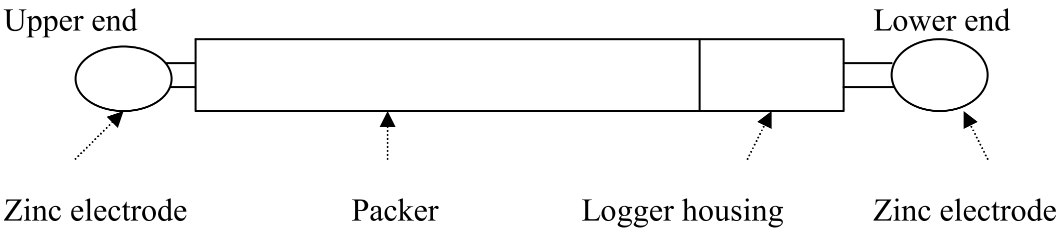


Figure 3-2. *A sketch of the gradient probe. The distance between the zinc electrodes is approximately 1.5 m. The voltage difference is presented as the voltage in the lower zinc electrode minus the voltage in the upper zinc electrode,* $V_{lower}–V_{upper}$.

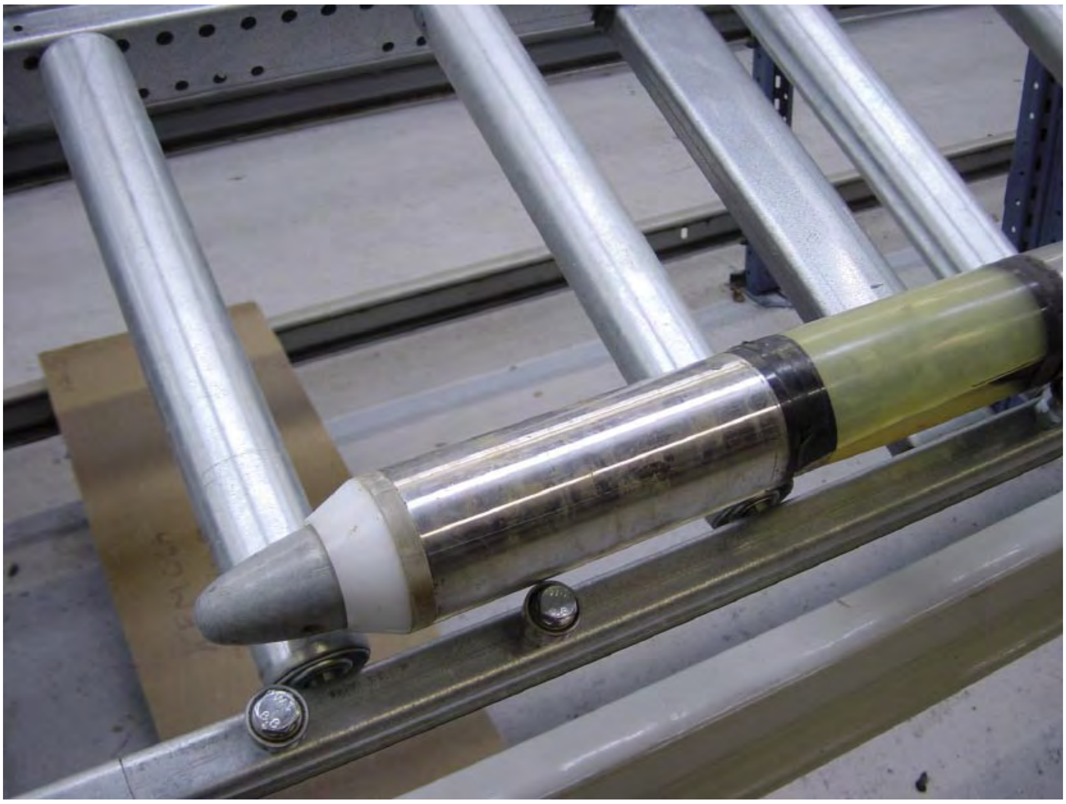


Figure 3-3. *The lower end of the gradient probe with zinc-electrode and logger housing.*

3.3 Description of the clamp ampere meter and logger

MULTI AC/DC Clamp Leaker M-600 F-nr 3962 was used to measure current in electrical ground wires. To compare current in the electric grounding wire and measurements with the gradient probe, a logger connected to the clamp ampere meter was used. Measurements were taken every minute.

Table 3-2. Technical specifications of the clamp ampere meter.

Product description	MULTI AC/DC Clamp Leaker M-600
Article number	3962
Ranges	200 mA DC 2 A DC 10 A DC 200 mA AC 50 HZ 2A AC 50 Hz 10 A AC 50 HZ

Table 3-3. Technical specifications of the data-logger.

Product description	Spectrum 4000
Article number	SP-4000-411
Technical data	4 Channels, 2 ch 0–10 V, 2 ch 0–1/10 V, 70000 readings, 12 bit resolution
Input impedance	> 1 MΩ
Range	0.0–0.1 V, 0–10 V
Uncertainty	± 0.15% of Full Scale (FS)
Measurement intervals	Adjustable in 10 seconds intervals up to 24 hours.

4 Execution

4.1 General

The surveys were carried out according to AP PF 400-04-68 with extensions. No method description is available at SKB for potential measurements of the kind performed in this activity. To investigate the source for the earth current (and thereby the corrosion), the measurements were compared with the actual current in Fennoskan HVDC-cable.

4.1.1 The Terrameter SAS1000

The logging of KFM04A with the Terrameter SAS1000 was done with one reference electrode on the ground surface, approximately 30 m away from the borehole, and with a non-polarized electrode in the borehole. The measurement equipment was located on the ground, and logged SP data during approximately 2 days.

The ground investigations, both in June and in August 2004, used the same reference electrode and a non-polarized electrode which were moved, together with the measurement equipment, along a profile from DS4 towards DS1 and around DS4.

4.1.2 The gradient probe

The measurements with the gradient probe were carried out during five different time periods:

2004-09-24 to 2004-09-27 at borehole length 230 m

2004-10-12 to 2004-10-20 at borehole length 240 m

2004-10-21 to 2004-10-28 at borehole length 240 m

2004-11-29 to 2004-12-02 at borehole length 225 m

Measurements in KFM07A and KFM08A were carried out from 2005-11-02 to 2005-11-07.

The logger was started and put into the housing before the gradient probe was lowered into the borehole by means of a rope together with the polyamide tube. At the measuring position the packer was expanded and pressurised to 20 bars.

4.1.3 The clamp ampere meter

To investigate the source of the current, seen on the complementary SP-mapping and the strange behaviour of other measurement systems used in KFM04A, single measurements were taken on the electrical grounding wires. These measurements show that there were unexpected currents running in the wires, see Section 5.3.

To compare data from the other measurements with DC currents in the electrical grounding wire, the clamp ampere meter was connected to a logger. The logger was programmed to take one measurement every minute. During the long-time measurement the clamp ampere meter with logger was placed inside a cabinet containing a connection point in the 20 kV systems. To avoid doubt about interference from the 20 kV systems, measurements were also taken on the electrical grounding wire between two connection points. Single measurements were also taken by moving the clamp ampere meter to different points were the electrical grounding wire was reachable.

4.2 Execution of field work

4.2.1 Measurements with Terrameter SAS1000

The profiling, i.e. mapping on the ground, was carried out along a profile from DS4 towards DS1, see Figure 4-1. SP- measurements were made every 10 m, giving 66 measurement points over a distance of 650 m. The location of the reference electrode follows from Figure 4-1.

For each 50 m the position of the profile is measured with an accuracy of 0.5–1 m, using a Trimble AgGPS with DGPS correction.

The complementary SP-mapping around DS4 was made at the following points, see Figure 4-2.

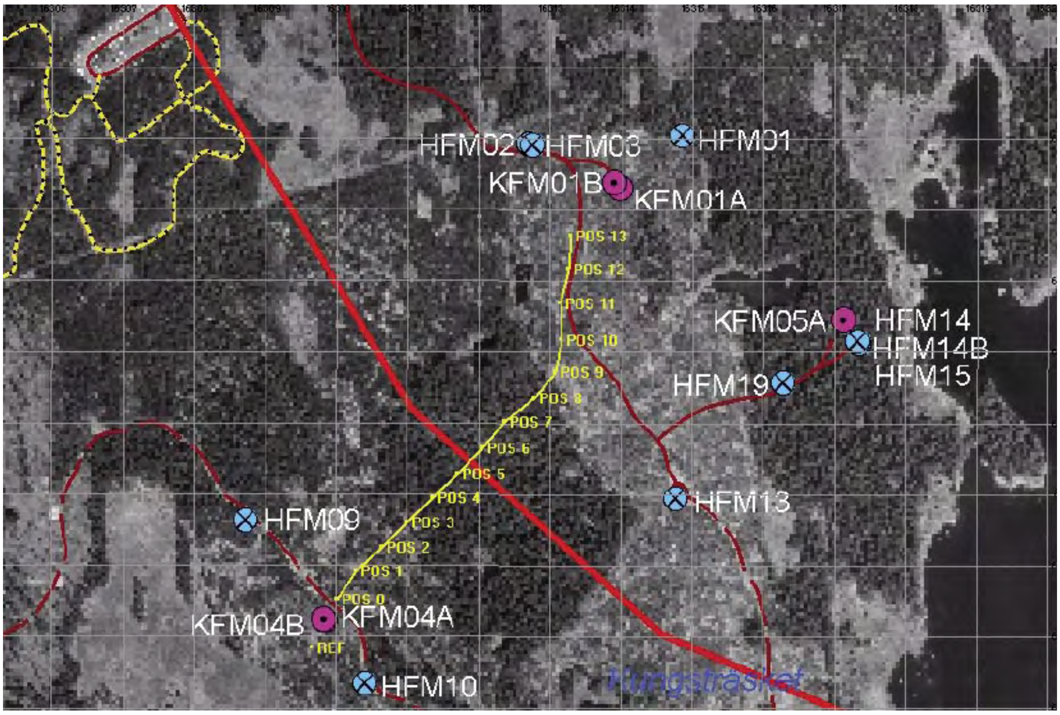


***Figure 4-1.** Map over the SP investigation site, showing the location of the reference electrode, boreholes KFM04A and KFM01A and the investigation points. The coordinates of the profile are measured each 50 m from POS 0 to POS 13.*

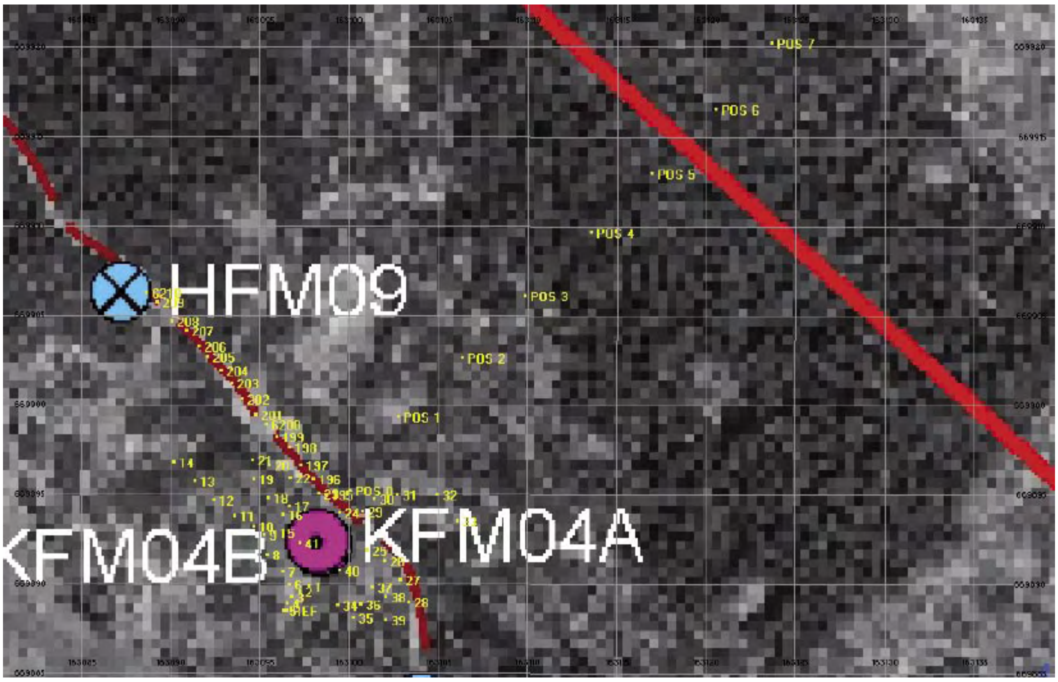


Figure 4-2. *Detailed map showing the location of the measurements around DS4.*

Monitoring of SP in KFM04A at 232 m was started 2004-06-15 09:38:53 and stopped 2004-06-17 08:18:41. The measurement equipment was checked and the borehole electrode lowered to a borehole length of 232 m, which was considered as the most interesting depth where corrosion on the chemical logging equipment was observed. SP-data had been collected every 30 seconds, giving approximately 5,400 readings.

4.2.2 Measurements with gradient probe

The measurements in KFM04A were made at four different occasions and measurements in KFM07A and KFM08A at two occasions. The logging of data starts as soon as the batteries are connected to the logger. The battery capacity lasts for approximately 6 days of continuous logging with one sample every minute. Internal connection between the logger and electrodes were checked by connecting an external source with known voltage to the electrodes, and reading the value on-line on the connected computer. The logger was then disconnected from the computer and placed into the logger housing. The gradient probe was then lowered into the borehole to the decided borehole length. For the four different measurements in KFM04A the probe was placed at borehole lengths 230 m, 240 m, 240 m and 225 m respectively. At the first period, channel 3 seemed to be malfunctioning. After every measuring period the logger was taken out of the probe and connected to a computer for offloading data. Data were stored in the logger as ASCII-code and therefore had to be transferred to Excel for analysis and plotting. As the logger does not have a real clock but only a timer, the correct time had to be added to the file.

To investigate influence of length and design of the gradient probe an additional measurement with a modified probe in KFM04A was also conducted. The gradient probe was extended at the upper end with a 7 m stainless steel rod and a second packer to simulate the chemical analysing equipment. The gradient probe was then placed at the same location (230.5 m to 237.64 m) as the chemical analysing equipment. The results were similar to the measurements with the original version of the gradient probe, and are not presented here.

4.2.3 Measurements with clamp ampere meter

The clamp ampere meter was placed mounted around the electric grounding wire at different spots. This was carried out at two different occasions, first with Fennoskan in normal operation and the second time with Fennoskan out of operation. To compare data from the clamp ampere meter with other measurement it was also used from 2004-10-21 to 2004-10-28 together with a logger. The logger was programmed to take one measurement every minute. After the measuring period the logger was connected to a computer for offloading data. Data ware stored in the logger as ASCII-code and therefore has to be transferred to Excel for analysing and plotting. As the logger does not have a real clock but only a timer, the correct time had to be added to the file.

4.3 Data handling/post processing

4.3.1 Terrameter SAS1000

The Terrameter SAS1000 saves data in binary format (.S4K), and data were transferred to a PC. Then the data processing of the collected SP data was done by transforming those to ASCII format (.AMP) and creating graphs (made in Excel). The variation in SP over time can be seen in Figures 5-1 and 5-5.

4.3.2 The gradient probe

Data were stored in the logger as ASCII code and after each measuring period the data were transferred to a PC. Excel was then used for processing and plotting. Data were then correlated with the other measurements and the power in the HVDC-cable, see Figures 5-3 and 5-5.

4.3.3 The clamp ampere meter

Data were stored in the logger as ASCII code and were after each measuring period transferred to a PC. Excel was then used for processing and plotting. Data were then correlated with the other measurements and the power variations in the HVDC-cable, see Figure 5-5.

4.4 Analyses and interpretations

The results from the logging were compared to Earth magnetic data from the Uppsala Observatory, and the power in Fennoskan (the High Voltage DC cable to Finland). The purpose was to investigate whether the variation in measured potential in KFM04A correlates to these variations, or has to be explained in another way.

4.5 Nonconformities

The reference electrode for Terrameter SAS1000 was located 39 m from the KFM04A, instead of 100 m as stated in the Activity Plan. The measurements around DS4, as well as the measurements in KFM07A and KFM08A and the measurements with the clamp amperemeter, were not described in the Activity Plan. The results of the logging with the gradient probe in KFM07A and KFM08A are presented in Appendix 2. In Appendix 3 some observations of corrosion in the borehole KLX03A located in Laxemar, Oskarshamn site investigation area, are described.

5 Results

The results from all measurements were delivered to SKB as tables in Excel-format before the field crew left the investigation site. The measurement data are registered in the SKB database SICADA where they are traceable by the activity plan number.

5.1 Logging with Terrameter SAS1000

The results from 12 hours of the SP logging in KFM04A 2004-06-16 are shown in Figure 5-1 below. Between 11:00 and 12:00 a decreased current in Fennoskan is seen to correlate with a change in the measured voltage between the reference electrode and the borehole electrode.

In Figure 5-2 the Earth magnetic field data are presented. As seen, no dramatic changes in the magnetic values are observed within the investigation period, and no correlation between the SP-variations and the magnetic variations are observed.

As the purpose of this investigation was to reveal if the SP anomalies measured were related to the transmitted power in the Fennoskan HVDC cable, the current in the latter was logged during the same time period, and the results are presented in Figure 5-3 below.

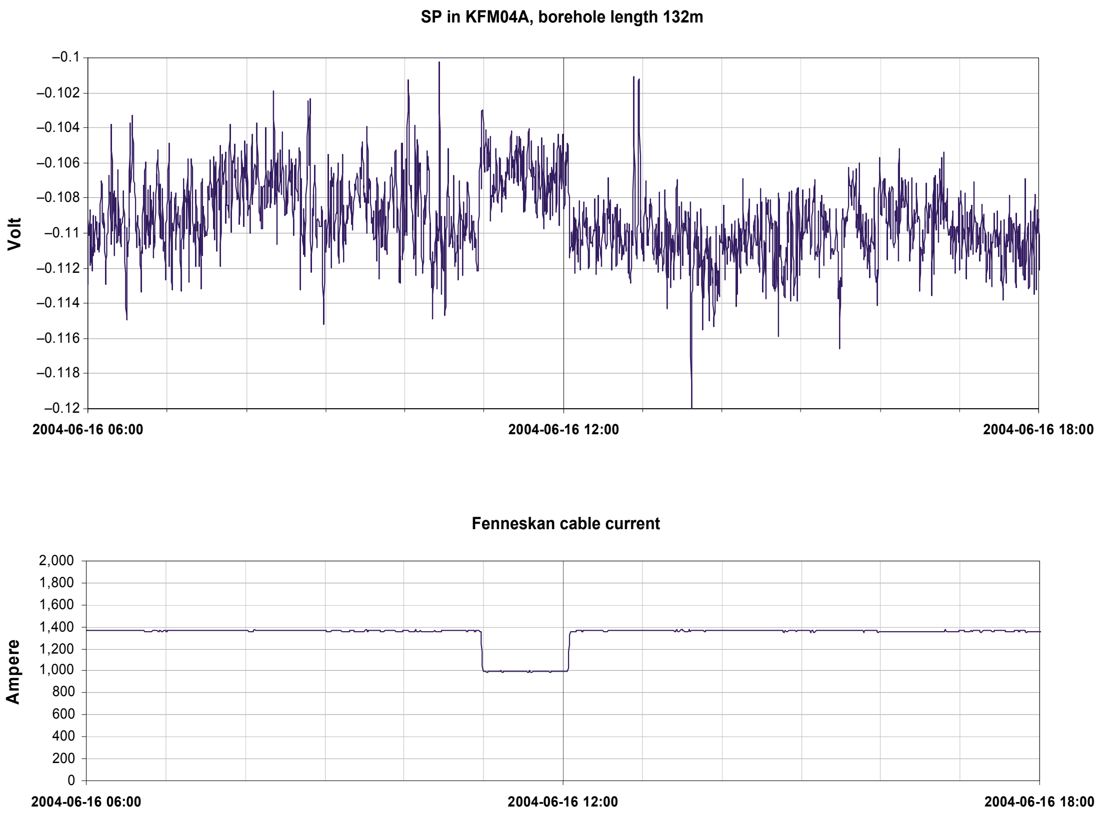


Figure 5-1. *Voltage in KFM04A at borehole length 232 m, measured with the Terrameter SAS1000 (upper diagram) compared with current in the Fennoskan cable (lower diagram).*

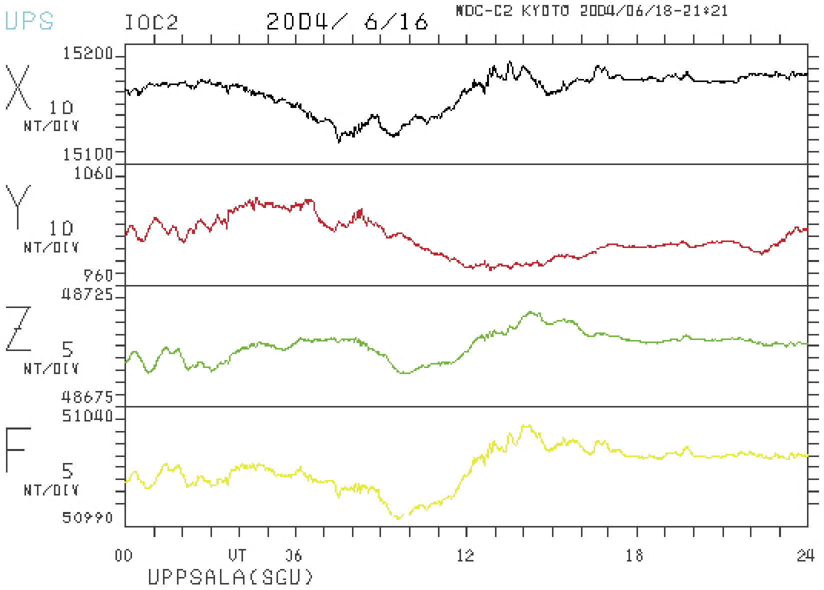


Figure 5-2. *Earth magnetic field data from the Uppsala Observatory from 2004-06-16. Between this diagram and the diagrams in Figure 5-1 there is a time shift of 2 hours (12:00 here corresponds to 14:00 in Figure 5-1).*

5.2 Logging with gradient probe

Figure 5-3 illustrates an example of a logging session with the gradient probe in KFM04A. A significant correlation between the voltage gradient and the power in the Fennoskan cable is observed. Similar correlations are observed in other boreholes also (KFM07A and KFM08A), see Appendix 2.

Measurement in KFM08A and the nearby borehole KFM07A were made during the period 2005-11-02 to 2005-11-07, and the results are presented in Appendix 2.

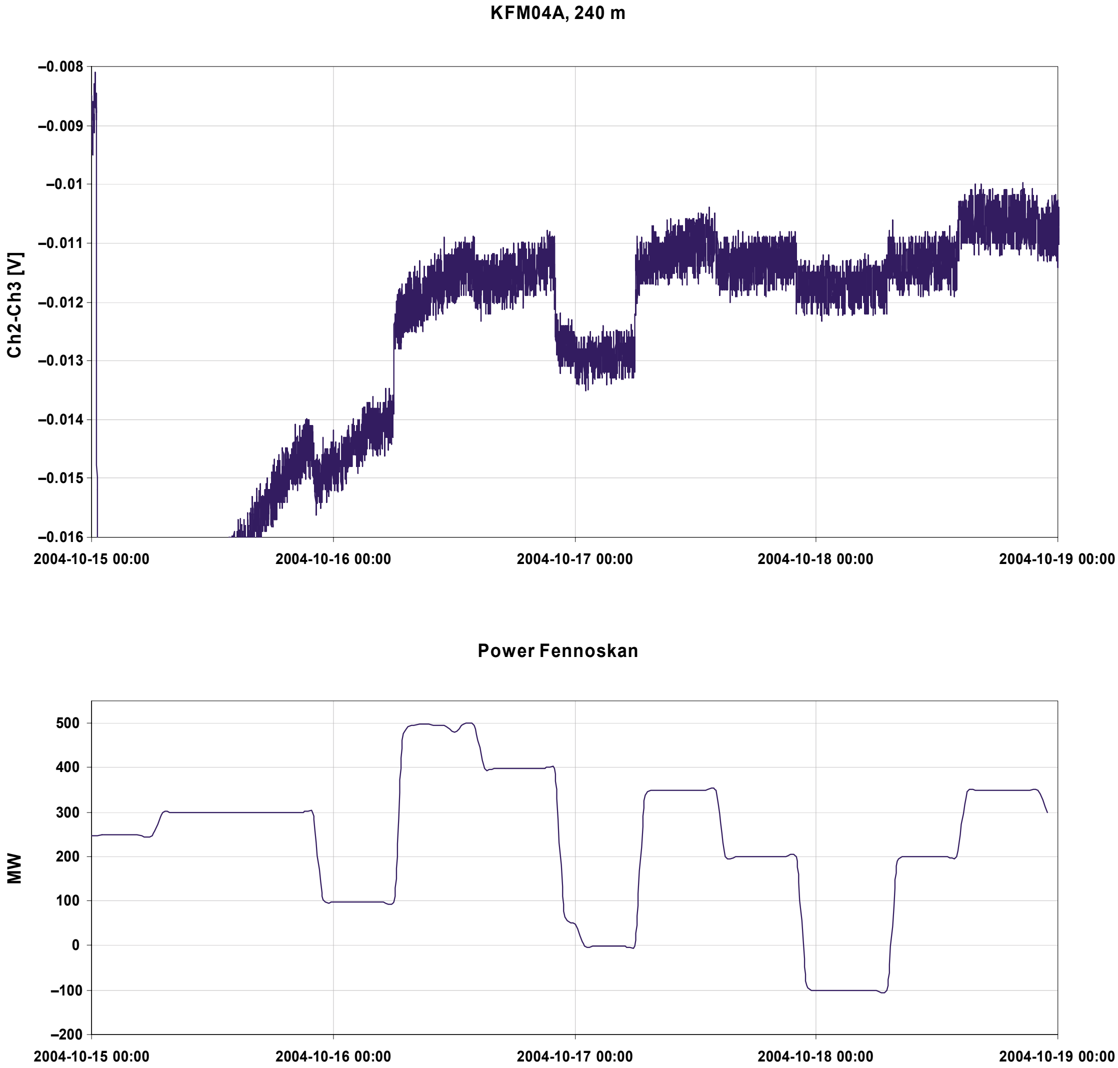


Figure 5-3. *Logging with the gradient probe in KFM04A at borehole length 240 m (upper diagram) and power in the Fennoskan cable (lower diagram) 2004-10-16 to 2004-10-18. A significant correlation between the power in the Fennoskan cable and the measured voltage gradient is clearly observed.*

5.3 Mesurements made with clamp ampere meter

Measurement were made on the electrical grounding wires by placing the clamp ampere meter around the wire at different spots. By comparing these measurements with those performed with Fennoskan out of operation, one can easily see the influence from the current in Fennoskan, see Figure 5-4.

The results from logging the current in the electrical grounding wires are presented in Figure 5-5.

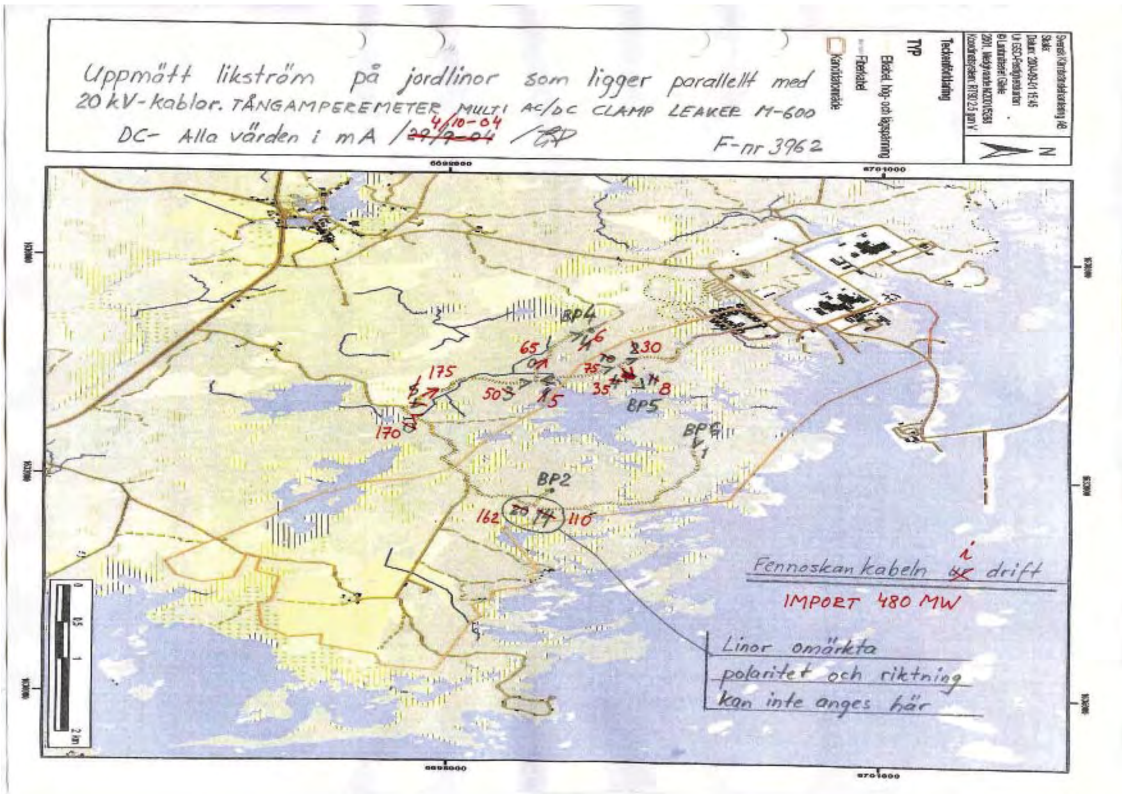


Figure 5-4. Map showing measured DC current in the electrical grounding wires at two different occasions, 2004-09-29 and 2004-10-04 (numbers in grey represent Fennoskan out of operation and numbers in red in operation).

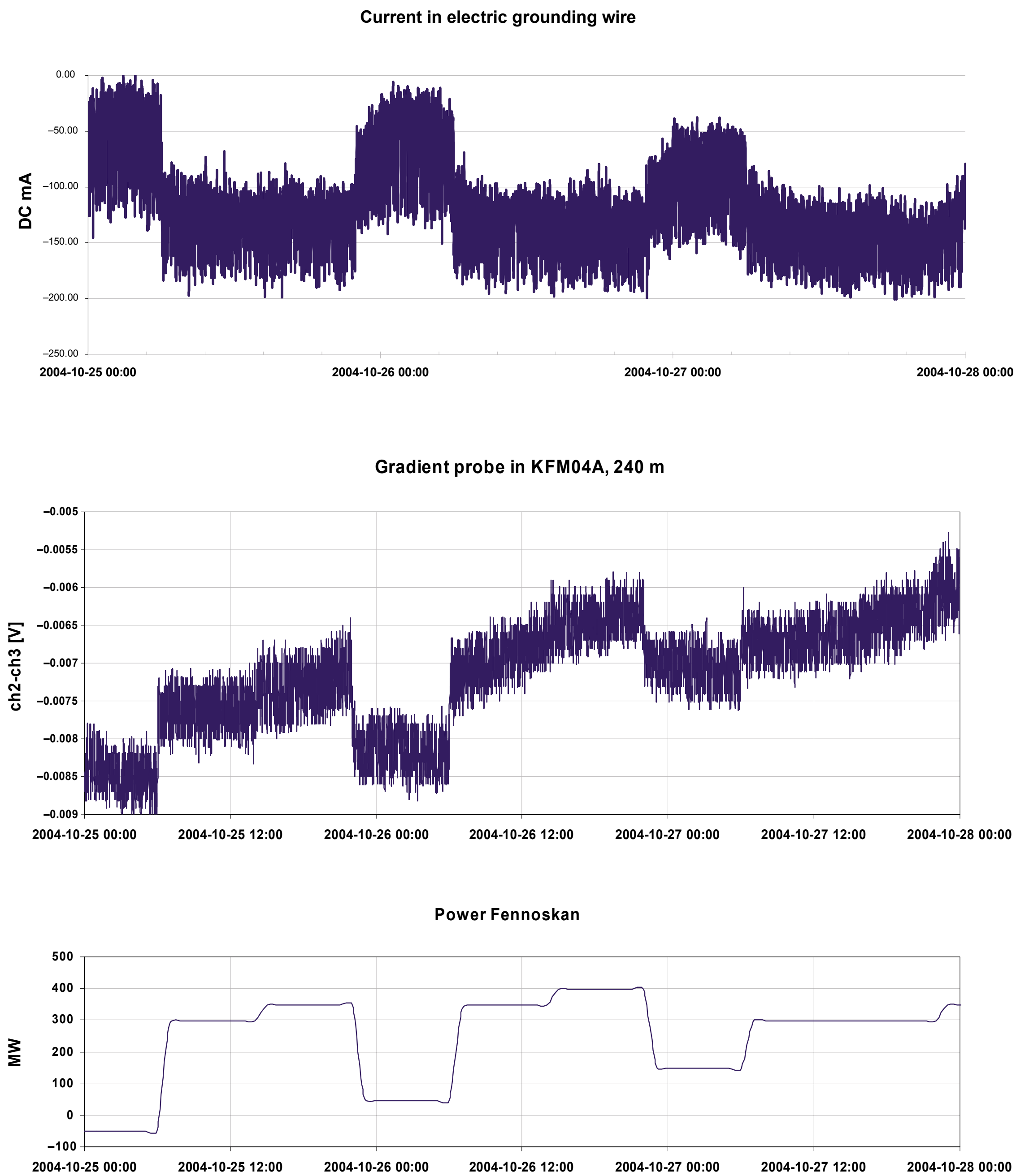


Figure 5-5. *Comparison between current in electrical grounding wire (upper diagram), voltage measured with the gradient probe in KFM04A (middle diagram) and power in the Fennoskan cable (lower diagram) 2004-10-26 to 2004-10-28. A significant correlation is observed.*

5.4 Ground measurements

The results from the SP measurements between DS4 and DS1 are illustrated in Figure 5-6 below. For the location of the measured line, see Figure 4-1.The first point in the graph is located approximately 39 m from borehole KFM04A, and the reference electrode is identical with the reference electrode from the logging (Section 5.1).

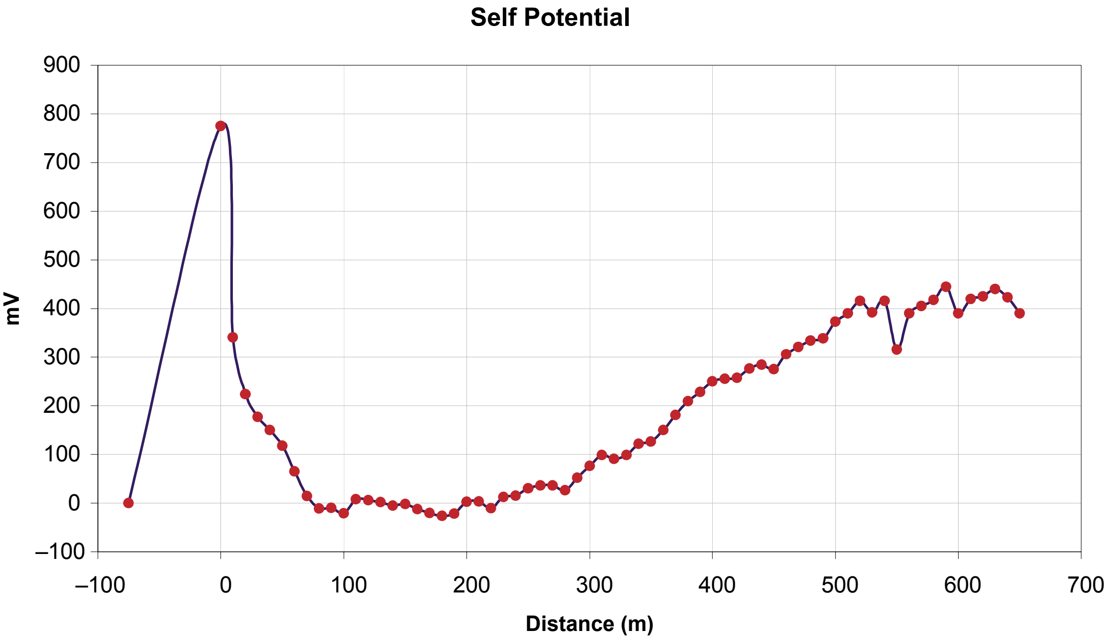


Figure 5-6. *The results of the ground SP measurements between DS4 and DS1. Position "0" corresponds to POS 0, position "50 m" with POS 1 etc in the table in Section 4.3. The reference electrode is located at position –75 m.*

The distance between the start of the profile and the reference electrode is approximately 75 m. By definition, the SP-reading will come close to zero (0) when approaching the reference electrode. This implies that the high readings in the beginning of the profile in fact are due to an isolated peak. The position of the peak corresponds to DS4.

In general, the quality of each reading is very good, in the sense that the readings are stable. This is confirmed by the fact, that the readings along the profile are distributed like a string of pearls with very little scattering. The anomalies along the profile are due to geological phenomena.

The results from the SP measurements around DS4 are seen in Figure 5-7. For the location of the measured points, see Figure 4-2.

The results are shown as surface maps of the self-potential (in mV) around the area of DS4. Observe that the interpolation is a mathematical calculation, were resulting values far away from a measured point can give misleading results.

In Figure 5-7 the results from the measurements in August 2004 are displayed and some of the results from June are also included.

Figure 5-7 clearly demonstrates that the self-potential is highest in the area around the electrical transformer, and decreasing clearly towards northwest. The self-potential is also higher in the area around the road to DS4, which probably to a large extent can be explained by the electric grounding wire installed along this road.

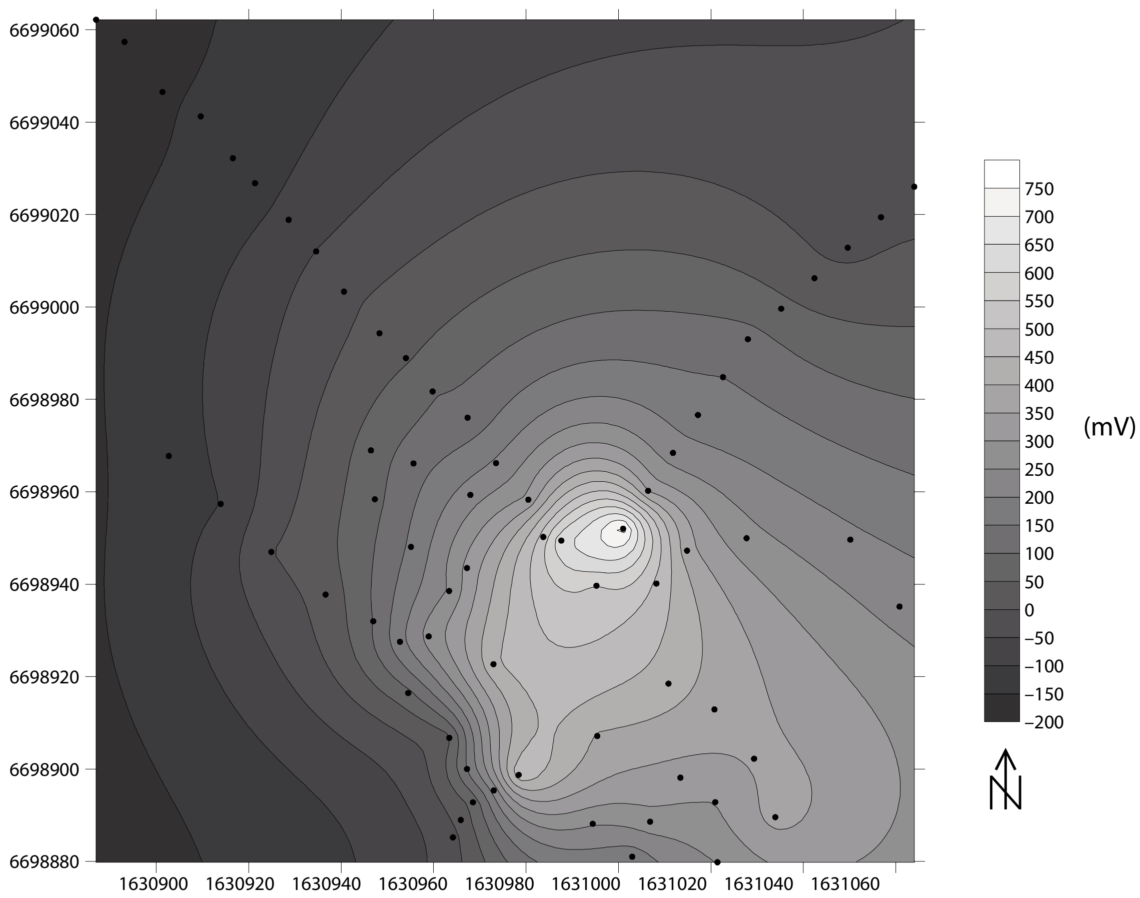


Figure 5-7. *Surface map of the self-potential in the area around DS 4. Measurements from June and August 2004.*

6 Conclusions and recommendations

6.1 Conclusions

Severe corrosion was observed on the chemical analysing equipment at three occasions in borehole KFM04A. The present study demonstrates the existence of a strong electrical voltage anomaly within and around borehole KFM04A. The ground current can be the explanation to the severe corrosion. Even with lower ground current, corrosion can occur, but at a slower rate. The study also demonstrates correlation between the current in the Fennoskan HVDC cable and the voltage gradient in the boreholes KFM04A, KFM07A and KFM08A. Furthermore, the study shows that there is a current (up to several hundred milliamps) running in the electric grounding wires in the investigation area, which is also correlated to the current in the Fennoskan cable. A possible explanation to these observations is the existence of geological zones with electrical conducting water, connecting the Fennoskan electrode with the Forsmark investigation area. These zones are penetrated by the inclined borehole KFM04A at 232 and 360 m borehole length.

Even though the current in the ground will be significantly lower with a future bipolar HVDC transmission under normal conditions, there is always an obvious risk for high ground currents during e.g. services or malfunction on one of the cables. Furthermore, as a consequence of establishing the future cable with higher rating than the old one, the anode and cathode electrodes in Sweden and Finland will be switched, and the implication of this is not known.

In order to gain corrosion of the observed amount, a minimum voltage of approximately 0.5–1.0 V is needed. Even with voltages not that high, corrosion due to electrical current will take place, but at a slower rate.

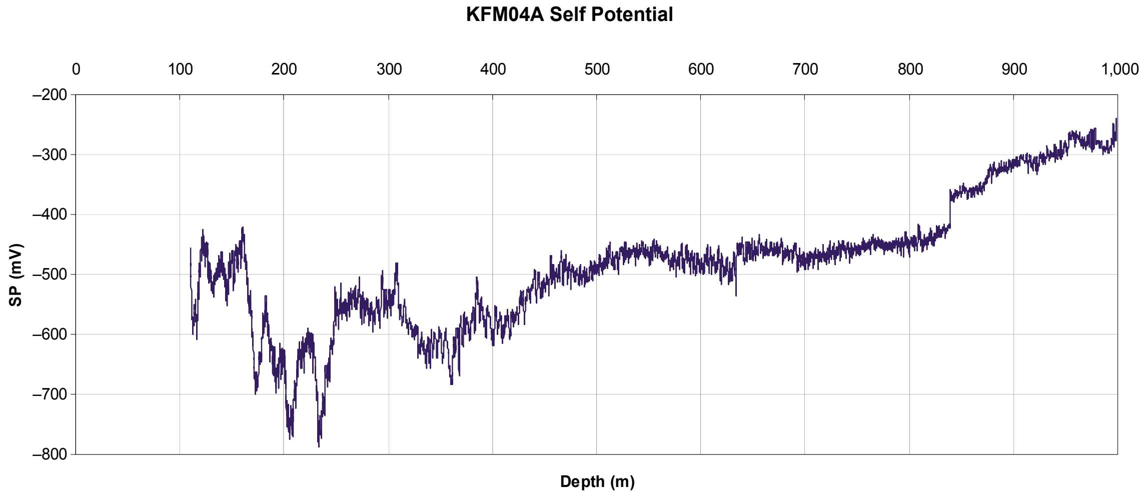
6.2 Recommendations

- An installation of Hydro Monitoring System (HMS) is not recommended in KFM04A, due to the obvious risk for severe corrosion.
- The possible consequences of the change of polarity of the Fennoskan cable (switch from anode to cathode) need to be investigated.
- The present study has demonstrated that the measured potential gradients are significantly lower in boreholes within the tectonic lens (KFM08A, KFM07A) compared to KFM04A. Furthermore, corrosion has never been observed in boreholes within the lens area in Forsmark. It is therefore recommended to investigate the electrical potential in other boreholes in Forsmark. This investigation can serve as the basis for an "electrical model" for the Forsmark area.
- Dummy probes consisting of 7 m long stainless steel rods should be constructed and installed in KFM04A (232 m) and other boreholes. This allows for an in-situ corrosion study.
- Some strange results in KFM04A from other measurement systems (e.g. Difference Flow Log and Pipe String System) need to be checked for reliability.

References

/1/ **SKB P-04-144.** Geophysical borehole logging in borehole KFM04A, KFM06A, HFM10, HFM11, HFM12 and HFM13. Forsmark site investigation. Svensk Kärnbränslehantering AB.

Selected example from geophysical logging



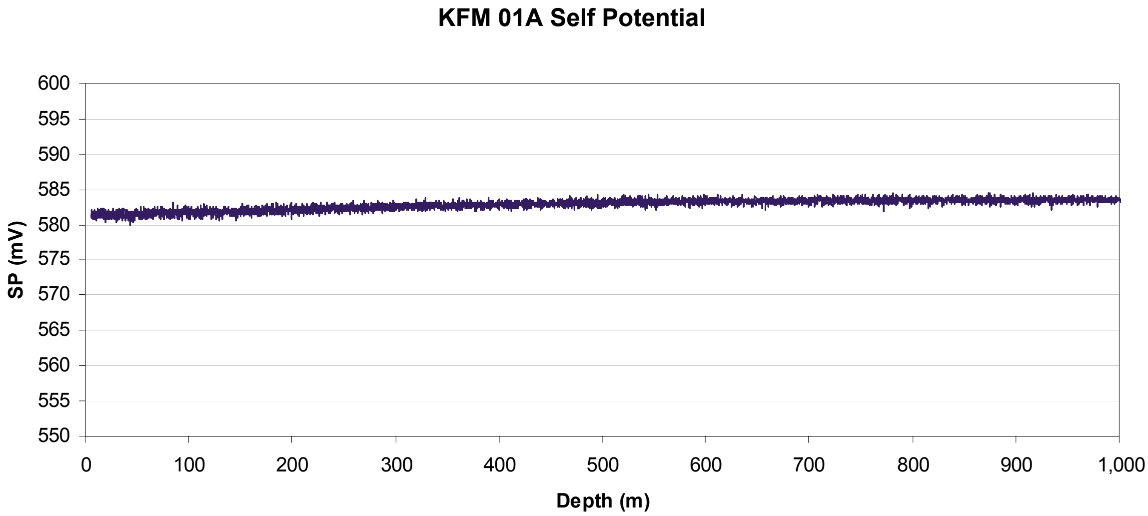


Figure A-1. *SP-logging in KFM04A (upper diagram) compared with KFM01A (lower diagram). The log shows 100 times larger SP-variations in KFM04A compared with nearby holes (KFM01A and KFM05A). The reference electrodes for these loggings are located on the concrete slab, ca 5 m from the hole.*

Appendix 2

Plot from logging of borehole KFM08A

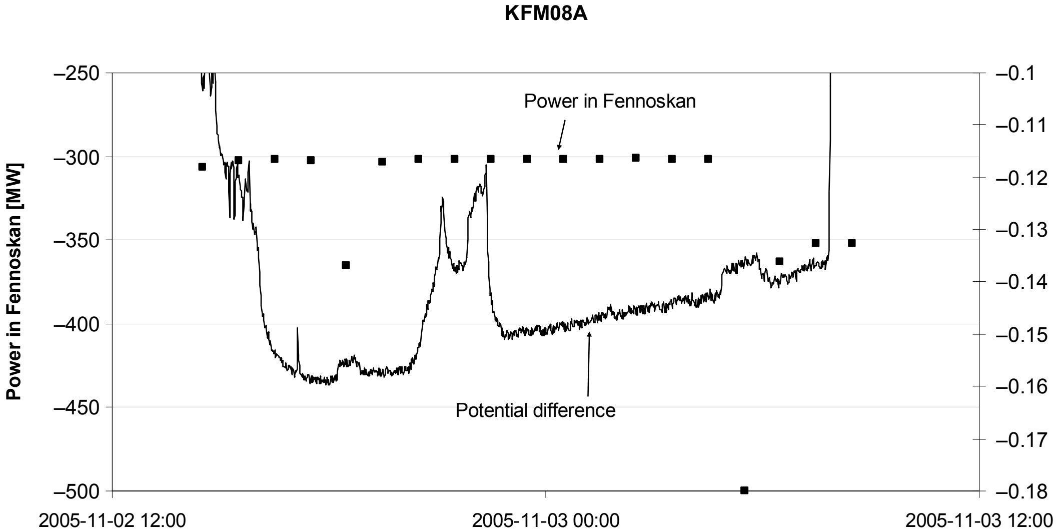


Figure A-2. *Logging with the gradient probe in KFM08A at borehole length 670 m and power in the Fennoskan cable 2005-11-02 to 2005-11-03. A correlation between the power in the Fennoskan cable and the measured voltage gradient is observed, although the time resolution (1 hour) of the power values hides the details. The reason for the strong potential variation on 2005-11-02 between 20:20 to 23:00 is unknown.*

Plot from logging of borehole KFM07A

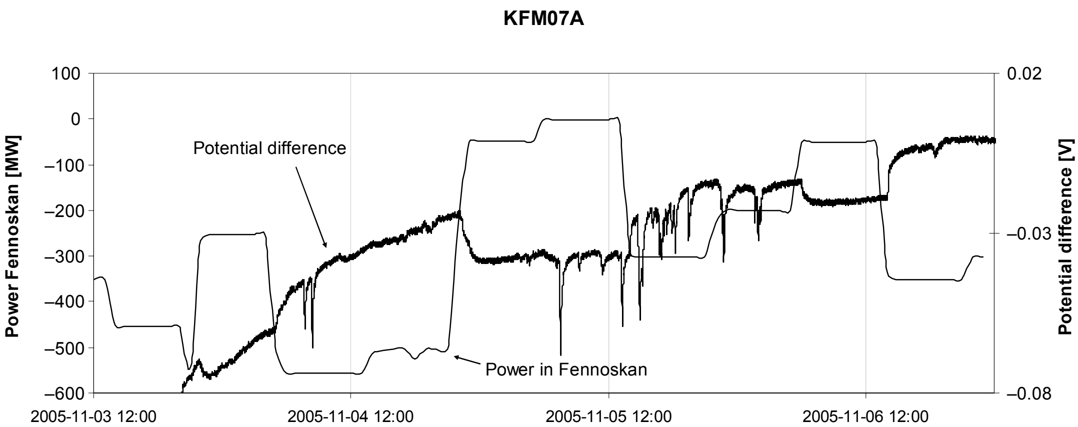


Figure A-3. *Logging with the gradient probe in KFM07A at borehole length 800 m and power in the Fennoskan cable 2005-11-03 to 2005-11-07. A significant correlation between the power in the Fennoskan cable and the measured voltage gradient is clearly observed.*

Appendix 3

Corrosion in borehole KLX03A

Corrosion was also observed on chemical analysing equipment in borehole KLX03A in the Oskarshamn site investigation area at two different occasions. The first sign of corrosion was observed after three weeks of use in the borehole at 970 m. After replacing malfunctioning borehole equipment, the system was used for another fourteen days and new spots of corrosion were observed even on the second equipment. The brief visual analysis indicated some spots of crevice corrosion but no pitting corrosion. The equipment was of the same type as used in Forsmark and made of stainless steel (SS2343). This type of corrosion was unexpected in the oxygen-free environment at 970 m.

A similar type of HVDC cable as the Fennoskan in Forsmark, is the HVDC-cable to Gotland. During a short time period, about the same time as the corrosion was observed, this cable was operated in monopolar drift. This can possibly explain the observed corrosion, and no other cause has been found so far.

Description of HVDC cable to Gotland

A connection for transferring High Voltage Direct Current exists between Gotland and the mainland. The power rating for this transmission is 150 MW and the power can be transferred in both directions. This HVDC cable is of a bipolar type which means that current is transferred in two parallel cables. However, there are electrodes in the seawater which can be employed with monopolar drift of the system, but this is only in abnormal operation, like malfunctioning and service. In those cases the current in the electrodes (Anode/Cathode) can be up too 1,000 A.

The connection is designed according to the wiring chart in Figure 2-1 with two sea water cables and electrodes. The mainland electrode is placed at the southern end of V. Eknö, approximately 30 km northeast of the Oskarshamn site investigation area at Laxemar.

In normal operation of the system an unbalanced DC current of at maximum 5 A are running between electrodes. As far as we know, only at one short period of 4 hours the system was at monopolar drift during the time when corrosion was observed. Therefore it is hard to believe that this could have caused the corrosion. No other explanation to the corrosion has been found so far but there is an obvious risk for corrosion to occur, similar as at Forsmark site investigation area, in the vicinity of HVDC cables.

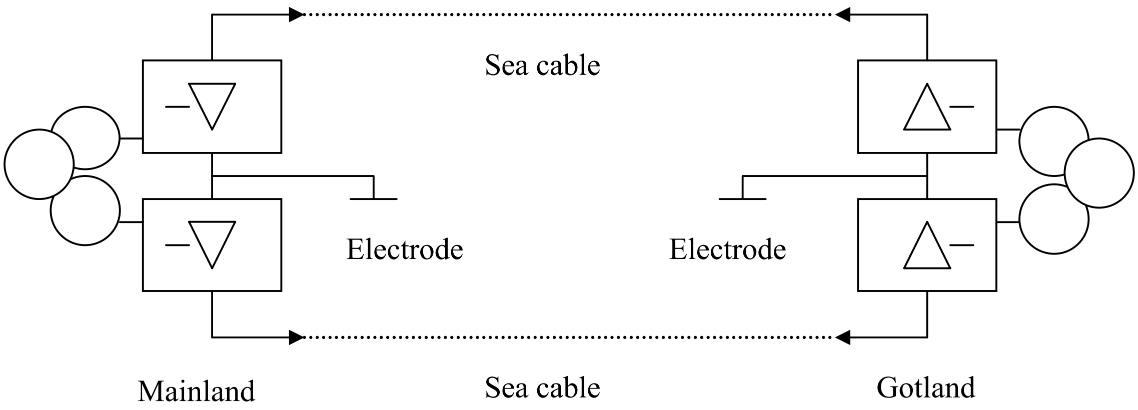


Figure A-4. *Wiring chart showing the High Voltage DC cable between the mainland and Gotland with electrodes.*