# P-05-76

# Forsmark site investigation

## Resistivity measurements and determination of formation factors on samples from KFM03A, KFM04A and KFM05A

Hans Thunehed, GeoVista AB

May 2005

**Svensk Kärnbränslehantering AB**
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-05-76

# Forsmark site investigation

## Resistivity measurements and determination of formation factors on samples from KFM03A, KFM04A and KFM05A

Hans Thunehed, GeoVista AB

May 2005

*Keywords:* AP PF 400-03-058, Resistivity, Formation factor.

# Abstract

This report presents the execution and the results from measurements of electrical resistivity on core samples from the boreholes KFM03A, KFM04A and KFM05A at Forsmark. The formation factor was calculated based on the results of the measurements. A total of 45 core samples were tested (5 from KFM03A, 17 from KFM04A and 23 from KFM05A). The resitivity was measured after soaking the samples in a 1 M NaCl-solution for 10 weeks. The resistivity values obtained were fairly uniform with a median value of 716 Ωm (1$^{st}$ quartile: 376 Ωm, 3$^{rd}$ quartile: 993 Ωm), corresponding to a median value of the formation factor of $1.56 \cdot 10^{-4}$. Two samples from KFM04A had significantly lower resistivity and consequently higher formation factor compared to the other samples. Both these samples came from parts of the hole that have been classified as possible deformation zones in the single-hole interpretation. Both anomalous samples contain sealed fracture networks.

# Sammanfattning

Denna rapport presenterar genomförandet och resultaten från mätningar av elektrisk resistivitet på borrkärneprover från KFM03A, KFM04A och KFM05A vid Forsmark. Formationsfaktorn har beräknats med mätningarna som underlag. Totalt 45 provbitar har undersökts (5 från KFM03A, 17 från KFM04A och 23 från KFM05A). Resistiviteten mättes efter det att proven legat i 1 M NaCl-lösning i tio veckor. Resistivitetsvärdena var tämligen enhetliga med ett medianvärde på 716 Ωm (första kvartil: 376 Ωm, tredje kvartil: 993 Ωm), svarande mot ett medianvärde för formationsfaktorn på $1.56 \cdot 10^{-4}$. Två prover från KFM04A hade signifikant lägre resistivitet och därmed högre formationsfaktor jämfört med övriga prover. Båda dessa prover kom från delar av hålet som klassificerats som möjliga deformationszoner vid den geologiska enhålstolkningen. Båda proverna uppvisar också läkta spricknätverk.

# Contents

# 1 Introduction

This document reports the data gained by the resistivity measurements on samples from KFM03A, KFM04A and KFM05A, 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 400-03-058. 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 sample preparations were performed by GeoVista AB and the measurements were made at the laboratory of the Division of Applied Geophysics at the University of Luleå. Sample preparations were done in December 2004 and the measurements were performed in March 2005 after the samples had been soaked in saline water for ten weeks.
The data from the measurements have been delivered to SKB for storage in SICADA and are traceable by the Activity Plan number.

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

| Activity plan | Number | Version |
|---|---|---|
| Provtagning och analyser av borrkärna från KFM01A- KFM06A för bestämning av transportegenskaper | AP PS 400-03-058 | 1.0 |
| **Method descriptions** | **Number** | **Version** |
| Mätning av bergarters petrofysiska egenskaper | 230.001 | 2.0 |

# 2 Objective and scope

The purpose of resistivity measurements and the calculation of the formation factor is to gain knowledge about the transport properties of the rock mass. The resistivity is a measure of the disability to conduct electric current in the form of ions in the pore space of a rock sample. Low resistivity will thus correspond to a high ability of conduction and vice versa. The resistivity of the water that the sample has been soaked in is often normalised with the resistivity of the sample. The resulting ratio is then referred to as the formation factor.

# 3 Equipment

## 3.1 Description of equipment/interpretation tools

The resistivity measurements were performed with an in-house two-electrode equipment of Luleå University /1/. The equipment has been calibrated against precision resistors and RC-circuits. The electric conductivity of the soaking water was measured with a Conductivity Meter 840039 from Sper Scientific. Plotting of the data and statistical calculations were made with Grapher v. 5.01 (Golden Software) and Microsoft Office Excel (Microsoft Corporation).

# 4 Execution

## 4.1 Sample preparation and measurements

The measurements were carried out in compliance with the SKB Method Description "Mätning av bergarters petrofysiska egenskaper". A summary of the method is given below.

The testing was performed on three cm long core pieces with plane-parallel end surfaces. The samples were dried at a temperature of 110°C for 24 hours. The end surfaces were then covered by protecting tape and the remaining sample surface was covered by silicon after which the tape was removed. The samples were placed in vacuum for three hours and then dropped into a 1.0 M NaCl-solution. The samples were kept in the solution for ten weeks, whereafter the resistivity along the sample axis was measured with an in-house equipment /1/ of Luleå University, Division of Applied Geophysics. The measurements are made with a two-electrode system at the frequencies 0.1, 0.6 and 4.0 Hz. The phase angle between applied current and measured potential difference was retrieved as a by-product during the measurements. A number of the samples were re-measured to check the repeatability of the results. All samples with suspicious or unstable phase angle values were also re-measured.

## 4.2 Data processing

The raw data of the measurements were entered into an MS Excel-file. The formation factor was calculated as the ratio between the resistivity of the soaking water and the resistivity of the samples at 0.1 Hz:

$$Formation\_factor = \frac{\rho_{water}}{\rho_{sample}}$$

Measurements were made at three base frequencies (see above) and their harmonics. The resistivity varied very little between the frequencies and the 0.1 Hz values can thus safely be used as an approximation of the true D.C. resistivity.

## 4.3 Nonconformities

The results from initial measurements were suspected to yield too high formation factors for some of the samples. Testing indicated that the surface of the silicone cover of the samples was easily wetted. Moist from the electrodes sometimes formed a thin water film on the outside of the samples. All samples were subsequently re-measured and close attention was paid on the silicone surface dryness. The repeatability of the results was thereafter very good.

One of the samples gave noisy results and large variations between repeated measurements (KFM04, borehole length 239.68–239.75 m). The reason for this was most likely that the galvanic contact between the electrodes and the pore space system in the sample was unstable. The sample was also of very low resistivity, implying that the contact resistance to the electrodes cannot be neglected. The sample showed small cavities in the contact surfaces to the electrodes. Such a sample should be measured with a four-electrode system to get accurate results. This is however not possible with the present sample preparation method. No other nonconformities appeared in the work.

# 5 Results

The resistivity values of the samples were fairly uniform. 716 Ωm (1st quartile: 376 Ωm, 3rd quartile: 993 Ωm), corresponding to a median value of the formation factor of $1.56 \cdot 10^{-4}$. Histograms of the formation factor results can be seen in Figures 5-1 and 5-2. Two samples with very large formation factor values from KFM04A are not included in the histograms.

A peak in the histograms can be seen at approximately $1.5 \cdot 10^{-4}$. The histograms for KFM04A and KFM05A show fairly similar distributions. The results for those holes are also comparable to data from KFM01A and KFM02A /2/.

Two samples from KFM04A (239.68–239.75 m and 420.25–420.32 m borehole length) had significantly lower resistivity and thus higher formation factor compared to the other samples (Figure 5-3). The resistivity recorded for the former of these samples was actually so low (4.17 Ωm) that the contact resistance to the sample no longer can be neglected and the accuracy of the value is therefore poor. It was also difficult to get stable readings for this sample, probably due to unstable galvanic contact through the sample surface that showed small cavities. Both anomalous samples show sealed fracture networks and they originate from borehole sections that have been classified as possible deformation zones in the geological single-hole interpretation /3/. Also, most other low-resistivity samples had sealed fractures, e.g.: KFM03A 660.39–660.49 m, KFM04A 120.00–120.07 m, and KFM05A 509.05–509.12 m.

The formation factors do not display any significant trends with respect to depth (Figure 5-3) if the most anomalous samples are disregarded.

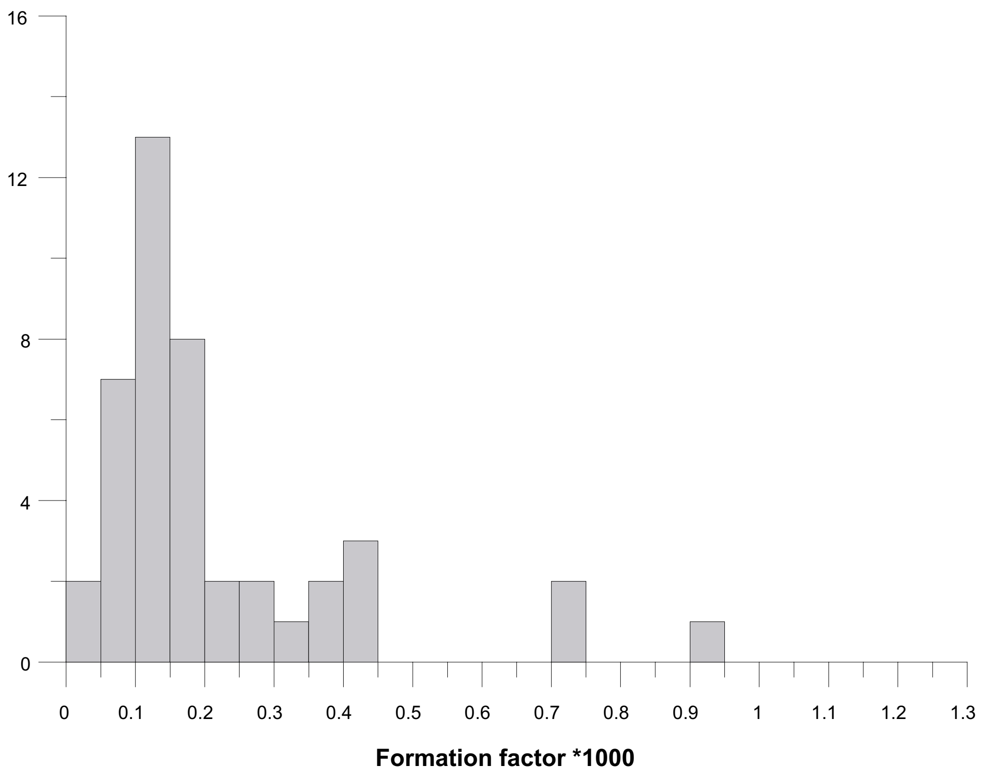


***Figure 5-1.*** *Histogram of calculated formation factor for samples from KFM03A, KFM04A and KFM05A. All samples merged together.*

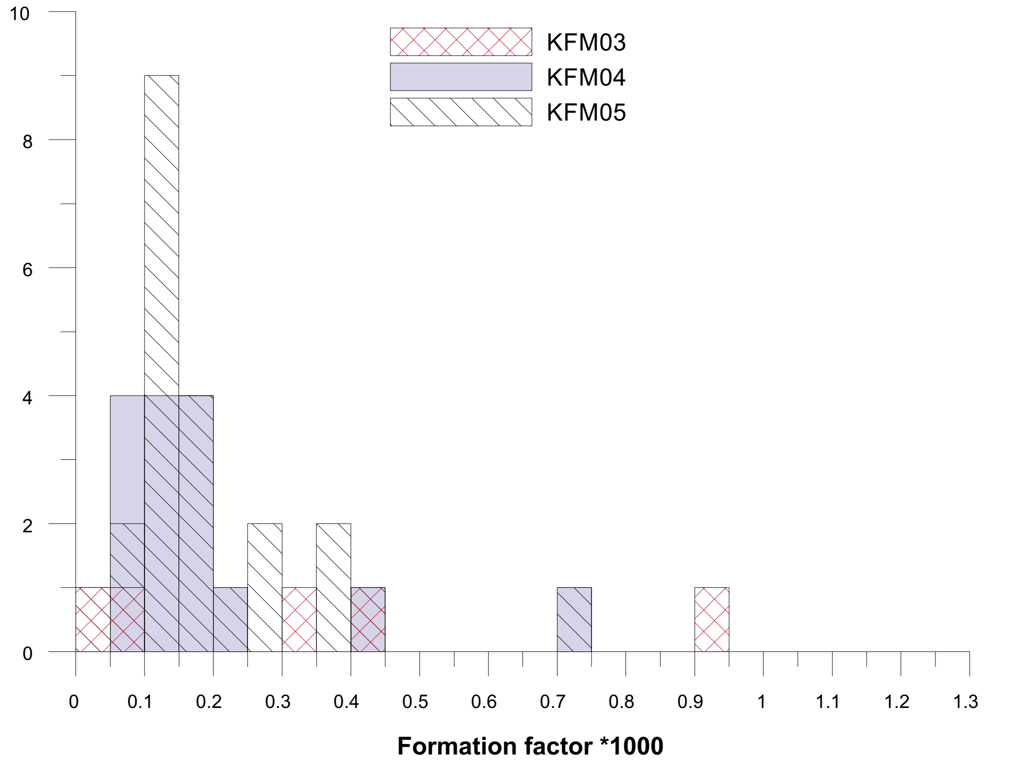


***Figure 5-2.*** *Histogram of calculated formation factor for samples from KFM03A, KFM04A and KFM05A.*

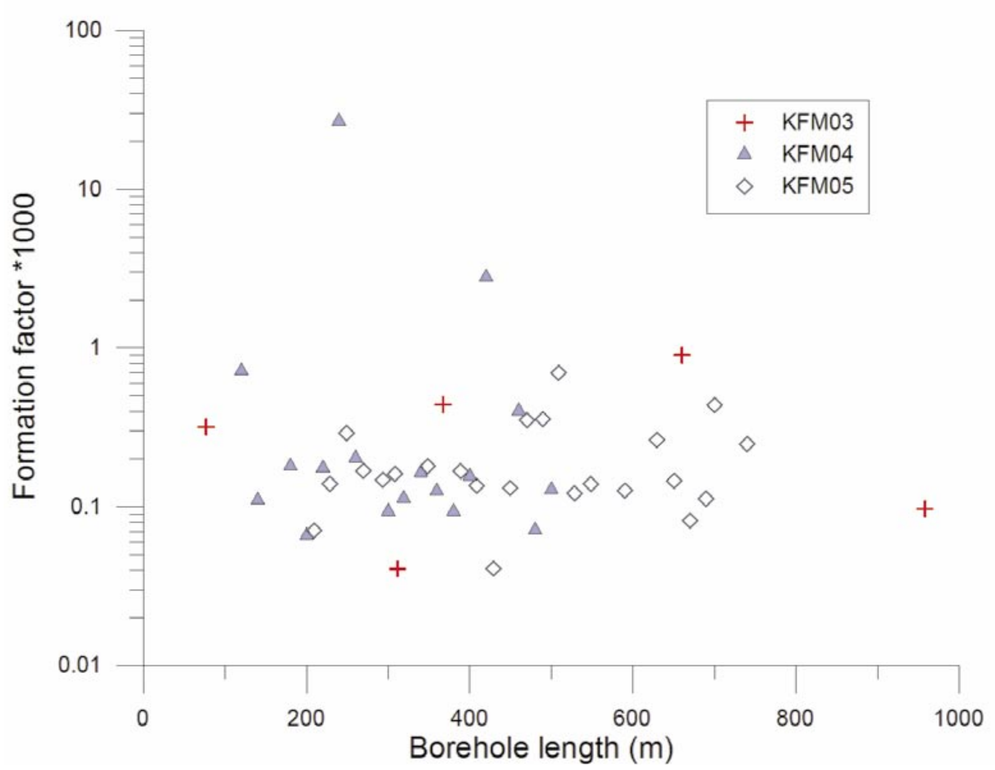


***Figure 5-3.*** *Formation factor plotted as a function of sampling depth along the cores.*

The phase angle measurements can be used to get an indication of possible presence of minerals with electronic conduction and also as a quality indicator. Small phase angles are expected when measurements are made in saline water for samples that do not contain any minerals with electronic conduction. Most samples in this study demonstrate small phase angles (Figure 5-4). The small phase angles of up to a few mrad might be explained by small amounts of magnetite in the samples. Such magnetite will probably not have any significant effect on the resistivity measurements. The samples from KFM04A generally show higher phase angle values (median 1.8 mrad at 0.1 Hz) than the samples from KFM03A (median 0.55 mrad) and KFM05A (median 0.96 mrad).

One sample from KFM04A (borehole length 120.00–120.07 m) and two samples from KFM05A (590.03–590.10 m and 669.93–670.00 m) exhibit phase angles above 5 mrad at 0.1 Hz. The KFM04A sample is of low resistivity with sealed fracture network, whereas both KFM05A samples are dark amphibolitic samples of fairly high resistivity. The reason for the large phase angles is not known, but only two explanations seem reasonable. It is possible that the samples contain significant amounts of either some mineral with electronic conduction or that the current is forced through very thin membrane pore paths. The latter can occur if the sample is of low porosity and/or contains fine-grained phyllosilicates. The resistivity of the samples might be affected by this, especially by membrane polarisation, resulting in an over-estimate of the formation factor compared to a case with simple electrolytic conduction only.

The following data have been delivered to SKB: Measured resistivity and phase angle at 0.1 Hz, calculated formation factor and resistivity of soaking water.

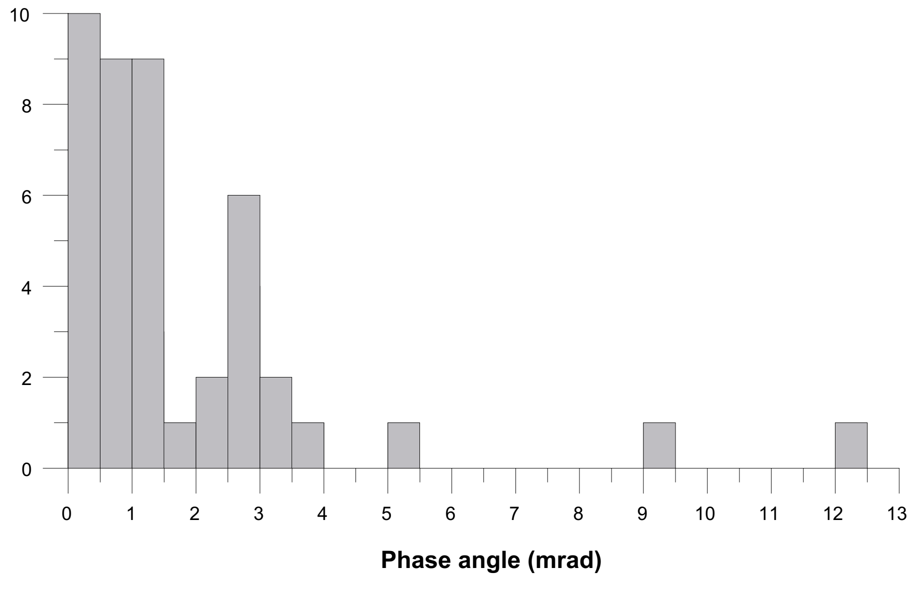


***Figure 5-4.*** *Histogram of measured phase angles (at 0.1 Hz) for samples from KFM03A, KFM04A and KFM05A. All samples merged together.*

# References


/1/ **Triumf C-A, Thunehed H, Antal I, 2000.** Bestämning av elektriska egenskaper hos vulkaniter från Skellefte- och Arvidsjaurgrupperna. SGU-2000:8.

/2/ **Thunehed H, 2005.** Forsmark site investigation. Resistivity measurements on samples from KFM01A and KFM02A. SKB P-05-26. Svensk Kärnbränslehantering AB.

/3/ **Carlsten S, Petersson J, Stephens M, Mattsson H, Gustafsson J, 2004.** Forsmark site investigation. Geological single-hole interpretation of KFM04A and HFM09-10 (DS4). SKB P-04-11. Svensk Kärnbränslehantering AB.