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Forsmark site investigation

Resistivity measurements on samples from KFM01A, KFM01B, KFM02A, KFM05A and KFM06A

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SKB

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Abstract

This report presents the execution and results from measurements of electrical resistivity on core samples from the boreholes KFM01A, KFM01B, KFM02A, KFM05A and KFM06A at Forsmark. The formation factor was calculated based on the results of the measurements. A total of 31 core samples were tested (11 from KFM01A, 1 from KFM01B, 13 from KFM02A, 4 from KFM05A and 2 from KFM06A). The resistivity was measured after soaking the samples in a 1 M NaCl-solution for nine weeks. The resistivity values were fairly uniform. The median value was 460 Ωm (1st quartile: 388 Ωm, 3rd quartile: 579 Ωm), corresponding to a median value of the formation factor of $2.32 \cdot 10^{-4}$. Most measurements resulted in small phase angles between the applied current and the measured potential. One sample from KFM01A (539.39–539.42 m) did however show relatively large phase angles corresponding to polarisation with a rather large time constant. This is interpreted to be due to some kind of mineralization that also might have affected the resistivity measurement of this sample.

Sammanfattning

Denna rapport presenterar genomförandet och resultaten från mätningar av elektrisk resistivitet på borrkärneprover från KFM01A, KFM01B, KFM02A, KFM05A och KFM06A i Forsmark. Formationsfaktorn har beräknats med mätningarna som underlag. Totalt 31 provbitar har undersökts (11 från KFM01A, 1 från KFM01B, 13 från KFM02A, 4 från KFM05A och 2 från KFM06A). Resistiviteten mättes efter det att proven legat i 1 M NaCl-lösning i nio veckor. Resistivitetsvärdena visade relativt liten spridning. Medianvärdet var 460 Ωm (första kvartil: 388 Ωm, tredje kvartil: 579 Ωm), svarande mot ett medianvärde på formationsfaktorn på $2,32 \cdot 10^{-4}$. De flesta mätningar resulterade i små fasvinklar mellan strömmen genom provet och den uppmätta potentialskillnaden. Ett prov från KFM01A (539,39–539,42 m) uppvisade emellertid relativt stora fasvinklar motsvarande en polarisation med relativt lång tidskonstant. Detta tolkas vara orsakat av mineralisering som också kan ha påverkat mätningen av resistivitet av detta prov.

Contents

1   Introduction

This document reports the data gained by the resistivity measurements on samples from KFM01A, KFM01B, KFM02A, KFM05A and KFM06A, 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 400-06-007. 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 by GeoVista AB at the laboratory of the Division of Applied Geophysics at the University of Luleå. Sample preparations were done in October 2006 and the measurements were performed in December 2006 after the samples had been soaked in saline water for nine weeks.

The data from the measurements have been delivered to SKB for storage in Sicada, traceable by the activity plan number.

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

Activity plan	Number	Version
Provtagning och analyser av borrkärnor under 2006 för bestämning av bergets transportegenskaper	AP PF 400-06-007	1.0
Method descriptions	**Number**	**Version**
Mätning av bergarters petrofysiska egenskaper (Bilaga 4)	SKB MD 230.001	2.0

2   Objective and scope

The purpose of resistivity measurements and the calculation of the formation factor are 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 samples were prepared and soaked in saline water in accordance with SKB MD 230.001, see Table 1-1. Resistivity measurements were then 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. 6.0 (Golden Software) and Microsoft Office Excel (Microsoft Corporation).

4 Execution

4.1 Sample preparation and measurements

The measurements were carried out in accordance with the method description SKB MD 230.001. A summary of the method is given below.

The testing was performed on core pieces (10, 30 or 50 mm long) with plane-parallel end surfaces. The samples were dried at a temperature of 110°C for 24 hours. The end surfaces were covered by protecting tape and the remaining sample surface was covered by silicon after which the tape was removed. The samples were then placed in vacuum for three hours and then dropped into a 1.0 M NaCl-solution. The samples were kept in the solution for nine weeks after which the resistivity along the sample axis was measured with an in-house equipment /1/ of Luleå University, Division of Applied Geophysics. The measurements were 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. Some 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. For the majority of the samples, 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 (see also Chapter 5).

4.3 Nonconformities

The samples should be soaked for ten weeks before measurements according to the method description. In order to have the results entered into Sicada before the end of 2006, the soaking time was reduced by one week. This is however not considered to affect the results in any significant way.

5   Results

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP PF 400-06-007). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. However, such revision of the database will not necessarily result in a revision of this report.

The resistivity values of the samples showed a quite moderate spread, see Appendix 1. The median value was 460 Ωm (1st quartile: 388 Ωm, 3rd quartile: 579 Ωm), corresponding to a median value of the formation factor of $2.32 \cdot 10^{-4}$. A histogram of the formation factor results can be seen in Figure 5-1 and a table with all formation factor values is presented in Appendix 1.

A majority of the samples have formation factor values around $2.0 \cdot 10^{-4}$. No outliers with significantly different formation factors have been found.

A fairly large number of the samples have been collected in groups of three adjacent to each other along the core and cut into 10, 30 and 50 mm core pieces respectively. The samples in such groups show quite similar characteristics. There is however a tendency that the 10 mm sample has a slightly higher measured resistivity compared to the other two samples. It is possible that the contact resistance between the electrode and the sample is not insignificant for such a short sample, although the number of measurements is too small to make any definite conclusion. It should however be noted that the resistivity values for 10 mm samples might be slightly over-estimated and hence the formation factor under-estimated, however probably by no more than say 10 to 20%.
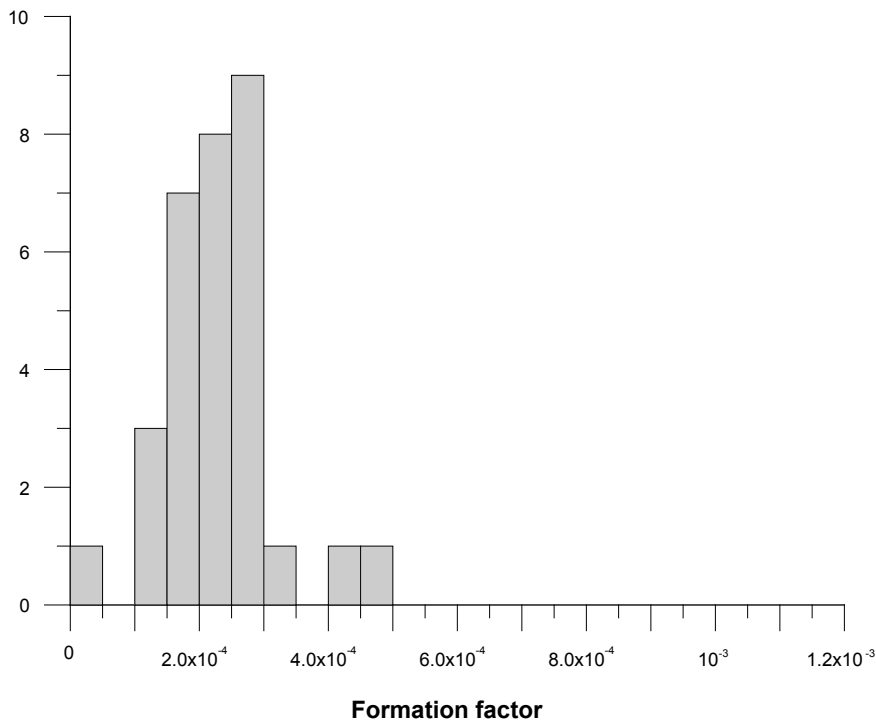
Figure 5-1. *Histogram of calculated formation factor for all samples in the study.*

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. The phase angle is due to induced polarisation in the samples. Two main mechanisms exist for such polarisation. The polarisation can arise at an interface between electrolytic and electric conduction, i.e. at the surface of conductive mineral grains like e.g. pyrite or magnetite. The other mechanism is due to a difference in diffusion speed between an-ions and cat-ions through thin membrane pores. Most samples show small phase angles (Figure 5-2). However, one sample displays a quite high phase angle. The complete measured resistivity-phase spectrum for this sample (KFM01A, 539.39–539.42 m) is plotted in Figure 5-3. A maximum in the phase angle and a negative gradient for the resistivity can be seen around 2 Hz, which corresponds to a rather large time-constant of the corresponding polarisation. Such behaviour is anomalous compared to all other samples, e.g. KFM01A, 740.01–740.04 m shown as a reference in Figure 5-3. The normal sample demonstrates a gently increasing phase angle with increasing frequency, indicating a polarisation with short time-constant. The anomalous property is interpreted to be due to polarisation at interfaces between pores and conducting minerals. It cannot be ruled out that such conductive minerals have biased the measurement of resistivity to a lower value for this sample.

A random selection of samples were re-mounted in the sample holder and re-measured to check the repeatability of the results. The maximum recorded difference between the two measurements was less than 3%.
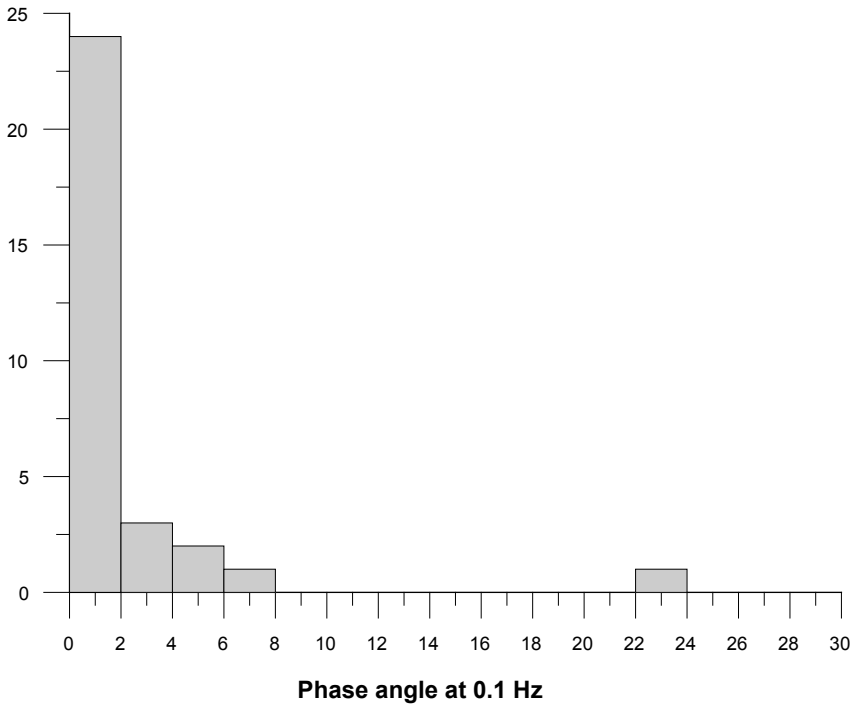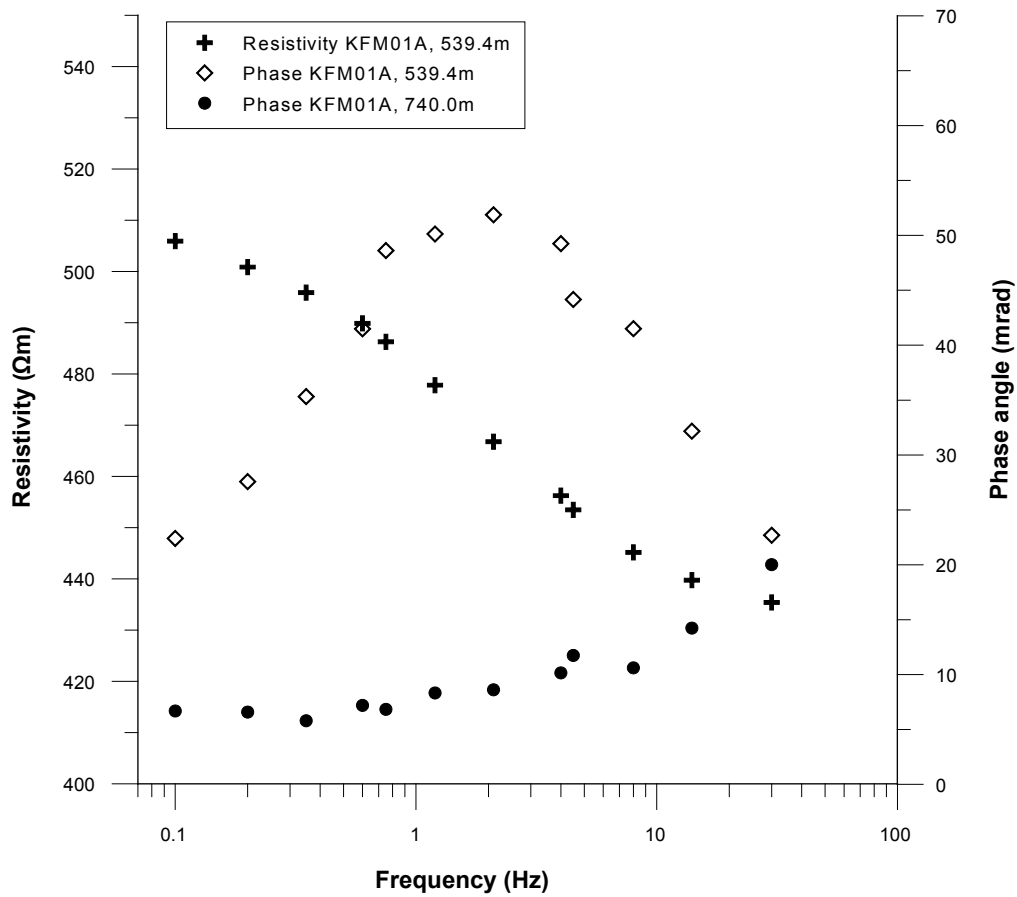

Figure 5-2. *Histogram of measured phase angles (at 0.1 Hz) for all samples from this study.*

Figure 5-3. *Resistivity and phase angle plotted versus measurement frequency for an anomalous sample (KFM01A, 539.39–539.42 m). Phase angle results for a normal sample (KFM01A, 740.01–740.04 m) are shown for reference.*

References

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

Resistivity and formation factor values

All samples where soaked in water with a resistivity of 0.107 m.

Borehole	Secup (m)	Seclow (m)	Resistivity at 0.1 Hz (Ωm)	Phase angle at 0.1 Hz (mrad)	Formation factor
KFM01A	539.39	539.42	506	22.4	2.11E–04
KFM01A	740.01	740.04	2,530	6.7	4.23E–05
KFM01A	999.96	999.99	244	0.5	4.38E–04
KFM01A	312.54	312.55	644	0.9	1.66E–04
KFM01A	312.56	312.59	478	0.6	2.24E–04
KFM01A	312.59	312.64	363	0.3	2.95E–04
KFM01A	312.66	312.67	520	0.6	2.06E–04
KFM01A	312.68	312.71	460	0.5	2.33E–04
KFM01A	312.71	312.76	393	0.5	2.72E–04
KFM01A	312.77	312.78	507	0.6	2.11E–04
KFM01A	312.81	312.86	431	4.1	2.48E–04
KFM01B	23.55	23.58	1,021	3.7	1.05E–04
KFM02A	554.60	554.61	579	0.8	1.85E–04
KFM02A	554.61	554.64	394	0.6	2.72E–04
KFM02A	554.65	554.70	387	0.3	2.76E–04
KFM02A	554.71	554.72	565	0.5	1.89E–04
KFM02A	554.72	554.75	368	0.6	2.91E–04
KFM02A	554.76	554.81	361	0.2	2.96E–04
KFM02A	554.84	554.85	579	0.8	1.85E–04
KFM02A	554.86	554.89	455	0.5	2.35E–04
KFM02A	554.90	554.95	401	0.3	2.67E–04
KFM02A	181.01	181.04	767	4.3	1.39E–04
KFM02A	300.96	300.99	235	3.5	4.54E–04
KFM02A	381.01	381.04	705	1.8	1.52E–04
KFM02A	481.01	481.04	862	1.6	1.24E–04
KFM05A	168.34	168.37	647	1.7	1.65E–04
KFM05A	369.23	369.26	390	0.5	2.74E–04
KFM05A	570.02	570.05	361	1.1	2.96E–04
KFM05A	396.60	396.63	547	3.3	1.95E–04
KFM06A	779.40	779.43	452	1.1	2.37E–04
KFM06A	331.78	331.81	321	0.9	3.34E–04