P-07-203

Oskarshamn site investigation

Complementary resistivity measurements on samples from KLX03, KLX04, KLX05, KLX10, KLX12A and KLX13A

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August 2007

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ISSN 1651-4416
SKB P-07-203

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Keywords: Resistivity, Formation factor.

Abstract

This report presents the execution and the results from measurements of electrical resistivity on core samples from the boreholes KLX03, KLX04, KLX05, KLX10, KLX12A and KLX13A at Oskarshamn site investigation area. The formation factor was calculated based on the results of the measurements. A total of 17 core samples were tested (6 from KLX03, 1 from KLX04, 1 from KLX05, 2 from KLX10, 3 from KLX12A and 4 from KLX11A). The resistivity was measured after soaking the samples in a 1 M NaCl-solution for eight weeks. The resistivity values showed a rather large spread. The median value was 3,478 Ωm (1st quartile: 724 Ωm, 3rd quartile: 5,154 Ωm), corresponding to a median value of the formation factor of $4.03 \cdot 10^{-5}$. A few of the samples had very high resistivities and consequently low formation factors. A positive correlation can be seen between the resistivity of the samples and the induced polarisation, indicating current flow in thin membrane pores for the high resistivity samples. One porous sample from KLX10 had very low resistivity and hence high formation factor.

Sammanfattning

Denna rapport presenterar genomförandet och resultaten från mätningar av elektrisk resistivitet på borrkärneprover från KLX03, KLX04, KLX05, KLX10, KLX12A och KLX13A i Oskarshamns platsundersökningsområde. Formationsfaktorn har beräknats med mätningarna som underlag. Totalt 17 provbitar har undersökts (6 från KLX03, 1 från KLX04, 1 från KLX05, 2 från KLX10, 3 från KLX12A och 4 från KLX11A). Resistiviteten mättes efter det att proven legat i 1 M NaCl-lösning i åtta veckor. Resistivitetsvärdena visade relativt stor spridning. Medianvärdet var 3 478 Ωm (första kvartil: 724 Ωm, tredje kvartil: 5 154 Ωm), svarande mot ett medianvärde på formationsfaktorn på $4{,}03 \cdot 10^{-5}$. Några prover uppvisade mycket höga resistiviteter och därmed låga värden på formationsfaktorn. En positiv korrelation kunde ses mellan provens resistivitet och den uppmätta inducerade polarisationen, vilket indikerar att strömmen fortplantas i tunna membranporer i de högresistiva proverna. Ett poröst prov från KLX10 uppvisade mycket låg resistivitet och därmed hög formationsfaktor.

Contents

1 Introduction

This document reports the data gained by the resistivity measurements on samples from KLX03, KLX04, KLX05, KLX10, KLX12A and KLX13A, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-06-023. 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 where performed by GeoVista AB and the measurements where made by GeoVista AB at the laboratory of the Division of Applied Geophysics at the University of Luleå. Sample preparations were done in January 2007 and the measurements were performed in March 2007 after the samples had been soaked in saline water for eight 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 PS 400-06-023	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 (Appendix 4), SKB internal document. 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 SKB MD 230.001, SKB internal document. A summary of the method is given below.

The testing was performed on core pieces (30 mm long) 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 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 eight weeks and the resistivity along the sample axis was then 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 a 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 section 5).

4.3 Nonconformities

The samples should be soaked in ten weeks before measurements according to the method description. In order to have the results entered into SICADA before March 31st, the soaking time was reduced by two weeks. This is however not considered to affect the results in any major way.

5 Results

The resistivity values of the samples showed a large spread. The range of resistivities covered more than three orders of magnitude. The median value was 3,478 Ωm (1st quartile: 724 Ωm, 3rd quartile: 5,154 Ωm), corresponding to a median value of the formation factor of $4.03 \cdot 10^{-5}$. Histograms of the formation factor results can be seen in Figure 5-1.

A majority of the samples have formation factor values below $1.0 \cdot 10^{-4}$. The sample that shows the largest formation factor value, and hence the lowest resistivity, had mm-sized open pore spaces (KLX10, 159.15 to 159.18 m).

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 to moderate phase angles (Figure 5-2). However, a significant number of the samples have fairly large phase angles (above 10 to 15 mrad). There is a clear positive correlation between resistivity and phase angle (Figure 5-3) which is also similar to previous measurements in the site investigation. This indicates that the large phase angles are caused by membrane polarisation that occurs when current is forced through very thin pores. This implies that the resistivity is, at least slightly, frequency dependent, especially for the high resistivity samples. The measurements in this study were however performed at such low frequencies that the resistivity values can be used as an approximation of the true D.C. resistivity.

Two samples show slightly different properties compared to the others. The sample from KLX12A, 430.50 to 430.53 m, has very high resistivity. The measurements on this sample also results in large phase angles, however larger than what is expected from the general trend in Figure 5-3. It is possible that the large phase angles for this sample are due to disseminated

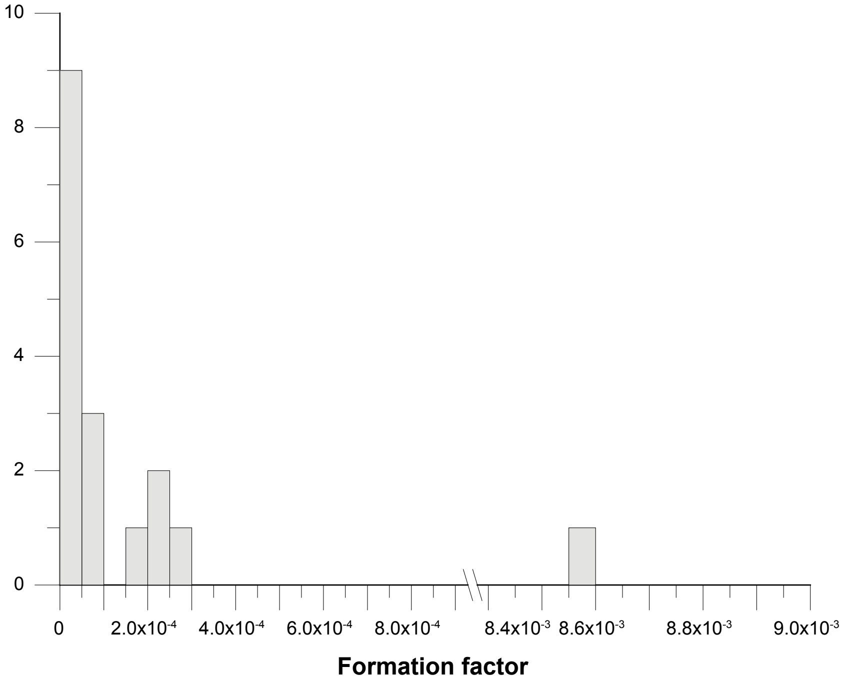

Figure 5-1. *Histogram of calculated formation factor for all samples in the study. Note the broken axis.*

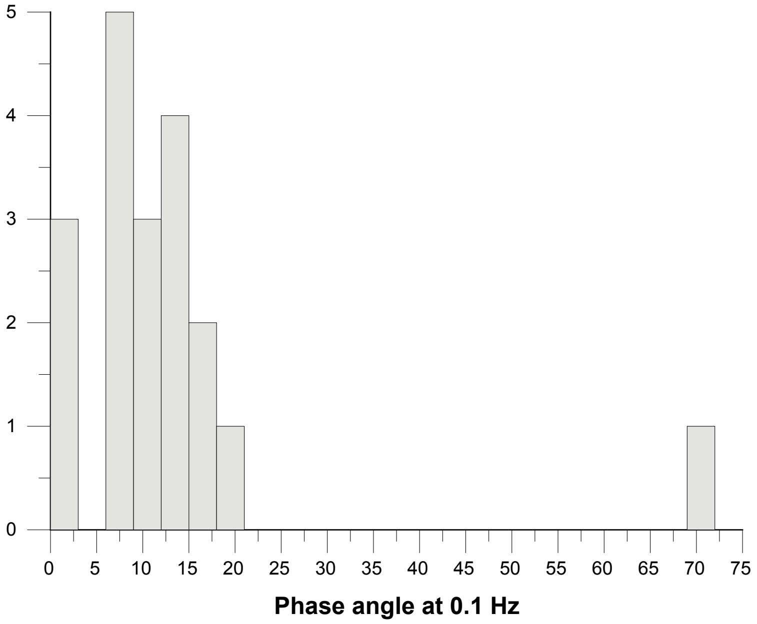

Figure 5-2. *Histogram of measured phase angles (at 0.1 Hz) for all samples from this study.*

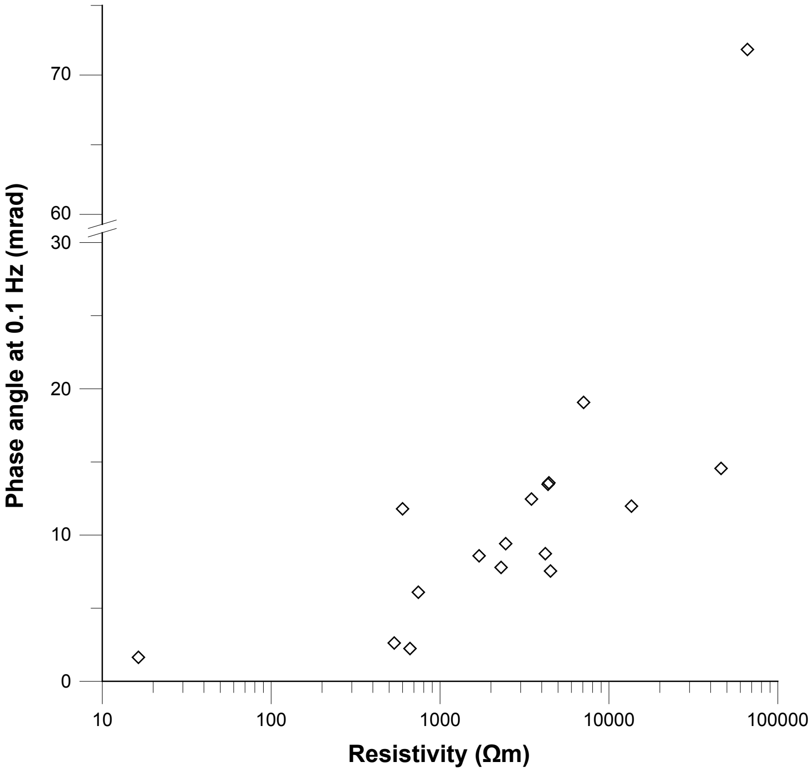

Figure 5-3. *Measured phase angle (at 0.1 Hz) as a function of resistivity of the samples. Note the broken axis.*

fine-grained magnetite. The phase angle increases with increasing frequency in the measurement interval (0.1 to 30 Hz) for all samples except one. The sample KLX03 590.15 to 590.18 m, has fairly large phase angles at low frequencies that decrease with increasing frequency. This might be indicative of presence of mineral grains with electronic conduction or possibly clay minerals.

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 2%.

References

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

Appendix 1

Resistivity and formation factor values

All samples where soaked in water with a resistivity of 0.14 Ωm.

Borehole	**Secup** **(m)**	**Seclow** **(m)**	**Resistivity at 0.1 Hz** **(Ωm)**	**Phase angle at 0.1 Hz** **(mrad)**	**Formation factor**
KLX03	355.66	355.69	535	2.6	2.61E–04
KLX03	524.52	524.55	664	2.2	2.11E–04
KLX03	590.15	590.18	599	11.8	2.34E–04
KLX03	803.05	803.08	2,448	9.4	5.72E–05
KLX03	894.32	894.35	1,702	8.6	8.22E–05
KLX03	979.42	979.45	4,361	13.5	3.21E–05
KLX04	419.62	419.65	744	6.1	1.88E–04
KLX05	364.02	364.05	46,123	14.6	3.04E–06
KLX10	159.15	159.18	16	1.6	8.56E–03
KLX10	768.03	768.06	13,600	12.0	1.03E–05
KLX12A	240.24	240.27	4,511	7.5	3.10E–05
KLX12A	240.69	240.72	3,478	12.5	4.03E–05
KLX12A	430.50	430.53	66,085	71.8	2.12E–06
KLX13	122.10	122.13	4,201	8.7	3.33E–05
KLX13A	373.36	373.39	4,409	13.6	3.18E–05
KLX13A	373.62	373.65	7,082	19.1	1.98E–05
KLX13A	121.06	121.09	2,298	7.8	6.09E–05