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Oskarshamn site investigation

Resistivity measurements and determination of formation factors on samples from KLX04 and KSH02

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Abstract

This report presents the execution and the results from measurements of electrical resistivity on core samples from the boreholes KLX04 and KSH02 at Oskarshamn. The formation factor was calculated based on the results of the measurements. A total of 45 core samples were tested (38 from KLX04 and 7 from KSH02). The resitivity was measured after soaking the samples in a 1 M NaCl-solution for 10 weeks. The resistivity values showed a rather large spread. The median value was 1,460 Ωm (1st quartile: 588 Ωm, 3rd quartile: 3,275 Ωm), corresponding to a median value of the formation factor of $7.67 \cdot 10^{-5}$. A few of the samples had very high resistivities and consequently low formation factors. Most of these samples consisted of dark dioritoid rocks. The samples with the lowest resistivities contained sealed fractures.

Sammanfattning

Denna rapport presenterar genomförandet och resultaten från mätningar av elektrisk resistivitet på borrkärneprover från KLX04 och KSH02 i Oskarshamn. Formationsfaktorn har beräknats med mätningarna som underlag. Totalt 45 provbitar har undersökts (38 från KLX04 och 7 från KSH02). Resistiviteten mättes efter det att proven legat i 1 M NaCl-lösning i tio veckor. Resistivitetsvärdena visade relativt stor spridning. Medianvärdet var 1 460 Ωm (första kvartil: 588 Ωm, tredje kvartil: 3 275 Ωm), svarande mot ett medianvärde på formationsfaktorn på $7.67 \cdot 10^{-5}$. Några prover uppvisade mycket höga resistiviteter och därmed låga värden på formationsfaktorn. De flesta av dessa prover bestod av mörk dioritoid. De prover som hade de lägsta resistiviteterna, och därmed de högsta formationsfaktorvärdena, innehöll läkta sprickor.

Contents

1 Introduction

This document reports the data gained by the resistivity measurements on samples from KLX04 and KSH02, 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 400-03-041 (KSH02) and AP PS 400-04-093 (KLX04). 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 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.

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

Activity plan	Number	Version
Provtagning och analyser av borrkärna från KSH01 och KSH02 för bestämning av transportegenskaper	AP PS 400-03-041	1.0
Provtagning och analyser av borrkärna från KLX01–KLX04 för bestämning av transportegenskaper	AP PS 400-03-093	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 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 the method description "Mätning av bergarters petrofysiska egenskaper". 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. 5.01 (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 SKB instruction “Mätning av bergarters petrofysiska egenskaper”. A summary of the method is given below.

The testing was performed on a few 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 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 ten 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. 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. 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 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.

5 Results

The resistivity values of the samples showed a large spread. The range of resistivities covered almost four orders of magnitude. The median value was 1,460 Ωm (1st quartile: 588 Ωm, 3rd quartile: 3,275 Ωm), corresponding to a median value of the formation factor of $7.67 \cdot 10^{-5}$. High resistivity values were particularly found for samples of dark, dioritoid rock with the very highest values from KSH02. Samples with low resistivity contained sealed fractures. Histograms of the formation factor results can be seen in Figures 5-1 and 5-2.

A majority of the samples have formation factor values below $1 \cdot 10^{-4}$. A minor peak in the histograms can also be seen at approximately $2 \cdot 10^{-4}$.

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. Most samples show small phase angles (Figure 4-3). The small phase angles of about one to five 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. A significant number of the samples have fairly high phase angles. There is clear positive correlation between resistivity and phase angle. This indicates that the high 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. 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.

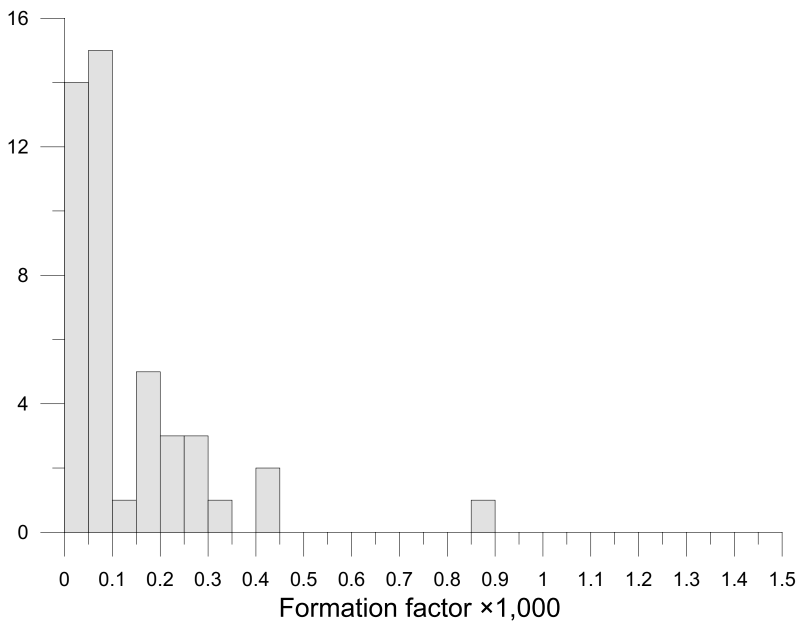

***Figure 5-1**. Histogram of calculated formation factor for samples from KLX04 and KSH02. All samples merged together.*

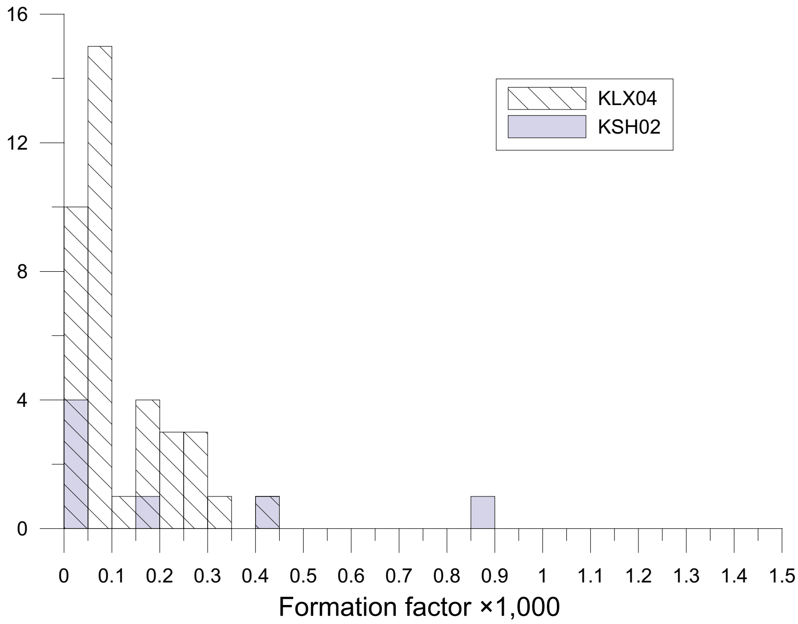

Figure 5-2. *Histogram of calculated formation factor for samples from KLX04 and KSH02.*

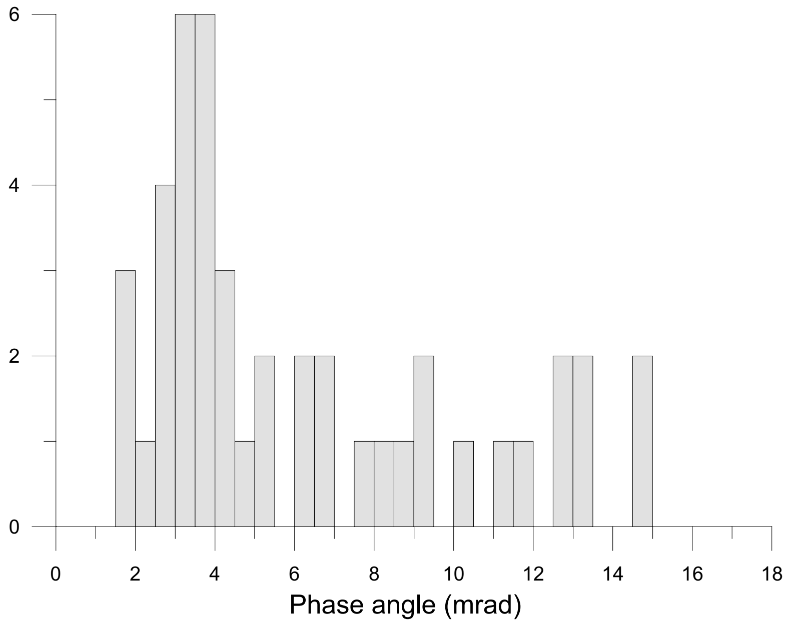

Figure 5-3. *Histogram of measured phase angles (at 0.1 Hz) for samples from KLX04 and KSH02. All samples merged together. One sample with large phase angle (34.4 mrad) is not included.*

The formation factor does not show any significant trend with respect to depth (Figure 5-4). The samples with the largest formation factor values (lowest resistivities) contain sealed fractures, e.g. KSH02 500.39–500.42 m length.

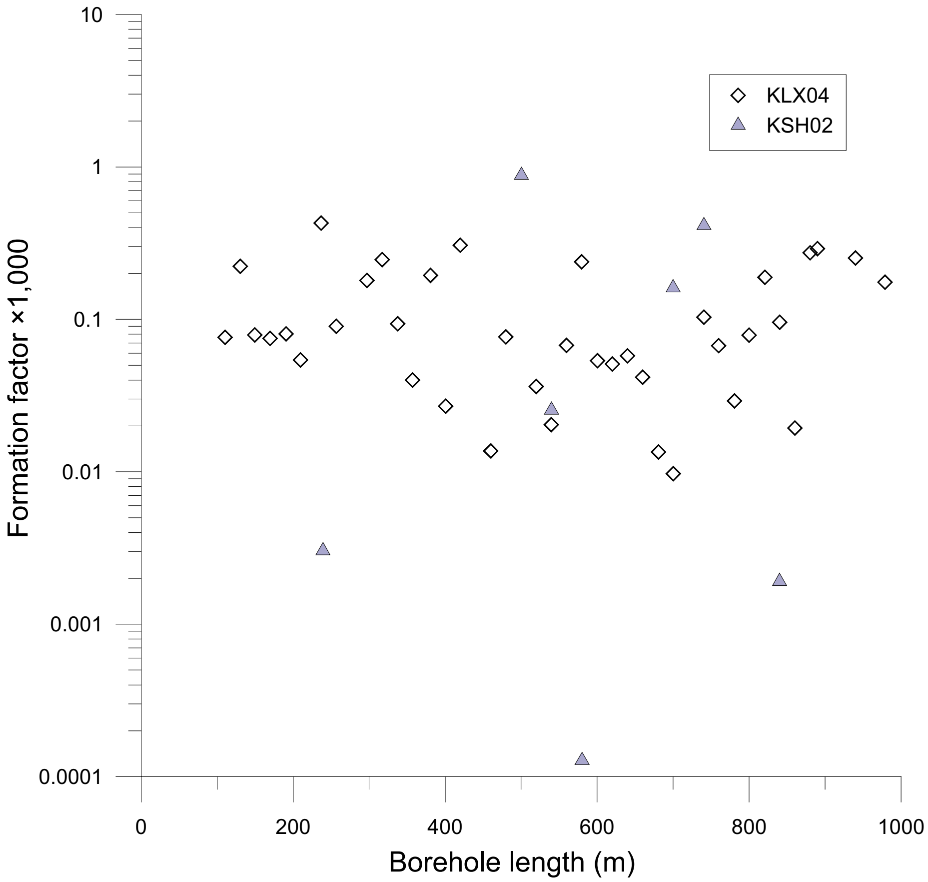

***Figure 5-4**. Formation factor plotted as a function of sampling depth along the cores.*

6 Data delivery

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.

References

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