

Oskarshamn site investigation

Resistivity measurements on samples from KSH01, KSH02, KLX02, KLX04 and KLX11A

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Abstract

This report presents the execution and the results from measurements of electrical resistivity on core samples from the boreholes KSH01, KSH02, KLX02, KLX04 and KLX11A at Oskarshamn site investigation area. The formation factor was calculated based on the results of the measurements. A total of 62 core samples were tested (9 from KSH01, 10 from KSH02, 15 from KLX02, 9 from KLX04 and 19 from KLX11A). The resistivity was measured after soaking the samples in a 1 M NaCl-solution for nine weeks. The resistivity values showed a rather large spread. The median value was 1,187 Ωm (1st quartile: 749 Ωm , 3rd quartile: 3,076 Ωm), corresponding to a median value of the formation factor of $0.0905 \cdot 10^{-3}$. A few of the samples had very high resistivities and consequently low formation factors. Most of these samples came from KLX11A. 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.

Sammanfattning

Denna rapport presenterar genomförandet och resultaten från mätningar av elektrisk resistivitet på borrhälsprover från KSH01, KSH02, KLX02, KLX04 och KLX11A, Oskarshamns platsundersökningsområde. Formationsfaktorn har beräknats med mätningarna som underlag. Totalt 62 provbitar har undersökts (9 från KSH01, 10 från KSH02, 15 från KLX02, 9 från KLX04 och 19 från KLX11A). Resistiviteten mättes efter det att proven legat i 1 M NaCl-lösning i nio veckor. Resistivitetsvärdena visade relativt stor spridning. Medianvärdet var 1 187 Ωm (första kvartil: 749 Ωm , tredje kvartil: 3 076 Ωm), svarande mot ett medianvärde på formationsfaktorn på $0,0905 \cdot 10^{-3}$. Några prover uppvisade mycket höga resistiviteter och därmed låga värden på formationsfaktorn. De flesta av dessa prover kom från KLX11A. 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.

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1 Introduction

This document reports the data gained by the resistivity measurements on samples from KSH01, KSH02, KLX02, KLX04 and KLX11A, 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 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 borrhärlor 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 the Method Description SKB MD 230.001, SKB internal document. 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 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 nine 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 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 samples should be soaked in 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, where they are traceable by the Activity Plan number (AP PS 400-06-023). Only data in SKB's 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. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

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 1,187 Ωm (1st quartile: 749 Ωm , 3rd quartile: 3,076 Ωm), corresponding to a median value of the formation factor of $0.0905 \cdot 10^{-3}$. High resistivity values were particularly found for samples from KLX11A. Histograms of the formation factor results can be seen in Figure 5-1.

A majority of the samples have formation factor values below $1.5 \cdot 10^{-4}$. Four samples from KLX11A have formation factors lower than 10^{-5} . The sample that shows the largest formation factor value, and hence the lowest resistivity, had a crack through it that might not be fully sealed.

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%.

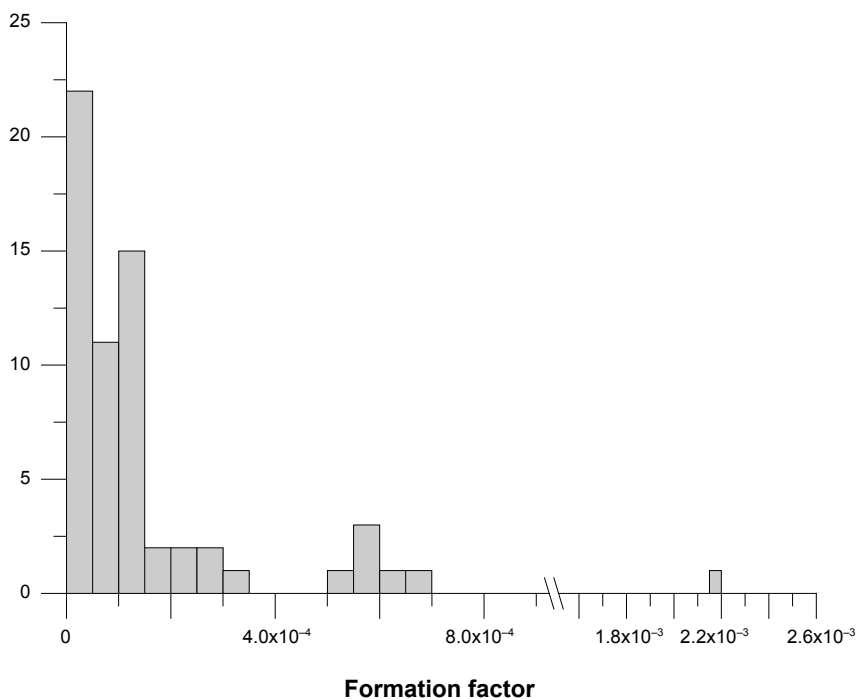


Figure 5-1. Histogram of calculated formation factor for all samples in the study. Note the broken axis.

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, a significant number of the samples have fairly high phase angles. There is a clear positive correlation between resistivity and phase angle (Figure 5-3). 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.

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%.

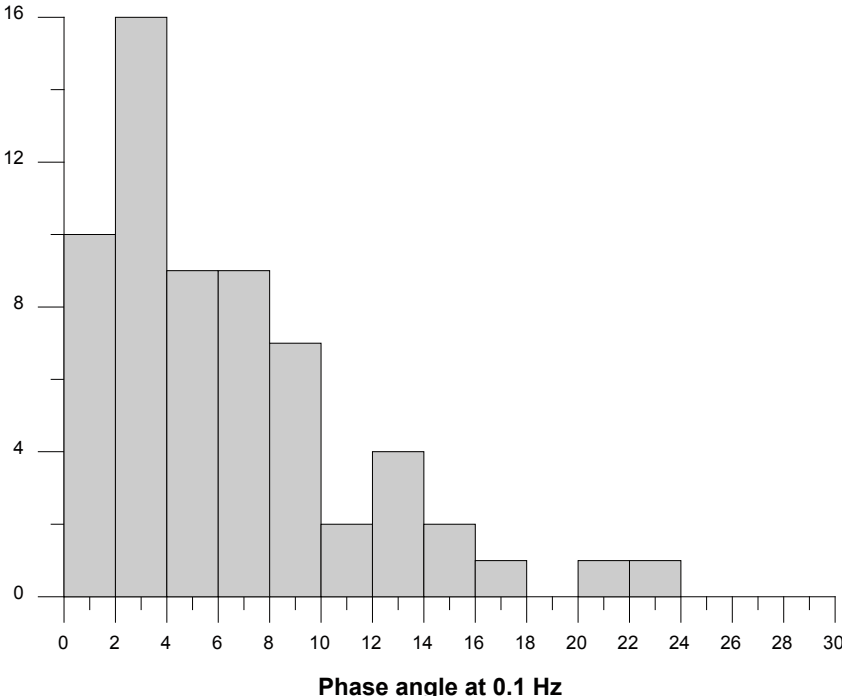
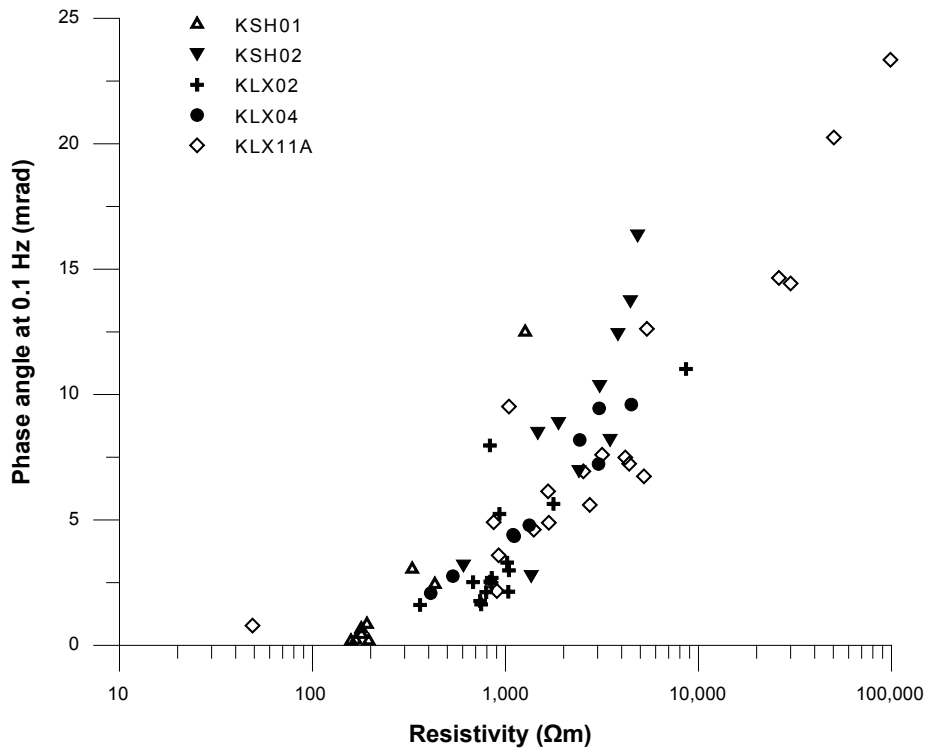


Figure 5-2. Histogram of measured phase angles (at 0.1 Hz) for all samples from this study.



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 were soaked in water with a resistivity of 0.107 Ωm .

Borehole	Secup (m)	Seclow (m)	Resistivity at 0.1Hz (Ωm)	Phase angle at 0.1 Hz (mrad)	Formation factor
KSH01	280.22	280.27	1,265	12.5	8.46E-05
KSH01	891.67	891.68	168	0.2	6.39E-04
KSH01	891.69	891.72	191	0.8	5.59E-04
KSH01	891.72	891.77	179	0.4	5.96E-04
KSH01	891.78	891.79	158	0.2	6.76E-04
KSH01	891.80	891.83	196	0.2	5.47E-04
KSH01	891.83	891.88	179	0.7	5.98E-04
KSH01	940.80	940.85	328	3.0	3.26E-04
KSH01	981.50	981.53	431	2.4	2.48E-04
KSH02	299.94	299.99	4,442	13.7	2.41E-05
KSH02	474.47	474.48	4,836	16.3	2.21E-05
KSH02	474.49	474.56	1,883	8.8	5.68E-05
KSH02	474.60	474.65	3,825	12.4	2.80E-05
KSH02	474.66	474.67	2,402	6.9	4.45E-05
KSH02	474.68	474.71	3,076	10.3	3.48E-05
KSH02	474.71	474.76	605	3.2	1.77E-04
KSH02	474.80	474.83	3,482	8.2	3.07E-05
KSH02	474.86	474.91	1,470	8.5	7.28E-05
KSH02	600.01	600.04	1,360	2.7	7.87E-05
KLX02	216.70	216.71	1,021	3.3	1.05E-04
KLX02	216.71	216.74	848	2.7	1.26E-04
KLX02	216.74	216.79	847	2.5	1.26E-04
KLX02	216.80	216.81	1,042	3.0	1.03E-04
KLX02	216.81	216.84	835	2.5	1.28E-04
KLX02	216.84	216.89	739	1.8	1.45E-04
KLX02	216.91	216.92	1,034	2.1	1.03E-04
KLX02	216.92	216.95	794	2.1	1.35E-04
KLX02	216.95	217.00	749	1.6	1.43E-04
KLX02	235.02	235.05	361	1.6	2.97E-04
KLX02	258.94	259.01	679	2.5	1.58E-04
KLX02	387.78	387.81	830	8.0	1.29E-04
KLX02	440.19	440.26	1,772	5.6	6.04E-05
KLX02	600.17	600.24	930	5.2	1.15E-04
KLX02	700.13	700.20	8,622	11	1.24E-05
KLX04	489.49	489.50	1,329	4.8	8.05E-05
KLX04	489.50	489.53	1,095	4.4	9.78E-05
KLX04	489.53	489.58	534	2.8	2.00E-04
KLX04	489.61	489.62	3,059	9.5	3.50E-05
KLX04	489.62	489.65	2,424	8.2	4.41E-05
KLX04	489.65	489.70	4,487	9.6	2.38E-05
KLX04	489.75	489.78	3,033	7.2	3.53E-05
KLX04	719.38	719.41	1,110	4.4	9.64E-05

KLX04	920.39	920.42	410	2.1	2.61E-04
KLX11A	306.37	306.40	902	2.2	1.19E-04
KLX11A	326.15	326.18	921	3.6	1.16E-04
KLX11A	366.35	366.38	1,402	4.6	7.63E-05
KLX11A	386.69	386.72	2,531	6.9	4.23E-05
KLX11A	406.18	406.21	1,676	4.9	6.38E-05
KLX11A	426.63	426.66	48.9	0.8	2.19E-03
KLX11A	446.92	446.95	3,166	7.6	3.38E-05
KLX11A	466.28	466.31	868	4.9	1.23E-04
KLX11A	486.49	486.52	5,407	12.6	1.98E-05
KLX11A	506.39	506.42	1,043	9.5	1.03E-04
KLX11A	526.92	526.95	50,300	20.3	2.13E-06
KLX11A	540.89	540.92	26,090	14.7	4.10E-06
KLX11A	565.14	565.17	4,173	7.5	2.56E-05
KLX11A	586.36	586.39	98,830	23.4	1.08E-06
KLX11A	607.35	607.38	30,010	14.4	3.57E-06
KLX11A	627.46	627.49	5,220	6.7	2.05E-05
KLX11A	646.63	646.66	2,732	5.6	3.92E-05
KLX11A	666.98	667.01	1,663	6.1	6.44E-05
KLX11A	686.13	686.16	4,375	7.2	2.45E-05
