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Revised September 2006

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX11A

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August 2006

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

A pdf version of this document can be downloaded from www.skb.se

Reading instruction

For revision no. 1 of this report a recalibration of the density logging data has been performed. The reason for this is that tests of the logging tool, performed by the contractor Rambøll, show that the there is a significant difference in the absolute density level between two calibrations performed by Rambøll in 2006-01-12 and 2006-05-29. The density data were corrected by use of petrophysical data from samples collected in the cored borehole KFM01D located in Forsmark.

Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored borehole KLX11A.

The main objective of the investigation is to use the results as supportive information during the geological core logging and mapping of drill cuttings and as supportive information during the geological single-hole interpretation.

The rocks in the vicinity of KLX11A are completely dominated by silicate density in the interval 2,730–2,800 kg/m$^{3.}$ However, a detailed study of the silicate density log shows that KLX11A can be divided into two parts. Part one, the upper half of the borehole (section c. 100–490 m), is dominated by rocks with silicate density in the interval 2,750–2,785 kg/m^3. Part two, the lower half (section c. 510–991 m) is dominated by rocks with silicate density in the interval 2,775–2,810 kg/m^3. The two halves are separated by a c. 20 m long section of relatively lower density (c. 2,650–2,730 kg/m^3), which coincides with a distinctly indicated deformation zone.

The natural gamma radiation is generally < 10 µR/h, apart for the section c. 100–155 m along which the radiation is slightly higher (mainly in the interval 10–20 µR/h). The division of KLX11A suggested by the density data is also seen in the natural gamma radiation, but much less distinct.

In the lower half of KLX11A the magnetic susceptibility mainly varies in the range 0.020–0.040 SI (with rapid ups and downs), and in the upper section the susceptibility is more stable, mainly in the range 0.025–0.035 SI. These variations may seem small but most likely correspond to variations in mineral composition.

The fracture frequency estimated for KLX11A shows large variations. Possible deformation zones are indicated in the sections c. 161–171 m, 242–268 m, 342–350 m, 485–543 m, 576–586 m and 851–861 m. All the indicated deformation zones are characterized by decreased resistivity, decreased magnetic susceptibility, partly decreased P-wave velocity, and also caliper anomalies. For the most prominent possible deformation zone (section c. 485–543 m), the decrease in bulk resistivity is almost two orders of magnitude according to the focused resistivity 300 logging data. The combination of physical properties in the possible deformation zones most likely indicates brittle deformation in combination with mineral alteration. This indicates that all of them may be water bearing.

The apparent porosity averages at c. 0.3–0.5%, which is considered normal for crystalline rock with a low fracture frequency. Sections with increased porosity coincide well with the possible deformation zones. The two most prominent sections with increased porosity are identified at c. 242–270 m and c. 485–540 m.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX11A.

Huvudsyftet med undersökningen är att ta fram ett material som på ett förenklat sätt åskådliggör resultaten av de geofysiska loggningarna, s k generaliserade geofysiska loggar. Materialet används dels som stödjande data vid borrkärne- och borrkaxkarteringen samt som underlag vid den geologiska enhålstolkningen.

Bergarterna i närheten av KLX11A domineras helt av silikatdensitet i intervallet 2 730–2 800 kg/m^3. En noggrann genomgång av silikatdensitetsloggen visar dock att borrhålet kan delas in i två halvor. En övre del (ca 100–490 m), som domineras av silikatdensitet i intervallet 2 750–2 785 kg/m^3, och en undre del (ca 510–991 m) som domineras av silikatdensitet i intervallet 2 775–2 810 kg/m^3. Mellan de två sektionerna finns ett ca 20 m långt avsnitt med silikatdensitet i intervallet ca 2 650–2 730 kg/m^3. Detta korta avsnitt sammanfaller med en tydligt indikerad möjlig deformationszon.

Den naturliga gammastrålningen är < 10 μR/h längs stora delar av borrhålet, förutom för sektionen ca 100–155 m, längs vilken gammastrålningen är i intervallet 10–20 μR/h. Låg naturlig gammastrålning är ofta liktydig med hög halt mörka mineral. Den uppdelning av KLX11A som indikeras av densitetsdata stöds även av den naturliga gammastrålningen, dock inte lika tydligt.

I den nedre halvan av KLX11A ligger den magnetiska susceptibiliteten i intervallet 0,020–0,040 SI och uppvisar snabba upp- och nedgångar, emedan den i borrhålets övre halva är mer stabil i intervallet ca 0,025–0,035 SI. Skillnaden kan tyckas liten med återspeglar troligen sanna variationer i bergets mineralogi längs borrhålet.

Den uppskattade sprickfrekvensen uppvisar stora variationer. Möjliga deformationszoner kan identifieras längs sektionerna ca 161–171 m, 242–268 m, 342–350 m, 485–543 m, 576–586 m och 851–861 m. Samtliga sektioner karaktäriseras av låg resistivitet, sänkt magnetisk susceptibilitet, delvis sänkt P-vågshastighet samt caliper-anomalier. För den största av de möjliga deformationszonerna (485–543 m) är nedgången i resistivitet nästan två tiopotenser (fokuserad resistivitet 300) i förhållande till omgivande sektioner. Loggdata indikerar att samtliga möjliga deformationszoner utsatts för spröd deformation och mineralomvandling, vilket medför att de potentiellt är vattenförande.

Den skenbara porositeten ligger i snitt i intervallet ca 0,3–0,5 %, vilket anses vara normalt för sprickfattigt kristallint berg. Förhöjd porositet sammanfaller i regel med möjliga deformationszoner, och de två längsta sektionerna med avvikande hög skenbar porositet finns vid ca 242–270 m och ca 485–540 m.

Innehåll

1 Introduction

SKB performs site investigations for localization of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark and Oskarshamn. This document reports the results gained from the interpretation of geophysical borehole logging data from the cored borehole KLX11A located in Laxemar, Oskarshamn.

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings, including estimated fracture frequency. Calculations of the salinity are also presented. The logging measurements were conducted in 2006 by Rambøll /1/.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (activity plan AP PS 400-06-049 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of borehole KLX11A.

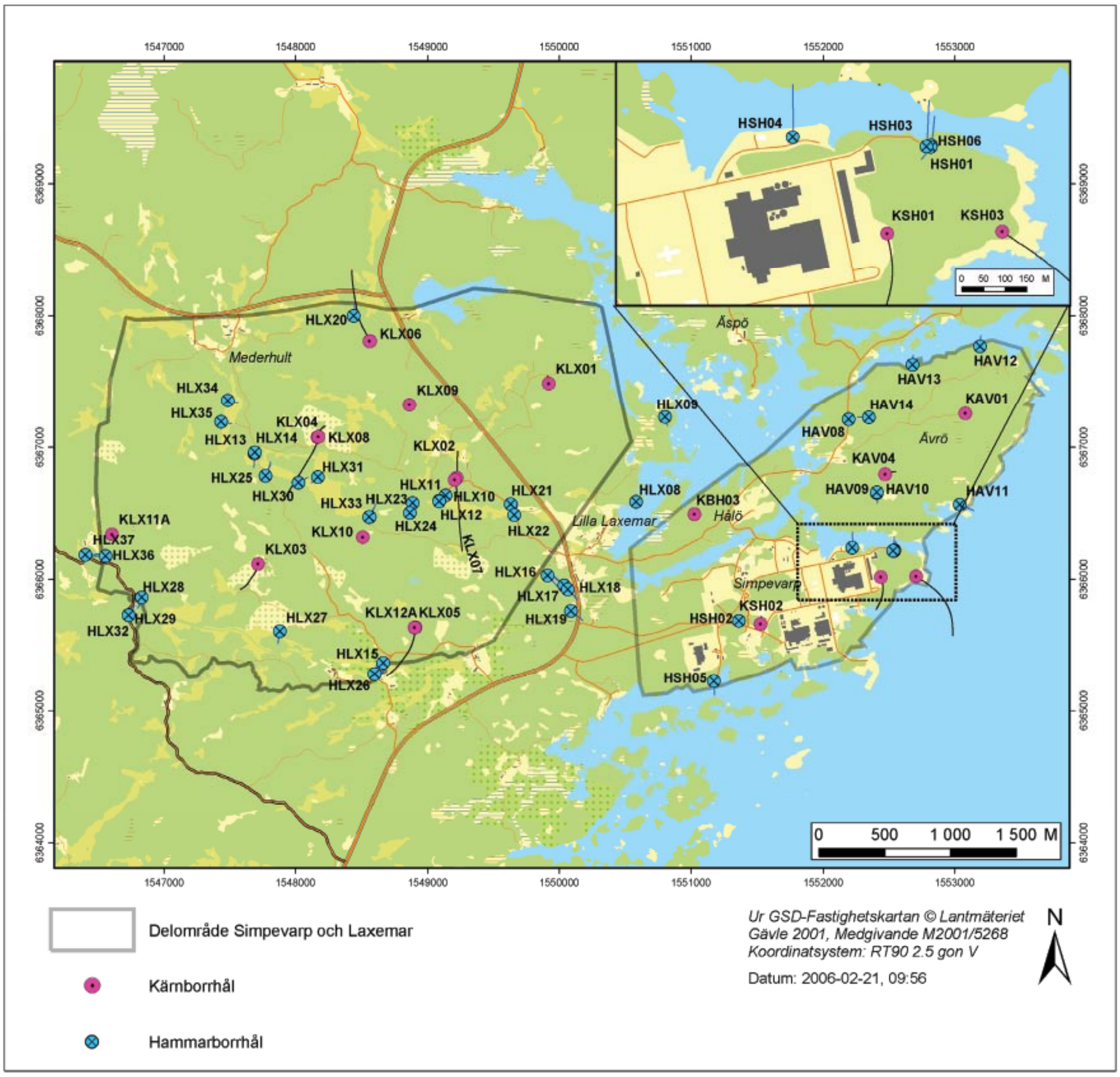


Figure 1-1. Location of the borehole KLX11A in the western part of the Laxemar area.

The interpreted results are stored in the primary data base SICADA and are traceable by the activity plan number.

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

Activity plan	Number	Version
Tolkning av borrhålsgeofysiska data från KLX11A.	AP PS 400-06-049	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

2 Objective and scope

The purpose of geophysical measurements in boreholes is to gain knowledge of the physical properties of the bedrock in the vicinity of the borehole. A combined interpretation of the "lithological" logging data; silicate density, magnetic susceptibility and natural gamma radiation, together with petrophysical data makes it possible to estimate the physical signature of different rock types. The three loggings are generalized and are then presented in a simplified way. The location of major fractures and an estimation of the fracture frequency along the borehole are calculated by interpreting data from the resistivity loggings; the single point resistance (SPR), caliper and sonic loggings.

An estimation of the salinity and the apparent porosity are presented for the borehole. These parameters indicate salinity variations in the borehole fluid and the transport properties of the rock volume in the vicinity of the borehole.

The main objective of these investigations is to use the results as supportive information during the geological core mapping and as supportive information during the so called "geological single-hole interpretation", which is a combined borehole interpretation of core logging (Boremap) data, geophysical data and radar data.

3 Equipment

3.1 Description of equipment for analyses of logging data

The software used for the interpretation are WellCad v 4.0 (ALT) and Strater 1.00.24 (Golden Software), that are mainly used for plotting, Grapher v 5 (Golden Software), mainly used for plotting and some statistical analyses, and a number of in-house software developed by GeoVista AB on behalf of SKB.

4 Execution

4.1 Interpretation of the logging data

The execution of the interpretation is summarized in the following four steps:

1. Preparations of the logging data (calculations of noise levels, filtering, error estimations, re-sampling, drift correction, length adjustment).

   The loggings are median or mean filtered (generally 5 point filters for the resistivity loggings and 3 point filters for other loggings) and re-sampled to common section co-ordinates (0.1 m point distance).

   The density (logging tool century 9139) and magnetic susceptibility logging data are calibrated with respect to petrophysical data. The magnetic susceptibility logging data were calibrated by use of a combination of petrophysical data from the boreholes KLX03, KSH01A, KSH02, KSH03A, KAV04A, and KLX10 see /2, 3, 4, 5, 6 and 7/. The density logging data were calibrated by use of petrophysical data from the borehole KFM01D /8/.

   The caliper 1D and caliper 3D logs are calibrated by use of borehole technical information supplied by SKB. The calibration procedure is described in detail in /9/.

2. Interpretation rock types (generalization of the silicate density, magnetic susceptibility and natural gamma radiation loggings).

   The silicate density is calculated with reference to /10/ and the data are then divided into 5 sections *indicating* a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /11/. The sections are bounded by the threshold values:

   granite < 2,680 kg/m^3
   2,680 kg/m^3 < granodiorite < 2,730 kg/m^3
   2,730 kg/m^3 < tonalite < 2,800 kg/m^3
   2,800 kg/m^3 < diorite < 2,890 kg/m^3
   2,890 kg/m^3 < gabbro

   The magnetic susceptibility logging is subdivided into steps of decades and the natural gamma radiation is divided into steps of ”low” (< 10μR/h), ”medium” (10 μR/h < gamma < 20 μR/h), ”high” (20 μR/h < gamma < 30 μR/h) and “very high” (> 30 μR/h).

3. For the cored borehole the normal resistivity loggings are corrected for the influence of the borehole diameter and the borehole fluid resistivity. The apparent porosity is calculated during the correction of the resistivity loggings. The calculation is based on Archie’s law /12/; $\sigma = a\,\sigma_w\,\varphi^m + \sigma_s$ where σ = bulk conductivity (S/m), σ_w = pore water conductivity (S/m), φ = volume fraction of pore space, σ_s = surface conductivity (S/m) and “a” and “m” are constants. Since “a” and “m” vary significantly with variations in the borehole fluid resistivity, estimations of the constants are performed with reference to the actual fluid resistivity in each borehole respectively.

4. Interpretation of the position of large fractures and estimated fracture frequency (classification to fracture logging and calculation of the estimated fracture frequency logging are based on analyses of the short and long normal resistivity, caliper mean, single point resistance (SPR), focused resistivity (140 and 300 cm) and sonic.

   The position of large fractures is estimated by applying a second derivative filter to the logging data and then locating maxima (or minima depending on the logging method) in the filtered logging. Maxima (or minima) above (below) a certain threshold value (Table 4-2) are selected as probable fractures. The result is presented as a column diagram where column height 0 = no fracture, column height 1 = fracture indicated by all logging methods.

The estimated fracture frequency is calculated by applying a power function to the weighted sum of the maxima (minima) derivative logging for each method respectively, and then calculating the total sum of all power functions. Parameters for the power functions were estimated by correlating the total weighted sum to the mapped fracture frequency in the cored boreholes KLX03 and KLX04 /2/. The powers and linear coefficients (weights) used are presented in Table 4-1.

5. Report evaluating the results.

4.2 Preparations and data handling

The logging data were delivered as Microsoft Excel files via email from Leif Stenberg, SKB. The data of each logging method is saved separately as an ASCII-file. The data processing is performed on the ASCII-files. The data used for interpretation are:

- Density (gamma-gamma)
- Magnetic susceptibility
- Natural gamma radiation
- Focused resistivity (300 cm)
- Focused resistivity (140 cm)
- Long normal resistivity (64 inch)
- Short normal resistivity (16 inch)
- Sonic (P-wave)
- Caliper mean
- Caliper 1D
- SPR
- Fluid resistivity
- Fluid temperature

The borehole technical information used for calibration of the caliper data is delivered as Microsoft Word files via email by SKB.

Table 4-1. Threshold values, powers and weights used for estimating position of fractures and calculate estimated fracture frequency, respectively.

	Borehole	Sonic	Focused res. 140	Focused res. 300	Caliper	SPR	Normal res. 64	Normal res. 16	Lateral res.
Threshold	KLX11A	1.5	2.2	1.8	1.0	3.0	–	5.0	–
Power	KLX11A	1.0	1.0	1.6	1.0	0.5	–	0.5	–
Weight	KLX11A	1.0	7.1	6.7	1.0	5.0	–	5.0	–

4.3 Analyses and interpretations

The analyses of the logging data are made with respect to identifying major variations in physical properties with depth as indicated by the silicate density, the natural gamma radiation and the magnetic susceptibility. Since these properties are related to the mineral composition of the rocks in the vicinity of the borehole they correspond to variations in lithology and in thermal properties.

The resistivity, sonic and caliper loggings are mainly used for identifying sections with increased fracturing and alteration. The interpretation products salinity and apparent porosity help identifying saline ground water and porous rocks.

4.4 Nonconformities

Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are not presented for the long normal resistivity logging. Apart from this, no nonconformities are reported.

For revision no. 1 of this report a recalibration of the density logging data has been performed. The reason for this is that tests of the logging tool, performed by the contractor Rambøll, show that the there is a significant difference in the absolute density level between two calibrations performed by Rambøll in 2006-01-12 and 2006-05-29. The density data were corrected by use of petrophysical data from samples collected in the cored borehole KFM01D located in Forsmark.

5 Results

5.1 Quality controll of the logging data

Noise levels of the raw data for each logging method are presented in Table 5-1. Noise levels are generally below or only slightly above the recommended level for all measured data. The magnetic susceptibility log has a noise level 3 times above the recommended, which is too high to be fully acceptable. However, to reduce the influence from the noise all data were average filtered prior to the evaluation.

A qualitative inspection was performed on the loggings. The data were checked for spikes and/or other obvious incorrect data points. Erroneous data were replaced by null values (–999) by the contractor Rambøll prior to the delivery of the data, and all null values were disregarded in the interpretation. Sections with null values are indicated by red and white stripes in the presentation of the generalized loggings.

5.2 Interpretation of the logging data

The presentation of interpretation products presented below includes:

- Classification of silicate density.
- Classification of natural gamma radiation.
- Classification of magnetic susceptibility.
- Position of inferred fractures (0 = no method, 1 = all methods).
- Estimated fracture frequency in 5 m sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and > 6 fractures/m).

Table 5-1. Noise levels in the investigated geophysical logging data of KLX11A.

Logging method	KLX11A	Recommended max noise level
Density (kg/m^3)	9	3–5
Magnetic susceptibility (SI)	$3*10^{-4}$	$1*10^{-4}$
Natural gamma radiation (μR/h)	0.3	0.3
Long normal resistivity (%)	0.2	2.0
Short normal resistivity (%)	0.1	2.0
Fluid resistivity (%)	0.1	2
Fluid temperature (ºC)	$4*10^{-4}$	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	0.1	No data
Caliper 1D	$7*10^{-6}$	$5*10^{-4}$
Caliper mean (m)	$4*10^{-6}$	$5*10^{-4}$
Focused resistivity 300 (%)	4	No data
Focused resistivity 140 (%)	1	No data
Sonic (m/s)	33	20

5.2.1 Interpretation of KLX11A

The results of the generalized logging data and fracture estimations of KLX11A are presented in Figure 5-1, and in a more detailed scale in Appendix 1.

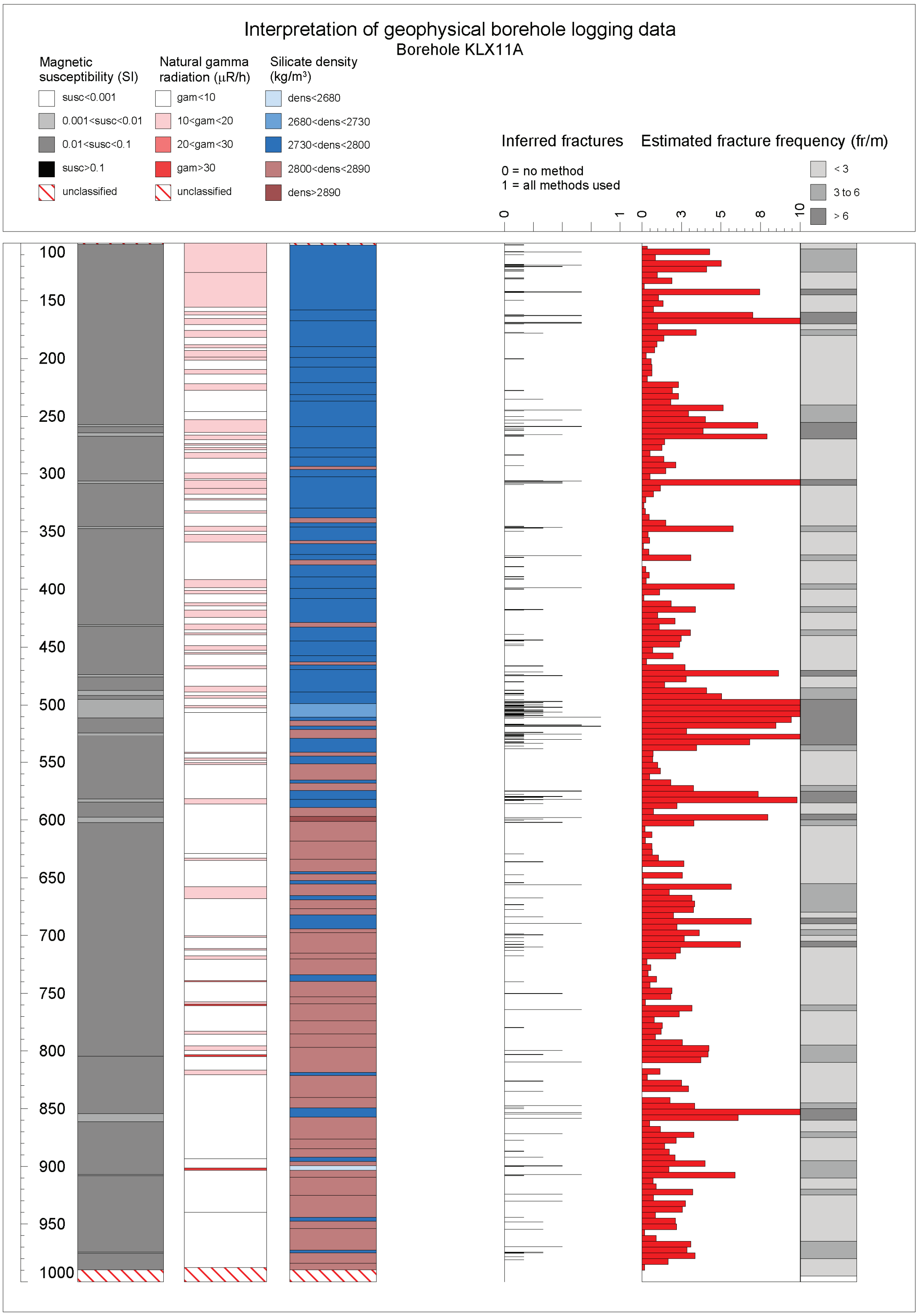


Figure 5-1. Generalized geophysical logs of KLX11A.

The rocks in the vicinity of KLX11A are completely dominated by silicate density in the interval 2,730-2,800 kg/m^3 (Figure 5-1). However, a detailed study of the silicate density log shows that KLX11A can be divided into two parts. Part one, the upper half of the borehole (section c. 100–490 m), is dominated by rocks with silicate density in the interval 2,750–2,785 kg/m^3. Part two, the lower half (section c. 510–991 m) is dominated by rocks with silicate density in the interval 2,775–2,810 kg/m^3. The two halves are separated by a c. 20 m long section of relatively lower density (c. 2,650–2,730 kg/m^3), which coincides with a distinctly indicated deformation zone (described in more detail below). The variations in the silicate density may, for example, indicate that the deformation zone coincides with a boundary between two units of Ävrö granite with different mineralogical compositions.

The natural gamma radiation is generally < 10 μR/h, apart for the section c. 100–155 m along which the radiation is slightly higher (mainly in the interval 10-20 μR/h). The division of KLX11A suggested by the density data is also seen in the natural gamma radiation, but much less distinct. The radiation level is only slightly higher in the upper half compared to the lower half of the borehole. However, there are more variations in the natural gamma radiation in the lower half as compared to the upper half. These variations are indicated by positive anomalies that most likely correspond to dykes of fine-grained granite or pegmatite.

A larger degree of inhomogeneity of the bedrock in the lower half of KLX11A is also indicated in the magnetic susceptibility data. In the lower section the magnetic susceptibility mainly varies in the range 0.020–0.040 SI (with rapid ups and downs), and in the upper section the susceptibility is more stable, mainly in the range 0.025–0.035 SI. These variations may seem small but are clearly seen in the data prior to calculation of the generalized log presented in Figure 5-1.

The fracture frequency estimated for KLX11A shows large variations. Possible deformation zones are indicated in the sections c. 161–171 m, 242–268 m, 342–350 m, 485–543 m, 576–586 m and 851–861 m. All the indicated deformation zones are characterized by decreased resistivity, decreased magnetic susceptibility, partly decreased P-wave velocity, and also caliper anomalies. For the most prominent possible deformation zone (section c. 485–543 m), the decrease in bulk resistivity is almost two orders of magnitude according to the focused resistivity 300 logging data. The combination of physical properties in the possible deformation zones most likely indicates brittle deformation in combination with mineral alteration. This indicates that all of them may be water bearing.

The estimated fluid water salinity (Figure 5-2) shows rather smooth variations in the interval c. 200–500 ppm NaCl, and there is no clear correlation between the salinity variations and the sections with possible deformation zones. The smooth variations indicate that the borehole fluid was most likely not in chemical equilibrium with the pore water fluid in the surrounding rocks at the time of the measurements.

The apparent porosity (black line in Figure 5-2) averages at c. 0.3–0.5 %, which is considered normal for crystalline rock with a low fracture frequency. Sections with increased porosity coincide well with the possible deformation zones. The two most prominent sections with increased porosity are identified at c. 242–270 m and c. 485–540 m.

Table 5-2. Distribution of silicate density classes with borehole length of KLX11A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
2,680 > dens	30	3
2,680 < dens < 2,730	83	10
2,730 < dens<2,800	736	83
2,800 < dens < 2,890	37	4
dens > 2,890	2	0

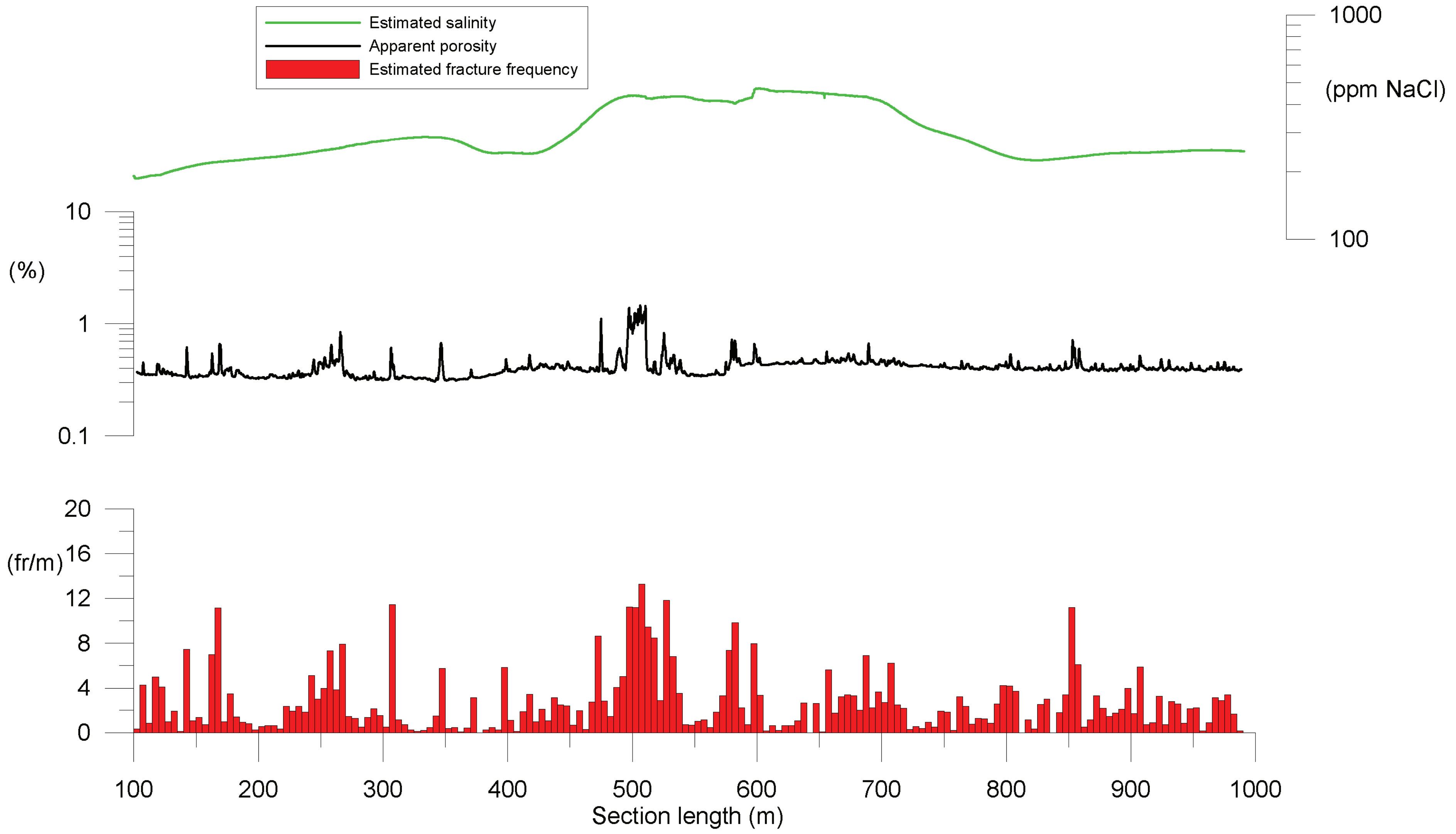


Figure 5-2. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX11A.*

References

/1/ **Nielsen U T, Ringgard J, Fris Dahl, J, 2006.** Geophysical borehole logging in KLX11A. Svensk Kärnbränslehantering AB. In press.

/2/ **Mattsson H, Thunehed H, Keisu, M, 2005.** Interpretation of geophysical borehole measurements and compilation of petrophysical data from KLX01, KLX03, KLX04, HLX21, HLX22, HLX23, HLX24, HLX25, HLX26, HLX27 and HLX28. SKB P-05-34, Svensk Kärnbränslehantering AB.

/3/ **Mattsson H, Thunehed H, 2004.** Interpretation of geophysical borehole data from KSH01A, KSH01B, KSH02 (0–100 m), HSH01, HSH02 and HSH03, and compilation of petrophysical data from KSH01A and KSH01B. SKB P-04-28, Svensk Kärnbränslehantering AB.

/4/ **Mattsson H, Thunehed H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KSH02 (80–1,000 m) and KAV01. SKB P-04-77, Svensk Kärnbränslehantering AB.

/5/ **Mattsson H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KSH03A (100–1,000 m), KSH03B, HAV09, HAV10 and KLX02 (200–1,000 m). SKB P-04-214, Svensk Kärnbränslehantering AB.

/6/ **Mattsson H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KAV04A (100–1,000 m), KAV04B, HLX13 and HLX14. SKB P-04-217, Svensk Kärnbränslehantering AB.

/7/ **Mattsson H, 2006.** Interpretation of geophysical borehole measurements and petrophysical data from KLX10. Svensk Kärnbränslehantering AB. In press.

/8/ **Mattsson H, 2006.** Interpretation of geophysical borehole measurements and petrophysical data from KFM01D. Svensk Kärnbränslehantering AB. In press.

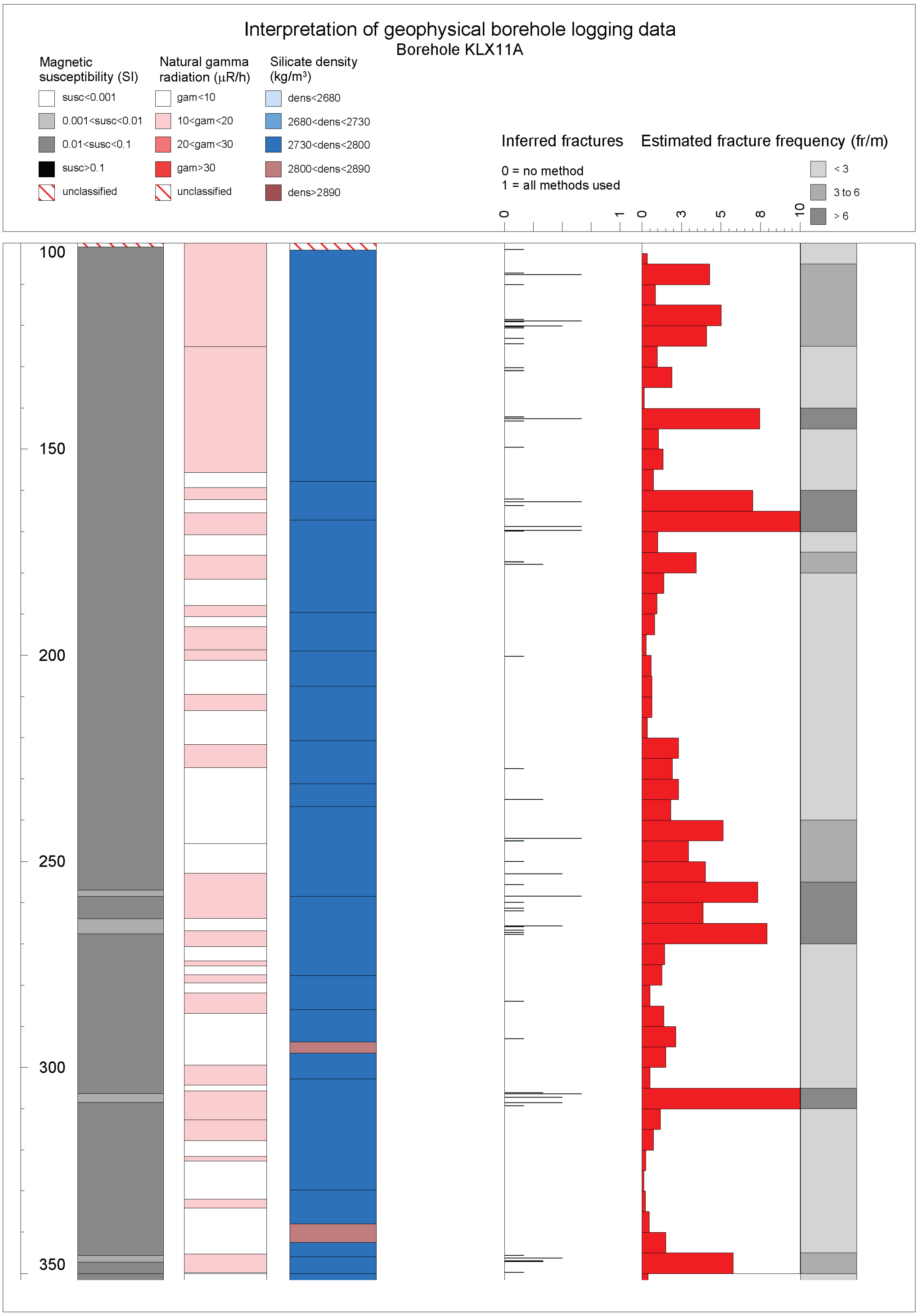
/9/ **Keisu M, 2006.** Calibration of 1D and 3D caliper data from core and percussion drilled boreholes. Svensk Kärnbränslehantering AB. In press.

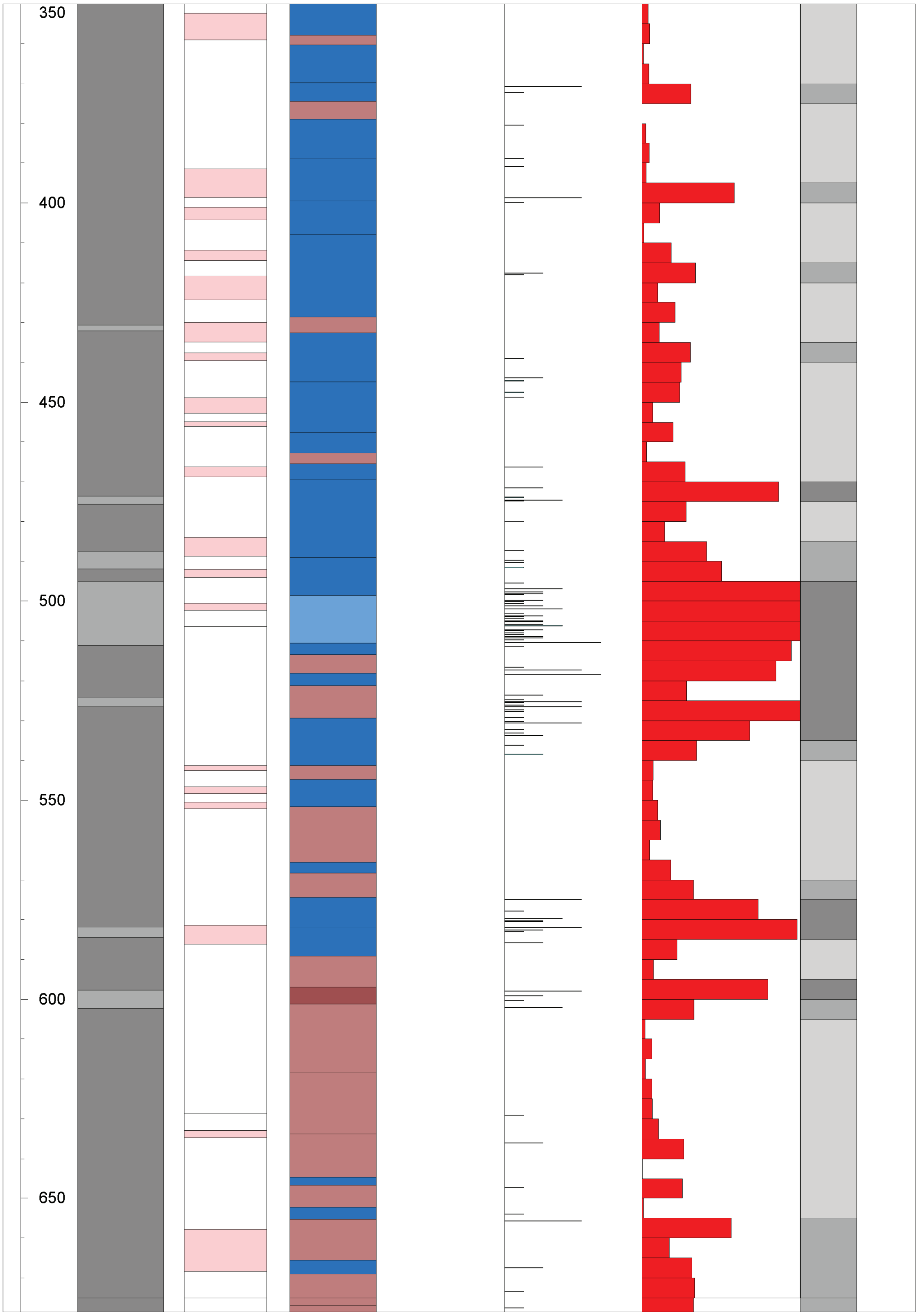
/10/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

/11/ **Puranen R, 1989.** Susceptibilities, iron and magnetite content of precambrian rocks in Finland. Geological survey of Finland, Report of investigations 90, 45 pp.

/12/ **Archie G E, 1942.** The electrical resistivity log as an aid in determining some reservoir characteristics: Trans. Am. Inst. Min., Metallurg., Petr.Eng., 146, 54–62.

Generalized geophysical loggings of KLX11A

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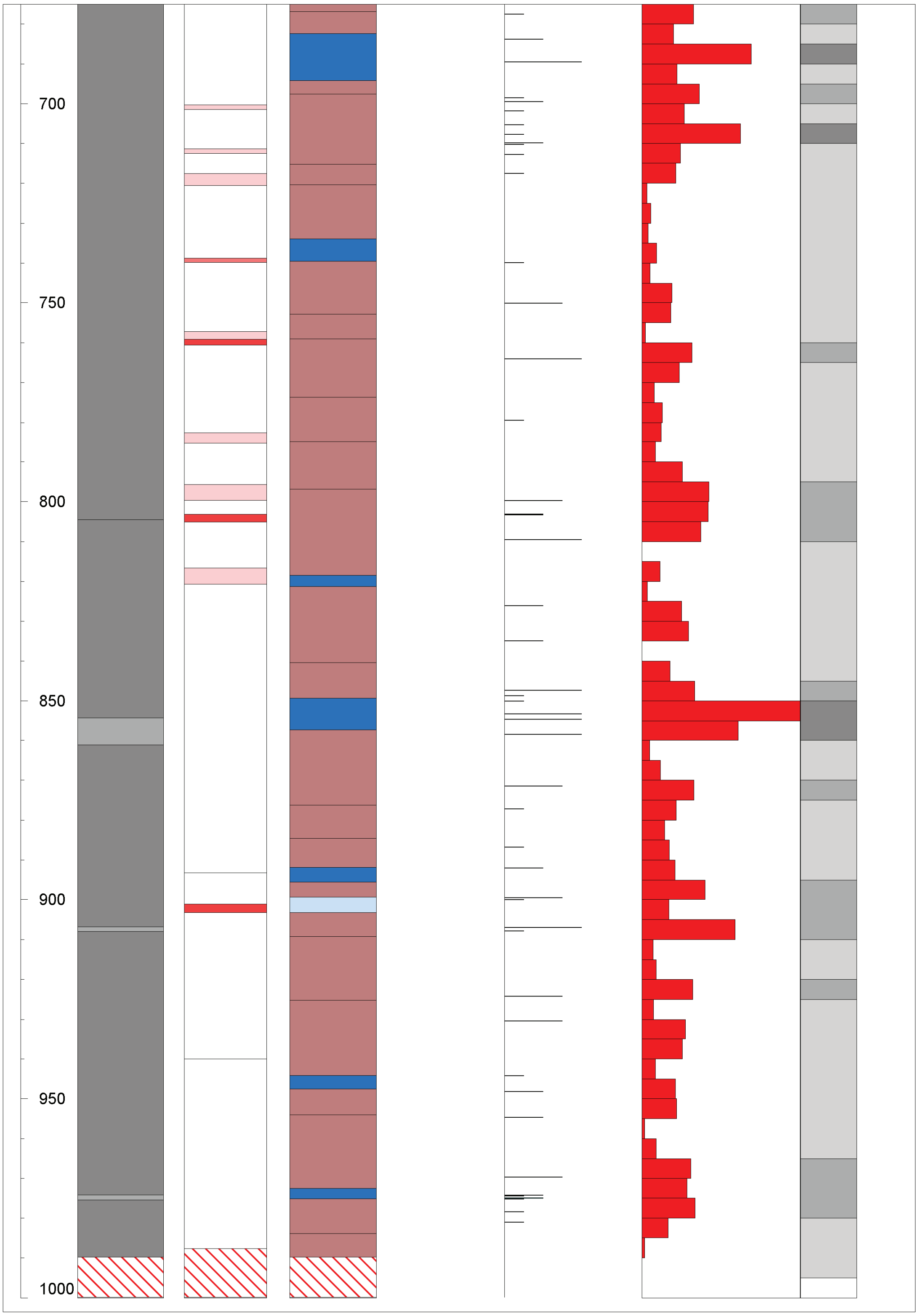
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