P-06-253

Revised January 2008

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX12A

Håkan Mattsson, GeoVista AB

November 2006

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 250, SE-101 24 Stockholm
Tel +46 8 459 84 00

ISSN 1651-4416
SKB P-06-253

Revised January 2008

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX12A

Håkan Mattsson, GeoVista AB

November 2006

Keywords: Borehole, Logging, Geophysics, Geology, Bedrock, Fractures.

Reading instruction

For revision no. 1 of this report a recalculation of density values has been done. A wrong calibration file was used for the density log. Hence an updating of Table 5-2, Figure 5-1 and Appendix 1 has been done as well as corresponding text in Section 5.2.1 and Abstract as well as in Sammanfattning. The recalculation of the density changes the physical properties so that they most likely corresponds to quartz monzodiorite or possibly (but less likely) Ävrö granite with low amount of quartz and high amount of dark minerals.

Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored borehole KLX12A.

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.

For almost 60% of the borehole length the silicate density classifies in the interval 2,730–2,800 kg/m^3. In the corresponding sections the magnetic susceptibility varies within the range 0.02–0.05 SI and the natural gamma radiation is generally < 10 µR/h. This combination of physical properties most likely corresponds to quartz monzodiorite or possibly (but less likely) Ävrö granite with low amount of quartz and high amount of dark minerals. The natural gamma radiation is unusually low and magnetic susceptibility > 0.04 SI is high in comparison to "normal" values for Ävrö granite.

Two significant sections with decreased density occur at c 133–140 m and c 218–230 m. The sections c 163–177 m and c 422–523 are characterized by high density values, 2,900–3,050 kg/m^3, low natural gamma radiation c 1–5 µR/h and partly very high magnetic susceptibility, c 0.08–0.15 SI. The combination of physical properties is typical for diorite/gabbro rocks.

In the lowermost ca 75 m of KLX12A (section c 523–600 m) there is a small but distinct increase in the natural gamma radiation (8–12 µR/h) that coincides with decreased magnetic susceptibility (0.01–0.02 SI). However, there is no corresponding variation in the density data.

Indications of fine-grained granite dykes occur along the entire borehole length, but they are concentrated in the intervals c 177–202 m, 275–305 m and 528–557 m.

The estimated fracture frequency shows a dominance of low fracturing, with only one short section which indicates increased fracture frequency (180–190 m). Some sections of moderate fracture frequency (slightly increased fracturing) are fairly long and occur abundantly in the uppermost c 150 m of the borehole. The data suggest the occurrences of single brittle fractures and no large deformation zone.

In the interval c 497–528 m (crossing the lower boundary between increased and "normal" density) there are several 2–5 m intervals of significantly decreased resistivity that coincide with minor caliper and low P-wave velocity anomalies, which most likely corresponds to increased fracturing.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX12A.

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.

Nästan 60 % av den undersökta borrhålslängden har en silikatdensitet i intervallet 2 730–2 800 kg/m^3. Längs dessa sektioner har berggrunden en magnetisk susceptibilitet i intervallet 0,02–0,05 SI och en naturlig gammastrålning < 10 µR/h. Kombinationen av fysikaliska egenskaper indikerar mest troligt förekomst av kvartsmonzodiorit eller (fast mindre troligt) Ävrögranit med avvikande hög halt av mörka mineral och lågt kvartsinnehåll. Den mycket låga naturliga gammastrålningen och höga magnetiska susceptibiliteten (delvis > 0,04 SI) är anomala värden i förhållande till ”normal” Ävrögranit.

Två intervall med avvikande låg densitet förekommer vid ca 133–140 m och 218–230 m. Sektionerna ca 163–177 m och 422–523 m karaktäriseras däremot av höga densitetsvärden, i intervallet 2 900–3 050 kg/m^3, i kombination med låg naturlig gammastrålning (1–5 µR/h) och bitvis mycket hög magnetisk susceptibilitet (0,08–0,15 SI). Kombinationen av fysikaliska egenskaper är typiska för diorit/gabbro.

Nära botten på borrhålet, intervallet ca 523–600 m, ligger den naturliga gammastrålningen på en något högre nivå (8–12 µR/h) och den magnetiska susceptibiliteten är något lägre (0,01–0,02) i förhållande till de övre delarna. Däremot finns ingen signifikant variation i densiteten längs detta intervall.

Det finns indikationer på förekomst av mindre finkorniga granitgångar längs hela den undersökta borrhålslängden, men dessa är främst koncentrerade till sektionerna ca 177–202 m, 275–305 m och 528–557 m.

Den uppskattade sprickfrekvensen i KLX12A är i huvudsak låg, med en enda kort sektion med indikerad högre sprickfrekvens (180–190 m). Det finns dock ett flertal relativt långa sektioner med moderat (något förhöjd) sprickfrekvens, särskilt längs sektionen 100–250 m. Loggdata indikerar att det troligen rör sig om enstaka sprickor och inte någon större deformationszon.

I intervallet ca 497–528 m (korsande den nedre kontakten mellan hög och ”normal” densitet) förekommer ett flertal 2–5 m långa intervall med kraftigt sänkt resistivitet i kombination med mindre caliperanomalier och något sänkt P-vågshastighet, något som troligen indikerar förhöjd sprickfrekvens.

Contents

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 KLX12A 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 400-06-050 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of borehole KLX12A.

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 KLX12A	AP PS 400-06-050	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

Figure 1-1. *Location of the borehole KLX12A in the southern part of Laxemar.*

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 logging 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 v4.0 (ALT) and Strater 1.00.24 (Golden Software), that are mainly used for plotting, Grapher v5 (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 can be summarized in the following five 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, 7/. The density logging *data* were calibrated by use of petrophysical data from the borehole KLX20A /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 (128 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 4-1) 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 (128 cm).
- 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. 128	Focused res. 300	Caliper	SPR	Normal res. 64	Normal res. 16	Lateral res.
Threshold	KLX12A	2.5	2.2	1.7	1.0	1.0	–	–	–
Power	KLX12A	1.0	1.0	1.6	1.0	0.5	–	–	–
Weight	KLX12A	1.0	7.1	6.7	1.0	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

Normal resistivity logging measurements were not performed in KLX12A. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore not presented in the report. Apart from this, no nonconformities are reported.

5 Results

5.1 Quality control 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 the recommended maximum noise level. However, the magnetic susceptibility data show a noise that is 7 times larger than what is recommended for this method. To reduce the influence from the noise all data were average filtered prior to the evaluation. The SPR data show a couple of abnormal anomalies at suspected fractures (sections 182–187 m and 270–272 m). The anomalies were rejected in the fracture interpretation.

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.

Table 5-1. Noise levels in the investigated geophysical logging data of KLX12A.

Logging method	KLX12A	Recommended max noise level
Density (kg/m^3)	7	3– 5
Magnetic susceptibility (SI)	$7 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Natural gamma radiation (µR/h)	0.2	0.3
Long normal resistivity (%)	No data	2.0
Short normal resistivity (%)	No data	2.0
Fluid resistivity (%)	0.02	2
Fluid temperature (°C)	0.0003	0.01
Lateral resistivity (%)	No data	2
Single point resistance (%)	0.2	No data
Caliper 1D	$0.1 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
Caliper mean (m)	$0.3 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
Focused resistivity 300 (%)	4.5	No data
Focused resistivity 140 (%)	0.6	No data
Sonic (m/s)	2	20

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 metre sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and > 6 fractures/m).

5.2.1 Interpretation of KLX12A

The results of the generalized logging data and fracture estimations of KLX12A are presented in Figure 5-1, and in a more detailed scale in Appendix 1.

For almost 60% of the borehole length the silicate density classifies in the interval 2,730–2,800 kg/m^3 (Table 5-2). In the corresponding sections the magnetic susceptibility varies within the range 0.02–0.05 SI and the natural gamma radiation is generally < 10 µR/h. This combination of physical properties most likely corresponds to quartz monzodiorite or possibly (but less likely) Ävrö granite with low amount of quartz and high amount of dark minerals. The natural gamma radiation is unusually low and magnetic susceptibility > 0.04 SI is high referring to "normal" values for Ävrö granite.

Two significant sections with decreased density occur at c 133–140 m and c 218–230 m. The former coincides with greatly increased natural gamma radiation and decreased magnetic susceptibility, which presumably indicates the occurrence of fine-grained granite. In the section c 218–230 m (density = 2,700–2,750 kg/m^3) there is only a minor decrease in the susceptibility and also a minor increase in the natural gamma radiation. The data could indicate a section with Ävrö granite, however with anomalously low natural gamma radiation, or possibly quartz monzodiorite with decreased density. It is not uncommon that the quartz monzodiorite and Ävrö granite rock types have overlapping physical properties.

The sections c 163–177 m and c 422–523 are characterized by high density values, 2,900–3,050 kg/m^3, low natural gamma radiation c 1–5 µR/h and partly very high magnetic susceptibility, c 0.08–0.15 SI. The combination of physical properties is typical for diorite/gabbro rocks. Significant magnetic lows occur within this section, at c 433–438 m, 447–455 m and 497–511 m, which may indicate rock alteration, probably oxidation of magnetite to hematite. The low magnetic sections may also indicate the occurrences of fine-grained diorite/gabbro, which is often low magnetic.

In the lowermost ca 75 m of KLX12A (section c 523–600 m) there is a small but distinct increase in the natural gamma radiation (8–12 µR/h) that coincides with decreased magnetic susceptibility (0.01–0.02 SI). However, there is no corresponding variation in the density data.

Table 5-2. Distribution of silicate density classes with borehole length of KLX12A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
2,680 > dens	11	2
2,680 < dens < 2,730	46	9
2,730 < dens < 2,800	281	57
2,800 < dens < 2,890	75	15
dens > 2,890	83	17

Short section (0.5–2.0 m long) of increased natural gamma radiation, decreased magnetic susceptibility and decreased density, which most likely indicate occurrences of fine-grained granite dykes, occur along the entire borehole length. However, these kinds of anomalies are concentrated in the intervals c 177–202 m, 275–305 m and 528–557 m.

The fracture frequency estimated for KLX12A shows a dominance of low fracturing, where only one short section indicates increased fracture frequency. However, some sections of moderate fracture frequency (slightly increased fracturing) are fairly long and occur abundantly in the uppermost c 150 m of the borehole (section c 100–250 m). This part of the borehole is mainly characterized by several thin low resistivity anomalies and only minor indications in the caliper and sonic (P-wave velocity) data, which suggests the occurrences of single brittle fractures and no large deformation zone.

The section c 180–190 m of indicated increased fracture frequency is mainly characterized by two significant low resistivity anomalies and no major indications in the caliper or sonic data. This indicates that the suggested fracture frequency is overestimated in this part of the borehole.

In the interval c 497–528 m (crossing the lower boundary between increased and "normal" density) there are several 2–5 m intervals of significantly decreased resistivity that coincide with minor caliper and low P-wave velocity anomalies, which most likely corresponds to increased fracturing.

The estimated fluid water salinity (Figure 5-2) increases stepwise with the borehole section length, from c 500 ppm NaCl at 100 m up to c 5,000 ppm NaCl at the end of the borehole. The two uppermost points of stepwise increasing salinity (at c 180–200 m and c 230–250 m) coincide with indicated increased fracture frequency, which may indicate that the suggested fractures are water bearing.

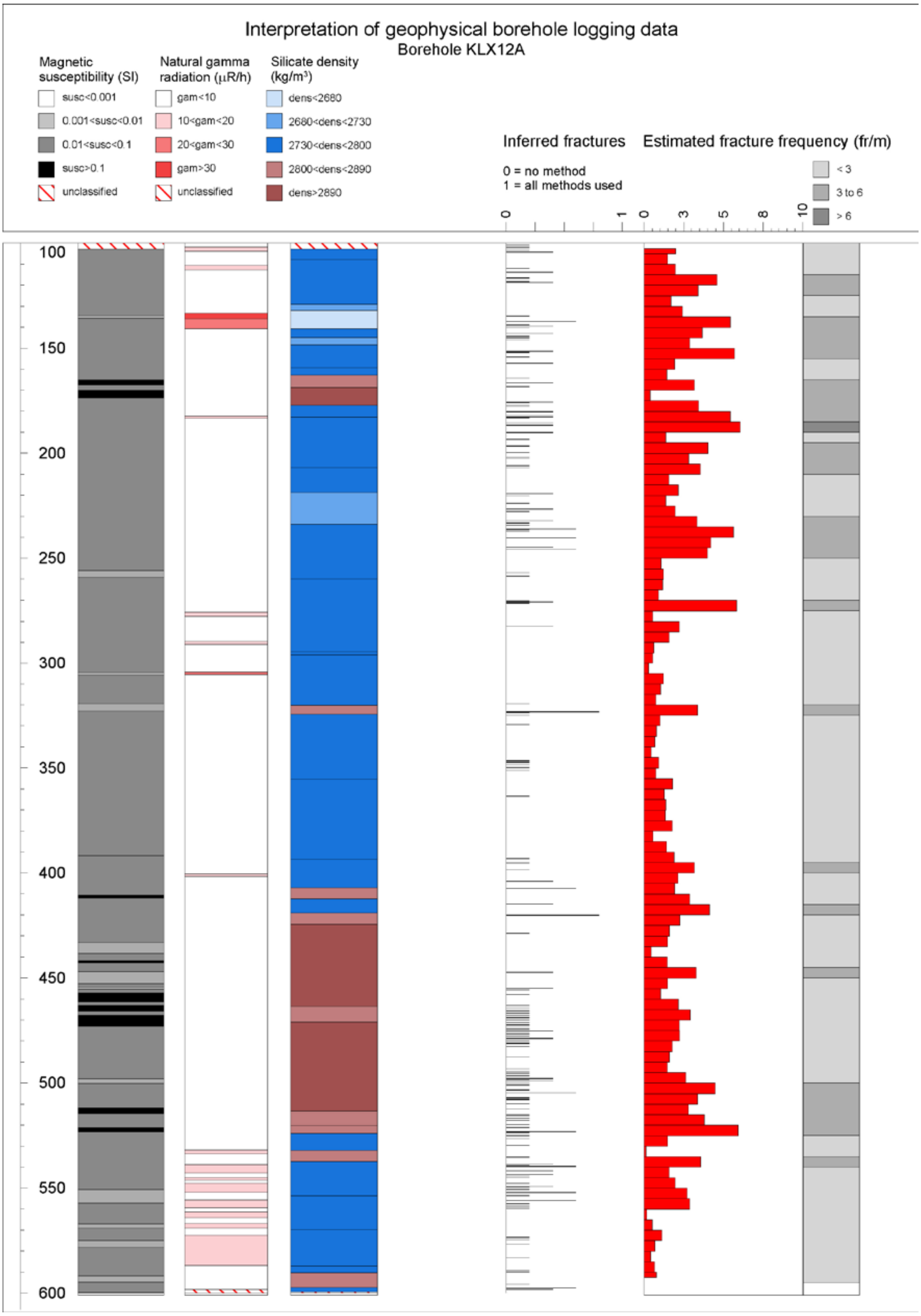


__Figure 5-1.__ Generalized geophysical logs of KLX12A.

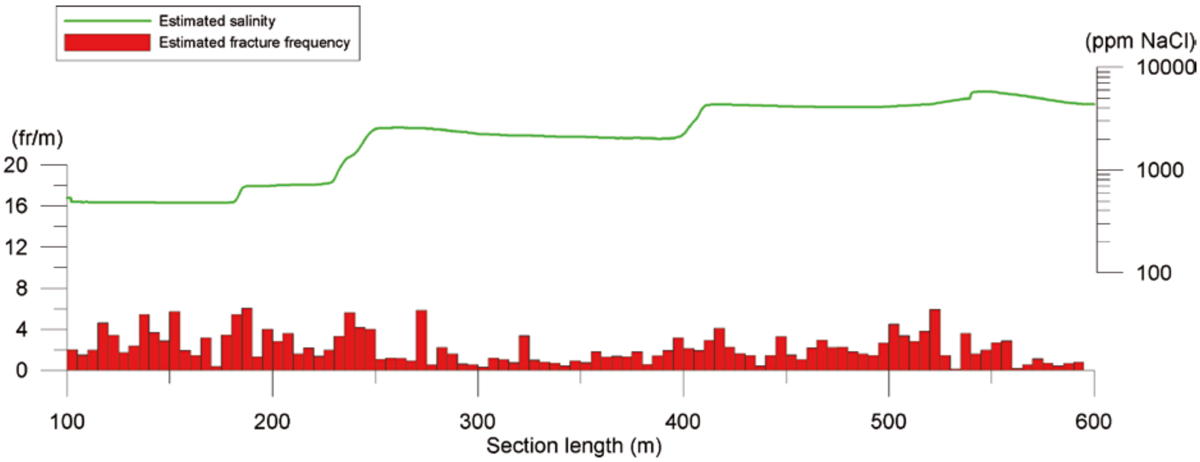


Figure 5-2. *Estimated salinity and estimated fracture frequency of KLX12A.*

References

/1/ **Nielsen U T, Ringgard J, 2006.** Geophysical borehole logging in boreholes KLX12A, KLX09G, KLX10B and KLX10C. SKB P-06-198, Svensk Kärnbränslehantering AB.

/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 (100–1,000m), 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, Keisu M, 2006.** Interpretation of geophysical borehole measurements and petrophysical data from KLX20A, KLX18A, KLX11B, KLX09B, KLX09D, KLX09F, HLX38, HLX39, HLX40 and HLX41. SKB P-06-167, Svensk Kärnbränslehantering AB.

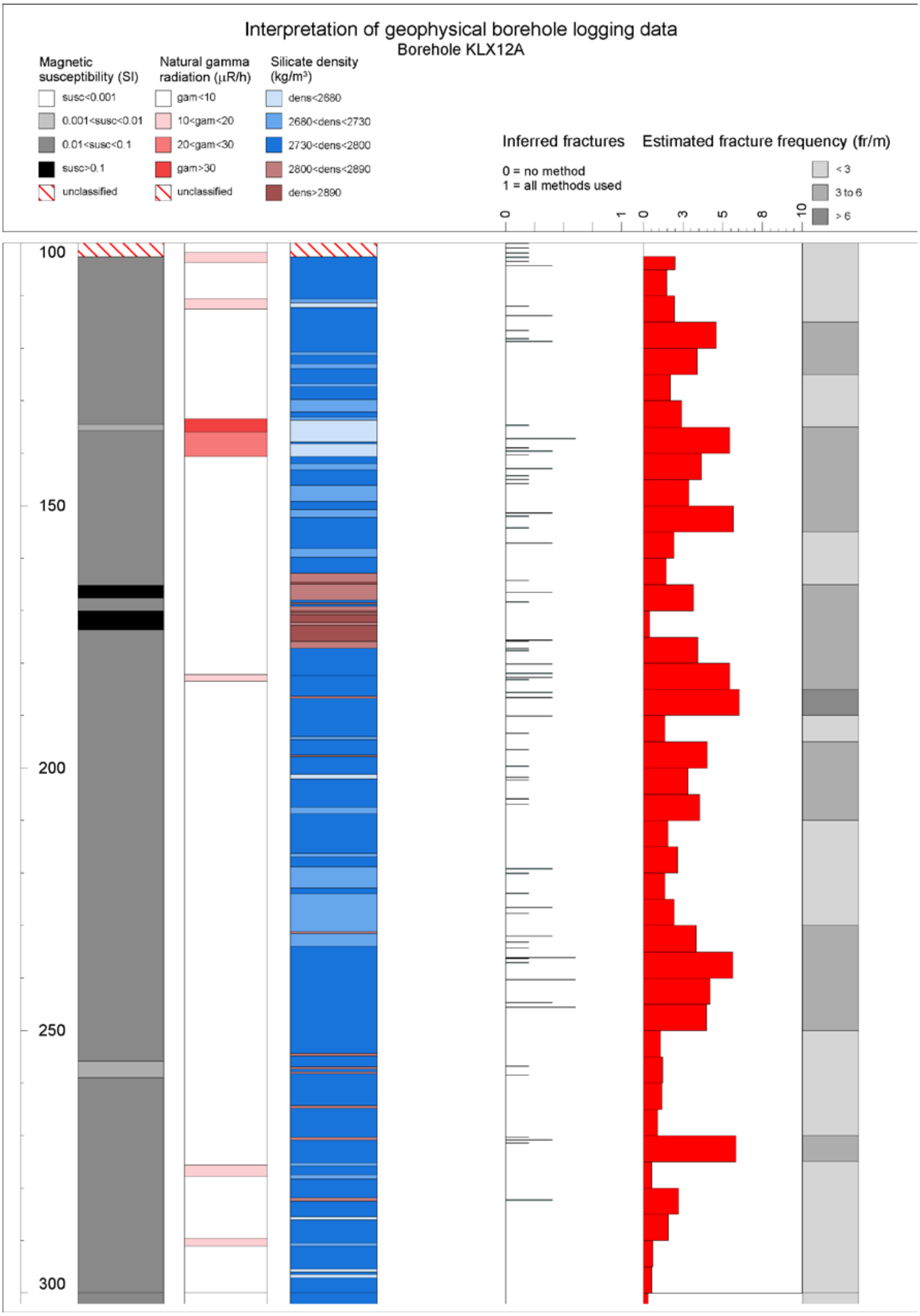
/9/ **Keisu M, 2006.** Calibration of 1D and 3D caliper data from core and percussion drilled boreholes. SKB P-06-153, Svensk Kärnbränslehantering AB.

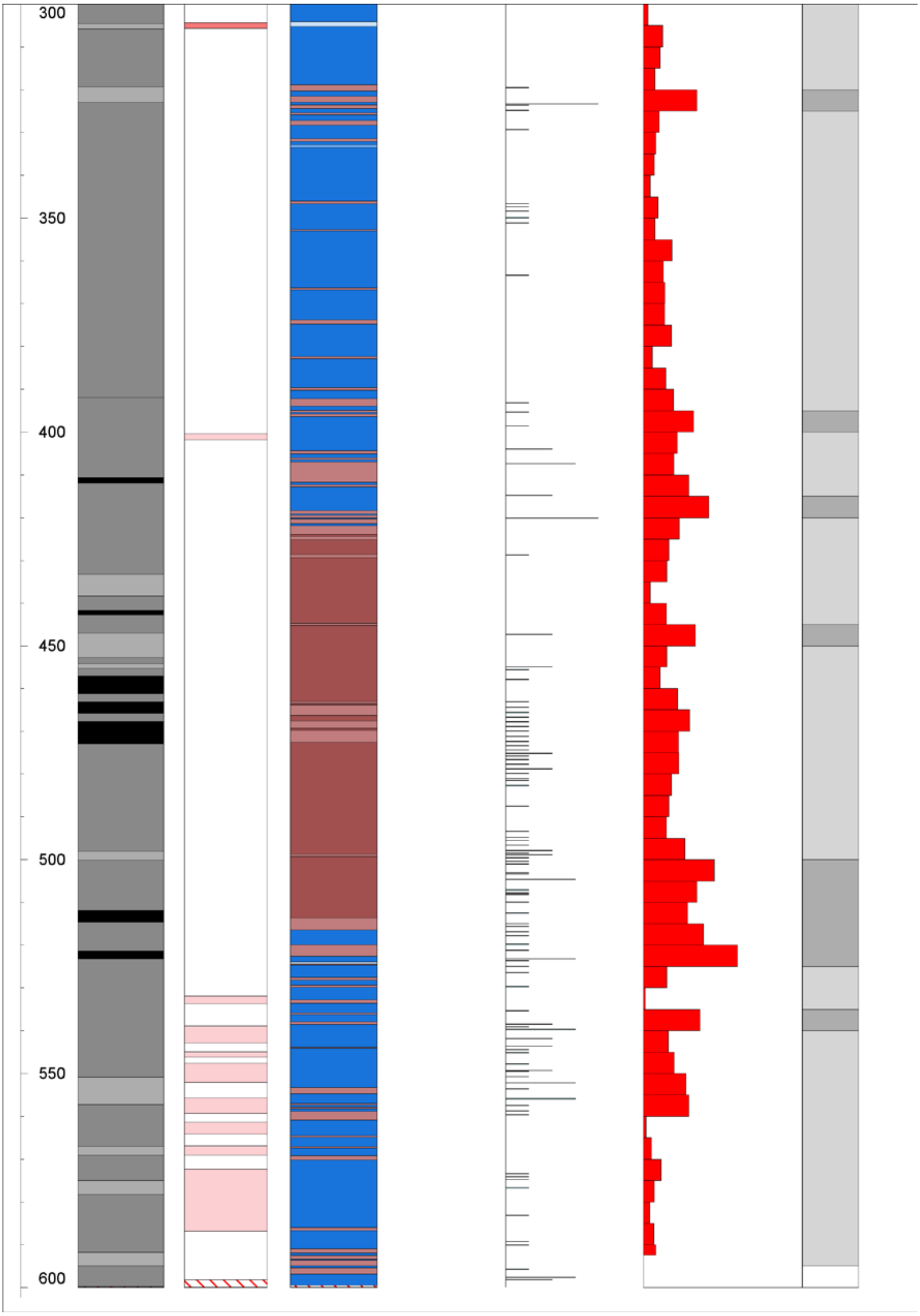
/10/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

/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 KLX12A




300
350
400
450
500
550
600