P-07-97

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX16A

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May 2007

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ISSN 1651-4416
SKB P-07-97

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

Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored borehole KLX16A.

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 distribution of silicate density in KLX16A is dominated by values in the range 2,730–2,800 kg/m^3 and the natural gamma radiation is mainly in the range ca 15–25 μR/h. The interpretation is that more than 60% of the rock in the vicinity of KLX16A is quartz monzodiorite (or possibly Ävrö granite with quartz monzodioritic composition).

In the lower half of the borehole, c 200–400 m, there is an increased occurrence of rocks with silicate density >2,800 kg/m^3 (mainly in the range 2,800–2,890 kg/m^3).

The magnetic susceptibility is roughly in the range 0.015–0.045 SI along the section c 11–207 m, which is normal for Ävrö granite and/or quartz monzodiorite. However, in the lower half of the borehole the magnetic susceptibility is greatly decreased, lying mainly in the range c 0.0010–0.0015 SI. This kind of major decrease in magnetic susceptibility is often related to mineral alteration and/or rock deformation. The decrease in magnetic susceptibility may also be related to the partly increased density reported above.

Positive anomalies in the natural gamma radiation occur abundantly along the entire borehole. The anomalies are generally less than 5 m long and they most likely indicate a frequent occurrence of fine-grained granite dykes.

The fracture frequency estimated from the geophysical logs indicates several sections with partly increased fracturing and also 9 possible deformation zones. The majorities of these possible deformation zones are characterized by decreased resistivity, decreased magnetic susceptibility and also partly decreased P-wave velocity and caliper anomalies.

Along the entire section c 327–403 m there is a general decrease in bulk resistivity, which suggests that the rocks along this interval has increased fracture frequency related to the other parts of the borehole.

The estimated fluid water salinity is rather constant at c 180 ppm NaCl along the upper half of KLX16A, section c 10–212 m. At c 212 m there is a significant increase in the salinity level, and the level is kept high through out the remaining part of the borehole. The significant increase in salinity along the lower half of the borehole corresponds well to the general decrease in magnetic susceptibility reported above and partly also to the decreased resistivity. The results indicate increased fracturing (possibly ware bearing fractures) and mineral alteration along the lower half of KLX16A.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX16A.

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.

Silikatdensitetsfördelningen i KLX16A domineras av värden i intervallet 2 730–2 800 kg/m^3 och den naturliga gammastrålningen är generellt ca 15–25 μR/h. Tolkningen av data är att mer än 60 % av berget i närheten av KLX16A består av kvartsmonzodiorit (eller möjligen Ävrögranit med kvartsmonzodioritisk sammansättning).

I den nedre halvan av borrhålet, ca 200–400 m, förekommer ett flertal sektioner med något förhöjd silikatdensitet, främst i intervallet 2 800–2 890 kg/m^3.

I borrhålets övre halva (11–207 m) ligger den magnetiska susceptibiliteten generellt i intervallet ca 0,015–0,045 SI, vilket är normalt för kvartsmonzodiorit eller Ävrögranit. I den nedre halvan av borrhålet är dock den magnetiska susceptibiliteten avvikande låg, med värden inom intervallet ca 0,0010–0,0015 SI. En sådan kraftig sänkning i magnetisering kan ofta kopplas till mineralomvandling och/eller deformation. Det kan även finnas en koppling till den delvis förhöjda densitet som beskrivs i avsnittet ovan.

Det finns ett stort antal positiva gammastrålningsanomalier längs hela borrhålet. De flesta av dessa är kortare än ca 5 meter och de indikerar troligen en relativ riklig förekomst av finkorniga granitgångar.

Den uppskattade sprickfrekvensen indikerar ett flertal sektioner med något förhöjd sprickfrekvens samt 9 st. möjliga deformationszoner. De flesta indikerade deformationszonerna karaktäriseras av sänkt resistivitet och magnetisk susceptibilitet och även delvis sänkt P-vågshastighet och caliperanomalier.

Längs sektionen ca 307–403 m förekommer en generell sänkning av bulkresistiviteten. Detta indikerar att berget längs denna sektion har en avvikande hög sprickfrekvens och/eller är påverkat av mineralomvandling.

I borrhålets övre del är den uppskattade saliniteten ganska konstant på nivån ca 180 ppm NaCl. Vid ca 212 m sker en kraftig förhöjning av salinitetsnivån upp till ca 900 ppm NaCl, som sedan är ganska konstant till hålets slut. Förhöjning sammanfaller relativt väl med den kraftiga sänkning av den magnetiska susceptibiliteten, och delvis även med den sänkning i resistivitet, som beskrivs ovan. Resultaten indikerar en avvikande hög frekvens av sprickor (möjlighen vattenförande) och/eller mineralomvandling längs den nedre halvan av KLX16A.

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 KLX16A, 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 2007 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 400-07-010 and method descriptions MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of the borehole KLX16A.

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 KLX16A	AP PS 400-07-010	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	3.0

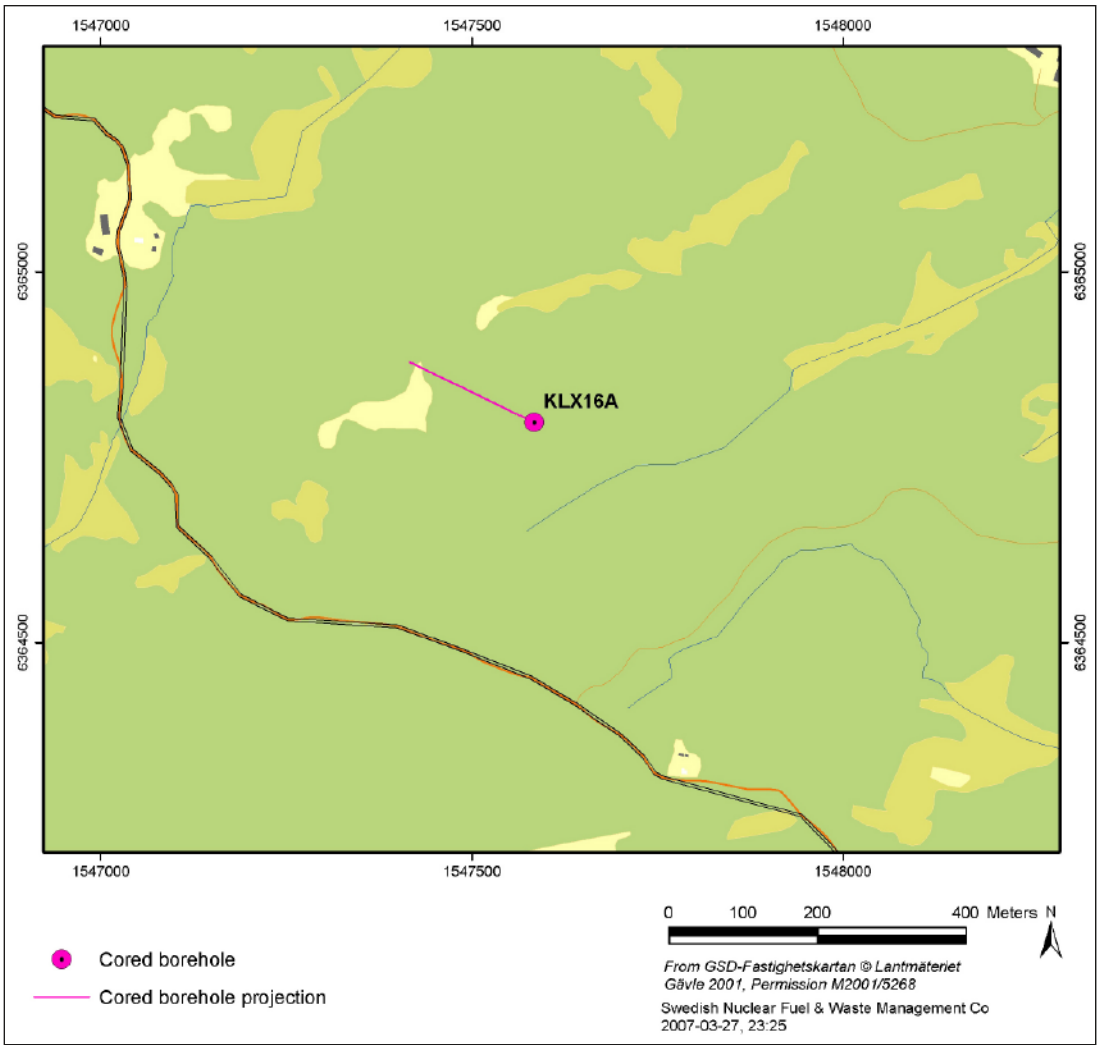

Figure 1-1. *Location of the borehole KLX16A in Laxemar.*

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 and 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 of 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 4-1) 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 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).
- 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.

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

In the borehole the long normal resistivity logging measurements show unrealistic levels. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore only presented for the short normal resistivity data. Apart from this, no nonconformities are reported.

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	KLX16A	2.0	1.5	1.5	1.0	1.5	6.0	6.0	–
Power	KLX16A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX16A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

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. The density, natural gamma radiation and magnetic susceptibility logging data have noise levels above the recommended levels. The noise levels of these methods are however low enough to allow a meaningful interpretation of the data. All other methods have noise levels below the recommended levels. 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 metre 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.

Logging method	KLX16A	Recommended max noise level
Density (kg/m^3)	8	3–5
Magnetic susceptibility (SI)	2×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	0.9	0.3
Long normal resistivity (%)	0.3	2.0
Short normal resistivity (%)	0.3	2.0
Fluid resistivity (%)	0.01	2
Fluid temperature (ºC)	5×10^{-4}	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	0.3	No data
Caliper 1D	1×10^{-6}	5×10^{-4}
Caliper mean (m)	2×10^{-5}	5×10^{-4}
Focused resistivity 300 (%)	14	No data
Focused resistivity 140 (%)	7	No data
Sonic (m/s)	16	20

5.2.1 Interpretation of KLX16A

The results of the generalized logging data and fracture estimations of KLX16A are presented in Figure 5-1 and in a more detailed scale in Appendix 1. The distribution of silicate density classes along the borehole is presented in Table 5-2.

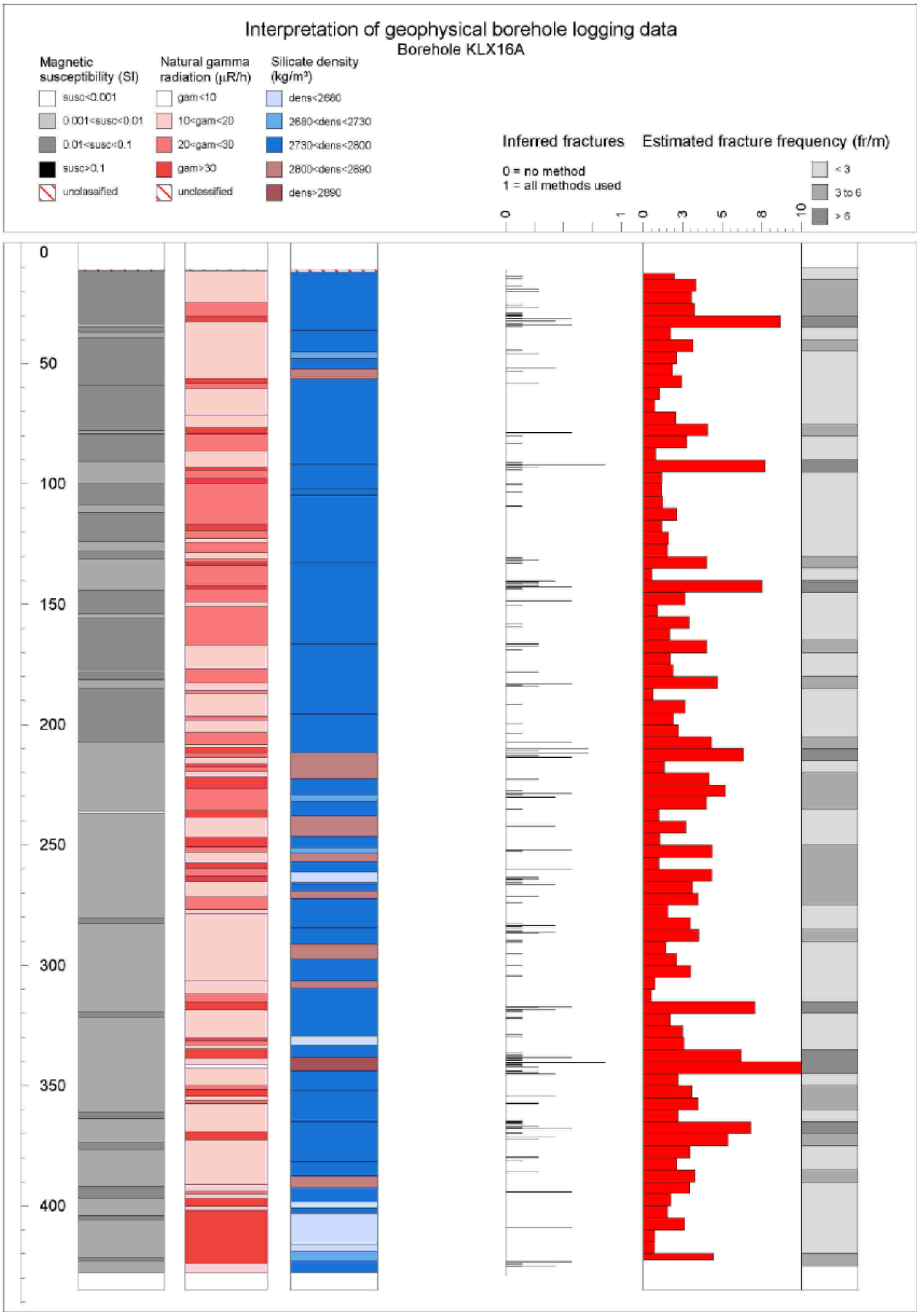

Figure 5-1. Generalized geophysical logs of KLX16A.

The distribution of silicate density in KLX16A is dominated by values in the range 2,730–2,800 kg/m^3, Table 5-1, and the natural gamma radiation is mainly in the range ca 15–25 μR/h. Silicate density of 2,730–2,800 kg/m^3 and natural gamma radiation of 10–20 μR/h generally indicates the occurrence of Ävrö granite with quartz monzodioritic composition or quartz monzodiorite. In KLX16A the natural gamma radiation is slightly increased, since the general level reaches up to c 25 μR/h. However, the interpretation is that more than 60% of the rock in the vicinity of KLX16A is quartz monzodiorite or Ävrö granite with quartz monzodioritic composition.

In the lower half of the borehole, c 200–400 m, there is an increased occurrence of rocks with silicate density >2,800 kg/m^3 (mainly in the range 2,800–2,890 kg/m^3). Along these sections the natural gamma radiation is generally in the range 10–20μR/h. This combination of properties most likely indicates the occurrence of quartz monzodiorite with a higher content of dark minerals (and/or lower content of quartz) relative to the surrounding sections.

In the section c 338–345 m there is a major increase in density, with levels up to c 2,900–2,950 g/m^3 in combination with decreased natural gamma radiation and magnetic susceptibility. This combination of properties indicates diorite/gabbro. The high density anomaly is also spatially related with intervals of increased natural gamma radiation and decreased density suggesting the occurrence of fine-grained granite, which all in all indicates the occurrences of so called composite dykes in this part of the borehole.

The magnetic susceptibility is roughly in the range 0.015–0.045 SI along the section c 11–207 m, which is normal for Ävrö granite and/or quartz monzodiorite. However, along the fairly long sections c 207–279 m and c 299–345 m the magnetic susceptibility is greatly decreased, lying mainly in the range c 0.0010–0.0015 SI. This kind of major decrease in magnetic susceptibility is often related to mineral alteration and/or rock deformation. The decrease in magnetic susceptibility may also be related to the partly increased density in the lower half of KLX16A as reported above.

A significant positive anomaly in the natural gamma radiation occurs in the lowermost c 30 m of the borehole. The density in this section varies greatly within the interval c 2,630–2,730 kg/m^3, and the interpretation is that the rocks in the vicinity of the borehole are fine-grained granite mixed with sections of Ävrö granite.

Positive anomalies in the natural gamma radiation occurs abundantly along the entire borehole. The anomalies are generally less than 5 m long and they most likely indicate a frequent occurrence of fine-grained granite dykes in KLX16A.

The fracture frequency estimated from the geophysical logs indicates several sections with partly increased fracturing and also 9 possible deformation zones. Section coordinates and geophysical anomalies related to these possible deformation zones are presented in Table 5-3 below.

Table 5-2. Distribution of silicate density classes with borehole length of KLX16A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	34	8
2,680 < dens < 2,730	50	12
2,730 < dens < 2,800	264	64
2,800 < dens < 2,890	64	15
dens > 2,890	4	1

Table 5-3. Possible deformation zones in KLX16A and their geophysical signature.

Section co-ordinates (m)	Resistivity	P-wave velocity (sonic)	Magnetic susceptibility	Borehole diameter (caliper)
29–35	Significantly decreased	Partly decreased	Partly decreased	No anomaly
90–95	Significantly decreased	Significantly decreased	Significantly decreased	One significant anomaly
139–144	Significantly decreased	Significantly decreased	Partly decreased	General increase
209–214	Partly decreased	Significantly decreased	Significantly decreased	One significant anomaly
260–265	Significantly decreased	Significantly decreased	Significantly decreased	One significant anomaly
299–306	Significantly decreased	Partly decreased	Significantly decreased	One significant anomaly
316–319	Partly decreased	Partly decreased	Significantly decreased	No anomaly
337–345	Significantly decreased	Significantly decreased at c 340 m	Significantly decreased	Large, general increase
365–369	Significantly decreased	Significantly decreased	Partly decreased	One minor anomaly

Along the entire section c 327–403 m there is a general decrease in bulk resistivity, which suggests that the rocks along this interval has increased fracture frequency related to the other parts of the borehole.

The estimated apparent porosity shows a general level at c 0.4–0.5%, which is considered normal for rocks in this area (Figure 5-2). Sections of increased porosity (generally c 5 m long) occur along the entire borehole and are clearly correlated to the possible deformation zones presented in Table 5-3.

The estimated fluid water salinity is rather constant at c 180 ppm NaCl along the upper half of KLX16A, section c 10–212 m (Figure 5-2). At c 212 m there is a significant increase in the salinity level. The increase continues to section length c 290 m, and below this coordinate through out the remaining part of the borehole the salinity level is fairly constant at c 900 ppm NaCl. The significant increase in salinity along the lower half of the borehole corresponds well to the general decrease in magnetic susceptibility reported above and partly also to the decreased resistivity. The results indicate increased fracturing (possibly ware bearing fractures) and mineral alteration along the lower half of KLX16A.

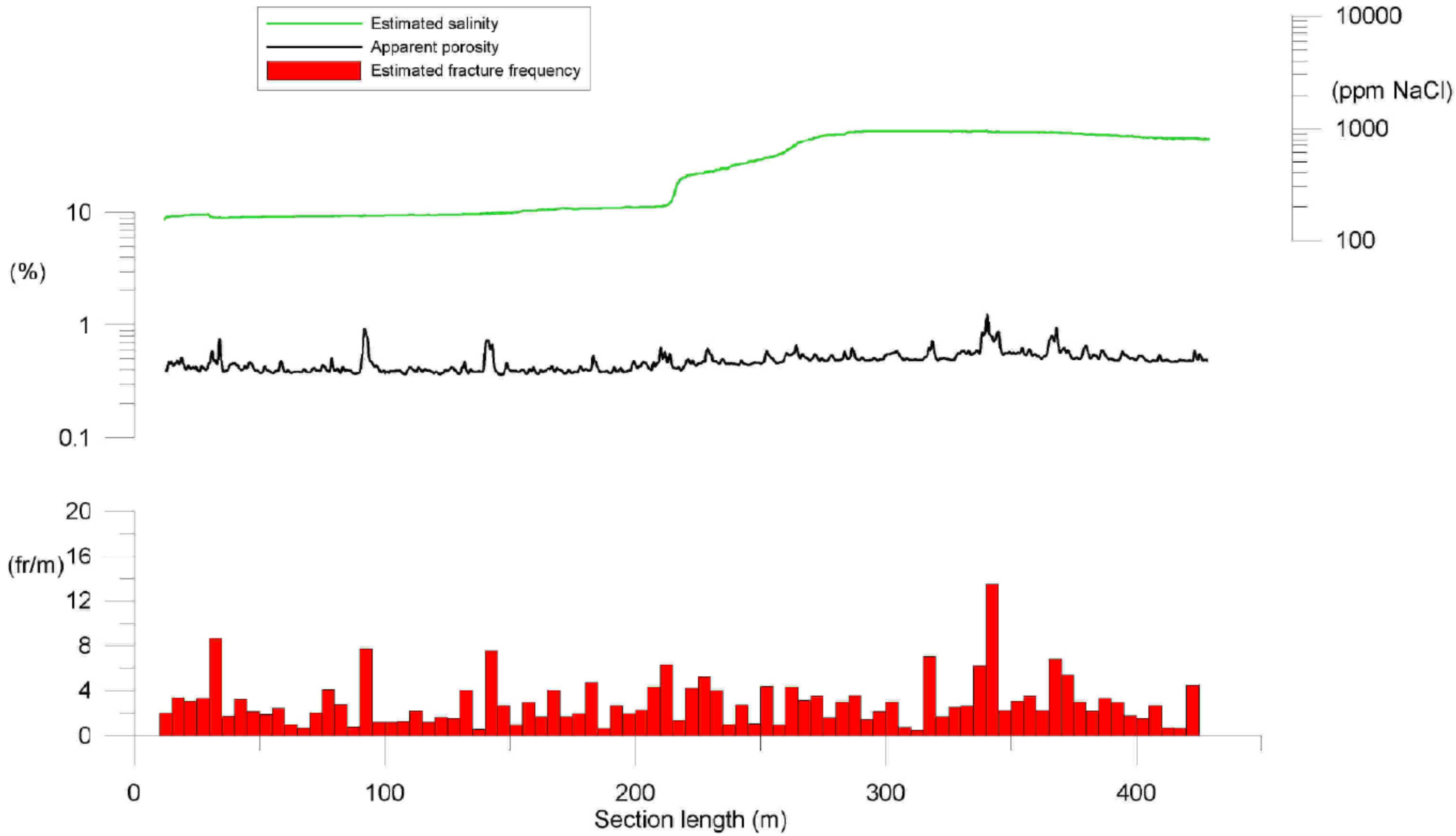

Figure 5-2. Estimated salinity, apparent porosity and estimated fracture frequency for KLX16A.

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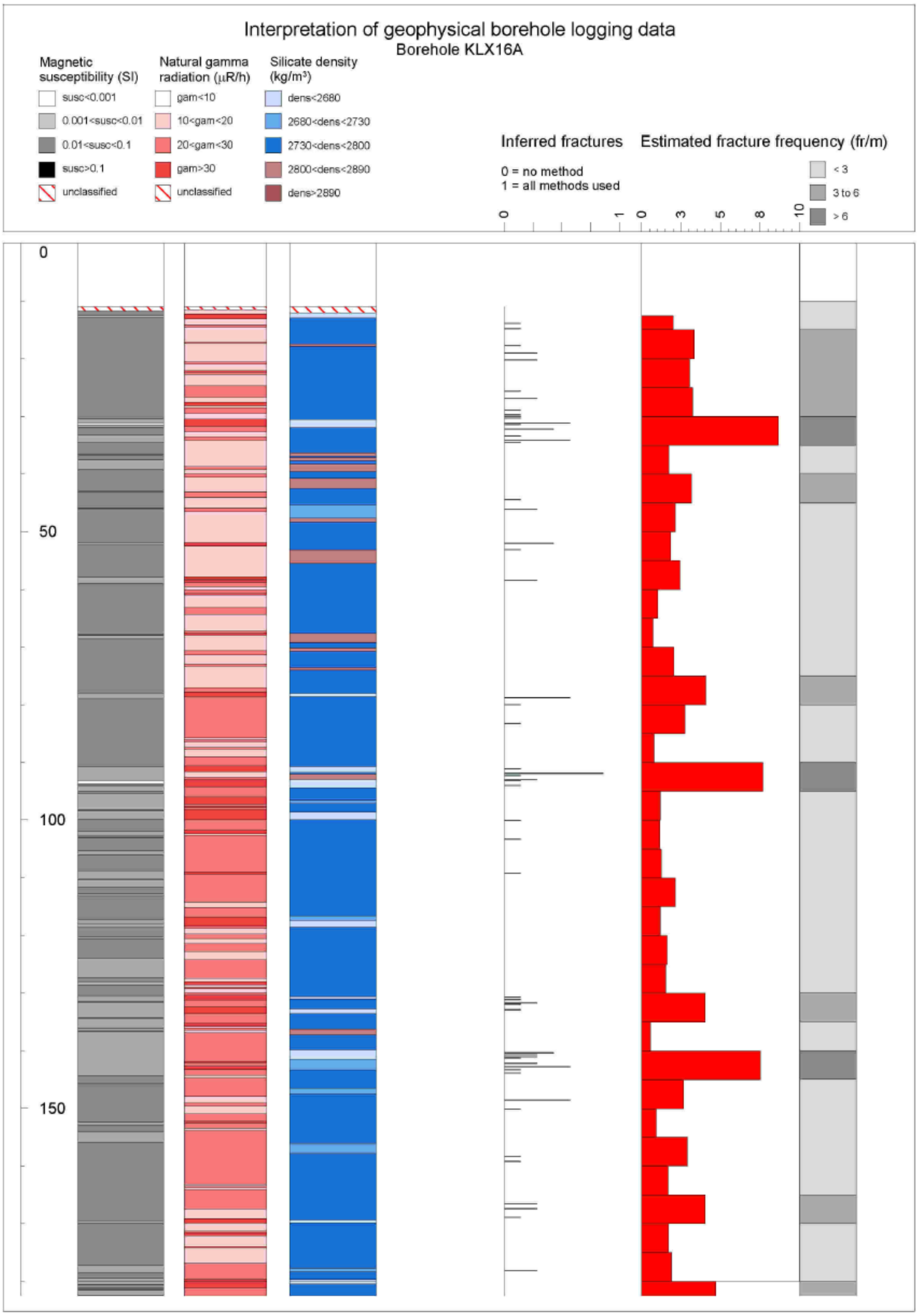
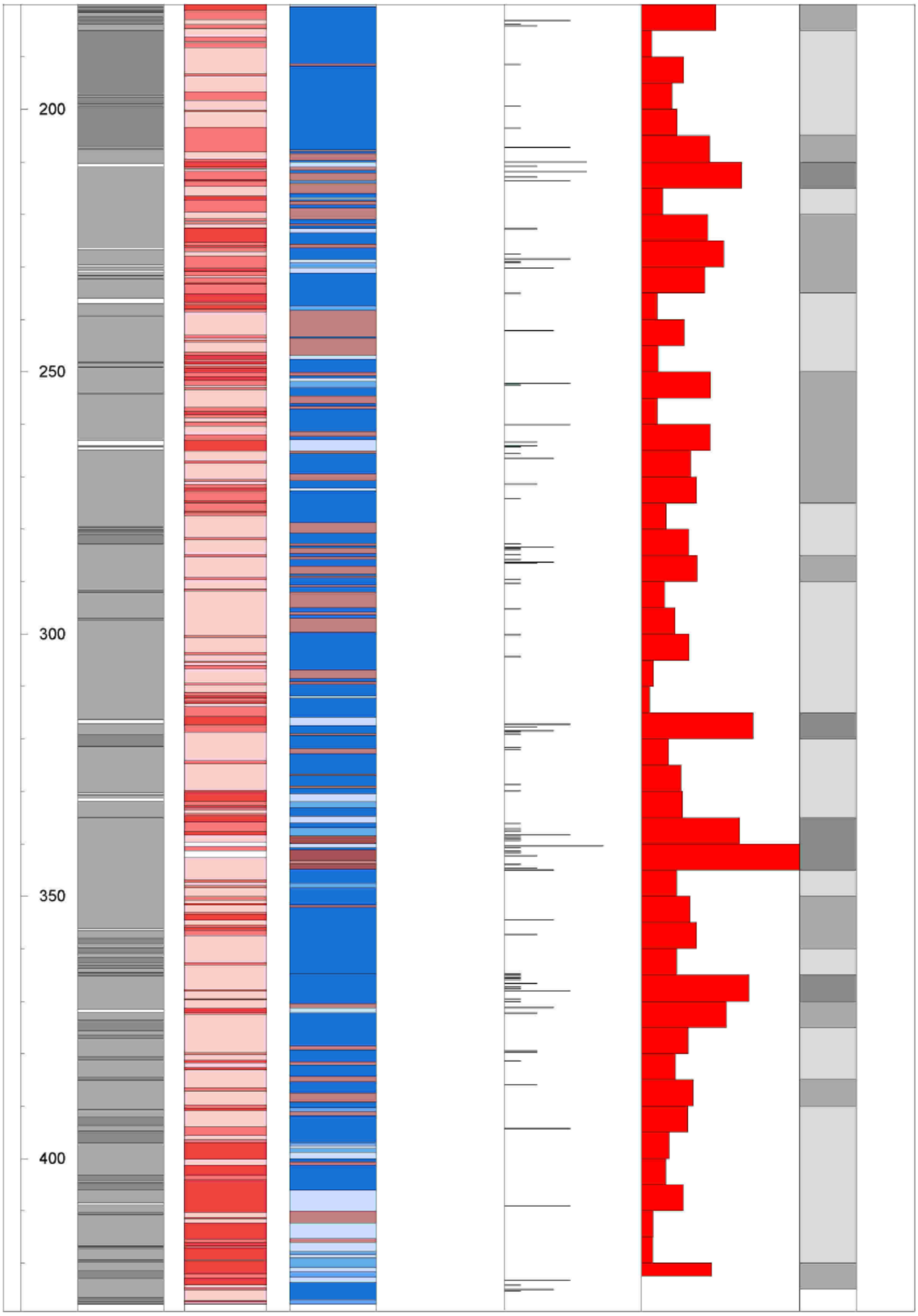
Appendix 1

Generalized geophysical logs for KLX16A

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