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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX27A

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Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored borehole KLX27A.

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 KLX27A is dominated by values in the range 2,730–2,800 kg/m^3, more than 70% of the rocks in the borehole have silicate densities within this range. The natural gamma radiation is 17–22 μR/h for the major part of the borehole length and the magnetic susceptibility is generally c. 0.020–0.030 SI. This combination of physical properties is typical for quartz monzodiorite, or possibly Ävrö granite with increased content of dark minerals.

The section c. 208–243 m is characterized by significantly decreased magnetic susceptibility, partly decreased density and large variations in natural gamma radiation. In this interval the fracture estimation indicates the occurrence of a major deformation zone, which is the most probable reason to the significant anomalies in physical properties.

There are only a few, very short sections with density > 2,850 kg/m^3, which indicates an almost complete absence of mafic rocks in the vicinity of the borehole KLX27A. However, there are several indications of occurrences of fine-grained granite.

The fracture frequency estimated from the geophysical logs indicates partly or significantly increased fracturing along large parts of the uppermost c. 175 m of the borehole (section 80–255 m), with the most intensely deformed parts located at c. 106–109 m, 130–133 m and 225–245 m. Increased fracturing is also indicated along the intervals c. 335–345 m, 370–375 m, 590–595 m, 625–630 m and 642–645 m.

The estimated apparent porosity averages at c. 0.6%, which is a normal value for crystalline rock in this area. The most significant porosity anomalies occur in the sections c. 83–111 m and 221–245 m, which overlaps with some of the larger possible deformation zones. The estimated fluid water salinity is almost constant along the entire borehole length, with an average value of c. 2,750 ppm NaCl.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX27A.

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.

Densitetsfördelningen i KLX27A domineras av silikatdensitet i intervallet 2 730–2 800 kg/m^3, för mer än 70 % av den uppmätta borrhålslängden har berggrunden silikatdensitet inom detta intervall. Den naturliga gammastrålningen ligger generellt i intervallet 17–22 µR/h och den magnetiska susceptibiliteten är ca 0,020–0,030 SI. Kombinationen av fysikaliska egenskaper är typisk för kvartsmonzodiorit eller möjligen Ävrögranit med förhöjt innehåll av mörka mineral.

Sektionen ca 208–243 m karaktäriseras av kraftigt sänkt magnetisk susceptibilitet i kombination med sänkt densitet och stora variationer i naturlig gammastrålning. Längs intervallet indikerar andra loggar förekomst av en större deformationszon. Deformationen kan säkerligen kopplas till de kraftiga anomalierna i densitet, susceptibilitet och naturlig gammastrålning.

Längs med borrhålet finns endast ett fåtal partier med silikatdensitet > 2 850 kg/m^3, vilket tyder på en nästan total avsaknad av basiska gångar i närheten av KLX27A. Däremot finns ett flertal indikationer på förekomst av finkornig granit.

Sprickfrekvensen som beräknas utifrån de geofysiska loggarna indikerar förhöjd, och delvis kraftigt förhöjd, uppsprickning längs stora delar av de översta ca 175 m av borrhålet (sektionen ca 80–255 m). De mest deformerade partierna förekommer längs ca 106–109 m, 130–133 m och 225–245 m. Förhöjd sprickfrekvens indikeras även förekomma längs ca 335–345 m, 370–375 m, 590–595 m, 625–630 m och 642–645 m.

Den beräknade skenbara porositeten har ett medelvärde om ca 0,6 %, vilket är normalt för kristallint berg i området. De kraftigaste porositetsanomalierna förekommer längs intervallen ca 83–111 m och 221–245 m. Partierna sammanfaller med indikerade deformationszoner. En beräkning av borrhålsvätskans salinitet indikerar i princip konstant salinitet om ca 2 750 ppm NaCl längs hela borrhålet.

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 KLX27A, 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 400-07-066 and method descriptions MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of the borehole KLX27A.

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 KLX27A.	AP PS 400-07-066	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata.	SKB MD 221.003	3.0

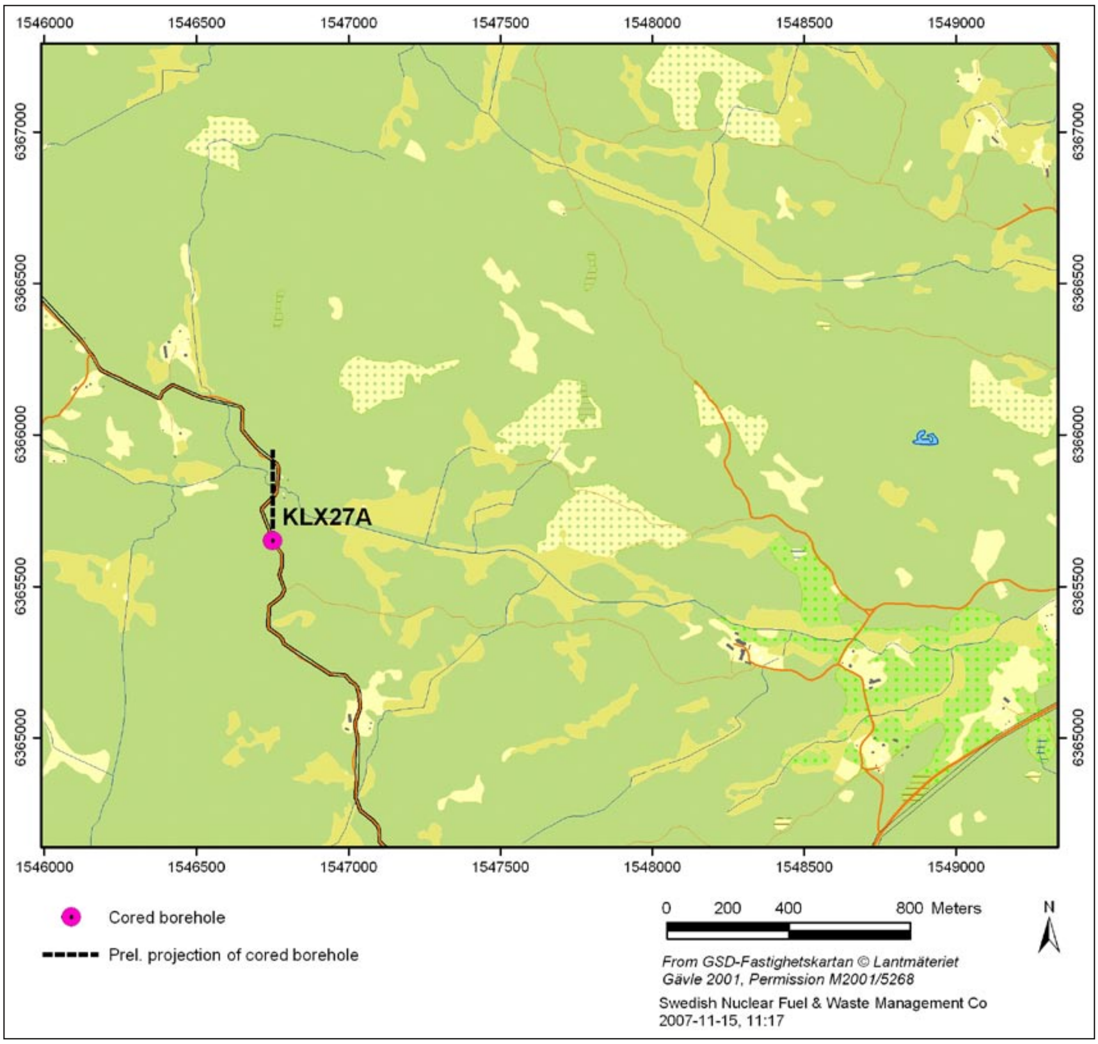

Figure 1-1. *Location of the borehole KLX27A in Laxemar.*

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” (< 10 μR/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/, $\sigma = a\,\sigma_w\,\phi^m + \sigma_s$ 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 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 calculating estimated fracture frequency, respectively.

	Borehole	Sonic	Focused res. 128	Focused res. 300	Caliper	SPR	Normal res. 64	Normal res. 16	Lateral res.
Threshold	KLX27A	1.5	2.0	1.5	1.0	1.0	5.0	6.0	–
Power	KLX27A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX27A	1.0	7.1	6.7	1.0	5.0	2.9	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

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. The density, natural gamma radiation and magnetic susceptibility logging data have noise levels significantly above the recommended levels. The high noise levels for these three methods may have had a significant effect on the interpretation of the data, especially for the possibility of resolving short wave length anomalies. 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	KLX27A	Recommended max noise level
Density (kg/m^3)	37	3–5
Magnetic susceptibility (SI)	$4\cdot10^{-4}$	$1\cdot10^{-4}$
Natural gamma radiation (µR/h)	2.9	0.3
Long normal resistivity (%)	0.7	2.0
Short normal resistivity (%)	0.3	2.0
Fluid resistivity (%)	0.07	2
Fluid temperature (ºC)	$9\cdot10^{-4}$	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	0.3	No data
Caliper 1D	$5\cdot10^{-6}$	$5\cdot10^{-4}$
Caliper mean (m)	$0.2\cdot10^{-4}$	$5\cdot10^{-4}$
Focused resistivity 300 (%)	6.4	No data
Focused resistivity 128 (%)	0.4	No data
Sonic (m/s)	11	20

5.2.1 Interpretation of KLX27A

The results of the generalized logging data and fracture estimations of KLX27A 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.

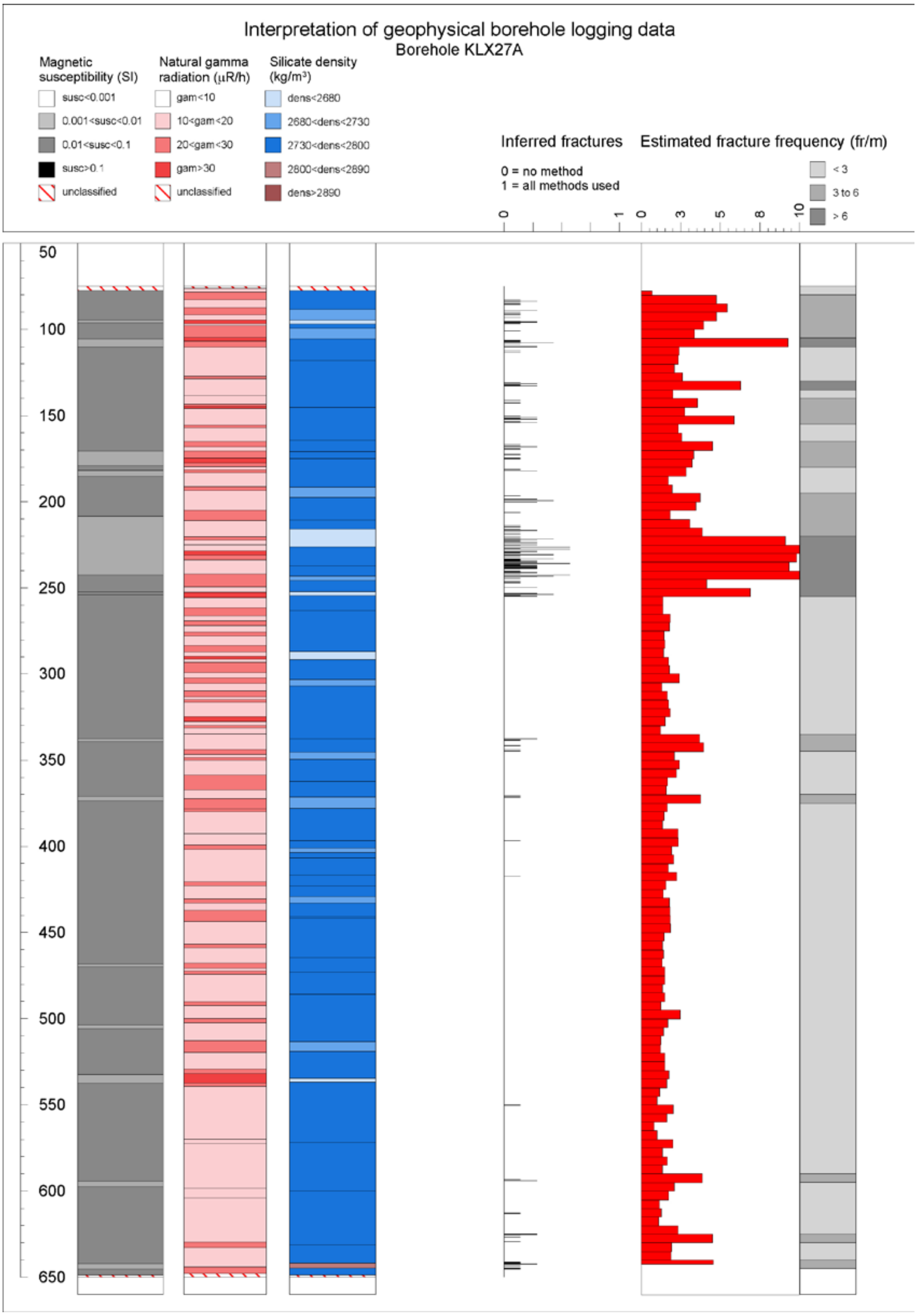

Figure 5-1. Generalized geophysical logs of KLX27A.

Table 5-2. Distribution of silicate density classes with borehole length of KLX27A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	19	4
2,680 < dens < 2,730	125	22
2,730 < dens < 2,800	413	72
2,800 < dens < 2,890	13	2
dens > 2,890	1	0

The distribution of silicate density in KLX27A is dominated by values in the range 2,730–2,800 kg/m^3, more than 70% of the rocks in the borehole have silicate densities within this range. The natural gamma radiation is 17–22 μR/h for the major part of the borehole length and the magnetic susceptibility is generally c. 0.020–0.030 SI. This combination of physical properties is typical for quartz monzodiorite, or possibly Ävrö granite with increased content of dark minerals.

In the section c. 77–110 m the density and magnetic susceptibility are decreased (wet density c. 2,710–2,770 kg/m^3 and magnetic susceptibility c. 0.010–0.20 SI) and the natural gamma radiation is increased, c. 20–24 μR/h. The data could indicate quartz monzodiorite with an increased content of quartz, or possibly Ävrö granite. However, the resistivity, caliper and sonic data clearly indicate increased fracture frequency in this section, so the most probable interpretation is that the rock type is “normal” quartz monzodiorite that has suffered from deformation and alteration.

Along the intervals c. 171–179 m and c. 532–538 m decreased density and magnetic susceptibility occurs in combination with increased natural gamma radiation. The data most likely indicate the occurrences of dykes of fine-grained granite. Short sections (< 1.0 m) with this geophysical signature occur, with a fairly even distribution, along the entire borehole.

The section c. 208–243 m is characterized by significantly decreased magnetic susceptibility, partly decreased density and large variations in natural gamma radiation. In this interval the fracture estimation indicates the occurrence of a major deformation zone (se below), and the deformation has most likely given rise to increased fracturing and destruction and/or alteration of magnetite.

There are only a few, very short sections with density > 2,850 kg/m^3, which indicates an almost complete absence of mafic rocks in the vicinity of the borehole KLX27A.

The fracture frequency estimated from the geophysical logs indicates partly or significantly increased fracturing along large parts of the uppermost c. 175 m of the borehole (section 80–255 m), with the most intensely deformed parts located at c. 106–109 m, 130–133 m and 225–245 m. Increased fracturing is also indicated along the intervals c. 335–345 m (coincide with indicated mafic and felsic dykes), 370–375 m, 590–595 m, 625–630 m and 642–645 m.

Section coordinates and geophysical anomalies related to interpreted possible deformation zones are presented in Table 5-3 below.

The estimated apparent porosity averages at c. 0.6%, which is a normal value for crystalline rock in this area (Figure 5-2). The most significant porosity anomalies occur in the sections c. 83–111 m and 221–245 m, which overlaps with some of the larger possible deformation zones (see Table 5-3).

The estimated fluid water salinity is almost constant along the entire borehole length, with an average value of c. 2,750 ppm NaCl.

Table 5-3. Possible deformation zones in KLX27A and their geophysical signature.

Section co-ordinates (m)	Resistivity	P-wave velocity (sonic)	Magnetic susceptibility	Borehole diameter (caliper)
87–93	Significantly decreased	Partly decreased	Partly decreased	Minor anomalies
106–109	Significantly decreased	Partly decreased	Significantly decreased	No anomalies
130–133	Partly decreased	Partly decreased	Partly decreased	Minor anomalies
208–213	Significantly decreased	Partly decreased	Significantly decreased	No anomalies
225–230	Significantly decreased	Significantly decreased	Significantly decreased	Major anomalies
230–240	Partly decreased	Partly decreased	Significantly decreased	Minor anomalies
240–245	Significantly decreased	Significantly decreased	Significantly decreased	Major anomalies
337–339	Significantly decreased	Partly decreased	Significantly decreased	Distinct anomalies
343–345	Significantly decreased	Partly decreased	Significantly decreased	No anomalies
371–375	Partly decreased	Minor anomalies	Significantly decreased	Minor anomalies
533–535	Significantly decreased	Minor anomalies	Significantly decreased	No anomalies
642–645	Partly decreased	Significantly decreased	Significantly decreased	No anomalies

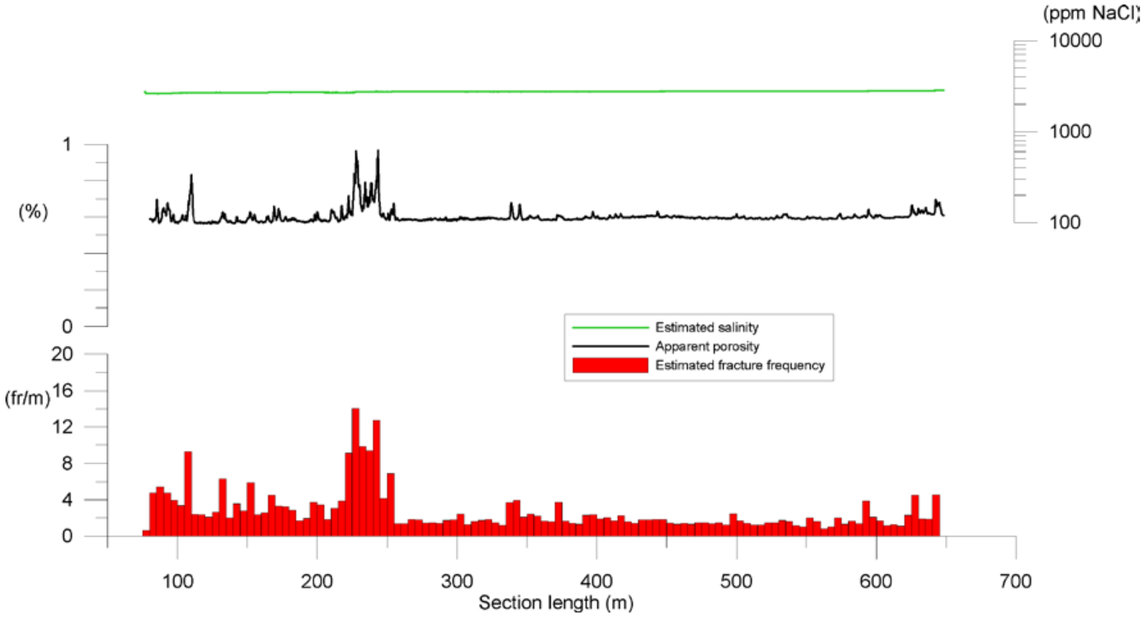

Figure 5-2. *Estimated salinity, apparent porosity and estimated fracture frequency for KLX27A.*

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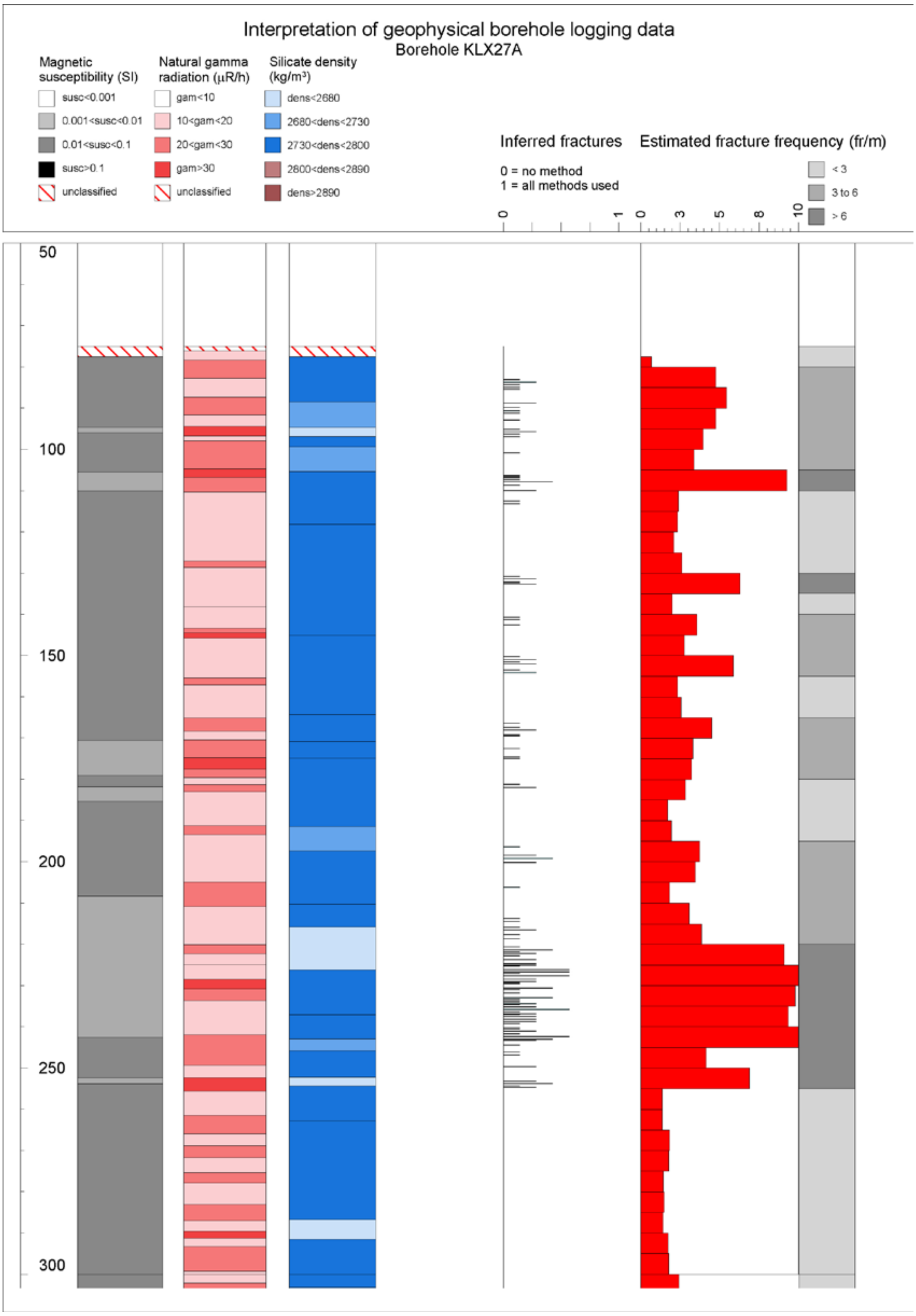
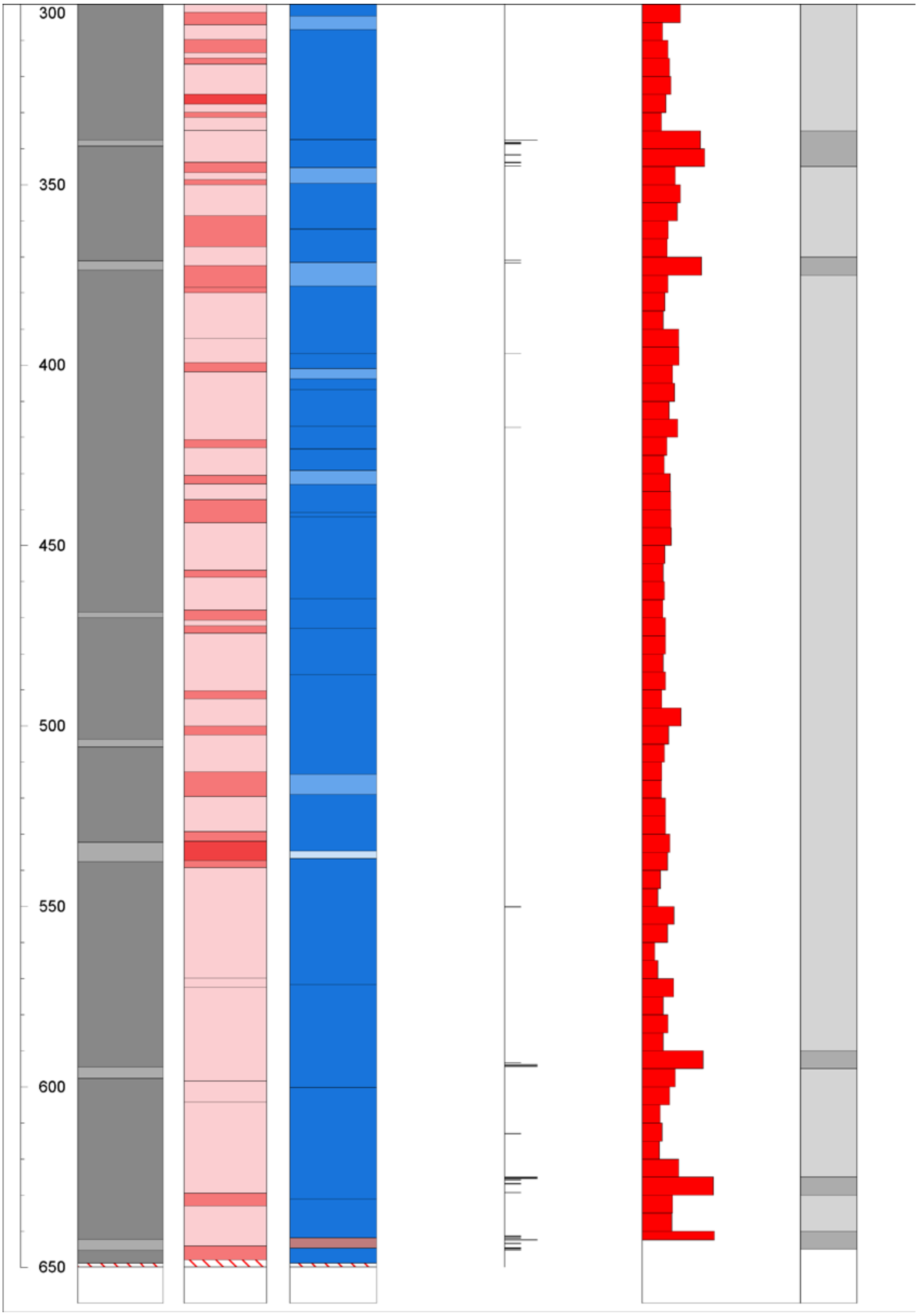
Generalized geophysical logs for KLX27A

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