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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX09G, KLX10B, KLX10C, HLX36 and HLX37

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

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

Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored boreholes KLX09G, KLX10B and KLX10C, and the percussion drilled boreholes HLX36 and HLX37.

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.

A majority of the rocks in the vicinity of KLX09G have silicate density in the range 2,730–2,800 kg/m^3, magnetic susceptibility of 0.01–0.03 SI and natural gamma radiation in the interval c 10–25 μR/h, which most likely indicates the occurrence of quartz monzodiorite (or possibly Ävrö granite with a low content of quartz and high content of dark minerals). The estimated fracture frequency of KLX09G is generally low, or partly moderate. Increased fracturing is indicated in the sections c 40–44 m and 58–61 m.

In KLX10B there is an indicated fine-grained granite dyke along the section c 10–20 m. The remaining part of the borehole (c 20–50 m) is characterized by physical properties that suggest a dominant occurrence of Ävrö granite. The estimated fracture frequency is mainly low and there are no indications of possible deformation zones.

The variations in physical properties in KLX10C indicate a heterogeneous distribution of rocks (or mineral composition). In the section c 10–60 m there is a dominance of rocks with silicate density in the intervals 2,680–2,730 kg/m^3 and 2,730–2,800 kg/m^3 and the rocks along this section are most likely Ävrö granite and/or quartz monzodiorite. In the section c 60–145 m a majority of the rocks have silicate density < 2,680 kg/m^3, natural gamma radiation in the range 20–30 μR/h and magnetic susceptibility that varies greatly within the range 0.0012–0.030 SI. The data indicate the occurrence of Ävrö granite. The estimated fracture frequency is generally low and partly moderate. A possible deformation zone is indicated at c 15–20 m.

The physical characteristics of HLX36 and HLX37 remind a great deal of each other. The rocks in the vicinities of the two boreholes are characterized by silicate density in the range 2,680–2,730 kg/m^3, natural gamma radiation in the range 15–25 μR/h and magnetic susceptibility in the range 0.011–0.018 SI. The combination of physical properties is typical for Ävrö granite with granodioritic mineral composition. In each borehole there is also a clear indication of the occurrence of a fairly long section of fine-grained diorite/gabbro (c 110–191 m in HLX36 and c 122–146 in HLX37). Along the sections with indicated fine-grained diorite/gabbro the geophysical logs indicate significant anomalies related to increased fracturing and deformation.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålen KLX09G, KLX10B och KLX10C, samt de hammarborrade borrhålen HLX36 och HLX37.

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.

En majoritet av bergarterna i närheten av KLX09G har en silikatdensitet i intervallet 2 730–2 800 kg/m^3, magnetisk susceptibilitet i intervallet 0,01–0,03 SI och naturlig gammastrålning i intervallet 10–25 µR/h. Kombinationen av fysikaliska egenskaper indikerar förekomst av kvartsmonzodiorit, eller möjligen Ävrögranit med låg kvartshalt och hög halt mörka mineral. Den uppskattade sprickfrekvensen i KLX09G är generellt låg och bara delvis något förhöjd. Hög sprickfrekvens indikeras förekomma längs ca 40–44 m och 58–61 m.

I KLX10B indikerar de geofysiska loggarna förekomst av finkornig granit längs sektionen ca 10–20 m. Resterande del av borrhålet (ca 20–50 m) domineras av fysikaliska egenskaper som är typiska för Ävrögranit. Den uppskattade sprickfrekvensen är låg och inga större deformationszoner indikeras längs borrhålet.

Variationen i fysikaliska egenskaper i KLX10C indikerar en mycket heterogen bergartsfördelning (eller varierande mineralsammansättning) längs hela borrhålet. Längs sektionen ca 10–60 m finns en dominans av bergarter (troligen Ävrögranit ev. i kombination med kvartsmonzodiorit) med silikatdensitet i intervallen 2 680–2 730 kg/m^3 och 2 730–2 800 kg/m^3. Längs sektionen ca 60–145 m är silikatdensiteten generellt < 2 680 kg/m^3, den naturliga gammastrålningen ligger i intervallet 20–30 µR/h och susceptibiliteten uppvisar stora variationer inom intervallet 0,0012–0,030 SI. Dessa data indikerar dominerande förekomst av Ävrögranit med granitisk mineralsammansättning. En möjlig deformationszon kan identifieras i KLX10C längs ca 15–20 m.

Variationen i fysikaliska egenskaper i berget längs borrhålen HLX36 och HLX37 är mycket likartad. Längs båda borrhålen finns en dominans av silikatdensitet i intervallet 2 680–2 730 kg/m^3, magnetisk susceptibilitet i intervallet 0,011–0,018 SI och naturlig gammastrålning i intervallet 15–25 µR/h. Kombinationen av fysikaliska egenskaper indikerar förekomst av Ävrögranit med granodioritisk mineralsammansättning. I båda borrhålen finns dessutom tydliga indikationer på uthålliga partier med finkornig diorit/gabbro (ca 110–191 m i HLX36 och ca 122–146 i HLX37). Dessa sektioner uppvisar tydliga indikationer på kraftigt förhöjd sprickfrekvens och deformation.

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 boreholes KLX09G, KLX10B and KLX10C, and the percussion drilled boreholes HLX36 and HLX37, 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 and 2/.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (activity plan AP PS 400-06-052 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of boreholes KLX09G, KLX10B, KLX10C, HLX36 and HLX37.

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 KLX09G, KLX10B, KLX10C, HLX36 och HLX37	AP PS 400-06-052	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

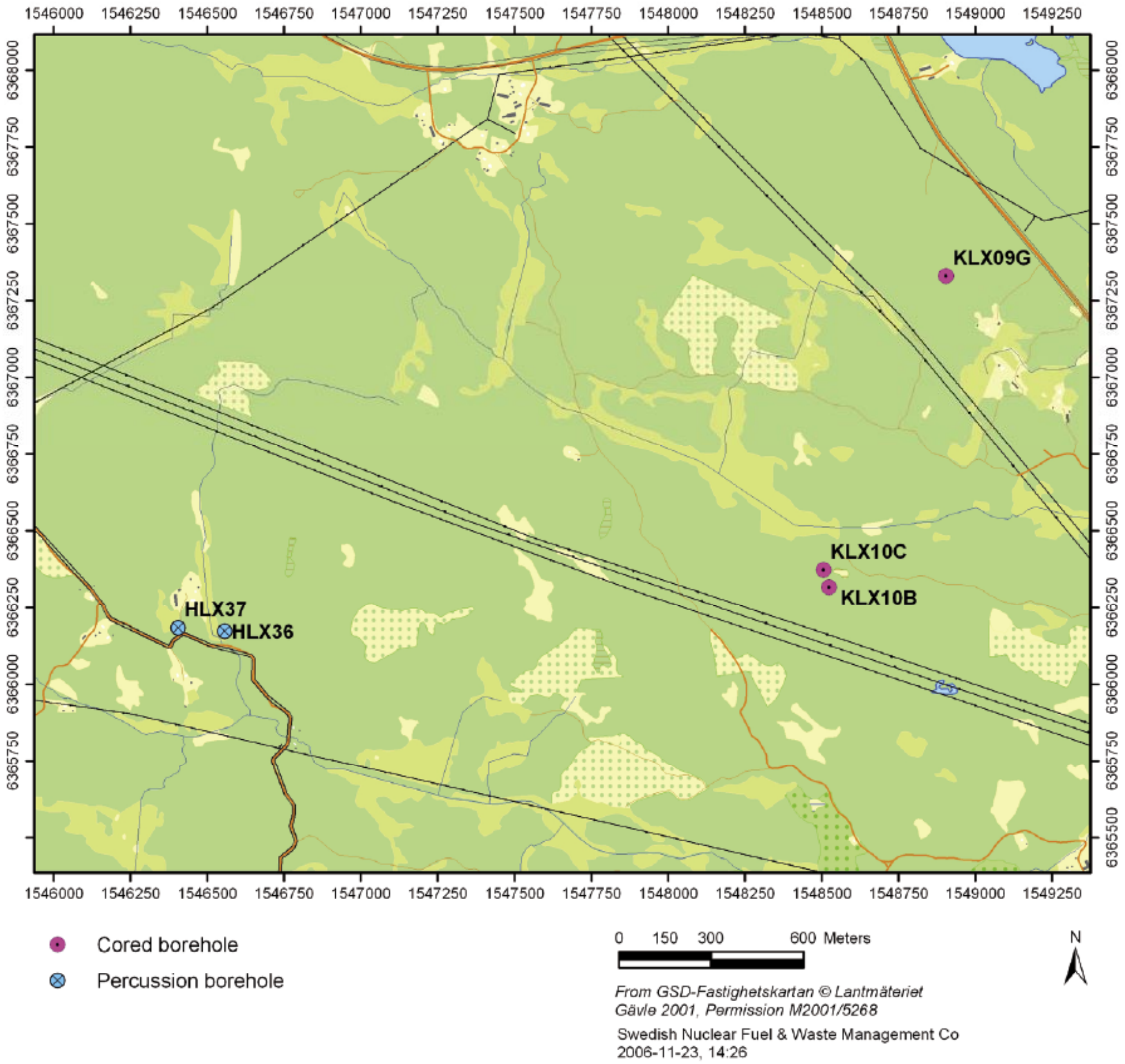

Figure 1-1. *Location of the boreholes KLX09G, KLX10B, KLX10C, HLX36 and HLX37 in Laxemar.*

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 /3, 4, 5, 6, 7 and 8/. The density logging data were calibrated by use of petrophysical data from the borehole KFM01D /9/.

   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 /10/.

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 /11/ and the data are then divided into 5 sections *indicating* a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /12/. 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 /13/; $\sigma = a\,\sigma_w\,\phi^m + \sigma_s$ 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 (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 /3/. The powers and linear coefficients (weights) used are presented in Table 4-1.

5. Report evaluating the results.

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	KLX09G	1.5	1.5	1.5	0.5	1.5	5.0	4.0	–
Power	KLX09G	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX09G	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX10B	1.0	1.5	1.5	0.5	1.0	–	–	–
Power	KLX10B	1.0	1.0	1.6	1.0	0.5	–	–	–
Weight	KLX10B	1.0	7.1	6.7	1.0	5.0	–	–	–
Threshold	KLX10C	1.0	1.1	1.5	0.5	1.2	–	–	–
Power	KLX10C	1.0	1.0	1.6	1.0	0.5	–	–	–
Weight	KLX10C	1.0	7.1	6.7	1.0	5.0	–	–	–
Threshold	HLX36	–	1.5	1.5	0.5	2.0	5.0	4.0	–
Power	HLX36	–	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	HLX36	–	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	HLX37	1.0	1.5	1.5	0.5	1.0	4.0	4.0	–
Power	HLX37	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	HLX37	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

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).
- 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

Normal resistivity logging measurements were not performed in KLX10B or KLX10C. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore not presented for these boreholes. Apart from this, no nonconformities are reported.

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. For the cored borehole KLX10B the density, natural gamma radiation and magnetic susceptibility logging data significantly exceed the recommended maximum noise levels. Noise levels are also increased for the density and natural gamma radiation logs of KLX10C, the density log of HLX36 and for the magnetic susceptibility logs of all boreholes in this investigation. 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/metre).

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

Logging method	KLX09G	KLX10B	KLX10C	HLX36	HLX37	Recommended max noise level
Density (kg/m^3)	7	16	17	15	7	3–5
Magnetic susceptibility (SI)	$3 \cdot 10^{-4}$	$5 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$2 \cdot 10^{-4}$	$3 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Natural gamma radiation (μR/h)	0.5	1.7	0.9	0.2	0.5	0.3
Long normal resistivity (%)	0.6	No data	No data	1.0	0.1	2.0
Short normal resistivity (%)	0.5	No data	No data	1.0	0.2	2.0
Fluid resistivity (%)	$0.6 \cdot 10^{-2}$	$6 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$6 \cdot 10^{-2}$	2
Fluid temperature (°C)	$0.2 \cdot 10^{-3}$	$0.5 \cdot 10^{-3}$	$0.6 \cdot 10^{-2}$	$0.8 \cdot 10^{-2}$	$0.1 \cdot 10^{-1}$	0.01
Lateral resistivity (%)	Not used	Not used	Not used	Not used	Not used	2
Single point resistance (%)	0.4	2.0	1.5	1.6	0.3	No data
Caliper 1D	$0.2 \cdot 10^{-5}$	$0.3 \cdot 10^{-5}$	$0.3 \cdot 10^{-5}$	$0.2 \cdot 10^{-3}$	$0.8 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
Caliper mean (m)	No data	$0.5 \cdot 10^{-4}$	No data	$0.6 \cdot 10^{-3}$	No data	$5 \cdot 10^{-4}$
Focused resistivity 300 (%)	10.9	34.6	6.8	16.3	8.7	No data
Focused resistivity 140 (%)	3.5	18.6	8.5	10.3	3.1	No data
Sonic (m/s)	7	5	6	No data	10	20

5.2.1 Interpretation of KLX09G

The results of the generalized logging data and fracture estimations of KLX09G are presented in Figure 5-1.

A majority of the rocks in the vicinity of KLX09G have silicate density in the range 2,730–2,800 kg/m³ (Table 5-2), magnetic susceptibility of 0.01–0.03 SI and natural gamma radiation in the interval c 10–25 μR/h. The combination of physical properties indicates the occurrence of quartz monzodiorite or possibly Ävrö granite with a low content of quartz and high content of dark minerals. In the section c 10–25 m the density is slightly increased (2,770–2,810 kg/m³) and the natural gamma radiation is slightly decreased (c 10–15 μR/h), which indicates rock with relatively higher content of dark minerals and lower content of quartz compared to the remaining part of the borehole.

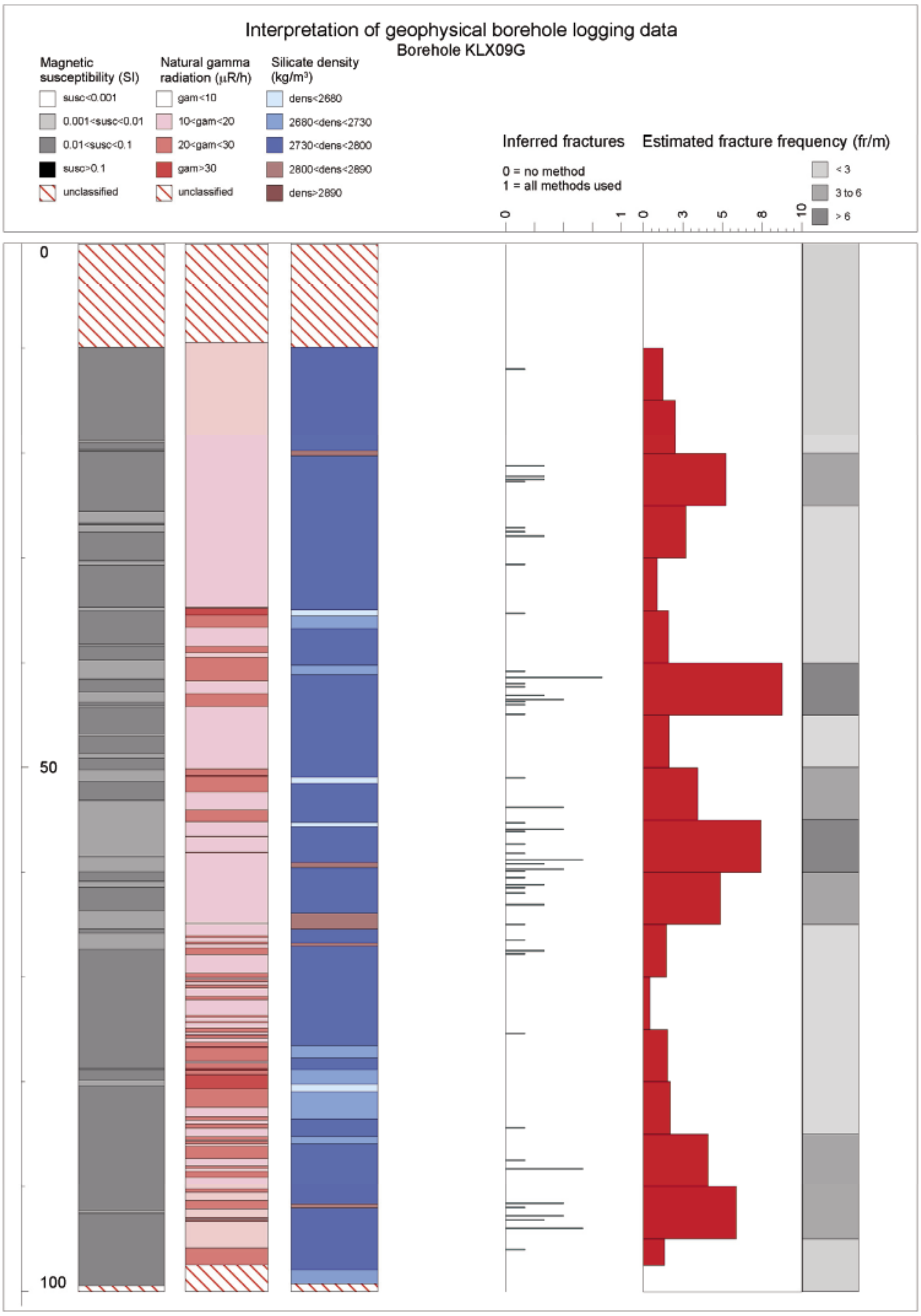

Figure 5-1. Generalized geophysical logs of KLX09G.

Table 5-2. Distribution of silicate density classes with borehole length of KLX09G.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	2	2
2,680 < dens < 2,730	16	18
2,730 < dens < 2,800	68	76
2,800 < dens < 2,890	3	4
dens > 2,890	0	0

Intervals with moderately increased natural gamma radiation (20–30 μR/h) in combination with decreased density occur fairly frequent in the section c 35–100 m. These intervals most likely correspond Ävrö granite with granitic to granodioitic mineral composition. Short sections with greatly increased natural gamma radiation, decreased magnetic susceptibility and density < 2,680 kg/m³ most likely correspond to fine-grained granite dykes, or possibly pegmatites.

A few short sections with density in the range 2,830–2,880 kg/m³ (light brown color in Figure 5-1), decreased natural gamma radiation and decreased magnetic susceptibility are identified. The anomalies most likely indicate rocks with mineral composition that corresponds to quartz diorite or diorite/gabbro.

The estimated fracture frequency of KLX09G is generally low, or partly moderate. Increased fracturing is indicated in the sections c 40–44 m and 58–61 m. These sections are characterized by decreased resistivity, partly decreased P-wave velocity and also minor caliper-anomalies in the section 40–44 m.

Apparent porosity (Figure 5-2) was only calculated for the section c 10–61 m and not for the full borehole length. The reason for this is that caliper data, which is part of the porosity estimation, are lacking below 61 m. The apparent porosity averages at c 0.45%, which is considered normal for crystalline rocks in this area. Minor porosity anomalies (c 0.6–0.8%) occur in sections with increased fracture frequency. The estimated salinity is 140–150 ppm NaCl in the section c 10–60 m. At c 60 m there is a stepwise increase in the salinity, up to a level of c 170 ppm NaCl that is kept fairly constant down to the bottom of the borehole.

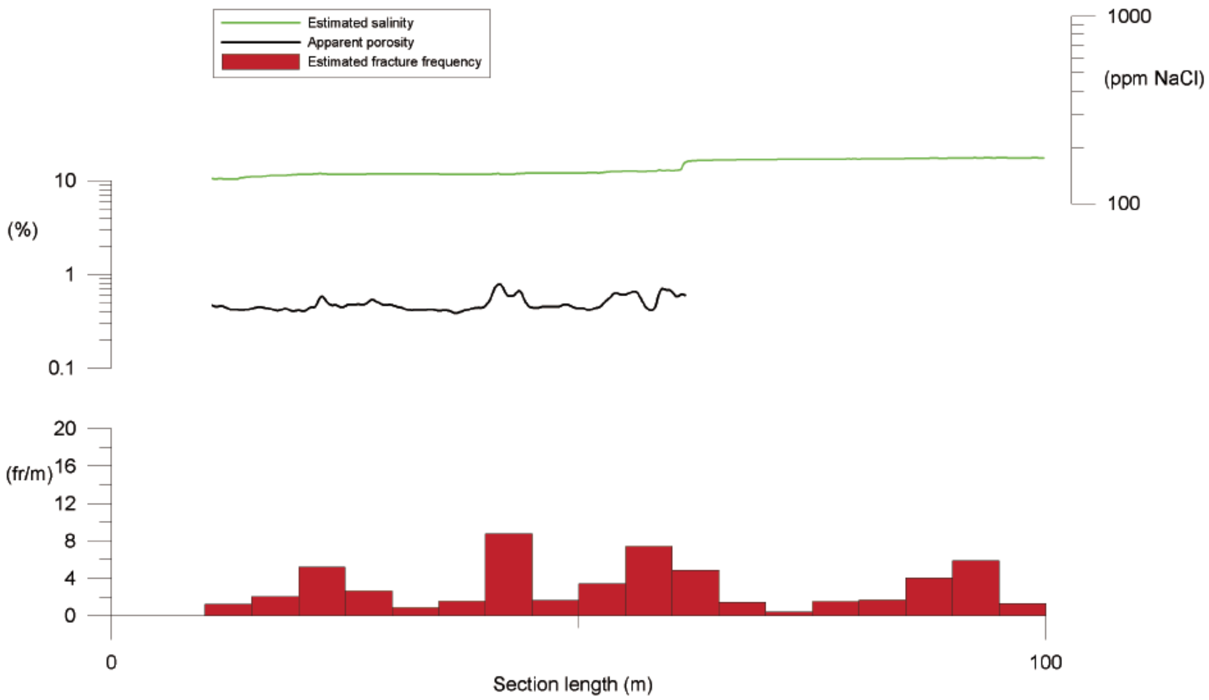

Figure 5-2. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX09G.*

5.2.2 Interpretation of KLX10B

The results of the generalized logging data and fracture estimations of KLX10B are presented in Figure 5-3 and the distribution of silicate density classes along the borehole is presented in Table 5-3.

The section c 10–20 m is characterized by silicate density < 2,680 kg/m³, magnetic susceptibility of c 0.0011 SI and natural gamma radiation in the range 40–45 μR/h. This combination of physical properties is typical for fine-grained granite.

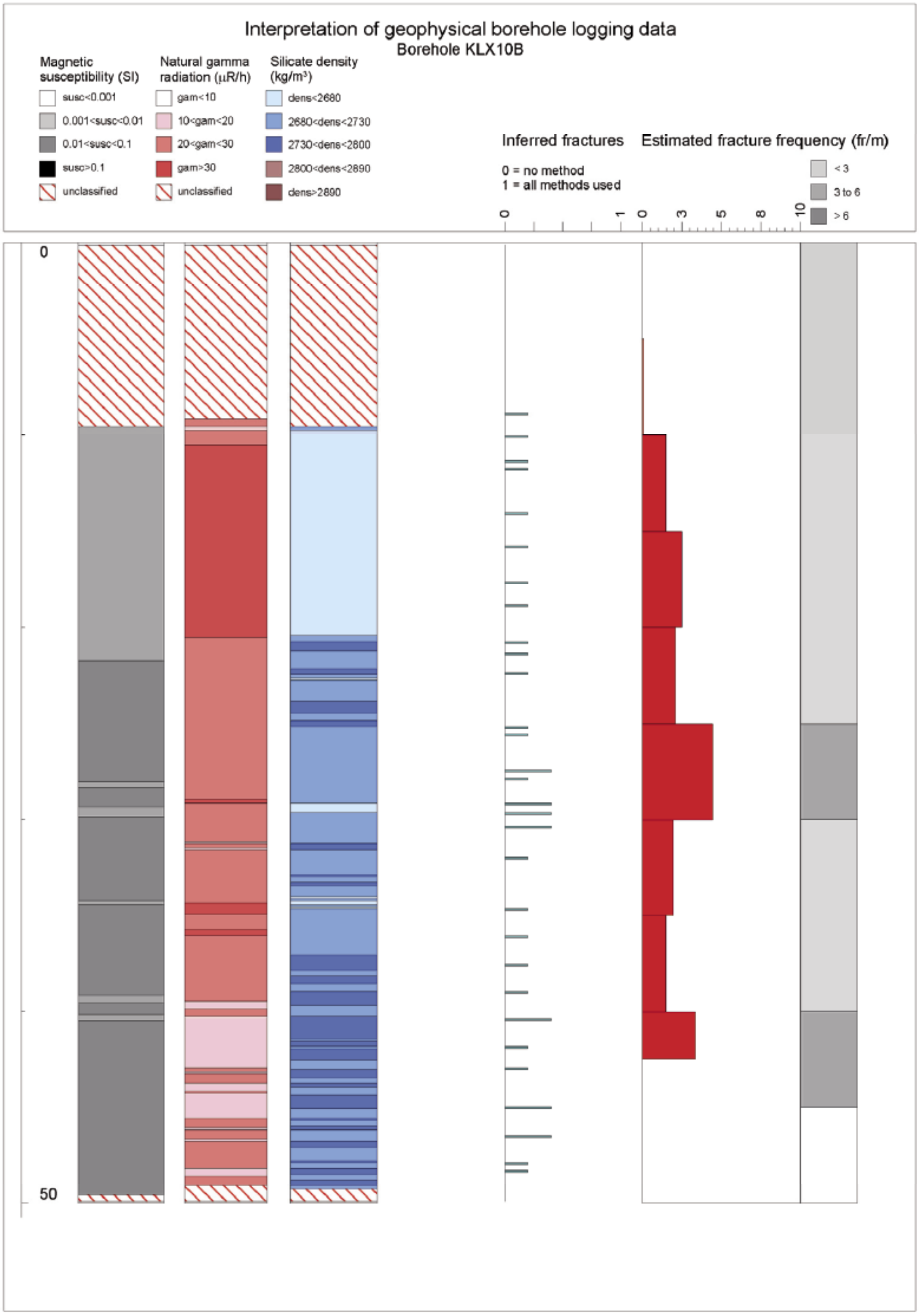

Figure 5-3. Generalized geophysical logs of KLX10B.

Table 5-3. Distribution of silicate density classes with borehole length of KLX10B.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	12	30
2,680 < dens < 2,730	19	47
2,730 < dens < 2,800	9	23
2,800 < dens < 2,890	0	0
dens > 2,890	0	0

In the remaining part of the borehole, c 20–50 m, the silicate density is mainly within the intervals 2,680–2,730 kg/m³ and 2,730–2,800 kg/m³, the natural gamma radiation is c 15–25 μR/h and the magnetic susceptibility is c 0.015–0.035 SI. The data indicate the occurrence of Ävrö granite. Observe the relatively larger occurrence of the higher silicate density class (2,730–2,800 kg/m³) in the lowest part of the borehole, c 40–50 m. This section is characterized by increased magnetic susceptibility and decreased natural gamma radiation relative to the upper section c 20–40 m. The small, but significant, differences in physical properties between the sections c 20–40 m and c 40–50 m, most likely correspond to variations in mineral composition (e.g. quartz content and content of dark minerals).

The estimated fracture frequency of KLX10B is low or moderate. In the sections c 25–30 m and c 40–45 m there are indications of slightly increased fracturing. The intervals are characterized by partly decreased resistivity, minor decrease in P-wave velocity and one distinct caliper anomaly at c 40.4 m.

The estimated salinity shows a fairly constant level of c 220–250 ppm NaCl (Figure 5-4). There is a minor increase in the level at c 28–30 m, which correlates with a large negative resistivity anomaly that possibly indicates the presence of a water bearing fracture.

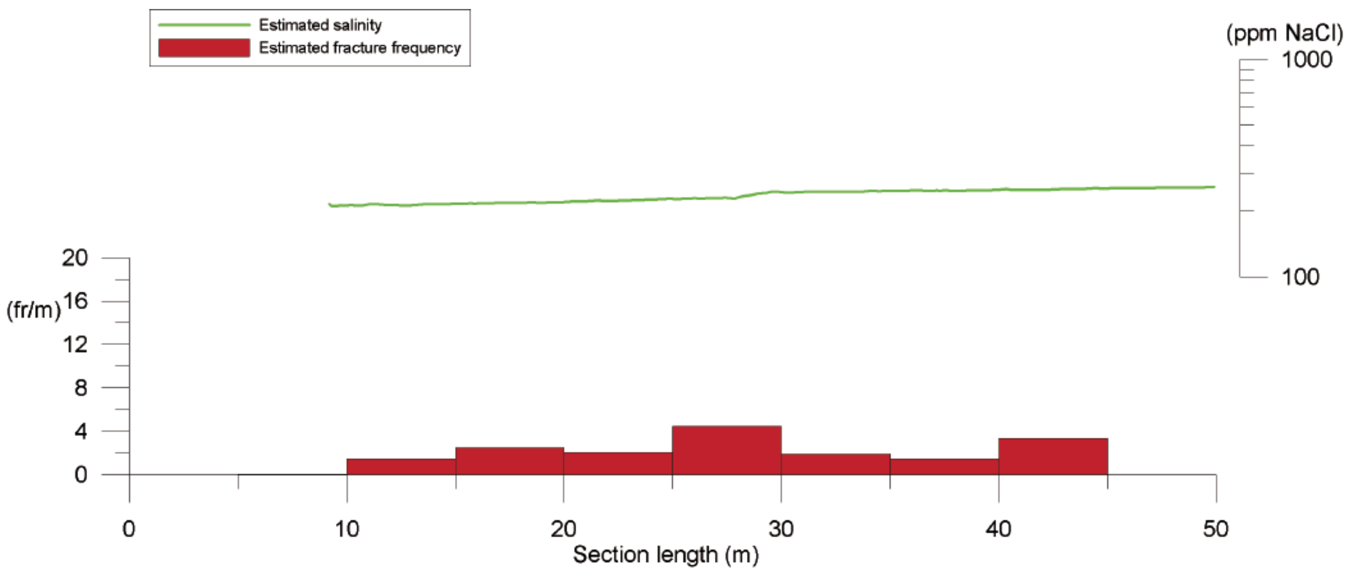

Figure 5-4. Estimated salinity and estimated fracture frequency of KLX10B.

5.2.3 Interpretation of KLX10C

The results of the generalized logging data and fracture estimations of KLX10C are presented in Figure 5-5 and the distribution of silicate density classes along the borehole is presented in Table 5-4.

The variations in the density, magnetic susceptibility and natural gamma radiation in KLX10C indicate a heterogeneous distribution of rocks (or mineral composition) along the entire borehole length. In the section c 10–60 m there is a dominance of rocks with silicate density in the intervals 2,680–2,730 kg/m^3 and 2,730–2,800 kg/m^3. Within this section the magnetic susceptibility is increased in the interval c 10–35 m (0.030–0.040 SI), apart from a major low at c 15–20 which is most likely related to fine-grained diorite/gabbro (increased density and decreased natural gamma radiation). The rocks along this section (10–60 m) are most likely Ävrö granite and/or quartz monzodiorite.

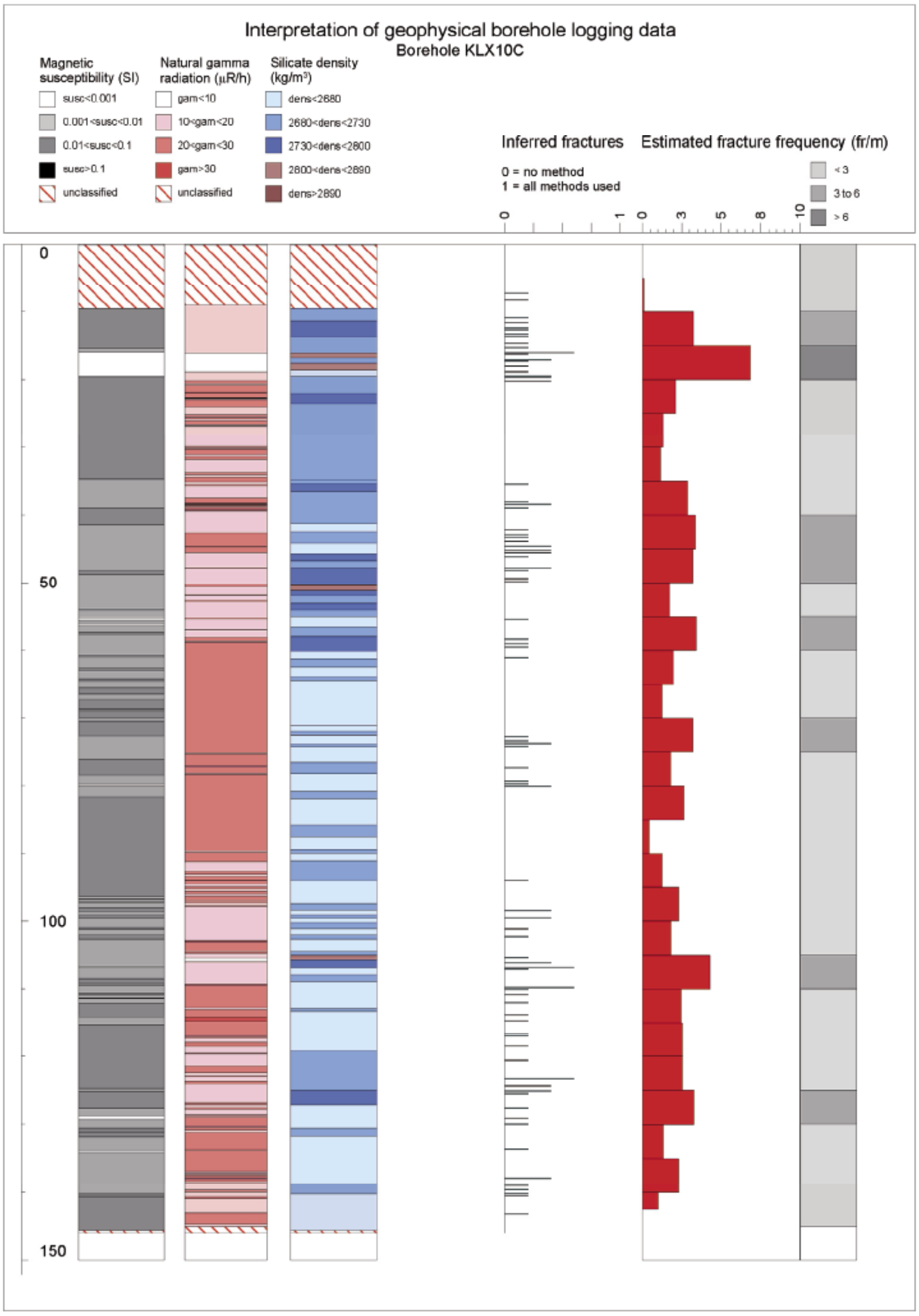

Figure 5-5. Generalized geophysical logs of KLX10C.

Table 5-4. Distribution of silicate density classes with borehole length of KLX10C.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	58	43
2,680 < dens < 2,730	59	43
2,730 < dens < 2,800	17	13
2,800 < dens < 2,890	2	1
dens > 2,890	0	0

In the section c 60–145 m a majority of the rocks have silicate density < 2,680 kg/m³, natural gamma radiation in the range 20–30 µR/h and magnetic susceptibility that varies greatly within the range 0.0012–0.030 SI. The data indicate the occurrence of Ävrö granite. Sections with increased density generally correlate with section of decreased natural gamma radiation, and vice versa, most likely corresponding to variations in mineral composition. One thin dyke of fine-grained granite or pegmatite is indicated at c 114.5 m. In the interval c 120–127 m the density and magnetic susceptibility is increased. In the section c 128–130 m there is significantly decrease in density and magnetic susceptibility. The anomalies coincide with decreased P-wave velocity, which suggests brittle fracturing.

The estimated fracture frequency of KLX10C is generally low and partly moderate. A possible deformation zone is indicated at c 15–20 m. The section is characterized by decreased bulk resistivity, decreased density, decrease magnetic susceptibility, decreased P-wave velocity and a distinctly wide caliper anomaly. The possible deformation zone coincides with the indicated occurrences of mafic dykes. Single major fractures (or minor deformation zones) are indicated in the intervals c 43–46 m, 79–80 m, 105–107 m, 115 m, 122–124 m and 129 m. These sections are characterized by decreased P-wave velocity and negative resistivity anomalies.

The estimated salinity is almost constant in the range c 180–210 ppm NaCl in the section c 10–124 m (Figure 5-6). At c 124 m there is a stepwise increase in the salinity up to c 620 ppm NaCl, and this level is kept constant through out the rest of the borehole length. The stepwise increase in the salinity level may indicate the presence of a water bearing fracture at c 124 m, which is supported by the presence of a negative sonic anomaly (decreased P-wave velocity) at that position.

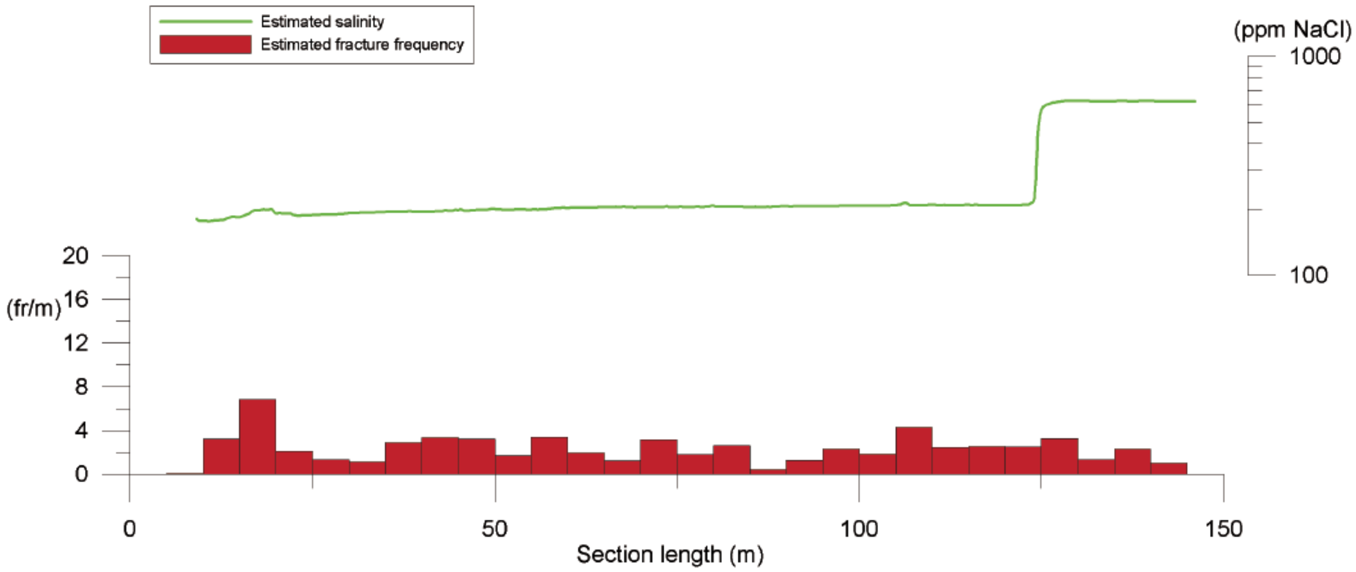

Figure 5-6. Estimated salinity and estimated fracture frequency of KLX10C.

5.2.4 Interpretation of HLX36

The results of the generalized logging data and fracture estimations of HLX36 are presented in Figure 5-7.

The "lithological" logs silicate density, natural gamma radiation and magnetic susceptibility indicate that the borehole HLX36 can be divided into two major parts. Part 1, section c 6–114 m, is characterized by silicate density in the range 2,680–2,730 kg/m^3, natural gamma radiation in the range 15–20 µR/h and magnetic susceptibility in the range 0.011–0.018 SI. The combination of physical properties is typical for Ävrö granite with granodioritic mineral composition. In the subsection c 100–114 m (lowermost part of part 1) the density is decreased, averaging at c 2,690 kg/m^3, which indicates Ävrö granite with granitic mineral composition. Along part 1 there are indications of four minor dykes of fine-grained granite (increased natural gamma radiation in combination with decreased density and decreased magnetic susceptibility). These section coordinates are c 17.0–18.0 m, 64.5 m, 72.0 m and 83.5–85.0 m.

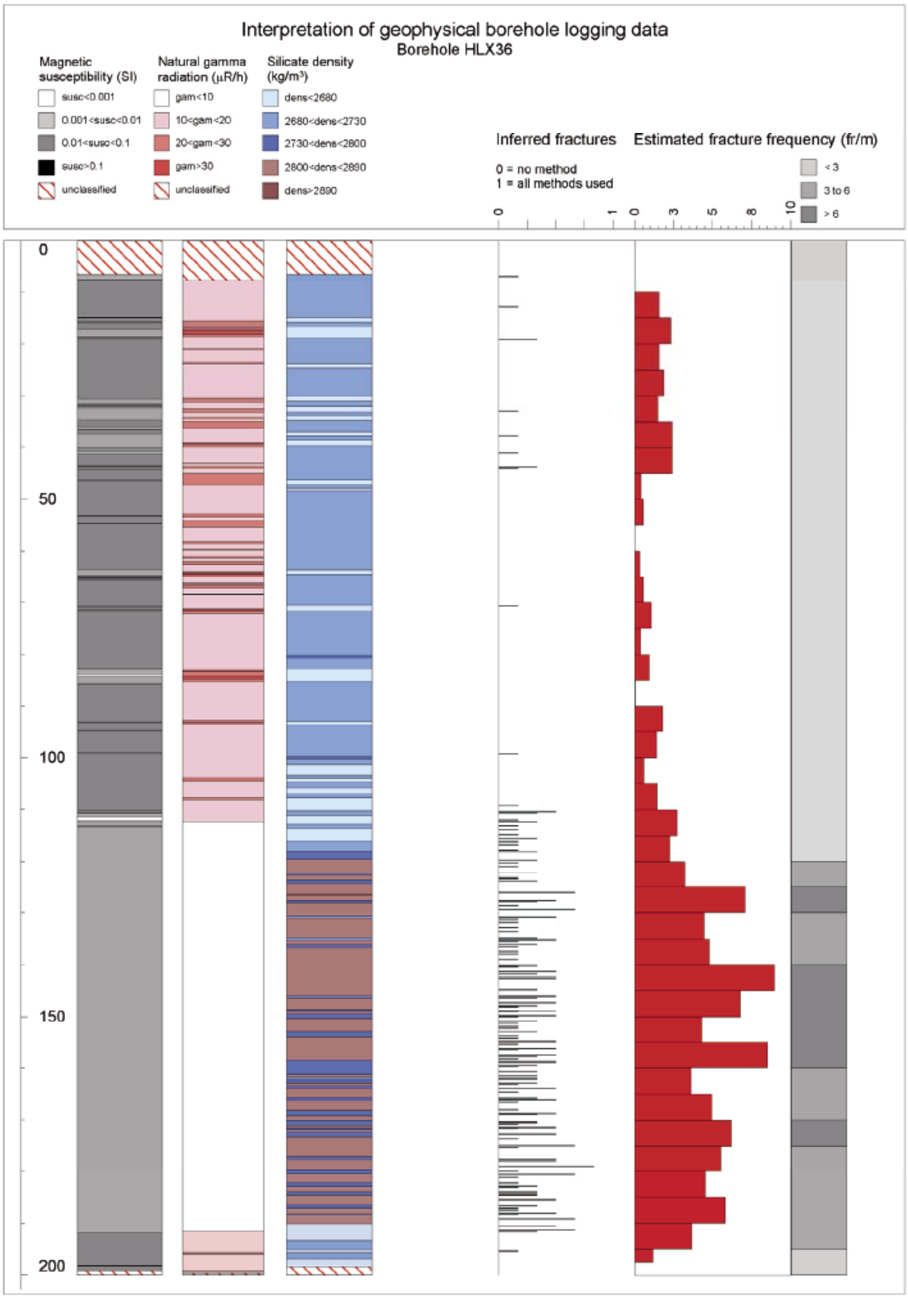

Figure 5-7. Generalized geophysical logs of HLX36.

Part 2, section c 114–191 m, is characterized by silicate density in the interval 2,800–2,890 kg/m^3, natural gamma radiation in the interval 3–4 μR/h and magnetic susceptibility in the range 0.004–0.006 SI. The silicate density corresponds to rock with dioritic mineral composition, which could indicate that the dominating rock type along this section is quartz monzodiorite. However, the "normal" quartz monzodiorite in the Laxemar area has slightly lower density and magnetic susceptibility in the range 0.02–0.04 SI, which is one order of magnitude higher than the susceptibility measured along this part of HLX36. The data therefore most likely indicate the occurrence of fine-grained diorite/gabbro.

The lowermost ca 9 m of HLX36 (section c 191–200 m) have the same physical characteristics as part 1 discussed above.

The estimated fracture frequency shows a clear relation to the lithological variations indicated by the density, magnetic susceptibility and natural gamma radiation data. In the section c 6–110 m the estimated fracture frequency is low and there are no major anomalies in the resistivity or caliper logs. In the section c 110–191 m there is a significant decrease in the bulk resistivity, by at least one order of magnitude, and there is also a large number of caliper anomalies along the entire interval. The data clearly suggest the occurrence of a large deformation zone along the entire section c 110–191 m. In the lowermost ca 9 m (section c 191–200 m) the indicated fracturing is low and the resistivity returns to a similar level as in the upper half of the borehole.

5.2.5 Interpretation of HLX37

The results of the generalized logging data and fracture estimations of HLX37 are presented in Figure 5-8.

For the major part of HLX37 the silicate density is fairly constant within the range 2,690–2,730 kg/m^3. The natural gamma radiation log indicates a more heterogeneous data distribution, but this is mainly caused by the fact that the data fall very close to the boundary set in the generalization procedure. The sections with silicate density in the interval 2,690–2,730 kg/m^3 generally have natural gamma radiation in the range c 15–23 μR/h, which is fairly constant but crosscuts the boundary set at 20 μR/h. The magnetic susceptibility in the corresponding sections averages at c 0.017 SI. The combination of physical properties is typical for Ävrö granite.

In the section c 122–146 m the silicate density is c 2,810–2,880 kg/m^3, the natural gamma radiation in the interval 4–7 μR/h and the magnetic susceptibility in the range 0.005–0.008 SI. The data most likely indicate the occurrence of fine-grained diorite/gabbro.

In the section c 65–155 m there is an increased occurrence of strong positive natural gamma radiation anomalies in combination with decreased density and decreased magnetic susceptibility, which indicates fine-grained granite (or possibly, but less likely, pegmatite).

The fracture frequency estimated for HLX37 is low apart for the section c 122–146 m, which corresponds to the indicated occurrence of fine-grained diorite/gabbro. The section is characterized by significantly decreased resistivity (by more than one order of magnitude), partly decreased P-wave velocity (mainly in the intervals c 122–125 m, 135–137 m and 144–147 m) and several caliper anomalies. The data clearly suggest the occurrence of a deformation zone along the entire section.

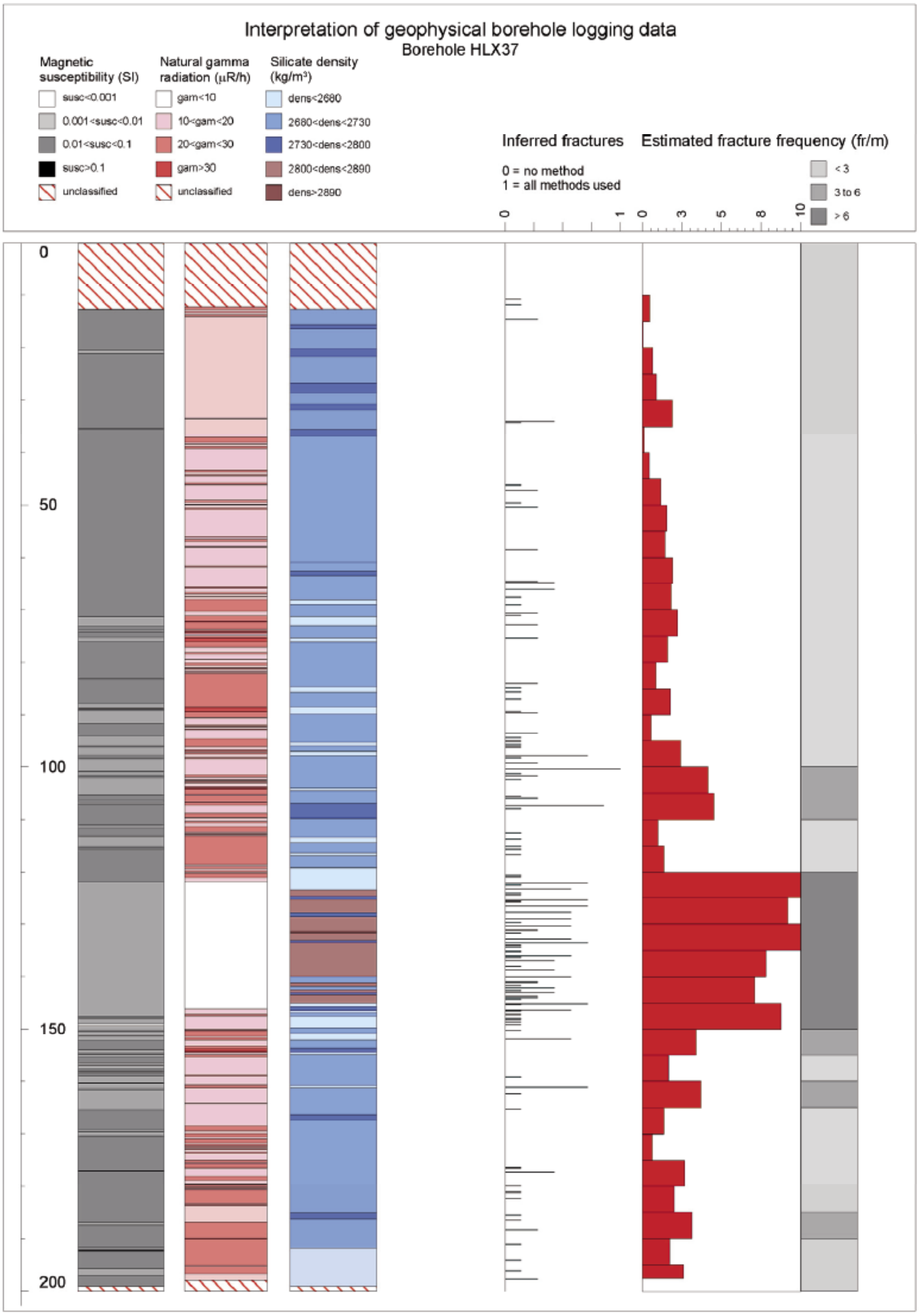

Figure 5-8. *Generalized geophysical logs of HLX37.*

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