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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX13A, KLX14A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A, KLX25A, KLX26A and KLX26B

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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 boreholes KLX13A, KLX14A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A, KLX25A, KLX26A and KLX26B.

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

A majority of the rocks in the vicinity of KLX13A, above a borehole length of 450 m have silicate density in the range 2,700–2,760 kg/m^3, whereas a majority of the rocks below that borehole length have a silicate density in the range 2,640–2,710 kg/m^3. The magnetic susceptibility is, in general, within the range 0.03–0.06 SI and the natural gamma radiation in the interval c 10–25 µR/h. Low magnetic susceptibility is however found below 490 m borehole length. The physical properties are typical of Ävrö granite, with higher quartz content in the lowermost part of the borehole compared to the upper part. The estimated fracture frequency of KLX13A is generally low above 350 m borehole length, and generally moderate below that length. Increased fracturing is indicated in the sections c 206–210 m, 254–256 m, 383–389 m, 494–506 m, 519–524 m and 554–559 m.

The silicate density of the rocks along KLX14A is primarily in the interval 2,730–2,800 kg/m^3. The natural gamma radiation is around 16–25 µR/h whereas the magnetic susceptibility is between 0.01 and 0.03 SI, except for a broad zone in the central part of the borehole, from 78 to 125 m borehole length where the magnetic susceptibility is low. The properties are typical of quartz monzodiorite. The estimated fracture frequency is in general low, except for the section 74 to 115 m where it is moderate to high. High estimated fracture frequency is found in the intervals 16–19 m, 42–44 m, 74 to 82 m, 96–99 m, 104–107 m and 112–115 m.

The rocks in the vicinities of KLX22A and KLX22B have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m^3. The estimated fracture frequency is mainly low or moderate. However, the estimated fracture frequency is high between 76 and 78 m in KLX22A.

The rocks in the vicinities of KLX23A and KLX23B have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m^3. The estimated fracture frequency is, in general, low. Narrow anomalies that indicate fracturing occur in the upper parts of the boreholes and at around 34 m, 80 m and 83 m borehole section in KLX23A.

In the vicinities of KLX24A and KLX25A the rocks have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m^3. The estimated fracture frequency is, in general, low in both boreholes. Narrow anomalies that indicate fracturing occur at around 20 m, 65 m and 75 m borehole section length in KLX24A and at around 17 m and 23 m length in KLX25A.

The rocks around KLX26A and KLX26B can be divided into three groups. The intervals 18–25 m and 74–97 m in KLX26A and 44–50 m in KLX26B have silicate density corresponding to gabbroic composition, low natural gamma radiation and high magnetic susceptibility (> 0.05 SI). The intervals 6–18 m and 46–74 m in KLX26A and 2–27 m in KLX26B have similar silicate density and natural gamma radiation but considerably lower magnetic susceptibility. The intervals 25–46 m in KLX26A and 27–44 m in KLX26B have properties typical of fine-grained granite with low magnetic susceptibility, high natural gamma radiation and silicate density below 2,680 kg/m^3. Narrow anomalies that indicate fracturing occur at around 17 m, 38 m, 47 m, 74 m and 98 m borehole section lengh in KLX26A and at around 14 m, 20 m and 27 m section length in KLX26B.

Sammanfattning

Denna rapport presenterar sammanställning och tolkning av geofysiska borrhålsloggningar utförda i kärnborrhålen KLX13A, KLX14A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A, KLX25A, KLX26A och KLX26B.

Det huvudsakliga syftet med arbetet är att resultaten ska vara användbara i den geologiska kärnkarteringen och som stödjande information vid den geologiska enhålstolkningen.

En majoritet av berget invid KLX13A, ovanför en borrhålslängd av 450 meter har en silikatdensitet i intervallet 2 700–2 760 kg/m^3, medan en majoritet av berget under detta djup har en silikatdensitet i intervallet 2 640–2 710 kg/m^3. Den magnetiska susceptibiliteten ligger i allmänhet i intervallet 0,03–0,06 SI och den naturliga gammastrålningen i intervallet 10–25 μR/h. Låg magnetisk susceptibilitet påträffas emellertid under 490 meters borrhålslängd. De fysikaliska parametrarna är typiska för Ävrögranit, med högre kvartshalt in den understa delen av hålet jämfört med de övre delarna. Den uppskattade sprickfrekvensen för KLX13A är i allmänhet låg ovanför 350 meters borrhålslängd, och i allmänhet moderat under detta djup. Förhöjd sprickfrekvens har indikerats i sektionerna 206–210 m, 254–256 m, 383–389 m, 494–506 m, 519–524 m och 554–559 m.

Silikatdensiteten för berget längs KLX14A ligger i allmänhet i intervallet 2 730–2 800 kg/m^3. Den naturliga gammastrålningen är ungefär 16–25 μR/h medan den magnetiska susceptibiliteten är mellan 0,01 och 0,03 SI, utom för en bred zon i den centrala delen av borrhålet, från 78 till 125 meters borrhålslängd där den magnetiska susceptibiliteten är låg. De fysikaliska egenskaperna är typiska för kvarts-monzodiorit. Den uppskattade sprickfrekvensen är i allmänhet låg, med undantag för sektionen 74 till 115 m där den är moderat till hög. Hög uppskattad sprickfrekvens har identifierats i intervallen 16–19 m, 42–44 m, 74 to 82 m, 96–99 m, 104–107 m och 112–115 m.

Berget kring KLX22A och KLX22B har fysikaliska egenskaper typiska för kvarts-monzodiorit med silikatdensitet huvudsakligen i intervallet 2 730–2 800 kg/m^3. Den uppskattade sprickfrekvensen är i allmänhet låg till moderat. Emellertid finns en zon med högre uppskattad sprickfrekvens mellan 76 och 78 meter i KLX22A.

Berget kring KLX23A och KLX23B har egenskaper som är typiska för kvarts-monzodiorit med silikatdensitet i intervallet 2 730–2 800 kg/m^3. Den uppskattade sprickfrekvensen är i allmänhet låg. Smala anomalier som indikerar uppskrickning finns i de ytnära delarna av hålen samt vid 34 m, 80 m och 83 m borrhålslängd i KLX23A.

Berget kring KLX24A och KLX25A har egenskaper som är typiska för kvarts-monzodiorit med silikatdensitet i intervallet 2 730–2 800 kg/m^3. Den uppskattade sprickfrekvensen är i allmänhet låg i bägge borrhålen. Smala anomalier som indikerar uppsprickning finns vid 20 m, 65 m and 75 m borrhålslängd i KLX24A och vid 17 m och 23 m borrhålslängd i KLX25A.

Berget kring KLX26A och KLX26B kan delas upp i tre grupper. Intervallen 18–25 m och 74–97 m i KLX26A och 44–50 m i KLX26B har silikatdensitet som motsvarar gabbrosammansättning, låg naturlig gammastrålning och hög magnetisk susceptibilitet (> 0,05 SI). Intervallen 6–18 m och 46–74 m i KLX26A och 2–27 m i KLX26B har liknande silikatdensitet och naturlig gammastrålning med avsevärt lägre magnetisk susceptibilitet. Intervallen 25–46 m i KLX26A och 27–44 m i KLX26B har egenskaper som är typiska för finkornig granit med låg magnetisk susceptibilitet, hög naturlig gammastrålning och en silikatdensitet under 2 680 kg/m^3. Smala anomalier som indikerar uppsprickning finns vid 17 m, 38 m, 47 m, 74 m och 98 m borrhålslängd i KLX26A och vid 14 m, 20 m och 27 m borrhålslängd i KLX26B.

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 KLX13A, KLX14A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A, KLX25A, KLX26A and KLX26B 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 400-06-096 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of boreholes KLX13A, KLX14A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A, KLX25A, KLX26A and KLX26B.

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 KLX13A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A och KLX25A	AP PS 400-06-096	1.0
Tillägg till AP PS 400-06-096 med tolkning av borrhålsgeofysiska data från KLX14A, KLX26A och KLX26B		
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

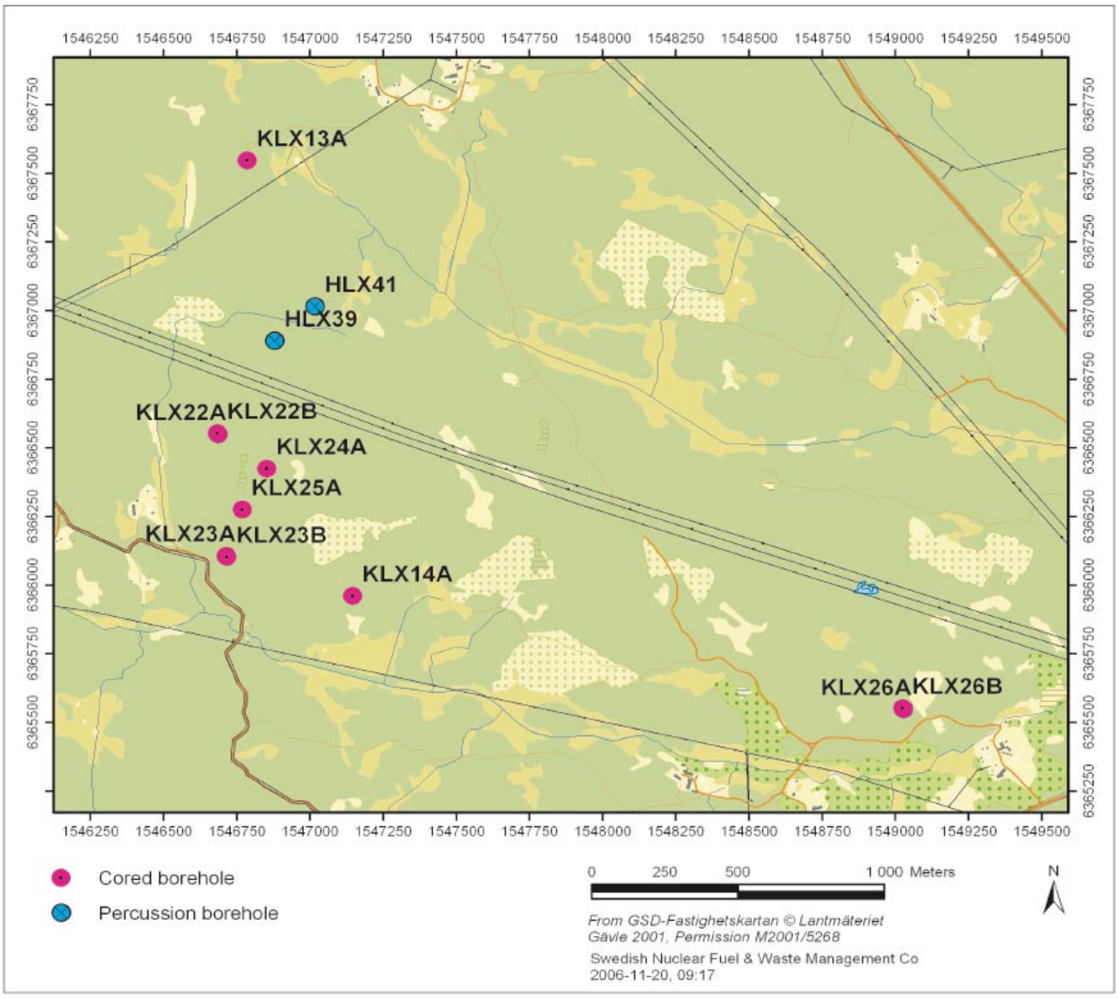

Figure 1-1. *Location of the boreholes KLX13A, KLX14A, KLX22A, KLX22B, KLX23A, KLX23B, KLX24A, KLX25A, KLX26A and KLX26B in Laxemar.*

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 "litho-logical" 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 v6 (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 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.

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	KLX13A	2.0	1.5	1.0	1.0	2.0	7.0	7.0	–
Power	KLX13A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX13A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX14A	1.5	1.5	1.5	1.0	1.5	5.0	5.0	–
Power	KLX14A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX14A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX22A	1.0	1.5	1.5	0.5	1.5	4.0	4.0	–
Power	KLX22A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX22A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX22B	1.0	1.5	1.5	0.5	1.5	4.0	4.0	–
Power	KLX22B	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX22B	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX23A	1.0	1.5	1.5	1.0	2.0	3.0	3.0	–
Power	KLX23A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX23A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX23B	2.0	0.5	0.5	1.0	2.0	1.0	1.0	–
Power	KLX23B	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX23B	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX24A	1.0	1.5	1.5	0.5	1.5	5.0	5.0	–
Power	KLX24A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX24A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX25A	1.0	1.5	1.5	0.5	1.0	5.0	5.0	–
Power	KLX25A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX25A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX26A	2.0	1.5	1.5	1.0	2.0	7.0	7.0	–
Power	KLX26A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX26A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX26B	1.3	1.5	1.2	0.5	1.2	4.0	4.0	–
Power	KLX26B	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX26B	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

4.3 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.

4.4 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.

4.5 Nonconformities

Magnetic susceptibility logging data are missing for parts of KLX26B. The silicate density has therefore not been possible to calculate for those parts of the borehole.

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. The noise levels for the density logs are higher than the recommended maximum noise level for all boreholes. The estimated noise levels are higher than the recommended also for the magnetic susceptibility and the natural gamma radiation. This might however partly be due to under-sampling of short wave-length anomalies. The high noise levels for the focused resistivity logs are probably due to the same reason. 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.

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

Logging method	KLX13A	KLX14A	KLX22A	KLX22B	KLX23A	Recommended max noise level
Density (kg/m^3)	13	13	18	13	12	3–5
Magnetic susceptibility (SI)	5×10^{-4}	3×10^{-4}	5×10^{-4}	3×10^{-4}	2×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	0.7	0.9	1.0	0.9	0.9	0.3
Long normal resistivity (%)	0.4	0.8	0.5	0.5	0.2	2.0
Short normal resistivity (%)	0.2	0.9	0.6	0.5	0.1	2.0
Fluid resistivity (%)	1×10^{-2}	10×10^{-2}	13×10^{-2}	5×10^{-2}	1×10^{-2}	2
Fluid temperature (ºC)	1.0×10^{-3}	1.0×10^{-2}	0.8×10^{-2}	3.7×10^{-2}	3×10^{-2}	0.01
Lateral resistivity (%)	Not used	Not used	Not used	Not used	Not used	2
Single point resistance (%)	0.2	0.8	0.4	0.5	0.07	No data
Caliper 1D	0.2×10^{-5}	0.2×10^{-5}	0.2×10^{-5}	0.4×10^{-5}	0.2×10^{-5}	5×10^{-4}
Caliper mean (m)	0.3×10^{-4}	0.2×10^{-4}	0.2×10^{-4}	2.5×10^{-4}	0.1×10^{-4}	5×10^{-4}
Focused resistivity 300 (%)	7.0	23.2	23.9	16.8	4.6	No data
Focused resistivity 140 (%)	3.9	7.0	3.0	2.1	0.6	No data
Sonic (m/s)	10	20	19	13	12	20

Table 5-1. Cont.

Logging method	KLX23B	KLX24A	KLX25A	KLX26A	KLX26B	Recommended max noise level
Density (kg/m^3)	12	12	17	13	14	3–5
Magnetic susceptibility (SI)	3×10^{-4}	4×10^{-4}	3×10^{-4}	9×10^{-4}	5×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	1.5	0.8	1.3	0.7	1.1	0.3
Long normal resistivity (%)	1.0	1.0	0.3	0.1	1.2	2.0
Short normal resistivity (%)	0.5	1.0	0.4	0.1	1.1	2.0
Fluid resistivity (%)	1.5×10^{-2}	2×10^{-2}	2×10^{-2}	0.5×10^{-2}	4×10^{-2}	2
Fluid temperature (ºC)	0.9×10^{-3}	0.9×10^{-3}	0.9×10^{-3}	0.3×10^{-3}	1.3×10^{-3}	0.01
Lateral resistivity (%)	Not used	Not used	Not used	Not used	Not used	2
Single point resistance (%)	0.1	0.6	0.3	0.1	0.9	No data
Caliper 1D	0.3×10^{-5}	0.7×10^{-5}	0.4×10^{-5}	0.3×10^{-5}	0.3×10^{-5}	5×10^{-4}
Caliper mean (m)	0.3×10^{-4}	0.3×10^{-4}	0.1×10^{-4}	0.4×10^{-4}	0.3×10^{-4}	5×10^{-4}
Focused resistivity 300 (%)	2.1	21.6	16.9	10.3	23.6	No data
Focused resistivity 140 (%)	0.6	4.1	1.3	3.5	12.8	No data
Sonic (m/s)	5	20	14	16	20	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 KLX13A

The results of the generalized logging data and fracture estimations of KLX13A are presented in Figure 5-1 and the distribution of silicate density classes along the borehole is presented in Table 5-2.

Table 5-2. Distribution of silicate density classes with borehole length of KLX13A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	75	15
2,680 < dens < 2,730	212	43
2,730 < dens < 2,800	136	28
2,800 < dens < 2,890	28	6
dens > 2,890	39	8

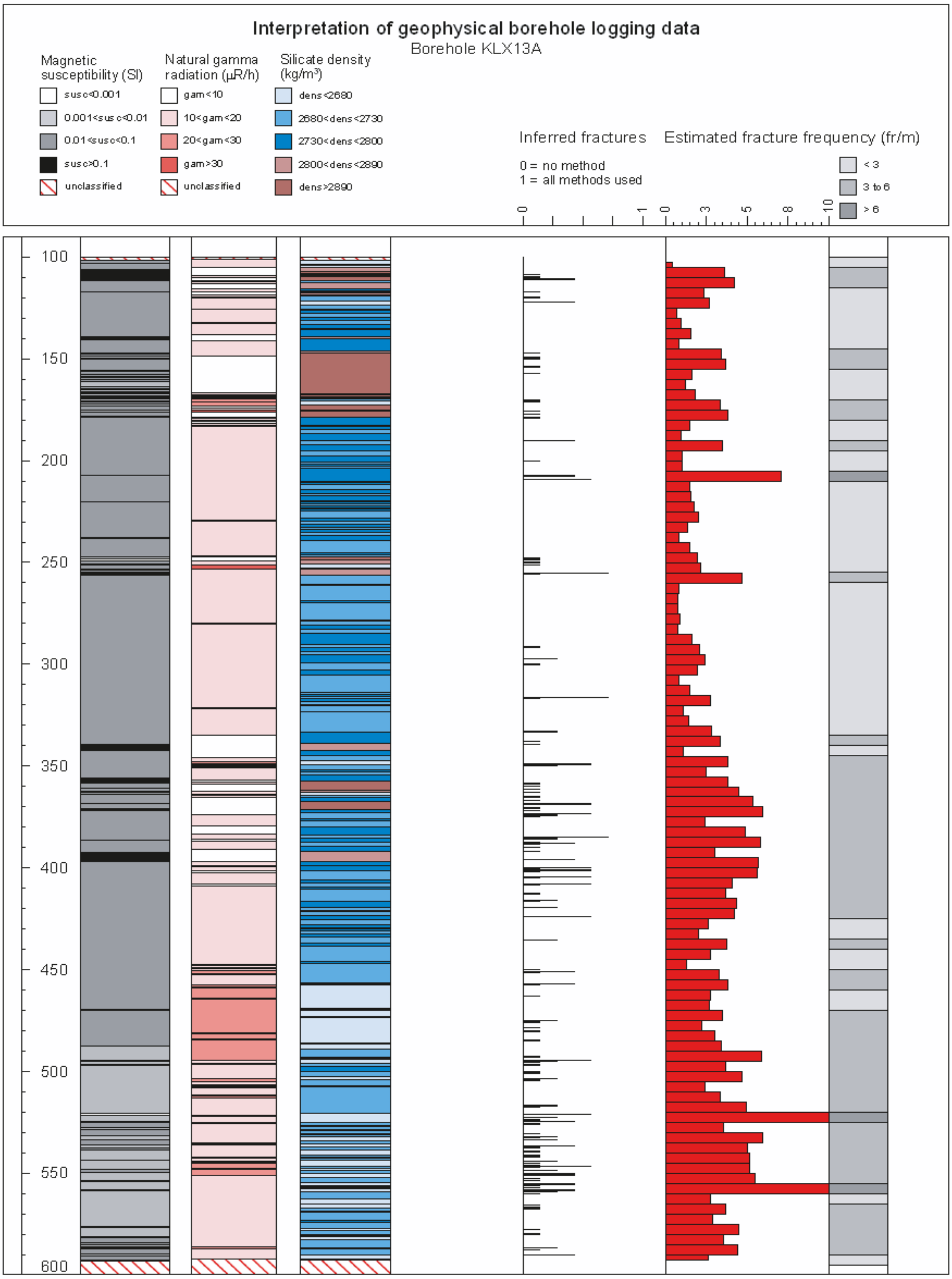

Figure 5-1. Generalized geophysical logs of KLX13A.

A majority of the rocks in the vicinity of KLX13A, above a borehole length of 450 m have silicate density in the range 2,700–2,760 kg/m^3, whereas a majority of the rocks below that length have a density in the range 2,640–2,710 kg/m^3. The magnetic susceptibility is, in general, within the range 0.03–0.06 SI and the natural gamma radiation in the interval c 10–25 μR/h. Low magnetic susceptibility is however found below 490 m borehole length. The physical properties are typical of Ävrö granite, with higher quartz content in the lowermost part of the borehole compared to the upper part.

Sections with high silicate density (> 2,800 kg/m^3) and low gamma radiation (< 10 μR/h) occur at several intervals in the borehole, in particular in the intervals above 180 m, 245–255 m and 335–400 m borehole length. The physical properties are typical of diorite/gabbro. These rocks can also be subdivided into two groups based on their magnetic properties. The sections 146–185 m and 245–255 m show very low magnetic susceptibility, whereas the other sections are dominated by rocks with a magnetic susceptibility in the range 0.06–0.16 SI. Short sections with high gamma radiation and low density are abundant in the same major intervals as the high-density rocks. These short sections most likely correspond to fine-grained granite or pegmatite.

The estimated fracture frequency of KLX13A is generally low above 350 m borehole length, and generally moderate below that length. Increased fracturing is indicated in the sections c 206–210 m, 254–256 m, 383–389 m, 494–506 m, 519–524 m and 554–559 m. These sections are characterized by decreased resistivity, low magnetic susceptibility, partly decreased P-wave velocity and also caliper-anomalies in the section 519–524 m. A change in gradient in the fluid resistivity and fluid temperature data suggests water movement in around 388 m borehole length.

The apparent porosity averages at 0.4–0.5%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-2). Minor positive anomalies occur in sections with increased fracture frequency. In the lowermost part of the borehole (section c 490–590 m) the diagram indicates a general increase of the porosity level. However, this indicated increase is only a result of the decreased fluid water resistivity (increased salinity), which the apparent porosity model fails to compensate for.

The estimated fluid water salinity is fairly constant at c 155 ppm NaCl in the section 100–400 m. At c 400 m the salinity starts to increase and reaches c 1,000 ppm NaCl at c 500 m section length. This level is kept fairly constant down to the bottom of the borehole.

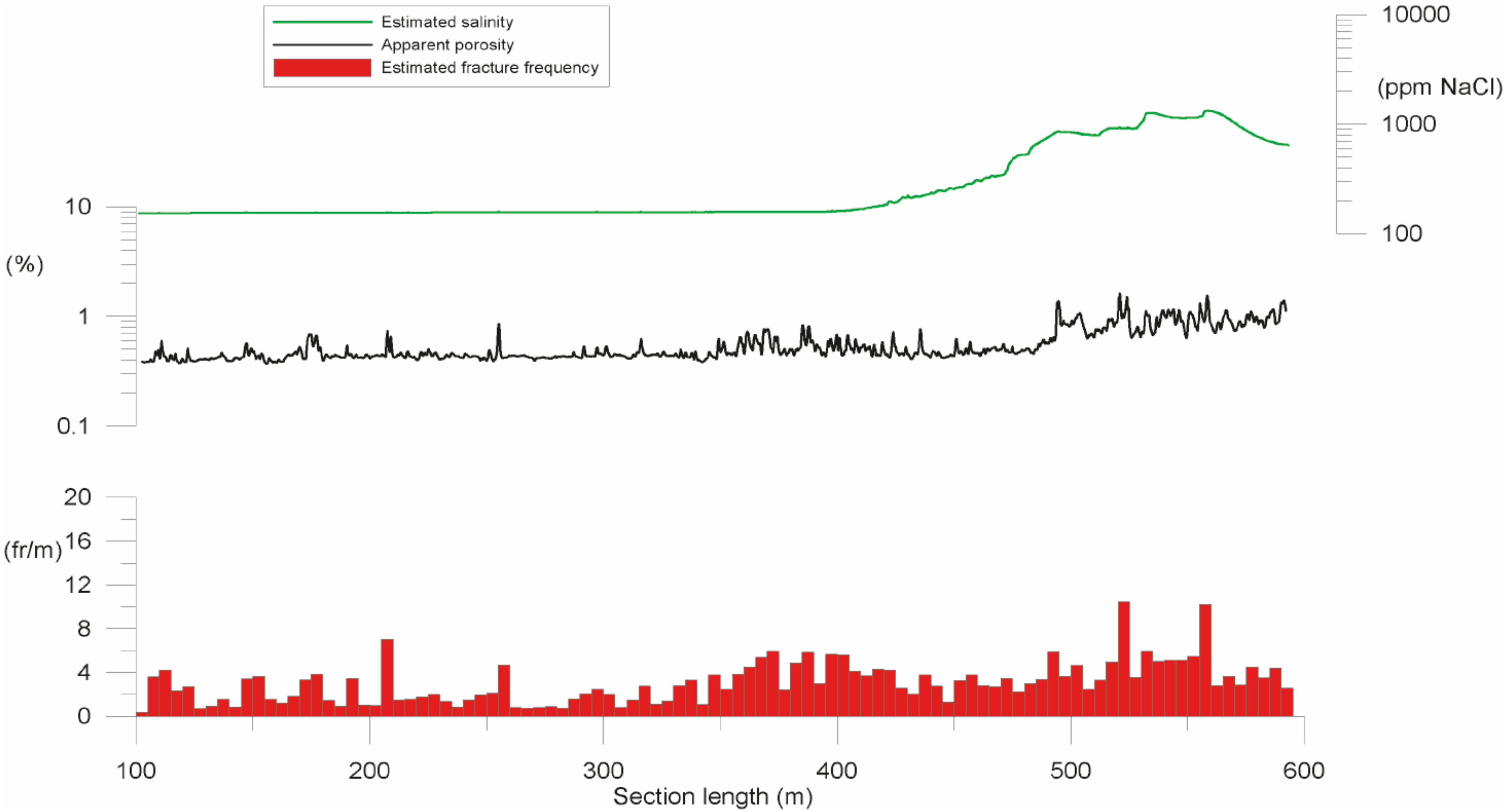

Figure 5-2. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX13A.*

5.2.2 Interpretation of KLX14A

The results of the generalized logging data and fracture estimations of KLX14A are presented in Figure 5-3 and the distribution of silicate density classes along the borehole is presented in Table 5-3.

The silicate density of the rocks found along KLX14A is primarily in the interval 2,730–2,800 kg/m^3. The natural gamma radiation is around 16–25 μR/h whereas the magnetic susceptibility is between 0.01 and 0.03 SI, except for a broad zone in the central part of the borehole, from 78 to 125 m borehole length where the magnetic susceptibility is low. The properties are typical of quartz monzodiorite. The natural gamma radiation is slightly higher and the silicate density slightly lower above 90 m borehole length compared to the rest of the borehole.

Thin sections with high gamma radiation and low silicate density, most likely corresponding to pegmatite or fine-grained granite, are scattered along the borehole. A broader zone with high radiation and density in the interval 2,660–2,750 kg/m^3 occur between 156–164 m borehole length . High-density rocks (> 2,830 kg/m^3) are more or less absent in the borehole.

The estimated fracture frequency is in general low, except for the section 74 to 115 m where it is moderate to high. High estimated fracture frequency is found in the intervals 16–19 m, 42–44 m, 74–82 m, 96–99 m, 104–107 m and 112–115 m. These intervals are characterized by low to very low electric resistivity, low P-wave velocity and low magnetic susceptibility. The magnetic susceptibility is often low also in neighboring areas. Caliper anomalies are found at 76, 88, 92 and 114 m.

Steep gradients in the fluid resistivity and temperature anomalies occur at 88, 93 and 118 m borehole length, indicating flowing water.

The apparent porosity averages at 0.4–0.5%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-4). In the section c 74–79 m there is a significant porosity increase that coincides with a possible deformation zone. Minor positive anomalies also occur in other sections with increased fracture frequency.

The estimated fluid water salinity is fairly constant at c 120–160 ppm NaCl in the section 15–88 m. At c 88 m there is a sharp increase in the salinity level up to c 450 ppm NaCl. This level is kept fairly constant down to the bottom of the borehole. The stepwise increase coincides with increased fracture frequency, and may indicate the presence of a water bearing fracture at c 88 m.

Table 5-3. Distribution of silicate density classes with borehole length of KLX14A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	8.5	5
2,680 < dens < 2,730	20	12
2,730 < dens < 2,800	128	77
2,800 < dens < 2,890	10	6
dens > 2,890	0	0

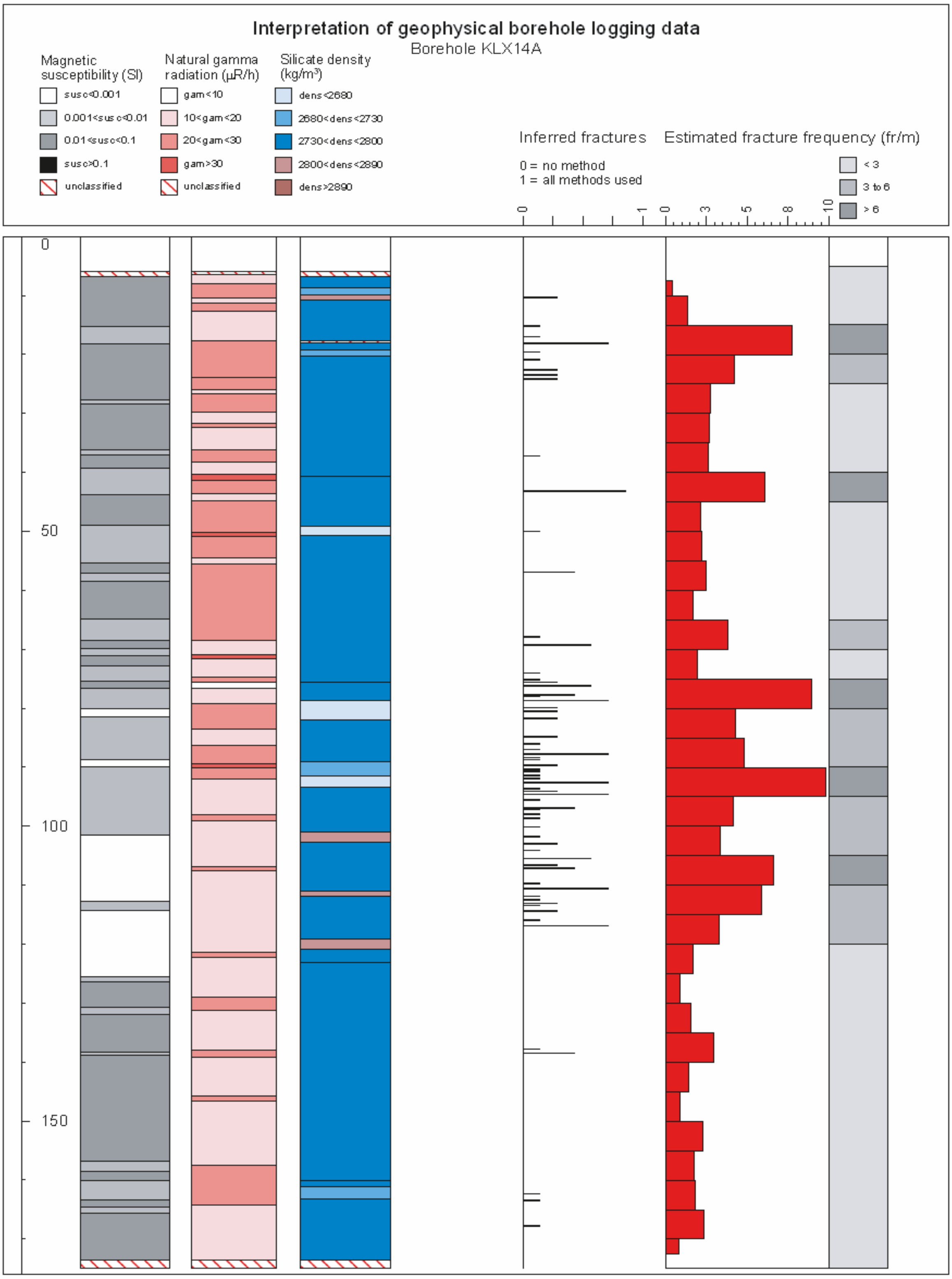

Figure 5-3. *Generalized geophysical logs of KLX14A.*

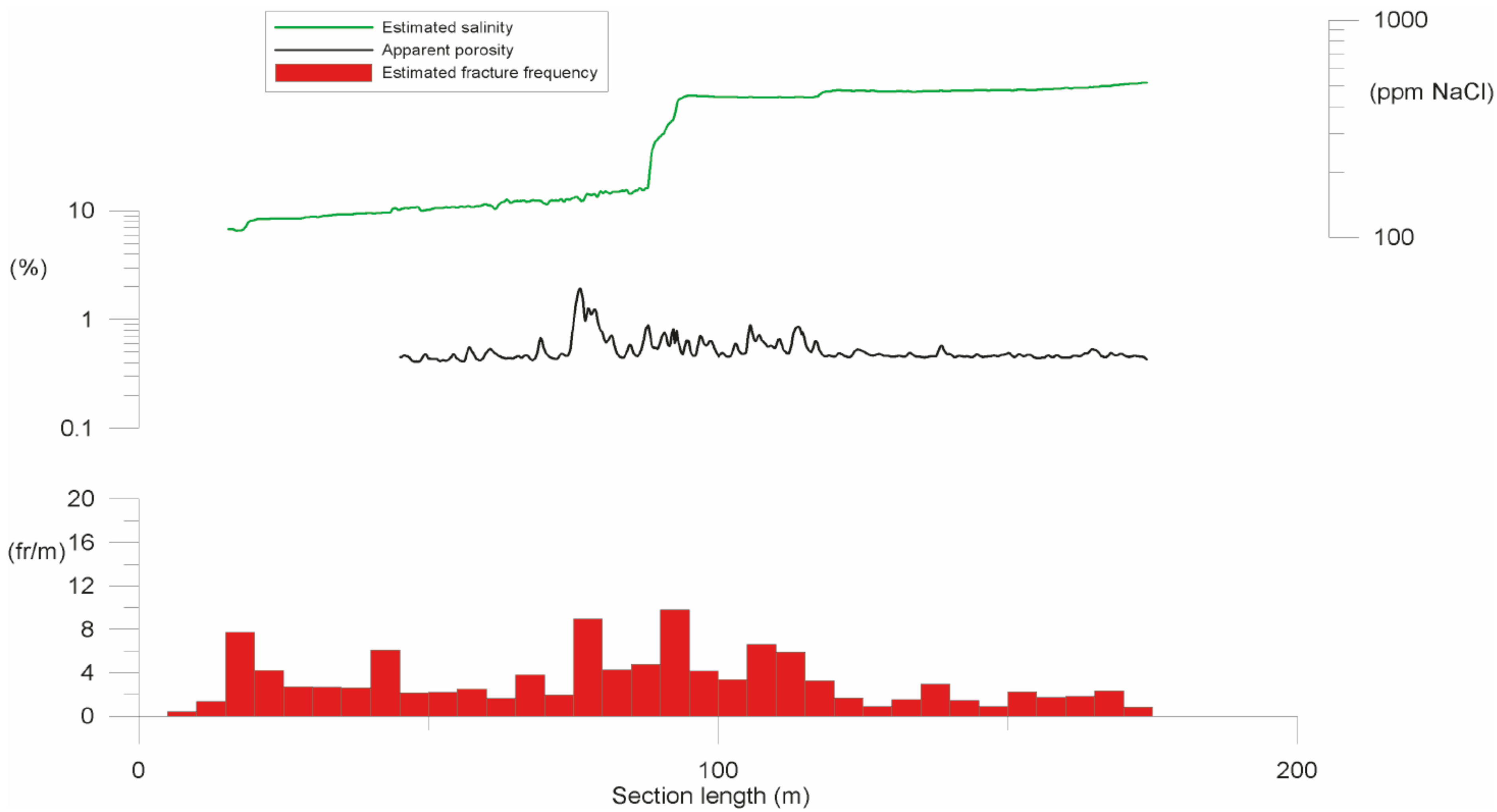

Figure 5-4. Estimated salinity, apparent porosity and estimated fracture frequency of KLX14A.

5.2.3 Interpretation of KLX22A

The rocks around KLX22A are dominated by rocks with a silicate density in the interval 2,730–2,800 kg/m^3 and with natural gamma radiation between 15 and 21 μR/h (Figure 5-5). These properties are typical of quartz monzodiorite. Low-denity rocks occur in sections between 53 and 70 m borehole length. High-density rocks are more or less absent.

The estimated fracture frequency is mainly low or moderate, except between 76 and 78 m borehole length. This section is characterized by low resistivity, P-wave velocity and magnetic susceptibility. A few minor scattered resistivity anomalies occur above 30 m, between 45 and 60 m and between 78 and 83 m. A steep gradient in the fluid resistivity and a temperature anomaly indicate flowing water at 83 m length. The resistivity logs are most likely disturbed by lack of borehole water during logging above 11 m length.

The apparent porosity averages at 0.3–0.4%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-6). There are no a significant porosity anomalies.

The estimated fluid water salinity is fairly constant at c 110–130 ppm NaCl along the entire borehole.

Table 5-4. Distribution of silicate density classes with borehole length of KLX22A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	6.5	7
2,680 < dens < 2,730	8.5	9
2,730 < dens < 2,800	78	82
2,800 < dens < 2,890	2	2
dens > 2,890	0	0

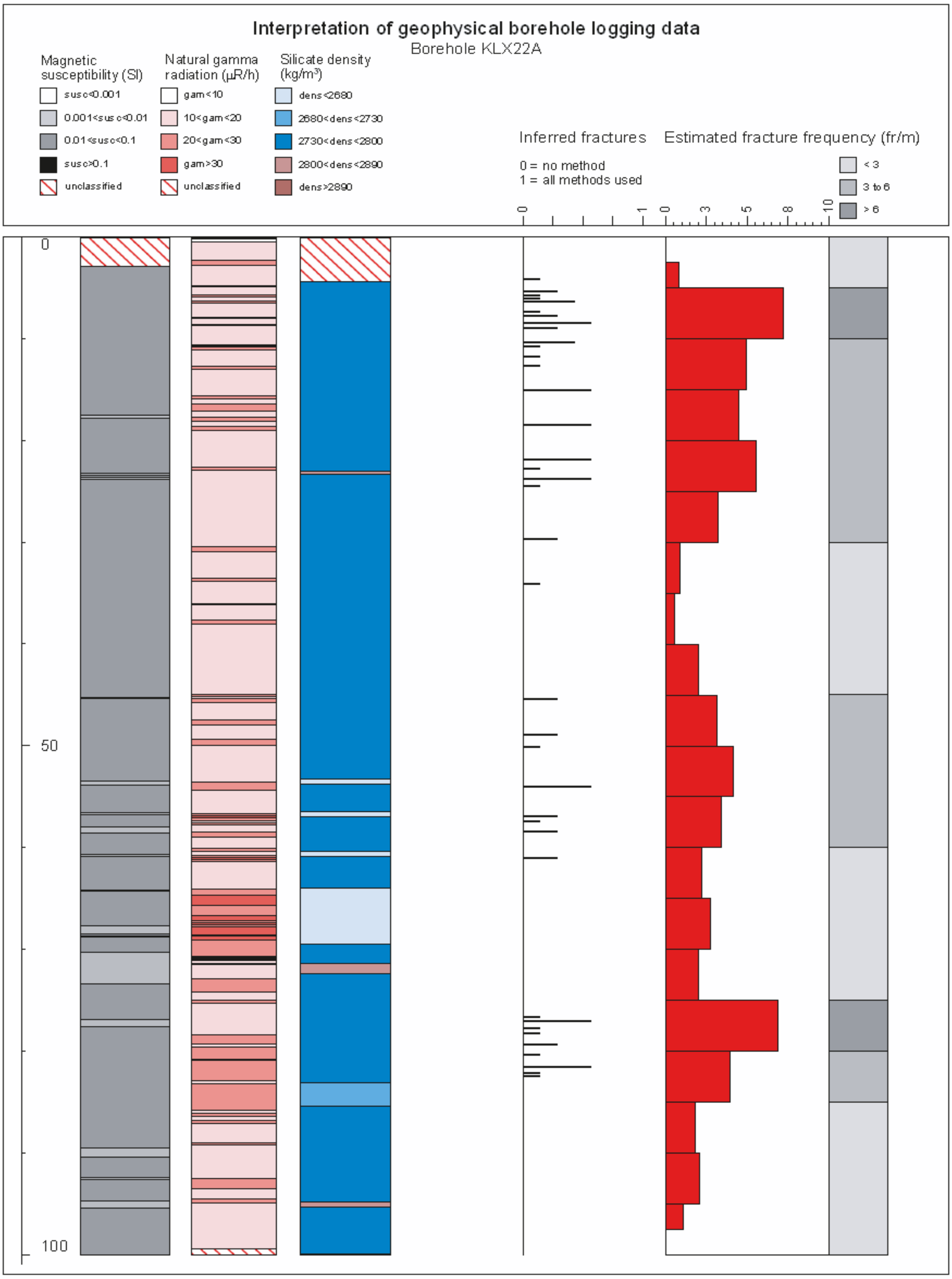

Figure 5-5. Generalized geophysical logs of KLX22A.

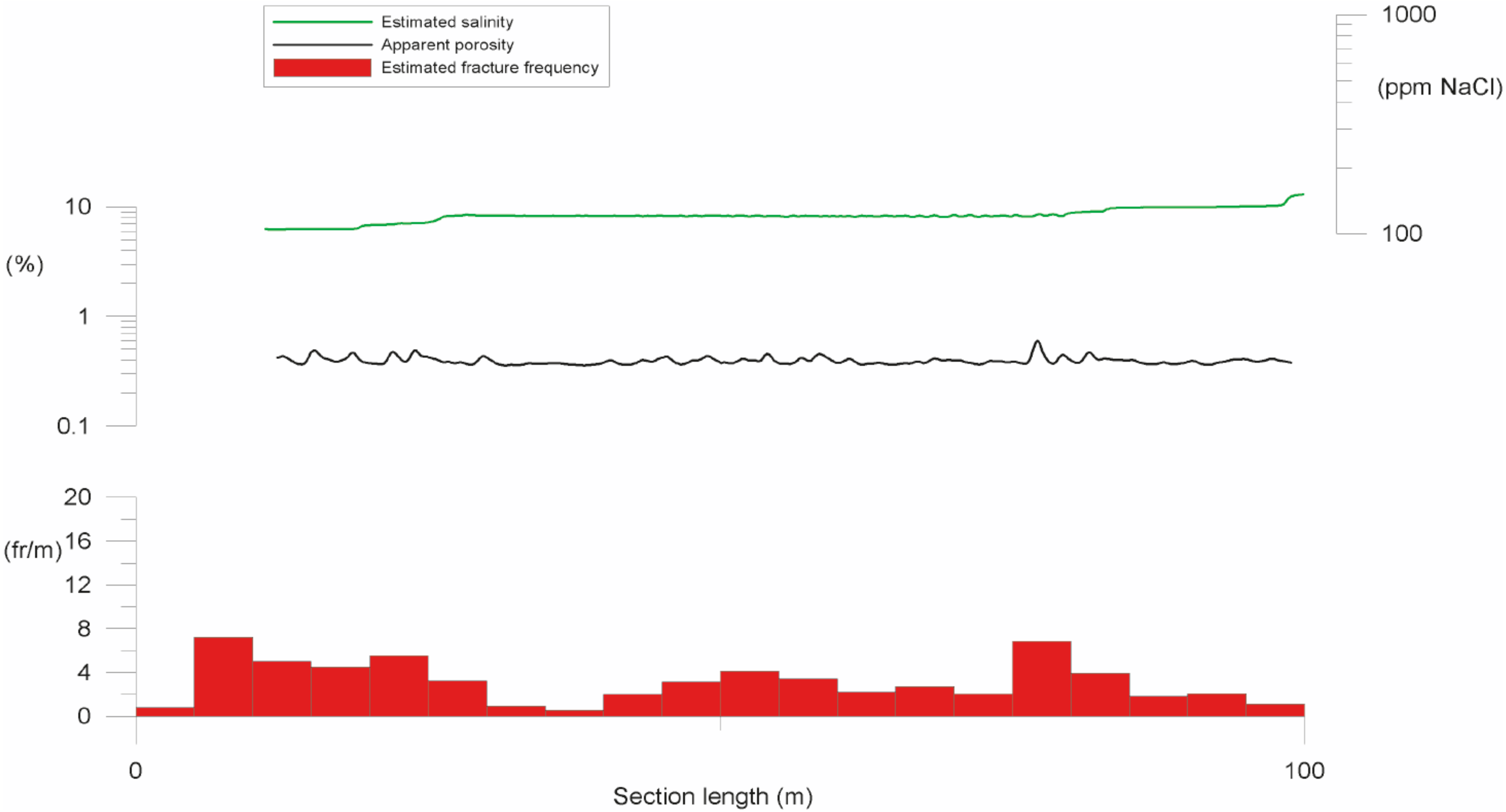

Figure 5-6. . *Estimated salinity, apparent porosity and estimated fracture frequency of KLX22A.*

5.2.4 Interpretation of KLX22B

The rocks around KLX22B are dominated by rocks with a silicate density in the interval 2,730–2,800 kg/m^3 and with natural gamma radiation between 15 and 19 µR/h (Figure 5-7). These properties are typical of quartz monzodiorite. The magnetic susceptibility is in general in the interval 0.025 to 0.035 SI, except for a broad zone of low susceptibility between 15 and 30 m borehole length and at some short sections characterized by either low or high density. Low-density rock occur between 56 and 62 m borehole length, which is very similar to the nearby KLX22A. High-density rocks occur in quite small amounts.

The estimated fracture frequency along KLX22B is low. Minor anomalies with low resistivity and low P-wave velocity occur at 17, 25 and 72 m borehole length. The resistivity logs are most likely disturbed by lack of borehole water during logging above 8 m borehole length.

The apparent porosity averages at 0.3–0.4%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-8). There are no a significant porosity anomalies.

The estimated fluid water salinity is fairly constant at c 90–105 ppm NaCl along the entire borehole.

Table 5-5. Distribution of silicate density classes with borehole length of KLX22B.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	6	6.5
2,680 < dens < 2,730	5	5.5
2,730 < dens < 2,800	80	84
2,800 < dens < 2,890	3.5	3.5
dens > 2,890	0.5	0.5

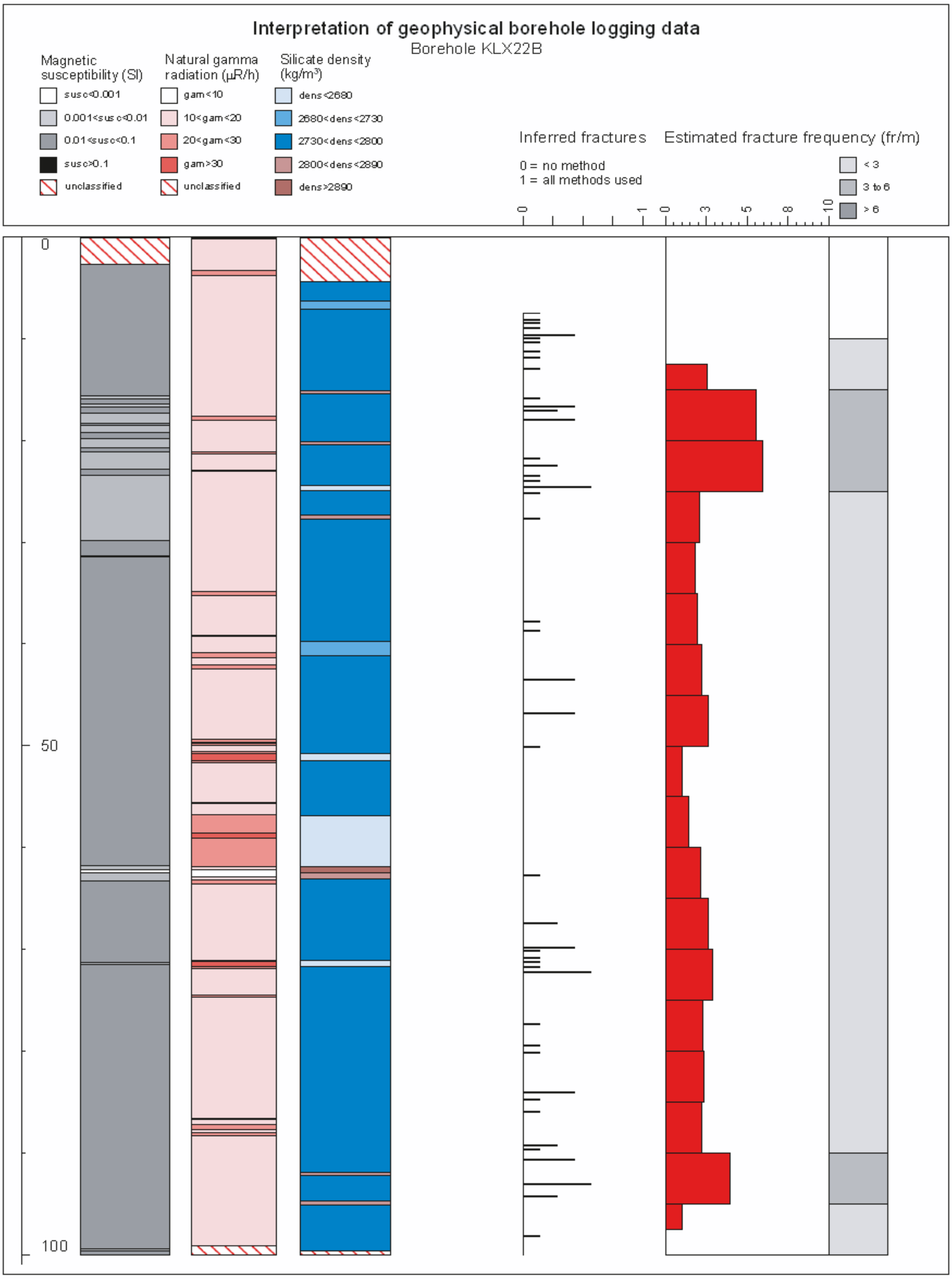

Figure 5-7. *Generalized geophysical logs of KLX22B.*

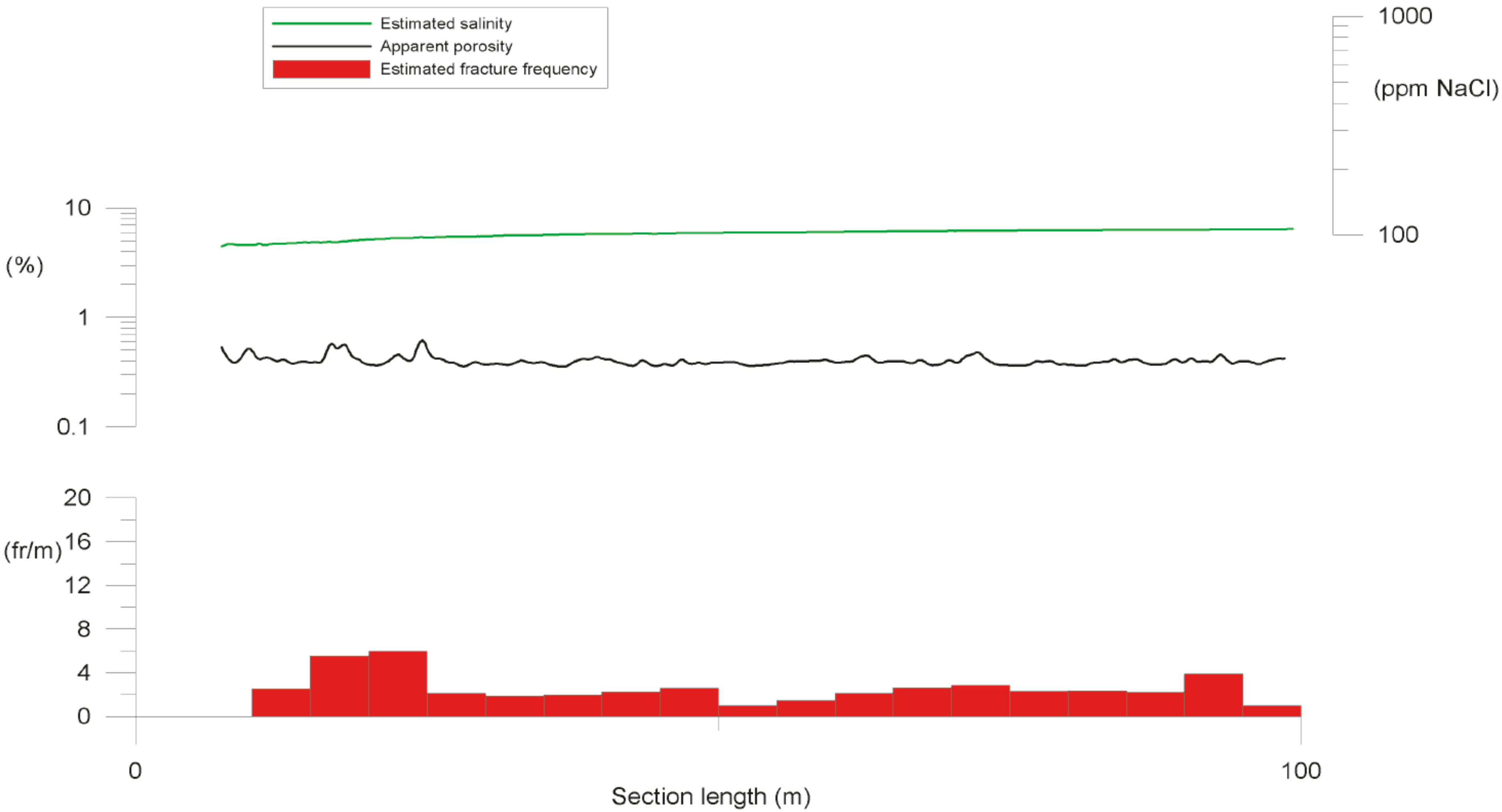

Figure 5-8. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX22B.*

5.2.5 Interpretation of KLX23A

The rocks around KLX23A have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m³ (Figure 5-9). The magnetic susceptibility and natural gamma radiation logs show quite uniform values around 0.02 SI and 20 µR/h respectively, with only a few thin sections with low susceptibility and high radiation indicating fine-grained granite or pegmatite. High-density rocks are absent.

The estimated fracture frequency is, in general, low. Narrow anomalies that indicate fracturing occur in the upper parts of the borehole and at around 34 m, 80 m and 83 m borehole length, characterized by resistivity anomalies. Gradients in the fluid resistivity that indicate flowing water can be seen at 23, 34 and 94 m borehole length. The resistivity and sonic logs are most likely disturbed by lack of borehole water during logging above 15 m length.

The apparent porosity averages at 0.4%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-10). There are no a significant porosity anomalies.

The estimated fluid water salinity is fairly constant at c 170–190 ppm NaCl along the entire borehole.

Table 5-6. Distribution of silicate density classes with borehole length of KLX23A.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	1.5	2
2,680 < dens < 2,730	26	29
2,730 < dens < 2,800	61	69
2,800 < dens < 2,890	0	0
dens > 2,890	0	0

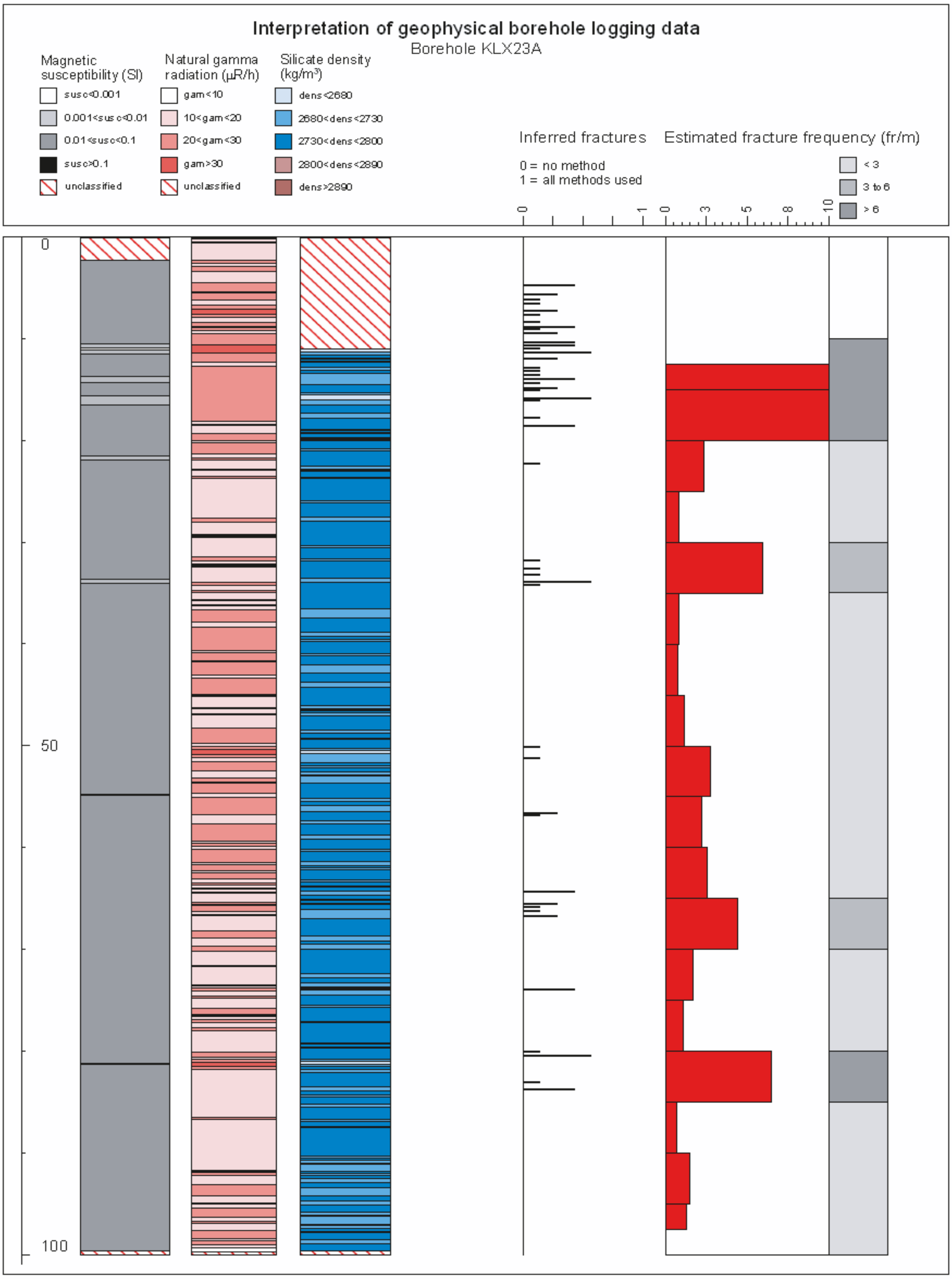

Figure 5-9. Generalized geophysical logs of KLX23A.

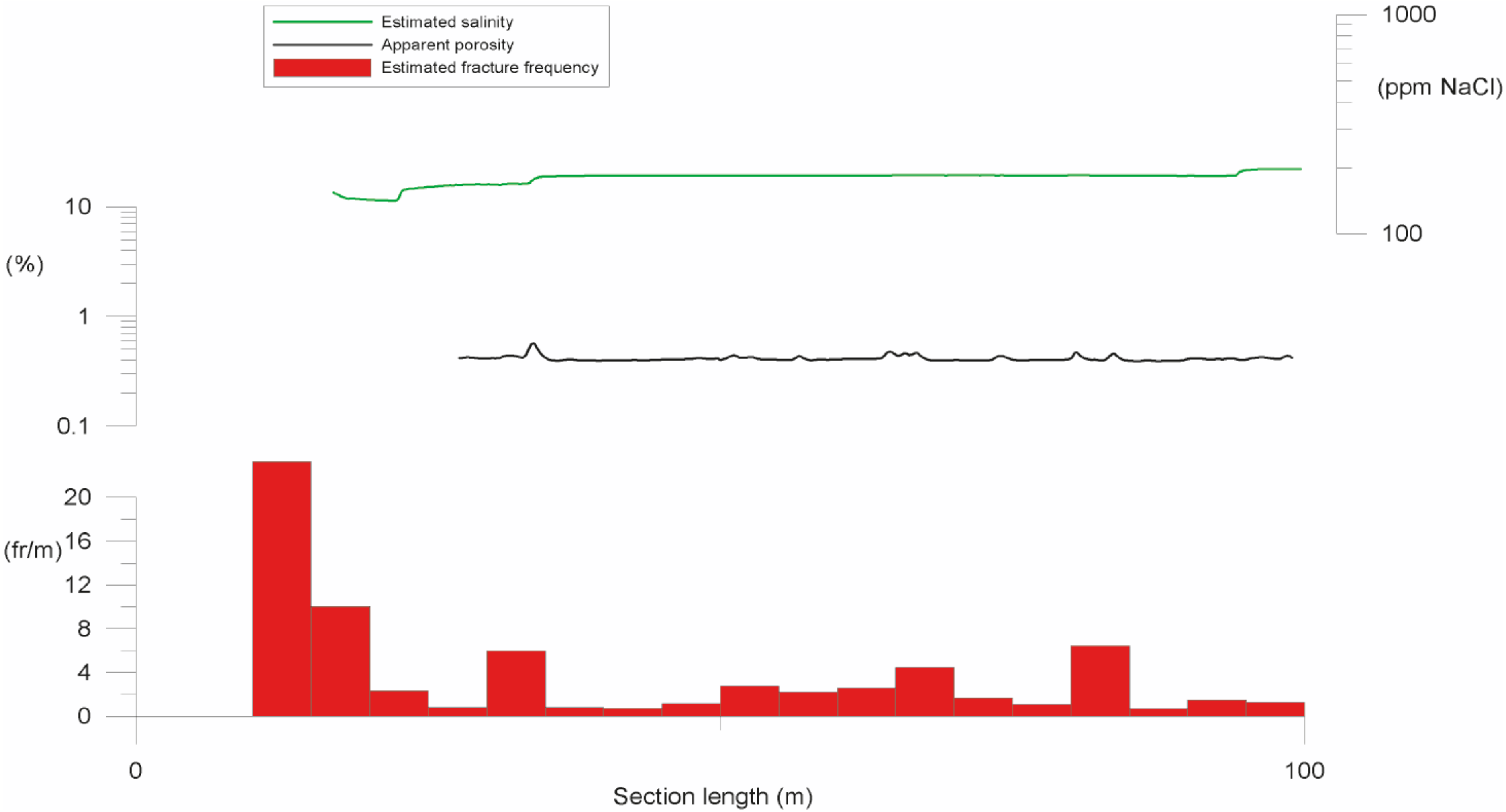

Figure 5-10. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX23A.*

5.2.6 Interpretation of KLX23B

The rocks around KLX23B have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m^3 (Figure 5-11). The magnetic susceptibility and natural gamma radiation logs show quite uniform values around 0.02 SI and 20 µR/h respectively, with only two thin sections with low susceptibility and high radiation indicating fine-grained granite or pegmatite. High-density rocks are absent.

The estimated fracture frequency is low. Hardly any significant resistivity or P-wave velocity anomalies occur along the borehole. Low magnetic susceptibility, which might be related to fracturing and alteration, occur between 13 and 15 m borehole length. A gradient in the fluid resistivity that indicates flowing water can be seen at 42 m borehole length, close to a section with properties typical of fine-grained granite or pegmatite. The resistivity and sonic logs are most likely disturbed by lack of borehole water during logging above 14 m length.

The apparent porosity averages at 0.4%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-12). There is an indication of increased porosity close to the start or the borehole, in the section with highly increased fracturing, but the porosity data do not cover the entire section length.

The estimated fluid water salinity is fairly constant at c 160 ppm NaCl along the section c 14–42 m. At 42 m there is a small but distinct increase in the salinity level up to c 190 ppm NaCl, and this level is kept constant through out the rest of the borehole length.

Table 5-7. Distribution of silicate density classes with borehole length of KLX23B.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	1.5	4
2,680 < dens < 2,730	9	22
2,730 < dens < 2,800	29.5	74
2,800 < dens < 2,890	0	0
dens > 2,890	0	0

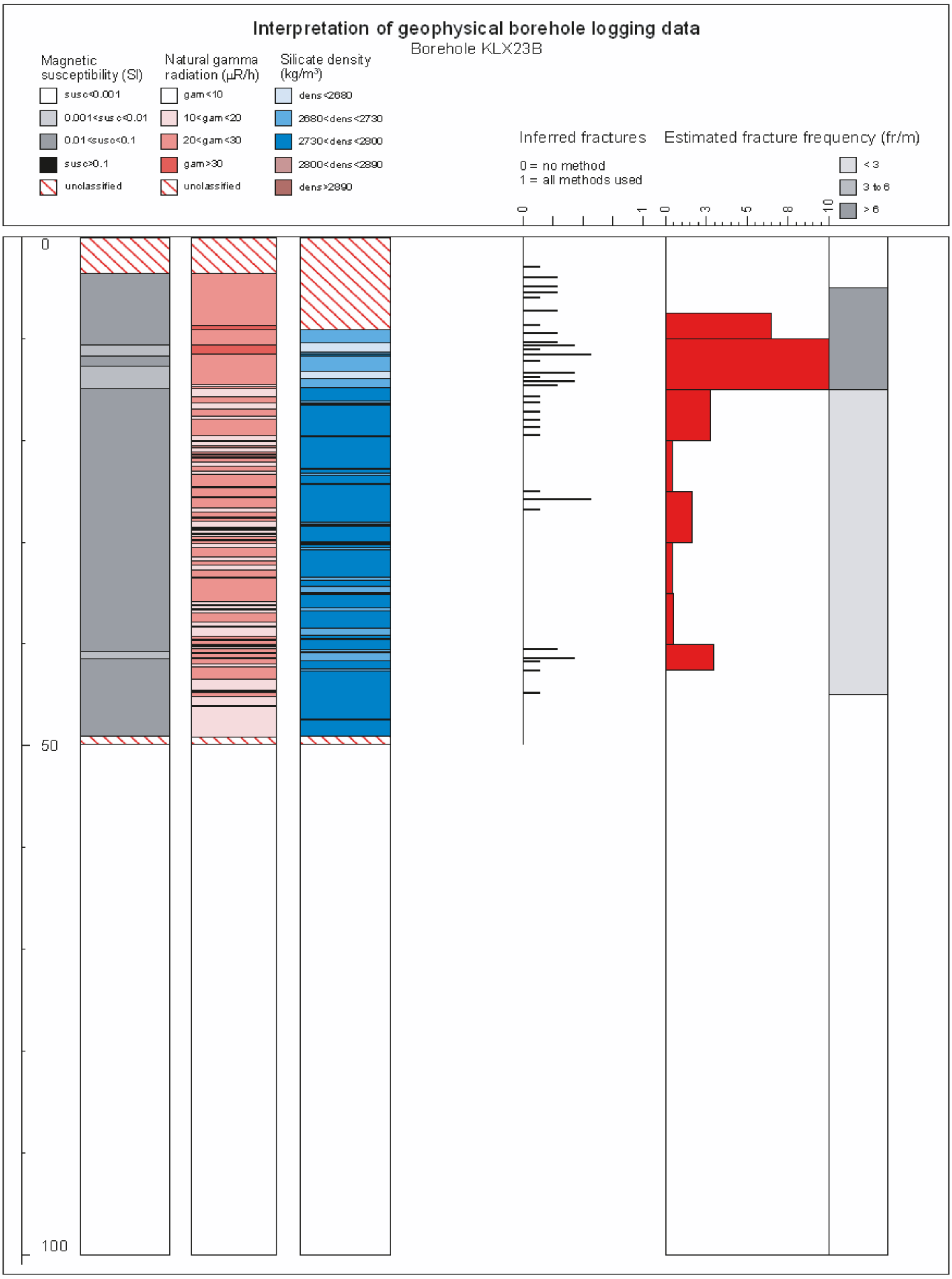

Figure 5-11. *Generalized geophysical logs of KLX23B.*

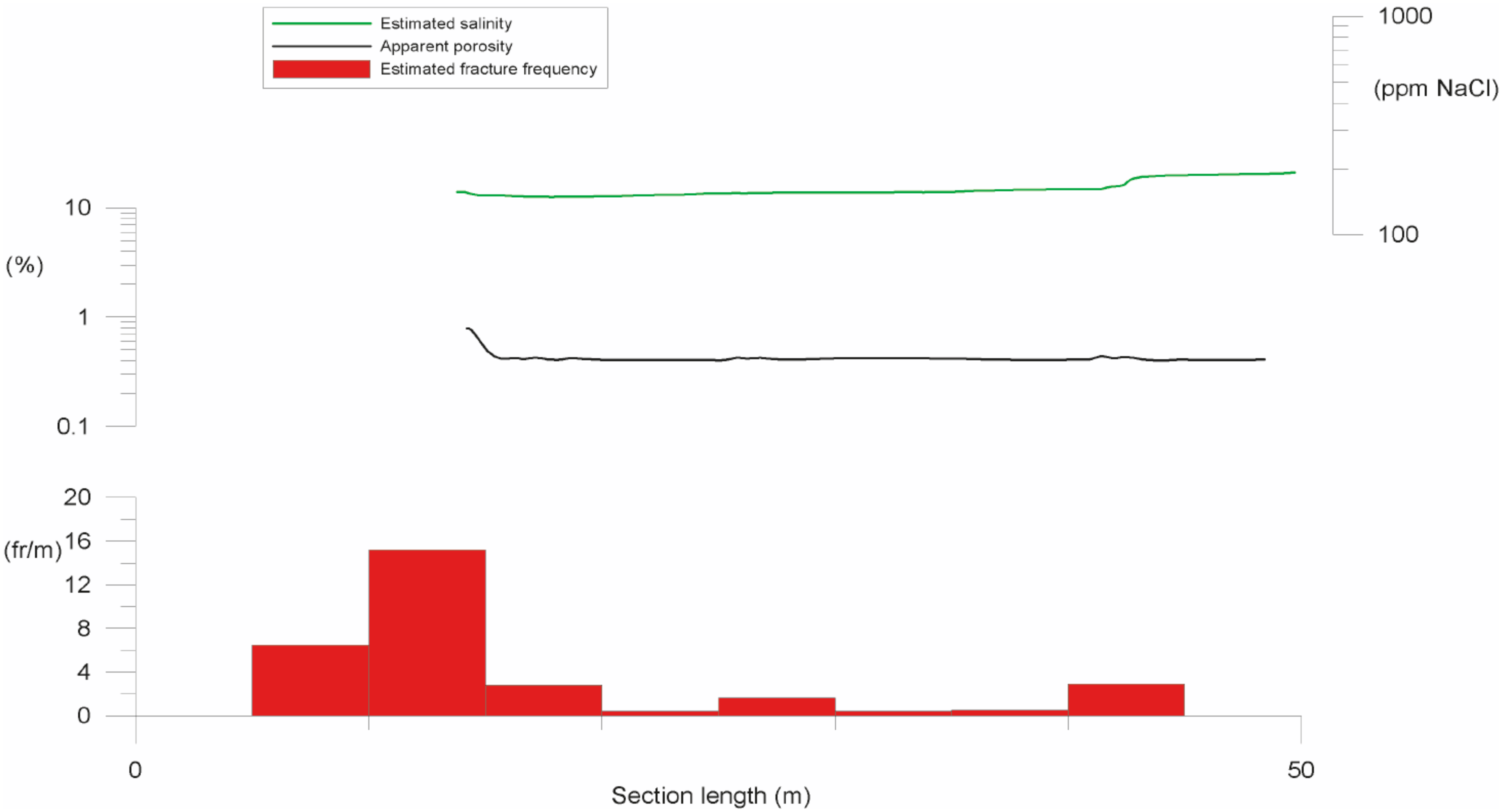

Figure 5-12. Estimated salinity, apparent porosity and estimated fracture frequency of KLX23B.

5.2.7 Interpretation of KLX24A

The rocks around KLX24A have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m^3 (Figure 5-13). Thin sections with high natural gamma radiation, low silicate density and low to moderate magnetic susceptibility occur frequently, especially in the upper 50 m of the borehole. High-density rocks are uncommon.

The estimated fracture frequency is, in general, low. Narrow geophysical anomalies that indicate fracturing occur at around 20 m, 65 m and 75 m borehole length. These sections are characterized by low resistivity, P-wave velocity and magnetic susceptibility. Gradients in the fluid resistivity occur at 20, 79 and 84 m borehole length, indicating flowing water. An anomaly in the temperature gradient can be seen at around 67 m borehole length. The resistivity and sonic logs are most likely disturbed by lack of borehole water during logging above 14 m length.

The apparent porosity averages at 0.3–0.4%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-14). There are three minor porosity anomalies at c 20.5 m, 65.0 m and 75.5 m; all three coincide with slightly increased fracturing.

The estimated fluid water salinity is fairly constant at c 125 ppm NaCl along the section 14–79 m. At 79 m there is a sharp increase in salinity up to c 180 ppm NaCl, and this level is kept constant to the end of the borehole. The sharp increase may indicate the occurrence of a water bearing fracture.

Table 5-8. Distribution of silicate density classes with borehole length of KLX24A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	5	5
2,680 < dens < 2,730	10	11
2,730 < dens < 2,800	78	82
2,800 < dens < 2,890	2.5	2
dens > 2,890	0	0

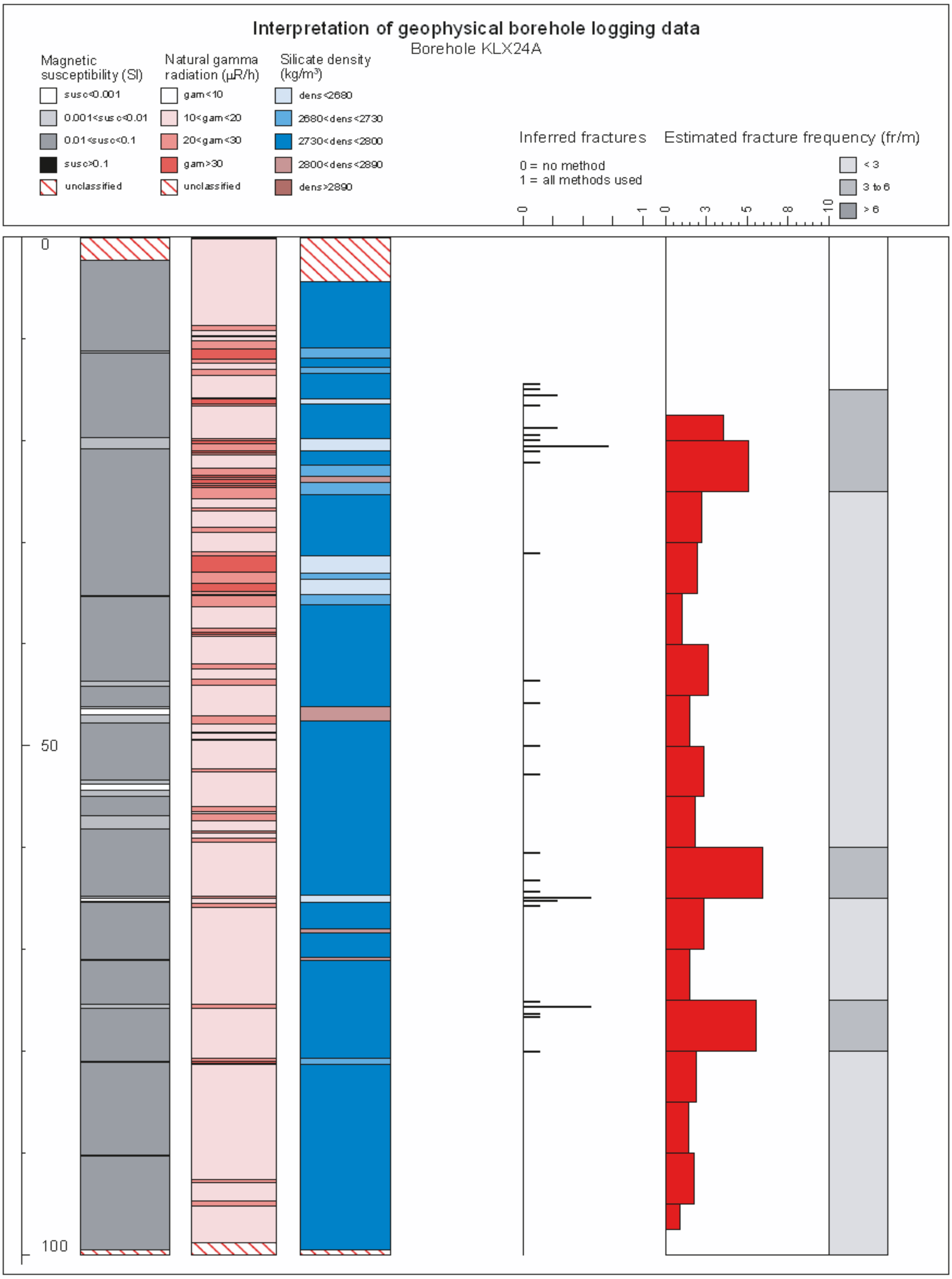

Figure 5-13. Generalized geophysical logs of KLX24A.

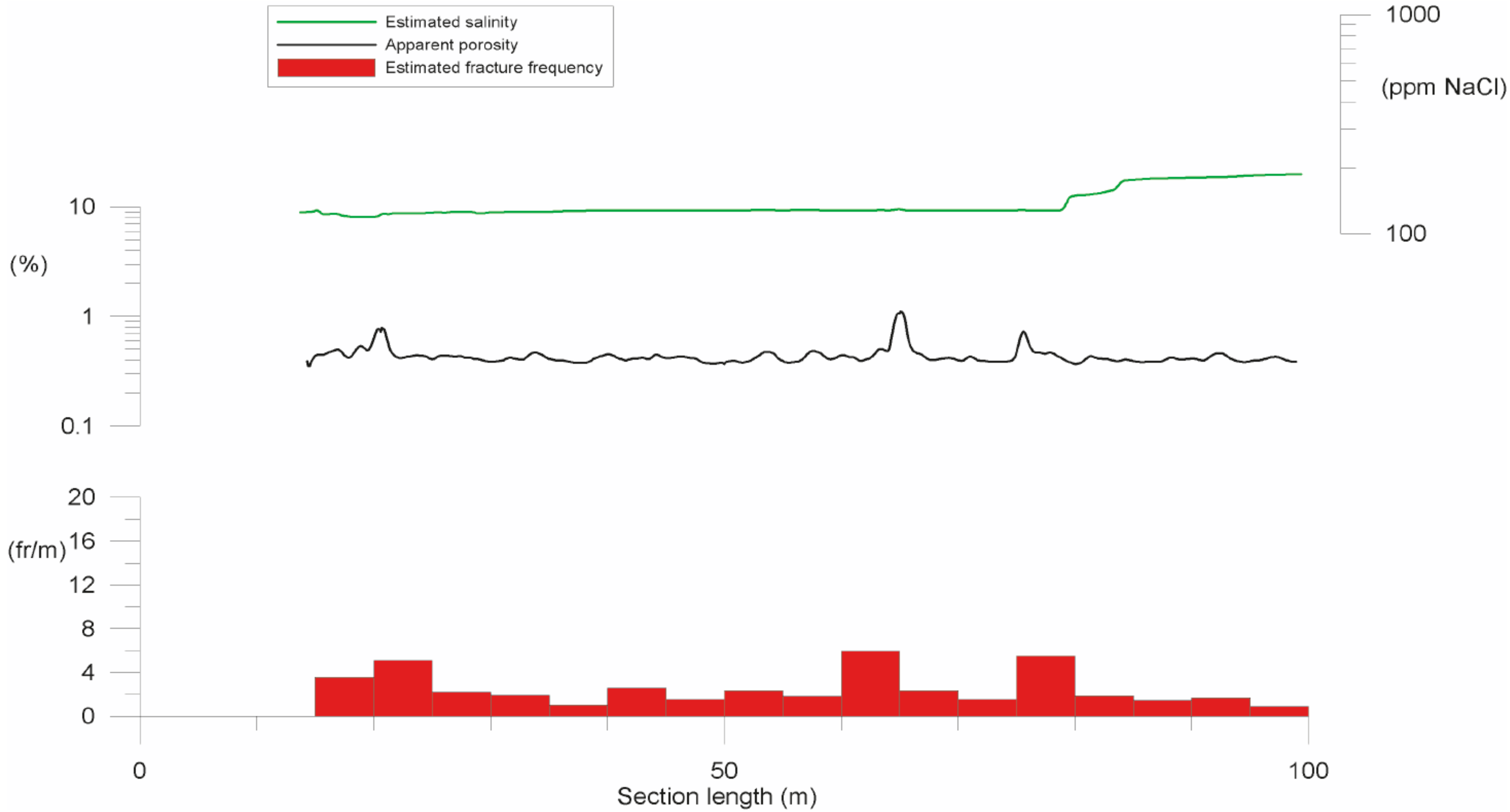

Figure 5-14. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX24A.*

5.2.8 Interpretation of KLX25A

The rocks around KLX25A have properties typical of quartz monzodiorite with silicate density mainly in the interval 2,730–2,800 kg/m^3 (Figure 5-15). A zone of low magnetic susceptibility occurs between 28 and 37 m borehole length. High-density as well as low-density rocks are uncommon.

The estimated fracture frequency is, in general, low. Narrow geophysical anomalies that indicate fracturing occur at around 17 m and 23 m length. These sections are characterized by low resistivity and low P-wave velocity. A sharp gradient in the fluid resistivity, indicating flowing water, occur at 47 m length.

The apparent porosity averages at 0.5–0.6%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-16). There is one minor porosity anomaly at c 17 m, which coincides with increased fracture frequency.

The estimated fluid water salinity is fairly constant at c 130–150 ppm NaCl along the entire borehole.

Table 5-9. Distribution of silicate density classes with borehole length of KLX25A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	0	0
2,680 < dens < 2,730	2	4
2,730 < dens < 2,800	40	92
2,800 < dens < 2,890	2	4
dens > 2,890	0	0

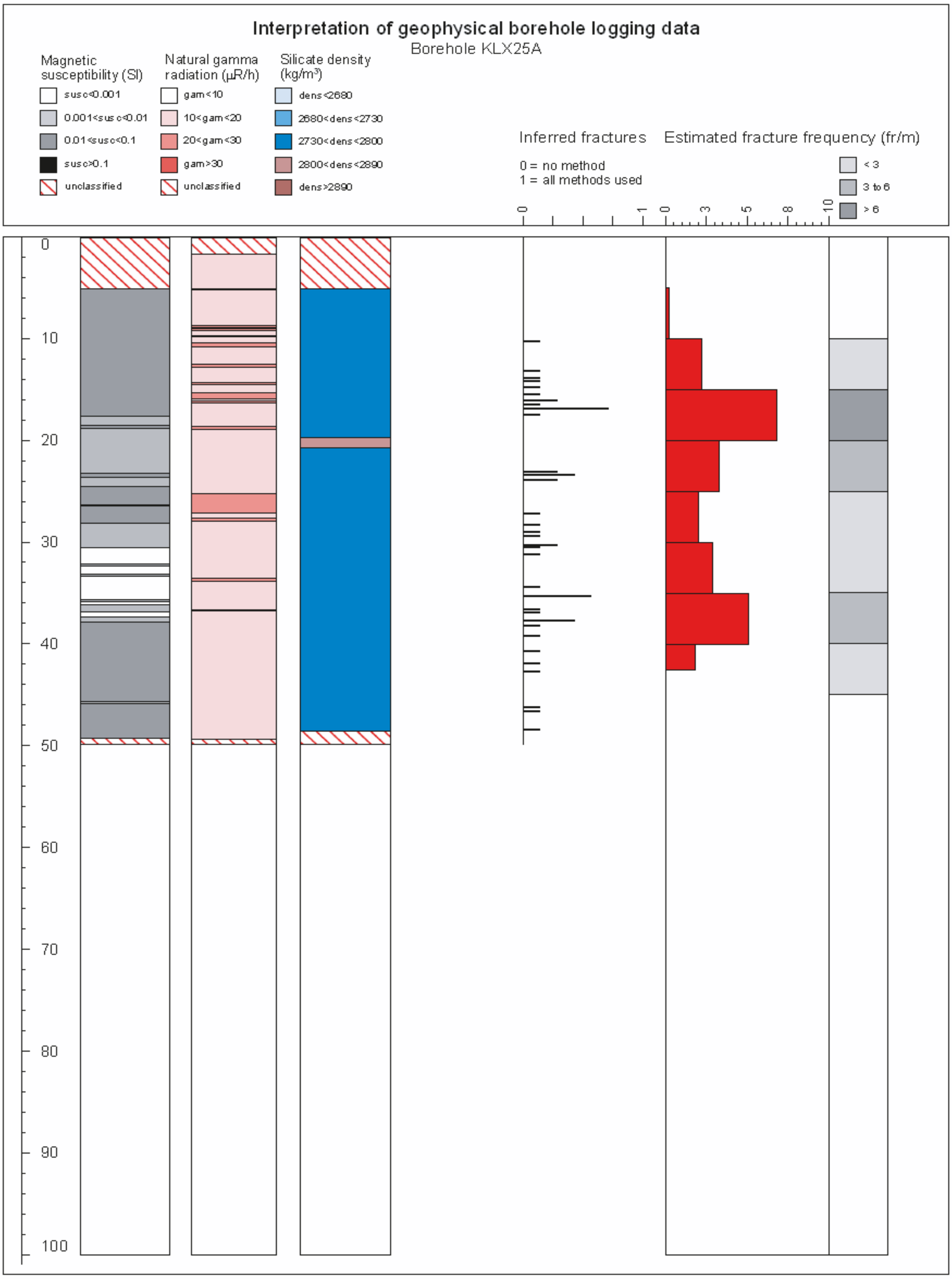

Figure 5-15. *Generalized geophysical logs of KLX25A.*

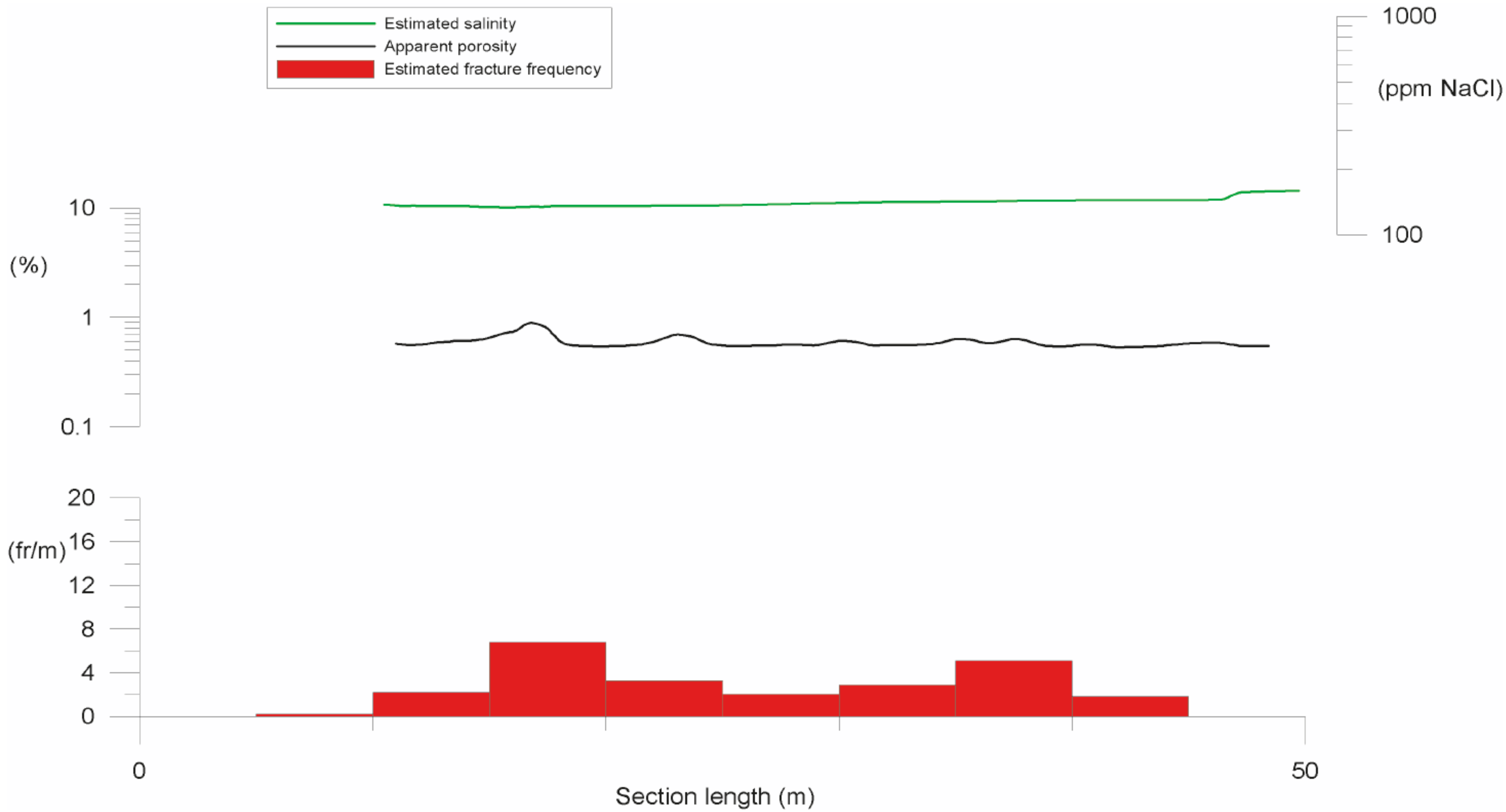

Figure 5-16. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX25A.*

5.2.9 Interpretation of KLX26A

The rocks around KLX26A can be divided into three groups (Figure 5-17). The intervals 18–25 m and 74–97 m have silicate density corresponding to gabbroic composition, low natural gamma radiation and high magnetic susceptibility (> 0.05 SI). The intervals 6–18 m and 46–74 m have similar silicate density and natural gamma radiation but considerably lower magnetic susceptibility. The interval 25–46 m has properties typical of fine-grained granite with low magnetic susceptibility, high natural gamma radiation and silicate density below 2,680 kg/m^3.

The estimated fracture frequency is, in general, moderate. Scattered minor resistivity anomalies are common throughout the borehole. Narrow, more promonent, anomalies that indicate fracturing occur at around 17 m, 38 m, 47 m, 74 m and 98 m borehole length. These sections are characterized by low resistivity and low P-wave velocity.

The apparent porosity averages at 0.4–0.5%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-18). There are no significant porosity anomalies, but there are three minor sections with increased porosity at c 17 m, 38 m and 74 m that coincide with increased fracturing.

The estimated fluid water salinity is fairly constant at c 315–370 ppm NaCl along the entire borehole.

Table 5-10. Distribution of silicate density classes with borehole length of KLX26A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	18	19
2,680 < dens < 2,730	3	3.5
2,730 < dens < 2,800	2.5	3
2,800 < dens < 2,890	8.5	9.5
dens > 2,890	59	65

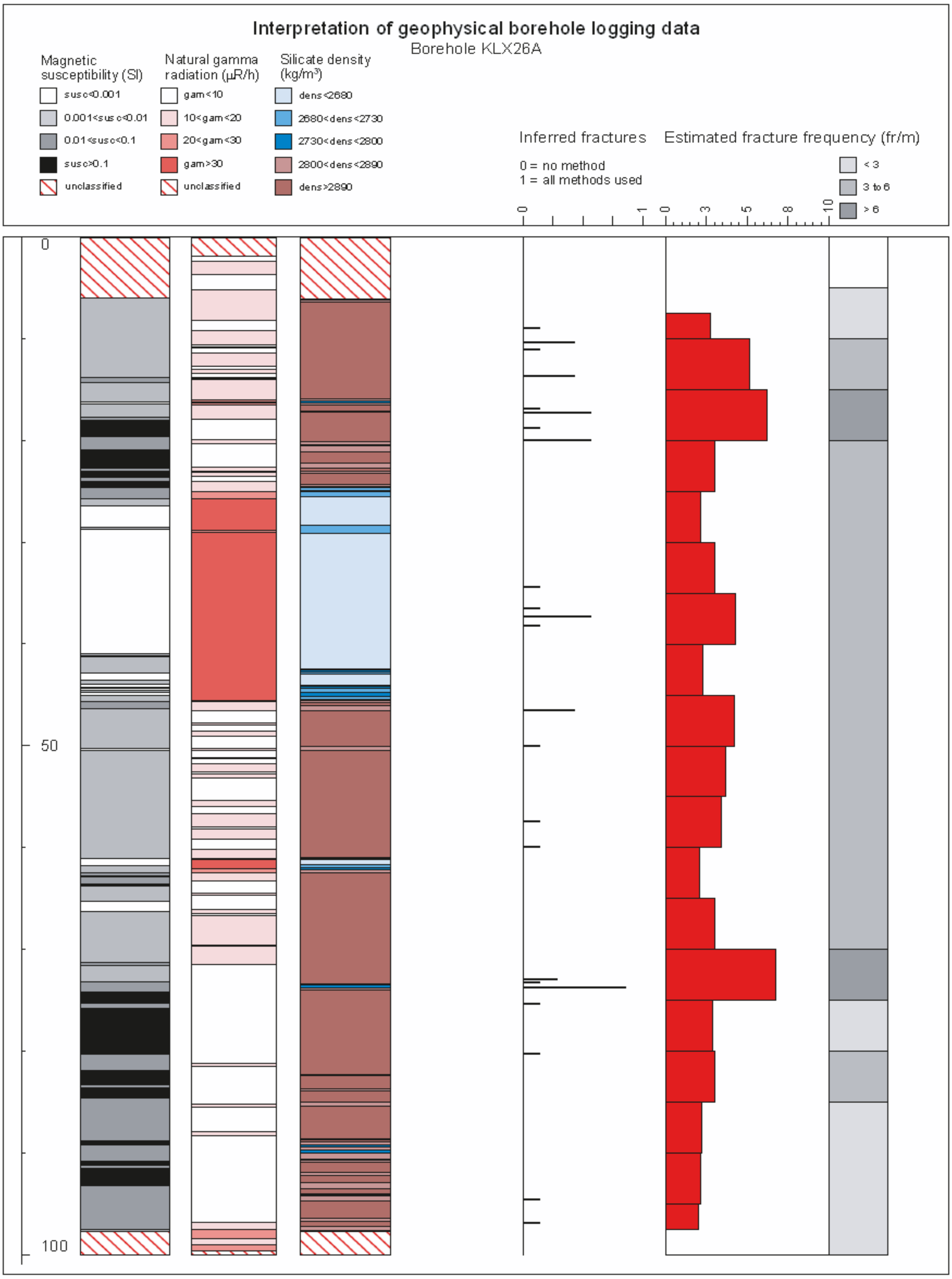

Figure 5-17. Generalized geophysical logs of KLX26A.

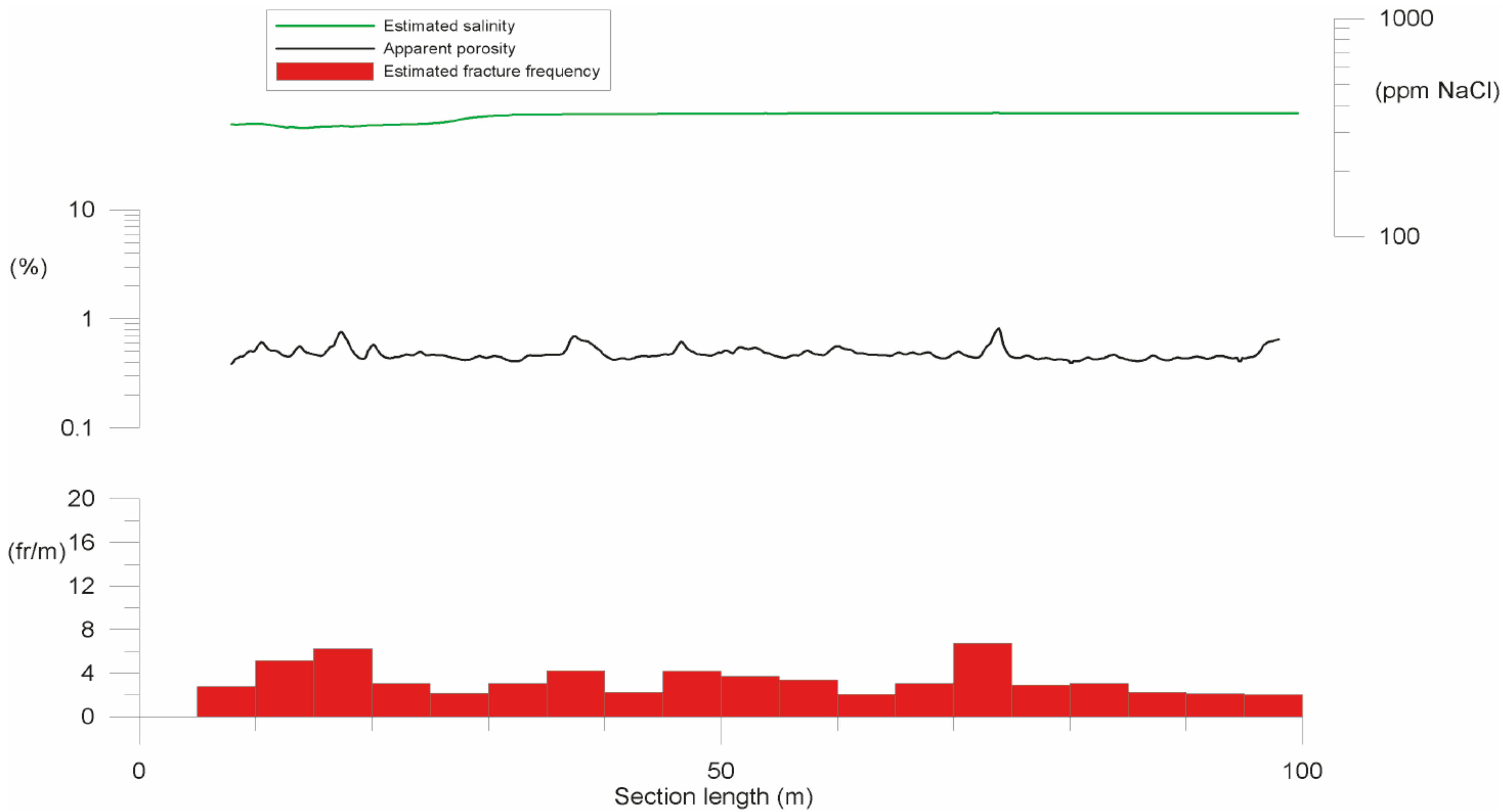

Figure 5-18. Estimated salinity, apparent porosity and estimated fracture frequency of KLX26A.

5.2.10 Interpretation of KLX26B

The rocks around KLX26B can be divided into three groups. The interval 44–50 m has silicate density corresponding to gabbroic composition, low natural gamma radiation and high magnetic susceptibility (> 0.05 SI). The interval 2–27 m has similar silicate density and natural gamma radiation but considerably lower magnetic susceptibility. The interval 27–44 m has properties typical of fine-grained granite with low magnetic susceptibility, high natural gamma radiation and silicate density below 2,680 kg/m^3. Magnetic susceptibility data are missing for parts of the borehole which means that silicate density has not been possible to calculate (Figure 5-19). Those sections are however dominated by low-density rock.

The estimated fracture frequency is, in general, low to moderate. Narrow anomalies that indicate fracturing occur at around 14 m, 20 m and 27 m borehole length. These sections are characterized by low resistivity, P-wave velocity and magnetic susceptibility.

The apparent porosity averages at 0.4–0.5%, which is fairly normal for crystalline rocks with low fracture frequency (Figure 5-20). There are no a significant porosity anomalies.

The estimated fluid water salinity is fairly constant at c 170–200 ppm NaCl along the entire borehole.

Table 5-11. Distribution of silicate density classes with borehole length of KLX26B. Note that parts of the borehole are unclassified due to missing magnetic susceptibility data (Figure 5-19). The unclassified sections are dominated by rocks with low density.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	6	19.5
2,680 < dens < 2,730	0.2	0.5
2,730 < dens < 2,800	0.7	2
2,800 < dens < 2,890	1.5	5
dens > 2,890	23	73

Figure 5-19. *Generalized geophysical logs of KLX26B.*

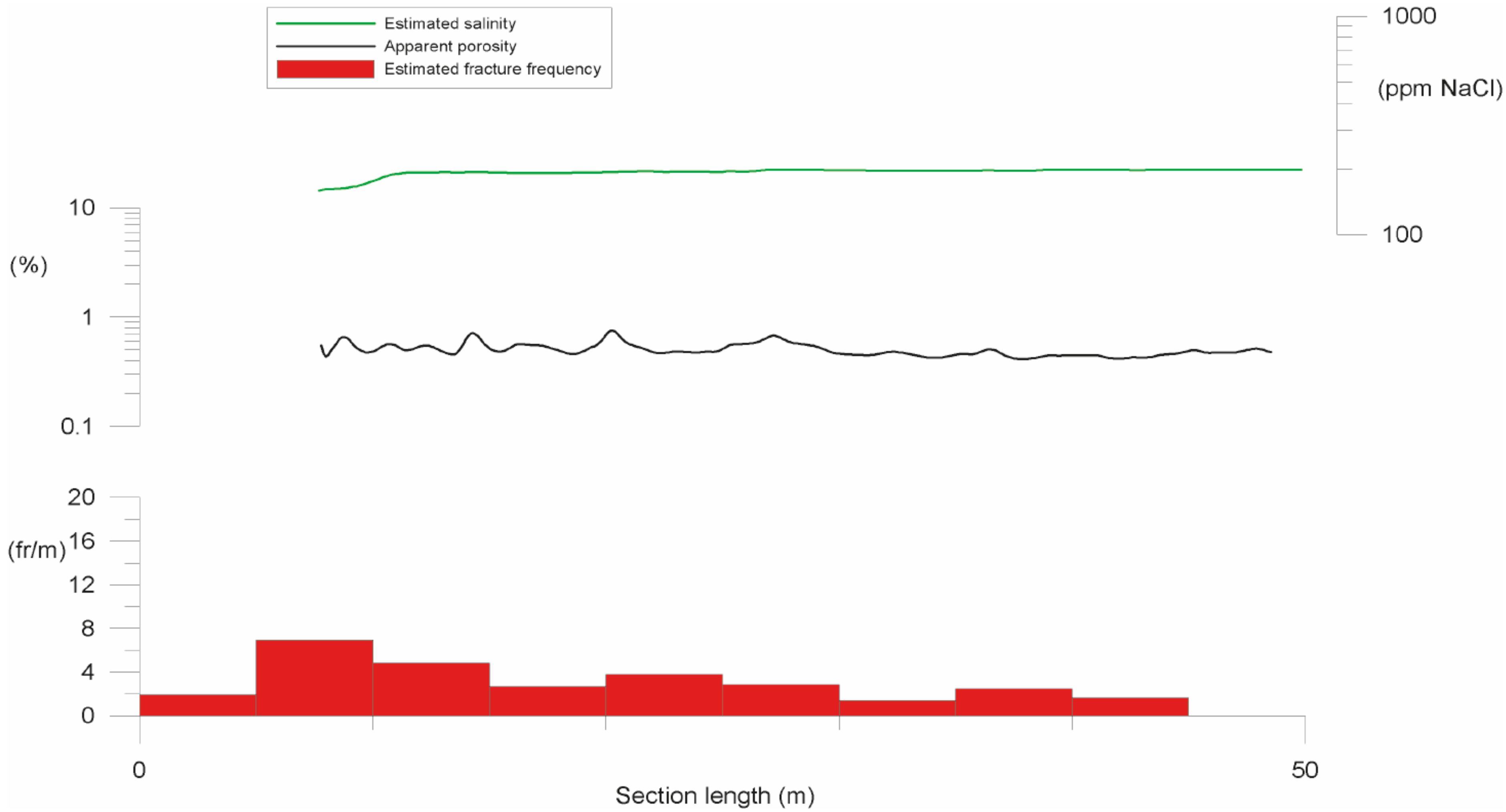

Figure 5-20. *Estimated salinity, apparent porosity and estimated fracture frequency of KLX26B.*

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