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Forsmark site investigation

Interpretation of geophysical borehole measurements from KFM02B, KFM08D and KFM11A

Håkan Mattsson, Mikael Keisu
GeoVista AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored boreholes KFM02B, KFM08D and KFM11A.

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

The silicate density distribution in KFM02B is completely dominated (92% of the borehole length) by silicate density < 2,680 kg/m^3. Along the majority of the borehole length the natural gamma radiation is 20–36 µR/h. This combination of physical properties is typical for metagranite rock. In the section c 328–428 m there is a significant increase in the natural gamma radiation and there is also a general decrease in density and in magnetic susceptibility, which may indicate that the bedrock along the section is dominated by pegmatitic granite. The estimated fracture frequency is generally low in KFM02B. Possible deformation zones are indicated along the sections c 100–115 m, 166–171 m, 411–432 m, 449–450 m, 463–473 m and 490–509 m.

The silicate density distribution in KFM08D is completely dominated (82% of the borehole length) by silicate density < 2,680 kg/m^3 (and mainly > 2,640 kg/m^3). The magnetic susceptibility is generally 0.005–0.010 SI. This indicates that the majority of the rocks in the vicinity of KFM08D have granitic mineral composition. In the section c 400–745 m there is a significant decrease in the natural gamma radiation; lower than the normal level for meta granitic rock in this area. Along the section there is no significant change in the density but there is a decrease in magnetic susceptibility. Along the section there is also a slight, but distinct, increase in estimated fracture frequency related to an increased occurrence of low resistivity anomalies. The data most likely indicates some kind of mineral alteration. The fracture frequency estimated for KFM08D is generally low and partly moderate. Sections with greatly increased fracturing (possible deformation zones) are indicated at c 145–150 m, 185–210 m, 385–393 m, 820–832 m, 902–908 m and 923–930 m.

The geophysical logs from KFM11A together indicate a heterogeneous distribution of rock types in the vicinity of the borehole. There is a general trend of high densities in the upper part of the borehole (indicating amphibolites), intermediate densities in the middle part (indicating granodioritic and tonalitic rocks) and low densities in the lowermost part, which corresponds to granite rocks. The estimated fracture frequency indicates a generally low degree of fracturing in KFM11A, but there are also several possible deformation zones. These are indicated in the sections c 75–101 m, 250–280 m, 373–382 m, 431–440 m, 497–546 m, 585–627 m, 679–704 m, 715–729 m, 788–802 m and 816–826 m.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålen KFM02B, KFM08D och KFM11A.

Syftet med denna undersökning är framförallt 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 borrkärnekarteringen samt som underlag vid den geologiska enhålstolkningen.

Fördelningen av silikatdensitet i KFM02B domineras helt (92 % av borrhålslängden) av silikatdensitet < 2 680 kg/m^3. Längs större delen av hålet är den naturliga gammastrålningen 20–36 μR/h och denna kombination av fysikaliska egenskaper är typisk för metagranit. Längs sektionen ca 328–428 m är den naturliga gammastrålningen förhöjd i kombination med sänkt densitet och magnetisk susceptibilitet. Detta kan indikera förekomst av pegmatitisk granit. Den uppskattade sprickfrekvensen i KFM02B är generellt låg, men möjliga deformationszoner kan identifieras längs sektionerna ca 100–115 m, 166–171 m, 411–432 m, 449–450 m, 463–473 m och 490–509 m.

Fördelningen av silikatdensitet i KFM08D domineras helt (82 % av borrhålslängden) av silikatdensitet < 2 680 kg/m^3 (och i huvudsak > 2 640 kg/m^3) samt magnetisk susceptibilitet i intervallet ca 0,005–0,010 SI. Data indikerar att huvuddelen av bergarterna i närheten av KFM08D har granitisk mineralsammansättning. Längs sektionen ca 400–745 m är det en tydlig nergång i naturlig gammastrålning, till en nivå som är lägre än den vanliga strålningsnivån för metagranit. Det finns ingen signifikant förändring i densitet men den magnetiska susceptibiliteten är något sänkt. I intervallet finns dessutom en liten, men tydlig, förhöjning av sprickfrekvensen kopplad till ett ökat antal resistivitetsanomalier. Data indikerar troligen någon form av mineralomvandling. Den uppskattade sprickfrekvensen för KFM08D är generellt sätt låg, men partier finns där den är förhöjd. Möjliga deformationszoner kan identifieras längs sektionerna ca 145–150 m, 185–210 m, 385–393 m, 820–832 m, 902–908 m och 923–930 m.

De geofysiska loggarna från KFM11A indikerar en väldigt heterogen bergartsfördelning i närheten av borrhålet. En generell trend kan identifieras med förhöjd densitet i borrhålets övre del (indikerar troligen amfibolit), medeldensitet i hålets mellersta del (motsvarande granodiorit och tonalit) samt generellt låg densitet i borrhålet nedersta del (motsvarande granitisk sammansättning). Den uppskattade sprickfrekvensen för KFM11A är generellt låg, men där finns ett flertal möjliga deformationszoner indikerade längs sektionerna ca 75–101 m, 250–280 m, 373–382 m, 431–440 m, 497–546 m, 585–627 m, 679–704 m, 715–729 m, 788–802 m och 816–826 m.

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 Simpevarp/Laxemar. This document reports the results gained from the interpretation of geophysical borehole logging data from the cored boreholes KFM02B, KFM08D and KFM11A in Forsmark (Figure 1-1).

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings, including estimated fracture frequency. Calculations of the estimated salinity and apparent porosity are also presented for the boreholes. The logging measurements were conducted in 2007 by Rambøll /1, 2/.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (Table 1-1).

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the activity plan number (AP PF 400-07-018). Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Tolkning av geofysiska borrhålsdata från KFM02B, KFM08D och KFM11A	AP PF 400-07-018	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	3.0

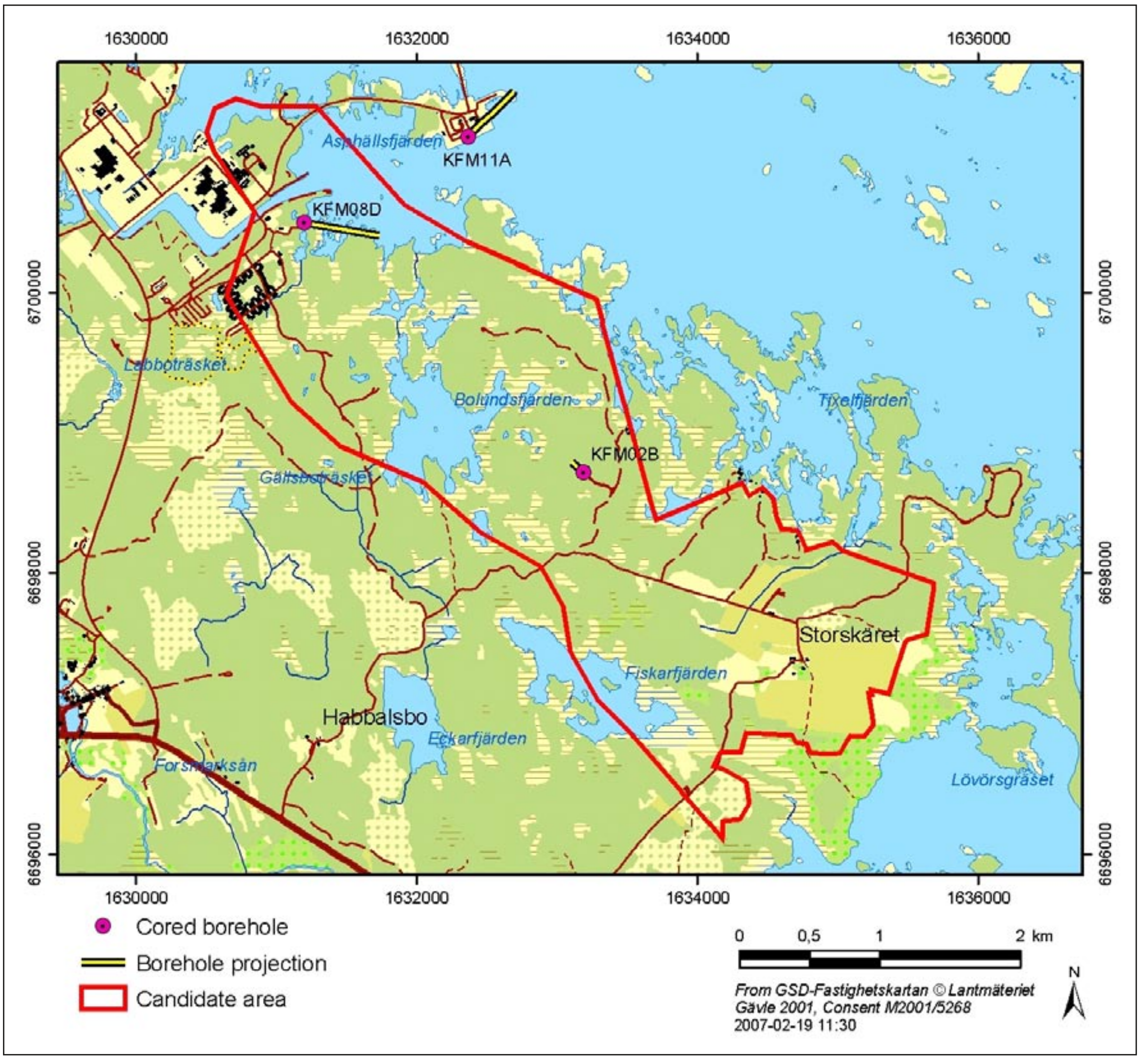

Figure 1-1. *Map of the Forsmark area, showing the location of the boreholes KFM02B, KM08D and KFM11A.*

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 cored boreholes. These parameters indicate saline water and the transportation 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 mappings and as supportive information during the so called "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 v3.2 (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, median 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 depth co-ordinates (0.1 m point distance).

The density logging data are calibrated with respect to petrophysical data from KLX20A /3/. The magnetic susceptibility logging data are calibrated with respect to a combination of petrophysical data from the boreholes KFM01A and KFM02A /4, 5/.

2. Interpretation rock types (generalization of the silicate density, magnetic susceptibility and natural gamma radiation loggings)

The silicate density is calculated with reference to /6/ and the data are then divided into 5 sections **indicating** a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /7/. The sections are bounded by the threshold values

		granite	<	2,680 kg/m³
2,680 kg/m³	<	granodiorite	<	2,730 kg/m³
2,730 kg/m³	<	tonalite	<	2,800 kg/m³
2,800 kg/m³	<	diorite	<	2,890 kg/m³
2,890 kg/m³	<	gabbro		

The magnetic susceptibility logging is subdivided into steps of decades and the natural gamma radiation is divided into steps of "low" (< 20 μR/h), "medium" (20 μR/h < gamma < 36 μR/h), "high" (36 μR/h < gamma < 53 μR/h) and "very high" (> 53 μR/h).

3. For the cored boreholes 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 /8/; $\sigma = a\,\sigma_w^k\,\phi^m + \sigma_s$ 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", "k" and "m" are constants. Since "a", "k" and "m" may vary with variations in the borehole fluid resistivity, estimations of the constants are performed with reference to the actual fluid resistivity in each borehole respectively.

The estimated water salinity is calculated as ppm NaCl in water following the simple relation from Crain's Petrophysical Handbook where:

$$WS = \frac{400000}{(1.8t + 32)\sqrt[0.88]{\rho}}$$

WS = Water salinity (ppm NaCl), *t* = temperature (°C) and ρ = resistivity (Ωm).

The salinity is only calculated for cored boreholes.

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 loggings. Parameters for the power functions were estimated by correlating the weighted sum to the mapped fracture frequency in the cored boreholes KFM01A and KFM02A. The linear coefficients (weights) used are presented in Table 4-1.

5. Report evaluating the results.

Table 4-1. Threshold values 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	KFM02B	1.0	1.5	1.5	1.0	1.5	4.0	4.0	–
Weight	KFM02B	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–
Threshold	KFM08D	2.0	2.5	2.5	1.0	1.5	5.0	5.0	–
Weight	KFM08D	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–
Threshold	KFM11A	1.5	1.5	1.5	1.0	1.5	6.0	6.0	–
Weight	KFM11A	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–

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 were saved separately in ASCII-files. The data processing was performed on the ASCII-files. The data used for interpretation were:

- Density (gamma-gamma)
- Magnetic susceptibility
- Natural gamma radiation
- Focused resistivity (300 cm)
- Focused resistivity (140 cm)
- Sonic (P-wave)
- Caliper mean
- Caliper 1D
- SPR (Single Point Resistance)
- Short normal resistivity (16 inch)
- Long normal resistivity (64 inch)
- Fluid resistivity
- Fluid temperature

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 of salinity and apparent porosity help identifying saline ground water and porous rocks.

4.4 Nonconformities

Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are not presented for the long normal resistivity loggings since the calculation show unrealistic values.

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 all boreholes the natural gamma radiation data have noise levels clearly above the recommended value of 0.3 μR/h. In KFM11A also the density and magnetic susceptibility data have noise levels significantly above the recommended levels. The high noise levels in KFM11A most likely affect the interpretation of high frequency anomalies in this borehole. To reduce the influence of the noise, all logs were average filtered prior to the interpretation.

A qualitative inspection was performed on the loggings. The data were checked for spikes and/or other obvious incorrect data points. Erroneous data were replaced by null values (–999) by the contractor Rambøll prior to the delivery of the data, and all null values were disregarded in the interpretation.

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	KFM02B	KFM08D	KFM11A	Recommended max noise level
Density (kg/m^3)	6	7	12	3–5
Magnetic susceptibility (SI)	$1\cdot10^{-4}$	$2\cdot10^{-4}$	$3\cdot10^{-4}$	$1\cdot10^{-4}$
Natural gamma radiation (μR/h)	0.8	0.6	1.0	0.3
Long normal resistivity (%)	0.4	0.1	0.8	2.0
Short normal resistivity (%)	0.09	0.07	0.3	2.0
Fluid resistivity (%)	0.02	0.01	0.03	2
Fluid temperature (°C)	$1\cdot10^{-4}$	$2\cdot10^{-4}$	$4\cdot10^{-4}$	0.01
Lateral resistivity (%)	Not used	Not used	Not used	2
Single point resistance (%)	0.4	0.1	0.8	No data
Caliper (meter)	$1\cdot10^{-6}$	$3\cdot10^{-5}$	$3\cdot10^{-5}$	0.0005
Focused resistivity 300 (%)	10	2.0	25	No data
Focused resistivity 140 (%)	3	0.8	7	No data
Sonic (m/s)	13	20	18	20

5.2.1 Interpretation of KFM02B

The results of the generalized logging data and fracture estimations of KFM02B are presented in Figure 5-1, and in a more detailed scale in Appendix 1. The distribution of silicate density classes with borehole length is presented in Table 5-2.

The silicate density distribution in KFM02B is completely dominated (92% of the borehole length) by silicate density < 2,680 kg/m³. Along the majority of the borehole length the natural gamma radiation is 20–36 μR/h. This combination of physical properties is typical for metagranite rock.

However, in the section c 328–428 m there is a significant increase in the natural gamma radiation, averaging at c 40–80 μR/h. Along this section there is a general decrease in the density, which averages at c 2,610 kg/m³, and also in the magnetic susceptibility which is mainly in the interval c 0.010–0.030 SI. A possible interpretation is that the bedrock along the section is dominated by pegmatitic granite.

In general, the magnetic susceptibility data shows large variations in the interval 0.0010–0.0100 SI, which indicates a very heterogenic distribution of magnetic minerals (most likely magnetite) in the rocks in the vicinity of the borehole.

Short sections (< 5 m long) with significantly increased density occur mainly in the intervals c 87–300 m and 450–540 m. The high density anomalies coincide with decreased magnetic susceptibility and natural gamma radiation, which suggests the occurrences of amphibolite dykes. Some of the indicated amphibolite dykes occur close to positive natural gamma radiation anomalies, which most likely indicate the occurrences of fine-grained granite or pegmatite and all in all this indicates that mafic and felsic dykes are spatially related.

The estimated fracture frequency is generally low in KFM02B. The geophysical signatures of the possible deformation zones are presented in Table 5-3. Possible deformation zones are indicated along the sections c 100–115 m, 166–171 m, 411–432 m, 449–450 m, 463–473 m and 490–509 m. All these section are characterized by decreased resistivity, magnetic susceptibility; some show caliper anomalies and the majority also show partly decreased P-wave velocity (Table 5-3). The sections 449–450 and 464–469 show partly increased P-wave velocity due to the indicated occurrences of amphibolites (mafic rocks generally have higher seismic velocities compared to granitic rocks).

The geophysical signature of the indicated deformation zones suggests brittle fracturing in combination with mineral alteration.

Table 5-2. Distribution of silicate density classes with borehole length in KFM02B.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680 (granite)	442	92
2,680 < dens < 2,730 (granodiorite)	14	3
2,730 < dens < 2,800 (tonalite)	8	1.5
2,800 < dens < 2,890 (diorite)	8	1.5
dens > 2,890 (gabbro)	12	2

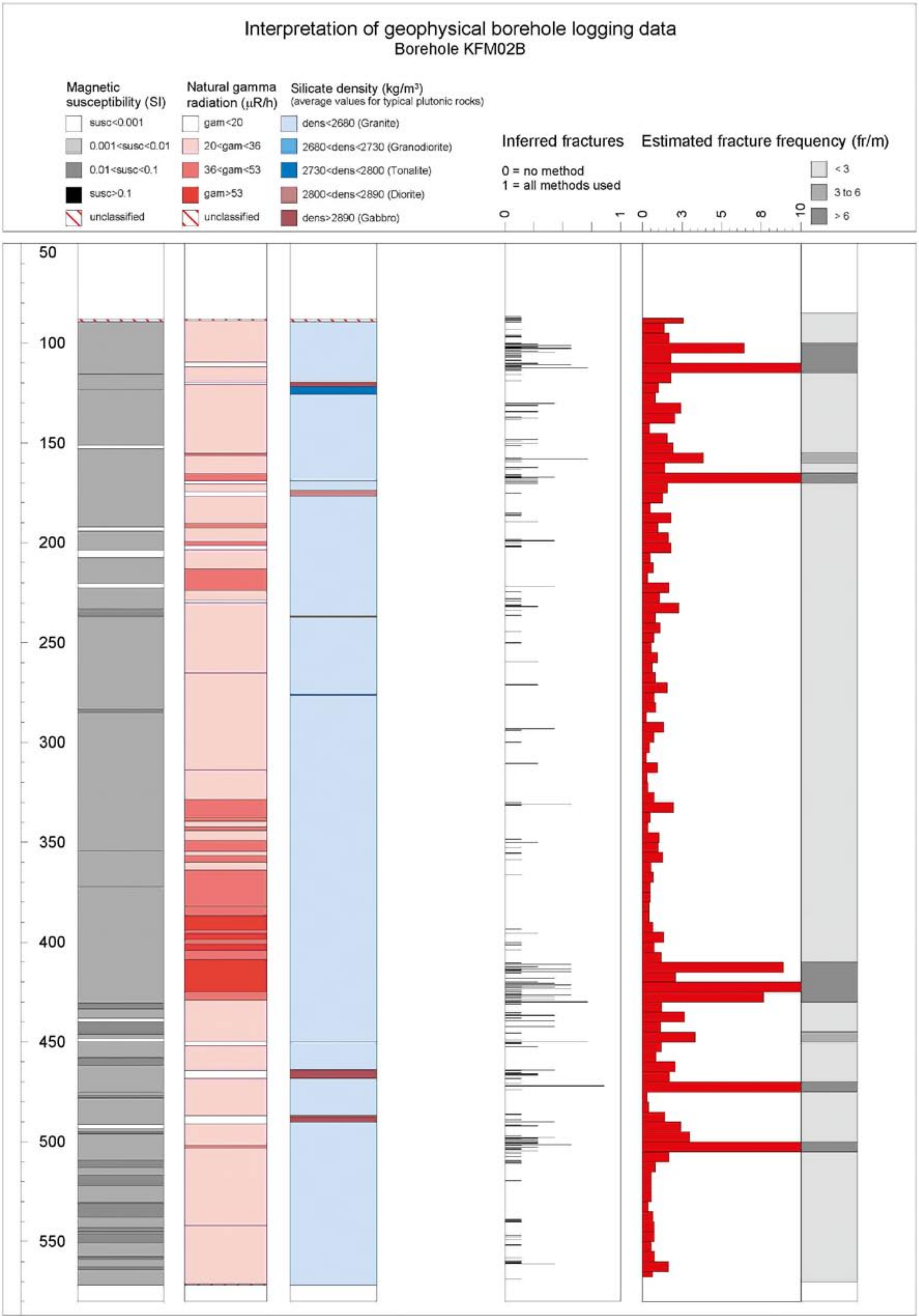

Figure 5-1. Generalized geophysical logs of KFM02B.

Table 5-3. Possible deformation zones in KFM02B and their geophysical signatures.

Borehole length (m)	Resistivity	P-wave velocity (sonic)	Magnetic susceptibility	Borehole diameter (caliper 1D)
100–115	Significantly decreased	Significantly decreased	Significantly decreased	Major anomalies
166–171	Significantly decreased	Significantly decreased	Significantly decreased	Major anomalies
411–432	Significantly decreased	Significantly decreased	Partly decreased	No anomalies
449–450	Significantly decreased	Partly decreased	Significantly decreased	Minor anomaly
463–473	Significantly decreased	Partly decreased	Significantly decreased	One major anomaly
490–509	Significantly decreased	Partly decreased	Partly decreased	Major anomalies

The apparent porosity of the rocks in the vicinity of KFM02B is presented in Figure 5-2 (black line). In general the porosity averages at c 0.7%, which is considered normal for crystalline rocks in this area. Sections with increased apparent porosity coincide very well with the possible deformation zones listed above. The vertical temperature gradient averages at c 11°C/km. Anomalies in the temperature gradient can be related to in or out flow of water, which indicates water bearing fractures. Significant temperature gradient anomalies occur at c 100 m, 414 m and 500 m, and all three anomalies coincide with indicated deformation zones. There are also minor temperature gradient anomalies in the sections c 114–180 m and 445–485 m.

In the section c 89–500 m the estimated fluid water salinity (green line in Figure 5-2) is rather constant at c 8,500 ppm NaCl. From 500 m and down to the end of the borehole (at c 572 m) the salinity decreases, ending at c 5,400 ppm NaCl.

5.2.2 Interpretation of KFM08D

The results of the generalized logging data and fracture estimations of KFM08D are presented in Figure 5-3, and in a more detailed scale in Appendix 2. The distribution of silicate density classes with borehole length is presented in Table 5-4.

The silicate density distribution in KFM08D is completely dominated (82% of the borehole length) by silicate density < 2,680 kg/m^3 (and mainly > 2,640 kg/m^3). The magnetic susceptibility is generally 0.005–0.010 SI. Silicate density in the interval 2,640–2,680 kg/m^3 indicates that the majority of the rocks in the vicinity of KFM08D have granitic mineral composition. Along the upper half of the borehole (section c 50–400 m) the natural gamma radiation is mainly in the interval 20–36 µR/h, which in combination with the density and magnetic susceptibility data is typical for meta granite.

In the section c 400–745 m there is a significant decrease in the natural gamma radiation, which averages at c 15–20 µR/h, and this is lower than the normal level for meta granitic rock in this area. Along the section there is no significant change in the density but there is a decrease in magnetic susceptibility. The fact that the density is unchanged suggests that there is no lithological (rock type) difference between the sections 50–400 m and 400–745 m, and the decrease in natural gamma radiation and magnetic susceptibility most likely indicates some kind of mineral alteration.

Along the intervals c 570–655 m and 895–935 m there is a mixture of sections with increased and decreased density that coincide with decreased and increased natural gamma radiation respectively. This indicates amphibolites occurring side by side with fine-grained granite, which suggests a spatial relation between mafic and felsic dykes.

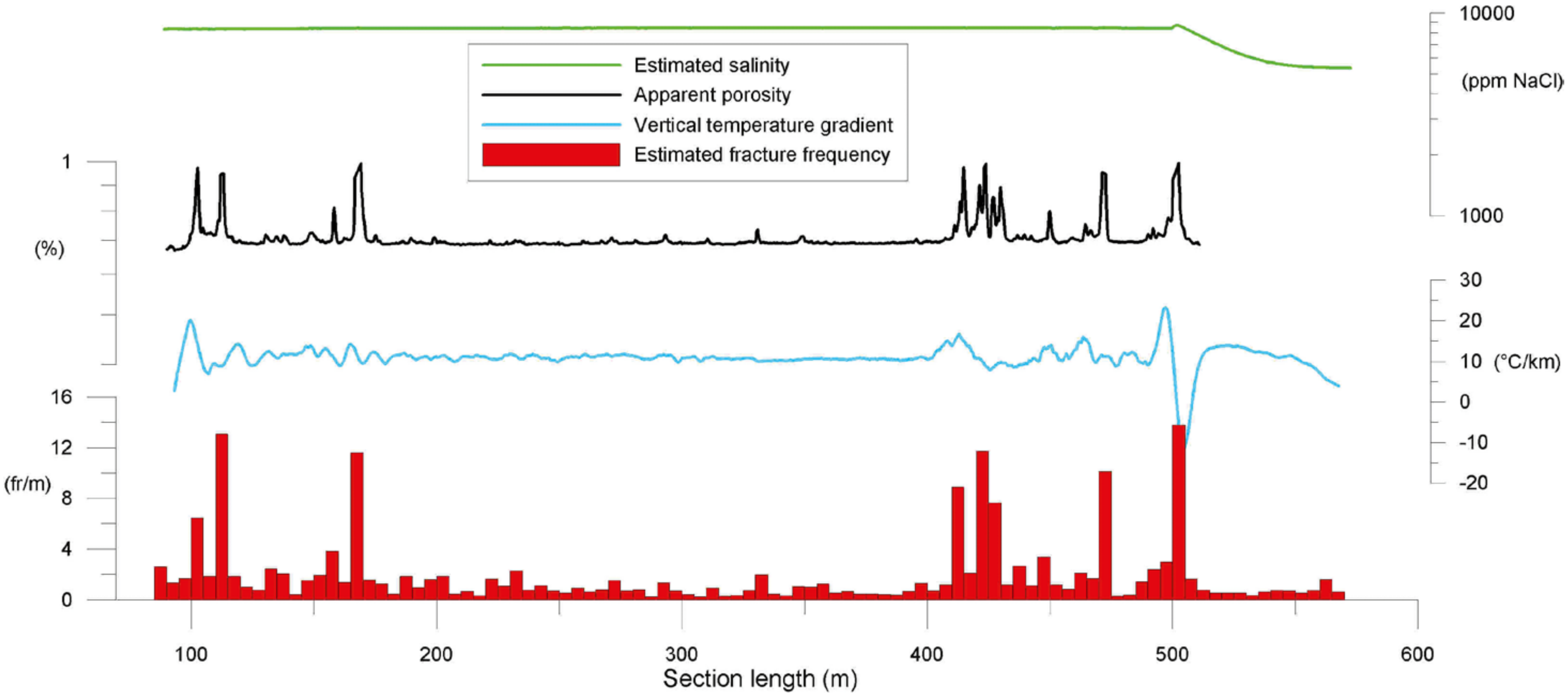

Figure 5-2. *Estimated salinity, apparent porosity, vertical temperature gradient and estimated fracture frequency of KFM02B.*

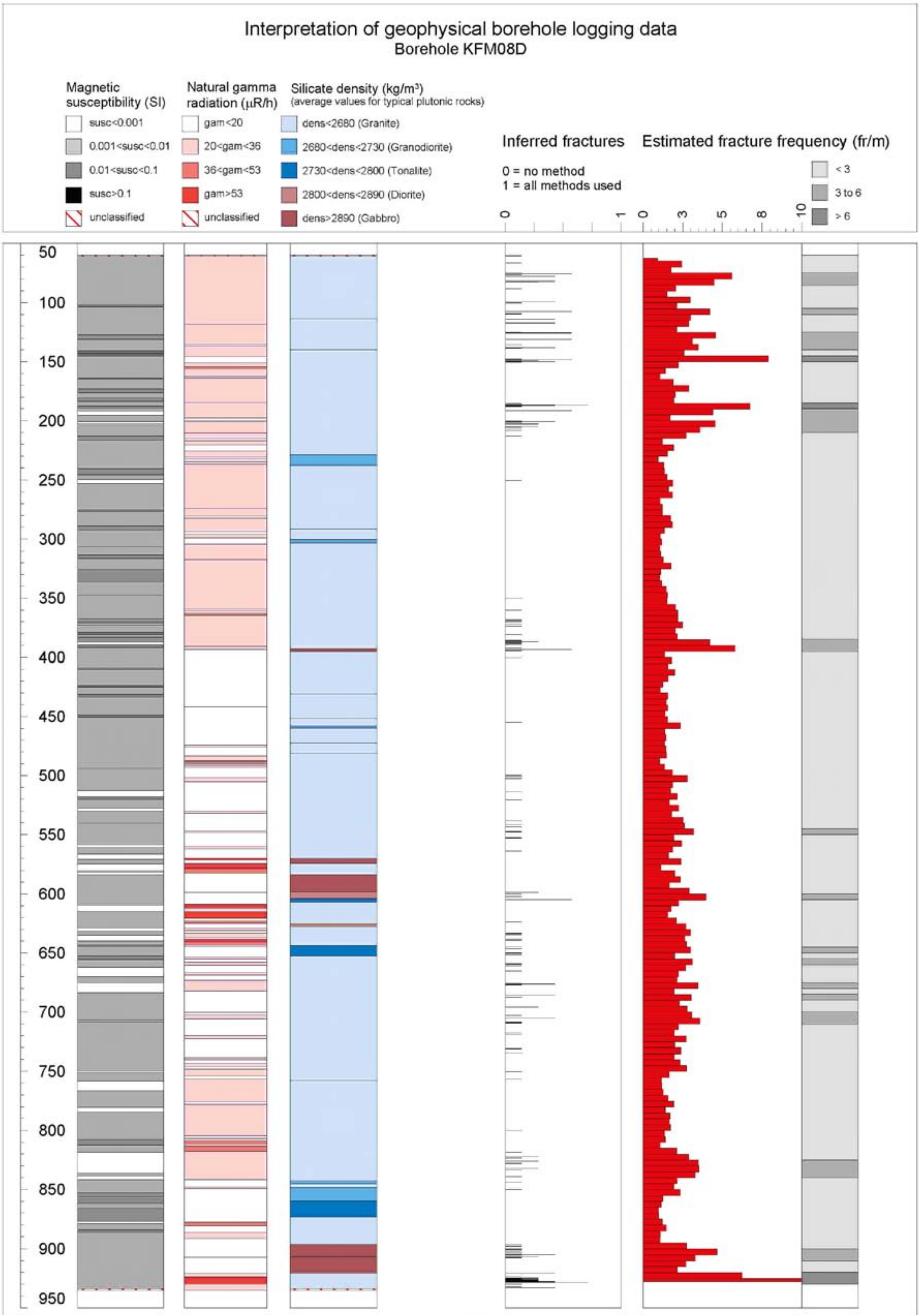

Figure 5-3. Generalized geophysical logs of KFM08D.

Table 5-4. Distribution of silicate density classes with borehole length in KFM08D.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680 (granite)	715	82
2,680 < dens < 2,730 (granodiorite)	70	8
2,730 < dens < 2,800 (tonalite)	38	4
2,800 < dens < 2,890 (diorite)	12	2
dens > 2,890 (gabbro)	37	4

There is a slight increase in the silicate density along the sections c 230–240 m and 840–876 m. In the upper section the density anomaly coincides with decreased magnetic susceptibility and no change in natural gamma radiation and in the lower section the increase in density coincides with decreased natural gamma radiation and increased magnetic susceptibility. The data corresponds to rocks with granodioritic to tonalitic mineral composition.

The fracture frequency estimated for KFM08D is generally low and partly moderate. Along the interval c 535–755 m there is a slight, but distinct, increase in estimated fracture frequency related to an increased occurrence of low resistivity anomalies. This increase in resistivity anomalies may be related to the decrease in natural gamma radiation and magnetic susceptibility discussed earlier. Sections with greatly increased fracturing (possible deformation zones) are indicated at c 145–150 m, 185–210 m, 385–393 m, 820–832 m, 902–908 m and 923–930 m. The geophysical signatures of the possible deformation zones are presented in Table 5-5.

The apparent porosity averages at c 0.6–0.7%, which is normal for crystalline rocks in this area. Significantly increased porosity occurs partly in the sections c 74–210 m, 382–398 m and 902–927 m, which coincides well with possible deformation zones (Figure 5-4). Water bearing fractures are indicated by vertical temperature gradient anomalies and these occur at c 77–210 m, 380–405 m, 670–693 m and 755–930 m. Note that the water bearing fractures indicated at 670–693 m and 755–770 m do not coincide with possible deformation zones, which suggests that they are related to single open fractures. Apart from this indication there is a clear correlation between possible deformation zones, temperature gradient anomalies and increased porosity.

Table 5-5. Possible deformation zones in KFM08D and their geophysical signatures.

Borehole length (m)	Resistivity	P-wave velocity (sonic)	Magnetic susceptibility	Borehole diameter (caliper 1D)
145–150	Significantly decreased	Significantly decreased	Significantly decreased	No anomalies
185–210	Significantly decreased	Partly decreased	Significantly decreased	One minor anomaly
385–393	Significantly decreased	No anomalies	Partly decreased	No anomalies
820–832	Partly decreased	Partly decreased	Significantly decreased	Major anomalies
902–908	Significantly decreased	Partly decreased	Significantly decreased	Major anomalies
923–930	Significantly decreased	Significantly decreased	Significantly decreased	Major anomalies

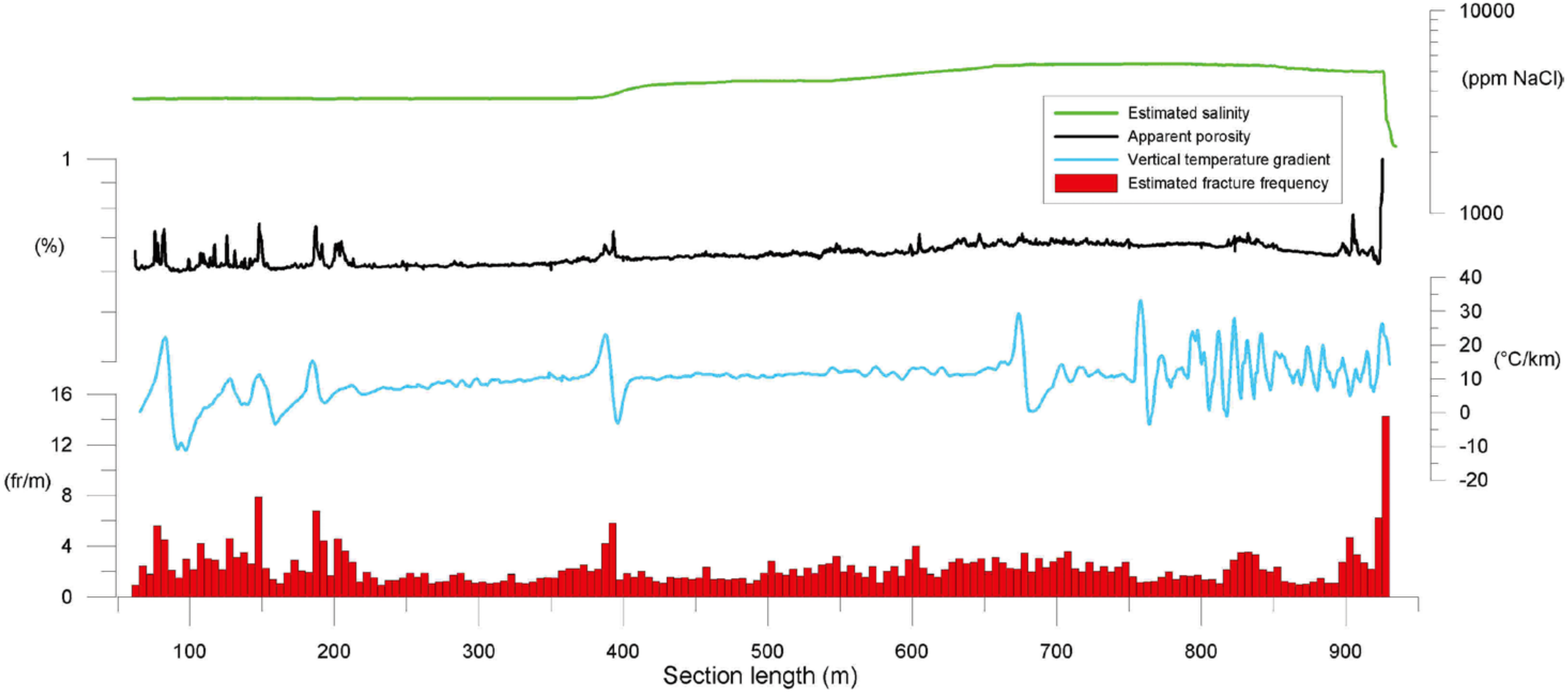

Figure 5-4. *Estimated salinity, apparent porosity, vertical temperature gradient and estimated fracture frequency of KFM08D.*

The estimated salinity is fairly constant at c 3,700 ppm NaCl in the interval 60–382 m. At c 382 m (close to an indicated water bearing fracture) the salinity increases up c 4,400 ppm NaCl, and at c 560 m the salinity shows a second increase up to c 5,400 ppm NaCl.

5.2.3 Interpretation of KFM11A

The results of the generalized logging data and fracture estimations of KFM11A are presented in Figure 5-5, and in a more detailed scale in Appendix 3. The distribution of silicate density classes with borehole length is presented in Table 5-6.

The generalized geophysical logs together indicate a heterogeneous distribution of rock types in the vicinity of KFM11A. In the section c 72–190 m there is a large occurrence of intervals with increased density and decreased natural gamma radiation and magnetic susceptibility. This combination of physical properties is typical for amphibolites. A c 20 m long interval with similar properties also occurs at c 357–377 m. Apart from this interval the section c 190–585 m is mainly characterized by silicate density in the range 2,680–2,730 kg/m^3, decreased natural gamma radiation and largely varying magnetic susceptibility. The silicate density data indicate rock with granodioritic mineral composition. At c 274–283 m there is significantly increased natural gamma radiation, decreased magnetic susceptibility and silicate density < 2,680 kg/m^3, which indicates the occurrence of fine-grained granite or pegmatite.

In the interval c 225–250 m the density averages at c 2,750 kg/m^3 and the magnetic susceptibility is c 0.015–0.040 SI, which corresponds to tonalite rock fairly rich in magnetite.

The lower third of KFM11A (section c 585–850 m) is characterized by silicate density < 2,680 kg/m^3, partly decreased magnetic susceptibility and natural gamma radiation of 20–36 μR/h. The combination of physical properties may correspond to meta granite rock. There is partly increased natural gamma radiation (40–50 μR/h) in the intervals c 702–722 m and 800–813 m. The density in these sections is c 2,610–2,640 kg/m^3, which is low and may indicate leucocratic granite.

The fracture frequency estimated from the geophysical logs indicates a generally low degree of fracturing in KFM11A, but there are also several possible deformation zones indicated by the data. The possible deformation zones are indicated in the sections c 75–101 m, 250–280 m, 373–382 m, 431–440 m, 497–546 m, 585–627 m, 679–704 m, 715–729 m, 788–802 m and 816–826 m. The geophysical signatures of the possible deformation zones are presented in Table 5-7.

Table 5-6. Distribution of silicate density classes with borehole length in KFM11A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680 (granite)	326	42
2,680 < dens < 2,730 (granodiorite)	238	31
2,730 < dens < 2,800 (tonalite)	101	13
2,800 < dens < 2,890 (diorite)	32	4
dens > 2,890 (gabbro)	77	10

Table 5-7. Possible deformation zones in KFM11A and their geophysical signatures.

Borehole length (m)	Resistivity	P-wave velocity (sonic)	Magnetic susceptibility	Borehole diameter (caliper 1D)
75–101	High frequency of negative anomalies	Increased (indicates mafic rock)	Partly decreased	Few, minor anomalies
250–280	High frequency of negative anomalies	Partly decreased	Decreased	Few, minor anomalies
373–382	Significant decrease	Minor decrease	Decreased	Several, minor anomalies
431–440	Significant decrease	Minor decrease	Partly decreased	No anomalies
497–546	Significant decrease	Partly decreased	Partly decreased	Several, major anomalies
585–627	Significant decrease	No anomalies	Partly decreased	Several, major anomalies
679–704	High frequency of negative anomalies	Partly decreased	Decreased	Few, distinct anomalies
715–729	Significant decrease	Partly decreased	Decreased	Several, minor anomalies
788–802	High frequency of negative anomalies	Partly decreased	Decreased	Several, minor anomalies
816–826	Decreased	Partly decreased	Decreased	Minor anomalies

The apparent porosity generally varies in the range 0.6–0.8%, with an average of c 0.7% (Figure 5-6). This is considered normal for crystalline rocks in this area. Significant high porosity anomalies mainly occur in the sections c 75–115 m, 375–380 m, 497–545 m, 590–627 m and 680–705 m, and all these anomalies coincide with possible deformation zones presented in Table 5-7.

In the section c 350–480 m there is a large number of anomalies in the vertical temperature gradient log (Figure 5-6) that indicate water bearing fractures. The estimated fracture frequency is rather low in this section but there are major variations in the density and natural gamma radiation logs, which suggests an increased occurrence of mafic and felsic dykes. The contact zones of dykes are often fractured and constitute possible conductors for water.

The vertical temperature data also indicate water bearing fractures in the possible deformation zones at c 497–546 m, 679–704 m and 788–802 m.

The estimated salinity is rather constant at c 6,350 ppm NaCl in the section c 70–535 m. In the interval c 535–590 m there is an increase in salinity up to c 11,500 ppm NaCl, and this level is kept fairly constant along the remaining part of the borehole.

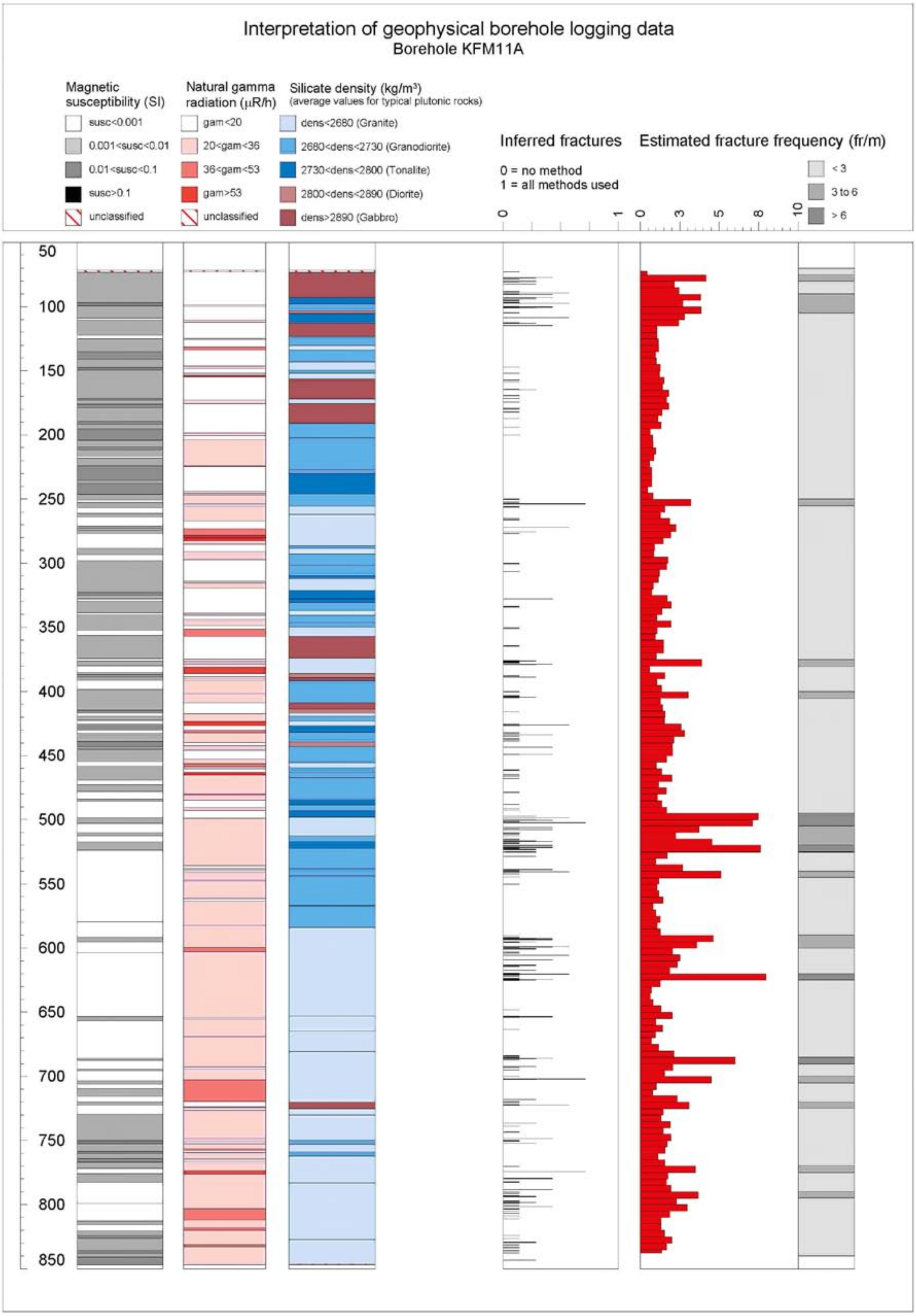

Figure 5-5. Generalized geophysical logs of KFM11A.

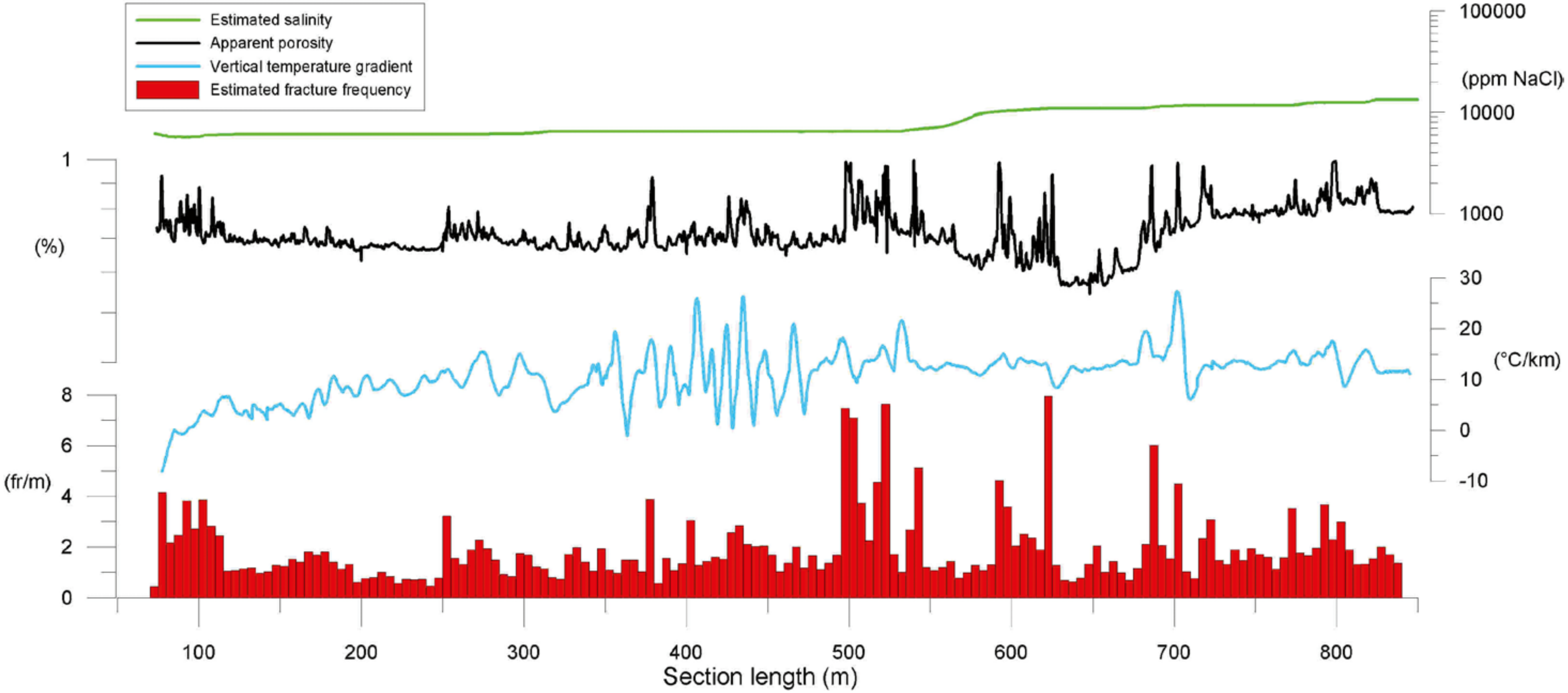

***Figure 5-6.** Estimated salinity, apparent porosity, vertical temperature gradient and estimated fracture frequency of KFM11A.*

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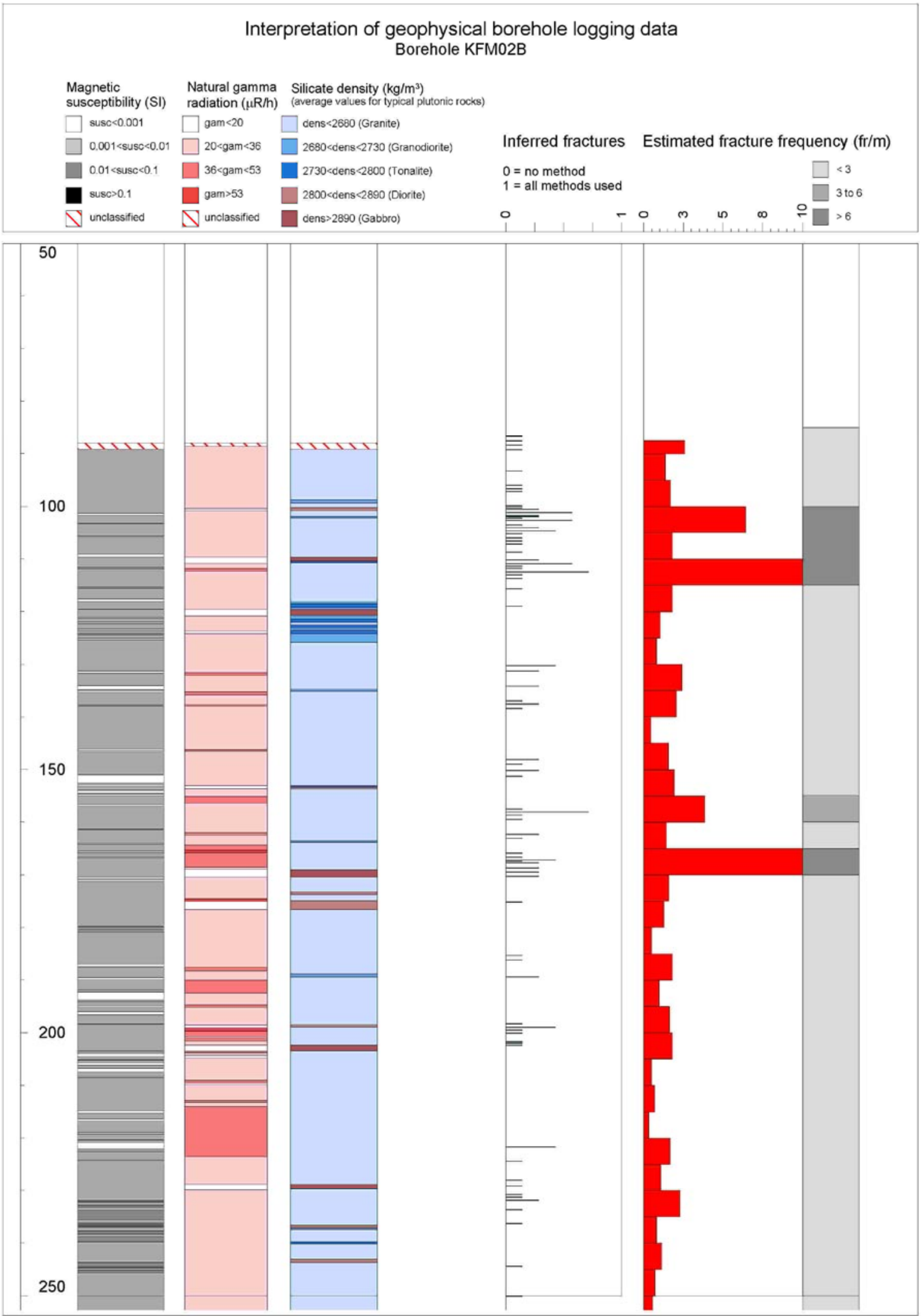
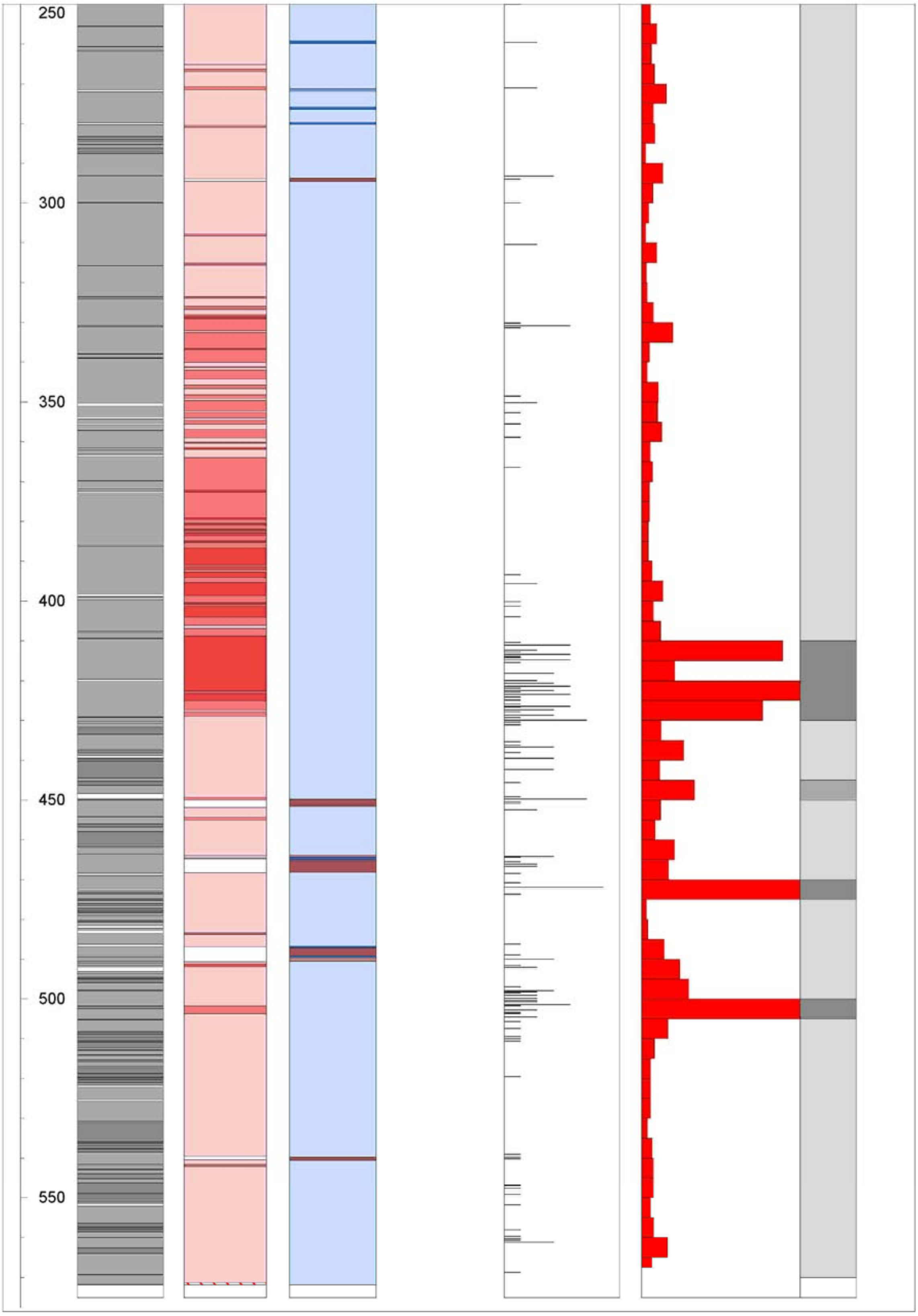
Generalized geophysical loggings of KFM02B

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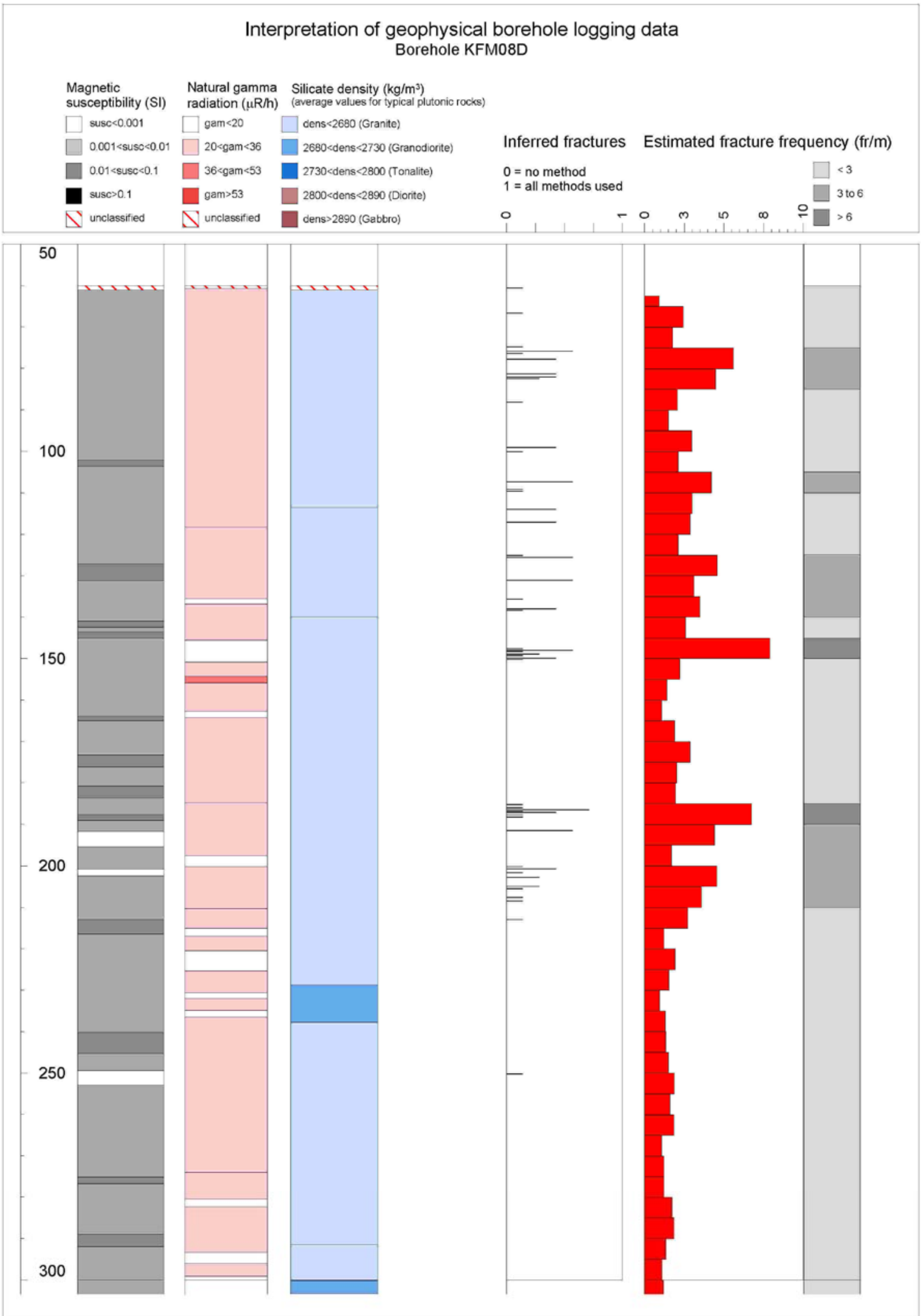
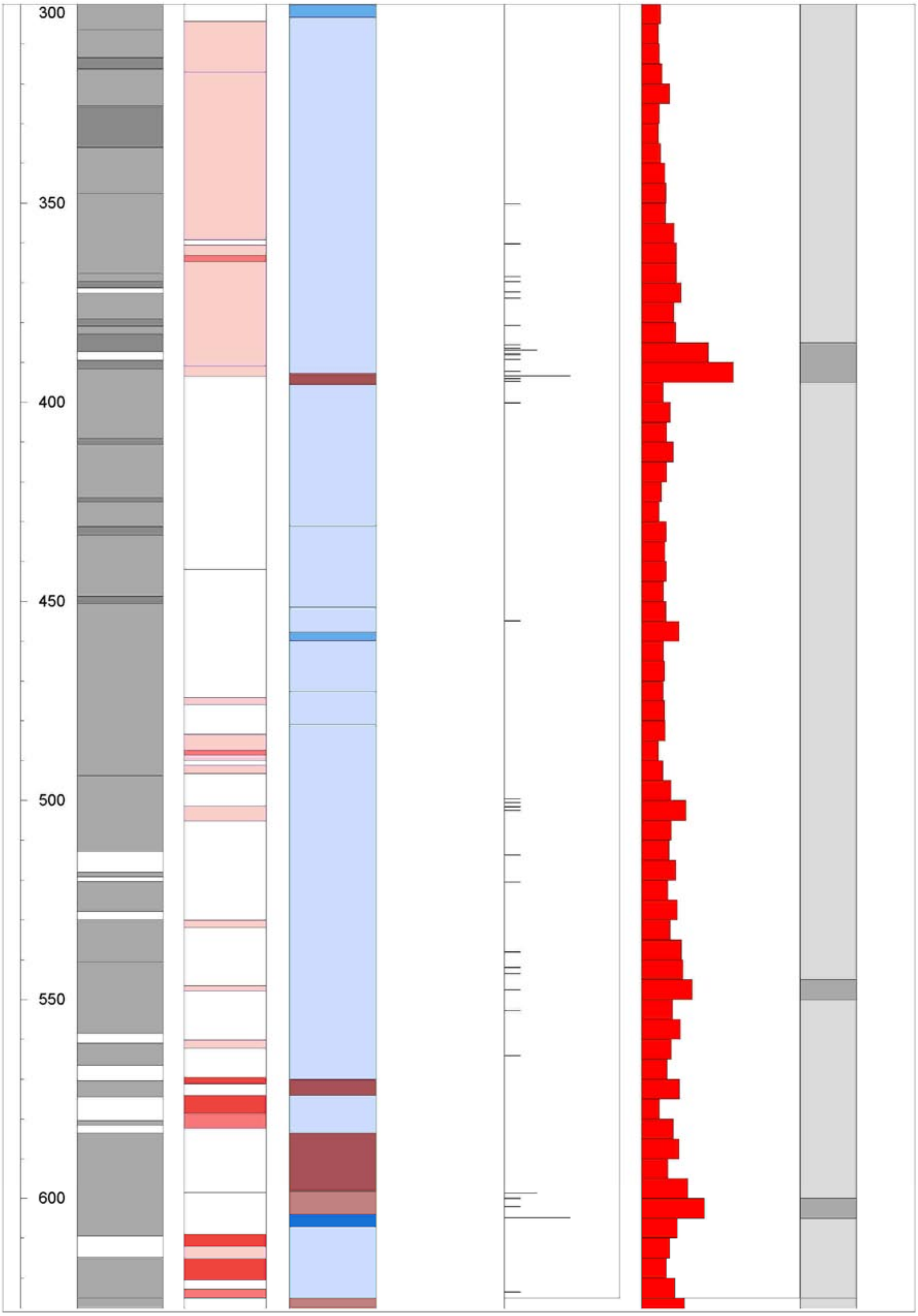
Appendix 2

Generalized geophysical loggings of KFM08D

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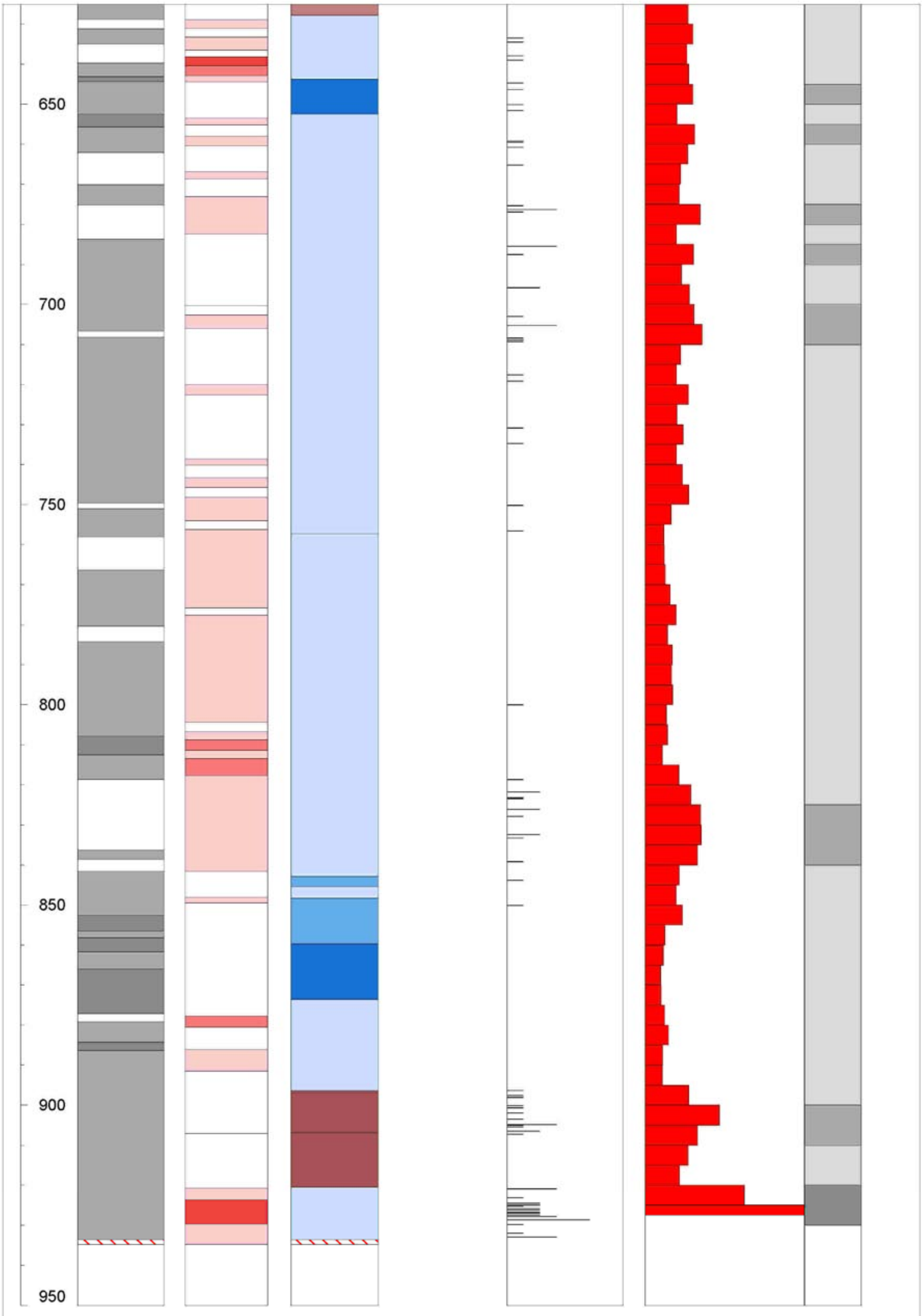
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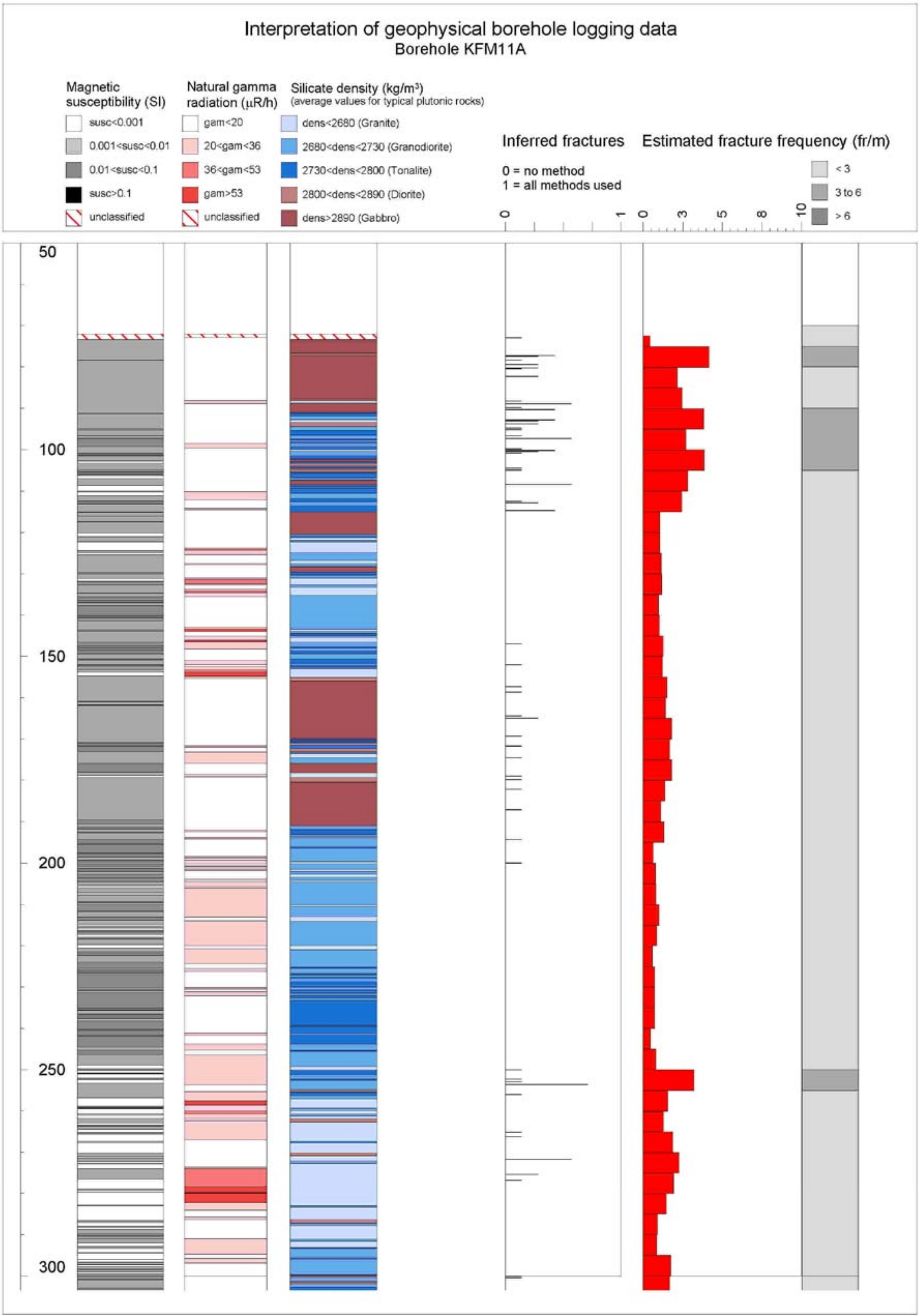
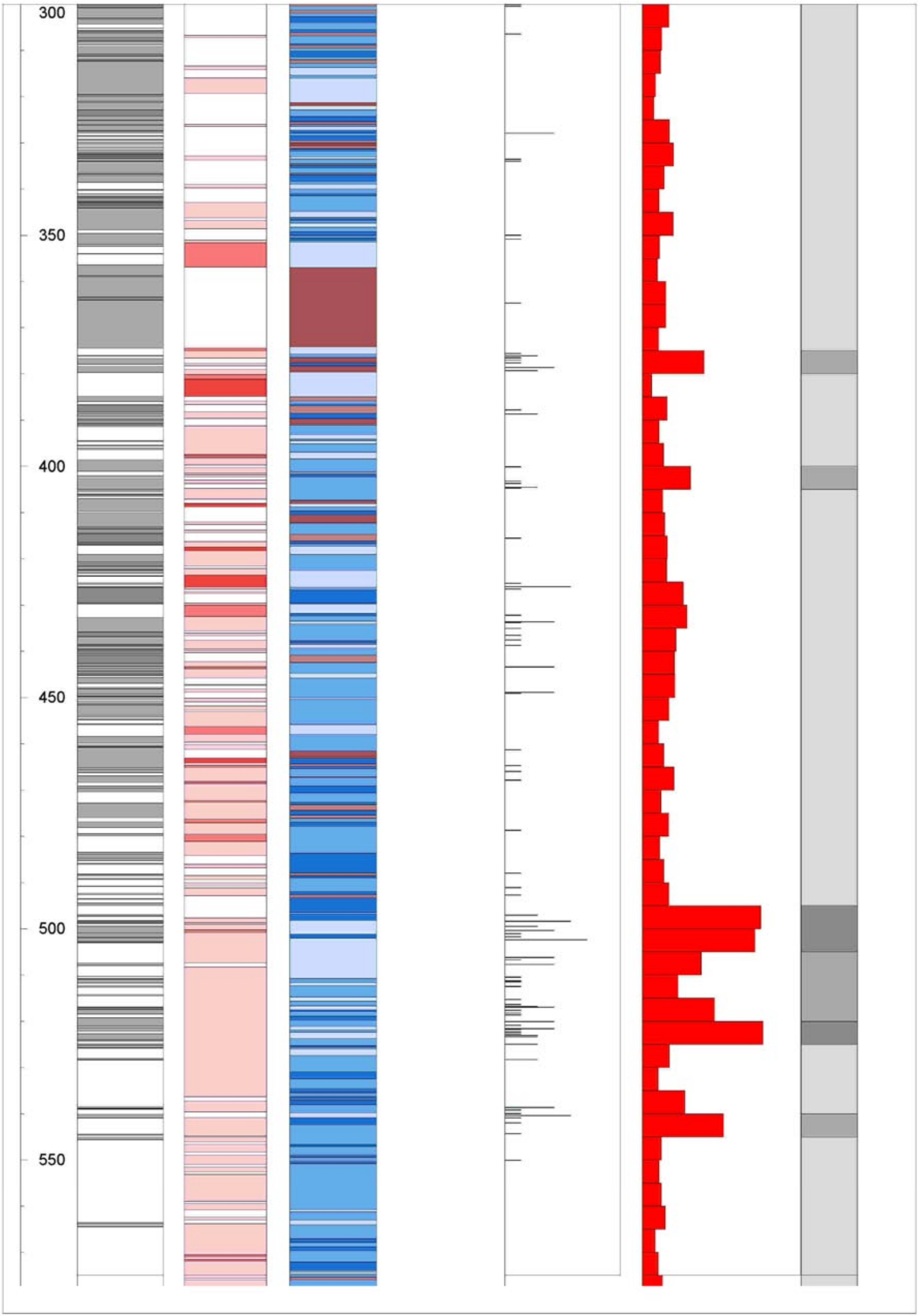
950

Generalized geophysical loggings of KFM11A

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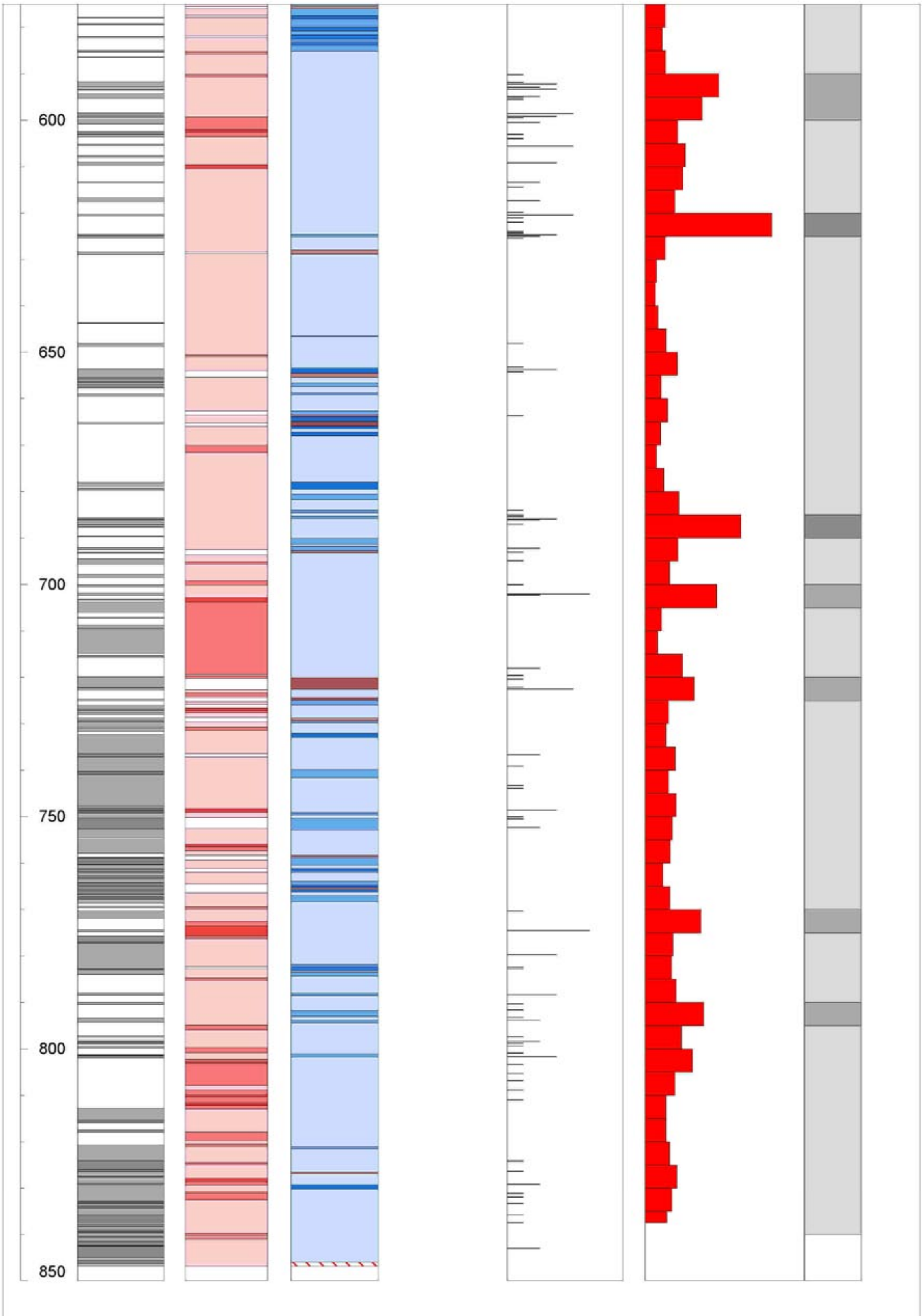
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