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Forsmark site investigation

Interpretation of geophysical borehole measurements from KFM01C, KFM09B, HFM07, HFM24, HFM26, HFM29 and HFM32

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 KFM01C and KFM09B, and the percussion drilled boreholes HFM07, HFM24, HFM26, HFM29 and HFM32.

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 single-hole interpretation.

Noise levels are low for a majority of the logging methods. However, the noise levels of the natural gamma radiation logs of HFM29 and HFM32 greatly exceed the recommended level. Due to measurement problems in KFM01C, density data exist only along the section interval c. 12–82 m.

In the section of KFM01C where density data were collected the rocks in the vicinity of the borehole are dominated by silicate density indicating a mineral composition that corresponds to granite rock. For the entire borehole, the natural gamma radiation is generally in the interval 20–36 μR/h and the magnetic susceptibility is generally in the interval 0.001–0.01 SI. Decreased magnetic susceptibility is identified in several long sections and many of these sections coincide with decreased natural gamma radiation, possibly indicating occurrences of mafic dykes, but without density data the interpretation is uncertain. The estimated fracture frequency of KFM01C is generally low. Possible deformation zones are indicated in the intervals c. 15–100 m and c. 235–245 m.

The rocks in the vicinity of KFM09B are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock. The magnetic susceptibility varies greatly within the interval 0.001–0.01 SI. Several sections with decreased magnetic susceptibility (< 0.001) do occur and many of the low susceptibility sections coincide with decreased natural gamma radiation and increased density, which indicates that amphibolites causes the anomalies. However, there is also a clear correlation between decreased susceptibility and increased fracture frequency. The natural gamma radiation is mainly in the interval 20–36 μR/h. Sections with increased natural gamma radiation (indicating felsic dykes) are concentrated in the intervals c. 75–145 m, 240–295 m and 530–590 m. The two longest sections with increased radiation level coincide with increased fracturing. The estimated fracture frequency is mainly low. Possible deformation zones are identified in the sections c. 10–130 m, c. 380–395 m, 525–535 m and 565–575 m.

The rocks in the vicinities of all five percussion drilled boreholes HFM07, HFM24, HFM26, HFM29 and HFM32 are dominated by silicate density indicating a mineral composition that corresponds to granite rock. Possible deformation zones are indicated for HFM07 at: 55–70 m, for HFM24 at: 20–30 m and 40–55 m, for HFM26 at: 160–200 m, for HFM29 at: 20–25 m, 65–85 m, 145–150 m, and for HFM32 no possible deformation zones are indicated. In the interval c. 50–115 m of HFM26 the estimated fracture frequency is mainly low. However, there is a major decrease in the magnetic susceptibility and bulk resistivity that may indicate alteration and/or deformation.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålen KFM01C och KFM09B, samt de hammarborrade hålen HFM07, HFM24, HFM26, HFM29 och HFM32.

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 enhålstolkningen.

De allra flesta loggdata uppvisar låga brusnivåer. Undantag utgörs av data från de naturliga gammastrålningsmätningarna i HFM29 och HFM32 som kraftigt överstiger den rekommenderade brusnivån. På grund av tekniska problem under loggningen av KFM01C finns densitetsdata för detta borrhål endast längs sektionen ca 12–82 m.

I den sektion av KFM01C för vilken det finns densitetsdata domineras berggrunden av silikatdensitet som motsvarar den för granit. För hela borrhålet ligger den naturliga gammastrålningen oftast i intervallet 20–36 µR/h och den magnetiska susceptibiliteten är 0,001–0,01 SI. Flera långa sektioner finns med låg susceptibilitet (< 0,001 SI), och många av dessa sammanfaller med låg gammastrålning, vilket troligen indikerar förekomst av amfibolitgångar (utan densitetsdata är tolkningen dock osäker). Den beräknade sprickfrekvens i KFM01C är generellt låg, men möjliga deformationszoner finns längs sektionerna ca 15–100 m och ca 235–245 m.

Berggrunden i närheten av KFM09B domineras helt av bergarter med silikatdensitet motsvarande den för granit. Den magnetiska susceptibiliteten uppvisar mycket stora variationer inom intervallet 0,001–0,01 SI. Flera lågmagnetiska sektioner förekommer, och många av dessa sammanfaller med låg naturlig gammastrålning och kraftigt förhöjd densitet vilket indikerar förekomst av amfibolit. Det finns dock även ett tydligt samband mellan låg susceptibilitet och hög sprickfrekvens. Den naturliga gammastrålningen ligger generellt intervallet 20–36 µR/h. Sektioner med förhöjd gammastrålning (troligen felsiska gångar) är främst koncentrerade längs ca 75–145 m, 240–295 m och 530–590 m. De två längsta sektioner med förhöjd strålning sammanfaller med hög sprickfrekvens. Den beräknade sprickfrekvens i KFM09B är generellt låg. Möjliga deformationszoner finns längs sektionerna ca 10–130 m, ca 380–395 m, 525–535 m och ca 565–575 m.

Berggrunden i närheten av samtliga undersökta hammarborrhål (HFM07, HFM24, HFM26, HFM29 och HFM32) domineras helt av silikatdensitet motsvarande den för granit. Möjliga deformationszoner kan identifieras för HFM07 längs ca 55–70 m, för HFM24 längs ca 20–30 m och 40–55 m, för HFM26 längs ca 160–200 m, för HFM29 längs ca 20–25 m, 65–85 m och 145–150 m. För HFM32 finns inga möjliga deformationszoner indikerade.

För HFM26 finns en längre sektion (ca 50–115 m) med låg beräknad sprickfrekvens, men längs vilken den magnetiska susceptibiliteten och resistiviteten båda är anomalt låga. Detta kan tyda på att berggrunden längs denna sektion är omvandlad och/eller har utsatts för 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 Simpevarp/Laxemar. This document reports the results gained from the interpretation of geophysical borehole logging data from the cored boreholes KFM01C and KFM09B, and the percussion drilled boreholes HFM07, HFM24, HFM26, HFM29 and HFM32 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 2005 by Rambøll /1/.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (Table 1-1). The interpretation of the percussion drilled hole HFM07 was not included in the activity plan. This hole has been logged several times, and acts as a “reference” hole.

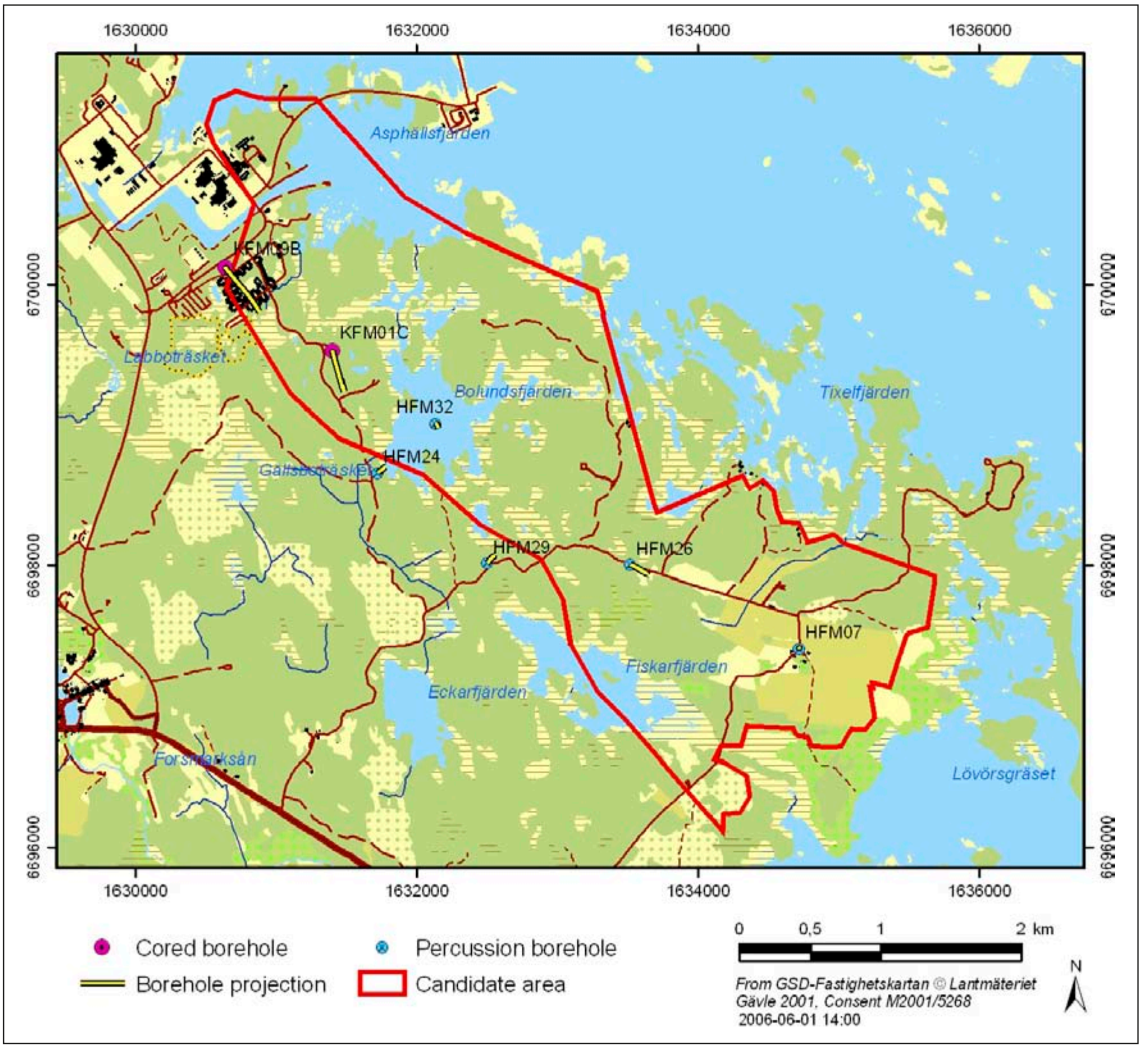

***Figure 1-1.** General overview over the Forsmark area showing the location of the boreholes KFM01C, KFM09B, HFM07, HFM24, HFM26, HFM29 and HFM32.*

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

Activity plan	Number	Version
Tolkning av geofysiska borrhålsdata från KFM01C, KFM09B, HFM24, HFM26, HFM29 och HFM32	AP PF 400-06-008	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PF 400-06-008). 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.

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 KFM09A /2/. The magnetic susceptibility logging data are calibrated with respect to a combination of petrophysical data from the boreholes KFM01A and KFM02A /3 and 4/.

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

The silicate density is calculated with reference to /5/ and the data are then divided into 5 sections indicating a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /6/. The sections are bounded by the threshold values in Table 4-1.

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 /7/; $\sigma = a\,\sigma_w^k\,\phi^m + \sigma_s$ 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 constants used in this investigation are presented in Table 4-2.

Table 4-1. Treshold values for the density of rock types.

		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		

Table 4-2. Values of the constants a, k and m in Archie's law used in the calculation of the apparent porosity.

Borehole	Average fluid resistivity (Ωm)	A	k	m
KFM01C	5.7	10	0.37	1.7
KFM09B	1.7	10	0.37	1.7

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

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

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 4-3) 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 4-3.

5. Report evaluating the results.

Table 4-3. 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	KFM01C	1.1	–	1.3	0.5	1.0	4.0	2.0	–
Weight	KFM01C	4.0	–	4.0	2.0	2.56	0.24	1.75	–
Threshold	KFM09B	2.0	–	1.7	0.4	1.5	5.0	5.0	–
Weight	KFM09B	4.0	–	4.0	2.0	2.56	0.24	1.75	–
Threshold	HFM07	1.0	1.3	1.5	0.6	1.0	4.0	4.0	–
Weight	HFM07	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–
Threshold	HFM24	1.2	1.2	1.3	0.5	1.0	3.5	3.6	–
Weight	HFM24	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–
Threshold	HFM26	1.2	1.2	1.3	0.5	1.0	3.5	3.6	–
Weight	HFM26	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–
Threshold	HFM29	1.0	0.7	1.0	0.5	1.0	4.0	4.0	–
Weight	HFM29	4.0	2.56	4.0	2.0	2.56	0.24	1.75	–
Threshold	HFM32	1.2	1.2	1.3	0.5	1.0	3.5	3.6	–
Weight	HFM32	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 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.
- 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 products 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 logging of KFM01C and for the short normal resistivity logging of KFM09B since the calculations show unrealistic values. Due to problems during the measurements with the gamma-gamma (density) and focused resistivity 140 logging tools in KFM01C reported by the logging contactor, data from these measurements exist only along the section interval c. 12–82 m.

The interpretation of the percussion drilled borehole HFM07 was not included in the activity plan. This hole has been logged several times, and acts as a “reference” hole for geophysical borehole logging.

No vertical temperature gradient calculations are described in this report due to an ongoing revision of the algorithm.

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. Noise levels are low for a majority of the logging methods. However, the noise levels of the natural gamma radiation logs are generally above the recommended level, and for HFM29 and HFM32 the noise levels greatly exceed the recommended level (by 5–7 times). To reduce the influence of the noise, the 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, in the Sections 5.2.1 to 5.2.7 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 meter sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and > 6 fractures/m).

5.2.1 Interpretation of KFM01C

The results of the generalized logging data and fracture estimations of KFM01C are presented in Figure 5-1 below, and in a more detailed scale in Appendix 1. Due to problems during the measurements with the gamma-gamma (density) and focused resistivity 140 logging tools, data from these measurements exist only along the section interval c. 12–82 m.

In the section where density data were collected (12–82 m) the rocks in the vicinity of the borehole are dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). In the interval c. 68–78 m there are indications of two amphibolite dykes (density > 2,900 kg/m^3, low natural gamma radiation and low magnetic susceptibility). A large part of the section 12–82 m is characterized by decreased magnetic susceptibility < 0.001 SI.

The natural gamma radiation is generally in the interval 20–36 μR/h. Short sections (< 1 m) with increased/decreased radiation level occur through out the entire borehole, and these most likely correspond to pegmatite or fin-grained granite/amphibolite dykes. However, without the support of density data the interpretation is uncertain.

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

Logging method	KFM01C	KFM09B	HFM07	HFM24	HFM26	HFM29	HFM32	Recommended max noise level
Density (kg/m^3)	7	6	7	6	7	8	4	3–5
Magnetic susceptibility (SI)	1×10^{-4}	2×10^{-4}	1×10^{-4}	0.5×10^{-4}	0.5×10^{-4}	2×10^{-4}	1×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	0.6	0.7	0.6	0.7	0.6	1.0	1.5	0.3
Long normal resistivity (%)	0.3	0.3	0.08	0.1	0.4	0.3	–	2.0
Short normal resistivity (%)	0.1	0.2	0.03	0.1	0.2	0.08	–	2.0
Fluid resistivity (%)	0.006	0.01	0.03	0.02	0.03	0.04	0.05	2
Fluid temperature (°C)	2×10^{-4}	1×10^{-4}	3×10^{-4}	4×10^{-4}	2×10^{-4}	4×10^{-4}	4×10^{-4}	0.01
Lateral resistivity (%)	–	–	–	–	–	–	–	2
Single point resistance (%)	0.1	0.1	0.3	0.6	0.3	0.3	–	No data
Caliper (m)	3×10^{-5}	1×10^{-4}	2×10^{-4}	2×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}	5×10^{-4}
Focused resistivity 300 (%)	5	7	8	12	11	11	17	No data
Focused resistivity 140 (%)	3	0.6	1	2	4	0.8	2	No data
Sonic (m/s)	7	5	12	6	–	12	4	20

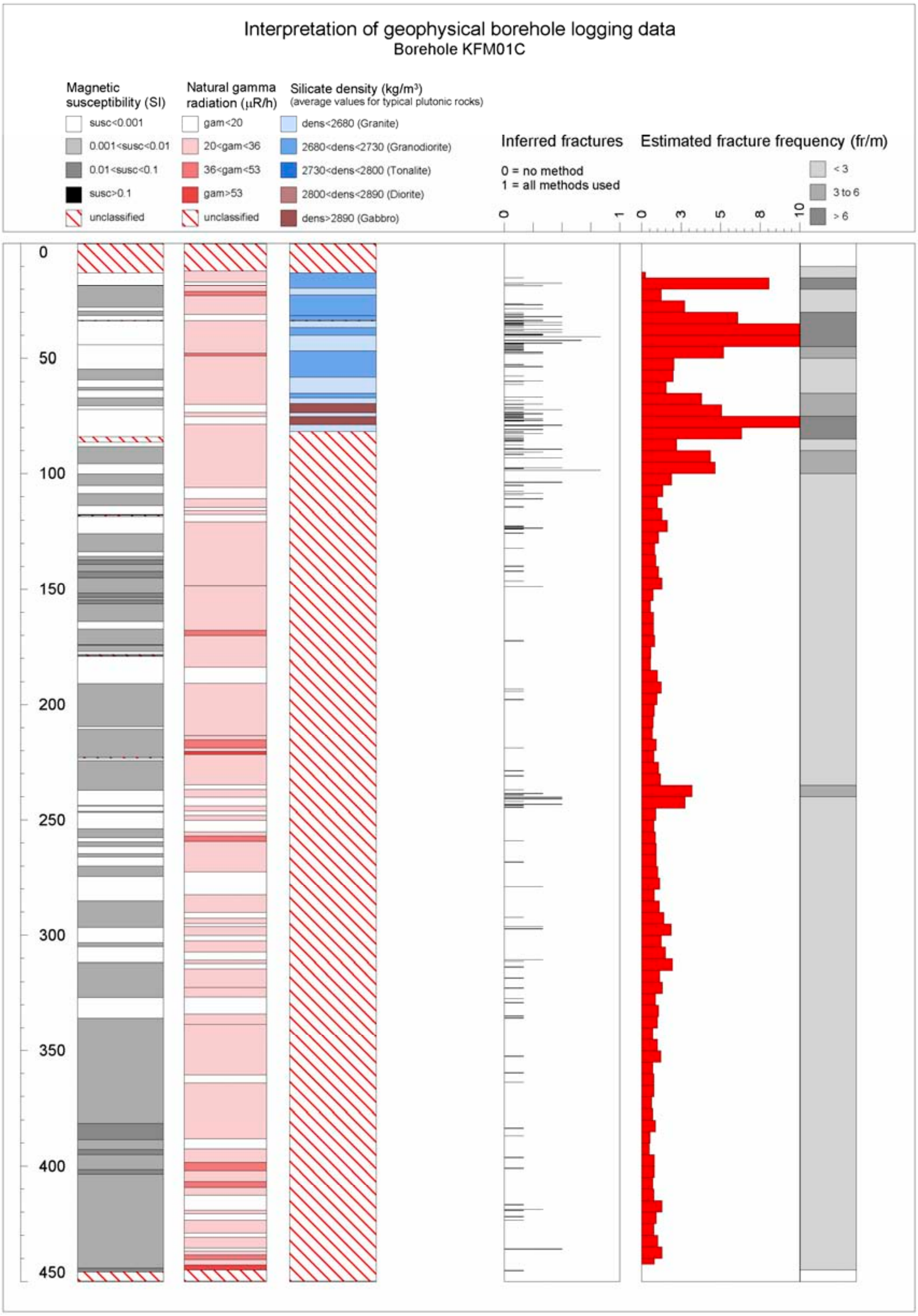

Figure 5-1. *Generalized geophysical logs of KFM01C.*

The magnetic susceptibility is generally in the interval 0.001–0.01 SI. Several fairly long sections with decreased susceptibility do occur. Decreased magnetic susceptibility is identified in a large part of the intervals 28–55 m, 96–124 m, 178–190 m, 240–280 m and c. 300–335 m. Many of the low susceptibility sections coincide with decreased natural gamma radiation, which indicates that amphibolites are the causes of these anomalies. However, as noted above, without the support of density data the interpretation is uncertain. Increased magnetic susceptibility (> 0.01 SI) occurs in the sections c. 130–165 m and c. 380–405 m. These high susceptibility intervals most likely reflect natural variations of the magnetite content in the bedrock.

The estimated fracture frequency of KFM01C is fairly high in the section c. 15–100 m. The section is characterized by several caliper anomalies, largely decreased resistivity and decreased magnetic susceptibility. The apparent porosity (Figure 5-2) is partly very high (> 1%) in the section, and there is a rapid increase in the fluid water salinity at the section coordinate c. 45 m, which may correspond to a water bearing fracture.

In the remaining part of the borehole (c. 100–450 m) the fracture frequency is mainly low and the apparent porosity averages at c. 0.6%, which is normal for solid crystalline rock in this area. However, increased fracturing is indicated in the interval c. 235–245 m, which is characterized by caliper anomalies and decreased resistivity. The anomalies coincide with decreased natural gamma radiation which suggests that the possible deformation zone occurs close to an wamphibolite dyke.

5.2.2 Interpretation of KFM09B

The results of the generalized logging data and fracture estimations of KFM09B are presented in Figure 5-3 below, and in a more detailed scale in Appendix 2.

The rocks in the vicinity of KFM09B are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3), see Table 5-2 and Figure 5-3.

Short sections (< 1 m) with highly increased density occur in all parts of the borehole, but tend to be concentrated in the intervals c. 30–90 m and 255–315 m. These high density intervals generally coincide with decreased natural gamma radiation and magnetic susceptibility, which suggest that they correspond to amphibolite dykes.

The magnetic susceptibility varies greatly within the interval 0.001–0.01 SI. Several sections with decreased magnetic susceptibility (< 0.001) do occur and many of the low susceptibility sections coincide with decreased natural gamma radiation and increased density, which indicates that amphibolites causes the anomalies. However, there is also a clear correlation between decreased susceptibility and increased fracture frequency (see for example sections c. 10–100 m, 525–530 m and 565–575 m).

The natural gamma radiation is in the interval 20–36 μR/h for the major part of KFM09B. Sections with increased natural gamma radiation (most of them < 2 m long) are concentrated in the intervals c. 75–145 m, 240–295 m and 530–590 m. The two most prominent high natural gamma radiation sections (c. 125–145 m and c. 565–590 m) may indicate major felsic dykes and both of them coincide with increased fracturing.

Sections with decreased natural gamma radiation (< 20 μR/h) generally coincide with highly increased density and most likely correspond to amphibolite dykes. However, in the intervals c. 360–365 m and 460–475 m the natural gamma radiation is < 20 μR/h and there is only a slight increase in the density (+20–30 kg/m^3), which indicates rocks with higher content of dark minerals (granodioritic to tonalitic mineral composition) relative to the remaining part of the borehole.

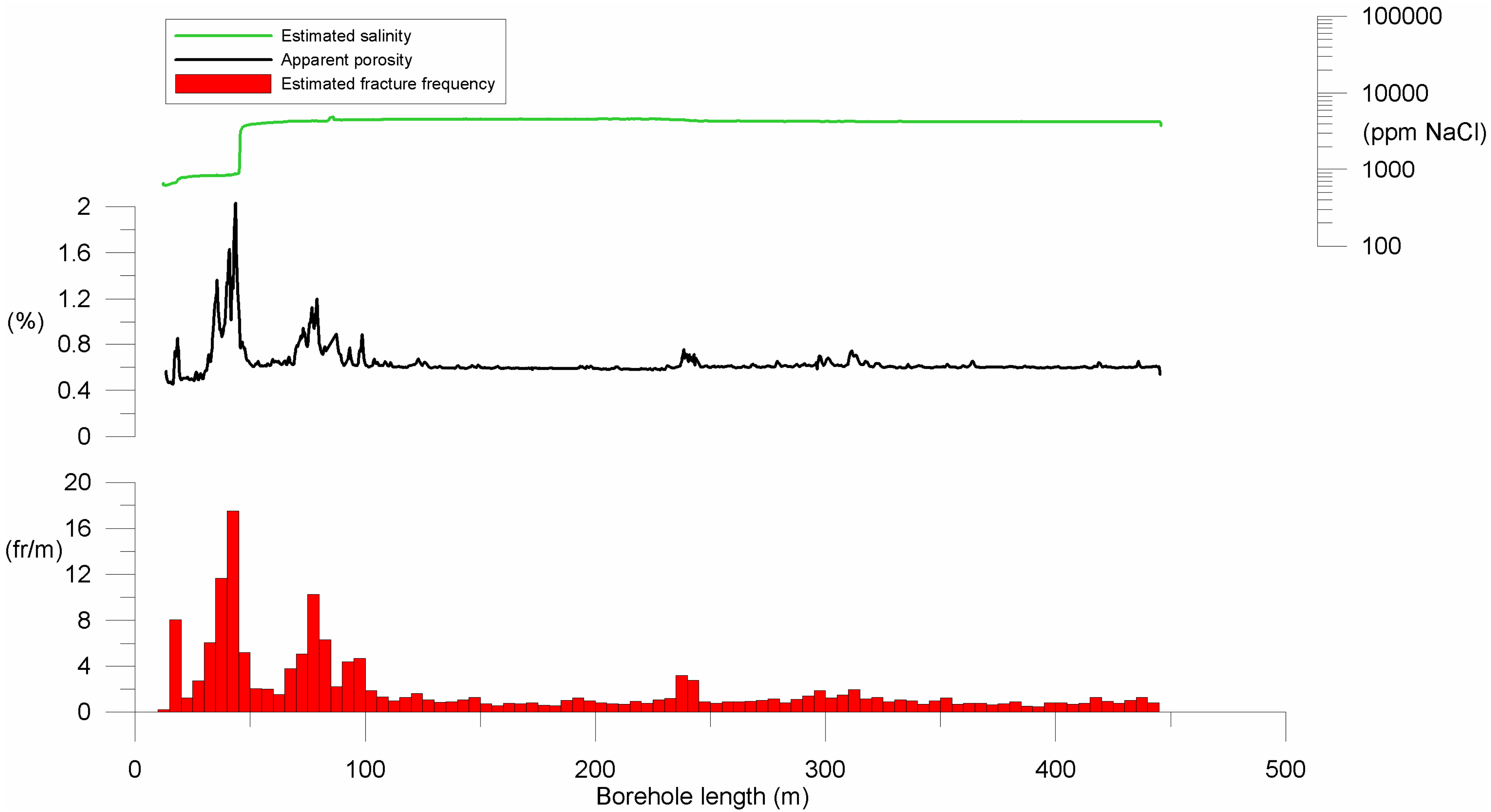

Figure 5-2. Estimated salinity, apparent porosity and estimated fracture frequency of KFM01C.

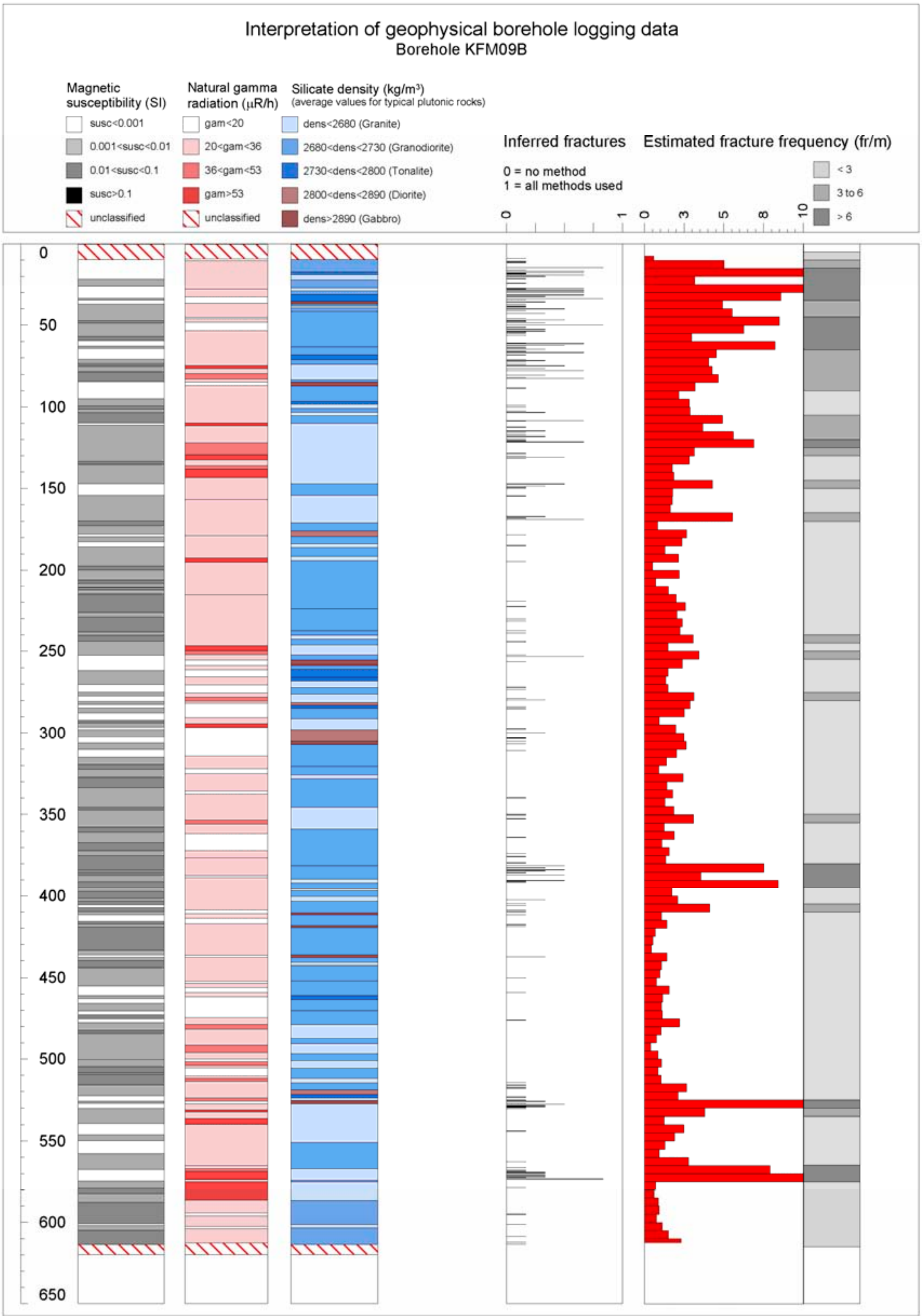

Figure 5-3. Generalized geophysical logs of KFM09B.

Table 5-2. Distribution of silicate density classes with borehole length of KFM09B.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
Dens < 2,680 (granite)	508	84
2,680 < dens < 2,730 (granodiorite)	52	9
2,730 < dens < 2,800 (tonalite)	21	3
2,800 < dens < 2,890 (diorite)	13	2
dens > 2,890 (gabbro)	9	2
SUM	603	100%

The estimated fracture frequency in KFM09B is mainly low apart from the uppermost c. 120 m that are dominated by increased fracturing. The subsection 15–20 m is characterized by strongly decreased P-wave velocity, resistivity and also major caliper anomalies that together indicated strong brittle deformation and crushed rock. The remaining parts of the uppermost 120 m are characterized by short intervals of decreased resistivity, low magnetic susceptibility and slightly decreased P-wave velocity.

Increased fracture frequency (possible deformation zones) are also indicated in the sections c. 380–395 m, 525–535 m and 565–575 m. The section 380–395 m is mainly characterized by decreased resistivity, partly decreased P-wave velocity and one single caliper anomaly a c. 390 m. In the section 525–535 m there is a distinct decrease in the bulk resistivity, decreased magnetic susceptibility, partly decreased P-wave velocity and major caliper anomalies. The section 565–575 m is characterized by distinctly decreased bulk resistivity, decreased magnetic susceptibility and partly decreased P-wave velocity.

The apparent porosity data estimated from the long normal resistivity log is in the interval c. 0.6–0.8% (Figure 5-4). Increased rock porosity is indicated in the intervals c. 15–170 m, 380–395 m, 525–535 m and 565–575 m. The high porosity anomalies coincide with the sections with increased fracture frequency listed above. The linear trend of slightly increasing porosity with depth is caused by variations in the fluid water salinity which the porosity calculation fails to compensate for. This trend is not geologically significant and should therefore be disregarded in any interpretation of these data.

The estimated salinity of the borehole fluid increases stepwise with the borehole depth, starting at c. 300 ppm NaCl and ending at c. 5,000 ppm NaCl (Figure 5-4). Observe that the points of increase seem to coincide with indicated deformation zones, which suggests that these zones are water bearing.

5.2.3 Interpretation of HFM07

The results of the generalized logging data and fracture estimations of HFM07 are presented in Figure 5-5 below.

The rocks in the vicinity of HFM07 are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m³). A few short sections (< 1 m) with increased density are evenly scattered along the borehole. These anomalies generally coincide with decreased natural gamma radiation and decreased magnetic susceptibility, which suggests that they correspond to mafic dykes (probably amphibolites).

The natural gamma radiation is mainly in the interval 20–36 μR/h. However, especially in the lower half of the borehole there are several sections with decreased natural gamma radiation that do not coincide with increased density (which is the normal combination for mafic rock). This may be an indication that the rocks along these sections have suffered from some kind of alteration. There are only a few indications of fesic dykes (increased natural gamma radiation) in HFM07.

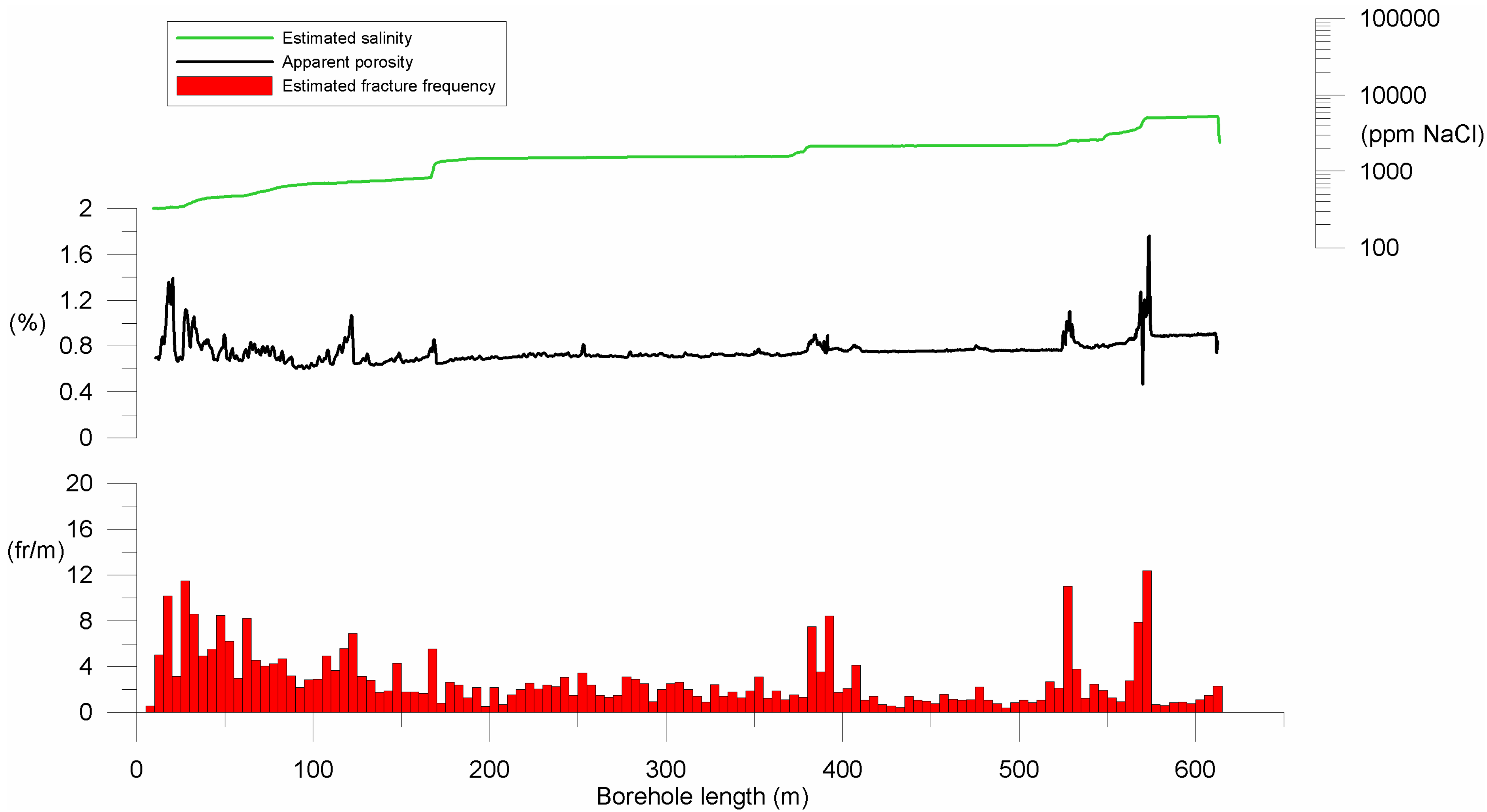

Figure 5-4. *Estimated salinity, apparent porosity and estimated fracture frequency of KFM09B.*

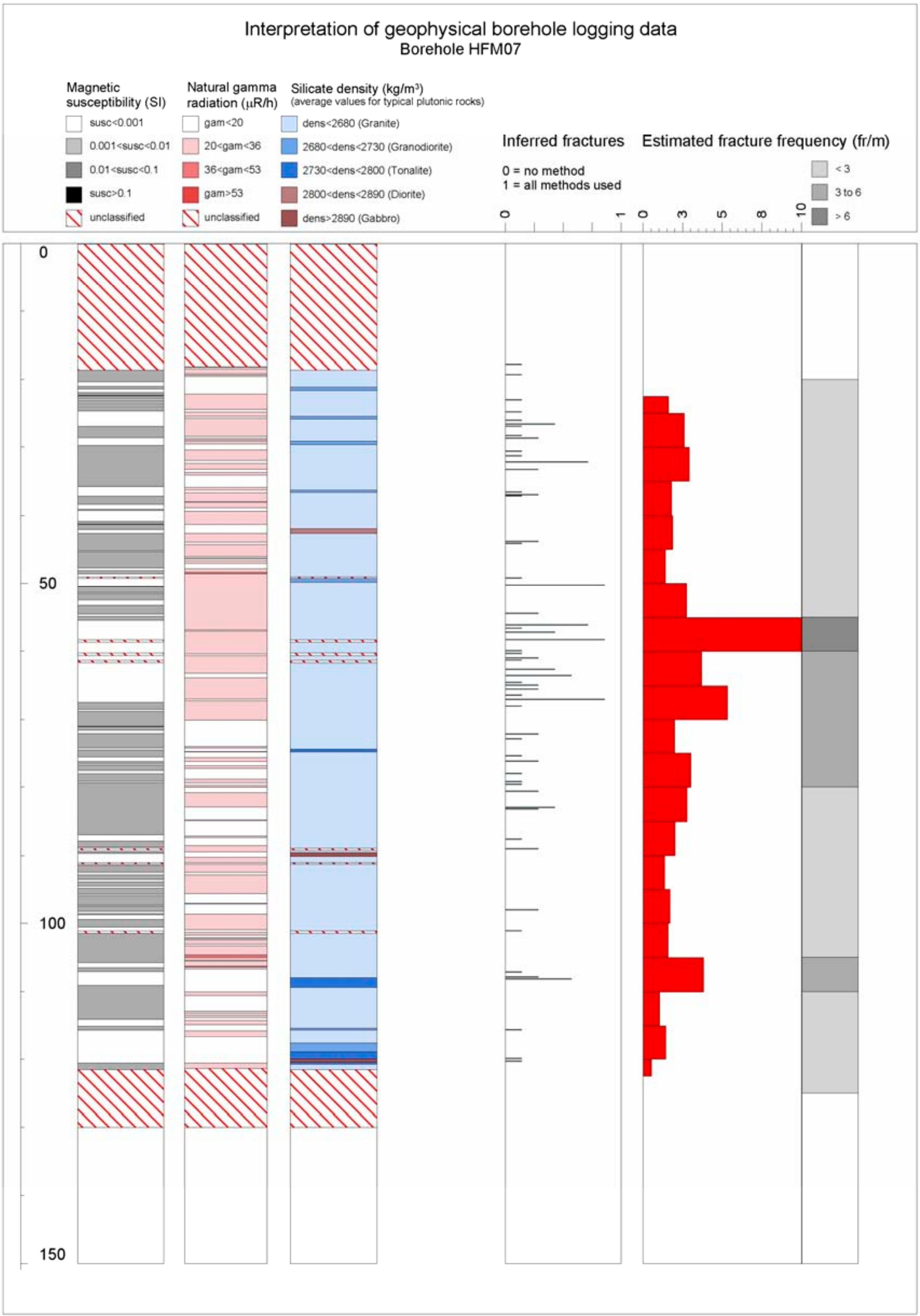

Figure 5-5. *Generalized geophysical logs of HFM07.*

The magnetic susceptibility is generally in the interval 0.001–0.01 SI. Most intervals with decreased susceptibility (< 0.001 SI) coincide with increased density and decreased natural gamma radiation, which usually indicates amphibolite. However, the section c. 55–67 m constitutes an exception (Figure 5-5). In this interval the decreased magnetic susceptibility is related to increased fracturing.

The fracture frequency of HFM07 is mainly low. A possible deformation zone is indicated in the interval c. 55–70 m. In the interval the logging data show several caliper anomalies, a major decrease in the bulk resistivity and (as noted above) decreased magnetic susceptibility. The sonic data is dominated by null values.

5.2.4 Interpretation of HFM24

The results of the generalized logging data and fracture estimations of HFM24 are presented in Figure 5-6 below.

The rocks in the vicinity of HFM24 are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). Several short sections (< 1 m) with increased density are evenly scattered along the borehole. These anomalies generally coincide with decreased natural gamma radiation and decreased magnetic susceptibility, which suggests that they correspond to amphibolite dykes.

The natural gamma radiation is mainly in the interval 20–36 μR/h. There is a large number of positive radiation anomalies evenly scattered along the borehole that most likely indicate the occurrences of felsic dykes (pegmatite and/or fine-grained granite).

The magnetic susceptibility is generally in the intervals 0.001–0.01 SI and < 0.001 SI. The major part of the sections c. 20–30 m and c. 50–115 m are dominated very low magnetic susceptibility. The low susceptibility in the interval c. 20–30 m coincides with increased fracturing (indicated by caliper anomalies and decreased bulk resistivity).

In the interval c. 50–115 m the estimated fracture frequency is mainly low; there are only few caliper and sonic anomalies. However, the low susceptibility coincides with a major decrease in the bulk resistivity (almost two orders of magnitude in the focused resistivity 300 log). This indicates that the rocks along this part of the borehole have suffered from alteration, and/or that there is a fairly large, probably ductile, deformation zone.

In the section c. 40–55 m there are several caliper and sharp low resistivity anomalies indicating the occurrences of brittle fractures.

5.2.5 Interpretation of HFM26

The results of the generalized logging data and fracture estimations of HFM26 are presented in Figure 5-7 below.

The rocks in the vicinity of HFM26 are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). In the interval c. 60–95 m there are three 5–10 m long sub-sections with highly increased density, decreased natural gamma radiation and magnetic susceptibility. The anomalies most likely correspond to amphibolite dykes. In the section c. 14–22 m there are indications of rocks with granodioritic to tonalitic mineral compositions.

The natural gamma radiation is mainly in the interval 20–36 μR/h. In the upper half of the borehole there are several long positive radiation anomalies. Some of them most likely indicate the occurrences of felsic dykes (pegmatite and/or fine-grained granite). The strongest positive anomaly occurs close to an indicated mafic dyke, which suggests that mafic and felsic dykes are partly spatially related.

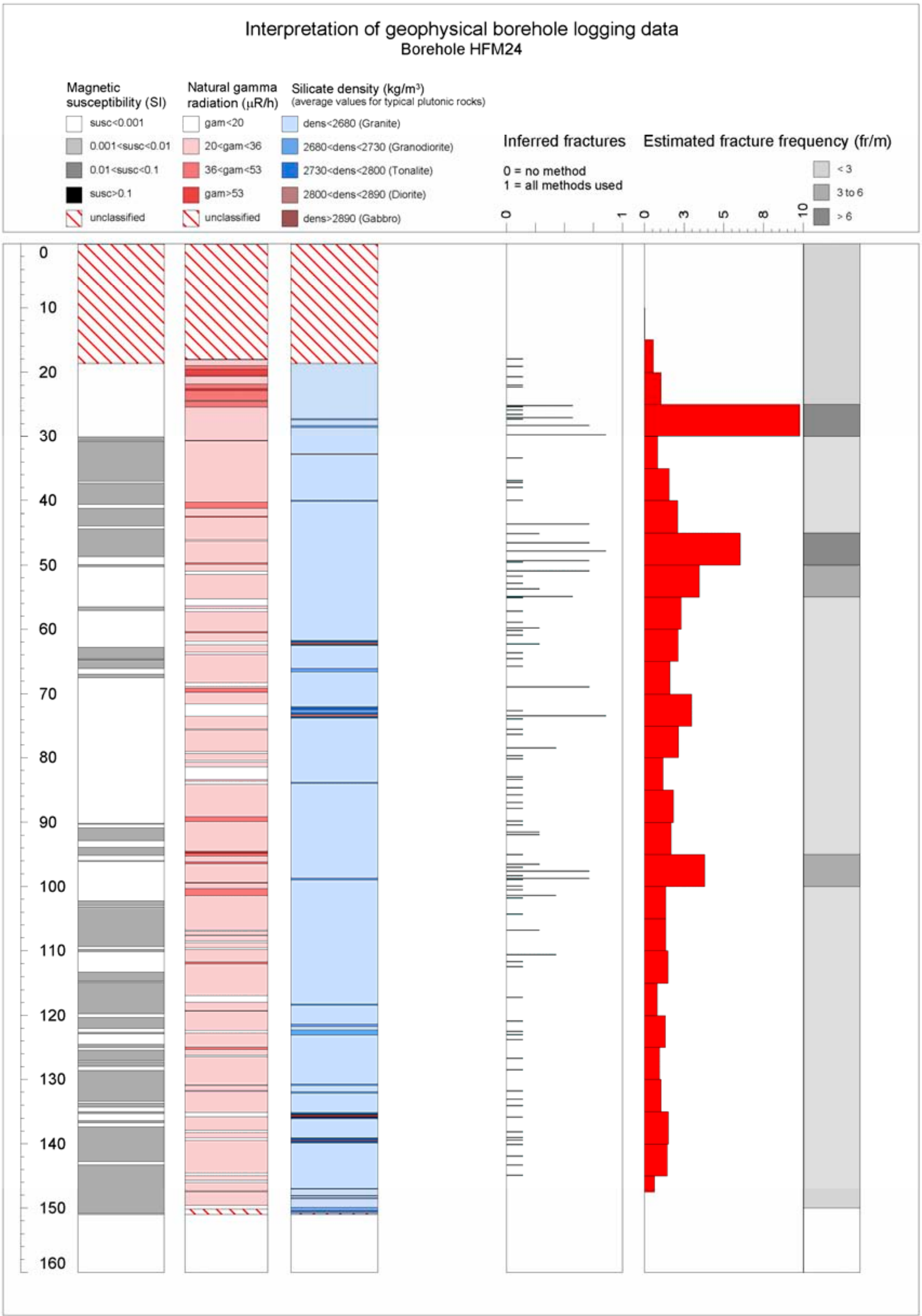

Figure 5-6. *Generalized geophysical logs of HFM24.*

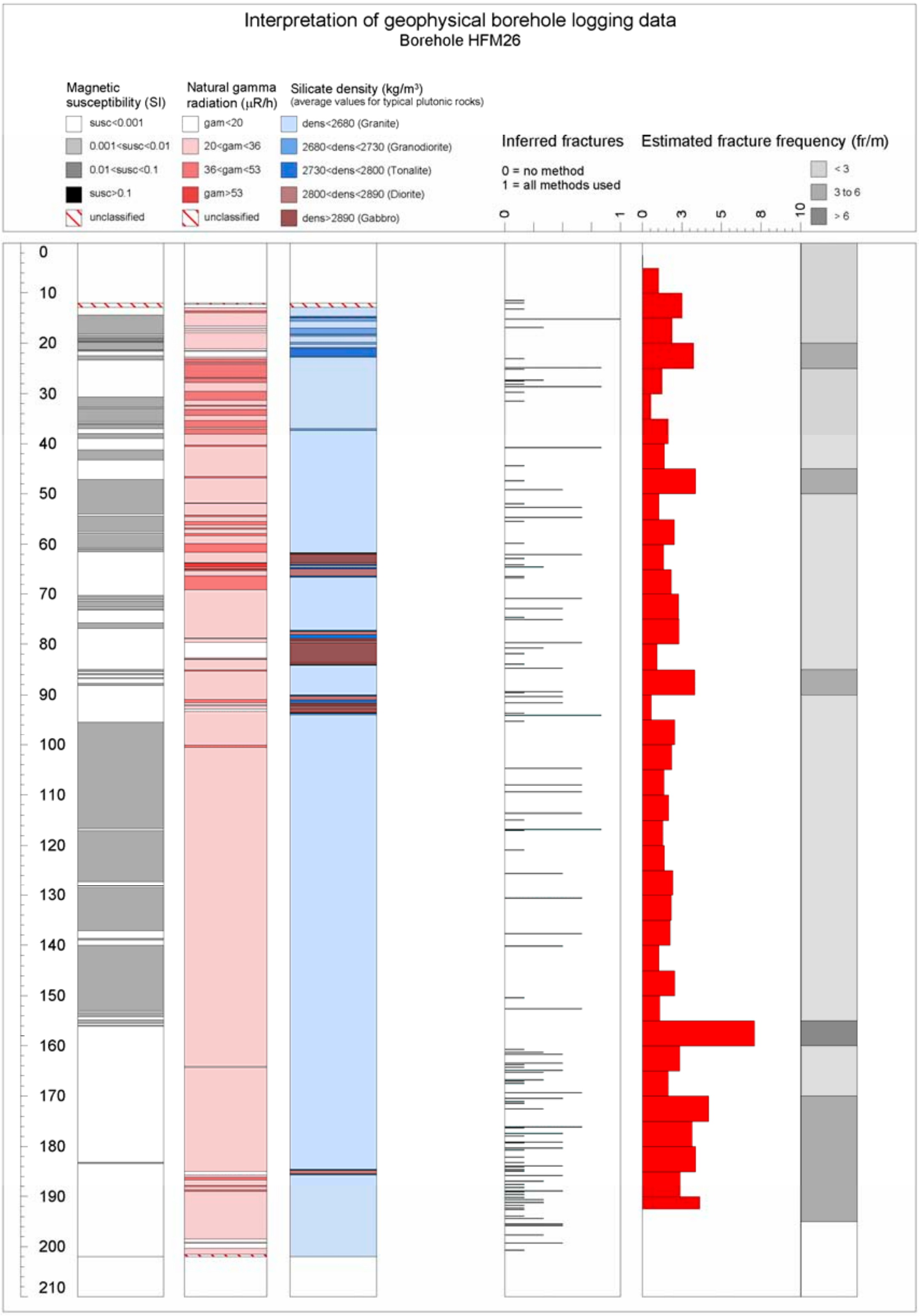

Figure 5-7. Generalized geophysical logs of HFM26.

The magnetic susceptibility is generally in the intervals 0.001–0.01 SI and < 0.001 SI. In the upper half the borehole the low susceptibility sections generally correspond to indicated mafic dykes (see the second paragraph above). However, in the lowermost part of HMF26 (section c. 155–200 m) the decreased magnetic susceptibility most likely corresponds to increased fracturing. At c. 160 m there is a stepwise decrease in the resistivity and the caliper data is anomalously noisy in the interval c. 160–200 m. The data may indicate a possible deformation zone in this part of the borehole. Apart from this section the estimated fracture frequency of HFM26 is mainly low or partly moderate.

5.2.6 Interpretation of HFM29

The results of the generalized logging data and fracture estimations of HFM29 are presented in Figure 5-8 below.

The rocks in the vicinity of HFM29 are dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). However, in this borehole there is a larger number of short sections (< 2 m) of increased density as compared to the other percussion drilled boreholes presented in the report. The silicate density data indicate rocks with granodioritic to tonalitic mineral compositions as well as dioritic to gabbroic compositions. The section c. 75–95 m is completely dominated by rocks with increased density and decreased natural gamma radiation and magnetic susceptibility.

There are large variations in the natural gamma radiation data that support the inhomogeneous rock type distribution as indicated by the density (gamma-gamma) log data. Note that the positive radiation anomalies in the interval c. 160–165 m coincide with high magnetic susceptibility. This is likely an indication of pegmatite dykes enriched in magnetite. Many of the negative radiation anomalies most likely correspond to amphibolite dykes.

The magnetic susceptibility is generally in the interval 0.001–0.01 SI. Sections with decreased magnetic susceptibility generally correspond to increased density (often related to mafic dykes).

The estimated fracture frequency of HFM29 is generally low. A possible deformation zone is indicated in the interval c. 20–25 m, which is characterized by caliper anomalies and several sharp low resistivity anomalies. Also the sections c. 65–85 and 145–150 m are characterized by caliper anomalies and several sharp low resistivity anomalies that may indicate deformation zones.

5.2.7 Interpretation of HFM32

The results of the generalized logging data and fracture estimations of HFM32 are presented in Figure 5-9 below.

The rocks in the vicinity of HFM32 are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). In the interval c. 6–20 m there is highly increased density (> 3,000 kg/m^3), deceased natural gamma radiation and magnetic susceptibility. This combination of physical properties is typical for amphibolites. A few shorter sections with similar characteristics also exist further down in the borehole (e.g. at c. 131–135 m).

The natural gamma radiation is mainly in the interval 20–36 μR/h. In the interval c. 120–170 m there is a fairly large number of short positive radiation anomalies that most likely correspond to felsic dykes (pegmatite and/or fine-grained granite). Just as for some of the previously presented boreholes there are indication in HFM32 that mafic and felsic dykes are partly spatially related.

The magnetic susceptibility is generally in the interval 0.001–0.01 SI. However, the section c. 120–170 m is dominated by very low magnetic susceptibility (c. 0.0005 SI), and in this interval of the borehole there is also a relatively lower density (2,560–2,600 kg/m^3) and high natural gamma radiation level. This combination of physical properties indicates that the rocks in the vicinity of the borehole have a composition corresponding to that of leucocratic granite.

The estimated fracture frequency of HFM32 is low. Decreased resistivity and caliper anomalies occur in the section c. 5–30 m, but apart from this there are few indications of major fractures in the geophysical logging data.

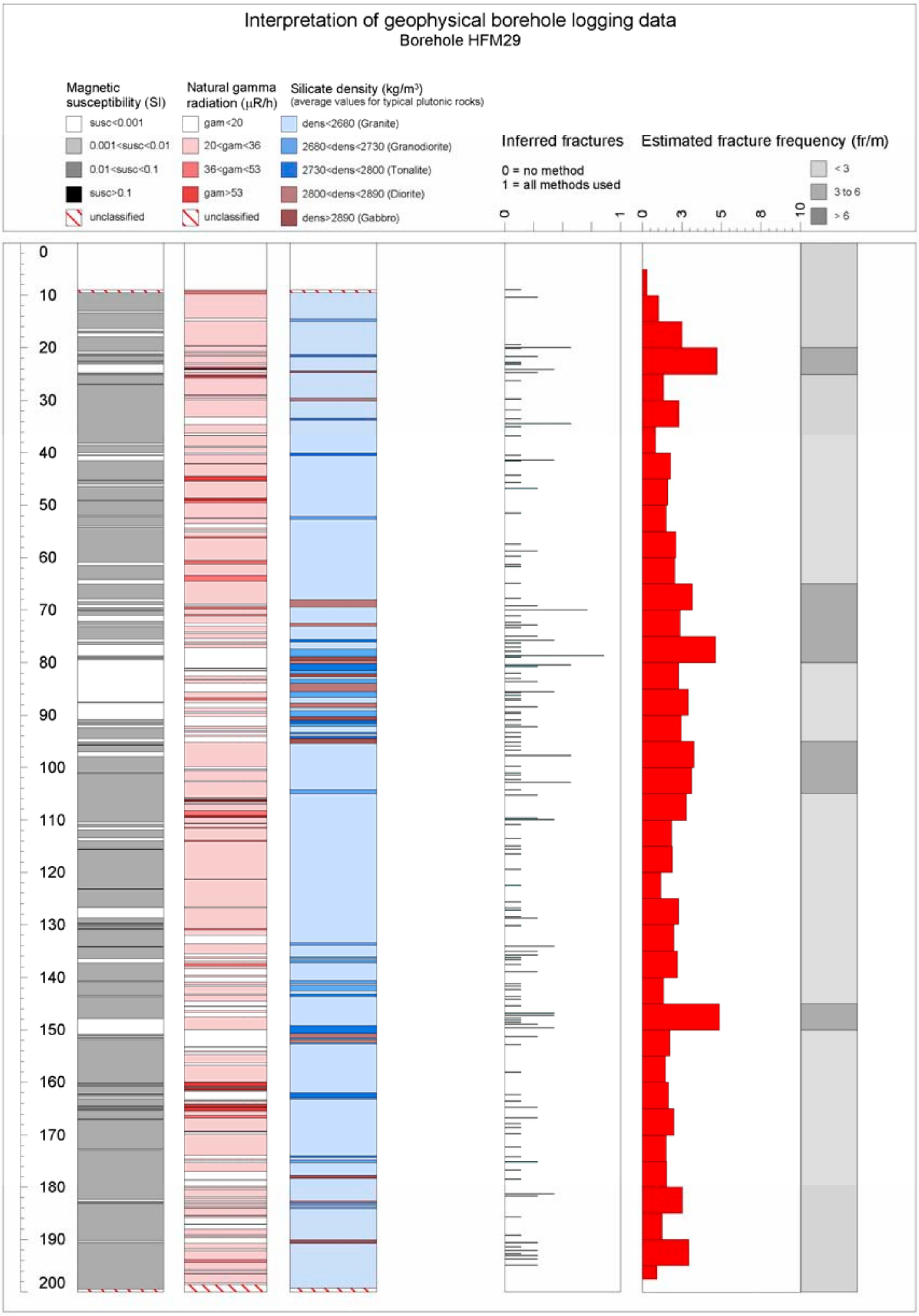

__Figure 5-8.__ Generalized geophysical logs of HFM29.

Figure 5-9. Generalized geophysical logs of HFM32.

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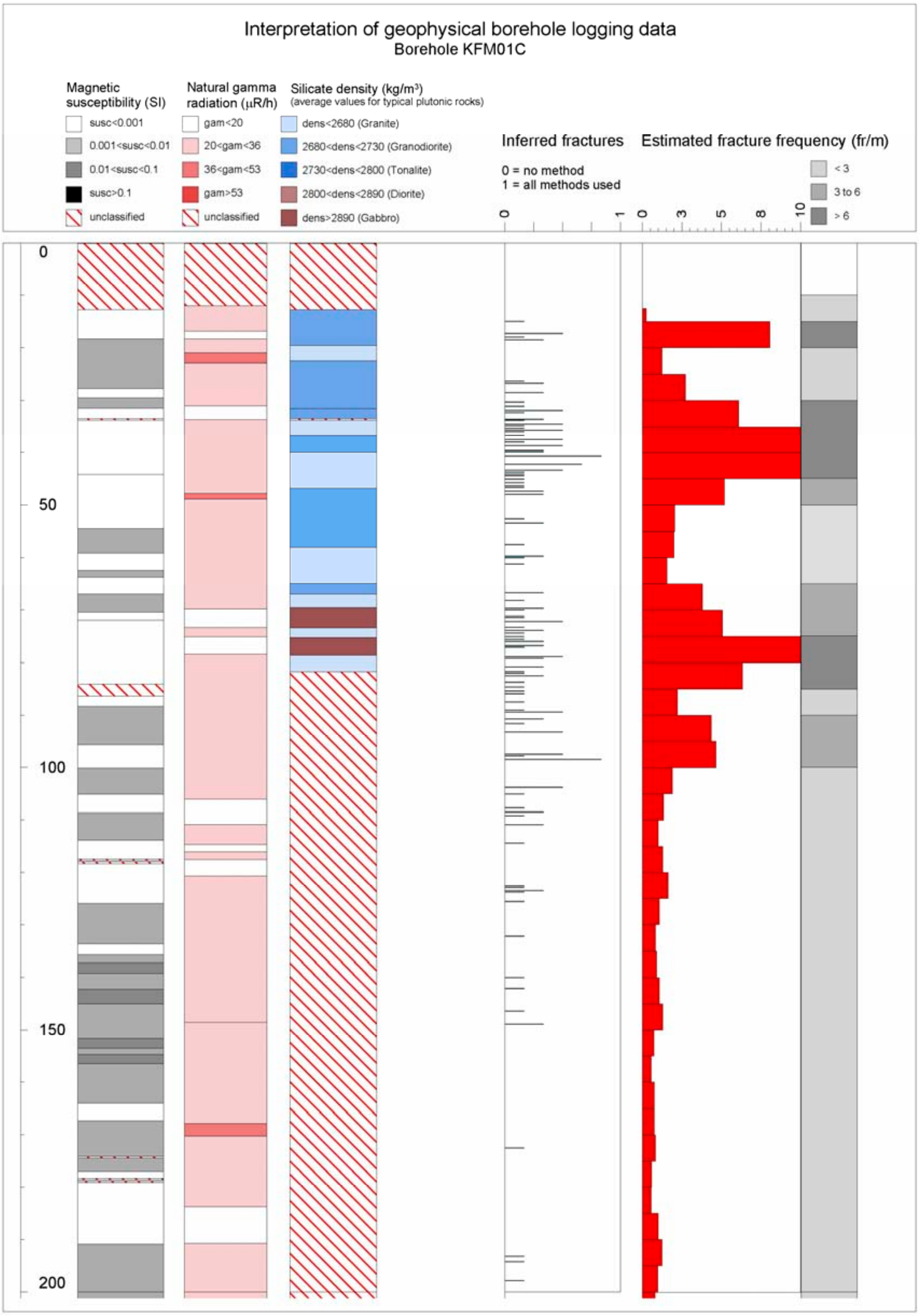
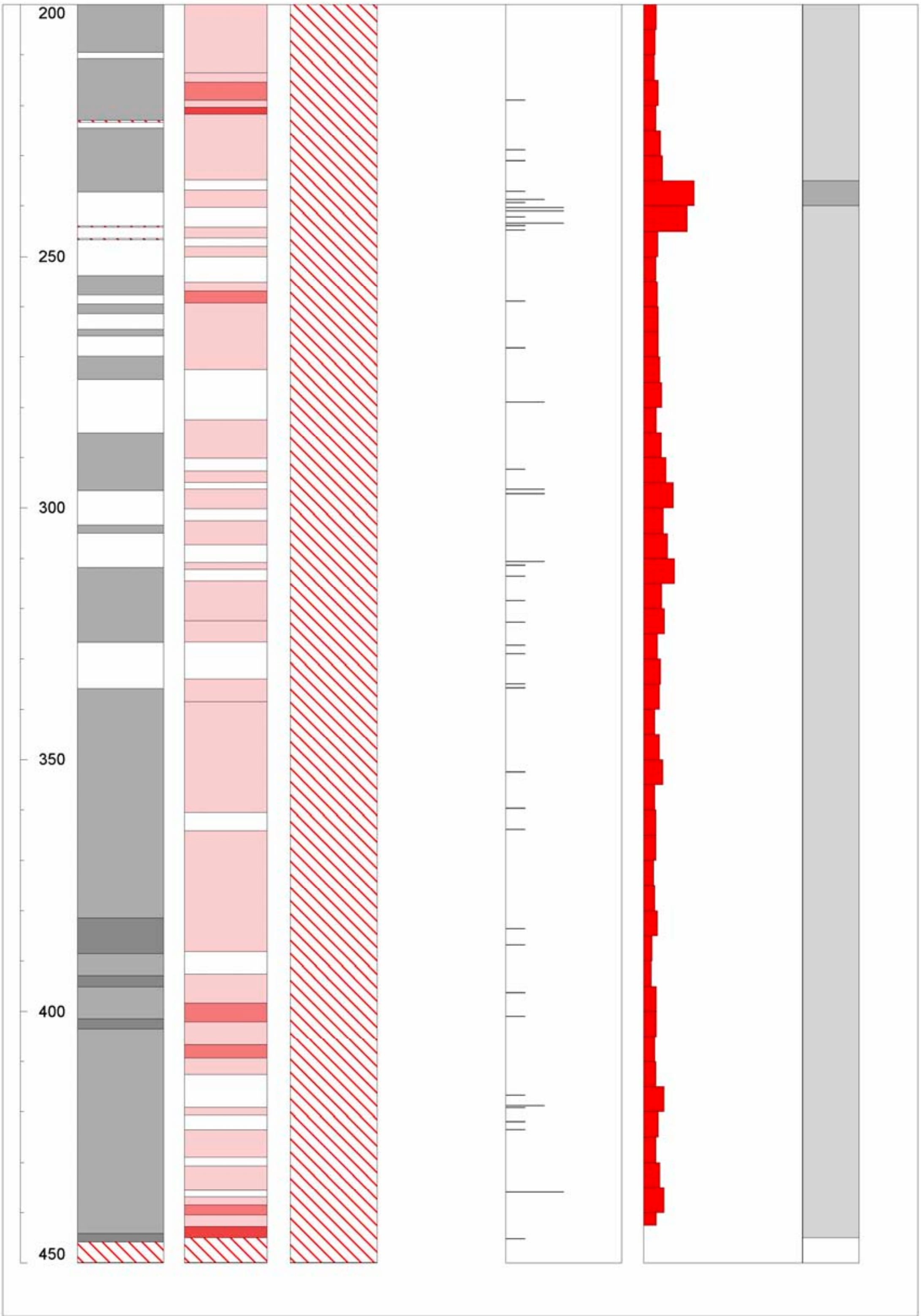
Generalized geophysical loggings of KFM01C

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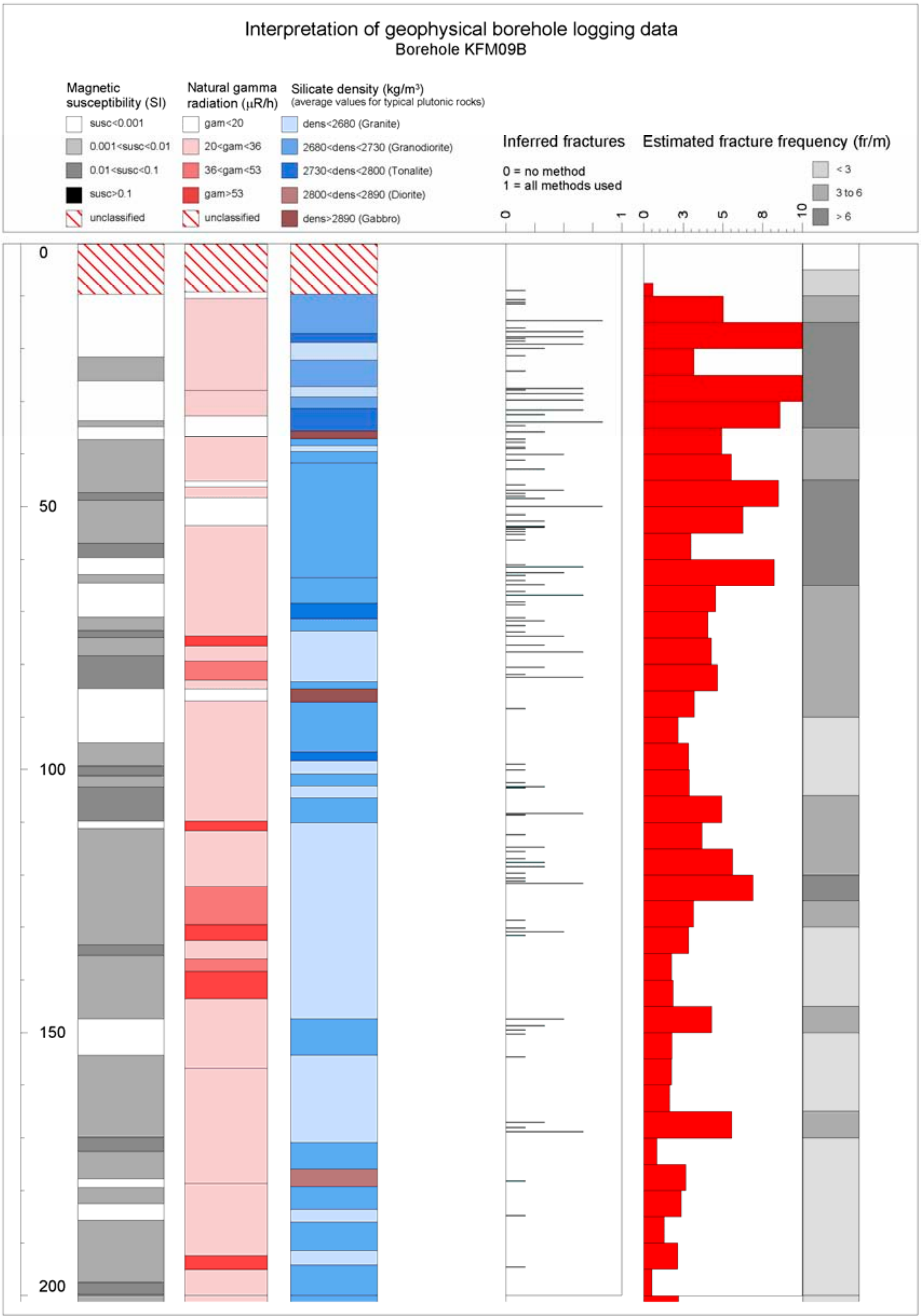
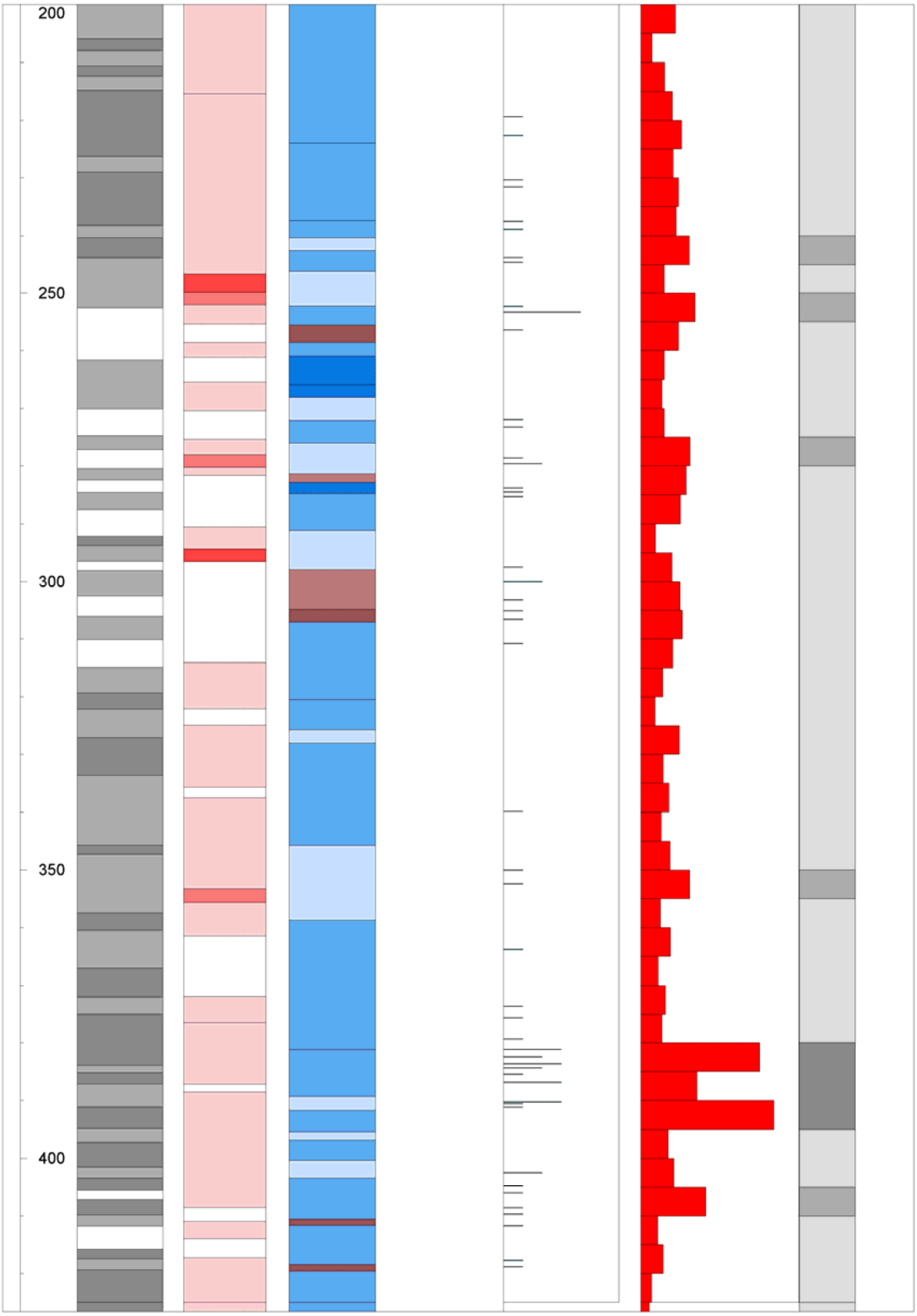
Generalized geophysical loggings of KFM09B

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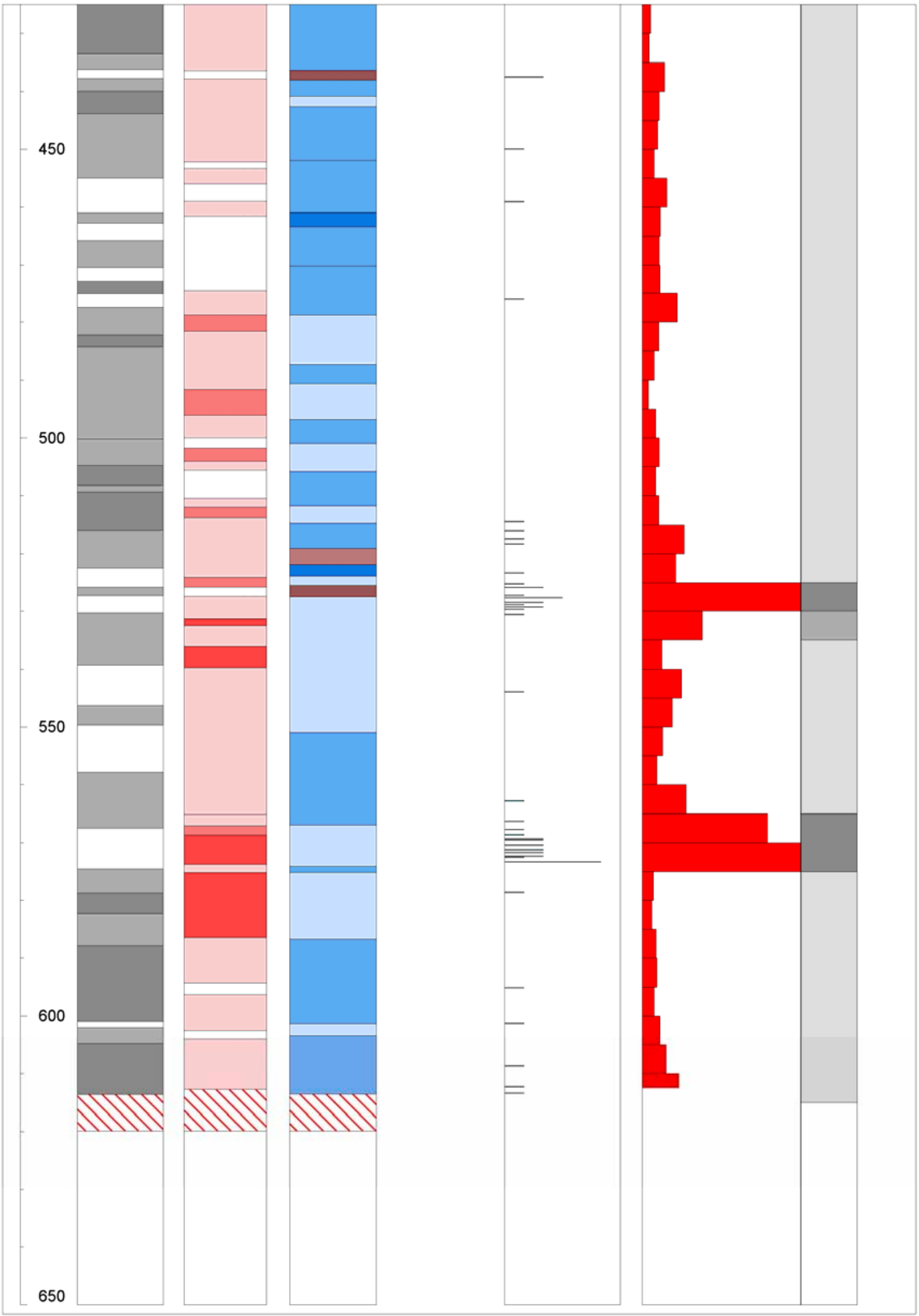
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