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Forsmark site investigation

Interpretation of geophysical borehole measurements from KFM06A and HFM20, HFM21 and HFM22

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

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Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored borehole KFM06A and the percussion drilled boreholes HFM20, HFM21 and HFM22.

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

The rocks in the vicinities of all four investigated boreholes are dominated by silicate densities indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). Subordinate short sections of rocks with higher densities generally occur in the boreholes. The highest densities, those indicating diorite or gabbro rocks, generally coincide with low susceptibility and low natural gamma radiation and they most likely indicate the occurrence of amphibolite dykes.

The natural gamma radiation is mainly in the interval 20–36 μR/h. Short sections with positive radiation anomalies occur in the boreholes, and these most likely indicate the presence of pegmatite or fine-grained granite dykes.

Special attention should be put to the section c 740–825 m of KFM06A in which the natural gamma radiation is unusually low (< 20 μR/h) and also the magnetic susceptibility and the density logs show anomalously low values. This calls for further investigations.

In KFM06A increased fracturing is mainly indicated in the upper part of the borehole, along the section c 100–370 m, with the most intense anomalies at c 120–145 m, 215–275 m and 320–360 m. The sections are mainly characterized by low resistivity and low magnetic susceptibility, and only minor anomalies in the caliper and sonic data, which indicates predominant ductile deformation or sealed fractures, and only partly open fractures.

Several indications of high fracture frequency seem to be spatially related to the occurrences of amphibolite dykes.

The measurements in the three percussion drilled boreholes HFM20, HFM21 and HFM22 all indicates a granitic dominated rock composition (< 2,680 kg/m^3) with a natural gamma radiation in the range 20–36 μR/h. The fracturing is generally low in all three boreholes. Some indications of increased or highly increased fracturing is seen in some parts in the section intervals 20–35 and 105–120 m in HFM20, 93–103 and 160–170 m in HFM21 and 55–90 m in HFM22.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KFM06A och de hammarborrade hålen HFM20, HFM21 och HFM22.

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.

Resultaten av undersökningarna visar att bergrunden i närheten av samtliga fyra borrhål helt domineras av bergarter med en silikatdensitet som indikerar en mineralsammansättning motsvarande granit (< 2 680 kg/m^3). Korta sektioner med hög densitet förekommer i alla borrhål. De allra högsta densitetsvärdena, de som indikerar diorit eller gabbro, sammanfaller ofta med låg naturlig gammastrålning och låg magnetisk susceptibilitet. Denna kombination av egenskaper är typisk för amfibolit.

Den naturliga gammastrålningen ligger huvudsakligen i intervallet 20–36 μR/h. Korta sektioner med hög naturlig gammastrålning förekommer bitvis i alla borrhål, och dessa anomalier indikerar troligen förekomst av pegmatitgångar och/eller gångar av finkornig granit.

Sektionen ca 740–825 m i KFM06A uppvisar avvikande låg naturlig gammastrålning (< 20 μR/h), i kombination med anomalt låg densitet och låg susceptibilitet. Detta bör föranleda vidare undersökningar av sektionen.

Förhöjd sprickfrekvens indikeras av de geofysiska loggarna längs stora delar av sektionen ca 100–370 m av KFM06A. De områdena med de kraftigaste anomalierna är ca 120–145 m, 215–275 m och 320–360 m. Dessa sektioner karakteriseras främst av låg resistivitet och låg susceptibilitet, och endast mindre anomalier i caliper och sonic data; vilket kan vara en indikation på en dominans av läkta sprickor och/eller plastisk deformation och endast lägre förekomst av spröda öppna sprickor.

Flertalet indikerade anomalier med förhöjd sprickfrekvens verkar ha ett rumsligt samband med förekomst av amfibolitgångar.

Hammarborrhålen HFM20, HFM21 och HFM22 visar alla att berggrunden domineras av granitisk sammansättning (< 2 680 kg/m^3) med en naturlig gammastrålning i intervallet 20–36 μR/h. Sprickfrekvensen är vanligtvis låg i alla tre hålen. Indikation på kraftigt förhöjd eller förhöjd sprickfrekvens finns inom smärre partier inom intervallen 20–35 och 105–120 m i HFM20, 93–103 och 160–170 m i HFM21 samt 55–90 m i HFM22.

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. This document reports the results gained from the interpretation of geophysical borehole logging data from the cored borehole KFM06A and the percussion drilled boreholes HFM20, HFM21 and HFM22 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 vertical temperature gradient, salinity and apparent porosity are also presented for KFM06A. The logging measurements were conducted in 2004 by Rambøll.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (activity plan AP PF 400-04-118 and method description MD 221.003, SKB internal controlling documents, Table 1-1).

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

Activity plan	Number	Version
Tolkning av borrhålsgeofysiska mätningar i KFM06A, HFM20, HFM21 och HFM22.	AP PF 400-04-118	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata.	SKB MD 221.003	2.0

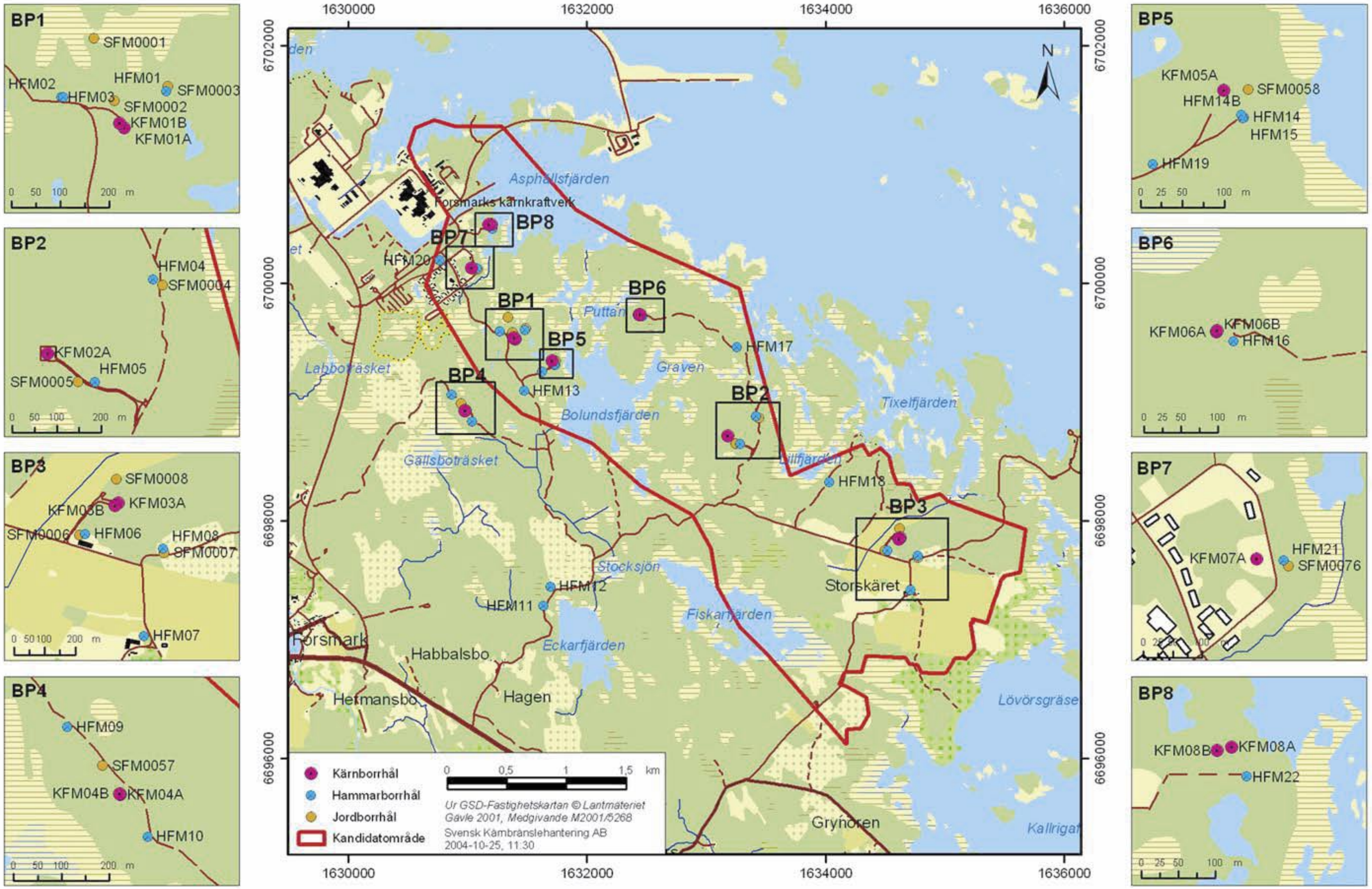

Figure 1-1. Map showing the location of the investigated boreholes KFM06A and HFM20, HFM21 and HFM22.

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.

The vertical temperature gradient, an estimation of the salinity and the apparent porosity are presented for the cored boreholes. These parameters indicate the presence of water bearing fractures, 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, filtering, error estimations, re-sampling, drift correction, length adjustment).

The loggings are median or average 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 and magnetic susceptibility logging data are calibrated with respect to petrophysical data. The logging data of KFM06A and HFM20–22 were calibrated by use of a combination of petrophysical data from the boreholes KFM01A and KFM02A /1, 2/.

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

The silicate density is calculated with reference to /3/ and the data are then divided into 5 sections indicating a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /4/. 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" (< 20µR/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 /5/; $\sigma = a\, \sigma_w^k\, \varphi^m + \sigma_s$ 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", "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 4-1.

Table 4-1. 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
KFM06A	0.3	10	0.37	1.7

The vertical temperature gradient (in degrees/km) is calculated from the fluid temperature logging for 9 m sections according to the following equation /6/:

$$TempGrad = \frac{1000\left[9\sum zt - \sum z \sum t\right]\sin\varphi}{9\sum z^2 - \left(\sum z\right)^2}$$

where z = depth co-ordinate (m), t = fluid temperature (°C) and φ = borehole inclination (°). 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 vertical temperature gradient and salinity are 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 4-2) 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, /1/. The linear coefficients (weights) used are presented in Table 4-2.

Table 4-2. 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	KFM06A	2.0	3.0	2.0	1.2	3.0	5.0	6.0	–
Weight	KFM06A	4.0	2.56	4.0	–	2.56	0.48	1.75	–
Threshold	HFM20	1.3	2; 0.3*	1.1	0.35	1.3	3.0	6.0	–
Weight	HFM20	4.0	2.56	4.0	–	2.56	0.48	1.75	–
Threshold	HFM21	1.0	0.9	1.0	0.35	0.9	3.0	2.5	–
Weight	HFM21	4.0	2.56	4.0	–	2.56	0.48	1.75	–
Threshold	HFM22	1.3	1.1	1.1	0.35	0.9	3.0	2.5	1.0
Weight	HFM22	4.0	2.56	4.0	–	2.56	0.48	1.75	–

* Two threshold values used above and below major drop in fluid resistivity

5. Report evaluating the results.

4.2 Preparations and data handling

The logging data were delivered as Microsoft Excel files via email from Rambøll. 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 vertical temperature gradient, salinity and apparent porosity help identifying water bearing fractures, 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 since the calculation show unrealistic values. Apart from this, no nonconformities are reported.

5 Results

5.1 Quality controll of the logging data

5.1.1 Noise levels

Noise levels of the raw data for each logging method are presented in Table 5-1. Noise levels are above the recommended levels for the density and the natural gamma radiation logs of all four boreholes (especially HFM20). Also the sonic logs of the percussion drilled boreholes exceed the recommended level. However, the levels are most likely low enough to allow a meaningful interpretation of the data. To reduce the influence of the noise, all logs were average or median 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.

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

Logging method	KFM06A	HFM20	HFM21	HFM22	Recommended max noise level
Density (kg/m^3)	12	26	13	12	3 – 5
Magnetic susceptibility (SI)	0.0002	0.00006	0.0001	0.0001	1*10^{-4}
Natural gamma radiation (μR/h)	0.5	0.7	0.5	0.5	0.3
Long normal resistivity (%)	0.07	0.2	0.9	0.7	2.0
Short normal resistivity (%)	0.04	0.2	0.4	0.1	2.0
Fluid resistivity (%)	0.2	Not used	Not used	Not used	2
Fluid temperature (°C)	0.001	Not used	Not used	Not used	0.01
Lateral resistivity (%)	Not used	0.2	0.6	0.2	2
Single point resistance (%)	0.06	0.2	0.7	0.2	No data
Caliper (meter)	0.00005	0.0001	0.0002	0.0001	0.0005
Focused resistivity 300 (%)	6.6	7.9	12.2	7.3	No data
Focused resistivity 140 (%)	1.0	4.6	2.1	1.0	No data
Sonic (m/s)	18	58	50	44	20

5.2 Interpretation of the logging data

The presentation of interpretation products presented below, in the Chapters 5.2.1–5.2.4 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 m sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and > 6 fractures/m).

5.2.1 Interpretation of KFM06A

The results of the generalized logging data and fracture estimations of KFM06A are presented in Figure 5-1 below, and in a more detailed scale in Appendix 1.

The rocks in the vicinity of KFM06A 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 5-1. Subordinate short sections of rocks with higher densities occur along the entire borehole length. A fairly long section at 582–627 m shows increased density, mainly in the interval 2,680–2,730 kg/m^3, which indicates a mineral composition corresponding to granodiorite. The highest densities, those indicating diorite or gabbro rocks, generally coincide with low susceptibility and low natural gamma radiation and they most likely indicate the occurrence of amphibolite dykes.

The natural gamma radiation is mainly in the interval 20–36 μR/h. Short sections with positive radiation anomalies occur fairly frequent in the borehole, though mainly along the interval c 100–550 m, and these most likely indicate the presence of pegmatite or fine-grained granite dykes. A major section with low natural gamma radiation is identified in the interval c 740–960 m. In the upper part of this interval, c 740–825 m, there is also a clear decrease in the density and the magnetic susceptibility logs. The density is here c 2,570–2,620 kg/m^3 and the susceptibility is 0.0002–0.0009 SI.

The magnetic susceptibility varies greatly in the borehole. The lowest values (< 0.001 SI) are encountered in the sections c 133–150 m, 342–366 m, 396–436 m, 532–542 m, 659–674 m and 742–819 m. The highest magnetizations (> 0.01 SI) mainly occur in the central part of the borehole, from c 330 m to 750 m, especially in the sections c 367–393 m, 456–533 m, 577–610 m and 699–714 m.

Increased fracturing is mainly indicated in the upper part of the borehole, along the section c 100–370 m, with the most intense anomalies at c 120–145 m, 215–275 m and 320–360 m. Partly increased fracturing is also indicated in the section 740–775 m. These sections are mainly characterized by low resistivity and low magnetic susceptibility, and only minor anomalies in the caliper and sonic data, which indicates that the possible deformation zones probably are dominated by ductile deformation or sealed fractures, and only partly contain open fractures.

Table 5-2. Distribution of silicate density classes with borehole length of KFM06A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
Dens < 2,680 (granite)	753	84
2,680 < dens < 2,730 (granodiorite)	94	11
2,730 < dens < 2,800 (tonalite)	21	2
2,800 < dens < 2,890 (diorite)	10	1
Dens > 2,890 (gabbro)	16	2

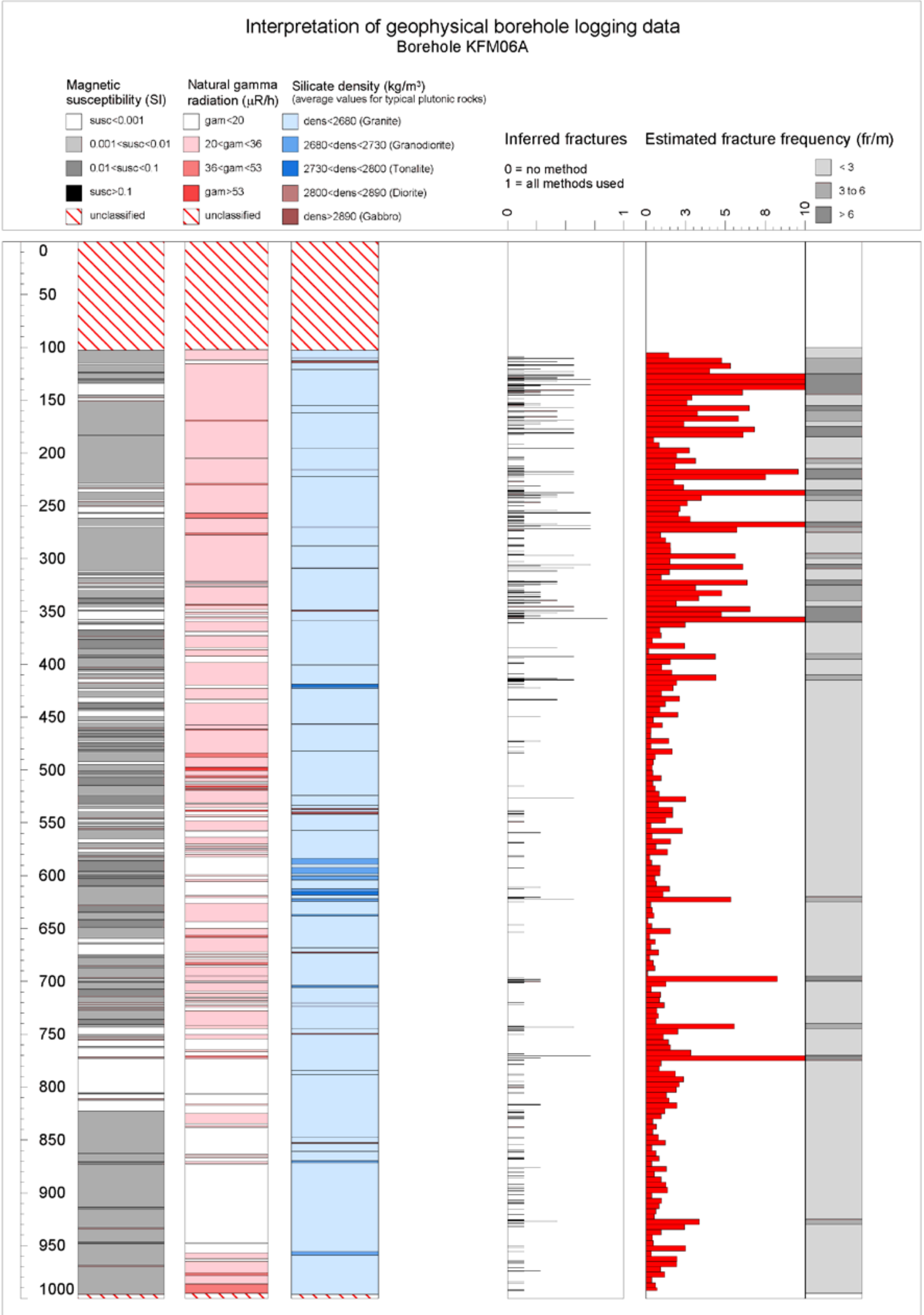

Figure 5-1. Generalized geophysical logs of KFM06A.

The estimated apparent porosity shown in Figure 5-2 (black line) is mainly in the interval 0.2–0.4%, which is reasonable in comparison to the petrophysical data from this area. High porosity anomalies occur mainly in the section c 100–370 m. The trend in the apparent porosity log, which is perfectly anti-correlated to the salinity log (the green line in Figure 5-2) is an effect of the extremely low fluid resistivity (high salinity), and it is most likely not related to true variations in the rock porosity. This is an indication that the borehole fluid is not in chemical equilibrium with the pore fluid of the rocks in the vicinity of the borehole, otherwise this trend should have been removed in the calculation of the apparent porosity (under the that assumption the fluid resistivity log is correct).

The fluid temperature gradient log shows several minor anomalies, mainly in the lowermost c 500 m of the borehole, that most likely correspond to water bearing fractures. The most prominent fluid temperature anomaly peaks at 132 m section length, which is in the centre of one of the sections with increased fracture frequency previously described.

5.2.2 Interpretation of HFM20

The results of the generalized logging data and fracture estimations of HFM20 are presented in Figure 5-3 below.

The rocks in the vicinity of HFM20 are dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3) and a rather large occurrence of short intervals with a silicate density indicating granodiorite rock. However, a majority of these possible granodiorite rocks have a silicate density only slightly above the boundary between the granite and granodiorite interval (2,680 kg/m^3), so when taking into account the high noise level of the density log of HFM20 (Table 5-1), it is possible that the indicated large occurrence of granodiorite rocks is incorrect.

The occurrences of amphibolites are indicated in the sections c 105.5–107 m, 134–147 m and 245–251 m. The sections are characterized by high density (> 2,890 kg/m^3), low natural gamma radiation (< 20 μR/h) and low magnetic susceptibility (< 0.001 SI).

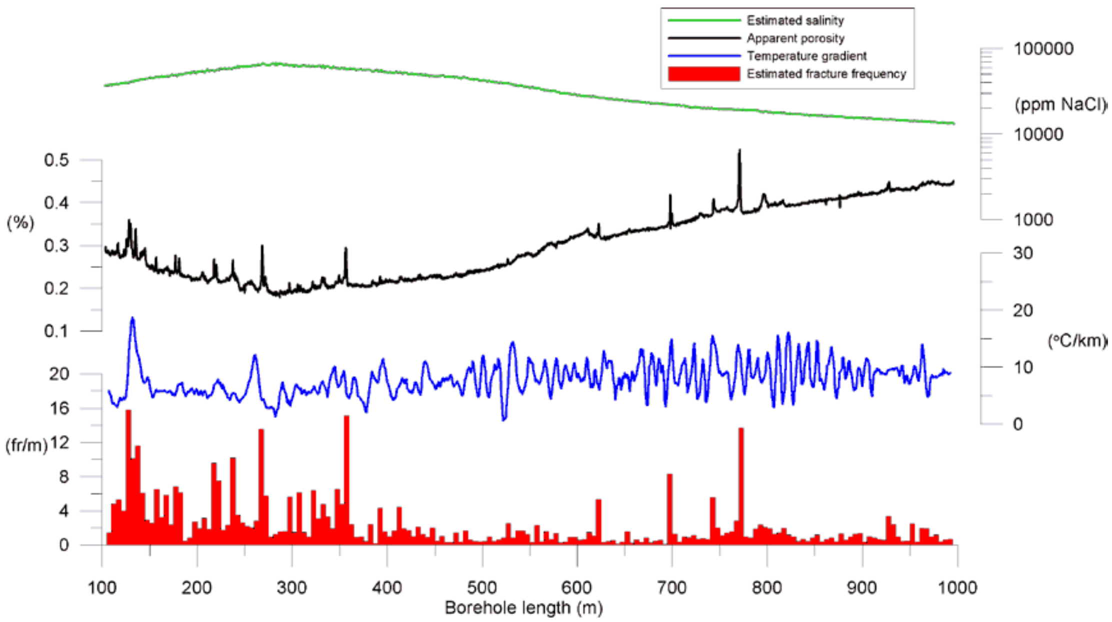

Figure 5-2. *Estimated salinity, apparent porosity, vertical temperature gradient and estimated fracture frequency of KFM06A.*

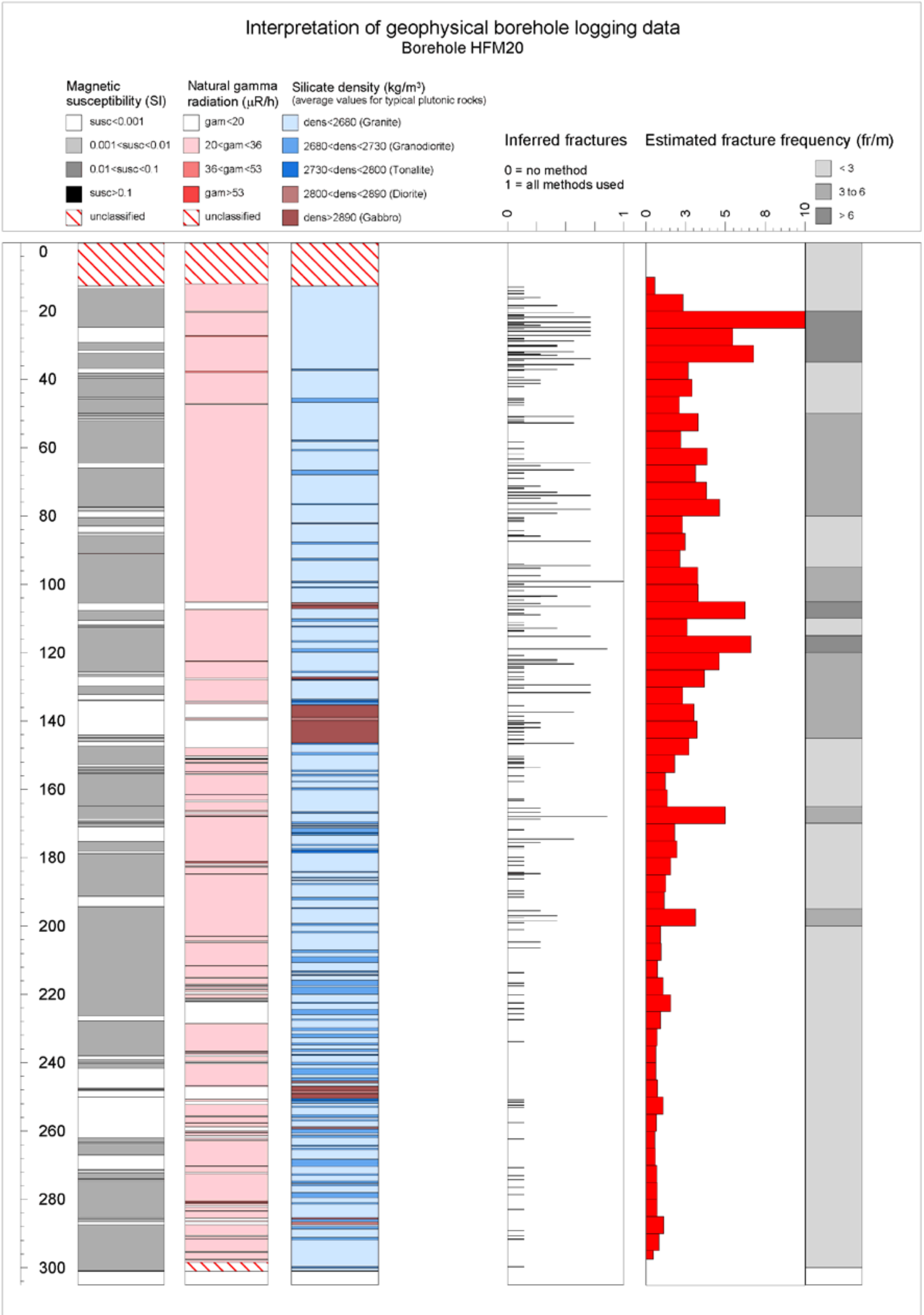

Figure 5-3. Generalized geophysical logs of HFM20.

The magnetic susceptibility is generally moderate, ranging from 0.002 SI to 0.006 SI for a major part of the borehole. Significant magnetic lows are identified in the sections c 77–87 m, 125–147 m and 238–275 m. The natural gamma radiation is fairly constant in the interval 20–36 µR/h, apart from the low radiation anomalies in connection to the sections with high density and a negative anomaly at c 220–228 m.

Due to the large drop in fluid resistivity at c 122–141 m in combination with the lack of sonic data beyond 200 m section length, the estimated fracture frequency would be underestimated below 141 m when using the standard technique with constant weights described in Chapter 4-1. To compensate for this fluid resistivity drop and the partial lack of sonic data, the estimated fracture frequency below 141 m is "corrected " by adding a factor 1.5 fr/m, which by visual inspections appears to restore the frequency to a more correct level. However, due to the circumstances described above, there is still a risk that the geophysical fracture frequency below c 141 m might fail to identify increased fracturing.

The estimated fracture frequency of HFM20 is mainly low to moderate in the section 10–200 m and low in the section 200–300 m. High degree of fracturing is indicated in the section c 20–35 m and partly in 105–120 m. The uppermost of these two sections is characterized by low resistivity, caliper anomalies and partly low magnetic susceptibility and density. The lower section with increased fracturing is mainly characterized by partly low resistivity and it coincides partly with a probable amphibolite dyke and also with the major drop in fluid resistivity reported above. It is possible that the large drop in fluid resistivity at c 122–141 m is related to a water bearing fracture in this section.

5.2.3 Interpretation of HFM21

The results of the generalized logging data and fracture estimations of HFM21 are presented in Figure 5-4 below.

The rocks in the vicinity of HFM21 are completely dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3). Minor occurrences of short intervals with silicate density indicating granodiorite rock are present in the borehole and a few indications of amphibolite dykes (high density, low natural gamma radiation and low magnetic susceptibility) are identified.

The magnetic susceptibility varies greatly between c 0.0007 and 0.007 SI along the entire borehole length. One major low magnetic section occurs at c 165–178 m. This section partly coincides with a possible amphibolite dyke.

The natural gamma radiation is fairly constant in the interval 20–36 µR/h, apart from a few minor negative and positive radiation anomalies.

The fluid resistivity in HFM21 is very low, generally below 1 ohmm, for the entire borehole. The low fluid resistivity has a significant effect on the amplitude variations of the normal resistivity and the single point resistance loggings, which in turn might lead to an underestimation of the fracture frequency level in the borehole.

The estimated fracture frequency of HFM21 is mainly low. Strongly increased fracturing is partly indicated in 93–103 m. The section is characterized by partly low resistivity, a decrease in the P-wave velocity, several caliper anomalies and partly low density and low magnetic susceptibility. Moderate degree of fracturing is indicated in the section c 160–170 m. This section is mainly characterized by low resistivity and it partly coincides with a possible amphibolite dyke.

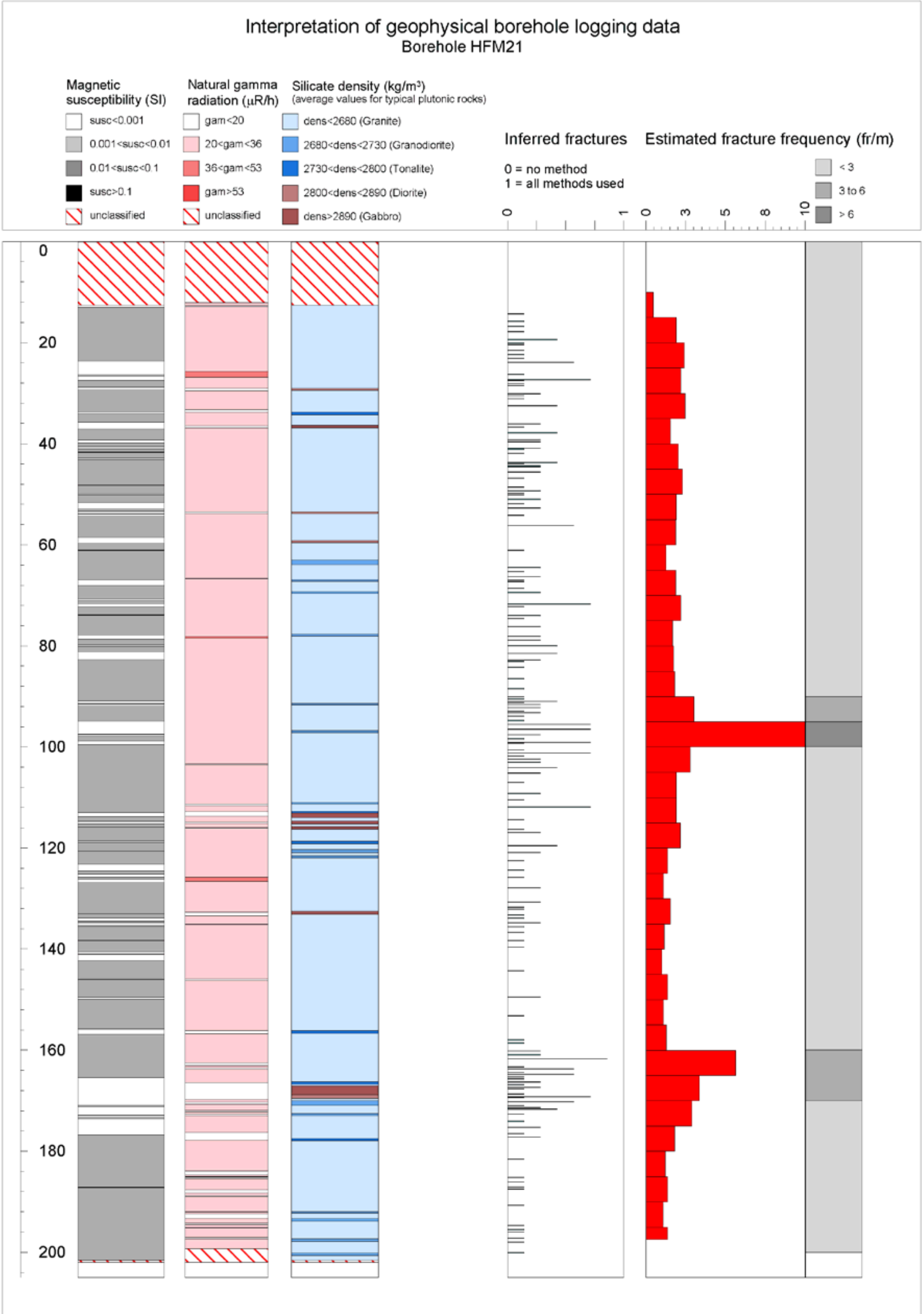

Figure 5-4. *Generalized geophysical logs of HFM21.*

5.2.4 Interpretation of HFM22

The results of the generalized logging data and fracture estimations of HFM22 are presented in Figure 5-5 below.

The rocks in the vicinity of HFM22 are dominated by silicate density indicating a mineral composition that corresponds to granite rock (< 2,680 kg/m^3) and a rather large occurrence of short intervals with a silicate density indicating granodiorite rock. In the section c 202–210 the silicate density is mainly in the interval 2,700–2,750 kg/m^3, which indicates a mineral composition that corresponds to granodiorite or tonalite rocks.

The magnetic susceptibility varies stepwise in the interval c 0.0007 SI to 0.01 SI. Significant magnetic lows are identified in the sections c 28–37 m, 101–120 m, partly 138–171 and partly 187–210 m.

The natural gamma radiation is fairly constant in the interval 20–36 μR/h, but there are several minor and moderate sections with low radiation level along the entire borehole length. A few positive natural gamma radiation anomalies are identified, mainly in the lower half of the borehole.

The fluid resistivity in HFM22 is very low, generally below 1 ohmm, for the entire borehole. The low fluid resistivity has a significant effect on the amplitude variations of the normal resistivity and the single point resistance loggings, which in turn might lead to an underestimation of the fracture frequency level in the borehole.

The estimated fracture frequency varies between mainly low and moderate in the section c 12–130 m, and below 130 m section length the estimated fracture frequency is low. Strongly increased fracturing is partly indicated in the interval c 55–90 m. The most intense parts are characterized by low resistivity, low P-wave velocity, caliper anomalies and partly low magnetic susceptibility. There seems to be a spatial relation between increased fracturing and a possible amphibolite dyke at c 68 m.

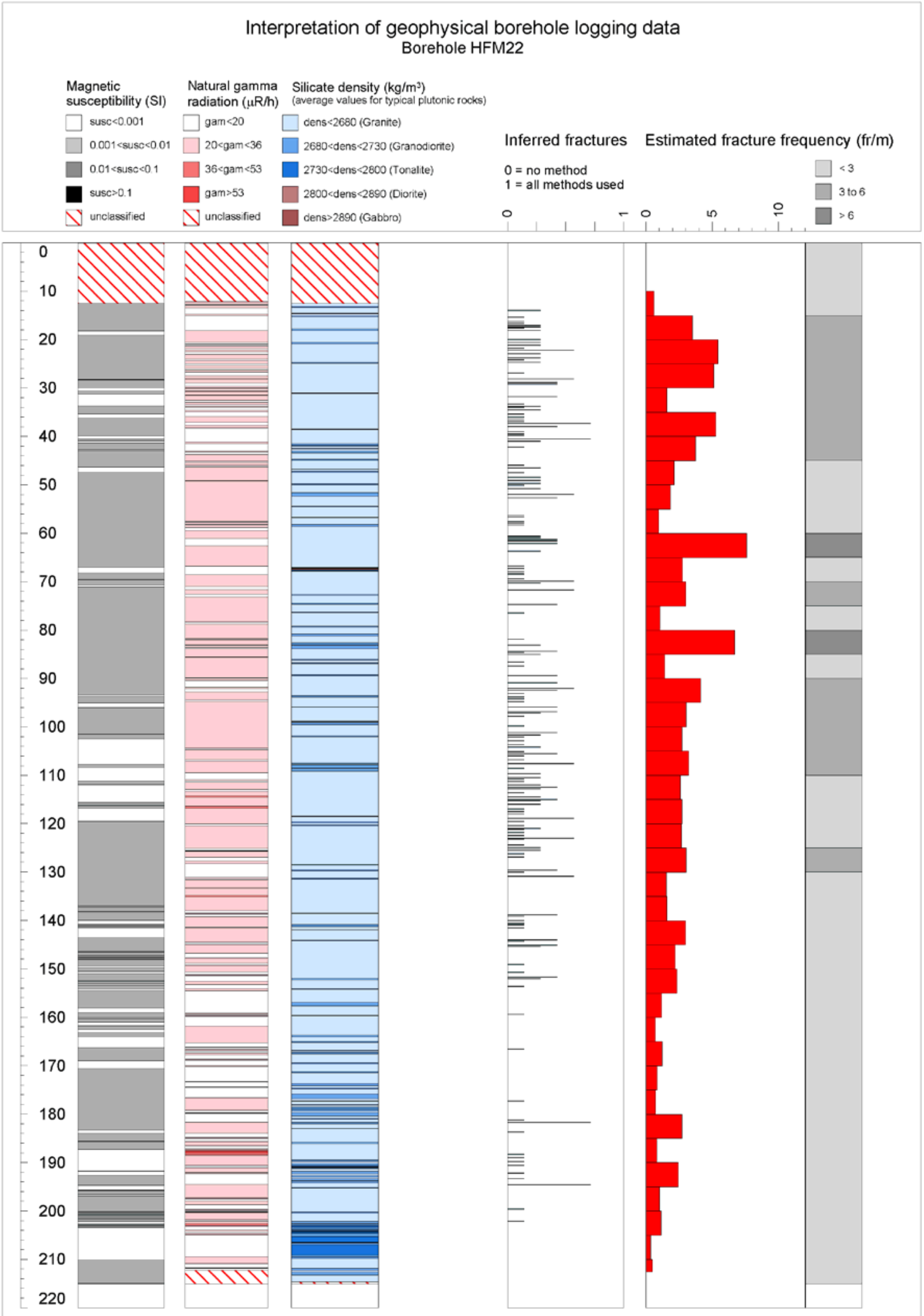

Figure 5-5. Generalized geophysical logs of HFM22.

References

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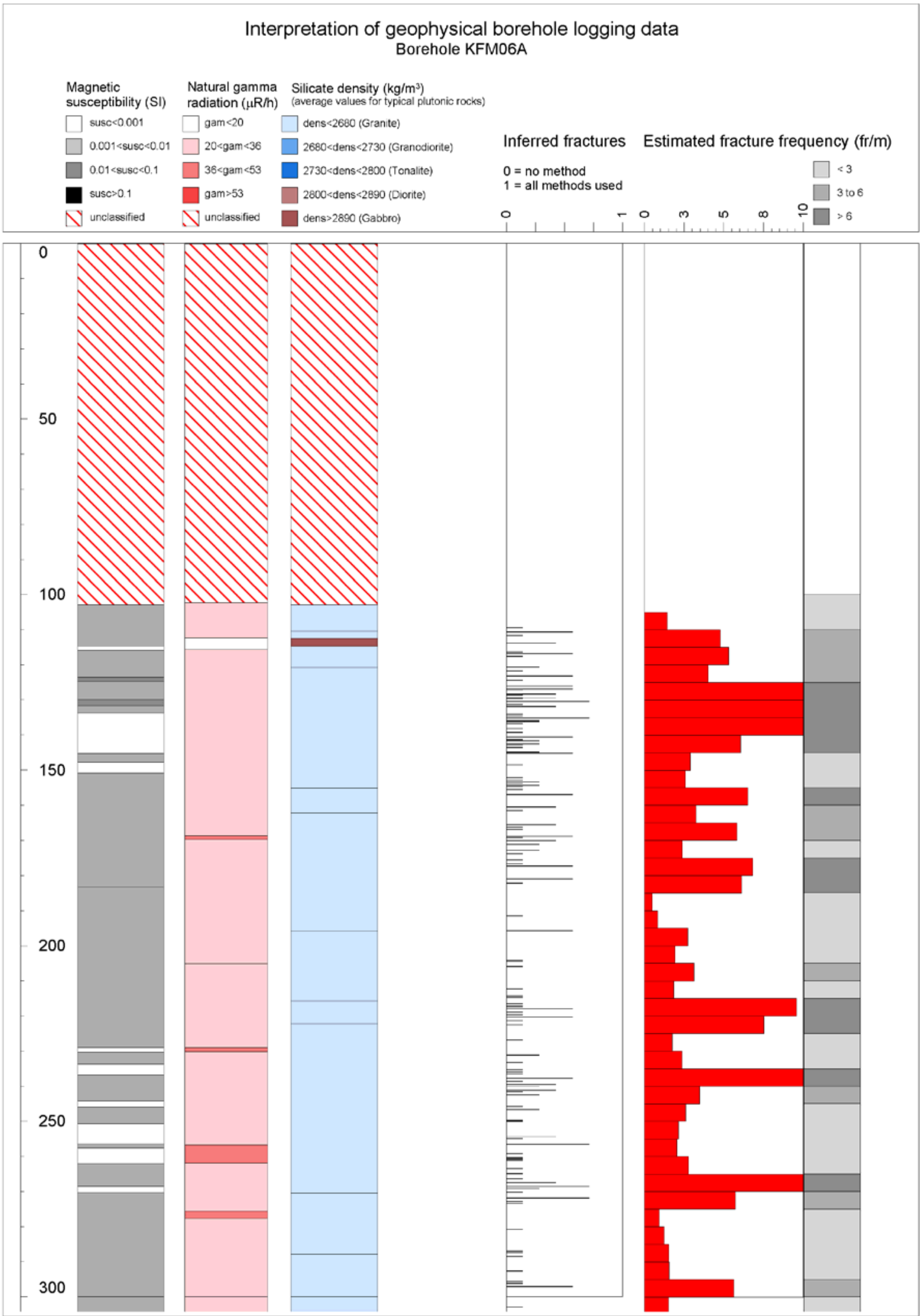
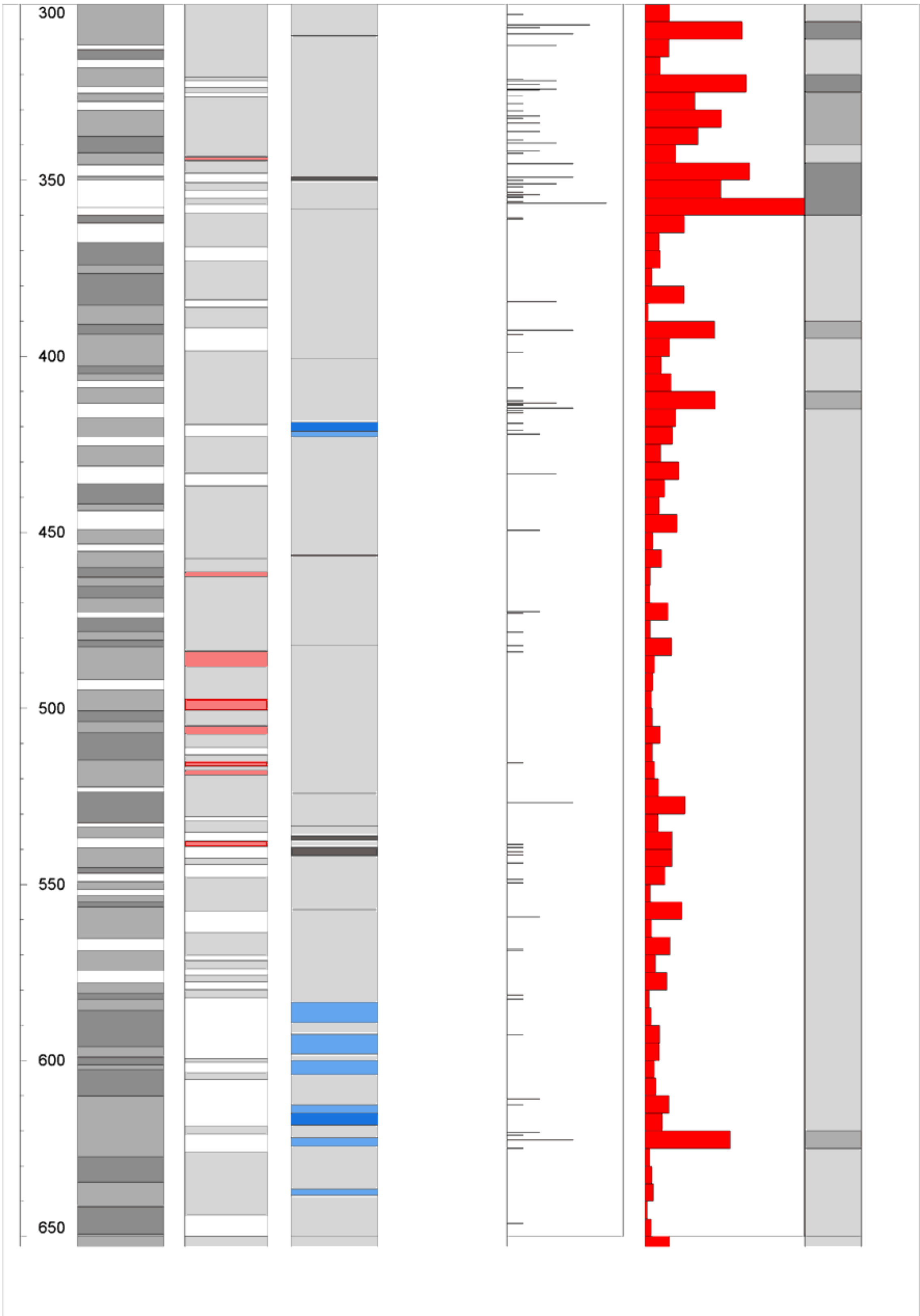
Generalized geophysical loggings of KFM06A





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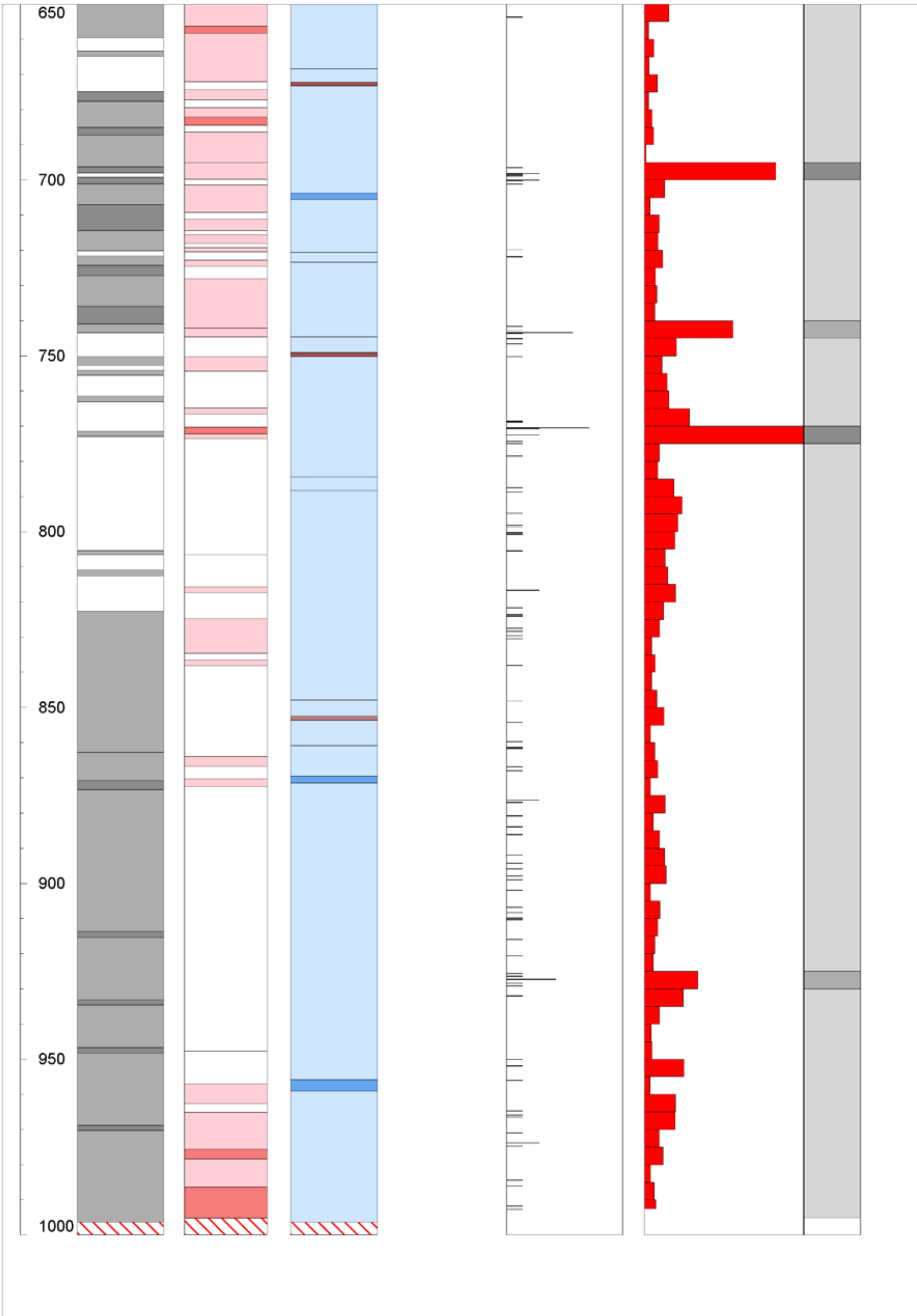
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