P-10-12

Site investigation SFR

Interpretation of geophysical borehole measurements and petrophysical data from KFR105, KFR106 and HFR106

Håkan Mattsson, Mikael Keisu
GeoVista AB

April 2010

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-10-12

Site investigation SFR

Interpretation of geophysical borehole measurements and petrophysical data from KFR105, KFR106 and HFR106

Håkan Mattsson, Mikael Keisu
GeoVista AB

April 2010

Keywords: P-report SKBDoc id 1241852, Review statement SKBDoc id 1241853, Borehole, Logging, Geophysics, Geology, Bedrock, Fractures, SFR, Forsmark, AP SFR-09-017, Project SFR extension.

Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored boreholes KFR105 and KFR106 and the percussion drilled borehole HFR106. The report also includes interpretation of density measurements on core samples from KFR106.

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

In KFR105 the silicate density distribution shows that silicate density < 2,680 kg/m^3 occurs along 51% of the total borehole length. The sections mainly occur in the intervals 0–80 m and 185–305 m and generally coincide with increased natural gamma radiation (> 60 μR/h) and significantly decreased magnetic susceptibility (close to 0.0 SI). The combination of physical properties is typical for pegmatitic granite. In the section c. 80–185 m the geophysical logging data indicate the occurrence of meta granite to granodiorite rock. Some 8–10 short sections with indicated amphibolites are scattered along the borehole length. The estimated fracture frequency is generally low in KFR105. However, there are six intervals with significantly decreased resistivity and with caliper anomalies that may correspond to deformation zones. The sections with the most significant geophysical anomalies occur at 8–15 m, 45–53 m, 77–79 m, 170–175 m, 267–282 m and 295–304 m.

For a majority of the rocks along KFR106 the silicate density is in the range 2,660–2,760 kg/m^3, the natural gamma radiation is in the range 30–40 μR/h and the magnetic susceptibility is decreased. The data indicate meta granite to granodiorite rock with a low content of magnetite. Along the sections c. 10–30 m, 73–75 m and 115–140 m the silicate density is significantly decreased, the magnetic susceptibility is < 10^{-3} SI and the natural gamma radiation is significantly increased > 60 μR/h. This combination of physical properties is typical for pegmatite or pegmatitic granite. Short sections with indicated amphibolites are scattered along the borehole length. The estimated fracture frequency is generally low in KFR106. However, there are three intervals with significantly decreased resistivity, and with caliper anomalies, that may correspond to deformation zones. The sections with the most significant geophysical anomalies occur at 15–20 m, 154–157 m and 258–264 m.

In HFR106 the wet density averages at c. 2,500 kg/m^3, which is unusually low even for rocks with very low content of dark minerals. The natural gamma radiation is in the range 20–40 μR/h, which is typical for meta granite to granodiorite rock and it is far too low to indicate for e.g. pegmatitic granite, which is known to have decreased density. It appears as if the calibration equation established for the density in KFR106 fails to properly correct the density data of HFR106. For the interpretation we conclude that the relative changes in density along the borehole seem to be physically reasonable, but the general background density level is assumed to be c. 150 kg/m^3 too low. In the sections c. 14–36 m, 65–72 m, large parts of 80–110 m and along 161–167 m the natural gamma radiation is partly increased and the density is decreased. It is likely that the geophysical logging data indicate the occurrence of pegmatite granite along these intervals of the borehole. In the remaining parts of the borehole the logging data indicate a dominant occurrence of meta granite to granodiorite rock, and also a few short sections that correspond to magnetite bearing amphibolite dykes. The estimated fracture frequency is generally low along the entire borehole. However, there are four intervals with significantly decreased resistivity, and with caliper anomalies, that may correspond to deformation zones. The sections with the most significant geophysical anomalies occur at c. 36–40 m, 124–127 m, 158–161 m and 178–181 m.

Sammanfattning

Föreliggande rapport presenterar resultat och tolkningar av geofysiska borrhålsmätningar i kärnborrhålen KFR105 och KFR106 samt i hammarborrhålet HFR106. Rapporten inkluderar även en utvärdering av densitetsmätningar på borrkärnebitar från KFR106.

Syftet med undersökningen var 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.

I KFR105 upptar silikatdensitet < 2 680 kg/m^3 51 % av den uppmätta borrhålslängden. Dessa sektioner med låg densitet förekommer främst längs intervallen 0–80 m och 185–305 m och de sammanfaller med förhöjd naturlig gammastrålning (> 60 µR/h) och kraftigt sänkt magnetisk susceptibilitet. Kombinationen av fysikaliska egenskaper är typisk för pegmatitisk granit. Längs borrhålssektionen 80–185 m indikerar de geofysiska loggarna förekomst av meta-granit till granodiorit. Ett tiotal korta sektioner med indikerad amfibolit förekommer relativt jämnt fördelat längs borrhålet. Den beräknade sprickfrekvensen är generellt låg. Det finns dock sex sektioner med avvikande låg resistivitet och caliper-anomalier, som sannolikt indikerar förekomst av deformationszoner. De identifierade sektionerna är 8–15 m, 45–53 m, 77–79 m, 170–175 m, 267–282 m och 295–304 m.

Majoriteten av bergarterna längs KFR106 har en silikatdensitet inom intervallet 2 660–2 760 kg/m^3, naturlig gammastrålning på 30–40 µR/h och låg magnetisk susceptibilitet. Denna kombination av fysikaliska egenskaper är typisk för meta-granit till granodiorit med litet innehåll av magnetit. Längs sektionerna 10–30 m, 73–75 m och 115–140 m är silikatdensiteten och den magnetiska susceptibiliteten båda avvikande låga i kombination med förhöjd naturlig gammastrålning, vilket är en typisk signatur för pegmatit eller pegmatitisk granit. Ett mindre antal korta sektioner med indikerad amfibolit förekommer relativt jämnt fördelat längs med borrhålet. Den beräknade sprickfrekvensen är generellt låg. Det finns dock tre sektioner med avvikande låg resistivitet och caliper-anomalier, som sannolikt indikerar förekomst av deformationszoner. De identifierade sektionerna är 15–20 m, 154–157 m och 258–264 m.

I HFR106 är medeldensiteten för hela hålet cirka 2 500 kg/m^3, vilket är ovanligt lågt även om berget skulle bestå av bergarter med mycket låg halt av mörka mineral. Dessutom är den naturliga gammastrålningen generellt 20–40 µR/h, vilket är en typisk nivå för meta-granit till granodiorit men alldeles för låg för till exempel pegmatitisk granit som ju annars är känd för avvikande låg densitet. Det framstår som uppenbart att den kalibreringsekvation som beräknats för densitetsdata i KFR106 inte fungerar för att på ett korrekt sätt kalibrera densitetsdata i HFR106. De relativa variationerna i densitet i HFR106 är rimliga men nivån verkar vara cirka 150 kg/m^3 för låg i förhållande till vad som kan antas vara rimligt. Utifrån dessa osäkerheter indikerar tolkningen av data att sektionerna cirka 14–36 m, 65–72 m, stora delar av 80–110 m samt längs 161–167 m domineras av förhöjd naturlig gammastrålning och sänkt densitet, vilket indikerar förekomst av pegmatitisk granit. För resterande delar av borrhålssektionen indikerar data dominerande förekomst av meta-granit till granodiorit samt enstaka kortare sektioner med amfibolit. Den beräknade sprickfrekvensen är generellt låg. Det finns dock fyra sektioner med avvikande låg resistivitet och caliper-anomalier, som sannolikt indikerar förekomst av deformationszoner. De identifierade sektionerna är 36–40 m, 124–127 m, 158–161 m och 178–181 m.

Contents

1	**Introduction**	7
2	**Objective and scope**	9
3	**Equipment**	11
3.1	Description of interpretation tools for analyses of logging data	11
3.2	Description of equipment for analyses of petrophysical data	11
4	**Execution**	13
4.1	Interpretation of logging data in general	13
4.2	Preparations and data handling	14
4.3	Analyses and interpretations	14
4.4	Nonconformities	14
5	**Results**	15
5.1	Quality control of the logging data	15
5.2	Calibration of density and magnetic susceptibility data	15
5.3	Interpretation of the logging data	17
	5.3.1 Interpretation of KFR105	17
	5.3.2 Interpretation of KFR106	19
	5.3.3 Interpretation of HFR106	21
6	**References**	23

1 Introduction

This document reports the interpretations of geophysical borehole measurements gained from the cored boreholes KFR105 and KFR106 and the percussion drilled borehole HFR106, which is one of the activities performed within the site investigation at SFR (Figure 1-1). The work was carried out in accordance with activity plan AP SFR-09-017. In Table 1-1 controlling documents for performing this activity are listed. Activity plans and method descriptions are SKB's internal controlling documents.

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings, including estimated fracture frequency. The logging measurements were conducted in 2009 by Rambøll /1, 2/.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB and under supervision of Johan Nissen, SKB.

The data and interpretation products are stored in the database Sicada and are traceable by the activity plan number.

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

Activity plan	Number	Version
Tolkning av geofysiska borrhålsdata från KFR105, KFR106 och HFR106	AP SFR-09-017	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	3.0

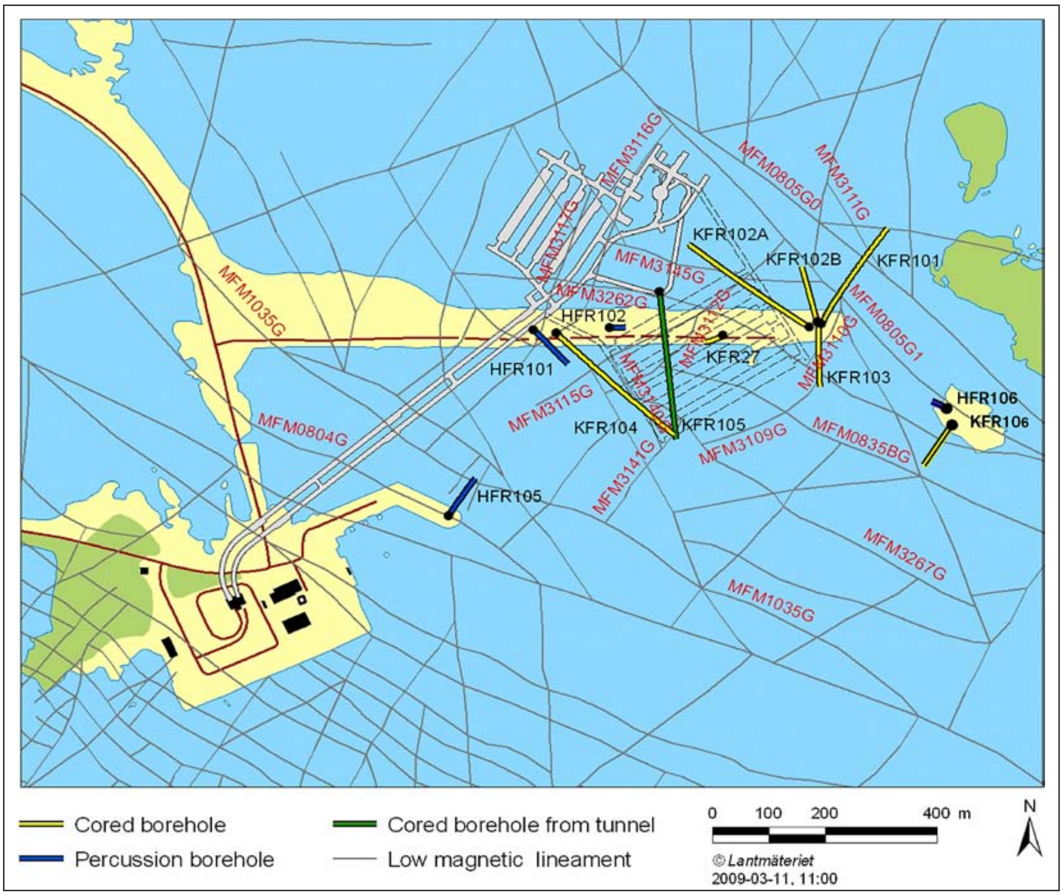

Figure 1-1. General overview over SFR site investigation area showing the locations of the investigated boreholes KFR105, KFR106 and HFR106.

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 and caliper loggings.

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 interpretation tools for analyses of logging data

The software used for the interpretation are WellCad v4.0 (ALT) and Strater 1.00.24 (Golden Software), that are mainly used for plotting, Grapher v5 (Golden Software), mainly used for plotting and some statistical analyses, and a number of in-house software developed by GeoVista AB on behalf of SKB.

3.2 Description of equipment for analyses of petrophysical data

Masses for the density determinations were measured with a digital Mettler Toledo PG 5002. The measurements were performed by the petrophysical laboratory at Luleå University of Technology.

4 Execution

4.1 Interpretation of logging data in general

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 and susceptibility logging data of KFR105 were calibrated with respect to petrophysical data from KFR101 /3/.

The density data of KFR106 and HFR106 were calibrated with respect to petrophysical data from KFR106. The magnetic susceptibility loggings of all three boreholes data were calibrated with respect to petrophysical data from KFR101 /3/.

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

The silicate density is calculated with reference to /4/ and the data are then divided into 5 sections *indicating* a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /5/. 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" (gamma < 20μR/h), "medium" (20 μR/h < gamma < 36 μR/h), "high" (36 μR/h < gamma < 53 μR/h) and "very high" (gamma > 53 μR/h).

3. The caliper mean data are calibrated with reference to borehole technical specifications (caliber ring diameter data) supplied by the SKB (extracted from Sicada). The calibration procedure is described in detail in /6/.

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 "caliper mean", "focused resistivity 128" and "focused resistivity 300" data. 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 previously estimated by correlating the weighted sum to the mapped fracture frequency in the cored boreholes KFM01A and KFM02A. The parameters were based on logging data from "sonic", "caliper", "normal resistivity", "SPR" and "focused resistivity" measurements. However, in the SFR investigation the only fracture indicative loggings used are the "focused resistivity" and "caliper mean". The parameters of the power functions have therefore been adjusted to fit a "back ground" fracture frequency in KFR101 of c. 2–3 fractures/m. The linear coefficients (weights) used are presented in Table 4-1.

Table 4-1. Threshold values and weights used for estimating position of fractures and calculate estimated fracture frequency, respectively.

	Borehole	Focused res. 128	Focused res. 300	Caliper
Threshold	KFR105	1.5	1.3	0.4
Weight	KFR105	2.56	4.0	2.0
Threshold	KFR106	1.2	1.3	0.4
Weight	KFR106	2.56	4.0	2.0
Threshold	HFR106	1.5	1.5	0.5
Weight	HFR106	2.56	4.0	2.0

5. Report evaluating the results.

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 (128 cm)
- Caliper mean
- 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 and caliper loggings are mainly used for identifying sections with increased fracturing and alteration.

4.4 Nonconformities

No nonconformities are reported.

5 Results

5.1 Quality control of the logging data

Noise levels of the raw data for each logging method are presented in Table 5-1. For all boreholes the density and natural gamma radiation data have noise levels significantly above the recommended value. 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 Calibration of density and magnetic susceptibility data

The density and magnetic susceptibility logging data of KFR105 were calibrated by use of calibration parameters established with petrophysical data from core samples of KFR101. This is according to standard procedures since the same logging equipment was used for these two boreholes and the instruments are assumed to be stable with time.

However, in KFR106 and HFR106 the logging measurements were conducted with new logging tools. Ten samples were therefore collected from the core and wet density was measured at the petrophysical laboratory of Luleå University of Technology, Table 5-2.

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

Logging method	KFR105	KFR106	HFR106	Recommended max noise level
Density (kg/m^3)	9	21	20	3–5
Magnetic susceptibility (SI)	1×10^{-4}	6×10^{-5}	7×10^{-5}	1×10^{-4}
Natural gamma radiation (μR/h)	1.4	1.7	1.5	0.3
Fluid resistivity (%)	0.02	0.007	0.01	2
Fluid temperature (°C)	3×10^{-4}	2×10^{-4}	2×10^{-4}	0.01
Caliper mean (meter)	2×10^{-5}	1×10^{-5}	7×10^{-4}	0.0005
Focused resistivity 300 (%)	10	13	7	No data
Focused resistivity 128 (%)	6	10	5	No data

Table 5-2. Borehole section and density for core samples collected in KFR106.

Borehole ID	Sample section length (m)	Density (kg/m^3)
KFR106	10.50–10.58	2,660
KFR106	35.55–35.63	2,620
KFR106	40.15–40.23	3,070
KFR106	99.30–99.38	2,670
KFR106	120.80–120.88	2,630
KFR106	142.44–142.52	2,990
KFR106	164.10–164.18	2,640
KFR106	179.89–179.97	2,670
KFR106	290.81–290.89	2,610
KFR106	293.12–293.20	2,990

By extracting data from the density log at the same borehole section co-ordinates as the core samples were collected at, it is possible to construct a cross-plot with logging data versus sample data, see Figure 5-1. The logging data were average filtered prior to the extraction in order to remove random noise. Linear regression analysis was used to estimate a calibration equation for the density data. The cross plotted density data do not show a clear linear distribution and the linear regression method is very sensible to single outlying data points. Three points, shown with red symbols in the diagram, do clearly not follow the trend of the majority of the data points. Removing data points is always a delicate matter since all data should be equally valued. However, all three outlying data points occur on gradients in the logging data, which gives a reason for removing them. After removing the diverging data points the linear fit is well established with a R^2 coefficient = 0.97 and residual mean value (RMS) of 20 kg/m³.

The susceptibility data of KFR105 were calibrated by use of parameters established with petrophysical data from core samples of KFR101 (just as with the density data). For KFR106 and HFR106 the new susceptibility logging tool that was used for the measurements made it necessary to perform a new calibration. This was done by constructing a cross-plot of two sets of logging data measured in the same reference borehole HFM07. One set of data was collected with the old logging tool and the other with the new tool. Since calibration parameters exist for the old tool (from petrophysical data of KFR101), we could thus calibrate the susceptibility data from KFR106 and HFR106 with petrophysical data from KFR101 via the correction in HFM07. A cross-plot of the data measured with the new and old tools in HFM07 is presented in Figure 5-2.

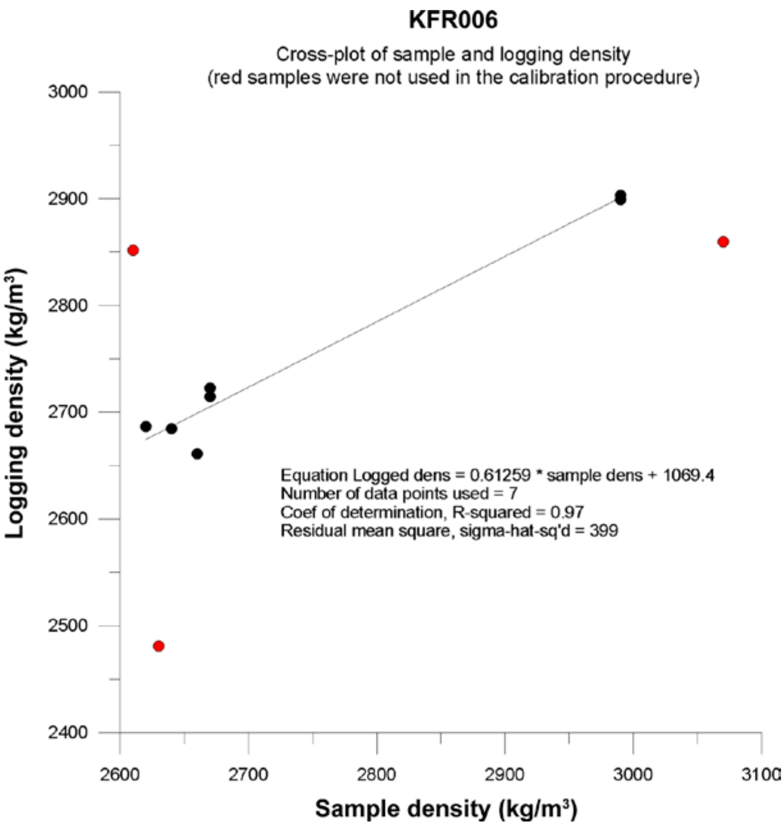

Figure 5-1. *Cross plot showing logging density data versus sample density data of KFR106.*

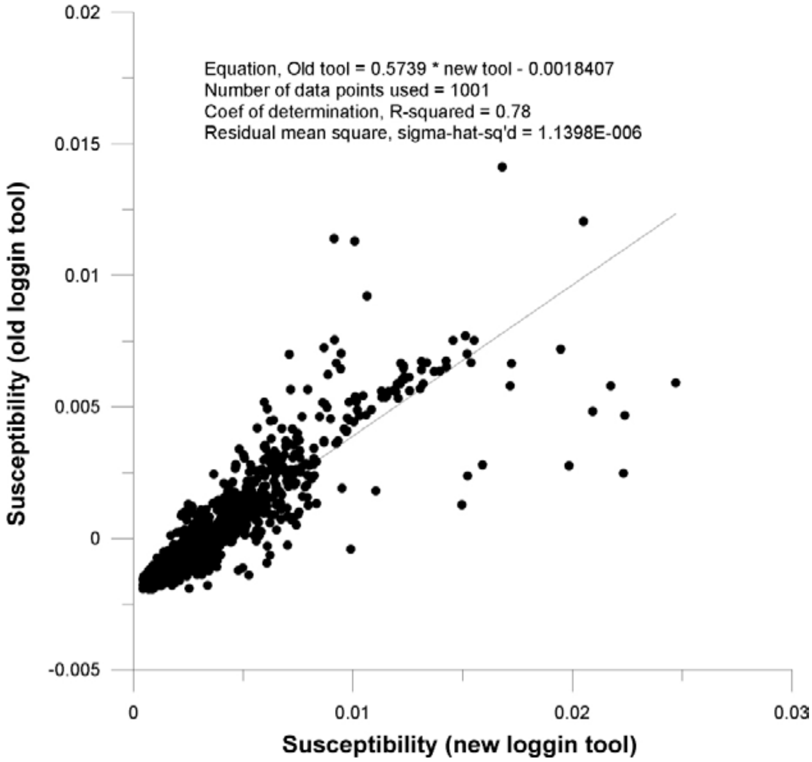

Figure 5-2. *Cross plot showing logged magnetic susceptibility with the old versus the new tool in the reference borehole HFM07.*

5.3 Interpretation of the logging data

The presentation of interpretation products presented below includes:

- Classification of silicate density
- Classification of natural gamma radiation
- Classification of magnetic susceptibility
- Position of inferred fractures (0 = no method, 1 = all methods)
- Estimated fracture frequency in 5 metre sections
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and > 6 fractures/m)

5.3.1 Interpretation of KFR105

The results of the generalized logging data and fracture estimations of KFR105 are presented in Figure 5-3. The distribution of silicate density classes with borehole length is presented in Table 5-3.

The silicate density distribution shows that silicate density < 2,680 kg/m^3 occurs along 51% of the total borehole length. The sections mainly occur in the intervals 0–80 m and 185–305 m and generally coincide with increased natural gamma radiation (> 60 µR/h) and significantly decreased magnetic susceptibility (close to 0.0 SI). The combination of physical properties is typical for pegmatitic granite.

Table 5-3. Distribution of silicate density classes with borehole length in KFR105.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680 (granite)	155	51
2,680 < dens < 2,730 (granodiorite)	128	42
2,730 < dens < 2,800 (tonalite)	18	6
2,800 < dens < 2,890 (diorite)	1	1
dens > 2,890 (gabbro)	0	0

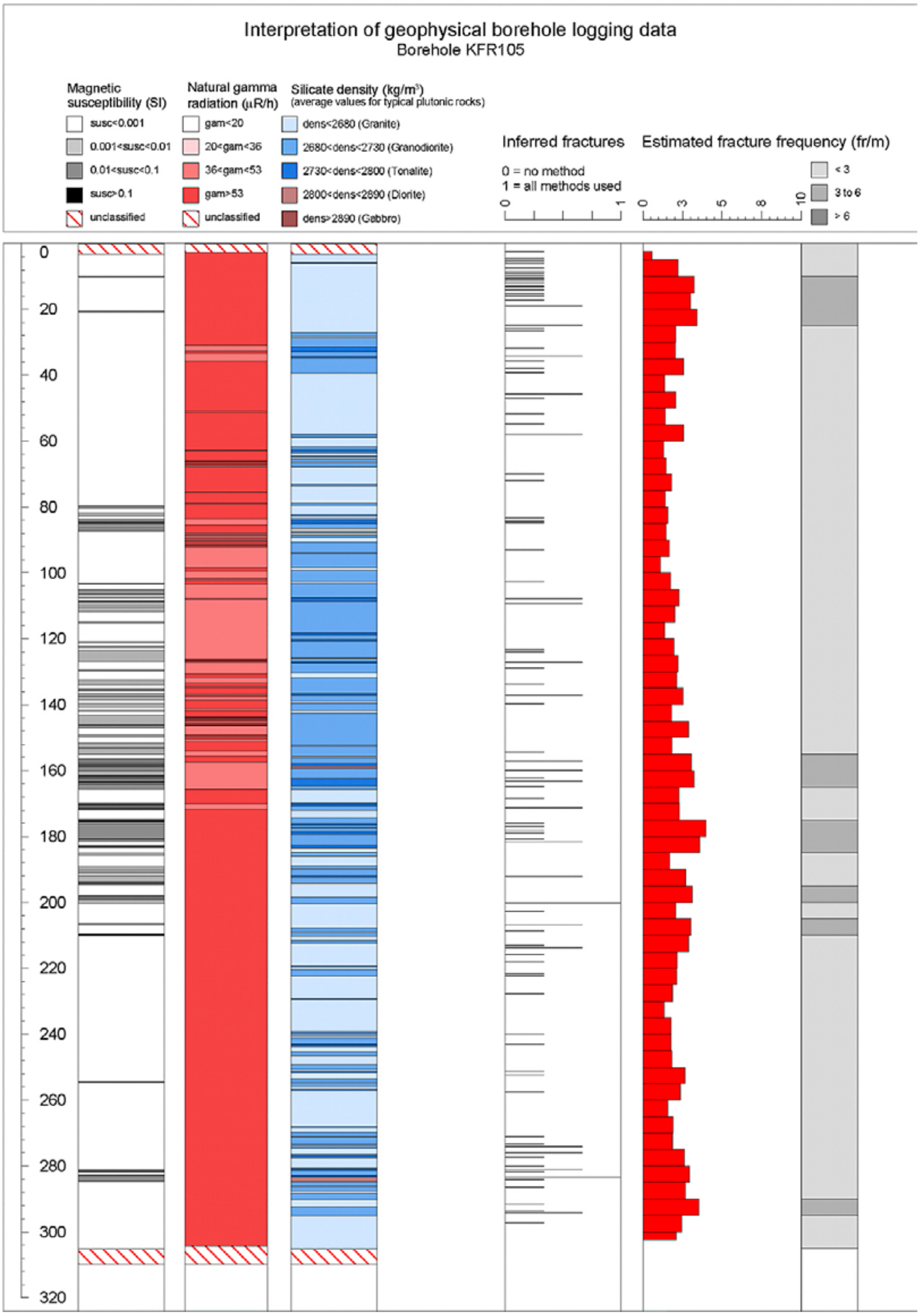

Figure 5-3. Generalized geophysical logs of KFR105.

In the section c. 80–185 m a majority of the rocks have silicate density of 2,680–2,720 kg/m^3, natural gamma radiation in the range 40–60 μR/h and partly increased magnetic susceptibility. The data may indicate meta granite to granodiorite rock.

Some 8–10 short sections (< 1 m long) with significantly increased density and magnetic susceptibility, and decreased natural gamma radiation, are scattered along the borehole length. These sections most likely correspond to magnetite bearing amphibolite dykes.

The estimated fracture frequency is generally low in KFR105. However, there are six intervals with significantly decreased resistivity and with caliper anomalies that may correspond to deformation zones. The sections with the most significant geophysical anomalies occur at 8–15 m, 45–53 m, 77–79 m, 170–175 m, 267–282 m and 295–304 m. In the three lowermost sections significant anomalies in the fluid temperature data occur, which most likely indicates in or out flow of water. A major fluid temperature anomaly also occurs at c. 134 m, possibly indicating a water bearing fracture or minor crush zone.

5.3.2 Interpretation of KFR106

The results of the generalized logging data and fracture estimations of KFR106 are presented in Figure 5-4. The distribution of silicate density classes with borehole length is presented in Table 5-4.

For a majority of the rocks along KFR106 the silicate density is in the range 2,660–2,760 kg/m^3, the natural gamma radiation is in the range 30–40 μR/h and the magnetic susceptibility is decreased. The data indicate meta granite to granodiorite rock with a low content of magnetite.

Along the sections c. 10–30 m, 73–75 m and 115–140 m the silicate density is significantly decreased, the magnetic susceptibility is < 10^{-3} SI and the natural gamma radiation is significantly increased > 60 μR/h. This combination of physical properties is typical for pegmatite or pegmatitic granite.

Short sections (< 1 m long) with significantly increased density and magnetic susceptibility, and decreased natural gamma radiation, are scattered along the borehole length. These sections most likely correspond to magnetite bearing amphibolite dykes.

The estimated fracture frequency is generally low in KFR106. However, there are three intervals with significantly decreased resistivity, and with caliper anomalies, that may correspond to deformation zones. The sections with the most significant geophysical anomalies occur at 15–20 m, 154–157 m and 258–264 m. In the two lowermost sections significant anomalies in the fluid temperature data occur, which most likely indicates in or out flow of water. Three distinct anomalies in the fluid temperature data also occurs at c. 71.5 m, 85.5 m and 100.5 m. They coincide with narrow but distinct anomalies in the resistivity data and most likely correspond to water bearing fractures or minor crush zones.

Table 5-4. Distribution of silicate density classes with borehole length in KFR106.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680 (granite)	154	53
2,680 < dens < 2,730 (granodiorite)	63	22
2,730 < dens < 2,800 (tonalite)	54	19
2,800 < dens < 2,890 (diorite)	16	5
dens > 2,890 (gabbro)	3	1

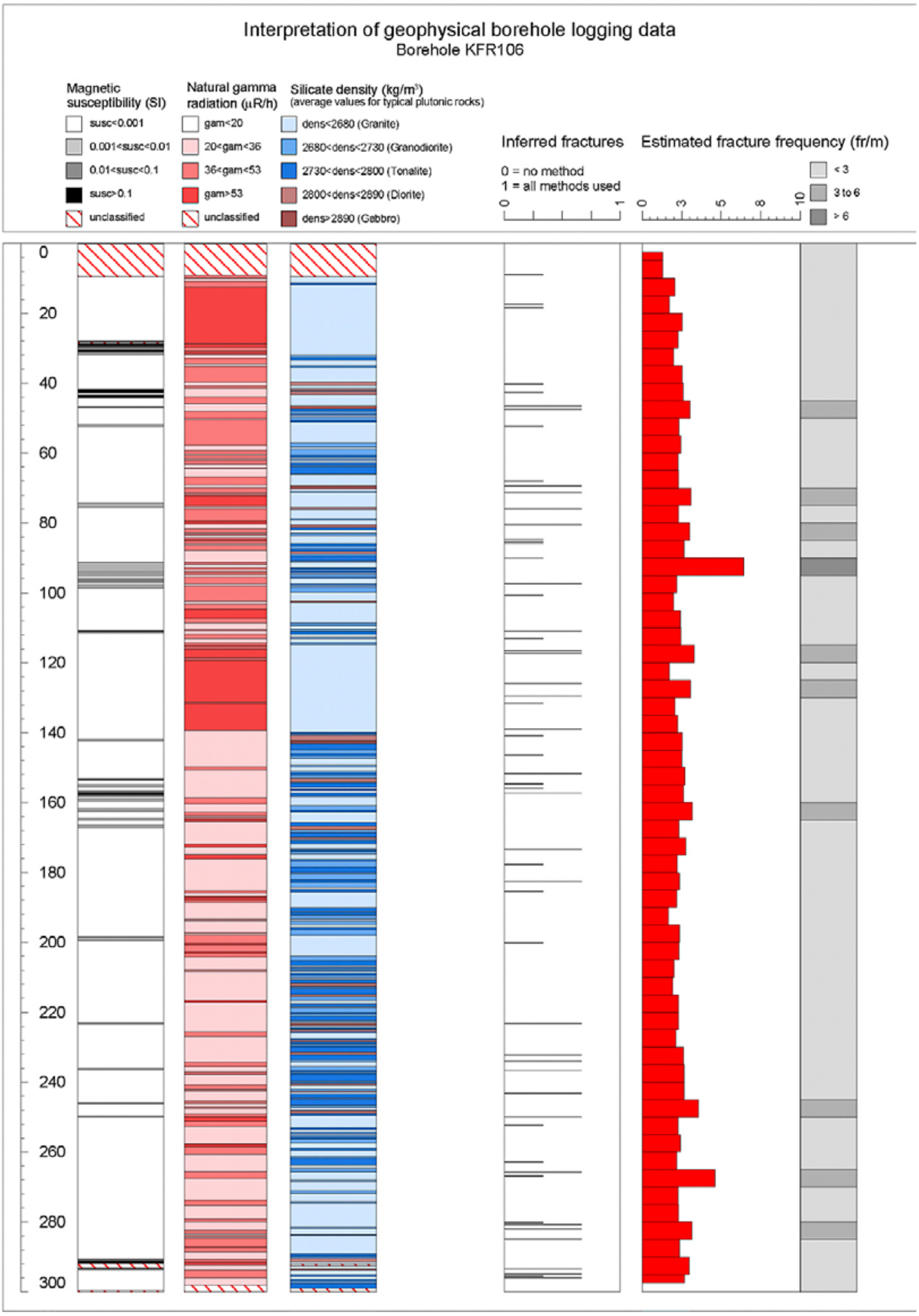

Figure 5-4. *Generalized geophysical logs of KFR106.*

5.3.3 Interpretation of HFR106

The results of the generalized logging data and fracture estimations of HFR106 are presented in Figure 5-5.

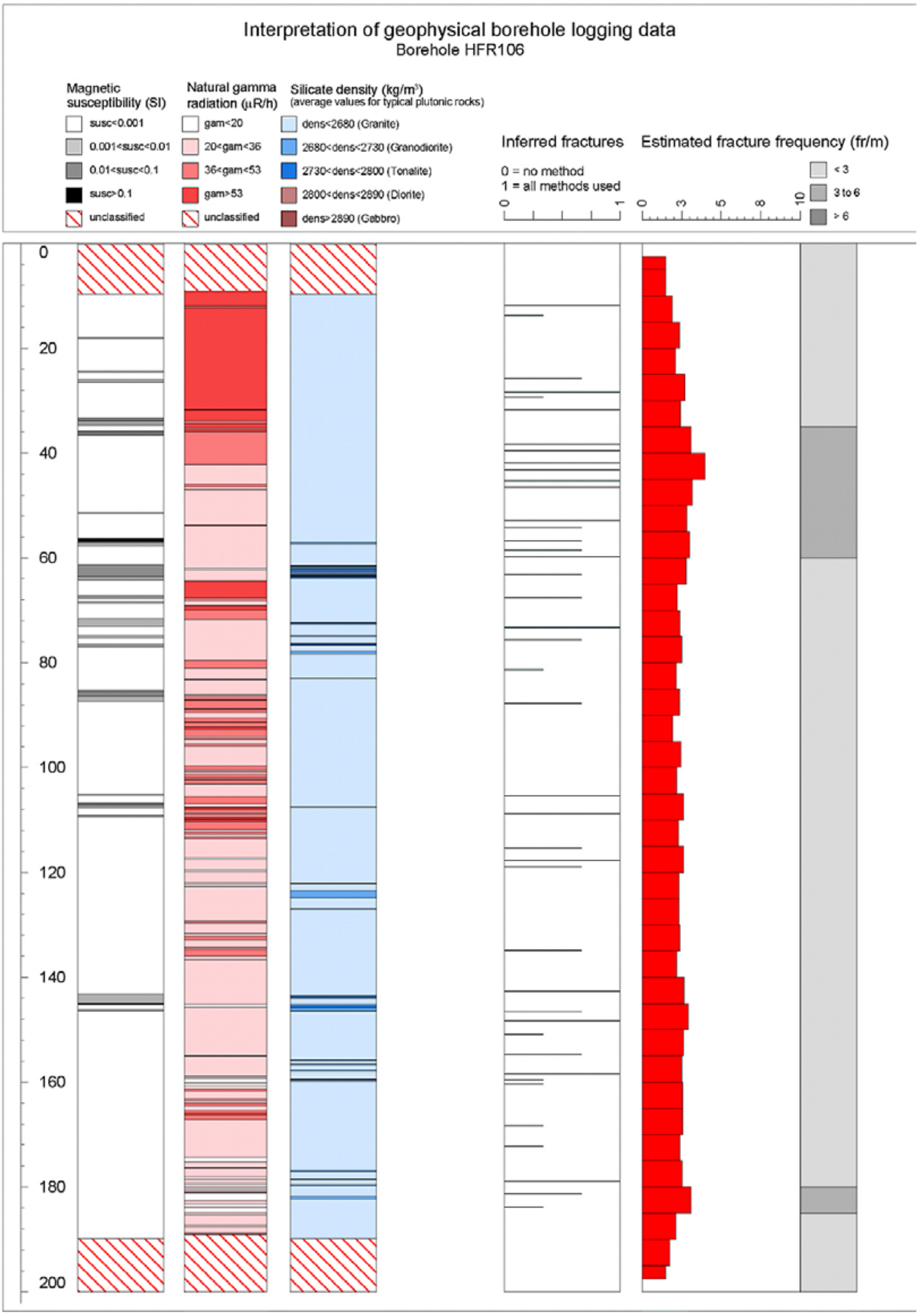

Figure 5-5. Generalized geophysical logs of HFR106.

The wet density along the entire borehole length averages at c. 2,500 kg/m^3, which is unusually low even for rocks with very low content of dark minerals. The natural gamma radiation is in the range 20–40 μR/h, which is typical for meta granite to granodiorite rock and it is far too low to indicate for e.g. pegmatitic granite, which is known to have decreased density. From earlier investigations it is known that the meta granite to granodiorite rock has an average density of around 2,650 kg/m^3. The un-calibrated density log of HFR106 averages at c. 2,600 kg/m^3, which is a more reasonable level but still a bit low. It appears as if the calibration equation established for the density in KFR106 fails to correct the density data of HFR106 to a proper level. For the interpretation we conclude that the relative changes in density along the borehole seem to be physically reasonable, for example when comparing with anomalies in the natural gamma radiation data, but the general background density level is assumed to be c. 150 kg/m^3 too low. This assumption is however not possible to test since we do not have any possibility to verify the rock density in a percussion drilled borehole.

In the sections c. 14–36 m, 65–72 m, large parts of 80–110 m and along 161–167 m the natural gamma radiation is partly increased and the density is decreased. It is likely that the geophysical logging data indicate the occurrence of pegmatite granite along these intervals of the borehole.

In the remaining parts of the borehole the logging data indicate a dominant occurrence of meta granite to granodiorite rock, and also a few short sections that correspond to magnetite bearing amphibolite dykes.

The estimated fracture frequency is generally low along the entire borehole. However, there are four intervals with significantly decreased resistivity, and with caliper anomalies, that may correspond to deformation zones. The sections with the most significant geophysical anomalies occur at c. 36–40 m, 124–127 m, 158–161 m and 178–181 m. At c. 179 m there is a significant anomaly in the fluid temperature data that most likely indicate in or out flow of water.

6 References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

/1/ **Nielsen U T, Ringgaard J, 2009.** Geophysical borehole logging in the boreholes KFR105 and HFM07. SKB P-09-76, Svensk Kärnbränslehantering AB.

/2/ **Nielsen U T, Ringgaard J, 2009.** Geophysical borehole logging in the boreholes KFR106, HFR106 and HFM07. SKB P-09-77, Svensk Kärnbränslehantering AB.

/3/ **Mattsson H, Keisu M, 2009.** Interpretation of geophysical borehole measurements and petrophysical data from KFR101, HFR101, HFR102 and HFR105. P-09-02, Svensk Kärnbränslehantering AB.

/4/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

/5/ **Puranen R, 1989.** Susceptibilities, iron and magnetite content of precambrian rocks in Finland. Geological survey of Finland, Report of investigations 90, 45 pp.

/6/ **Keisu M, Mattsson H, 2007.** Calibration of one arm caliper and caliper mean data from core and percussion drilled boreholes. Forsmark site investigation. SKB P-07-35, Svensk Kärnbränslehantering AB.