P-06-65

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX08, HLX30, HLX31 and HLX33

Håkan Mattsson, Mikael Keisu
GeoVista AB

May 2006

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

ISSN 1651-4416
SKB P-06-65

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX08, HLX30, HLX31 and HLX33

Håkan Mattsson, Mikael Keisu
GeoVista AB

May 2006

Keywords: Borehole, Logging, Geophysics, Geology, Bedrock, Fractures.

Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored borehole KLX08 and the percussion drilled boreholes HLX30, HLX31 and HLX33.

The main objective of the investigation is to use the results as supportive information during the geological core and mapping of drill cuttings and as supportive information during the single-hole interpretations. In KLX08 two different density logging tools were used, the old century 9030 and a new century 9139. A secondary aim of this study was to compare and evaluate the data from the two different logging tools.

Noise levels are generally below, or only slightly above, the recommended level for all investigated data. The comparison between the density data collected with the different logging tools indicates that the two data sets in general coincide well, even though the 9030-data show slightly more scatter. All major anomalies occur at similar section co-ordinates and have similar width. However, in a detailed scale (< 1 m), there are fairly large differences between the data from the different tools, with variations of 15 kg/m^3 up to as much as 60 kg/m^3 at corresponding borehole section.

A majority of the rocks in the vicinity of KLX08 have silicate density below 2,680 kg/m^3 and natural gamma radiation levels in the interval 20–30 µR/h, and this most likely indicates the presence of Ävrö granite. In the borehole there is also a fair amount of sections with relatively higher density, mainly in the intervals 2,680–2,730 kg/m^3 and 2,730–2,800 kg/m^3. Most of these high density sections coincide with a relative decrease of the natural gamma radiation and they often also coincide with a general increase of the magnetic susceptibility. This combination of physical properties is typical for quartz monzodiorite rock. Indications of high density rocks generally occur in the lower half of the borehole (section c. 585–989 m). The only prominent section of indicated diorite to gabbro rock is identified at c. 675–700 m. Short sections with natural gamma radiation > 30 µR/h, that indicate fine-grained granite or pegmatite, occur in scattered sections mainly in the uppermost c. 600 m of the borehole.

The estimated fracture frequency in KLX08 varies greatly and the most prominent section with indicated increased fracturing is identified at c. 105–305 m. This section is characterized by a large number of anomalies of low resistivity, low P-wave velocity and increased borehole diameter, which strongly suggests the existence of a major deformation zone. There is also increased apparent porosity of c. 0.5–1.5% along the entire section. Other sections of increased fracture frequency (possible deformation zones) are indicated at c. 395–410 m, 475–485 m, 610–615 m, 650–700 m and 765–775 m.

The rocks in the vicinities of HLX30, HLX31 and HLX33 generally have silicate density < 2,680 kg/m^3 and natural gamma radiation in the interval 15–25 µR/h, which most likely indicates the presence of Ävrö granite. The estimated fracture frequency indicates a few minor deformation zones in HLX30 (10–40 m, 85–90 m and 126–138 m), in HLX31 (70–130 m) and in HLX33 (10–20 m, 35–40 m and 175–180 m).

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX08 samt hammarborrhålen HLX30, HLX31 och HLX33.

Huvudsyftet med undersökningen är 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 borrkärne- och borrkaxkarteringen samt som underlag vid enhålstolkningen. I KLX08 har två olika densitetssonder använts, dels en s k *century 9030* och dels en s k *century 9139*. Ett annat syfte med denna undersökning var därför att jämföra och utvärdera resultaten från dessa två mätningar.

Brusnivåer ligger generellt under, eller bara något över, rekommenderade brusnivåer för samtliga undersökta loggar. Jämförelsen mellan data från de två olika densitetsmätningarna i KLX08 visar på en generellt god överensstämmelse, även om sonden 9030 har en något högre brusnivå. Alla större anomalier överensstämmer beträffande bredd och amplitud. I detaljerad skala (< 1,0 m) föreligger dock ganska stora skillnader mellan mätningarna, med variationer på 15–60 kg/m^3 i en och samma borrhålssektion.

En majoritet av bergarterna i närheten av KLX08 har en silikatdensitet < 2 680 kg/m^3 och en naturlig gammastrålning i intervallet 20–30 μR/h, vilket sannolikt indikerar förekomst av Ävrögranit. Det finns även en relativt stor andel sektioner med högre densitet, främst i intervallen 2 680–2 730 kg/m^3 och 2 730–2 800 kg/m^3. De flesta av dessa sektioner sammanfaller med relativt låg naturlig gammastrålning men även med förhöjd magnetisk susceptibilitet. Denna kombination av egenskaper är typisk för kvartsmonzodiorit. Sektioner med förhöjd densitet förekommer mestadels i borrhålets nedre halva (ca 585–989 m). En relativt lång sektion med möjlig diorit till gabbro kan identifieras vid ca 675–700 m. Korta sektioner med kraftigt förhöjd naturlig gammastrålning, som kan indikera finkornig granit eller pegmatit, förekommer i spridda områden främst längs borrhålets översta ca 600 m.

Den uppskattade sprickfrekvensen i KLX08 varierar kraftigt. En större möjlig deformationszon kan identifieras längs intervallet ca 105–305 m. Sektionen karaktäriseras av ett flertal anomalier med låg resistivitet, sänkt P-vågshastighet och förstorad borrhålsdiameter. Det är också en avvikande hög skenbar porositet (0,5–1,5 %) längs hela sektionen. Andra sektioner med indikerad förhöjd sprickfrekvens (möjliga deformationszoner) har identifierats vid ca 395–410 m, 475–485 m, 610–615 m, 650–700 m och 765–775 m.

Bergarterna i närheten av borrhålen HLX30, HLX31 och HLX33 domineras av en silikatdensitet < 2 680 kg/m^3 och naturlig gammastrålning i intervallet 15–25 μR/h, och detta indikerar troligen förekomst av Ävrögranit. Den uppskattade sprickfrekvensen indikerar förekomst av några mindre deformationszoner i HLX30 (10–40 m, 85–90 m och 126–138 m), i HLX31 (70–130 m) och i HLX33 (10–20 m, 35–40 m och 175–180 m).

Contents

1 Introduction

SKB performs site investigations for localization of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark and Oskarshamn. This document reports the results gained from the interpretation of geophysical borehole logging data from the cored borehole KLX08 and the percussion drilled boreholes HLX30, HLX31 and HLX33, all located in Laxemar, Oskarshamn.

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings, including estimated fracture frequency. Calculations of the salinity and apparent porosity are presented for the cored 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 (activity plan AP PS 400-05-060 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of boreholes KLX08, HLX30, HLX31 and HLX33 in Laxemar. The interpreted results are stored in the primary data base SICADA and are traceable by the activity plan number.

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

Activity plan	Number	Version
Tolkning av borrhålsgeofysiska data från KLX08, HLX30, HLX31 och HLX33.	AP PS 400-05-060	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

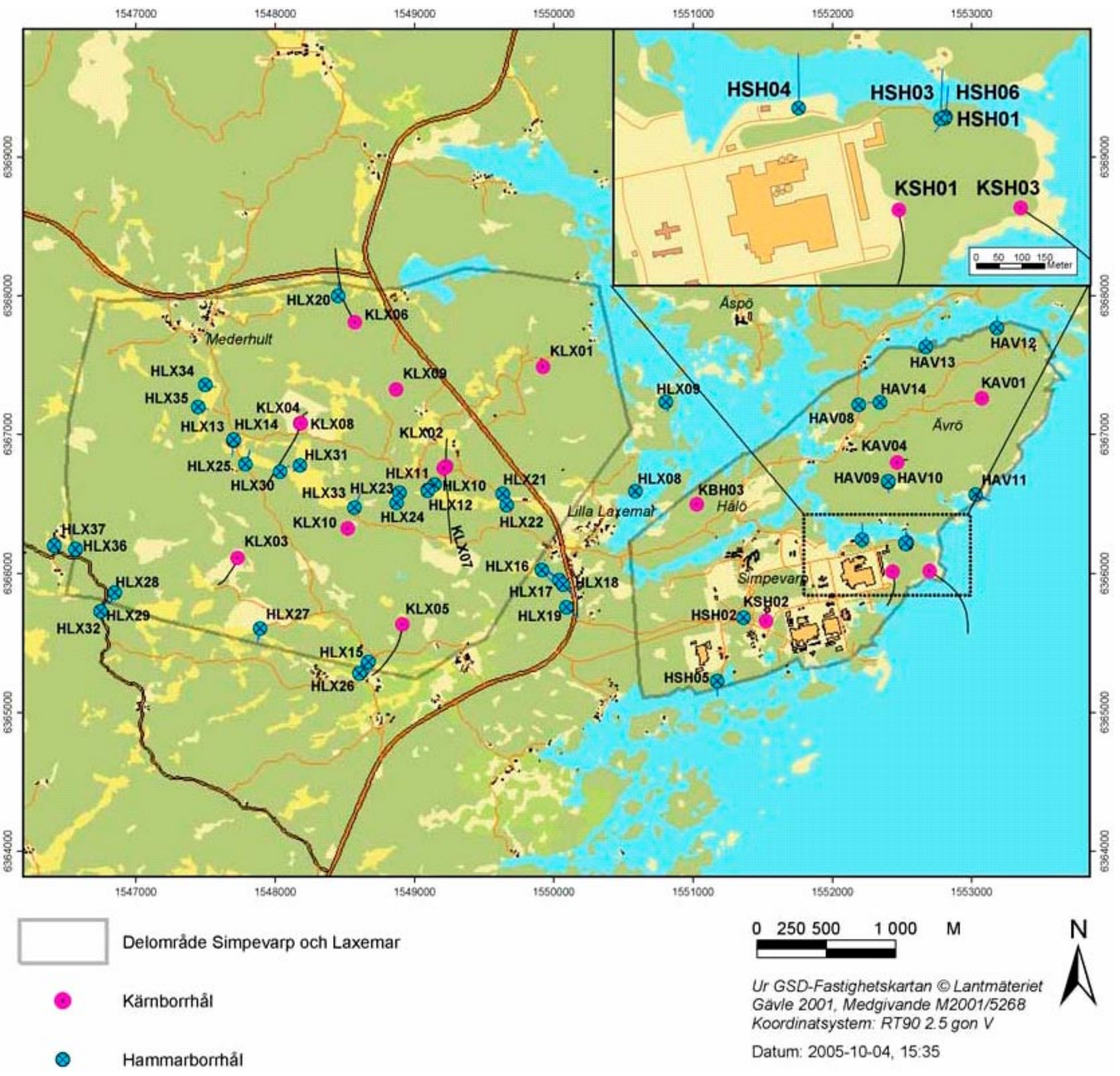


Figure 1-1. *Location of the boreholes KLX08, HLX30, HLX31 and HLX33.*

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 borehole. These parameters indicate salinity variations in the borehole fluid and the transport properties of the rock volume in the vicinity of the borehole.

The main objective of these investigations is to use the results as supportive information during the geological core mapping 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.

The logging contractor Rambøll has begun to use a new density logging tool (Century 9139). In order to compare the data from this tool with the old tool (Century 9030), used in all previously measured boreholes, the density logging measurements in KLX08 were performed with both tools. A secondary objective of these investigations was therefore to compare and evaluate the density data from the two different logging tools.

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 four steps:

1. Preparations of the logging data (calculations of noise levels, filtering, error estimations, re-sampling, drift correction, length adjustment).

   The loggings are median or mean filtered (generally 5 point filters for the resistivity loggings and 3 point filters for other loggings) and re-sampled to common section co-ordinates (0.1 m point distance).

   The density (old logging tool century 9030) and magnetic susceptibility logging data are calibrated with respect to petrophysical data. The logging data were calibrated by use of a combination of petrophysical data from the boreholes KLX02, KLX03, KLX04, KSH01A, KSH02, KSH03A and KAV04A, see /2, 3, 4, 5 and 6/.

   The density data collected with the new tool (century 9139) was calibrated by linear function between the calibrated 9030- density data and raw 9139- density data.

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

   The silicate density is calculated with reference to /7/ and the data are then divided into 5 sections indicating a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /8/. 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" (< 10 μR/h), "medium" (10 μR/h < gamma < 20 μR/h), "high" (20 μR/h < gamma < 30 μR/h) and "very high" (> 30 μR/h).

3. For the cored borehole the normal resistivity loggings are corrected for the influence of the borehole diameter and the borehole fluid resistivity. The apparent porosity is calculated during the correction of the resistivity loggings. The calculation is based on Archie's law /9/; $\sigma = a\,\sigma_w\,\varphi^m + \sigma_s$ where σ = bulk conductivity (S/m), σ_w = pore water conductivity (S/m), φ = volume fraction of pore space, σ_s = surface conductivity (S/m) and "a" and "m" are constants. Since "a" and "m" vary significantly with variations in the borehole fluid resistivity, estimations of the constants are performed with reference to the actual fluid resistivity in each borehole respectively.

4. Interpretation of the position of large fractures and estimated fracture frequency (classification to fracture logging and calculation of the estimated fracture frequency logging are based on analyses of the short and long normal resistivity, caliper mean, single point resistance (SPR), focused resistivity (140 and 300 cm) and sonic).

   The position of large fractures is estimated by applying a second derivative filter to the logging data and then locating maxima (or minima depending on the logging method) in the filtered logging. Maxima (or minima) above (below) a certain threshold value (Table 4-1) are selected as probable fractures. The result is presented as a column diagram where column height 0 = no fracture, column height 1 = fracture indicated by all logging methods. The estimated fracture frequency is calculated by applying a power function to the weighted sum of the maxima (minima) derivative logging for each method respectively, and then calculating the total sum of all power functions. Parameters for the power functions were estimated by correlating the total weighted sum to the mapped fracture frequency in the cored boreholes KLX03 and KLX04 /2/. The powers and linear coefficients (weights) used are presented in Table 4-1.

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

	Borehole	Sonic	Focused res. 140	Focused res. 300	Caliper	SPR	Normal res. 64	Normal res. 16	Lateral res.
Threshold	KLX08	2.0	2.2	2.3	1.0	3.0	–	7.0	–
Power	KLX08	1.0	1.0	1.6	1.0	0.5	–	0.6	–
Weight	KLX08	1.0	7.1	6.7	1.0	5.0	–	5.0	–
Threshold	HLX30	2.0	2.0	1.6	0.5	–	–	–	–
Power	HLX30	1.0	1.0	1.6	1.0	–	–	–	–
Weight	HLX30	1.0	7.1	6.7	1.0	–	–	–	–
Threshold	HLX31	1.0	1.6	1.6	0.5	–	–	–	–
Power	HLX31	1.0	1.0	1.6	1.0	–	–	–	–
Weight	HLX31	1.0	7.1	6.7	1.0	–	–	–	–
Threshold	HLX33	1.5	1.5	1.5	0.8	1.0	6.0	4.0	–
Power	HLX33	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	HLX33	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

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) (Tool 9139 was used in KLX08 and HLX30. Tool 9030 was used in KLX08, HLX31 and HLX33.)
- Magnetic susceptibility
- Natural gamma radiation
- Focused resistivity (300 cm)
- Focused resistivity (140 cm)
- Sonic (P-wave)
- Caliper mean
- SPR
- 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

No normal resistivity or SPR data were collected in HLX30 or HLX31. The long normal resistivity log of KLX08 was not used in the interpretation at all due to its abnormal behavior. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are not presented for the long normal resistivity loggings of KLX08 since the logging data show dubious values. 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 generally below or only slightly above the recommended level for all measured data.

A qualitative inspection was performed on the loggings. The data were checked for spikes and/or other obvious incorrect data points. Erroneous data were replaced by null values (–999) by the contractor Rambøll prior to the delivery of the data, and all null values were disregarded in the interpretation. Sections with null values are indicated by red and white stripes in the presentation of the generalized loggings (see for example Figure 5-3).

Table 5-1. Noise levels in the investigated geophysical logging data of KLX08, HLX30, HLX31 and HLX33.

Logging method	KLX08	HLX30	HLX31	HLX33	Recommended max noise level
Density (kg/m^3) tool 9030	8.0	Not used	9.7	11.1	3–5
Density (kg/m^3) tool 9139	5.6	8.2	Not used	Not used	3–5
Magnetic susceptibility (SI)	3×10^{-4}	2×10^{-4}	1×10^{-4}	2×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	0.5	0.4	0.3	0.3	0.3
Long normal resistivity (%)	Not used	Not used	Not used	0.5	2.0
Short normal resistivity (%)	0.3	Not used	Not used	0.3	2.0
Fluid resistivity (%)	0.01	0.03	0.02	0.03	2
Fluid temperature (ºC)	0.0003	3×10^{-4}	1×10^{-4}	5×10^{-5}	0.01
Lateral resistivity (%)	Not used	Not used	Not used	Not used	2
Single point resistance (%)	0.2	Not used	Not used	0.5	No data
Caliper mean (m)	1×10^{-4}	3×10^{-4}	4×10^{-4}	5×10^{-4}	5×10^{-4}
Focused resistivity 300 (%)	7.9	13.7	11.0	10.1	No data
Focused resistivity 140 (%)	4.7	6.5	7.2	6.6	No data
Sonic (m/s)	9	4	8	7	20

5.2 Interpretation of the logging data

The presentation of interpretation products presented below, in section 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 KLX08

The results of the generalized logging data and fracture estimations of KLX08 are presented in Figure 5-3, and in a more detailed scale in Appendix 1.

Raw density data collected with the two different tools 9030 and 9139 are presented in Figure 5-1 below. The level difference between the two data sets can be related to the lack of calibration, and clearly emphasizes the importance of high quality petrophysical data. A visual inspection of the data shows that the two data sets in general coincide very well, even though the 9030-data show slightly more scatter. All major anomalies occur at similar section length and have similar width. Statistically there is also a well defined correlation between the two measurements (Figure 5-2). However, in a detailed scale, wave

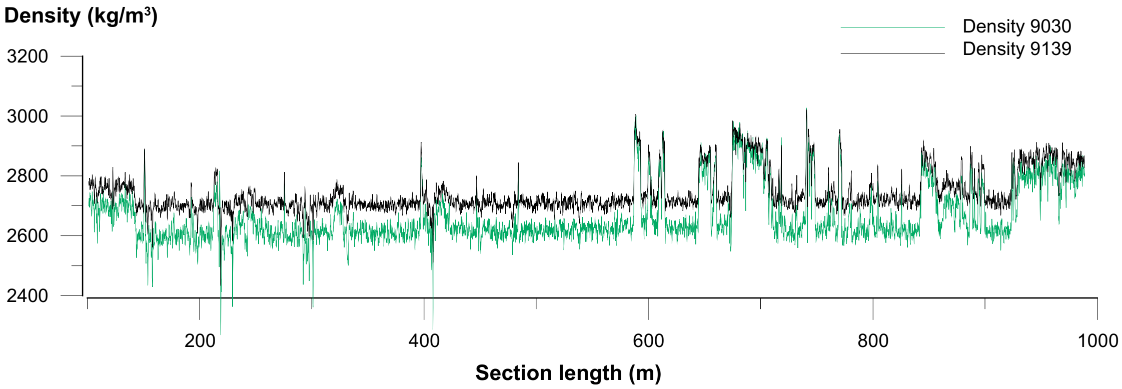


Figure 5-1. *Raw density logging data from KLX08 measured with the two different logging tools Century 9030 (old tool) and Century 9139 (new tool).*

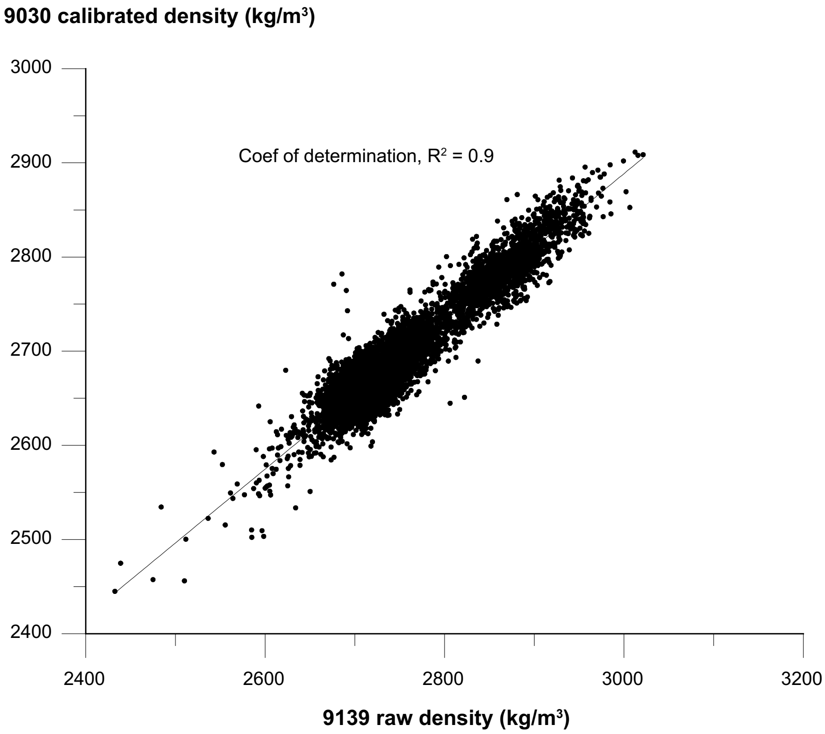


Figure 5-2. *Cross plot (including linear regression curve) of calibrated density measured with the 9030 tool versus raw density measured with the 9139 tool.*

length < 1 m, there are fairly large differences between the data from the different tools, with variations of 15 kg/m^3 up to as much as 60 kg/m^3. The differences in the density data are also indicated by the width of the distribution around the straight line in Figure 5-2, averaging at c. ± 25 kg/m^3.

A majority (c. 75%) of the rocks in the vicinity of KLX08 have silicate density below 2,680 kg/m^3, see Figure 5-3 and Table 5-2 below. In the section c. 135–585 m there is a clear dominance of low density rocks and natural gamma radiation levels in the interval 20–30 μR/h, and this most likely indicates the presence of Ävrö granite with a granite to granodiorite mineral composition. In the borehole there is also a fair amount of sections with relatively higher density, mainly in the intervals 2,680–2,730 kg/m^3 and 2,730–2,800 kg/m^3 (Table 5-2). Some of the most prominent sections with increased density occur at c. 100–140 m, 585–615 m (discontinuous), 644–660 m, 675–710 m, 840–899 m (discontinuous) and 920–989 m. Most of these high density sections coincide with a relative decrease of the natural gamma radiation and, especially worth noting, they often also coincide with a general increase of the magnetic susceptibility. The combination of silicate density in the interval 2,730–2,800 kg/m^3 and a high magnetic susceptibility is typical for quartz monzodiorite rock. Indications of high density rocks (most likely quartz monzodiorite) generally occur in the lower half of the borehole, in the section c. 585–989 m. Indications of diorite to gabbro rocks (density > 2,800 kg/m^3) are few, and the only prominent section is identified at c. 675–700 m.

Sections with very high natural gamma radiation (> 30 μR/h), that indicate fine-grained granite or pegmatite are rare. However, short intervals (< 1.0 m) of very high natural gamma radiation do occur in scattered sections, mainly in the uppermost 600 m of the borehole.

In the section c. 100–300 m there are major variations in magnetic susceptibility, most likely related to increased fracture frequency. For a major part of the remaining borehole length (c. 300–1,000 m), the magnetic susceptibility is fairly constant in the interval 0.025–0.030 SI. However, as noted in the first paragraph there is a number of sections with relatively high magnetic susceptibility (c. 0.035–0.060 SI) that coincide with increased density.

The estimated fracture frequency in KLX08 varies greatly and there are several sections of "low", "moderate" and "high" fracture frequency (Figures 5-3 and 5-4). The most prominent section with indicated increased fracturing is identified at c. 105–305 m. The section is characterized by a large number of anomalies of low resistivity, low P-wave velocity and increased borehole diameter, which strongly suggests the existence of a major deformation zone. There is also increased apparent porosity of c. 0.5–1.5% along the entire section.

Other sections of increased fracture frequency are indicated at c. 395–410 m, 475–485 m, 610–615 m, 650–700 m and 765–775 m.

Table 5-2. Distribution of silicate density classes with borehole length of KLX08 (logging tool century 9139).

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
2,680 > dens	665	75
2,680 < dens < 2,730	89	10
2,730 < dens < 2,800	116	13
2,800 < dens < 2,890	17	2
dens > 2,890	0	0

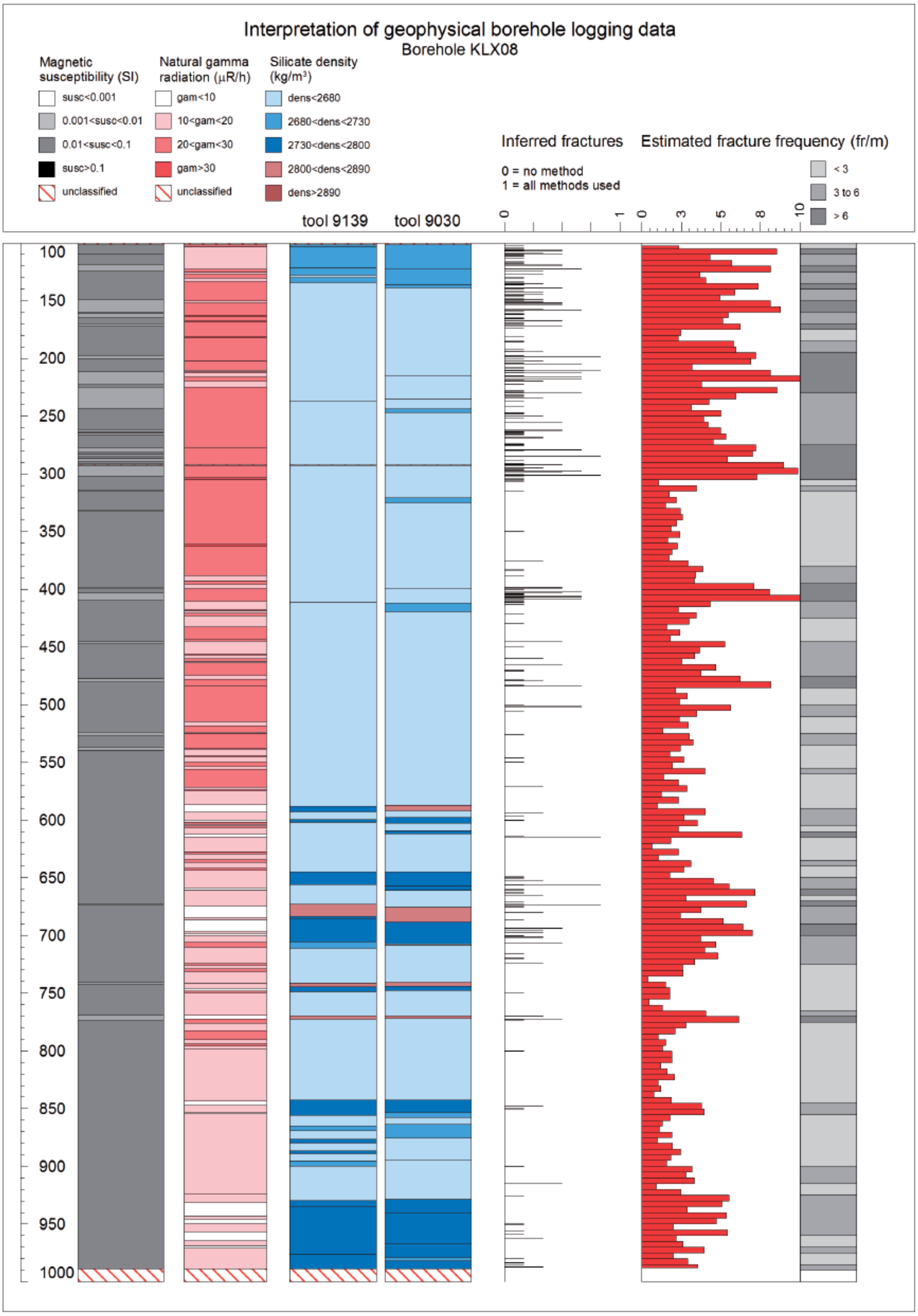


Figure 5-3. Generalized geophysical logs of KLX08.

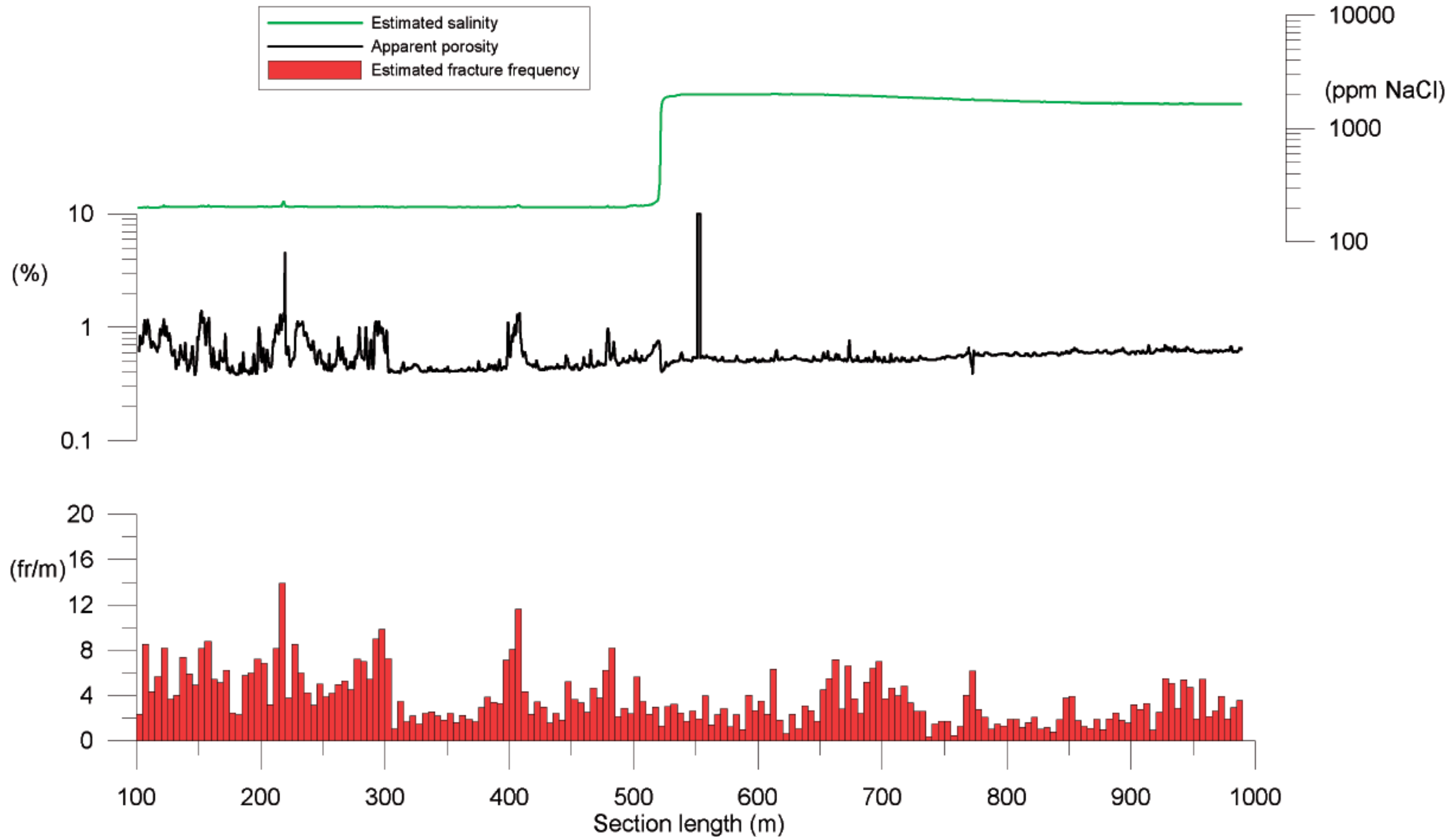


Figure 5-4. Estimated salinity, apparent porosity and estimated fracture frequency of KLX08.

The section 395–410 m coincides with increased apparent porosity (0.8–1.3%). The section is also characterized by a general decrease in the bulk resistivity, low P-wave velocity and increased borehole diameter.

The section 650–700 m is mainly characterized by a large number of low resistivity anomalies. Low P-wave velocity occurs at c. 660–670 m, but there is an indication of slightly increased P-wave velocity in the section 670–700 m. This may indicate that the uppermost c. 10–20 m (section 650–670 m) of the possible deformation zone is characterized by open fractures, whereas the lower part of the possible deformation zone (section 670–700 m) is mainly characterized by sealed fractures.

The estimated fluid water salinity is almost constant at c. 200 ppm NaCl in the section c. 100–520 m. At section coordinate c. 520 m there is a rapid increase up to c. 2,000 ppm NaCl, and this level is kept fairly constant in the remaining part of the borehole.

5.2.2 Interpretation of HLX30

The results of the generalized logging data and fracture estimations of HLX30 are presented in Figure 5-5.

The silicate density is generally below 2,680 kg/m^3 for large parts of KLX30 and this suggests that a majority of the rocks in the vicinity of the borehole have a mineral composition that corresponds to granite. A few short sections of increased density occur in the lower half of the borehole. The highest densities, c. 2,800 kg/m^3 occurring at c. 84–86 m and 143–144 m, coincide with decreased natural gamma radiation and also decreased magnetic susceptibility, which indicates that they correspond to fine-grained diorite to gabbro. The other high density sections generally coincide with decreased natural gamma radiation and increased magnetic susceptibility, which suggests that they correspond to quartz monzodiorite.

The natural gamma radiation is in the interval 20–30 μR/h along the section c. 15–45 m. In the other parts of the borehole the natural gamma radiation is mainly in the interval 10–20 μR/h. There are only two thin anomalies at c. 18–21 m with natural gamma radiation > 30 μR/h, which indicates that fine-grained granite or pegmatite dykes hardly occur at all in the vicinity of HLX30.

The magnetic susceptibility varies greatly along the borehole. Sections with very low magnetic susceptibility (< 0.001 SI), that may correspond to increased fracturing and/or alteration, occur at c. 9–21 m, c. 30–40 m (inhomogeneous), c. 84–90 m and c. 131–136 m.

The estimated fracture frequency is generally low or moderate. The sections c. 10–40 m and 126–138 m are characterized by major decrease in the resistivity and "null-values" in the sonic data (missing data), that may indicate increased fracturing. At c. 85–90 m there is an indicated minor deformation zone that coincides with the indicated occurrence of mafic rock (possibly fine-grained diorite to gabbro).

Figure 5-5. Generalized geophysical logs of HLX30.

5.2.3 Interpretation of HLX31

The results of the generalized logging data and fracture estimations of HLX31 are presented in Figure 5-6.

The section c. 10–40 m of HLX31 is characterized by density in the interval 2,640–2,700 kg/m^3, magnetic susceptibility of 0.015–0.025 SI and a natural gamma radiation of c. 20 µR/h. This combination of physical properties differs significantly from the remaining part of the borehole, c. 40–133 m, which is characterized by lower density in the interval 2,520–2,600 kg/m^3, largely varying magnetic susceptibility of 0.0009–0.015 SI and a natural gamma radiation of c. 20 µR/h. There is one indication of a thin (< 1.0 m) fine-grained granite or pegmatite dyke at c. 11 m. Apart from this positive anomaly, the natural gamma radiation is almost constant at c. 20 µR/h along the borehole (the indicated variations in natural gamma radiation in the generalized log in Figure 5-6 is caused by minor variations close to the interval limit at 20 µR/h).

The estimated fracture frequency of HLX31 is low or moderate. Slightly increased fracturing is indicated in the section c. 70–130 m, and in this part of the borehole there are a number of thin, but distinct, low resistivity and caliper anomalies that most likely correspond to open fractures

5.2.4 Interpretation of HLX33

The results of the generalized logging data and fracture estimations of HLX33 are presented in Figure 5-7.

The distribution of physical properties in HLX33 reminds a great deal of that in HLX31. The density is mainly in the interval 2,490–2,630 kg/m^3, there is largely varying magnetic susceptibility of 0.0009–0.025 SI and a natural gamma radiation of mainly 15–23 µR/h. This likely indicates that the rocks in the vicinity of HLX33 have a mineral composition that corresponds to granite. Sections with decreased magnetic susceptibility, that may correspond to increased fracturing and/or alteration, occur at c. 13–28 m, 57–92 m (discontinuous) and 120–127 m.

The natural gamma radiation is mainly in the interval 10–20 µR/h. There is one indication of a thin, c. 1.0 m long section, of fine–grained granite or pegmatite dyke at c. 146 m.

The estimated fracture frequency of HLX33 is mainly moderate. Increased fracturing is indicated in the sections c. 10–20 m, 35–40 m and 175–180 m. There is general decrease in the bulk resistivity in the section 10–28 m (no sonic data are available in this section). The sections 35–40 m and 175–180 m are characterized by thin low resistivity anomalies and null values (no data) in the sonic log and no significant caliper anomalies.

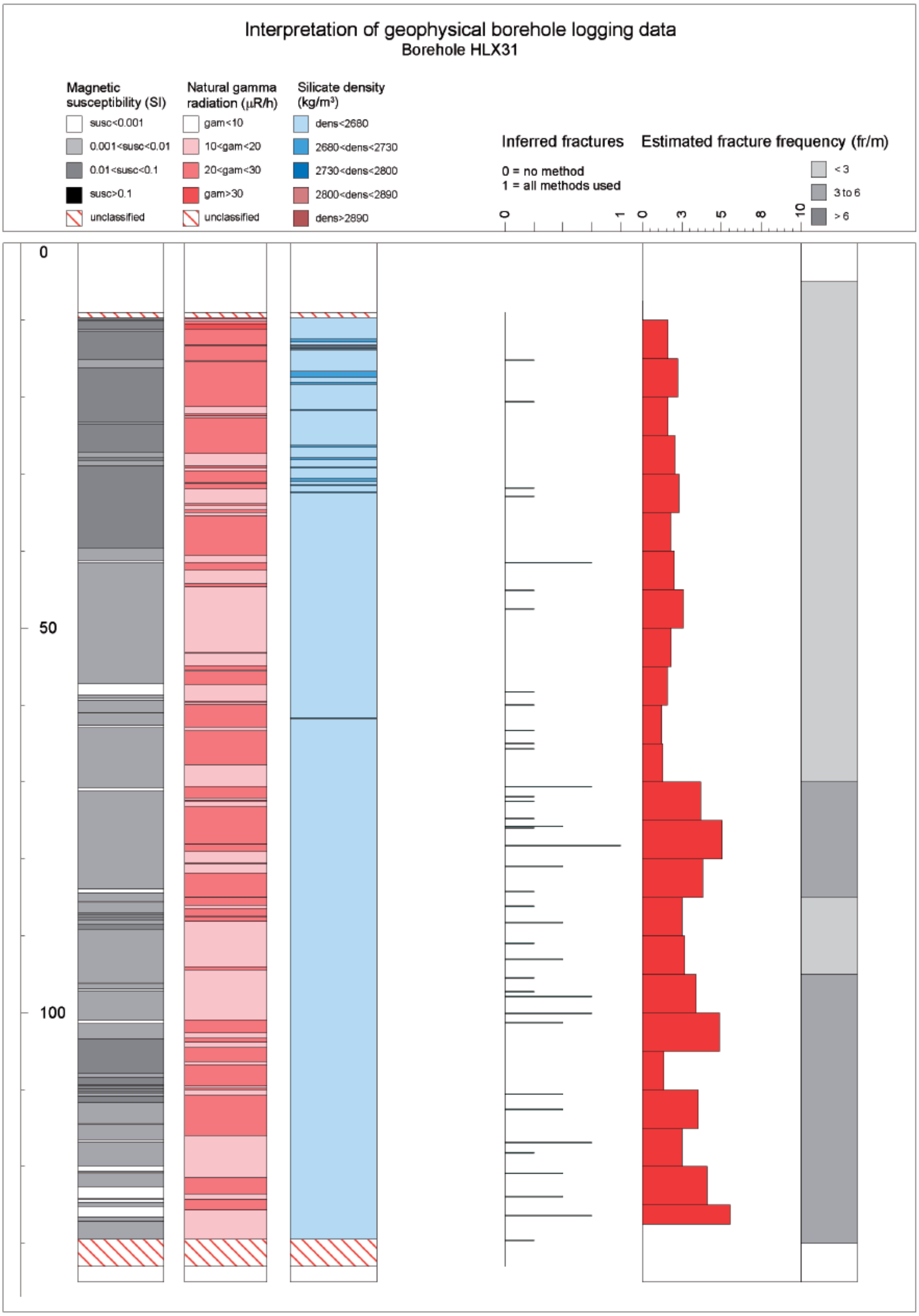


Figure 5-6. Generalized geophysical logs of HLX31.

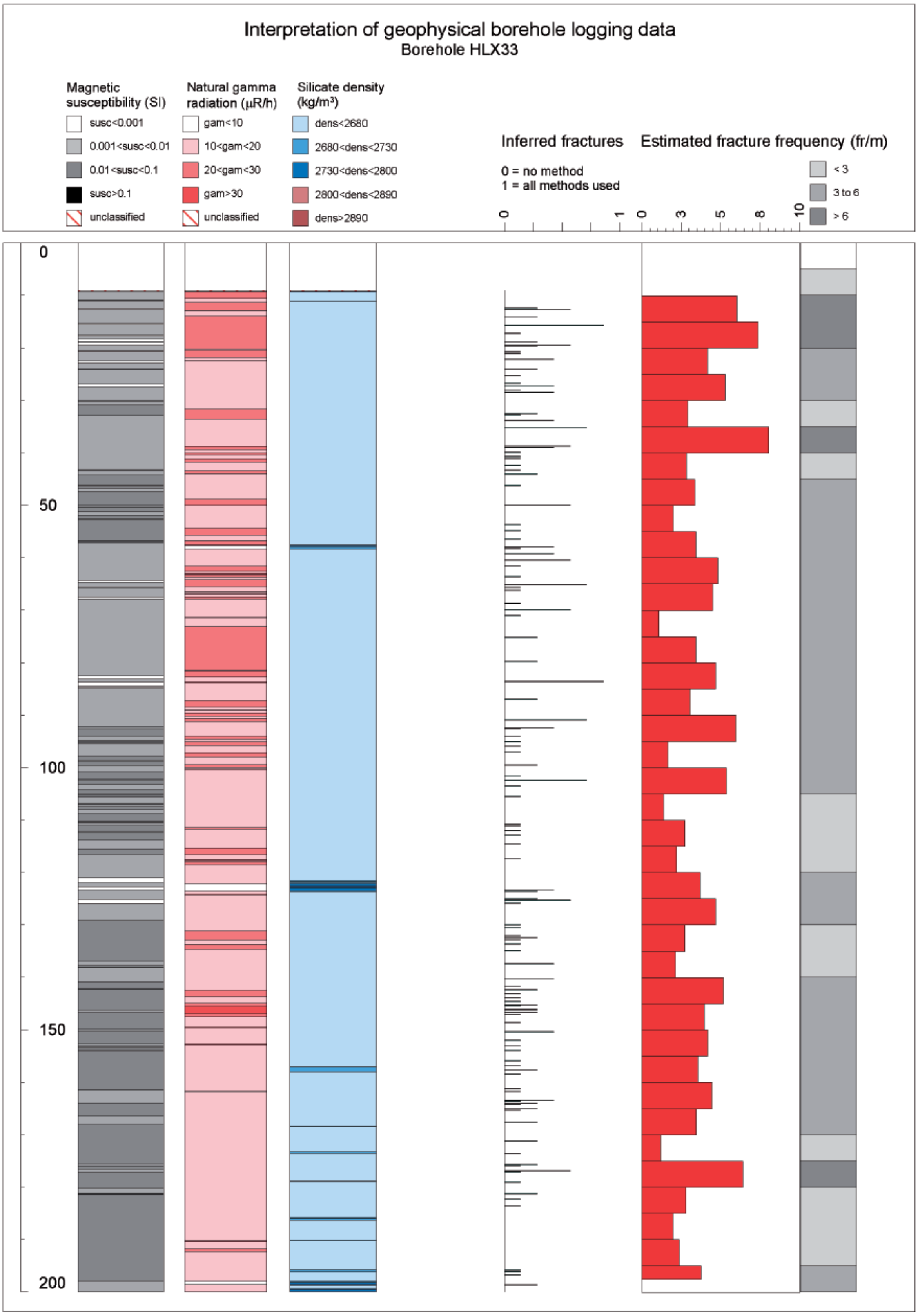


__Figure 5-7.__ Generalized geophysical logs of HLX33.

References

/1/ **Nielsen U T, Ringgard J, 2005.** Geophysical borehole logging in KLX08, HLX30, HLX31 and HLX33. SKB P-05-270. Svensk Kärnbränslehantering AB.

/2/ **Mattsson H, Thunehed H, Keisu M, 2005.** Interpretation of geophysical borehole measurements and compilation of petrophysical data from KLX01, KLX03, KLX04, HLX21, HLX22, HLX23, HLX24, HLX25, HLX26, HLX27 and HLX28. SKB P-05-34. Svensk Kärnbränslehantering AB.

/3/ **Mattsson H, Thunehed H, 2004.** Interpretation of geophysical borehole data from KSH01A, KSH01B, KSH02 (0–100 m), HSH01, HSH02 and HSH03, and compilation of petrophysical data from KSH01A and KSH01B. SKB P-04-28. Svensk Kärnbränslehantering AB.

/4/ **Mattsson H, Thunehed H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KSH02 (80–1,000 m) and KAV01. SKB P-04-77. Svensk Kärnbränslehantering AB.

/5/ **Mattsson H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KSH03A (100–1,000 m), KSH03B, HAV09, HAV10 and KLX02 (200–1,000 m). SKB P-04-214. Svensk Kärnbränslehantering AB.

/6/ **Mattsson H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KAV04A (100–1,000 m), KAV04B, HLX13 and HLX14. SKB P-04-217. Svensk Kärnbränslehantering AB.

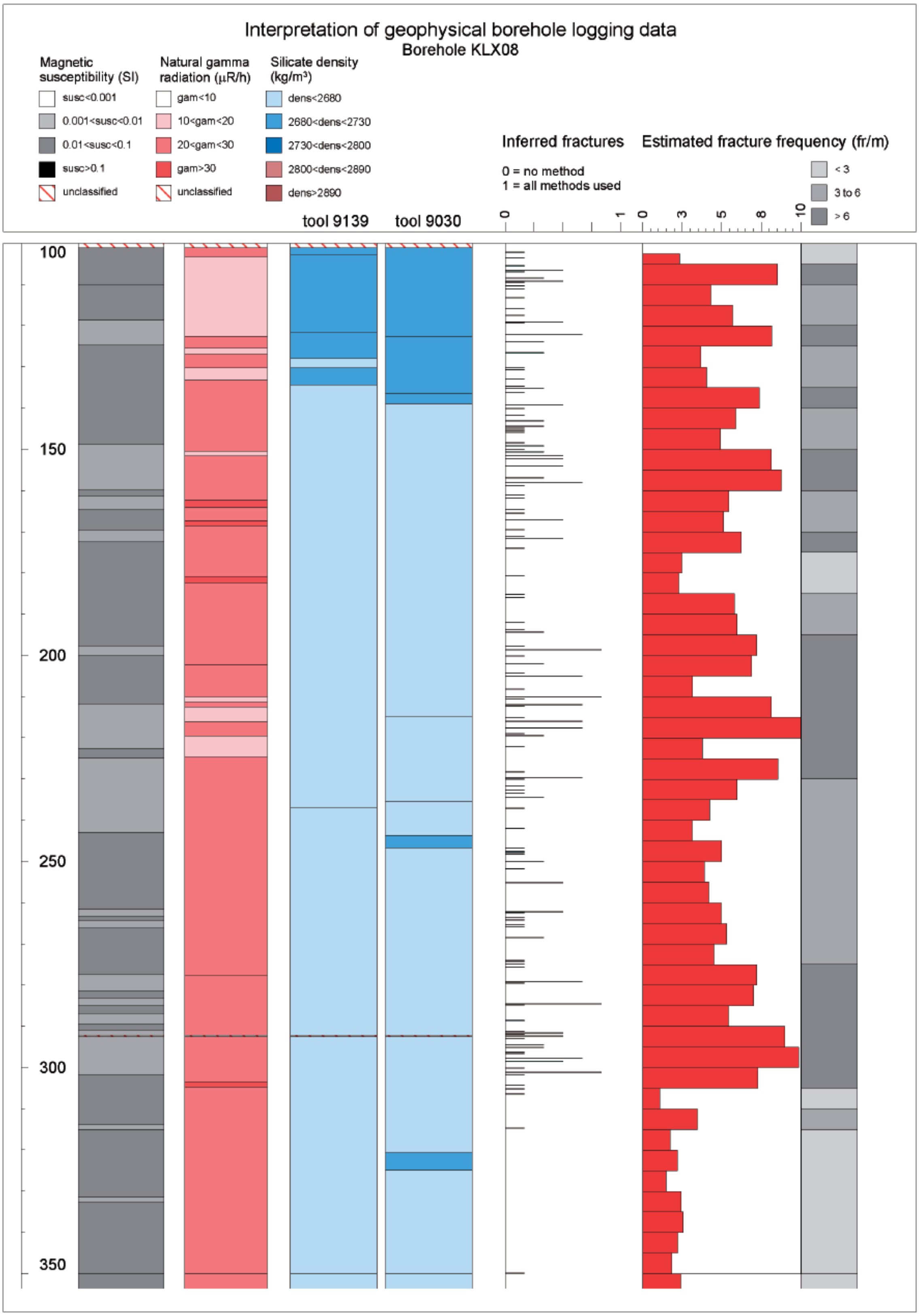
/7/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

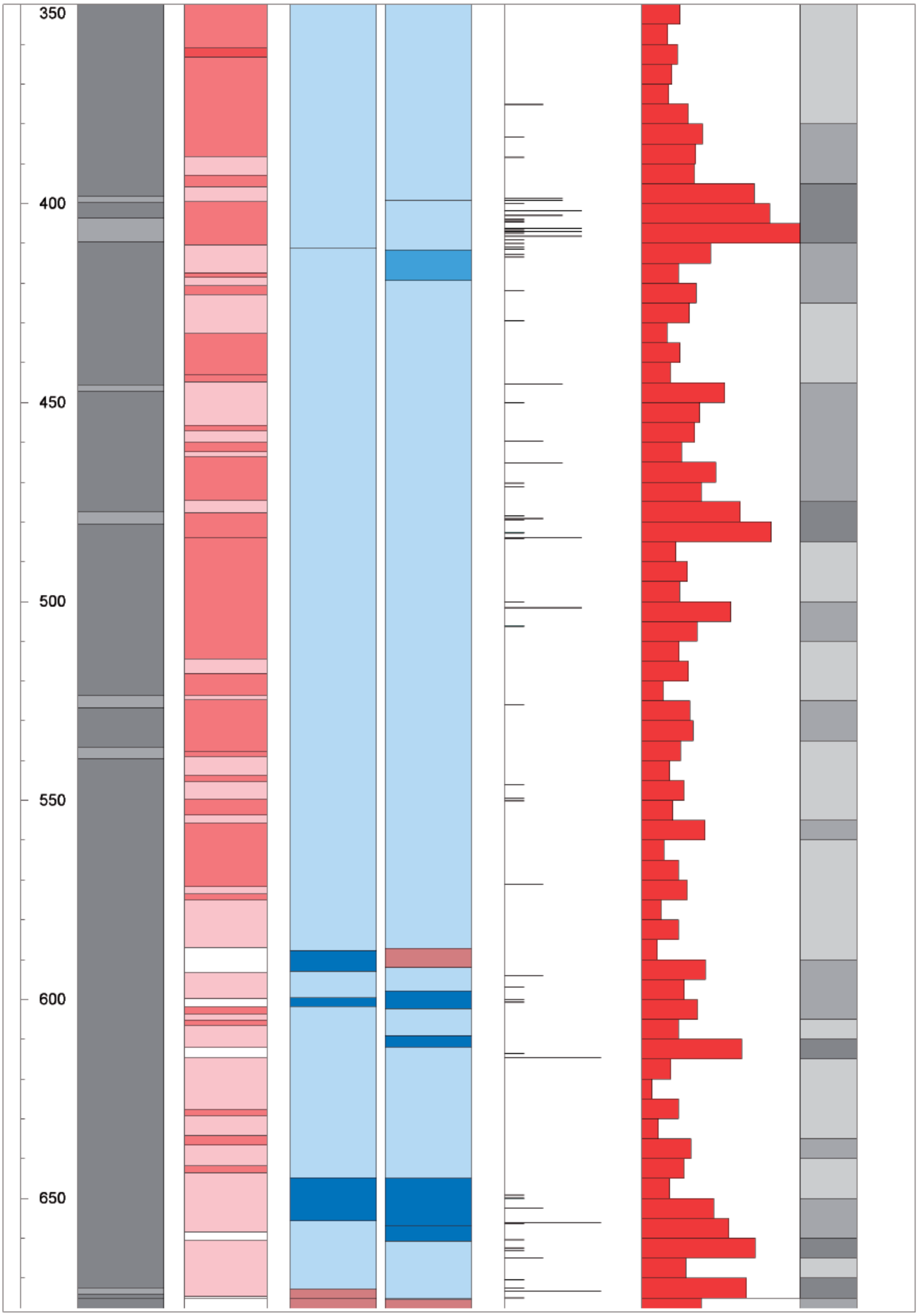
/8/ **Puranen R, 1989.** Susceptibilities, iron and magnetite content of precambrian rocks in Finland. Geological survey of Finland, Report of investigations 90, 45 pp.

/9/ **Archie G E, 1942.** The electrical resistivity log as an aid in determining some reservoir characteristics: Trans. Am. Inst. Min., Metallurg., Petr.Eng., 146, 54–62.

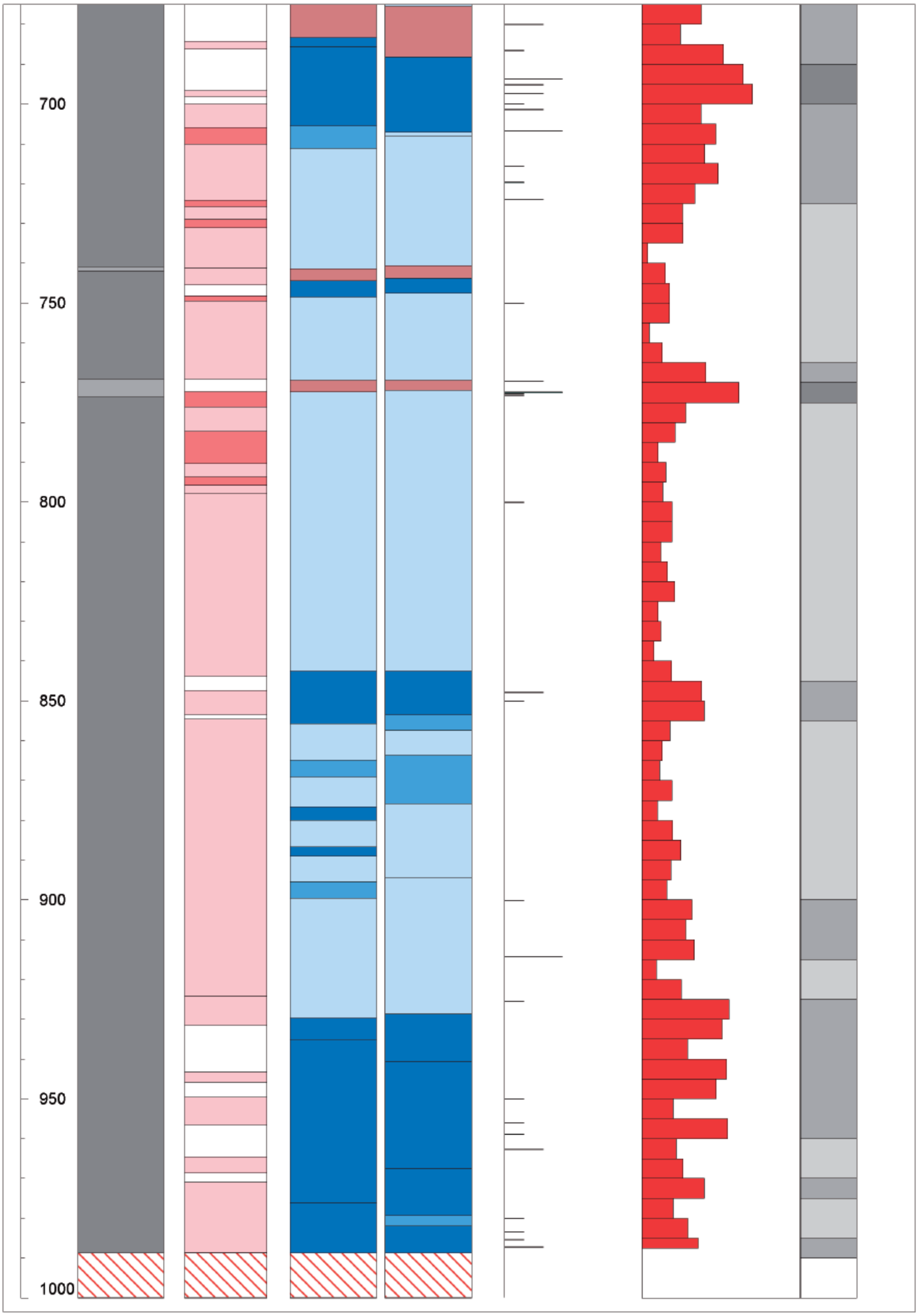
Appendix 1

Generalized geophysical loggings of KLX08





350
400
450
500
550
600
650


700
750
800
850
900
950
1000