P-07-25

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX17A and HLX43

Håkan Mattsson, Mikael Keisu
GeoVista AB

February 2007

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-07-25

Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX17A and HLX43

Håkan Mattsson, Mikael Keisu
GeoVista AB

February 2007

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

Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored borehole KLX17A and the percussion drilled borehole HLX43.

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

The distribution of silicate density in KLX17A is heterogeneous with large variations along the entire borehole. The large density variations are likely to be related to compositional variations in the surrounding rock volume, but there may also be a connection to the fairly high fracture frequency in the section c 80–520 m.

In the sections c 65–376 m and 441–484 m the geophysical data indicate dominant occurrences of Ävrö granite with quartz monzodioritic mineral composition. In the sections c 376–441 m and c 484–700 m the geophysical data indicate dominant occurrences of Ävrö granite with granodioritic mineral composition.

Intervals with highly increased density mainly occur along the upper half of the borehole, section c 130–485 m. The fracture frequency estimated from the geophysical logs indicates several long intervals with increased fracturing in the section c 80–520 m. There is a fairly clear spatial relation between sections with increased fracturing and increased density (indicated mafic rock). In KLX17A possible deformation zones are indicated along the intervals c 105–114 m, 191–226 m, 354–358 m, 422–430 m and 663–668 m.

The rock volume in the vicinity of HLX43 seems to be dominated by Ävrö granite, and there is an indication of dolerite along the interval c 31–72 m. In both the upper and lower boundaries to the dolerite the logging data indicate the occurrences of fine-grained diorite/gabbro and fine-grained granite, e.g. composite dykes. One major possible deformation zone is indicated in HLX43 along the section c 33–82 m.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX17A och hammarborrhålet HLX43.

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 den geologiska enhålstolkningen.

Densitetsfördelningen i KLX17A är mycket heterogen med stora variationer längs hela borrhålet. De kraftiga densitetskontrasterna är troligen kopplade till variationer i mineralsammansättning i berget men det finns säkerligen också en koppling till den relativt höga sprickfrekvens som förekommer längs flera avsnitt i sektionen ca 80–520 m.

Intervallen ca 65–376 m och 441–484 m domineras av silikatdensitet som indikerar Ävrögranit med kvartsmonzodioritisk mineralsammansättning. Längs sektionerna ca 376–441 m och 484–700 m indikerar de geofysiska loggarna en dominerande förekomst av Ävrögranit med granodioritisk mineralsammansättning.

Intervall med kraftigt förhöjd densitet förekommer främst i borrhålets övre halva, sektionen ca 130–485 m. Den för borrhålet uppskattade sprickfrekvensen indikerar generellt förhöjd sprickighet längs ca 80–520 m. Det finns ett tydligt rumsligt samband mellan sektioner med förhöjd sprickighet och förhöjd densitet (indikerad mafisk bergart). I KLX17A kan möjliga deformationszoner identifieras längs intervallen ca 105–114 m, 191–226 m, 354–358 m, 422–430 m och 663–668 m.

Berget i närheten av borrhålet HLX43 tolkas domineras av Ävrögranit och en längre sektion med diabas (ca 31–72 m). De geofysiska loggarna indikerar att diabasens övre och undre kontakter omges av en kombination av finkornig diorit/gabbro och finkornig granit, s k ”composite dykes”. En större möjlig deformationszon indikeras förekomma längs sektionen ca 33–82 m av HLX43.

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 KLX17A and the percussion drilled borehole HLX43, 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 are also presented. The logging measurements were conducted in 2006 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 400-06-137 and method descriptions MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of boreholes KLX17A and HLX43.

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 KLX17A och HLX43.	AP PS 400-06-137	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata.	SKB MD 221.003	3.0

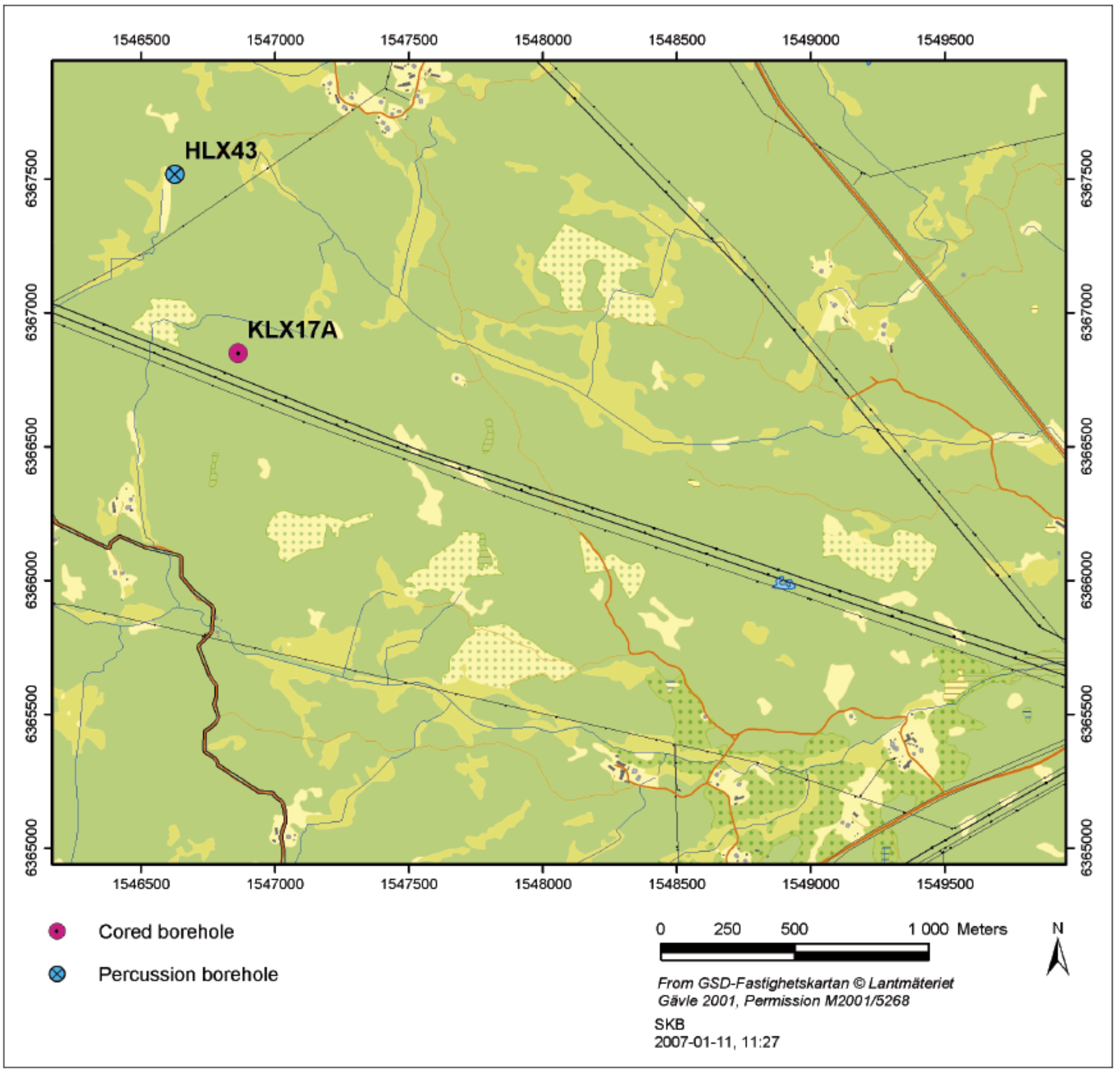


Figure 1-1. *Location of the boreholes KLX17A and HLX43 in Laxemar.*

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 "litho-logical" 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 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 logging and as supportive information during the so called "geological 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 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.

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 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 (logging tool century 9139) and magnetic susceptibility logging data are calibrated with respect to petrophysical data. The magnetic susceptibility logging data were calibrated by use of a combination of petrophysical data from the boreholes KLX03, KSH01A, KSH02, KSH03A, KAV04A and KLX10 see /2, 3, 4, 5, 6, 7/. The density logging data were calibrated by use of petrophysical data from the borehole KLX20A /8/.

The caliper 1D and caliper 3D logs are calibrated by use of borehole technical information supplied by SKB. The calibration procedure is described in detail in /9/.

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

The silicate density is calculated with reference to /10/ and the data are then divided into 5 sections *indicating* a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /11/. 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 /12/; $\sigma = a\, \sigma_w\, \varphi^m + \sigma_s$ 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.

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 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
- Caliper 1D
- SPR
- Fluid resistivity
- Fluid temperature

The borehole technical information used for calibration of the caliper data is delivered as Microsoft Word files via email by SKB.

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	KLX17A	1.5	2.0	2.0	0.5	2.0	5.0	5.0	–
Power	KLX17A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX17A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	HLX43	2.0	1.0	1.5	0.5	1.0	5.0	5.0	–
Power	HLX43	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	HLX43	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

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

In some boreholes the long normal resistivity logging measurements show unrealistic anomalies. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore only presented for the short normal resistivity data. Apart from this, 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. The density, natural gamma radiation and magnetic susceptibility logging data have noise levels above the recommended levels for both the investigated boreholes. All other methods have noise levels below, or only slightly above, the recommended levels. To reduce the influence from the noise all data were average filtered prior to the evaluation.

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.

5.2 Interpretation of the logging data

The presentation of interpretation products presented below includes:

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

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

Logging method	KLX17A	HLX43	Recommended max noise level
Density (kg/m^3)	12	15	3–5
Magnetic susceptibility (SI)	$7\cdot10^{-4}$	$4\cdot10^{-4}$	$1\cdot10^{-4}$
Natural gamma radiation (μR/h)	0.8	1.0	0.3
Long normal resistivity (%)	0.5	0.3	2.0
Short normal resistivity (%)	0.3	0.2	2.0
Fluid resistivity (%)	0.01	0.03	2
Fluid temperature (°C)	0.004	$6\cdot10^{-4}$	0.01
Lateral resistivity (%)	Not used	Not used	2
Single point resistance (%)	0.2	0.5	No data
Caliper 1D	$2\cdot10^{-6}$	$3\cdot10^{-4}$	$5\cdot10^{-4}$
Caliper mean (m)	$2\cdot10^{-5}$	$6\cdot10^{-4}$	$5\cdot10^{-4}$
Focused resistivity 300 (%)	12	6	No data
Focused resistivity 140 (%)	2	4	No data
Sonic (m/s)	8	22	20

5.2.1 Interpretation of KLX17A

The results of the generalized logging data and fracture estimations of KLX17A are presented in Figure 5-1 and in a more detailed scale in Appendix 1. The distribution of silicate density classes along the borehole is presented in Table 5-2.

The distribution of silicate density in KLX17A is heterogeneous with large variations along the entire borehole (Figure 5-1). This is also clearly reflected in Table 5-2. The large density variations are likely to be related to compositional variations in the surrounding rock volume, but there may also be a connection to the fairly high fracture frequency in the section c 65–500 m (see possible deformation zones below).

In the sections c 65–376 m and 441–484 m there is a dominance of density in the range 2,720–2,790 kg/m^3, magnetic susceptibility of 0.040–0.060 SI and natural gamma radiation of 8–15 μR/h, which most likely indicates a dominant occurrence of Ävrö granite with quartz monzodioritic mineral composition.

The sections 376–441 m and c 484–700 m are characterized by density in the range 2,665–2,715 kg/m^3, magnetic susceptibility of 0.025–0.040 SI and natural gamma radiation in the range 12–25 μR/h, which suggests dominant occurrence of Ävrö granite with granodioritic mineral composition.

Intervals with highly increased density (brown colour in Figure 5-1) mainly occur along the upper half of the borehole, section c 130–485 m. In the sections c 130–137 m, 141–149 m, 209–211 m and 344–350 m the increased density coincides with increased magnetic susceptibility, and this combination of physical properties is typical for diorite/gabbro. In the sections c 213–216 m, 350–356 m, 424–431 m and 475–483 m the increased density coincides with decreased magnetic susceptibility, which is typical for fine-grained diorite/gabbro. Some of the intervals with increased density (for example at 209–211 m) coincide with sections of strongly increased natural gamma radiation that most likely correspond to fine-grained granite. This suggests that mafic and felsic dykes in some cases are spatially related.

There are few strong positive natural gamma radiation anomalies in KLX17A, which suggests a relatively low occurrence of dykes of fine-grained granite or pegmatite.

The fracture frequency estimated from the geophysical logs indicates several long intervals with increased fracturing in the section c 80–520 m. There is a fairly clear spatial relation between sections of increased fracturing and increased density (indicated mafic rock).

Possible deformation zones are indicated in the intervals c 105–114 m, 191–226 m, 354–358 m, 422–430 m and 663–668 m. The interval 105–114 m is characterized by decreased bulk resistivity, decreased magnetic susceptibility, partly decreased P-wave velocity and caliper anomalies, which suggests that the rock has suffered from strong brittle deformation. In the section c 191–226 m several thin low resistivity anomalies and partly decreased P-wave velocity coincides with a mixture of intervals with increased natural gamma radiation beside intervals

Table 5-2. Distribution of silicate density classes with borehole length of KLX17A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	147	23
2,680 < dens < 2,730	254	40
2,730 < dens < 2,800	169	27
2,800 < dens < 2,890	34	6
dens > 2,890	27	4

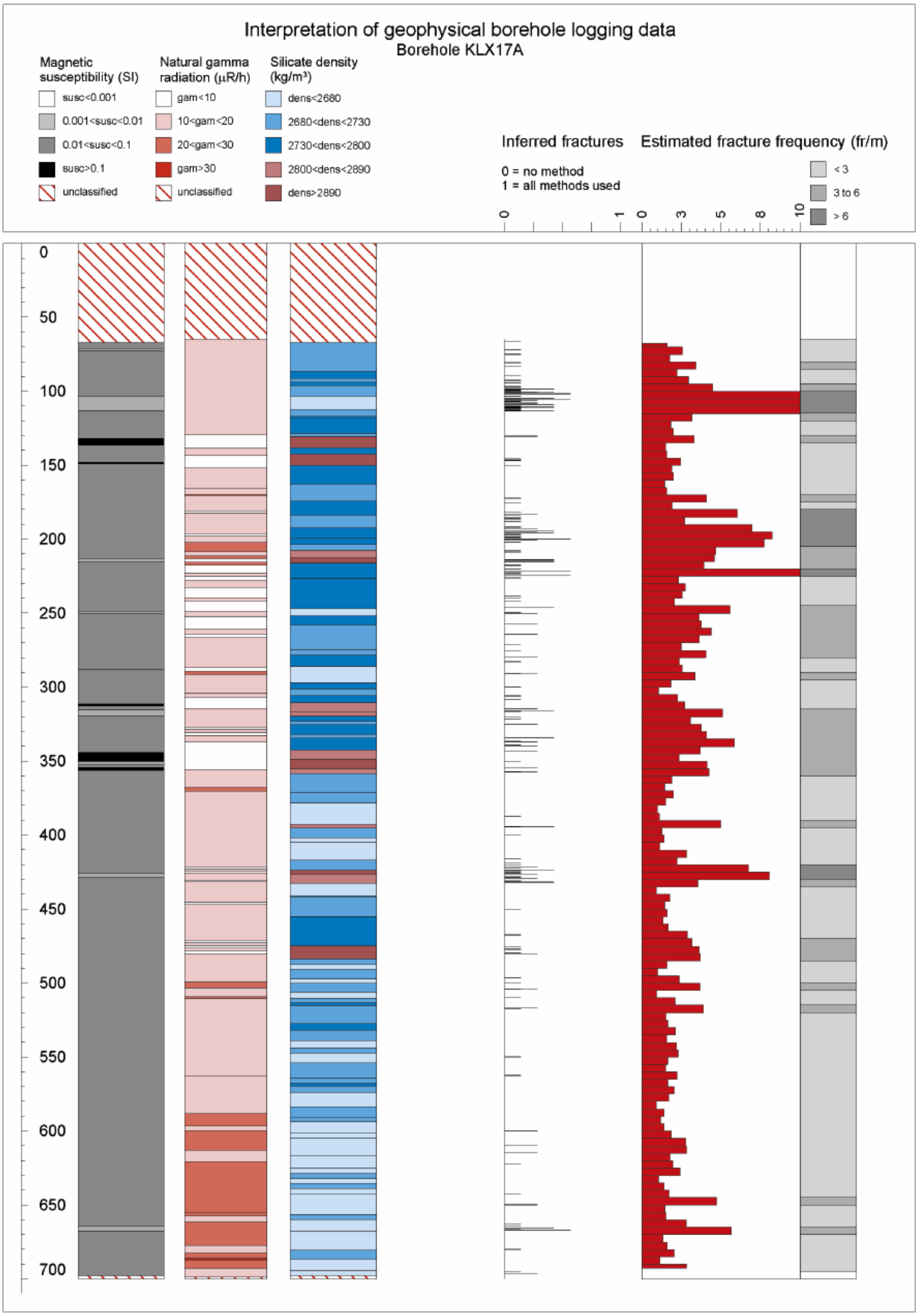


Figure 5-1. Generalized geophysical logs of KLX17A.

with increased density. This suggests that the possible deformation zone is spatially related with the occurrences of fine-grained diorite/gabbro and fine-grained granite, so called composite dykes.

The section c 354–358 m indicates a minor deformation zone which is mainly characterized by decreased resistivity and decreased magnetic susceptibility. The possible deformation at c 422–430 m coincides with the indicated occurrence of fine-grained diorite/gabbro. The interval is mainly characterized by decreased resistivity and decreased magnetic susceptibility. The lower boundary of this possible deformation zone is very close to a stepwise increase in the fluid water salinity (Figure 5-2), which may indicate the presence of a significant water bearing fracture in this part of the borehole.

The lowermost possible deformation zones occurs at c 663–668 m and it is characterized by decreased resistivity, P-wave velocity and also decreased magnetic susceptibility.

The estimated apparent porosity averages at 0.4–0.5%, which is normal for crystalline rock in this area. Intervals with increased porosity coincide with the occurrences of possible deformation zones. The most significant porosity anomalies occur at c 98–114 m and 193–225 m.

In the section c 60 m to 433 m the estimated fluid water salinity is almost constant at c 350 ppm NaCl. At c 433 m there is a stepwise increase in the salinity level up to c 880 ppm NaCl, and this level is kept constant through out the rest of the borehole. As suggest in a previous paragraph, the salinity increase may indicate the presence of a significant water bearing fracture.

5.2.2 Interpretation of HLX43

The results of the generalized logging data and fracture estimations of HLX43 are presented in Figure 5-3.

The sections c 7–15 m and c 96–170 m are dominated by silicate density of 2,680–2,730 kg/m^3, natural gamma radiation of 10–20 µR/h and magnetic susceptibility in the range 0.020–0.030 SI. This combination of physical properties is typical for Ävrö granite.

The sections c 15–31 m and 81–96 m are characterized by increased density (2,880–2,930 kg/m^3), decreased magnetic susceptibility and mainly decreased natural gamma radiation. However, there are thin anomalies within these sections with greatly increased natural gamma radiation. The combination of physical properties is typical for fine-grained diorite/gabbro mixed with fine-grained granite, so called composite dykes.

The interval c 31–72 m is governed by density in the range 2,760–2,860 kg/m^3, showing major high frequency variations. The magnetic susceptibility is fairly stable at c 0.005–0.006 SI and the natural gamma radiation is also stable at c 4–5 µR/h. This combination of physical properties most likely indicates the occurrence of dolerite rock.

The remaining section, c 72–81 m is characterized by decreased density (2,625–2,650 kg/m^3), natural gamma radiation of 10–15 µR/h and magnetic susceptibility in the range 0.010–0.015 SI. The rock in the vicinity of the borehole along this section is most likely Ävrö granite with granodioritic mineral composition, or possibly medium to coarse grained granite.

Along the major part of the indicated occurrence of dolerite rock the estimated fracture frequency is increased. The section c 33–82 m is generally characterized by significantly decreased resistivity, partly decreased P-wave velocity and large occurrences of caliper anomalies. This indicates strong brittle deformation, possibly in combination with clay alteration. Two minor possible deformation zones are indicated along the sections c 138–142 m and 150–151 m. The intervals are characterized by decreased resistivity, P-wave velocity, magnetic susceptibility and caliper anomalies.

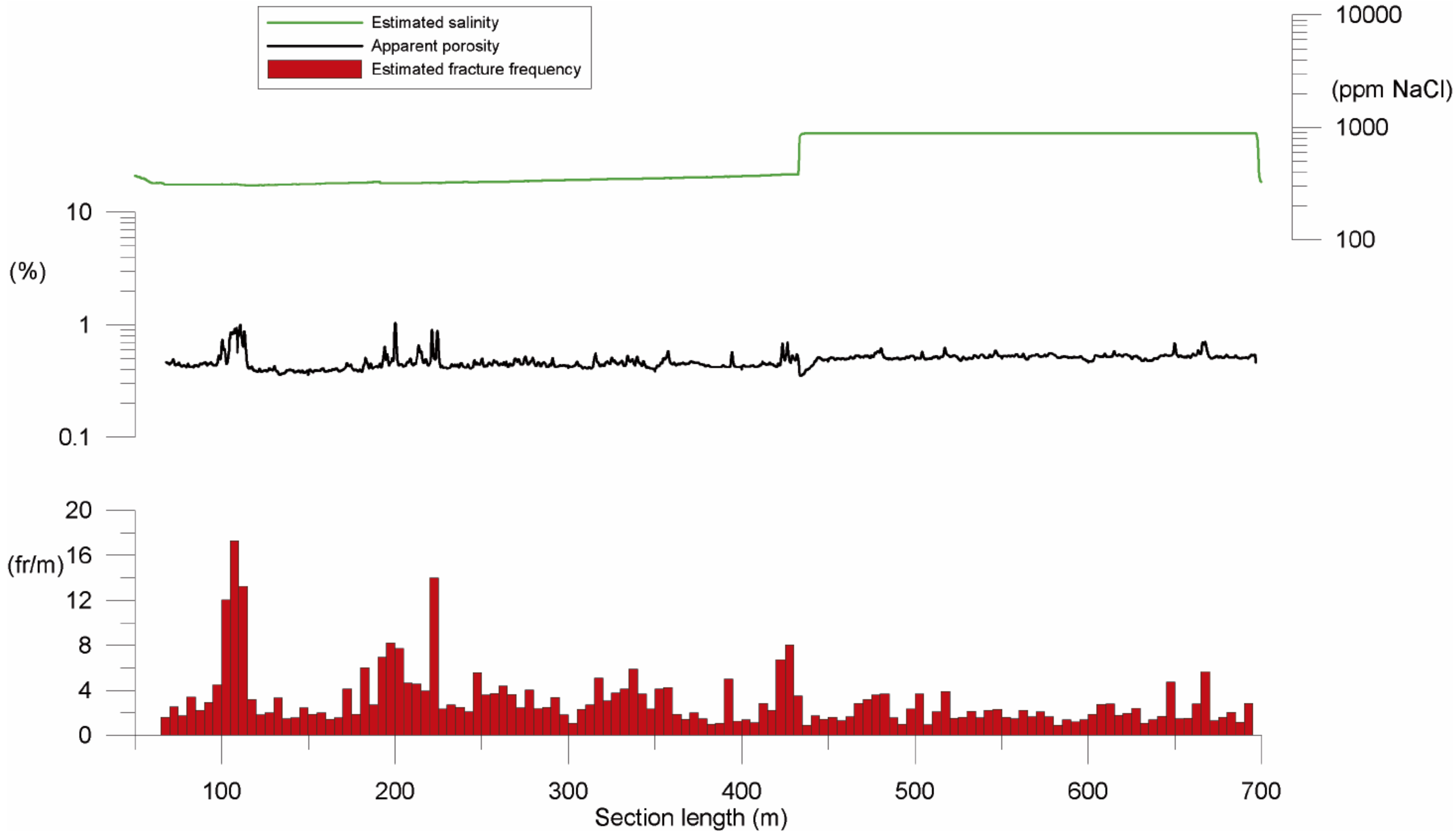


Figure 5-2. Estimated salinity, apparent porosity and estimated fracture frequency for KLX17A.

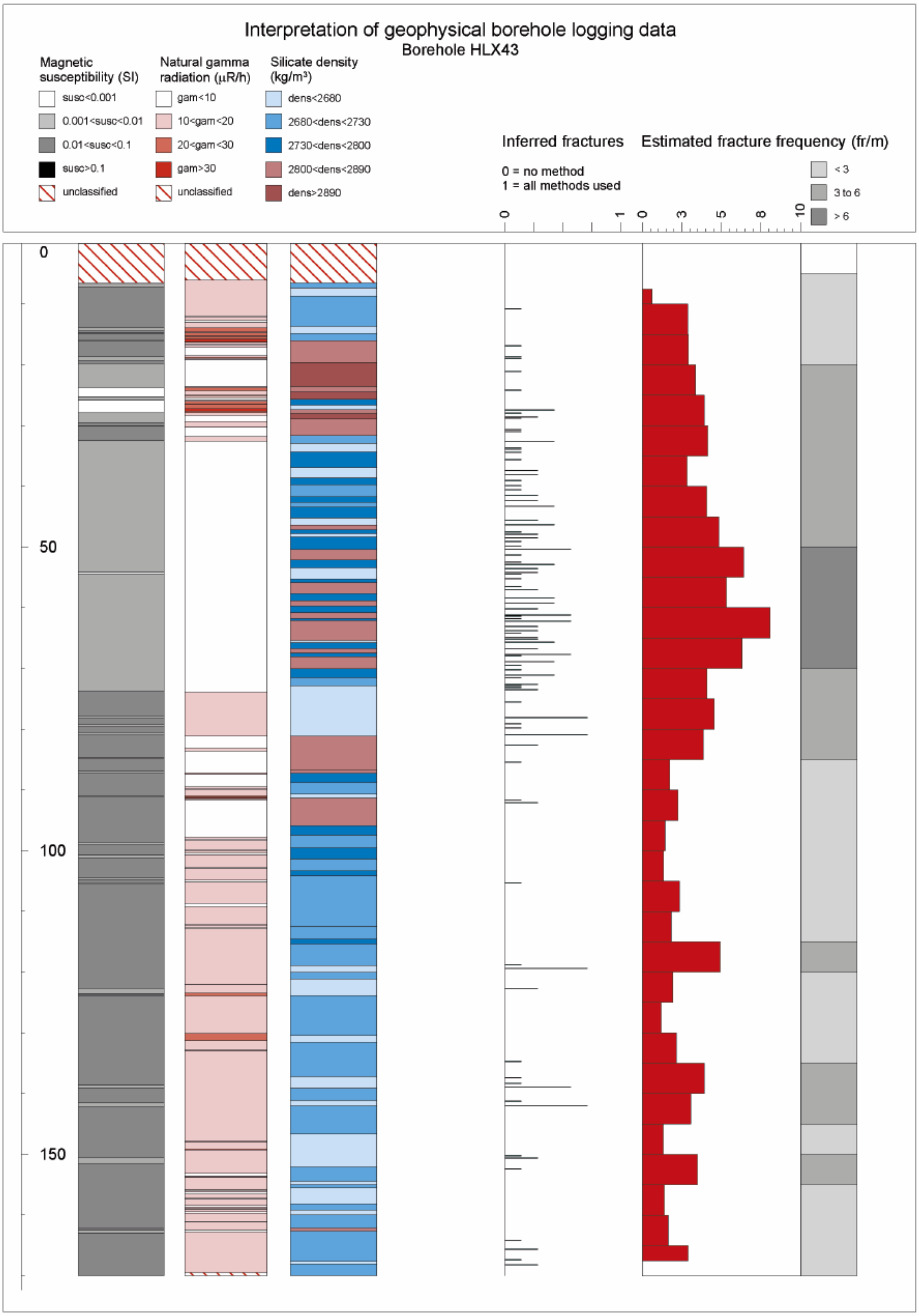


Figure 5-3. Generalized geophysical logs for HLX43.

References

/1/ **Nielsen U T, Ringgaard J, 2006.** Geophysical borehole logging in boreholes KLX17A and HLX43. SKB P-06-315, Svensk Kärnbränslehantering AB. In Press.

/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/ **Mattsson H, 2006.** Interpretation of geophysical borehole measurements and petrophysical data from KLX10. SKB P-06-162, Svensk Kärnbränslehantering AB.

/8/ **Mattsson H, Keisu M, 2006.** Interpretation of geophysical borehole measurements from KLX18A, KLX20A, KLX09B, KLX09D, KLX09F, KLX11B, HLX38, HLX39, HLX40, HLX41 and interpretation of petrophysical data from KLX20A. SKB P-06-292, Svensk Kärnbränslehantering AB. In press.

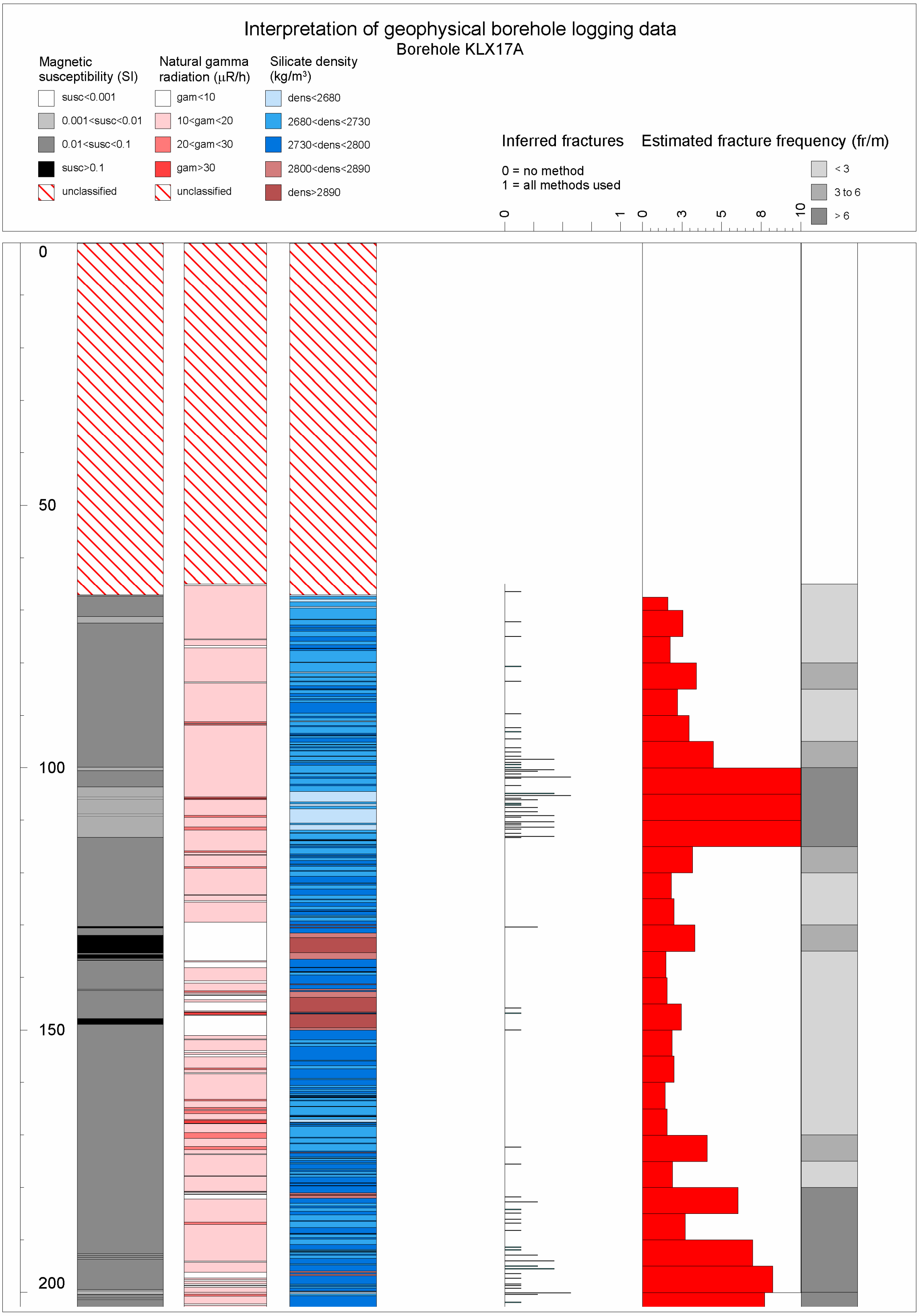
/9/ **Keisu M, 2006.** Calibration of 1D and 3D caliper data from core and percussion drilled boreholes. SKB P-06-153, Svensk Kärnbränslehantering AB.

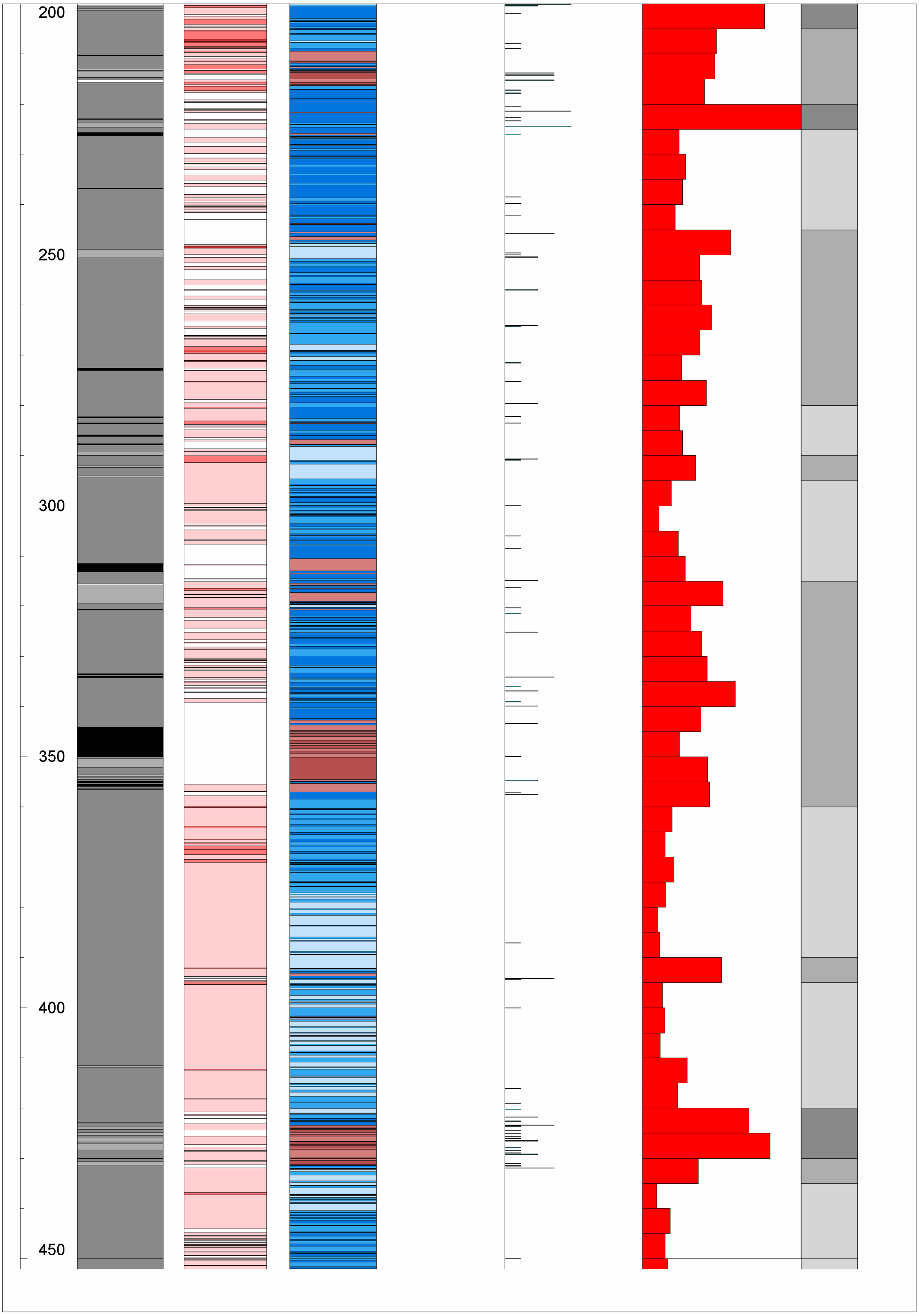
/10/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

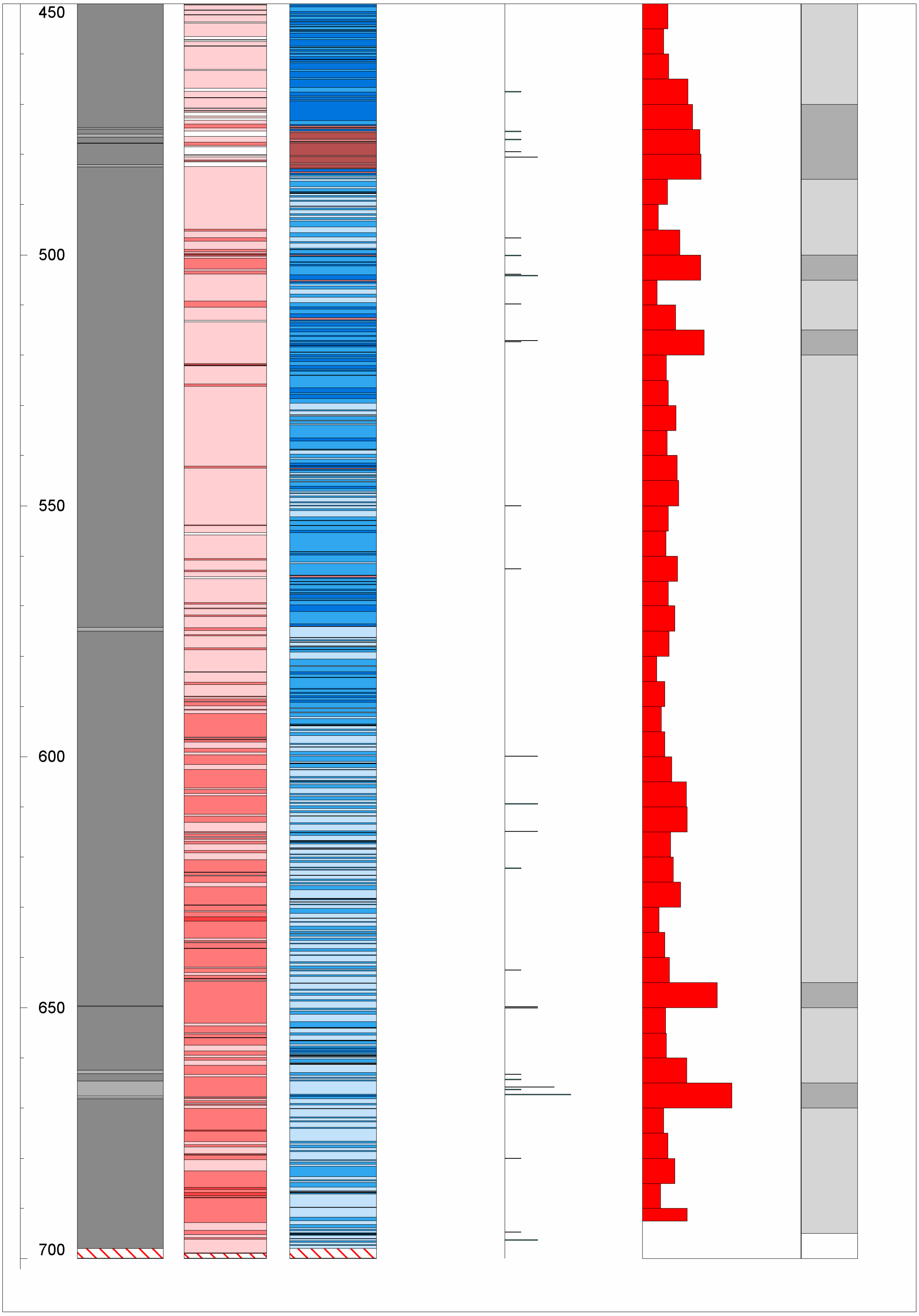
/11/ **Puranen R, 1989.** Susceptibilities, iron and magnetite content of precambrian rocks in Finland. Geological survey of Finland, Report of investigations 90, 45 pp.

/12/ **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.

Generalized geophysical logs for KLX17A




200
250
300
350
400
450


450
500
550
600
650
700