P-06-162

Oskarshamn site investigation

Interpretation of geophysical borehole measurements and petrophysical data from KLX10

Håkan Mattsson, GeoVista AB

August 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-06-162

Oskarshamn site investigation

Interpretation of geophysical borehole measurements and petrophysical data from KLX10

Håkan Mattsson, GeoVista AB

August 2006

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

Abstract

This report presents the compilation and interpretations of geophysical logging data and petrophysical data (wet density and magnetic bulk susceptibility) of 10 core samples from the cored borehole KLX10.

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 interpretations.

A majority (> 90%) of the rocks in the vicinity of KLX10 have silicate density < 2,730 kg/m^3, natural gamma radiation in the interval 15–30 μR/h and magnetic susceptibility of 0.02–0.03 SI, which suggests that the dominant rock type is Ävrö granite. This interpretation is supported by the results from the petrophysical measurements. A few short intervals of indicated fine-grained diorite to gabbro and fine-grained granite occur in scattered places in the borehole. The lowermost c 100 m of KLX10 (section c 900–1,000 m) seem to be dominated by quartz monzodiorite rock.

The estimated fracture frequency of KLX10 is fairly high in the section c 100–450 m and mainly low in the section 450–1,000 m. Possible deformation zones are indicated at the section intervals c 106–116 m, 150–162 m, 187–207 m, 244–270 m, 300–360 m, 395–445 m, 690–710 m, 785–795 m and 965–980 m. For the majority of these possible deformation zones there are distinct caliper anomalies, there is a major decrease in the bulk resistivity, there are several intervals of decreased P-wave velocity and there is also a major decrease in the magnetic susceptibility. The occurrences of caliper anomalies and decreased P-wave velocity indicate brittle fracturing, and the decrease in bulk resistivity together with decreased magnetic susceptibility may indicate rock alteration.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX10 samt bearbetning och tolkning av petrofysiska mätningar (våtdensitet och magnetisk volymssusceptbilitet) på 10 bergartsprover från detta borrhål.

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.

En majoritet (> 90 %) av bergarterna i närheten av KLX10 har en silikatdensitet < 2 730 kg/m^3, en naturlig gammastrålning i intervallet 15–30 μR/h och magnetisk susceptibilitet på 0,02–0,03 SI, vilka är typiska värden för bergarten Ävrögranit. Denna tolkning stöds även av resultaten från de petrofysiska mätningarna. Ett fåtal korta sektioner med indikerad förekomst av finkornig diorit till gabbro samt finkornig granit förekommer längs stora delar av borrhålet. De nedersta ca 100 m av KLX10 (sektionen ca 900–1 000 m) domineras troligen av bergarten kvartsmonzodiorit.

Den uppskattade sprickfrekvensen är relativt hög längs sektionen ca 100–450 m och mestadels låg längs sektionen ca 450–1 000 m. Möjliga större deformationszoner kan identifieras längs sektionerna ca 106–116 m, 150–162 m, 187–207 m, 244–270 m, 300–360 m, 395–445 m, 690–710 m, 785–795 m och 965–980 m. De allra flesta av dessa möjliga zoner karaktäriseras av distinkta caliperanomalier, signifikant lägre elektrisk resistivitet, flera sektioner med låg P-vågshastighet samt en kraftigt sänkt magnetisk susceptibilitet. Caliperanomalier och låg P-vågshastighet indikerar spröda sprickor medan avvikande låg resistivitet och magnetisk susceptibilitet ofta kan kopplas till mineralomvandling.

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 KLX10 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 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 400-05-094 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of borehole KLX10.

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 KLX10.	AP PS 400-05-094	1.0
Method descriptions	**Number**	**Version**
Method description for determining density and porosity of intact rock.	SKB MD 160.002e	2.0
Metodbeskrivning för mätning av bergarters petrofysiska egenskaper.	SKB MD 230.001	2.0
Metodbeskrivning för tolkning avgeofysiska borrhålsdata.	SKB MD 221.003	2.0

Figure 1-1. *Location of the borehole KLX10 in the centre of the Laxemar subarea.*

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 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 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.

3.2 Description of equipment for analyses of petrophysical data

The measurements of magnetic susceptibility were performed with a KLY-3 Kappabridge from Geofyzika Brno. 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 Laboratory measurements

The sampling covers 10 samples from KLX10 (Table 4-1), collected by SKB. Preparations of the drill cores were performed by a technician at the laboratory of the Division of Applied Geophysics, Luleå University of Technology. The measurements of the magnetic susceptibility were performed according to MD 230.001 (SKB internal controlling document). The measurements of the wet density were performed according to MD 160.002e (SKB internal controlling document). The instruction is written to conform to rock mechanical measurements on drill cores from deep drillings, where the density determinations are parts of other types of measurements, not directly relevant for the geological core logging. The time to soak the samples (48 hours in this investigation) is e.g. shorter than what is recommended in MD 160.002.

Calibration of instruments for measurements of petrophysical parameters were performed in accordance to the manual for each instrument respectively.

The laboratory measurements of petrophysical parameters produce raw-data files in ascii, binary or Microsoft Excel formats. All data files were delivered via email from the laboratory at the Luleå University of Technology to GeoVista AB. The data were then rearranged and placed in Microsoft Excel files. Back-up files of all raw-data are stored both at GeoVista AB and at the laboratory.

Sample information, section up and section low, for KLX10 is given in Table 4-1.

Table 4-1. Sample information for KLX10.

Section up (m)	Section low (m)
117.33	117.43
157.29	157.39
202.29	202.39
260.60	260.70
306.69	306.79
330.45	330.55
447.20	447.30
701.20	701.30
768.52	768.62
982.93	983.03
117.33	117.43

4.2 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 KLX02, KLX03, KLX04, KSH01A, KSH02, KSH03A and KAV04A, see /2, 3, 4, 5, 6/. The density logging data were calibrated by use of petrophysical data from the borehole KLX10 (evaluated in this report).

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” (< 10µR/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 4-2) 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 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 4-2.

Table 4-2. 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	KLX10	2.0	2.2	1.7	1.2	–	–	–	–
Power	KLX10	1.0	1.0	1.6	1.0	–	–	–	–
Weight	KLX10	1.0	7.1	6.7	1.0	–	–	–	–

5. Report evaluating the results.

4.3 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.
- 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.

4.4 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.

4.5 Nonconformities

No normal resistivity or SPR data were collected in KLX10. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore not presented for the normal resistivity loggings. Apart from this, no nonconformities are reported.

5 Results

5.1 Petrophysical properties of KLX10

The rock type classifications diagram in Figure 5-1 shows the distribution of the magnetic susceptibility versus density for the 10 samples (including section length centre of each sample).

The petrophysical data indicate that the samples collected at c 202 m, 307 m and 447 m classify as Ävrö granite. The samples from c 117 m, 261 m and 983 m classify, according to the diagram, as quartz monzodiorite and the samples at c 769 m and 331 m should most likely be classified as diorite to gabbro (probably fine-grained diorite to gabbro because of their low magnetic susceptibility). The samples collected at c 157 m and 701 m are both located within possible deformation zones, which most likely has affected their physical properties, giving rise to anomalously low density values and also low magnetic susceptibility. No petrophysical rock classification is therefore suggested for these two samples.

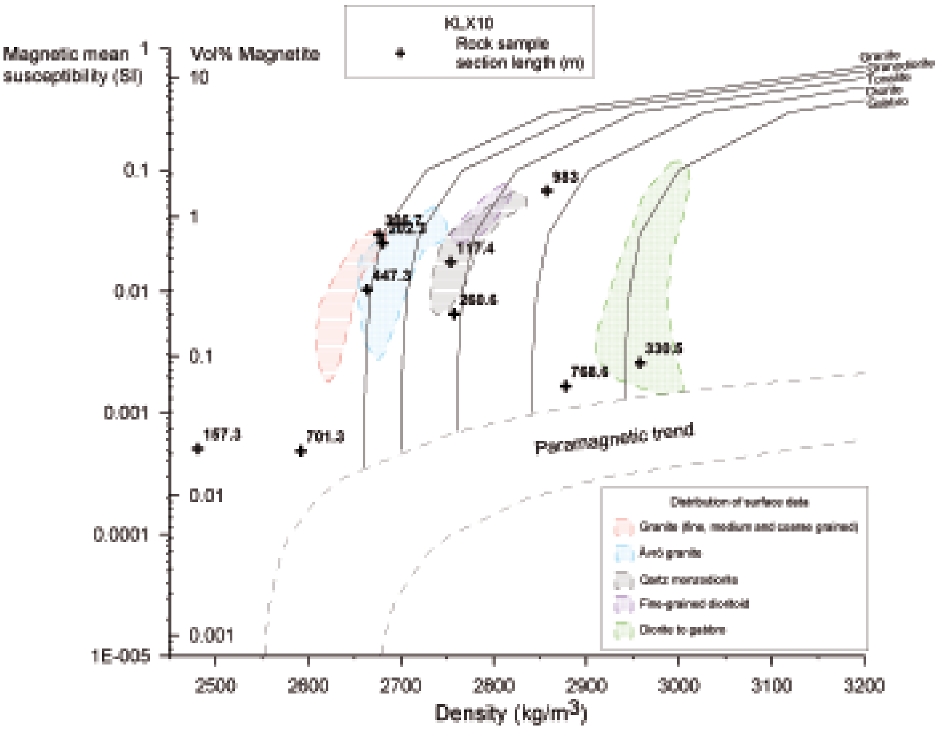


Figure 5-1. *Susceptibility – density rock classification diagram. The shaded areas indicate the distribution of some of the rock types group from the collection of samples on the surface in the Laxemar and Simpevarp areas.*

5.2 Quality control 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. The magnetic susceptibility log has a noise level 2.5 times above the recommended, which is too high to be fully acceptable.

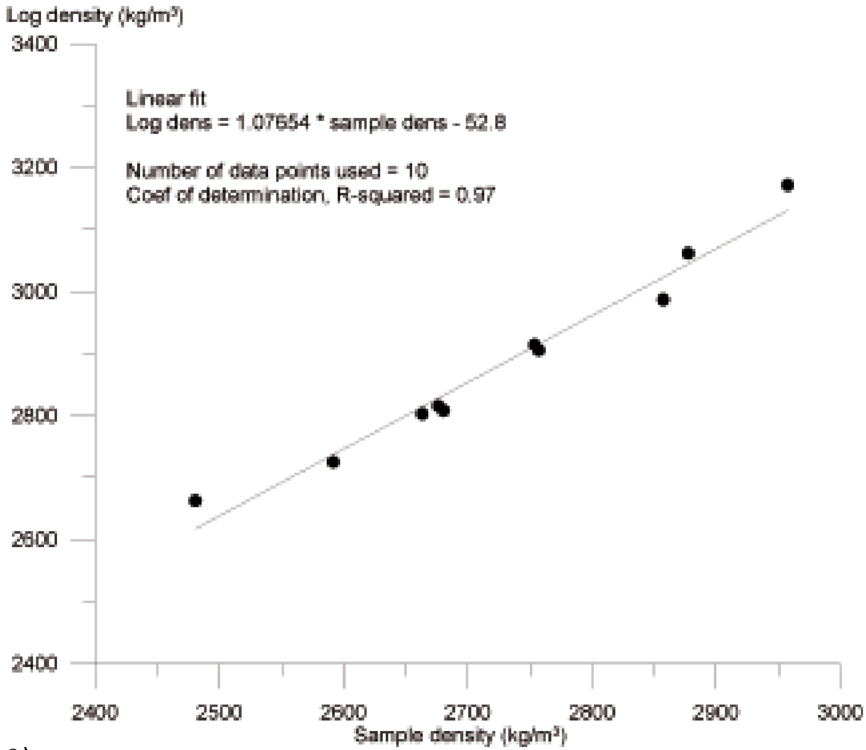
A qualitative inspection was performed on the loggings. The data were checked for spikes and/or other obvious incorrect data points. Erroneous data were replaced by null values (–999) by the contractor Rambøll prior to the delivery of the data, and all null values were disregarded in the interpretation.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

The calibration of the density and susceptibility logs is performed by plotting the sample data versus the log data at the corresponding section length coordinate (a so called cross-plot), and then performing a linear regression analysis. In Figures 5-2a and 5-2b cross plots of the density and magnetic susceptibility data of KLX10 are displayed for each property respectively.

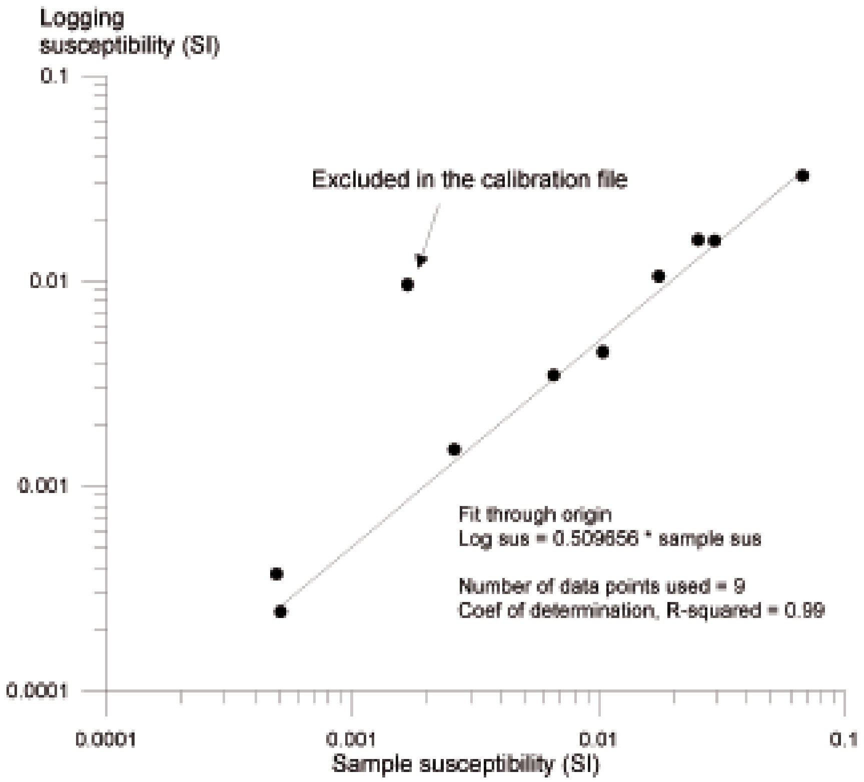
The density data show a nice linear distribution with a low amount of scatter and the fitted line is very well defined. The slope of the fitted line is fairly close to 1.0 (it is 1.077) but observe the rather large density value of 52.8 kg/m^3 for the density log when the sample density equals zero. Also the magnetic susceptibility data show a nice linear distribution and the fit through the origin is statistically well defined. However, the slope of the fitted line differs significantly from 1.0.

Table 5-1. Noise levels in the investigated geophysical logging data of KLX10.

Logging method	KLX10	Recommended max noise level
Density (kg/m^3)	6	3–5
Magnetic susceptibility (SI)	$2.5 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Natural gamma radiation (μR/h)	0.4	0.3
Long normal resistivity (%)	Not used	2.0
Short normal resistivity (%)	Not used	2.0
Fluid resistivity (%)	0.05	2
Fluid temperature (ºC)	$3 \cdot 10^{-4}$	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	Not used	No data
Caliper mean (m)	$3 \cdot 10^{-6}$	$5 \cdot 10^{-4}$
Focused resistivity 300 (%)	7.5	No data
Focused resistivity 140 (%)	0.7	No data
Sonic (m/s)	7	20



a)



b)

Figure 5-2. *a) Cross plot of logging density versus sample density for KLX10. b) Cross plot of logging susceptibility versus sample susceptibility for KLX10.*

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 m sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and > 6 fractures/m).

5.3.1 Interpretation of KLX10

The results of the generalized logging data and fracture estimations of KLX10 are presented in Figure 5-3, and in a more detailed scale in Appendix 1.

A majority (93%) of the rocks in the vicinity of KLX10 have silicate density <2,730 kg/m^3, with an approximate average of c 2,650 kg/m^3 (Table 5-2). The natural gamma radiation in the corresponding sections is in the range 15–30 µR/h, and these data suggest that the dominant rock type in the vicinity of KLX10 is Ävrö granite. Intervals with higher silicate density, probably indicating quartz monzodiorite rock, mainly occur in the sections c 100–130 m and 900–1,000 m. The magnetic susceptibility is mainly in the interval 0.02–0.03 SI, apart from sections with increased fracture frequency. There is a distinct increase in the magnetic susceptibility (c 0.04–0.05 SI) in the section 900–1,000 m (not visible in Figure 5-3 due to the classification of the magnetic susceptibility data). Two thin (<5 m) dykes of probable fine-grained diorite to gabbro rock are indicated at c 330 m and 347 m, and three fine-grained diorite to gabbro dykes also seem to occur in the section interval 765–795 m.

The section c 232–240 m is dominated by high natural gamma radiation (> 30 µR/h), decreased density and decreased magnetic susceptibility, which suggest the occurrence of fine-grained granite. About 10 short intervals (< 1 m) with natural gamma radiation > 30 µR/h that most likely correspond to fine-grained granite occur in scattered places, mainly in the section 200–700 m.

The natural gamma radiation data indicate that KLX10 can be divided into three subsections. Subsection c 10–400 m is inhomogeneous with large variations between the interval 10–20 µR/h and 20–30 µR/h. In this part of the borehole there is a clear indication of increased fracturing and the occurrences of several possible deformation zones. The second subsection, c 400–700 m, is dominated by natural gamma radiation in the interval 20–30 µR/h and the lowermost c 300 m of the borehole (section c 700–1,000 m) is dominated by a radiation level < 20 mR/h.

The estimated fracture frequency of KLX10 is fairly high in the section c 100–450 m and mainly low in the section 450–1,000 m. Possible deformation zones are indicated at the section intervals c 106–116 m , 150–162 m, 187–207 m, 244–270 m, 300–360 m , 395–445 m, 690–710 m, 785–795 m and 965–980 m. For the majority of these possible deformation zones there are distinct caliper anomalies, there is a major decrease in the bulk resistivity, there are several intervals of decreased P-wave velocity and there is also a major decrease in the magnetic susceptibility. The occurrences of caliper anomalies and decreased P-wave velocity indicate brittle fracturing, and the decrease in bulk resistivity together with decreased magnetic susceptibility may indicate rock alteration.

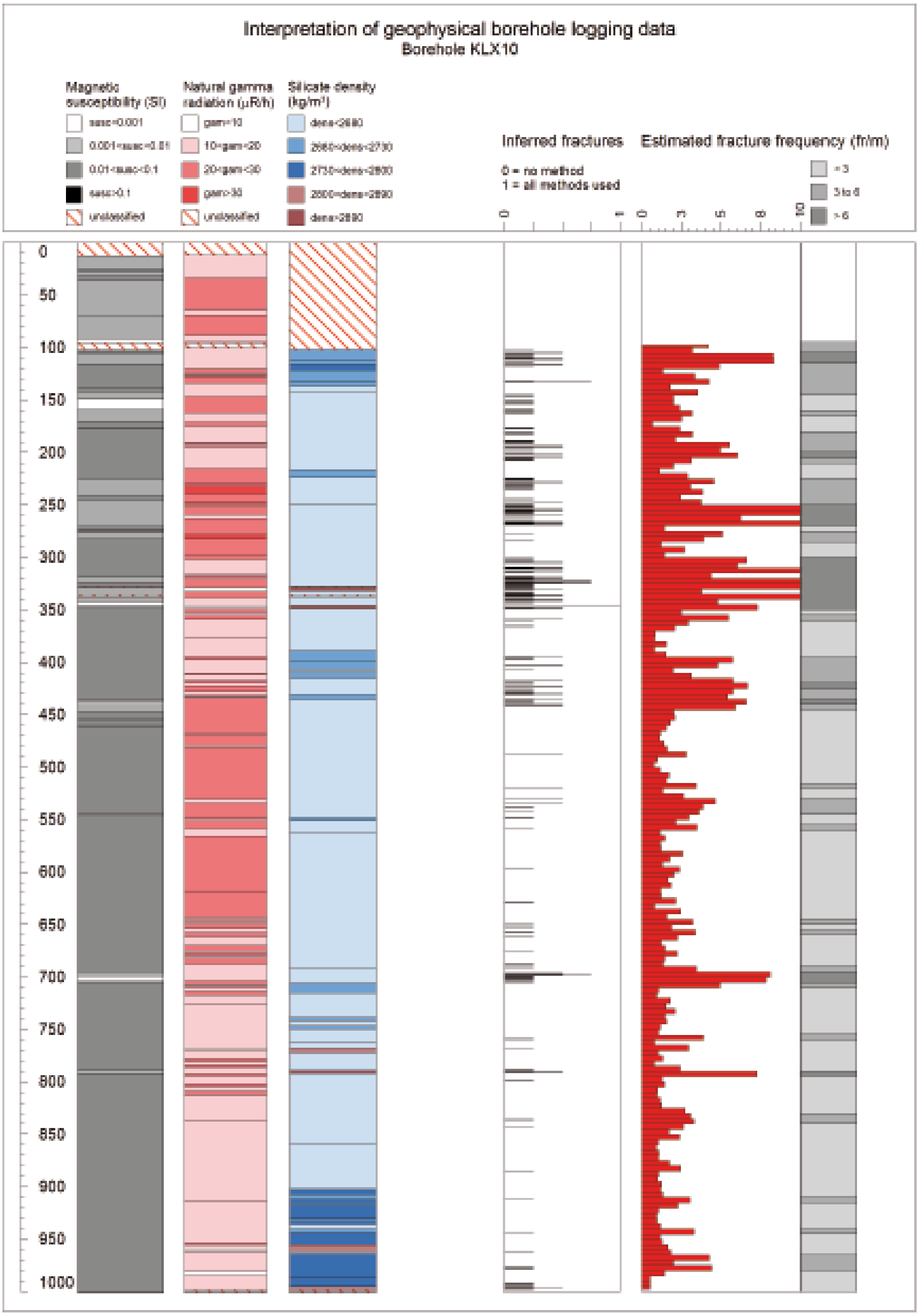


***Figure 5-3.** Generalized geophysical logs of KLX10.*

However, the possible deformation zone indicated in the section c 395–445 m is partly an exception since the resistivity along this interval is dominated by large but thin negative and positive anomalies (there is hardly any decrease in the bulk resistivity) and only a short interval with decreased P-wave velocity. This most likely reflects thin partly sealed (or only slightly open) fractures and no or only minor occurrences of e.g. alteration or clay minerals.

The estimated fluid water salinity (Figure 5-4) shows unnatural variations that most likely indicate that the borehole fluid was not in chemical equilibrium with the surrounding pore water fluid at the time of the measurement of the fluid water resistivity.

Table 5-2. Distribution of silicate density classes with borehole length (100–1,000 m) of KLX10.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
2,680>dens	730	81
2,680<dens<2,730	104	12
2,730<dens<2,800	51	6
2,800<dens<2,890	7	1
dens>2,890	3	0

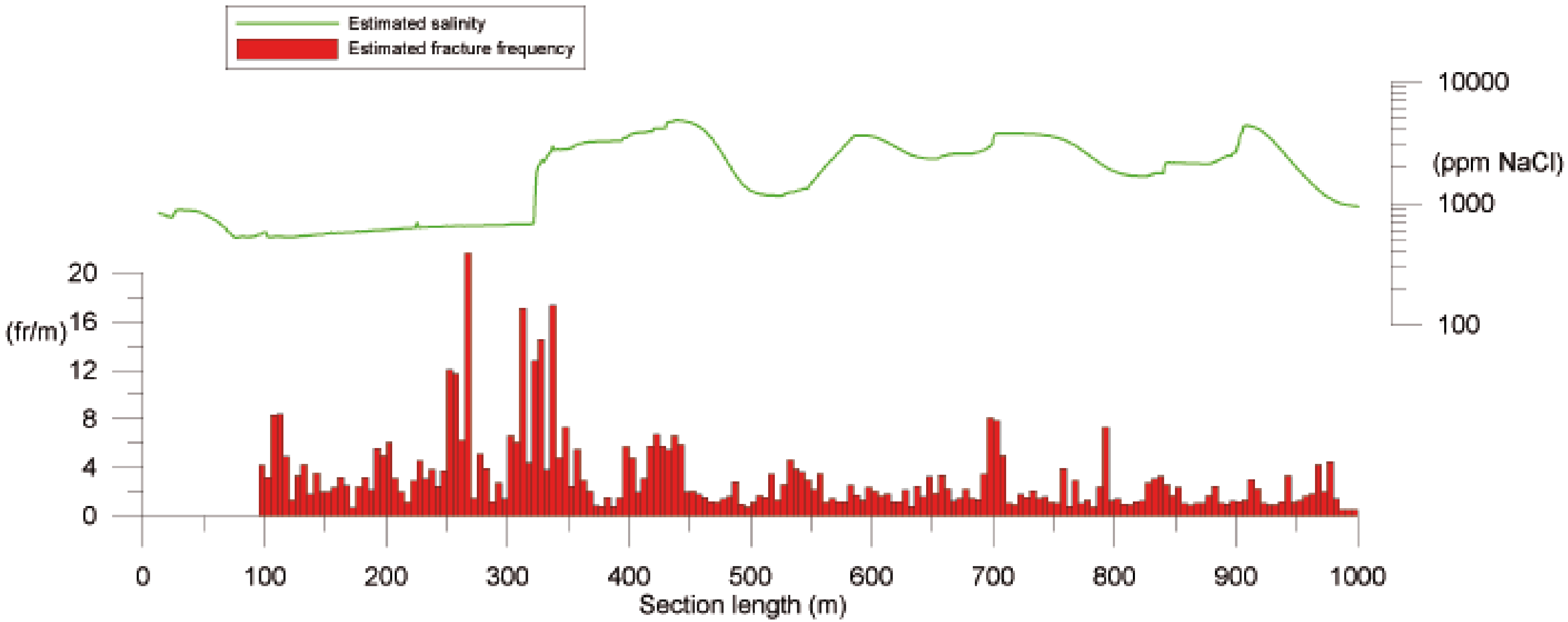


Figure 5-4. *Estimated salinity and estimated fracture frequency of KLX10.*

References

/1/ **Nielsen U T, Ringgard J, Fris Dahl J, 2005.** Geophysical borehole logging in KLX10. SKB P-06-20, 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 (0–100m), 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 (80–1,000m) 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 (100–1,000m), KSH03B, HAV09, HAV10 and KLX02 (200–1,000m). SKB P-04-214, Svensk Kärnbränslehantering AB.

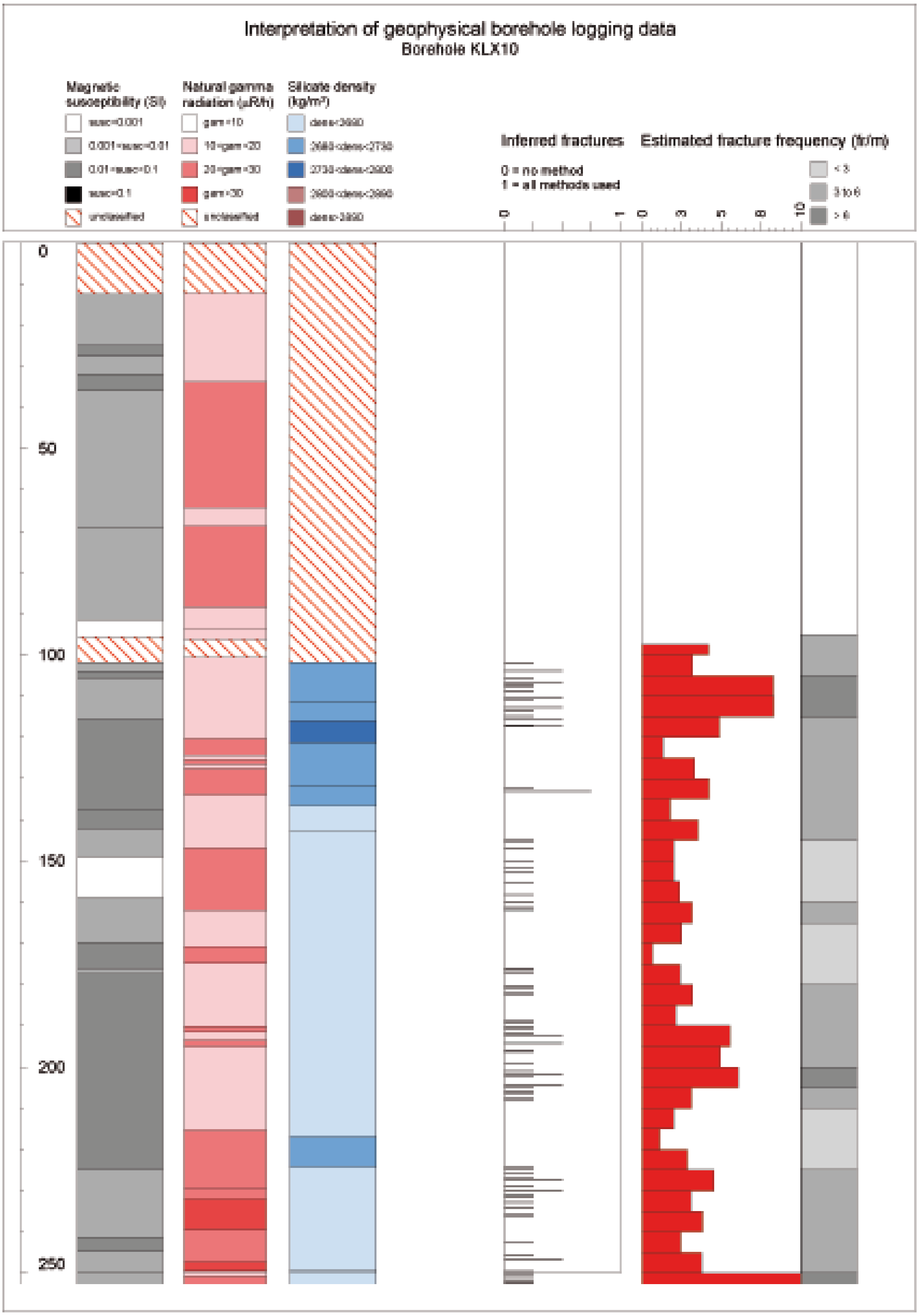
/6/ **Mattsson H, 2004.** Interpretation of geophysical borehole data and compilation of petrophysical data from KAV04A (100–1,000m), KAV04B, HLX13 and HLX14. SKB P-04-217, Svensk Kärnbränslehantering AB.

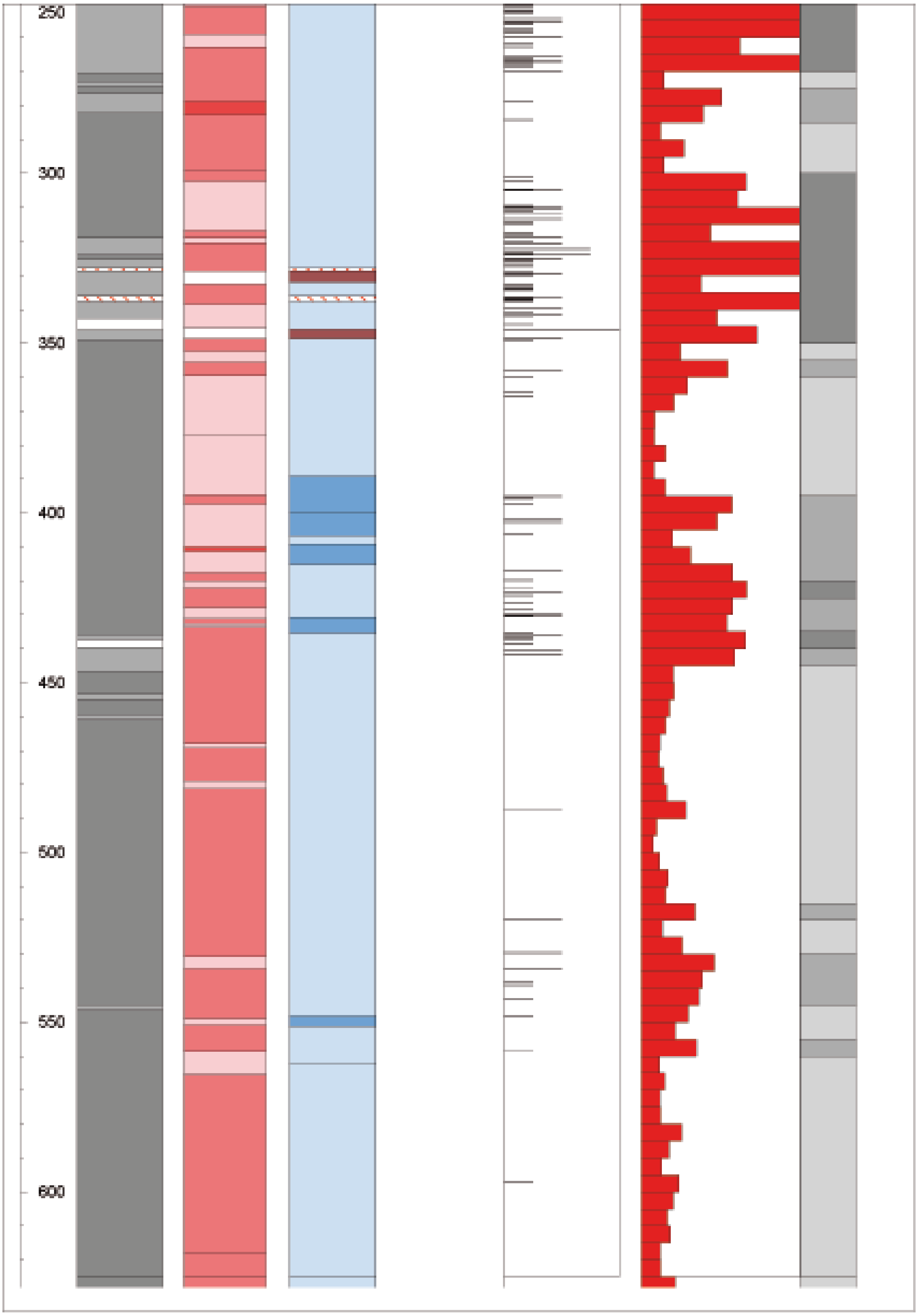
/7/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

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

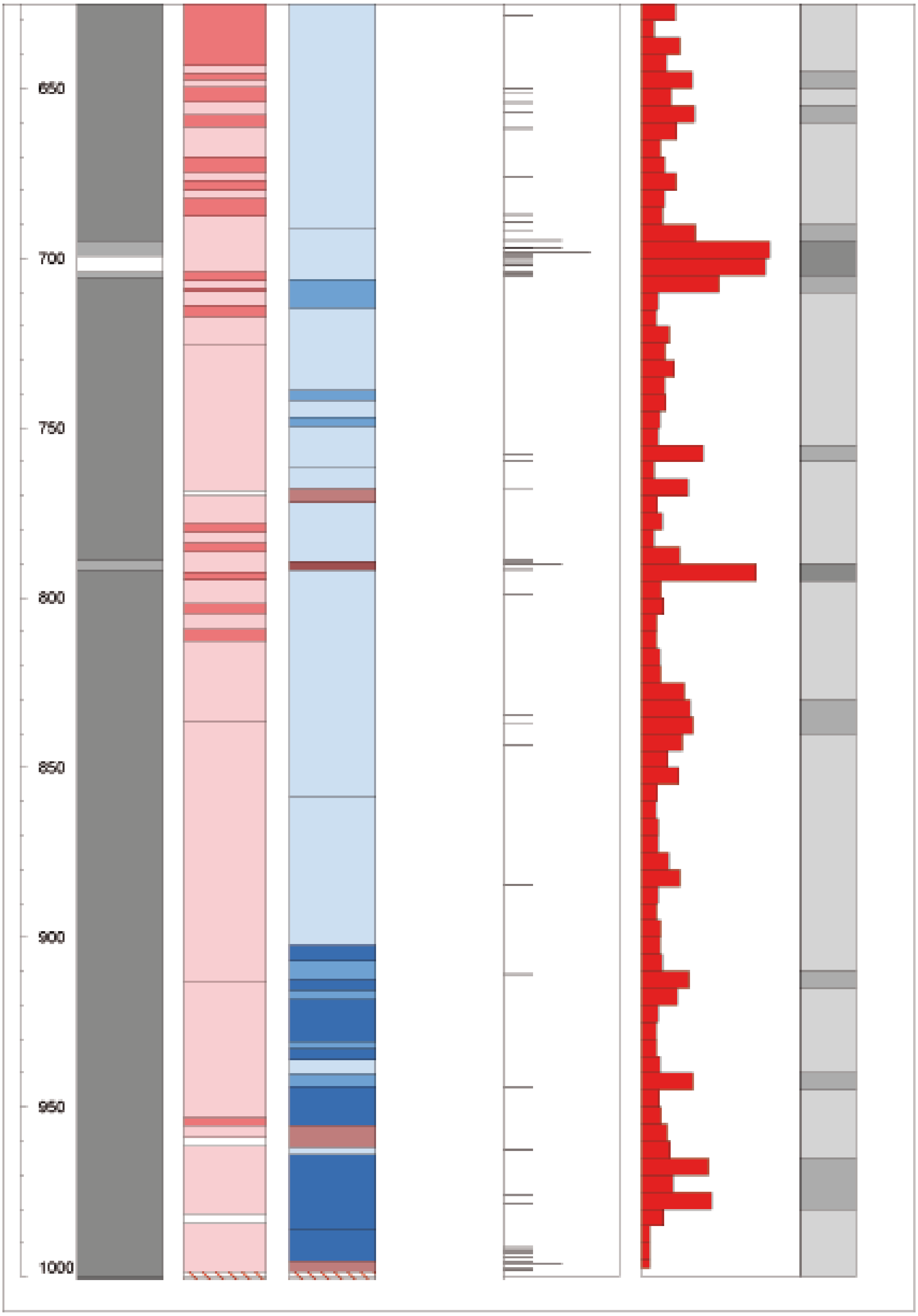
/9/ **Archie G E, 1942.** The electrical resistivity log as an aid in determining some reservoir characteristics: Trans. Am. Inst. Min., Metallurg., Petr.Eng., 146, 54–62.

Generalized geophysical loggings of KLX10





250
300
350
400
450
500
550
600


650
700
750
800
850
900
950
1000