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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX21B

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April 2007

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

Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored borehole KLX21B.

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 KLX21B is dominated by the two lower classes < 2,680 kg/m^3 and 2,680–2,730 kg/m^3; these two classes cover approximately 75% of the total borehole length. Rocks with density in the lowermost density class (< 2,680 kg/m^3) mainly occur in the upper half of the borehole, section c 100–540 m. In this section the natural gamma radiation is generally in the range 20–30 μR/h, whereas in the lower part of the borehole, section c 650–860 m, the natural gamma radiation is mainly in the range 10–20 μR/h. The decrease in natural gamma radiation coincides with increased density along this interval. There are very few indicated occurrences of fine-grained granite or diorite/gabbro rocks in KLX21B.

Silicate density < 2,680 kg/m^3 and natural gamma radiation of 20–30 μR/h most likely indicates the occurrence of Ävrö granite with granitic to granodioritic mineral composition. Silicate density of 2,680–2,800 kg/m^3 and natural gamma radiation of 10–20 μR/h most likely indicates the occurrence of Ävrö granite with quartz monzodioritic composition or quartz monzodiorite.

In the sections c 151–155 m, 208–216 m, 445–478 m and 589–707 m there is a significant decrease in magnetic susceptibility, which most likely indicates mineral alteration possibly caused by rock deformation (see possible deformation zones below).

Intervals with the significantly decreased resistivity are often correlated with caliper anomalies and decreased P-wave velocity which suggests brittle deformation indicating possible deformation zones. These sections are located at c 101–110 m, 148–156 m, 211–214 m, 227–231 m, 448–456 m, 472–479 m, 567–569 m, 604–612 m, 624–627 m and 684–707 m.

The estimated apparent porosity shows fairly large variations within the interval 0.5–1.0%. Since the porosity estimation is based on the short normal resistivity log the porosity data reflect the fairly large resistivity variations measured in KLX21B. The apparent porosity log indicates that the sections with increased density also have increased porosity and vice versa (this is mainly valid for the borehole section c 100–650 m). The interpretation of these data is that Ävrö granite with granitic mineral composition has less porous and/or have lower fracture frequency as compared to Ävrö granite with quartz monzodioritic mineral composition.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX21B.

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 KLX21B domineras av de två lägsta densitetsklasserna < 2 680 kg/m^3 och 2 680–2 730 kg/m^3. Dessa två klasser förekommer längs 75 % av den totala längden i borrhålet. Bergarter inom den lägsta klassen (< 2 680 kg/m^3) förekommer främst i borrhålets övre halva, ca 100–540 m, och längs denna sektion är den naturliga gammastrålningen generellt 20–30 µR/h. I den nedre delen av KLX21B, sektionen ca 650–860 m, är den naturliga gammastrålningen generellt i intervallet 10–20 µR/h, och densiteten är något förhöjd. Endast ett fåtal indikationer på basiska eller sura gångar förekommer i borrhålet.

Partier med silikatdensitet < 2 680 kg/m^3 och naturliga gammastrålning i intervallet 20–30 µR/h indikerar förekomst av Ävrögranit med granitisk till granodioritisk mineralsammansättning. Silikatdensitet i intervallet 2 680–2 730 kg/m^3 och naturliga gammastrålning i intervallet 10–20 µR/h indikerar förekomst av Ävrögranit med kvartsmonzodioritisk mineralsammansättning eller kvartsmonzodiorit.

Den magnetiska susceptibiliteten är mycket låg längs sektionerna ca 151–155 m, 208–216 m, 445–478 m och 589–707 m, vilket troligen kan kopplas till mineralomvandling och/eller deformation (se möjliga deformationszoner nedan).

Intervall med kraftigt sänkt resistivitet sammanfaller ofta med sänkt P-vågshastighet och caliperanomalier, vilket indikerar förekomst av möjliga deformationszoner. Dessa sektioner förekommer vid ca 101–110 m, 148–156 m, 211–214 m, 227–231 m, 448–456 m, 472–479 m, 567–569 m, 604–612 m, 624–627 m och 684–707 m.

Den beräknade skenbara porositeten varierar kraftigt inom intervallet 0,5–1,0 %. Eftersom den skenbara porositeten beräknas utifrån den korta normala resistivitetsloggen speglar porositeten de ganska stora variationer i resistivitet som uppmätts i KLX21B. Det finns även ett tydligt samband mellan förhöjd densitet och förhöjd porositet (gäller främst sektionen ca 100–650 m), vilket indikerar att Ävrögranit med granitisk till granodioritisk mineralsammansättning har lägre porositet (och möjligen lägre sprickfrekvens) än Ävrögranit med kvartsmonzodioritisk sammansättning.

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 KLX21B, 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 2007 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 400-06-157 and method descriptions MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of the borehole KLX21B.

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 KLX21B.	AP PS 400-06-157	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	3.0

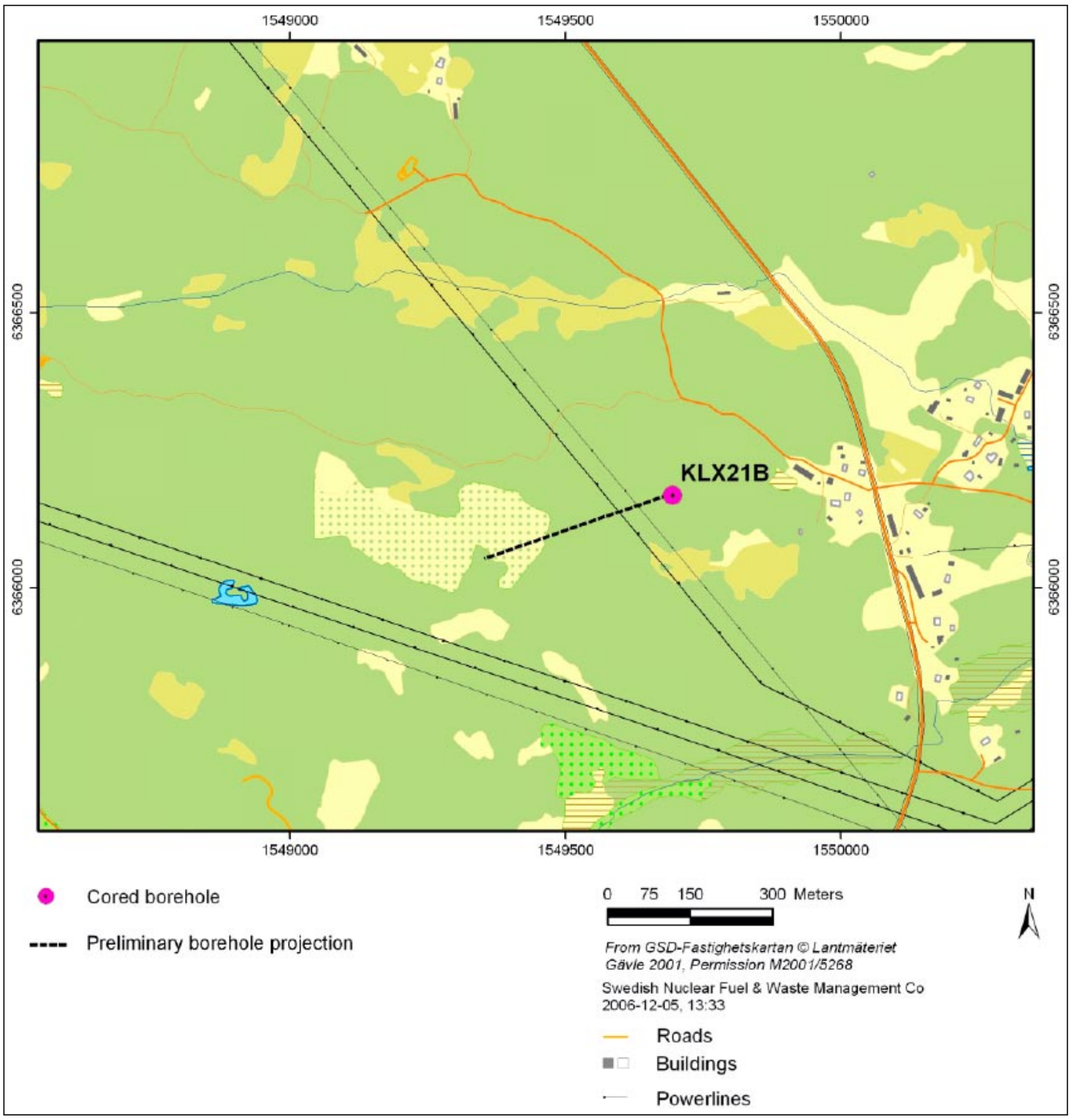

Figure 1-1. *Location of the borehole KLX21B in Laxemar.*

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 and 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" (< 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 /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.

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 the borehole 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.

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	KLX21B	1.0	1.5	1.5	1.0	3.0	6	5	–
Power	KLX21B	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX21B	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

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. 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	KLX21B	Recommended max noise level
Density (kg/m^3)	11	3–5
Magnetic susceptibility (SI)	$5\cdot10^{-4}$	$1\cdot10^{-4}$
Natural gamma radiation (μR/h)	1.0	0.3
Long normal resistivity (%)	2.1	2.0
Short normal resistivity (%)	1.6	2.0
Fluid resistivity (%)	0.1	2
Fluid temperature (ºC)	$6\cdot10^{-4}$	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	0.3	No data
Caliper 1D	$1\cdot10^{-6}$	$5\cdot10^{-4}$
Caliper mean (m)	$1\cdot10^{-5}$	$5\cdot10^{-4}$
Focused resistivity 300 (%)	13	No data
Focused resistivity 140 (%)	5	No data
Sonic (m/s)	9	20

5.2.1 Interpretation of KLX21B

The results of the generalized logging data and fracture estimations of KLX21B 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.

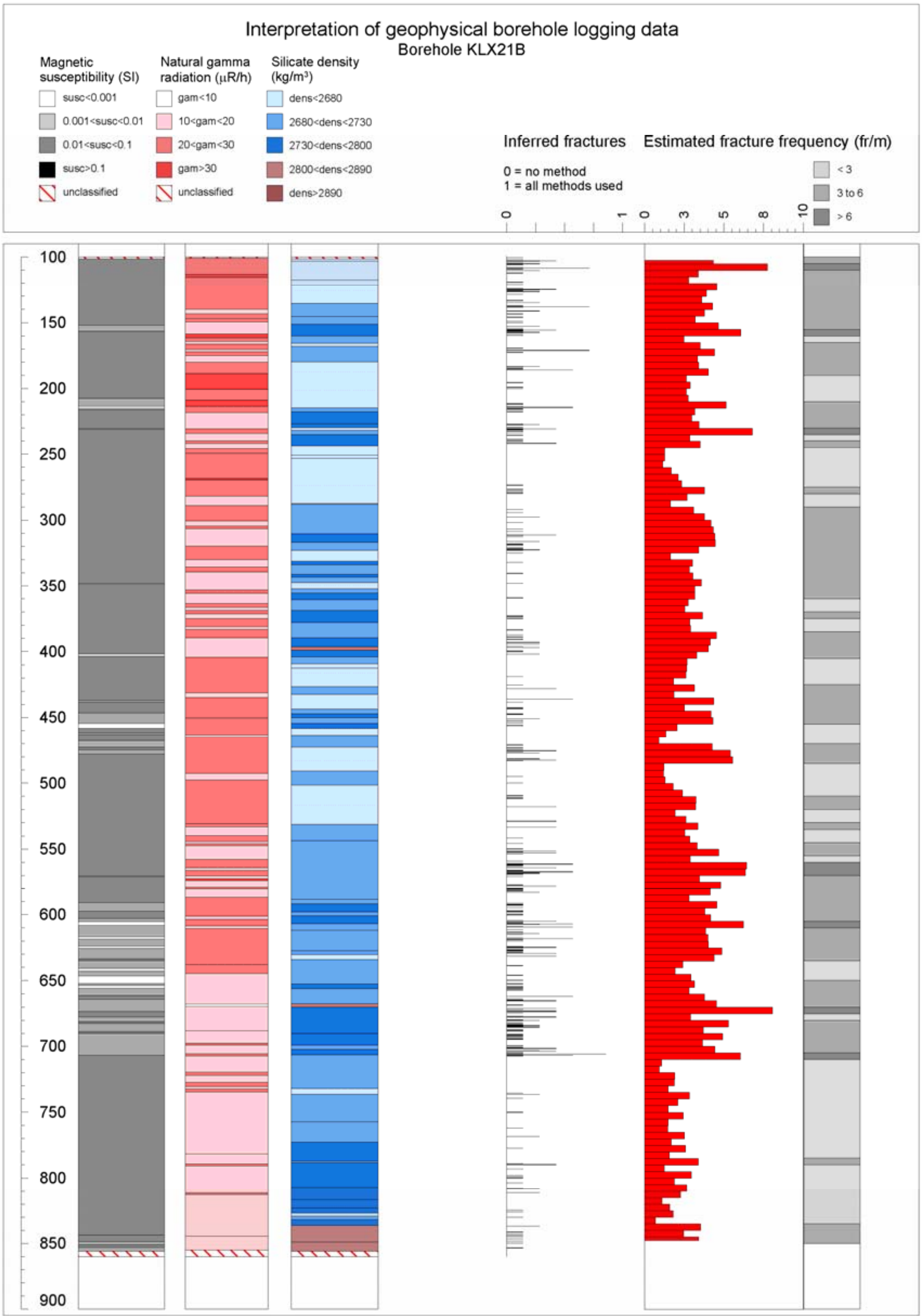

Figure 5-1. Generalized geophysical logs of KLX21B.

Table 5-2. Distribution of silicate density classes with borehole length of KLX21B.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	223	30
2,680 < dens < 2,730	339	45
2,730 < dens < 2,800	164	22
2,800 < dens < 2,890	26	3
dens > 2,890	2	0

The distribution of silicate density in KLX21B is dominated by the two lower classes < 2,680 kg/m^3 and 2,680–2,730 kg/m^3; these two classes cover approximately 75% of the total borehole length (Table 5-2). Rocks with density in the lowermost density class (< 2,680 kg/ m^3) mainly occur in the upper half of the borehole, section c 100–540 m. In this section the natural gamma radiation is generally in the range 20–30 μR/h, whereas in the lower part of the borehole, section c 650–860 m, the natural gamma radiation is mainly in the range 10–20 μR/h. The decrease in natural gamma radiation coincides with increased density along this interval.

Silicate density < 2,680 kg/m^3 and natural gamma radiation of 20–30 μR/h most likely indicates the occurrence of Ävrö granite with granitic to granodioritic mineral composition. Silicate density of 2,680–2,800 kg/m^3 and natural gamma radiation of 10–20 μR/h most likely indicates the occurrence of Ävrö granite with quartz monzodioritic composition or quartz monzodiorite.

The magnetic susceptibility is fairly constant within the interval 0.015–0.060 SI along the entire borehole. However, in more detail small but significant variations in the susceptibility are correlated to the variations in density and natural gamma radiation. The sections with decreased density have magnetic susceptibility in the interval c 0.015–0.025 SI and the sections with increased density have magnetic susceptibility in the range c 0.030–0.060 SI.

In the sections c 151–155 m, 208–216 m, 445–478 m and 589–707 m there is a significant decrease in magnetic susceptibility, which most likely indicates mineral alteration possibly caused by rock deformation (see possible deformation zones below).

There are very few indicated occurrences of fine-grained granite or diorite/gabbro rocks in KLX21B. In the section c 180–220 m the natural gamma radiation is significantly increased, which most likely corresponds to fine-grained granite and in the very lowermost part of the borehole, section c 835–855 m, greatly increased density suggest the occurrence of diorite/gabbro.

The intervals with the lowest resistivities are often correlated with caliper anomalies and decreased P-wave velocity which suggests brittle deformation indicating possible deformation zones. These sections are generally < 10 m long and are located at c 101–110 m, 148–156 m, 211–214 m, 227–231 m, 448–456 m, 472–479 m, 567–569 m, 604–612 m, 624–627 m and 684–707 m.

The estimated apparent porosity shows fairly large variations within the interval 0.5–1.0% (Figure 5-3). Since the porosity estimation is based on the short normal resistivity log the porosity data reflect the resistivity variations discussed in the previous paragraph. The apparent porosity log indicates that the sections with increased density also have increased porosity and vice versa (this is mainly valid for the borehole section c 100–650 m). The interpretation of these data is that Ävrö granite with granitic mineral composition has less porous and/or have lower fracture frequency as compared to Ävrö granite with quartz monzodioritic mineral composition.

The fracture frequency estimated from the geophysical logs indicates partly increased fracturing along fairly long sections of KLX21B (Figure 5-1). This is related to the fact that the focused resistivity 300 cm log and the short normal resistivity log both indicate major variations in bulk resistivity along large parts of the borehole. A comparison between the focused resistivity 300 cm and the density logs shows that there is partly very clear negative correlation between these two properties (Figure 5-2), which suggest that that the low density sections are less porous and/or have less fractures compared to the more high density intervals.

The estimated fluid water salinity is almost constant at c 275 ppm NaCl in the section c 100–670 m. At the section coordinate c 670 m there is a significant increase in the salinity level up to c 4,430 ppm NaCl, which then decreases slightly towards the bottom of the borehole. The increase at 670 m coincides with a distinct increase in the density and decrease in the natural gamma radiation, which suggests the occurrence of a mafic dyke. Contact zones between dykes and host rock are often fractured and therefore constitute possible zones for water flow. However there is no significant resistivity, caliper or sonic anomaly in this part of the borehole, which either suggests that the fracture is small or that the salinity anomaly is related to something else, for example the boundary between fresh and saline ground water.

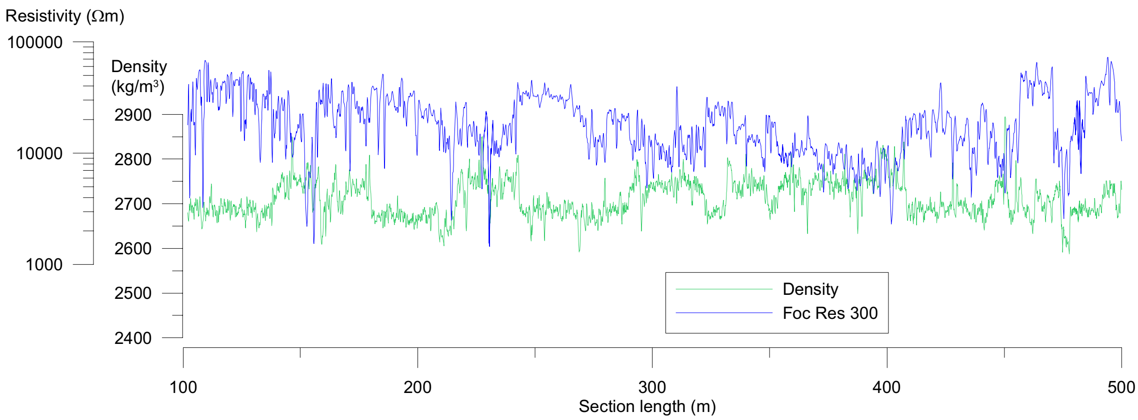

Figure 5-2. *Focused resistivity 300 cm and density for the section 100–500 m of KLX21B.*

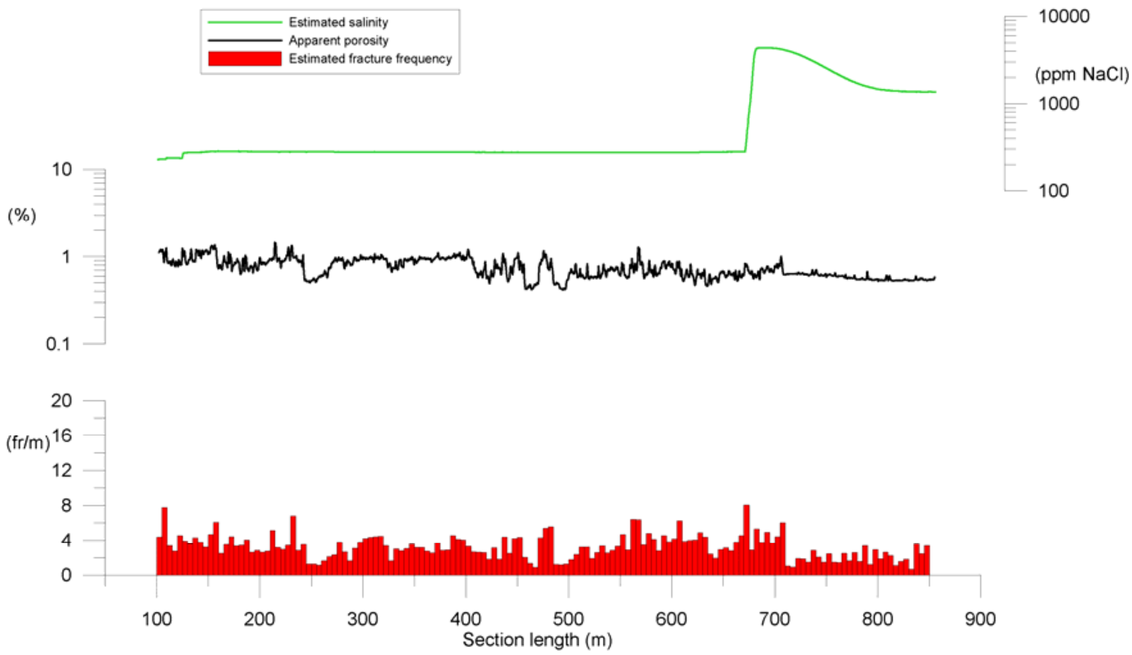

Figure 5-3. *Estimated salinity, apparent porosity and estimated fracture frequency for KLX21B.*

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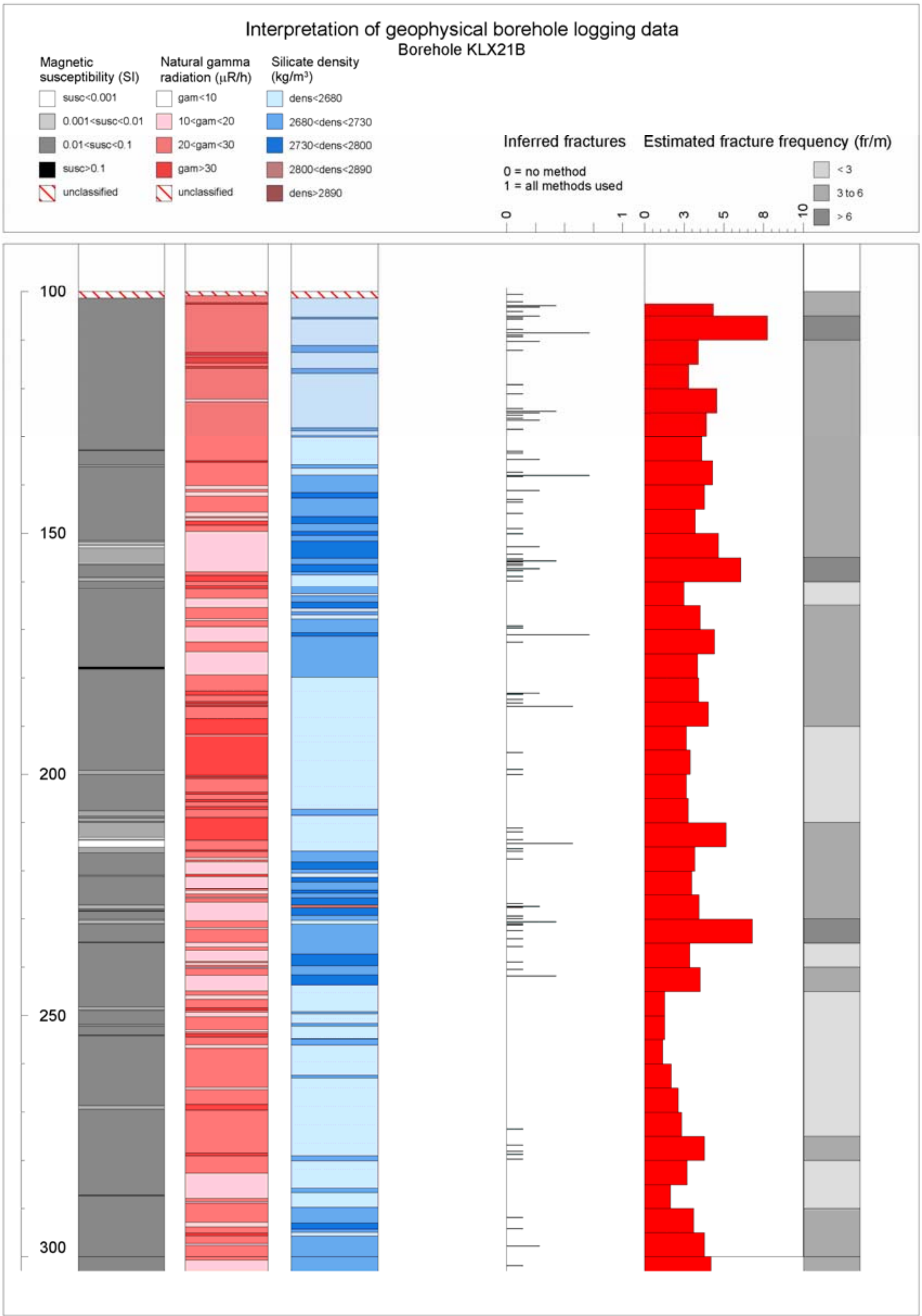
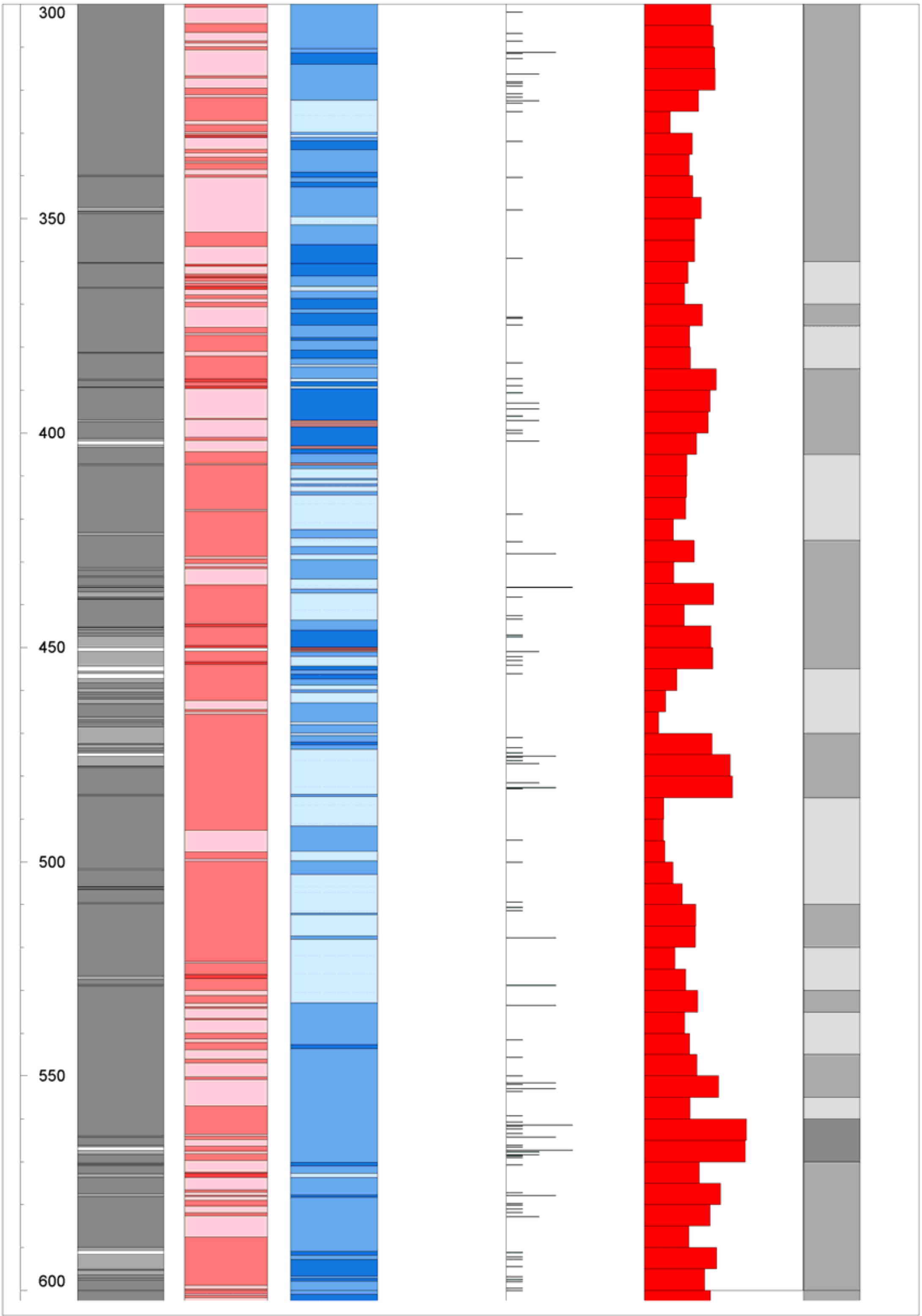
Generalized geophysical logs for KLX21B

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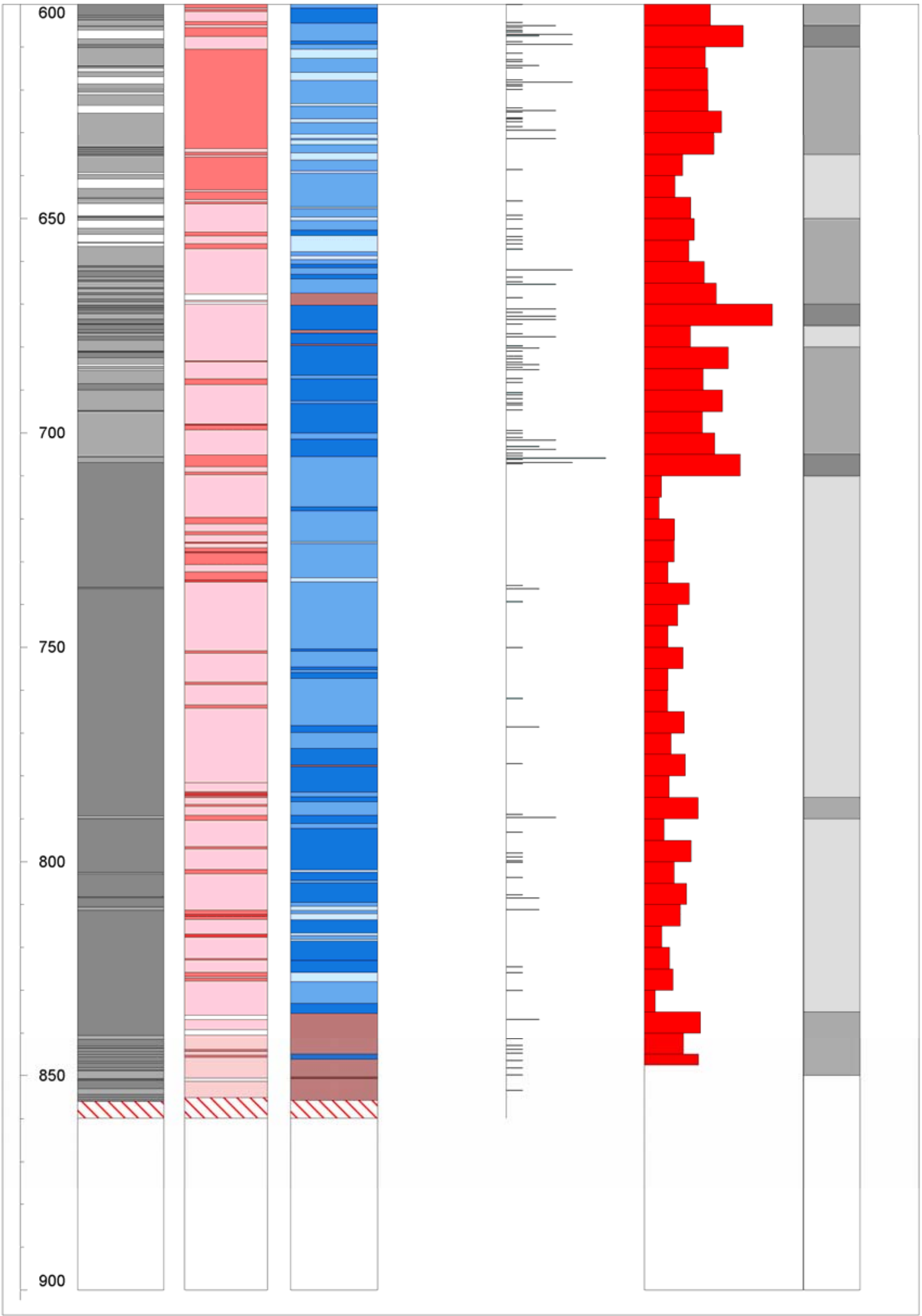
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