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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX15A

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Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored borehole KLX15A.

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 KLX15A is completely dominated (84% of the total borehole length) by values in the range 2,730–2,800 kg/m^3. The natural gamma radiation is generally in the range 10–20 μR/h and the magnetic susceptibility is 0.015–0.025 SI for the major part of the borehole. This combination of physical properties is typical for quartz monzodiorite or possibly Ävrö granite with quartz monzodioritic mineral composition.

There is a significant and continuous decrease in the magnetic susceptibility along the section c 680–750 m; the susceptibility is c 0.0010–0.0035 SI, which indicates that the rocks along this interval have suffered from alteration and/or deformation. There is only one anomaly with significantly increased density along the entire borehole length, and it occurs in the section c 196–199 m.

Short intervals with increased natural gamma radiation and decreased density occur along large parts of the borehole and these anomalies most likely correspond to fine-grained granite dykes or in some cases pegmatite. However, in the section c 750–950 m there are very few indicated occurrences of felsic dykes.

The fracture frequency estimated for KLX15A varies greatly along the entire borehole and there are several fairly long sections with indicated increased fracturing. Possible deformation zones (sections with indicated significantly increased fracturing) are identified in the sections c 127–142 m, 193–200 m, 260–270 m, 378–384 m, 502–506 m, 604–608 m, 629–635 m, 705–720 m, 762–780 m and 913–919 m. The majority of the possible deformation zones are characterized by decreased resistivity, magnetic susceptibility and P-wave velocity and in some cases also by increased borehole diameter.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX15A.

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.

Silikatdensitetsfördelningen i KLX15A domineras helt (84 % av den totala borrhålslängden) av värden i intervallet 2 730–2 800 kg/m^3. Den naturliga gammastrålningen ligger generellt i intervallet 10–20 μR/h och den magnetiska susceptibiliteten är ca 0,015–0,025 SI. Denna kombination av fysikaliska egenskaper är typisk för kvartsmonzodiorit eller möjligen Ävrögranit med kvartsmonzodioritisk mineralsammansättning.

I intervallet ca 680–750 m är den magnetiska susceptibiliteten avvikande låg (0,0010–0,0035 SI), vilket troligen indikerar att bergarterna längs intervallet påverkats av mineralomvandling och/eller deformation. Längs hela borrhålet finns bara ett kort avsnitt (ca 196–199 m) med kraftigt förhöjd densitet.

Korta sektioner med förhöjd naturlig gammastrålning förekommer längs stora delar av KLX15A och dessa anomalier indikerar troligen förekomst av finkornig granit eller i vissa fall pegmatit. I intervallet ca 750–950 m är dock andelen positiva strålningsanomalier låg vilket indikerar ringa förekomst av felsiska gångar.

Den sprickfrekvens som uppskattas från de geofysiska loggarna indikerar stora variationer i sprickighet längs hela borrhålet och det finns flera längre partier med förhöjd sprickfrekvens. Möjliga deformationszoner (sektioner med kraftigt förhöjd sprickfrekvens) förekommer längs ca 127–142 m, 193–200 m, 260–270 m, 378–384 m, 502–506 m, 604–608 m, 629–635 m, 705–720 m, 762–780 m och 913–919 m. Majoriteten av dessa karaktäriseras av avvikande låg resistivitet, P-vågshastighet och magnetisk susceptibilitet samt i vissa fall förstorad borrhålsdiameter.

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 KLX15A, 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 400-07-040 and method descriptions MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of the borehole KLX15A.

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 KLX15A.	AP PS 400-07-040	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata.	SKB MD 221.003	3.0

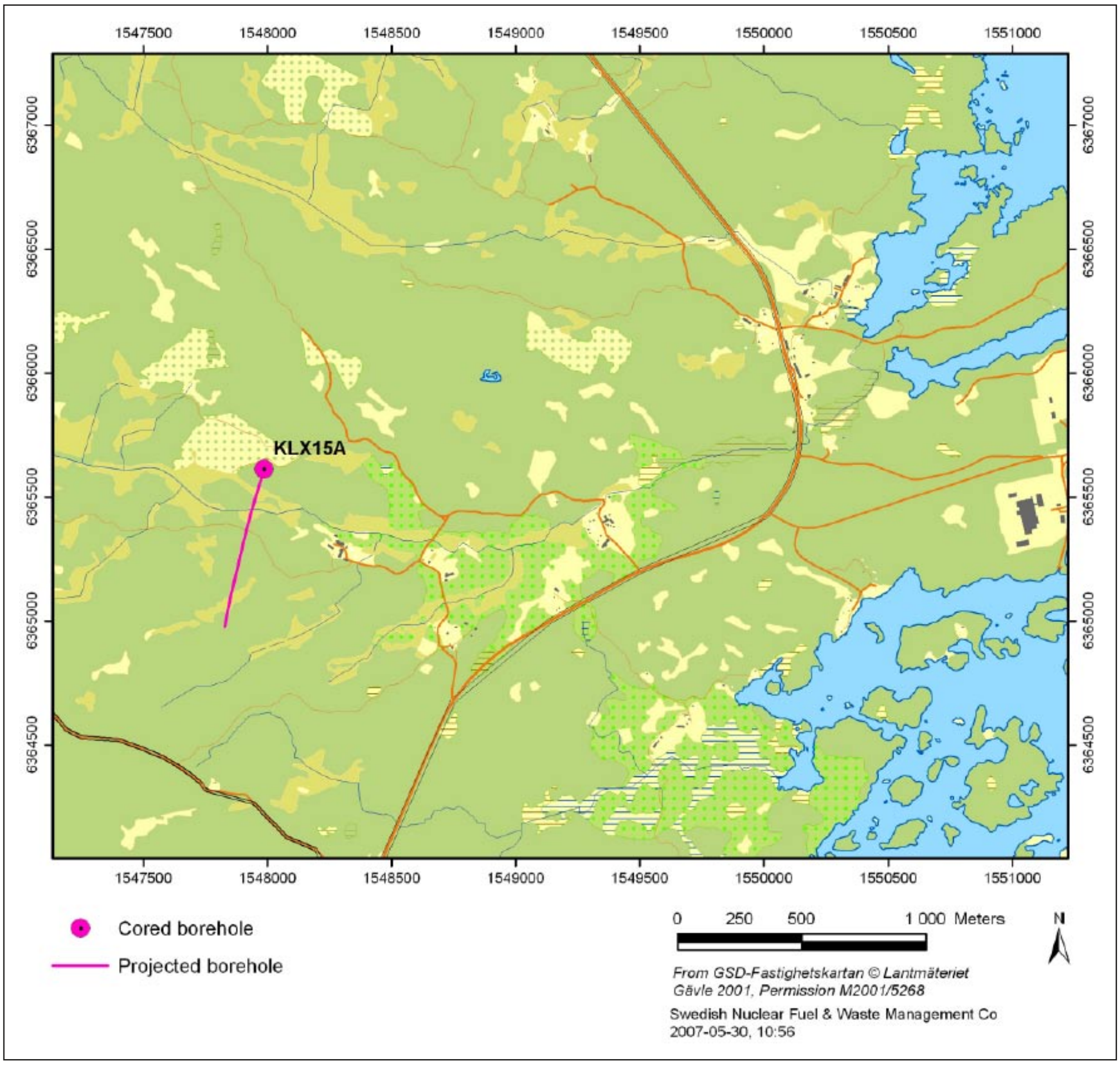

Figure 1-1. *Location of the borehole KLX15A in Laxemar.*

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 "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 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" (< 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/; $\sigma = a\,\sigma_w\,\phi^m + \sigma_s$ 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 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.

4.3 Nonconformities

In the borehole the long normal resistivity logging measurements show unrealistic levels. 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 (1D)	SPR	Normal res. 64	Normal res. 16	Lateral res.
Threshold	KLX15A	1.0	1.5	1.5	1.0	3.0	6.0	5.0	–
Power	KLX15A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX15A	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. The noise levels of these methods are however low enough to allow a meaningful interpretation of the data. All other methods have noise levels below 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	KLX15A	Recommended max noise level
Density (kg/m^3)	7	3–5
Magnetic susceptibility (SI)	$1.5 \cdot 10^{-4}$	$1 \cdot 10^{-4}$
Natural gamma radiation (μR/h)	0.8	0.3
Long normal resistivity (%)	0.3	2.0
Short normal resistivity (%)	0.1	2.0
Fluid resistivity (%)	0.02	2
Fluid temperature (°C)	$3 \cdot 10^{-4}$	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	0.1	No data
Caliper 1D	$0.8 \cdot 10^{-6}$	$5 \cdot 10^{-4}$
Caliper mean (m)	No data	$5 \cdot 10^{-4}$
Focused resistivity 300 (%)	14	No data
Focused resistivity 140 (%)	0.5	No data
Sonic (m/s)	12	20

5.2.1 Interpretation of KLX15A

The results of the generalized logging data and fracture estimations of KLX15A 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.

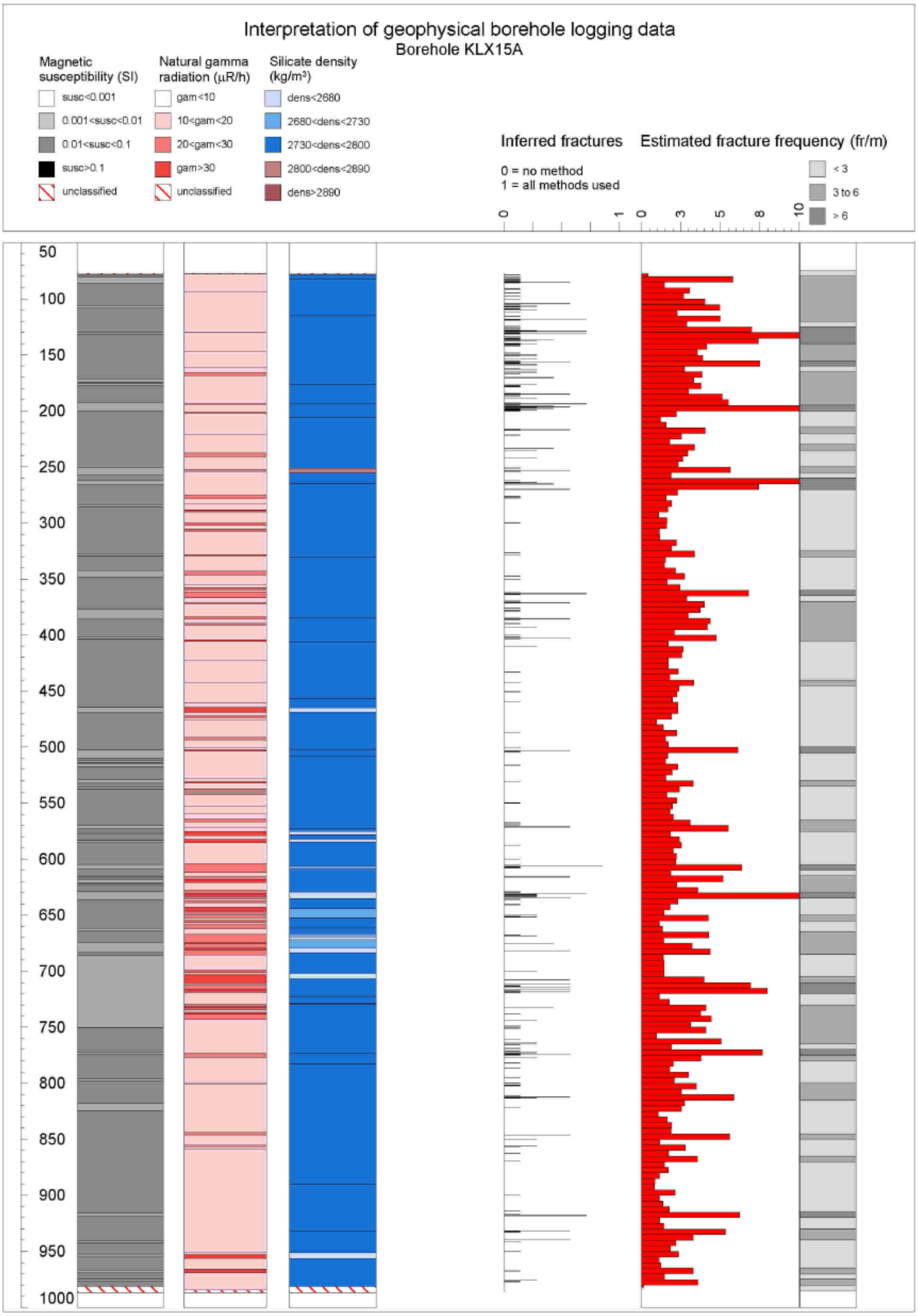

Figure 5-1. Generalized geophysical logs of KLX15A.

Table 5-2. Distribution of silicate density classes with borehole length of KLX15A.

Silicate density interval (kg/m³)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	39	4
2,680 < dens < 2,730	67	8
2,730 < dens < 2,800	758	84
2,800 < dens < 2,890	37	4
dens > 2,890	2	0

The distribution of silicate density in KLX15A is completely dominated (84% of the length) by values in the range 2,730–2,800 kg/m³. The natural gamma radiation is generally in the range 10–20 μR/h and the magnetic susceptibility is 0.015–0.025 SI for the major part of the borehole. This combination of physical properties is typical for quartz monzodiorite or possibly Ävrö granite with quartz monzodioritic mineral composition.

In the section c 550–750 m there are increased occurrences of positive natural gamma radiation anomalies. These anomalies coincide with partly decreased density and magnetic susceptibility in the section c 630–750 m. There is a significant and continuous decrease in the magnetic susceptibility along the section c 680–750 m, the susceptibility is c 0.0010–0.0035 SI, which indicates that the rocks along this interval have suffered from alteration and/or deformation.

There is only one anomaly with significantly increased density along the entire borehole length, and it occurs in the section c 196–199 m. The anomaly coincides with decreased magnetic susceptibility and natural gamma radiation, which suggests the occurrence of fine-grained diorte/gabbro. The high density section is surrounded by short intervals with decreased density and increased natural gamma radiation most likely indicating fine-grained granite. The spatial relation between mafic and felsic rocks indicates the occurrence of so called composite dykes.

Short intervals with increased natural gamma radiation and decreased density occur along large parts of the borehole and these anomalies most likely correspond to fine-grained granite dykes or in some cases pegmatite. However, in the section c 750–950 m there are very few indicated occurrences of felsic dykes.

The fracture frequency estimated for KLX15A varies greatly along the entire borehole and there are several fairly long sections with indicated increased fracturing. Possible deformation zones (sections with indicated significantly increased fracturing) are identified in the sections c 127–142 m, 193–200 m, 260–270 m, 378–384 m, 502–506 m, 604–608 m, 629–635 m, 705–720 m, 762–780 m and 913–919 m. Geophysical anomalies related to these possible deformation zones are presented in Table 5-3 below.

The estimated apparent porosity (black line in Figure 5-2) shows a general level at c 0.6% which is considered normal for crystalline rocks in this area. Porosity variations are small and there is only one significant increase in the porosity which occurs at c 633 m. The anomaly coincides with a possible deformation zone (Table 5-3).

The estimated fluid water salinity (green line in Figure 5-2) is rather constant at c 900 ppm NaCl in the section 76–130 m. At 130 m there is a stepwise increase in the salinity up to c 1,700 ppm NaCl. This significant and discontinuous increase in salinity is spatially related to a possible deformation zone (Table 5-3) which suggests that the fractures within the zone are water bearing. Along the interval 400–480 m the salinity level increases again up to c 2,800 ppm NaCl. This level is kept fairly constant down to the section coordinate c 930 m at which the salinity shows a third increase, which continues all the way down to the bottom of the borehole.

Table 5-3. Possible deformation zones in KLX15A and their geophysical signature.

Section co-ordinates (m)	Resistivity	P-wave velocity (sonic)	Magnetic susceptibility	Borehole diameter (caliper 1D)
127–142	Partly decreased	Significantly decreased	Partly decreased	Minor anomaly
193–200	Significantly decreased	Partly decreased	Significantly decreased	Minor anomaly
260–270	Significantly decreased	Significantly decreased	Significantly decreased	One major anomaly
378–384	Significantly decreased	Partly decreased	Significantly decreased	No anomaly
502–506	Significantly decreased	Partly decreased	Significantly decreased	No anomaly
604–608	Significantly decreased	Significantly decreased	Significantly decreased	No anomaly
629–635	Significantly decreased	Significantly decreased	Significantly decreased	General increase
705–720	Partly decreased	Partly decreased	Significantly decreased	No anomaly
762–780	Significantly decreased	Significantly decreased in 2 short intervals	Partly decreased	No anomaly
913–919	Significantly decreased	Partly decreased	Significantly decreased	No anomaly

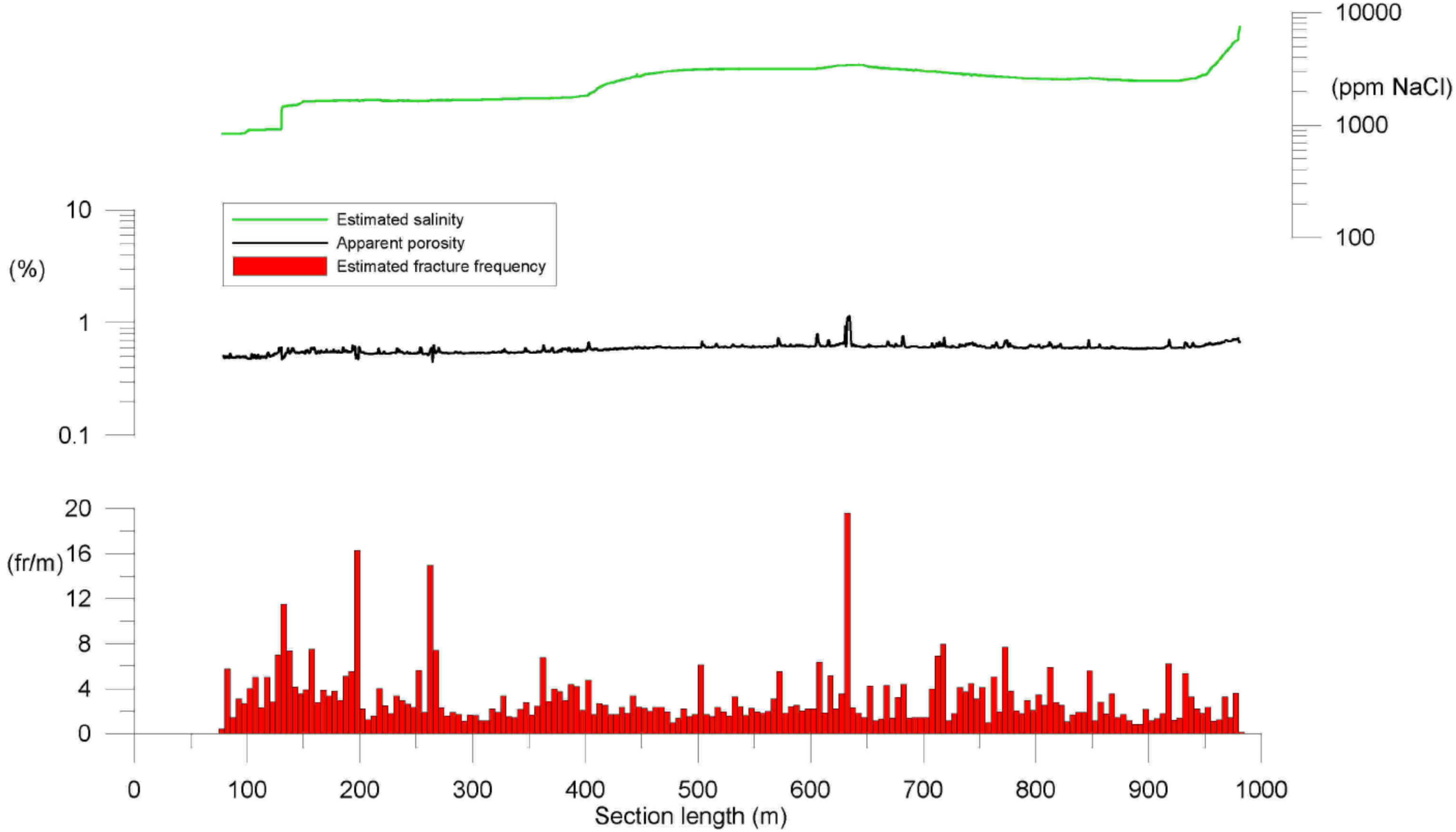

Figure 5-2. Estimated salinity, apparent porosity and estimated fracture frequency for KLX15A.

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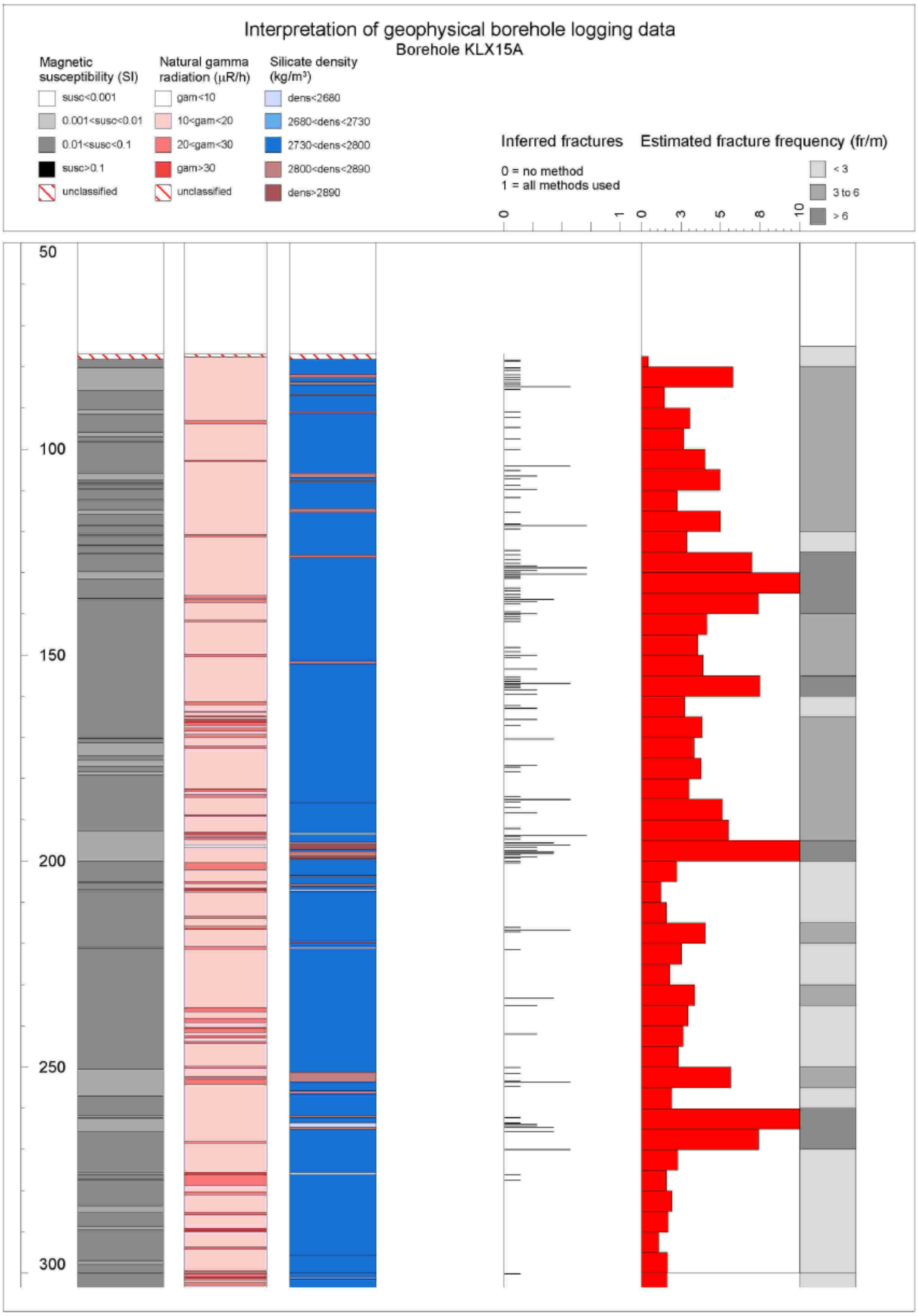
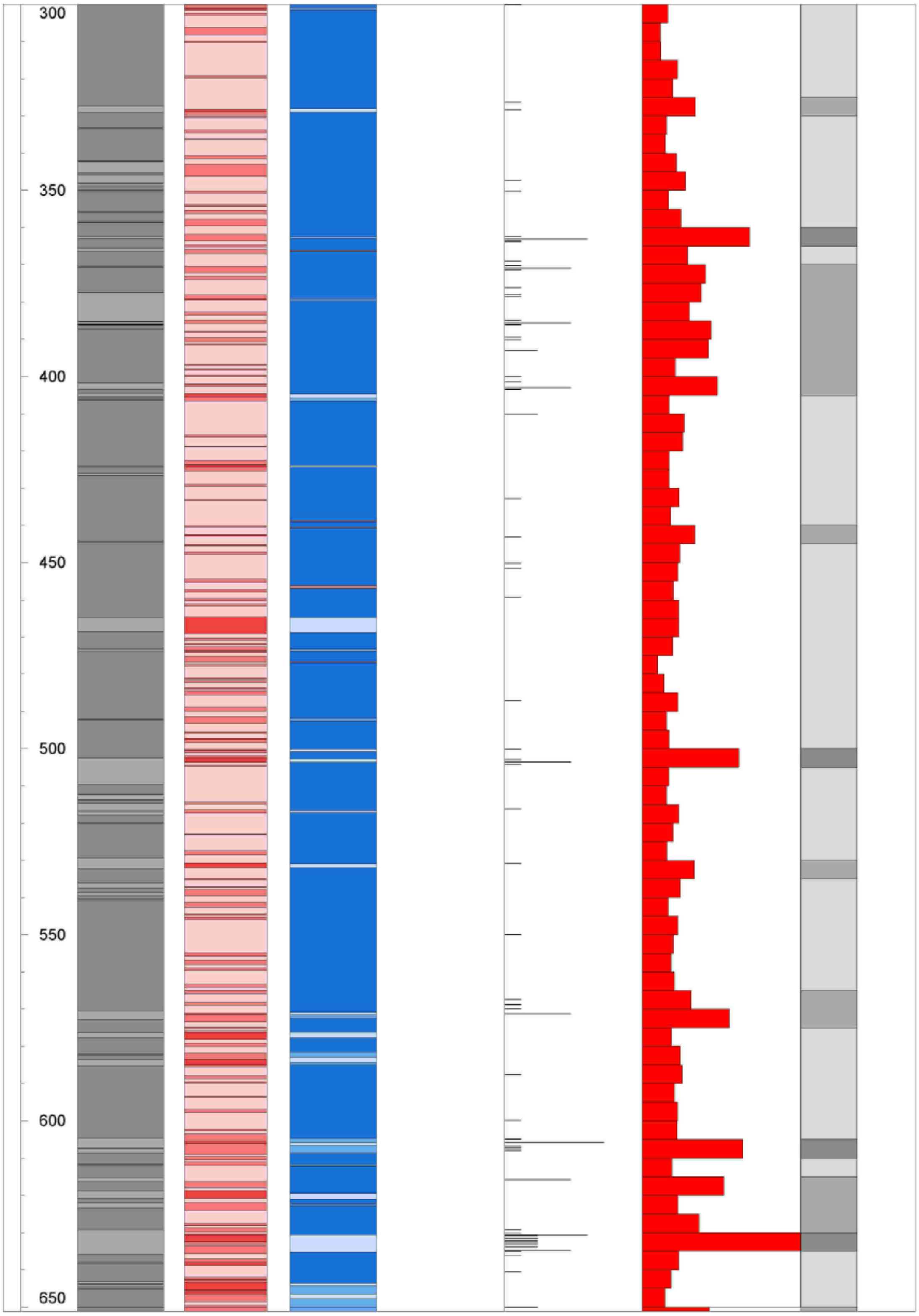
Generalized geophysical logs for KLX15A

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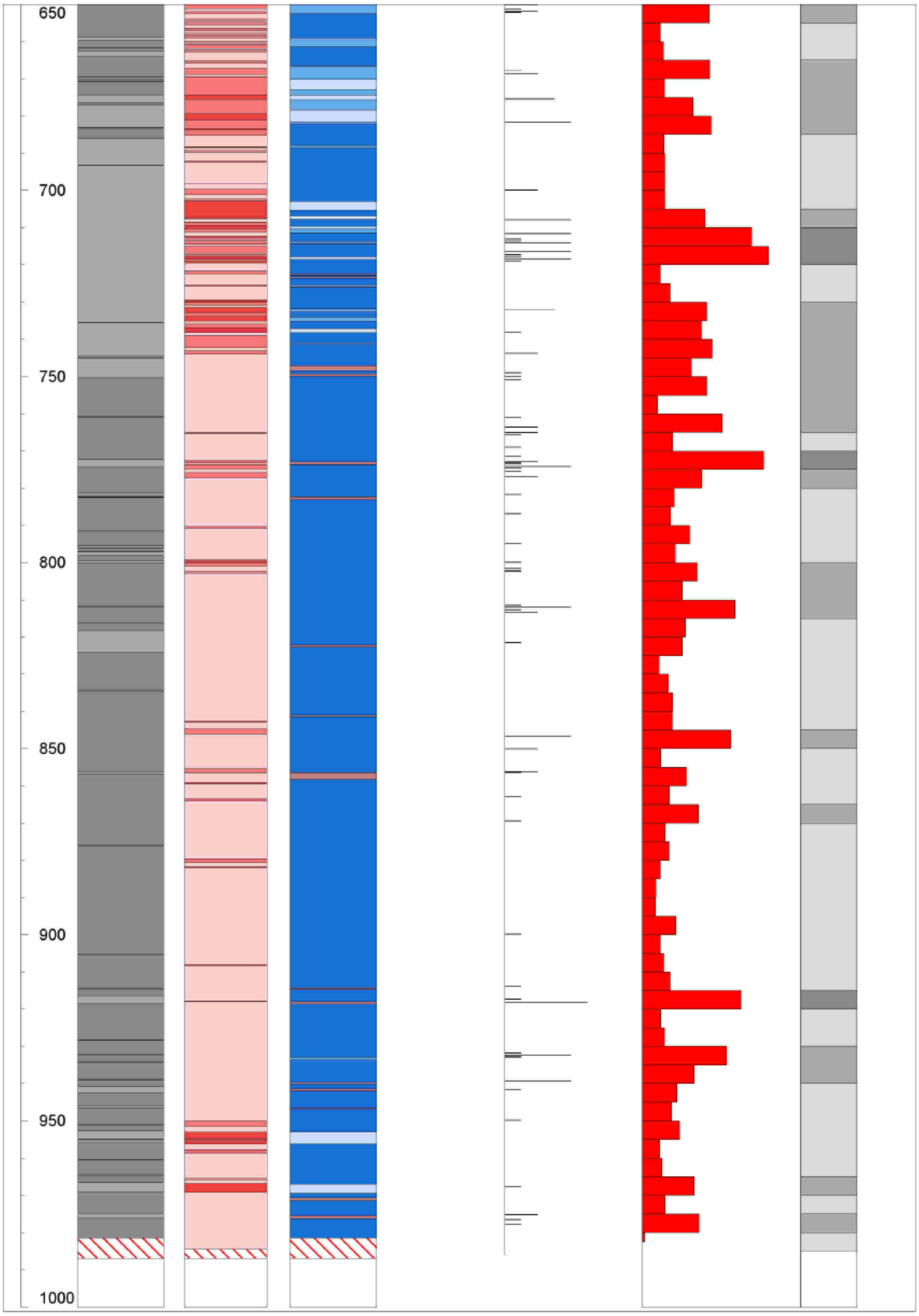
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