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# Oskarshamn site investigation

# Interpretation of geophysical borehole measurements from KLX09

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April 2006

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

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

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# Abstract


This report presents the compilation and interpretations of geophysical logging data from the cored borehole KLX09.

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 single-hole interpretations.

A majority (78%) of the rocks in the vicinity of KLX09 have silicate density < 2,730 kg/m$^3$. In the corresponding sections the magnetic susceptibility is in the range c 0.02–0.03 SI and the natural gamma radiation is in the range c 20–30 μR/h. This combination of physical properties is typical for Ävrö granite.

In the intervals c 115–150 m, c 475–495 m and c 795–825 m the silicate density is mainly in the range c 2,700–2,800 kg/m$^3$ and the magnetic susceptibility is in the range 0.03–0.04 SI, which most likely indicates the occurrences of quartz monzodiorite (possibly in combination and mixed with high magnetic Ävrö granite). Sections with silicate density > 2,800 kg/m$^3$, which generally indicate the occurrence of diorite to gabbro, are identified at c 340–385 m, 460–465 m, 553–590 m, 638–648 m and 728–788 m. The magnetite content (indicated by the magnetic susceptibility) varies greatly for these high density rocks.

There are more than 20 strong positive natural gamma radiation anomalies (> 30 μR/h), generally only a few meters long, with an evenly scattered distribution along the borehole. These anomalies most likely correspond to fine-grained granite dykes (or possibly pegmatite dykes).

The estimated fracture frequency is generally low in the section c 100–500 m. The lower half of the borehole, section c 500–875 m is characterized by fairly high fracture frequency. Possible major deformation zones are indicated at c 490–510 m, 520–560 m, 605–645 m, 690–720 m, 750–760 m and 795–815 m.

Most of the possible deformation zones are characterized by a major decrease in the bulk resistivity and magnetic susceptibility and also decreased P-wave velocity. The combination of physical properties most likely indicates strong brittle deformation and mineral alteration. The possible deformation zones in the sections 605–645 m and 795–815 m are mainly characterized by decreased resistivity and partly decreased susceptibility, and hardly any indications in the sonic and caliper data. This probably indicates sealed fractures and/or plastic deformation combined with mineral alteration.

# Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX09.

Huvudsyftet med undersökningen är att ta fram ett material som på ett förenklat sätt åskådliggör resultaten av de geofysiska loggningarna, s.k. generaliserade geofysiska loggar. Materialet används dels som stödjande data vid borrkärne- och borrkaxkarteringen samt som underlag vid enhålstolkningen.

En majoritet (78 %) av bergarterna i närheten av KLX09 har en silikatdensitet < 2 730 kg/m$^3$. Längs dessa avsnitt i borrhålet är den naturliga gammastrålningen ca 20–30 µR/h och den magnetiska susceptibiliteten är ca 0,02–0,03 SI. Kombinationen av fysikaliska egenskaper är typisk för Ävrögranit.

Längs sektionerna ca 115–150 m, 475–495 m och 795–825 m är silikatdensiteten till stor del i intervallet 2 700–2 800 kg/m$^3$ och den magnetiska susceptibiliteten har värden på ca 0,03–0,04 SI. Dessa data indikerar troligen förekomst av kvartsmonzodiorit, möjligen uppblandad med högmagnetisk Ävrögranit. I borrhålet förekommer ett flertal sektioner (ca 340–385 m, 460–465 m, 553–590 m, 638–648 m och 728–788 m) med silikatdensitet > 2 800 kg/m$^3$, vilket troligen indikerar diorit till gabbro. Flera av dessa sektioner uppvisar mycket stora variationer i magnetisk susceptibilitet.

Fler än 20 st kraftigt positiva anomalier i den naturliga gammastrålningen (> 30 µR/h) kan identifieras i KLX09. De allra flesta är endast några få meter långa och indikerar troligen förekomst av finkornig granit eller pegmatitgångar.

Den uppskattade sprickfrekvensen är relativt låg längs sektionen ca 100–500 m medan den är avvikande hög längs borrhålets nedre halva (500–875 m). Möjliga större deformationszoner kan identifieras längs sektionerna ca 490–510 m, 520–560 m, 605–645 m, 690–720 m, 750–760 m och 795–815 m.

Majoriteten av de indikerade deformationszonerna karaktäriseras av kraftigt sänkt resistivitet och magnetisk susceptibilitet samt även sänkt P-vågshastighet. Detta tyder på spröd deformation i kombination med mineralomvandling. De två möjliga deformationszonerna vid 605–645 m och 795–815 m karaktäriseras främst av sänkt resistivitet och delvis sänkt magnetisk susceptibilitet och inga anomalier i caliper- eller sonicdata, vilket troligen indikerar att dessa zoner domineras av slutna sprickor och/eller plastisk deformation i kombination med 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 KLX09 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 400-05-095 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of borehole KLX09.

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 KLX09. | AP PS 400-05-095 | 1.0 |
| **Method descriptions** | **Number** | **Version** |
| Metodbeskrivning för tolkning av geofysiska borrhålsdata. | SKB MD 221.003 | 2.0 |


***Figure 1-1.*** *Location of the borehole KLX09.*

# 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 mapping and as supportive information during the so called "single-hole interpretation", which is a combined borehole interpretation of core logging (Boremap) data, geophysical data and radar data.

# 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 four steps:

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

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

   The density (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.
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 intervals *indicating* a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /8/. The sections in the borehole are bounded by the threshold values

   | | | | | |
   |---|---|---|---|---|
   | | | granite | < | 2,680 kg/m$^3$ |
   | 2,680 kg/m$^3$ | < | granodiorite | < | 2,730 kg/m$^3$ |
   | 2,730 kg/m$^3$ | < | tonalite | < | 2,800 kg/m$^3$ |
   | 2,800 kg/m$^3$ | < | diorite | < | 2,890 kg/m$^3$ |
   | 2,890 kg/m$^3$ | < | gabbro | | |

   The magnetic susceptibility logging is subdivided into steps of decades and the natural gamma radiation is divided into steps of “low” (< 10 µR/h), “medium” (10 µR/h < gamma < 20 µR/h), “high” (20 µR/h < gamma < 30 µR/h) and “very high” (> 30 µR/h).

3. For the cored borehole the normal resistivity loggings are corrected for the influence of the borehole diameter and the borehole fluid resistivity. The apparent porosity is calculated during the correction of the resistivity loggings. The calculation is based on Archie’s law /9/; $\sigma = a\, \sigma_w\, \varphi^m + \sigma_s$ where $\sigma$ = bulk conductivity (S/m), $\sigma_w$ = pore water conductivity (S/m), $\varphi$ = volume fraction of pore space, $\sigma_s$ = 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.

**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 | 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 | – | – | – | – |

## 4.2 Preparations and data handling

The logging data were delivered as Microsoft Excel files via email from Leif Stenberg, 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.

## 4.3 Analyses and interpretations

The analyses of the logging data are made with respect to identifying major variations in physical properties with depth as indicated by the silicate density, the natural gamma radiation and the magnetic susceptibility. Since these properties are related to the mineral composition of the rocks in the vicinity of the borehole they correspond to variations in lithology and in thermal properties.

The resistivity, sonic and caliper loggings are mainly used for identifying sections with increased fracturing and alteration. The interpretation products salinity and apparent porosity help identifying saline ground water and porous rocks.

## 4.4 Nonconformities

No normal resistivity or SPR data were collected in KLX09. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore not presented for the normal resistivity loggings. Fracture estimations are presented for the section 100–985 m, and not for the uppermost section 10–100 m. The reason for this is the lack of sonic data in the upper section. 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. Noise levels are generally below or only slightly above the recommended level for all measured data. The magnetic susceptibility log has a noise level 3 times above the recommended and the natural gamma radiation has a noise level that is 2 times the recommended level, and the noise levels for these two logging methods is too high to be fully acceptable. However, 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.

**Table 5-1. Noise levels in the investigated geophysical logging data of KLX09.**

| Logging method | KLX09 | Recommended max noise level |
|---|---|---|
| Density (kg/m$^3$) | 6 | 3–5 |
| Magnetic susceptibility (SI) | $3\times10^{-4}$ | $1\times10^{-4}$ |
| Natural gamma radiation (µR/h) | 0.6 | 0.3 |
| Long normal resistivity (%) | Not used | 2.0 |
| Short normal resistivity (%) | Not used | 2.0 |
| Fluid resistivity (%) | 1 | 2 |
| Fluid temperature (ºC) | $4\times10^{-4}$ | 0.01 |
| Lateral resistivity (%) | Not used | 2 |
| Single point resistance (%) | Not used | No data |
| Caliper 1D | $3\times10^{-6}$ | $5\times10^{-4}$ |
| Caliper mean (m) | $4\times10^{-6}$ | $5\times10^{-4}$ |
| Focused resistivity 300 (%) | 10 | No data |
| Focused resistivity 140 (%) | 7 | No data |
| Sonic (m/s) | 5 | 20 |

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

### 5.2.1 Interpretation of KLX09

The results of the generalized logging data and fracture estimations of KLX09 are presented in Figure 5-1, and in a more detailed scale in Appendix 1.

A majority (78%) of the rocks in the vicinity of KLX09 have silicate density < 2,730 kg/m$^3$ (Table 5-2). In the corresponding sections the magnetic susceptibility is in the range c 0.02–0.03 SI and the natural gamma radiation is in the range c 20–30 µR/h. The combination of physical properties is typical for Ävrö granite.

Sections with silicate density > 2,730 kg/m$^3$ occur fairly commonly in KLX09. In the intervals c 115–150 m, c 475–495 m and c 795–825 m the silicate density is mainly in the range c 2,700–2,800 kg/m$^3$ and the magnetic susceptibility is in the range 0.03–0.04 SI, which most likely indicates the occurrences of quartz monzodiorite (possibly in combination and mixed with high magnetic Ävrö granite).

Sections with silicate density > 2,800 kg/m$^3$, which generally indicates the occurrence of diorite to gabbro, are identified at c 340–385 m, 460–465 m, 553–590 m, 638–648 m and 728–788 m. The natural gamma radiation is generally < 15 µR/h along these sections. However, the magnetite content (indicated by the magnetic susceptibility) varies greatly for these high density rocks. For example, in the high density section 340–385 m the magnetic susceptibility is generally < 0.01 SI but in the sections 638–648 m and 728–788 m there are several short intervals with high magnetic susceptibility > 0.03 SI.

Close to the high density section 638–648 m there are several strong positive natural gamma radiation anomalies that most likely correspond to fine-grained granite dykes, which in combination with the probable diorite to gabbro rocks indicate so called "composite dykes" in this part of the borehole.

There are more than 20 strong positive natural gamma radiation anomalies (> 30 µR/h), generally only a few meters long, with an evenly scattered distribution along the borehole. These anomalies most likely correspond to fine-grained granite dykes (or possibly pegmatite dykes).

The estimated fracture frequency is generally low in the section c 100–500 m. A few minor deformation zones (< 5 m) are indicated in this section; these are mainly characterized by short intervals with low P-wave velocity and a sharp decrease in the resistivity. Caliper anomalies occur in the section c 105–125 m. At c 430–450 m there is a decrease in the bulk resistivity in combination with partly decreased magnetic susceptibility, which most likely indicates increased fracturing (possibly sealed fractures) and mineral alteration.

**Table 5-2. Distribution of silicate density classes with borehole length (10–875 m) of KLX09.**

| Silicate density interval (kg/m$^3$) | Borehole length (m) | Relative borehole length (%) |
|---|---|---|
| 2,680 > dens | 516 | 60 |
| 2,680 < dens < 2,730 | 151 | 18 |
| 2,730 < dens < 2,800 | 62 | 7 |
| 2,800 < dens < 2,890 | 83 | 10 |
| dens > 2,890 | 44 | 5 |

The lower half of the borehole, section c 500–875 m is characterized by fairly high fracture frequency. Possible major deformation zones are indicated at c 490–510 m, 520–560 m, 605–645 m, 690–720 m, 750–760 m and 795–815 m.

The sections 520–560 m and 750–760 m are characterized by a major decrease in the bulk resistivity and magnetic susceptibility, decreased P-wave velocity and several caliper anomalies. The sections 490–510 m and 690–720 are also characterized by a major decrease in the bulk resistivity and magnetic susceptibility and decreased P-wave velocity, but no caliper anomalies. The combination of physical properties in these four possible deformation zones most likely indicates strong brittle deformation and mineral alteration.

The possible deformation zones in the sections 605–645 m and 795–815 m are mainly characterized by decreased resistivity and partly decreased susceptibility, and hardly any indications in the sonic and caliper data. This probably indicates sealed fractures and/or plastic deformation combined with mineral alteration.

The estimated fluid water salinity (Figure 5-2) is almost constant along the entire borehole length. An increase in the salinity starts at c 750 m and continues along the remaining part of the borehole. The shape of this anomaly indicates that the borehole fluid was most likely not in chemical equilibrium with the pore water fluid in the surrounding rocks at the time of the measurements.

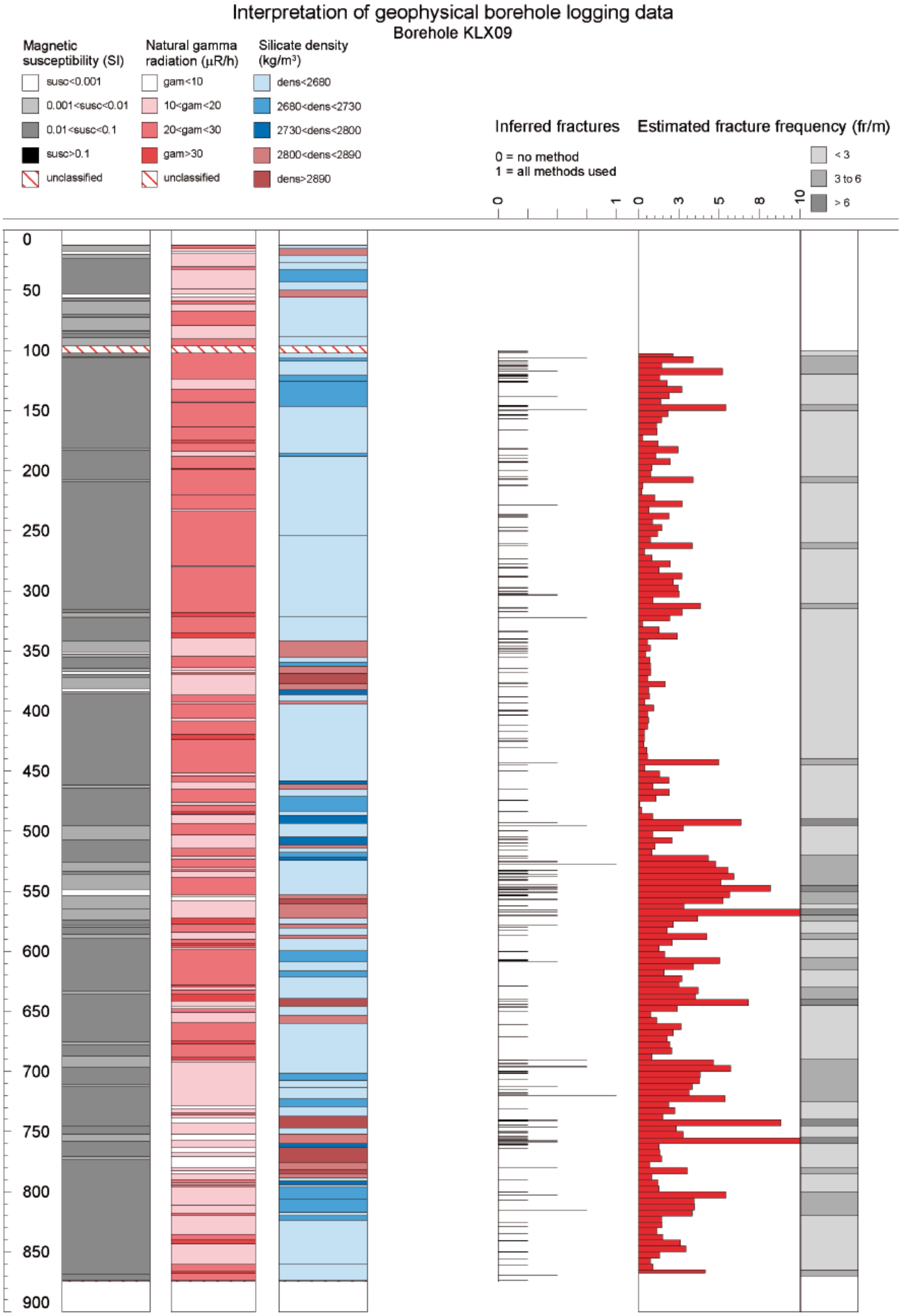


*__Figure 5-1.__ Generalized geophysical logs of KLX09.*

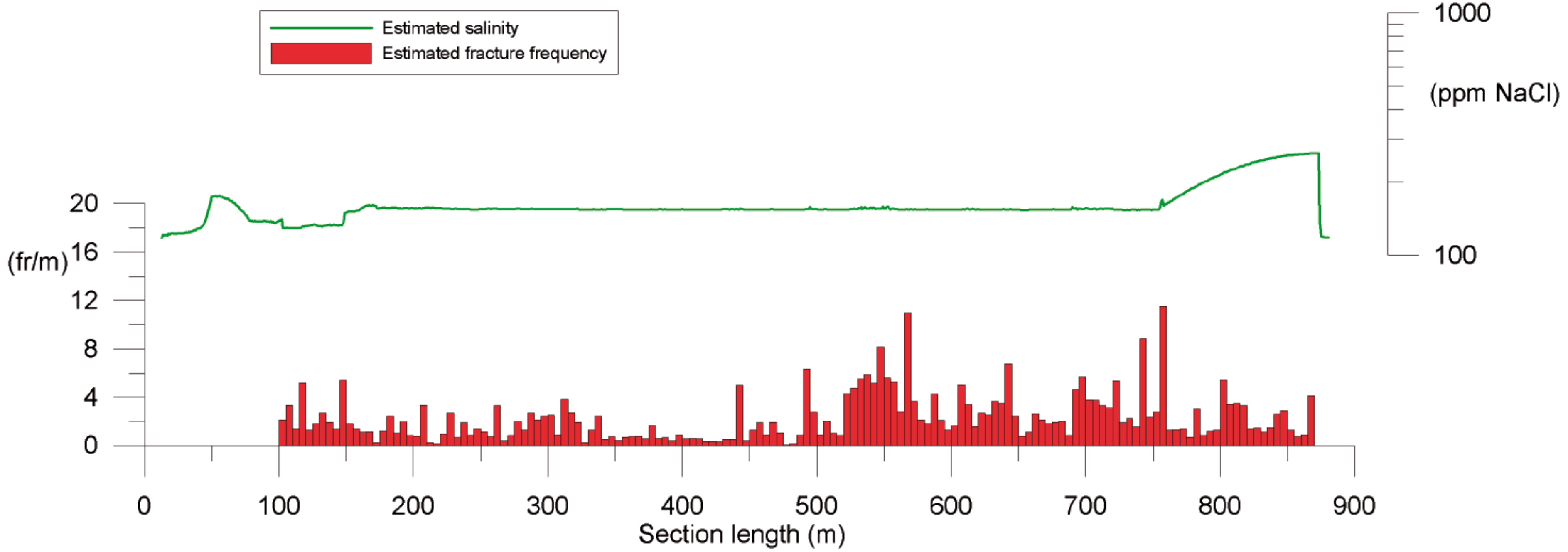


***Figure 5-2.*** *Estimated salinity and estimated fracture frequency of KLX09.*

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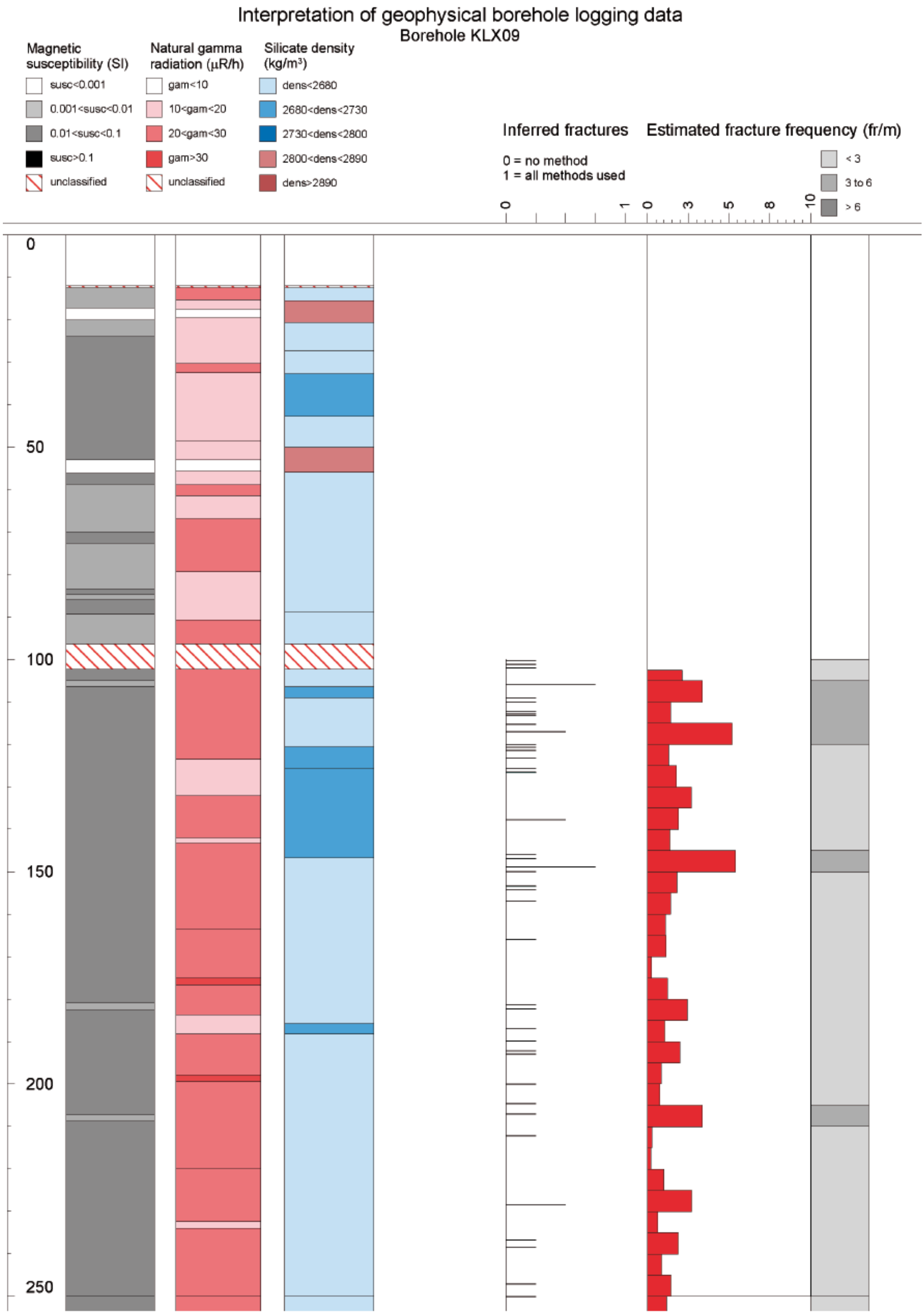
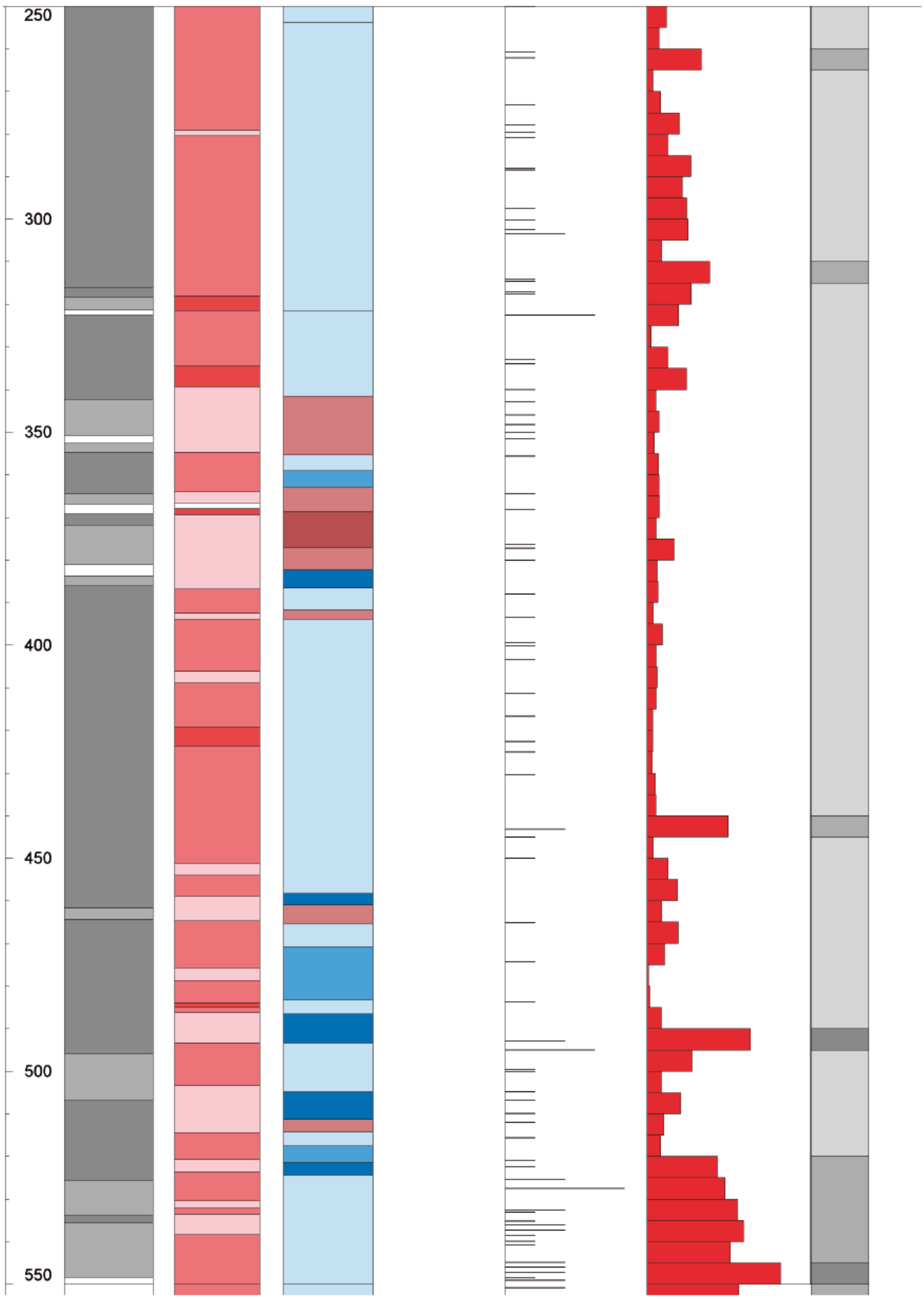
# Appendix 1

## Generalized geophysical loggings of KLX09

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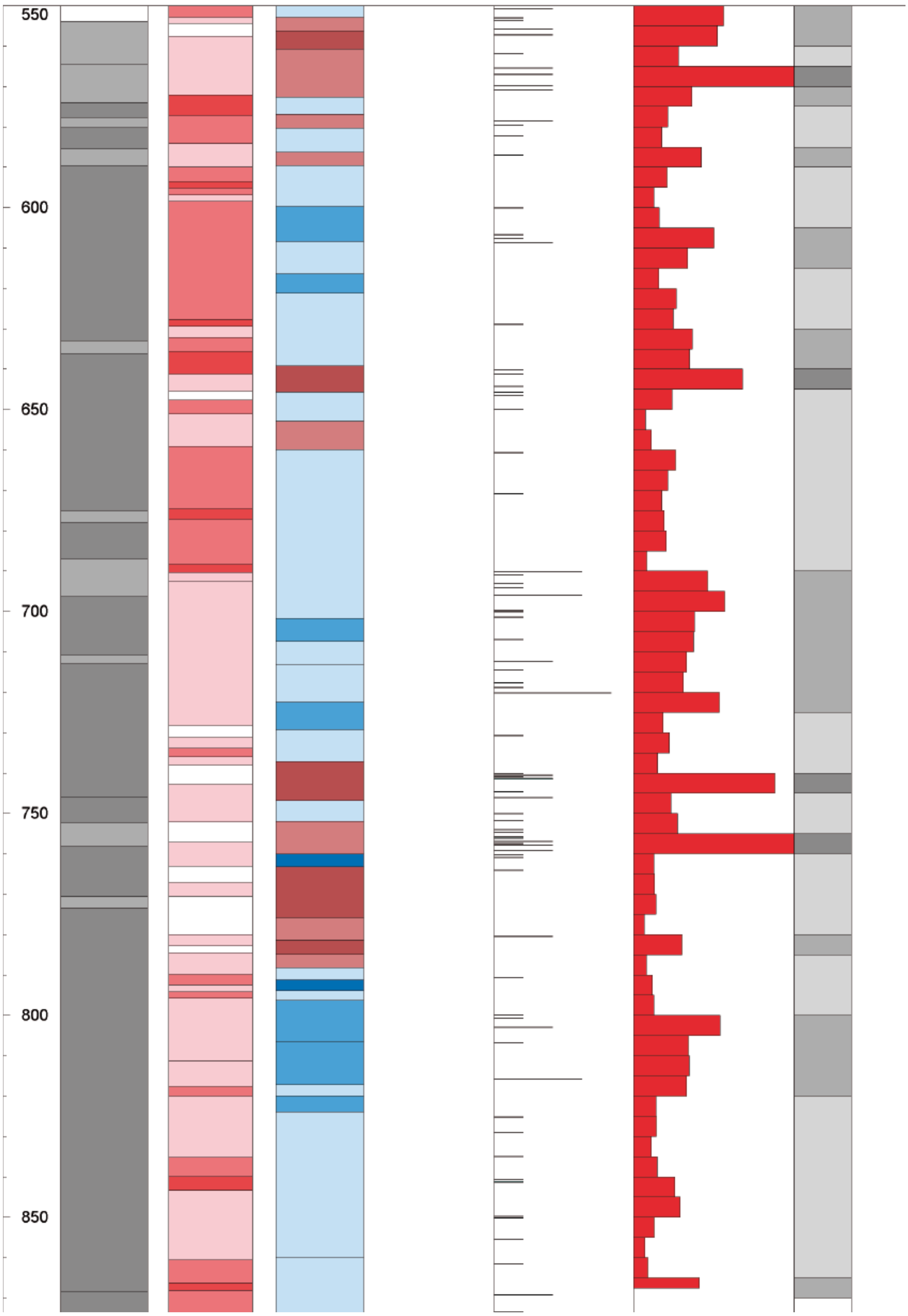
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