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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX05

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GeoVista AB

June 2005

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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.

A pdf version of this document can be downloaded from www.skb.se

Abstract

This report presents the compilation and interpretations of geophysical logging data from the cored borehole KLX05.

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

The rocks in the vicinity of KLX05 show large variations in physical properties and based on the silicate density logging data the borehole is divided into 5 subsections.

Subsection 1 (c 12–290 m) is dominated by low silicate density, mainly below 2,680 kg/m^3, moderate or low natural gamma radiation (10–20 μR/h) and the magnetic susceptibility is fairly low or moderate. Subsection 2 (c 290–520 m) is dominated by high silicate density values, in the range of 2,730–3,000 kg/m^3, and the natural gamma radiation is often below 10 μR/h, a combination which is a typical indication for diorite to gabbro rocks. The magnetic susceptibility is moderate or high, along short sections it reaches above 0.1 SI.

Along subsection 3 (c 520–690 m) the silicate density is in the interval 2,730–2,800 kg/m^3. Along the major part of the subsection the natural gamma radiation is in the range of 10–20 μR/h. The magnetic susceptibility is mainly low or moderate (roughly 0.005–0.03 SI). Subsection 4 (c 690–752 m) is dominated by low silicate density (2,600–2,670 kg/m^3), high natural gamma radiation (mainly 40–50 μR/h) and low magnetic susceptibility of 0.002–0.007 SI. This combination of properties is typical for fine-grained granite dykes.

The lowermost subsection 5 (c 752–990 m) is characterized by fairly constant silicate density at c 2,760 kg/m^3 and moderate natural gamma radiation, mainly in the range of 10–20 μR/h. The magnetic susceptibility shows large variations, mainly in the range of 0.002–0.02 SI. Along the entire borehole the natural gamma radiation is increased at some shorter intervals that also show decreased density, which most likely indicate the occurrences of pegmatite or fine-grained granite dykes.

The estimated fracture frequency is mainly low or moderate. However, there are several short intervals (c 5–10 m long) with indicated high fracture frequency. These occur in the section c 12–710 m. Several of these intervals coincide with narrow distinct low resistivity, sonic and caliper anomalies that most likely correspond to single fractures. Along the section 650–715 m there is a continuous increase in the borehole diameter and several low resistivity anomalies, which may indicate a possible deformation zone. It must be noted that the lack of normal resistivity logging data decreases the reliability of the estimated fracture frequency. A sharp gradient in the estimated salinity data at c 849 m section length coincides with one of the most prominent anomalies in the fluid temperature gradient data, which indicates the presence of a significant water bearing fracture at that coordinate.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålet KLX05.

Syftet med denna undersökning är framförallt 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 borrkärnekarteringen samt som underlag vid enhålstolkningen.

Berggrunden i närheten av KLX05 uppvisar stora variationer i fysikaliska egenskaper. Baserat på silikatdensitet kan borrhålet delas in i fem delsektioner.

Delsektion 1 (ca 12–290 m) domineras av en silikatdensitet som ofta understiger 2 680 kg/m^3, medelhög eller låg naturlig gammastrålning (10–20 μR/h) och relativt låg magnetisk susceptibilitet. Delsektion 2 (ca 290–520 m) domineras av hög silikatdensitet, 2 730–3 000 kg/m^3, och naturlig gammastrålning som bitvis understiger 10 μR/h. Denna kombination är typisk för bergarten diorit till gabbro. Den magnetiska susceptibiliteten är bitvis hög, och överstiger 0,1 SI längs kortare avsnitt.

Längs delsektion 3 (ca 520–690 m) varierar silikatdensiteten mellan 2 730 kg/m^3 och 2 800 kg/m^3. Längs större delen av delsektionen är den naturliga gammastrålningen 10–20 μR/h och den magnetiska susceptibiliteten varierar mellan 0,005 SI och 0,03 SI. Delsektion 4 (ca 690–752 m) karaktäriseras av låg silikatdensitet (2 600–2 670 kg/m^3), hög naturlig gammastrålning (i snitt 40–50 μR/h) och låg magnetisk susceptibilitet (0,002–0,007 SI). Denna kombination av fysikaliska egenskaper är typisk för finkornig granit.

Den sista delsektionen, nr 5 (ca 752–990 m) domineras av relativt konstant silikatdensitet, i medeltal ca 2 760 kg/m^3, och medelhög naturlig gammastrålning (10–20 μR/h). Den magnetiska susceptibiliteten varierar bitvis mycket, främst i intervallet 0,002–0,02 SI. Längs hela borrhålet förkommer korta sektioner med förhöjd naturlig gammastrålning i kombination med låg densitet, vilket troligen är en indikation på förekomst av gångar av finkornig granit eller pegmatit.

Den uppskattade sprickfrekvensen i KLX05 är oftast låg eller medelhög. Det förkommer dock ett flertal kortare sektioner (5–10 m) med indikerad hög sprickfrekvens, främst längs intervallet 12–710 m. De flesta av dessa kortare sektioner sammanfaller med enstaka tunna men distinkta anomalier med låg resistivitet, låg P-vågshastighet och ökad borrhålsdiameter, vilket troligen indikerar förekomst av sprickor. Längs sektionen 650–715 m visar caliper-loggen generellt större borrhålsdiameter i kombination med flera lågresistiva anomalier, något som kan indikera förekomst av en deformationszon. Det bör påpekas att avsaknaden av båda normalresistivitetsloggar gör att den uppskattade sprickfrekvensloggen kan vara något missvisande. Vid sektionskoordinaten ca 849 m finns en momentan ökning av borr-hålsvätskans uppskattade salinitet samt även en kraftig anomali i vertikaltemperaturgradient loggen vilket är en tydlig indikation på förekomst av en vattenförande spricka.

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 KLX05 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 vertical temperature gradient, salinity and apparent porosity are also presented. The logging measurements were conducted in 2005 by Rambøll.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (activity plan AP PS 400-05-006 and method description MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of borehole KLX05 in Laxemar. 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 KLX05	AP PS 400-05-006	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

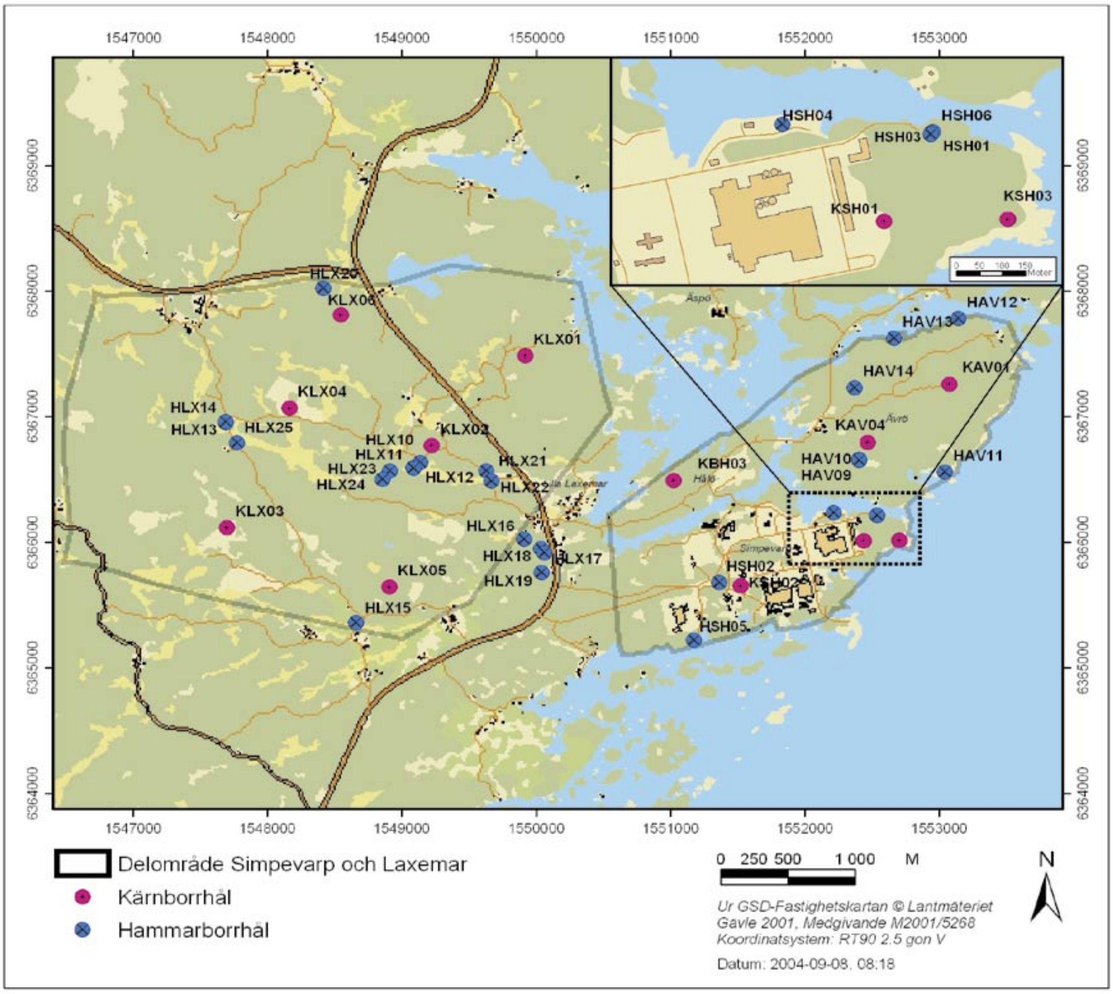

Figure 1-1. *Location of the core drilled borehole KLX05.*

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.

The vertical temperature gradient, an estimation of the salinity and the apparent porosity are presented for the cored borehole. These parameters indicate the presence of water bearing fractures, saline water and the transportation 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 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.

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 depth co-ordinates (0.1 m point distance).

The density and magnetic susceptibility logging data are calibrated with respect to petrophysical data. The logging data of KLX05 were calibrated by use of a combination of petrophysical data from the boreholes KLX02, KLX03, KLX04, KSH01A, KSH02, KSH03A and KAV04A, see /1, 2, 3, 4, 5/.

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

The silicate density is calculated with reference to /6/ and the data are then divided into 5 sections **indicating** a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /7/. 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 /8/; $\sigma = a\,\sigma_w\,\varphi^m + \sigma_s$ 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.

The vertical temperature gradient (in degrees/km) is calculated from the fluid temperature logging for 9 m sections according to the following equation /9/:

$$TempGrad = \frac{1000\left[9\sum zt - \sum z \sum t\right]\sin\varphi}{9\sum z^2 - \left(\sum z\right)^2}$$

where z = depth co-ordinate (m), t = fluid temperature (°C) and φ = borehole inclination (°). The vertical temperature gradient is only calculated for cored boreholes.

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 /1/. 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	KLX05	3.0	3.0	3.0	0.5	2.0	–	–	–
Power	KLX05	1.0	1.0	1.6	1.0	0.4	–	–	–
Weight	KLX05	0.5	7.1	6.7	1.0	5.0	–	–	–

4.2 Preparations and data handling

The logging data from KLX05 were delivered as Microsoft Excel files via email from Rambøll. 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.
- SPR.
- Short normal resistivity (16 inch).
- Long normal resistivity (64 inch).
- 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 vertical temperature gradient, salinity and apparent porosity help identifying water bearing fractures, saline ground water and porous rocks.

4.4 Nonconformities

The two normal resistivity logs were not used in the interpretation due to their abnormal behaviors. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are not presented for the two normal resistivity loggings since the logging data show dubious values. Apart from this, no nonconformities are reported.

5 Results

5.1 Quality controll of the logging data

5.1.1 Noise levels

Noise levels of the raw data for each logging method are presented in Table 5-1. Noise levels are above the recommended levels for the density log, the magnetic susceptibility log and the natural gamma radiation log. However, the levels are most likely low enough to allow a meaningful interpretation of the data. To reduce the influence of the noise, all logs were average or median filtered prior to the interpretation.

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.

There is a gap in the data for all methods in the section c 71–108 m.

Table 5-1. Noise levels in the investigated geophysical logging data of KLX05.

Logging method	KLX05	Recommended max noise level
Density (kg/m^3)	14	3–5
Magnetic susceptibility (SI)	0.0003	1×10^{-4}
Natural gamma radiation (μR/h)	0.47	0.3
Long normal resistivity (%)	Not used	2.0
Short normal resistivity (%)	Not used	2.0
Fluid resistivity (%)	0.005	2
Fluid temperature (°C)	0.0002	0.01
Lateral resistivity (%)	Not used	2
Single point resistance (%)	0.03	No data
Caliper (m)	0.9×10^{-5}	0.0005
Focused resistivity 300 (%)	5.5	No data
Focused resistivity 140 (%)	5.3	No data
Sonic (m/s)	3.9	20

5.2 Interpretation of the logging data

The presentation of interpretation products presented below, in chapter 5.2.1 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 KLX05

The results of the generalized logging data and fracture estimations of KLX05 are presented in Figure 5-1 below, and in a more detailed scale in Appendix 1.

The rocks in the vicinity of KLX05 show large variations in silicate density. The silicate density log data indicate that the borehole roughly can be divided into to five parts, or subsections.

Subsection 1 (c 12–290 m) is dominated by low silicate density, mainly below 2,680 kg/m^3, which indicates a mineral composition corresponding to granite rock (Table 5-2). The natural gamma radiation is mainly moderate to low (10–20 µR/h), with a few exceptions of high radiation anomalies most likely indicating the presence of pegmatite or fine-grained granite dykes. One of these, at c 200 m, coincides with a major low in the magnetic susceptibility. Apart from this low, the magnetic susceptibility along subsection 1 is fairly low or moderate.

Subsection 2 (c 290–520 m) is dominated by high or very high silicate density values, in the range of 2,730–3,000 kg/m^3. In the sections where silicate density reaches above 2,800 kg/m^3 the natural gamma radiation is often below 10 µR/h, a combination which is a typical indication for diorite to gabbro rocks. The magnetic susceptibility is moderate or high along the subsection, and reaches above 0.1 SI at c 355 m section length.

Table 5-2. Distribution of silicate density classes with borehole length of KLX05.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680 (granite)	267	28
2,680 < dens < 2,730 (granodiorite)	146	16
2,730 < dens < 2,800 (tonalite)	395	42
2,800 < dens < 2,890 (diorite)	107	11
dens > 2,890 (gabbro)	24	3

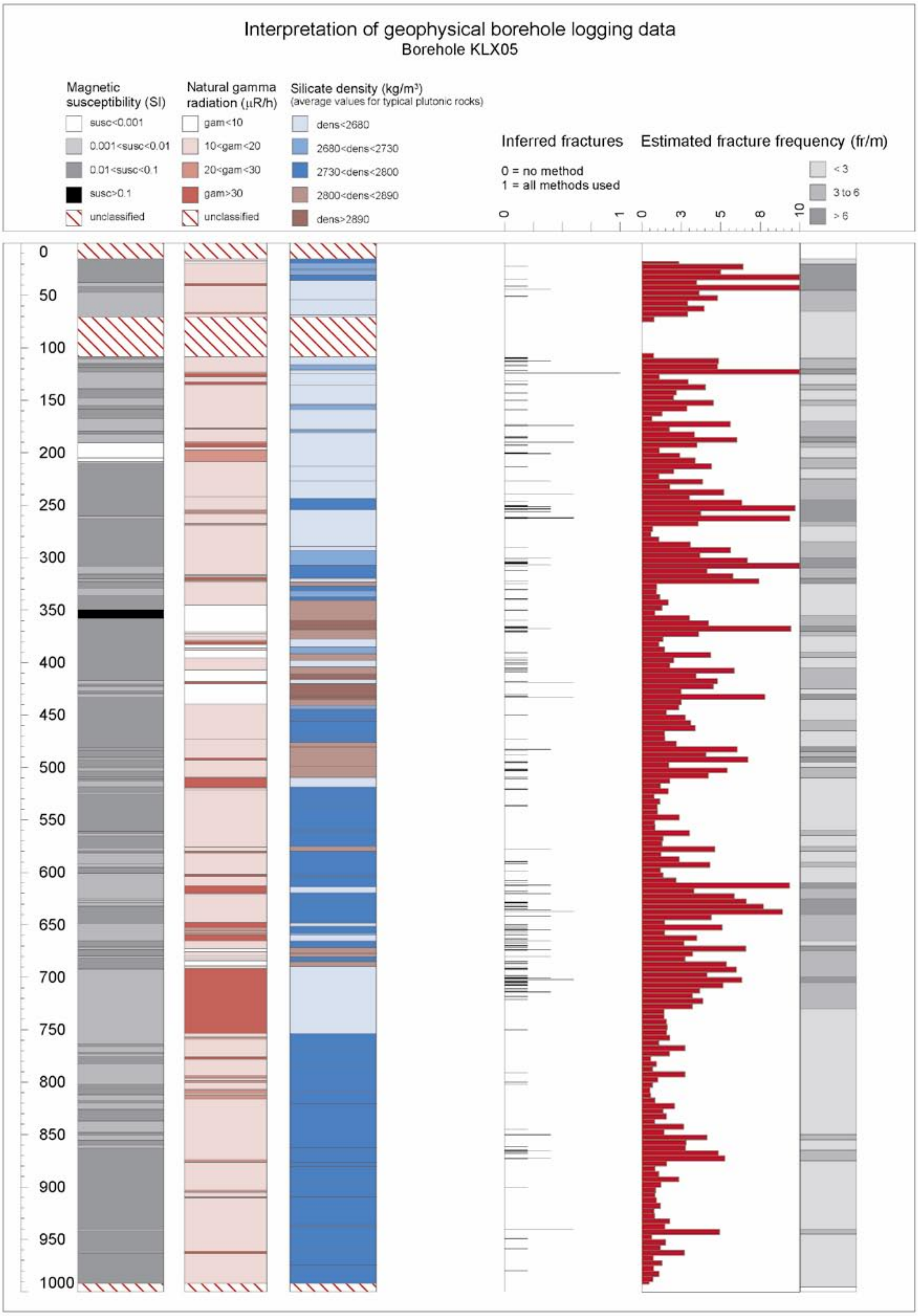

Figure 5-1. Generalized geophysical logs of KLX05.

Along subsection 3 (c 520–690 m) the silicate density is fairly constant in the interval 2,730–2,800 kg/m^3. The natural gamma radiation is increased at some shorter intervals that also show decreased density, which indicates pegmatite or fine-grained granite dykes. Along the major part of the subsection the natural gamma radiation is in the range of 10–20 μR/h. The magnetic susceptibility is mainly low or moderate (roughly 0.005–0.03 SI).

Subsection 4 (c 690–752 m) is dominated by low silicate density (2,600–2,670 kg/m^3), high natural gamma radiation (mainly 40–50 μR/h) and low magnetic susceptibility of 0.002–0.007 SI. This combination of properties is typical for fine-grained granite dykes.

The lowermost subsection 5 (c 752–990 m) is characterized by fairly constant silicate density at c 2,760 kg/m^3 and moderate natural gamma radiation, mainly in the range of 10–20 μR/h. The magnetic susceptibility shows large variations in the section 752–875 m (in the range of 0.002–0.02 SI), and below 875 m section down to 990 m the magnetic susceptibility is fairly constant at c 0.02 SI.

The estimated fracture frequency is mainly low or moderate along KLX05. However, there are several short intervals (c 5–10 m long) with indicated high fracture frequency in the section c 12–710 m. Several of these intervals coincide with narrow distinct low resistivity, sonic and caliper anomalies that most likely indicate single fractures. Along the section 650–715 m there is a continuous increase in the borehole diameter and several low resistivity anomalies, which may indicate a possible deformation zone. It must be noted that the lack of normal resistivity logging data decreases the reliability of the estimated fracture frequency.

The fluid temperature gradient data indicate the presence of water bearing fractures in the section c 240–340 m, c 410–530 m and c 590–880 m (Figure 5-2). The most prominent anomalies occur at c 626 m, c 777 m and c 849 m. The estimated fluid water salinity increases stepwise with depth from c 300 ppm NaCl near the ground surface up to c 1,100 ppm NaCl at the bottom of the borehole. Note that the sharp salinity gradient at c 849 m section length coincides with one of the most prominent anomalies in the fluid temperature gradient data.

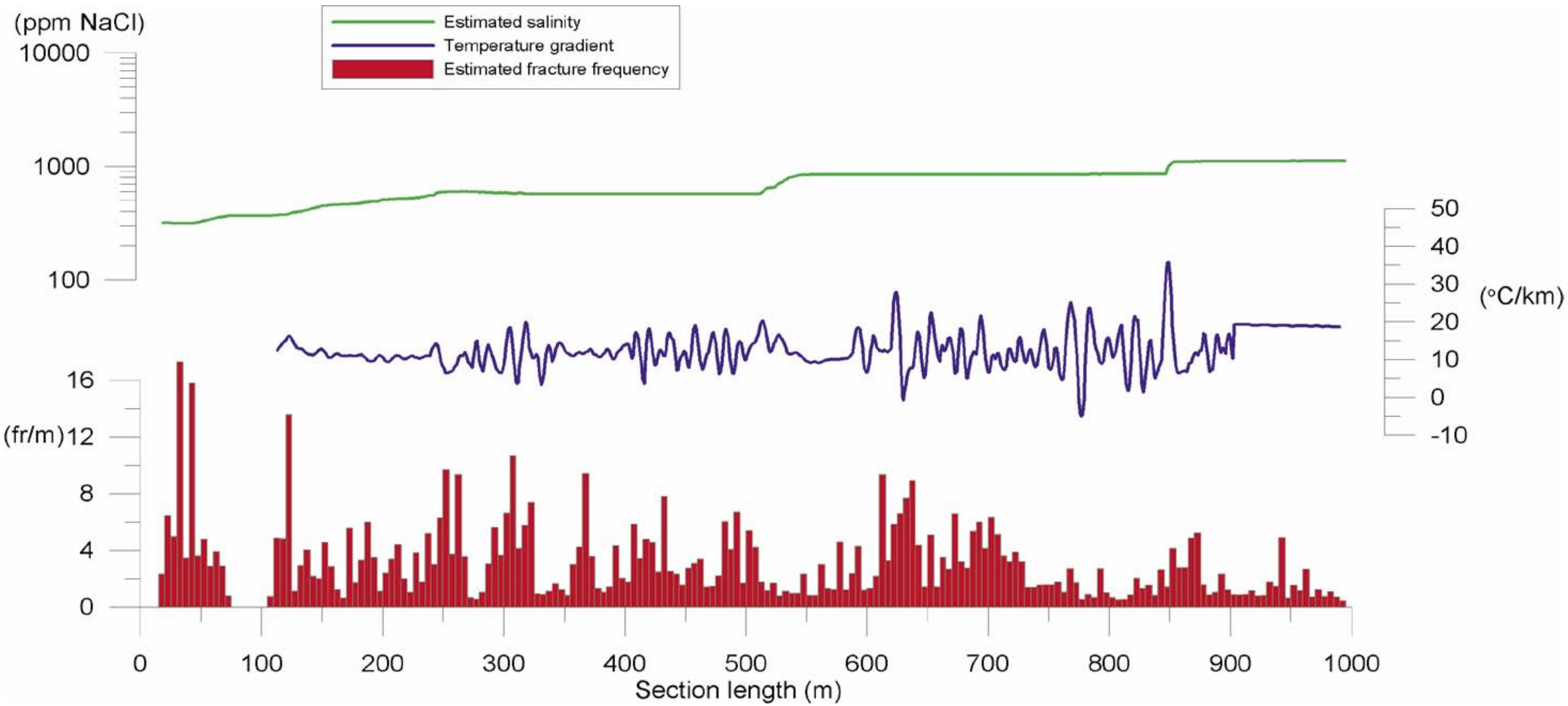

Figure 5-2. *Estimated salinity, vertical temperature gradient and estimated fracture frequency of KLX05.*

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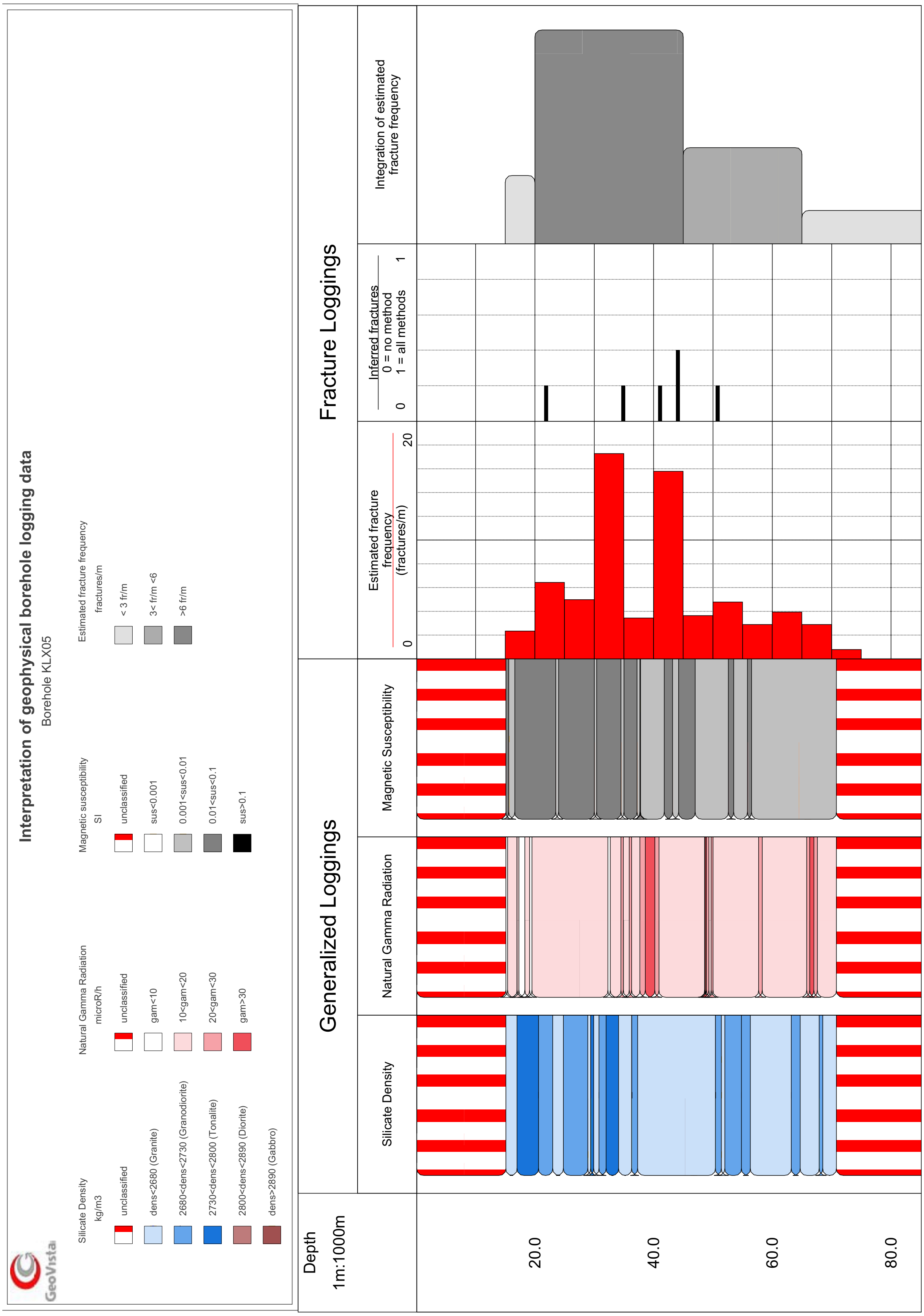
Appendix 1

Generalized geophysical loggings of KLX05



Interpretation of geophysical borehole logging data
Borehole KLX05
GeoVista
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Natural Gamma Radiation
microR/h
unclassified
gam<10
10<gam<20
20<gam<30
gam>30
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
sus>0.1
Estimated fracture frequency
fractures/m
< 3 fr/m
3< fr/m <6
>6 fr/m
Depth
1m:1000m
Generalized Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Fracture Loggings
Estimated fracture frequency (fractures/m)
0
20
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
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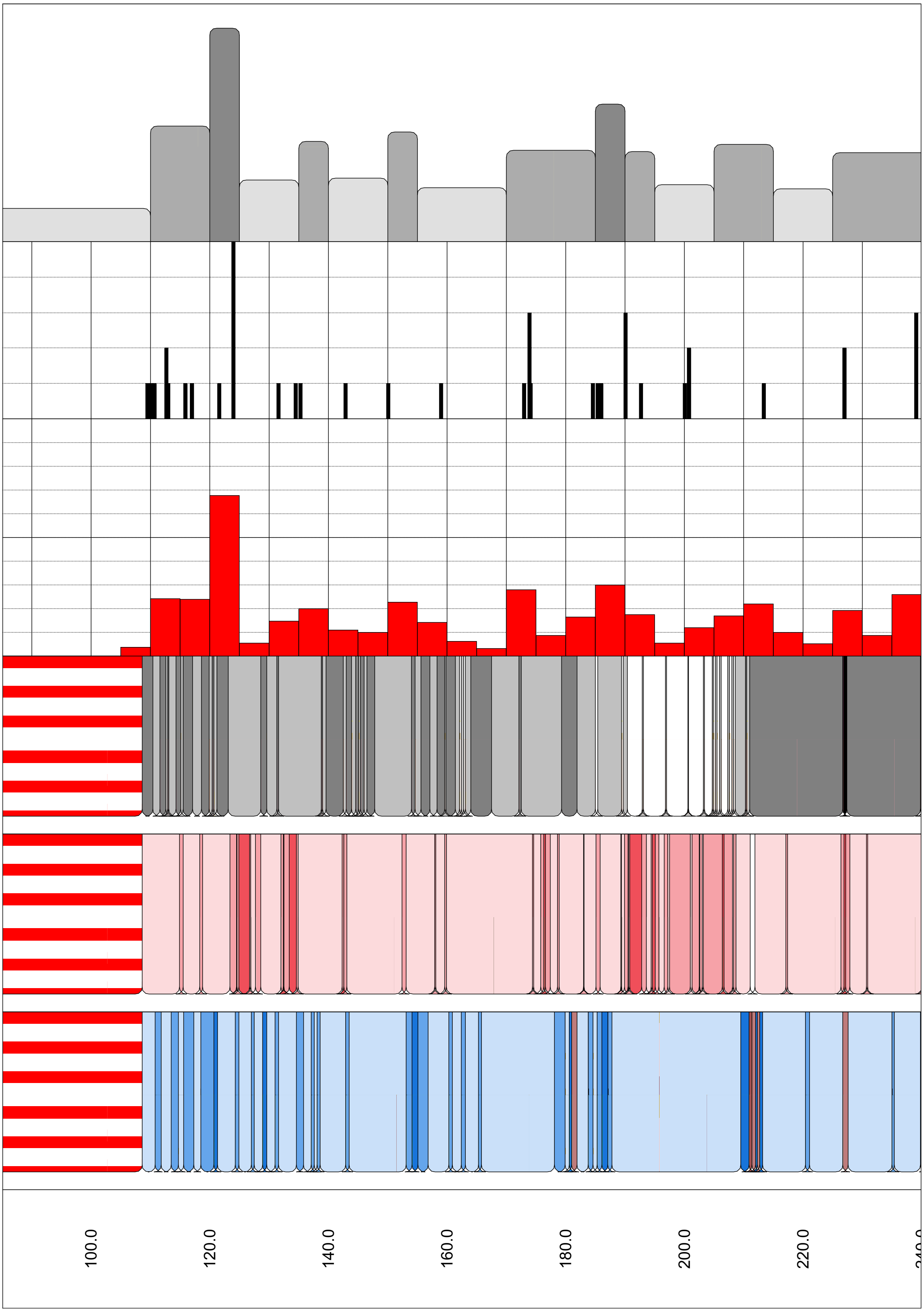
40.0
60.0
80.0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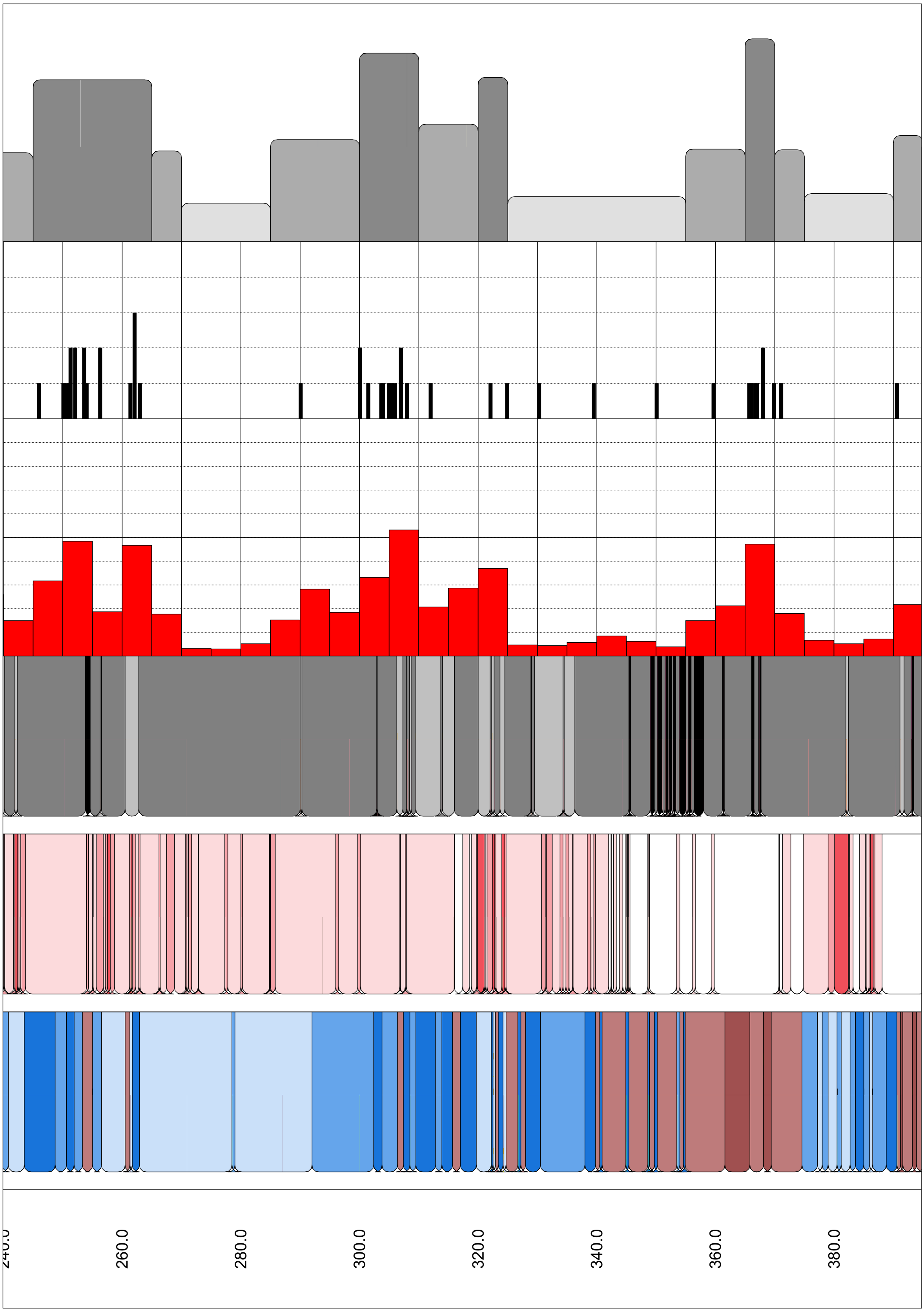
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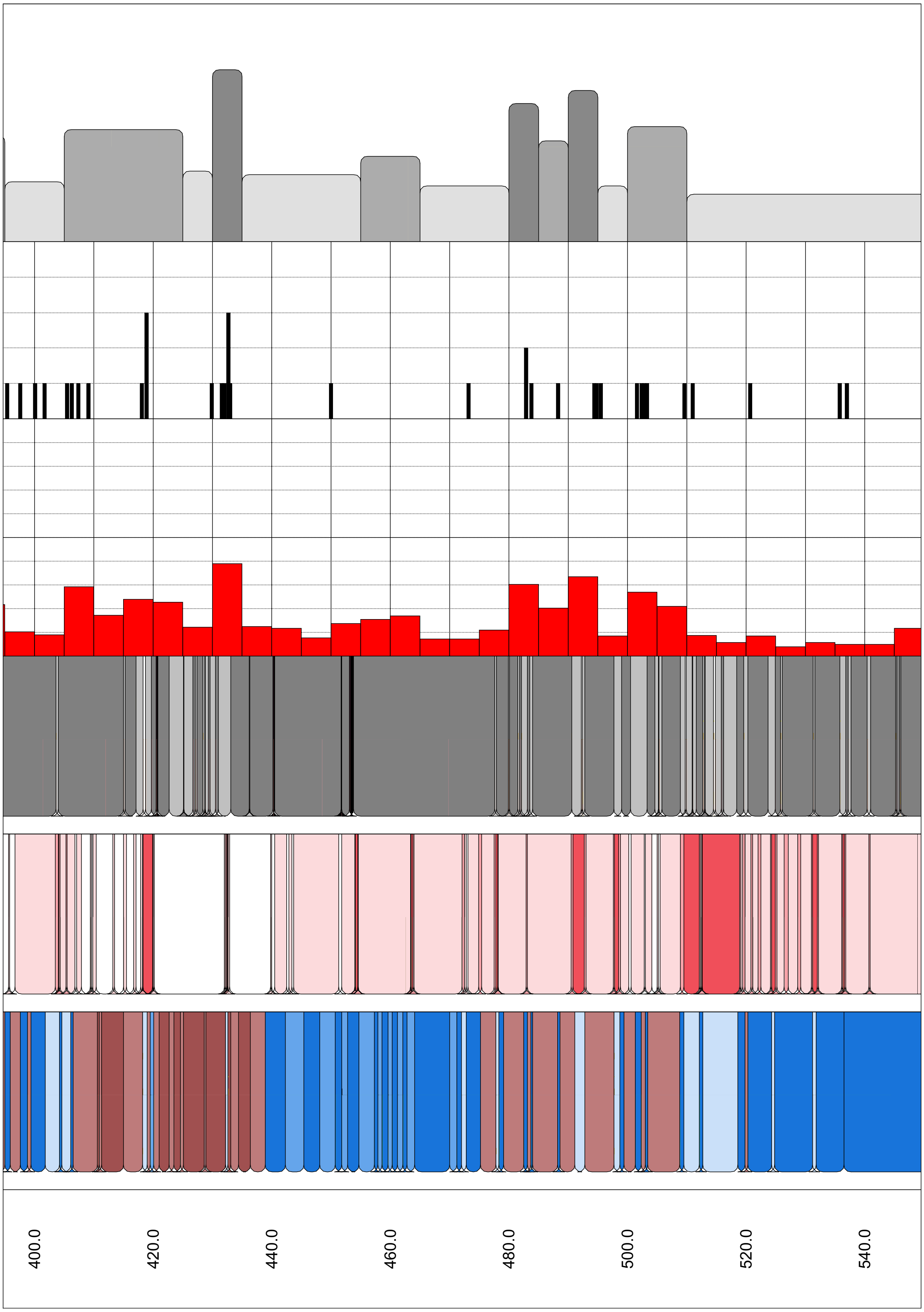
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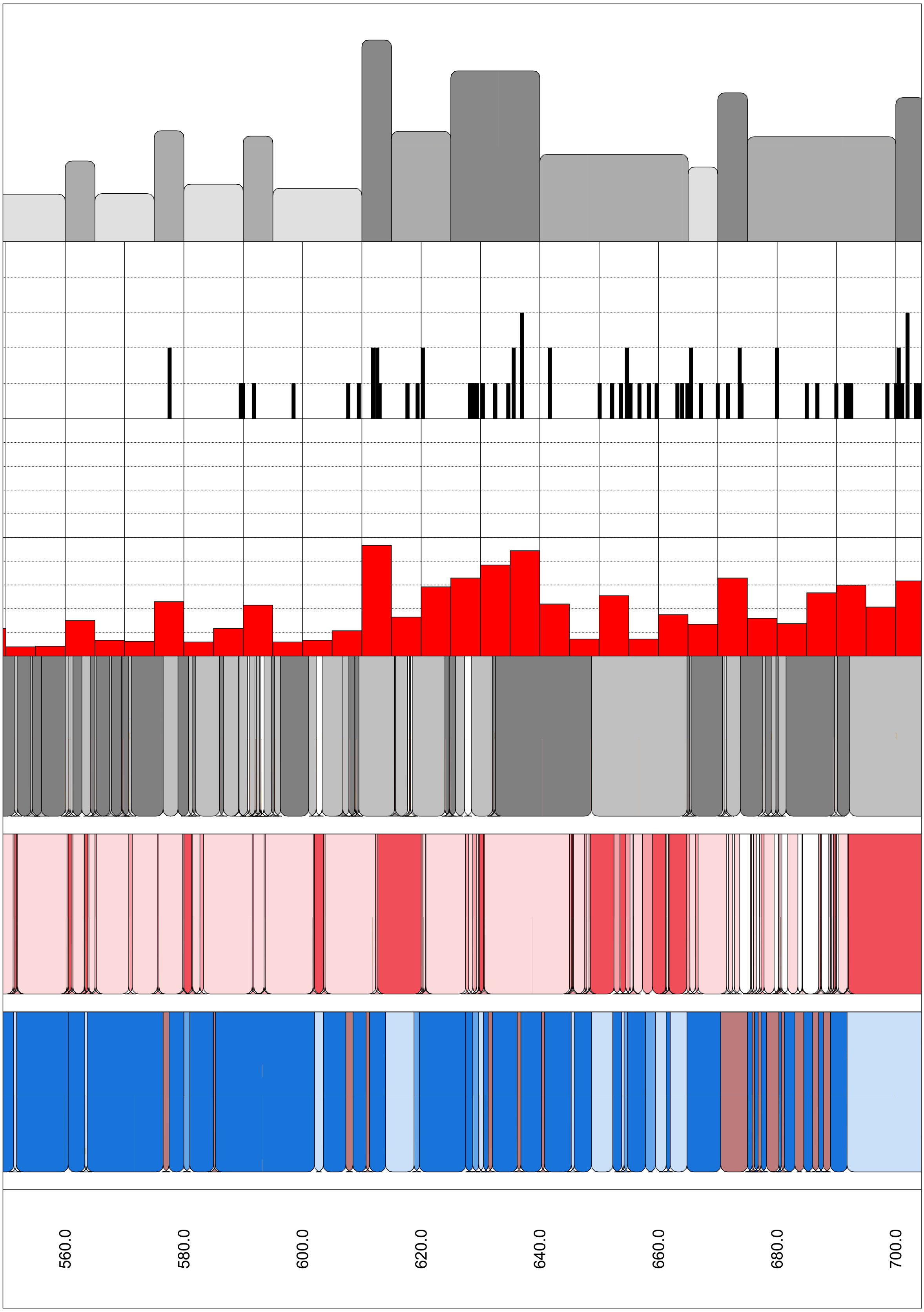

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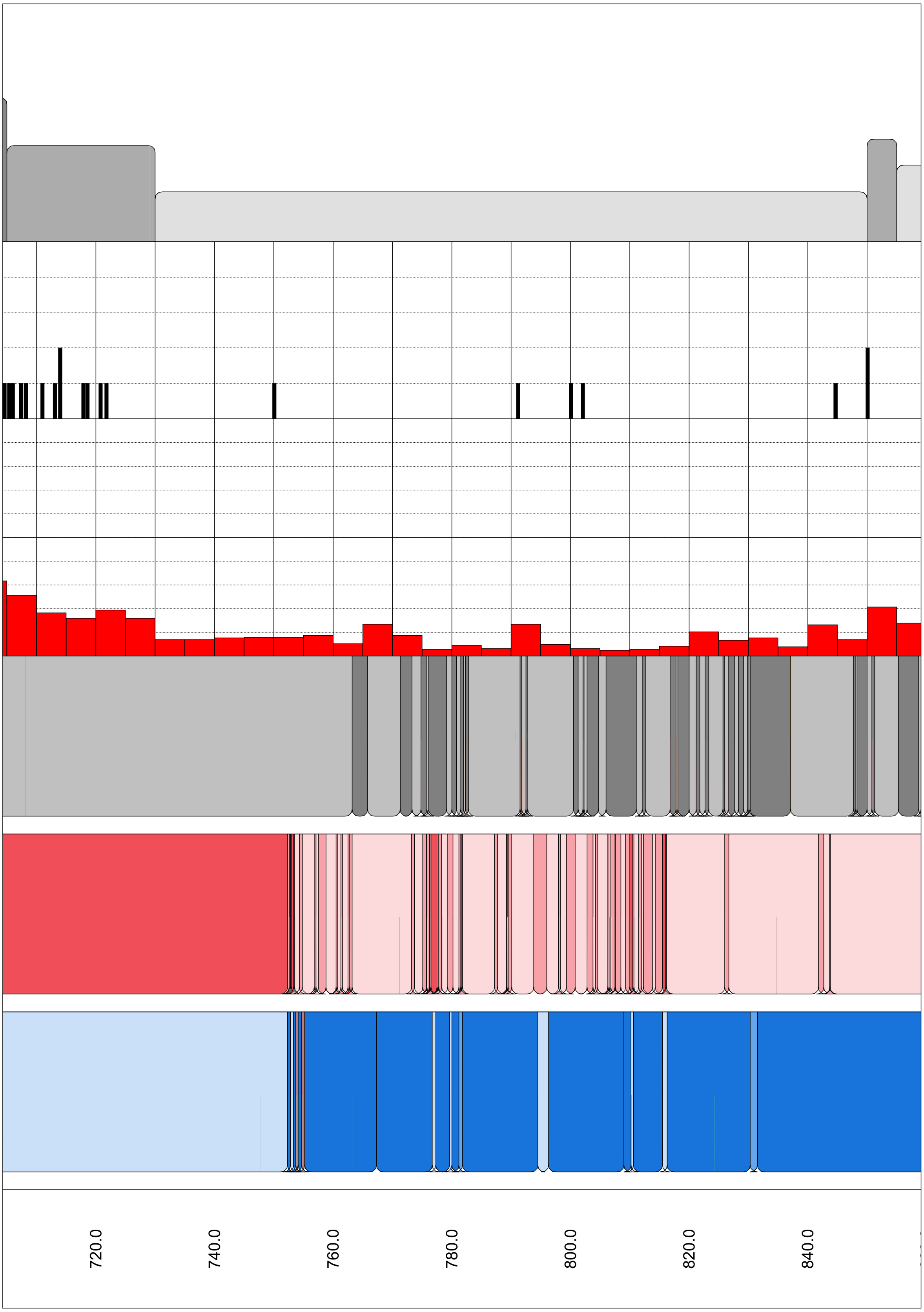
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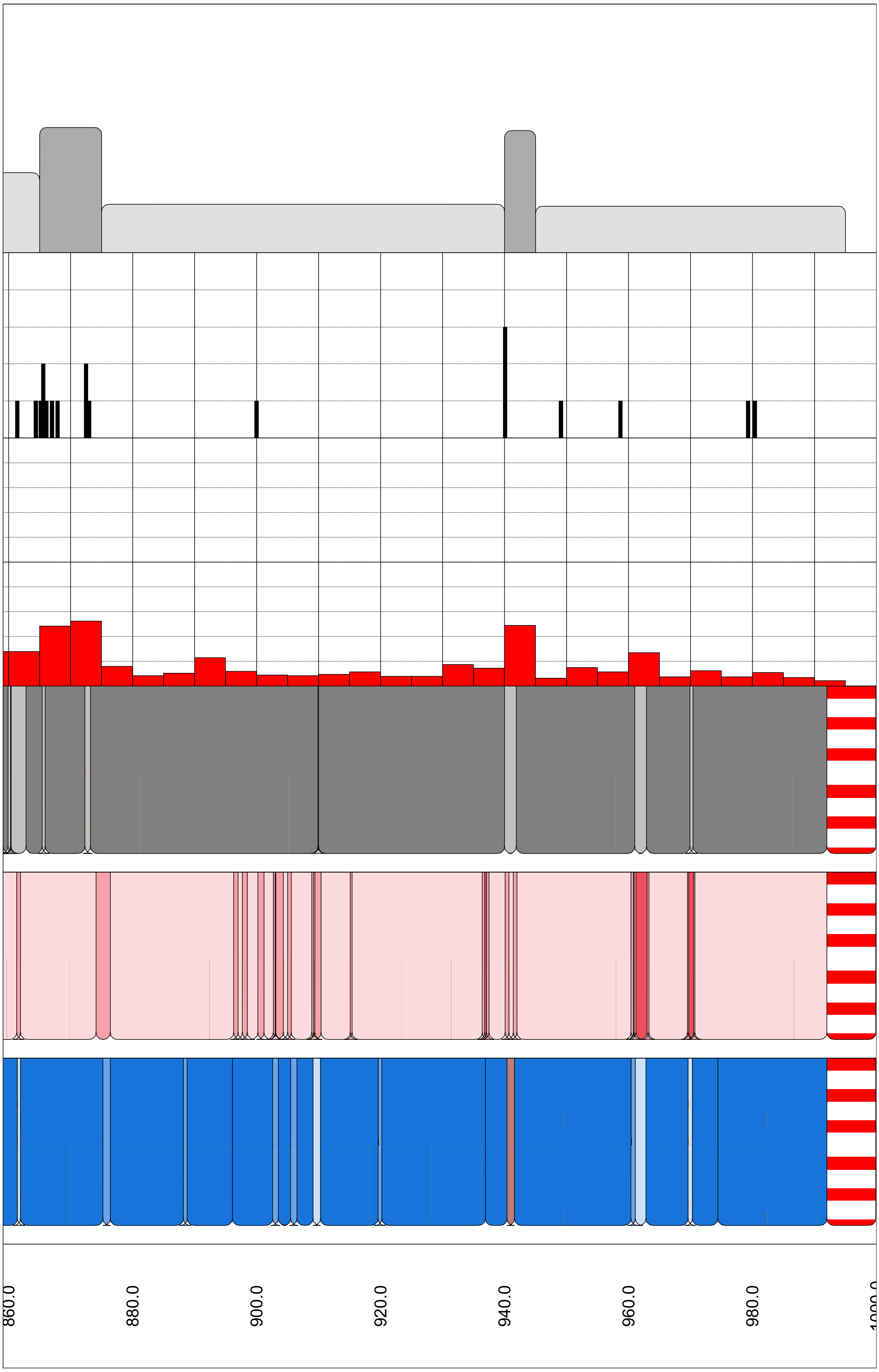
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