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Oskarshamn site investigation

Interpretation of geophysical borehole data and compilation of petrophysical data from KSH03A (100–1,000 m), KSH03B, HAV09, HAV10 and KLX02 (200–1,000 m)

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June 2004

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

Abstract

This report presents the compilation and interpretations of geophysical logging data and petrophysical measurements on rock samples from the cored boreholes KSH03A and KSH03B (the Simpevarp peninsula), HAV09 and HAV10 (the Ävrö Island) and KLX02, 200–1,000 m depth (Laxemar).

The main objective of these investigations is to use the results as supportive information during the geological core mappings and as supportive information during the single-hole interpretation. The petrophysical data are used to perform quality controls of the logging data and constitute supportive information to the rock type classification. The sonic data of KLX02 include both P-wave and S-wave measurements. Elastic moduli-logs (shear-, bulk- and Young's modulus) were therefore calculated for this borehole.

The rocks in the vicinity of the four boreholes KSH03A, KSH03B, HAV09 and HAV10 are mainly dominated by silicate densities that indicate a mineral composition corresponding to granite. However, in KSH03B there are two fairly long sections of significantly higher densities, indicating a mineral composition mainly corresponding to diorite or gabbro. Also in the other three boreholes there are scattered occurrences of high density rocks. The natural gamma radiation is mainly moderate in KSH03A, and mainly low in KSH03B, HAV09 and HAV10. Short sections of high natural gamma radiation occur rather frequent in all four boreholes. They most likely correspond to fine-grained granite or pegmatite dykes. The magnetic susceptibility is dominated by moderate magnetization levels (0.01–0.1 SI). Low magnetic sections co-vary with increased fracturing and/or zones of possible alteration. Strongly increased fracturing and alteration is indicated along the section 100–300 m of KSH03A and section 70–105 m of HAV09. These two sections most likely indicate occurrences of deformation zones. Several sections of mainly moderate fracture frequency are also indicated in KSH03B. The petrophysical data of samples from KSH03A indicate that the Ävrö granite varies a great deal in density.

The data of KLX02 are fairly different compared to those from the Ävrö Island and the Simpevarp peninsula. Section c. 200–400 m is dominated by silicate densities mainly indicating granitic mineral composition. Along the section c. 400–700 m there is a frequent occurrence of rocks with indicated granodiorite-tonalite silicate densities. From c. 700 m depth down to 1,000 m depth, there are several long sections where the silicate density indicates a mineral composition that corresponds to diorite-gabbro. The estimated fracture frequency is generally low from 200 m down to c. 750 m depth. Below c. 750 m depth, down to c. 975 m depth, there is clear increase in the fracture frequency, varying between moderate and high, which may indicate the occurrence of a deformation zone. The elastic moduli estimated for KLX02 appear to be reasonable for "normal" crystalline rocks.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsdata och petrofysiska data från kärnborrhålen KSH03A och KSH03B på Simpevarpshalvön, HAV09 och HAV10 på Ävrö samt KLX02, 200–1 000 m, i Laxemar.

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 för respektive borrhål. Petrofysikdata används främst för att kontrollera kvaliteten på vissa geofysiska loggar. Eftersom både kompressions- och skjuvvågsmätningar finns tillgängliga i sonicdata för KLX02 gjordes beräkningar av de elastiska modulerna skjuvmodul, bulkmodul och Young's modul för detta borrhål.

Berget i närheten av KSH03A, KSH03B, HAV09 och HAV10 domineras av en silikatdensitet som indikerar en mineralsammansättning motsvarande granit. I KSH03B finns dock två relativt långa sektioner (sammanlagt ca 45 m) där silikatdensiteten indikerar en mineralsammansättning motsvarande diorit till gabbro. Även i de andra tre borrhålen förekommer kortare sektioner med förhöjd densitet. Den naturliga gammastrålningen ligger generellt på en medelhög nivå i stora delar av KSH03A, medan den är i huvudsak låg i KSH03B, HAV09 och HAV10. Korta sektioner med hög gammastrålning förekommer ofta i alla fyra borrhål. Dessa anomalier är troligen orsakade av pegmatitgångar eller gångar med finkornig granit. Den magnetiska susceptibiliteten varierar i huvudsak mellan 0.01 SI och 0.1 SI. Lågmagnetiska sektioner förekommer ofta i samband med ökad sprickighet och/eller omvandling (oxidation). Kraftigt förhöjd sprickighet och omvandling indikeras längs sektionen 100–300 m av KSH03A och 70–105 m av HAV09. Dessa två områden kan troligen kopplas till två större deformationszoner. Flera sektioner med något förhöjd sprickighet förekommer längs hela KSH03B.

De petrofysiska mätningarna på prover från KSH03A påvisar en relativt stor spridning i densitet för bergarten Ävrögranit.

Loggningsdata från KLX02 skiljer sig en hel del jämfört med data från Ävrö och Simpevarpshalvön. De översta tolkade ca 200 m av hålet (sektion 200–400 m) domineras av silikatdensitet som indikerar en mineralsammansättning motsvarande granit. Längs 400–700 m djup ökar inslaget av bergarter med medelhöga densiteter (indikerad granodiorit-tonalit sammansättning). Från 700 m djup ned till 1 000 m djup finns ett flertal mäktiga (> 10 m) sektioner med en silikatdensitet motsvarande diorit eller gabbro. Den uppskattade sprickfrekvensen är generellt låg från 200 m ned till ca 750 m djup. Mellan 750 m och 975 m djup syns en tydlig ökning av sprickighet och möjlig omvandling, vilket troligen indikerar förekomst av en större deformationszon.

Beräkningarna av elasticitetsmoduler för KLX02 synes resultera i värden som är rimliga för "normal" kristallin berggrund.

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 Simpevarp. This document reports the results gained from the interpretation of borehole geophysical logging data from the cored boreholes KSH03A and KSH03B at the Simpevarp peninsula, HAV09 and HAV10 at the Ävrö Island and KLX02 (200–1,000 m) at Laxemar. A compilation of petrophysical data from measurements on 11 core samples from KSH03A is also presented. The work was carried out in accordance with activity plan AP PS 400-04-003 (SKB internal controlling document). In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Tolkning av borrhålsgeofysiska data samt mätning och bearbetning av petrofysiska data från KSH03A, KSH03B, HAV09, HAV10 och KLX02	AP PS 400-04-003	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings (including estimated fracture frequency) and possible alteration. The logging measurements of KSH03A, KSH03B, HAV09 and HAV10 were conducted in 2004 by Rambøll. The data from KLX02 is a combination of three separate logging performances in 1993 by Malå GeoScience, and in 2000 and 2002 by Rambøll.

The petrophysical determinations of KSH03A include magnetic susceptibility and wet density. The measurements were performed at the laboratory of the Division of Applied Geophysics, Luleå University of Technology.

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 in the borehole software WellCad. 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 main objective of these investigations is to use the results as supportive information during the geological core mappings 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.

The petrophysical data are used to perform quality controls of the logging data and constitute supportive information to the rock type classification.

The sonic data of KLX02 include both P-wave and S-wave measurements. Special emphasis was therefore put on calculating the elastic moduli (shear-, bulk- and Young's modulus) for this borehole.

3 Equipment

3.1 Description of equipment for petrophysical measurements

The measurements of magnetic remanence were performed with a cryogenic DC-SQUID magnetometer from 2G Enterprises and the anisotropy of magnetic susceptibility (AMS), including the magnetic volume susceptibility, was measured with a KLY-3 Kappabridge from Geofyzika Brno. Masses for the density and porosity determinations were measured with a digital Mettler Toledo PG 5002. The electric resistivity and induced polarization measurements were performed by use of a two-electrode in-house equipment (Luleå University of Technology) /1/.

3.2 Description of equipment for analyses of logging data

The software used for the interpretation are WellCad v3.2 (ALT), which is mainly used for plotting, Grapher v4 (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 Laboratory measurements

The sampling covers 11 samples from KSH03A (Table 4-1), collected and preliminary classified by Thomas Kisiel (SKB, SICADA field note no 215). Preparations of the drill cores were performed by a technician at the laboratory of the Division of Applied Geophysics, Luleå University of Technology. The measurements of the magnetic susceptibility were performed according to MD 230.001 (SKB internal controlling document). The measurements of the wet density were performed according to MD 160.002 (SKB internal controlling document). The instruction is written to conform to rock mechanical measurements on drill cores from deep drillings, where the density determinations are parts of other types of measurements, not directly relevant for the geological core logging. The time to soak the samples (48 hours in this investigation) is e.g. shorter than what is recommended in MD 160.002.

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

4.2 Preparations of the data

4.2.1 Petrophysical data

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

Sample information for KSH03A is given in Table 4-1 below.

Table 4-1. Sample information for KSH03A.

Section up (m)	Section low (m)	Rock type	Comment
103.38	103.50	Fine-grained dioritoid	
201.80	201.97	Fine-grained dioritoid	Sealed fractures, oxidized
296.44	296.56	Ävrö granite	Sealed fractures
409.95	410.07	Ävrö granite	
501.36	501.48	Ävrö granite	
600.50	600.62	Ävrö granite	
700.27	700.39	Ävrö granite	
799.18	799.30	Ävrö granite	Dyke?
849.55	849.67	Fine-grained dioritoid	Mafic?
891.54	891.66	Ävrö granite	
999.90	1,000.02	Ävrö granite	

4.2.2 Logging data KSH03A, KSH03B, HAV09 and HAV10

The logging data were delivered as a Microsoft Excel file via email from Rambøll. The data used for interpretation are:

- Density (gamma-gamma)
- Magnetic susceptibility
- Natural gamma radiation
- Focused resistivity (300 cm)
- Sonic (P-wave only)
- Caliper mean
- SPR
- Short normal resistivity (16 inch)

The short normal resistivity of KSH03A lack data from 100 m down to 237.5 m, and the sonic log lack data along the sections 204–255 m and 900.5–995.5 m. Density data are missing from 902–1,000 m and susceptibility data are missing from 923–1,000 m. Null values were disregarded. The levels of the gamma-gamma and magnetic susceptibility loggings were adjusted by use of petrophysical data (see Section 5.2.2).

4.2.3 Logging data KLX02

Parts of the logging data were delivered as a Microsoft Excel file via email from Rambøll and parts were retrieved from the SICADA database of SKB. Data from three different logging performances were used in the analyses of KLX02, according to the list below:

- Density (gamma-gamma) (2002)
- Magnetic susceptibility (2002)
- Natural gamma radiation (2002)
- Focused resistivity (300 cm) (2002)
- Sonic (P-wave) (2000)
- Sonic (S-wave) (2000)
- Caliper 3D (2002)
- Caliper 1D (1993)
- SPR (1993)
- Short normal resistivity (16 inch) (1993)

Only data from the section 200 m to 1,000 m were used for interpretation. The older loggings (from 1993) were measured by Malå GeoScience. Old logging data in SICADA are not length adjusted. The 1D caliper log was adjusted with the 3D caliper as reference, and the short normal resistivity and the SPR logs were adjusted with the focused resistivity 300 as reference.

4.3 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, median filtering, error estimations, re-sampling, drift correction, length adjustment).

The loggings are median 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).

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

The silicate density is calculated with reference to /2/ and the data are then divided into 5 sections indicating a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /3/. 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 "low", "medium" or "high" radiation, where the threshold values for each level are adjusted with respect to the geological environment at the measurement site.

A "possible alteration logging" is estimated by identifying sections along the boreholes where the silicate density, natural gamma radiation and magnetic susceptibility simultaneously lay below certain threshold values. The threshold values were determined by analyzing logging data from KSH01A from sections where the geological core mapping indicates various degrees of alteration /4/. The applied threshold values are:

silicate density ≤ 2,800 kg/m^3
natural gamma radiation ≤ 20 μR/h
magnetic susceptibility ≤ 0.003 SI

3. 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 normal resistivity, caliper mean, single point resistance (SPR), focused resistivity (300 cm) and sonic for KSH03A, KSH03B, HAV09 and HAV10, and on sonic (P-wave), 1D-caliper, focused resistivity (300 cm), short normal resistivity and SPR for KLX02.

The position of large fractures is estimated by applying a second derivative filter to the logging data and then locating maxima (or minima depending on the logging method) in the filtered logging. Maxima (or minima) above (below) a certain threshold value (Table 4-2) are selected as probable fractures. The result is presented as a column diagram where column height 0 = no fracture, column height 1 = fracture indicated by one logging method, column height 2 = fracture indicated by two logging methods and so on. The estimated fracture frequency is calculated by applying a power function to the weighted sum of the maxima (minima) derivative loggings. Power functions have previously been estimated by correlating the weighted sum to the mapped fracture frequency in the cored borehole KSH01A and in the percussion drilled borehole HSH02 /4/. The power function used in this study for KSH03A, KSH03B, HAV09 and HAV10 is:

Estimated fracture frequency = 1.15 (weighted sum)$^{0.88}$ –1.

KLX02 is located in different rock types compared to the rocks of the Simpevarp peninsula. New weights and a new power function were therefore established for this borehole. The weights (see Table 4-2) and the power function were estimated by correlating the geophysical log data to the mapped fracture frequency of KLX02. The power function used for KLX02 is:

Estimated fracture frequency = 1.35 (weighted sum)$^{0.9}$.

Table 4-2. Threshold values and weights used for estimating position of fractures and calculate estimated fracture frequency, respectively.

	Borehole	Sonic	Focused res. 300	Caliper	SPR	Normal res. 16
Threshold	KSH03 (A,B) HAV09, 10	0.4	0.4	0.15	1.0	2.5
Weight	KSH03 (A,B) HAV09, 10	2.5	2.3	3.3	1.8	0.55
Threshold	KLX02	0.4	1.0	0.15	1.0	2.5
Weight	KLX02	9.1	4.3	10*	3.1	1.2

* 1D-caliper

4. Report evaluating the results (this report).

4.4 Data handling

The delivered data have been inserted in the database (SICADA) of SKB. The SICADA reference to the present activity is field note no 303.

5 Results

5.1 Petrophysical properties of KH03A

The sampling covers 11 samples from KSH03A (Table 4-1, Section 4.2.1), collected and preliminary classified by Thomas Kisiel (SKB, SICADA field note no 215). Only wet density and magnetic volume susceptibility were measured. Each rock type group conforms to the SKB standard.

The rock type classifications diagram in Figure 5-1 shows the distribution of the magnetic susceptibility versus density for each sample group. Four of the eight samples preliminary classified as Ävrö granite plot close to the granite rock type curve. The remaining four (depth c. 296 m, 410 m, 600 m and 891 m) are clearly denser and plot between the granodiorite and tonalite classification curves, which indicate that these rock samples have a mineral composition that is more basic than what is expected from "normal" granite. Two of the three fine-grained diorite samples plot close to the diorite classification curve, whereas the remaining samples (depth c. 202 m) fall very close to the granodiorite curve. This sample is fractured and oxidized, which probably has given rise to a higher porosity and thus a lower density. The low susceptibility of the sample at depth c. 849 m (within the paramagnetic trend indication) could indicate that this rock sample is altered mafic volcanite.

It must be noted that the rock types used in the rock classification diagram do not conform perfectly to the geology of the Simpevarp area. There is for example no corresponding rock type curve for fine-grained dioritoid, a rock type that occurs frequently in the area. This misfit is caused by the lack of high quality average density data and corresponding petrology data for these rock types. We therefore suggest that the data in rock classification diagram such as shown in Figure 5-1 should be used as indicators of the compositional variation between different rock types (or groups of rocks), and that these diagrams will be used to help identifying possible faulty rock.

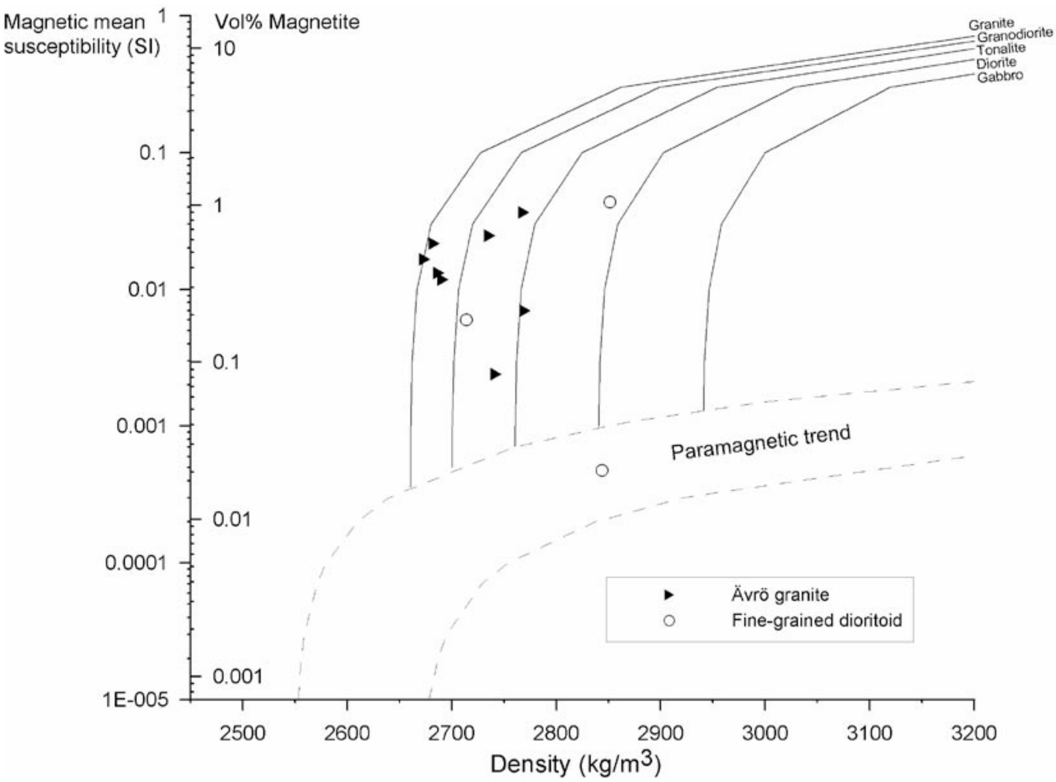


Figure 5-1. *Density-susceptibility rock classification diagram for KSH03A. See the text for explanation.*

5.2 Control of the logging data

5.2.1 Noise levels and qualitative control

Noise levels of the raw data for each logging method are presented in Table 5-1 below. The density logs of KSH03A, HAV10 and KLX02 have noise levels that greatly exceed the recommended level. HAV10 is a percussion drilled borehole, which could explain an increased noise level, but a comparison with HAV09, which is also percussion drilled, shows a significantly lower noise in that borehole. A possible explanation to the high level of KSH03A could be the influence of so called "road-noise" caused by the rather shallow dip of this borehole, but KSH03B has a similar dip but a much lesser noise. Thus, the reason for the high noise levels in the density data of these boreholes is not understood. Also the P-wave sonic data show very high levels of the noise for HAV09, HAV10 and KLX02. The high levels of HAV09 and HAV10 are, at least partly, related to the fact that these boreholes are percussion drilled. However, for 8 investigated percussion drilled boreholes in Forsmark the noise levels are only between 20 and 40 m/s. 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 for KSH03A, KSH03B, HAV09 and HAV10 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. However, negative susceptibility values were discovered at three positions in the log from KSH03A, and these data were replaced by "0" since they occur along sections with very low magnetization.

The 3D-caliper, focused resistivity and density logs of KLX02 were measured with a sampling distance of 0.01 m. These logs were resampled to 0.1 m spacing prior to the interpretation. The 3D-caliper appears to be marred by some kind of error and was therefore replaced in the interpretations by the 1D-caliper (measured by Malå GeoScience in 1993).

Table 5-1. Noise levels in geophysical logging data for KSH03A, KSH03B, HAV09, HAV10 and KLX02.

Logging method	KSH03A	KSH03B	HAV09	HAV10	KLX02	Recommended max noise level
Density (kg/m^3)	60	13	12	55	64	3–5
Magnetic susceptibility (SI)	$2*10^{-4}$	$4*10^{-4}$	$2*10^{-4}$	$4*10^{-4}$	$6*10^{-4}$	$1*10^{-4}$
Natural gamma radiation (μR/h)	1.8	0.2	0.4	1.8	2.4	0.3
Short normal resistivity (%)	0.6	2.3	0.2	0.2	0.9	2.0
Single point resistance (%)	0.8	0.5	0.1	0.2	0.4	No data
Caliper (metre)	0.0003	0.00002	0.0001	0.0001	0.00002^{+}	0.0005
Focused resistivity 300 (%)	9	14	7	11	7	No data
Sonic (m/s)	16	40	260	111	129, 19*	20

*S-wave sonic, $^{+}$1D-caliper from 1993.

5.2.2 Comparison between logging and petrophysical data for KSH03A

A quality control of the gamma-gamma and the magnetic susceptibility loggings is performed by comparing the logging data to the petrophysical data from KSH03A at the corresponding depths. In Figure 5-2 the gamma-gamma (density) logging data (after 3 point average filtering) is plotted versus wet density sample measurements. The correlation is clear but weak. Even though the log data has been filtered there is a fairly large scatter instead of the desired straight line. Two samples (depth 103 m and 799 m) were collected close to sharp gradients in the log data and should therefore be taken with care. The linear function (see Figure 5-2) appears to fit better to the data than the straight line through the origin. However, if disregarding the two samples noted above the fit through origin becomes almost just as good as the linear fit. The large scatter in the log data in combination with the poor correlation between log and petrophysical data, led to the decision to keep the density logging data unchanged.

A cross plot between the susceptibility log data and susceptibility measured on core samples is shown in Figure 5-3. There is an excellent correlation between logging and petrophysical data. However the slope of the fitted line (through origin) is 0.564, which indicates that the logging measurements underestimate the true magnetic susceptibility. Prior to the interpretation, the logging data of KSH03A, KSH03B, HAV09 and HAV10 were corrected by use of the equation from the fit through origin. The susceptibility log data from KLX02 were not corrected since this measurement was performed 2 years earlier and in a different geological setting than that of KSH03A.

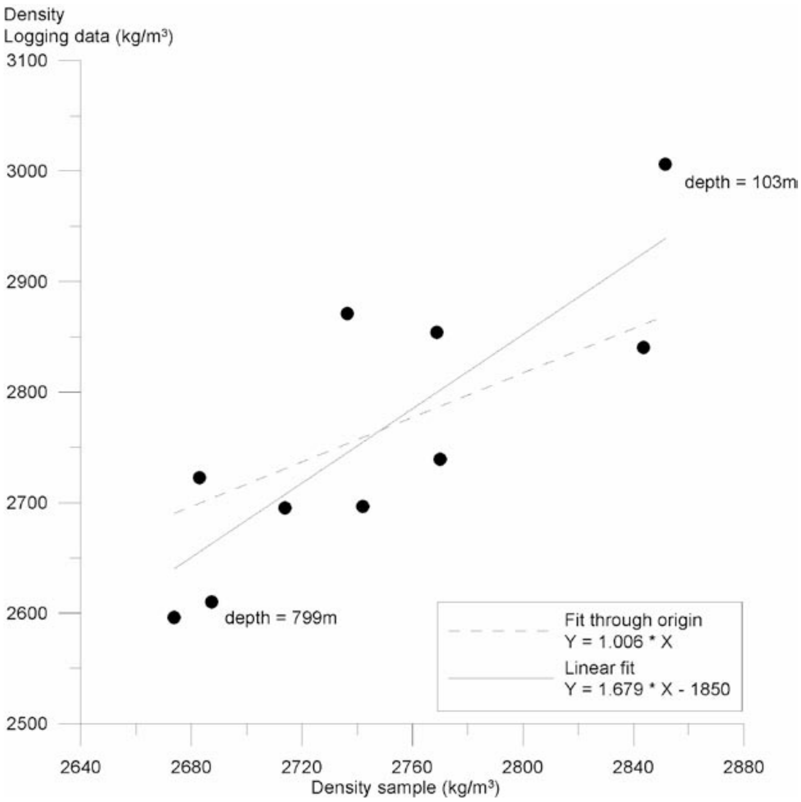


Figure 5-2. *Cross plot of density logging data versus density data from core samples in KSH03A.*

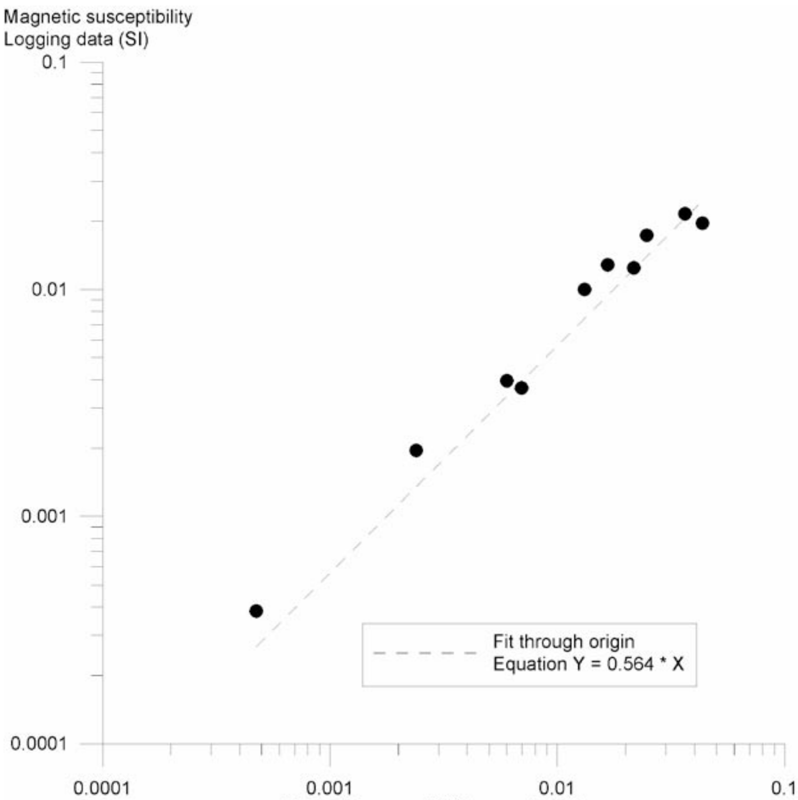


Figure 5-3. *Cross plot of magnetic susceptibility logging data versus susceptibility data from core samples in KSH03A.*

5.3 Interpretation of the logging data

A complete presentation of all processed loggings and interpretation products is given in Appendices 1–5.

The presentation of interpretation products presented below, in Sections 5.3.1 to 5.3.5, includes:

- Classification of silicate density.
- Classification of natural gamma radiation.
- Classification of magnetic susceptibility.
- Position of inferred fractures (0 = no method, 5 = all methods).
- Estimated fracture frequency in 5 metre sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and >6 fractures/m).

5.3.1 Interpretation of KSH03A

The results of the generalized data, possible alteration and fracture estimations of KSH03A are presented in Figure 5-4 below, and in a more detailed scale in Appendix 1.

The rocks in the vicinity of KSH03A (100–1,000 m) are mainly dominated by a silicate density indicating a mineral composition that corresponds to granite. However, there are a few fairly long sections with higher densities, mainly corresponding to tonalite or diorite rock compositions. These occur at the depths c. 170–190 m, 360–440 m and 560–650 m. The natural gamma radiation decreases along the high density sections, which is a clear indication that the rock in the vicinity of the borehole has a more basic composition. Below 650 m depth there is an increase of thin high density sections that could be related to veins or dykes.

Increased fracturing and possible alteration are indicated along large sections between 100 m and 300 m depth. The increased fracturing and alteration is also indicated by the decreased magnetic susceptibility from 100 m down to c. 350 m depth. Parts of the magnetite of the rock have most likely been oxidized to hematite. A slight increase in the fracture frequency is also indicated along the last c. 150 m of the borehole.

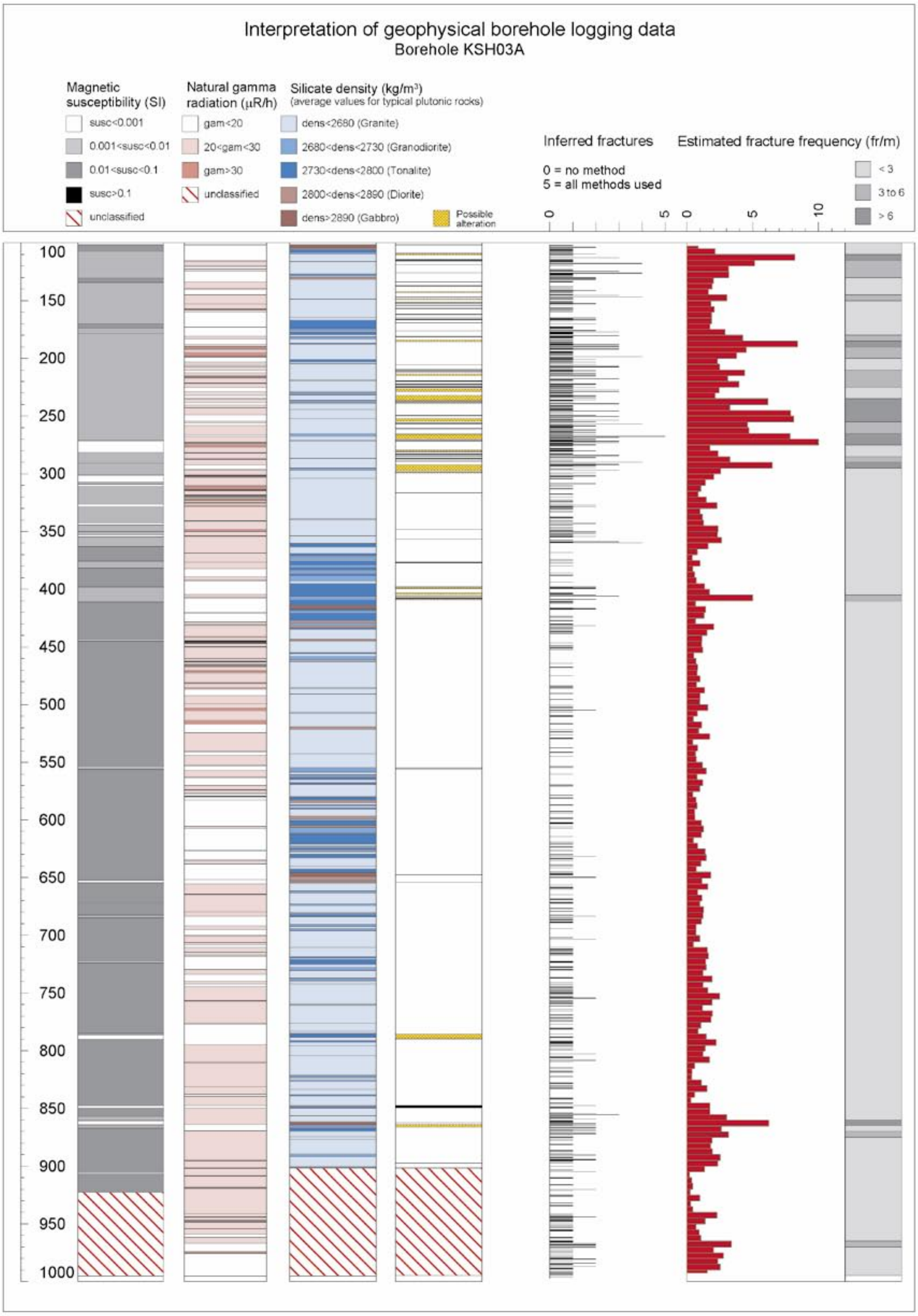


***Figure 5-4.** Generalized geophysical logs for KSH03A (100–1,000 m).*

5.3.2 Interpretation of KSH03B

The results of the generalized data, possible alteration and fracture estimations of KSH03B are presented in Figure 5-5 below, and in a more detailed scale in Appendix 2.

Along the sections c. 10–25 m and 60–90 m of KSH03B, the rock in the vicinity of the borehole is mainly dominated by a silicate density indicating a mineral composition that corresponds to diorite. Note the low natural gamma radiation along these sections, which supports the indication of a rock with a relatively high basic composition. Between 25 m and 60 m depth, and below 90 m depth, the silicate density mainly indicates a mineral composition that corresponds to granite. Minor high natural gamma radiation anomalies may indicate the occurrence of fine-grained granite dykes.

The estimated fracture frequency indicates that fairly large parts of the borehole show moderate or slightly increased fracturing.

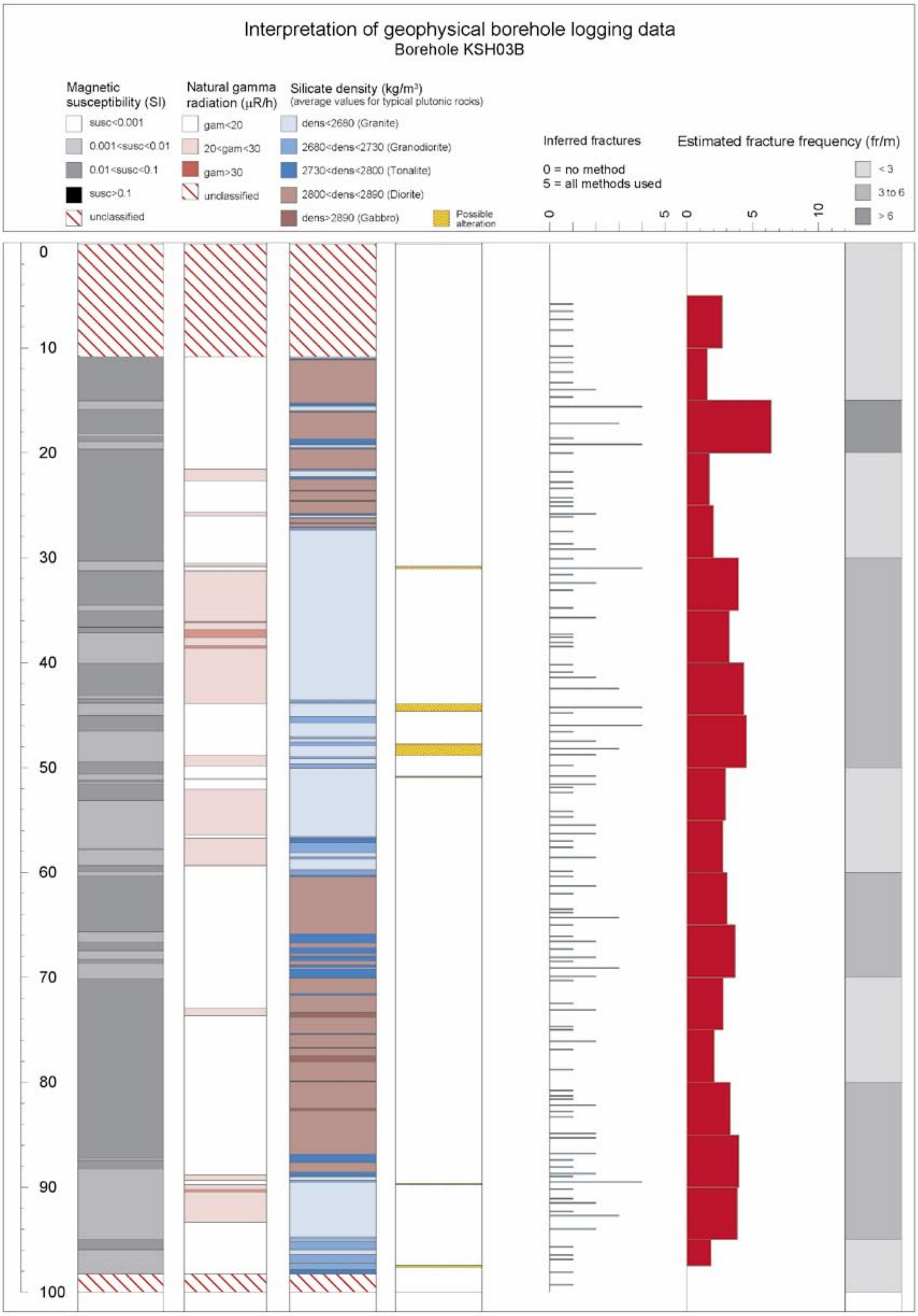


Figure 5-5. *Generalized geophysical logs for KSH03B.*

5.3.3 Interpretation of HAV09

The results of the generalized data, possible alteration and fracture estimations of HAV09 are presented in Figure 5-6 below, and in a more detailed scale in Appendix 3.

The rocks in the vicinity of HAV09 are mainly dominated by a silicate density indicating a mineral composition that corresponds to granite. However, there are two fairly long sections with higher densities, one at c.125–140 m depth with densities mainly corresponding to diorite or gabbro rock compositions, and one at c. 165–175 m depth, with densities mainly corresponding to tonalite rock composition.

A possible deformation zone is indicated by largely increased fracture frequency and possible alteration at c. 70–105 m depth. Several positive natural gamma radiation anomalies also occur along this section, which possibly indicates the existence of fine-grained granite dykes (or pegmatite), known to coincide with water bearing fractures. Increased fracturing and the occurrence of alteration is also indicated along c. 5 m long sections at 40 m and 150 m depth.

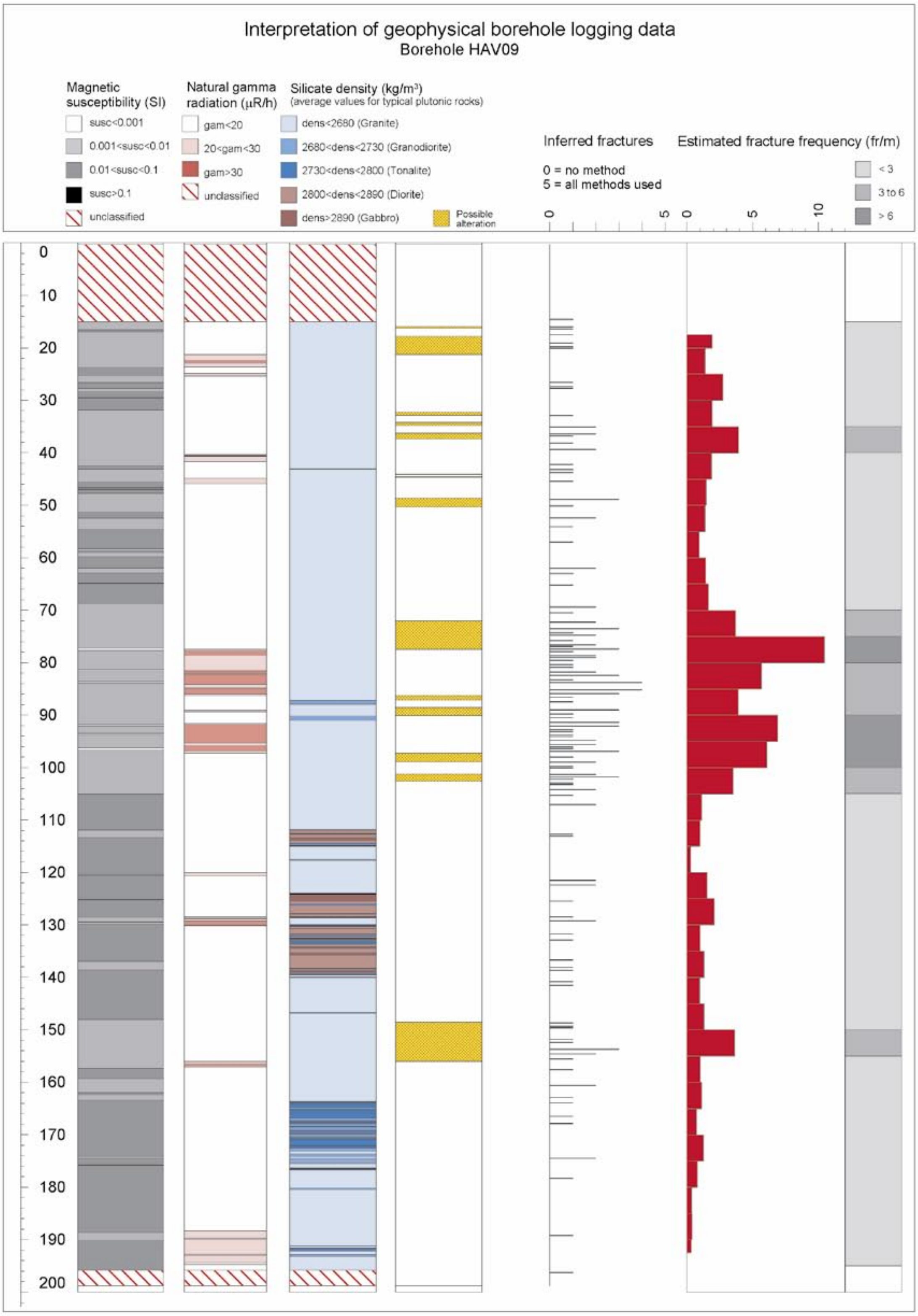


***Figure 5-6.** Generalized geophysical logs for HAV09.*

5.3.4 Interpretation of HAV10

The results of the generalized data, possible alteration and fracture estimations of HAV10 are presented in Figure 5-7 below, and in a more detailed scale in Appendix 4.

The rocks in the vicinity of HAV10 are completely dominated by a silicate density indicating a mineral composition that corresponds to granite. Several thin anomalies of slightly higher densities occur along the entire borehole length. These could be related to veins or dykes of rocks with more basic composition. The natural gamma radiation is generally low, but shows a fairly high number of thin positive anomalies, and one long section at c. 40–45 m depth with increased radiation. Some of these anomalies are probably related to pegmatite or fine-grained granite dykes.

The fracture frequency is generally low except for a short section at c. 18 m depth, where possible alteration is also partly indicated. Alteration is also indicated at three other short sections of the borehole.

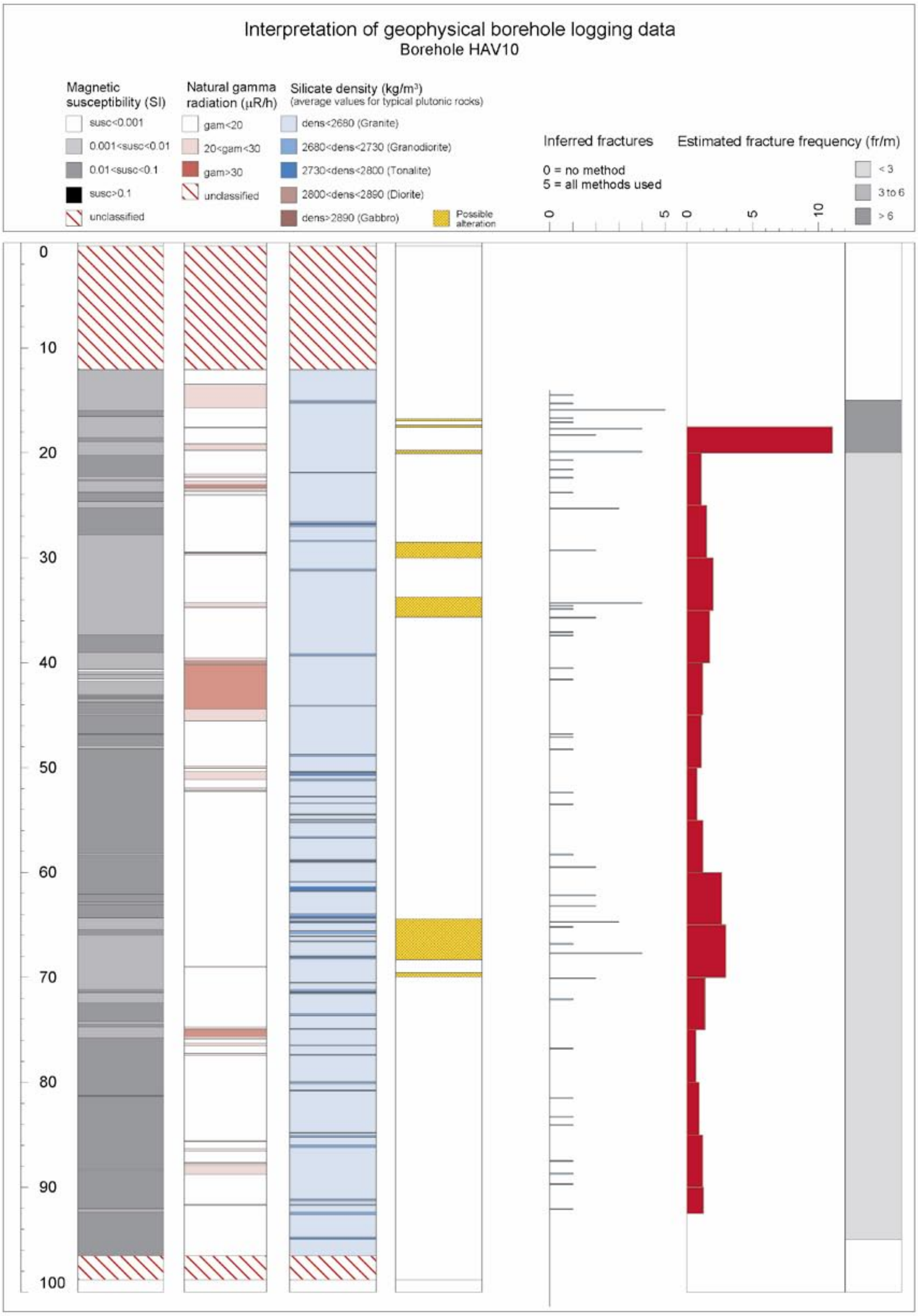


Figure 5-7. Generalized geophysical logs for HAV10.

5.3.5 Interpretation of KLX02

The results of the generalized data, possible alteration and fracture estimations of KLX02 are presented in Figure 5-8 below, and in a more detailed scale in Appendix 5.

The silicate density varies a great deal in KLX02, which indicates large variations in mineral composition of the rocks in the vicinity of the borehole. Section c. 200–400 m is dominated by silicate densities that indicate a mineral composition corresponding to granite. Thin anomalies of higher densities, possibly related to more basic dykes, also occur. Between c. 400 m and c. 670 m depth, sections of higher densities (mainly indicating granodiorite and tonalite mineral compositions, but also even rocks of higher density) occur much more frequently, and these parts are generally longer than for the depth section 200–400 m. From c. 670 m depth down to 1,000 m, fairly long sections (>20 m) of rocks with an indicated diorite-gabbro composition occur frequently between sections where the silicate density indicates mainly granitic mineral composition. Between 200 m and c. 780 m depth the magnetic susceptibility is generally high, in the range of 0.01–0.1 SI. Minor sections of low and moderate magnetic susceptibility are also indicated. From 780 m depth down to c. 950 m depth, the number and length of the low-moderate magnetic susceptibility sections is increased. The natural gamma radiation shows a clear co-variation with the silicate density. Between 200 m and 650 m depth the natural gamma radiation mainly varies from moderate to high levels (probably indicating a larger occurrence of more felsic rocks), whereas from c. 650 depth down to 1,000 m depth the radiation level is mainly moderate to low. The latter most likely corresponds to rocks with a dominant basic composition.

At c. 200–750 m depth the estimated fracture frequency is generally low, apart from about 10 scattered short section of slightly increased fracturing. Below c. 750 m depth, down to c. 975 m depth, there is clear increase in the fracture frequency, varying between moderate and high, which may indicate the occurrence of a large deformation zone. There are several short to moderate sections of possible alteration indicate along the entire borehole. However, these are mainly concentrated between 400–600 m depth and 700–1,000 m depth.

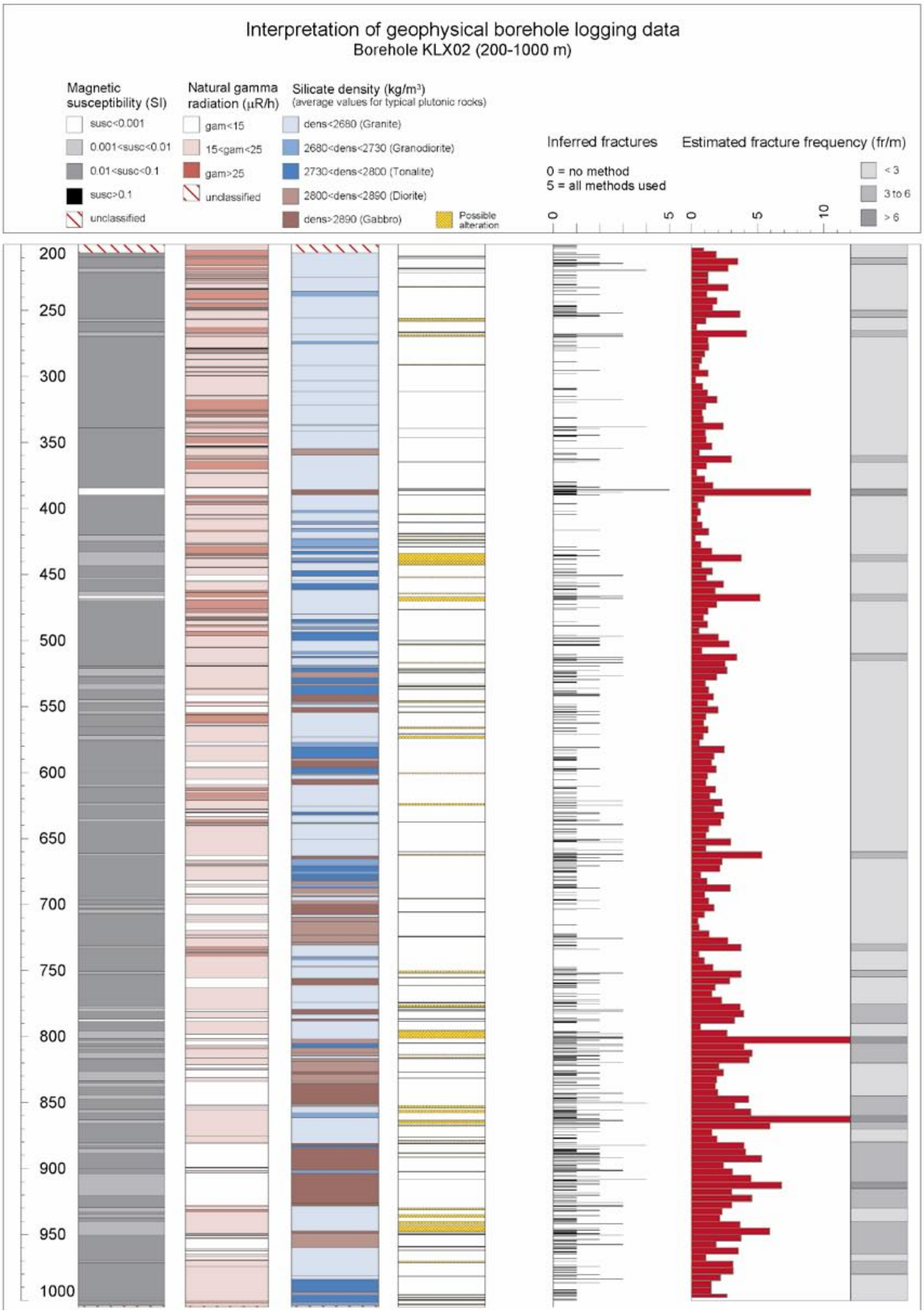


Figure 5-8. *Generalized geophysical logs for KLX02 (200–1,000 m).*

5.3.6 Elastic moduli of KLX02

Since the logging contractor has delivered both P-wave velocity (v_p) and S-wave velocity (v_s) sonic logs, as well as a density (ρ) log for KLX02, it is possible to calculate estimations of the shear modulus (μ), the bulk modulus (K) and Young's modulus (E) according to the following equations from /5/:

$$\mu = v_s^2$$

$$K = \rho v_p^2 - \frac{4}{3}\mu$$

$$E = \frac{9K\mu}{3K + \mu}$$

A coarsely generalized result is presented in Figure 5-9 below, and more detailed elastic moduli logs are presented in Appendix 5 together with the other geophysical logs of KLX02.

Between c. 200 m and 500 m depth the bulk modulus is mainly in the range of 40–50 GPa and Young's modulus mainly is in the range of 70–80 GPa. Along the section c. 500 m down to 730 m, the bulk modulus increases to 50–60 GPa and Young's modulus is mainly 80–90 GPa. At c. 730–810 m depth the bulk and the Young's moduli decrease to the levels 40–50 GPa and 70–80 GPa respectively, and there is another increase in the bulk and Young's moduli at c. 810–850 m depth. The shear modulus lay fairly constant at the level 30–35 GPa, apart from a few minor ups and lows, from 200 m down to c. 850. Between 850 m and 880 m depth all three elastic moduli decrease, and at c. 880 m depth they all partly reach their maximum levels, down to c. 930 m depth.

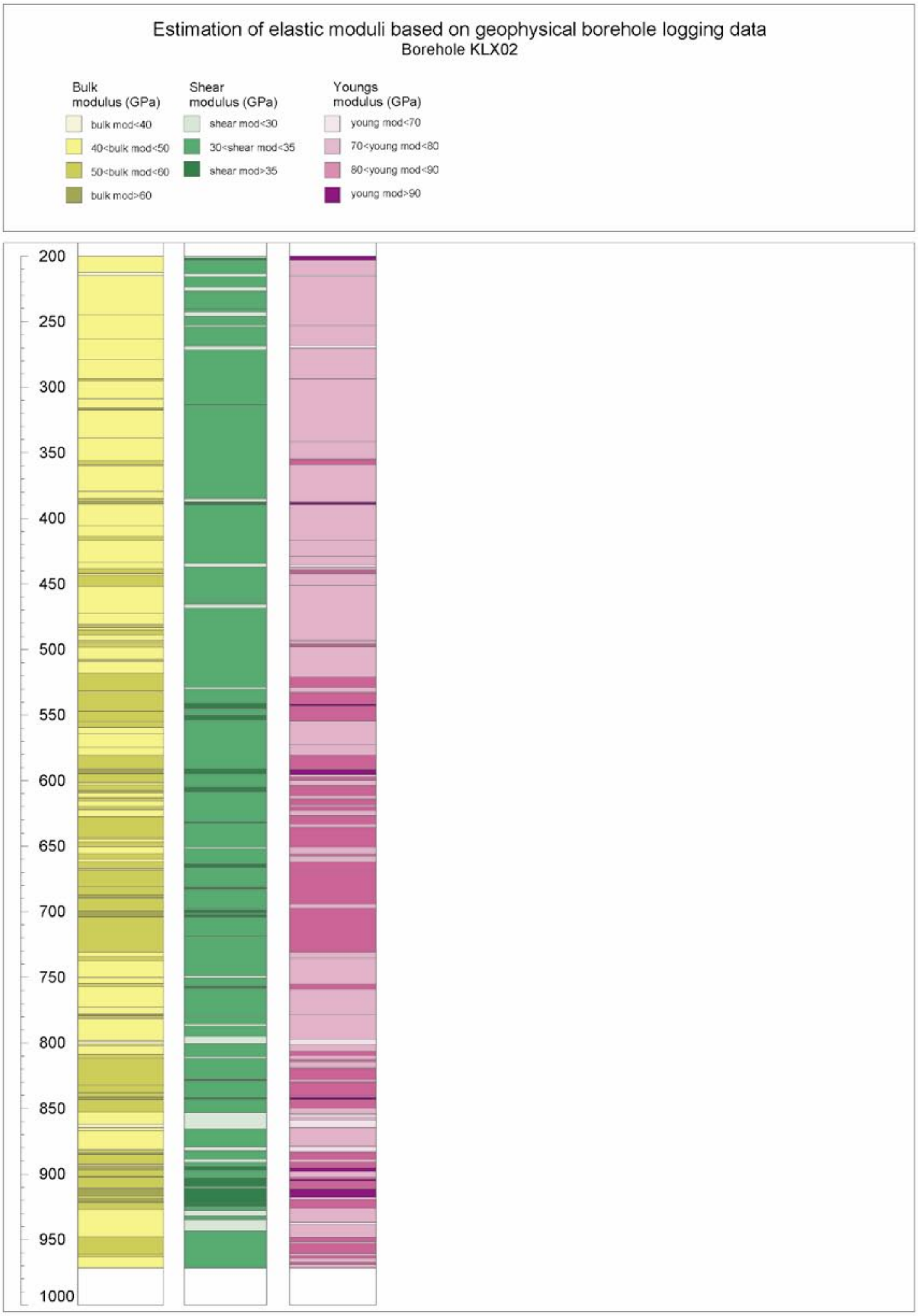


Figure 5-9. *Generalized elastic moduli logs for KLX02 (200–1,000 m). See the text for explanation.*

6 Discussion and conclusions

The density log data of KSH03A, HAV10 and KLX02, and the sonic log data from HAV09, HAV10 and KLX02, all show unacceptably high noise levels. Even though it is possible to largely suppress the noise by different kinds of filtering, it is still possible that the high noise levels have affected the interpretation products presented in this report.

The rocks in the vicinity of the four boreholes KSH03A, KSH03B, HAV09 and HAV10 are mainly dominated by silicate densities that indicate a mineral composition corresponding to granite. However, in KSH03B there are two fairly long sections (covering about 50% of the borehole length) of significantly higher densities, indicating a mineral composition mainly corresponding to diorite or gabbro. Also in the other three boreholes there are scattered occurrences of mainly short (a few 5–20 m long) parts of high density rocks. It must be pointed out that the susceptibility-density rock classification diagram (Figure 5-1, Section 5.1) shows that the Ävrö granite of KSH03A carries a silicate density indicating a composition varying from granite up to tonalite rock (bearing in mind that the rock sample classification is only preliminary). The natural gamma radiation is mainly moderate in KSH03A, and mainly low in KSH03B, HAV09 and HAV10. Short sections of high natural gamma radiation occur rather frequent in all four boreholes. They most likely correspond to fine-grained granite or pegmatite dykes. The magnetic susceptibility is dominated by moderate magnetization levels (0.01–0.1 SI). Low magnetic sections co-vary with increased fracturing and/or zones of possible alteration. Strongly increased fracturing and alteration is indicated along the section 100–300 m of KSH03A and section 70–105 m of HAV09. These two sections most likely indicate occurrences of deformation zones. Several sections of mainly moderate fracture frequency are also indicated in KSH03B.

No control of the absolute levels of the magnetic susceptibility log and the density log of KLX02 (200–1,000 m) was performed, since no petrophysical data were available. The data of KLX02 are fairly different compared to those from the Ävrö Island and the Simpevarp peninsula. Section c. 200–400 m is dominated by silicate densities mainly indicating granite mineral composition. Along the section c. 400–700 m there is a frequent occurrence of rocks with indicated granodiorite-tonalite silicate densities. From c. 700 m depth down to 1,000 m depth, there are several long sections where the silicate density indicates a mineral composition that corresponds to diorite-gabbro. The estimated fracture frequency is generally low from 200 m down to c.750 m depth. Below c. 750 m depth, down to c. 975 m depth, there is clear increase in the fracture frequency, varying between moderate and high, which may indicate the occurrence of a deformation zone.

The reliability of the elastic moduli calculated for KLX02 mainly depends on the quality of the sonic P and S wave determinations. Both P and S wave data show reasonable mean levels and variation magnitudes (though the P-wave data are rather noisy). Also the estimated elastic moduli appear to be reasonable for crystalline rocks.

References

/1/ **Mattsson H, Thunehed H, 2003.** Measurements of petrophysical parameters on rock samples during autumn 2002. SKB P-03-19, Svensk Kärnbränslehantering AB.

/2/ **Henkel H, 1991.** Petrophysical properties (density and magnetization) of rock from the northern part of the Baltic Shield. Tectonophysics 192, 1–19.

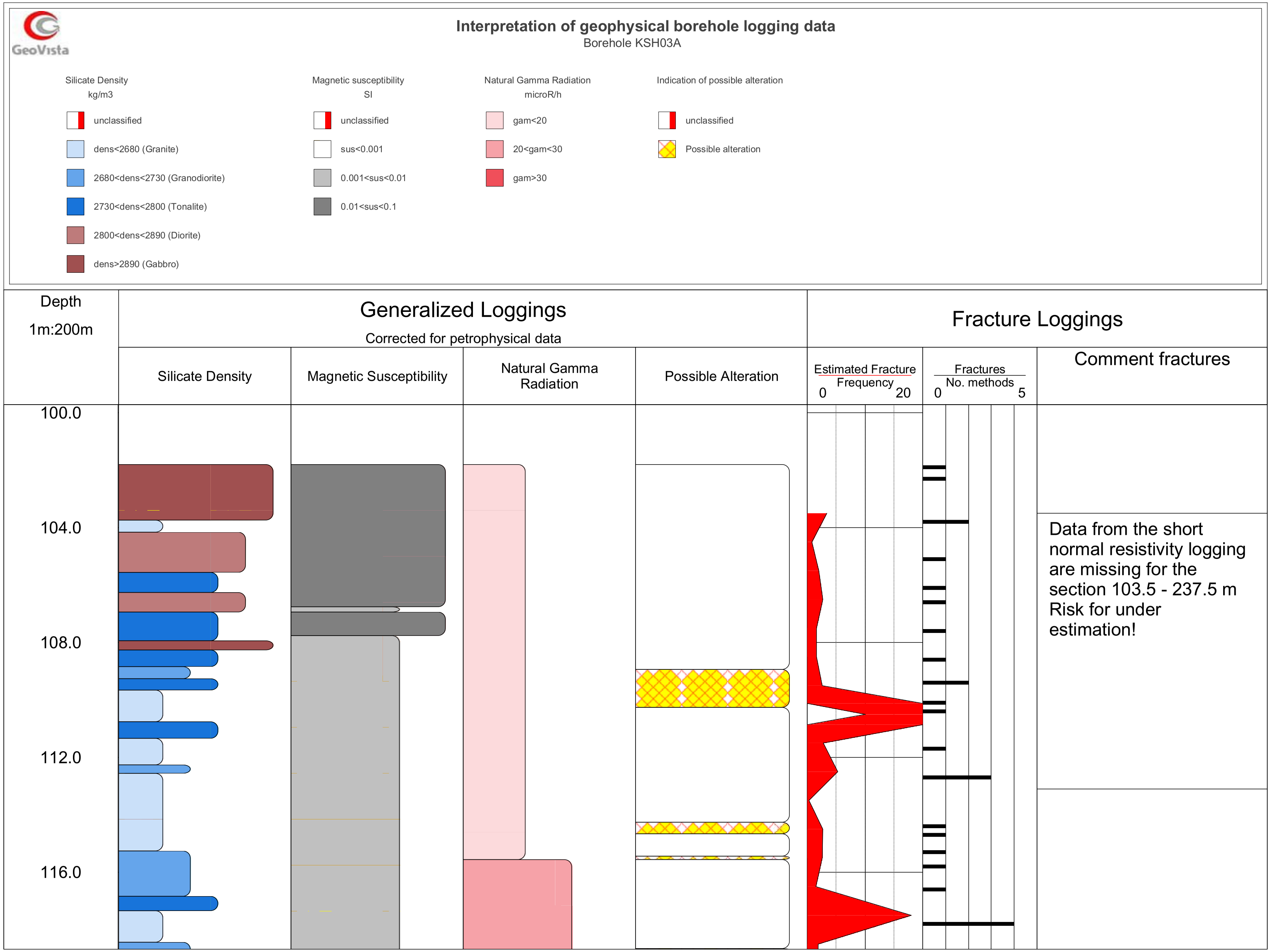
/3/ **Puranen R, 1989.** Susceptibilities, iron and magnetite content of precambrian rocks in Finland. Geological survey of Finland, Report of investigations 90, 45 pp.

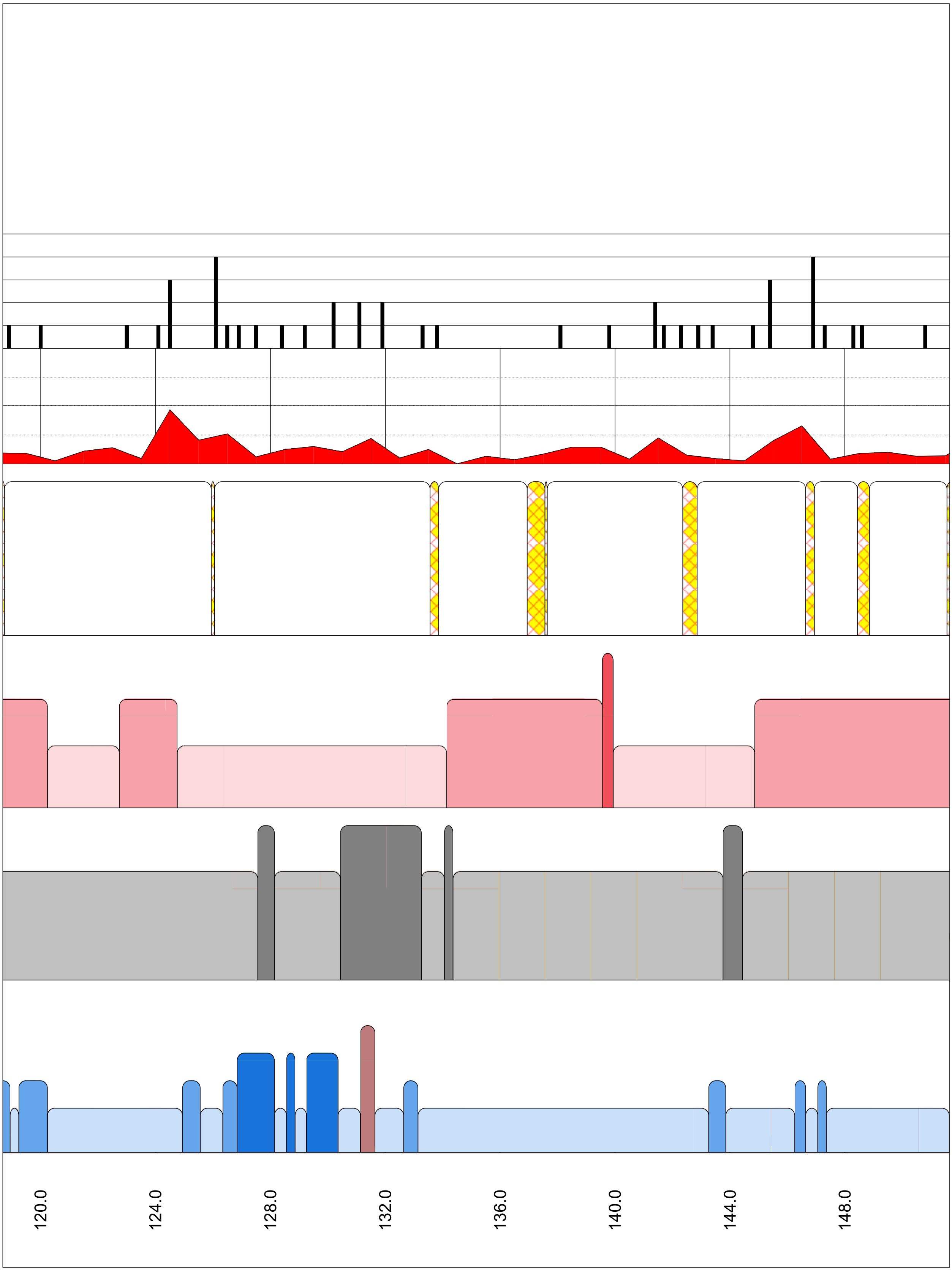
/4/ **Mattsson H, Thunehed H, 2004.** Interpretation of geophysical borehole data from KSH01A, KSH01B, KSH02 (0–100 m), HSH01, HSH02 and HSH03, and compilation of petrophysical data from KSH01A and KSH01B. SKB P-04-28, Svensk Kärnbränslehantering AB.

/5/ **Kulhánek O, 1993.** Propagation of seismic waves, lecture notes. Seismological department, Uppsala University, 161 pp.

Appendix 1

Generalized geophysical loggings for the borehole KSH03A (100–1,000 m)


GeoVista
Interpretation of geophysical borehole logging data
Borehole KSH03A
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Natural Gamma Radiation
microR/h
gam<20
20<gam<30
gam>30
Indication of possible alteration
unclassified
Possible alteration
Depth
1m:200m
Generalized Loggings
Corrected for petrophysical data
Silicate Density
Magnetic Susceptibility
Natural Gamma Radiation
Possible Alteration
Fracture Loggings
Estimated Fracture Frequency
0
20
Fractures
No. methods
0
5
Comment fractures
100.0
104.0
108.0
112.0
116.0
Data from the short normal resistivity logging are missing for the section 103.5 - 237.5 m
Risk for under estimation!



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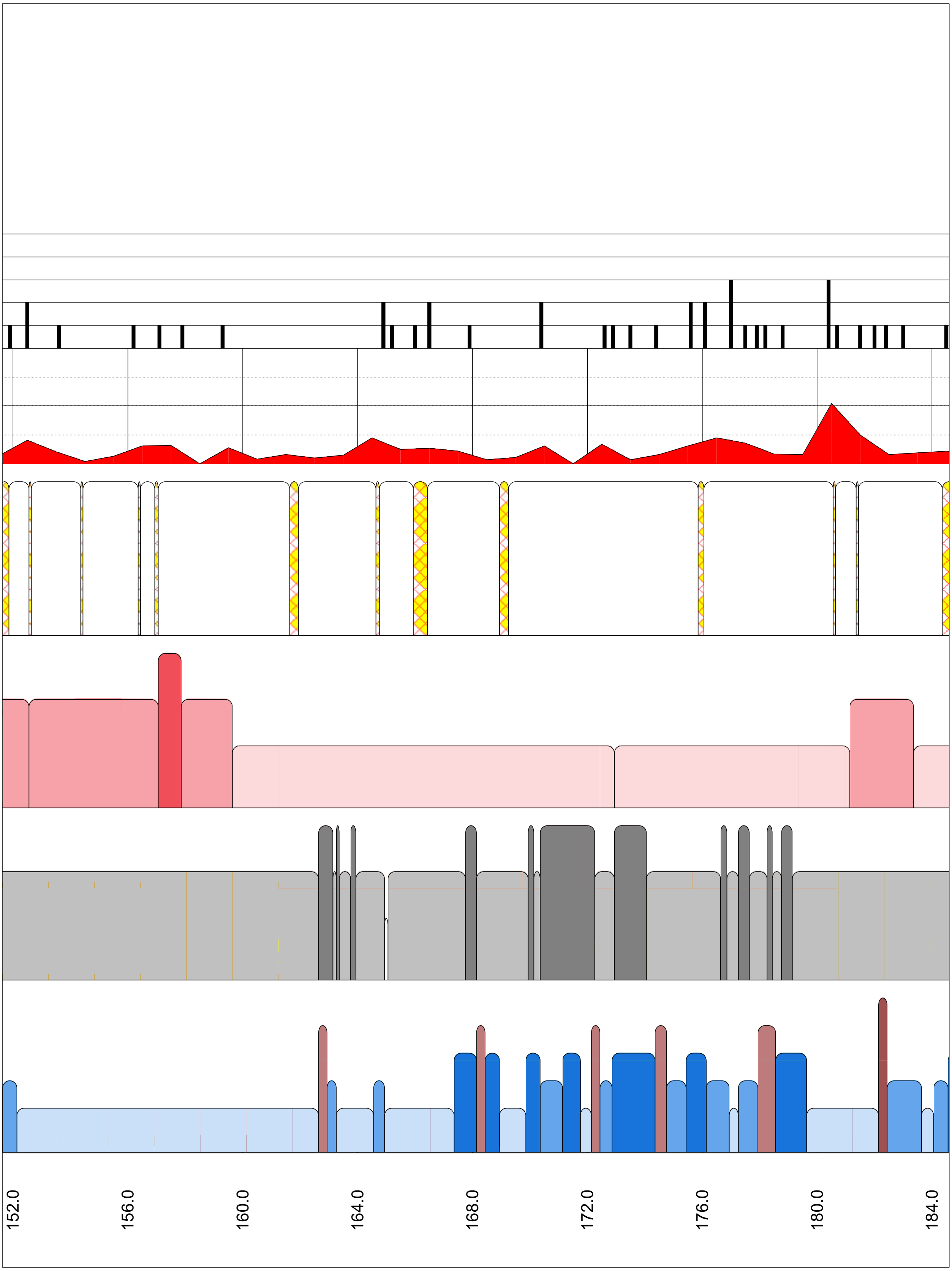
124.0
128.0
132.0
136.0
140.0
144.0
148.0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180.0
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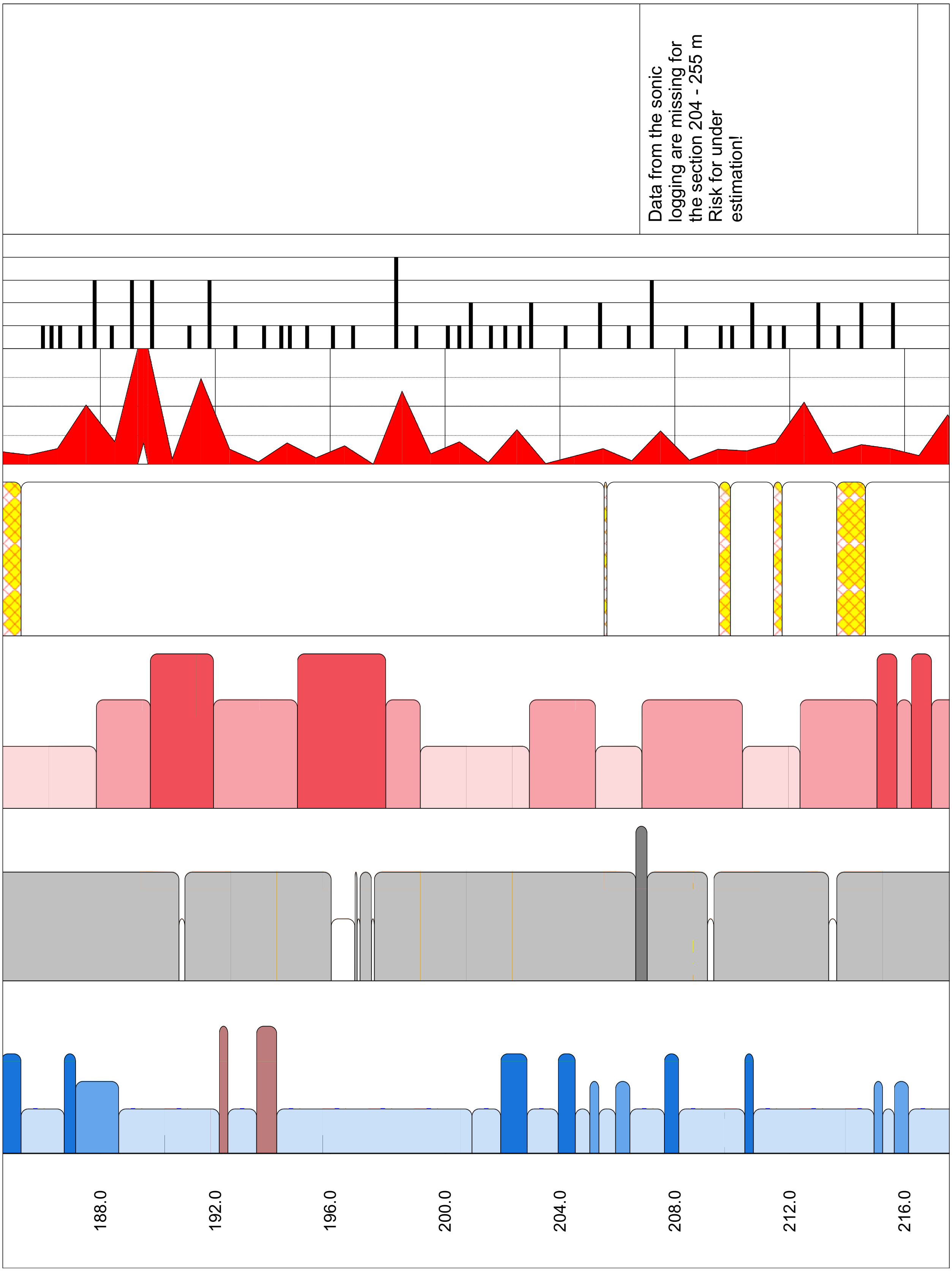
Data from the sonic logging are missing for the section 204 - 255 m Risk for under estimation!
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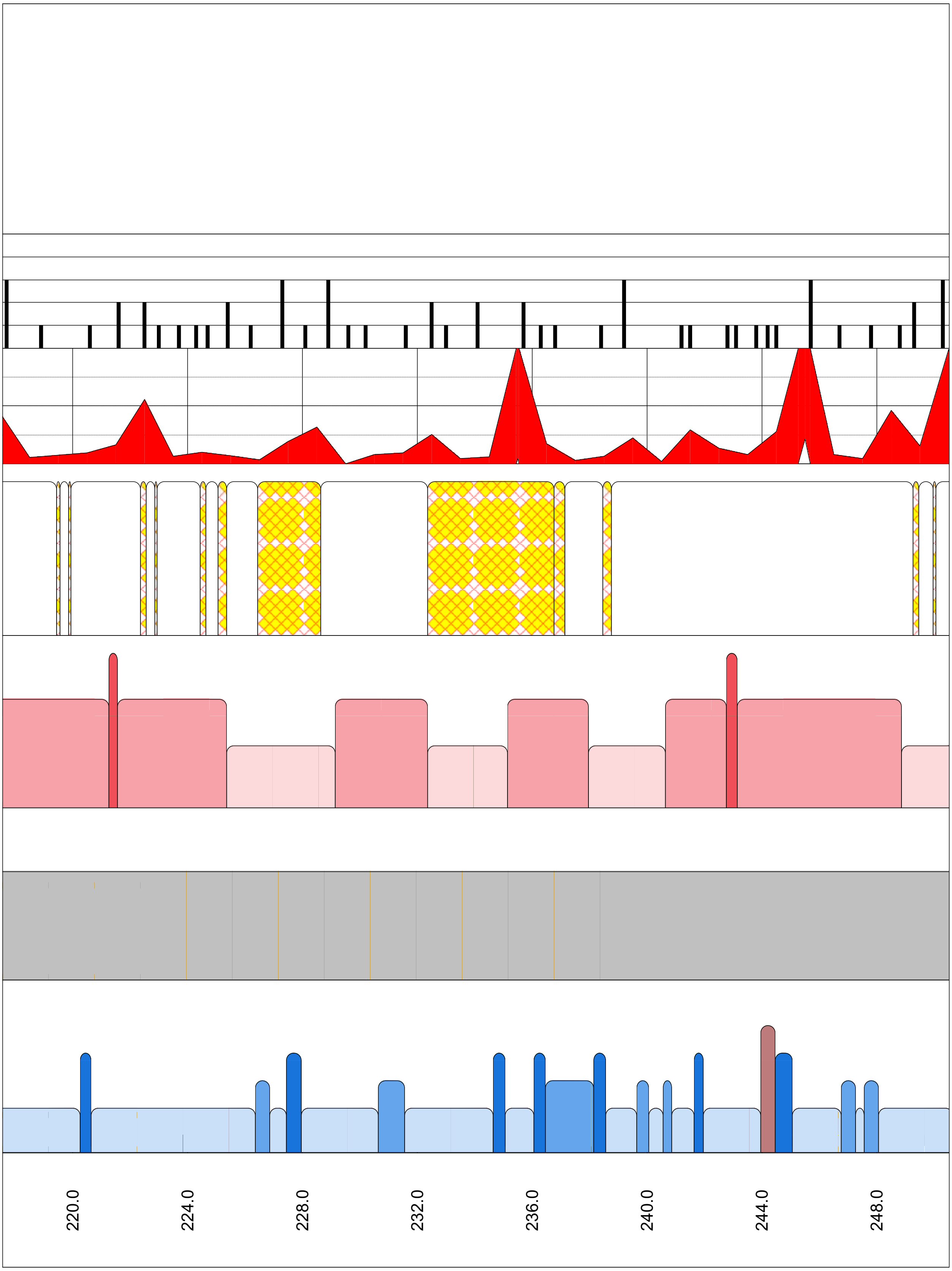
192.0
196.0
200.0
204.0
208.0
212.0
216.0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228.0
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244.0
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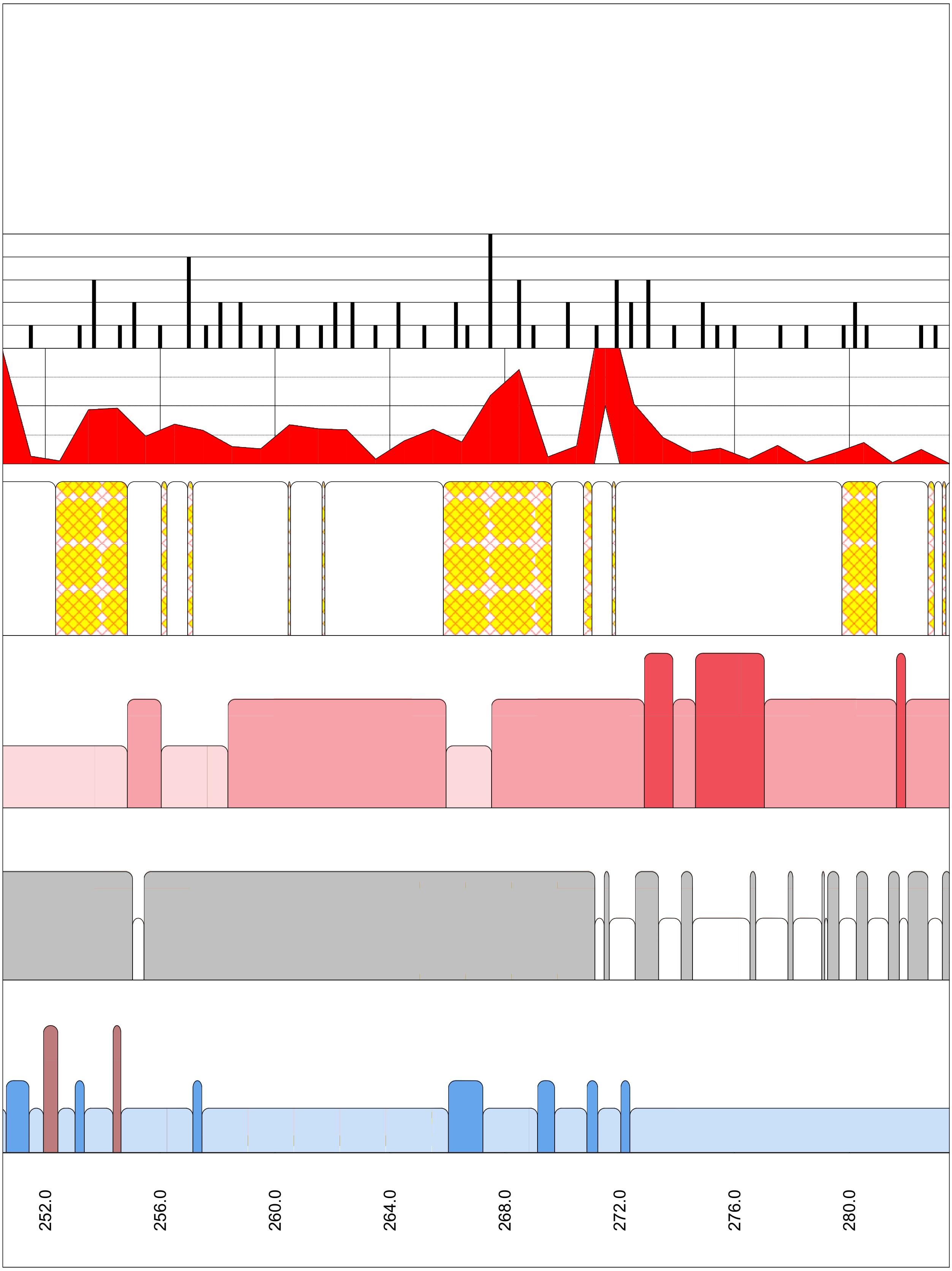
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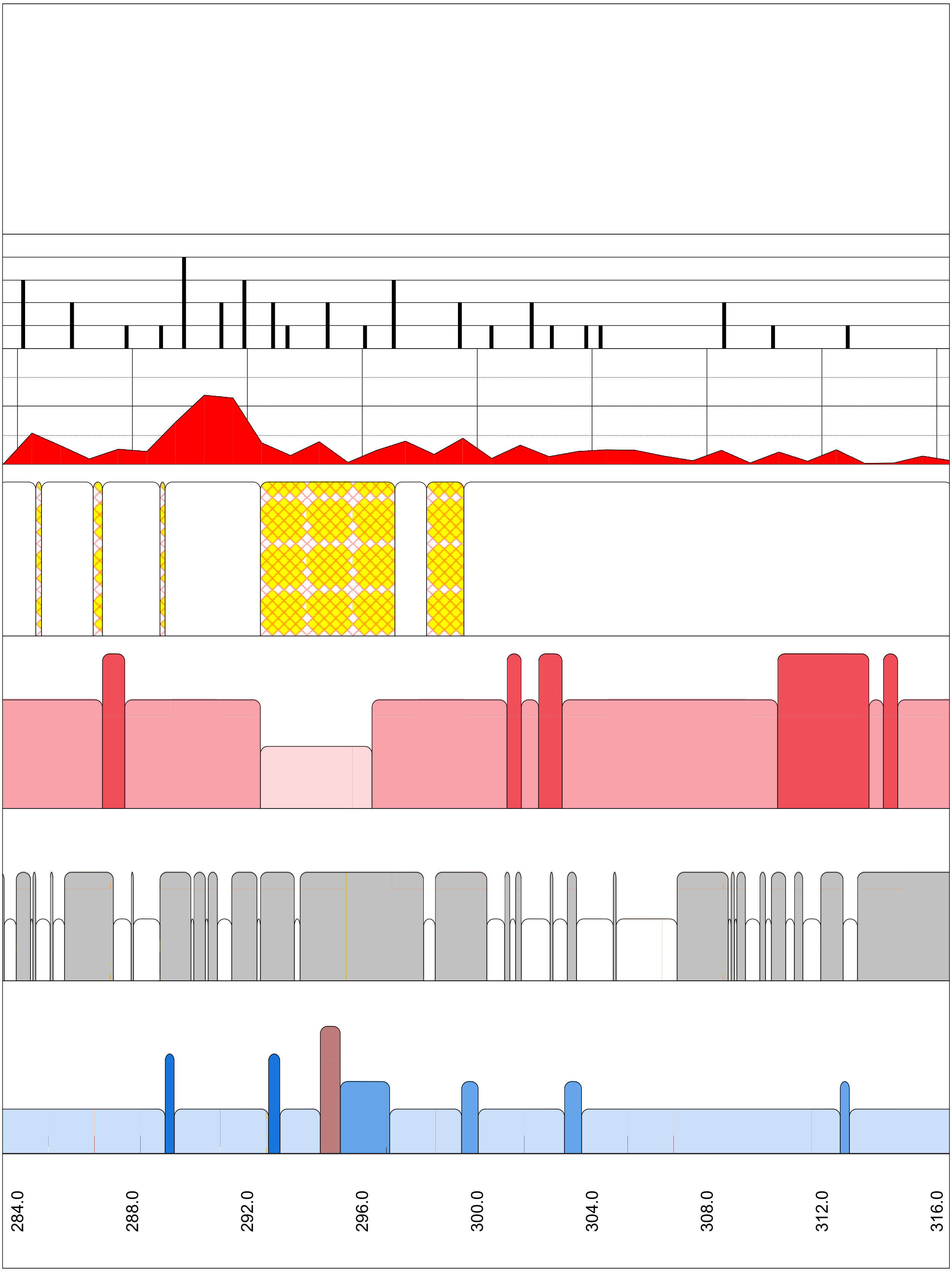
272.0
276.0
280.0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300.0
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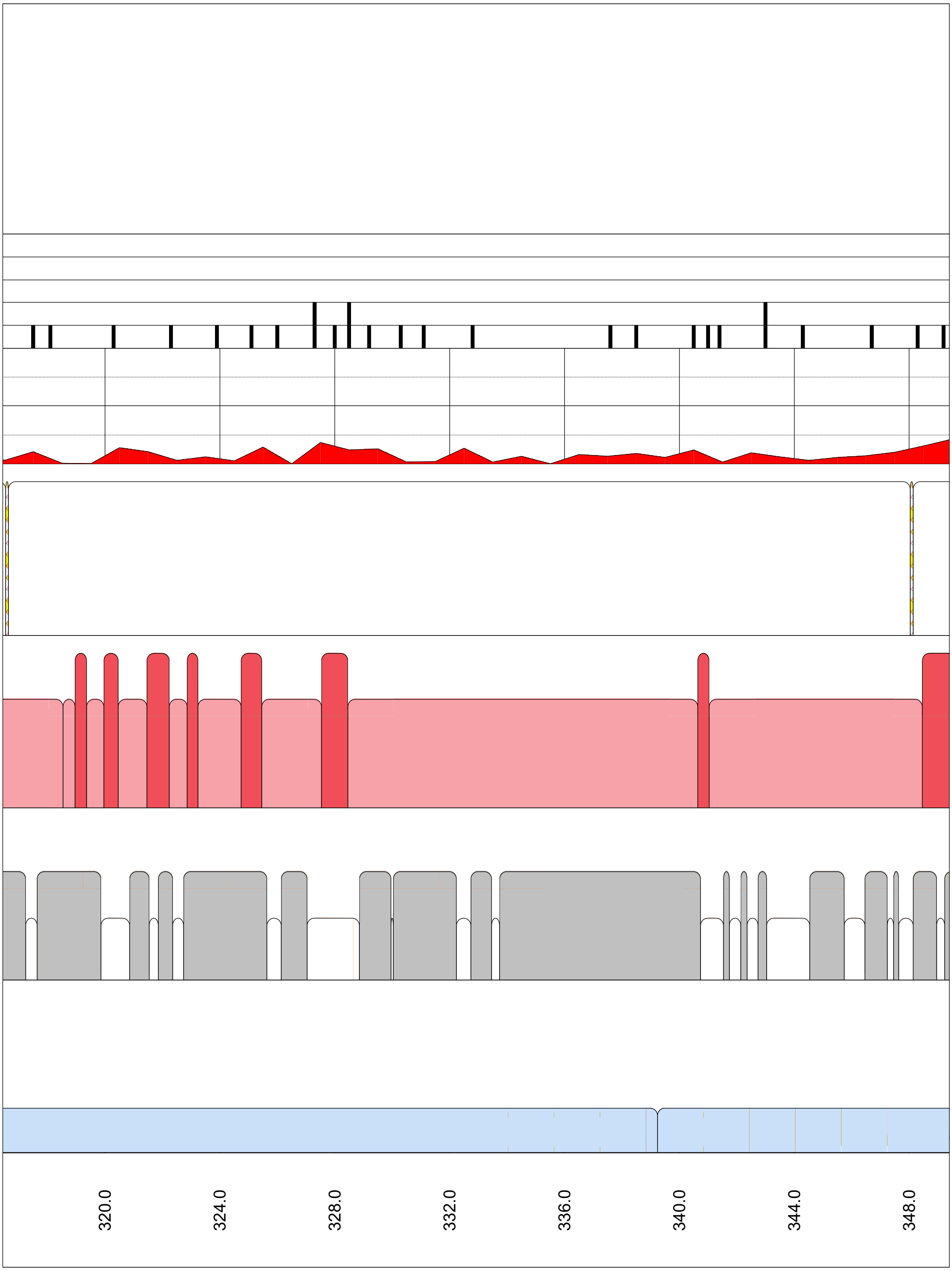
308.0
312.0
316.0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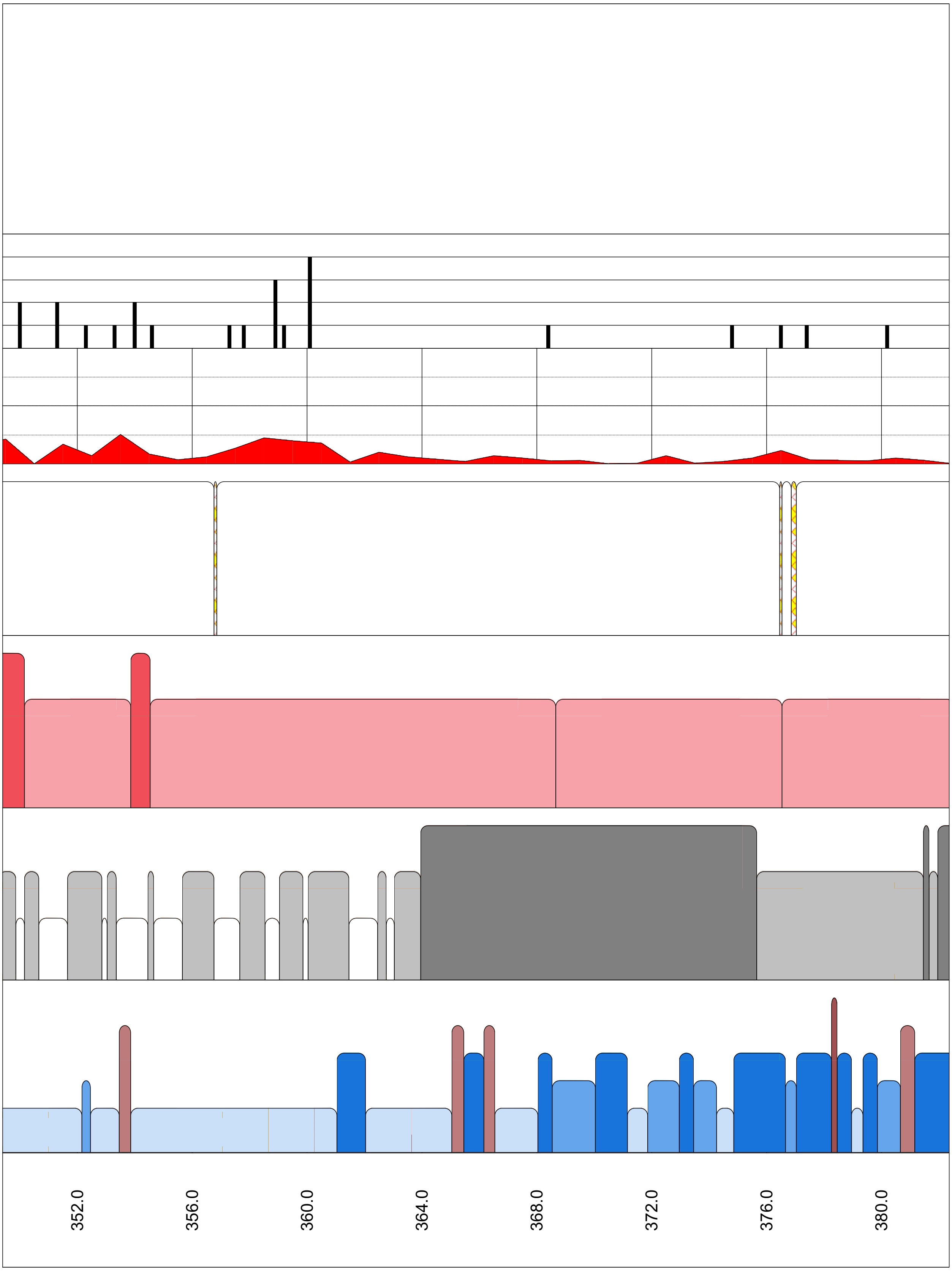
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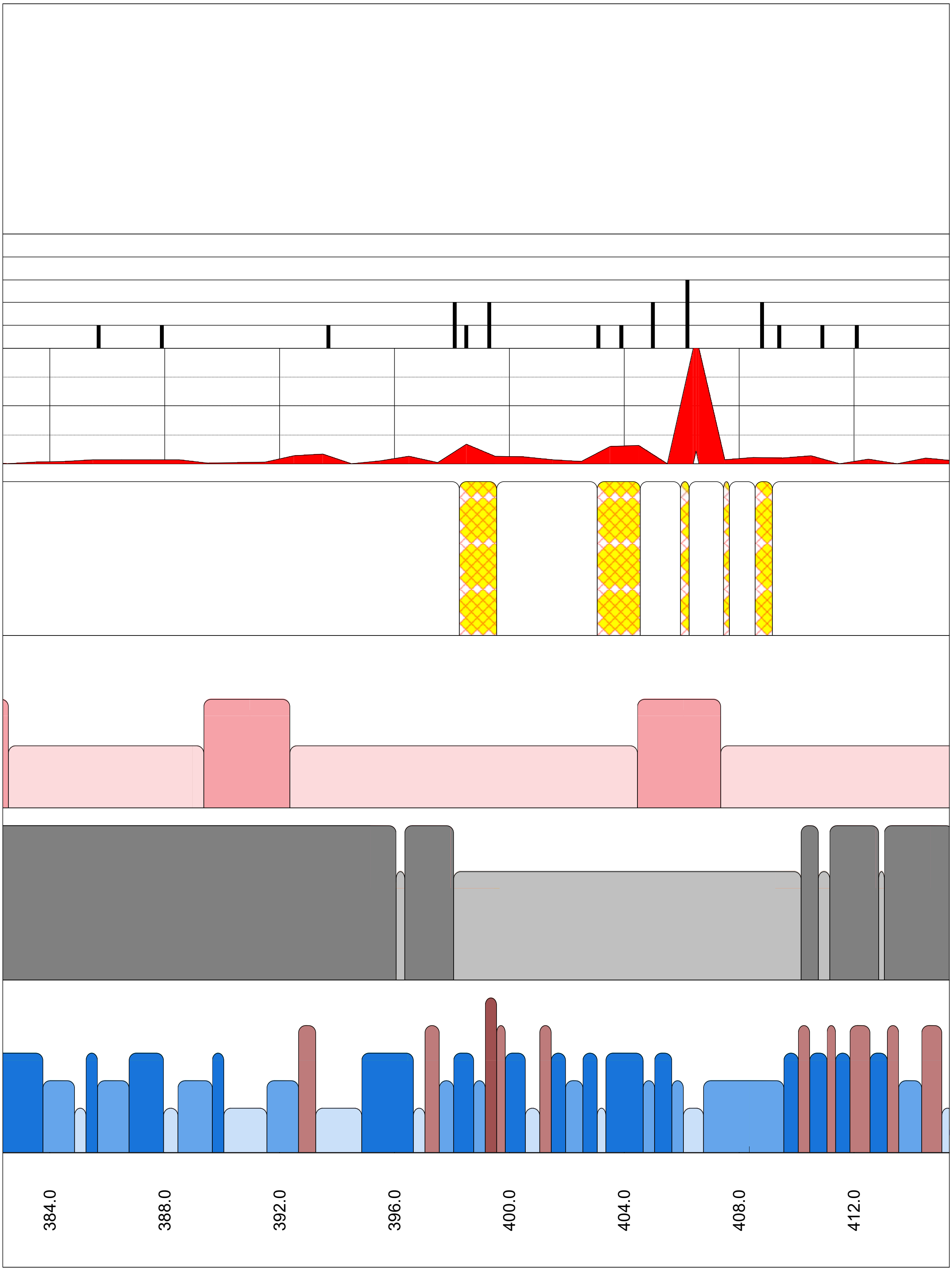
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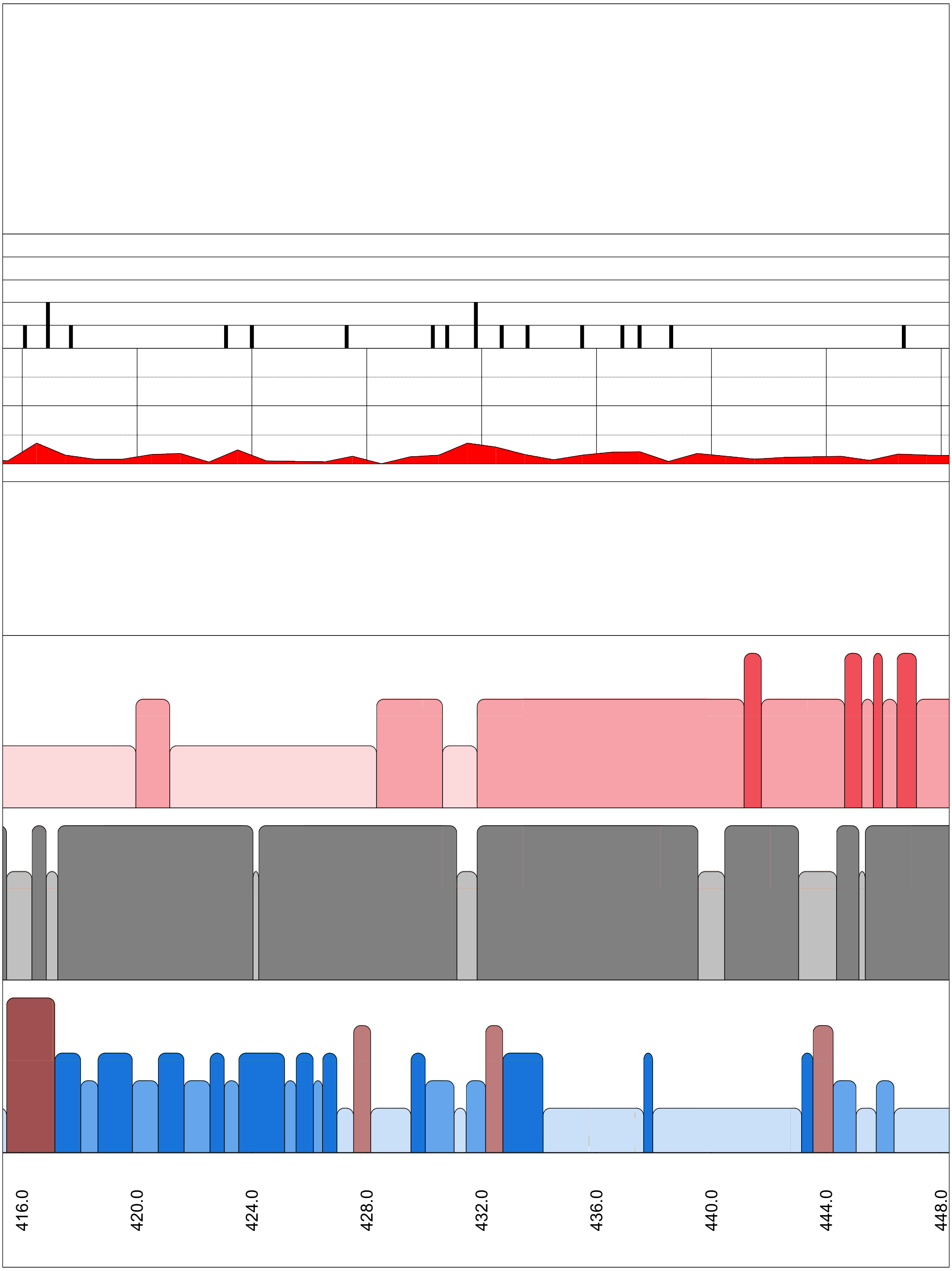
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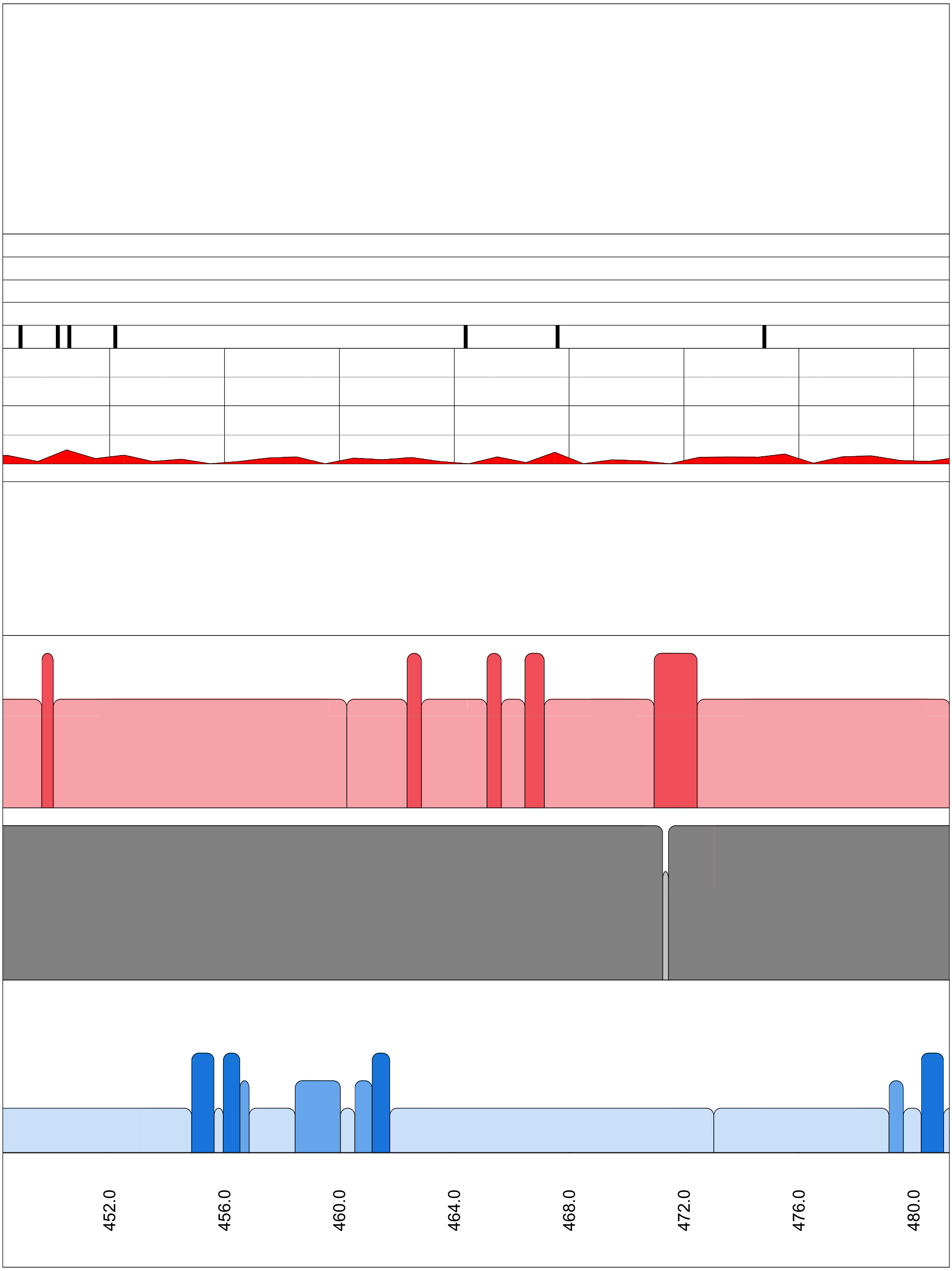
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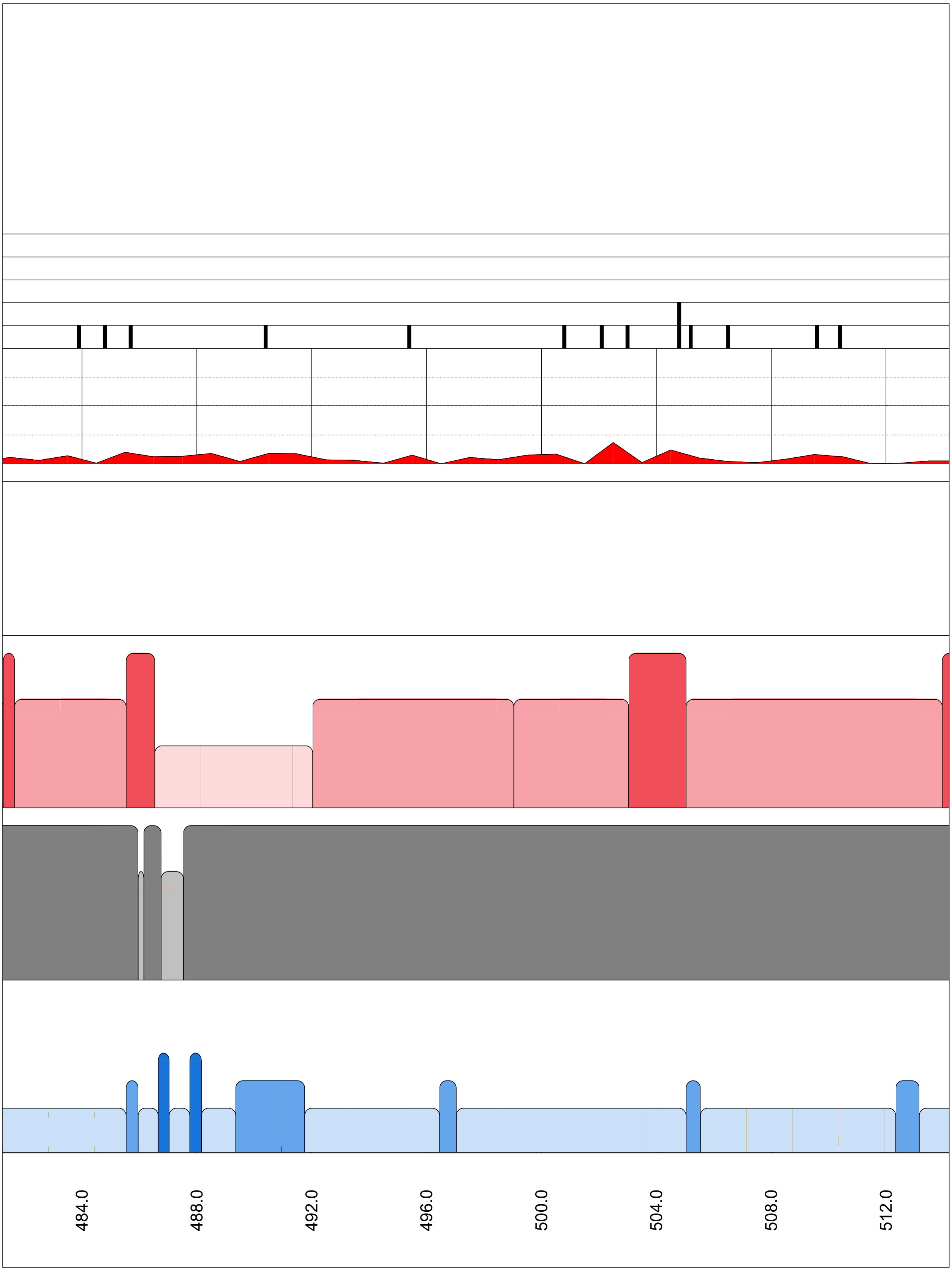
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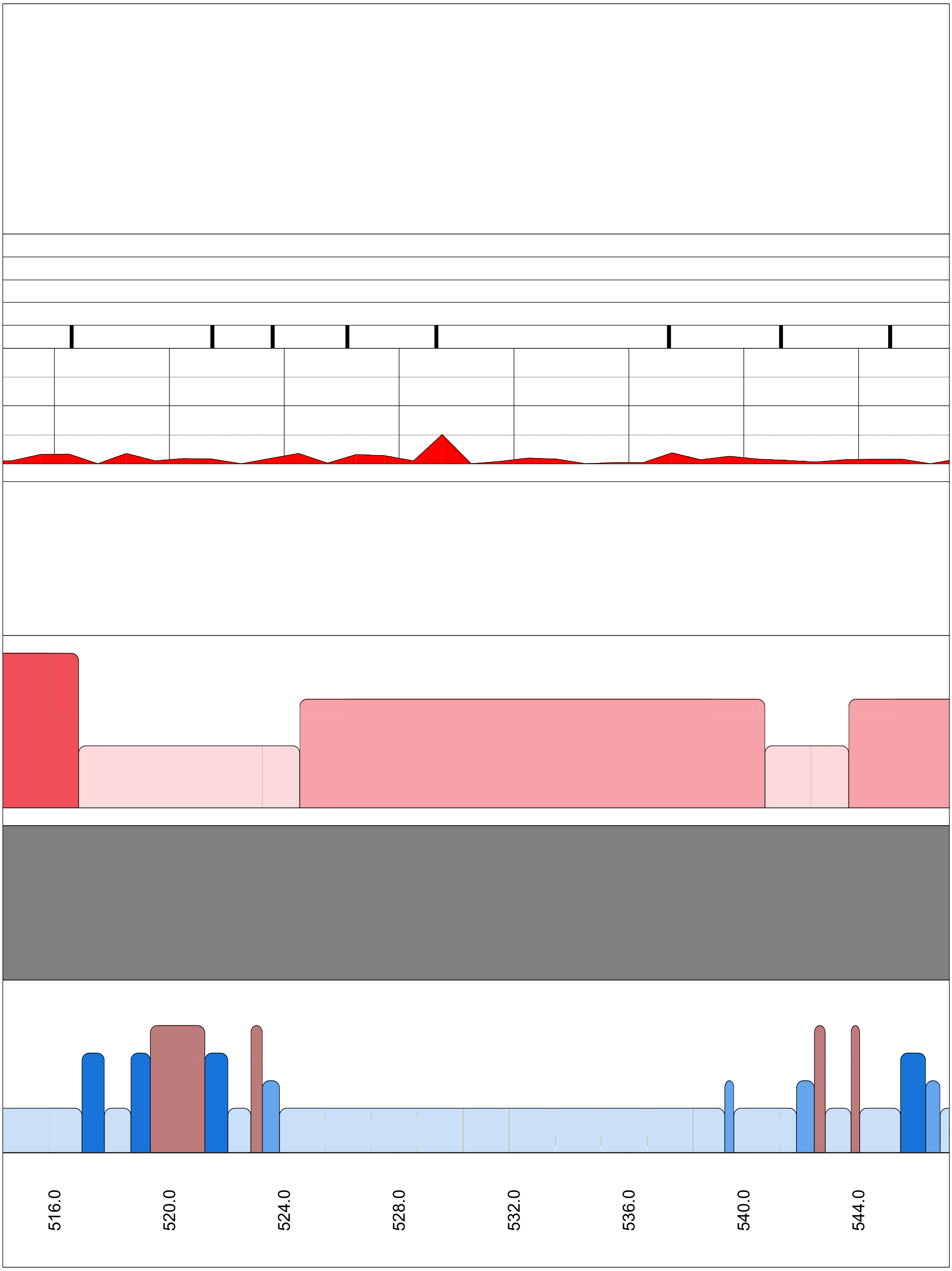
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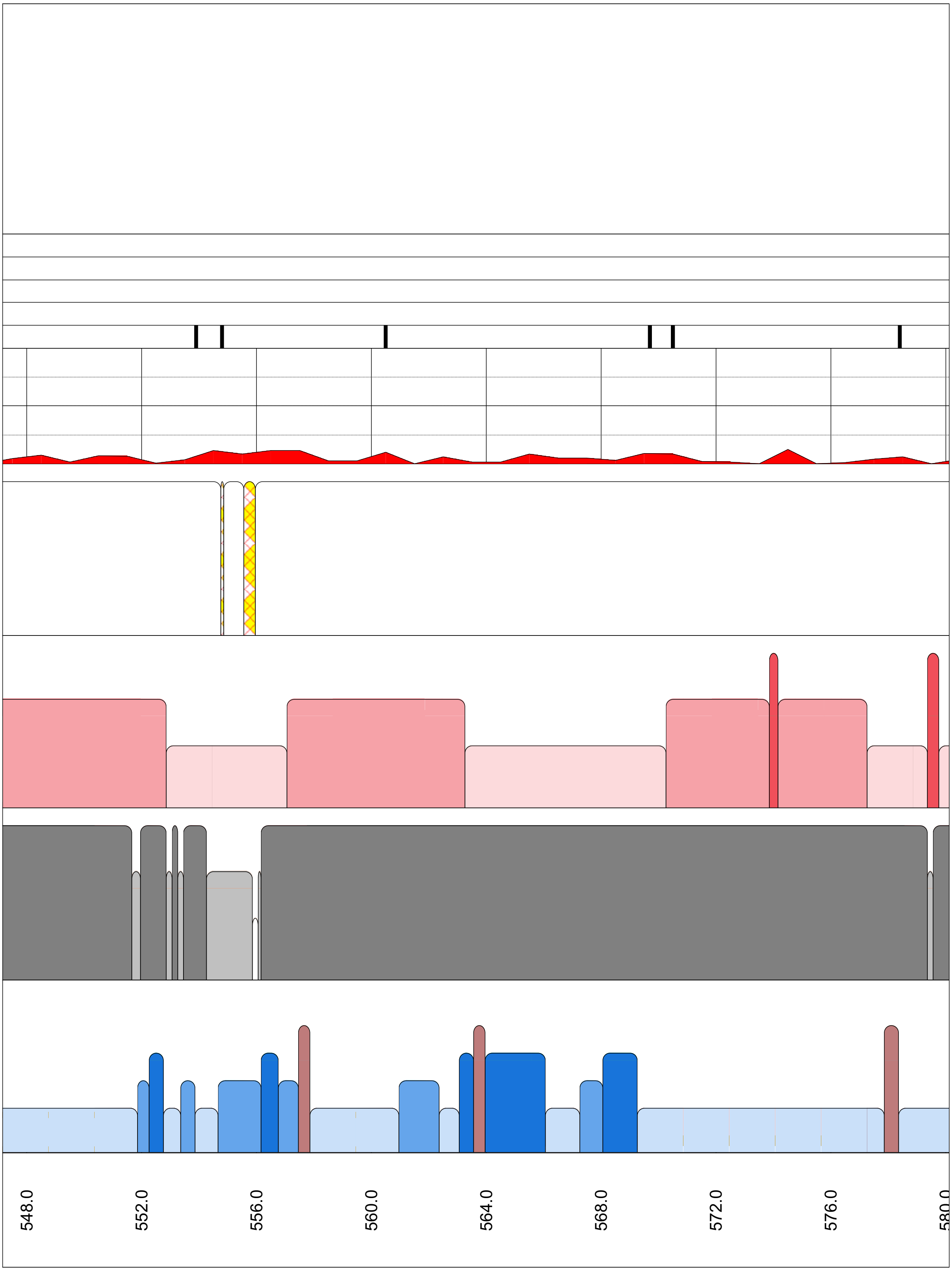
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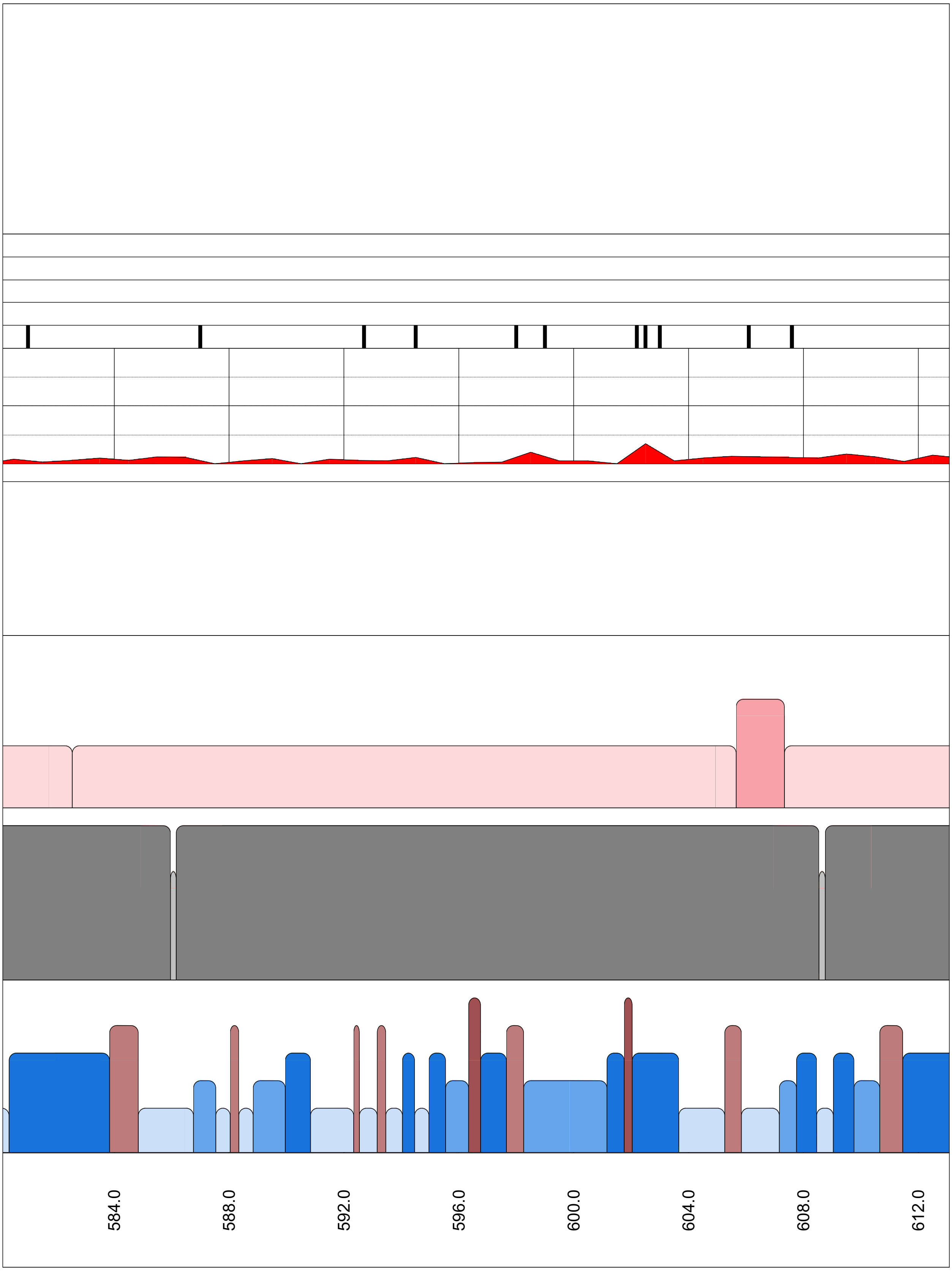
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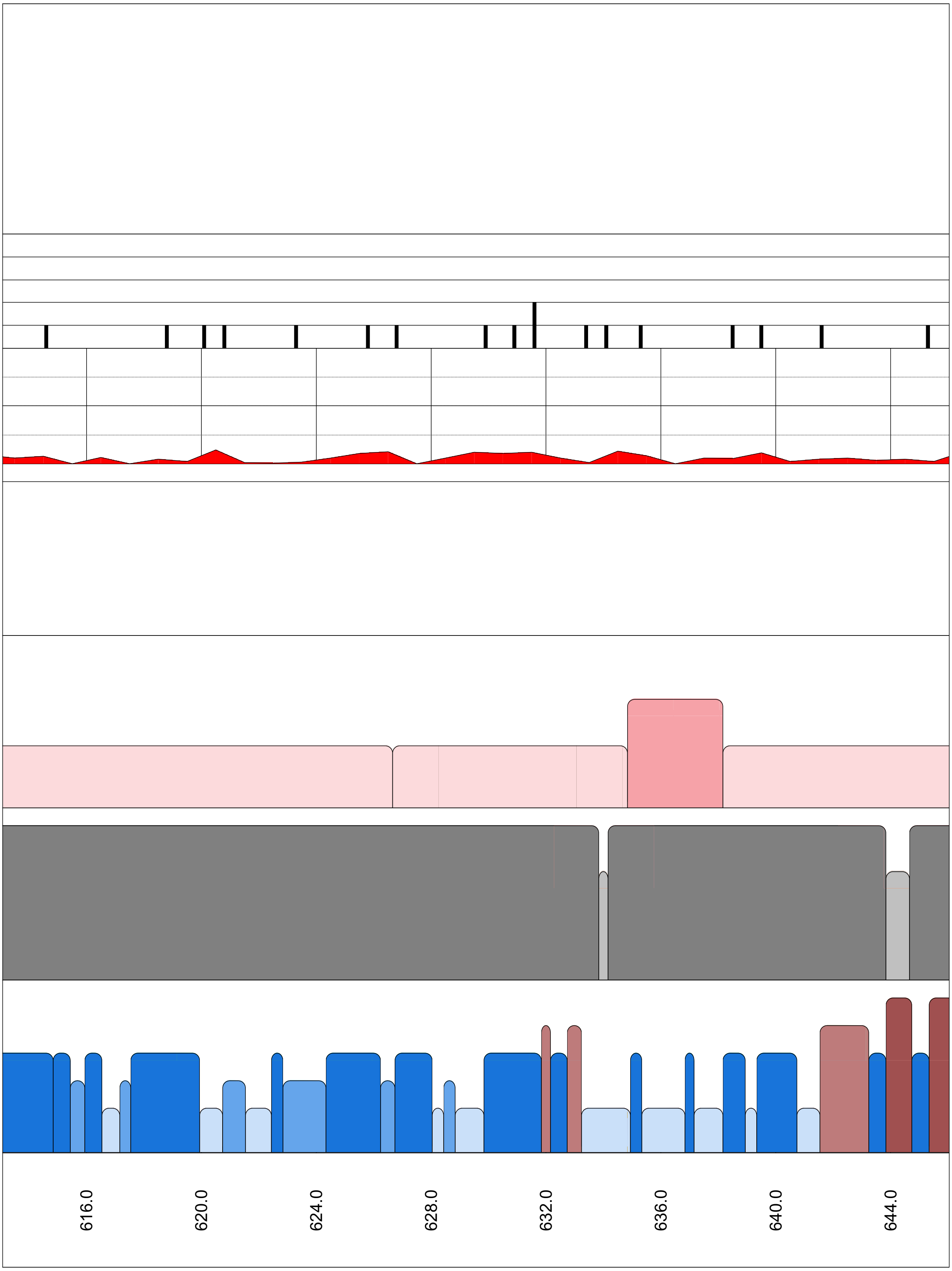
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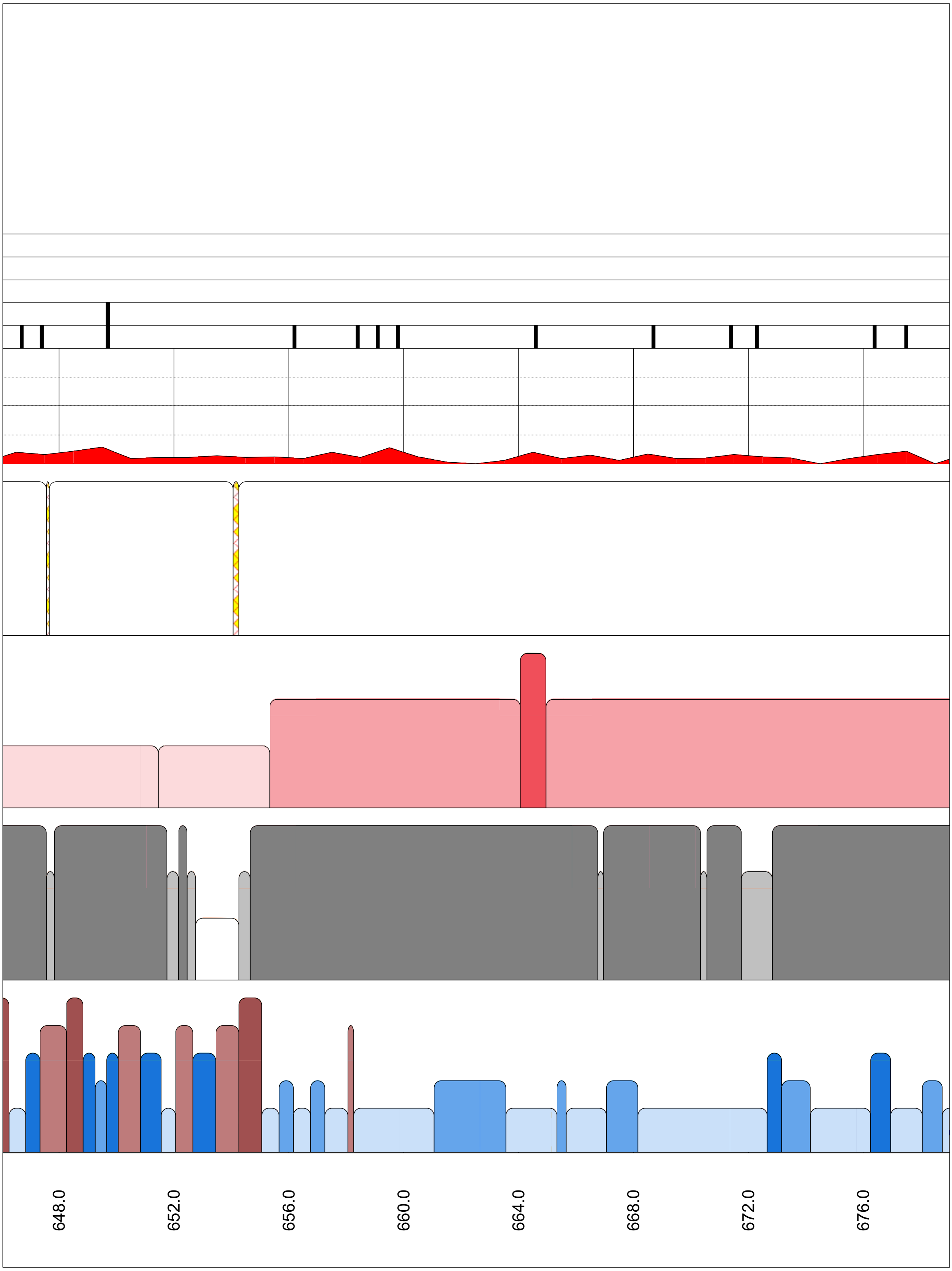
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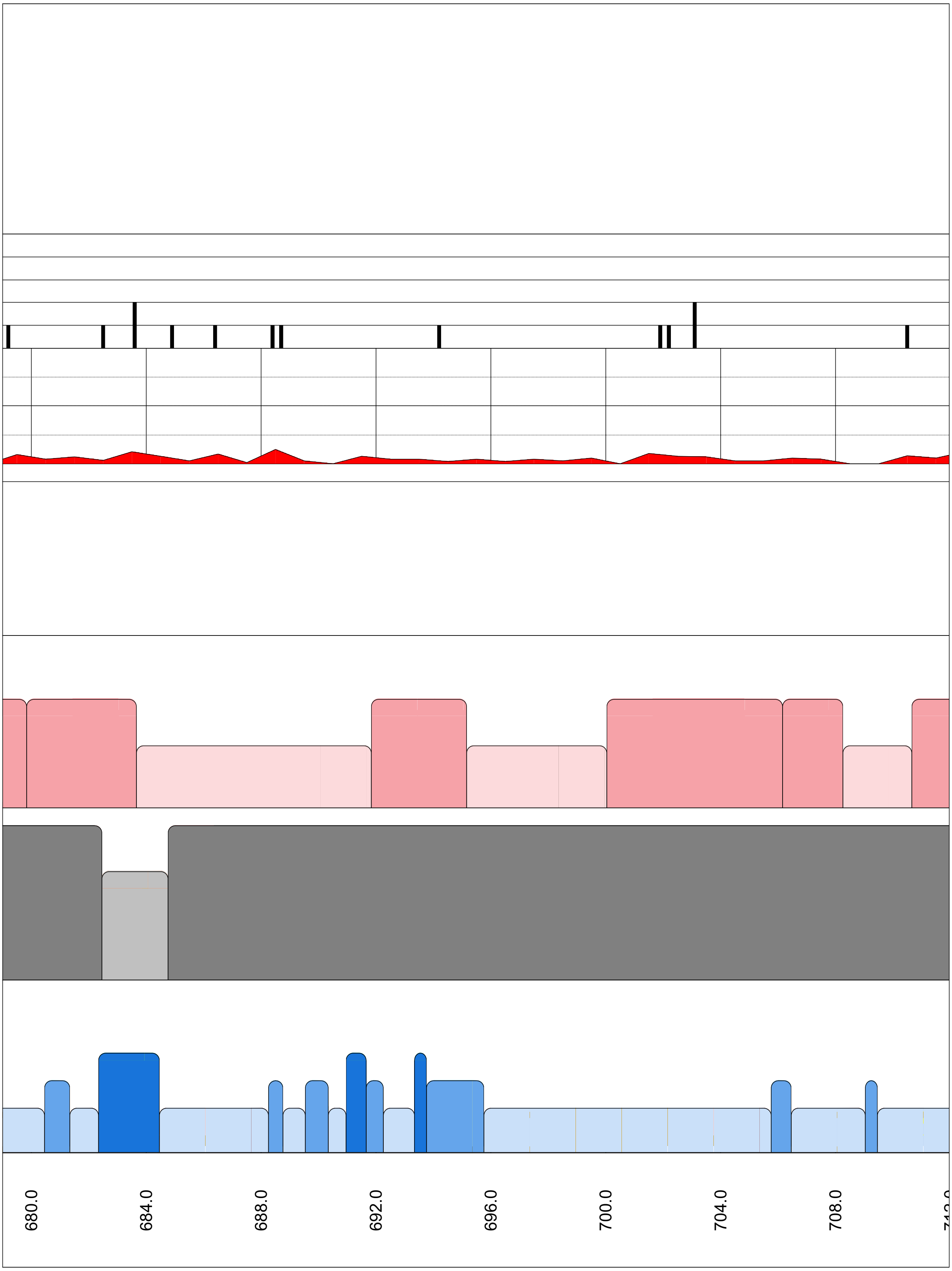
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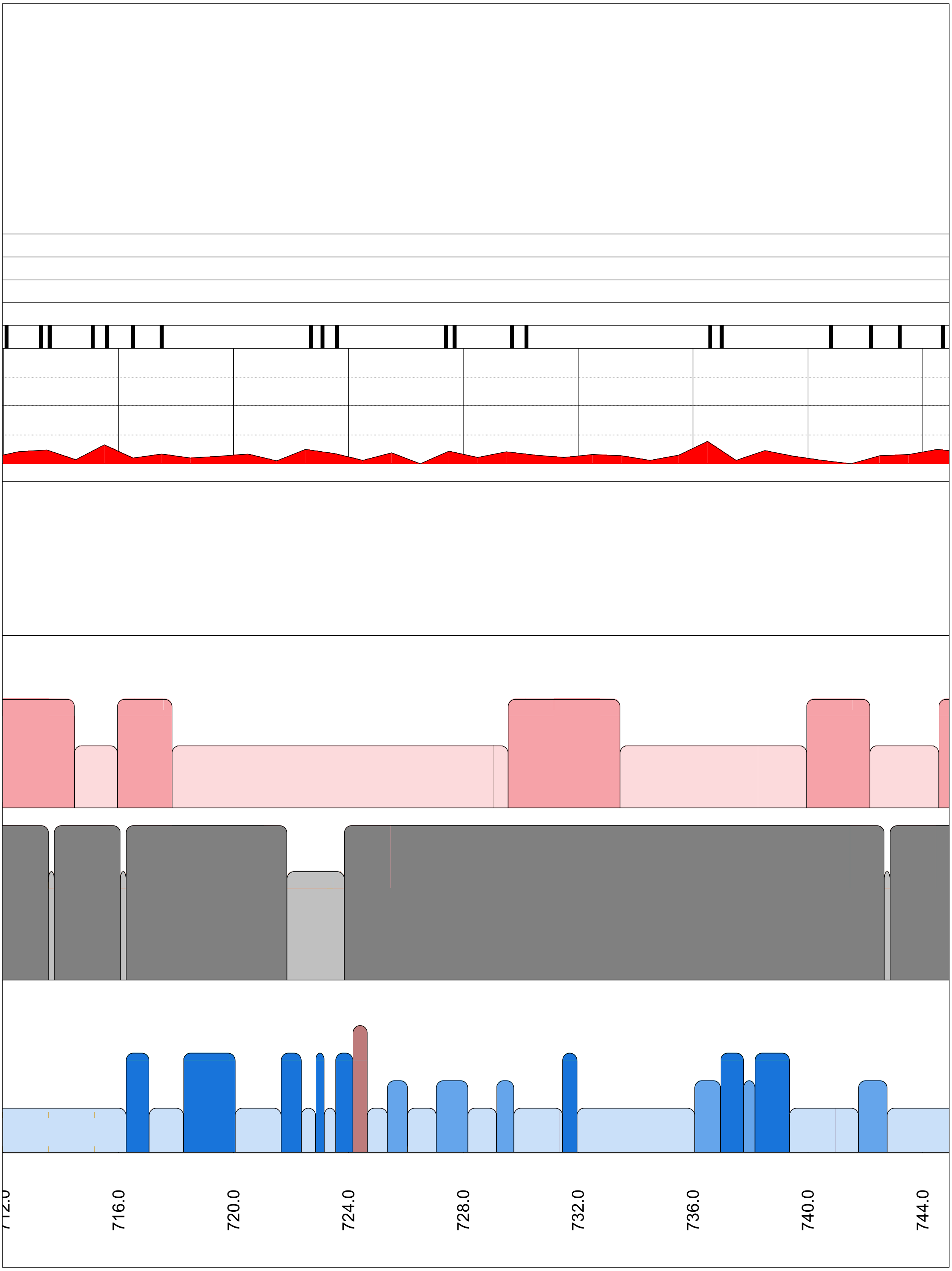
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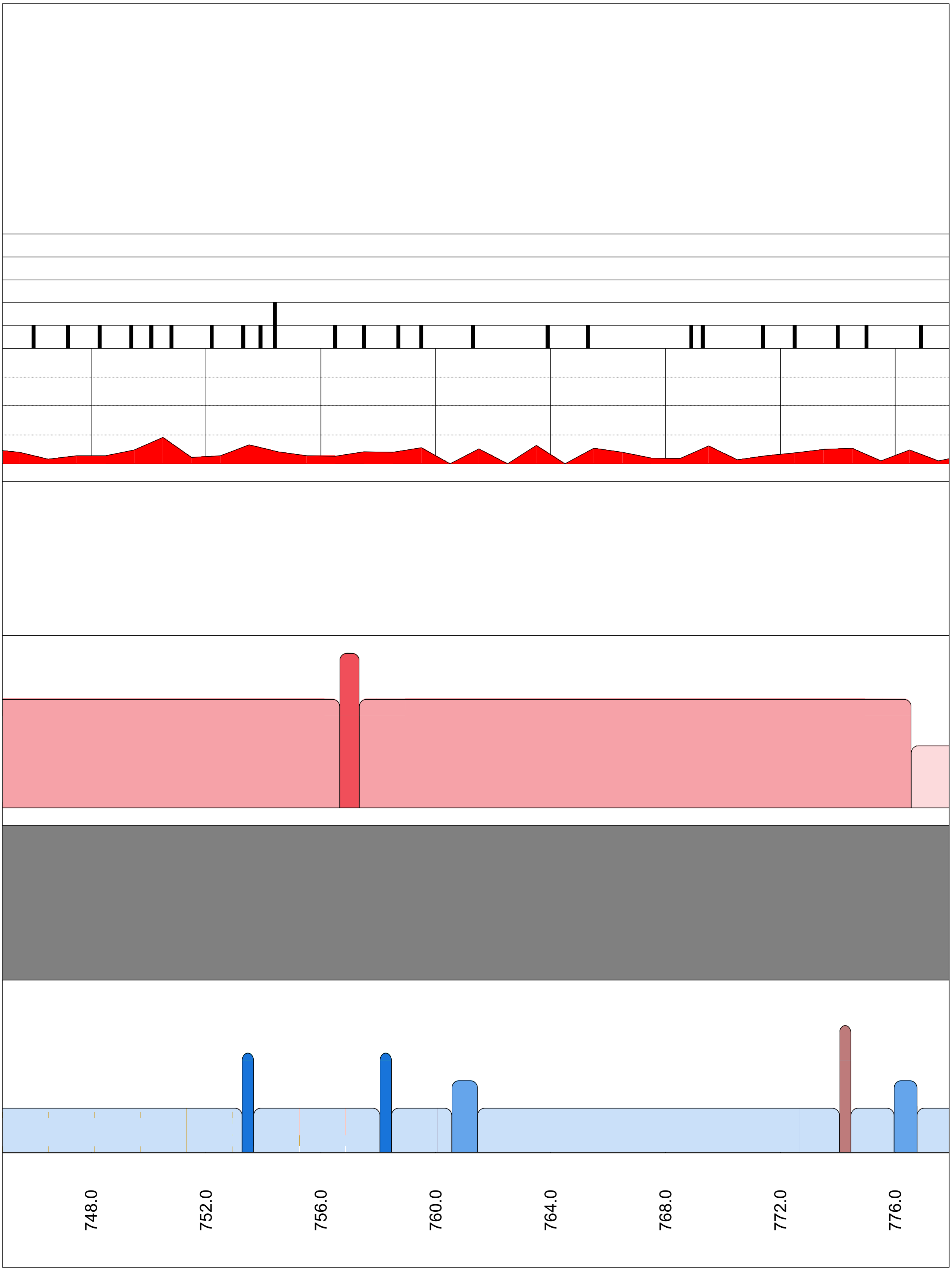
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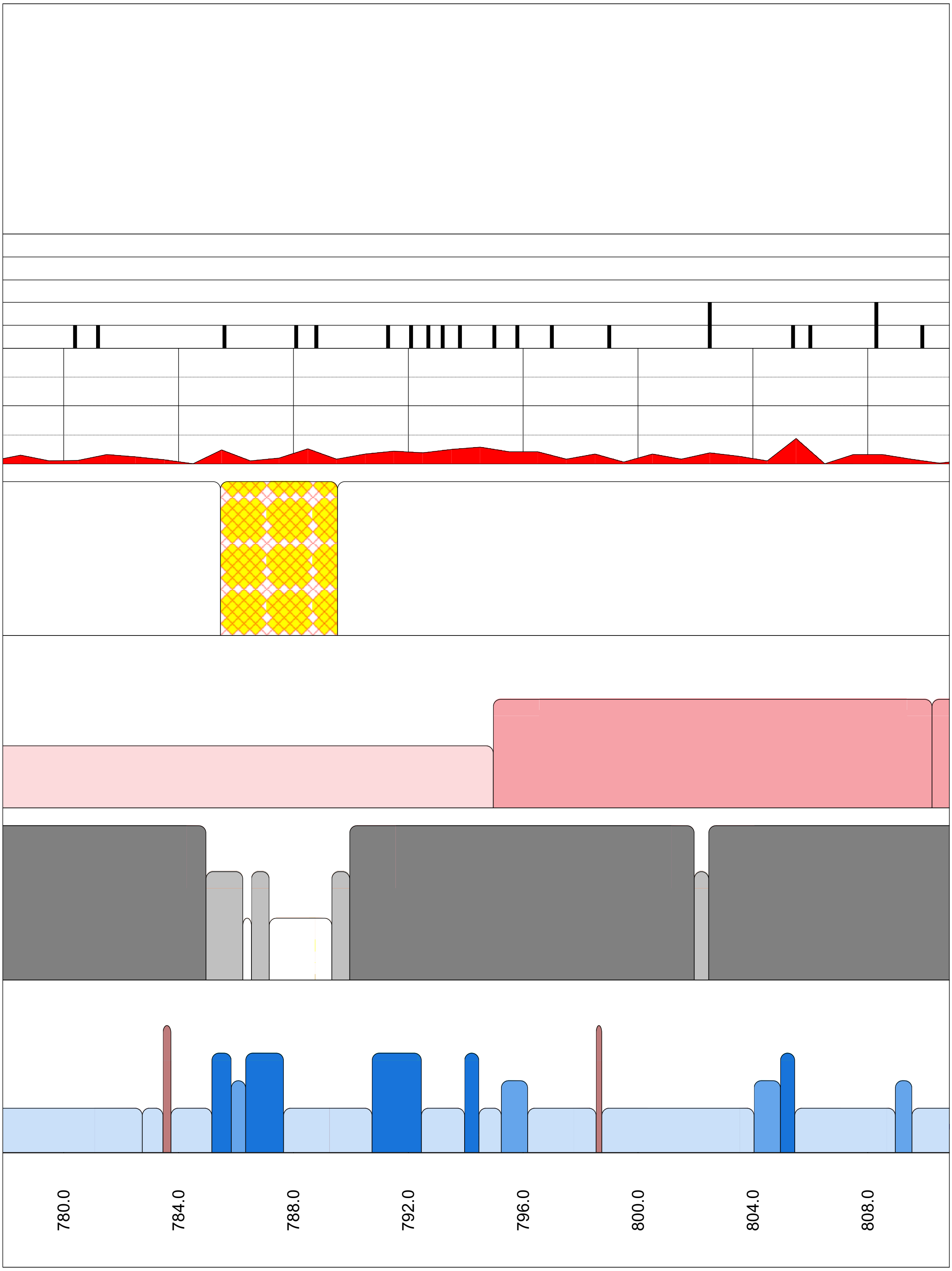
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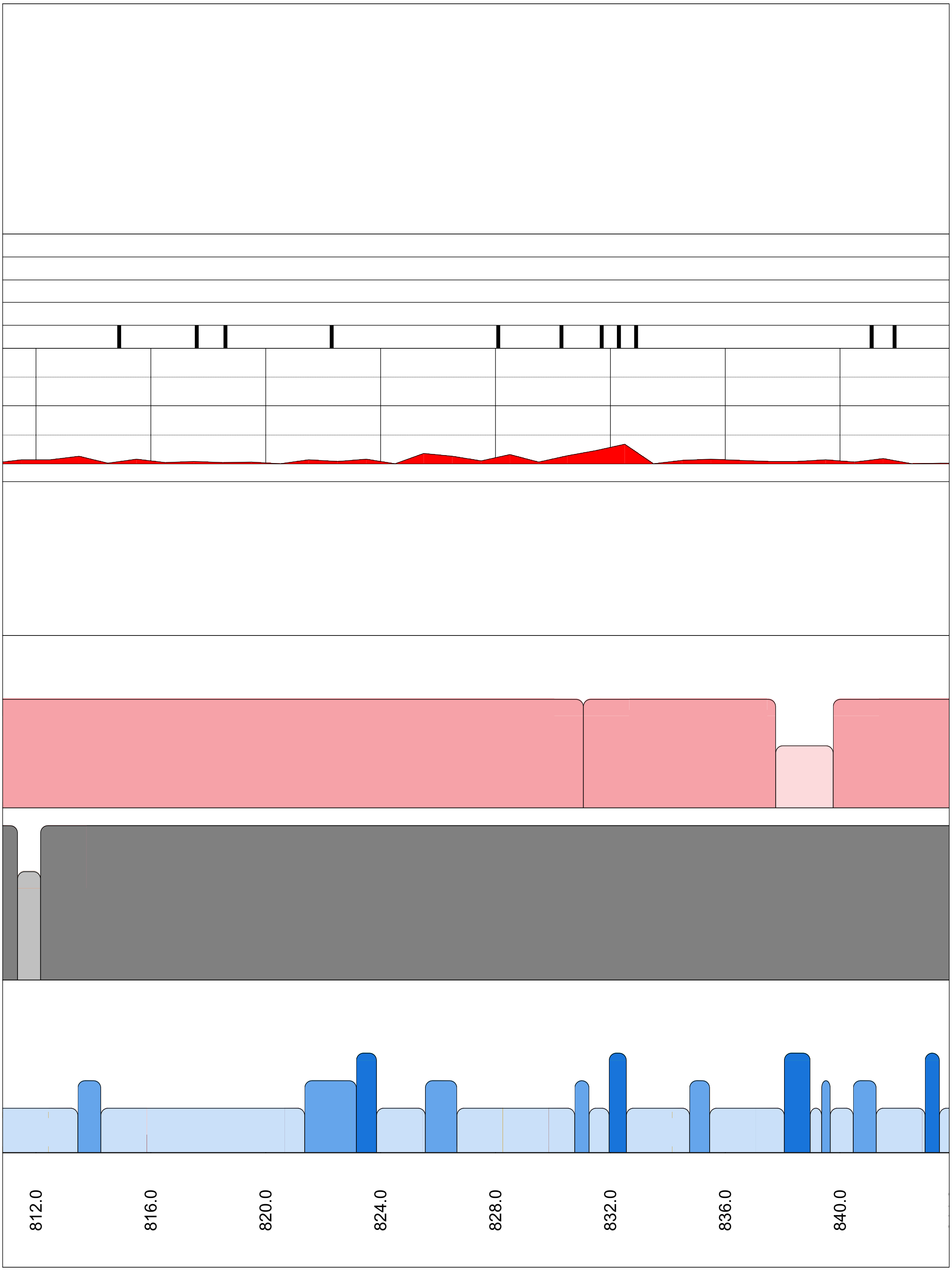
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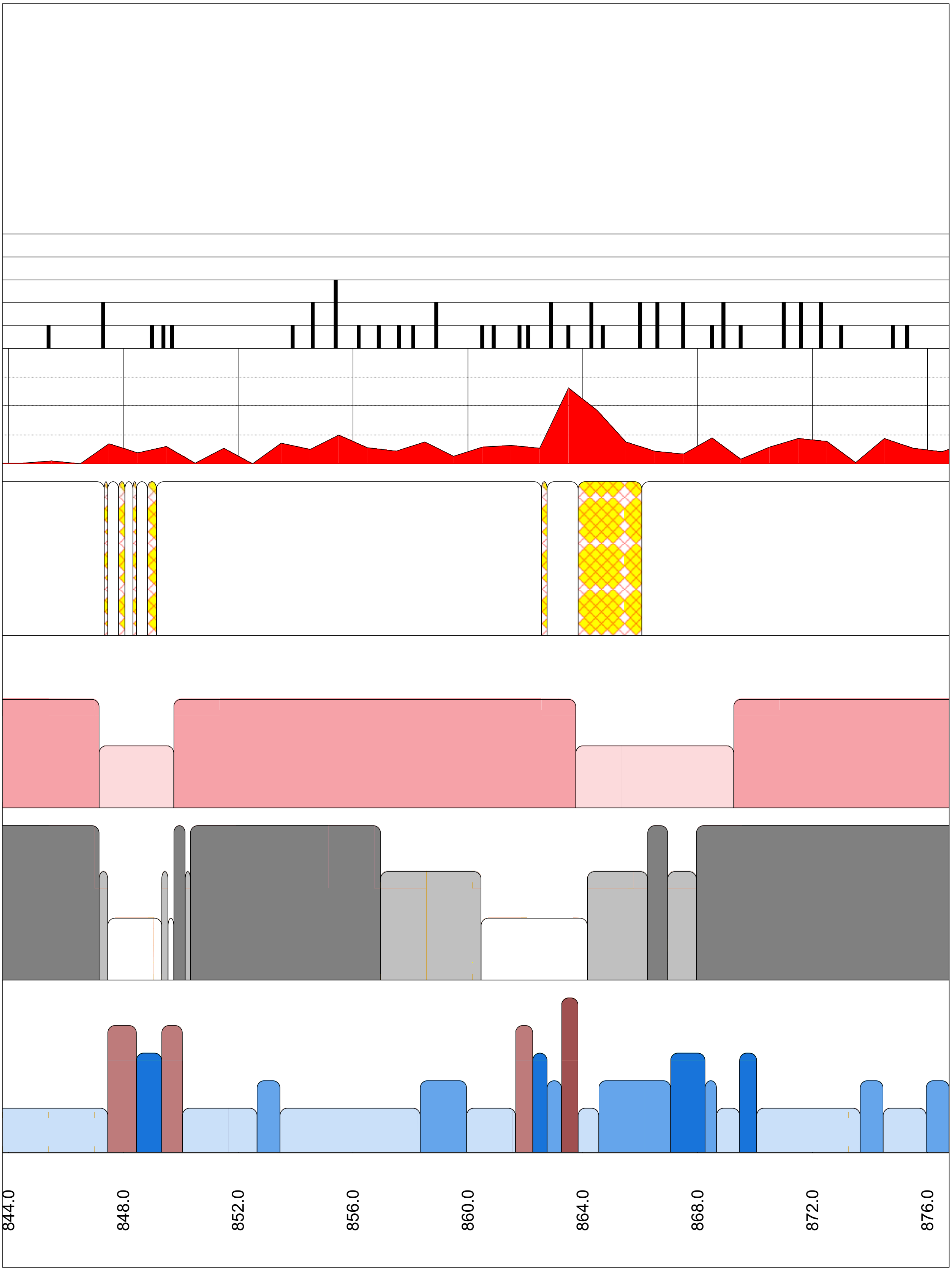
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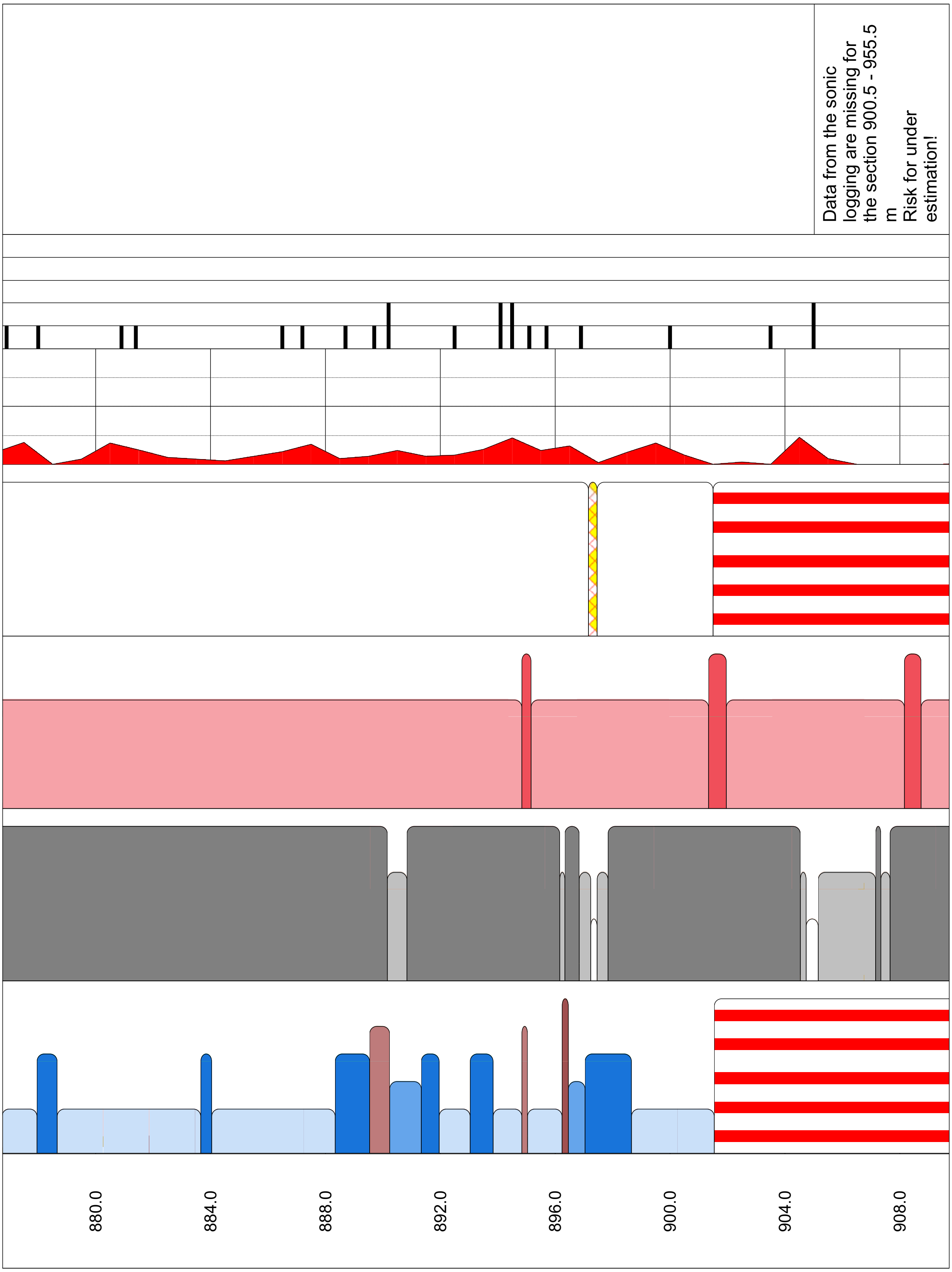
Data from the sonic logging are missing for the section 900.5 - 955.5 m
Risk for under estimation!
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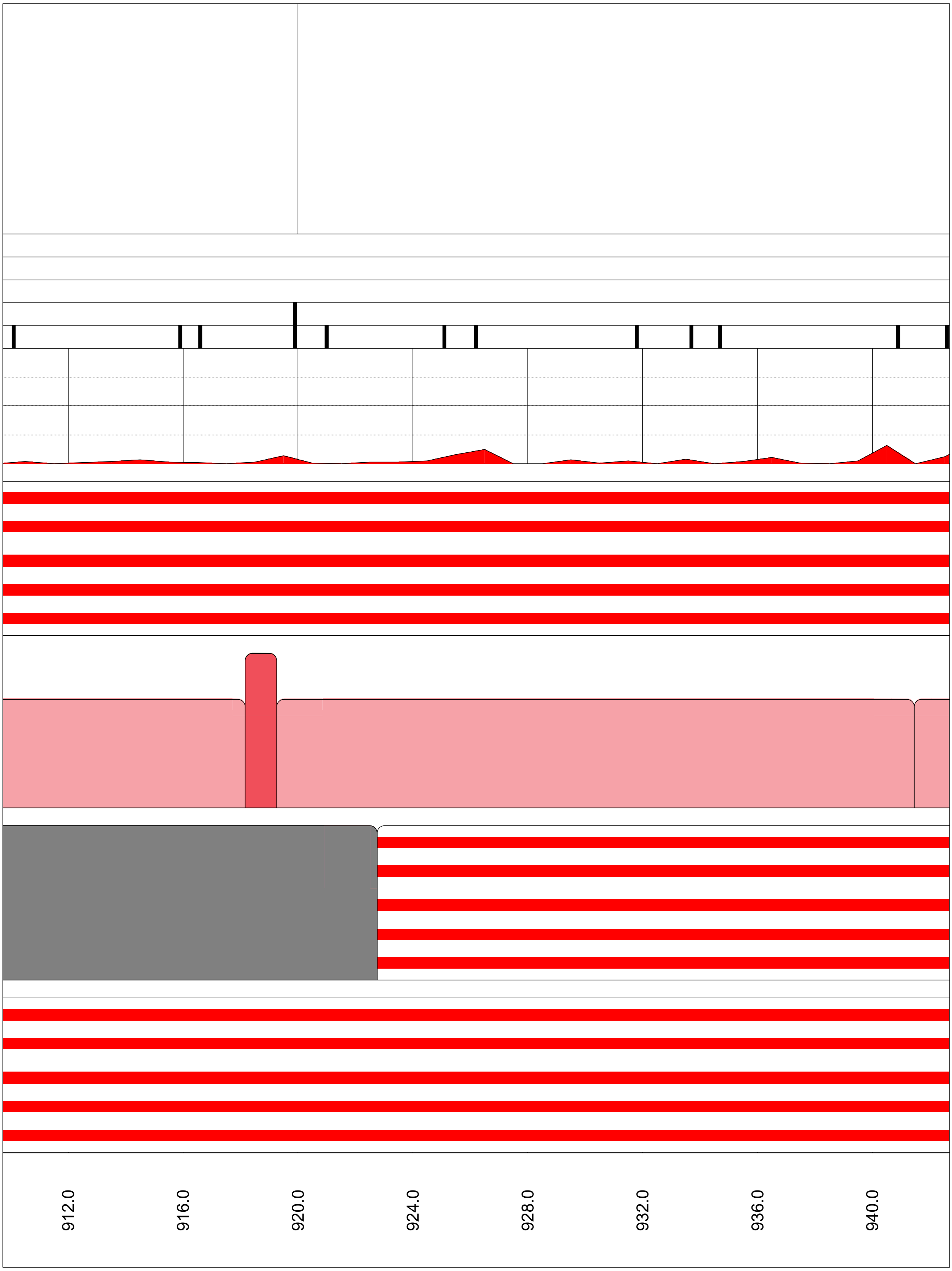
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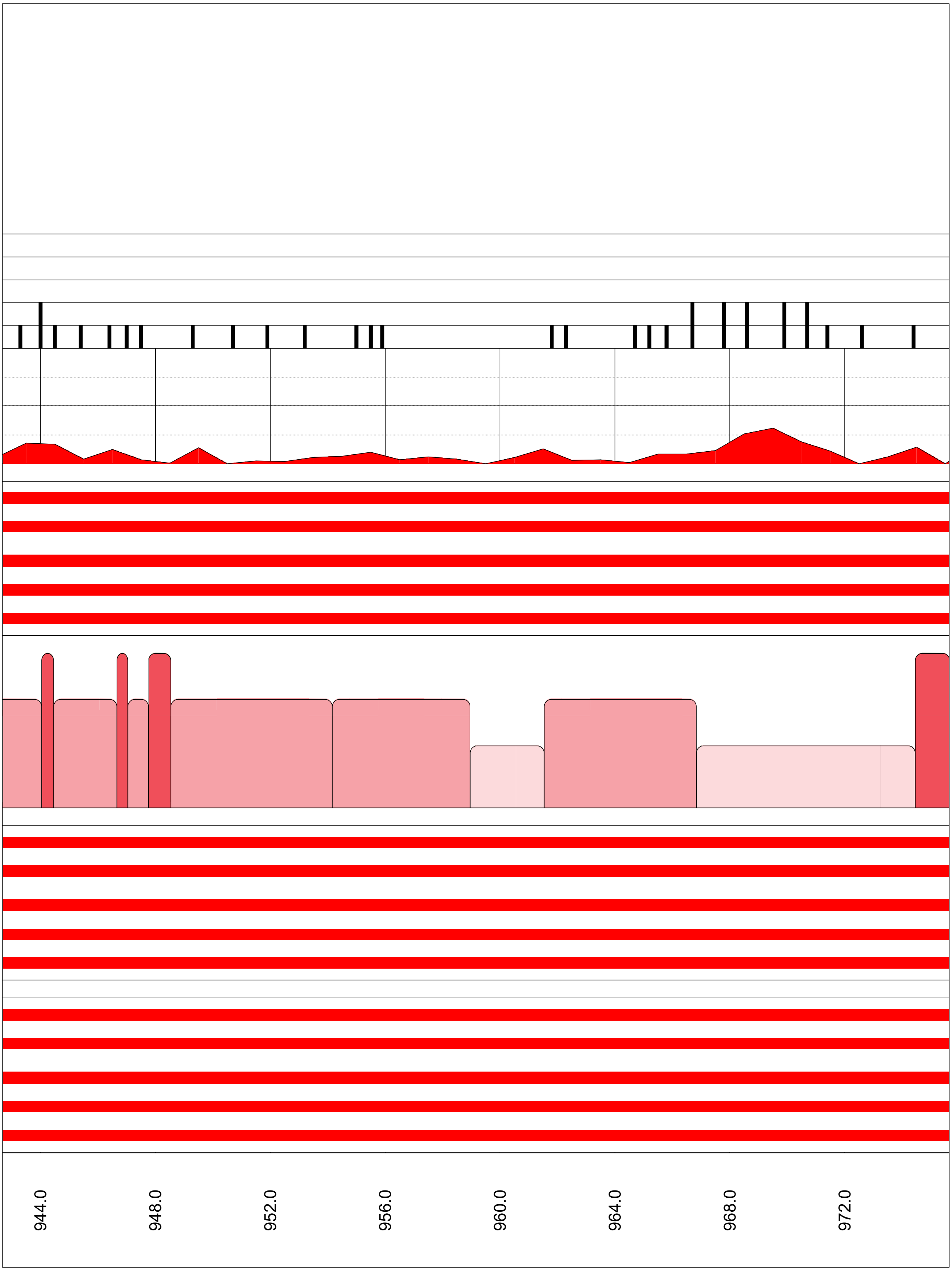
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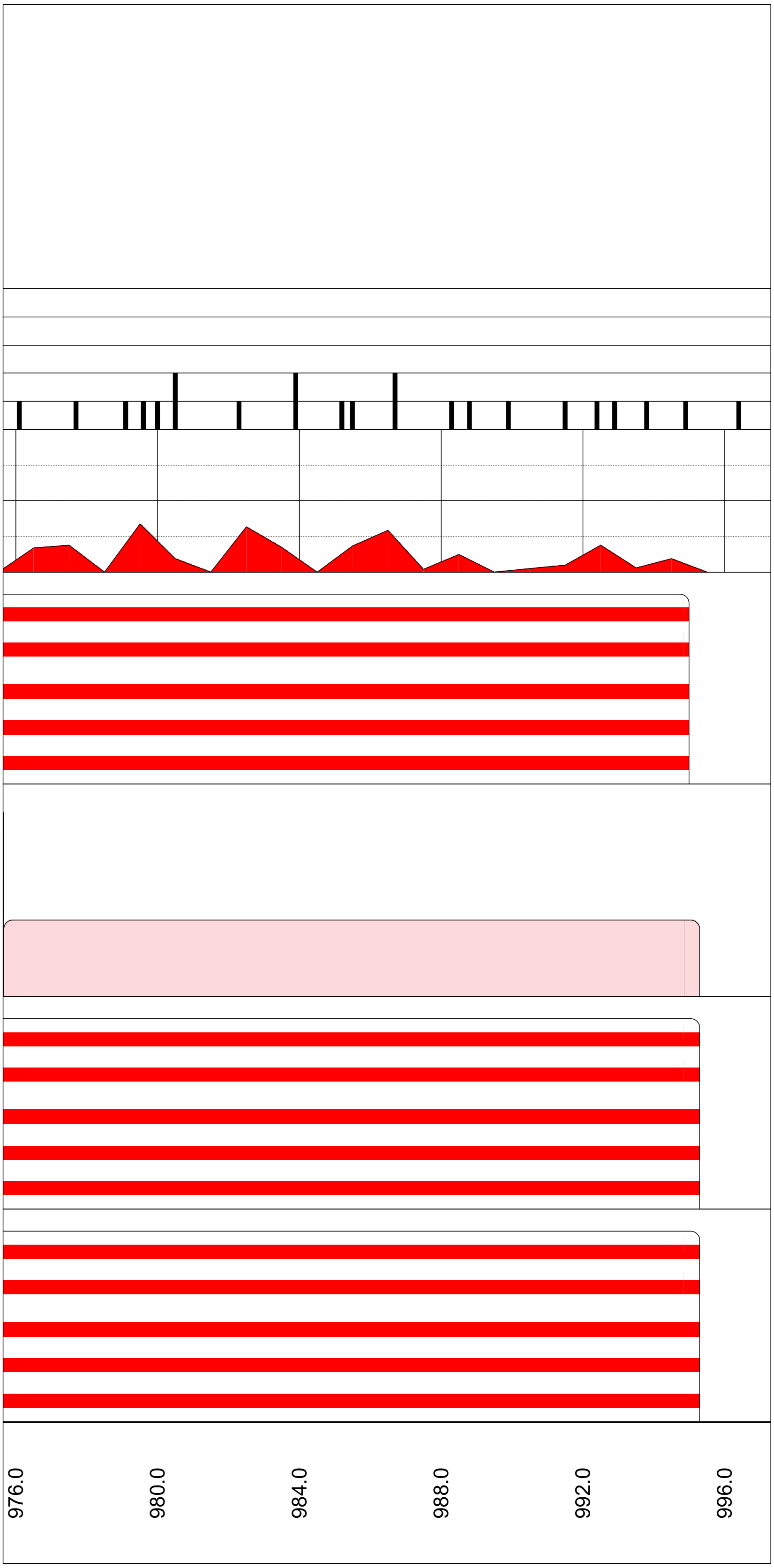
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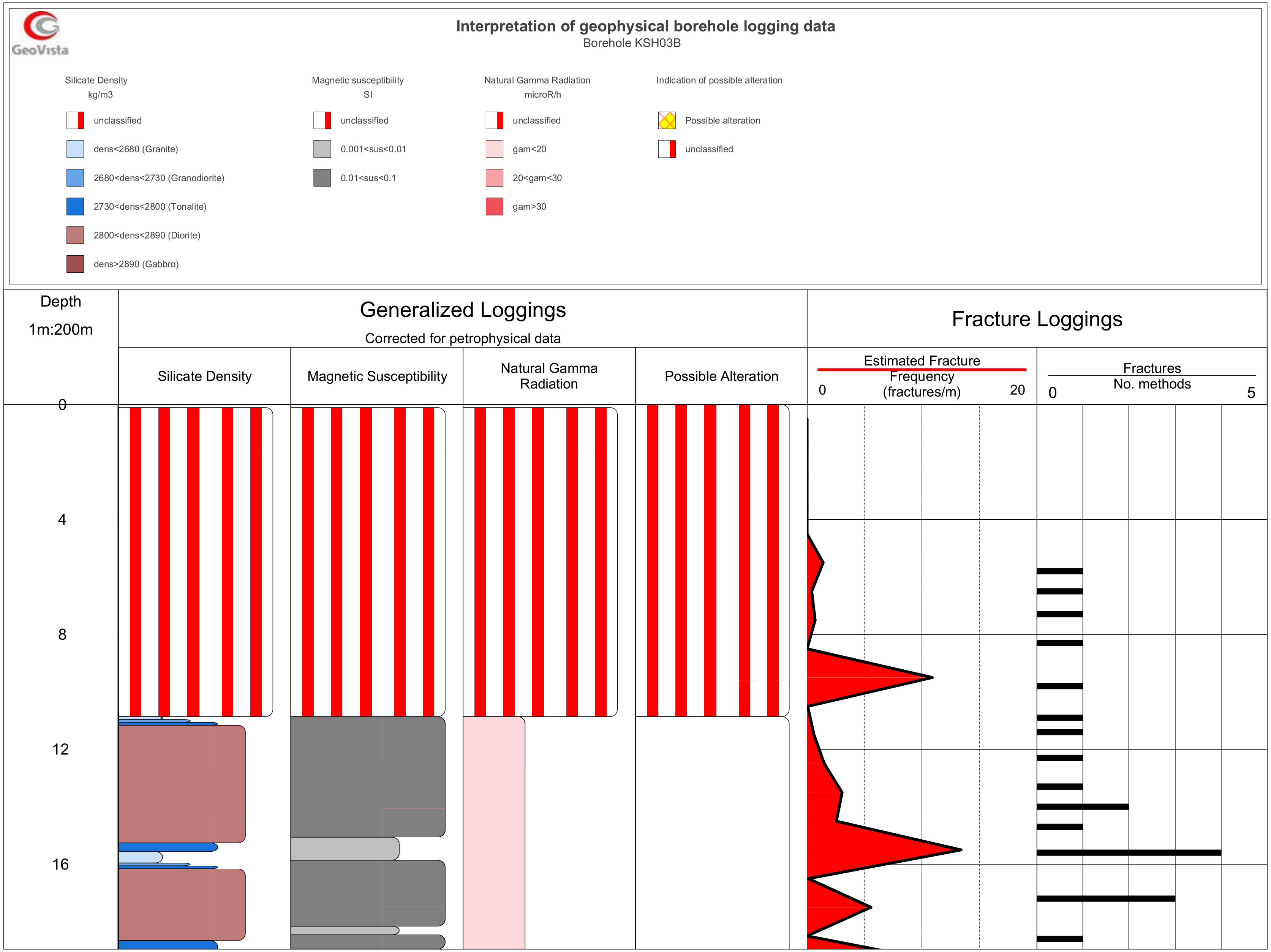
Appendix 2

Generalized geophysical loggings for the borehole KSH03B


GeoVista
Interpretation of geophysical borehole logging data
Borehole KSH03B
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Magnetic susceptibility
SI
unclassified
0.001<sus<0.01
0.01<sus<0.1
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<30
gam>30
Indication of possible alteration
Possible alteration
unclassified
Depth
1m:200m
Generalized Loggings
Corrected for petrophysical data
Silicate Density
Magnetic Susceptibility
Natural Gamma Radiation
Possible Alteration
Fracture Loggings
Estimated Fracture Frequency (fractures/m)
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Fractures
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5
0
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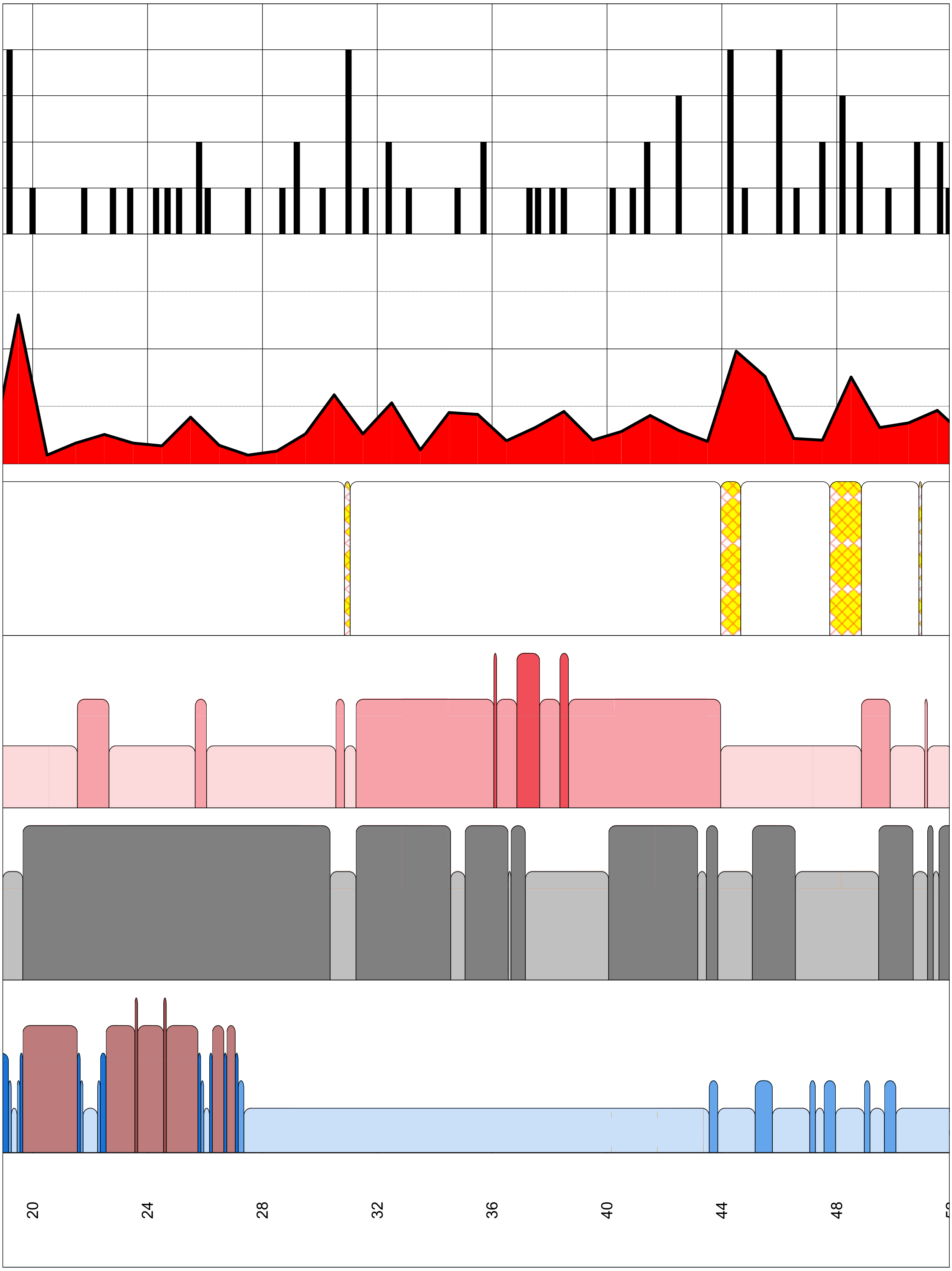
8
12
16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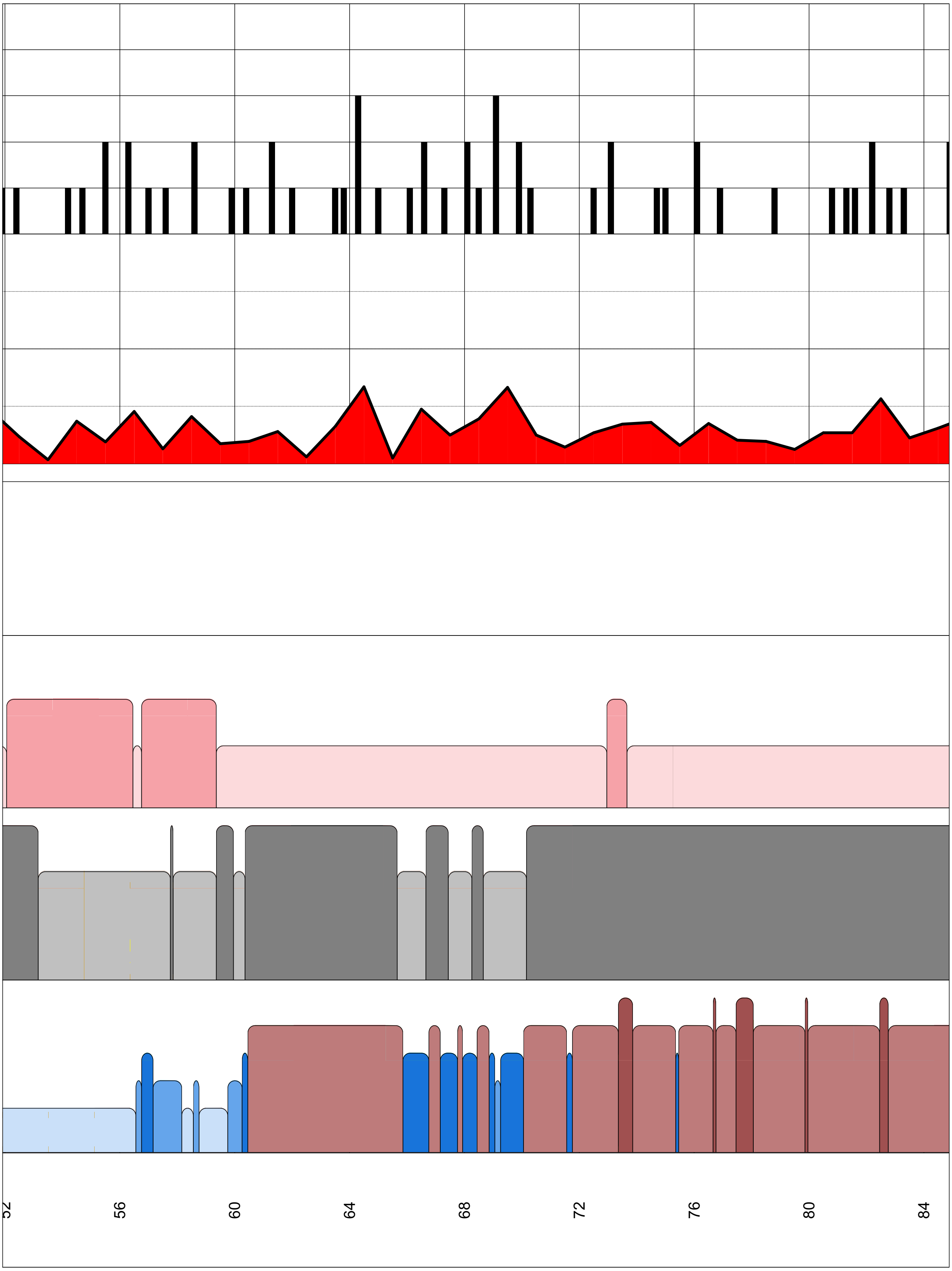
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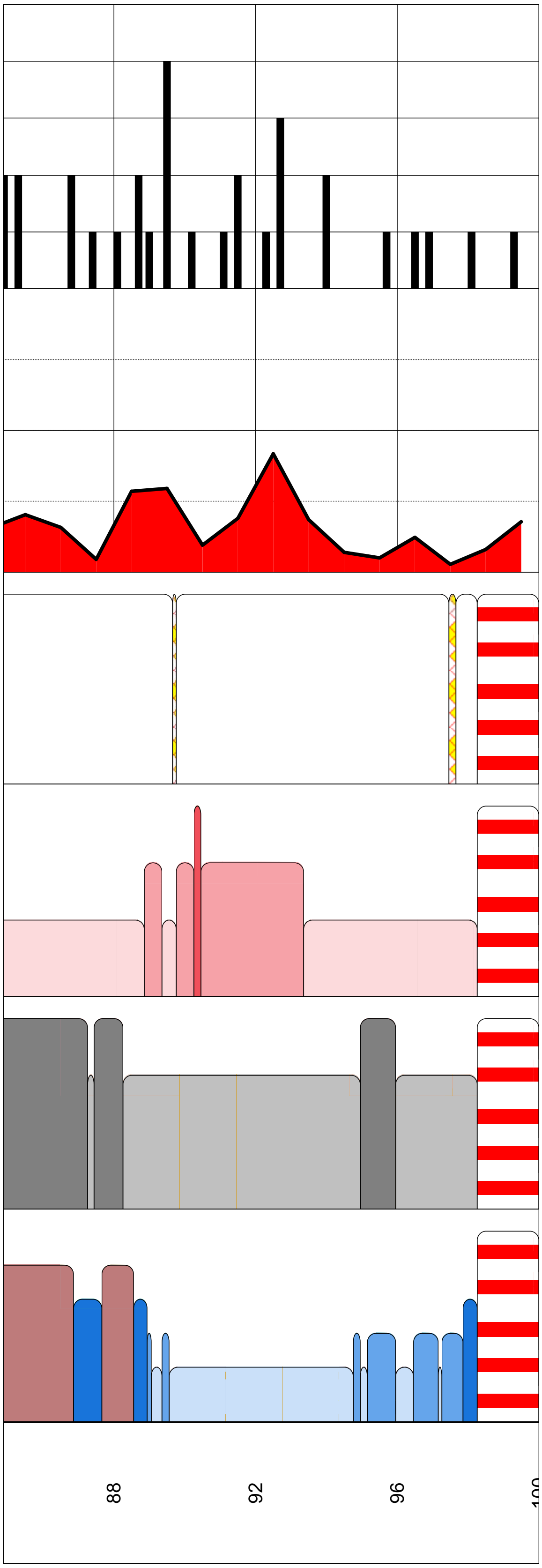
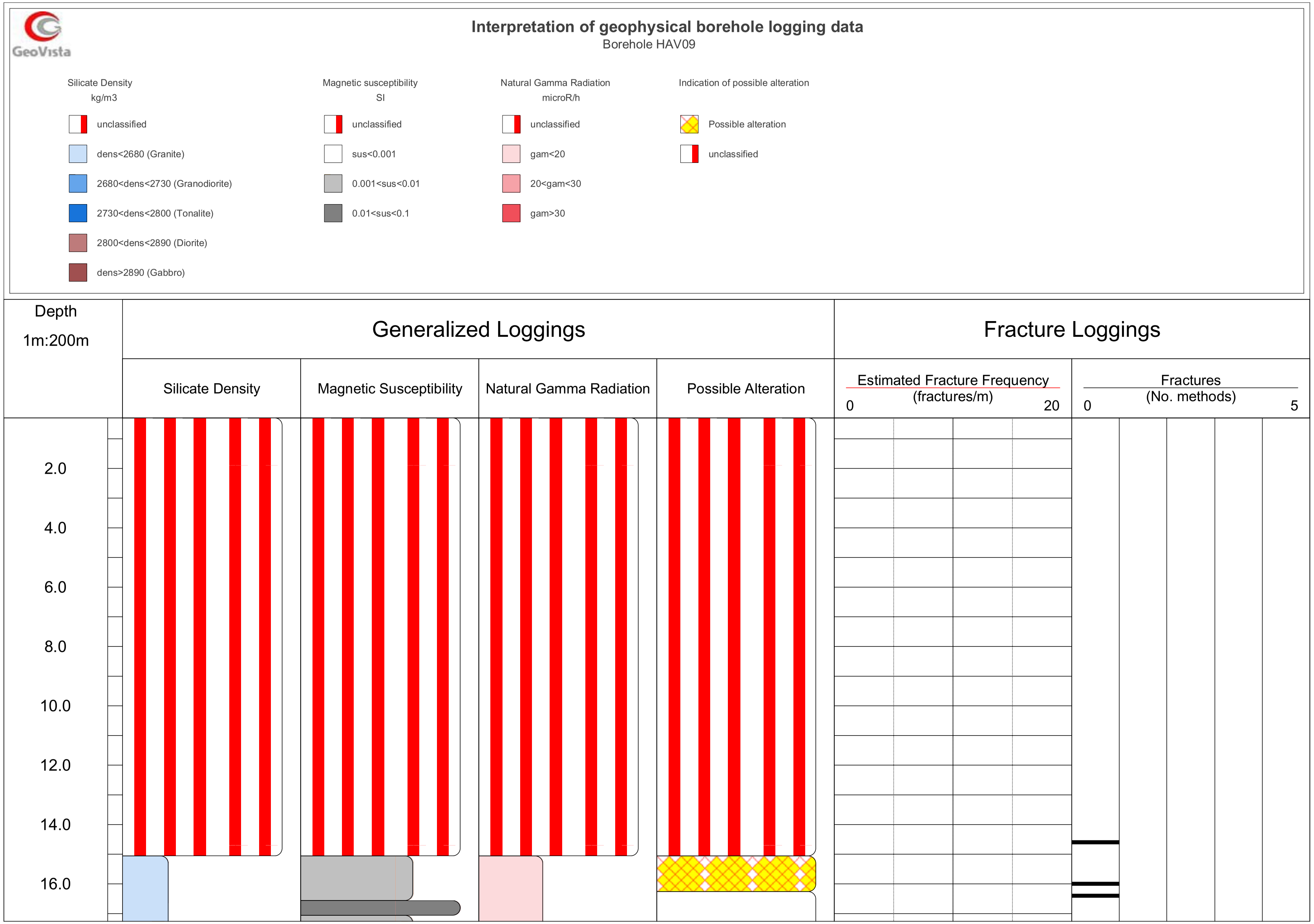
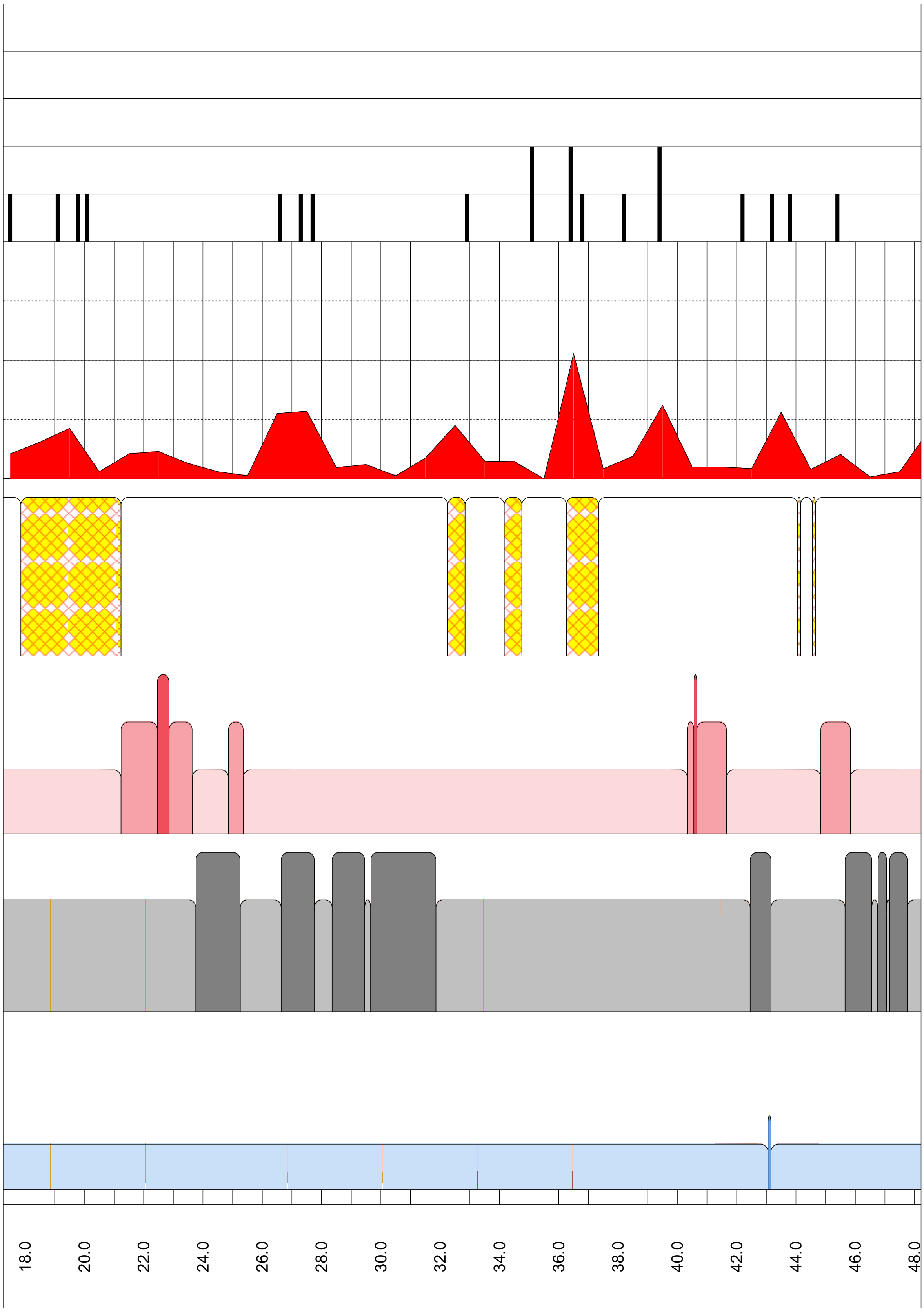
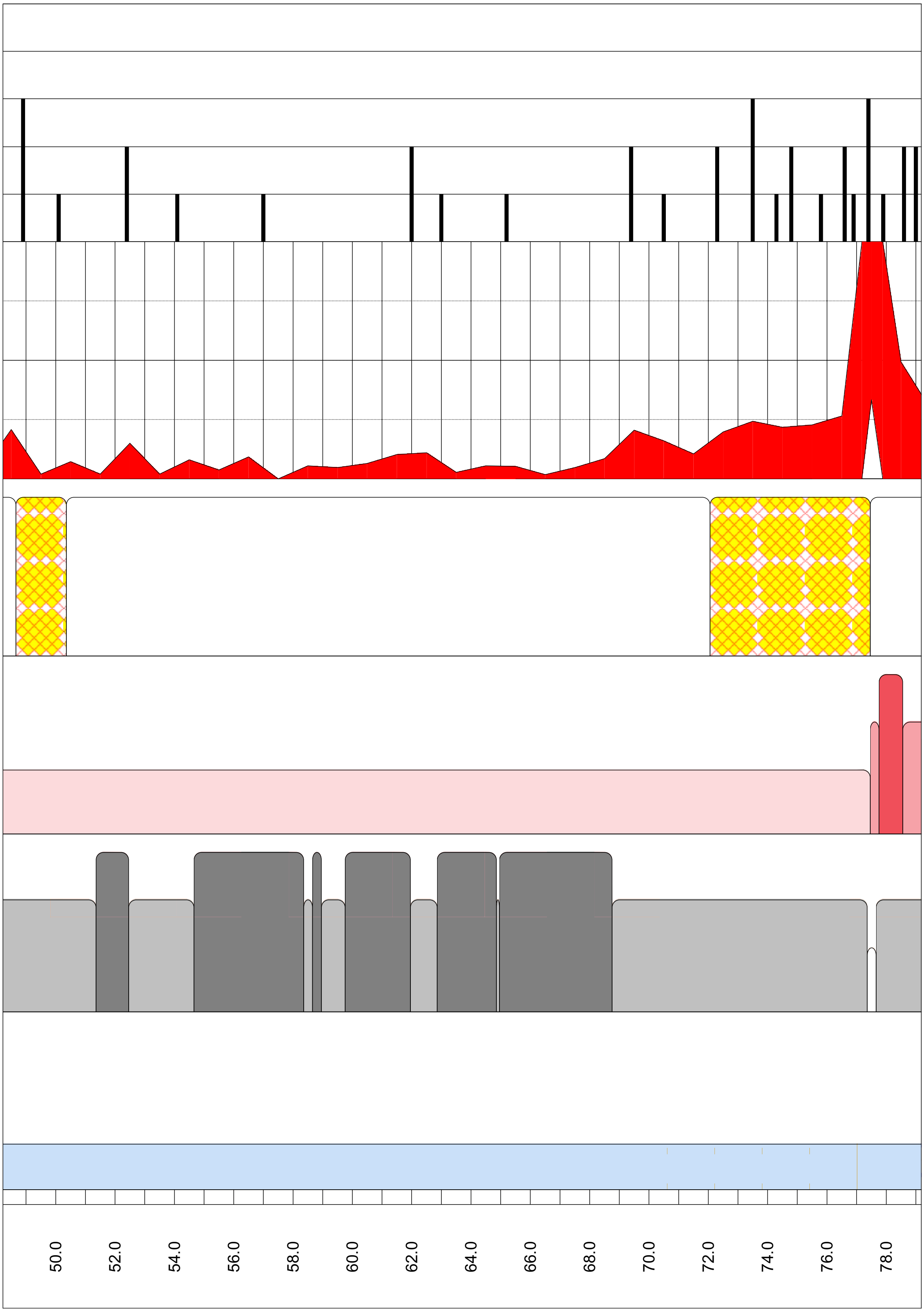

88
92
96
100

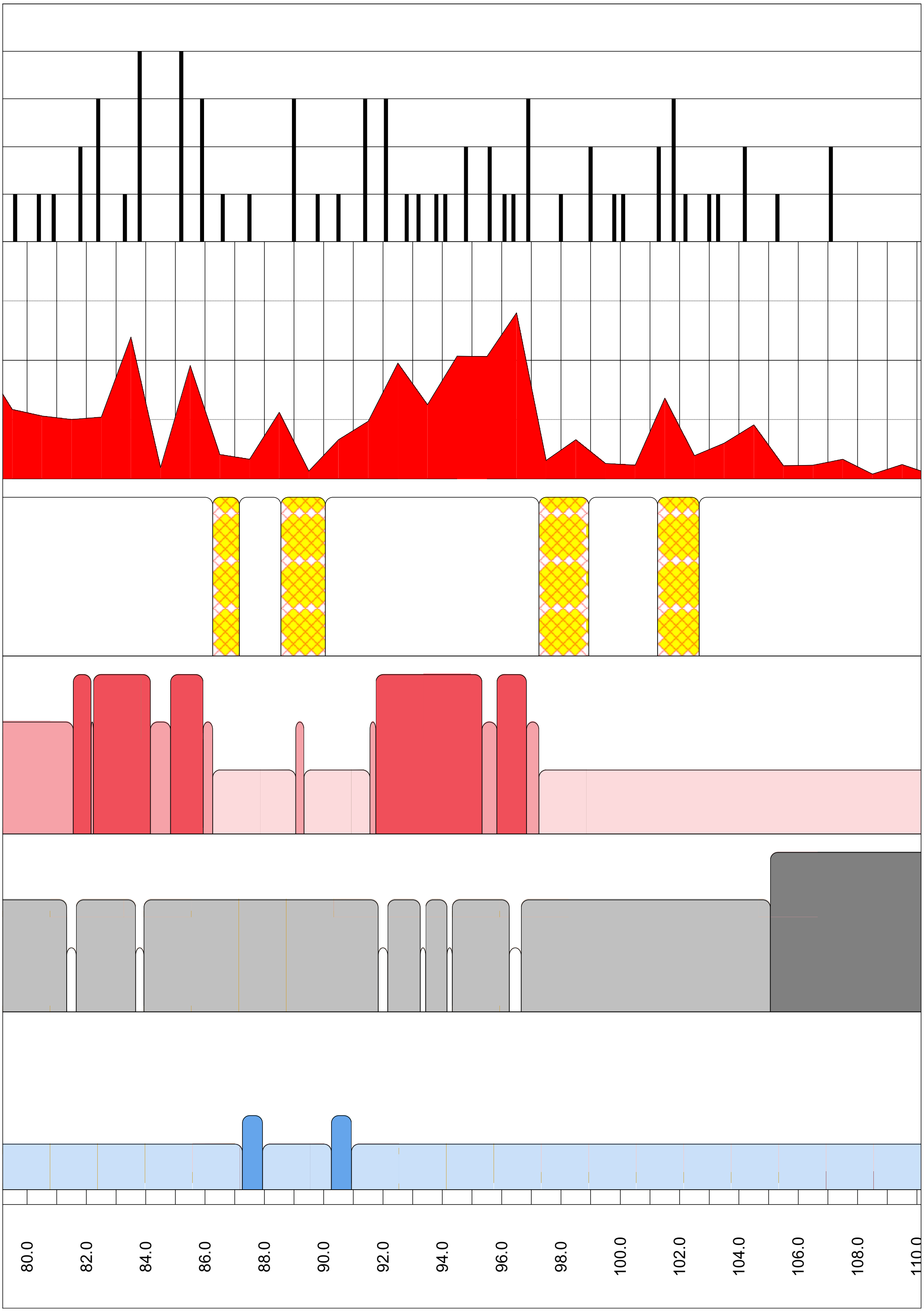
Appendix 3

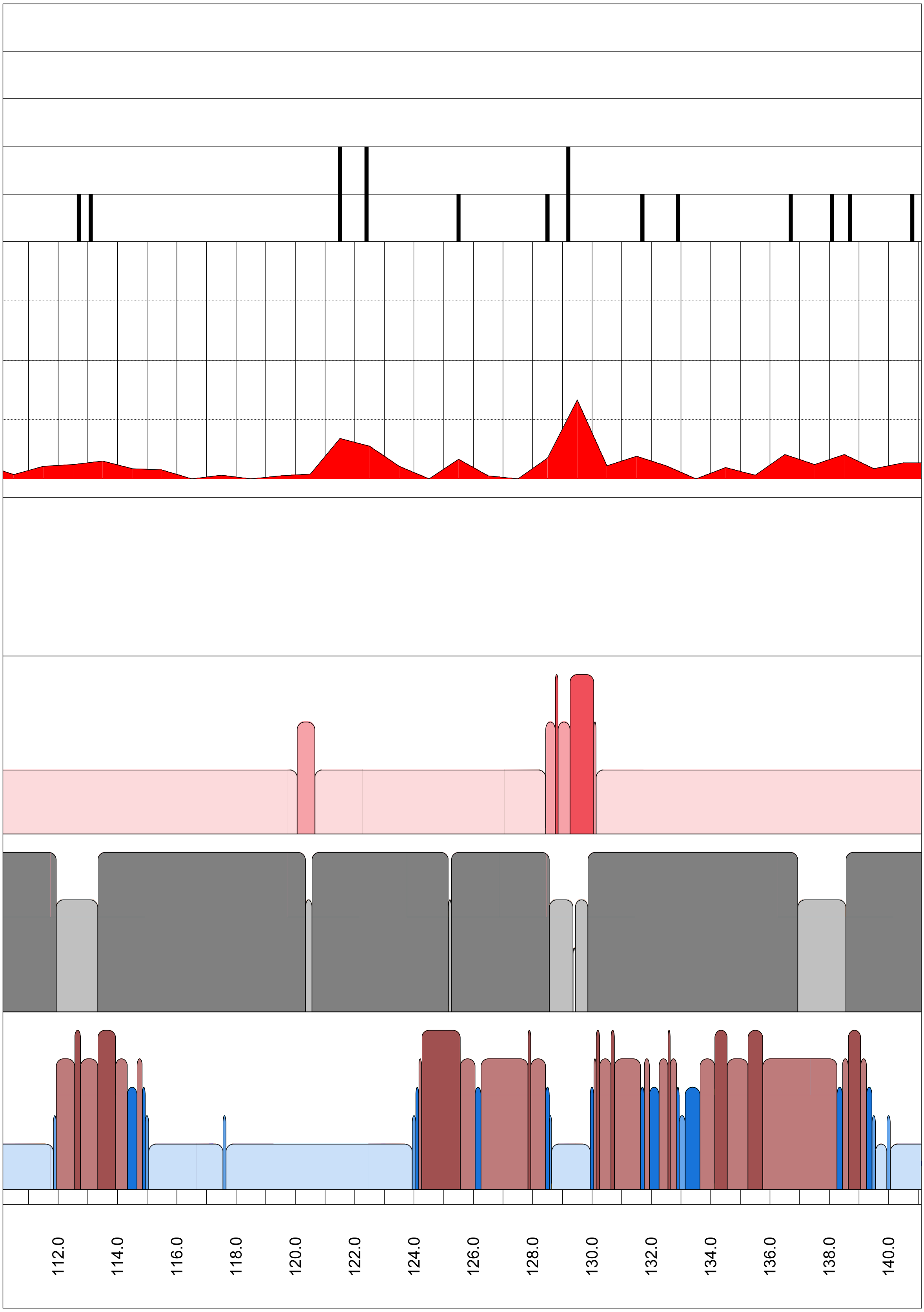
Generalized geophysical loggings for the borehole HAV09

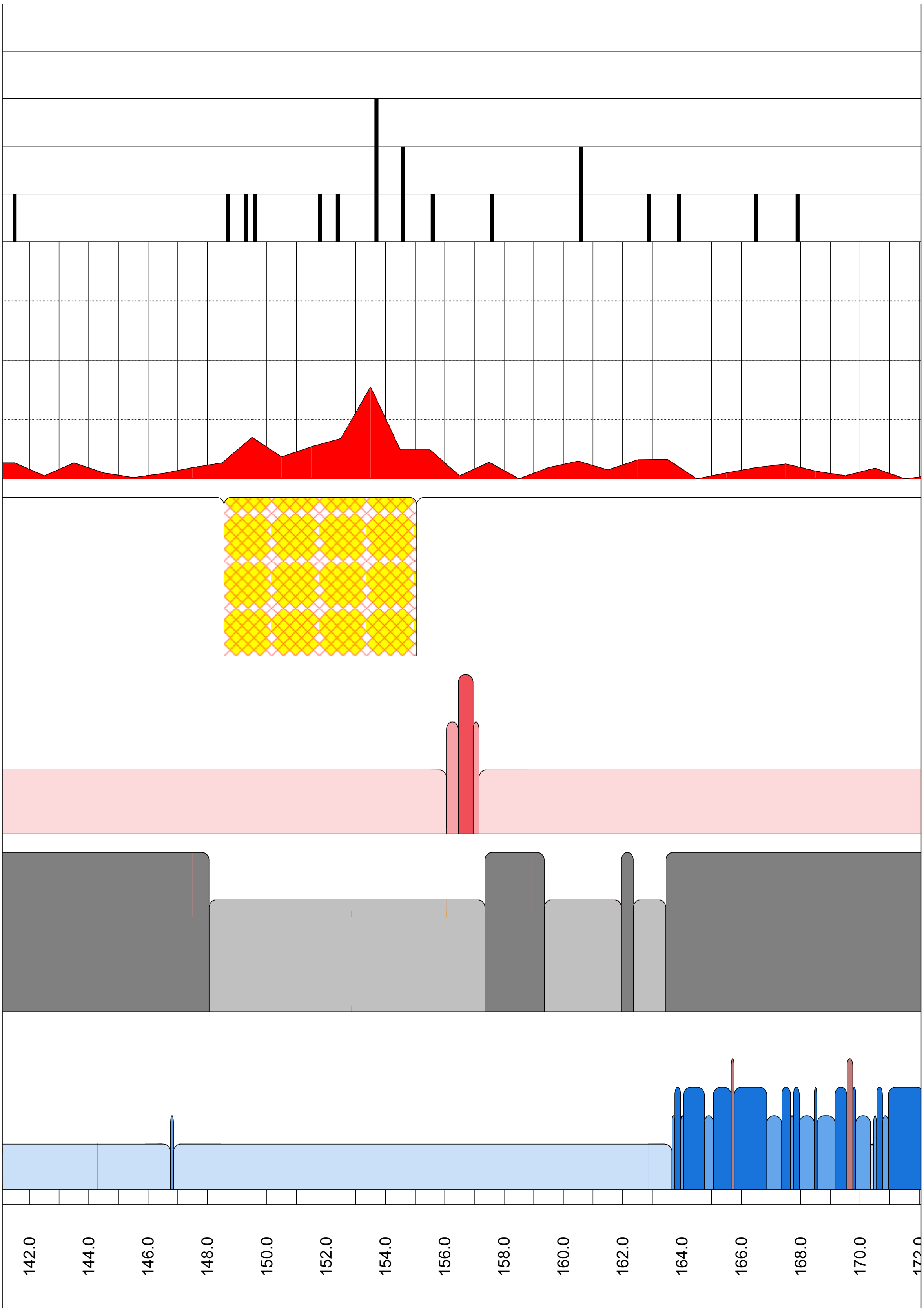

GeoVista
Interpretation of geophysical borehole logging data
Borehole HAV09
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<30
gam>30
Indication of possible alteration
Possible alteration
unclassified
Depth
1m:200m
Generalized Loggings
Fracture Loggings
Silicate Density
Magnetic Susceptibility
Natural Gamma Radiation
Possible Alteration
Estimated Fracture Frequency
(fractures/m)
0
20
Fractures
(No. methods)
0
5
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0


18.0
20.0
22.0
24.0
26.0
28.0
30.0
32.0
34.0
36.0
38.0
40.0
42.0
44.0
46.0
48.0

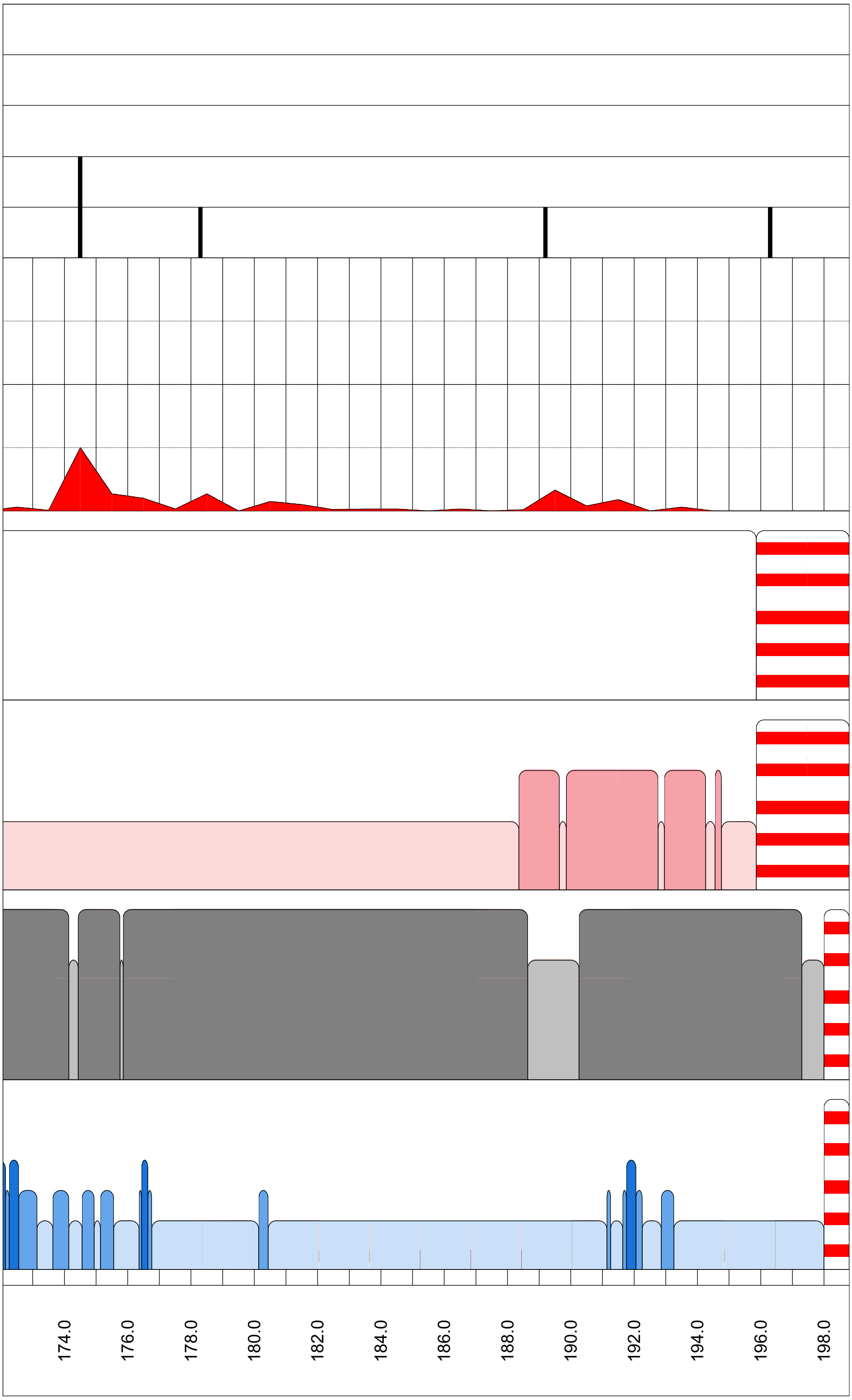

50.0
52.0
54.0
56.0
58.0
60.0
62.0
64.0
66.0
68.0
70.0
72.0
74.0
76.0
78.0


80.0
82.0
84.0
86.0
88.0
90.0
92.0
94.0
96.0
98.0
100.0
102.0
104.0
106.0
108.0
110.0


112.0
114.0
116.0
118.0
120.0
122.0
124.0
126.0
128.0
130.0
132.0
134.0
136.0
138.0
140.0

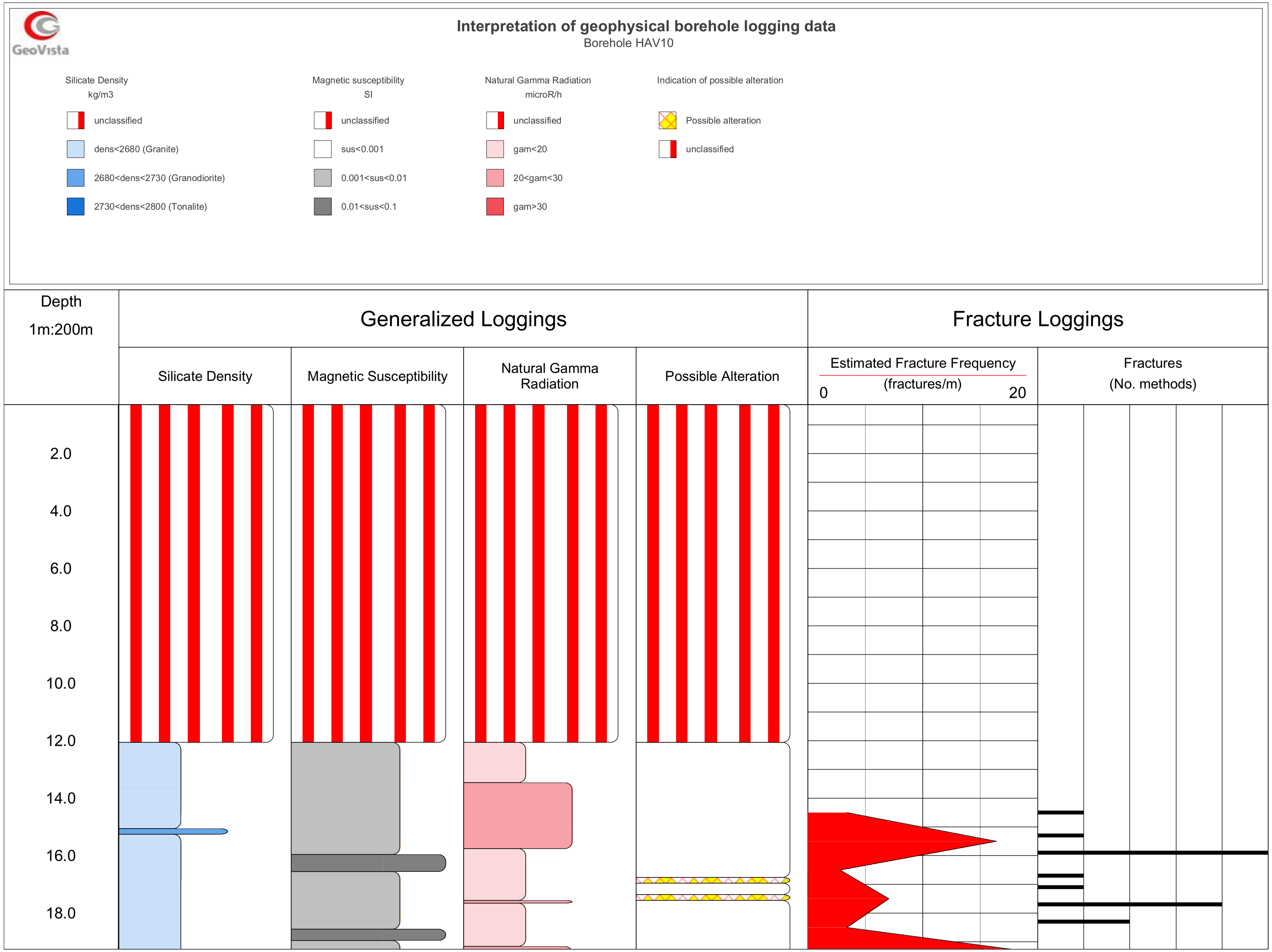


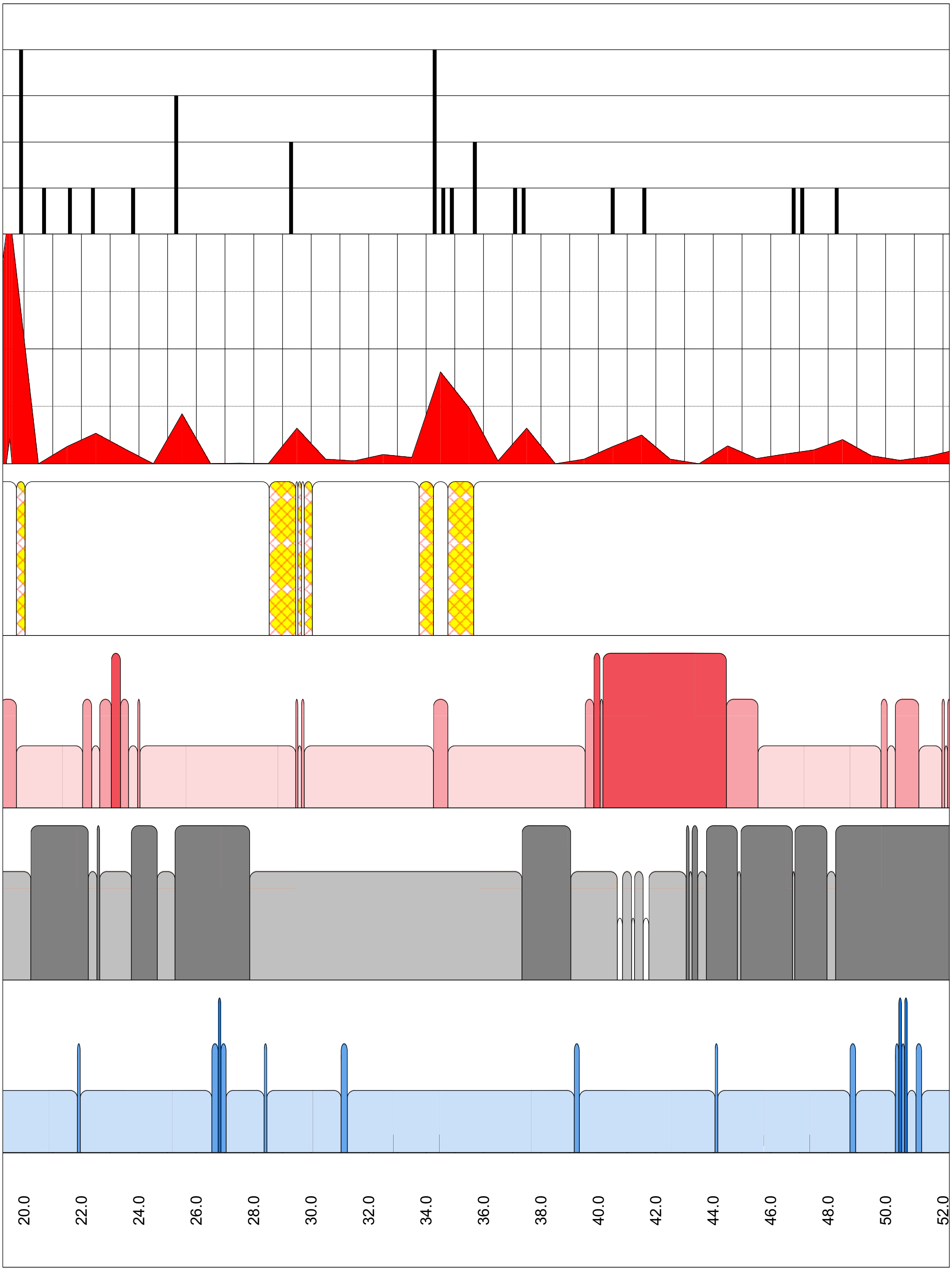
142.0
144.0
146.0
148.0
150.0
152.0
154.0
156.0
158.0
160.0
162.0
164.0
166.0
168.0
170.0
172.0

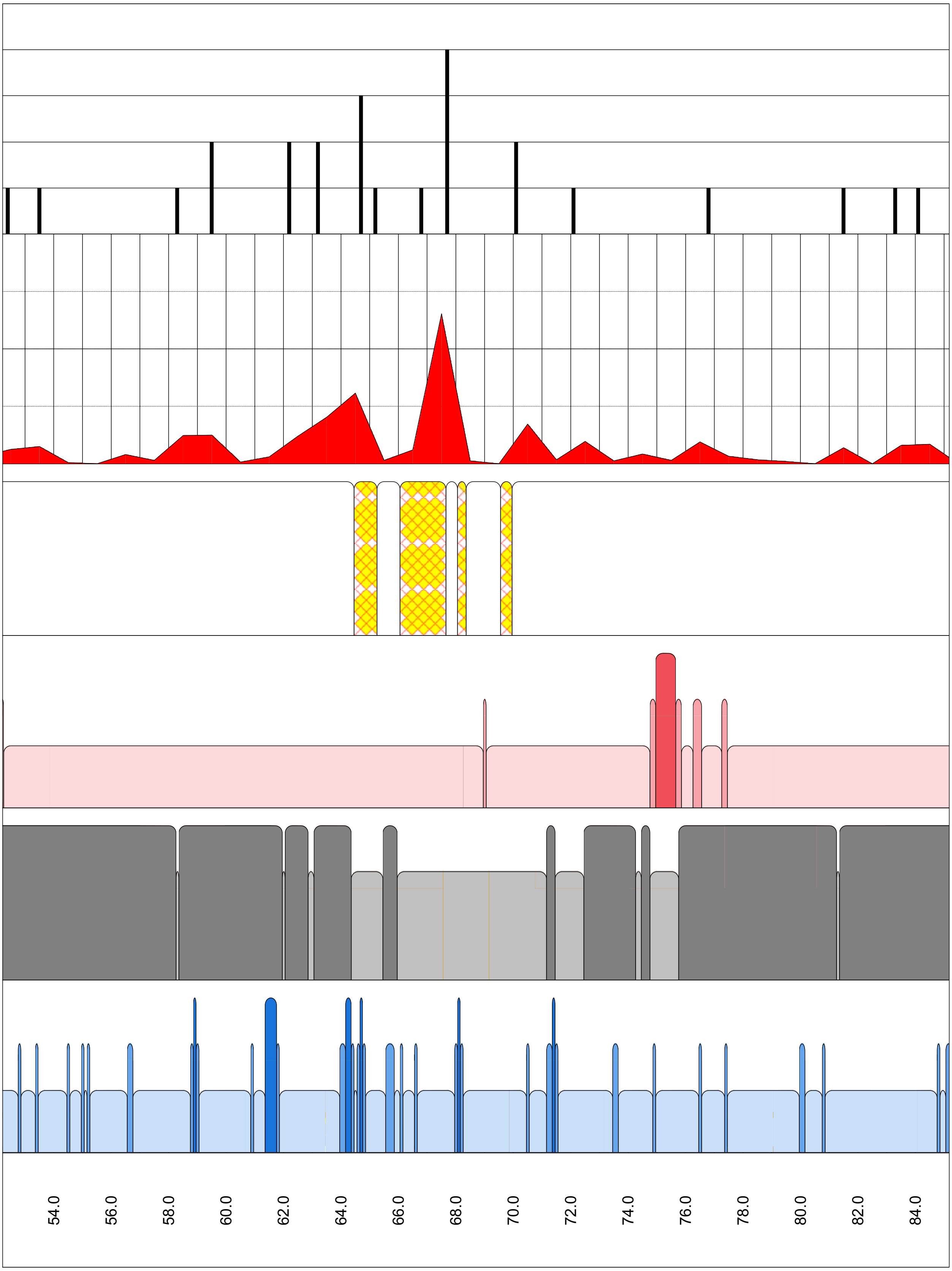

174.0
176.0
178.0
180.0
182.0
184.0
186.0
188.0
190.0
192.0
194.0
196.0
198.0

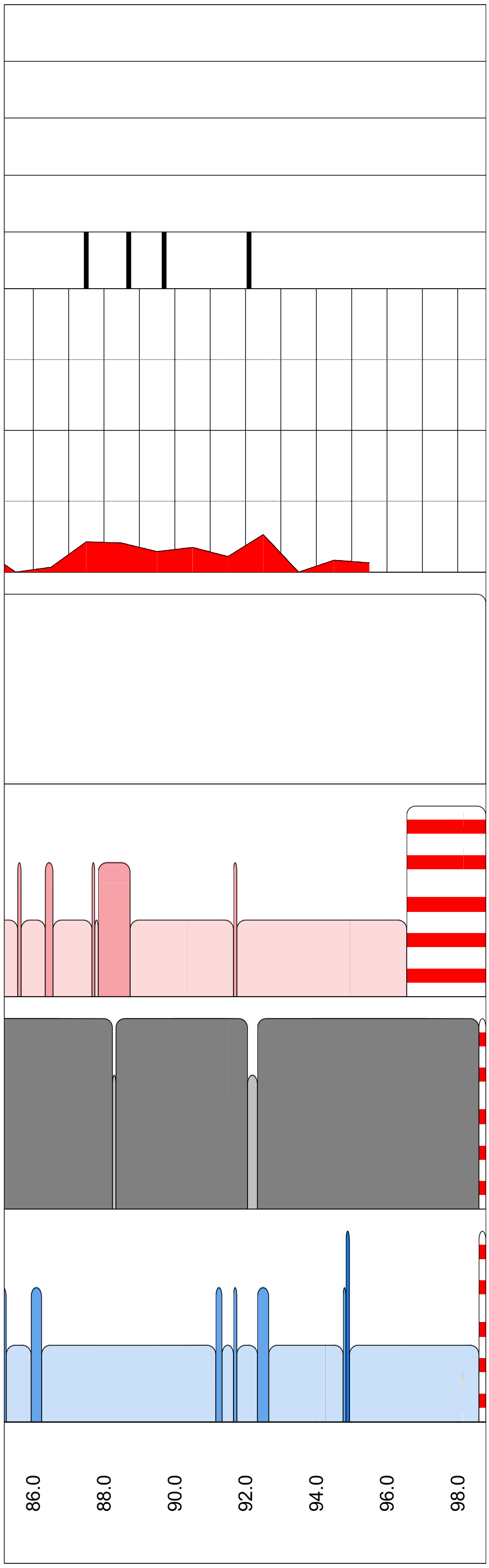
Appendix 4

Generalized geophysical loggings for the borehole HAV10


GeoVista
Interpretation of geophysical borehole logging data
Borehole HAV10
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<30
gam>30
Indication of possible alteration
Possible alteration
unclassified
Depth
1m:200m
Generalized Loggings
Fracture Loggings
Silicate Density
Magnetic Susceptibility
Natural Gamma Radiation
Possible Alteration
Estimated Fracture Frequency
(fractures/m)
0
20
Fractures
(No. methods)
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0

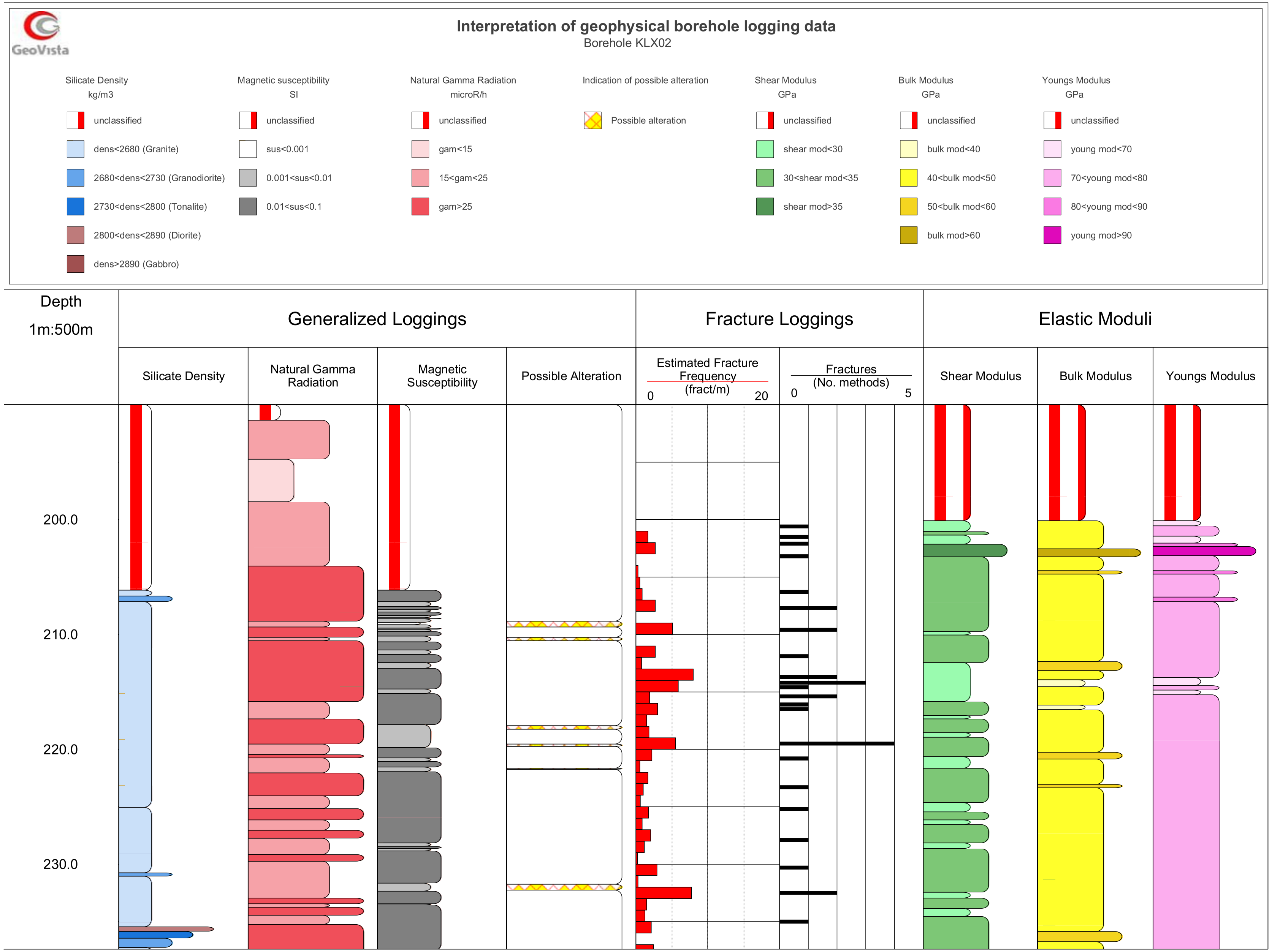

20.0
22.0
24.0
26.0
28.0
30.0
32.0
34.0
36.0
38.0
40.0
42.0
44.0
46.0
48.0
50.0
52.0

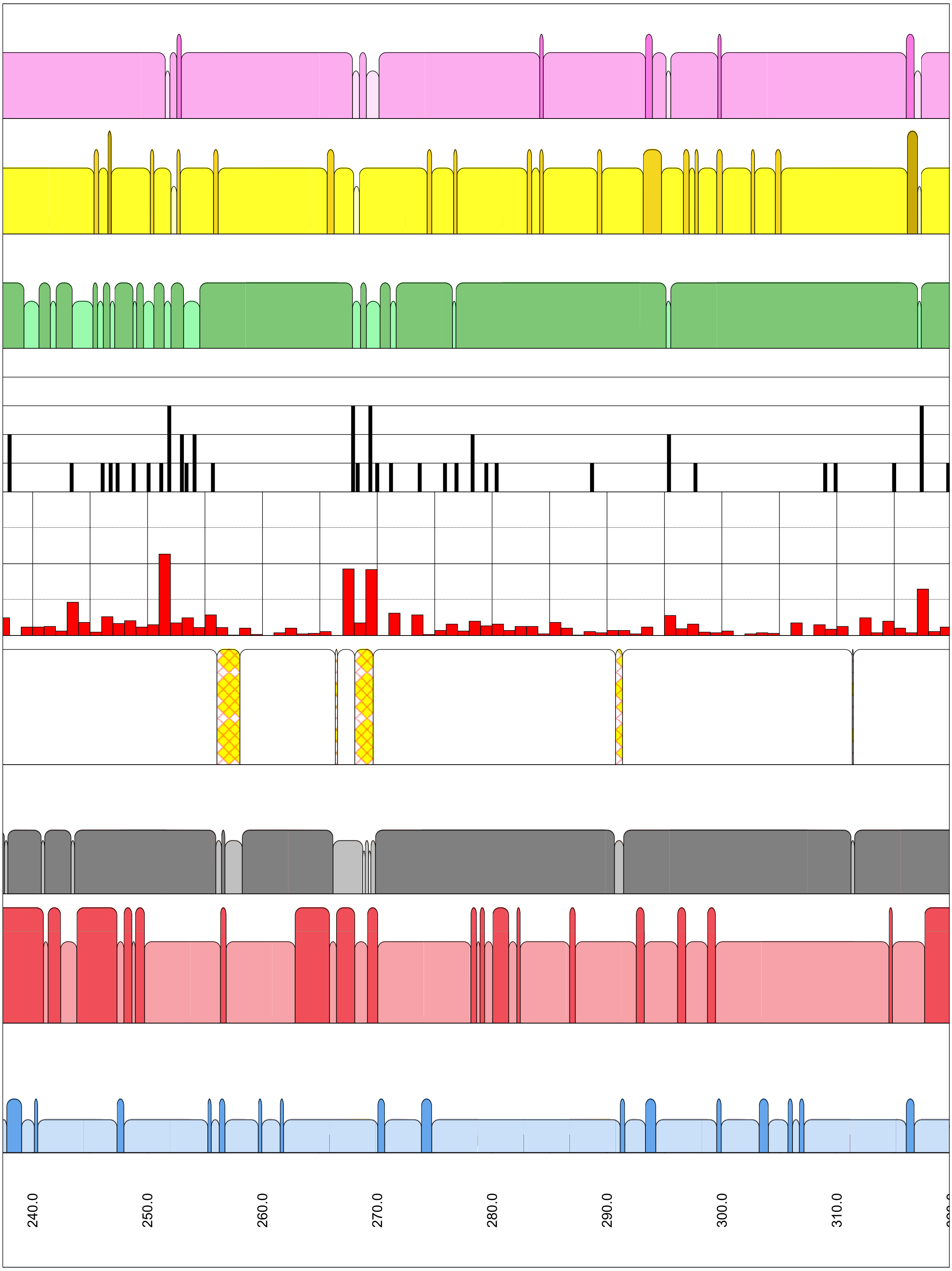

54.0
56.0
58.0
60.0
62.0
64.0
66.0
68.0
70.0
72.0
74.0
76.0
78.0
80.0
82.0
84.0

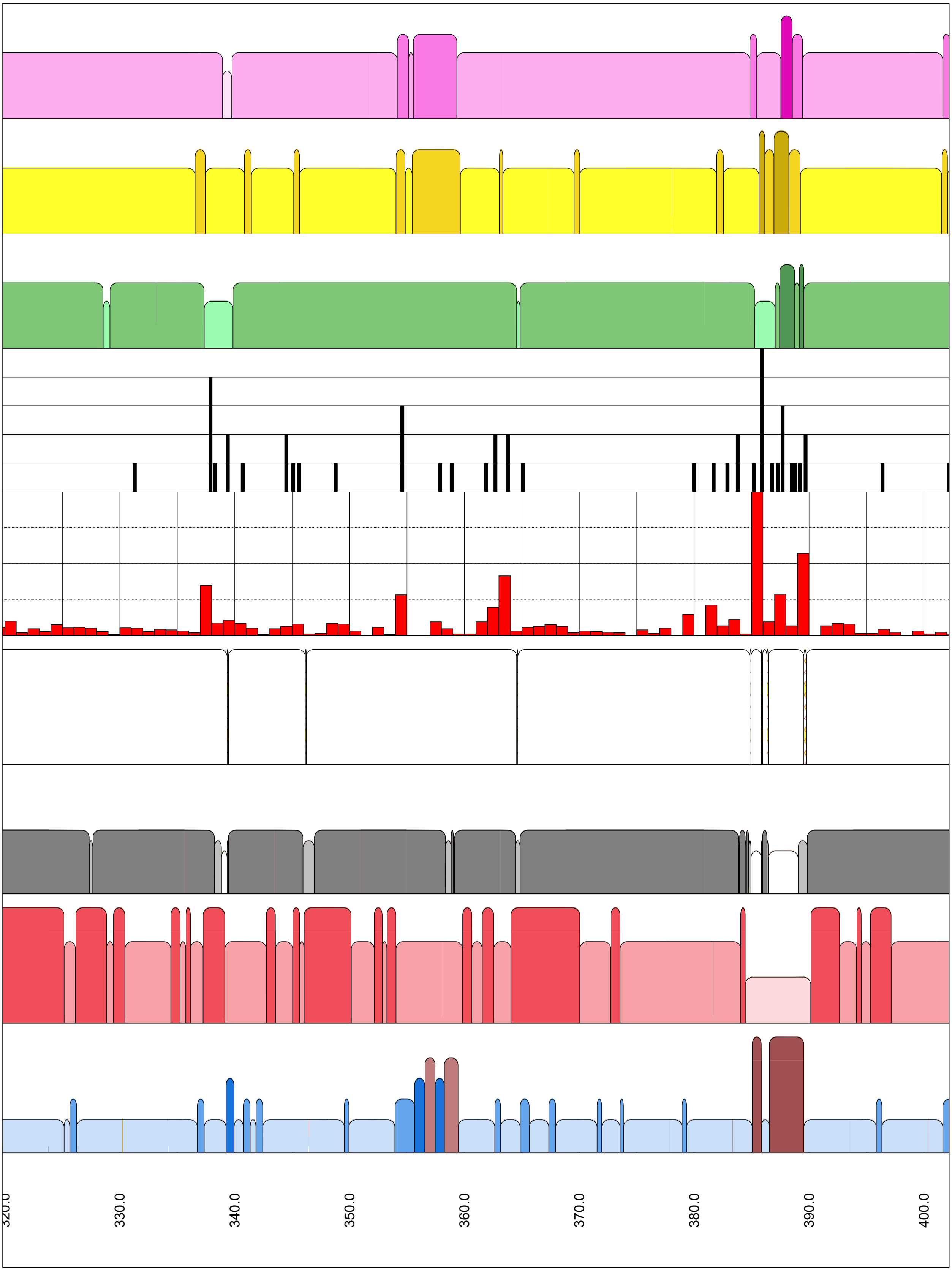

86.0
88.0
90.0
92.0
94.0
96.0
98.0

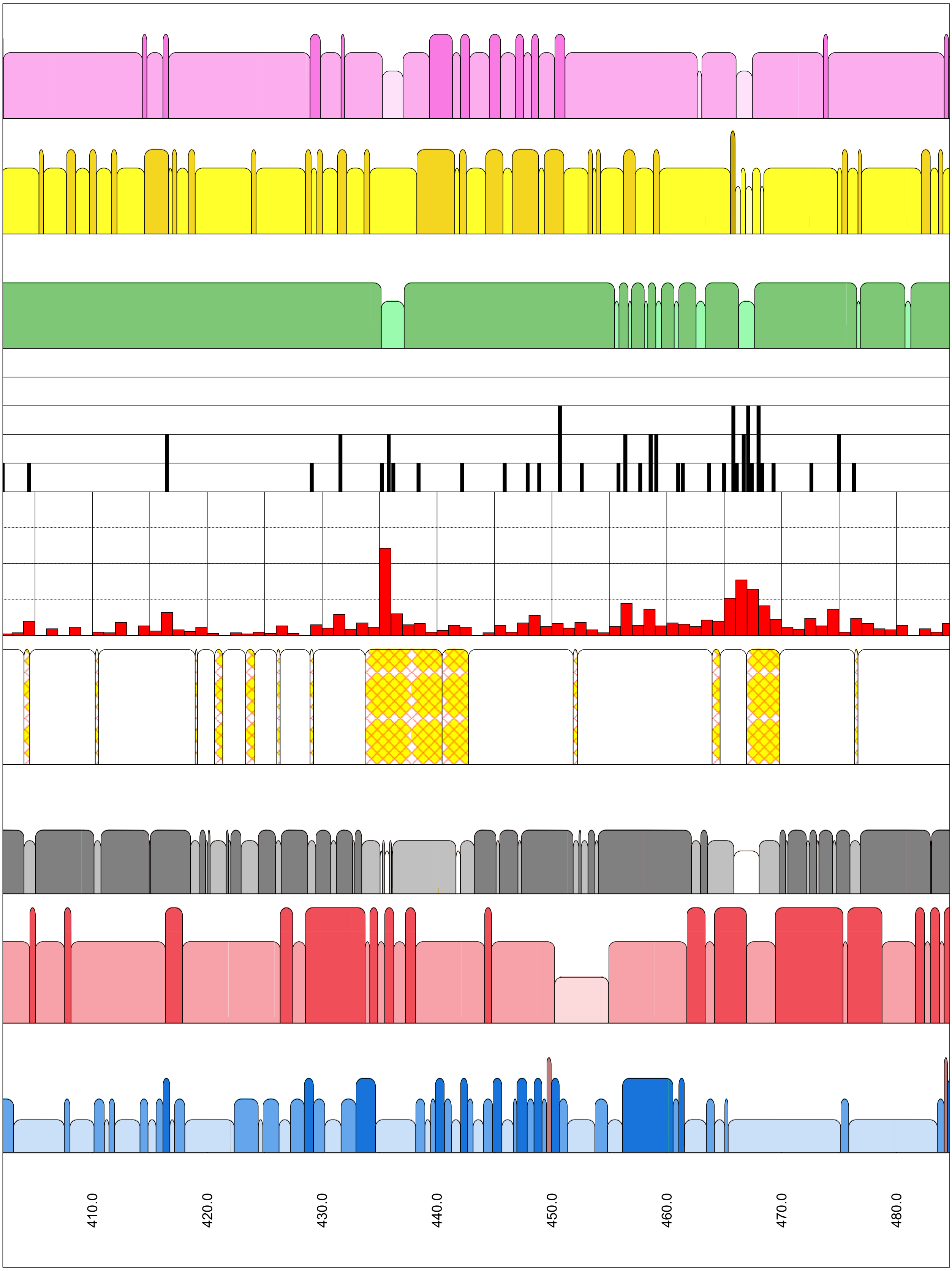
Appendix 5

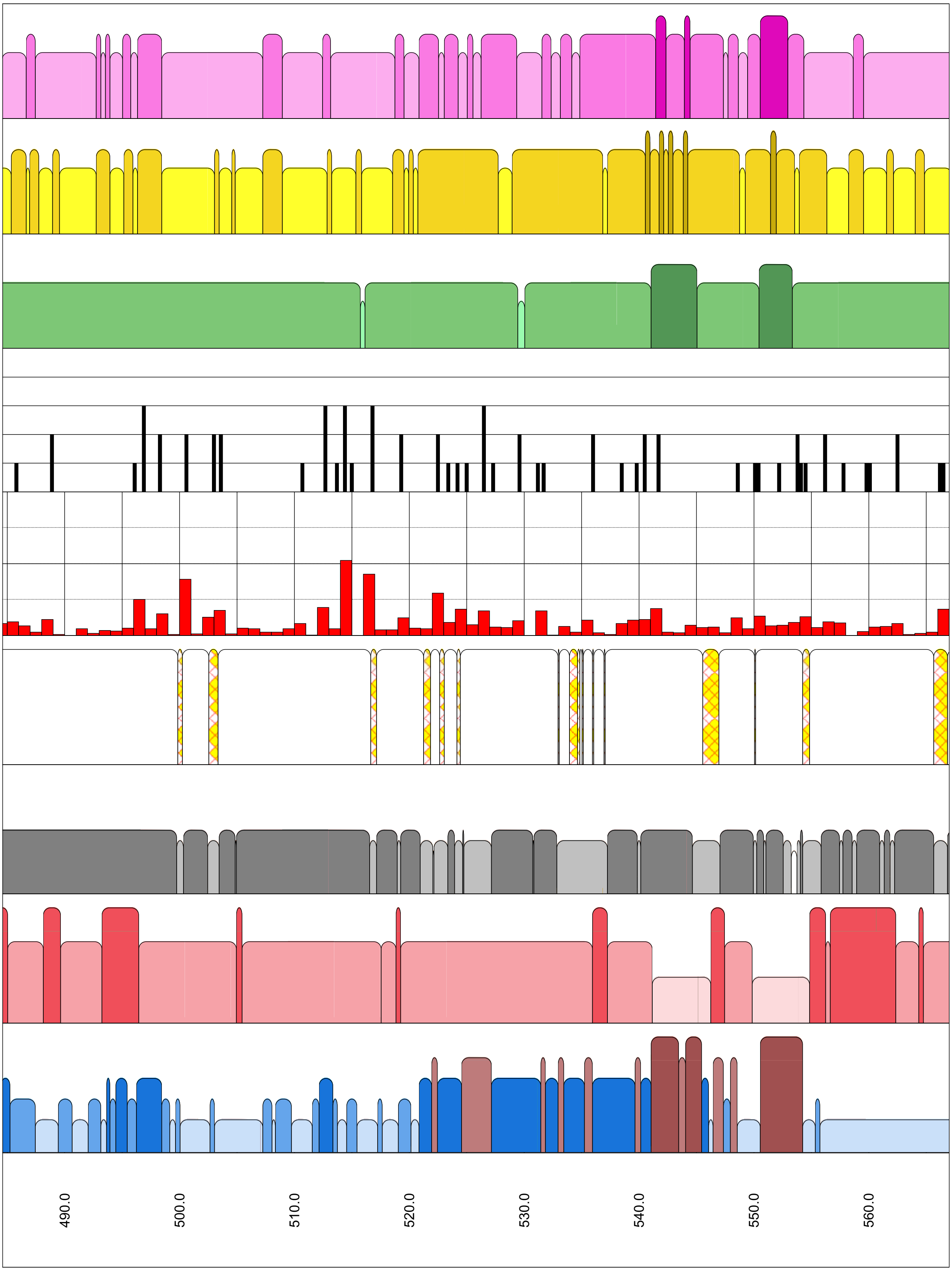
Generalized geophysical loggings and estimated elastic moduli data for the borehole KLX02 (200–1,000 m)

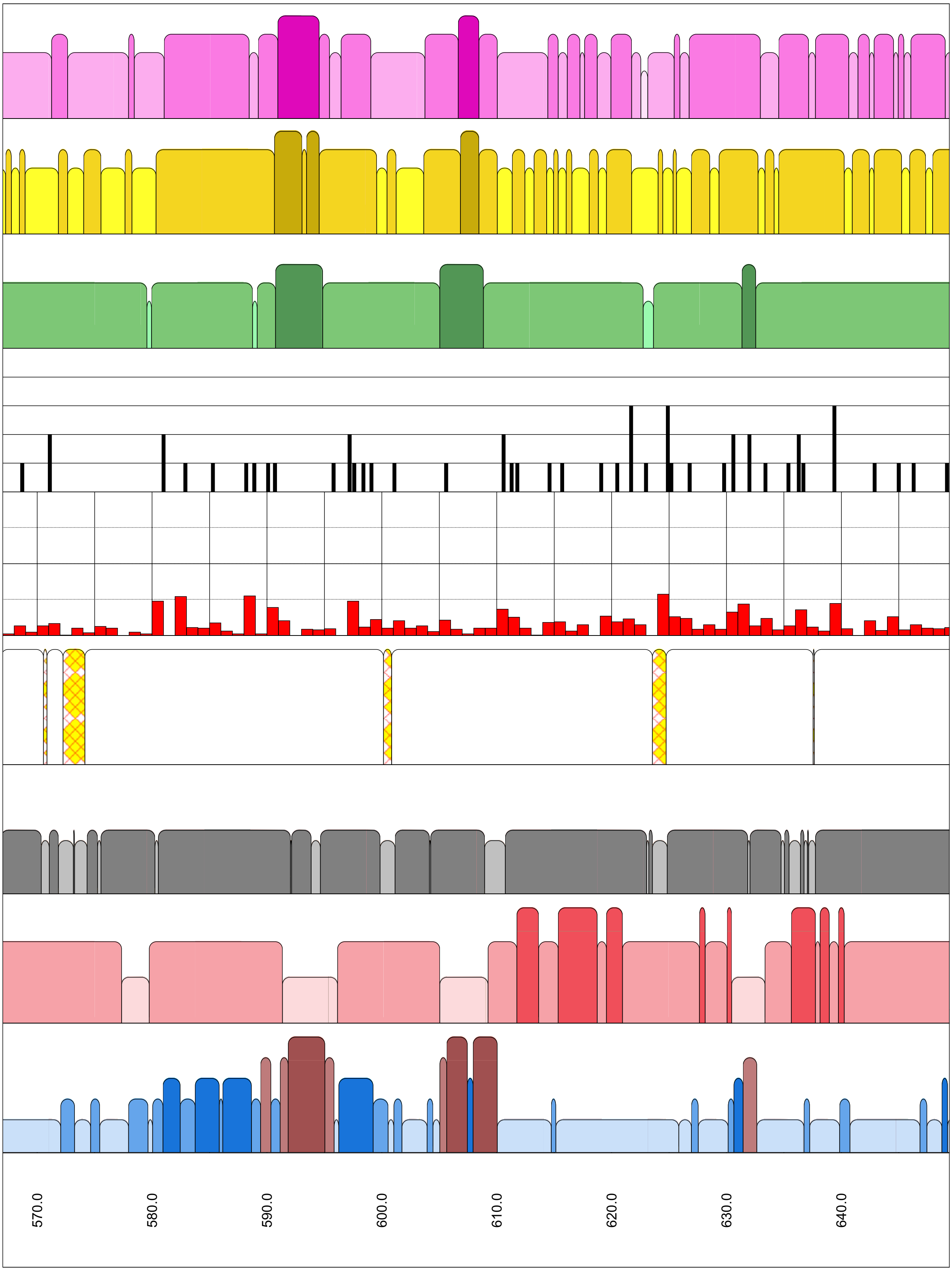

GeoVista
Interpretation of geophysical borehole logging data
Borehole KLX02
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Natural Gamma Radiation
microR/h
unclassified
gam<15
15<gam<25
gam>25
Indication of possible alteration
Possible alteration
Shear Modulus
GPa
unclassified
shear mod<30
30<shear mod<35
shear mod>35
Bulk Modulus
GPa
unclassified
bulk mod<40
40<bulk mod<50
50<bulk mod<60
bulk mod>60
Youngs Modulus
GPa
unclassified
young mod<70
70<young mod<80
80<young mod<90
young mod>90
Depth
1m:500m
Generalized Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Possible Alteration
Fracture Loggings
Estimated Fracture Frequency (fract/m)
0
20
Fractures (No. methods)
0
5
Elastic Moduli
Shear Modulus
Bulk Modulus
Youngs Modulus
200.0
210.0
220.0
230.0


240.0
250.0
260.0
270.0
280.0
290.0
300.0
310.0

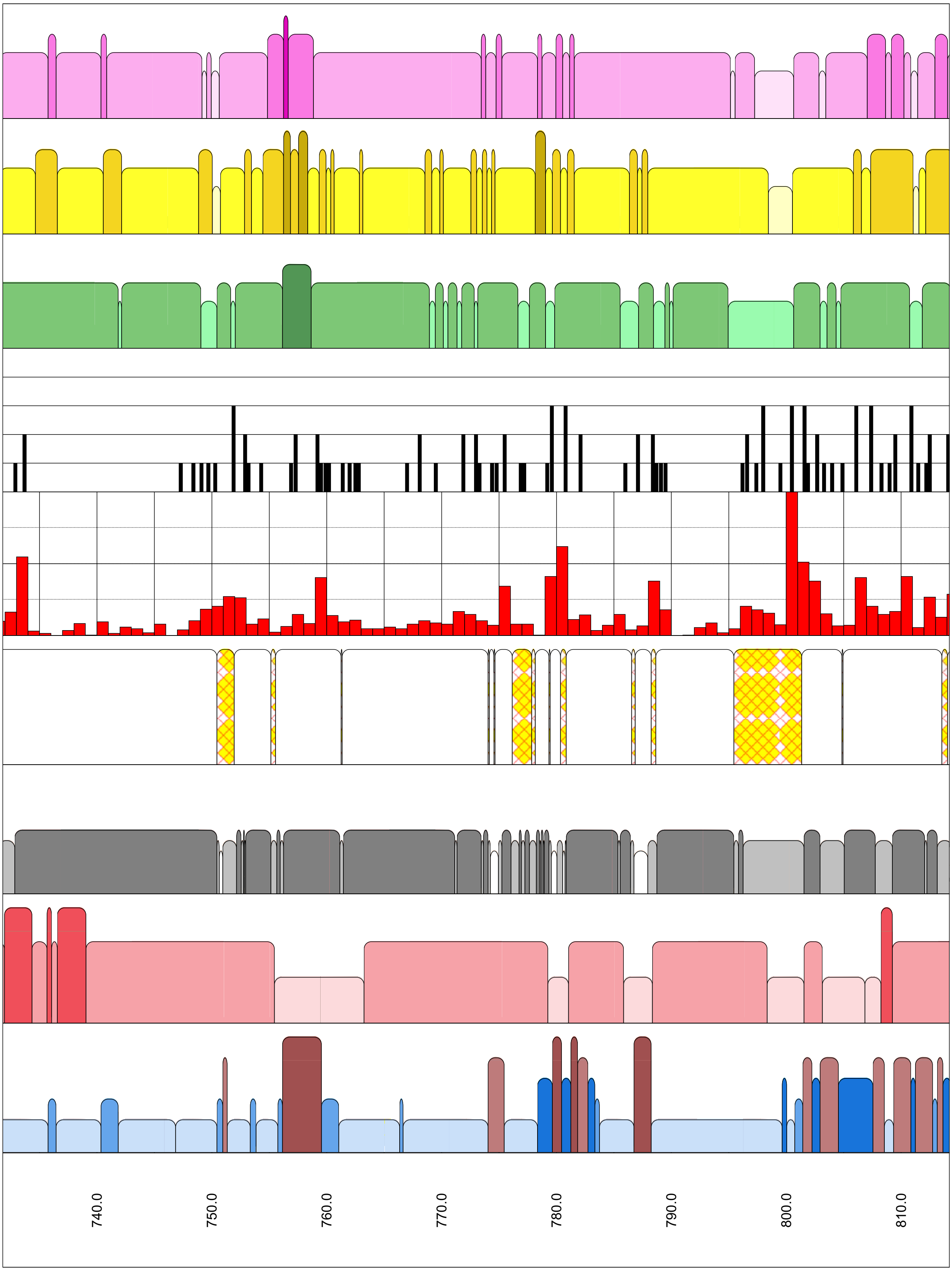

320.0
330.0
340.0
350.0
360.0
370.0
380.0
390.0
400.0

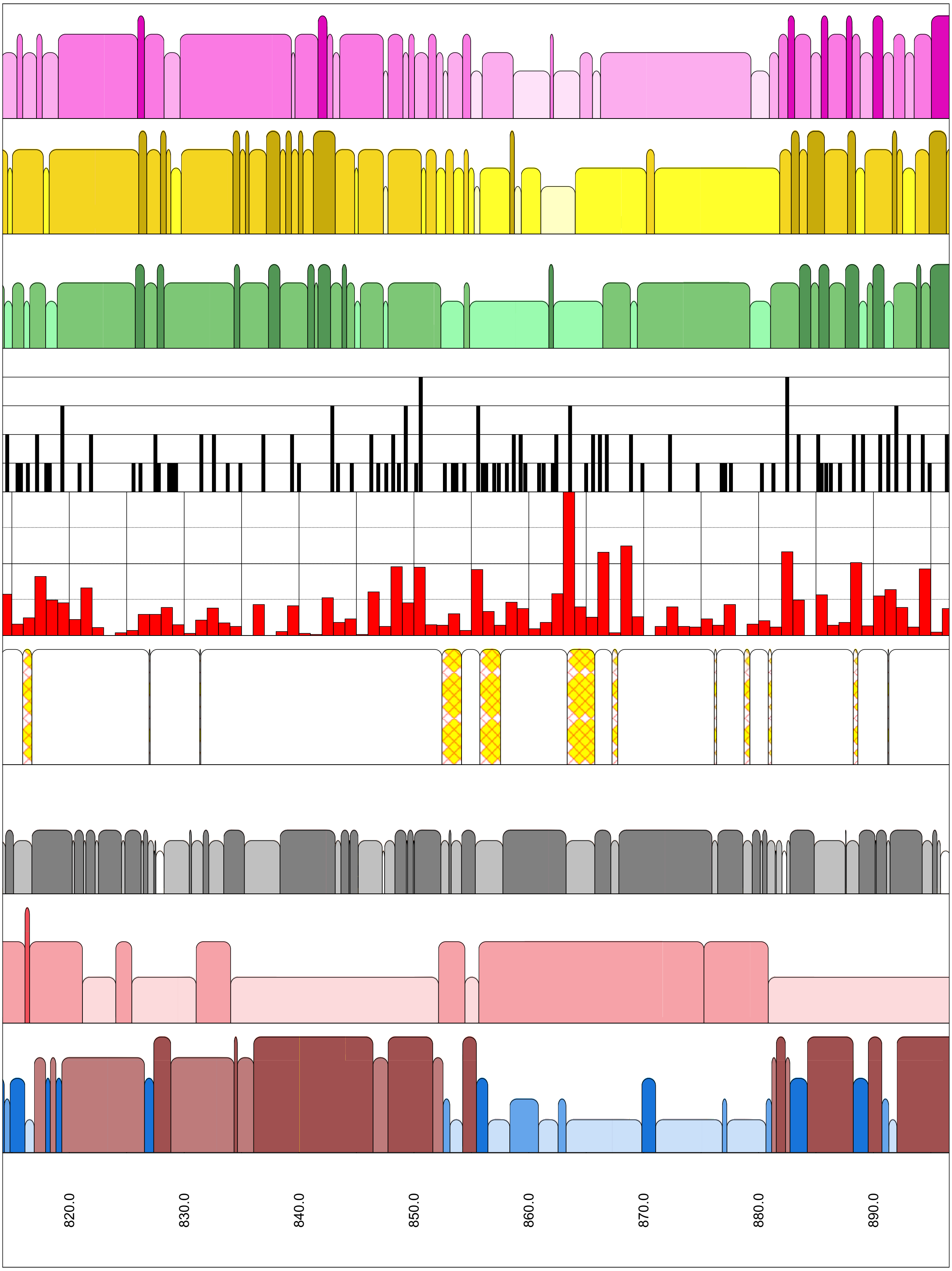

410.0
420.0
430.0
440.0
450.0
460.0
470.0
480.0

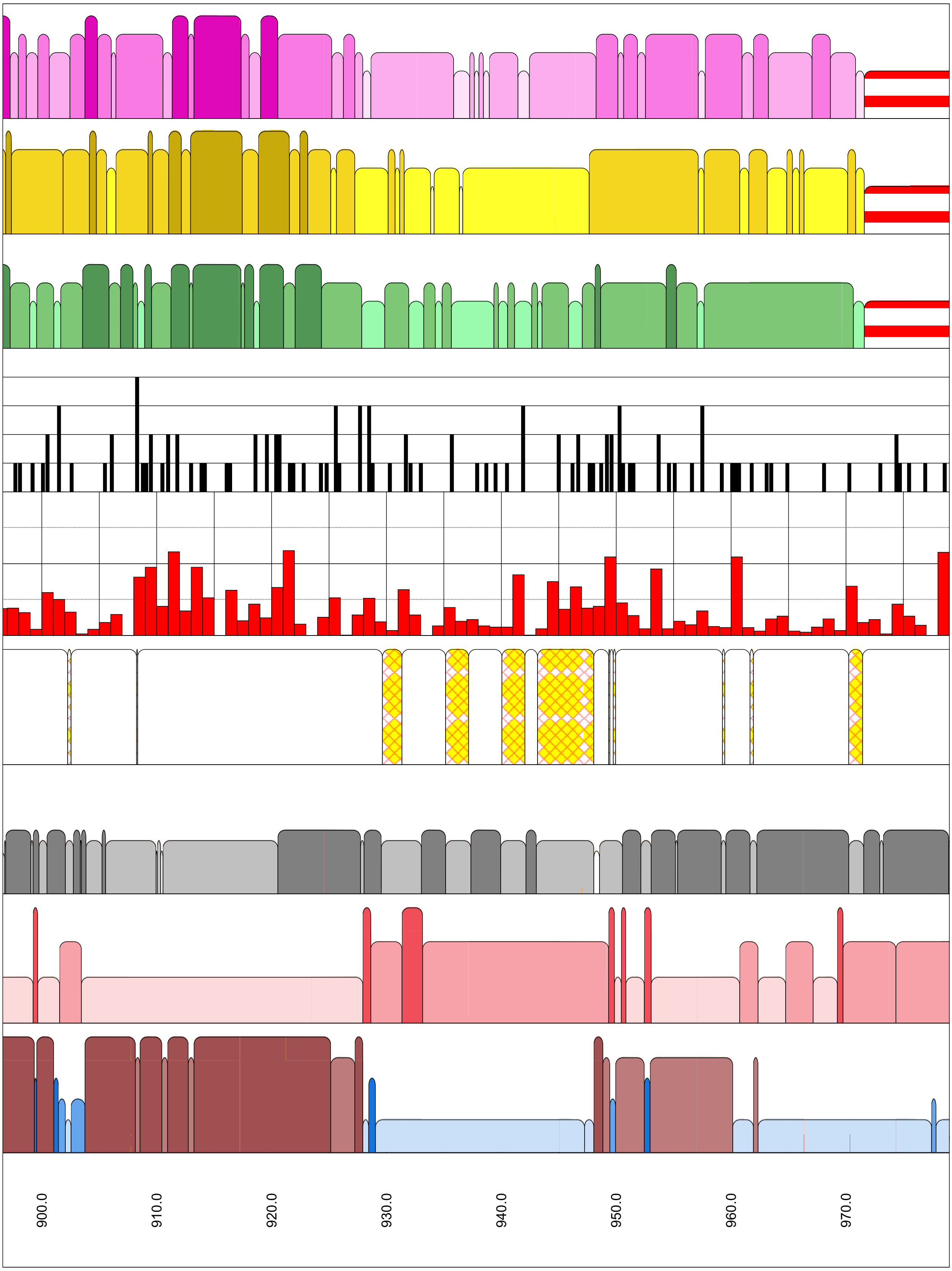

490.0
500.0
510.0
520.0
530.0
540.0
550.0
560.0

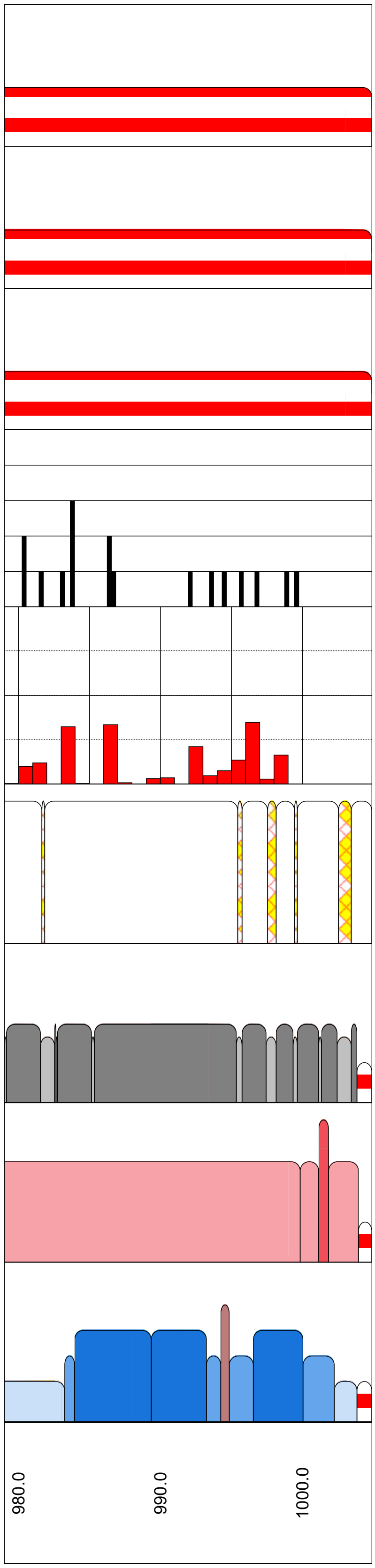

570.0
580.0
590.0
600.0
610.0
620.0
630.0
640.0


650.0
660.0
670.0
680.0
690.0
700.0
710.0
720.0
730.0


740.0
750.0
760.0
770.0
780.0
790.0
800.0
810.0


820.0
830.0
840.0
850.0
860.0
870.0
880.0
890.0


900.0
910.0
920.0
930.0
940.0
950.0
960.0
970.0


980.0
990.0
1000.0