P-04-217

Oskarshamn site investigation

Interpretation of geophysical borehole data and compilation of petrophysical data from KAV04A (100–1000 m), KAV04B, HLX13 and HLX15

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September 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 KAV04A and KAV04B (the Ävrö Island), and the percussion drilled boreholes HLX13 and HLX15 (Laxemar).

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

The uppermost c. 290 m of the bedrock in the vicinity of KAV04A and KAV04B is dominated by rocks with a silicate density indicating a mineral composition that corresponds to granodiorite. Between c. 290 m depth and c. 610 depth, there is a higher frequency of rocks with higher density (indicated tonalite-diorite mineral composition). The section c. 610–860 m of KAV04A is dominated by 4 coherent sub-sections (10–50 m long) with high natural gamma radiation and silicate densities corresponding to granite. The combination of low density and high natural gamma radiation indicates the occurrence of fine-grained granite along these sections. Below 860 m depth, there is a complete dominance of silicate density that indicates a mineral composition corresponding to tonalite. From a natural gamma radiation point of view, the borehole can be coarsely subdivided into an upper low radiation part (c. 100–610 m depth) and a lower high radiation part (c. 610–1,000 m depth). Between c. 550 m depth and c. 900 m depth there are several fairly long sections along which the magnetic susceptibility is low, possibly corresponding to rock alteration. A possible deformation zone is indicated in KAV04A at c. 250 m depth.

The section c. 15–75 m of HLX13 is dominated by moderately high gamma radiation levels and silicate density that corresponds to granite. A deformation zone is strongly indicated at c. 80–110 m depth. The rocks below the possible deformation zone (110–200 m) are dominated by moderately low natural gamma radiation and silicate density that corresponds mainly to granodiorite and tonalite. The rocks in the vicinity of HLX15 show rather high densities, mainly corresponding to tonalite. In HLX15 a large occurrence of fine-grained granite dykes is indicated by low silicate density and high natural gamma radiation anomalies.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhållsdata och petrofysiska data från kärnborrhålen KAV04A och KAV04B på Ävrö samt de hammarborrade hålen HLX13 och HLX15 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.

De översta ca 290 m av berggrunden i närheten av borrhålen KAV04A och KAV04B domineras av bergarter med en silikatdensitet motsvarande granodiorit. Mellan ca 290 m och 610 m djup finns flera relativt långa sektioner där silikatdensiteten når upp till värden som indikerar en mineralsammansättning motsvarande tonalit till diorit. Längs sektionen 610–860 m kan 4 st ca 10–50 m långa avsnitt identifieras som har avvikande hög naturlig gammastrålning och en silikatdensitet motsvarande granit, vilket indikerar att dessa sannolikt utgörs av finkornig granit. Nedanför 860 m nivån domineras berggrunden runt KAV04A av bergarter med en silikatdensitet motsvarande tonalit. Med avseende på naturlig gammastrålning kan KAV04A, grovt sett, delas in i en lågstrålande övre del (100–610 m djup) och en högstrålande nedre del (610–1,000 m djup). Mellan ca 550 m djup och ca 900 m djup finns flera längre sektioner med mycket låg magnetisk susceptibilitet, vilket kan vara en indikation på omvandling av berget. En möjlig deformationszon kan identifieras på ca 250 m djup i KAV04A.

De översta ca 75 m i HLX13 domineras av relativt hög naturlig gammastrålning och låg densitet. Mellan ca 80 m och 110 m djup kan en trolig deformationszon identifieras. Längs detta avsnitt är den naturliga gammastrålningen mycket låg. Från 110 m och ned till botten av borrhålet (200 m), indikerar silikatdensiteten en mineralsammansättning motsvarande granodiorit till tonalit. Bergrunden runt HLX15 domineras till stora delar av bergarter med relativt hög densitet, motsvarande tonalit. Ett flertal positiva strålningsanomalier, vilka ofta sammanfaller med låg densitet, indikerar en relativt hög frekvens av finkorniga granitgångar.

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 KAV04A and KAV04B (the Ävrö Island), and the percussion drilled boreholes HLX13 and HLX15 (Laxemar). A compilation of petrophysical data from measurements on 10 core samples from KAV04A is also presented. The work was carried out in accordance with activity plan AP PS 400-04-051 (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.

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings, including estimated fracture frequency. The logging measurements were conducted in 2004 by Rambøll.

The petrophysical determinations of KAV04A include magnetic susceptibility and wet density. The measurements were performed at the laboratory of the Division of Applied Geophysics, Luleå University of Technology.

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 KAV04A, KAV04B, HLX13 och HLX15	AP PS 400-04-051	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	2.0

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.

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 10 samples from KAV04A (Table 4-1), collected and preliminary classified by Thomas Kisiel (SKB, SICADA field note no. 362). 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 KAV04A is given in Table 4-1 below.

Table 4-1. Sample information for KAV04A.

Section up (m)	Section low (m)	Rock type
179.90	180.00	Ävrö granite
200.00	200.10	Ävrö granite
339.25	339.35	Fine-grained diorite-gabbro
400.52	400.62	Fine-grained diorite-gabbro
591.00	590.10	Ävrö granite
701.55	701.65	Fine-grained granite
852.65	852.75	Fine-granied granite
875.45	875.55	Fine-grained dioritoid
919.05	919.15	Fine-grained dioritoid
931.20	931.30	Fine-grained dioritoid

4.2.2 Logging data

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).
- Focused resistivity (140 cm).
- Sonic (P-wave).
- Caliper mean.
- SPR.
- Short normal resistivity (16 inch).
- Long normal resistivity (64 inch).

The gamma-gamma, natural gamma radiation and magnetic susceptibility loggings of HLX15 start at c. 12 m depth whereas the other logging methods start at c. 42 m depth. 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).

4.3 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.

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 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 4-2) 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 all logging methods. 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 KLX02. No such correlation has been possible to make for data collected at the Ävrö Island, and the power function estimated for KLX02 constitutes a special case, since it is based on old and slightly different methods compared to those used during the ongoing site investigations. The estimated fracture frequency calculations for KAV04A, KAV04B, HLX13 and HLX15 are based on individual power functions for each method, and the levels of the weights were set so that the background frequency (in "solid" rock) would be c. 1–2 fractures/m. The amplitudes are therefore uncertain.

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. 501.

Table 4-2. 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
Threshold	KAV04A	1.5	0.6	0.6	0.6	0.5	5.0	0.6
Power	KAV04A	1.5	1.0	1.6	Not used	0.5	0.5	0.6
Weight	KAV04A	5.3	7.1	6.7	Not used	5.0	2.9	5.0
Threshold	KAV04B	1.5	0.6	0.6	0.6	0.5	5.0	0.6
Power	KAV04B	1.5	1.0	1.6	Not used	0.5	0.5	0.6
Weight	KAV04B	5.3	7.1	6.7	Not used	5.0	2.9	5.0
Threshold	HLX13	0.7	0.9	0.9	0.15	1.0	4.0	4.0
Power	HLX13	1.5	1.0	1.6	Not used	0.5	0.5	0.6
Weight	HLX13	5.3	7.1	6.7	Not used	5.0	2.9	5.0
Threshold	HLX15	0.9	1.4	1.4	0.35	1.0	4.0	4.0
Power	HLX15	1.5	1.0	1.6	Not used	0.5	0.5	0.6
Weight	HLX15	5.3	7.1	6.7	Not used	5.0	2.9	5.0

5 Results

5.1 Petrophysical properties of KAV04A

The sampling covers 10 samples from KAV04A (Table 4-1, section 4.2.1), collected and preliminary classified by Thomas Kisiel (SKB, SICADA field note no. 362). 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. The two fine-grained granite samples classify as granite whereas the Ävrö granite samples plot closer to the granodiorite classification curve. The fine-grained dioritoid samples and one of the fine-grained diorite to gabbro samples plot between the tonalite and diorite classification curves, and the remaining fine-grained diorite to gabbro sample plot between the diorite and the gabbro classification curves.

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. 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 and within different rock types (or groups of rocks).

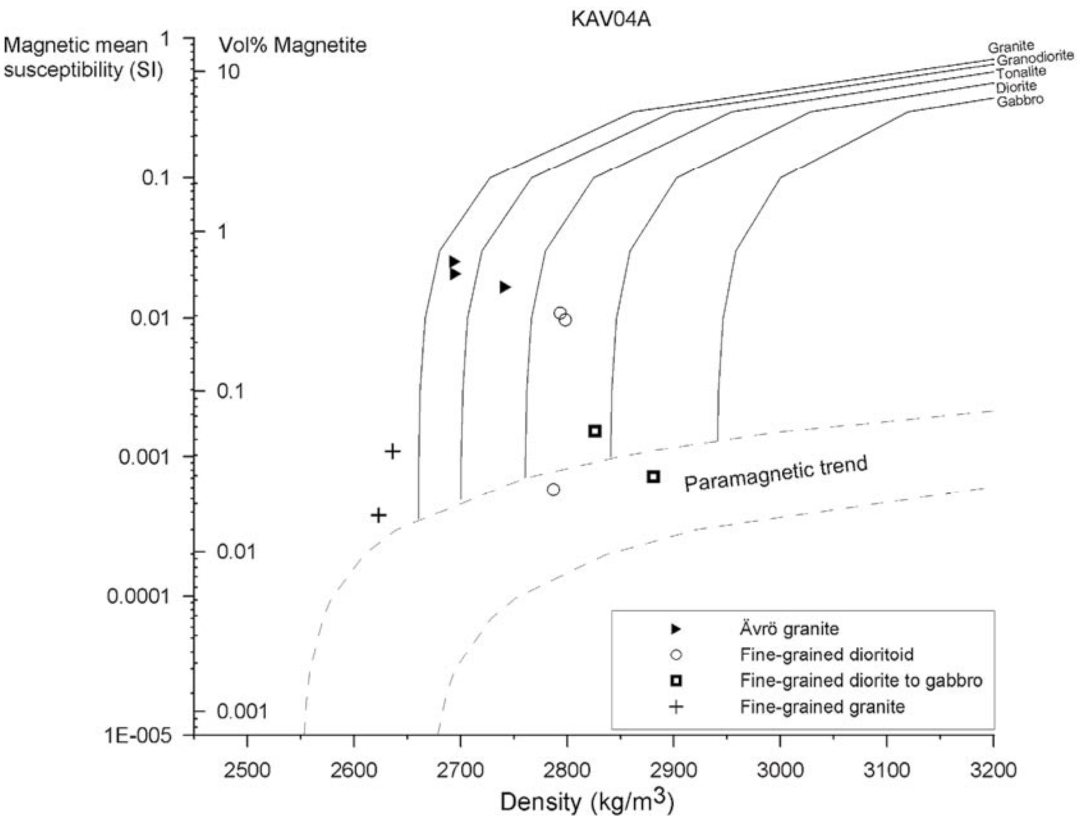

__Figure 5-1.__ Density-susceptibility rock classification diagram for KAV04A. See the text for explanation.

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 and natural gamma radiation logs of KAV04A and HLX15 have noise levels far above the recommended levels. To reduce the influence of the noise, all logs were average or median filtered prior to the interpretation. However, the very high noise levels of the density and the natural gamma radiation data of KAV04A and HLX15 may have a significant affect on the quality of the interpretation of these boreholes, especially regarding the possibility of resolving anomalies produced by thin veins or dykes.

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.

5.2.2 Comparsion between logging and petrophysical data for KAV04A

A quality control of the gamma-gamma and the magnetic susceptibility loggings is performed by comparing the logging data to the petrophysical data 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 fair for the linear fit and rather bad for the fit through the origin. Note the scatter in the data even though the logging data are filtered. The density logs of KAV04A, KAV04B, HLX13 and HLX15 were all calibrated by use of the equation gained from the linear fit.

A cross plot between the susceptibility log data and susceptibility measured on core samples is shown in Figure 5-3. There is a good correlation between logging and petrophysical data. However the slope of the fitted line (through origin) is 0.69, which indicates that the logging measurements underestimate the true magnetic susceptibility. Prior to the interpretations, the logging data of all investigated boreholes were calibrated based on the petrophysical data from KAV04A.

Table 5-1. Noise levels in geophysical logging data for KAV04A, KAV04B, HLX13 and HLX15.

Logging method	KAV04A	KAV04B	HLX13	HLX15	Recommended max noise level
Density (kg/m^3)	60	22	22	63	3–5
Magnetic susceptibility (SI)	5×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	2.2	0.8	0.6	2.0	0.3
Long normal resistivity (%)	0.7	0.1	0.08	0.2	2.0
Short normal resistivity (%)	0.3	0.1	0.05	0.4	2.0
Single point resistance (%)	0.6	0.1	0.07	0.2	No data
Caliper (meter)	4×10^{-5}	8×10^{-6}	4×10^{-4}	1×10^{-4}	0.0005
Focused resistivity 300 (%)	10	13	3	13	No data
Focused resistivity 140 (%)	7	8	2	3	No data
Sonic (m/s)	54	25	54	43	20

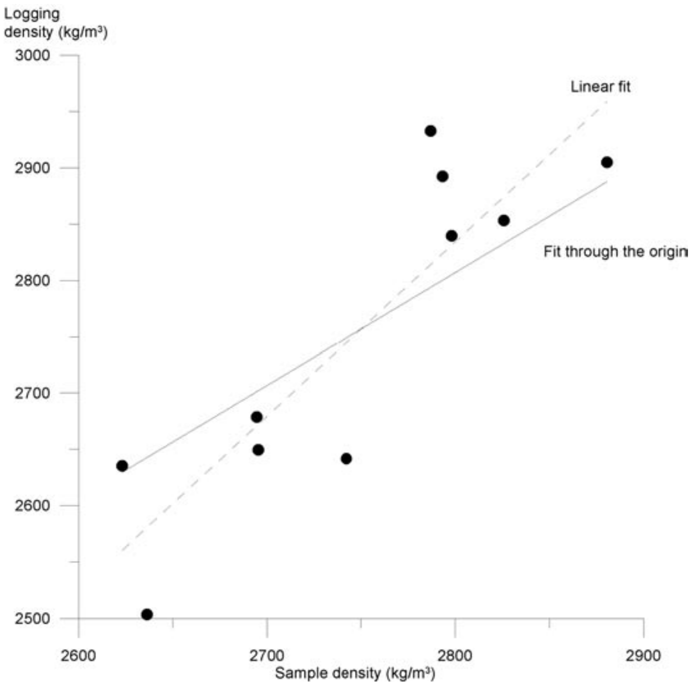

Figure 5-2. *Cross plot of density logging data versus density data from core samples.*

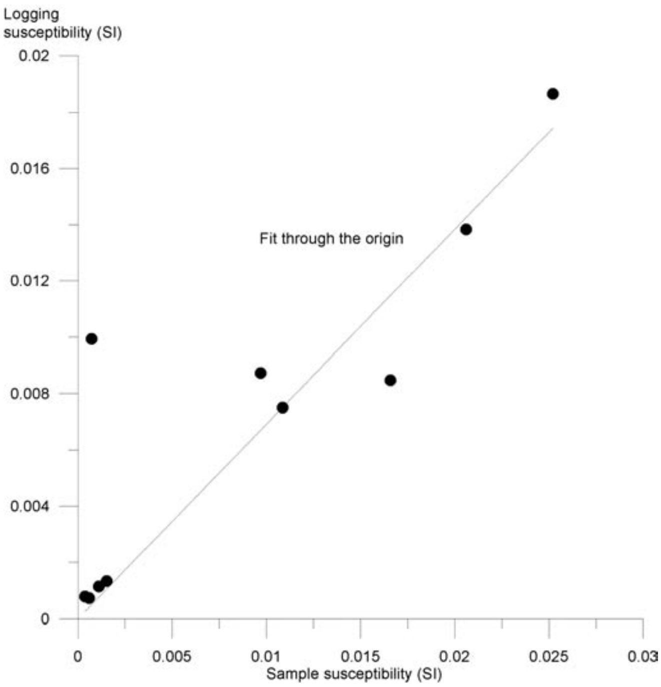

Figure 5-3. *Cross plot of magnetic susceptibility logging data versus susceptibility data from core samples*

5.3 Interpretation of the logging data

The presentation of interpretation products presented below, in sections 5.3.1 to 5.3.4, 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 meter sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and >6 fractures/m).

5.3.1 Interpretation of KAV04A

The results of the generalized logging data and fracture estimations of KAV04A are presented in Figure 5-4 below, and in a more detailed scale in Appendix 1.

The rocks in the vicinity of KAV04A (100–1,000 m) show large density variations with depth, which indicates a heterogenic mineral composition along the borehole. Section 100–290 m is dominated by a silicate density that corresponds to granodiorite. Between c. 290 m depth and c. 610 depth, there is a higher frequency of rocks with higher density, shown by several >10 m long sections with a silicate density that corresponds to tonalite and diorite. The section c. 610–860 m is dominated by 4 coherent sub-sections (10–50 m long) with high natural gamma radiation and silicate densities corresponding to granite. The combination of low density and high natural gamma radiation indicates the occurrence of fine-grained granite along these sections. Below 860 m depth, there is a complete dominance of silicate density that indicates a mineral composition corresponding to tonalite. From a natural gamma radiation point of view, the borehole can be coarsely subdivided into an upper low radiation part (c. 100–610 m depth) and a lower high radiation part (c. 610–1,000 m depth). Between c. 550 m depth and c. 900 m depth there are several fairly long sections along which the magnetic susceptibility is low, possibly corresponding to rock alteration.

The estimated fracture frequency of KAV04A (100–1,000 m) mainly varies between low (<3 fr/m) and moderate (3–6 fr/m). One section of high fracture frequency, possibly related to a deformation zone, is indicated at the section c. 220–270 m.

5.3.2 Interpretation of KAV04B

The results of the generalized data and fracture estimations of KAV04B are presented in Figure 5-5 below.

The bedrock in the vicinity of the borehole KAV04B is completely dominated by a silicate density indicating a mineral composition that correspond to granodiorite. Several short sections classified as granite are present, and some of these correspond to a high natural gamma radiation level which indicates the occurrence of fine-grained granite. The natural gamma radiation along the borehole is generally moderate, but low along the deepest c. 30 m. The magnetic susceptibility generally varies between 0.001 SI and 0.1 SI. Low susceptibility mainly occurs below c. 55 m depth.

The estimated fracture frequency of KAV04B mainly varies between low (<3 fr/m) and moderate (3–6 fr/m). Three short sections with indicated high frequency are located at c. 10 m, 55 m and 100 m depth.

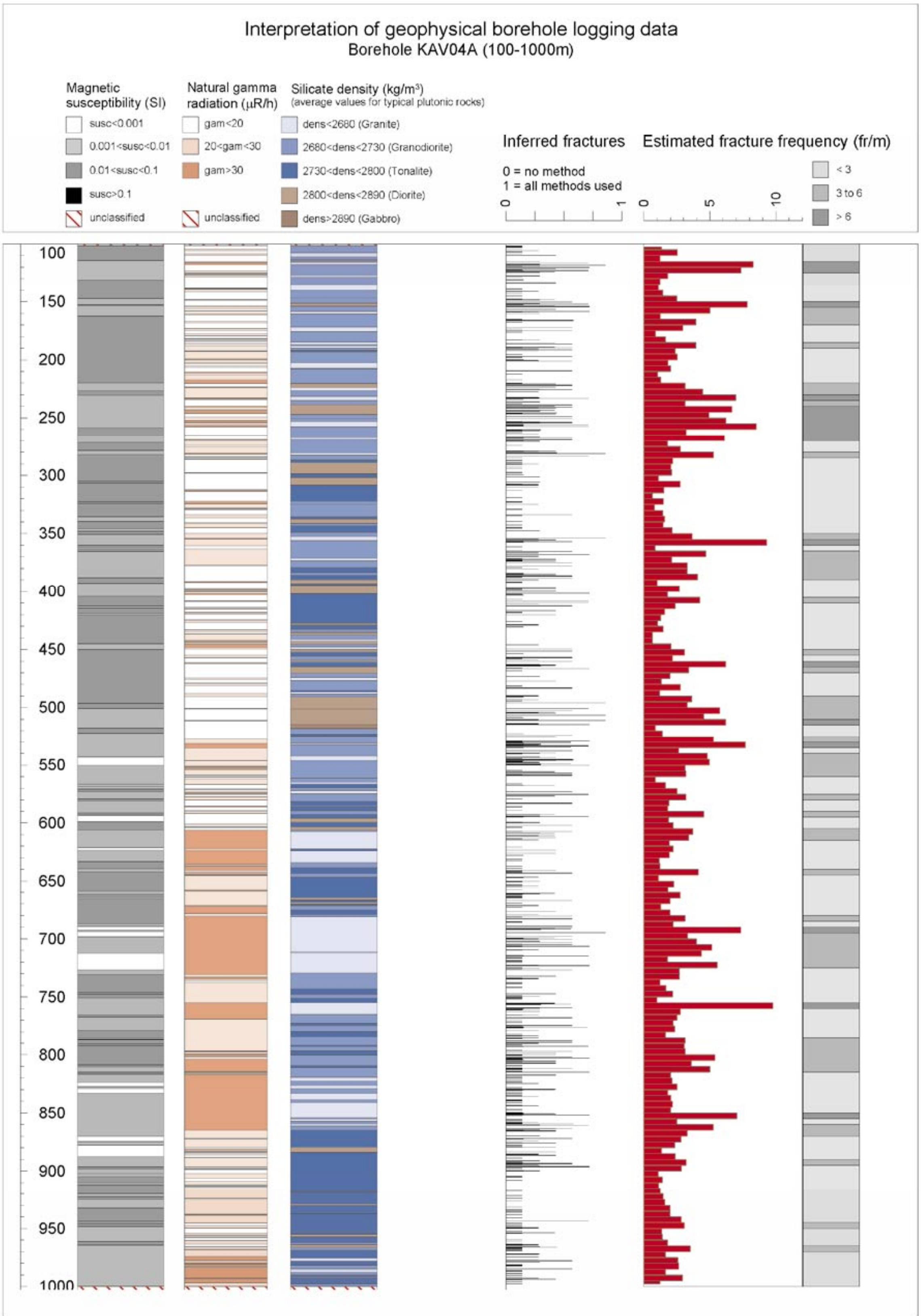

Figure 5-4. *Generalized geophysical logs for KAV04A (100–1,000 m).*

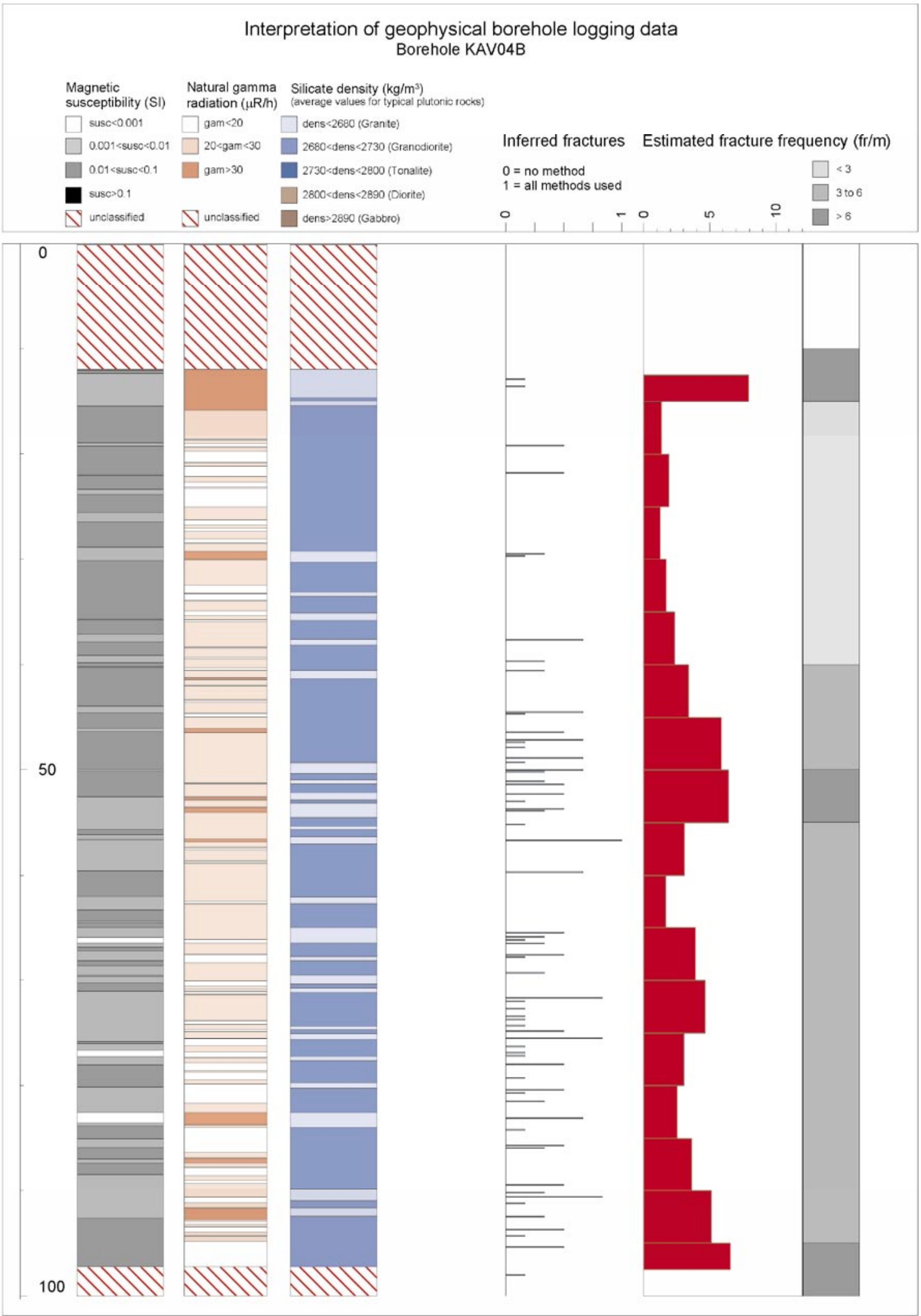

Figure 5-5. *Generalized geophysical logs for KAV04B.*

5.3.3 Interpretation of HLX13

The results of the generalized data and fracture estimations of HLX13 are presented in Figure 5-6 below.

The borehole HLX13 can coarsely be subdivided into three sub-sections. Section 10–70 m is dominated by fairly high natural gamma radiation, a silicate density that corresponds to granite and variable susceptibility. Section 70–110 m is dominated by low natural gamma radiation, moderately low magnetic susceptibility and a silicate density that corresponds mainly to tonalite. The third sub-section (110–195 m) is dominated by moderate natural gamma radiation, moderately high magnetic susceptibility and a silicate density that corresponds to granodiorite to tonalite.

The estimated fracture frequency is generally moderate (3–6 fr/m) along the uppermost c. 80 m. From c. 80 m depth down to c. 110 m depth there is a probable deformation zone, and below c. 110 m depth the rock in the vicinity of the borehole seems to be only slightly fractured.

5.3.4 Interpretation of HLX15

The results of the generalized data and fracture estimations of HLX15 are presented in Figure 5-7 below.

The rocks in the vicinity of section 15–45 m of HLX15 seem to be crosscut by several thin fine-grained granite dykes indicated by high natural gamma radiation anomalies together with a silicate density that corresponds mainly to granite. Section 45–150 m is completely dominated by a silicate density that corresponds to tonalite. At c. 90 m depth a c. 10 m long section shows high natural gamma radiation and a silicate density that corresponds to granite. This is a clear indication of the occurrence of fine-grained granite. A few thin high density anomalies occur along the borehole, and these high density anomalies most likely correspond to mafic enclaves.

The estimated fracture frequency of HLX13 varies between low (<3 fr/m) and moderate (3–6 fr/m).

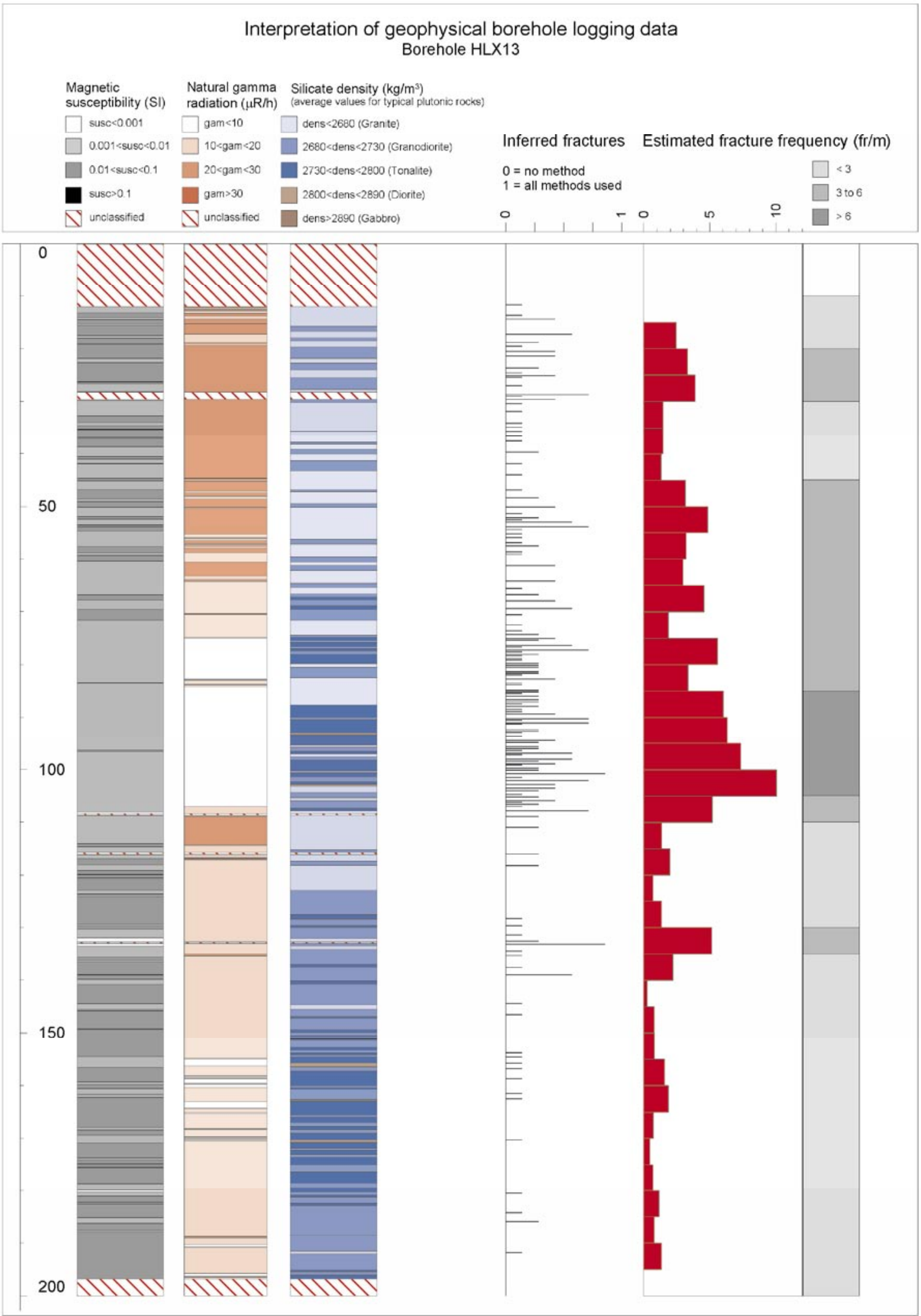

Figure 5-6. *Generalized geophysical logs for HLX13.*

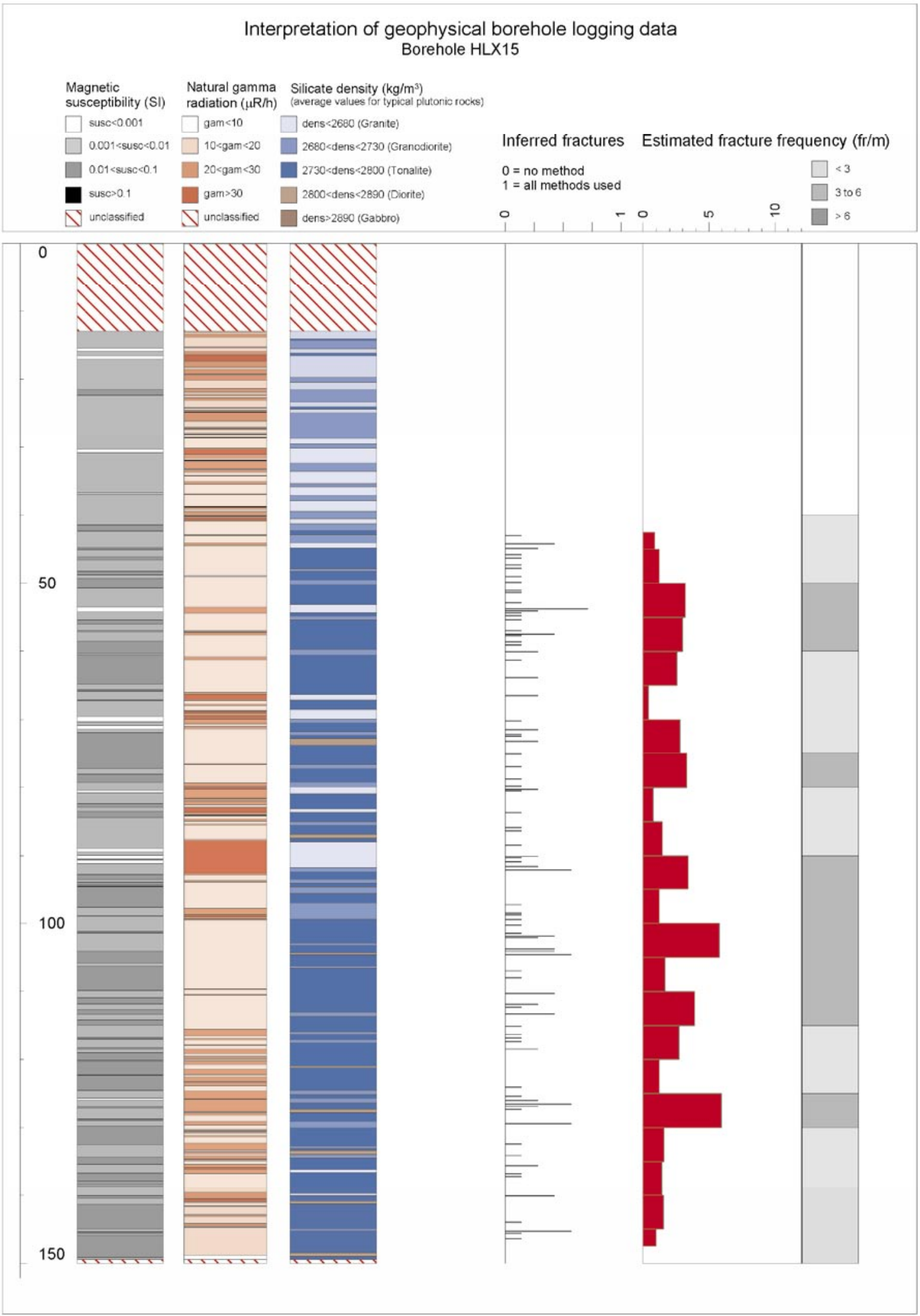

Figure 5-7. Generalized geophysical logs for HLX15.

6 Discussion

The density and natural gamma radiation log data of KAV04A and HLX15 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.

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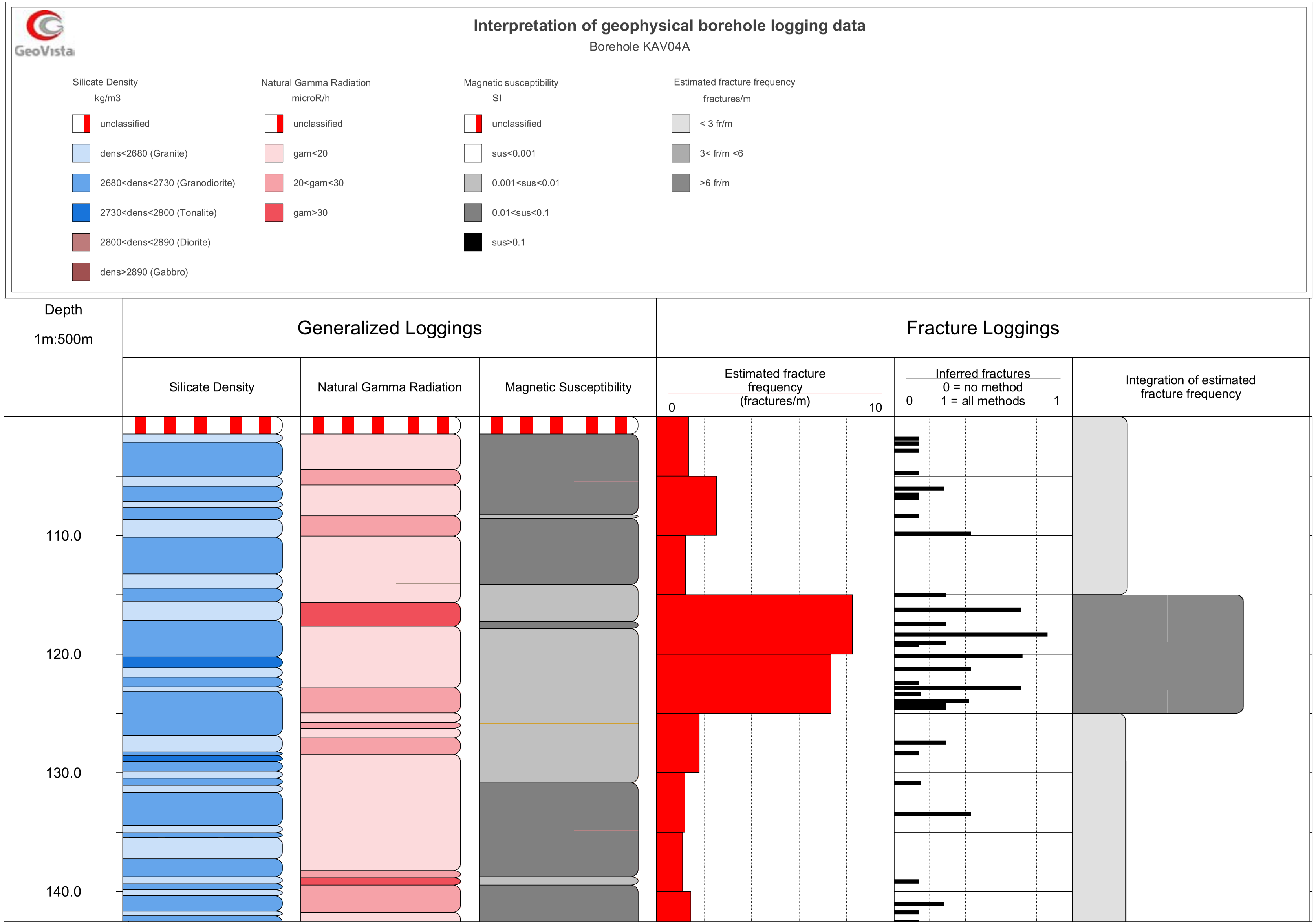
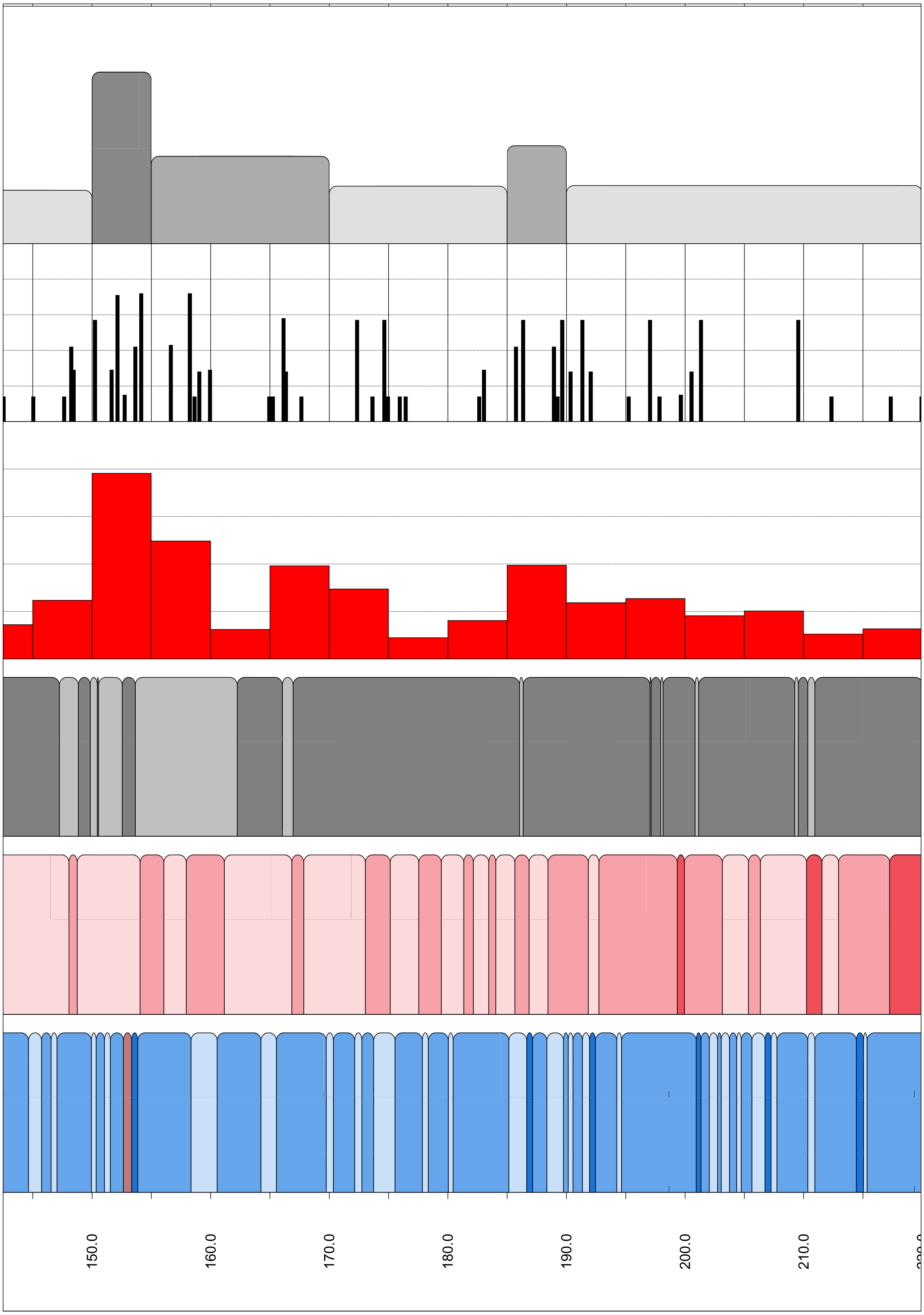
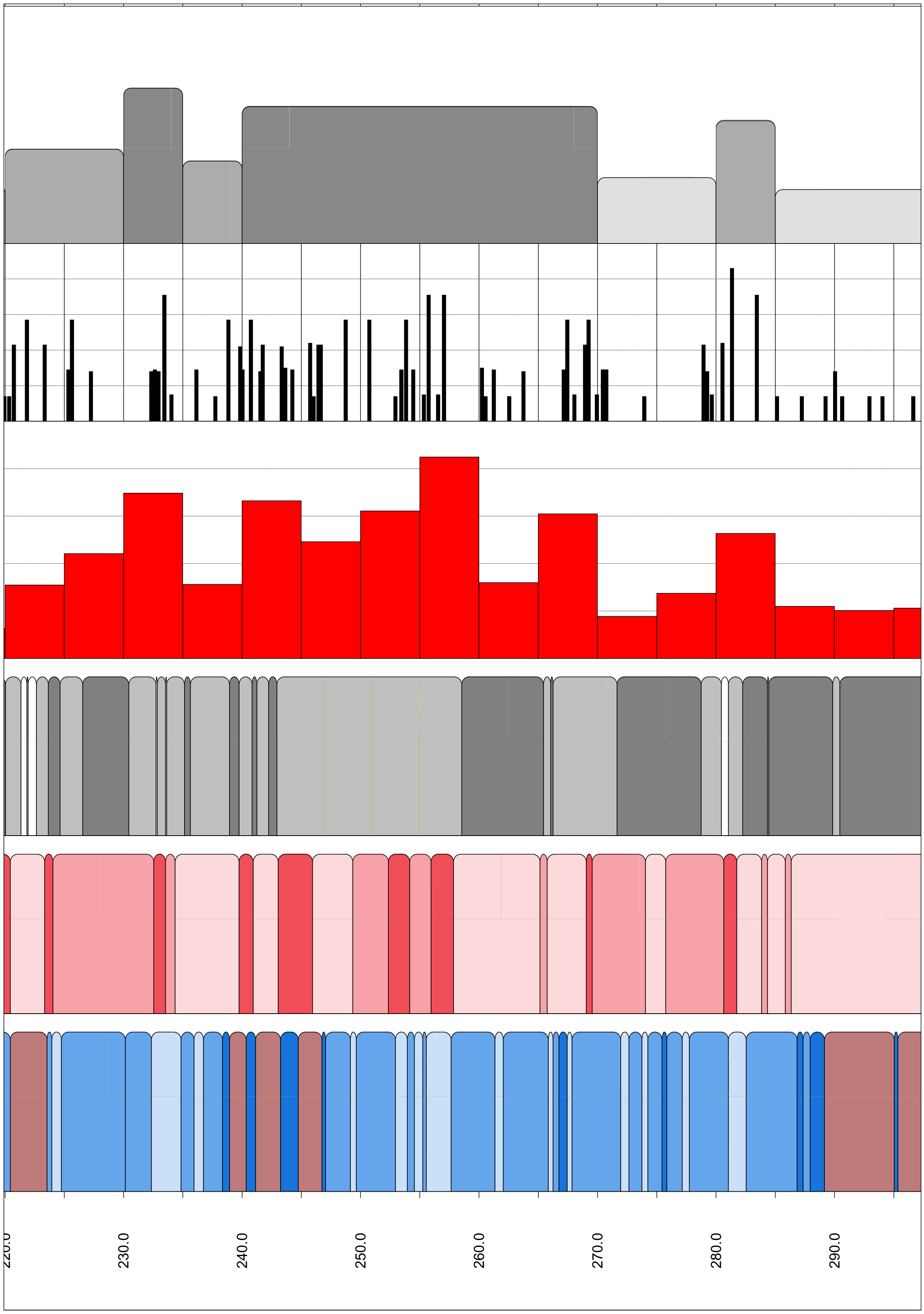
Appendix 1

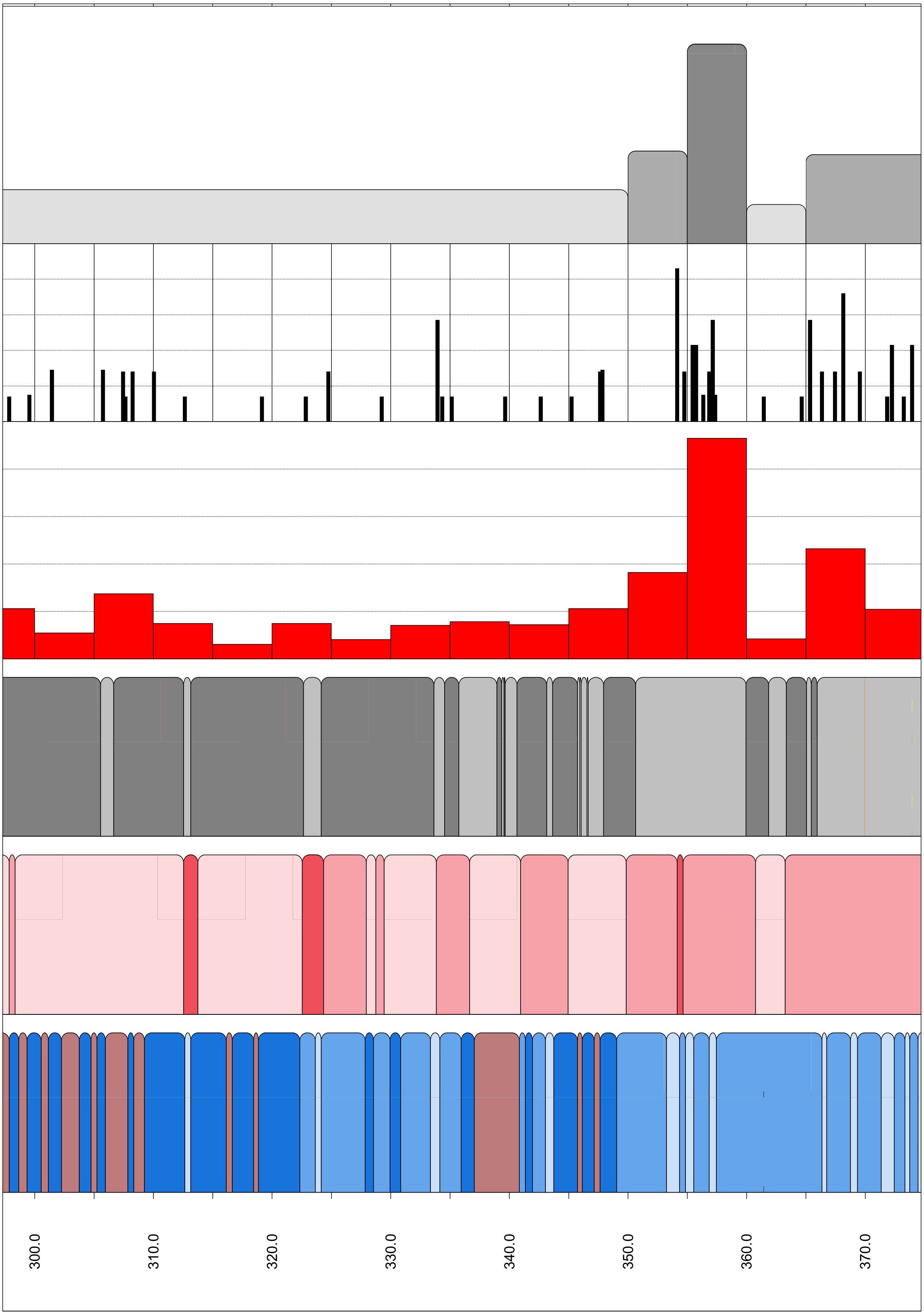
Generalized geophysical loggings for the borehole KAV04A (100–1,000 m)

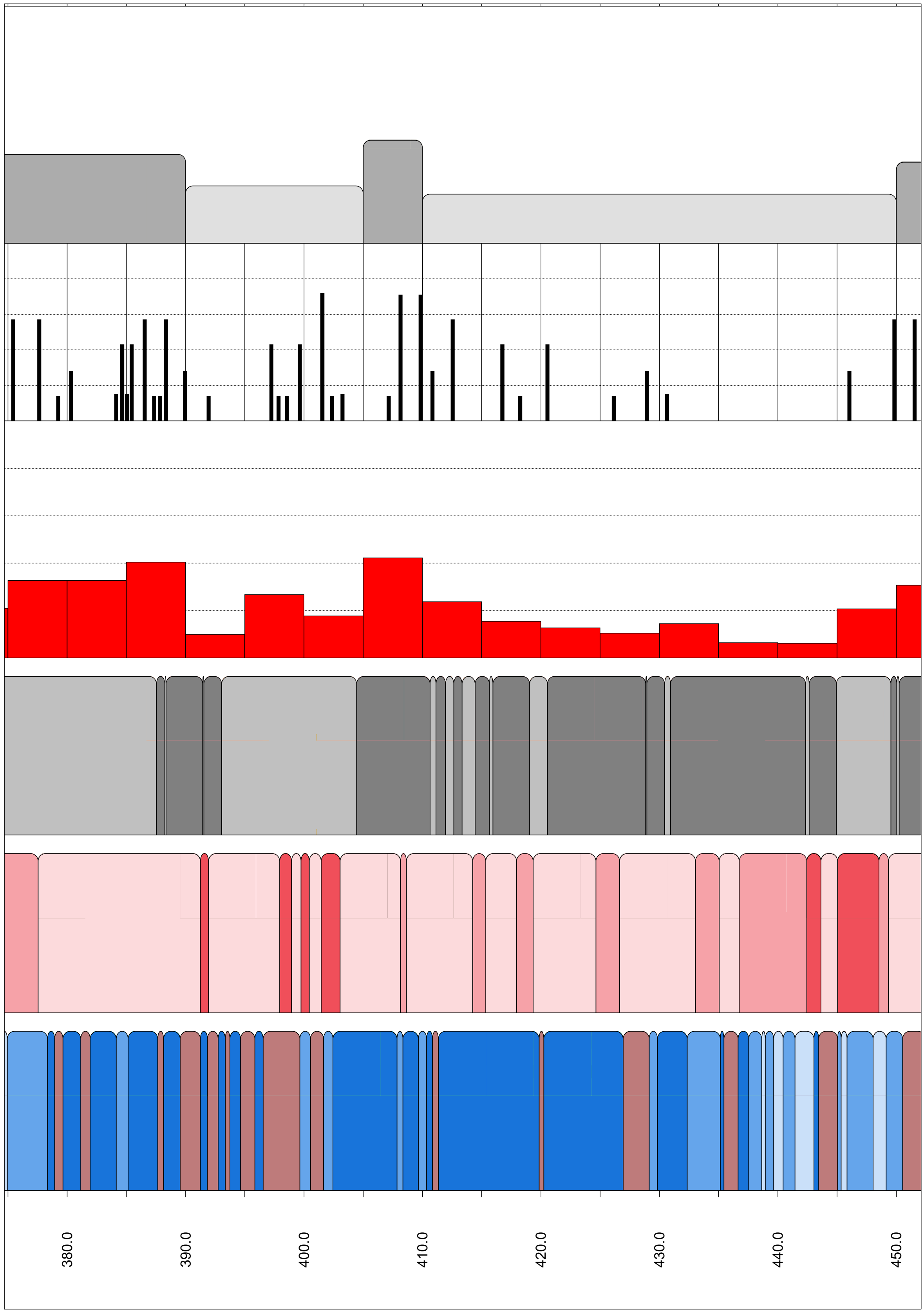


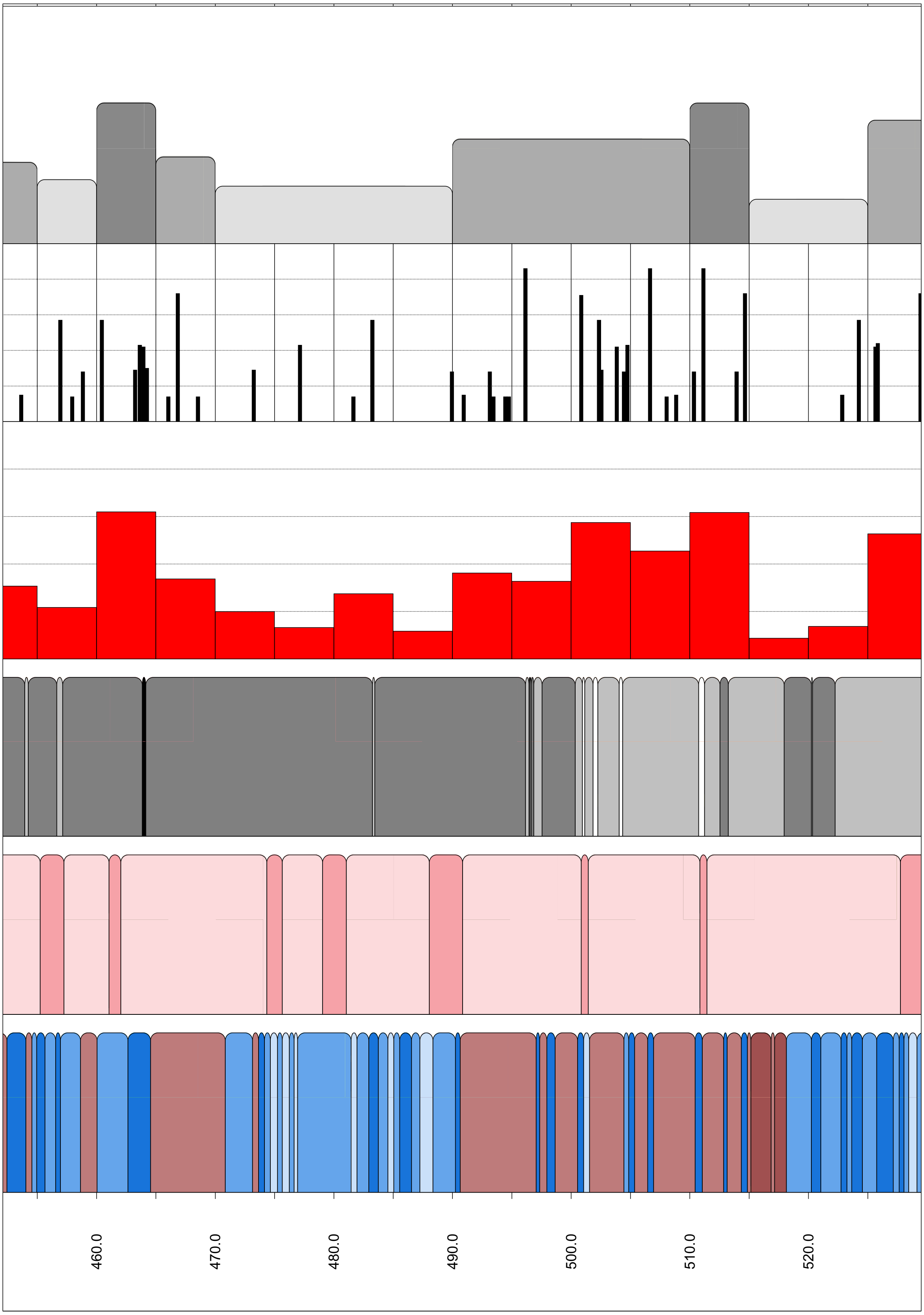
Interpretation of geophysical borehole logging data
Borehole KAV04A
GeoVista
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<30
gam>30
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:500m
Generalized Loggings
Fracture Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Estimated fracture frequency (fractures/m)
0
10
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
110.0
120.0
130.0
140.0

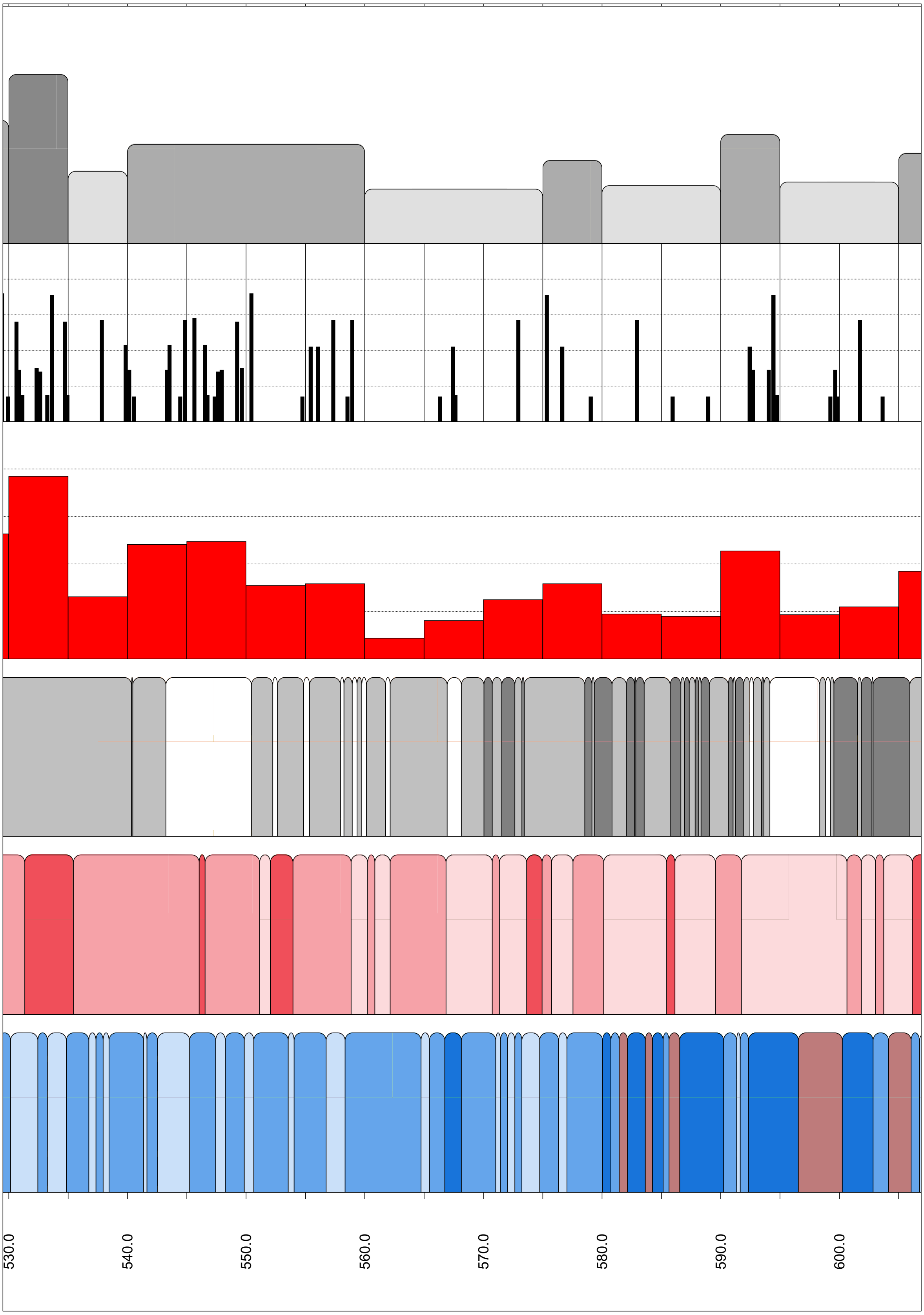

150.0
160.0
170.0
180.0
190.0
200.0
210.0

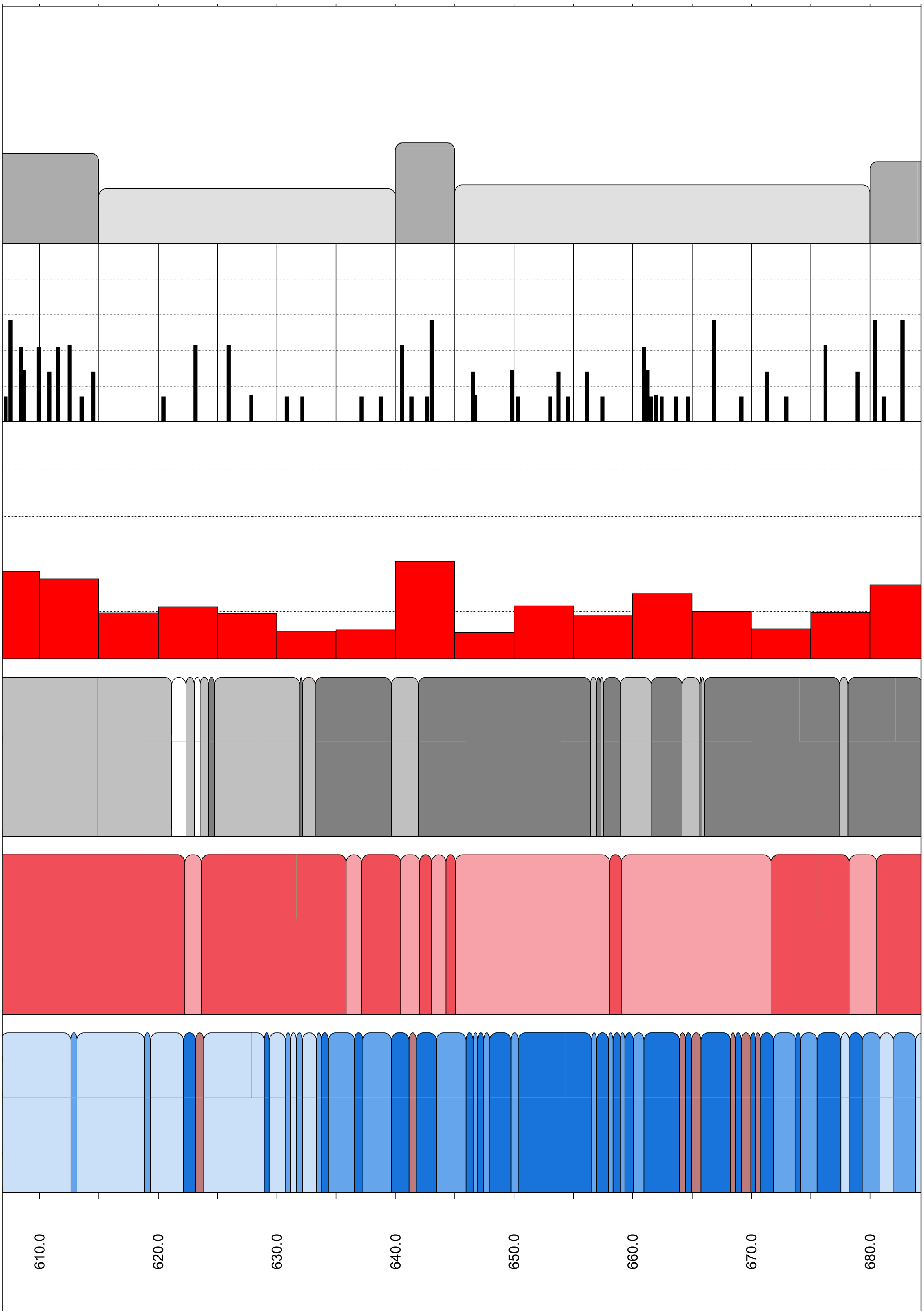

220.0
230.0
240.0
250.0
260.0
270.0
280.0
290.0

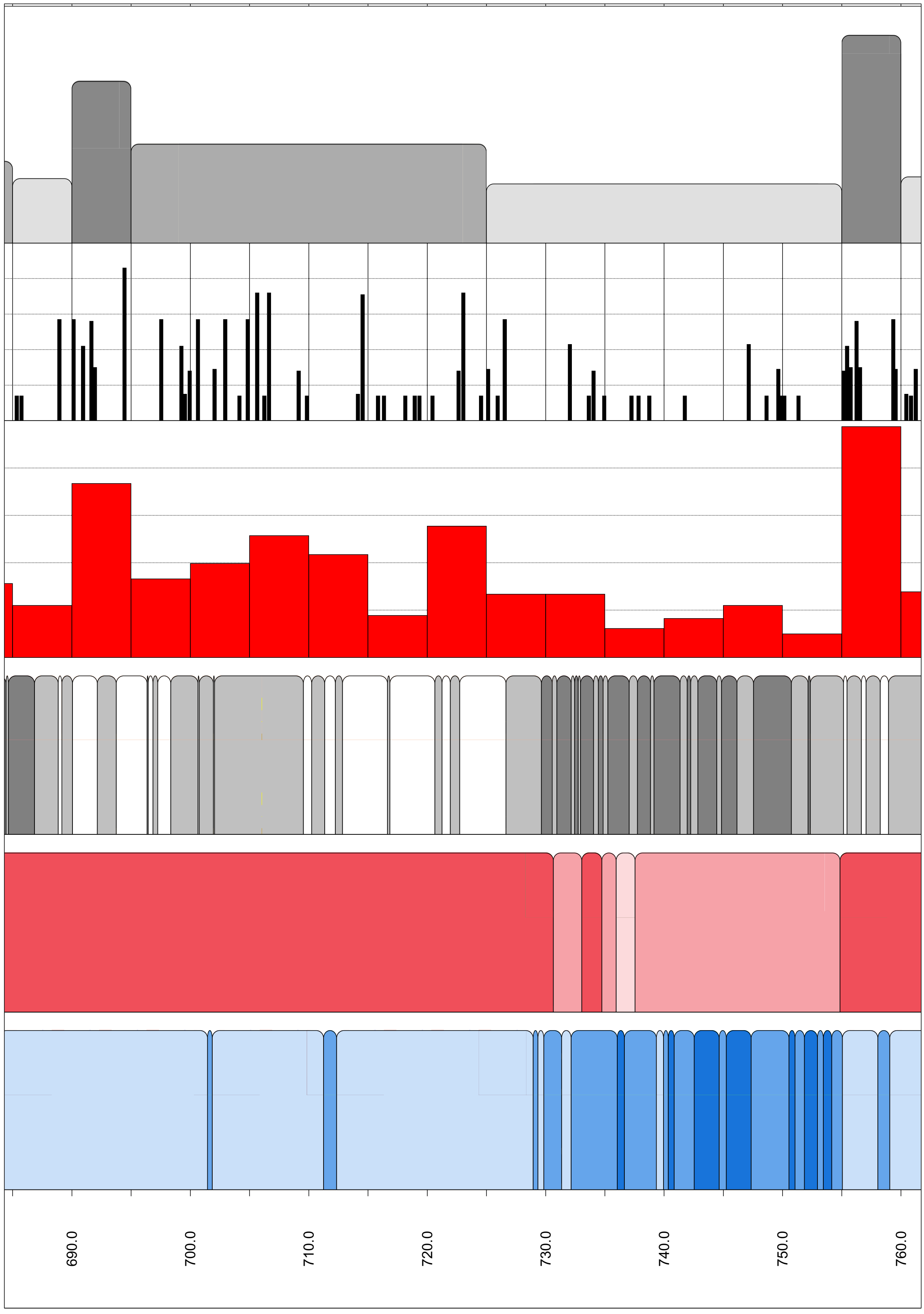

300.0
310.0
320.0
330.0
340.0
350.0
360.0
370.0


380.0
390.0
400.0
410.0
420.0
430.0
440.0
450.0

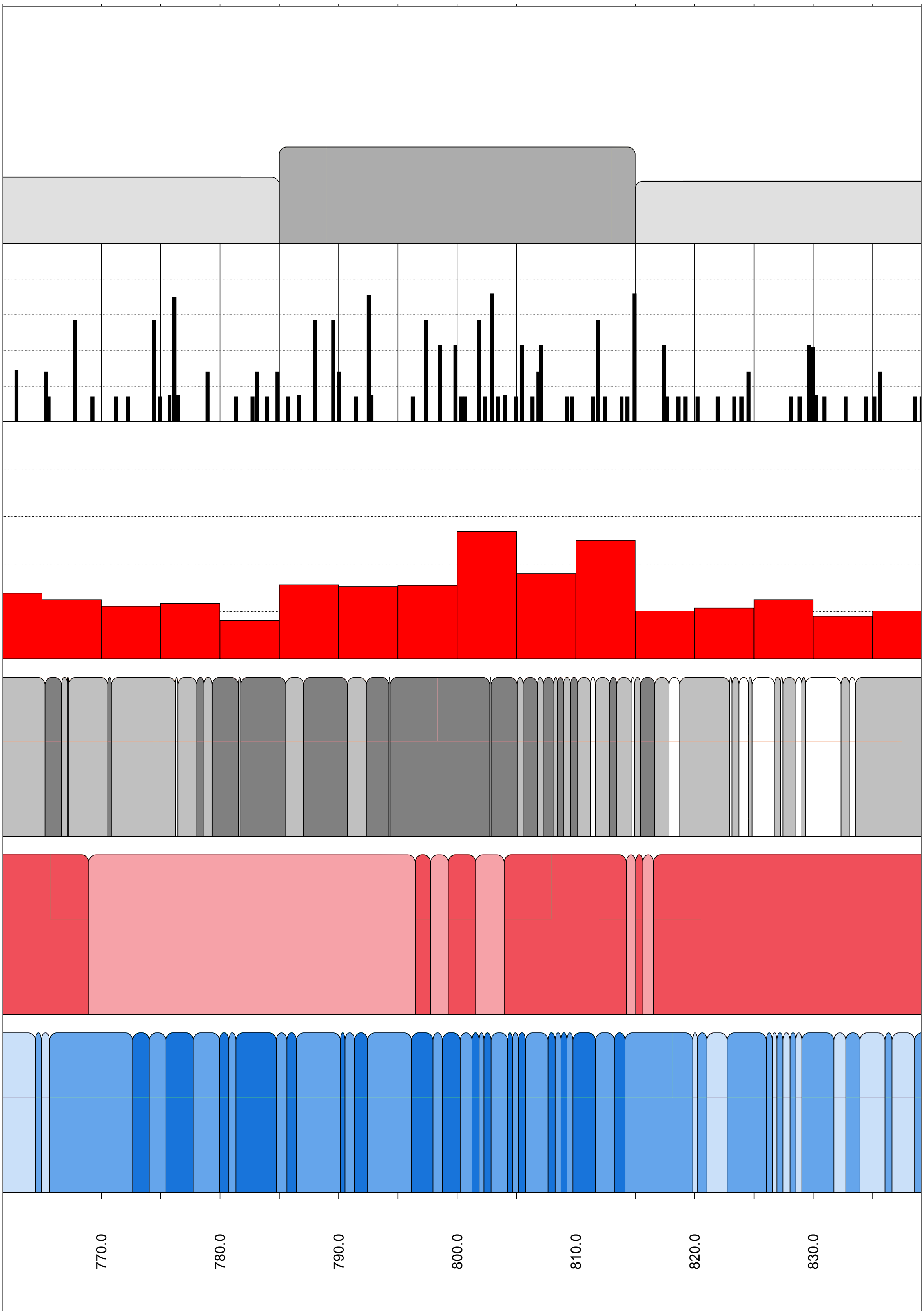

460.0
470.0
480.0
490.0
500.0
510.0
520.0

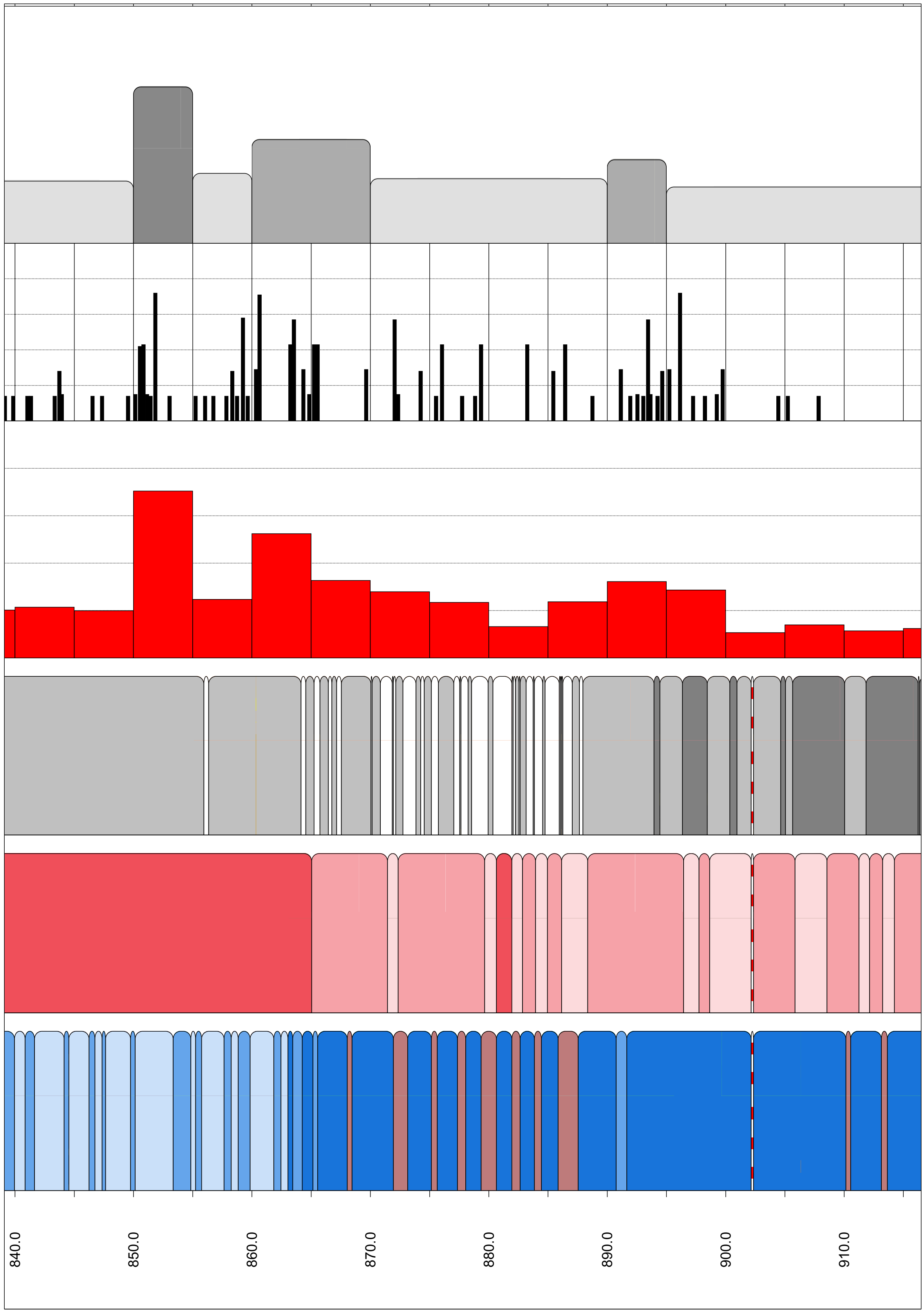

530.0
540.0
550.0
560.0
570.0
580.0
590.0
600.0

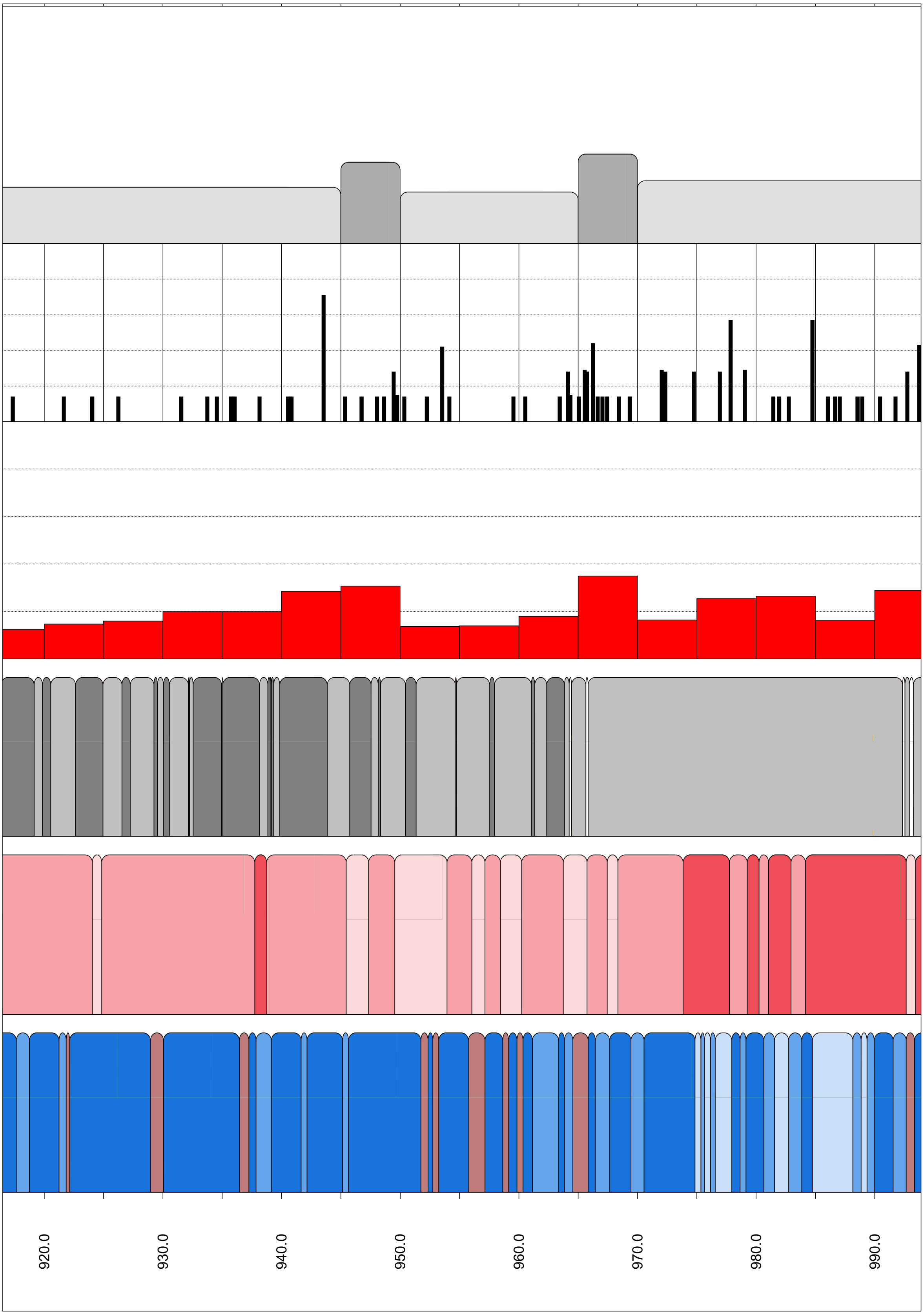

610.0
620.0
630.0
640.0
650.0
660.0
670.0
680.0

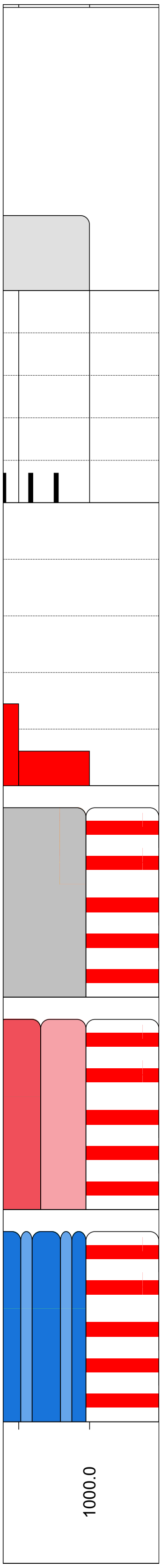


690.0
700.0
710.0
720.0
730.0
740.0
750.0
760.0


770.0
780.0
790.0
800.0
810.0
820.0
830.0

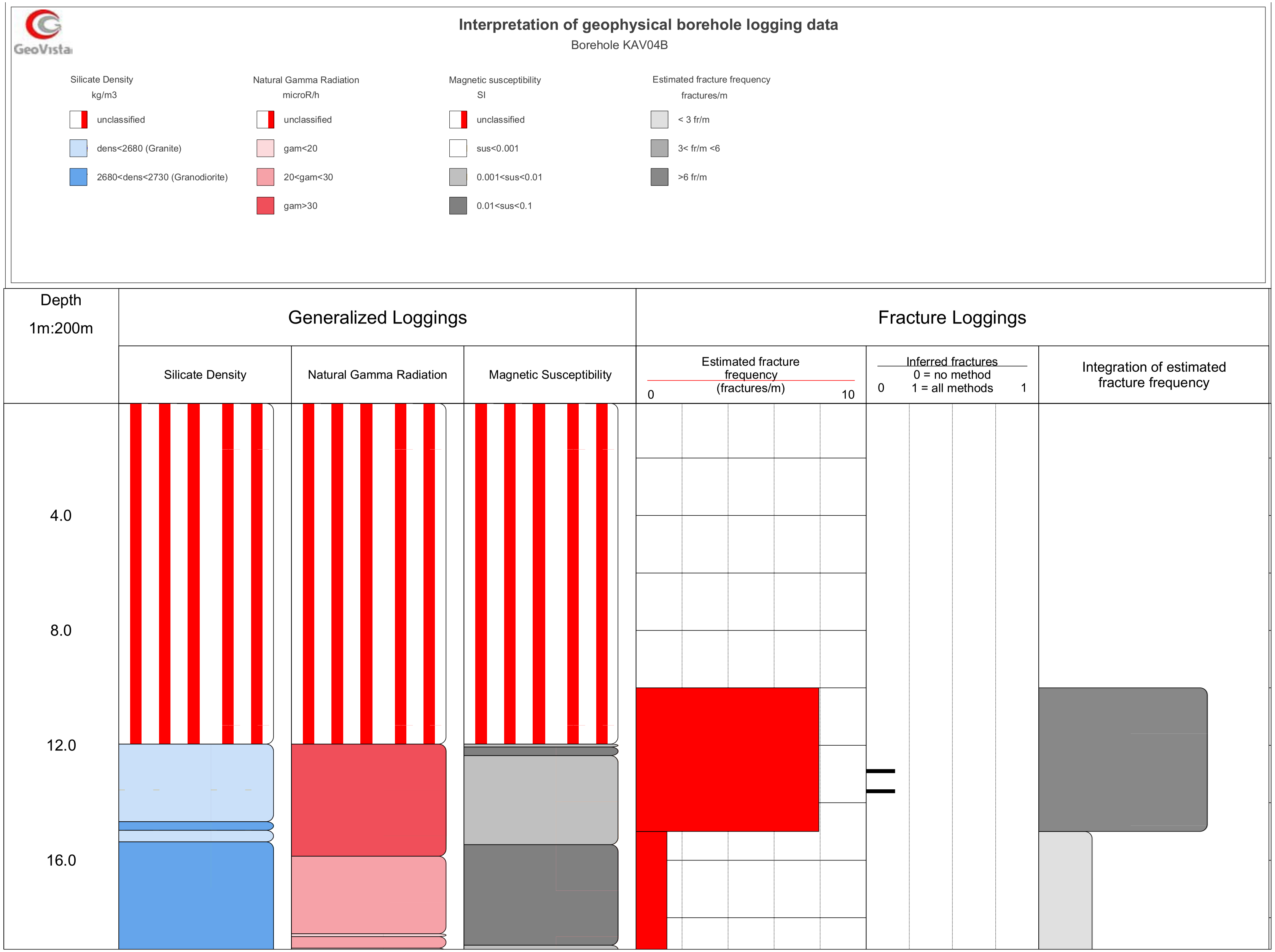

840.0
850.0
860.0
870.0
880.0
890.0
900.0
910.0


920.0
930.0
940.0
950.0
960.0
970.0
980.0
990.0

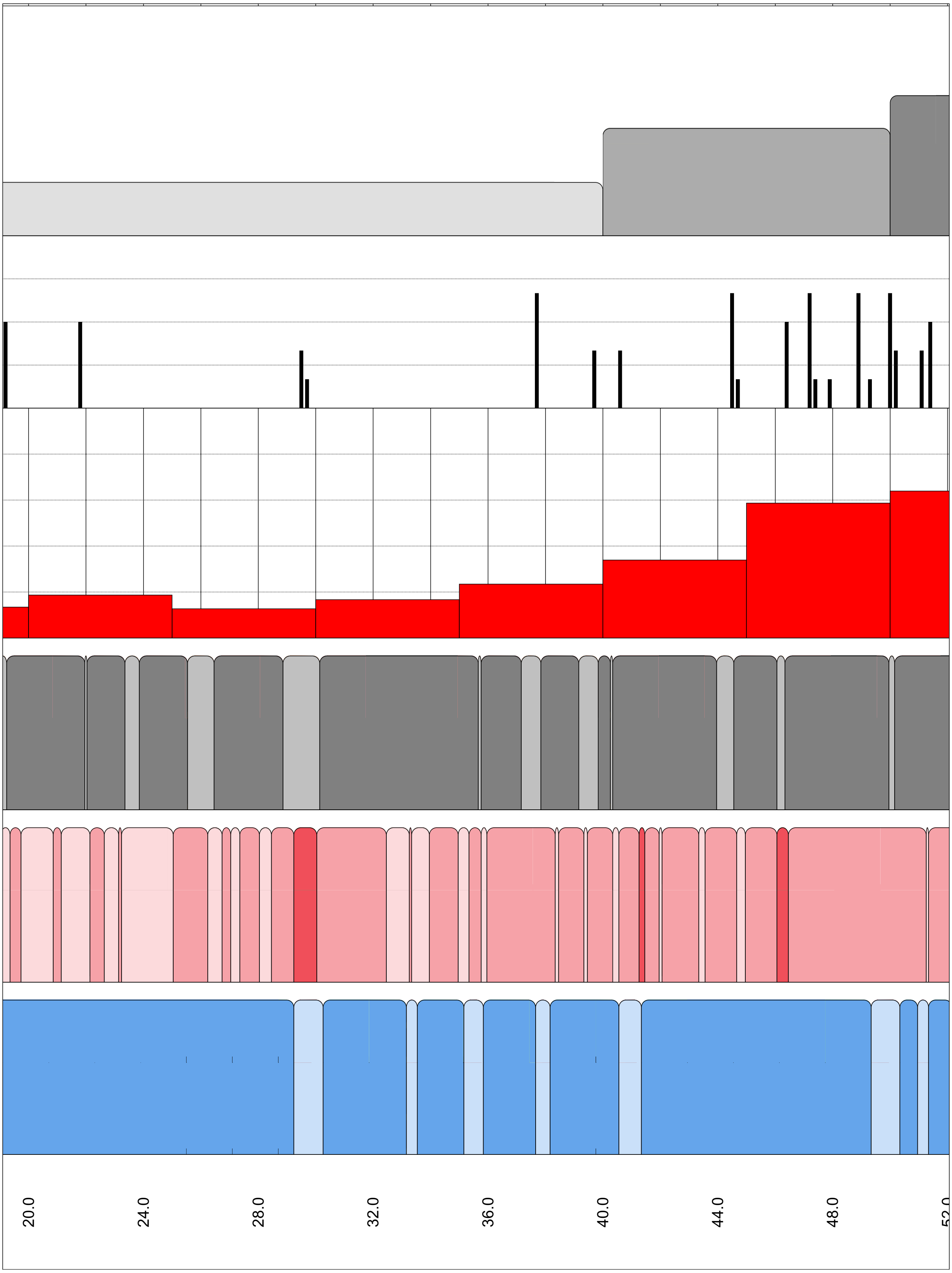

1000.0

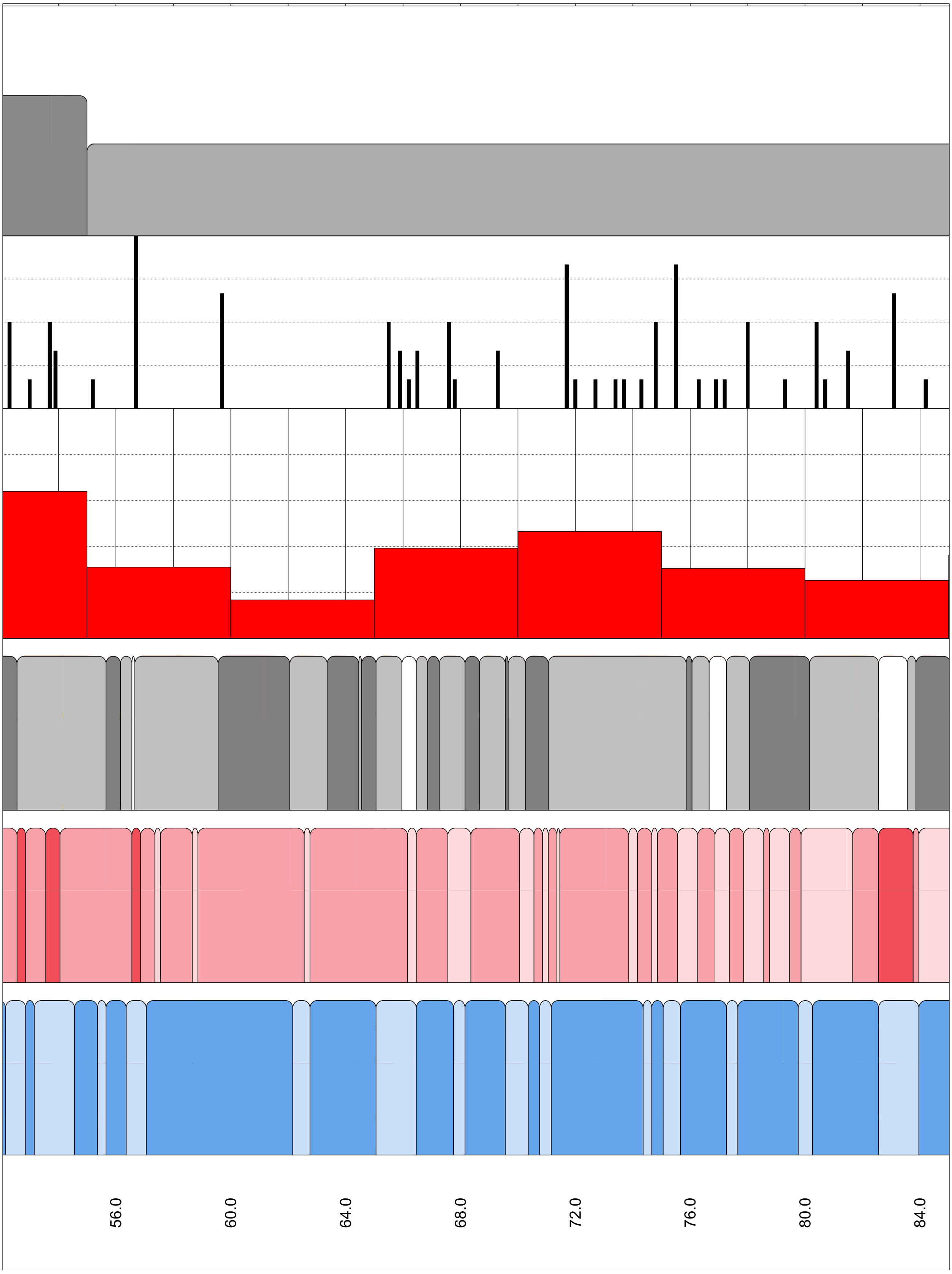
Appendix 2

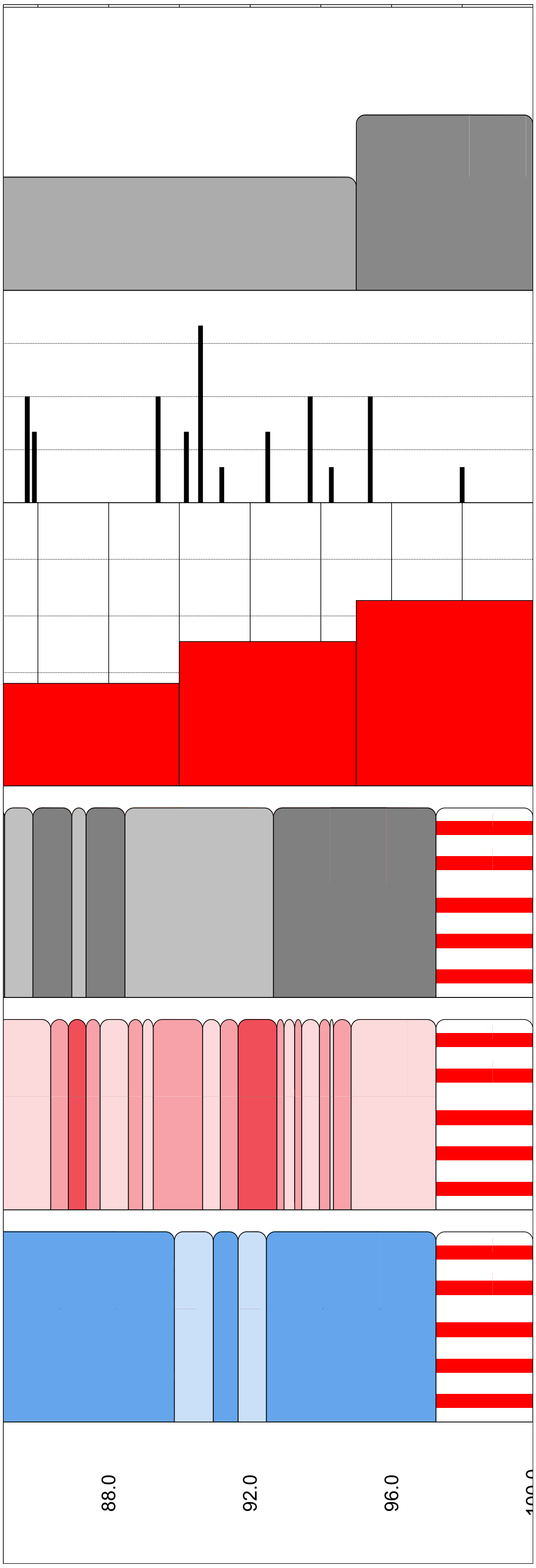
Generalized geophysical loggings for the borehole KAV04B



Interpretation of geophysical borehole logging data
Borehole KAV04B
GeoVista
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
Natural Gamma Radiation
microR/h
unclassified
gam<20
20<gam<30
gam>30
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Estimated fracture frequency
fractures/m
< 3 fr/m
3< fr/m <6
>6 fr/m
Depth
1m:200m
Generalized Loggings
Fracture Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Estimated fracture frequency (fractures/m)
0
10
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
4.0
8.0
12.0
16.0

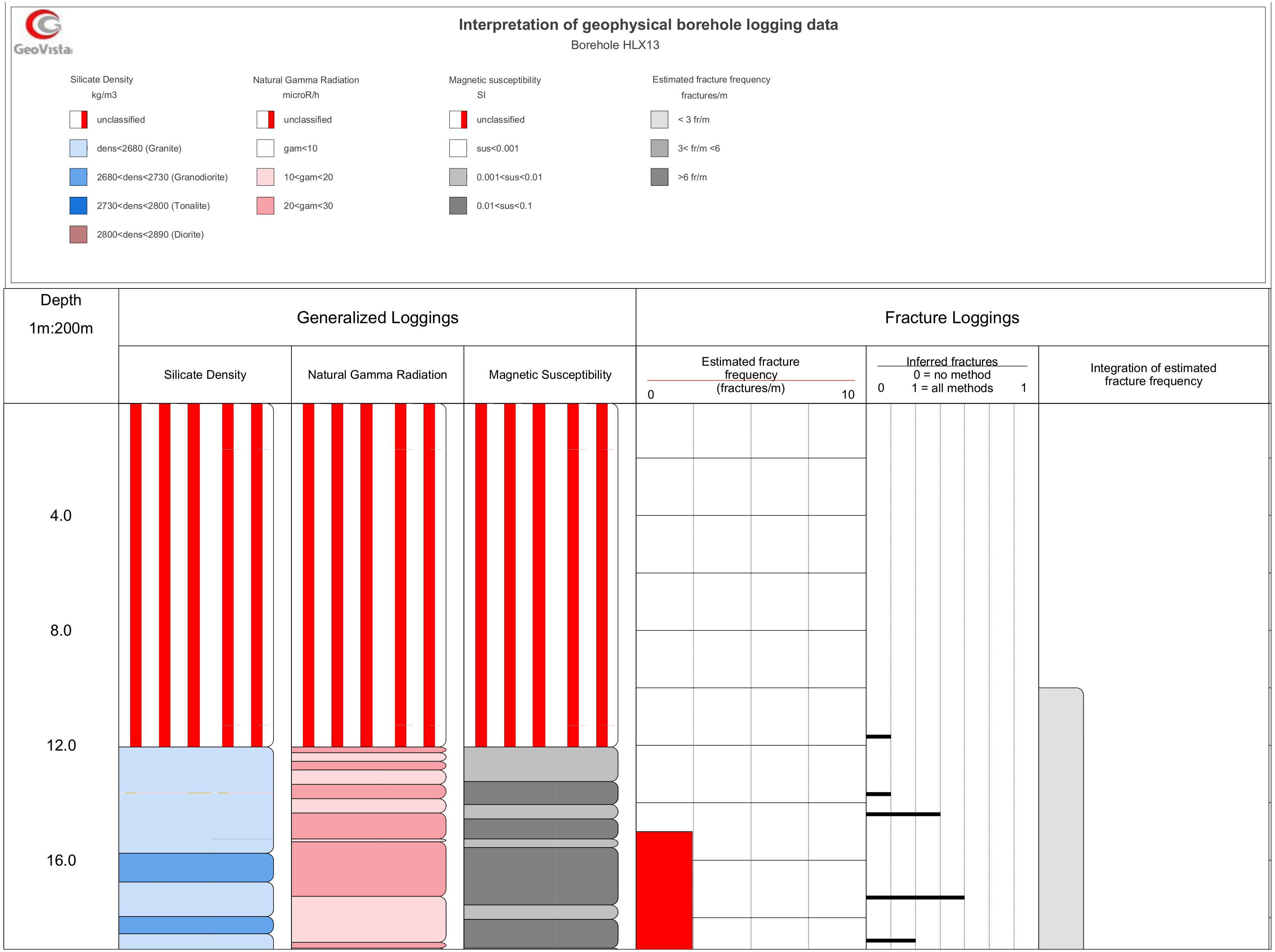

20.0
24.0
28.0
32.0
36.0
40.0
44.0
48.0


56.0
60.0
64.0
68.0
72.0
76.0
80.0
84.0

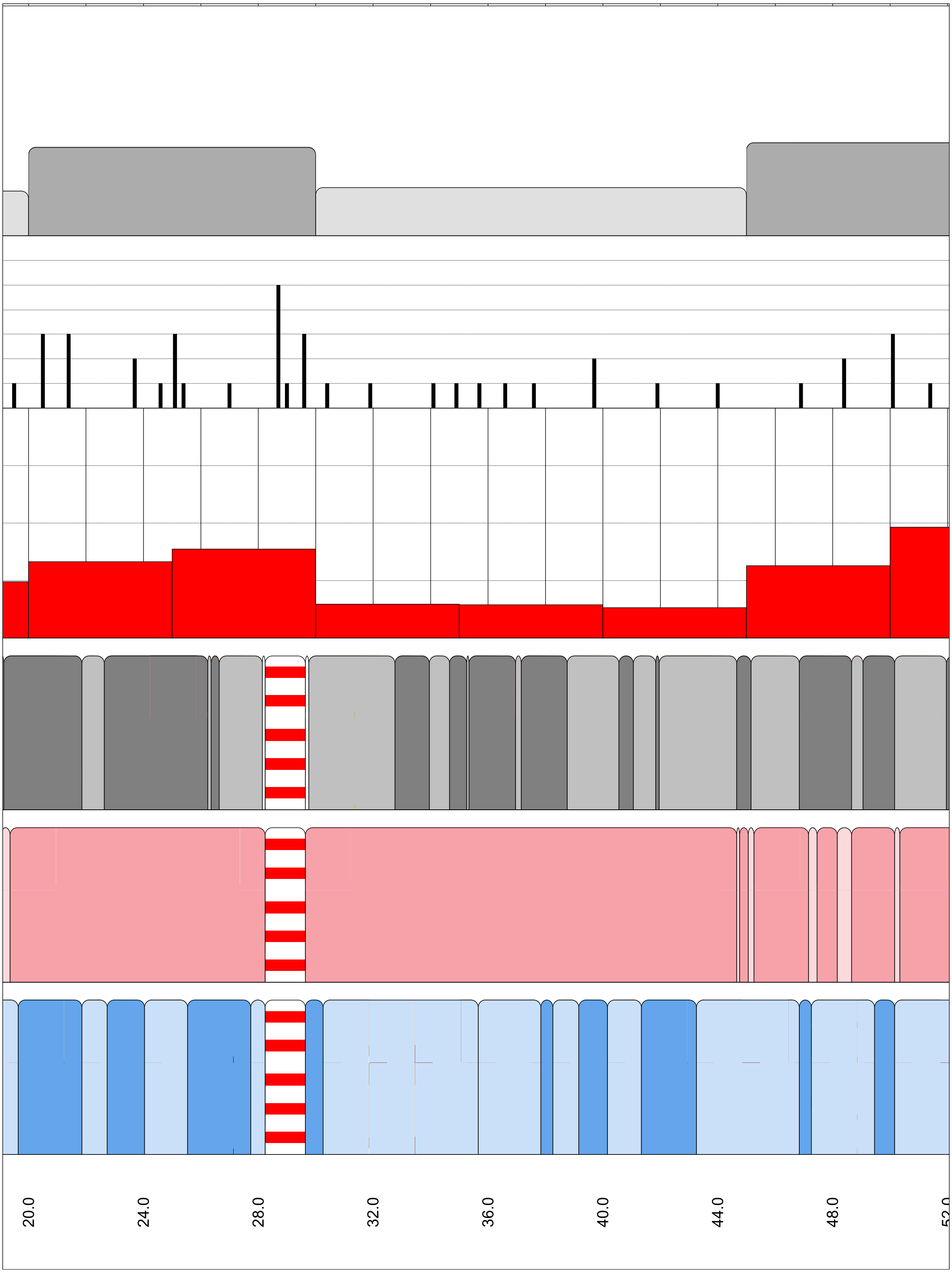

88.0
92.0
96.0

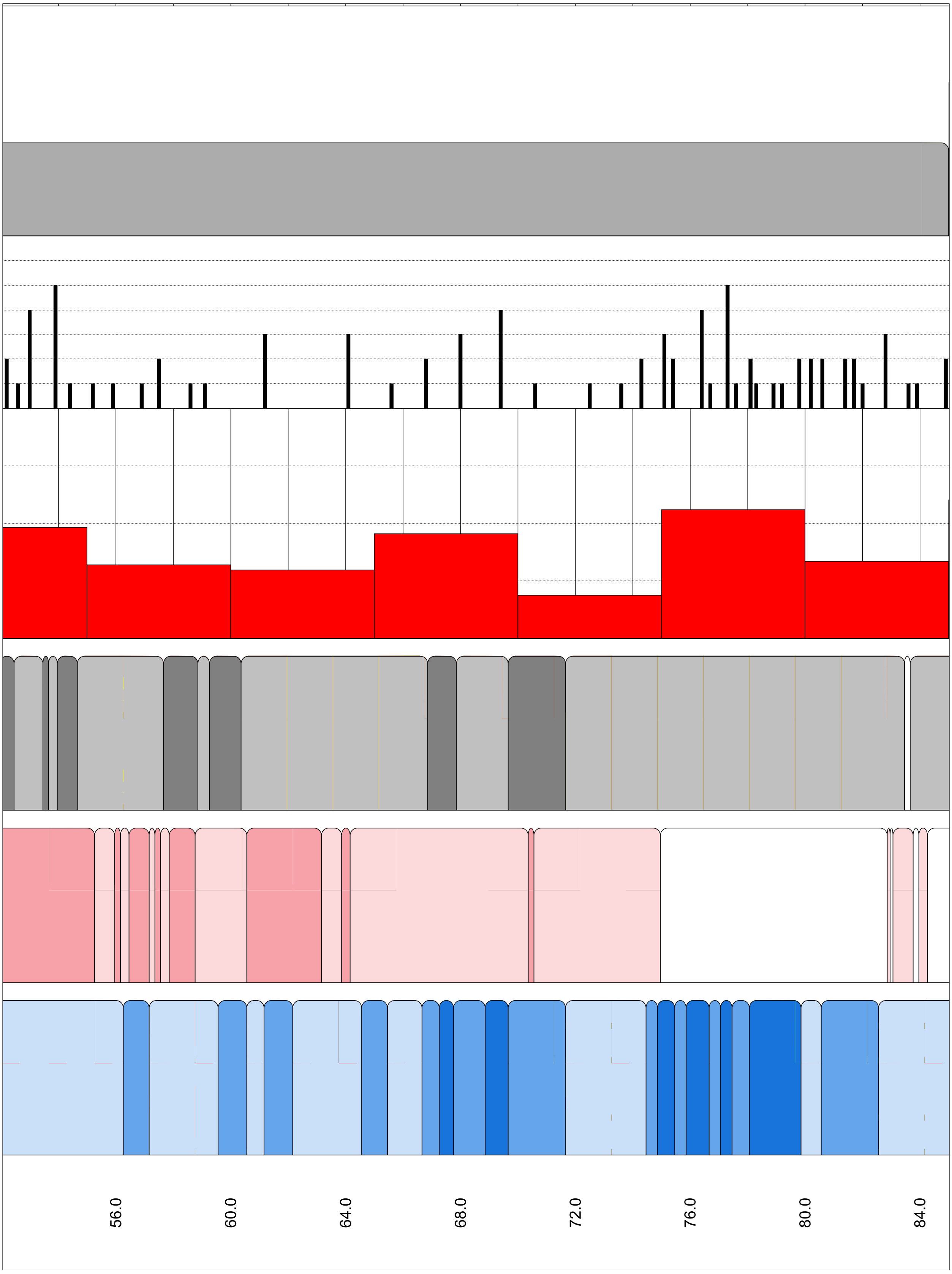
Appendix 3

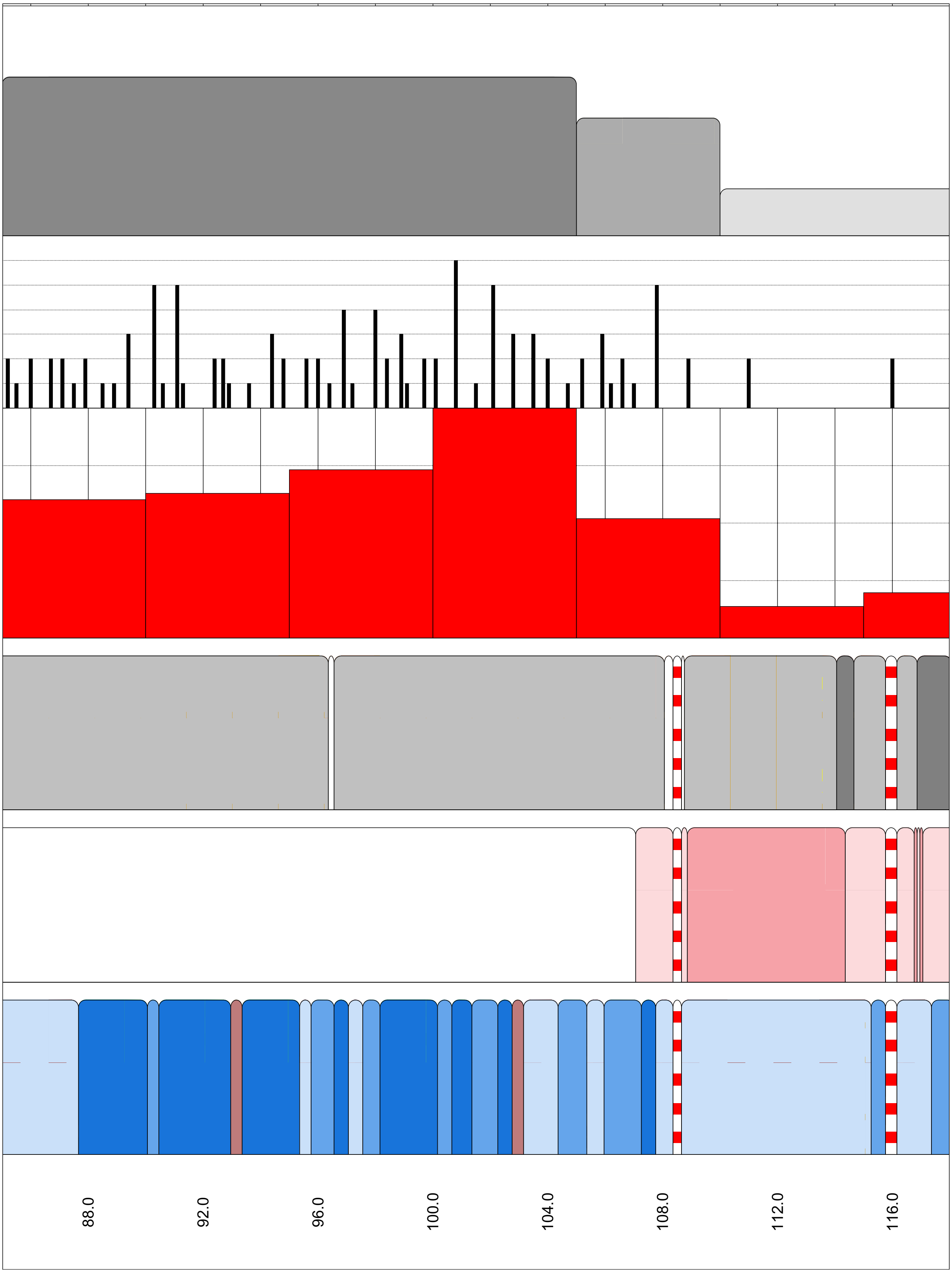
Generalized geophysical loggings for the borehole HLX13

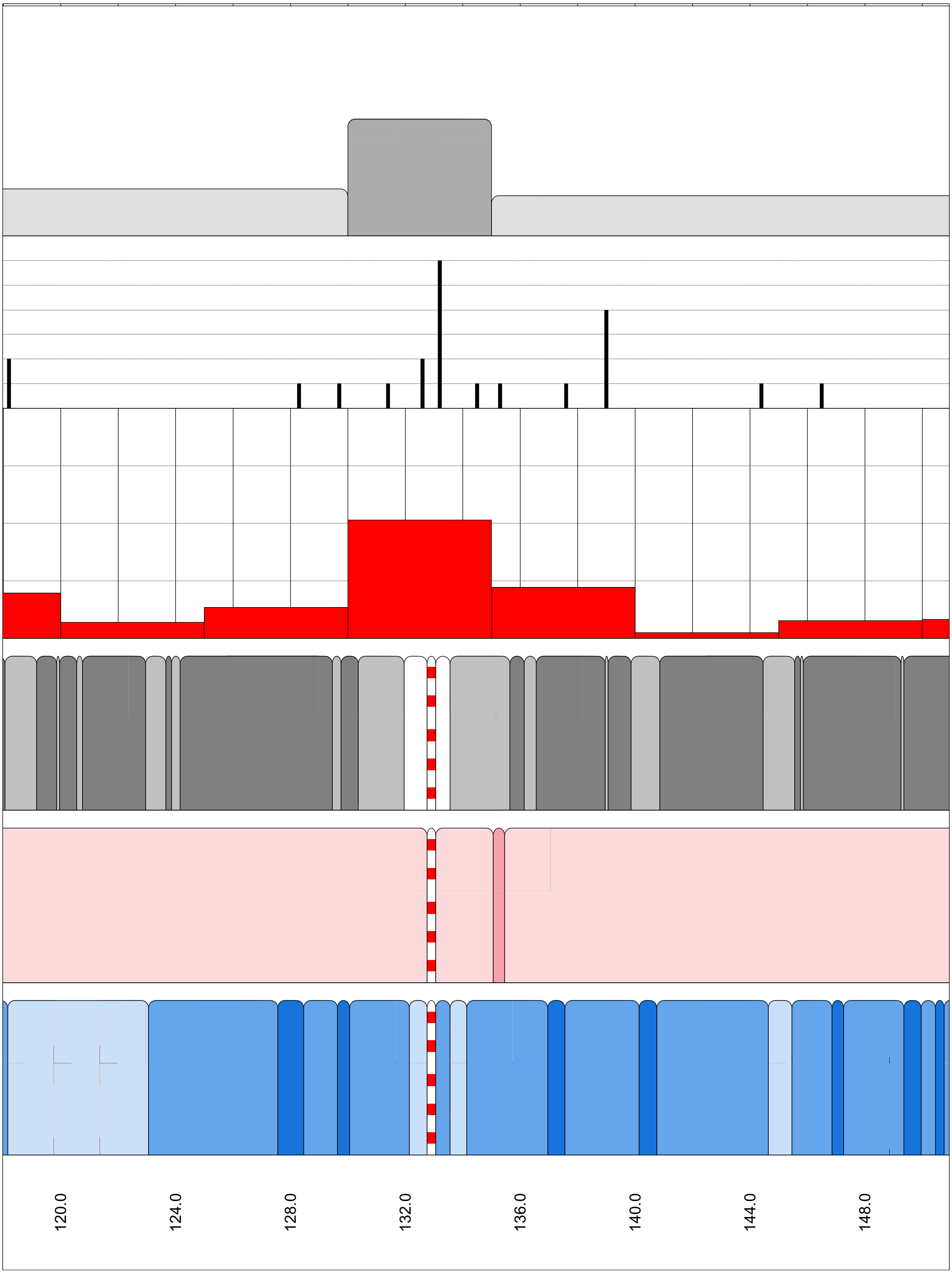


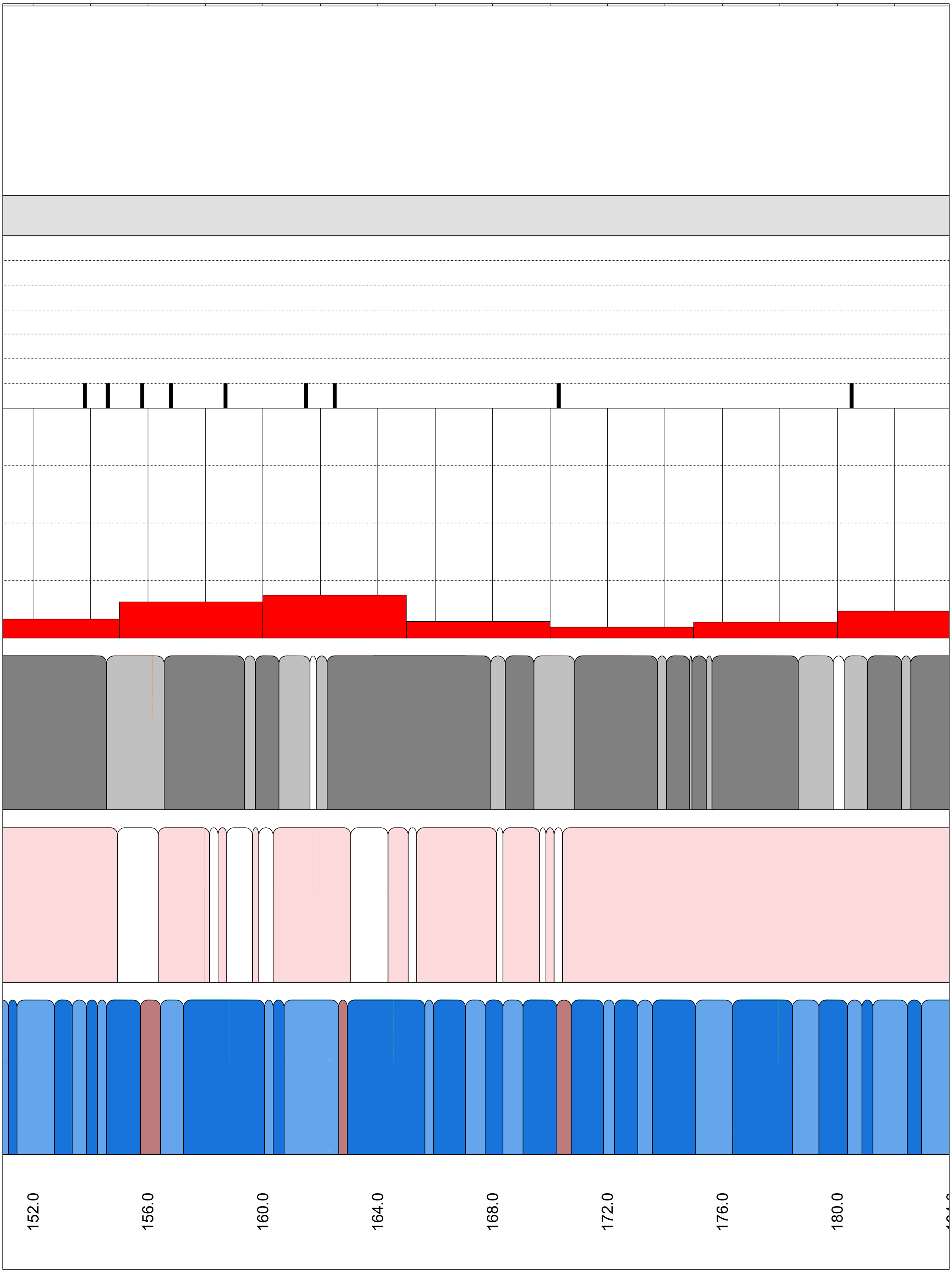
GeoVista
Interpretation of geophysical borehole logging data
Borehole HLX13
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
Natural Gamma Radiation
microR/h
unclassified
gam<10
10<gam<20
20<gam<30
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Estimated fracture frequency
fractures/m
< 3 fr/m
3< fr/m <6
>6 fr/m
Depth
1m:200m
Generalized Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Fracture Loggings
Estimated fracture frequency (fractures/m)
0
10
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
4.0
8.0
12.0
16.0

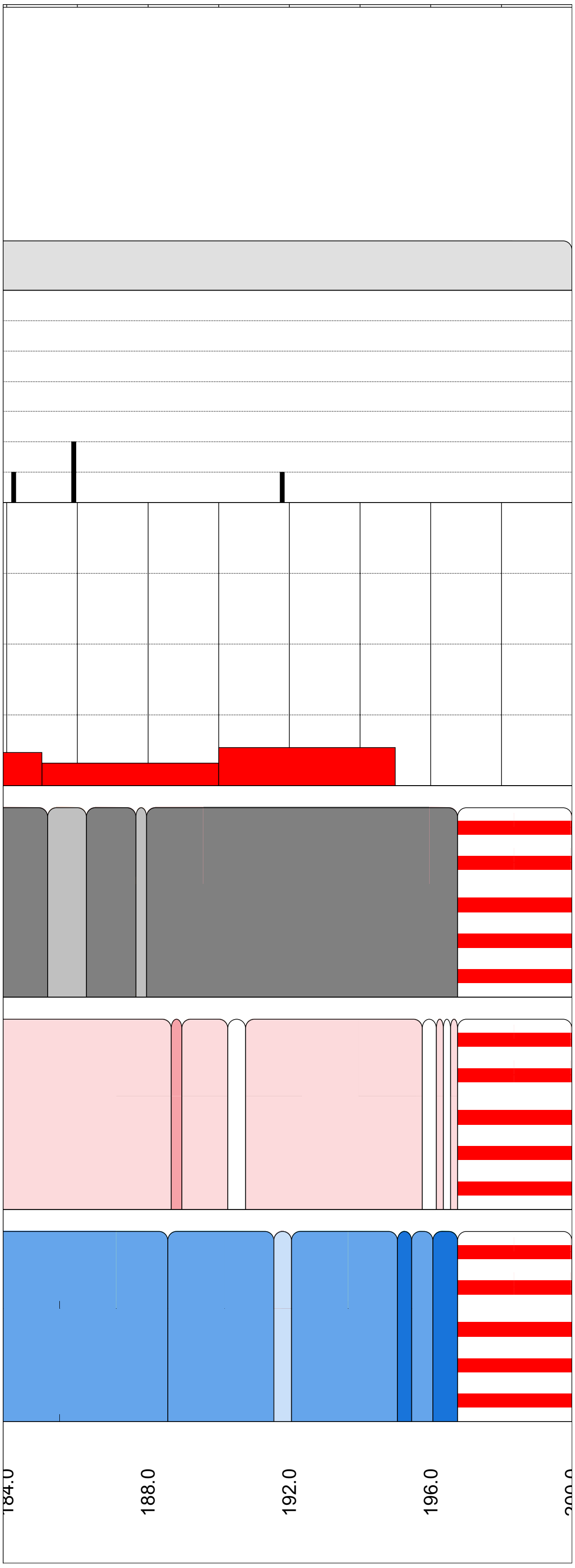

20.0
24.0
28.0
32.0
36.0
40.0
44.0
48.0


56.0
60.0
64.0
68.0
72.0
76.0
80.0
84.0


88.0
92.0
96.0
100.0
104.0
108.0
112.0
116.0

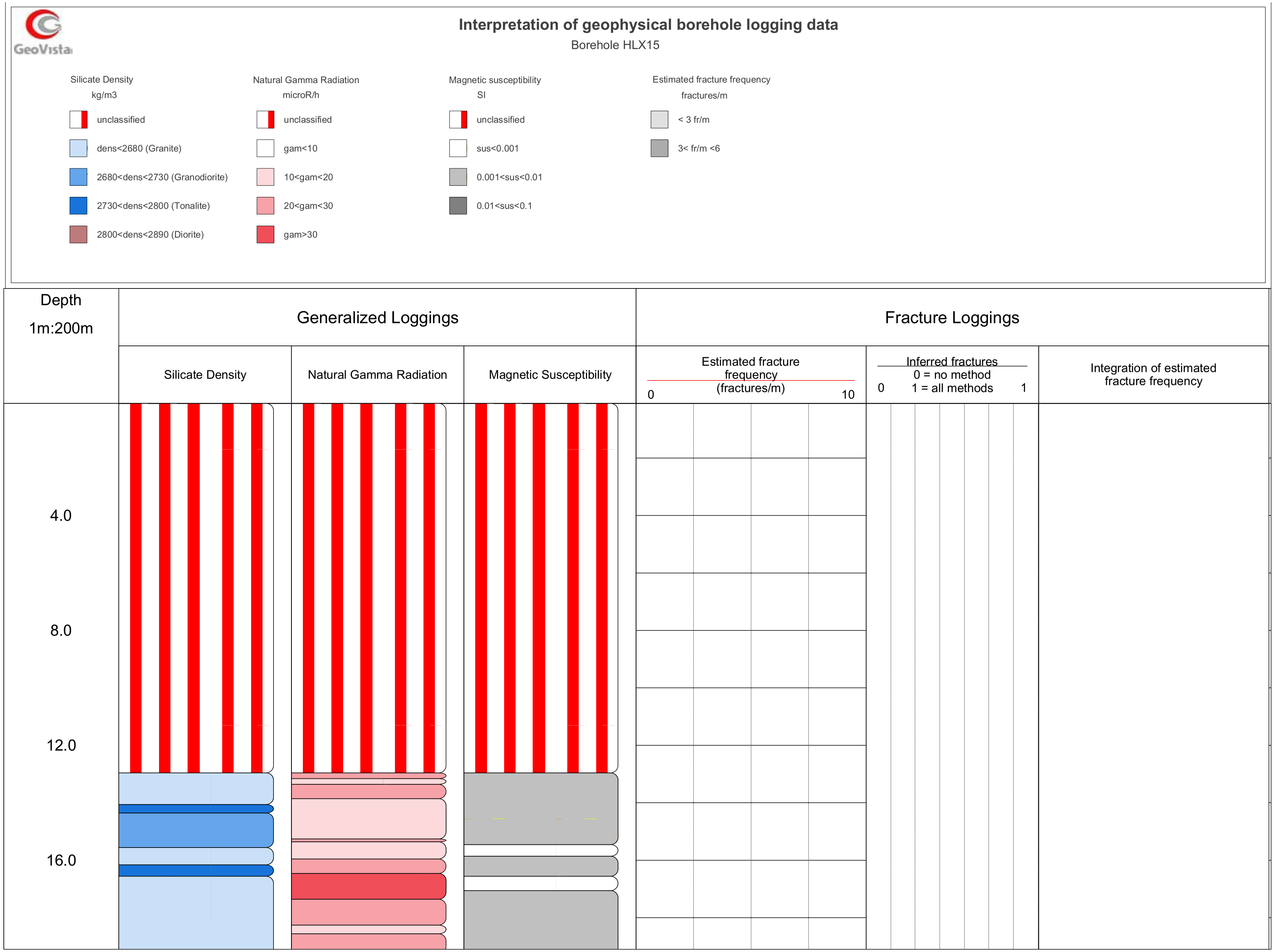

120.0
124.0
128.0
132.0
136.0
140.0
144.0
148.0

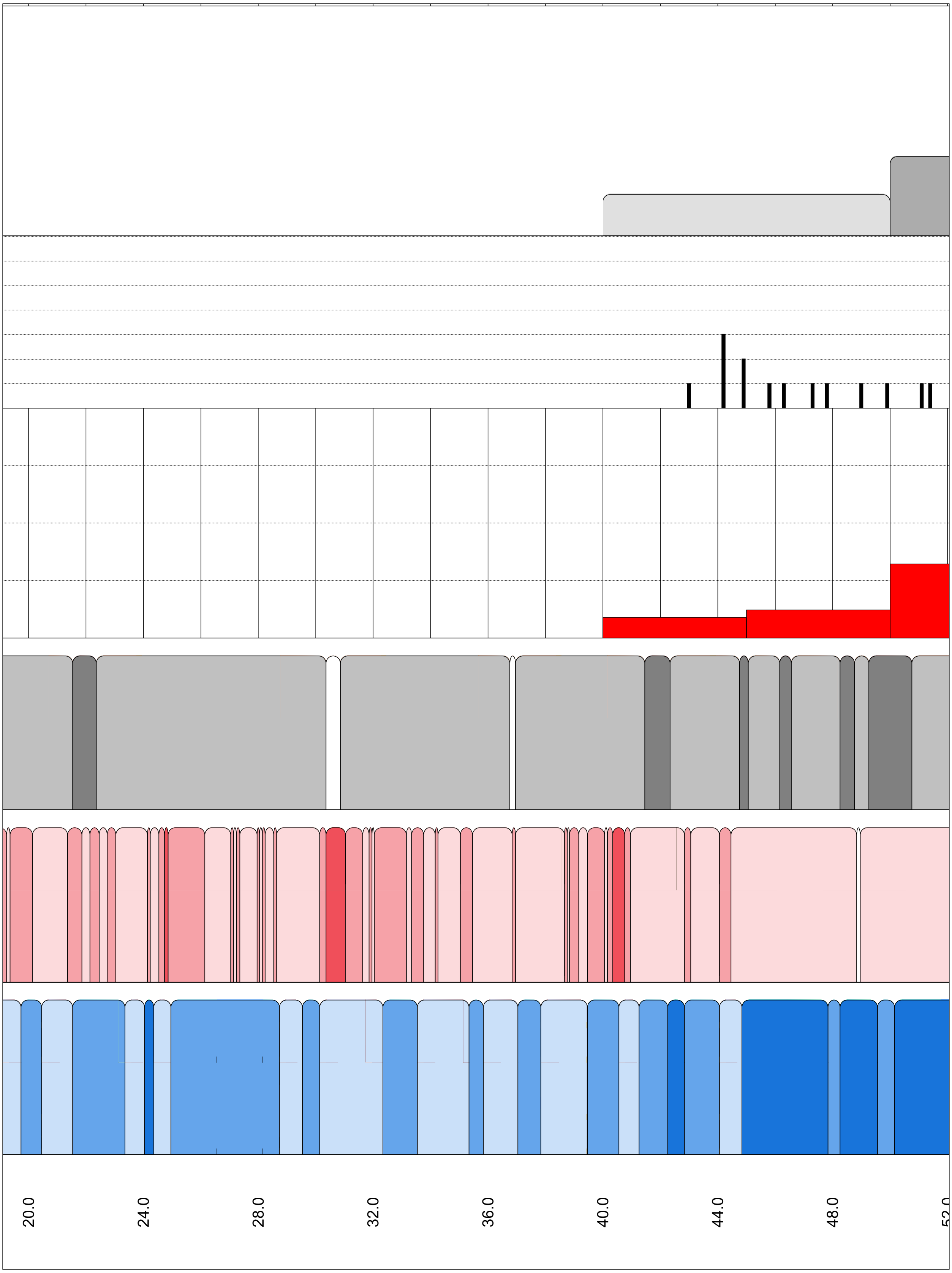

152.0
156.0
160.0
164.0
168.0
172.0
176.0
180.0


184.0
188.0
192.0
196.0

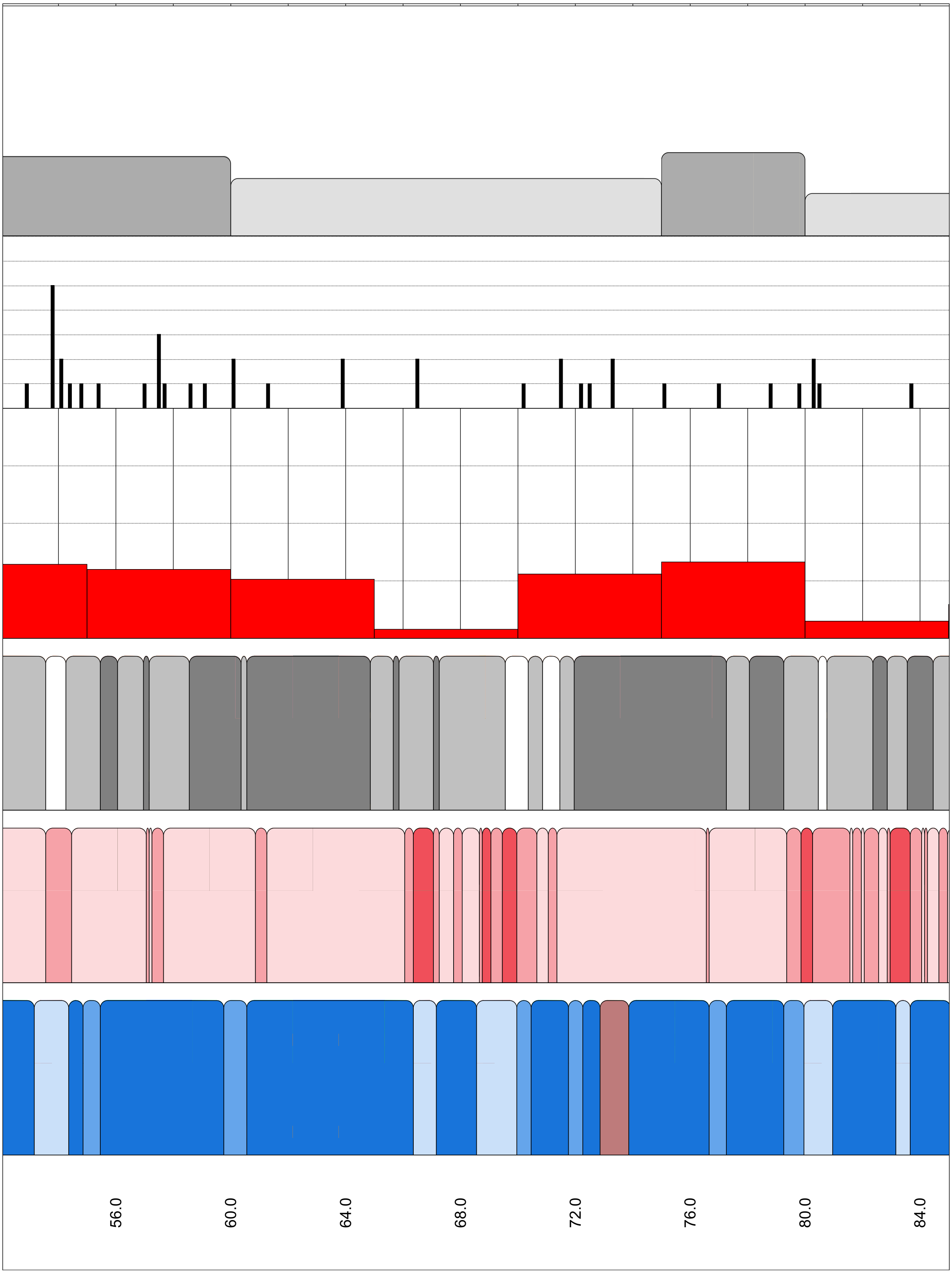
Appendix 4

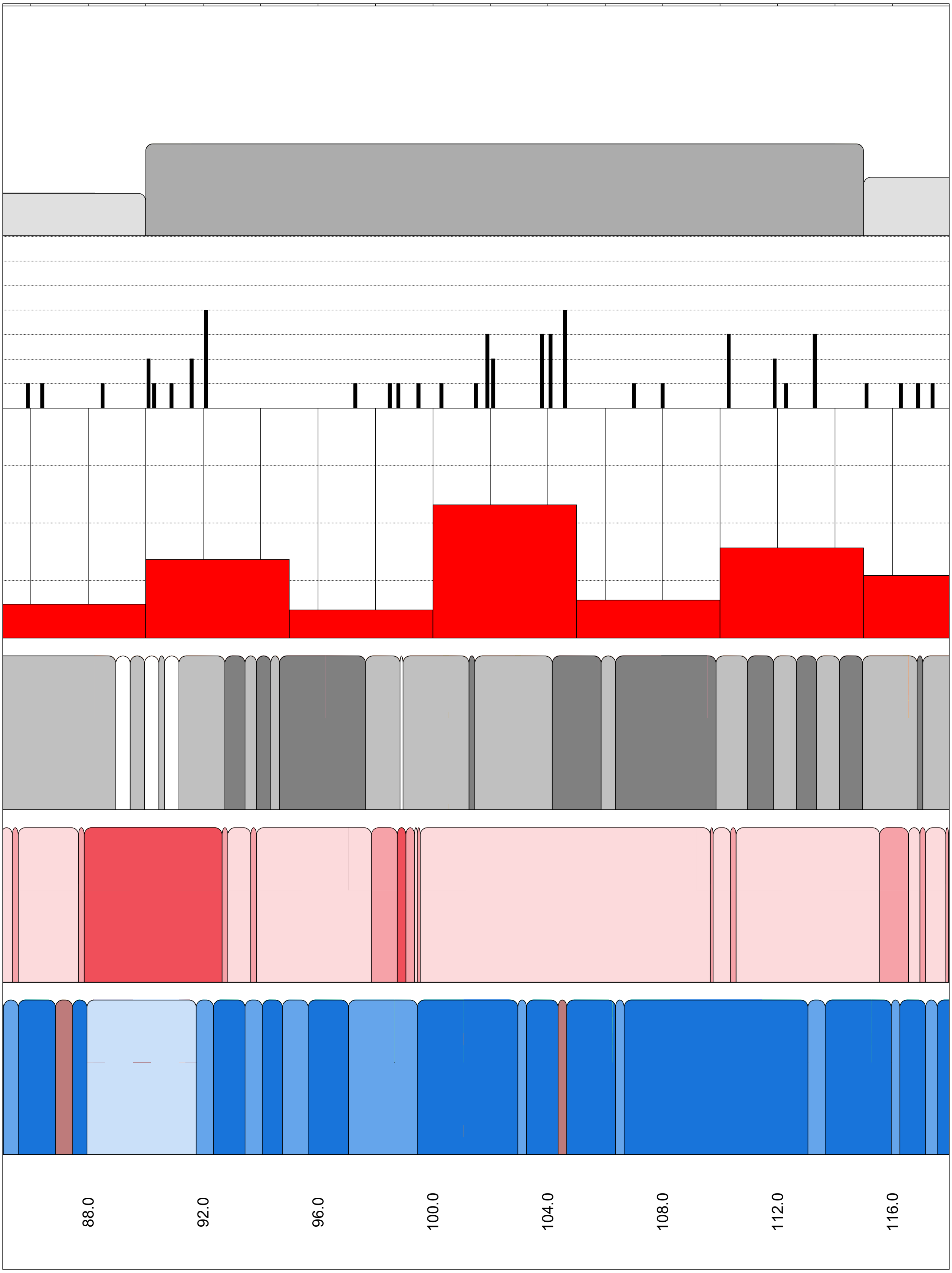
Generalized geophysical loggings for the borehole HLX15

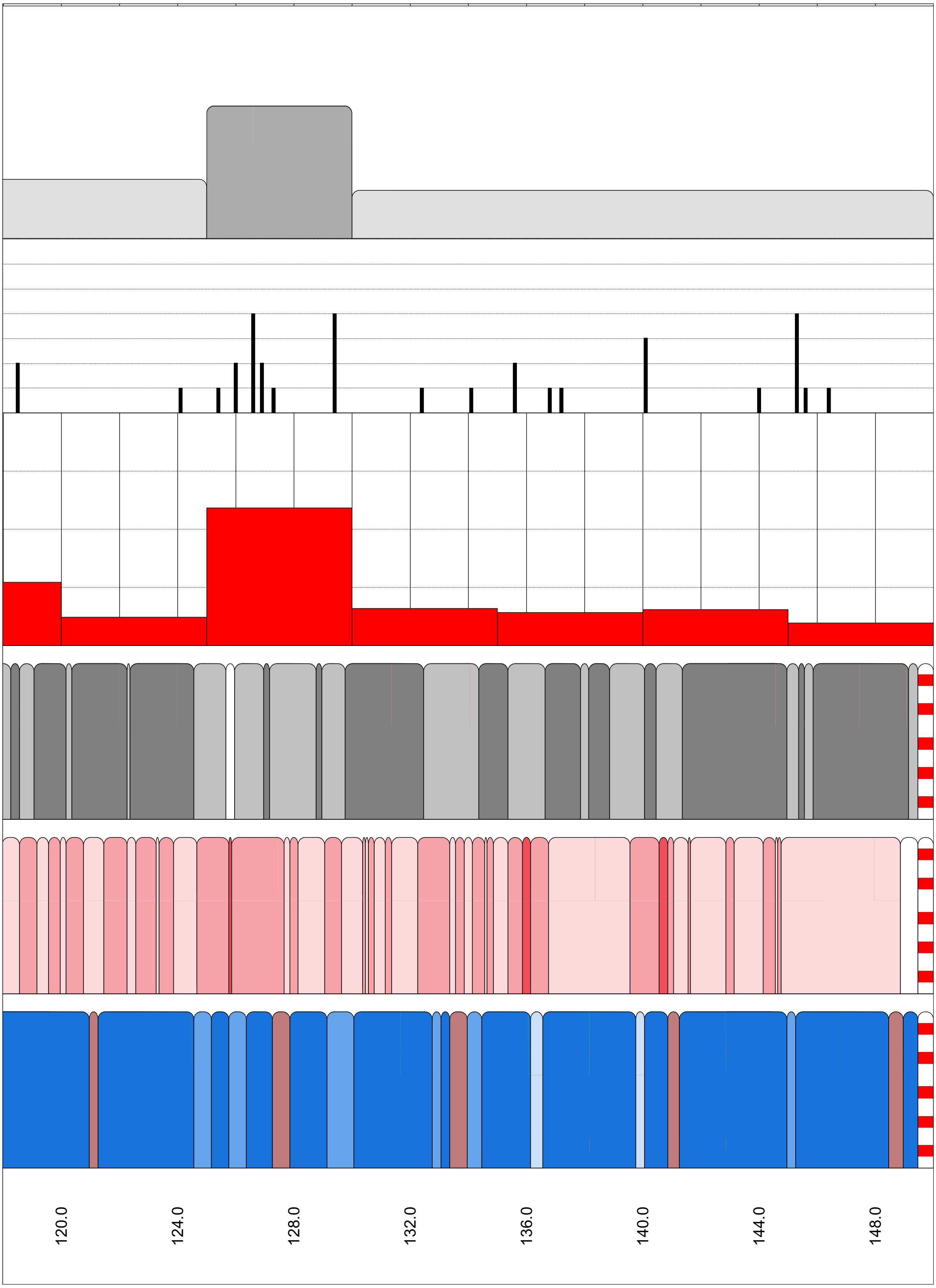

Interpretation of geophysical borehole logging data
Borehole HLX15
Silicate Density
kg/m3
unclassified
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
Natural Gamma Radiation
microR/h
unclassified
gam<10
10<gam<20
20<gam<30
gam>30
Magnetic susceptibility
SI
unclassified
sus<0.001
0.001<sus<0.01
0.01<sus<0.1
Estimated fracture frequency
fractures/m
< 3 fr/m
3< fr/m <6
Depth
1m:200m
Generalized Loggings
Fracture Loggings
Silicate Density
Natural Gamma Radiation
Magnetic Susceptibility
Estimated fracture frequency (fractures/m)
0
10
Inferred fractures
0 = no method
1 = all methods
0
1
Integration of estimated fracture frequency
4.0
8.0
12.0
16.0



20.0
24.0
28.0
32.0
36.0
40.0
44.0
48.0
52.0


56.0
60.0
64.0
68.0
72.0
76.0
80.0
84.0


88.0
92.0
96.0
100.0
104.0
108.0
112.0
116.0


120.0
124.0
128.0
132.0
136.0
140.0
144.0
148.0