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Oskarshamn site investigation

Interpretation of geophysical borehole measurements from KLX19A, KLX28A and KLX29A

Håkan Mattsson, Mikael Keisu
GeoVista AB

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Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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

Abstract

This report presents the compilation and interpretation of geophysical logging data from the cored boreholes KLX19A, KLX28A and KLX29A.

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

The rocks in the vicinities of all three investigated boreholes are completely dominated by silicate density in the interval 2,730–2,800 kg/m^3, natural gamma radiation of c 10–20 μR/h and magnetic susceptibility in the interval c 0.010–0.045 SI. The combination of physical properties indicates the occurrence of quartz monzodiorite, or Ävrö granite with quartz monzodioritic mineral composition.

The occurrence of dolerite rock is indicated along the sections c 482–507 m and 520–552 m in KLX19A, and there are also several indicated occurrences of fine-grained granite in this borehole. In KLX28A and KLX29A there are some indicated occurrences of fine-grained diorite/gabbro and few dykes of fine-grained granite.

The estimated fracture frequency for KLX19A is mainly low and partly moderate. Sections with significantly increased fracturing, possible deformation zones, are indicated at c 105–110 m, 295–305 m, 410–415 m, 435–465 m and 475–555 m.

The most prominent possible deformation zone, at c 475–555 m, coincides with the indicated occurrence of dolerite and it is characterized by significantly decreased resistivity, partly decreased P-wave velocity and several strong caliper anomalies. The combination of physical properties indicates strong brittle deformation, possibly in combination with clay alteration.

The estimated fracture frequency in KLX28A is mainly moderate. Two possible deformation zones are indicated in the sections ca 15–20 m and 25–30 m. In KLX29A the section c 12–26 m is characterized by decreased bulk resistivity, intervals with decrease P-wave velocity and decreased magnetic susceptibility. The estimated fracture frequency is increased along this section, which most likely indicates the occurrence of a deformation zone. In the remaining part of the borehole the estimated fracture frequency is mainly low.

Sammanfattning

Föreliggande rapport presenterar en sammanställning och tolkning av geofysiska borrhålsmätningar från kärnborrhålen KLX19A, KLX28A och KLX29A.

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

Berget i närheten av samtliga tre undersökta borrhål domineras helt av silikatdensitet i intervallet 2 730–2 800 kg/m^3, naturlig gammastrålning i intervallet 10–20 µR/h och magnetiska susceptibilitet i intervallet 0,010–0,045 SI. Kombinationen av fysikaliska parametrar indikerar förekomst av kvatsmonzodiorit eller Ävrögranit med kvartsmonzodioritisk mineralsammansättning.

Längs sektionerna ca 482–507 m och 520–552 m av KLX19A indikerar de geofysiska loggarna förekomst av diabas. Längs hela borrhålet finns även ett flertal indikationer på förekomst av finkornig granit. I KLX28A och i KLX29A finns ett par sektioner med indikerad förekomst av finkornig diorit/gabbro och ett fåtal indikerade finkorniga granitgångar.

Den uppskattade sprickfrekvensen för KLX19A är generellt låg och delvis moderat. Förekomst av möjliga deformationszoner indikeras längs sektionerna 105–110 m, 295–305 m, 410–415 m, 435–465 m och 475–555 m.

Den största möjliga deformationszonen sammanfaller med de indikerade förekomsterna av diabas. Sektionerna karaktäriseras av kraftigt sänkt resistivitet, delvis sänkt P-vågshastighet och ett flertal signifikanta caliper-anomalier. Detta tyder på kraftig spröd deformation, möjligen i kombination med leromvandling.

Den uppskattade sprickfrekvensen för KLX28A är mestadels moderat. Två möjliga deformationszoner finns indikerade längs sektionerna ca 15–20 m och 25–30 m. I KLX29A karaktäriseras hela sektionen ca 12–26 m av sänkt resistivitet i kombination med kortare intervall med sänkt P-vågshastighet och sänkt magnetisk susceptibilitet. Den uppskattade sprickfrekvensen är hög längs detta intervall och indikerar förekomst av en möjlig deformationszon. I övriga delar av borrhålet är den uppskattade sprickfrekvensen generellt låg.

Contents

1 Introduction

SKB performs site investigations for localization of a deep repository for high level radioactive waste. The site investigations are performed at two sites, Forsmark and Oskarshamn. This document reports the results gained from the interpretation of geophysical borehole logging data from the cored boreholes KLX19A, KLX28A and KLX29A, located in Laxemar, Oskarshamn.

Generalized geophysical loggings related to lithological variations are presented together with indicated fracture loggings, including estimated fracture frequency. Calculations of the salinity are also presented. The logging measurements were conducted in 2006 by Rambøll /1/.

The interpretation presented in this report is performed by GeoVista AB in accordance with the instructions and guidelines from SKB (activity plan AP PS 400-06-118 and method descriptions MD 221.003, SKB internal controlling documents), Table 1-1.

Figure 1-1 shows the location of boreholes KLX19A, KLX28A and KLX29A.

The interpreted results are stored in the primary data base SICADA and are traceable by the activity plan number.

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

Activity plan	Number	Version
Tolkning av borrhålsgeofysiska data från KLX19A, KLX28A and KLX29A	AP PS 400-06-118	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för tolkning av geofysiska borrhålsdata	SKB MD 221.003	3.0

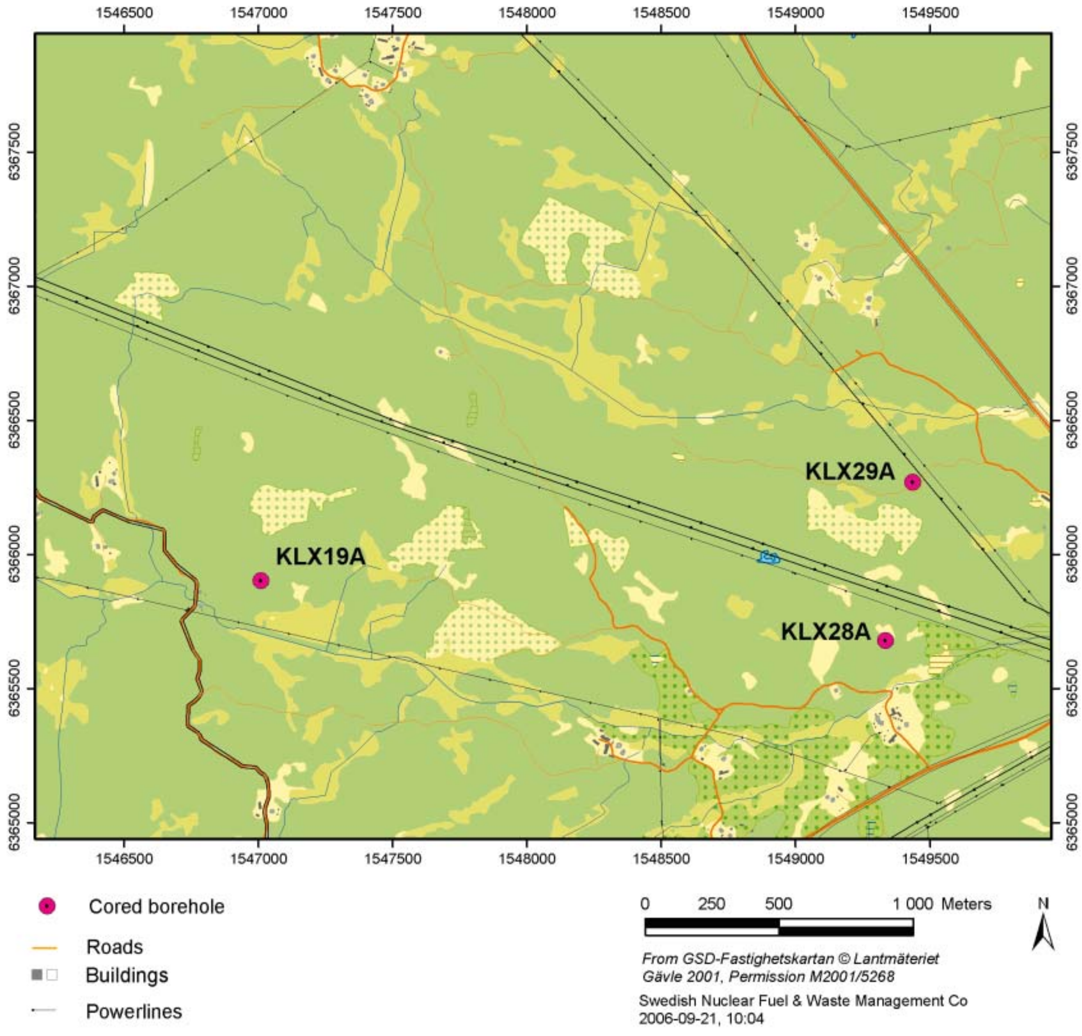

Figure 1-1. *Location of the boreholes KLX19A, KLX28A and KLX29A in Laxemar.*

2 Objective and scope

The purpose of geophysical measurements in boreholes is to gain knowledge of the physical properties of the bedrock in the vicinity of the borehole. A combined interpretation of the "lithological" logging data; silicate density, magnetic susceptibility and natural gamma radiation, together with petrophysical data makes it possible to estimate the physical signature of different rock types. The three loggings are generalized and are then presented in a simplified way. The location of major fractures and an estimation of the fracture frequency along the borehole are calculated by interpreting data from the resistivity loggings, the single point resistance (SPR), caliper and sonic loggings.

An estimation of the salinity and the apparent porosity are presented for the borehole. These parameters indicate salinity variations in the borehole fluid and the transport properties of the rock volume in the vicinity of the borehole.

The main objective of these investigations is to use the results as supportive information during the geological core logging and as supportive information during the so called "geological single-hole interpretation", which is a combined borehole interpretation of core logging (Boremap) data, geophysical data and radar data.

3 Equipment

3.1 Description of equipment for analyses of logging data

The software used for the interpretation are WellCad v4.0 (ALT) and Strater 1.00.24 (Golden Software), that are mainly used for plotting, Grapher v5 (Golden Software), mainly used for plotting and some statistical analyses, and a number of in-house software developed by GeoVista AB on behalf of SKB.

4 Execution

4.1 Interpretation of the logging data

The execution of the interpretation can be summarized in the following five steps:

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

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

The density (logging tool century 9139) and magnetic susceptibility logging data are calibrated with respect to petrophysical data. The magnetic susceptibility logging data were calibrated by use of a combination of petrophysical data from the boreholes KLX03, KSH01A, KSH02, KSH03A, KAV04A and KLX10 see /2, 3, 4, 5, 6 and 7/. The density logging data were calibrated by use of petrophysical data from the borehole KLX20A /8/.

The caliper 1D and caliper 3D logs are calibrated by use of borehole technical information supplied by SKB. The calibration procedure is described in detail in /9/.

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

The silicate density is calculated with reference to /10/ and the data are then divided into 5 sections indicating a mineral composition corresponding to granite, granodiorite, tonalite, diorite and gabbro rocks, according to /11/. The sections are bounded by the threshold values

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

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

3. For the cored borehole the normal resistivity loggings are corrected for the influence of the borehole diameter and the borehole fluid resistivity. The apparent porosity is calculated during the correction of the resistivity loggings. The calculation is based on Archie's law /12/; $\sigma = a\,\sigma_w\,\varphi^m + \sigma_s$ where σ = bulk conductivity (S/m), σ_w = pore water conductivity (S/m), φ = volume fraction of pore space, σ_s = surface conductivity (S/m) and "a" and "m" are constants. Since "a" and "m" vary significantly with variations in the borehole fluid resistivity, estimations of the constants are performed with reference to the actual fluid resistivity in each borehole respectively.

4. Interpretation of the position of large fractures and estimated fracture frequency (classification to fracture logging and calculation of the estimated fracture frequency logging are based on analyses of the short and long normal resistivity, caliper mean, single point resistance (SPR), focused resistivity (140 and 300 cm) and sonic.

The position of large fractures is estimated by applying a second derivative filter to the logging data and then locating maxima (or minima depending on the logging method) in the filtered logging. Maxima (or minima) above (below) a certain threshold value (Table 4-1) are selected as probable fractures. The result is presented as a column diagram where column height 0 = no fracture, column height 1 = fracture indicated by all logging methods. The estimated fracture frequency is calculated by applying a power function to the weighted sum of the maxima (minima) derivative logging for each method respectively, and then calculating the total sum of all power functions. Parameters for the power functions were estimated by correlating the total weighted sum to the mapped fracture frequency in the cored boreholes KLX03 and KLX04 /2/. The powers and linear coefficients (weights) used are presented in Table 4-1.

5. Report evaluating the results.

4.2 Preparations and data handling

The logging data were delivered as Microsoft Excel files via email from SKB. The data of each logging method is saved separately as an ASCII-file. The data processing is performed on the ASCII-files. The data used for interpretation are:

- Density (gamma-gamma).
- Magnetic susceptibility.
- Natural gamma radiation.
- Focused resistivity (300 cm).
- Focused resistivity (140 cm).
- Sonic (P-wave).
- Caliper mean.
- Caliper 1D.
- SPR.
- Fluid resistivity.
- Fluid temperature.

The borehole technical information used for calibration of the caliper data is delivered as Microsoft Word files via email by SKB.

Table 4-1. Threshold values, powers and weights used for estimating position of fractures and calculate estimated fracture frequency, respectively.

	Borehole	Sonic	Focused res. 140	Focused res. 300	Caliper	SPR	Normal res. 64	Normal res. 16	Lateral res.
Threshold	KLX19A	1.0	3.0	2.2	1.0	3.0	8.0	8.0	–
Power	KLX19A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX19A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX28A	1.5	1.5	1.5	2.0	1.5	5.0	5.0	–
Power	KLX28A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX28A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–
Threshold	KLX29A	1.0	1.0	1.0	2.0	1.5	4.0	4.0	–
Power	KLX29A	1.0	1.0	1.6	1.0	0.5	0.5	0.6	–
Weight	KLX29A	1.0	7.1	6.7	1.0	5.0	2.9	5.0	–

4.3 Analyses and interpretations

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

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

4.4 Nonconformities

In some boreholes the long normal resistivity logging measurements show unrealistic anomalies. Apparent porosity calculations and corrections for the borehole diameter and fluid resistivity are therefore only presented for the short normal resistivity data. Apart from this, no nonconformities are reported.

5 Results

5.1 Quality control of the logging data

Noise levels of the raw data for each logging method are presented in Table 5-1. The density, natural gamma radiation and magnetic susceptibility logging data have noise levels above the recommended levels for all the investigated boreholes. Especially for KLX28A and KLX29A the noise for these three methods is so high that it probably has a significant negative influence on the interpretation of the data. To reduce the influence from the noise all data were average filtered prior to the evaluation.

A qualitative inspection was performed on the loggings. The data were checked for spikes and/or other obvious incorrect data points. Erroneous data were replaced by null values (–999) by the contractor Rambøll prior to the delivery of the data, and all null values were disregarded in the interpretation. Sections with null values are indicated by red and white stripes in the presentation of the generalized loggings.

5.2 Interpretation of the logging data

The presentation of interpretation products presented below includes:

- Classification of silicate density.
- Classification of natural gamma radiation.
- Classification of magnetic susceptibility.
- Position of inferred fractures (0 = no method, 1 = all methods).
- Estimated fracture frequency in 5 metre sections.
- Classification of estimated fracture frequency (0 to 3, 3 to 6 and >6 fractures/m).

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

Logging method	KLX19A	KLX28A	KLX29A	Recommended max noise level
Density (kg/m^3)	12	16	20	3 – 5
Magnetic susceptibility (SI)	2×10^{-4}	7×10^{-4}	6×10^{-4}	1×10^{-4}
Natural gamma radiation (μR/h)	0.8	0.9	1.3	0.3
Long normal resistivity (%)	0.4	0.5	1.3	2.0
Short normal resistivity (%)	0.2	0.4	1.3	2.0
Fluid resistivity (%)	0.01	0.01	0.03	2
Fluid temperature (°C)	3×10^{-4}	7×10^{-3}	8×10^{-3}	0.01
Lateral resistivity (%)	Not used	2×10^{-5}	Not used	2
Single point resistance (%)	0.1	0.4	1.4	No data
Caliper 1D	2×10^{-6}	3×10^{-6}	3×10^{-6}	5×10^{-4}
Caliper mean (m)	2×10^{-5}	3×10^{-5}	4×10^{-5}	5×10^{-4}
Focused resistivity 300 (%)	8	16	24	No data
Focused resistivity 140 (%)	18	10	17	No data
Sonic (m/s)	8	17	20	20

5.2.1 Interpretation of KLX19A

The results of the generalized logging data and fracture estimations of KLX19A are presented in Figure 5-1 and in a more detailed scale in Appendix 1. The distribution of silicate density classes along the borehole is presented in Table 5-2.

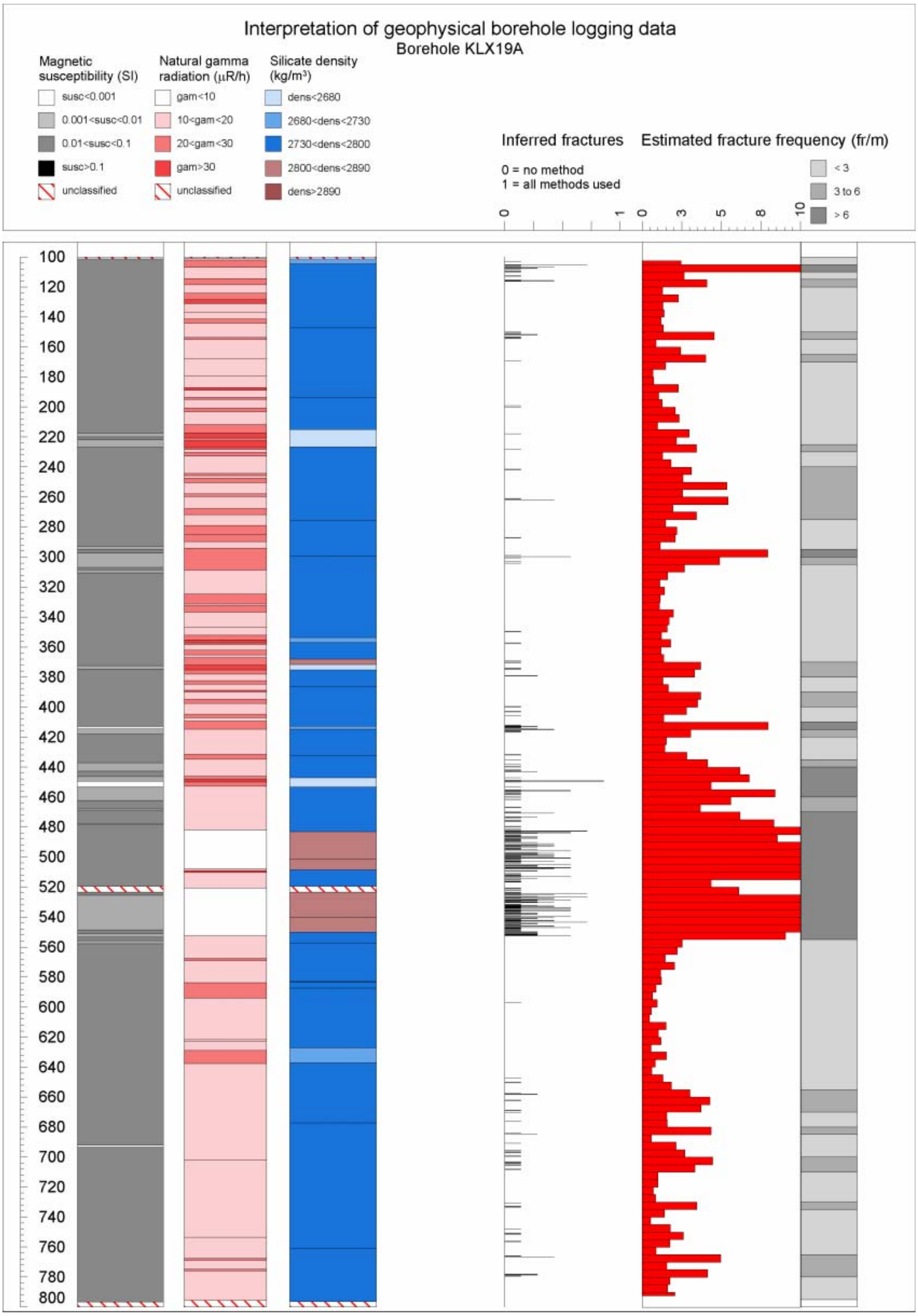

Figure 5-1. Generalized geophysical logs of KLX19A.

Table 5-2. Distribution of silicate density classes with borehole length of KLX19A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative bore-hole length (%)
dens < 2,680	24	3
2,680 < dens < 2,730	53	8
2,730 < dens < 2,800	559	81
2,800 < dens < 2,890	50	7
dens > 2,890	4	1

The rocks in the vicinity of KLX19A are totally dominated by silicate density in the interval 2,730–2,800 kg/m^3. Along these sections the natural gamma radiation mainly is 13–22 μR/h and the magnetic susceptibility varies in the range 0.015–0.035 SI. This combination of physical parameters is typical for quartz monzodiorite, or possibly Ävrö granite with quartz monzodioritic composition.

In the sections c 482–507 m and 520–552 m the density is significantly increased (c 2,830–2,930 kg/m^3), the magnetic susceptibility is decreased (c 0.08–0.015 SI) and the natural gamma radiation is greatly decreased down to c 4–5 μR/h. This combination of physical parameters is typical for mafic rocks, and most likely indicates the occurrence of dolerite.

The section c 216–227 m is characterized by decreased density, decreased magnetic susceptibility and increased natural gamma radiation, which typically indicates the occurrence of fine-grained granite. Along the entire borehole there are 25–30 similar geophysical anomalies, usually < 1 m long, that most likely correspond to dykes of fine-grained granite.

In the section c 629–635 m the density is fairly low, c 2,670–2,700 kg/m^3, there is a slight increase in the natural gamma radiation and the magnetic susceptibility is only slightly decreased. This most likely indicates the occurrence of Ävrö granite with granodioritic mineral composition or possibly "normal" granite.

The estimated fracture frequency for KLX19A is mainly low and partly moderate. Sections with significantly increased fracturing, possible deformation zones, are indicated at c 105–110 m, 295–305 m, 410–415 m, 435–465 m and 475–555 m.

The most prominent possible deformation zone, at c 475–555 m, coincides with the indicated occurrence of dolerite and it is characterized by significantly decreased resistivity, partly decreased P-wave velocity and several strong caliper anomalies. The combination of physical properties indicates strong brittle deformation, possibly in combination with clay alteration.

The indicated deformation zone at c 435–465 m seems to have a core in the section c 447–451 m, which is characterized by decreased resistivity, decreased P-wave velocity and several strong caliper anomalies. The surrounding subsections also show decreased resistivity and decreased P-wave velocity but no caliper anomalies.

The sections c 105–110 m, 295–305 m, 410–415 m are all characterized by decreased resistivity and decreased P-wave velocity, which suggests brittle fracturing. Along the two uppermost sections there are also caliper anomalies.

The estimated apparent porosity (Figure 5-2) averages at c 0.4–0.5%. Two major anomalies with increased porosity coincide with the indicated occurrences of dolerite. Increased porosity is also indicated along the other four possible deformation zones.

In the section c 100–350 m the estimated fluid water salinity is fairly constant at c 330–350 ppm NaCl. Along the section c 350–600 m there is a minor increase in the salinity, ending at c 620 ppm NaCl. From 600 m down to the bottom of the borehole the salinity shows a linear increase up to c 8,650 ppm NaCl.

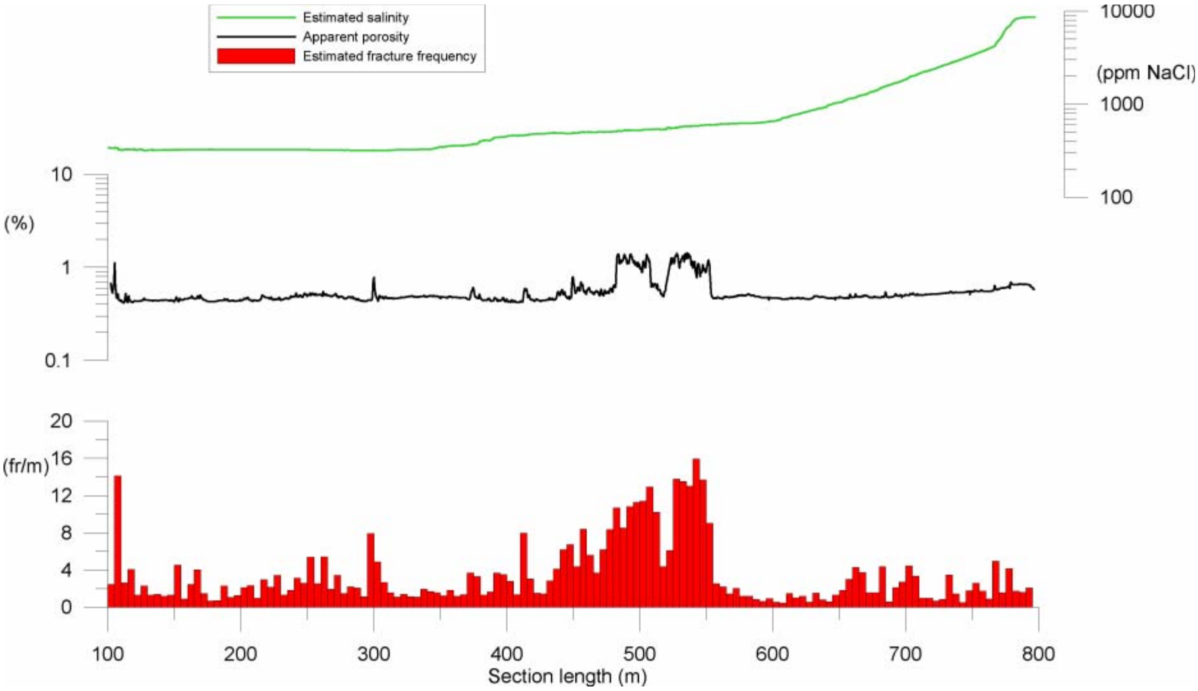

Figure 5-2. *Estimated salinity, apparent porosity and estimated fracture frequency for KLX19A.*

5.2.2 Interpretation of KLX28A

The results of the generalized logging data and fracture estimations of KLX28A are presented in Figure 5-3. The distribution of silicate density classes along the borehole is presented in Table 5-3.

The rocks in the vicinity of KLX28A are dominated by silicate density in the interval 2,730–2,800 kg/m^3, natural gamma radiation of 10–20 μR/h and magnetic susceptibility of c 0.025–0.045 SI. The combination of physical properties indicates the occurrence of quartz monzodiorite, or Ävrö granite with quartz monzodioritic composition. In the section c 27–30 m the density is increased (2,820–2,880 kg/m^3), the magnetic susceptibility and natural gamma radiation logs both show decreased levels. This indicates the occurrence of mafic rock. In direct vicinity of the section there are several anomalies with decreased density and increased natural gamma radiation, which most likely correspond to fine-grained granite. The combination of mafic rock (fine-grained diorite/gabbro) and fine-grained granite is typical for so called composite dykes.

Table 5-3. Distribution of silicate density classes with borehole length of KLX28A.

Silicate density interval (kg/m^3)	Borehole length (m)	Relative borehole length (%)
dens < 2,680	3	4
2,680 < dens < 2,730	13	18
2,730 < dens < 2,800	54	74
2,800 < dens < 2,890	4	4
dens > 2,890	0	0

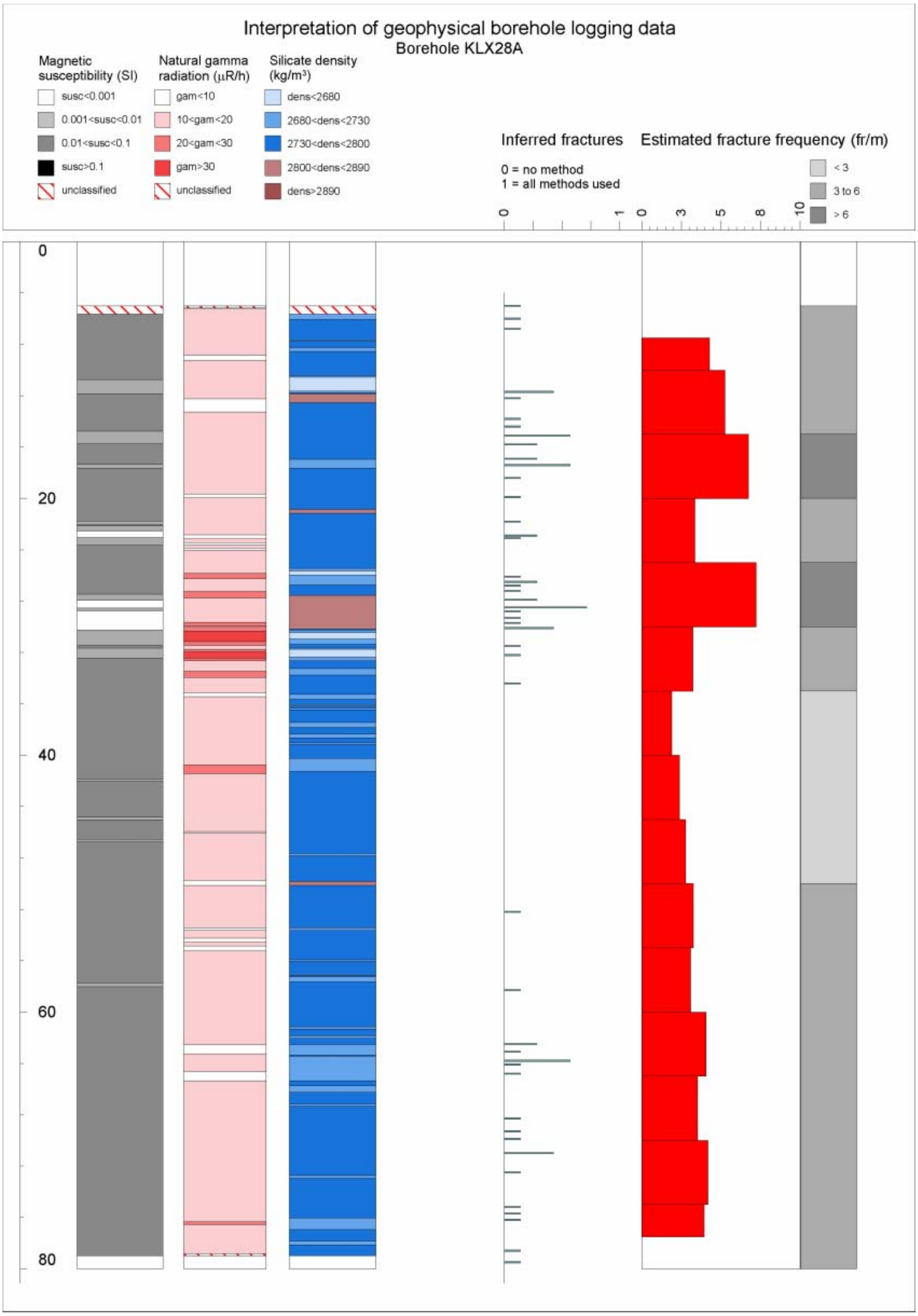

Figure 5-3. Generalized geophysical logs for KLX28A.

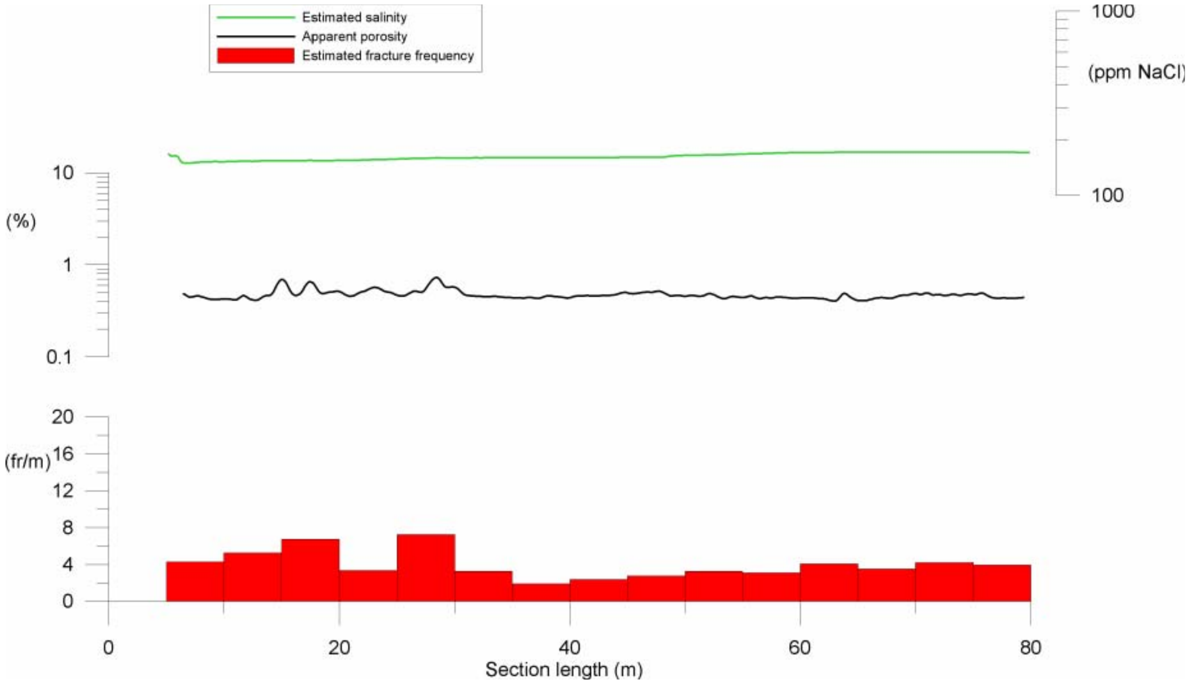

Figure 5-4. *Estimated salinity, apparent porosity and estimated fracture frequency for KLX28A.*

In the section c 62.5–65.5 m the density is decreased in combination with decreased magnetic susceptibility. However, there is no change in the natural gamma radiation. In the central part of this interval there is also decreased resistivity and decrease P-wave velocity, which indicates the occurrence of a minor deformation zone. The deformation has most likely resulted in rock alteration and brittle fracturing.

The estimated fracture frequency is mainly moderate. Two possible deformation zones are indicated in the sections ca 15–20 m and 25–30 m. Both sections are characterized by decreased resistivity and decreased P-wave velocity. Along the lower section there are also several caliper anomalies. Along the entire section c 12.5–31.5 m, which includes both possible deformation zones, there is decreased bulk resistivity, which suggests that the rocks along this interval are altered and/or deformed.

The apparent porosity log indicates an average porosity of 0.4–0.5%, with slightly increased porosity along the sections with possible deformation zones. The estimated fluid water salinity is almost constant along the entire borehole, with an average of c 160 ppm NaCl.

5.2.3 Interpretation of KLX29A

The results of the generalized logging data and fracture estimations of KLX29A are presented in Figure 5-5 and the distribution of silicate density classes along the borehole is presented in Table 5-4.

The rocks in the vicinity of KLX29A are completely dominated (84%) by silicate density in the interval 2,730–2,800 kg/m^3. The natural gamma radiation is c 10–20 μR/h and the magnetic susceptibility varies greatly, but it is mainly in the interval c 0.010–0.040 SI. The combination of physical properties indicates the occurrence of quartz monzodiorite, or Ävrö granite with quartz monzodioritic composition.

In the section c 12.5–15.5 m there are two anomalies of increased density (2,930–2,970 kg/m^3) that coincide with decreased magnetic susceptibility. There is no change in the natural gamma radiation. The data most likely indicate the occurrences of fine-grained diorite/gabbro.

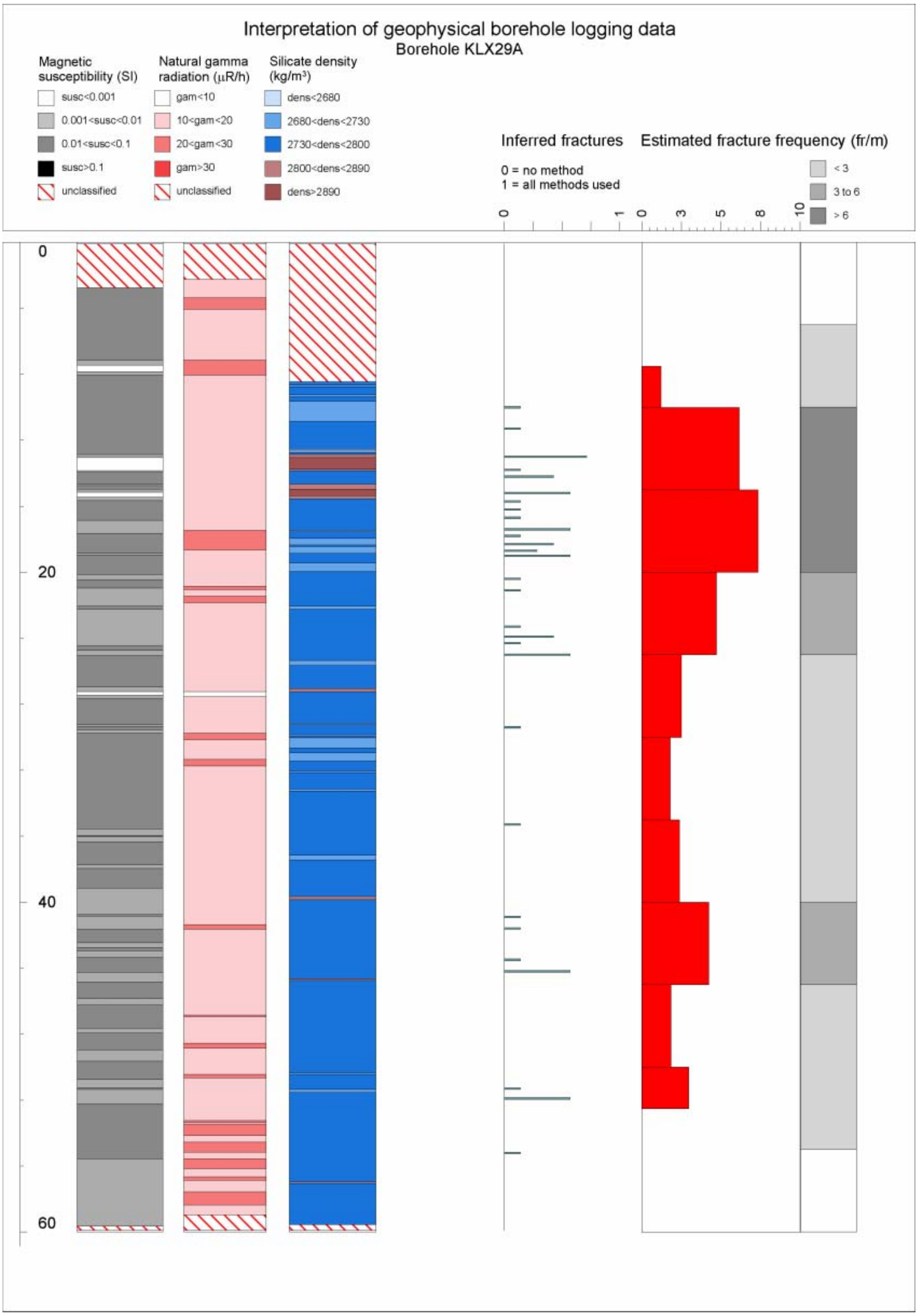

Figure 5-5. Generalized geophysical logs for KLX29A.

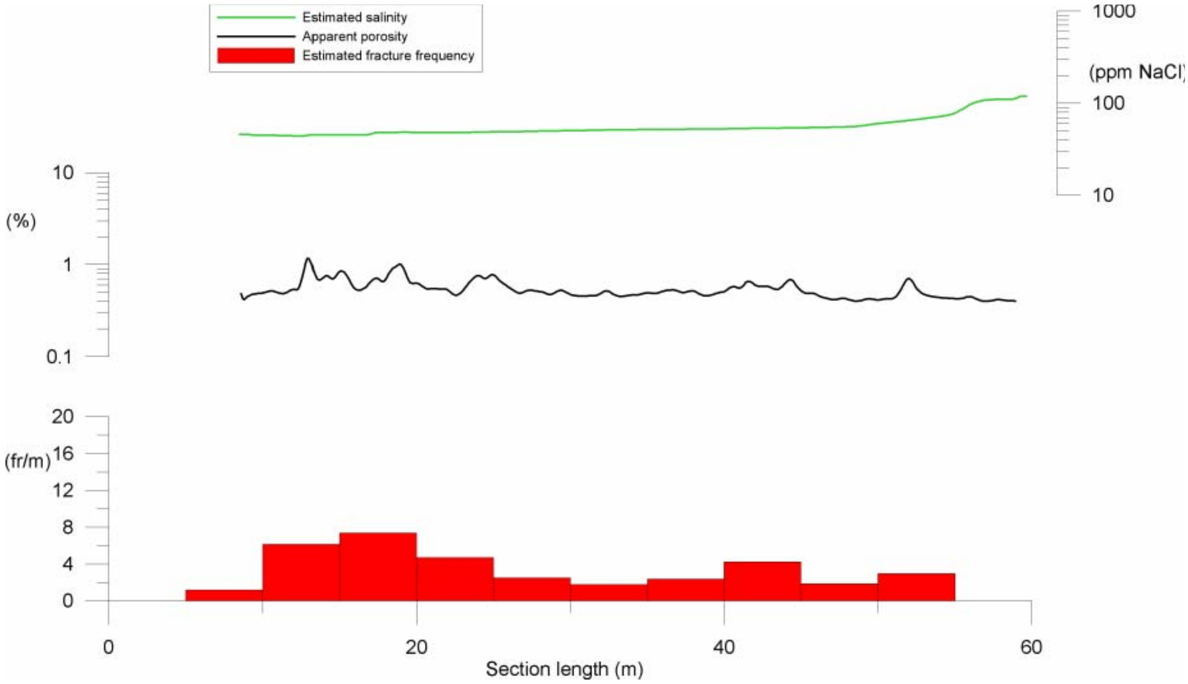

Figure 5-6. *Estimated salinity, apparent porosity and estimated fracture frequency for KLX29A.*

Table 5-4. Distribution of silicate density classes with borehole length of KLX29A.

Silicate density interval (kg/m³)	Borehole length (m)	Relative bore-hole length (%)
dens < 2,680	0	0
2,680 < dens < 2,730	6	12
2,730 < dens < 2,800	43	84
2,800 < dens < 2,890	1	2
dens > 2,890	1	2

The section c 12–26 m is characterized by decreased bulk resistivity (and several sharp negative resistivity anomalies), intervals with decrease P-wave velocity and decreased magnetic susceptibility. The estimated fracture frequency is increased along this section, which most likely indicates the occurrence of a deformation zone. In the remaining part of the borehole the estimated fracture frequency is mainly low. However, at c 51–52 m there is decreased P-wave velocity, decreased resistivity and decreased magnetic susceptibility, which indicates the occurrence of a minor deformation zone (or single significant fracture).

The apparent porosity log indicates an average porosity of 0.4–0.5%, with partly increased porosity along the section with the possible deformation zone. The estimated fluid water salinity is almost constant along the entire borehole, with an average of c 50 ppm NaCl, apart for the lowermost ca 10 m along which the salinity level slightly increases.

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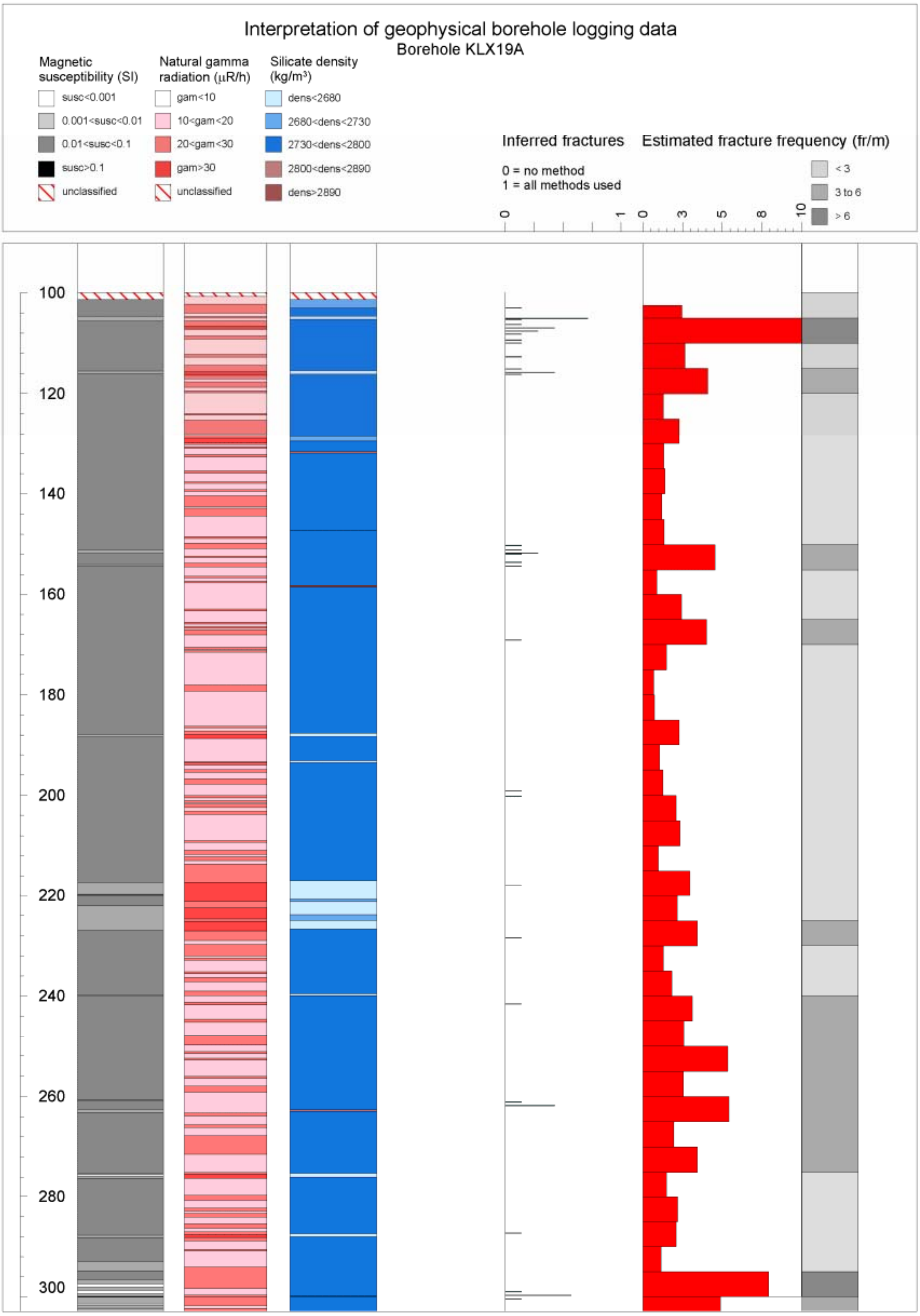
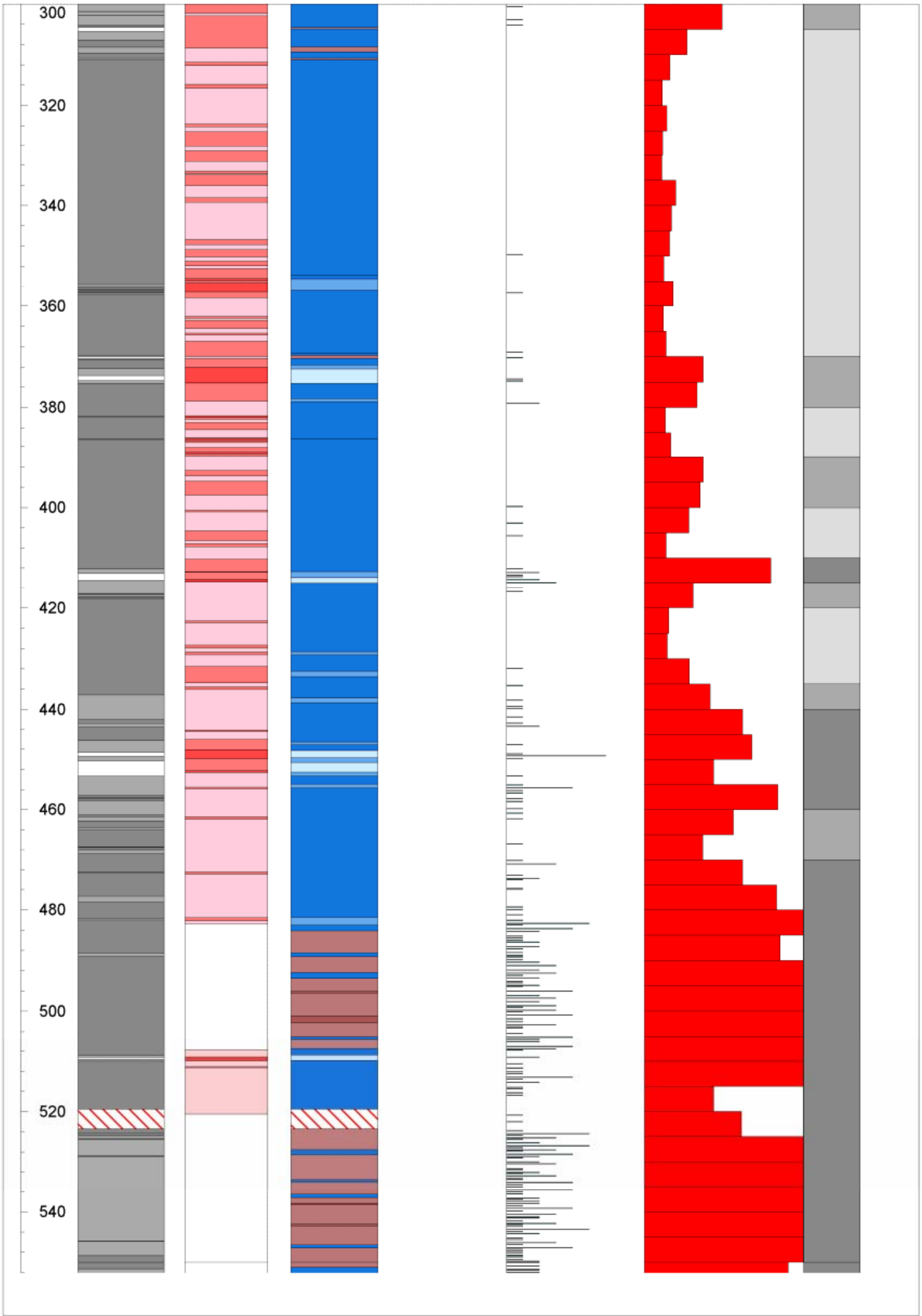
Generalized geophysical logs of KLX19A

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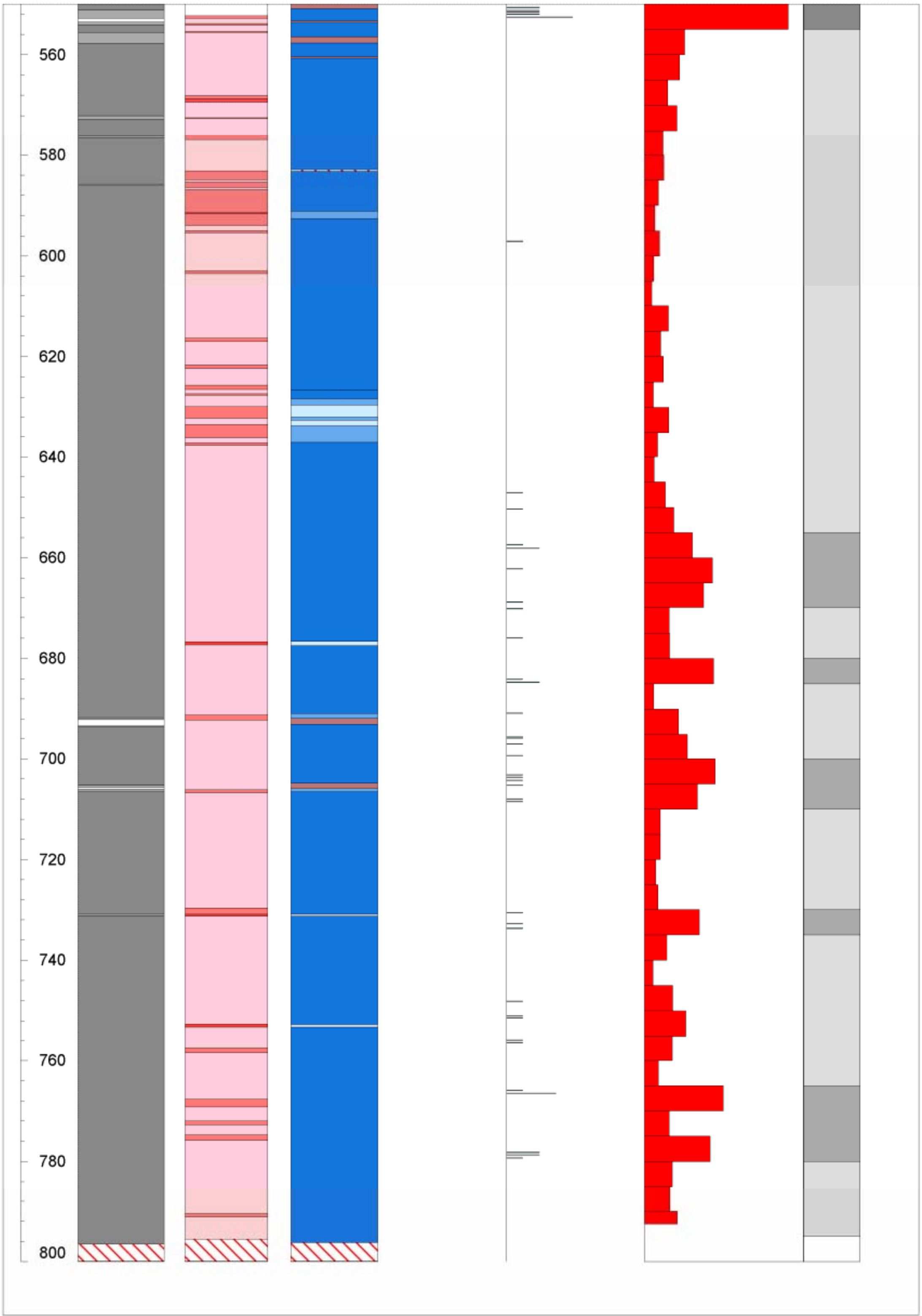

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