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Site Investigation SFR

Boremap mapping of core drilled boreholes KFR102B and KFR103

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Abstract

This report presents the result from the Boremap mapping of the core drilled boreholes KFR102B and KFR103, which are drilled from the eastern part of the pier next to the existing repository for low- and intermediate-level waste (SFR). The boreholes were drilled during August 2008 with the aim to gather information about the geological and hydrogeological properties of the near surface bedrock as well as to verify the geohydrological model. In addition, four interpreted low magnetic lineaments were checked.

The geological mapping of the boreholes was started in September 2008 and finished in November 2008. The mapping is based on the simultaneous study of the drill core and the borehole image (BIPS) supported by generalized, as well as detailed geophysical logs.

The dominating rock type in KFR102B and KFR103 is a mostly foliated, somewhat folded metagranite-granodiorite (> 50%). Younger pegmatite to pegmatitic granite and fine- to medium-grained granite occur also, as well as amphibolite and felsic to intermediate metavolcanic rock. The rock types are mostly fresh exhibiting only oxidation in some intervals and metamorphic muscovite in the upper part of KFR103.

KFR102B exhibits the following fracture frequencies: 3.7 open fractures/m (crush excluded), 0.4 partly open fractures/m and 9.1 sealed fractures/m (sealed fracture networks excluded). There is one 5 cm wide crushed interval in KFR102B. Sealed fracture networks are mapped along a total borehole length of 14.5 m.

The corresponding fracture frequencies for KFR103 is as follows: 3.7 open fractures/m (crush excluded), 0.2 partly open fractures/m and 6.1 sealed fractures/m (sealed fracture networks excluded). There are three thin ~ 10 cm wide crushed intervals in KFR103. Sealed fracture networks are mapped along a total borehole length of 22 m.

No conspicuous sections of deformed or strongly altered rock have been observed in the boreholes.

Sammanfattning

Denna rapport presenterar resultaten från Boremapkarteringen av kärnborrhålen KFR102B och KFR103, vilka är borrade från den östra delen av piren intill det befintliga förvaret för låg- och medelaktivt avfall (SFR). Borrningen utfördes under augusti 2008 med syftet att samla information rörande ytbergets geologiska och hydrogeologiska egenskaper, samt att verifiera den geohydrologiska modellen. Det var dessutom en kontroll av huruvida tolkade lågmagnetiska lineamenten är deformationszoner.

Den geologiska karteringen av borrhålen påbörjades i september 2008 och slutfördes i november 2008. Karteringen är baserad på simultan undersökning av borrkärna och borrhålsbild (BIPS) och den är understödd av generaliserade och detaljerade geofysiska loggar.

Den dominerande bergarten i KFR102B och KFR103 är en mestadels folierad, något veckad metagranit-granodiorit (> 50 %). Yngre pegmatiter och pegmatitisk granit samt fin- till medelkornig granit förekommer också liksom amfibolit och felsisk till intermediär metavulkanit. Bergarterna är mestadels fräscha och uppvisar enbart oxidering i begränsade intervall och metamorf muskovit i övre delen av KFR103.

KFR102B uppvisar följande sprickfrekvenser: 3,7 öppna sprickor/m (krossar exkluderade), 0,4 delvis öppna sprickor/m och 9,1 läkta sprickor/m (läkta spricknätverk exkluderade). Det finns endast ett 5 cm brett krossat intervall i KFR102B. Läkta spricknätverk har karterats för totalt 14,5 m av borrkärnan.

De motsvarande sprickfrekvenserna för KFR103 är följande: 3,7 öppna sprickor/m (krossar exkluderade), 0,2 delvis öppna sprickor/m och 6,1 läkta sprickor/m (läkta spricknätverk exkluderade). Det finns tre tunna, ~ 10 cm breda, krossade intervall i KFR103 och 22 m av borrkärnan består av läkta spricknätverk.

Inga framträdande deformerade eller kraftigt omvandlade sektioner kan ses i någotdera av borrhålen.

Contents

1 Introduction

SKB intends to enlarge the repository for low- and intermediate-level waste in Forsmark (SFR), which was completed and ready for operation in 1988. It was then the first of its kind in the world. Protection clothing, trash and filters that are used to clean the reactor water are examples of radioactive waste that are stored in SFR. In the future, SFR is also going to host the waste that arises from the demolishing of the nuclear power plants. An extension of SFR is therefore planned and it is estimated to be ready in 2020.

A lot of information about the bedrock and groundwater has already been gathered during the building of SFR, but some complementary studies have to be done. This document reports the data gained by the Boremap mapping of two core drilled boreholes, KFR102B and KFR103, which is one of the activities performed within the site investigation programme. Locations of the boreholes are presented in Figure 1-1. The work was carried out in accordance with activity plan AP SFR-08-015. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

The core drilled boreholes were drilled in the autumn 2008 and were after completion investigated with several logging methods, such as conventional geophysical logging and TV-logging. The latter method implies logging with a colour TV-camera to produce images of the borehole wall, so called BIPS-images (**B**orehole **I**mage **P**rocessing **S**ystem).

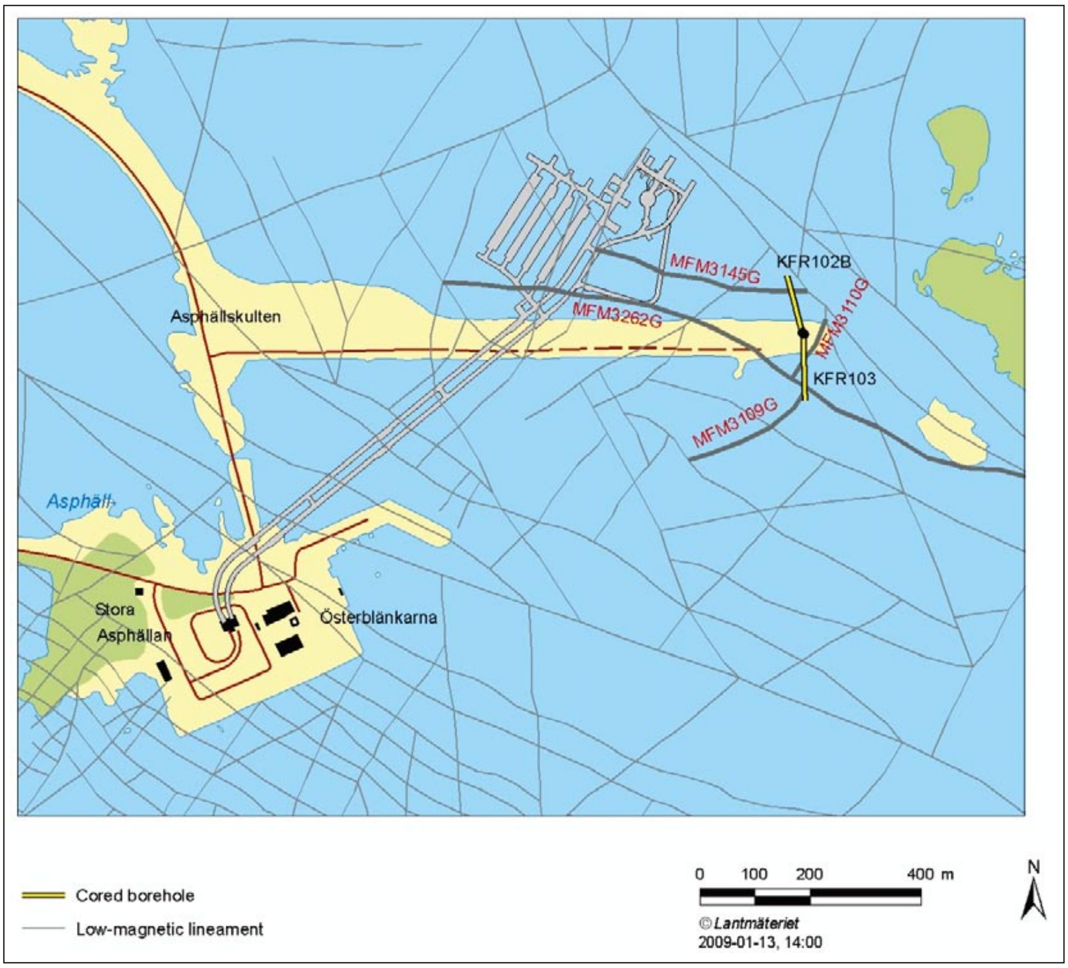

__Figure 1-1.__ Location of core drilled boreholes KFR102B and KFR103 in relation to SFR. Intersected lineaments are also shown. Four lineaments with low magnetic intensity, expected to be intersected by the boreholes, are highlighted.

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

Activity plan	Number	Version
Boremapkartering av kärnborrhål KFR102B och KFR103	AP SFR-08-015	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för Boremapkartering	SKB MD 143.006	2.0
Mätsystembeskrivning för Boremap	SKB MD 146.005	1.0
Instruktion: Regler för bergarters benämningar vid platsundersökningen i Forsmark	SKB MD 132.005	1.0
Nomenklatur vid Boremapkartering	SKB MD 143.008	1.0
Instruktion för längdkalibrering vid undersökningar I kärnborrhål	SKB MD 620.010	2.0

The boreholes were mapped in the period August 2008–November 2008. Mapping of cored boreholes according to the Boremap method is based on simultaneous study of the drill core and the use of BIPS-images of the borehole wall. The mapping was also supported by generalized geophysical logs (Appendix 2).

The BIPS-images enable the study of the distribution of fractures along the borehole. Fracture characteristics like aperture, colour of fracture minerals, etc are possible to study as well. Furthermore, since the BIPS software has the potential of calculating strike and dip of planar structures such as foliations, rock contacts and fractures intersecting the borehole, also the orientation of each planar structure is documented with the Boremap method.

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP SFR-08-015). Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Possible revisions of data will not necessarily result in a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

2 Objective and scope

The boreholes KFR102B and KFR103 were drilled with the aim to gather information about the geological and hydrogeological properties of the near surface bedrock as well as to verify the geohydrological model. To this, four interpreted lineaments with low magnetic intensity were checked. Lithologies, alterations, ductile structures and the occurrence and character of fractures in the bedrock penetrated by the core drilled boreholes KFR102B and KFR103 were documented. Other data obtained from the core drilled boreholes, such as thickness of soil cover, soil stratigraphy, groundwater level and groundwater flow, will not be treated in this report.

3 Equipment

3.1 Description of equipment and interpretation tools

Mapping of the boreholes based on BIPS-images was performed with the software Boremap v.3.9.6.4. Boremap software is loaded with the rock types and mineral standard used for surface mapping at the Forsmark investigation site, in order to enable correlation with the surface geology. Inclination, bearing and diameter of the borehole are used as in-data for the calculations. The BIPS-image lengths were calibrated by reference marks in the borehole wall.

Schematic presentations of the boreholes are presented in WellCAD-diagrams (Appendix 1).

The following equipment has been used to facilitate the core mapping: folding rule, 10% hydrochloric acid, rock hardness tool, hand lens, paint brush and tap water.

3.2 Used BIPS-file and image quality

Information about Used BIPS-files is listed in Table 3-1.

The following factors may disturb the mapping:

- Blackish coatings probably related to the drilling equipment.
- Vertical bleached bands on the borehole walls from the drill cuttings in suspension.
- Light and dark bands at high angle to the borehole related to the automatic aperture of the video camera.
- Vertical enlargement of pixels due to stick-slip movement of the camera probe.

The BIPS-image qualities of the boreholes are listed in Table 3-2. The results from the BIPS-loggings are presented in /1/.

Table 3-1. Used BIPS-files.

Borehole	BIPS-file	Logging date	Logging time	From (m)	To (m)
KFR102B	KFR102B_13–179_20080910.BIP	2008-09-10	13:26	13:00	178.712
KFR103	KFR103_13–199m_20080911.BIP	2008-09-11	8:23	13:00	199.089

Table 3-2. BIPS-image quality of used BIPS-files.

Borehole	from	to	visible %	Comment
	13	20	100	Good.
KFR102B	20	33	90	Quite good. Lower side of borehole wall is overexposed. Especially dark rock types are affected.
	33	41.2	100	Good.
	41.2	78	90	Quite good. Lower side of borehole wall is overexposed. Especially dark rock types are affected.
	78	117	70–100	Quite good. Lower side of borehole wall is strongly overexposed. Especially dark rock types are affected.
	117	178.67	60–100	Acceptable. Suspensions on lower side of borehole wall which is also overexposed.
	178.67	178.71	0	Not used. Mud.
	13	15	100	Quite good. Lower half of borehole wall is strongly overexposed.
KFR103	15	100	100	Good.
	100	198.3	60–80	Acceptable. Rock on lower side borehole wall which is mostly non-visible.
	198.3	199.089	0	Not used. Mud.

4 Execution

4.1 General

Boremap mappings of the core drilled boreholes KFR102B and KFR103 were performed and documented according to activity plan AP SFR-08-015 (SKB, internal document). Geophysical logs of the boreholes supported the mapping. The mapping was performed in accordance with the SKB method description for Boremap mapping SKB MD 143.006, as well as SKB MD 146.001 (SKB internal controlling documents) and /2/. Information from earlier performed investigations in the area were also helpful in the interpretations /3, 4, 5, 6/.

4.2 Preparations

Background data collected from Sicada prior to the Boremap mapping included:

- borehole diameter (Appendix 3),
- reference marks in the borehole wall (Appendix 3),
- total borehole length (Appendix 3),
- borehole deviation data.

These background data, except for borehole diameter, are imported from Sicada by semiautomatic routines.

Detailed plots of resampled and calibrated geophysical logging data, as well as generalized geophysical logs from Geovista AB were used as supporting data for the mapping of the boreholes (Appendix 2).

General information about the boreholes is listed in Table 4-1 and applied length adjustments are listed in Table 4-2.

Table 4-1. Borehole data for KFR102B and KFR103.

ID-code	Northing	Easting	Bearing (degrees)	Inclination (degrees)	Diameter (mm)	Borehole length (m)	Mapping interval (m)	End of casing
KFR102B	6701740.53	1633343.91	344.9	–54.1	76	180.08	13.949–180.08	13.95
KFR103	6701737.13	1633347.20	179.9	–53.9	76	200.5	13.339–200.5	13.33

Table 4-2. Applied length adjustments in KFR102B and KFR103.

Borehole	Recorded length (m)	Adjusted length (m)	Difference (m)
KFR102B	49.835	50	0.165
	99.676	100	0.324
	148.466	149	0.534
KFR103	49.859	50	0.141
	100.715	101	0.285
	149.616	150	0.384
	189.48	190	0.520

4.3 Execution of measurements

4.3.1 Fracture definitions

Definitions of different fracture types and apertures, crush zones and sealed fracture network are found in SKB MD 143.008 and "Kalibrering av Boremapkartering" (v.0.9), which is planned to be implemented in the next version of SKB MD 143.006.

Two types of fractures are mapped in Boremap; broken and unbroken. Broken fractures are those that split the core, while unbroken fractures do not split the core. All fractures are described with their fracture minerals and other characteristics (e.g. width, aperture and roughness). Visible aperture is measured down to 1 mm in the BIPS-image. Aperture less than 1 mm, which is impossible to measure in the BIPS-image, are denoted a value of 0.5 mm. If the aperture is very small but still visible in BIPS, it is mapped as 0.5 mm wide and the confidence is considered "certain". If no aperture is visible in BIPS, and the core pieces do not fit well, the confidence of the aperture is considered "probable". If the core pieces do fit well, but the fracture surfaces are dull or altered, the confidence of the aperture is considered "possible". Tight broken fractures having voids are mapped with a 0.5 mm aperture which is considered "probable". This is because these fractures are considered only partly open, while broken fracture with certain aperture is considered fully open).

Broken fractures that are partly unbroken are mapped as being "irregular rough", since they are partly sealed and the method descriptions does not give any answer to how the roughness of this kind of fractures should be treated. Unbroken fractures with possible channelling are mapped as unbroken with certain/probable/possible aperture. A possible aperture is given if the fracture filling is soft and may have been flushed away.

All fractures with aperture > 0 mm are presented as open in the Sicada database. Unbroken fractures have normally apertures = 0 mm, but some have apertures > 0 mm. These are presented as partly open, and are included in the open fracture category in Sicada. The frequency of open and sealed fractures are calculated and shown in the WellCad-diagram (Appendix 1).

4.3.2 Fracture alteration and joint alteration number

Joint alteration number is mainly related to the thickness of, and the clay content in a fracture /7/. Fractures > 1 mm wide and rich in clay minerals, are usually given joint alteration numbers between 2 and 4. The majority of the broken fractures are very thin to extremely thin and do seldom contain clay minerals or very small amounts of clay and chlorite. These fractures have joint alteration numbers between 1 and 2. Since most fractures are within this span, a subdivision with joint alteration number = 1.5 was performed to facilitate both the evaluation process for fracture alterations, and the possibility to compare the alterations between different fractures in the boreholes.

4.3.3 Mapping of fractures not visible in the BIPS-image

Not all fractures are visible in the BIPS-image, and these fractures are oriented using the *guideline method* /8/. The orientation performed in this work is based on the following data:

- Amplitude (measured along the drill core), which is the interval between fracture extremes along the drill core.
- The relation between the rotation of the fracture trace, and a well defined structure visible in both drill core and BIPS-image. This rotation is measured with measuring tape on the drill core.
- Absolute depth relative to a well defined structure visible in both drill core and BIPS-image.

The fractures mapped with the guide-line method are registered in Boremap as "non-visible in BIPS", and can therefore be separated from fractures visible in BIPS.

4.3.4 Mineral codes

In cases where properties or minerals are not represented in the mineral list, the following mineral codes have been used in the mapping of KFR102B and KFR103:

- X1 = Bleached fracture walls.
- X3 = The drill core is broken at a right angle, and the broken surfaces have a polished appearance. This is caused by rotation of two core pieces along an intermediate fracture wearing away possible mineral filling. It is impossible to decide whether this fracture was open or sealed in situ.
- X5 = Probable cataclastic filling, white to beige in colour, resembles feldspar.
- X8 = Epidotized walls.

4.3.5 Foliation and lineation

The metagranite-granodiorite which occupies most of the area in Forsmark is usually LS tectonites, where lineation dominates over foliation /4/. In the SFR-area, the foliation is usually dominating in the metagranite-granodiorite and therefore it is mostly foliation that is mapped. In the SFR area there are also signs of folding, resulting in varying intensity of the foliation and lineation. An estimated average intensity is mapped for rock types.

The higher strain in the SFR-area relative to the candidate area of the Forsmark site investigation also appears in the somewhat finer grain-size of the metagranite-granodiorite, which is mostly mapped as “fine- to medium-grained” in the SFR-area.

4.3.6 Lithologies and correlation with geophysical data

As mentioned in chapter 4.3.5, the rock types in the SFR-area are generally more deformed relative to the rock types in the candidate area of Forsmark site investigation. This complicates the determination of rock types, because different rock types may have a very similar appearance in the SFR-area.

Detailed plots of resampled and calibrated geophysical logging data from the boreholes /9/, as well as generalized geophysical logs shwn in Appendix 2, were helpful where there were difficulties in deermining the rock type macroscopially, see example in Figure 4-1.

4.3.7 Definition of veins and dikes

A rock sequence that covers less than 1 m of the drill core is mapped as a *rock occurrence* in Boremap. Rock occurrences that cover more than 1 m of the drill core are mapped as a separate *rock type*. If evidence for intrusion is visible in the drill core, two different types of rock occurrences are mapped: veins and dikes. These two are separated by their respectively length in the drill core; veins are set to 0–20 cm and dikes are set to 20–100 cm. If the rock occurrence cannot be classified as a vein or a dyke, the occurrence type is mapped as “unspecified”. In Forsmark there are boudinated veins, xenoliths, blobs, etc and the occurrence type is usually difficult to determine from the drill core.

4.4 Data handling/post processing

The Boremap mappings of KFR102B and KFR103 were performed on SKB’s network, while a backup was saved on a local computer before each break, exceeding 15 minutes. When the mappings were finished and quality checked by a routine in Boremap, the data was submitted to SKB for exportation to Sicada.

All data are stored in the SKB Sicada database, and it is only these data that should be used for further interpretation.

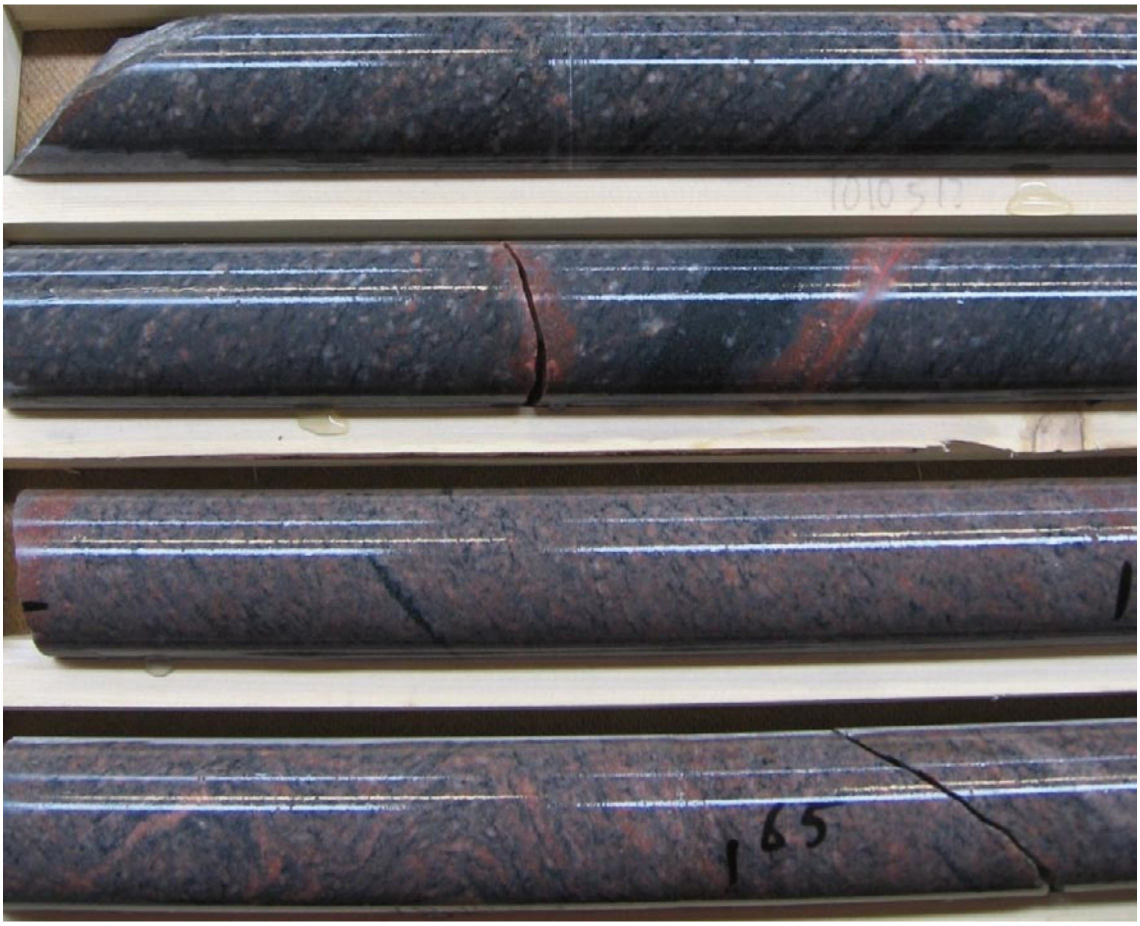

Figure 4-1. Example from 62–65 m borehole length in KFR102B showing either textural change in metagranite-granodiorite (101057) or two different granitic rock types. Based on the geophysical data it is concluded that the section is constituted by the same rock type.

4.5 Nonconformities

4.5.1 Core loss

There are two core losses in KFR102, one at 27.96–28.00 m and the other at 29.79–29.80 m. The first one is mechanical and the other is a missing core piece.

There are three core losses in KFR103. These occur in the following intervals: 181.16–181.22, 181.28–181.40 and 181.96–182.00 m. The first one is due to missing core piece, the second is mechanical and the third is in a crush zone. The BIPS-image still enabled mapping in the intervals.

4.5.2 Overrepresented fracture mineral

The frequency of calcite in fractures is overrepresented relative to other minerals, since it is detected by reaction with diluted hydrochloric acid even though it is macroscopically invisible.

Hematite is also usually overrepresented due to its strong colouration of other minerals or mineral aggregates. Hematite has only been mapped if a red streak can be observed, otherwise it is considered to occur only as pigmentation (impurity in other minerals).

5 Results

Data from the Boremap mappings of KFR102B and KFR103 are stored in Sicada and it is only these data that shall be used for further interpretation and modelling. The user of these data should be aware of the assumptions mentioned in Chapter 4. Graphical presentations of the data are given as WellCAD-diagrams in Appendix 1. Summaries of rock types and fracture frequency in the boreholes are presented in Tables 5-1 and 5-2.

The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

5.1 KFR102B

5.1.1 Lithology

The dominating rock type in KFR102B is a fine- to medium-grained metagranite-granodiorite (101057), which is mostly moderately foliated (Table 5-1). Locally, the lineation dominates over the foliation. Other frequently occurring rock types are amphibolite (102017), pegmatite (101061), felsic to intermediate metavolcanic rock (103076) and fine- to medium-grained granite (111058).

5.1.2 Alterations

KFR102B is generally composed of fresh rock, which only displays oxidation in some intervals. Other alteration types occur, but very rarely.

5.1.3 Fractures

A total amount of 1,569 unbroken and 625 broken fractures were documented in KFR102B. Of the unbroken fractures 69 show an aperture, while none of the broken fractures is considered artificial and have aperture = 0. This result in the following interpreted fracture frequencies: 9.1 sealed fractures/m (sealed fractures in sealed fracture networks excluded), 3.7 open fractures/m (crushes excluded) and 0.4 partly open fractures/m.

Table 5-1. Distribution of rock types in KFR102B and KFR103 (expressed as %, rock occurrences excluded).

Borehole	101057	101061	102017	103076	111058
KFR102B	55.3	13.1	17.8	9.3	4.4
KFR103	58.3	20.5	7.0	12.8	1.4

Table 5-2. Fracture frequencies in KFR102B and KFR103 (crush and sealed fracture networks excluded) expressed as fractures/m.

Borehole	Open fractures	Partly open fractures	Sealed fractures
KFR102B	3.7	0.4	9.1
KFR103	3.7	0.2	6.1

Three dominating sets of open and partly open fractures with the orientations 230°/05°, 090°/70° and 050°/90° (Figure 5-1) can be distinguished. There is one strongly dominating orientation of sealed fractures: 090°/65° (Figure 5-2), and four subordinate sets: 040°/90°, 140°/85°, 085°/25° and 230°/05°.

The most frequently occurring minerals in the open fractures are in decreasing order: chlorite, calcite, laumontite, no detectable mineral, adularia and pyrite. Almost 20% of the open fractures have oxidized walls.

The most frequently occurring minerals in sealed fractures are calcite, chlorite, laumontite, quartz and adularia. About 70% of the sealed fractures have oxidized walls.

Only one, approximately 5 cm wide crushed interval has been documented in KFR102B (150.01–150.06 m borehole length).

74 open fractures with no detectable mineral have been mapped. The orientations of these fractures are mainly horizontal to sub-horizontal (Figure 5-3).

5.1.4 Deformation

The foliation in the borehole is rather consistent with an orientation of 120°/75°, and when lineation is observed it is also sub-vertical, trending 175° with a plunge of 75 (Figure 5-4). A few thin deformation bands are observed (Figure 5-4), for example brittle-ductile shear bands, breccia (Figure 5-5) and cataclasite. These are also oriented roughly 120°/75°, i.e. parallel with the foliation.

5.2 KFR103

5.2.1 Lithology

The geology in KFR103 is very similar to KFR102B (Table 5-1). The dominating rock type in KFR103 is a fine- to medium-grained metagranite-granodiorite (101057), which is mostly moderately foliated. Locally, the lineation dominates over the foliation. Other frequently occurring rock types are pegmatite (101061), felsic to intermediate metavolcanic rock (103076), amphibolite (102017) and fine- to medium-grained granite (111058).

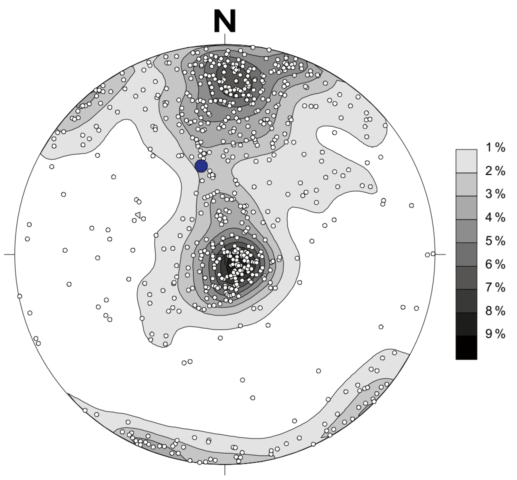

Figure 5-1. Stereographic projection showing contoured poles to open and partly open fracture planes (n=684) in KFR102B, Schmidt net, lower hemisphere. Blue dot represents borehole projection.

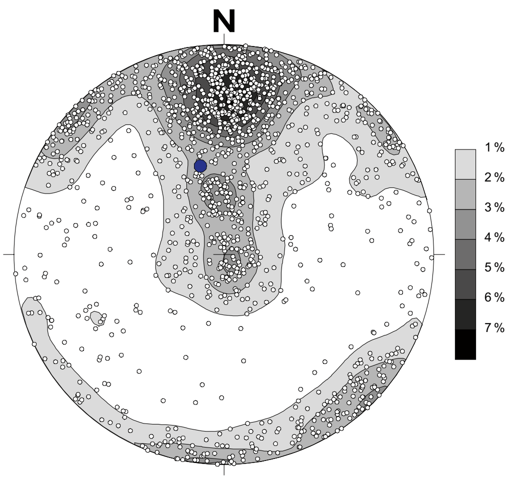

Figure 5-2. Stereographic projection showing contoured poles to sealed fracture planes (n=1,510) in KFR102B, Schmidt net, lower hemisphere. Blue dot represents borehole projection.

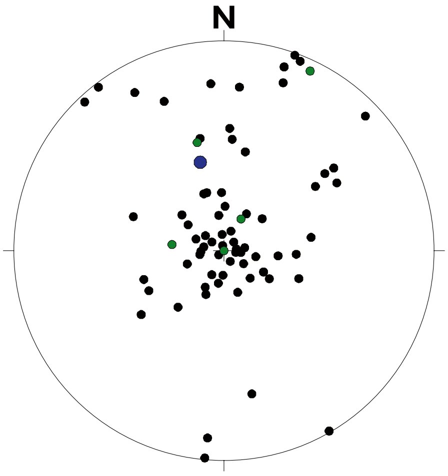

Figure 5-3. *Stereographic projection showing poles to open fracture planes with no detectable mineral in KFR102B (Schmidt net, lower hemisphere). ● = fresh (n=69), ● = slightly altered (n=5), ● = borehole projection.*

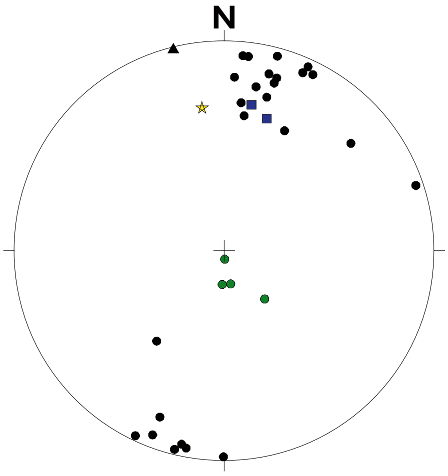

Figure 5-4. *Stereographic projection showing poles to deformation planes and lineations in KFR102B. ● = foliation (n=25), ● = lineation (n=4), ■ = brittle ductile shear zone (n=2), ▲ = breccia (n=1) and ☆ = cataclasite (n=1).*

Figure 5-5. *Sealed breccia in KFR102B at 69.0 m, with calcite, prehnite and probable iron hydroxide.*

5.2.2 Alterations

The most frequently occurring alteration type in KFR103 is muscovitization (mapped as sericitization). Muscovite seems to replace biotite in the foliation planes and is most likely of metamorphic origin. It cannot directly be related to the existence of brittle structures. In almost 20% of the drill core muscovite is present to some extent. Oxidation or red staining is relatively rare in KFR103 (affects only ~ 10% of the borehole).

5.2.3 Fractures

A total amount of 1,866 unbroken and broken fractures were documented in KFR103. Of the unbroken fractures, 37 show an aperture, while only one of the broken fractures are considered artificial and have apertures = 0. This result in the following interpreted fracture frequencies: 6.1 sealed fractures/m (sealed fractures in sealed fracture networks excluded), 3.7 open fractures/m (crushes excluded) and 0.2 partly open fractures/m.

Two dominating sets of open and partly open fractures are observed. They are oriented 270°/05° and 085°/90° (Figure 5-6). The dominating orientations of sealed fractures are 080°/90°, 045°/90°, 335°/80° or sub-horizontal striking roughly E-W (Figure 5-7).

The most frequently occurring minerals in the open fractures are in decreasing order: calcite, chlorite, muscovite, laumontite, clay minerals and hematite.

Roughly 15% of the open fractures have oxidized walls.

The most frequent minerals in sealed fractures are calcite, chlorite, laumontite and quartz. About 70% of the sealed fractures have oxidized walls.

Six thin, 5–15 cm wide, crushed intervals have been documented in KFR103. Some are real crushes (Figure 5-8a) while other are densely fractured sections (Figure 5-8b and c), where the individual fractures could not be mapped separately in the drill core.

Ninety eight open fractures with no detectable mineral have been mapped. The orientations of these fractures are mainly horizontal to sub-horizontal (Figure 5-9).

5.2.4 Ductile deformation

The foliation orientation (Figure 5-10) and intensity (Figure 5-11) in KFR103 varies but it is mostly oriented roughly 300°/75°. When lineation is observed it is sub-vertical (Figure 5-10).

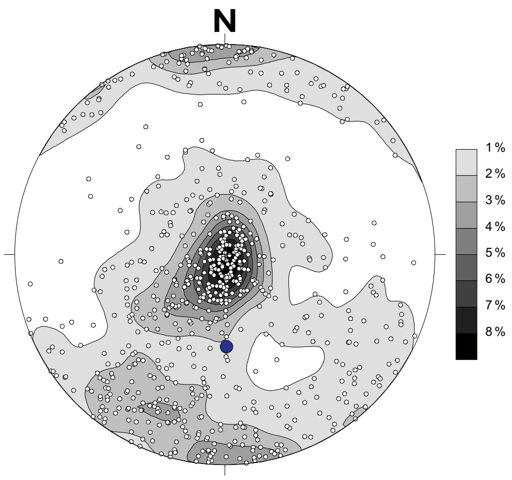

Figure 5-6. Stereographic projection showing contoured poles to open and partly open fracture planes (n=720) in KFR103, Schmidt net, lower hemisphere. Blue dot represents borehole projection.

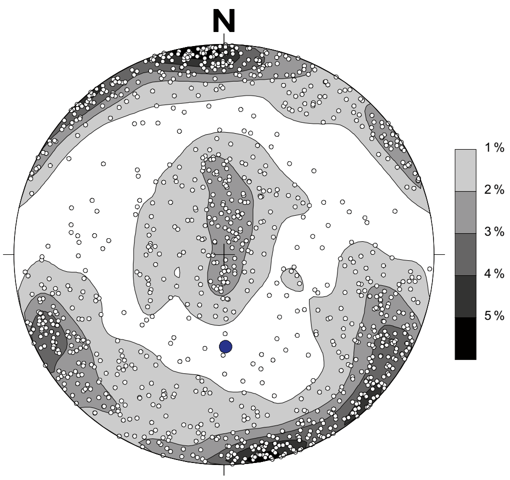

Figure 5-7. Stereographic projection showing contoured poles to sealed fracture planes (n=1,132) in KFR103, Schmidt net, lower hemisphere. Blue dot represents borehole projection.

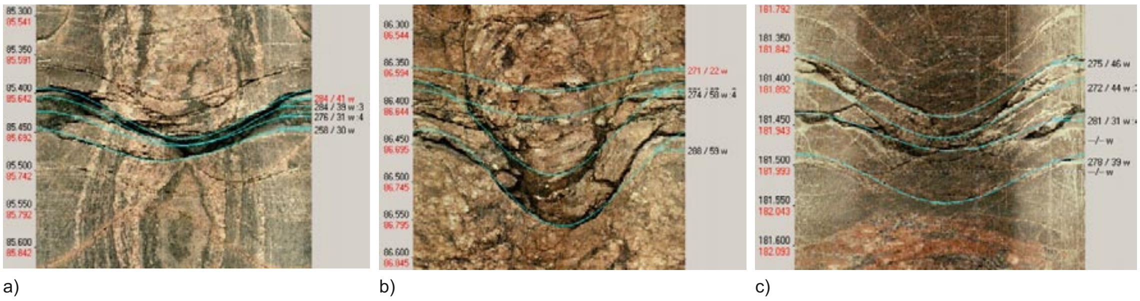

Figure 5-8. *Crushed intervals in KFR103. a) 85.42 m, b) 86.36 m and c) 181.40 m borehole length.*

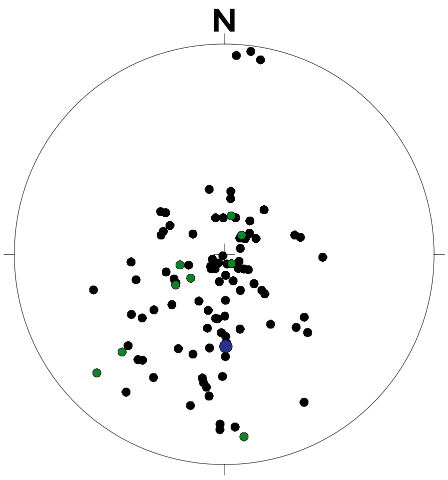

Figure 5-9. *Stereographic projection showing poles to open fracture planes with no detectable mineral in KFR103 (Schmidt net, lower hemisphere). ● = fresh (n=89), ● = slightly altered (n=9), ● = borehole projection.*

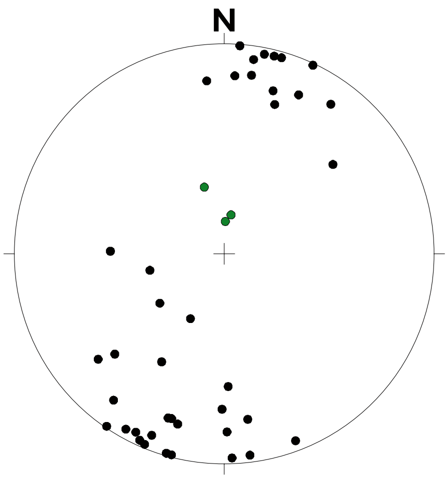

Figure 5-10. *Stereographic projection showing lineation (●, n=4) and poles to foliation planes (●, n=25) in KFR103.*

Figure 5-11. *Example of high strain in metagranite-granodiorite, KFR103, ca 63 m borehole length.*

References

/1/ **Gustafsson J, Gustafsson G, 2008.** Site Investigation SFR. BIPS-logging in the core drilled boreholes KFR102A, KFR102B, KFR103, KFR104 and KFR27 (140–500 m) and radar logging in KFR27 (0–500 m), KFR102A and KFR104. SKB P-09-11, Svensk Kärnbränslehantering AB.

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/3/ **Stephens M B, Lundqvist S, Bergman T, Andersson J, Ekström M, 2003.** Forsmark site investigation. Bedrock mapping – Rock types, their petrographic and geochemical characteristics, and a structural analysis of the bedrock based on Stage 1 (2002) surface data. SKB P-03-75, Svensk Kärnbränslehantering AB.

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/6/ **Döse C, Stråhle A, Mattsson K-J, Carlsten S, 2008.** Site Investigation SFR. Boremap mapping of core drilled borehole KFR101. SKB P report in progress, Svensk Kärnbränslehantering AB.

/7/ **Barton, N, 2002.** Some new Q-value correlations to assist in site characterization and tunnel design. International Journal of Rock Mechanics and Mining Sciences Vol 39 (2002), pp 185–216.

/8/ **Ehrenborg J, Steiskal V, 2004.** Oskarshamn Site Investigation. Boremap mapping of core drilled boreholes KSH01A and KSH01B. SKB P-04-01, Svensk Kärnbränslehantering AB.

/9/ **Mattson H, Keisu M, 2009.** Site Investigation SFR. Interpretation of geophysical borehole measurements from KFR102A, KFR102B, KFR103, KFR104 and KFR27 (0–500 m). SKB P-09-26, Svensk Kärnbränslehantering AB.

WellCad-diagrams of KFR102B and KFR103

Title	LEGEND FOR FORSMARK - SFR	KFR102B

Site	FORSMARK - SFR
Borehole	KFR102B
Plot Date	2009-10-06 23:01:52
Signed data	

ROCKTYPE FORSMARK - SFR

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granitoid, metamorphic
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Granodiorite, metamorphic
- Tonalite to granodiorite, metamorphic
- Diorite, quarts diorite and gabbro, metamorphic
- Ultramafic rock, metamorphic
- Amphibolite
- Calc-silicate rock (skarn)
- Magnetite mineralization associated with calc-silicate rock (skarn)
- Sulphide mineralization
- Felsic to intermediate volcanic rock, metamorphic
- Mafic volcanic rock, metamorphic
- Sedimentary rock, metamorphic
- Cataclastic rock

ROCK ALTERATION TYPE

- Oxidized
- Chloritisized
- Epidotisized
- Weathered
- Tectonized
- Sericitisized
- Quartz dissolution
- Silicification
- Argillization
- Albitization
- Carbonatization
- Saussuritization
- Steatitization
- Uralitization
- Laumontitization
- Fract zone alteration

MINERAL

- Epidote
- Hematite
- Calcite
- Chlorite
- Quartz
- Unknown
- Pyrite
- Clay Minerals
- Laumontite
- Asphalt
- Oxidized Walls

STRUCTURE

- Cataclastic
- Schistose
- Gneissic
- Mylonitic
- Ductile Shear Zone
- Brittle-Ductile Zone
- Veined
- Banded
- Massive
- Foliated
- Brecciated
- Lineated

TEXTURE

- Hornfelsed
- Porphyritic
- Ophitic
- Equigranular
- Augen-Bearing
- Unequigranular
- Metamorphic

GRAINSIZE

- Aphanitic
- Fine-grained
- Fine to medium grained
- Medium to coarse grained
- Coarse-grained
- Medium-grained

STRUCTURE ORIENTATION

- Cataclastic
- Brecciated
- Bedded
- Schistose
- Mylonitic
- Foliated
- Lineated
- Veined
- Ductile Shear Zone
- Banded
- Brittle-Ductile Shear Zone
- Gneissic

ROCK ALTERATION INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

CRUSH ALTERATION

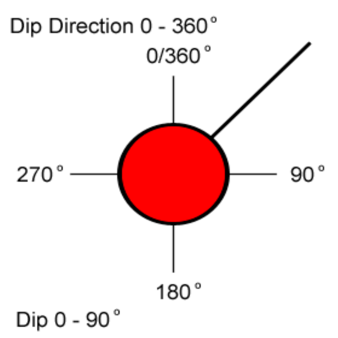
- Slightly Altered
- Moderately Altered
- Highly Altered
- Completley Altered
- Gouge
- Fresh

FRACTURE ALTERATION

- Highly Altered
- Completely Altered
- Gouge
- Fresh
- Slightly Altered
- Moderately Altered

FRACTURE DIRECTION

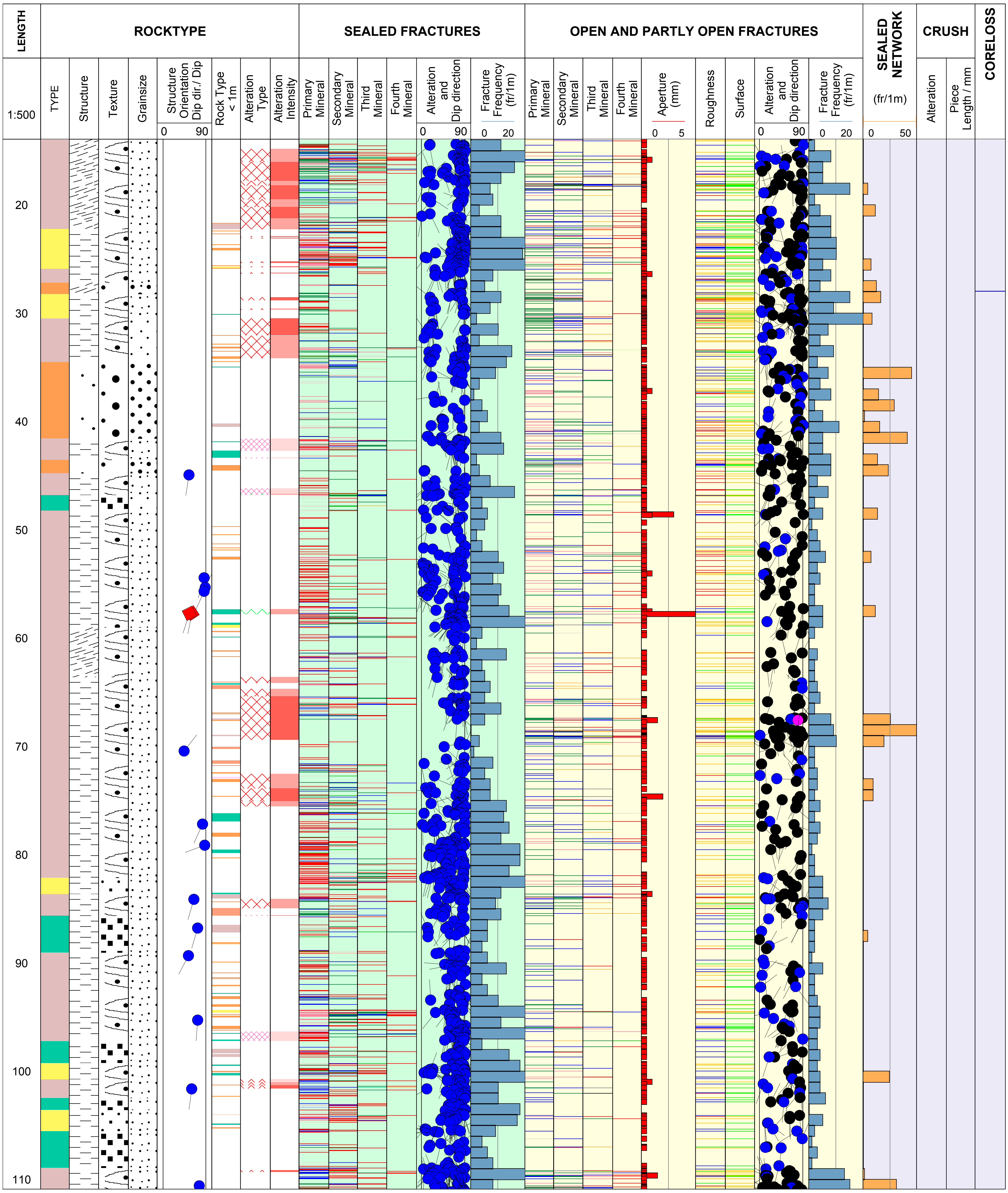
STRUKTURE ORIENTATION



Title GEOLOGY IN KFR102B

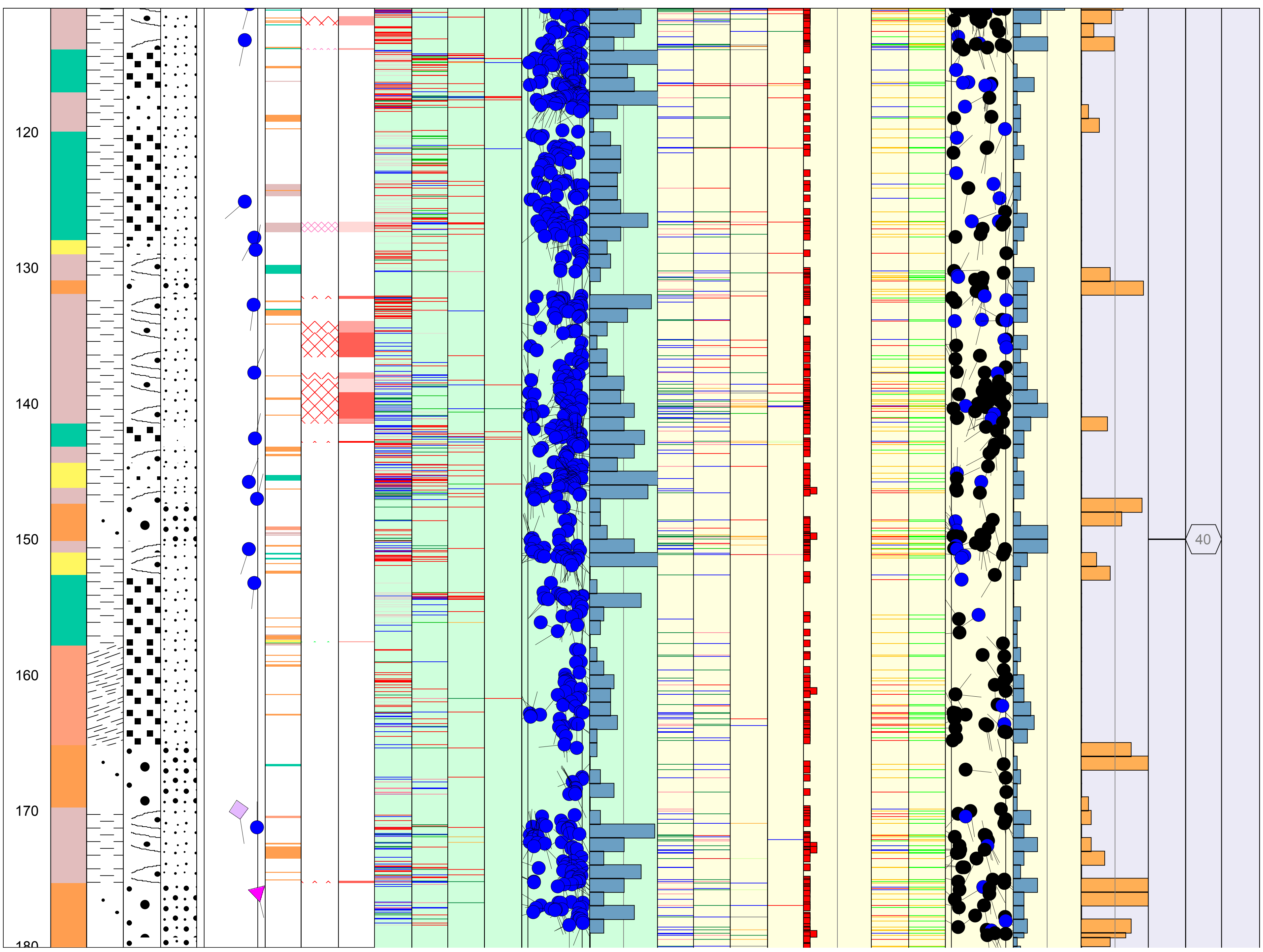
Appendix: 1

Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	KFR102B	**Northing [m]**	6701740.53
Diameter [mm]	76	**Easting [m]**	1633343.91
Length [m]	180.080	**Elevation [m.a.s.l.]**	2.51
Bearing [°]	344.89	**Drilling Start Date**	2008-08-06 07:55:00
Inclination [°]	-55.09	**Drilling Stop Date**	2008-08-13 20:43:00
Date of coremapping	2008-09-29 14:13:00	**Plot Date**	2009-10-24 23:01:44
Rocktype data from	p_rock	**Signed data**	



P-09-38

29



Title LEGEND FOR FORSMARK - SFR KFR103

Site FORSMARK - SFR
Borehole KFR103
Plot Date 2009-10-06 23:01:52
Signed data

ROCKTYPE FORSMARK - SFR

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granitoid, metamorphic
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Granodiorite, metamorphic
- Tonalite to granodiorite, metamorphic
- Diorite, quarts diorite and gabbro, metamorphic
- Ultramafic rock, metamorphic
- Amphibolite
- Calc-silicate rock (skarn)
- Magnetite mineralization associated with calc-silicate rock (skarn)
- Sulphide mineralization
- Felsic to intermediate volcanic rock, metamorphic
- Mafic volcanic rock, metamorphic
- Sedimentary rock, metamorphic
- Cataclastic rock

STRUCTURE

- Cataclastic
- Schistose
- Gneissic
- Mylonitic
- Ductile Shear Zone
- Brittle-Ductile Zone
- Veined
- Banded
- Massive
- Foliated
- Brecciated
- Lineated

TEXTURE

- Hornfelsed
- Porphyritic
- Ophitic
- Equigranular
- Augen-Bearing
- Unequigranular
- Metamorphic

GRAINSIZE

- Aphanitic
- Fine-grained
- Fine to medium grained
- Medium to coarse grained
- Coarse-grained
- Medium-grained

STRUCTURE ORIENTATION

- Cataclastic
- Brecciated
- Bedded
- Schistose
- Mylonitic
- Foliated
- Lineated
- Veined
- Ductile Shear Zone
- Banded
- Brittle-Ductile Shear Zone
- Gneissic

ROCK ALTERATION TYPE

- Oxidized
- Chloritisized
- Epidotisized
- Weathered
- Tectonized
- Sericitisized
- Quartz dissolution
- Silicification
- Argillization
- Albitization
- Carbonatization
- Saussuritization
- Steatitization
- Uralitization
- Laumontitization
- Fract zone alteration

ROCK ALTERATION INTENSITY

- No intensity
- Faint
- Weak
- Medium
- Strong

ROUGHNESS

- Planar
- Undulating
- Stepped
- Irregular

SURFACE

- Rough
- Smooth
- Slickensided

CRUSH ALTERATION

- Slightly Altered
- Moderately Altered
- Highly Altered
- Completley Altered
- Gouge
- Fresh

MINERAL

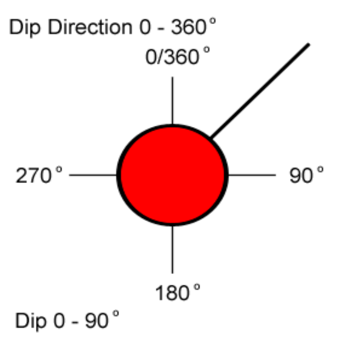
- Epidote
- Hematite
- Calcite
- Chlorite
- Quartz
- Pyrrhotite
- Muscovite
- Unknown
- Pyrite
- Clay Minerals
- Laumontite
- Prehnite
- Oxidized Walls

FRACTURE ALTERATION

- Highly Altered
- Completely Altered
- Gouge
- Fresh
- Slightly Altered
- Moderately Altered

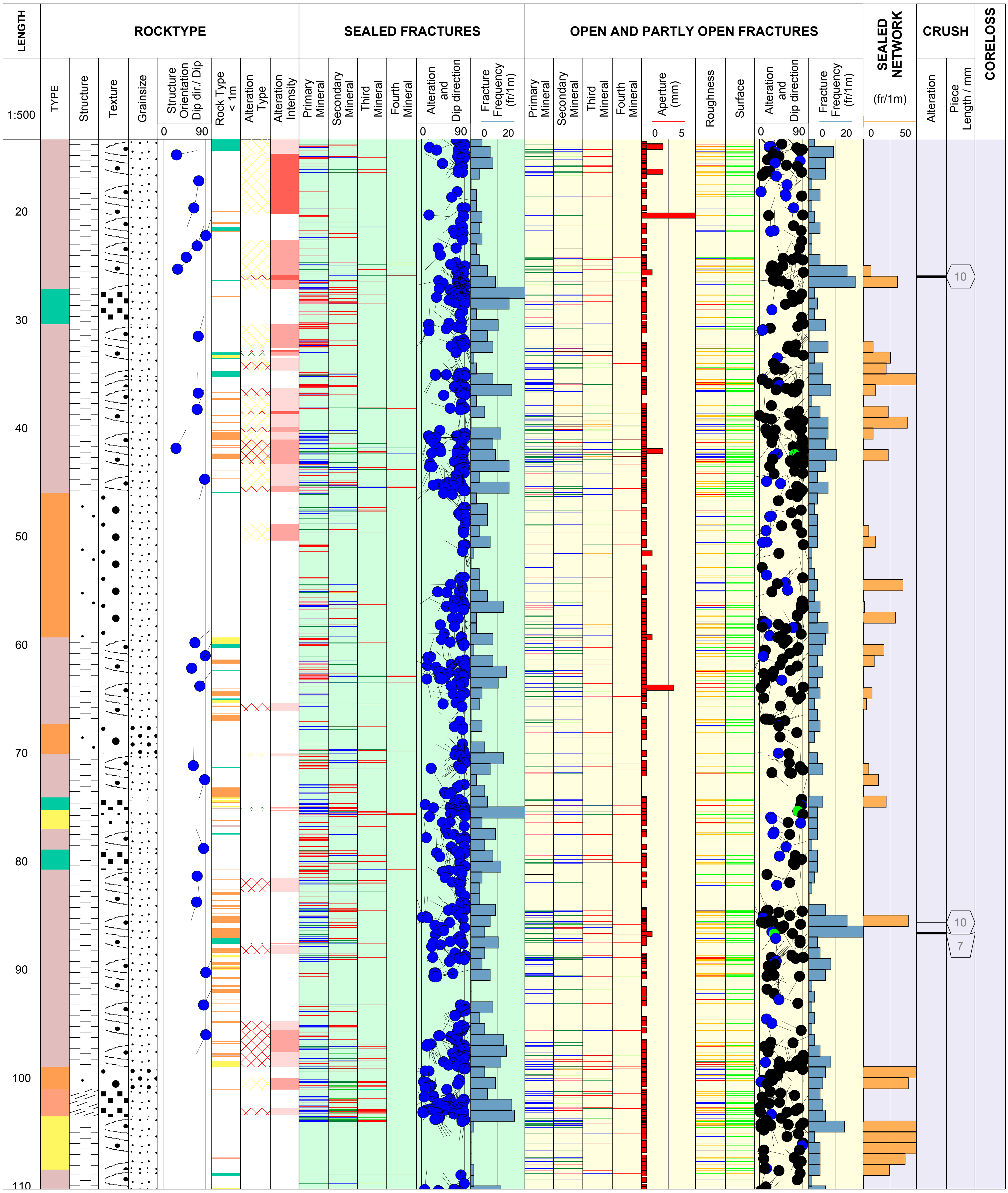
FRACTURE DIRECTION

STRUKTURE ORIENTATION

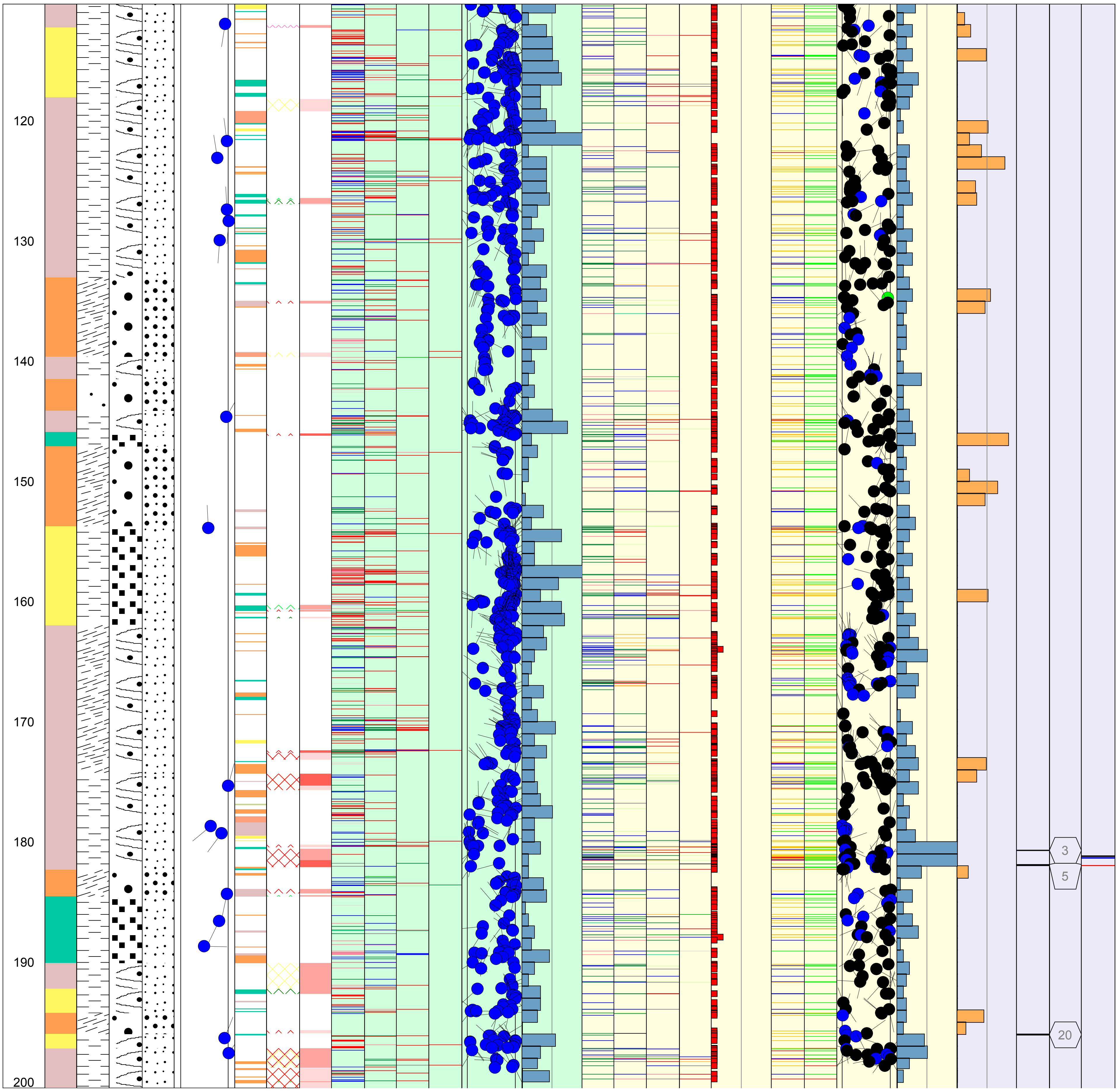


Title **GEOLOGY IN KFR103** **Appendix: 1**

Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	KFR103	**Northing [m]**	6701737.13
Diameter [mm]	76	**Easting [m]**	1633347.20
Length [m]	200.500	**Elevation [m.a.s.l.]**	2.43
Bearing [°]	179.90	**Drilling Start Date**	2008-08-15 14:53:00
Inclination [°]	-55.09	**Drilling Stop Date**	2008-08-26 11:16:00
Date of coremapping	2008-10-23 13:17:00	**Plot Date**	2009-10-24 23:01:44
Rocktype data from	p_rock	**Signed data**	



P-09-38



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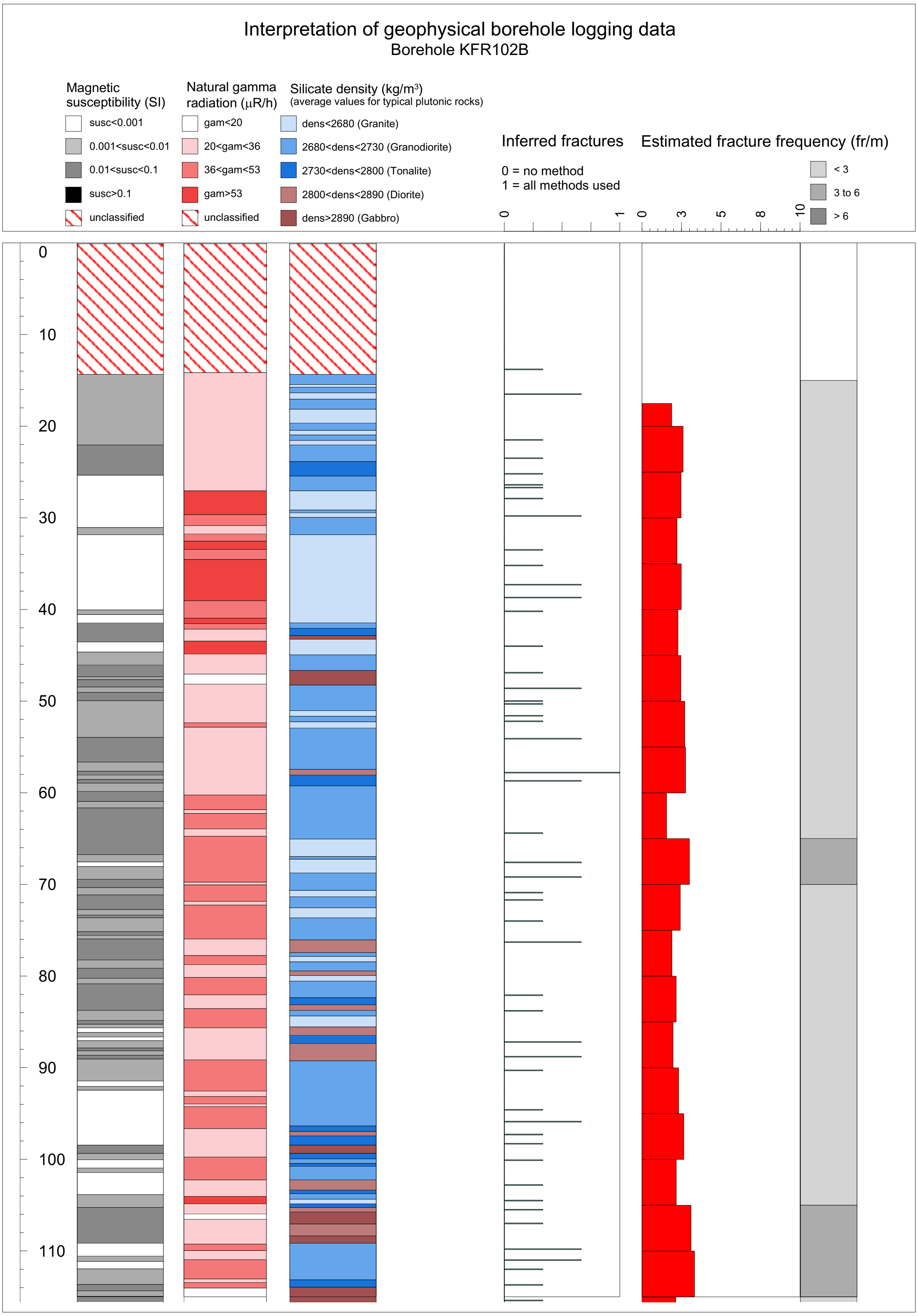
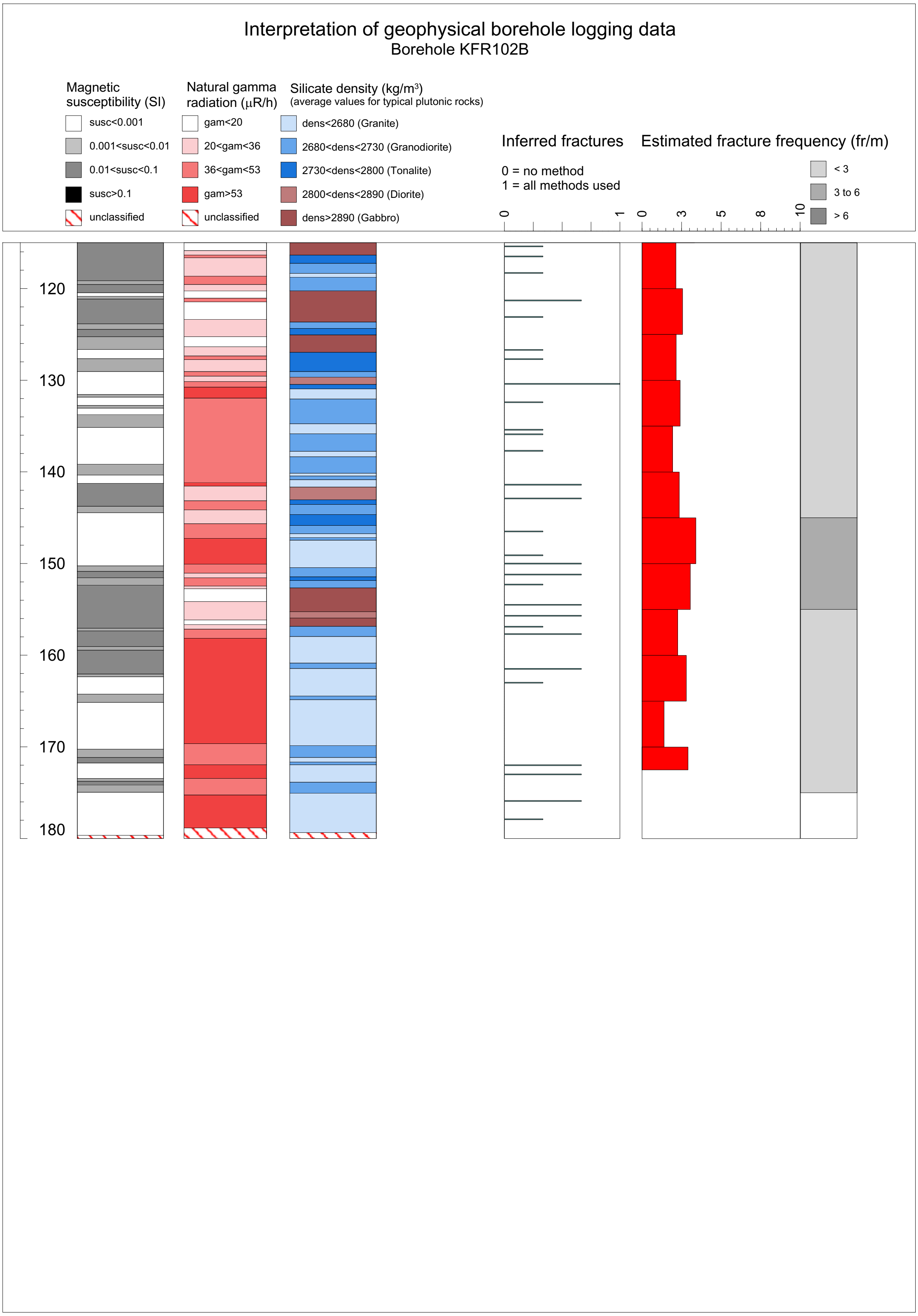
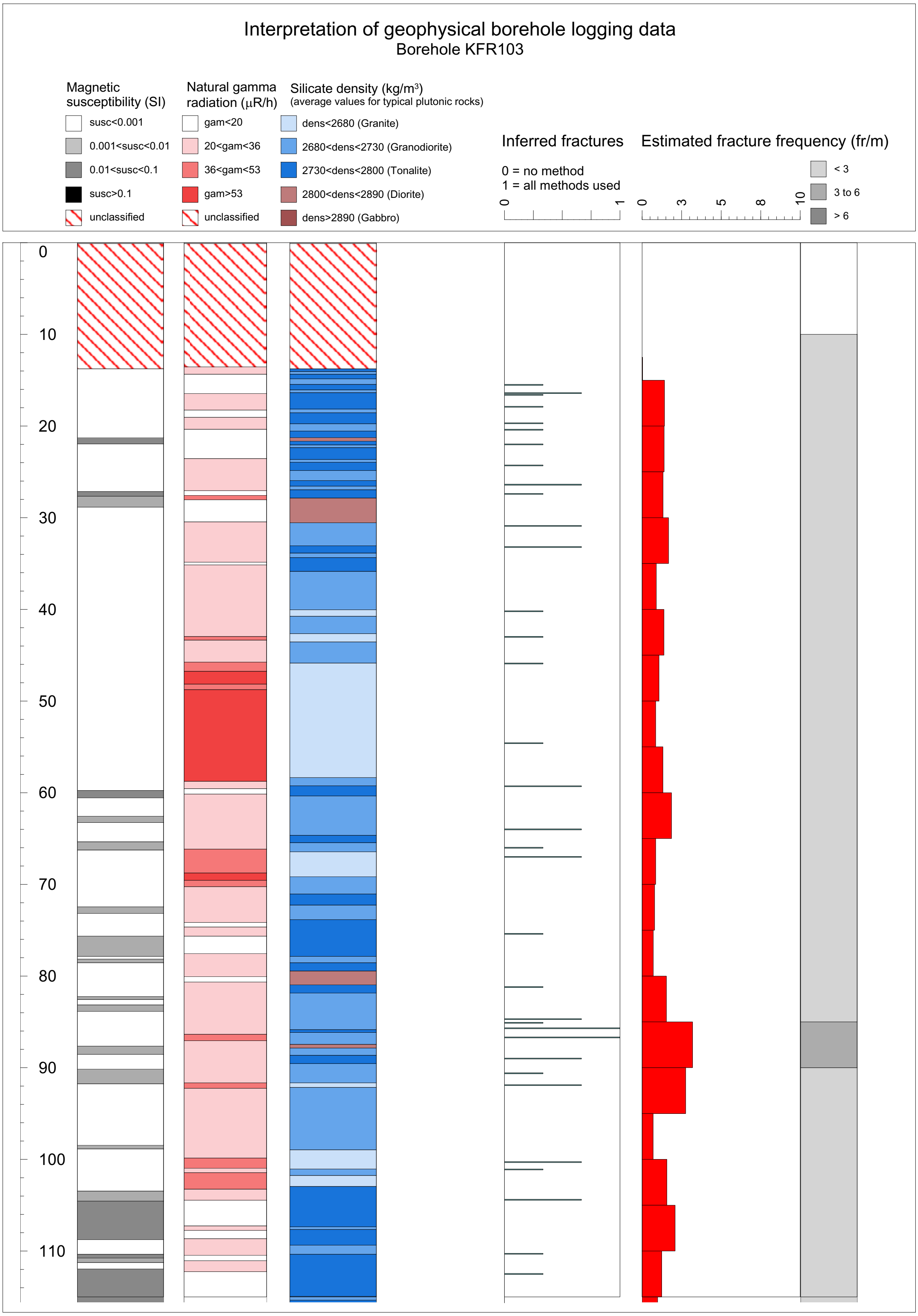
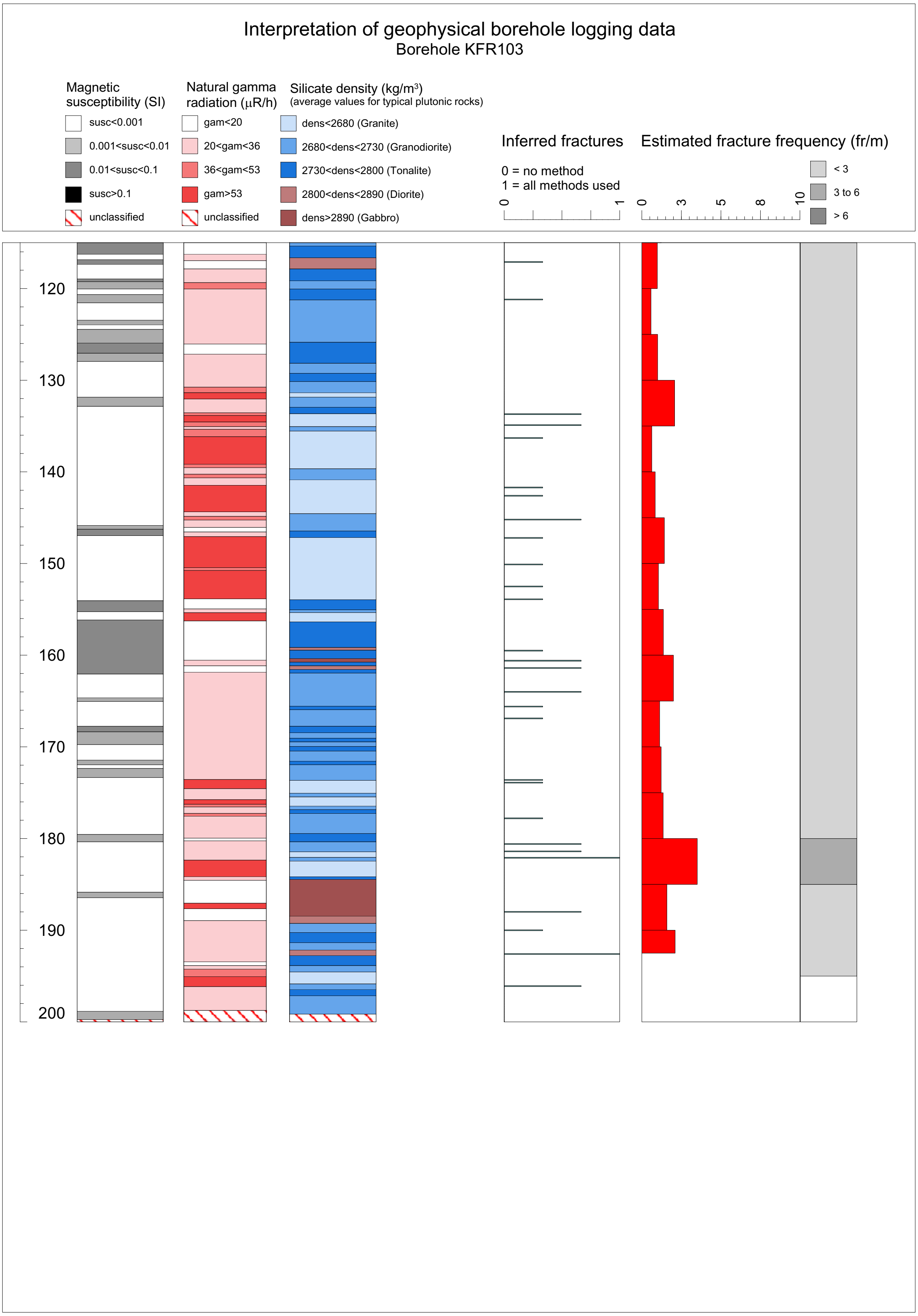
Generalized geophysical logs and plots of resampled and calibrated geophysical data from KFR102B and KFR103

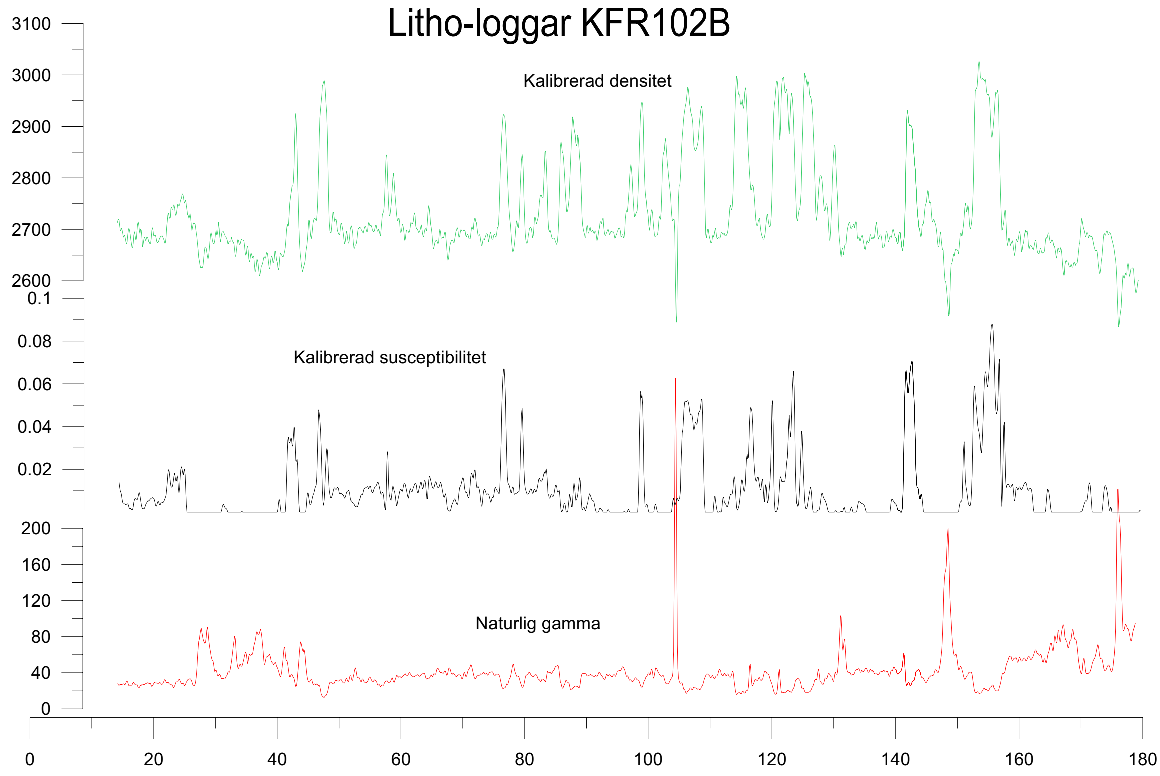


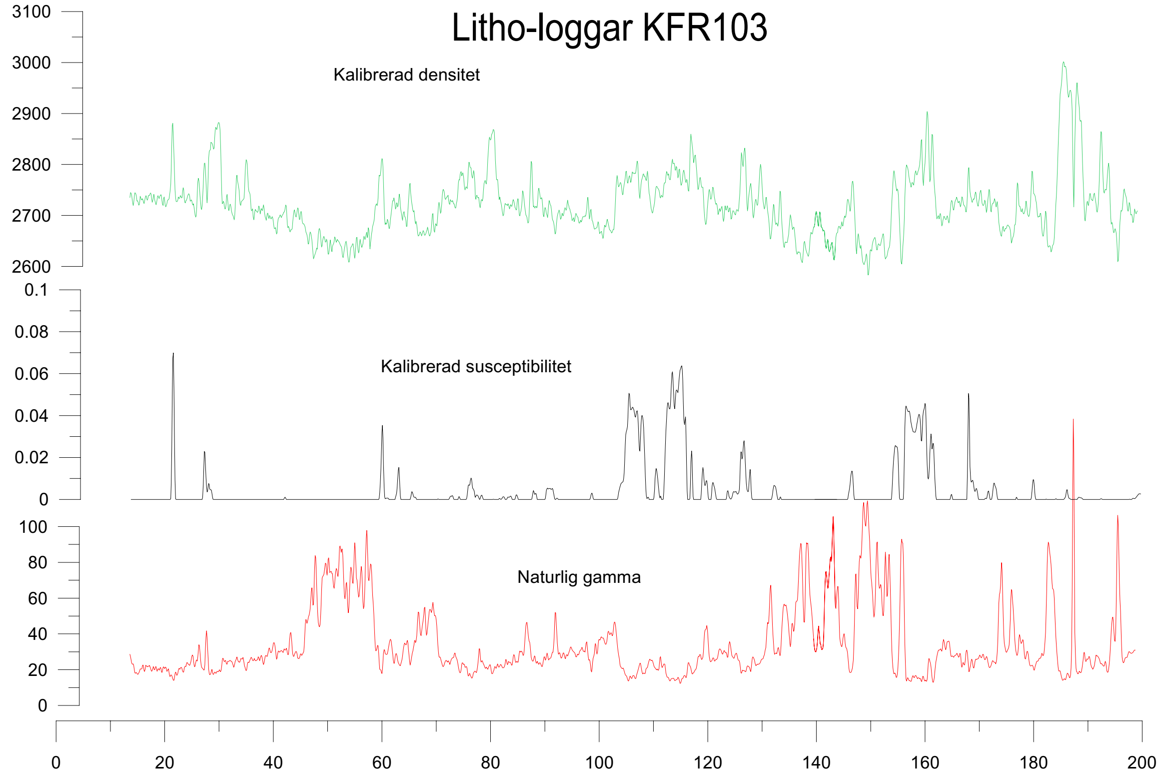


Interpretation of geophysical borehole logging data
Borehole KFR102B
Magnetic susceptibility (SI)
susc<0.001
0.001<susc<0.01
0.01<susc<0.1
susc>0.1
unclassified
Natural gamma radiation (μR/h)
gam<20
20<gam<36
36<gam<53
gam>53
unclassified
Silicate density (kg/m3)
(average values for typical plutonic rocks)
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Inferred fractures
0 = no method
1 = all methods used
Estimated fracture frequency (fr/m)
< 3
3 to 6
> 6
0
1
0
3
5
8
10
120
130
140
150
160
170
180


Interpretation of geophysical borehole logging data
Borehole KFR103
Magnetic susceptibility (SI)
susc<0.001
0.001<susc<0.01
0.01<susc<0.1
susc>0.1
unclassified
Natural gamma radiation (μR/h)
gam<20
20<gam<36
36<gam<53
gam>53
unclassified
Silicate density (kg/m³)
(average values for typical plutonic rocks)
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Inferred fractures
0 = no method
1 = all methods used
Estimated fracture frequency (fr/m)
< 3
3 to 6
> 6
0
10
20
30
40
50
60
70
80
90
100
110


Interpretation of geophysical borehole logging data
Borehole KFR103
Magnetic susceptibility (SI)
susc<0.001
0.001<susc<0.01
0.01<susc<0.1
susc>0.1
unclassified
Natural gamma radiation (μR/h)
gam<20
20<gam<36
36<gam<53
gam>53
unclassified
Silicate density (kg/m³)
(average values for typical plutonic rocks)
dens<2680 (Granite)
2680<dens<2730 (Granodiorite)
2730<dens<2800 (Tonalite)
2800<dens<2890 (Diorite)
dens>2890 (Gabbro)
Inferred fractures
0 = no method
1 = all methods used
0
1
Estimated fracture frequency (fr/m)
0
3
5
8
10
< 3
3 to 6
> 6
120
130
140
150
160
170
180
190
200


Litho-loggar KFR102B
Kalibrerad densitet
3100
3000
2900
2800
2700
2600
Kalibrerad susceptibilitet
0.1
0.08
0.06
0.04
0.02
Naturlig gamma
200
160
120
80
40
0
0
20
40
60
80
100
120
140
160
180


Litho-loggar KFR103
Kalibrerad densitet
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Kalibrerad susceptibilitet
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0.06
0.04
0.02
0
Naturlig gamma
100
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200

Appendix 3

In-data

Hole Diam T – Drilling: Borehole diameter

KFR102B, 2008-08-06 07:55:00 – 2008-08-13 20:43:00 (13.950–180.080 m).

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment	QC
13.950	180.080	0.0758	Corac N3/50	*

Printout from SICADA 2008-12-04 10:11:33.

Borehole Direction T – Surveying: Borehole direction

KFR102B, 2008-07-07 09:25:00.

Length (m)	Bearing (degrees)	Inclination (degrees)	Bearing Err (degrees)	Inclination Err (degrees)	Magnetic Bearing (degrees)	In Use Flag	Coord System	QC
0.00	344.8731	–54.1360	0.2000	0.2000		*	RT90-RHB70	*

Printout from SICADA 2008-12-04 10:18:16.

Borehole Surveying T – Surveying: Borehole coordinates

KFR102B, 2008-07-07 09:25:00.

Length (m)	Northing (m)	Easting (m)	Elevation (m.a.s.l.)	Northing Err (m)	Easting Err (m)	Elevation Err (m)	Coord System	Is Endpoint	Comment	QC
0.00	6701740.532	1633343.910	2.512	0.010	0.010	0.010	RT90-RHB70	N	Casing	*
3.00	6701742.228	1633343.451	0.081	0.010	0.010	0.010	RT90-RHB70	N		*

Printout from SICADA 2008-12-04 10:16:41.

Hole Diam T – Drilling: Borehole diameter

KFR103, 2008-08-15 14:53:00 – 2008-08-26 11:16:00 (13.330–200.500 m).

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment	QC
13.330	200.500	0.0758	Corac N3/50	*

Printout from SICADA 2008-12-04 10:14:00.

Borehole Direction T – Surveying: Borehole direction

KFR103, 2008-06-10 15:00:00.

Length (m)	Bearing (degrees)	Inclination (degrees)	Bearing Err (degrees)	Inclination Err (degrees)	Magnetic Bearing (degrees)	In Use Flag	Coord System	QC
0.00	179.8902	–53.9060	0.2000	0.2000		*	RT90-RHB70	*

Printout from SICADA 2008-12-04 10:20:48.

Borehole Surveying T – Surveying: Borehole coordinates

KFR103, 2008-06-10 15:00:00.

Length (m)	Northing (m)	Easting (m)	Elevation (m.a.s.l.)	Northing Err (m)	Easting Err (m)	Elevation Err (m)	Coord System	Is Endpoint	Comment	QC
0.00	6701737.131	1633347.204	2.429	0.010	0.010	0.010	RT90-RHB70	N	casing	*
3.00	6701735.363	1633347.208	0.004	0.010	0.010	0.010	RT90-RHB70	N		*

Printout from SICADA 2008-12-04 10:22:17.

Reference Mark T – Reference mark in drillhole

KFR103, 2008-08-26 15:30:00 – 2008-08-26 19:00:00 (50.000–190.000 m).

Bhlen (m)	Rotation Speed (rpm)	Start Flow (l/h)	Stop Flow (l/h)	Stop Pressure (bar)	Cutter Time (s)	Trace Detectable	Cutter Diameter (mm)	Comment	QC
50.00	400.00	180.000	350.000	40.0	40.00	JA	84.7	Klar signal OK	*
101.00	400.00	180.000	350.000	35.0	35.00	JA	84.7	Klar signal OK	*
150.00	400.00	180.000	350.000	40.0	40.00	JA	84.7	Klar signal OK	*
190.00	400.00	180.000	380.000	45.0	45.00	JA	84.7	Klar signal OK	*

Printout from SICADA 2008-10-23 13:24:29.