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Site investigation SFR

Boremap mapping of core drilled borehole KFR101

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June 2009

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Abstract

This report presents the result from the Boremap mapping of the core drilled borehole KFR101, which is situated by the pier outside Forsmark nuclear power plant adjacent to the existing repository for low- and intermediate-level waste (SFR). KFR101 was drilled during summer 2008 with the aim to gather information about the geological and hydrogeological properties of the bedrock, as well as to investigate the deterministically modelled deformation zone ZFMNW0805 (zone 8), which is expected to be intersected by KFR101. It was also expected to gather information about the character of two low magnetic lineaments that are possible deformation zones, namely MFM0805G1 and MFM3111G.

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

The first half of the borehole (13–163 m borehole length) is dominated by metagranite-granodiorite, which is fine- to medium-grained and usually moderately to strongly foliated. The borehole interval 163–303 m is dominated by pegmatite to pegmatitic granite and fine- to medium-grained granite. The pegmatites and granites are mostly lineated or massive and the natural gamma radiation usually exceeds 36 μR/h. The end of the borehole, 303–342 m, is dominated by a foliated, fine- to medium-grained aplitic metagranite. The metagranite-granodiorite, which predominates the upper half of the borehole, is also present in the lowermost part of the borehole.

Subordinate rock types are amphibolite, felsic to intermediate metavolcanic rock, fine- to medium-grained metagranitoid, and quartz-dominated hydrothermal vein. Amphibolite occurs preferably within the metagranite-granodiorite.

The borehole exhibits the following fracture frequencies: 8.4 sealed fractures/m (sealed fractures in sealed fracture networks excluded), 4.1 open fractures/m (crush excluded) and 0.7 partly open fractures/m. Two dominating sets of open and partly open fractures are observed, which are oriented 170°/05° and 110°/80°. The dominating orientations of sealed fractures are 160°/90°, 100°/75° and 110°/30°.

Seven thin crushed intervals have been documented in KFR101 of which the one at 108.27–108.32 m (oriented roughly 331°/74°) is most conspicuous. The crush is situated within a polymict fault breccia, which in turn is surrounded by a brittle-ductile shear zone.

Sections rich in sealed fractures are mapped as sealed fracture networks. 144 sealed fracture networks have been mapped in KFR101. Sealed fractures are very frequent in the lower part of the borehole.

Sammanfattning

Denna rapport redovisar resultaten från Boremapkartering av kärnborrhål KFR101, som är beläget på piren utanför Forsmark kärnkraftverk och intill det befintliga förvaret för låg- och medelradioaktivt avfall (SFR). KFR101 borrades under sommaren 2008 med syftet att samla in värdefull information om de geologiska och hydrogeologiska förhållandena i berggrunden, samt att undersöka den deterministiskt modellerade deformationszonen ZFMNW0805 (zon 8). Förutom ZFMNW0805 passerar KFR101 två lågmagnetiska lineament (MFM0805G1 och MFM3111G), vilka kan vara deformationszoner.

Den geologiska karteringen av borrhålet påbörjades i augusti 2008 och avslutades i oktober 2008. Karteringen är baserad på simultan undersökning av borrkärna och tillhörande borrhålsbild (BIPS), tillsammans med generaliserade och detaljerade geofysiska loggar.

Den första halvan av borrhålet (13–163 m borrhålslängd) domineras av metagranit-granodiorit, som är fin- till medelkornig och vanligen moderat till starkt folierad. Borrhålsintervallet 163–303 m domineras av pegmatit till pegmatitisk granit och fin- till fint medelkornig granit. Dessa pegmatiter och graniter är mestadels stängliga eller massiva och den naturliga gammastrålningen överstiger vanligen 36 µR/h. Slutet av borrhålet, 303–342 m, domineras av en folierad, fin- till medelkornig aplitisk metagranit. Metagranit-granodioriten som dominerar övre halvan av borrhålet förekommer också i den nedersta delen av borrhålet.

Underordnade bergarter är amfibolit, felsisk till intermediär metavulkanit, fin- till medelkornig metagranitoid och kvartsdominerad hydrotermal gångbergart. Amfibolit förekommer företrädesvis inom metagranit-granodioriten.

Borrhålet uppvisar följande sprickfrekvenser: 8,4 läkta sprickor/m (läkta sprickor i läkta spricknätverk exkluderade), 4,1 öppna sprickor/m (krossar exkluderade) och 0,7 delvis öppna sprickor/m. Två dominerande set av öppna och delvis öppna sprickor kan definieras. Dessa är orienterade 170°/05° och 110°/80°. De dominerade orienteringarna hos läkta sprickor är 160°/90°, 100°/75° och 110°/30°.

Sju tunna krossade sektioner har dokumenterats i KFR101 av vilka den på 108,27–108,32 m (orienterad ~331°/74°) är mest påtaglig. Det krossade intervallet är beläget i en polymikt förkastningsbreccia, vilken i sin tur är omgiven av en spröd till plastisk deformationszon.

Sektioner rika på läkta sprickor karteras som läkta spricknätverk. 144 läkta spricknätverk har karterats i borrhålet. Speciellt den nedre delen av borrhålet är mycket rik på läkta sprickor.

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 are needed. This document reports the data gained by the Boremap mapping of the core drilled borehole, KFR101, which is one of the activities performed within the project SFR Extension.

KFR101 is drilled in the easternmost part of the pier at Asphällskulten (Figure 1-1). The borehole has a length of 341.76 m, a bearing of 029° and an inclination of –55.5°. The borehole intersects three lineaments with low magnetic intensity: MFM0805G0 (ZFMNW0805/zone 8), MFM0805G1 and MFM3111G. The first mentioned is a deterministically modelled zone, while the nature and existence of the others are not well known.

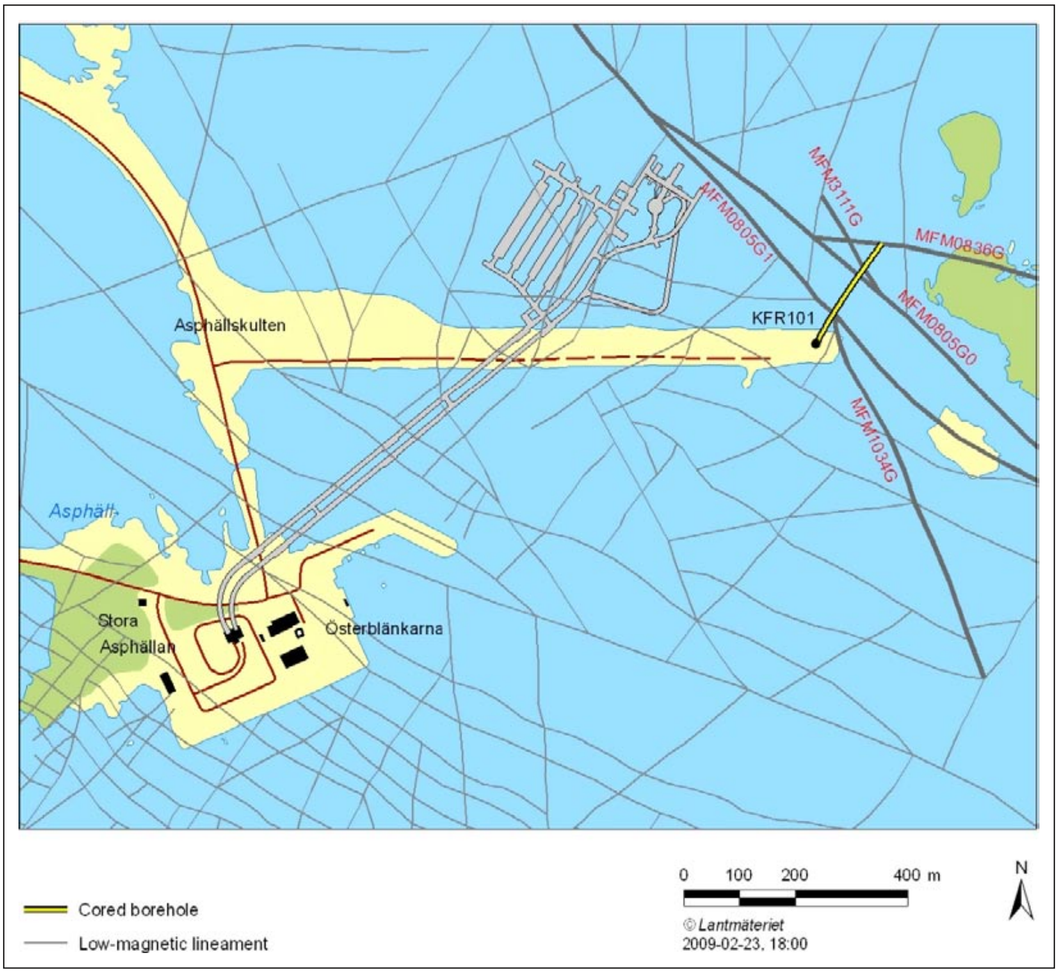

Figure 1-1. *Location of core drilled borehole KFR101 in relation to SFR . Lineaments with low magnetic intensity, expected to be intersected by the borehole, are highlighted.*

The core drilled borehole was, after completion of drilling, 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 (Borehole Image Processing System).

The work was carried out in accordance with activity plan AP SFR-08-006. 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 borehole was mapped during the period August 2008 – October 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 08-006). 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.

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

Activity plan	**Number**	**Version**
Boremapkartering av hammarborrhål HFR101–102, HFR105, kärnborrhål KFR101 samt borrhål KFR27.	AP SFR-08-006	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

2 Objective and scope

The aim of this activity was to document lithologies, alterations, ductile structures and the occurrence and character of fractures in the bedrock penetrated by the core drilled boreholes KFR101. The deterministically modelled deformation zone ZFMNW0805/zone 8 is expected to be intersected by KFR101. KFR101 is also expected to give information on two low magnetic lineaments that are possible deformation zones, namely MFM0805G1 and MFM3111G.

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/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 BIPS-image quality

The used BIPS-image 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 quality of the borehole is generally acceptable. There are some places with suspensions in the borehole fluid and the lower side of the borehole wall is generally overexposed. In the lower part of the borehole drill cuttings have precipitated on the lower side of the borehole wall. In some sections there is also a brownish coating on the upper side of the borehole wall, originating from the drill rod. The shortcomings of the BIPS-image quality have not aggravated the mapping considerably. The results from the BIPS-loggings are presented in a P-report /1/.

Table 3-1. Used BIPS-image.

Borehole	BIPS-image	Logging date	Logging time	From (m)	To (m)
KFR101	KFR101_13_335m_20080710.BIP	2008-07-10	09:08	13.000	335.581

4 Execution

4.1 General

Boremap mapping of the core drilled borehole KFR101 was performed and documented according to activity plan AP SFR-08-006 (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, 7 and 8/.

The mapping was performed by Christin Döse, Allan Stråhle, Karl-Johan Mattsson and Seje Carlsten (Geosigma AB).

4.2 Preparations

Background data collected from Sicada prior to the Boremap mapping are presented in Appendix 3 and included:

- borehole diameter,
- reference marks in the borehole wall,
- total borehole length,
- borehole deviation data.

All background data collected from Sicada, except for borehole diameter, are imported by an automatic routine into Boremap.

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)/9/.

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

Table 4-1. Borehole data for KFR101.

ID-code	Northing	Easting	Bearing (degrees)	Inclination (degrees)	Diameter (mm)	Borehole length (m)	Mapping interval (m)	End of casing
KFR101	6701736.32	1633351.40	28.79	–55.50	76	341.760	13.72–341.76	13.72

Table 4-2. Applied length adjustments for BIPS-images.

Recorded borehole length (m)	Adjusted borehole length (m)	Length adjustment (m)	Mapping Type
50.844	51	0.156	
99.776	100	0.224	Mapping
149.645	150	0.355	with
199.518	200	0.482	BIPS
271.204	272	0.796	
335.200	336.306	1.106	
340.810	341.760	0.950	No BIPS

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 (SKB internal controlling document).

Broken and unbroken fractures

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, it is mapped as 0.5 mm wide and the confidence is considered "certain". If no aperture is visible, 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".

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.

Fracture alteration and joint alteration number

Joint alteration number is mainly related to the thickness of, and the clay content in a fracture /10/. 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 borehole.

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 /11/. 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 borehole length relative to a well defined structure visible in both drill core and BIPS-image.

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

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 KFR101:

- X1 = Bleached fracture walls.
- X2 = Interpreted grouting, which is only observed in the borehole wall and hence in the BIPS-image (not used in this borehole).
- 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.
- X7 = Light green, very hard semitransparent, fine-grained to aphanitic mineral with disseminated calcite observed at 136.165 m in KFR101. Possibly feldspar.
- X8 = Epidotized walls.

4.3.2 Lithologies and correlation with geophysical data

The determination of rock types can be difficult due to the relatively high strain in the area resulting in a very similar appearance of felsic rocks in the SFR-area.

Detailed plots of resampled and calibrated geophysical logging data from the boreholes were helpful in interpreting the rock type when there were difficulties in determining the rock type only by inspection of the drill core. In a few cases, rock type was determined only on the basis of geophysics (upper contact for metavolcanic rock at 63.87 m and aplitic metagranite at 307.15–329.91 m).

4.3.3 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 mapping of KFR101 was performed on SKB's computer 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 the author and 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.

4.5 Nonconformities

4.5.1 Core loss

Five core losses have been documented. All are less than 2 cm wide and most are missing core pieces between two individual fractures.

4.5.2 Over- and underrepresented fracture minerals

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

Hematite is 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).

Oxidized walls are usually clearly observable in borehole intervals where the host rock is not or only slightly oxidized, but in borehole intervals where oxidation is moderate or strong, the alteration cannot be connected to single fractures. In these intervals "oxidized walls" is underestimated.

4.5.3 Borehole length

The borehole length below 272 m is not perfectly adjusted and length information in the interval 280–340 m may vary with up to 10 cm from the real borehole length. The reason for this is that the last reference slot is at 272 m, i.e. almost 70 m from the end of the borehole. The inadequate length adjustment is conspicuous when performing the length adjustments for the last part of the borehole, for which no BIPS-image is available (Table 4-2).

4.5.4 Partly broken and partly unbroken fractures

In the mapping of KFR101 the terminology partly broken and partly unbroken fractures (in "Calibration of Boremap mapping", v.0.9, a suggested complement to SKB MD 143.006) have not been used. As long as a part of a fracture is unbroken in the drill core, the fracture is mapped as unbroken, independent of whether it is broken in the borehole axis or not. However, the broken part of the fracture may have been given an aperture.

5 Results

The Boremap mapping of KFR101 is stored in Sicada, and it is only these data that shall be used for further interpretation and modelling. The user of this data should be aware of the assumptions mentioned in Section 4. The 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 Table 5-1 and Table 5-2, respectively.

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 General lithology

The first half of KFR101 (13–163 m borehole length) is dominated by a pinkish grey to greyish red fine- to medium-grained metagranite-granodiorite (101057), which is usually moderately to strongly foliated. The foliation intensity varies with the folding as does the appearance of a linear fabric. In the stereographic projection of the poles to the foliation planes (Figure 5-2a) there is an intimation of a girdle (axis of 115/20) with two clusters along this girdle.

The borehole interval 163–303 m is dominated by a light red to light greyish red pegmatite to pegmatitic granite (101061). The pegmatites are mostly lineated or massive and the natural gamma radiation usually exceeds 36 μR/h. The pegmatites are usually associated with the third most common rock type: a fine- to medium-grained granite (111058). The usually red, fine- to medium-grained granite also displays a linear fabric and an anomalous natural gamma radiation.

The end of the borehole, 303–342 m, is dominated by a foliated, dark red, fine- to medium-grained aplitic metagranite (101058). Metagranite-granodiorite (101057) is also present.

Subordinate rock types are amphibolite (102017), felsic to intermediate metavolcanic rock (103076, Figure 5-1), fine- to medium-grained metagranitoid (101051), and quartz-dominated hydrothermal vein (8021). Amphibolite occurs preferably within the metagranite-granodiorite.

The interval 321.7–322.4 m is mapped as “hybrid rock”. The rock seems to be a mostly strongly foliated amphibolite with a large component of granitic material. Sporadic epidotization is also present.

5.2 Alterations

The by far most frequently occurring alteration type is oxidation (Appendix 1). Oxidized intervals occur throughout the borehole, but they are rather sparse in the interval 125–244 m borehole length. Muscovite-alteration (mapped as sericitization) is also rather common and can be observed in the intervals 23.74–25.01 m and 293.16–310.10 (not continuously). Laumontization occurs in the interval 293.15–310.10 m, but it is not observed outside this interval.

Table 5-1. Rock type distribution in KFR101 (rock occurrences excluded).

Rock type	%
Metagranite-granodiorite (101057)	50.7
Pegmatite to pegmatitic granite (101061)	24.1
Fine- to medium-grained granite (111058)	9.6
Aplitic metagranite (101058)	7.0
Amphibolite (102017)	5.2
Felsic to intermediate metavolcanic rock (103076)	2.7
Fine- to medium-grained metagranitoid (101051)	0.8

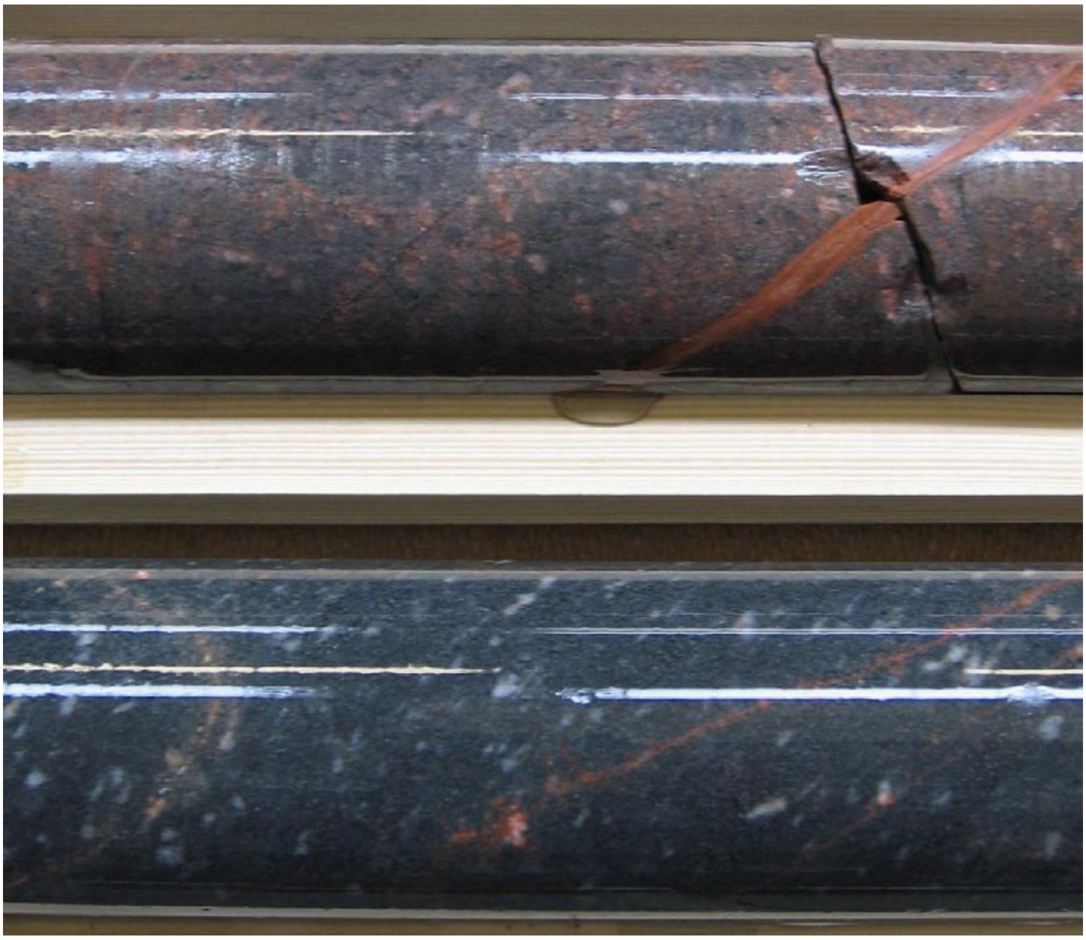

Figure 5-1. Similar appearance of metagranite-granodiorite (above, ~63.3 m) and felsic to intermediate meta-volcanic rock (below, ~64.5m) in KFR101. Exact position of rock contact is determined from geophysical data.

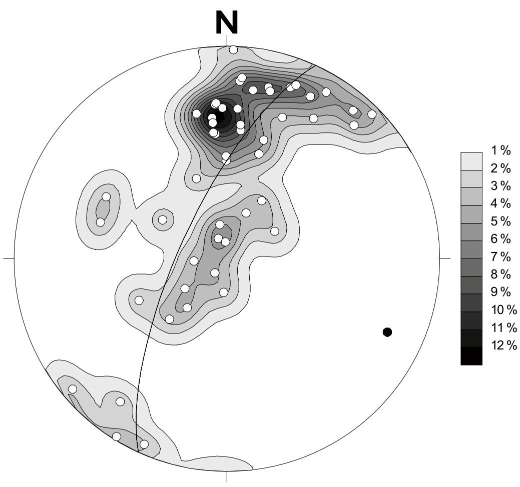

Figure 5-2a. *Equal area projection showing contoured poles to foliation planes (n=51) on lower hemisphere. Girdle and pole to girdle (black dot) are also plotted.*

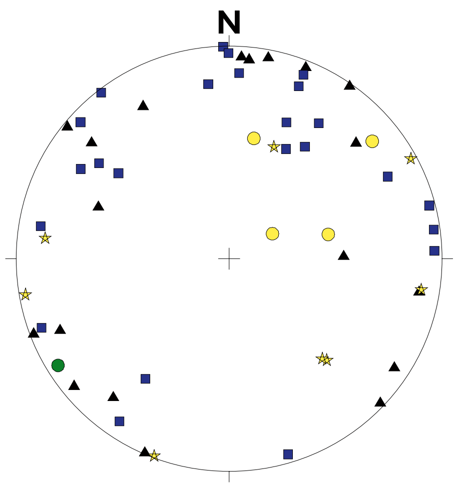

Figure 5-2b. *Equal area projection showing poles to thin deformation planes on lower hemisphere. ▲= breccia (n=19),■ = brittle-ductile shear zone (n=24), ● = ductile shear zone (n=4), ☆ = cataclasite (n=8), ● = mylonite (n=1)*

Argillization occurs in intervals rich in clay filled open and sealed fractures. The following intervals are argillizated: 38.00–38.03, 252.89–253.09, 261.93–262.16, 299.83–299.87 and 300.76–301.25 m.

Other types of alterations are rare and are of low intensity (faint to weak). Chloritization and/or epidotization are observed in some amphibolites. Albitization of the wall rock next to amphibolites is locally present. Silicification is observed in one single interval at 33.15–33.50 m, as quartz-dissolution at 252.88–252.99 m. Sporadic saussuritization has also been observed.

5.3 Fractures and crush

A total amount of 2,826 unbroken and 1,414 broken fractures were documented in KFR101. Of the unbroken fractures 210 show aperture, while 94 of the broken fractures are considered artificial and have apertures = 0. This result in the following interpreted fracture frequencies: 8.4 sealed fractures/m (sealed fractures in sealed fracture networks are excluded), 4.1 open fractures/m (crush is excluded) and 0.7 partly open fractures/m.

Two dominating sets of open and partly open fractures are observed with the orientations 170°/05° and 110°/80° (Figure 5-3a). The sub-horizontal set is also visible among the sealed fractures, but it is not as pronounced as for open fractures. The dominating orientations of sealed fractures are 160°/90°, 100°/75° and 110°/30° (Figure 5-3b). The fracture set 110°/30° is overrepresented in the borehole relative to the other fracture sets since it is perpendicular to the borehole.

The most frequently occurring minerals in the open fractures are in decreasing order: calcite, chlorite, clay minerals (Figure 5-4 and 5-5), hematite, laumontite, pyrite, adularia, muscovite, quartz and epidote. There are as many as 63 open fractures with no detectable mineral. Almost 15% of the open fractures have oxidized walls.

The most frequently occurring minerals in sealed fractures are calcite, laumontite, quartz, chlorite, adularia and epidote. As many as 53% of the sealed fractures have oxidized walls.

Table 5-2. Fracture frequencies in KFR101 (crush and sealed fracture networks excluded).

Open fractures/m	Partly open fractures/m	Sealed fractures/m
4.1	0.7	8.4

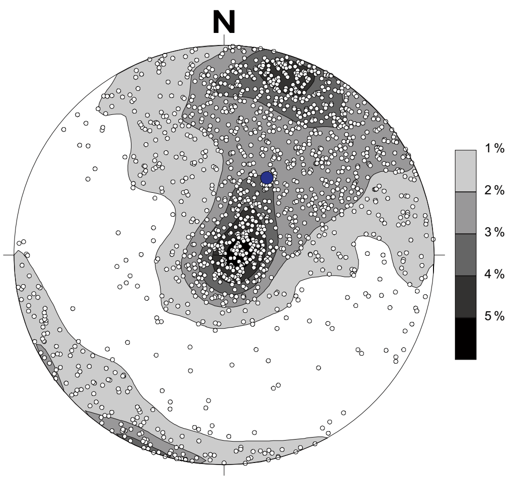

Figure 5-3a. *Stereographic projection (equal area, lower hemisphere) showing open and partly open fractures (n=1521) in KFR101. Blue dot represents borehole projection.*

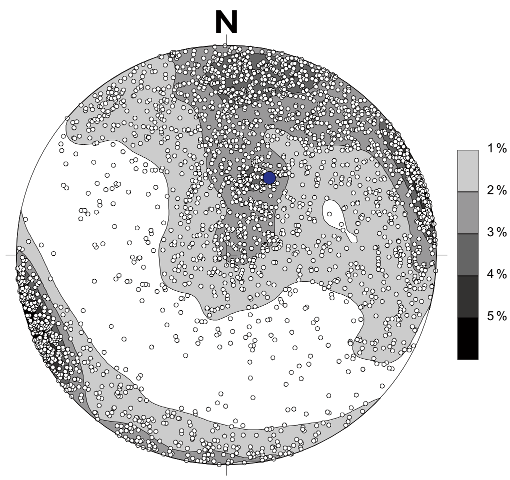

Figure 5-3b. *Stereographic projection (equal area, lower hemisphere) showing sealed fractures (n=2718) in KFR101. Blue dot represents borehole projection.*

Figure 5-4. *Clay-filled open fracture at 103.03 m borehole length in KFR101.*

Figure 5-5. *Clay-hematite-calcite filled open fracture at 109.97 m borehole length in KFR101.*

Seven thin crushed intervals have been documented in KFR101:

- 108.27–108.32 m, striking roughly 331°/74°
- 180.95–181.01 m, oriented 124°/18°
- 261.58–261.60 m, oriented 099°/64°
- 294.18–294.26 m, oriented 135°/65°
- 295.14–295.23 m, oriented 311°/88°
- 300.02–300.5 m, oriented roughly 126°/29°
- 338.67–338.71 m, unknown orientation (no BIPS-image).

Sections rich in sealed fractures are mapped as sealed fracture networks. 144 sealed fracture networks have been mapped.

5.3.1 Fractures with no detectable minerals

Sixtieeight open fractures with no detectable mineral have been mapped. Many of these fractures have a very fresh and artificial appearance in the drill core, while other fractures have a dull appearance. The orientations of these fractures are mainly horizontal to sub-horizontal (Figure 5-6a) and most of them occur in the upper 160 m borehole length, but they are also present elsewhere (Figure 5-6b).

These fractures may be, for example, either drill induced or a result from the current stress release in the uppermost crust after the last glaciation.

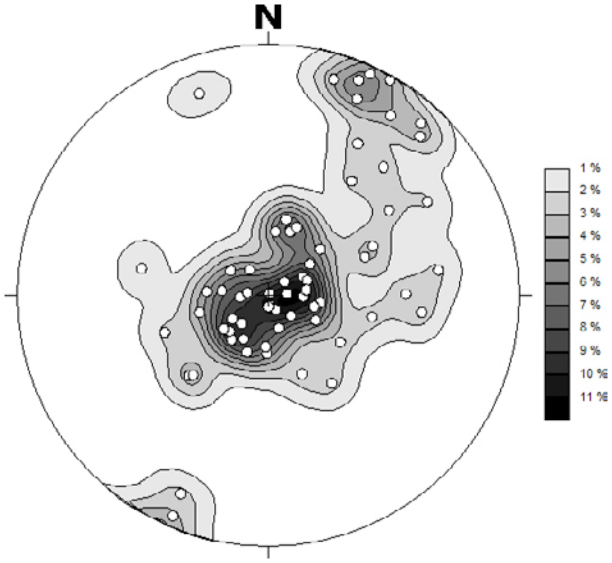

Figure 5-6a. *Stereographic projection showing the orientation of open fractures mapped with no detectable mineral (n=68). Contoured poles to planes on lower hemisphere, Schmidt net.*

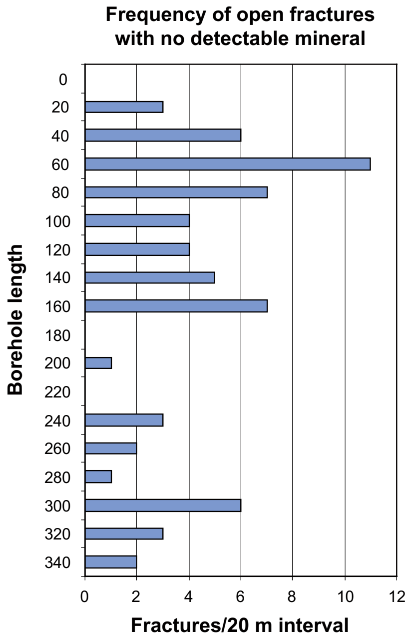

Figure 5-6b. *Frequency of open fractures with no detectable mineral. Frequency calculated per 20 m borehole interval.*

5.4 Ductile deformation

Based upon deformation character the borehole could be sectioned into the following intervals: 13–132 m, 132–240 m and 240–341.76 m.

Several thin, usually a few cm wide deformation bands, occur in the borehole, mapped as rock occurrences. There are 46 observed breccias, 49 brittle-ductile shear zones, 18 cataclasites, 14 ductile shear zones and 3 mylonites. They occur preferably in the intervals 61–119 m, 192–203 m and 244–341 m and have a varying orientation, which is mostly vertical to sub-vertical (Figure 5-2b).

5.4.1 Borehole interval 13–132 m

Clay minerals are frequently occurring (40%) in open fractures. These fractures are often accompanied by calcite, chlorite, pyrite and oxidized walls. However, some of these fractures are probably reactivated. Many clay-sealed fractures have voids which results in a large number of partly open fractures (0.8 partly open fractures/m). The clay is mostly grey to green in colour. In the interval 37.99–38.02 the rock has a vuggy appearance, but with quartz, pyrite and clay minerals. This is mapped as argillization. There are also signs of older fractures: quartz–epidote sealed fractures are cut by laumontite sealed fractures with oxidized walls. The fracture frequency for the interval is relatively high for open fractures (4.8 fractures/m) and high for sealed fractures (15.3 fractures/m, intervals with sealed networks excluded). Approximately 18% of the interval is mapped as a sealed network.

The core of a possible deformation zone is found in the interval 107.30–109.64 m (Figure 5-7) which is mapped as a brittle ductile shear zone with polymict fault breccia and a crushed interval. Next to the breccia fractures filled with probably cataclastic material (beige-coloured), mapped as X5, can be observed at least to 120 m.

Calcite–chlorite sealed fracture networks with oxidized walls and some laumontite or clay are frequent in the interval 29–40 m, while quartz-epidote sealed fracture networks with some adularia, calcite and usually oxidized walls are frequent in the interval 101–114 m.

Figure 5-7. *Character of deformation in the interval ~107–110 m borehole length, KFR101. Lineated fine- to medium-grained granite at ~106 m, lineated metagranite-granodiorite at ~107 m. Brittle-ductile shear zone at ~107.30–110 m with a core consisting of a polymict fault breccia and minor crush.*

5.4.2 Borehole interval 132–240 m

The interval 132–240 m is composed of less ductile deformed rock relative to the borehole interval above and below this section. The metagranite-granodiorite is mostly moderately foliated and hence shows a relatively strong ductile deformation, but the fracture frequencies are lower than the average for the borehole. There are 1.9 open fractures/m (crush excluded), 8.7 sealed fractures/m (intervals with sealed fracture networks excluded) and 0.2 partly open fractures/m in the borehole interval. Approximately 12% of the interval is mapped as a sealed network. The dominating fracture minerals in the interval are chlorite, calcite, muscovite and clay minerals in open fractures, while calcite, chlorite, quartz and adularia with oxidized walls are the most frequent fillings in sealed fractures.

5.4.3 Borehole interval 240–341.76 m

The borehole interval is very rich in sealed fractures and approximately 50% of the interval is mapped as sealed fracture networks. They are also different generations of fractures in these networks. Some are laumontite-calcite dominated (± adularia), while other are epidote–quartz–dominated (± white feldspar and/or ± adularia). Some sealed fracture networks seem to be reactivated, and one sealed fracture network actually may consist of two generations of fractures.

If sections with sealed fracture networks are excluded the frequency of sealed fractures/m is 7.5. The interval is also relatively rich in open fractures and has an open fracture frequency of 5.7 fractures/m and 0.7 partly open fractures/m. Clay minerals are frequently occurring in the open fractures (in 43% of the open fractures), but can also be found in sealed (4.7%) and partly open fractures (40%). The clay in this interval is often coloured by hematite. Laumontite is common in sealed fractures also outside sealed fracture networks (31%). From ~314 m laumontization of the rock is also present. Calcite, chlorite, adularia, muscovite, quartz and epidote are also common sealed fracture minerals.

The interval 326.32–329.92 m is mapped as a weak brittle-ductile shear zone, but this interval is clearly dominated by sealed network like deformation with only minor signs of ductile deformation. This may be the core of the deformed interval.

6 References

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Appendix 1

WellCAD diagrams

Title	LEGEND FOR FORSMARK - SFR	KFR101

SKB

Site FORSMARK - SFR
Borehole KFR101
Plot Date 2009-04-21 23:10:54
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
- White Feldspar
- Hematite
- Calcite
- Chlorite
- Quartz
- Muscovite
- Pyrite
- Caolinite
- Clay Minerals
- Laumontite
- Prehnite
- 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
- Ductile Shear Zone
- Veined
- Gneissic
- Brittle-Ductile Shear Zone
- Banded

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

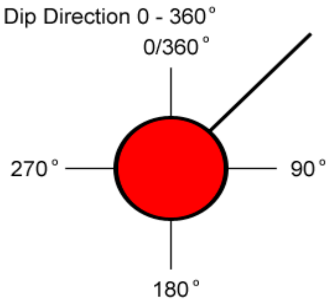
FRACTURE ALTERATION

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

FRACTURE DIRECTION

STRUKTURE ORIENTATION

Dip Direction 0 - 360°

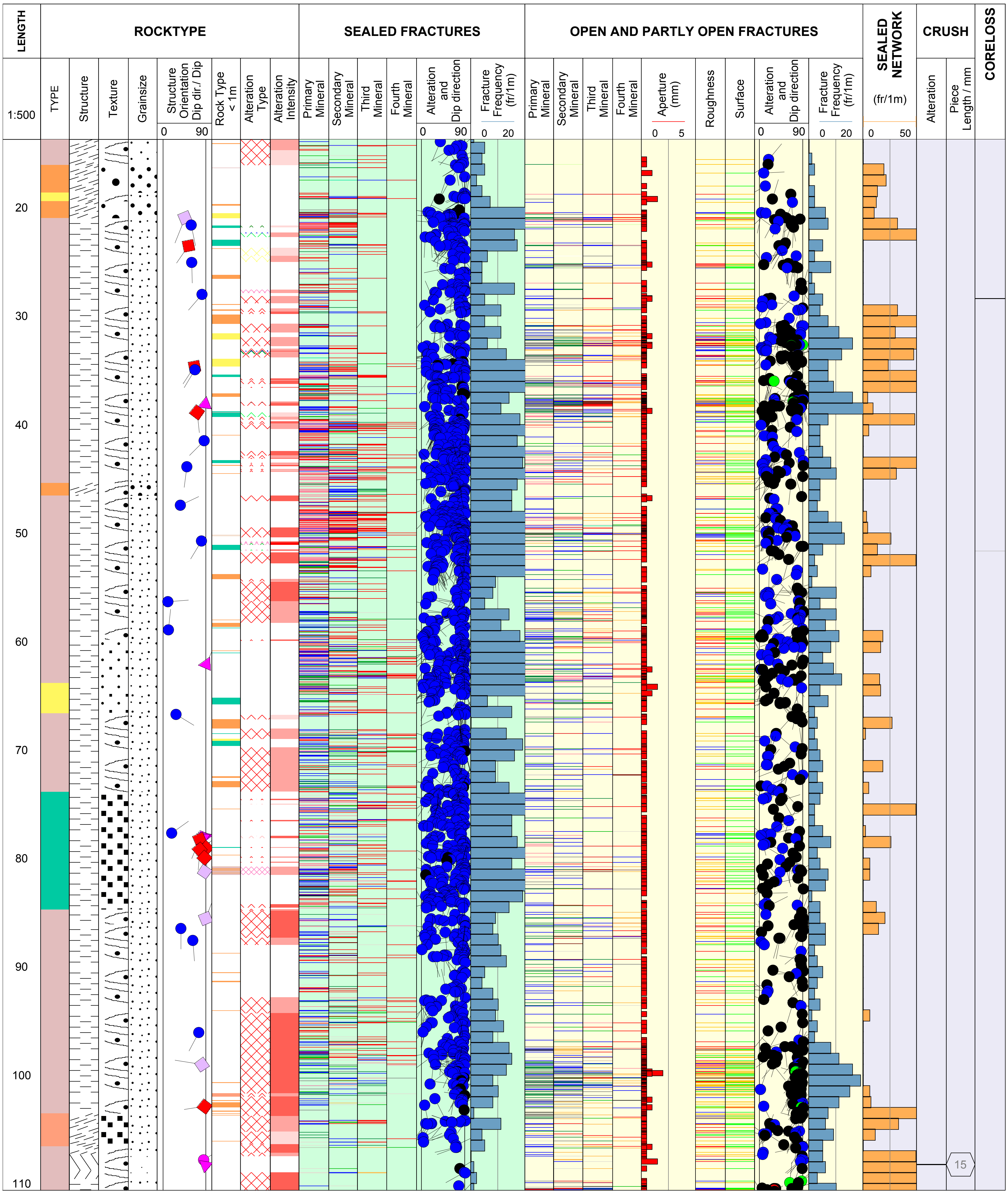


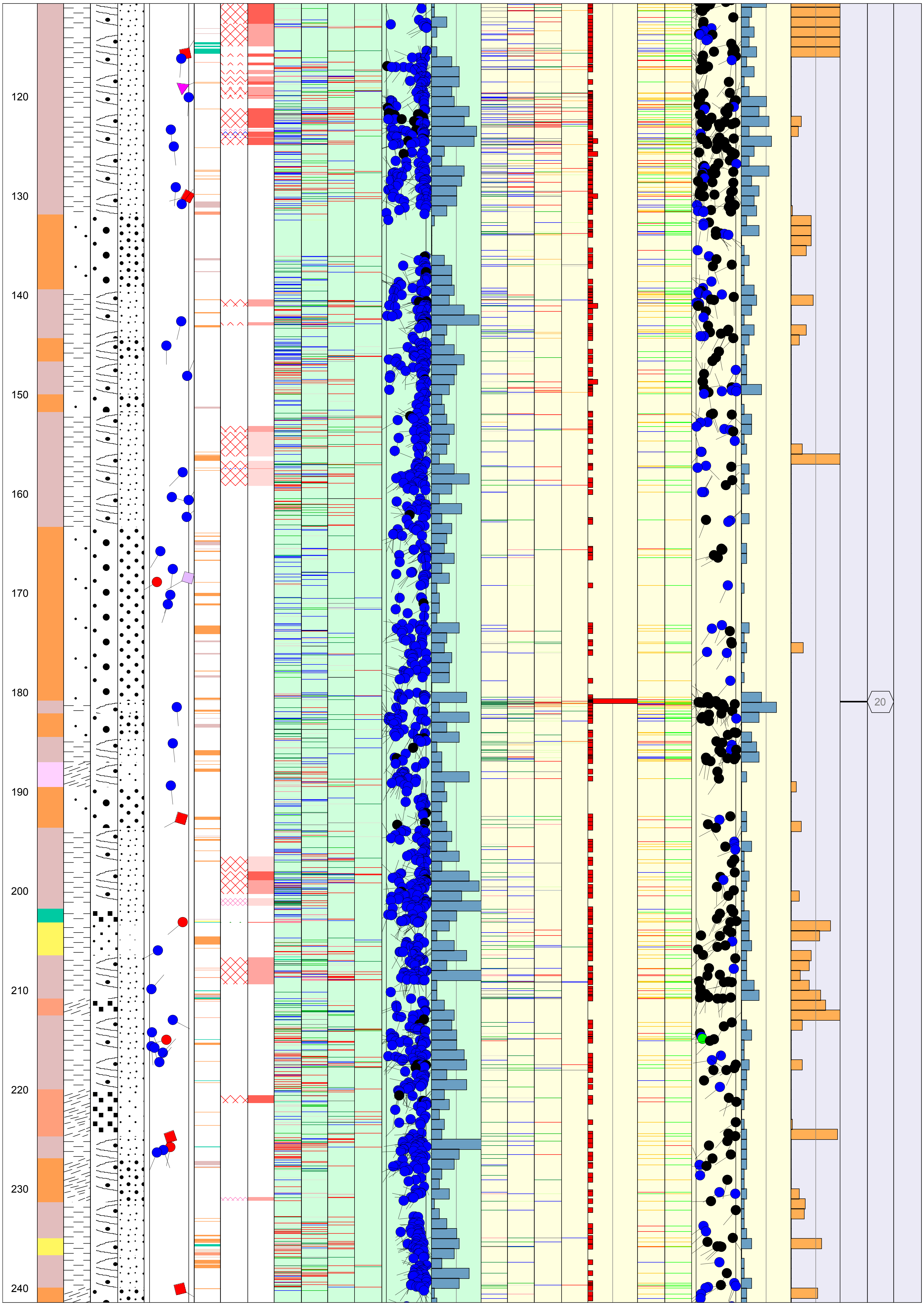
Dip 0 - 90°

Title GEOLOGY IN KFR101

Appendix: 1

Site	FORSMARK - SFR	**Coordinate System**	RT90-RHB70
Borehole	KFR101	**Northing [m]**	6701736.32
Diameter [mm]	76	**Easting [m]**	1633351.40
Length [m]	341.760	**Elevation [m.a.s.l.]**	2.44
Bearing [°]	28.79	**Drilling Start Date**	2008-06-12 10:00:00
Inclination [°]	-55.49	**Drilling Stop Date**	2008-07-02 14:00:00
Date of coremapping	2008-07-08 09:56:00	**Plot Date**	2009-10-24 23:01:44
Rocktype data from	p_rock	**Signed data**	

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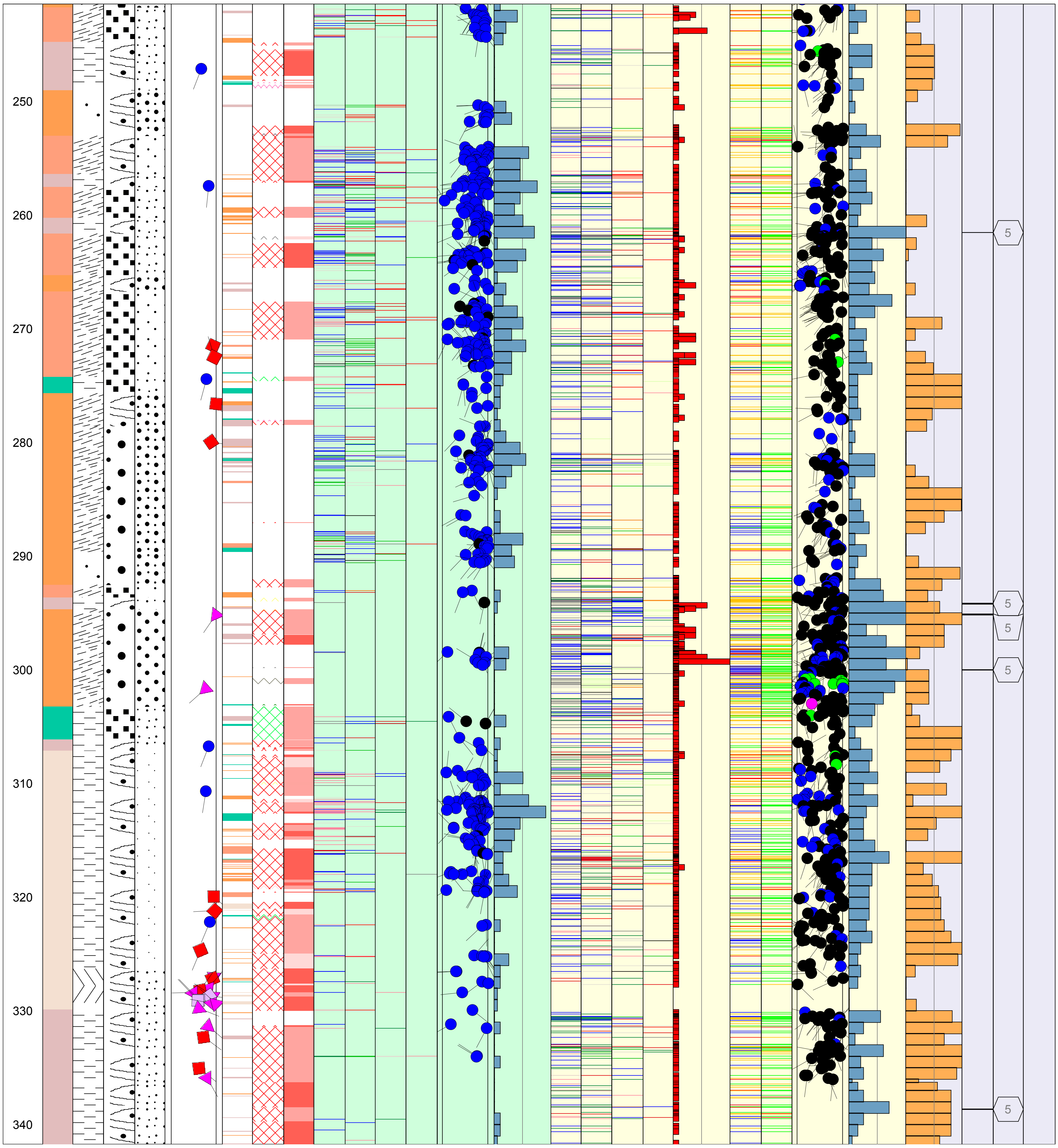

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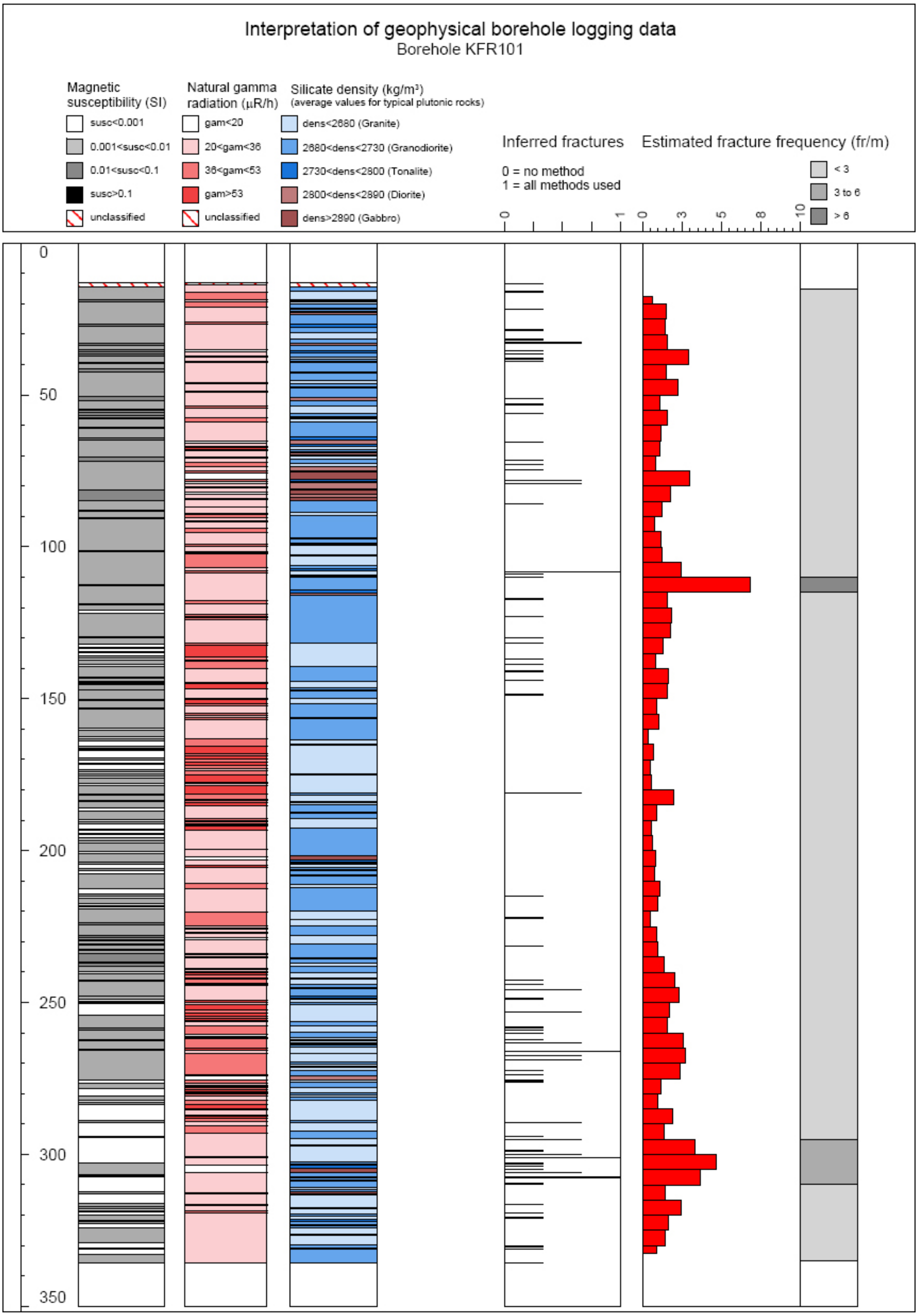
Generalized geophysical logs



Appendix 3

In-data

Hole Diam T – Drilling: Borehole diameter

KFR101, 2008-06-12 10:00:00 – 2008-07-02 14:00:00 (13.720–341.760 m)

Sub Secup (m)	Sub Seclow (m)	Hole Diam (m)	Comment	QC
13.720	341.760	0.0758	Corac	*

Printout from SICADA 2008-11-19 14:44:40.

Borehole Surveying T – Surveying: Borehole coordinates

KFR101, 2008-06-10 14:40:00

Length (m)	Northing (m)	Easting (m)	Elevation (m.a.s.l.)	Northing Err (m)	Easting Err (m)	Elevation Err (m)	Coord System	Comment	QC
0.00	6,701,736.320	1,633,351.398	2.438	0.010	0.010	0.010	RT90-RHB70	casing	*
3.00	6,701,737.850	1,633,352.238	–0.009	0.010	0.010	0.010	RT90-RHB70		*

Printout from SICADA 2008-11-19 14:49:58.