P-09-34

Site investigation SFR

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Abstract

This report presents the geological single-hole interpretations of the cored borehole KFR101 and the percussion boreholes HFR101, HFR102 and HFR105 at SFR. The interpretation combines the geological mapping, generalized geophysical logs, borehole radar measurements and subsequently hydrogeological logs to identify where rock units and possible deformation zones occur in the boreholes. A brief description of each rock unit and possible deformation zone is provided.

Borehole KFR101 has been divided into nine different rock units, RU1–RU9. The predominant rock type in RU1, RU3, RU5 and RU9 is a moderately to strongly foliated metagranite-granodiorite (101057), whereas RU4 and RU7 mainly consist of pegmatitic granite (101061). The other rock units, RU2, RU6 and RU8, are dominated by amphibolite (102017), fine- to medium-grained granite (111058) and aplitic metagranite (101058), respectively. Five possible deformation zones of brittle character and locally with a component of ductile strain have been interpreted in KFR101 (DZ1–DZ5), one with a medium degree of confidence and the other four with a high degree of confidence.

Borehole HFR101 has been divided into six different rock units, RU1–RU6, of which RU1, RU2 and RU4 occur repeatedly. Except for RU3, which is dominated by a felsic to intermediate meta-volcanic rock (103076), all rock units consist of metagranite-granodiorite (101057), pegmatitic granite (101061) and fine- to medium-grained granite (111058) in varying proportions. Four possible deformation zones of brittle character have been interpreted in HFR101 (DZ1–DZ4), one with a high degree of confidence and the other three with a low degree of confidence.

Both percussion boreholes HFR102 and HFR105 have each been divided into two different rock units, RU1–RU2. The predominant rock types in HFR102 are pegmatitic granite (101061) and metagranite-granodiorite (101057), whereas HFR105 are inferred to contain fine- to medium-grained granite (111058) in addition to the other two rock types. No possible deformation zone has been identified in HFR102. Three possible deformation zones of brittle character have been interpreted in HFR105 (DZ1–DZ3), one with a high degree of confidence, one with a medium degree of confidence and one with a low degree of confidence.

Sammanfattning

Denna rapport presenterar den geologiska enhålstolkningen från kärnborrhål KFR101 och hammarborrhålen HFR101, HFR102 och HFR105 i anslutning till SFR. Tolkningen kombinerar den geologiska karteringen, generaliserade geofysiska loggar, data från borrhålsradar och därefter hydrogeologisk data för att identifiera litologiska enheter och möjliga deformationszoner i borrhålen. En översiktlig beskrivning av varje litologisk enhet och möjlig deformationszon presenteras.

Kärnborrhål KFR101 har delats upp i nio litologiska enheter, RU1–RU9. Den dominerande bergarten i RU1, RU3, RU5 och RU9 är en medel till starkt folierad metagranit-granodiorit (101057), medan RU4 och RU7 huvudsakligen består av pegmatitisk granit (101061). De andra litologiska enheterna, RU2, RU6 och RU8, domineras av amfibolit (102017), fin- till medelkornig granit (111058) i varierande proportioner. Fem möjliga deformationszoner av spröd karaktär, lokalt med en plastisk komponent, har tolkats i KFR101 (DZ1–DZ5), en med medelhög grad av tillförlitlighet och de övriga fyra med hög grad av tillförlitlighet.

Hammarborrhål HFR101 har delats upp i sex litologiska enheter, RU1–RU6, av vilka RU1, RU2 och RU4 förekommer upprepade gånger. Bortsett från RU3, som domineras av en felsisk till intermediär metavulkanisk bergart (103076), består alla litologiska enheter av metagranit-granodiorit (101057), pegmatitisk granit (101061) och fin- till medelkornig granit (111058) vi varierande proportioner. Fyra möjliga deformationszoner med spröd karaktär har tolkats i HFR101 (DZ1–DZ4), en med en hög grad av tillförlitlighet och de andra tre med en låg grad av tillförlitlighet.

Både HFR102 och HFR105 har delats upp i två olika litologiska enheter, RU1–RU2. De dominerande litologiska enheterna i HFR102 är pegmatitisk granit (101061) och metagranit-granodiorit (101057), medan det i HFR105 utöver dessa enheter dessutom förekommer en fin- till mediumkornig granit (111058). Inga möjliga deformationszoner har identifierats i HFR102. Tre möjliga deformationszoner av spröd karaktär har tolkats i HFR105 (DZ1–DZ3), en med en hög grad av tillförlitlighet, en med en medelhög grad av tillförlitlighet och en med låg grad av tillförlitlighet.

Contents

1 Introduction

During 2008, SKB has initiated an investigation programme for the future expansion of the final repository for low and intermediate-level radioactive waste, SFR. An essential part in this project is the drilling of three percussion and six core drilled boreholes. Each borehole should be thoroughly documented by means of geological mapping by the so-called Boremap system, as well as geophysical and radar borehole measurements. After storage in the SKB database Sicada, the data needs to be integrated and synthesized before they can be used for modelling in the 3D-CAD Rock Visualization System (RVS). This procedure follows SKB's established methodology of geological single-hole interpretation, which is based on an integrated series of different logs and accompanying descriptive documents. However, a difference in the methodology compared to that applied during the site investigation programme (i.e. SKB MD 810.003) is the incorporation of hydrogeological borehole data in the interpretation process.

This document outlines the results of the geological single-hole interpretation of boreholes KFR101, HFR101, HFR102 and HFR105. The horizontal projections of the boreholes are shown in Figure 1-1.

The work was carried out in accordance with activity plan AP SFR-08-009. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

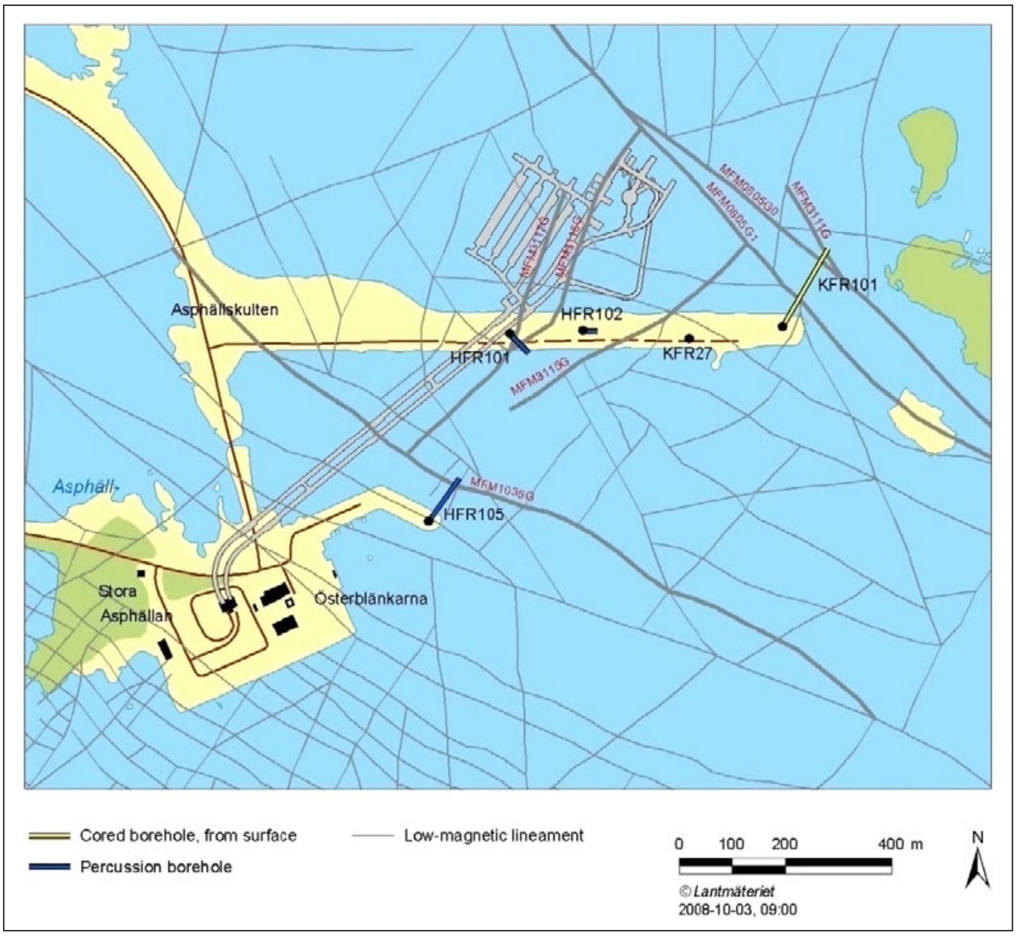

Figure 1-1. Map showing position and horizontal projection of the cored borehole KFR101 together with the percussion boreholes HFR101, HFR102 and HFR105 relative to SFR.

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

Activity plan	Number	Version
Geologisk enhålstolkning av hammarborrhål HFR101, HFR102, HFR105 samt kärnborrhål KFR27, KFR101, KFR102A, KFR102B, KFR103 och KFR104.	AP SFR-08-009	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning.	SKB MD 810.003	3.0

Original data from the reported activity are stored in the primary database Sicada. 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. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the associated P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

2 Objective and scope

A geological single-hole interpretation is carried out in order to identify and to describe the general characteristics of major rock units and possible deformation zones within a borehole. The work involves an integrated interpretation of data from the geological mapping of a drill core. Hydrogeological borehole data from all four boreholes was used to identify flow anomalies and transmissive sections of the boreholes.

The result from the geological single-hole interpretation is presented in a WellCAD plot. A detailed description of the technique is provided in the Method Description (SKB MD 810.003). The work reported here concerns stage 1 in the single-hole interpretation, as defined in the Method Description.

3 Data used for the geological single-hole interpretation

The following data have been used for the single-hole interpretation of the boreholes KFR101, HFR101, HFR102 and HFR105.

- Boremap data (including BIPS-image and geological mapping /Döse 2009, Döse et al. 2009/.
- Generalized geophysical logs and their interpretation /Mattsson and Keisu 2009/.
- Radar data and their interpretation /Gustafsson and Gustafsson 2009/.
- Borehole flow logging data and their interpretation /Jönsson et al. 2009, Pekkanen et al. 2009/.

The geological mapping of the cored borehole, KFR101, involves documentation of the drill core in combination with inspection of the oriented image of the borehole walls, obtained by a Borehole Image Processing System (BIPS). The mapping of the percussion boreholes focuses, on the other hand, on integrated interpretation of the geophysical data and the BIPS-images. For this reason, the results from the percussion borehole mapping are more uncertain.

The basis for the geological single-hole interpretation was a WellCAD plot consisting of parameters from the geological mapping, as well as geophysical, radar and hydrogeological data. The latter was included after that the geological single-hole interpretation was performed, i.e. the rock units and the possible deformation zones were defined. An example of a WellCAD plot used during geological single-hole interpretation is shown in Figure 3-1. The plot consists of eight main columns and several subordinate columns. These include:

1: Length along the borehole

2: Rock type
  2.1: Rock type
  2.2: Rock type < 1 m
  2.3: Rock type structure
  2.4: Rock structure intensity
  2.5: Rock type texture
  2.6: Rock type grain size
  2.7: Structure orientation
  2.8: Rock alteration
  2.9: Rock alteration intensity

3: Geophysics
  3.1: Silicate density
  3.2: Natural gamma radiation
  3.3: Magnetic susceptibility
  3.4: Estimated fracture frequency

4: Unbroken fractures
  4.1: Primary mineral
  4.2: Secondary mineral
  4.3: Third mineral
  4.4: Fourth mineral
  4.5: Width
  4.6: Alteration, dip direction

5: Broken fractures
  5.1: Primary mineral
  5.2: Secondary mineral
  5.3: Third mineral
  5.4: Fourth mineral
  5.5: Width
  5.6: Aperture

   5.7: Roughness
   5.8: Surface
   5.9: Slickenside
   5.10: Alteration, dip direction

6: Crush zones
   6.1: Piece (mm)
   6.2: Sealed network
   6.3: Core loss

7: Fracture frequency
   7.1: Open fractures
   7.2: Sealed fractures

8: Hydrogeology
   8.1: Transmissivity flow anomalies
   8.2: Transmissivity 5-m sections (not available in the percussion boreholes)

The use of the geophysical, radar and hydrogeological parameters during the single-hole interpretation is as follows:

Silicate density: Indicates the density of the rock after subtraction of the magnetic component of the rock. It provides general information on the mineral composition of the rock and serves as a support for rock classification.

Natural gamma radiation: The rock has been classified into sections of low, medium and high natural gamma radiation. Low radiation may indicate mafic rock types and high radiation may indicate younger, fine-grained granite (111058) or pegmatitic granite (101061).

Magnetic susceptibility: The rock has been classified into sections of low, medium, high and very high magnetic susceptibility. The susceptibility measurement is strongly connected to the magnetite content of the rock.

Radar data: Inspection of the borehole radar data was carried out during the interpretation process, especially during the identification of possible deformation zones. The occurrence and orientation of radar anomalies within the possible deformation zones are commented upon in the text that describes these zones.

Transmissivity: The transmissivity from flow logging is related to the transmissivity of individual fractures and to the connectivity of the water-bearing fracture network. The resolution of individual flow anomalies is much better for the difference flow logging in the core drilled borehole (KFR101) than for the spinner flow logging in the percussion drilled boreholes.

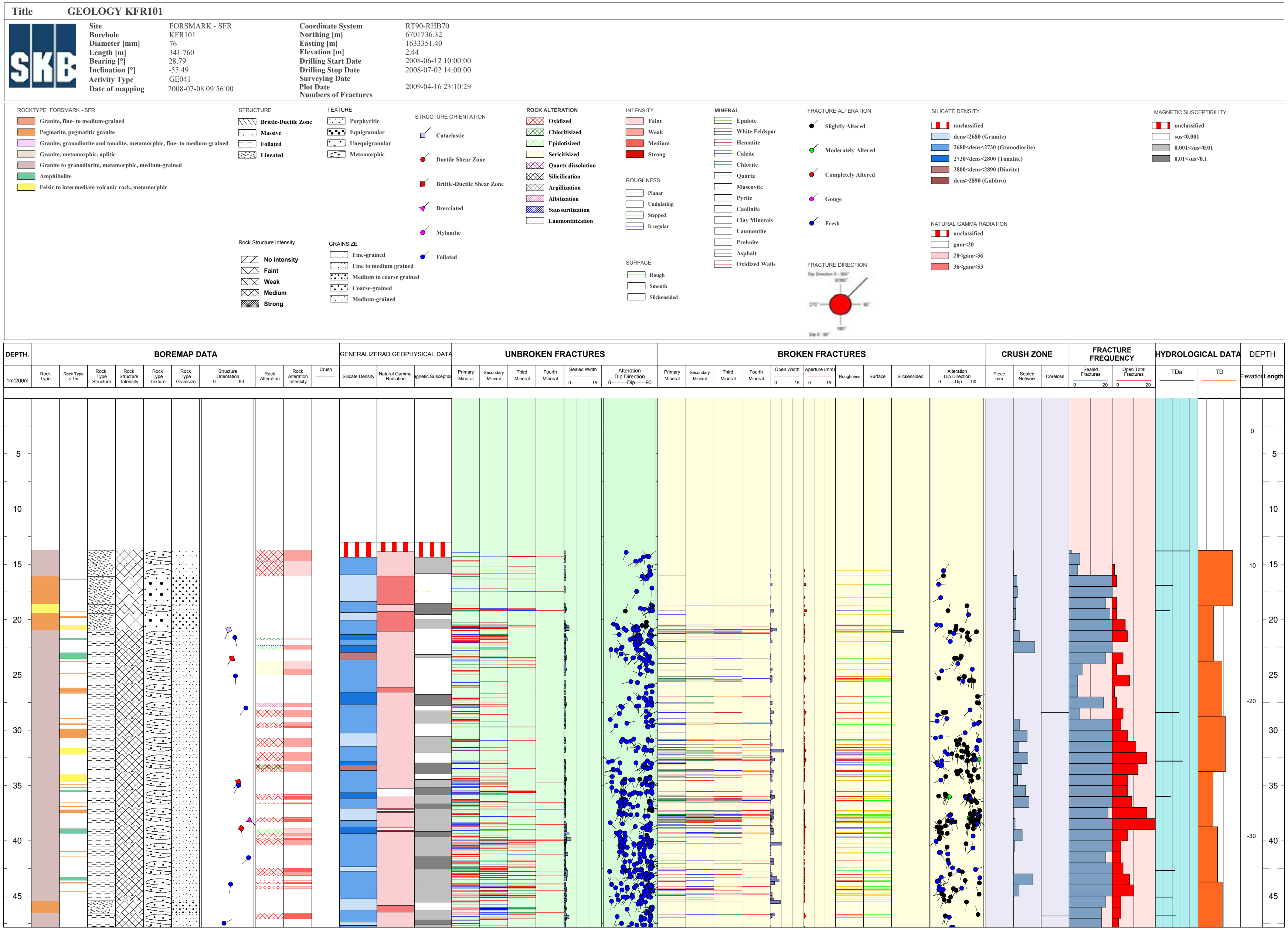

Figure 3-1. *Example of WellCAD plot (from borehole KFR101) used as basis for the geological single-hole interpretation.*

4 Execution

4.1 Geological single-hole interpretation

The geological single-hole interpretation has been carried out by a group of geoscientists, consisting of geologists, geophysicists and hydrogeologists. Several of them previously participated in the development of the source material. All data to be used (see Chapter 3) are presented side by side in a borehole document extracted from the software WellCAD. The working procedure is summarized in Figure 4-1 and in the text below.

The first step in the working procedure is to study all types of data related to the character of the rock type and to merge sections of similar rock types, or sections where one rock type is very dominant, into rock units. A minimum length of about 5 m was used for the single-hole interpretations during the site investigation. This minimum length was generally also used during this work, but not consistently, since the SFR model volume is considerably less. Each rock unit is defined in terms of the borehole length interval and provided with a brief description for inclusion in the WellCAD plot. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

The second step in the working procedure is to identify possible deformation zones by visual inspection of the results of the geological mapping (fracture frequency, fracture mineral, alteration, etc) in combination with available geophysical and radar data. The section of each identified possible deformation zone is defined in terms of the borehole length interval and provided with a brief description for inclusion in the WellCAD plot. This includes a brief description of the rock types affected by the possible deformation zone. Mineral fillings registered in at least 10% of the open/sealed fractures in the interval or eight individual fractures are noted. The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

Inspection of BIPS images is carried out wherever it is judged necessary during the working procedure. Furthermore, following the definition of rock units and possible deformation zones, with their respective confidence estimates, the drill cores are inspected in order to check the selection of the boundaries between these geological entities. If judged necessary, the boundaries are adjusted.

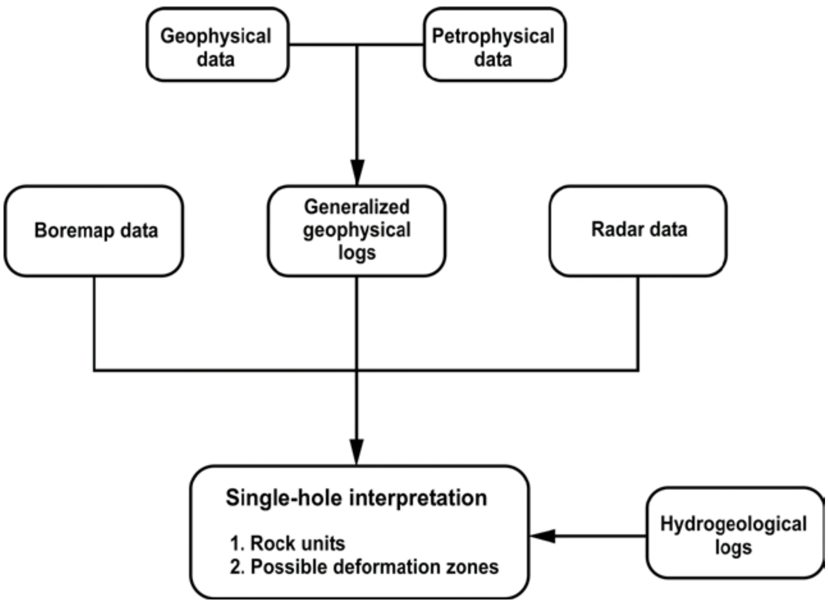

Figure 4-1. *Schematic chart showing the procedure for the development of a geological single-hole interpretation.*

Possible deformation zones that are brittle in character have been identified primarily on the basis of the frequency of fractures, according to the concept presented in /Munier et al. 2003/. Brittle deformation zones defined by an increased frequency of extensional fractures (joints) or shear fractures (faults) are not distinguished. Both the transitional part, with a fracture frequency in the range 4–9 fractures/m, and the core part, with a fracture frequency > 9 fractures/m, have been included in each zone (Figure 4-2). The frequencies of open and sealed fractures have been assessed in the identification procedure, and the character of the zone has been described accordingly. Partly open fractures are included together with open fractures in the brief description of each zone. The presence of bedrock alteration, the occurrence and, locally, orientation of radar reflectors, the resistivity, caliper and magnetic susceptibility logs have all assisted in the identification of the zones. The anomalies in these parameters that assist with the interpretation are presented in the short description.

Since the frequency of fractures is of key importance for the definition of the possible deformation zones, moving average plots for this parameter are shown for the cored borehole KFR101 and the percussion boreholes HFR101, HFR102 and HFR105 (Figure 4-3 to Figure 4-6). A 5 m window and 1 m steps have been used in the calculation procedure. The moving average for open fractures alone, the total number of open (including open, partly open and crush), the sealed fractures alone, and the total number of sealed fractures (including sealed and sealed fracture networks) are shown in each diagram.

The occurrence and orientation of radar anomalies within the possible deformation zones are used during the identification of these zones. Overview of the borehole radar measurement in KFR101 is shown in Figure 4-7. A conductive environment causes attenuation of the radar wave, which in turn decreases the penetration. The effect of attenuation can be observed in the borehole and is conspicuous in the interval 100–110 m and the lowermost 50 m (Figure 4-7). The effect of attenuation varies between the different antenna frequencies (in this case 20 and 60 MHz directional antenna). In some cases, alternative orientations for oriented radar reflectors are presented. One of the alternatives is considered to be correct, but due to uncertainty in the interpretation of radar data, a decision concerning which of the alternatives that represent the true orientation cannot be made. Orientations from directional radar are presented as strike/dip using the right-hand-rule method.

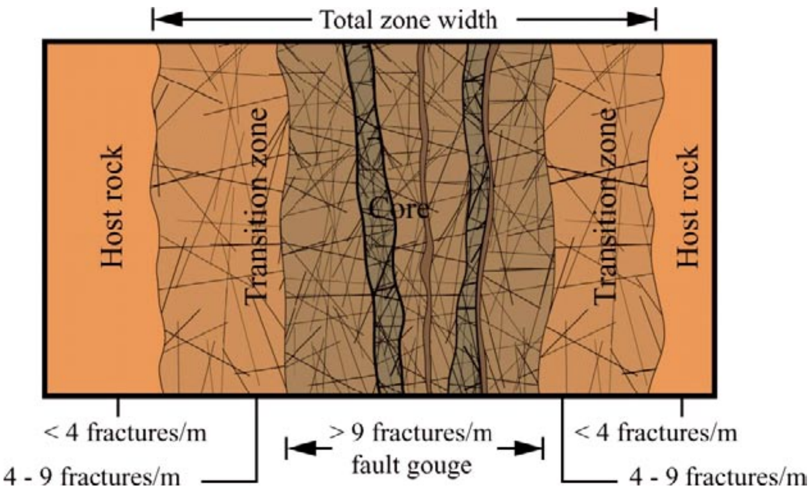

Figure 4-2. *Schematic illustration of the structure of a brittle deformation zone. After /Munier et al. 2003/.*

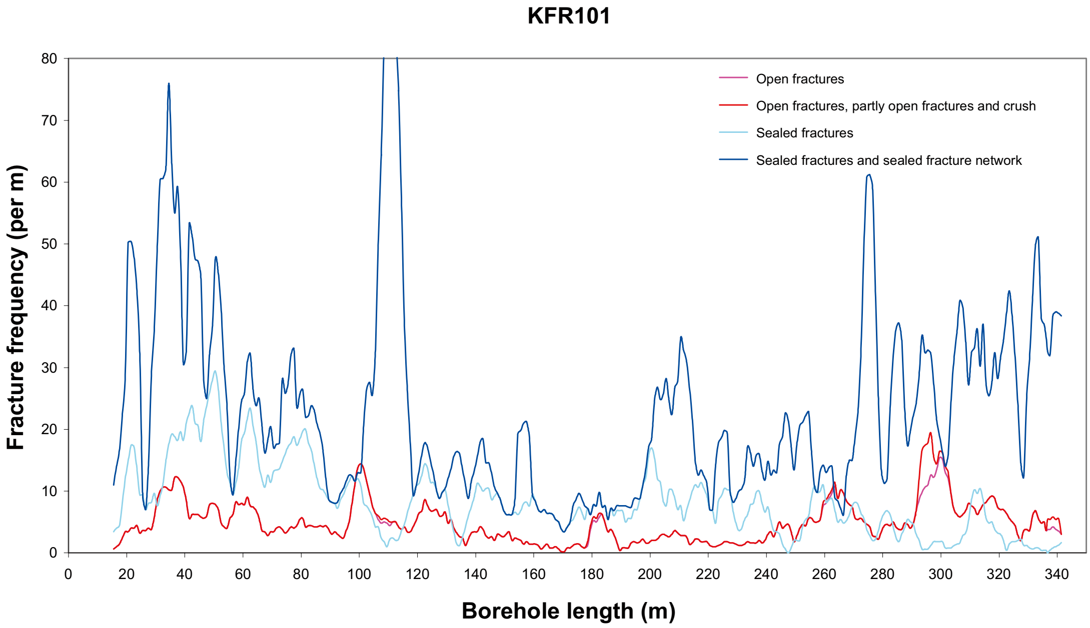

Figure 4-3. Fracture frequency plot for KFR101. Moving average with a 5 m window and 1 m steps.

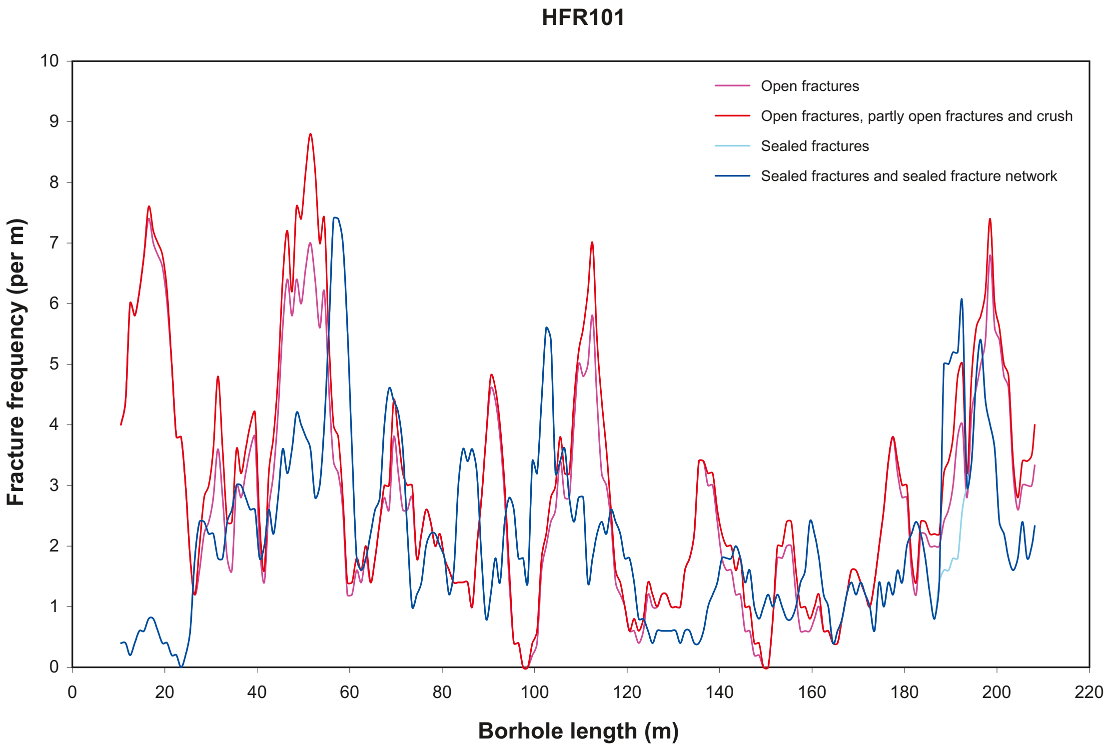

Figure 4-4. Fracture frequency plot for HFR101. Moving average with a 5 m window and 1 m steps.

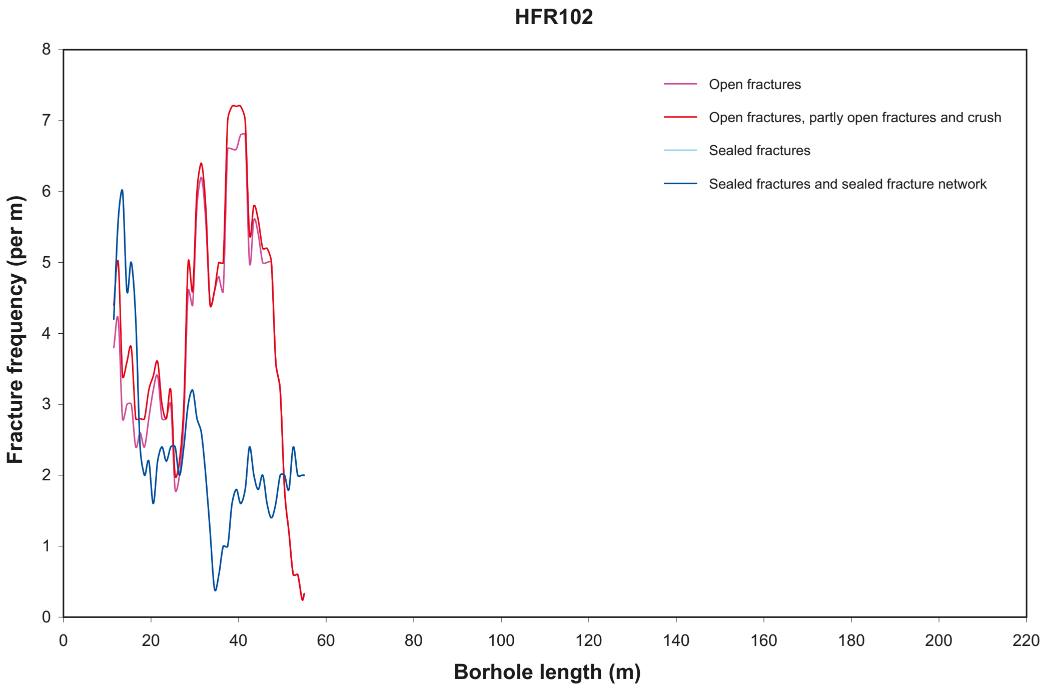

__Figure 4-5.__ Fracture frequency plot for HFR102. Moving average with a 5 m window and 1 m steps.

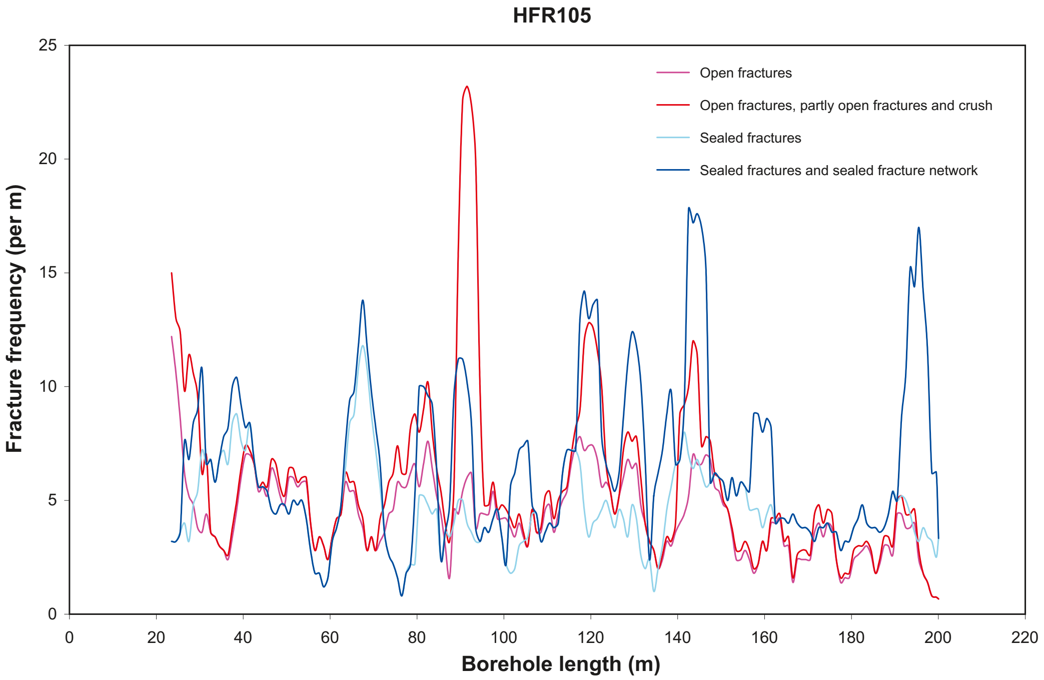

__Figure 4-6.__ Fracture frequency plot for HFR105. Moving average with a 5 m window and 1 m steps.

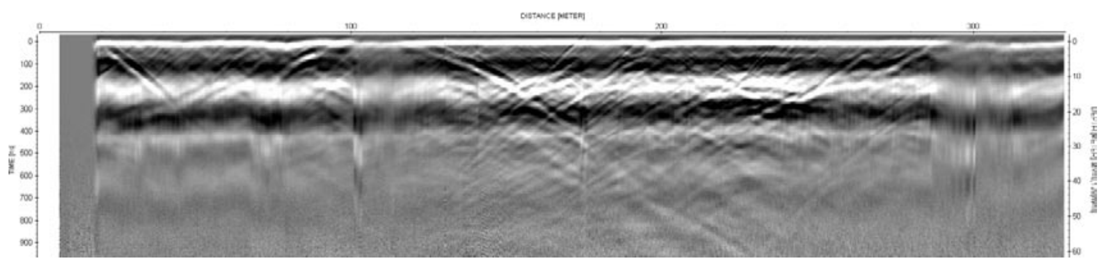

__Figure 4-7.__ Overview (20 MHz data) of the borehole radar measurements in KFR101.

4.2 Hydrogeological single-hole interpetation

The hydrogeological single-hole interpretation has been carried out by a hydrogeologist as a second step after, but in immediate connection to, the geological single-hole interpretation. All data to be used are presented side by side in the same borehole document as the geological and geophysical data. The hydrogeological columns were however not accessible at the geological interpretation stage.

In this particular case the single-hole interpretation concerned one core drilled borehole with difference flow logging data and three percussion drilled boreholes with spinner flow logging data. There was therefore no possibility to study the flow anomalies at fracture level for the percussion drilled boreholes.

The methodology of the hydrogeolocial single-hole interpretation was to study the hydrogeological data for the identified possible deformation zones. The flow anomalies and hydraulic properties of each zone were then evaluated and described in comparison to the properties of the whole borehole.

4.3 Nonconformities

A difference in the currently applied methodology compared to earlier single-hole interpretations (SKB MD 810.003) is that hydrogeological single-hole interpretation was performed after that the rock units and the possible deformation zones were defined for each borehole.

The last 5.45 m (336.31–341.76 m) of KFR101 was mapped without access to BIPS-image.

Borehole radar measurements were only performed in KFR101, with two different antenna frequencies, the 20 MHz dipole antenna and the 60 MHz directional antenna.

The data used for calibration of the magnetic susceptibility logs are from the preceding Forsmark site investigation for a deep repository.

5 Results

The results of the geological single-hole interpretations of KFR101, HFR101, HFR102 and HFR105 are presented as print-outs from the software WellCAD in Appendix 1.

5.1 KFR101

The orientation at the beginning of the borehole is 028.8°/–55.5°.

Rock Units

The borehole can be divided into nine different rock units, RU1–RU9. All rock units have been interpreted with a high degree of confidence.

13.72–73.90 m

RU1: Generally moderately foliated metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and amphibolite (102017). Magnetic susceptibility is increased along the entire section. Confidence level = 3.

73.90–84.79 m

RU2: Amphibolite (102017) with minor occurrences of pegmatitic granite (101061) and metagranite-granodiorite (101057). The density is significantly increased along the entire section, however the magnetic susceptibility is increased only in the interval 80–85 m. Confidence level = 3.

84.79–163.39 m

RU3: Generally moderately foliated metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061). One minor occurrence of fine- to medium grained granite (111058) and one of amphibolite (102017). Confidence level = 3.

163.39–180.89 m

RU4: Pegmatitic granite (101061) with minor occurrences of metagranite-granodiorite (101057). Confidence level = 3.

180.89–239.97 m

RU5: Generally moderately foliated metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061), fine- to medium-grained granite (111058), felsic to intermediate metavolcanic rock (103076), amphibolite (102017) and one occurrence of fine- to medium-grained metagranodiorite-tonalite (101051). Along the interval 220–239.97 m the magnetic susceptibility is increased. Confidence level = 3.

239.97–279.29 m

RU6: Fine- to medium-grained granite (111058) and pegmatitic granite (101061) with subordinate occurrence of strongly foliated metagranite-granodiorite (101057) and amphibolite (102017). Confidence level = 3.

274.29–307.15 m

RU7: Pegmatitic granite (101061) with subordinate occurrences of amphibolite (102017), metagranite-granodiorite (101057) and fine- to medium-grained granite (111058). Confidence level = 3.

307.15–329.91 m

RU8: Aplitic metagranite (101058) with subordinate occurrence of pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

329.91–341.76 m

RU9: Generally moderately foliated metagranite-granodiorite (101057). Confidence level = 3.

Possible deformation zones

Five possible deformation zones of brittle and locally brittle-ductile character have been interpreted in KFR101, one with a medium degree of confidence and the other four with a high degree of confidence.

13.72–88 m

DZ1: Increased frequency of open fractures, sealed fracture networks and especially sealed fractures. Occasional slickensides. Fractures aperture up to 1.5 mm. Locally faint to medium oxidation. Several minor intervals (< 1 dm) of breccias, cataclasites, mylonite and brittle-ductile shear zones. Predominant minerals in sealed fractures are calcite, laumontite, chlorite, quartz and epidote, and in open fractures are calcite, chlorite, clay minerals, laumontite and pyrite. Decreased resistivity in the section c. 30–50 m and one distinct caliper anomaly at c. 33 m. The magnetic susceptibility is increased along the entire interval defining the deformation zone. Moderately foliated metagranite-granodiorite (101057), amphibolite (102017), pegmatitic granite (101061) and felsic to intermediate metavolcanic rock (103076). Confidence level = 3.

Increased frequency of flow anomalies in the section 14–65 m but no flow anomalies below 65 m. The total transmissivity of the interval is quite high (about $5 \cdot 10^{-6}$ m^2/s if the dominating flow at the lower edge of the casing is removed). The caliper anomaly at c. 33 m corresponds to a single high-transmissive flow anomaly.

97–116 m

DZ2: Increased frequency of broken and unbroken fractures and sealed networks. One crushed interval at 108.07–108.32 m. Occasional slickensides. Fractures aperture up to 2 mm. Generally weak to medium oxidation. Intervals exceeding a few centimetres of breccia at 108.03–108.51 and of mylonite at 108.51–108.71 and 109.21–109.32 m. Brittle-ductile shear zones at 102.86–102.97 and 107.30–109.64 m. Predominant minerals in sealed fractures are calcite, quartz, adularia, epidote, chlorite and pyrite and in open fractures are calcite, clay minerals, chlorite, pyrite, adularia, hematite and quartz. Significantly decreased resistivity along the entire section and one distinct caliper anomaly at c. 108.5 m. One distinct radar reflector at 106.4 m oriented 313°/87° or 331°/30°, and a prominent radar wave attenuation in the interval c. 100–110 m. Moderately foliated metagranite-granodiorite (101057), fine- to medium-grained granite (111058), amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3.

One single high-transmissive flow anomaly (about $8 \cdot 10^{-6}$ m^2/s) at c. 108.3 m corresponding to the caliper anomaly.

179–186 m

DZ3: Increased frequency of open fractures. Occasional slickensides. One crushed interval at 180.95–181.01 m. Fractures aperture 0.5 mm or less with one fracture at 17 mm. Predominant minerals in open fractures and the crushed interval are chlorite, muscovite, clay mineral, hematite, calcite and goethite. One distinct low resistivity anomaly at c. 181 m. One radar reflector at 181 m oriented 076°/21°. Pegmatitic granite (101061) and moderately foliated metagranite-granodiorite (101057). Confidence level = 3.

One single high-transmissive flow anomaly (about $1 \cdot 10^{-5}$ m^2/s) at c. 181.0 m corresponding to the crushed interval.

197–213 m

DZ4: Increased frequency of sealed fractures and sealed fracture networks. Occasional slickensides. Fractures aperture 0.5 mm or less. Locally weak to medium oxidation. Predominant minerals in sealed fractures are calcite, chlorite, adularia, laumontite and quartz. No significant anomalies in the geophysical logging data. Moderately foliated metagranite-granodiorite (101057), felsic to intermediate metavolcanic rock (103076), fine- to medium-grained granite (111058), amphibolite (102017) and pegmatitic granite (101061). Confidence level = 2.

No flow anomalies and transmissivity below the measurement limit in this interval.

242–341.76 m

DZ5: Increased frequency of broken and unbroken fractures and sealed networks. More highly increased frequency of broken fractures at 294–304 m. Five crushed interval at 261.58–261.60, 294.18–294.26, 295.14–295.23, 300.03–300.05 and 338.67–338.71 m. Occasional slickensides. Fractures aperture up to 5 mm. Locally weak to medium oxidation. Interval of vuggy granite affected by argillization at 300.76–301.25 m. Several intervals of breccias, cataclasites and brittle-ductile shear zones, ranging up to a few decimetres in length. One more extensive brittle-ductile shear zones at 326.32–329.91 m. Predominant minerals in sealed fractures are calcite, laumontite, quartz, adularia, epidote and chlorite and in open fractures and crushed intervals calcite, chlorite, clay minerals, hematite, adularia, muscovite, laumontite and quartz. Increased frequency of low resistivity anomalies in the section c. 242–276 m and there is a significant decrease in bulk resistivity in the interval 293–336 m. At 295 m there is one distinct caliper anomaly. Two distinct radar reflectors oriented 041°/47°, and 296°/16° or 296°/87°, and a prominent radar wave attenuation from c. 290 m to the end of the borehole. Pegmatitic granite (101061), aplitic metagranite (101058), fine- to medium-grained granite (111058), moderately foliated metagranite-granodiorite (101057) and amphibolite (102017). Confidence level = 3.

Increased frequency of flow anomalies in the section, particularly in the interval 294–304 m. No flow anomalies below c. 326 m and no flow logging data available below 332 m. The total transmissivity of the interval is quite high (about $9 \cdot 10^{-6}$ m^2/s) where about 90% is concentrated to the interval 294–304 m.

5.2 HFR101

The orientation at the beginning of the borehole is 133.6°/–70.0°.

Rock units

The borehole can be divided into six different rock units, RU1–RU6. Rock units 2 and 4 occur each in two separate length intervals. All rock units have been interpreted with a high degree of confidence.

8.04–36.80 m

RU1: Fine- to medium-grained granite (111058) and pegmatitic granite (101061) with one occurrence of metagranite-granodiorite (101057). The section 8.04–15.0 meter shows significantly increased natural gamma radiation and decreased density. Confidence level = 3.

36.80–59.51 m

RU2a: Metagranite-granodiorite (101057) with subordinate occurrence of pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

59.51–74.30 m

RU3: Felsic to intermediate metavolcanic rock (103076) with subordinate occurrence of pegmatitic granite (101061) and one of metagranite-granodiorite (101057). Magnetic susceptibility is increased along the entire interval. Confidence level = 3.

74.30–93.26 m

RU2b: Metagranite-granodiorite (101057) with subordinate occurrence of pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

93.26–155.78 m

RU4a: Pegmatitic granite (101061). Confidence level = 3.

155.78–170.34 m

RU5: Fine- to medium-grained granite (111058) with subordinate occurrence of pegmatitic granite (101061). Confidence level = 3.

170.34–187.99 m

RU4b: Pegmatitic granite (101061). Confidence level = 3.

187.99–208.12 m

RU6: Metagranite-granodiorite (101057) with subordinate occurrence of pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and amphibolite (102017). Confidence level = 3.

Possible deformation zones

Three possible deformation zones of brittle character have been interpreted in HFR101, one with a high degree of confidence and the other two with a low degree of confidence.

8.04–58 m

DZ1: Increased frequency of open and sealed fractures. Fracture aperture up to 2 mm. Locally weak to medium oxidation. Significantly decreased bulk resistivity along the entire section and minor caliper anomalies. Metagranite-granodiorite (101057), pegmatitic granite (101061), fine- to medium-grained granite (111058), amphibolite (102017) and felsic to intermediate metavolcanic rock (103076). Confidence level = 3.

No flow anomaly in this interval.

101–115 m

DZ2: Increased frequency of open and sealed fractures. Fracture aperture up to 1.5 mm. Generally weak oxidation. The geophysical logging data show significant low resistivity anomalies and caliper anomalies. Pegmatitic granite (101061). Confidence level = 1.

One flow anomaly at 107.3–108.0 m with a quite high transmissivity (about $3 \cdot 10^{-6}$ m^2/s). Corresponds to an increased estimated fracture frequency. This is one of the two observed flow anomalies in the borehole.

190–202 m

DZ3: Increased frequency of open fractures, sealed fractures and sealed fracture network. Fracture aperture up to 1 mm. Locally weak to medium oxidation. Inferred minor brittle-ductile shear zone at

200.25–200.54 m. Partly decreased bulk resistivity and caliper anomalies. Metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017). Confidence level = 1.

One flow anomaly at 196.0–197.0 m with a moderate transmissivity (about $3 \cdot 10^{-7}$ m^2/s). Corresponds to an increased estimated fracture frequency. This is one of the two observed flow anomalies in the borehole.

5.3 HFR102

The orientation at the beginning of the borehole is 085.0°/–59.1°.

Rock Units

The borehole can be divided into two different rock units, RU1–RU2. Both rock units have been interpreted with a high degree of confidence.

9.04–28.61 m

RU1: Pegmatitic granite (101061) with minor occurrences of amphibolite (102017) and metagranite-granodiorite (101057). Confidence level = 3.

28.61–55.04 m

RU2: Metagranite-granodiorite (101057) with subordinate occurrence of fine- to medium-grained granite (111058), pegmatitic granite (101061) and one occurrence of amphibolite (102017). Confidence level = 3.

Possible deformation zones

No deformation zone has been identified in HFR102.

5.4 HFR105

The orientation at the beginning of the borehole is 035.4°/–61.9°.

Rock Units

The borehole can be divided into two different rock units, RU1–RU2. Both rock units have been interpreted with a high degree of confidence.

21.12–164.16 m

RU1: Metagranite-granodiorite (101057) with subordinate occurrences of felsic to intermediate metavolcanic rock (103076), fine to medium grained granite (111058), pegmatitic granite (101061), amphibolite (102017) and fine to medium grained metagranodiorite-tonalite (101051). Confidence level = 3.

164.16–199.78 m

RU2: Pegmatitic granite (101061) and fine- to medium-grained granite (111058) with minor occurrences of metagranite-granodiorite (101057) and amphibolite (102017). Confidence level = 3.

Possible deformation zones

Three possible deformation zones of brittle character have been interpreted in HFR105, one with a high degree of confidence, one with a medium degree of confidence and one with a low degree of confidence.

21.12–31 m

DZ1: Increased frequency of open fractures. Three crushed intervals at 22.16–22.31, 27.48–27.53 and 29.45–29.95 m. Fracture aperture up to 5 mm, with one aperture 20 mm. Weak to medium oxidation throughout the interval. Significantly decreased bulk resistivity and major caliper anomalies along the entire section. Metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017). Confidence level = 1.

No flow anomaly in this interval. Also a complimentary pumping test in the section above 38 m showed that the transmissivity of this interval is low.

88–92 m

DZ2: Increased frequency of open and sealed fractures and sealed networks. Two crushed interval at 89.73–89.75 and 91.37–92.32 m. Fracture aperture 0.7 mm or less. Generally medium to strong oxidation. Minor brecciated interval at 89.75–89.90 m. The geophysical logging data show significantly decreased bulk resistivity and major caliper anomalies along the entire section. Metagranite-granodiorite (101057) and pegmatitic granite (101061). Confidence level = 3.

One flow anomaly at 89.1–89.5 m with a quite high transmissivity (about $6 \cdot 10^{-6}$ m^2/s). This is one of three observed flow anomalies in the borehole.

119–147 m

DZ3: Increased frequency of open fractures, sealed fractures and sealed fracture network. Four crushed intervals at 120.16–120.34, 120.90–121.06, 129.49–129.51 and 142.58–142.75 m. Fracture aperture 0.7 mm or less. Locally weak to medium oxidation. Significantly decreased bulk resistivity and major caliper anomalies along the intervals c. 118–120 m and c. 141–147 m. At c. 118 m the density is significantly decreased. Metagranite-granodiorite (101057), pegmatitic granite (101061), fine- to medium-grained granite (111058), amphibolite (102017) and fine- to medium-grained metagranodiorite-tonalite (101051). Confidence level = 2.

One flow anomaly at 119.4–120.0 m with a high transmissivity (about $1 \cdot 10^{-5}$ m^2/s). This is one of three observed flow anomalies in the borehole.

6 References

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WellCAD images

Title	SINGLE HOLE INTERPRETATION KFR101					
Site	FORSMARK - SFR	Inclination [°]	-55.49	Elevation [m.a.s.l.]	2.44	Signed data
Borehole	KFR101	Date of mapping	2008-07-08 09:56:00	Drilling Start Date	2008-05-06 13:00:00	
Diameter [mm]	76	Coordinate System	RT90-RHB70	Drilling Stop Date	2008-05-13 19:00:00	
Length [m]	341.760	Northing [m]	6701736.32	Surveying Date		
Bearing [°]	28.79	Easting [m]	1633351.40	Plot Date	2009-06-09 23:09:46	

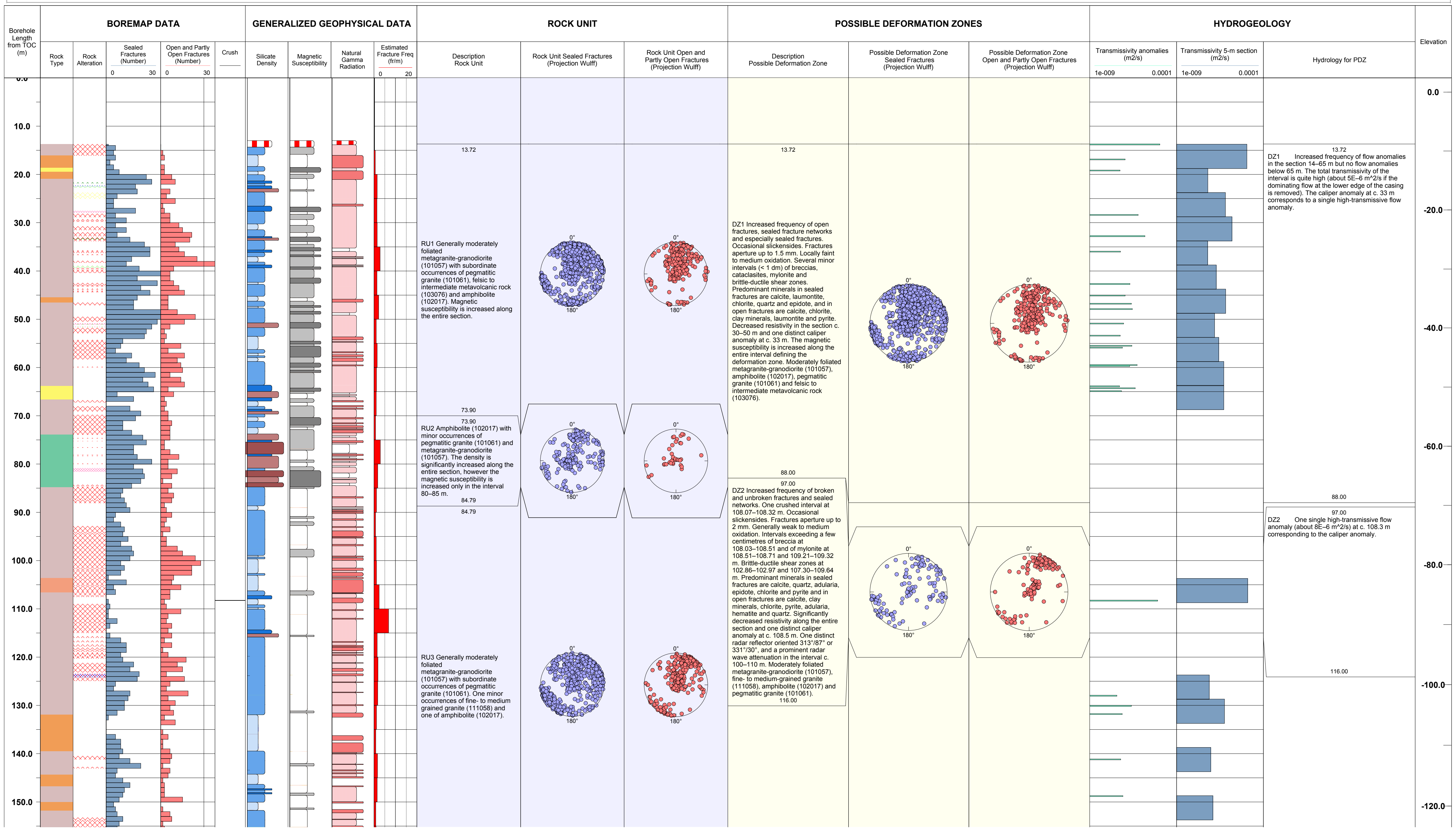
ROCKTYPE FORSMARK - SFR
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

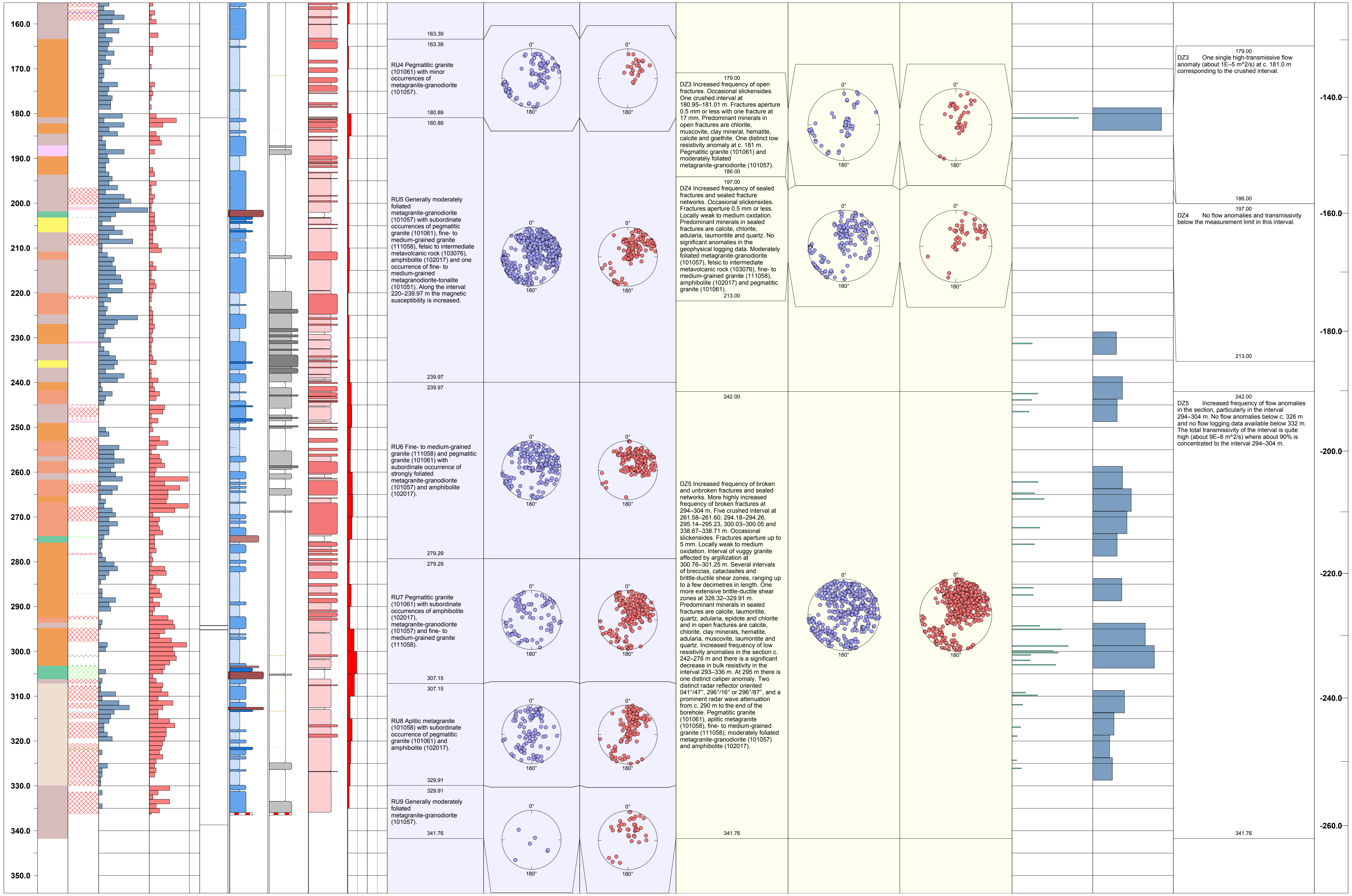
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Sericitisized
- Quartz dissolution
- Silicification
- Argillization
- Albitization
- Saussuritization
- Laumontitization

SILICATE DENSITY (kg/m³)
- unclassified
- dens<2680 (Granite)
- 2680<dens<2730 (Granodiorite)
- 2730<dens<2800 (Tonalite)
- 2800<dens<2890 (Diorite)
- dens>2890 (Gabbro)

SUSCEPTIBILITET (SI)
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

NATURAL GAMMA (µR/h)
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53





160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
240.0
250.0
260.0
270.0
280.0
290.0
300.0
310.0
320.0
330.0
340.0
350.0
163.39
163.39
RU4 Pegmatitic granite (101061) with minor occurrences of metagranite-granodiorite (101057).
180.89
180.89
RU5 Generally moderately foliated metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061), fine- to medium-grained granite (111058), felsic to intermediate metavolcanic rock (103076), amphibolite (102017) and one occurrence of fine- to medium-grained metagranodiorite-tonalite (101051). Along the interval 220–239.97 m the magnetic susceptibility is increased.
239.97
239.97
RU6 Fine- to medium-grained granite (111058) and pegmatitic granite (101061) with subordinate occurrence of strongly foliated metagranite-granodiorite (101057) and amphibolite (102017).
279.29
279.29
RU7 Pegmatitic granite (101061) with subordinate occurrences of amphibolite (102017), metagranite-granodiorite (101057) and fine- to medium-grained granite (111058).
307.15
307.15
RU8 Aplitic metagranite (101058) with subordinate occurrence of pegmatitic granite (101061) and amphibolite (102017).
329.91
329.91
RU9 Generally moderately foliated metagranite-granodiorite (101057).
341.76
0°
180°
179.00
DZ3 Increased frequency of open fractures. Occasional slickensides. One crushed interval at 180.95–181.01 m. Fractures aperture 0.5 mm or less with one fracture at 17 mm. Predominant minerals in open fractures are chlorite, muscovite, clay mineral, hematite, calcite and goethite. One distinct low resistivity anomaly at c. 181 m. Pegmatitic granite (101061) and moderately foliated metagranite-granodiorite (101057).
186.00
197.00
DZ4 Increased frequency of sealed fractures and sealed fracture networks. Occasional slickensides. Fractures aperture 0.5 mm or less. Locally weak to medium oxidation. Predominant minerals in sealed fractures are calcite, chlorite, adularia, laumontite and quartz. No significant anomalies in the geophysical logging data. Moderately foliated metagranite-granodiorite (101057), felsic to intermediate metavolcanic rock (103076), fine- to medium-grained granite (111058), amphibolite (102017) and pegmatitic granite (101061).
213.00
242.00
DZ5 Increased frequency of broken and unbroken fractures and sealed networks. More highly increased frequency of broken fractures at 294–304 m. Five crushed interval at 261.58–261.60, 294.18–294.26, 295.14–295.23, 300.03–300.05 and 338.67–338.71 m. Occasional slickensides. Fractures aperture up to 5 mm. Locally weak to medium oxidation. Interval of vuggy granite affected by argillization at 300.76–301.25 m. Several intervals of breccias, cataclasites and brittle-ductile shear zones, ranging up to a few decimetres in length. One more extensive brittle-ductile shear zones at 326.32–329.91 m. Predominant minerals in sealed fractures are calcite, laumontite, quartz, adularia, epidote and chlorite and in open fractures are calcite, chlorite, clay minerals, hematite, adularia, muscovite, laumontite and quartz. Increased frequency of low resistivity anomalies in the section c. 242–276 m and there is a significant decrease in bulk resistivity in the interval 293–336 m. At 295 m there is one distinct caliper anomaly. Two distinct radar reflector oriented 041°/47°, 296°/16° or 296°/87°, and a prominent radar wave attenuation from c. 290 m to the end of the borehole. Pegmatitic granite (101061), aplitic metagranite (101058), fine- to medium-grained granite (111058), moderately foliated metagranite-granodiorite (101057) and amphibolite (102017).
341.76
179.00
DZ3 One single high-transmissive flow anomaly (about 1E–5 m^2/s) at c. 181.0 m corresponding to the crushed interval.
186.00
197.00
DZ4 No flow anomalies and transmissivity below the measurement limit in this interval.
213.00
242.00
DZ5 Increased frequency of flow anomalies in the section, particularly in the interval 294–304 m. No flow anomalies below c. 326 m and no flow logging data available below 332 m. The total transmissivity of the interval is quite high (about 9E–6 m^2/s) where about 90% is concentrated to the interval 294–304 m.
341.76
-140.0
-160.0
-180.0
-200.0
-220.0
-240.0
-260.0

Title	SINGLE HOLE INTERPRETATION HFR101					
Site	FORSMARK - SFR	**Inclination [°]**	-70.03	**Elevation [m.a.s.l.]**	2.63	**Signed data**
Borehole	HFR101	**Date of mapping**	2008-09-24 16:00:00	**Drilling Start Date**	2008-04-23 10:10:00	
Diameter [mm]	137	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	2008-04-28 17:30:00	
Length [m]	209.300	**Northing [m]**	6701725.15	**Surveying Date**		
Bearing [°]	133.55	**Easting [m]**	1632838.91	**Plot Date**	2009-06-09 23:09:46	

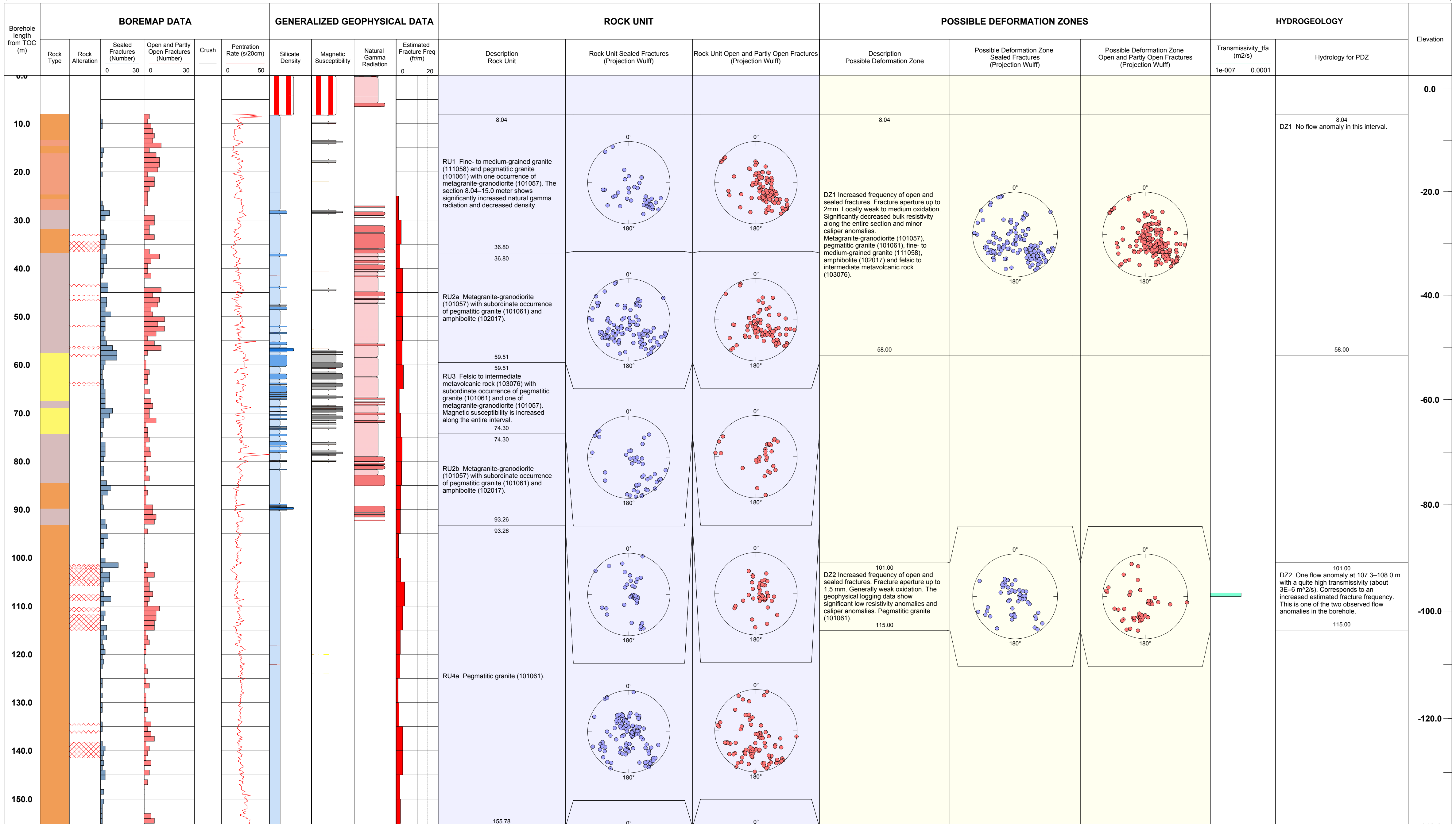
ROCKTYPE FORSMARK - SFR
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained
- Felsic to intermediate volcanic rock, metamorphic

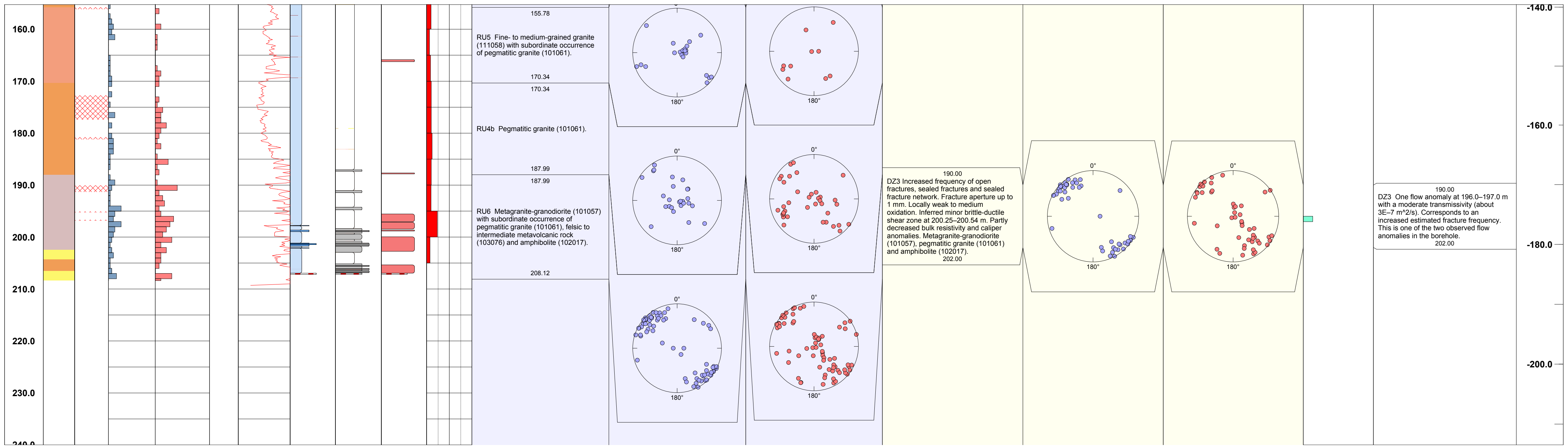
ROCK ALTERATION
- Oxidized

SILICATE DENSITY (kg/m³)
- unclassified
- dens<2680 (Granite)
- 2680<dens<2730 (Granodiorite)
- 2730<dens<2800 (Tonalite)

SUSCEPTIBILITET (SI)
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

NATURAL GAMMA (μR/h)
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53




160.0
170.0
180.0
190.0
200.0
210.0
220.0
230.0
240.0
155.78
RU5 Fine- to medium-grained granite (111058) with subordinate occurrence of pegmatitic granite (101061).
170.34
170.34
RU4b Pegmatitic granite (101061).
187.99
187.99
RU6 Metagranite-granodiorite (101057) with subordinate occurrence of pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and amphibolite (102017).
208.12
0°
180°
190.00
DZ3 Increased frequency of open fractures, sealed fractures and sealed fracture network. Fracture aperture up to 1 mm. Locally weak to medium oxidation. Inferred minor brittle-ductile shear zone at 200.25–200.54 m. Partly decreased bulk resistivity and caliper anomalies. Metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017).
202.00
190.00
DZ3 One flow anomaly at 196.0–197.0 m with a moderate transmissivity (about 3E–7 m^2/s). Corresponds to an increased estimated fracture frequency. This is one of the two observed flow anomalies in the borehole.
202.00
-140.0
-160.0
-180.0
-200.0

Title	SINGLE HOLE INTERPRETATION HFR102					
Site	FORSMARK - SFR	Inclination [°]	-59.13	Elevation [m.a.s.l.]	2.32	Signed data
Borehole	HFR102	Date of mapping	2008-06-26 19:41:00	Drilling Start Date	2008-04-29 13:00:00	
Diameter [mm]	138	Coordinate System	RT90-RHB70	Drilling Stop Date	2008-05-05 15:00:00	
Length [m]	55.040	Northing [m]	6701728.55	Surveying Date		
Bearing [°]	85.00	Easting [m]	1632974.54	Plot Date	2009-06-04 23:09:38	

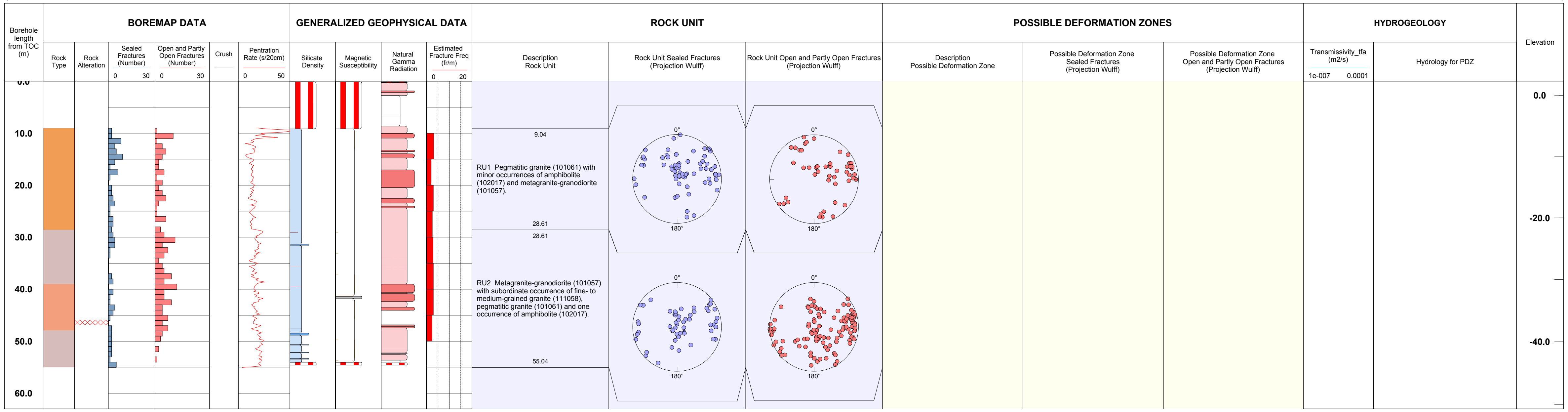
ROCKTYPE FORSMARK - SFR
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained

ROCK ALTERATION
- Oxidized

SILICATE DENSITY (kg/m³)
- unclassified
- dens<2680 (Granite)
- 2680<dens<2730 (Granodiorite)

SUSCEPTIBILITET (SI)
- unclassified
- sus<0.001
- 0.001<sus<0.01

NATURAL GAMMA (μR/h)
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53



Title	**SINGLE HOLE INTERPRETATION HFR105**					
Site	FORSMARK - SFR	**Inclination [°]**	-61.90	**Elevation [m.a.s.l.]**	3.27	**Signed data**
Borehole	HFR105	**Date of mapping**	2008-05-21 11:07:00	**Drilling Start Date**	2008-04-16 08:45:00	
Diameter [mm]	140	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	2008-04-22 10:45:00	
Length [m]	200.500	**Northing [m]**	6701376.55	**Surveying Date**		
Bearing [°]	35.43	**Easting [m]**	1632686.82	**Plot Date**	2009-06-09 23:09:46	

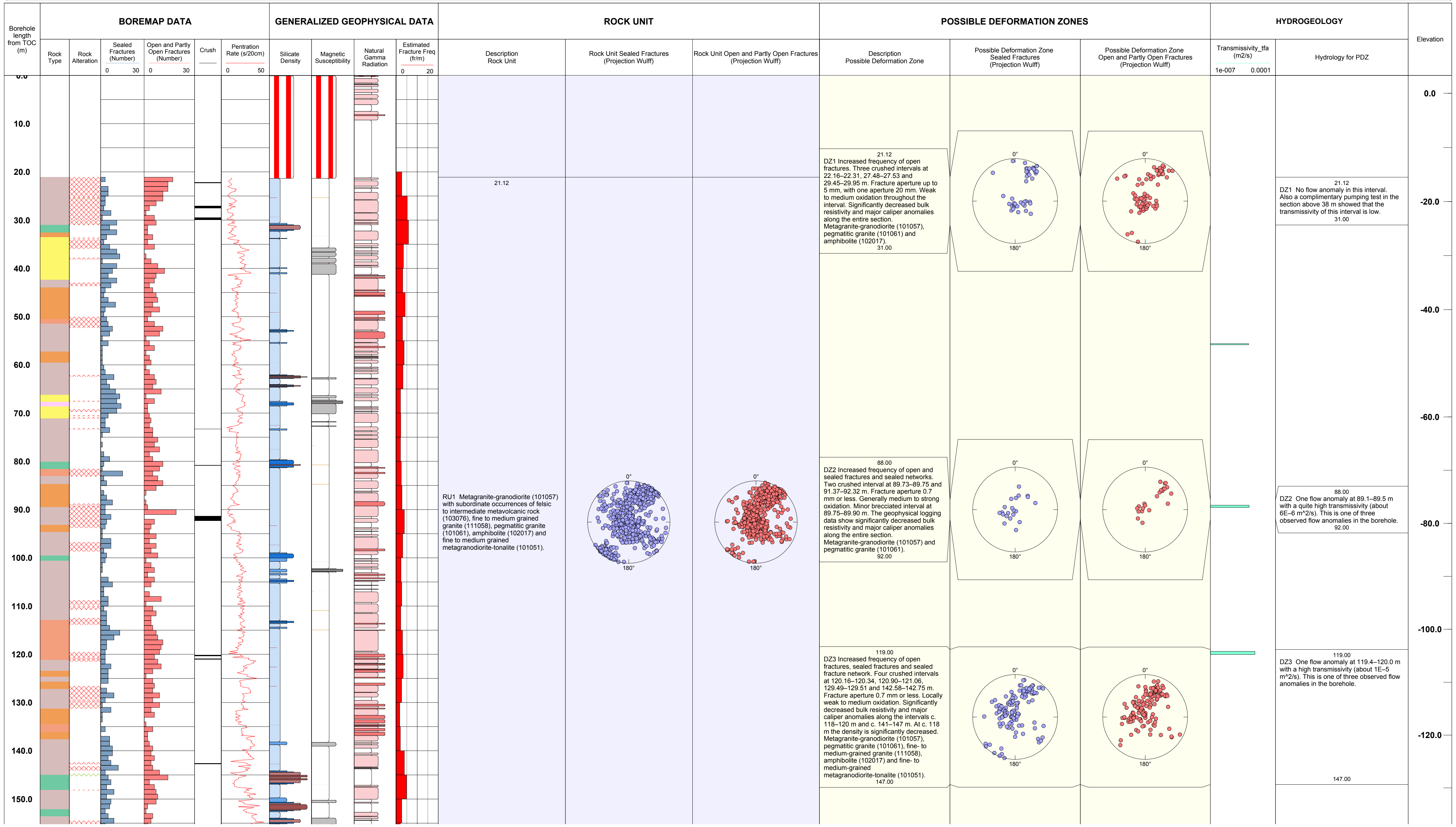
ROCKTYPE FORSMARK - SFR
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

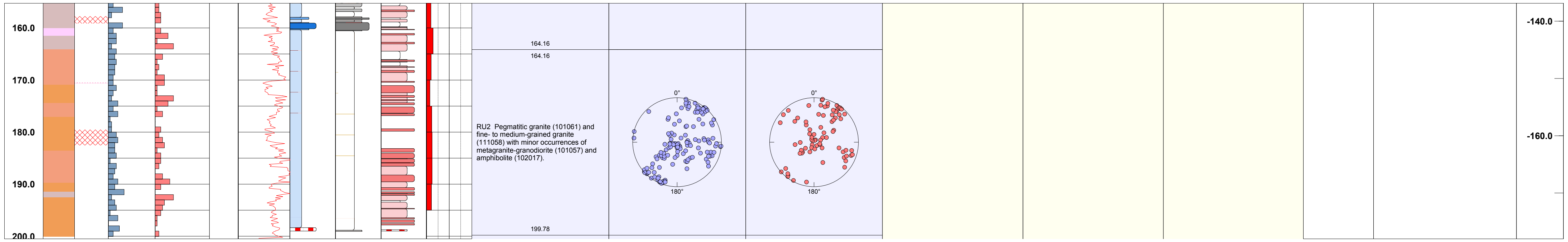
ROCK ALTERATION
- Oxidized
- Epidotized
- Albitization

SILICATE DENSITY (kg/m³)
- unclassified
- dens<2680 (Granite)
- 2680<dens<2730 (Granodiorite)
- 2730<dens<2800 (Tonalite)
- 2800<dens<2890 (Diorite)
- dens>2890 (Gabbro)

SUSCEPTIBILITET (SI)
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

NATURAL GAMMA (μR/h)
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53




160.0
170.0
180.0
190.0
200.0
164.16
164.16
RU2 Pegmatitic granite (101061) and fine- to medium-grained granite (111058) with minor occurrences of metagranite-granodiorite (101057) and amphibolite (102017).
199.78
0°
180°
0°
180°
-140.0
-160.0