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Abstract

This report presents the geological single-hole interpretations of the cored boreholes KFR104 and KFR27 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 KFR104 has been divided into four different rock units, RU1–RU4, of which RU1 and RU2 each occur in two separate length intervals. The predominant rock type in RU1 and RU2 is pegmatitic granite (101061), whereas RU3 mainly consists of a lineated to foliated metagranite-granodiorite (101057), which locally is muscovite-bearing and faintly albitized. Rock unit 4 consists of fine- to medium-grained granite (111058), pegmatitic granite (101061), and a felsic to intermediate metavolcanic rock (103076) in approximately equal proportions. Six possible deformation zones of brittle character have been interpreted in KFR104 (DZ1–DZ6), one with a low degree of confidence and the other five with a high degree of confidence.

The geological mapping of borehole KFR27 consists of two parts: a broached part down to 147.5 m where no other information than geophysics and the BIPS-image were available, and below that level a part where the mapping was made by use of drill core, geophysics and BIPS-image. The borehole has been divided into five different rock units, RU1–RU5, of which RU2 and RU4 each occur in two separate length intervals and RU3 occurs in three separate length intervals. Pegmatitic granite (10106) and lineated metagranite-granodiorite (101057) predominates RU1, whereas RU2, RU3 and RU4 mainly consist of pegmatitic granite (101061), metagranite-granodiorite (101057; locally strongly foliated) and amphibolite, respectively. Rock unit 5 is dominated by metagranite-granodiorite (101057; locally strongly foliated) and fine- to medium-grained granite (111058) in approximately equal proportions. Four possible deformation zones of brittle character have been interpreted in KFR27 (DZ1–DZ4), one with a low degree of confidence, one with a medium degree of confidence and the other two with a high degree of confidence. The lowermost possible deformation zone, DZ4, is composite and locally characterised by strong brittle-ductile deformation.

Sammanfattning

Denna rapport presenterar den geologiska enhålstolkningen från kärnborrhålen KFR104 och KFR27 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 KFR104 har delats upp i fyra litologiska enheter, RU1–RU4, av vilka RU1 och RU2 vardera förekommer i två separata längdintervall. Den dominerande bergarten i RU1 och RU2 är pegmatitisk granit (101061), medan RU3 huvudsakligen består av en stänglig till folierad metagranit-granodiorit (101057), som lokalt är muskovitförande och svagt albitiserad. RU4 består av fin- till medelkornig granit (111058), pegmatitisk granit (101061) och en felsisk till intermediär metavulkanisk bergart (103076) i ungefär likartade proportioner. Sex möjliga deformationszoner av spröd karaktär har tolkats i KFR104 (DZ1–DZ6), en med låg grad av tillförlitlighet och de andra fem med en hög grad av tillförlitlighet.

Den geologiska karteringen av kärnborrhål KFR27 består av två delar: en upprymd del ner till 147,5 m där ingen information utöver geofysik och BIPS-bild varit tillgänglig, samt under denna nivå en del där karteringen dessutom är baserad på tillgänglig borrkärna. Kärnborrhål KFR27 har delats upp i fem litologiska enheter, RU1–RU5, av vilka RU2 och RU4 vardera förekommer i två separata längdintervall och RU3 förekommer i tre separata längdintervall. Pegmatitisk granit (101061) och stänglig metagranit-granodiorite (101057) dominerar RU1, medan RU2, RU3 och RU4 huvudsakligen består av pegmatitisk granit (101061),metagranit-granodiorit (101057; lokalt skaftigt folierad) respektive amfibolit (102017). RU5 domineras av metagranit-granodiorit (101057; lokalt kraftigt folierad) och fin- till medelkornig granit (111058) i ungefär likartade proportioner. Fyra möjliga deformationszoner av spröd karaktär har tolkats i KFR27 (DZ1–DZ4), en med låg grad av tillförlitlighet, en med medelhög grad av tillförlitlighet och de två övriga med en hög grad av tillförlitlighet. Den understa möjliga deformationszonen, DZ4, är sammansatt och karaktäriseras lokalt av kraftig spröd-plastisk deformation.

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 KFR104 and KFR27. 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.

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.

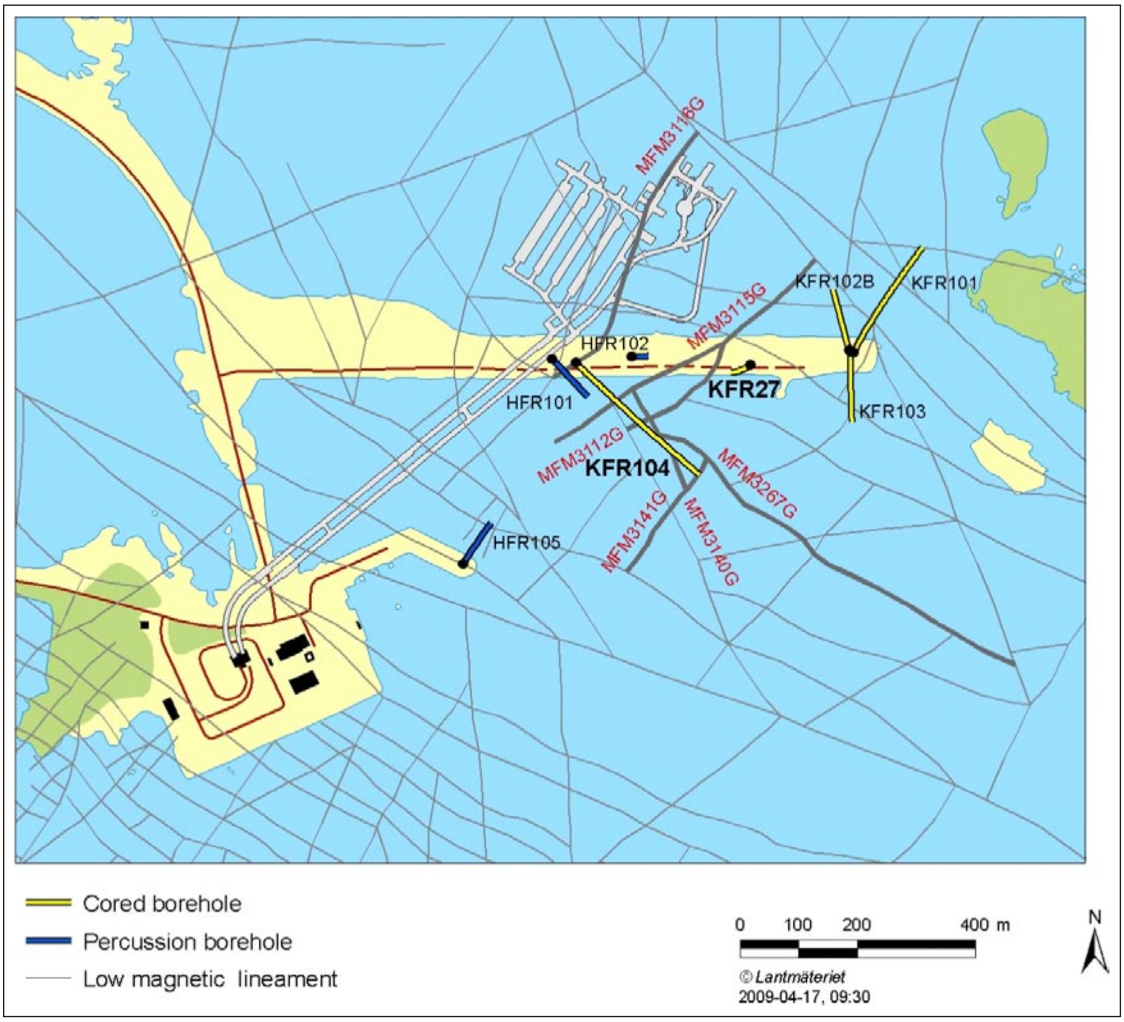

Figure 1-1. *Map showing position and horizontal projection of the cored boreholes KFR104 and KFR27 relative to SFR and other boreholes in the drilling programme.*

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

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 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 KFR104 and KFR27.

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

The geological mapping of the boreholes 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 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.

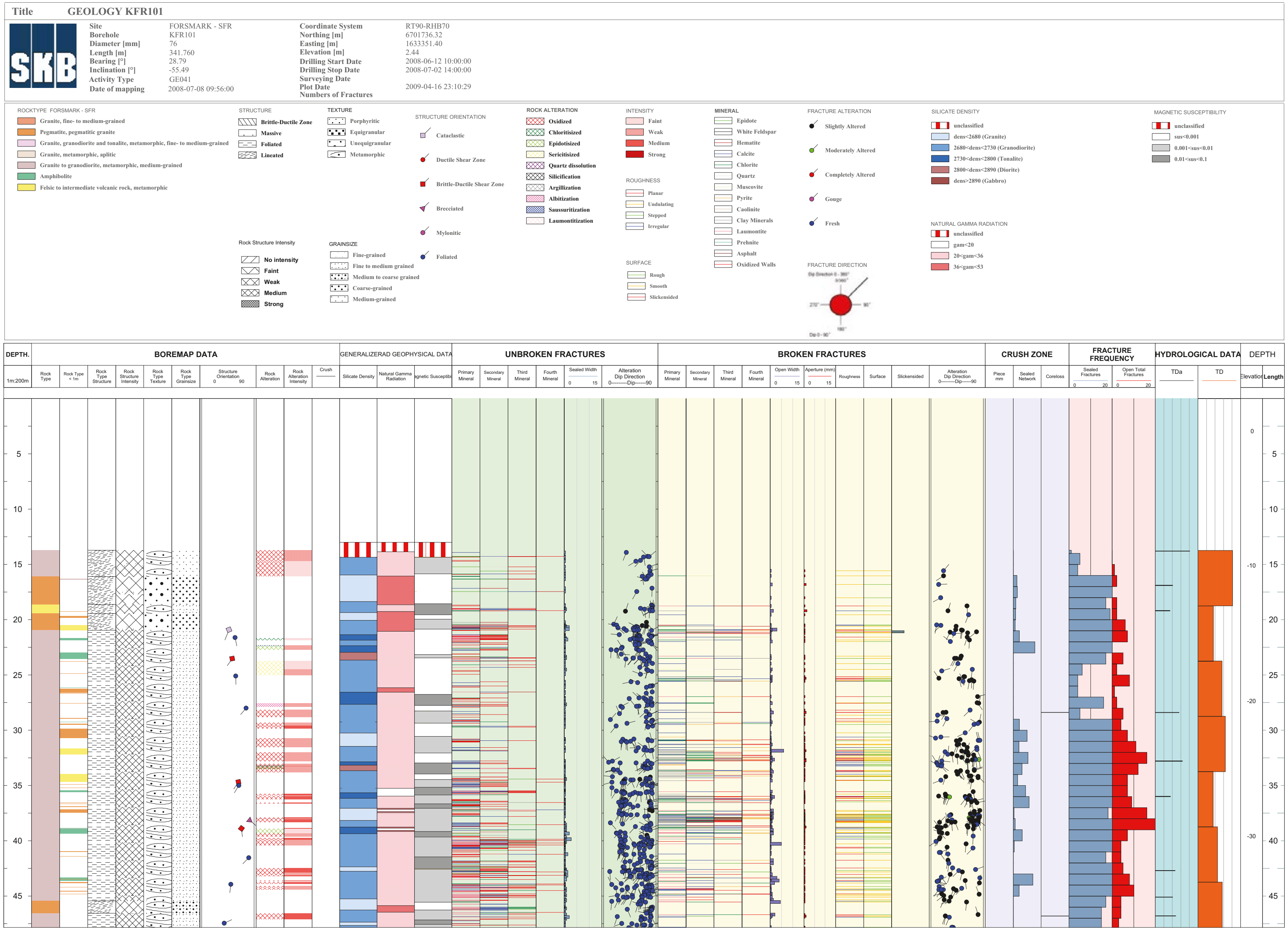

Figure 3-1. Example of WellCAD plot (from borehole KFR101) used as basis for the geological single-hole interpretation.

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 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.

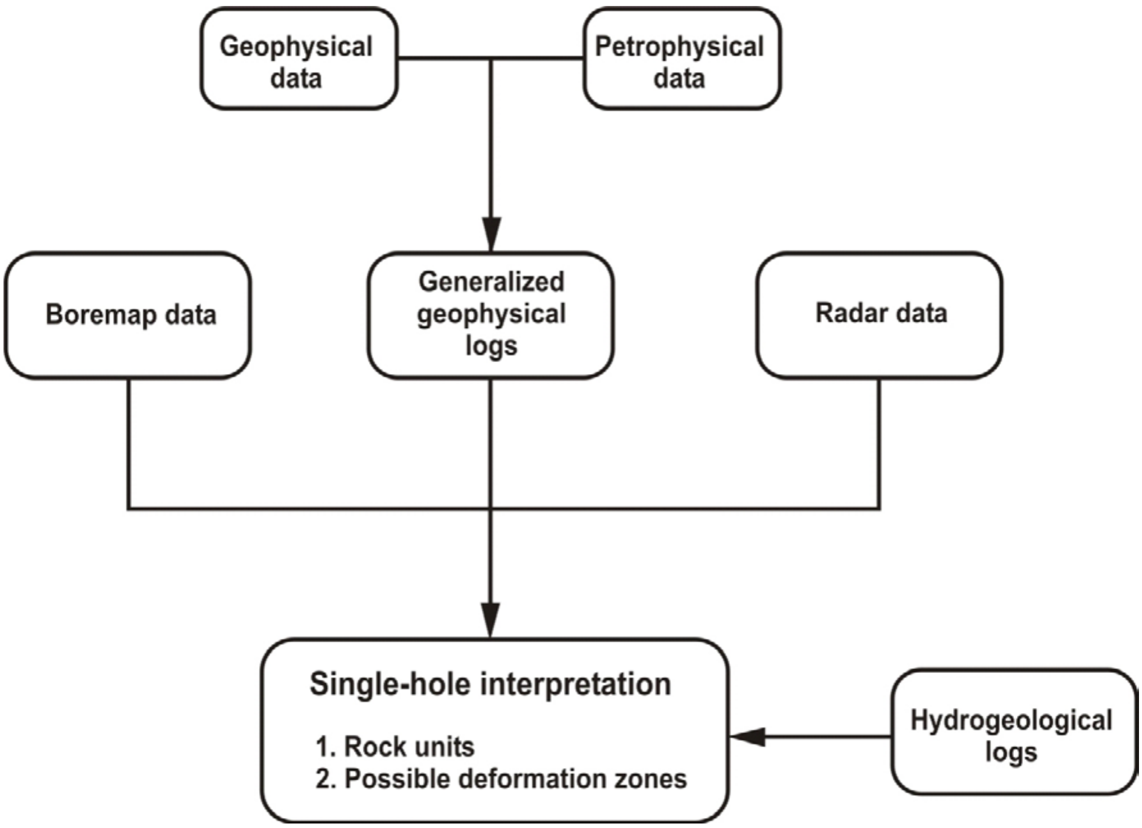

Figure 4-1. *Schematic chart showing the procedure for the development of a geological single-hole interpretation.*

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.

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, SPR, 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 boreholes KFR104 and KFR27 (Figure 4-3 and Figure 4-4). 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 measurements, based on 20 MHz dipole data, are presented in Figure 4-5 and Figure 4-6. Along some intervals in the boreholes, e.g. in KFR27 from 425 m to 480 m, the penetration is very limited due to relatively high electrical conductivity in the borehole fluid. The effect of attenuation varies between the different antenna frequencies (in this case 20 MHz dipole and 60 MHz directional antenna). In some cases, alternative orientations for oriented radar reflectors are presented, and a decision concerning which of the alternatives that represent the true orientation cannot be made. Orientations from the directional radar are presented as strike/dip using the right-hand-rule method.

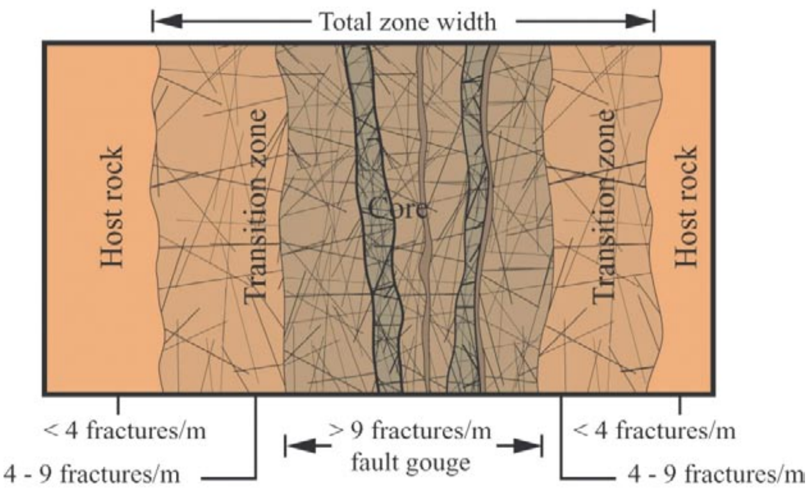

***Figure 4-2.** Schematic illustration of the structure of a brittle deformation zone. After /Munier et al.2003/.*

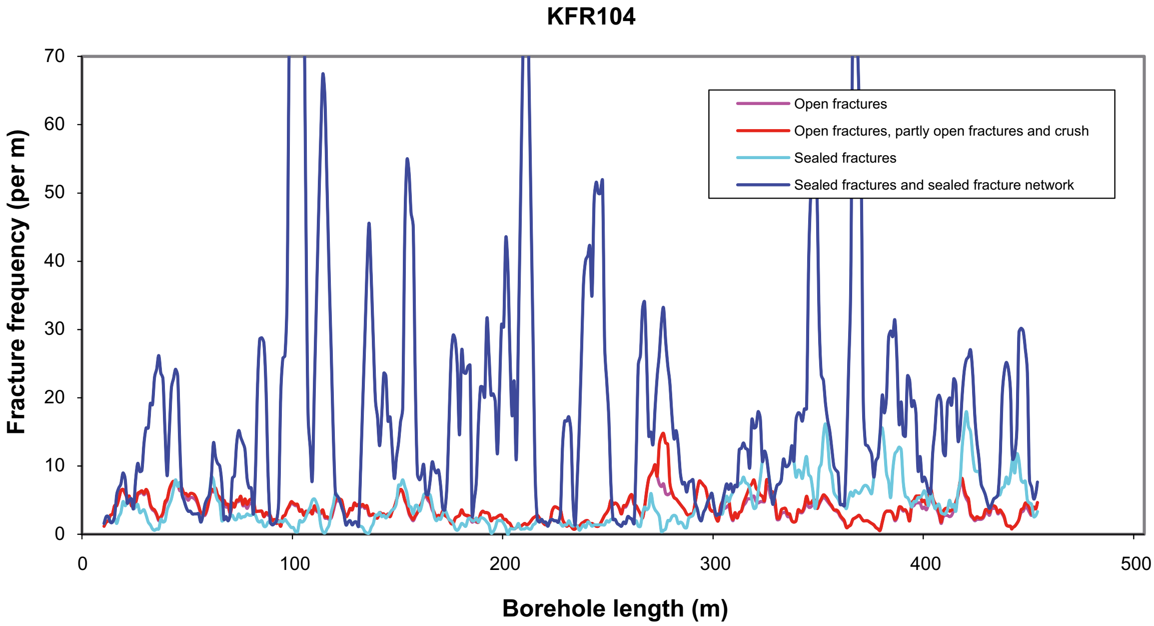

Figure 4-3. *Fracture frequency plot for KFR104. Moving average with a 5 m window and 1 m steps.*

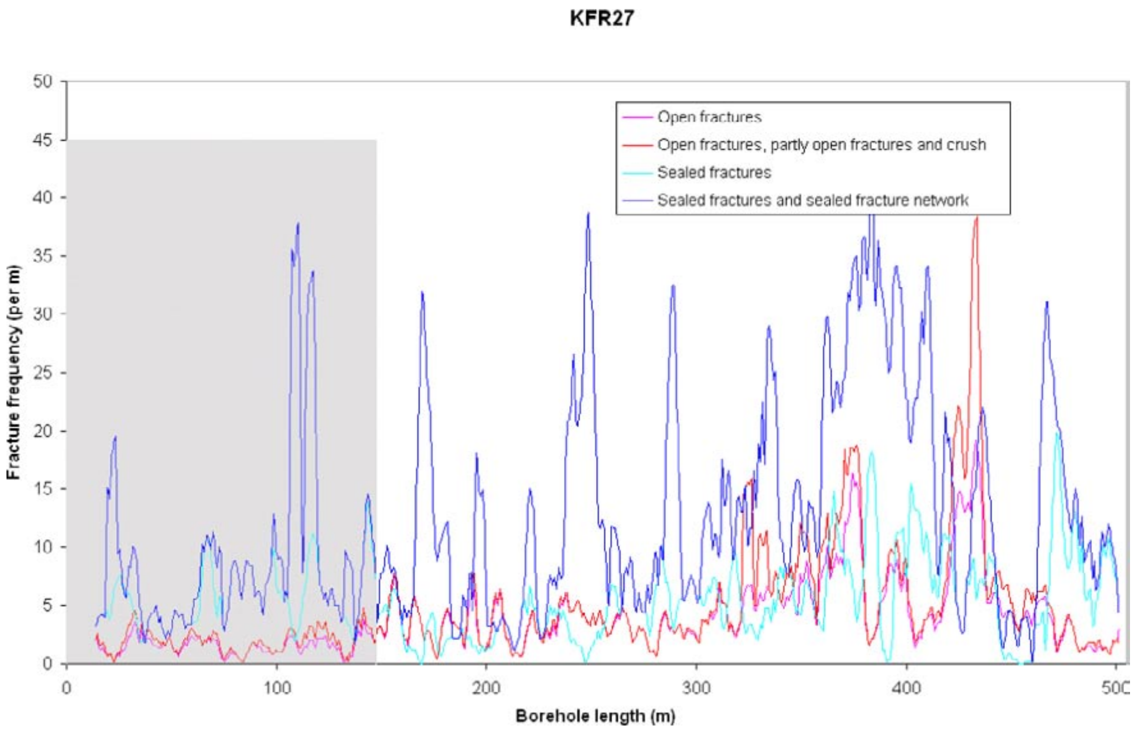

Figure 4-4. *Fracture frequency plot for KFR27. Moving average with a 5 m window and 1 m steps. The upper part down to 147.5 m, which is mapped without access to drill core is shaded.*

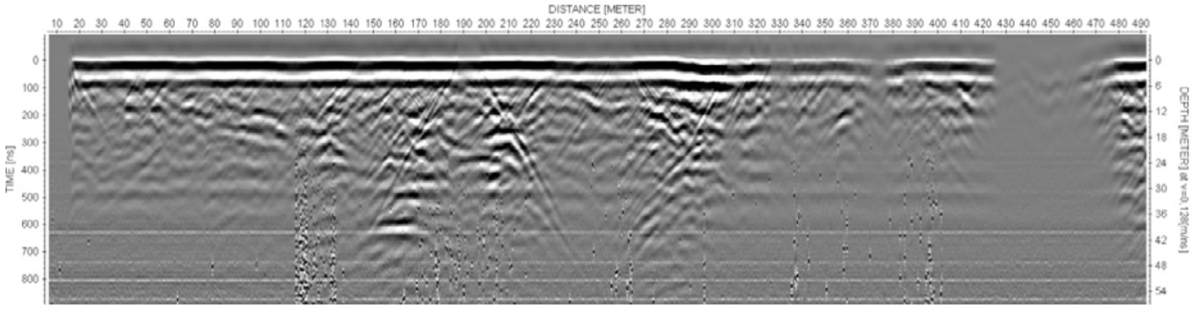

Figure 4-5. Overview (20 MHz data) of the radar data for borehole KFR27 (0–500 m).

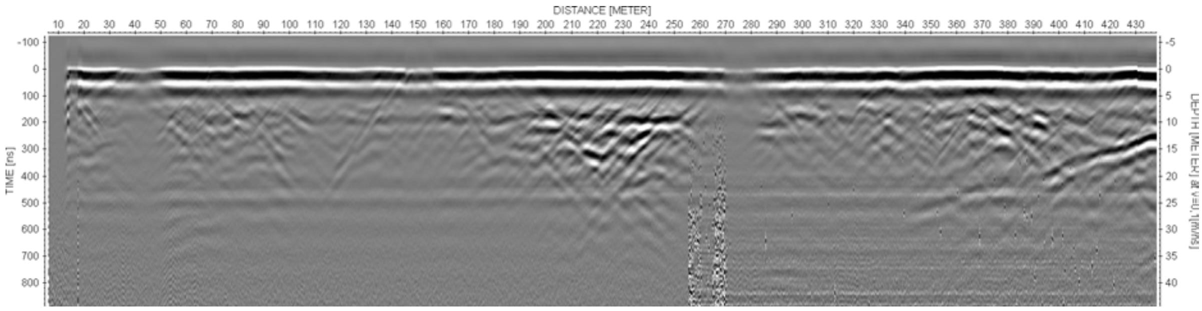

Figure 4-6. Overview (20 MHz data) of the radar data for boreholes KFR104. Observe a clear sub-parallel structure at the end part of the borehole.

4.2 Hydrogeological single-hole interpretation

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 hydro-geological columns were however not accessible at the geological interpretation stage.

In this particular case the single-hole interpretation concerned two cored boreholes with differential flow logging data.

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

KFR27 is a cored borehole that was drilled 1981 during the construction of SFR in order to measure the rock stress. However, the drill core is now lost. During the present site investigation programme it was decided to broach and extend the borehole from 148.51 m down to 501.64 m. Thus, the interval between 11.82 and 147.49 m has been mapped as a percussion borehole, with no other information than a BIPS-image (cf. /Döse 2009/). The interval from 147.49 to 500.97 m has been mapped as a regular cored borehole. The last 0.67 m (500.97–501.64 m) was also mapped without access to BIPS-image.

The interval between 430.80 and 433.00 m of KFR27 was according to Sicada drilled at c. 84 mm, instead of c. 76 mm, which is the regular diameter of the cored boreholes drilled during the site investigations. The orientations of observations within this interval have therefore overestimated alpha-angles, resulting in wrongly calculated strikes and dips.

The last 12.52 m (442.05–454.57 m) of KFR104 was mapped without access to BIPS-image.

Geophysical logging was performed in KFR27 both before it was extended and afterwards. The results of the total gamma radiation log differed significantly between the two loggings (Figure 4-7). The interval down to 146.5 m borehole length has been logged twice. In the first log, before the hole was extended, the radiation levels are comparable to other holes around Forsmark. However, the radiation levels are higher below around 60 m borehole length in the second log compared to the first log, the difference being around 30 to 60 µR/h, increasing towards depth. The radiation level in the second log is also much higher than expected for deeper parts of the hole, to at least 460 m borehole length. Local radiation anomalies are more or less identical in the two logs, apart from the difference in background level. There is no expected measurement error in the second logging that can explain the anomalous results. A plausible but yet unverified explanation is that radon has entered the hole at around 460 m borehole length and has migrated upwards.

In KFR104 there is a tendency towards slightly elevated gamma radiation levels between 78 and 210 m borehole length that could be due to radon influx. It is however quite possible that the rocks within this interval have a higher than average content of radioactive elements, for this type of lithology.

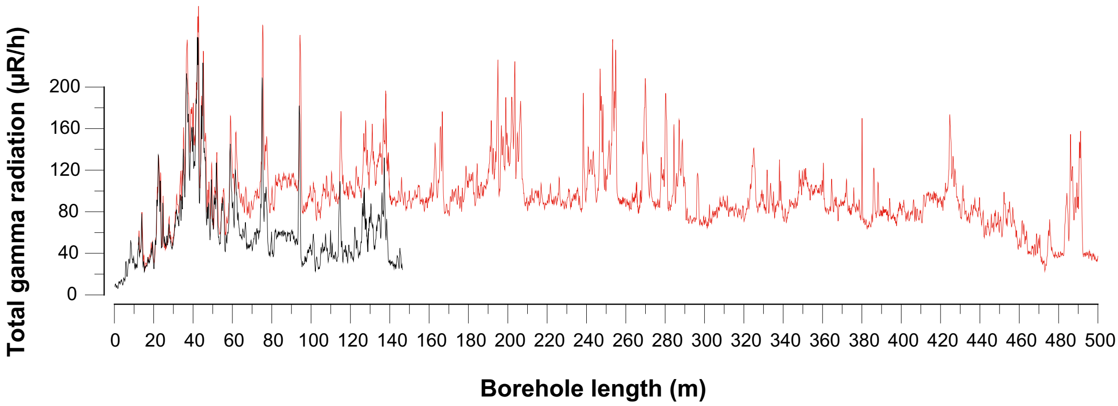

Figure 4-7. *Results from total gamma radiation logs in KFR27. The black line shows results from a logging before the hole was extended and the red curve shows a log from after the hole was extended.*

5 Results

The results of the geological single-hole interpretations of KFR104 and KFR27 are presented as print-outs from the software WellCAD in Appendix 1.

5.1 KFR104

The orientation at the beginning of the borehole is 133.8°/–53.8°.

Rock Units

The borehole can be divided into four different rock units, RU1–RU4. Rock units 1 and 2 occur each in two separate length intervals. All rock units have been interpreted with a high degree of confidence.

8.73–76.82 m

RU1a: Pegmatitic granite (101061) with subordinate metagranite-granodiorite (101057), locally strongly foliated. Minor amounts of felsic to intermediate metavolcanic rock (103076) and amphibolite (102017). Confidence level = 3.

76.82–118.98 m

RU2a: Pegmatitic granite (101061) with one occurrence of fine- to medium-grained granite (111058). Confidence level = 3.

118.98–307.99 m

RU1b: Pegmatitic granite (101061) with subordinate metagranite-granodiorite (101057), locally strongly foliated. Minor amounts of aplitic metagranite (101058), felsic to intermediate metavolcanic rock (103076), fine- to medium-grained granite (111058) and amphibolite (102017). Decreased bulk resistivity in pegmatitic granite. Confidence level = 3.

307.99–358.63 m

RU3: Lineated to foliated metagranite-granodiorite (101057) locally muscovite-bearing accompanied by faint albitization. Subordinate occurrences of pegmatitic granite (101061) and minor occurrences of amphibolite (102017). Confidence level = 3.

358.63–416.25 m

RU2b: Pegmatitic granite (101061) with minor occurrence of felsic to intermediate metavolcanic rock (103076), metagranite-granodiorite (101057) and amphibolite (102017). Confidence level = 3.

416.25–454.57 m

RU4: Fine- to medium-grained granite (111058), pegmatitic granite (101061), metagranite-granodiorite (101057) and felsic to intermediate metavolcanic rock (103076) in approximately equal proportions. Minor occurrences of amphibolite (102017). Confidence level = 3.

A distinct radar reflector, sub-parallel to borehole (063°/42° or 055°/63°), extends from 340 m to the end of the borehole. The reflector is predicted to intersect the borehole at 555 m borehole length.

Possible deformation zones

Six possible deformation zones of brittle character have been interpreted in KFR104, one with a low degree of confidence and the other five with a high degree of confidence.

30–45.5 m

DZ1: Increased frequency of sealed fracture networks. Faint oxidation in the lower half of the interval and quarts dissolution at 38.30–40.75 m where vugs are filled with calcite. Fracture apertures up to 1 mm with a single aperture at 3 mm. Predominant minerals in sealed fracture networks are chlorite, adularia and hematite. Low electric resistivity. Pegmatitic granite (101061) and metagranite-granodiorite (101057). Confidence level = 1.

Rather high, but not anomalous, transmissivity of the interval ($2 \cdot 10^{-7}$ m^2/s).

149–154 m

DZ2: Increased frequency of open and sealed fractures. Fractures aperture up to 1 mm. A few moderately altered open fractures. Minor intervals of brecciation at 150.96–151.38 and 153.64–153.80 m. Locally weak to moderate argillization. Predominant minerals in sealed fractures are calcite, chlorite and laumontite and in open fractures are chlorite, calcite and hematite. Low electric resistivity. One distinct radar reflector at the lower end of the interval oriented 105°/15°. Pegmatitic granite (101061), metagranite-granodiorite (101057) and amphibolite (102017). Confidence level = 3.

Low transmissivity of the interval ($4 \cdot 10^{-9}$ m^2/s).

268–283 m

DZ3: Increased frequency of open fractures and sealed fracture network. Two crushes at 276.36–276.64 and 277.46–277.75 m. Fracture apertures up to 0.5 mm with a single aperture at 3 mm. Generally weak to moderate oxidation and one interval of carbonatization at 275.06–275.95 m. Predominant minerals in open fractures are chlorite, laumontite, hematite and calcite. Very low electric resistivity and one caliper anomaly. Two radar reflectors of which one is oriented (109°/20° or 232°/85°). Pegmatitic granite (101061), aplitic metagranite (101058), metagranite-granodiorite (101057) and amphibolite (102017). Confidence level = 3.

Two single flow anomalies where the transmissivity of the interval ($1 \cdot 10^{-7}$ m^2/s) is dominated by the anomaly at 276 m.

382–387 m

DZ4: Increased frequency of sealed fracture networks. One minor cataclasite at 383.34–383.36 m. Locally faint to moderate oxidation. Fracture aperture up to 1mm. Predominant minerals in sealed fracture networks are adularia, laumontite, chlorite and calcite. One minor resistivity anomaly. One oriented radar reflector (216°/70° or 184°/11°). Felsic to intermediate metavolcanic rock (103076) and pegmatitic granite (101061). Confidence level = 3.

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

396–405 m

DZ5: Increased frequency of open fractures. One minor cataclasite along the lower limit of the possible zone at 400.39–400.41 m. Fracture apertures up to 2 mm. Several moderately altered open fractures. Varying degrees of argillization and epidotization in the lower half of the interval. Predominant minerals in open fractures are clay minerals, chlorite and calcite. Low electric resistivity and one minor caliper anomaly. Pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

One single flow anomaly ($T = 1 \cdot 10^{-8}$ m^2/s) at 405 m. This is the only flow anomaly in the borehole below 350 m.

447–454.57 m

DZ6: Increased frequency of sealed fractures and sealed fracture network in the upper half of the interval. One brecciated interval at 452.97–453.05 m. Locally faint to strong oxidation and laumontization. No BIPS image of the interval. Predominant minerals in sealed fractures are laumontite, calcite and chlorite. Low electric resistivity and one major caliper anomaly. Fine to medium grained granite (111058), pegmatitic granite (101061) and metagranite-granodiorite (101057). Confidence level = 3.

No hydraulic data from this interval.

5.2 KFR27

The orientation at the beginning of the borehole is 248.2°/–87.4°.

Rock Units

The borehole can be divided into five different rock units, RU1–RU5. Rock units 2 and 4 occur each in two separate length intervals, whereas RU3 occurs in three separate length intervals. All rock units have been interpreted with a high degree of confidence.

11.82–121.10 m

RU1: Pegmatitic granite (101061) and lineated metagranite-granodiorite (101057) in approximately equal proportions. One interval of fine- to medium-grained granite (111058). Minor occurrence of felsic to intermediate metavolcanic rock (103076) and amphibolite (102017) in the lower half of the rock unit. Confidence level = 3.

121.10–140.17 m

RU2a: Pegmatitic granite (101061) with two minor occurrence of metagranite-granodiorite (101057). Confidence level = 3.

140.17–190.19 m

RU3a: Locally strongly foliated metagranite-granodiorite (101057) with subordinate pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076), amphibolite (102017) and one occurrence of fine- to medium-grained granite (111058). Confidence level = 3.

190.19–207.84 m

RU2b: Pegmatitic granite (101061) with minor occurrences of metagranite-granodiorite (101057), aplitic metagranite (101058) and amphibolite (102017). One crush at 192.51–192.71 m corresponding to very low resistivity anomaly and a deflection in temperature gradient. One very distinct radar reflector at approximately 195 m (090°/15°). Confidence level = 3.

207.84–290.53 m

RU3b: Locally strongly foliated metagranite-granodiorite (101057) with subordinate pegmatitic granite (101061). Minor occurrence of amphibolite (102017), fine- to medium-grained granite (111058) and one occurrence of felsic to intermediate metavolcanic rock (103076). Low bulk resistivity in the interval 220–270 m. Confidence level = 3.

290.53–323.03 m

RU4a: Amphibolite (102017) with subordinate foliated metagranite-granodiorite (101057) and pegmatitic granite (101061). High to very high magnetic susceptibility related to high density. Confidence level = 3.

323.03–436.55 m

RU5: Locally strongly foliated metagranite-granodiorite (101057) and fine- to medium-grained granite (111058) in approximately equal proportions. Subordinate amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3.

436.55–474.65 m

RU4b: Amphibolite (102017) with subordinate foliated metagranite-granodiorite (101057) and pegmatitic granite (101061). Confidence level = 3.

474.65–501.64 m

RU3c: Foliated metagranite-granodiorite (101057) and pegmatitic granite (101061). Confidence level = 3.

Possible deformation zones

Four possible deformation zones of brittle character have been interpreted in KFR27, one with a low degree of confidence, one with a medium degree of confidence and the other two with a high degree of confidence. The lowermost possible deformation zone is composite and locally characterised by strong brittle-ductile deformation.

108–120 m

DZ1: Increased frequency of sealed fractures and sealed fracture networks. Locally weak to moderate oxidation. No core available. Moderate resistivity anomalies. One radar reflector intersecting the borehole at approximately 118 m with an intersection angle of 6°. Pegmatitic granite (101061), metagranite-granodiorite (101057) and felsic to intermediate metavolcanic rock (103076). Confidence level = 1.

Medium transmissivity of this interval ($T = 8 \cdot 10^{-8}$ m^2/s).

323–379.5 m

DZ2: Several shorter intervals with increased frequency of open and sealed fractures and a more extensive interval in the lower most part of the possible deformation zone. Thirteen crush sections throughout the interval and one minor breccia at 338.51–338.52 m. Fracture aperture up to 1mm. Locally faint to moderate oxidation and faint to weak argillization. Predominant minerals in open fractures are calcite, chlorite, clay minerals and hematite. Low electric resistivity especially in the lower part of the section. A minor deflection in the temperature gradient. Three radar reflectors, two oriented (352°/01° or 332°/11° and 334°/65° or 154°/53°) and one without orientation. Fine- to medium-grained granite (111058), metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

Increased frequency of flow anomalies. The total transmissivity of the interval is $1 \cdot 10^{-6}$ m^2/s.

389–401 m

DZ3: Increased frequency of sealed and open fractures and sealed fracture networks. One crush at the interval 394.71–394.75 m. Fracture aperture up to 0.5 mm and one single aperture at 3 mm. Generally weak to moderate oxidation. Predominant minerals in open fractures are chlorite, laumontite and clay minerals, in sealed fractures calcite, laumontite and quartz and in the crushed interval chlorite and clay minerals. Moderate resistivity anomalies. Metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017). Confidence level = 2.

One single low-transmissive ($T = 1 \cdot 10^{-9}$ m^2/s) flow anomaly at 392.1 m.

421–469 m

DZ4: The possible deformation zone can be divided in to three different characteristic intervals. The uppermost interval, extending down to c.442 m, is characterized by increased frequency of sealed and especially open fractures. Six crushed sections with a concentration between 431.4–433.5 m. Fracture aperture up to 3 mm Generally faint to moderate oxidation and faint to strong quarts dissolution. Predominant minerals in open fractures are hematite, calcite, clay minerals and adularia, in sealed fractures adularia, epidote, calcite and quartz and in crushed intervals clay minerals and adularia. Very low resistivity especially in the central part. Several calliper anomalies and a moderate deflection in the temperature gradient. The central sub interval extends from c. 442 m to c. 463 m, is characterized by strong brittle-ductile deformation and intense alteration that includes oxidation, quarts dissolution, argillization, chloritization and epidotization. Three crushes at 446.86–446.91, 448.12–448.14 and 458.30–458.33 m. Several moderately altered open fractures. Apertures ranging up to 2 mm. Predominant mineral in open fractures are clay minerals. The lower most interval, from c.463m, is characterized by increased frequency of sealed and open fractures. A few moderately to strongly altered open fractures. Generally weak oxidation and locally chloritization. Apertures ranging up to 3 mm. Predominant minerals in open fractures are chlorite and clay minerals and in sealed fractures adularia, laumontite and calcite. Very low resistivity especially in the central part. Several calliper anomalies and a moderate deflection in the temperature gradient. Amphibolite (102017), metagranite-granodiorite (101057), fine- to medium-grained granite (111058) and pegmatitic granite (101061). Confidence level = 3.

A cluster of flow anomalies at 410–436 m. The transmissivity is concentrated to the section 423–429 m. No flow anomaly below 436 m. The total transmissivity of the interval is $4 \cdot 10^{-6}$ m^2/s.

6 References

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WellCAD images

Title	SINGLE HOLE INTERPRETATION KFR104					
Site	FORSMARK - SFR	Inclination [°]	-54.86	Elevation [m.a.s.l.]	2.83	Signed data
Borehole	KFR104	Date of mapping	2008-11-10 14:37:00	Drilling Start Date	2008-09-02 11:50:00	
Diameter [mm]	76	Coordinate System	RT90-RHB70	Drilling Stop Date	2008-09-29 18:15:00	
Length [m]	454.570	Northing [m]	6701719.45	Surveying Date		
Bearing [°]	133.78	Easting [m]	1632879.34	Plot Date	2009-06-11 23:09:53	

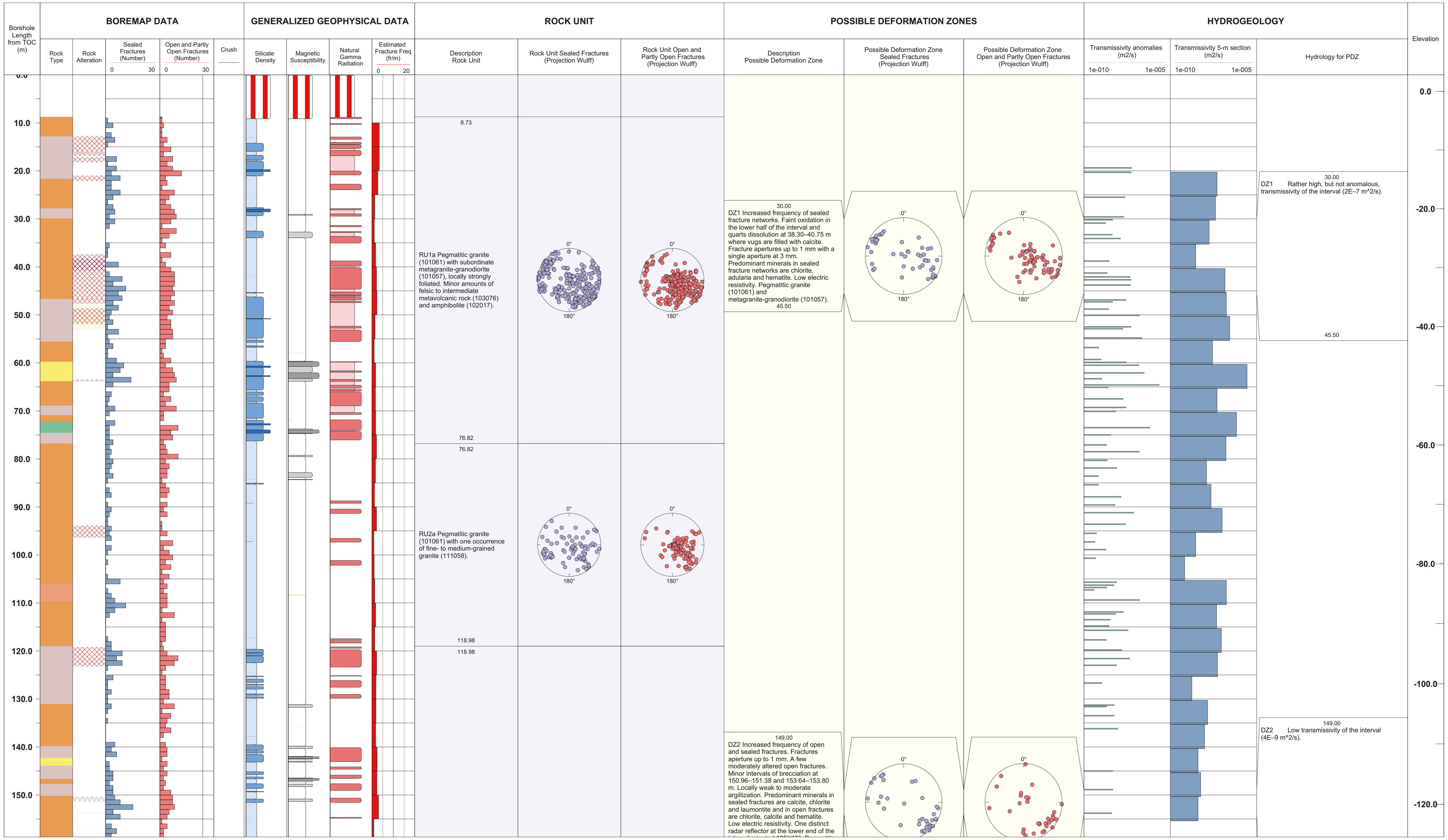
ROCKTYPE FORSMARK - SFR
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

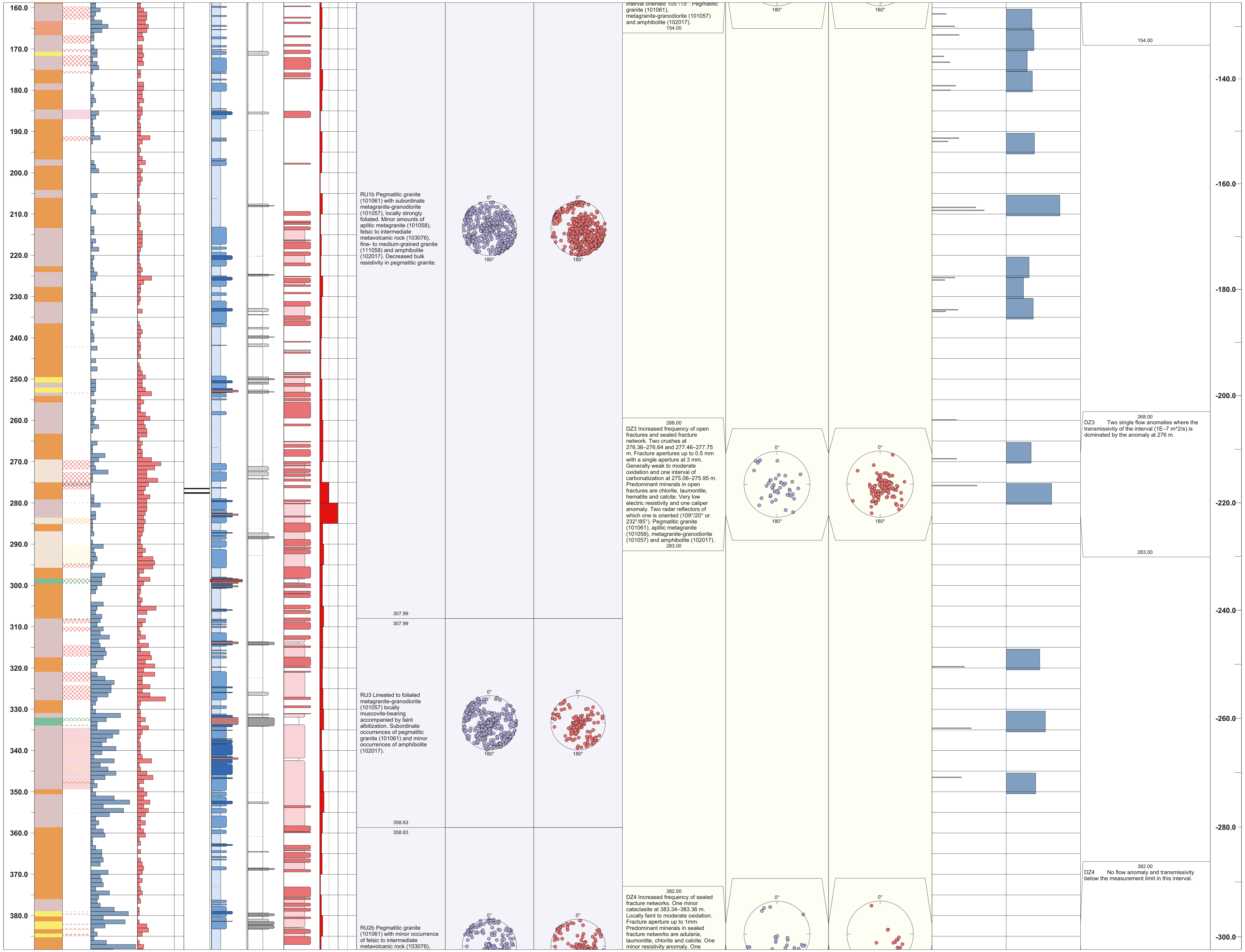
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Sericitisized
- Quartz dissolution
- Argillization
- Albitization
- Carbonatization
- Laumontitization

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
360.0
370.0
380.0
RU1b Pegmatitic granite (101061) with subordinate metagranite-granodiorite (101057), locally strongly foliated. Minor amounts of aplitic metagranite (101058), felsic to intermediate metavolcanic rock (103076), fine- to medium-grained granite (111058) and amphibolite (102017). Decreased bulk resistivity in pegmatitic granite.
307.99
307.99
RU3 Lineated to foliated metagranite-granodiorite (101057) locally muscovite-bearing accompanied by faint albitization. Subordinate occurrences of pegmatitic granite (101061) and minor occurrences of amphibolite (102017).
358.63
358.63
RU2b Pegmatitic granite (101061) with minor occurrence of felsic to intermediate metavolcanic rock (103076),
0°
180°
interval oriented 105°/15°. Pegmatitic granite (101061), metagranite-granodiorite (101057) and amphibolite (102017).
154.00
268.00
DZ3 Increased frequency of open fractures and sealed fracture network. Two crushes at 276.36–276.64 and 277.46–277.75 m. Fracture apertures up to 0.5 mm with a single aperture at 3 mm. Generally weak to moderate oxidation and one interval of carbonatization at 275.06–275.95 m. Predominant minerals in open fractures are chlorite, laumontite, hematite and calcite. Very low electric resistivity and one caliper anomaly. Two radar reflectors of which one is oriented (109°/20° or 232°/85°). Pegmatitic granite (101061), aplitic metagranite (101058), metagranite-granodiorite (101057) and amphibolite (102017).
283.00
382.00
DZ4 Increased frequency of sealed fracture networks. One minor cataclasite at 383.34–383.36 m. Locally faint to moderate oxidation. Fracture aperture up to 1mm. Predominant minerals in sealed fracture networks are adularia, laumontite, chlorite and calcite. One minor resistivity anomaly. One
154.00
268.00
DZ3 Two single flow anomalies where the transmissivity of the interval (1E–7 m^2/s) is dominated by the anomaly at 276 m.
283.00
382.00
DZ4 No flow anomaly and transmissivity below the measurement limit in this interval.
-140.0
-160.0
-180.0
-200.0
-220.0
-240.0
-260.0
-280.0
-300.0

390.0
400.0
410.0
420.0
430.0
440.0
450.0
460.0
470.0
metagranite-granodiorite (101057) and amphibolite (102017).
416.25
416.25
RU4 Fine- to medium-grained granite (111058), pegmatitic granite (101061), metagranite-granodiorite (101057) and felsic to intermediate metavolcanic rock (103076) in approximately equal proportions. Minor occurrences of amphibolite (102017). A distinct radar reflector, sub-parallel to borehole (063°/42° or 055°/63°), extends from 340 m to the end of the borehole. Predicted intersection at 555 m.
454.57
0°
180°
oriented radar reflector (216°/70° or 184°/11°). Felsic to intermediate metavolcanic rock (103076) and pegmatitic granite (101061).
387.00
396.00
DZ5 Increased frequency of open fractures. One minor cataclasite along the lower limit of the possible zone at 400.39–400.41 m. Fracture apertures up to 2 mm. Several moderately altered open fractures. Varying degrees of argillization and epidotization in the lower half of the interval. Predominant minerals in open fractures are clay minerals, chlorite and calcite. Low electric resistivity and one minor caliper anomaly. Pegmatitic granite (101061) and amphibolite (102017).
405.00
447.00
DZ6 Increased frequency of sealed fractures and sealed fracture network in the upper half of the interval. One brecciated interval at 452.97–453.05 m. Locally faint to strong oxidation and laumontization. No BIPS image of the interval. Predominant minerals in sealed fractures are laumontite, calcite and chlorite. Low electric resistivity and one major caliper anomaly. Fine to medium grained granite (111058), pegmatitic granite (101061) and metagranite-granodiorite (101057).
454.57
387.00
396.00
DZ5 One single flow anomaly (T = 1E–8 m^2/s) at 405 m. This is the only flow anomaly in the borehole below 350 m.
405.00
447.00
DZ6 No hydraulic data from this interval.
454.57
-320.0
-340.0
-360.0

Title SINGLE HOLE INTERPRETATION KFR27

Site	FORSMARK - SFR	**Inclination [°]**	-87.60	**Elevation [m.a.s.l.]**	2.87
Borehole	KFR27	**Date of mapping**	2008-11-12 19:04:00	**Drilling Start Date**	1981-08-06 00:00:00
Diameter [mm]	76	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	1981-09-10 00:00:00
Length [m]	501.640	**Northing [m]**	6701714.42	**Surveying Date**	
Bearing [°]	248.20	**Easting [m]**	1633175.52	**Plot Date**	2009-06-11 23:09:53

Signed data

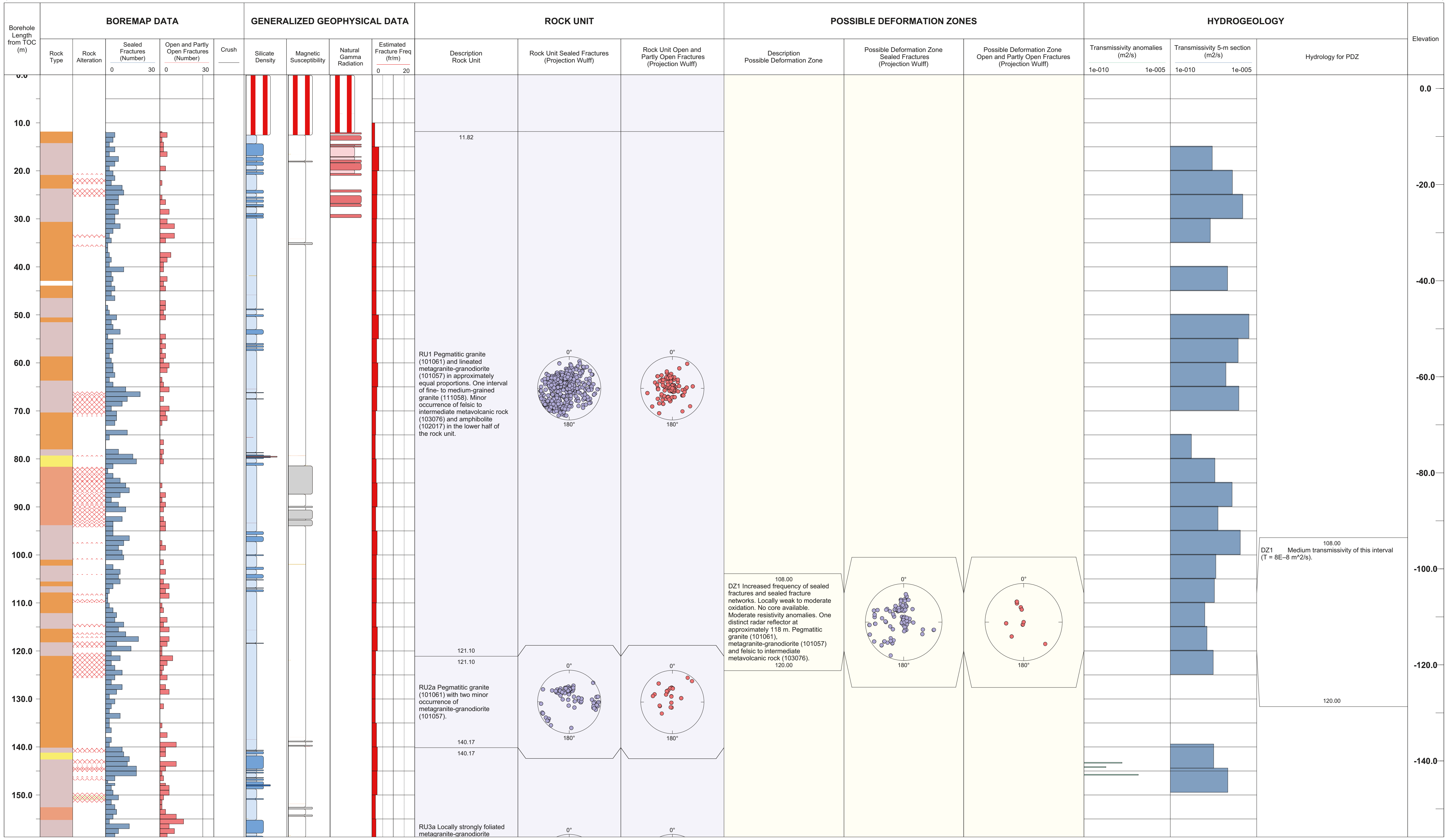
ROCKTYPE FORSMARK - SFR
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

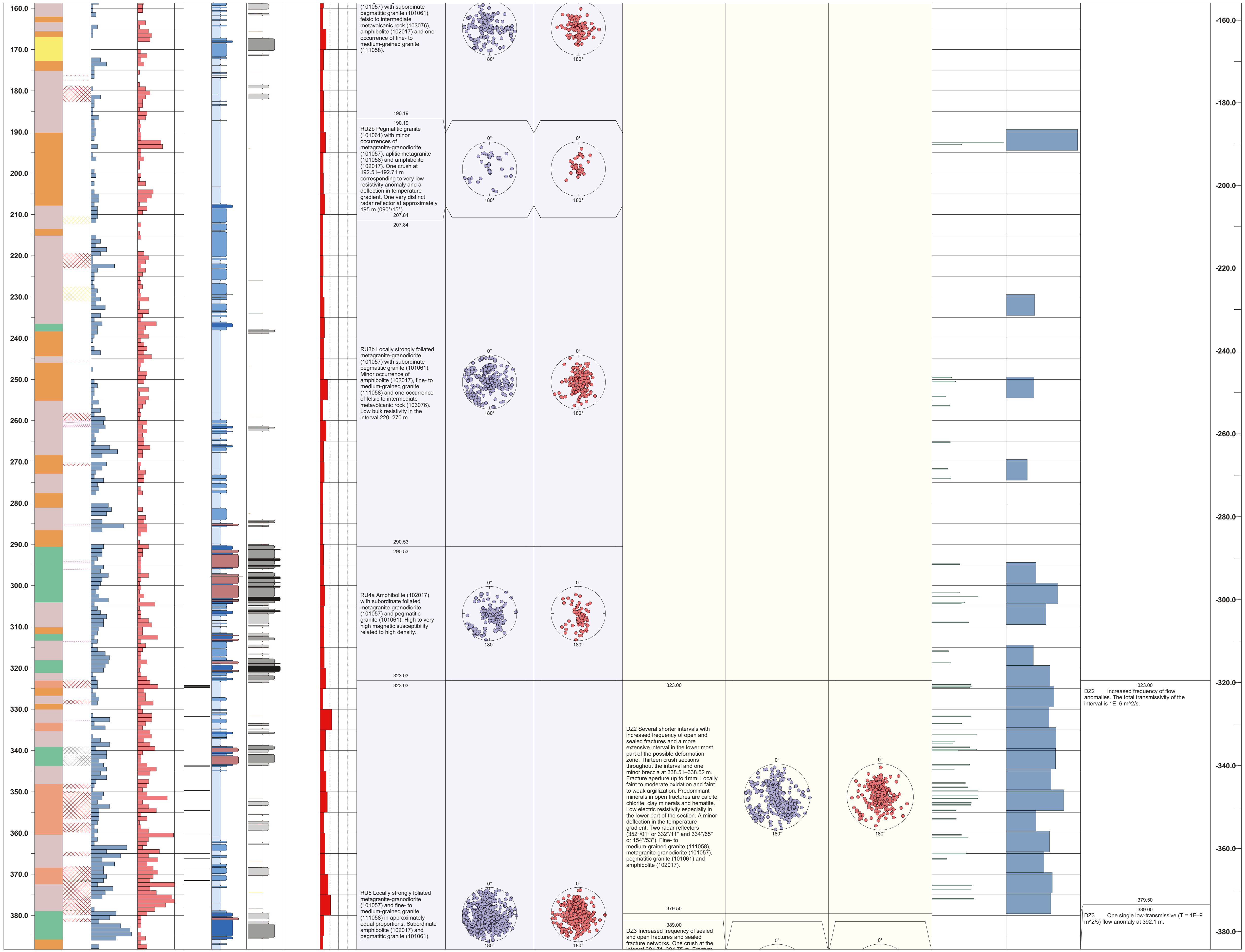
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Sericitisized
- Quartz dissolution
- Silicification
- Argillization
- Albitization
- Laumontitization

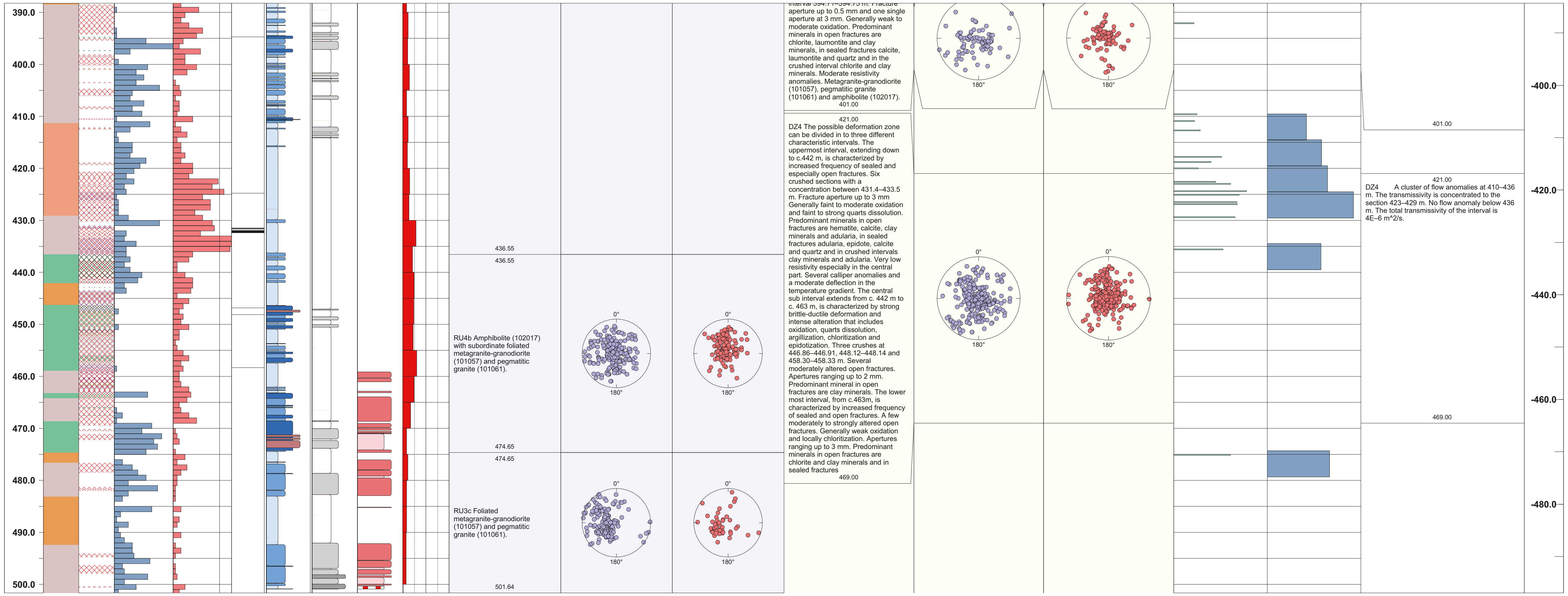
SILICATE DENSITY (kg/m³)
- unclassified
- dens<2680 (Granite)
- 2680<dens<2730 (Granodiorite)
- 2730<dens<2800 (Tonalite)
- 2800<dens<2890 (Diorite)
- dens>2890 (Gabbro)

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

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




(101057) with subordinate pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076), amphibolite (102017) and one occurrence of fine- to medium-grained granite (111058).
190.19
190.19
RU2b Pegmatitic granite (101061) with minor occurrences of metagranite-granodiorite (101057), aplitic metagranite (101058) and amphibolite (102017). One crush at 192.51–192.71 m corresponding to very low resistivity anomaly and a deflection in temperature gradient. One very distinct radar reflector at approximately 195 m (090°/15°).
207.84
207.84
RU3b Locally strongly foliated metagranite-granodiorite (101057) with subordinate pegmatitic granite (101061). Minor occurrence of amphibolite (102017), fine- to medium-grained granite (111058) and one occurrence of felsic to intermediate metavolcanic rock (103076). Low bulk resistivity in the interval 220–270 m.
290.53
290.53
RU4a Amphibolite (102017) with subordinate foliated metagranite-granodiorite (101057) and pegmatitic granite (101061). High to very high magnetic susceptibility related to high density.
323.03
323.03
RU5 Locally strongly foliated metagranite-granodiorite (101057) and fine- to medium-grained granite (111058) in approximately equal proportions. Subordinate amphibolite (102017) and pegmatitic granite (101061).
323.00
DZ2 Several shorter intervals with increased frequency of open and sealed fractures and a more extensive interval in the lower most part of the possible deformation zone. Thirteen crush sections throughout the interval and one minor breccia at 338.51–338.52 m. Fracture aperture up to 1mm. Locally faint to moderate oxidation and faint to weak argillization. Predominant minerals in open fractures are calcite, chlorite, clay minerals and hematite. Low electric resistivity especially in the lower part of the section. A minor deflection in the temperature gradient. Two radar reflectors (352°/01° or 332°/11° and 334°/65° or 154°/53°). Fine- to medium-grained granite (111058), metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017).
379.50
389.00
DZ3 Increased frequency of sealed and open fractures and sealed fracture networks. One crush at the
323.00
DZ2 Increased frequency of flow anomalies. The total transmissivity of the interval is 1E–6 m^2/s.
379.50
389.00
DZ3 One single low-transmissive (T = 1E–9 m^2/s) flow anomaly at 392.1 m.


390.0
400.0
410.0
420.0
430.0
440.0
450.0
460.0
470.0
480.0
490.0
500.0
436.55
436.55
RU4b Amphibolite (102017) with subordinate foliated metagranite-granodiorite (101057) and pegmatitic granite (101061).
474.65
474.65
RU3c Foliated metagranite-granodiorite (101057) and pegmatitic granite (101061).
501.64
0°
180°
aperture up to 0.5 mm and one single aperture at 3 mm. Generally weak to moderate oxidation. Predominant minerals in open fractures are chlorite, laumontite and clay minerals, in sealed fractures calcite, laumontite and quartz and in the crushed interval chlorite and clay minerals. Moderate resistivity anomalies. Metagranite-granodiorite (101057), pegmatitic granite (101061) and amphibolite (102017).
401.00
421.00
DZ4 The possible deformation zone can be divided in to three different characteristic intervals. The uppermost interval, extending down to c.442 m, is characterized by increased frequency of sealed and especially open fractures. Six crushed sections with a concentration between 431.4–433.5 m. Fracture aperture up to 3 mm Generally faint to moderate oxidation and faint to strong quarts dissolution. Predominant minerals in open fractures are hematite, calcite, clay minerals and adularia, in sealed fractures adularia, epidote, calcite and quartz and in crushed intervals clay minerals and adularia. Very low resistivity especially in the central part. Several calliper anomalies and a moderate deflection in the temperature gradient. The central sub interval extends from c. 442 m to c. 463 m, is characterized by strong brittle-ductile deformation and intense alteration that includes oxidation, quarts dissolution, argillization, chloritization and epidotization. Three crushes at 446.86–446.91, 448.12–448.14 and 458.30–458.33 m. Several moderately altered open fractures. Apertures ranging up to 2 mm. Predominant mineral in open fractures are clay minerals. The lower most interval, from c.463m, is characterized by increased frequency of sealed and open fractures. A few moderately to strongly altered open fractures. Generally weak oxidation and locally chloritization. Apertures ranging up to 3 mm. Predominant minerals in open fractures are chlorite and clay minerals and in sealed fractures
469.00
401.00
421.00
DZ4 A cluster of flow anomalies at 410–436 m. The transmissivity is concentrated to the section 423–429 m. No flow anomaly below 436 m. The total transmissivity of the interval is 4E–6 m^2/s.
469.00
-400.0
-420.0
-440.0
-460.0
-480.0