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Forsmark site investigation

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Abstract

This report presents geological single-hole interpretations of the cored boreholes KFM09A and KFM07B at Forsmark. The interpretation combines the geological core mapping, interpreted geophysical logs and borehole radar measurements to identify where rock units and possible deformation zones occur in the boreholes. A brief description of the character of each rock unit and deformation zone is provided.

The geological single-hole interpretation shows that nine rock units (RU1–RU9) occur in KFM09A. However, the borehole can be divided into ten separate sections due to the repetition of RU1 (RU1a and RU1b). Medium-grained metagranite-granodiorite (101057) dominates the borehole. Sections with fine- to medium-grained metagranitoid (101051), pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and a heterogeneous mixture of medium-grained metagranite-granodiorite (101057), amphibolite (102017), aplitic metagranite (101058), pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and fine- to medium-grained metagranitoid (101051) also occur. Subordinate rock types in the different units are amphibolite (102017), pegmatitic granite (101061), aplitic metagranite (101058), medium-grained metagranite-granodiorite (101057), felsic to intermediate metavolcanic rock (103076), fine- to medium-grained metagranitoid (101051), quartz-bearing metadiorite (101033), metatonalite to granodiorite (101054) and metagranodiorite (101056). Rock units have also been distinguished on the basis of the intensity of ductile deformation and the frequency of fractures. Five possible deformation zones of brittle character have been identified in KFM09A (DZ1–DZ5).

The geological single-hole interpretation shows that two rock units (RU1–RU2) occur in KFM07B. The borehole is dominated by medium-grained metagranite-granodiorite (101057). Subordinate rock types are pegmatitic granite (101061), amphibolite (102017) and fine- to medium-grained metagranitoid (101051). Rock units have also been distinguished on the basis of the frequency of fractures. Four possible deformation zones of brittle character have been identified in KFM07B (DZ1–DZ4).

Sammanfattning

Denna rapport behandlar geologisk enhålstolkning av kärnborrhålen KFM09A och KFM07B i Forsmark. Den geologiska enhålstolkningen syftar till att utifrån den geologiska karteringen, tolkade geofysiska loggar och borrhålsradarmätningar indikera olika litologiska enheters fördelning i borrhålet samt möjliga deformationszoners läge och utbredning. En kort beskrivning av varje bergenhet och deformationszon presenteras.

Denna undersökning visar att det i KFM09A finns nio litologiska enheter (RU1–RU9). Baserat på repetition av enheten RU1 (RU1a och RU1b) kan borrhålet delas in i tio sektioner. Medelkornig metagranit-granodiorit (101057) dominerar borrhålet. Sektioner med fin- till medelkornig metagranitoid (101051), pegmatitisk granit (101061), felsisk till intermediär vulkanisk bergart (103076) samt en heterogen blandning av medelkornig metagranit-granodiorit (101057), amfibolit (102017), aplitisk metagranit (101058), pegmatitisk granit (101061), felsisk till intermediär vulkanisk bergart (103076) och fin- till medelkornig metagranitoid (101051). I mindre omfattning i de olika litologiska enheterna förekommer amfibolit (102017), pegmatitisk granit (101061), aplitisk metagranit (101058), medelkornig metagranit-granodiorit (101057), felsisk till intermediär vulkanisk bergart (103076), fin- till medelkornig metagranitoid (101051), kvartsförande metadiorit (101033), metatonalit till granodiorit (101054) och metagranodiorit (101056). Vid indelning av litologiska enheter har även intensiteten av plastisk deformation och sprickfrekvensen utnyttjats. Fem möjliga deformationszoner som är spröda har identifierats i KFM09A (DZ1–DZ5).

Den geologiska enhålstolkningen visar att det finns två litologiska enheter (RU1–RU2) i KFM07B. Medelkornig metagranit-granodiorit (101057) dominerar borrhålet. I mindre omfattning förekommer pegmatitisk granit (101061), amfibolit (102017) och fin- till medelkornig metagranitoid (101051). Även sprickfrekvensen har utnyttjats vid indelning av litologiska enheter. Fyra möjliga deformationszoner som är spröda har identifierats i KFM07B (DZ1–DZ4).

Contents

1 Introduction

Much of the primary geological and geophysical borehole data stored in the SKB database SICADA need to be integrated and synthesized before they can be used for modelling in the 3D-CAD Rock Visualization System (RVS). The end result of this procedure is a geological single-hole interpretation, which consists of an integrated series of different logs and accompanying descriptive documents.

This document reports the geological single-hole interpretations of boreholes KFM09A and KFM07B in the Forsmark area. The horizontal projections of the boreholes are shown in Figure 1-1. The work was carried out in accordance with activity plan SKB PF 400-06-011. The controlling documents for performing this activity are listed in Table 1-1. Both the activity plan and method description are SKB's internal controlling documents.

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

Activity plan	Number	Version
	AP PF 400-06-011	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

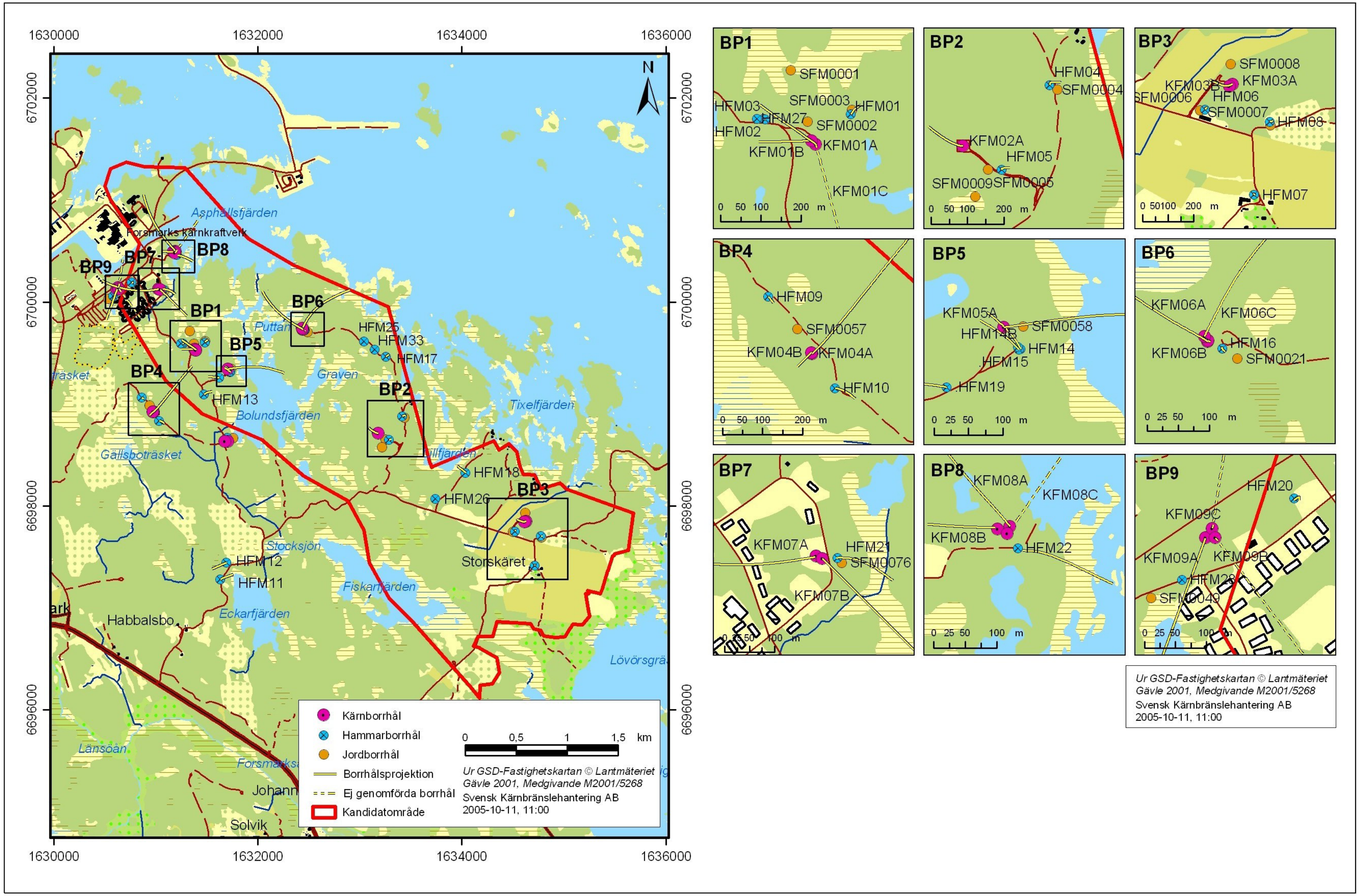


Figure 1-1. Map showing position and horizontal projection of the boreholes within and outside the candidate area including the cored boreholes KFM09A and KFM07B.

2 Objective and scope

A geological single-hole interpretation is carried out in order to identify and to describe briefly the 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 the borehole (Boremap), different borehole geophysical logs and borehole radar data.

The geological mapping of the cored boreholes involves a documentation of the character of the bedrock in the drill core. This work component is carried out in combination with an inspection of the oriented image of the borehole walls that is obtained with the help of the *B*orehole *I*mage *P*rocessing *S*ystem (BIPS). The geological mapping of the percussion boreholes focuses more attention on an integrated interpretation of the information from the geophysical logs and the BIPS images. For this reason, the results from the percussion borehole mapping are more uncertain. The interpretations of the borehole geophysical and radar logs are available when the single-hole interpretation is completed. The result from the geological single-hole interpretation is presented in a WellCad plot. A more detailed description of the technique is provided in the method description for geological single-hole interpretation (SKB MD 810.003, internal document). 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 and interpretations have been used for the single-hole interpretation of the boreholes KFM09A and KFM07B:

- Boremap data (including BIPS and geological mapping data) /1, 2/.
- Generalized geophysical logs and their interpretation /3/.
- Radar data and their interpretation /4/.

The material used as a basis for the geological single-hole interpretation was a WellCad plot consisting of parameters from the geological mapping in the Boremap system, geophysical logs and borehole radar. An example of a WellCad plot used during geological single-hole interpretation is shown in Figure 3-1. The plot consists of ten main columns and several subordinate columns. These include:

1: Length along the borehole

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

3: Unbroken fractures
  3.1: Primary mineral
  3.2: Secondary mineral
  3.3: Third mineral
  3.4: Fourth mineral
  3.5: Alteration, dip direction

4: Broken fractures

4.1: Primary mineral
  4.2: Secondary mineral
  4.3: Third mineral
  4.4: Fourth mineral
  4.5: Aperture (mm)
  4.6: Roughness
  4.7: Surface
  4.8: Alteration, dip direction

5: Crush zones

5.1: Primary mineral
  5.2: Secondary mineral
  5.3: Third mineral
  5.4: Fourth mineral
  5.5: Roughness
  5.6: Surface

- 5.7: Crush alteration, dip direction
- 5.8: Piece (mm)
- 5.9: Sealed network
- 5.10: Core loss

6: Fracture frequency
- 6.1: Open fractures
- 6.2: Sealed fractures

7: Geophysics
- 7.1: Magnetic susceptibility
- 7.2: Natural gamma radiation
- 7.3: Possible alteration
- 7.4: Silicate density
- 7.5: Estimated fracture frequency

8: Radar
- 8.1: Length
- 8.2: Angle

9: Reference mark (not used for percussion-drilled boreholes)

10: BIPS

The geophysical logs are described below:

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 in the different rock types.

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 or pegmatite. The rocks with high natural gamma radiation have been included in the younger, Group D intrusive suite /5/.

Possible alteration: This parameter has not been used in the geological single-hole interpretation in the Forsmark area.

Silicate density: This parameter indicates the density of the rock after subtraction of the magnetic component in the rock. It provides general information on the mineral composition of the rock types, and serves as a support during classification of rock types.

Estimated fracture frequency: This parameter provides an estimate of the fracture frequency along 5 m sections, calculated from short and long normal resistivity, SPR, P-wave velocity as well as focused resistivity 140 and 300. The estimated fracture frequency is based on a statistical connection after a comparison has been made between the geophysical logs and the mapped fracture frequency. The log provides an indication of sections with low and high fracture frequencies.

Close 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.

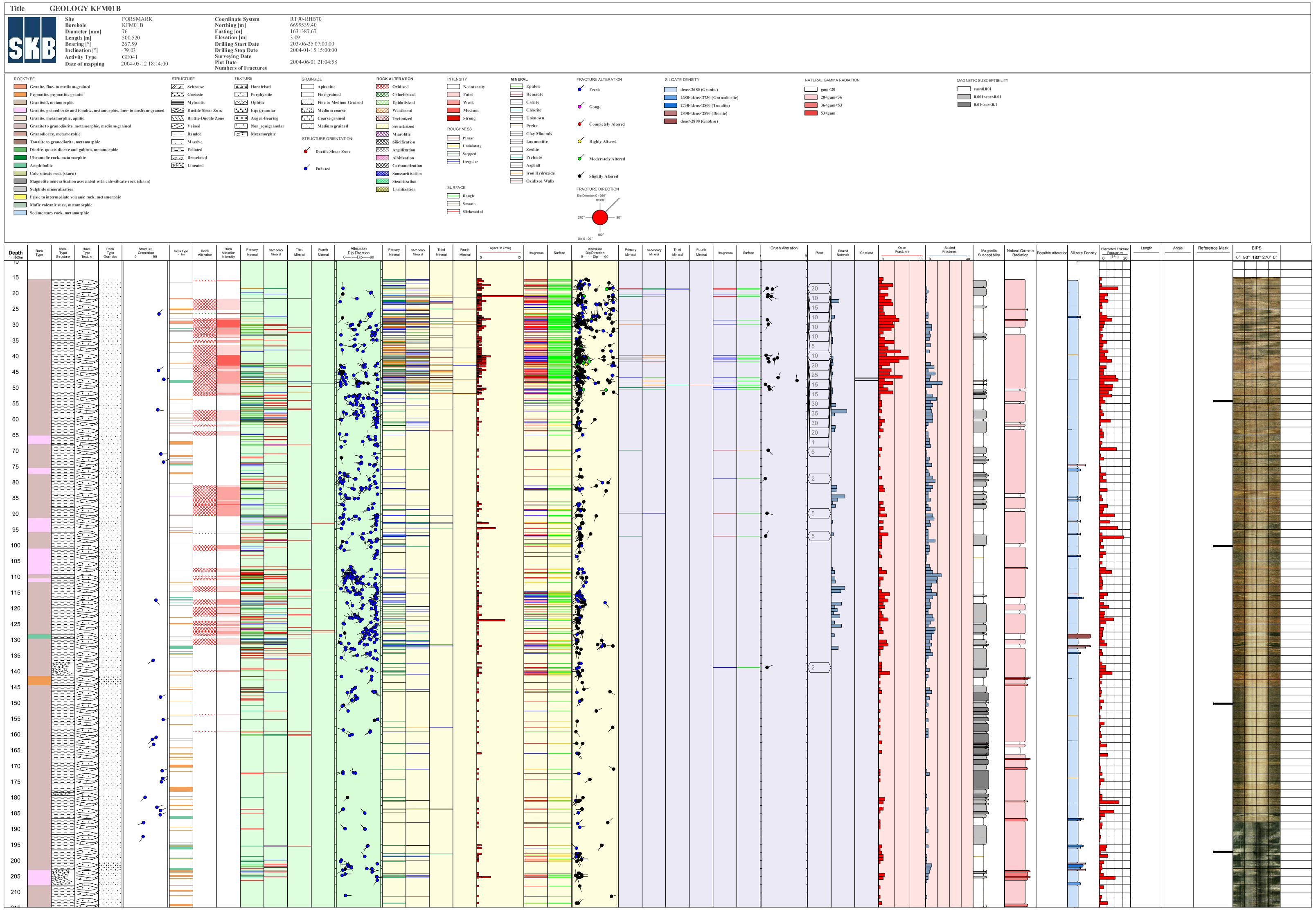


Figure 3-1. *Example of WellCad plot (from borehole KFM01B) used as a basis for the single-hole interpretation.*

4 Execution of the geological single-hole interpretation

4.1 General

The geological single-hole interpretation has been carried out by a group of geoscientists consisting of both geologists and geophysicists. Several of these geoscientists previously participated in the development of the source material for the single-hole interpretation. All data to be used (see above) are visualized 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 (rock type, rock alteration, silicate density, natural gamma radiation, etc) 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 (minimum length of c 5 m). 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 made on the following basis: 3 = high, 2 = medium and 1 = low.

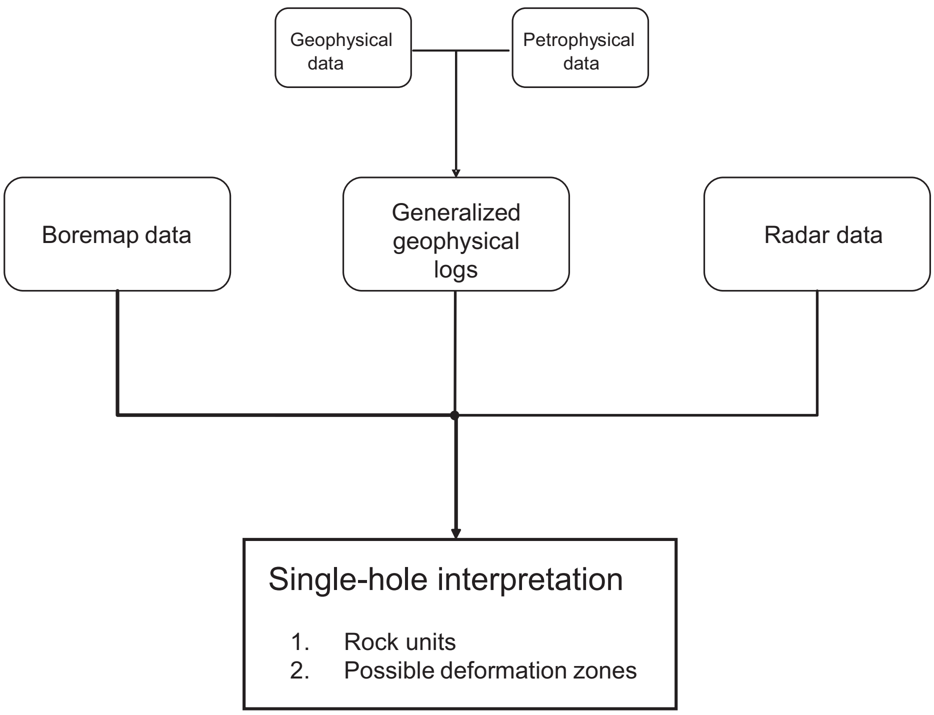


Figure 4-1. *Schematic chart that shows the procedure for the development of a geological single-hole interpretation.*

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, aperture, alteration, etc) in combination with the geophysical logging 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. The confidence in the interpretation of a possible deformation zone is made on the following basis: 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 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 location of these boundaries is 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 /6/. Brittle deformation zones defined by an increased fracture 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, inferred orientation of radar reflectors, the resistivity, SPR, P-wave velocity, caliper and magnetic susceptibility logs have all assisted in the identification of the zones. The anomalies in these parameters that assist with the identification are presented in the short description.

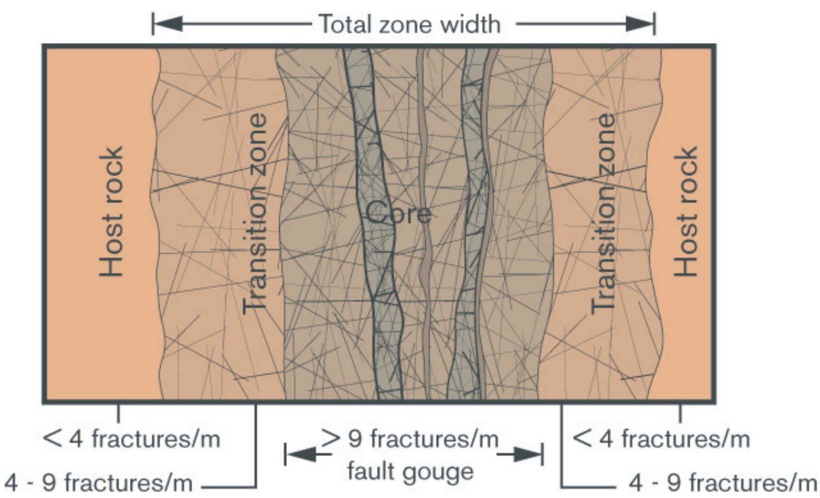


Figure 4-2. *Terminology for brittle deformation zones (after /6/).*

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 KFM09A and KFM07B (Figures 4-3 and 4-4). A 5 m window and 1 m steps have been used in the calculation procedure. The moving averages for open fractures alone, the total number of open fractures (open, partly open and crush), the sealed fractures alone, and the total number of sealed fractures (sealed and sealed fracture network) are shown in each diagram.

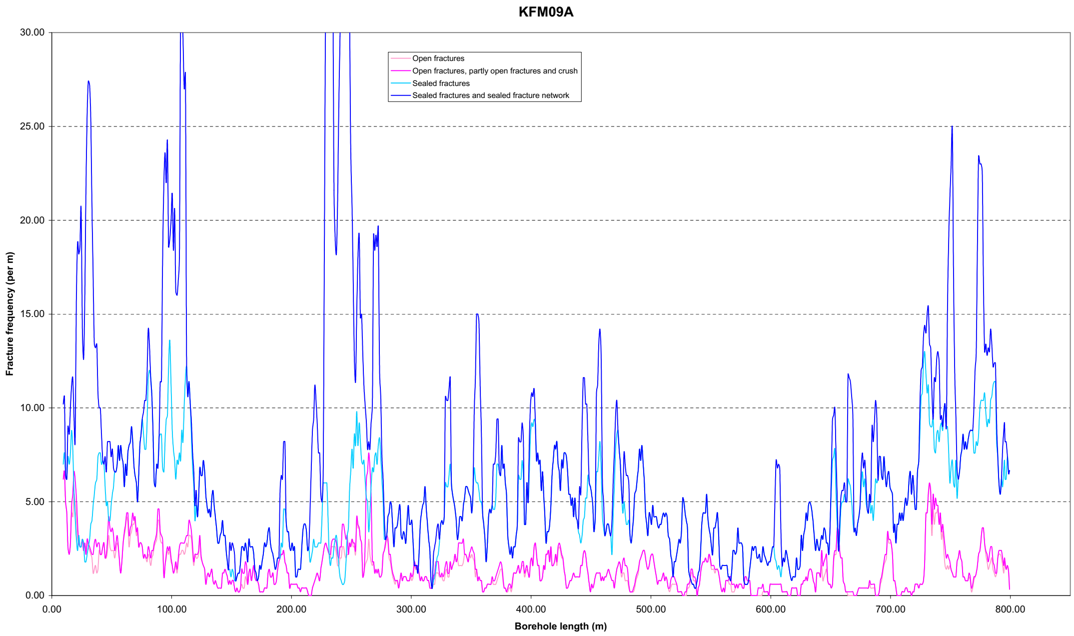


Figure 4-3. *Fracture frequency plot for KFM09A. Moving average with a 5 m window and 1 m steps.*

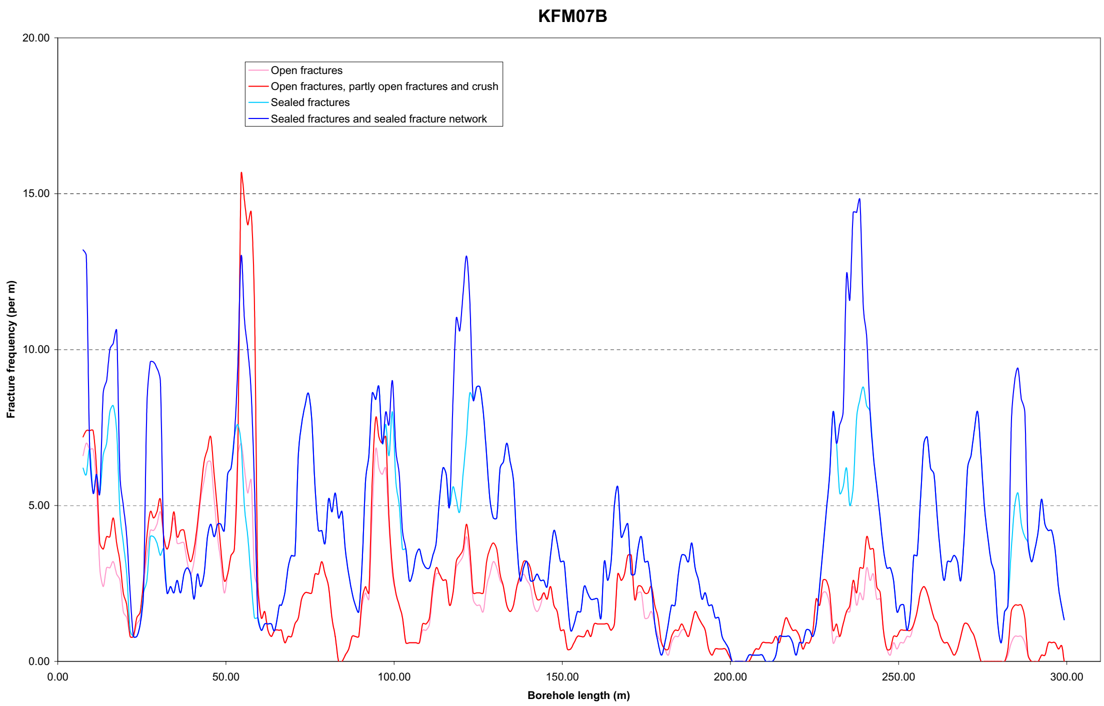


Figure 4-4. *Fracture frequency plot for KFM07B. Moving average with a 5 m window and 1 m steps.*

The occurrence and orientation of radar anomalies within the possible deformation zones are used during the identification of these zones. An overview of the borehole radar measurement in KFM09A and KFM07B is shown in Figures 4-5 and 4-6, respectively. 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.

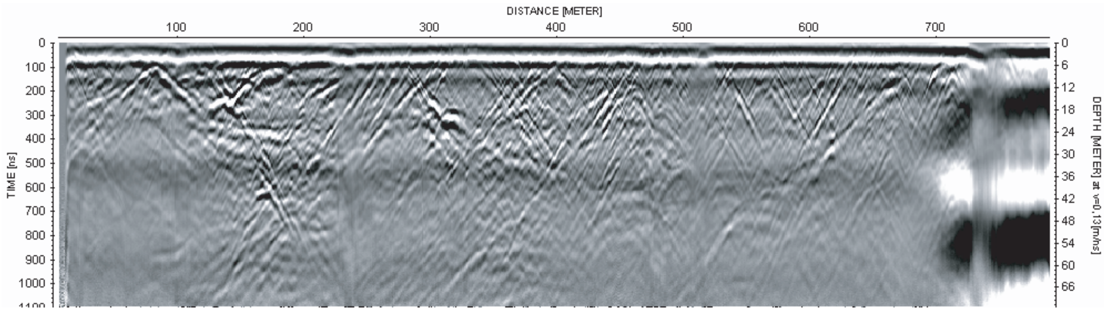


Figure 4-5. *Overview (20 MHz data) of the borehole radar measurements in KFM09A.*

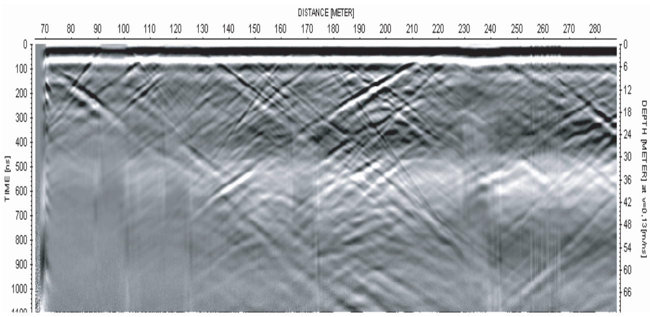


Figure 4-6. *Overview (20 MHz data) of the borehole radar measurements in KFM07B.*

5 Results

The result of the geological single-hole interpretation is presented as print-outs from the software WellCad (Appendix 1 for KFM09A and Appendix 2 for KFM07B).

5.1 KFM09A

The borehole direction at the start is 200.1/–59.5.

Rock units

The borehole can be divided into nine different rock units, RU1–RU9, all of which have been recognized with a high degree of confidence. Rock unit RU1 occurs at two separate borehole intervals. These are distinguished using the identification codes RU1a and RU1b.

7.80–20.69 m

RU1a: Medium-grained metagranite-granodiorite (101057), locally rich in biotite and with intense ductile deformation. Subordinate occurrences of amphibolite (102017) and pegmatitic granite (101061). Increased frequency of open fractures relative to the bedrock outside possible deformation zones beneath 124 m. Confidence level = 3.

20.69–52.45 m

RU2: Pegmatitic granite (101061) with high natural gamma radiation. Confidence level = 3.

52.45–123.90 m

RU1b: Medium-grained metagranite-granodiorite (101057), locally rich in biotite and with intense ductile deformation. Subordinate occurrences of amphibolite (102017), pegmatitic granite (101061) and one occurrence of aplitic metagranite (101058). Increased frequency of open fractures relative to the bedrock outside possible deformation zones beneath 124 m. Confidence level = 3.

123.90–241.74 m

RU3: Fine- to medium-grained metagranitoid (101051) with subordinate occurrences of pegmatitic granite (101061), medium-grained metagranite-granodiorite (101057) and amphibolite. One crush-zone at 160 m. Subparallel radar reflector 20–25 m outside the borehole along the interval 125–200 m. Confidence level = 3.

241.74–440 m

RU4: Medium-grained metagranite-granodiorite (101057), generally rich in biotite and with intense ductile deformation. Heterogeneous with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017), felsic to intermediate metavolcanic rock (103076), aplitic metagranite (101058) and fine- to medium-grained metagranitoid (101051).

Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. One crush-zone at 342 m. Subparallel radar reflector 20–40 m outside the borehole along the interval 290–400 m, weak below 330 m. Confidence level = 3.

440–511.75 m

RU5: Heterogeneous mixture of medium-grained metagranite-granodiorite (101057), amphibolite (102017), aplitic metagranite (101058), pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and fine- to medium-grained metagranitoid (101051). Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. Two fractures at 480 m have an aperture of 6 and 8 mm. They correspond to a section with decreased resistivity. Confidence level = 3.

511.75–522.24 m

RU6: Pegmatitic granite (101061) and, in the upper part, medium-grained metagranite-granodiorite (101057), both of which are oxidized and vuggy. Rock unit corresponds to increased natural gamma radiation, decreased magnetic susceptibility and resistivity. Confidence level = 3.

522.24–640.80 m

RU7: Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017) and felsic to intermediate metavolcanic rock (103076). One crush-zone at 592 m. Confidence level = 3.

640.80–758.06 m

RU8: Medium-grained metagranite-granodiorite (101057), generally with intense ductile deformation, and with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017), fine- to medium-grained metagranitoid (101051) and felsic to intermediate metavolcanic rock (103076). These occurrences are somewhat thicker and occur together with quartz-bearing metadiorite (101033) and metatonalite-granodiorite (101054) in the lower part of the rock unit. Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. One crush-zone at 644 m. Confidence level = 3.

758.06–799.55 m

RU9: Felsic to intermediate metavolcanic rock (103076) with subordinate occurrences of metagranodiorite (101056), amphibolite (102017), metagranite-granodiorite (101057), metatonalite-granodiorite (101054) and fine- to medium-grained metagranitoid (101051). Virtually the whole borehole section has been affected by intense ductile deformation. Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. Confidence level = 3.

Possible deformation zones

Five possible deformation zones of brittle character that have been recognised with a high degree of confidence are present in KFM09A:

15–40 m

DZ1: Increased frequency of sealed fractures and sealed fracture networks. Increased frequency of open fractures in the upper part. Apertures range up to 5 mm. Two crush zones occur in the interval. Subhorizontal fractures dominate. Steeply dipping fractures with a variable orientation are also present. Predominant fracture minerals are calcite, chlorite, hematite, adularia, laumontite and clay minerals. Locally faint oxidation. Between 15 and 20 m decreased resistivity and a single caliper anomaly. Variable magnetic susceptibility. Seven radar reflectors occur in the interval 15–40 m, one oriented at 19 m borehole length (192/11). The upper five meters consists of medium-grained metagranite-granodiorite (101057). The remaining part consists of pegmatitic granite (101061). Confidence level = 3.

86–116 m

DZ2: Increased frequency of sealed fractures and sealed fracture networks. Apertures in open fractures are generally less than 1 mm, locally 2 mm. The open and partly open fractures are gently dipping to subhorizontal. The sealed fractures are gently dipping to subhorizontal or strike NW or SW with variable dips to the NE and to the NW, respectively. Predominant fracture minerals are calcite, chlorite, laumontite, adularia, hematite, pyrite and clay minerals. High ductile strain and saussuritization in the upper part. Locally faint to weak oxidation. Geophysical anomaly with decreased resistivity (94–106 m) and caliper anomaly (100 m). Variable magnetic susceptibility. Twelve radar reflectors of which two oriented at 97 m (318/70) and 111 m (206/67). Dominant rock type is medium-grained metagranite-granodiorite (101057), with subordinate pegmatitic granite (101061). Confidence level = 3.

217–280 m

DZ3: Increased frequency of sealed fractures and sealed fracture networks. Increased frequency of open fractures in the lower part. Apertures in open fractures are generally less than 1 mm, locally up to 10 mm. One single crush zone in the lower part. Fractures show variable orientation. Predominant fracture minerals are calcite, chlorite, laumontite, pyrite, hematite and clay minerals. Locally faint to weak oxidation. Minor interval of weak epidotization in the upper part of the possible zone. Geophysical anomaly with decreased resistivity (230–250 m) and caliper anomalies. Variable magnetic susceptibility. 24 radar reflectors of which four are oriented at 247 m (154/71), 266 m (139/16), 274 m (219/57) and 278 m (195/44). The upper 25 m consist of fine- to medium-grained metagranitoid (101051), with subordinate pegmatitic granite (101061). The remaining part consists of medium-grained metagranite-granodiorite (101057), with subordinate pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

723–754 m

DZ4: Increased frequency of open fractures, sealed fractures and sealed fracture networks. No apertures in open fractures exceed 1 mm. Fractures show variable orientation. A conspicuous set strikes NW and dips steeply. Predominant fracture minerals are calcite, chlorite, laumontite, hematite, pyrite and clay minerals. Locally faint to medium oxidation. Geophysical anomaly with decreased resistivity (730–750 m) and caliper anomalies. Low magnetic susceptibility between 743–746 m. Five radar reflectors of which one is oriented at 730 m (360/07). The zone consists of medium-grained metagranite to granodiorite (101057), with subordinate pegmatitic granite (101061), amphibolite (102017), quartz- bearing metadiorite (101033), fine- to medium-grained metagranitoid (101051), metatonalite-granodiorite (101054) and felsic to intermediate metavolcanic rock (103076). Confidence level = 3.

770–790 m

DZ5: Increased frequency of sealed fractures and sealed fracture networks. No apertures in open fractures exceed 1 mm. Fractures show variable orientation. Conspicuous sets are gently dipping to subhorizontal and strike NW and are steeply dipping. Predominant fracture minerals are calcite, chlorite, quartz, laumontite, adularia and clay minerals. Locally faint to weak oxidation. Geophysical anomaly with decreased resistivity (778–788 m). Four radar reflectors of which one has an uncertain orientation at 784 m (313/84 or 044/14). Dominating rock type is felsic to intermediate metavolcanic rock (103076). Subordinate rock types are amphibolite (102017), metagranodiorite (101056) and fine- to medium-grained metagranitoid (101051). Confidence level = 3.

5.2 KFM07B

The borehole direction at the start is 134.3/–53.7.

Rock units

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

5.18–195 m

RU1: Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017) and a single occurrence of fine- to medium-grained metagranitoid (101051) in the interval 63.6–72.9 m. Increased frequency of gently dipping fractures and open fractures relative to the bedrock outside possible deformation zones in the lower part of the borehole (RU2). Confidence level = 3.

195–298.43 m

RU2: Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Between 195 and 225 m there are very few fractures. Confidence level = 3.

Possible deformation zones

Four possible deformation zones of brittle character that have been recognised with a variable degree of confidence are present in KFM07A:

51–58 m

DZ1: Increased frequency of open fractures, sealed fractures and sealed fracture networks. No apertures in open fractures exceed 2 mm. One crush zone in the lower part of the interval. The open and partly open fractures are predominantly gently dipping to subhorizontal. This set is also present in the sealed fractures which also strike SSE and dip steeply to the WSW. Predominant fracture minerals are calcite and chlorite. Generally weak to medium oxidation. No geophysical data available. Five radar reflectors of which one has an uncertain orientation at 53 m (295/61 or 153/71). The zone consists of medium-grained metagranite-granodiorite (101057), with subordinate amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3.

93–102 m

DZ2: Increased frequency of open fractures, sealed fractures and sealed fracture networks. Apertures are generally less than 1 mm except for three open fractures with inferred apertures of 2, 5, and 15 mm (grouted fractures). The open and partly open fractures are predominantly gently dipping to subhorizontal. This set is also present in the sealed fractures. Sealed fractures with other orientations are present. Predominant fracture minerals are calcite, chlorite, hematite and adularia. Locally weak to medium oxidation. Geophysical anomaly with decreased resistivity. High variability in the P-wave velocity between 93 and 102 m. Low magnetic susceptibility. Five radar reflectors of which one has an uncertain orientation at 96 m (221/54 or 209/19). The zone consists of medium-grained metagranite-granodiorite (101057), with minor occurrences of amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3.

119–135 m

DZ3: Increased frequency of predominantly sealed fractures and sealed fracture networks. No aperture of open fractures exceeds 1 mm. Gently dipping to subhorizontal fractures are conspicuous. Steeply dipping sealed fractures with an ENE-strike and variable dip are also present. Predominant fracture minerals are calcite, adularia and hematite. Generally weak and locally medium oxidation. Geophysical anomaly with decreased resistivity in the interval 119–121 m. Oriented radar reflectors at 120 m (195/90) and at 127 m (145/64). The zone consists of medium-grained metagranite-granodiorite (101057), with minor occurrences of amphibolite (102017) and pegmatitic granite (101061). Confidence level = 2.

225–245 m

DZ4: Increased frequency of open fractures, sealed fractures and sealed fracture networks. No aperture of open fractures exceeds 1 mm. Steeply dipping fractures that strike SE to SSE as well as NE dominate. More gently dipping fractures are also present. Predominant fracture minerals are calcite, laumontite, adularia and chlorite. Weak to medium oxidation in the lower part of the interval. Geophysical anomaly with decreased resistivity in the interval 225–240 m. Caliper anomaly at 225 m and between 233–235 m. Seven radar reflectors of which one is oriented at 232 m (153/79). The zone consists of medium-grained metagranite-granodiorite (101057), with subordinate amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3.

6 Comments

The results of the geological single-hole interpretations of KFM09A and KFM07B are presented in WellCad plots (Appendix 1 and Appendix 2). The WellCad plot consists of the following columns:

1: Depth (Length along the borehole)

2: Rock type

3: Rock alteration

4: Sealed fractures

5: Open and partly open fractures

6: Crush zones

7: Silicate density

8: Magnetic susceptibility

9: Natural gamma radiation

10: Estimated fracture frequency

11: Description: Rock unit

12: Stereogram for sealed fractures in rock unit (blue symbols)

13: Stereogram for open and partly open fractures in rock unit (red symbols)

14: Description: Possible deformation zone

15: Stereogram for sealed fractures in possible deformation zone (blue symbols)

16: Stereogram for open and partly open fractures in possible deformation zone (red symbols)

References

/1/ **Petersson J, Skogsmo G, von Dalwigk I, Wängnerud A, Berglund J, 2006**. Boremap mapping of core drilled borehole KFM09A. Forsmark site investigation. SKB P-06-xx (in prep). Svensk Kärnbränslehantering AB.

/2/ **Döse C, Samuelsson E, 2006.** Boremap mapping of core drilled borehole KFM07B. Forsmark Site Investigation. SKB P-06-xxx (in prep). Svensk Kärnbränslehantering AB.

/3/ **Mattsson H, Keisu M, 2006.** Interpretation of geophysical borehole measurements from KFM07B, KFM09A, HFM25, HFM27 and HFM28. Forsmark site investigation. SKB P-06-xxx (in prep). Svensk Kärnbränslehantering AB.

/4/ **Gustafsson J, Gustafsson C, 2005.** RAMAC and BIPS logging in boreholes KFM07B, KFM09A, HFM25 and HFM28. Forsmark site investigation. SKB P-06-44 (in prep). Svensk Kärnbränslehantering AB.

/5/ **Stephens M B, Lundqvist S, Bergman T, Andersson J, 2003.** Forsmark site investigation. Bedrock mapping. Rock types, their petrographic and geochemical characteristics, and a structural analysis of the bedrock based on Stage 1 (2002) surface data. SKB P-03-75. Svensk Kärnbränslehantering AB.

/6/ **Munier R, Stenberg L, Stanfors R, Milnes A G, Hermanson J, Triumf C-A, 2003.** Geological site descriptive model. A strategy for the model development during site investigations. SKB R-03-07. Svensk Kärnbränslehantering AB.

Appendix 1

Geological single-hole interpretation of KFM09A

Title SINGLE HOLE INTERPRETATION KFM09A

Site	FORSMARK	**Inclination [°]**	-59.45	**Elevation [m.a.s.l.]**	4.29
Borehole	KFM09A	**Date of mapping**	2005-11-29 20:07:00	**Drilling Start Date**	2005-08-31 00:00:00
Diameter [mm]	77	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	2005-10-27 13:00:00
Length [m]	799.670	**Northing [m]**	6700115.04	**Surveying Date**	
Bearing [°]	200.08	**Easting [m]**	1630647.50	**Plot Date**	2006-09-20 21:10:12

Signed data

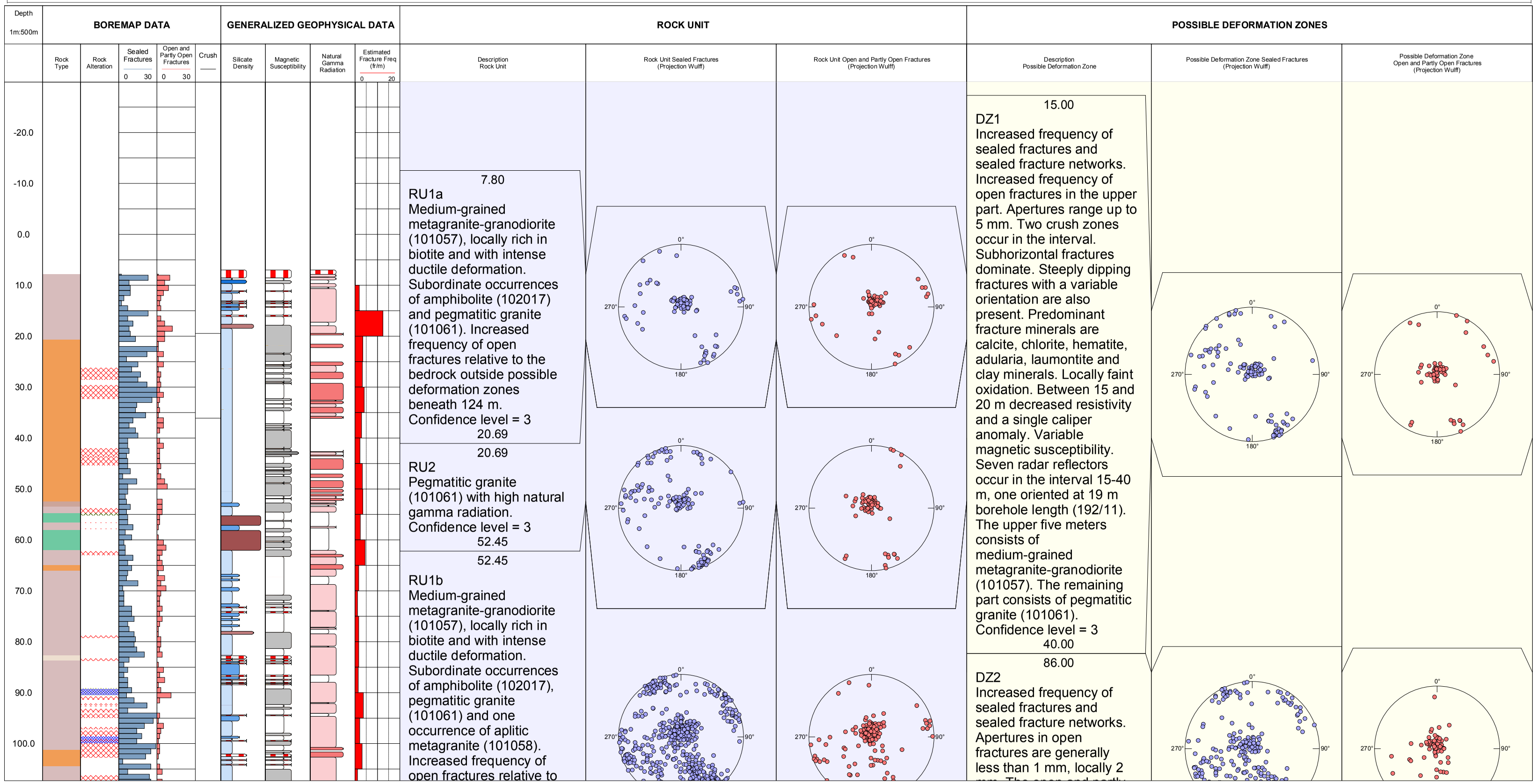
ROCKTYPE FORSMARK
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Granodiorite, metamorphic
- Tonalite to granodiorite, metamorphic
- Diorite, quarts diorite and gabbro, metamorphic
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

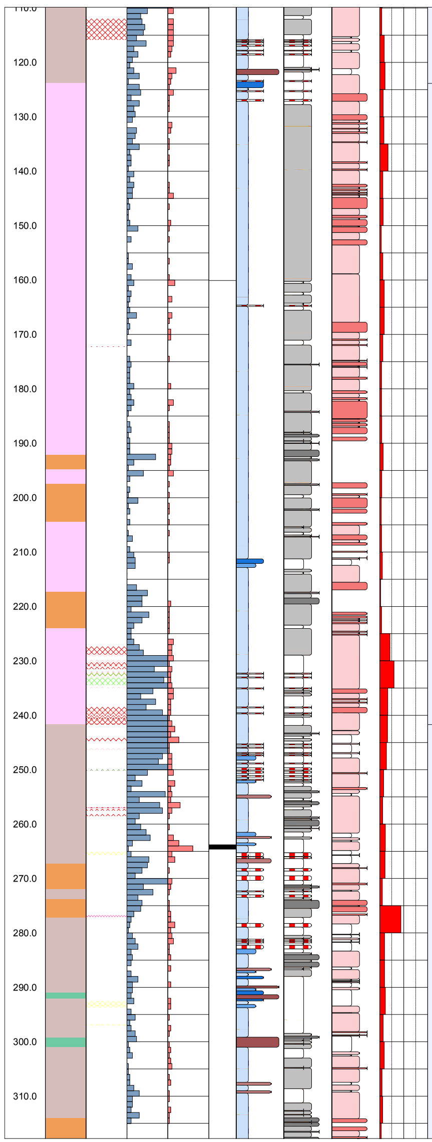
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Sericitisized
- Quartz dissolution
- Argillization
- Albitization
- Saussuritization
- Laumontitization

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

SUSCEPTIBILITET
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

NATURAL GAMMA
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53





possible deformation zones beneath 124 m. Confidence level = 3

123.90

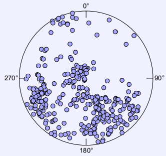
123.90

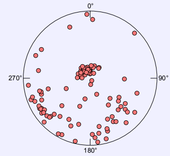
RU3
Fine- to medium-grained metagranitoid (101051) with subordinate occurrences of pegmatitic granite (101061), medium-grained metagranite-granodiorite (101057) and amphibolite. One crush-zone at 160 m. Subparallel radar reflector 20-25 m outside the borehole along the interval 125-200 m. Confidence level = 3

241.74

241.74

RU4
Medium-grained metagranite-granodiorite (101057), generally rich in biotite and with intense ductile deformation. Heterogeneous with



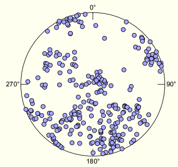


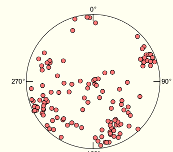
open fractures are gently dipping to subhorizontal. The sealed fractures are gently dipping to subhorizontal or strike NW or SW with variable dips to the NE and to the NW, respectively. Predominant fracture minerals are calcite, chlorite, laumontite, adularia, hematite, pyrite and clay minerals. High ductile strain and saussuritization in the upper part. Locally faint to weak oxidation. Geophysical anomaly with decreased resistivity (94-106 m) and caliper anomaly (100 m). Variable magnetic susceptibility. Twelve radar reflectors of which two oriented at 97 m (318/70) and 111 m (206/67). Dominant rock type is medium-grained metagranite-granodiorite (101057), with subordinate pegmatitic granite (101061). Confidence level = 3

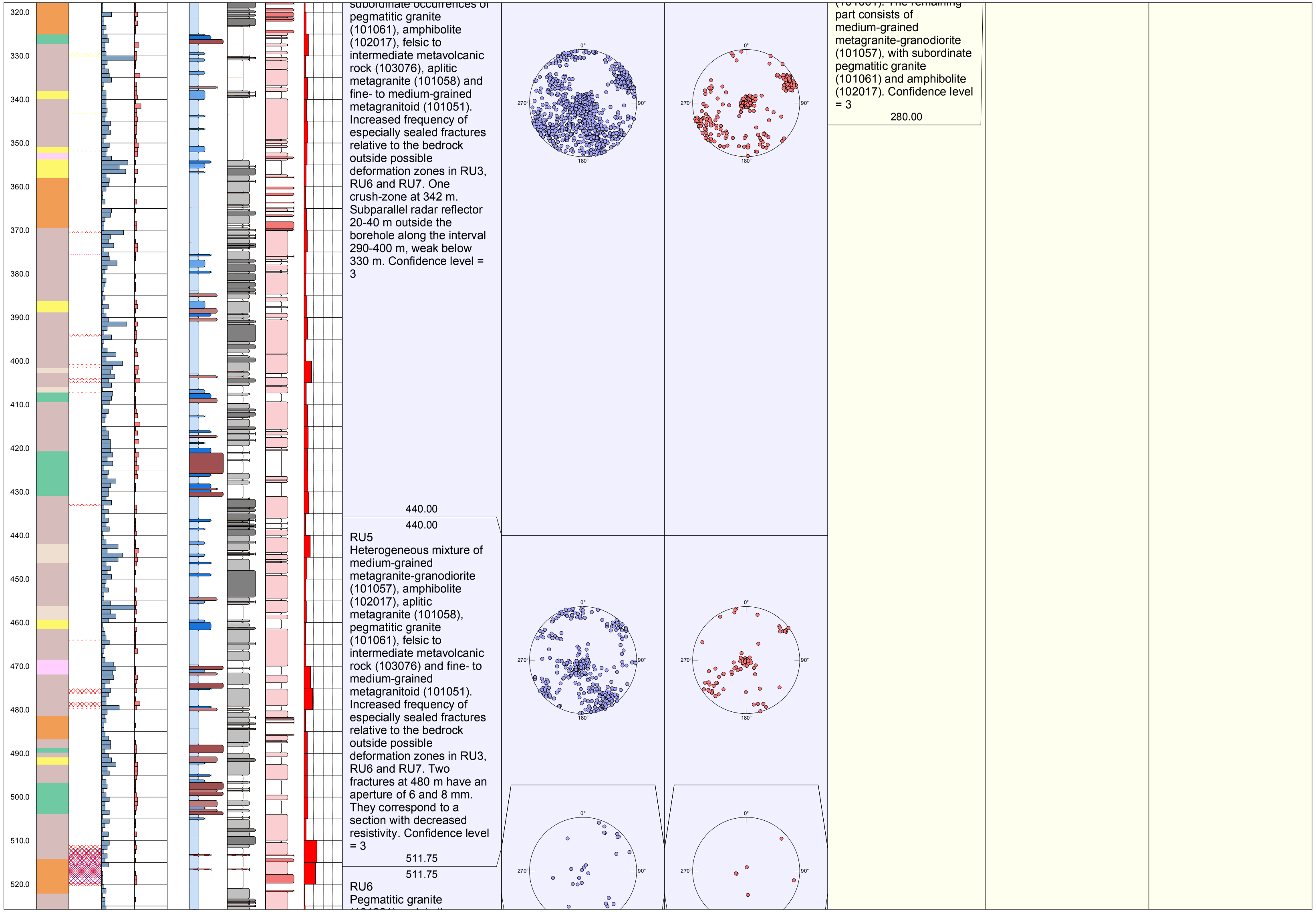
116.00

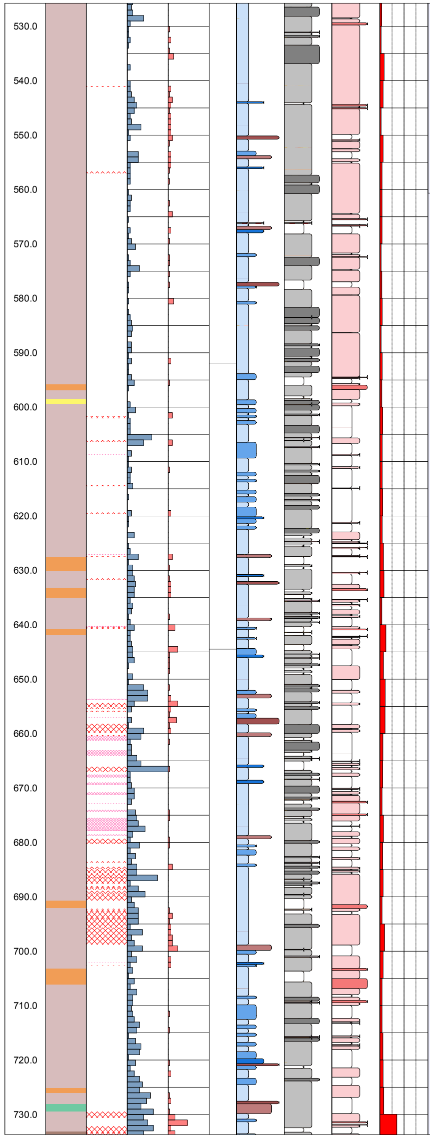
217.00

DZ3
Increased frequency of sealed fractures and sealed fracture networks. Increased frequency of open fractures in the lower part. Apertures in open fractures are generally less than 1 mm, locally up to 10 mm. One single crush zone in the lower part. Fractures show variable orientation. Predominant fracture minerals are calcite, chlorite, laumontite, pyrite, hematite and clay minerals. Locally faint to weak oxidation. Minor interval of weak epidotization in the upper part of the possible zone. Geophysical anomaly with decreased resistivity (230-250 m) and caliper anomalies. Variable magnetic susceptibility. 24 radar reflectors of which four are oriented at 247 m (154/71), 266 m (139/16), 274 m (219/57) and 278 m (195/44). The upper 25 m consist of fine- to medium-grained metagranitoid (101051), with subordinate pegmatitic granite






320.0
330.0
340.0
350.0
360.0
370.0
380.0
390.0
400.0
410.0
420.0
430.0
440.0
450.0
460.0
470.0
480.0
490.0
500.0
510.0
520.0
subordinate occurrences of pegmatitic granite (101061), amphibolite (102017), felsic to intermediate metavolcanic rock (103076), aplitic metagranite (101058) and fine- to medium-grained metagranitoid (101051). Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. One crush-zone at 342 m. Subparallel radar reflector 20-40 m outside the borehole along the interval 290-400 m, weak below 330 m. Confidence level = 3
440.00
440.00
RU5
Heterogeneous mixture of medium-grained metagranite-granodiorite (101057), amphibolite (102017), aplitic metagranite (101058), pegmatitic granite (101061), felsic to intermediate metavolcanic rock (103076) and fine- to medium-grained metagranitoid (101051). Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. Two fractures at 480 m have an aperture of 6 and 8 mm. They correspond to a section with decreased resistivity. Confidence level = 3
511.75
511.75
RU6
Pegmatitic granite
0°
90°
180°
270°
(101061). The remaining part consists of medium-grained metagranite-granodiorite (101057), with subordinate pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3
280.00



(101061) and, in the upper part, medium-grained metagranite-granodiorite (101057), both of which are oxidized and vuggy. Rock unit corresponds to increased natural gamma radiation, decreased magnetic susceptibility and resistivity. Confidence level = 3

522.24

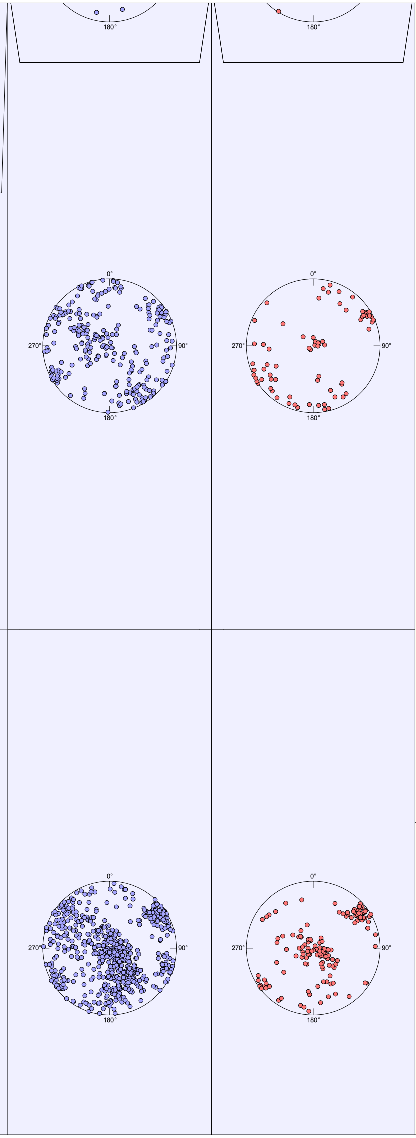
522.24

RU7
Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017) and felsic to intermediate metavolcanic rock (103076). One crush-zone at 592 m. Confidence level = 3

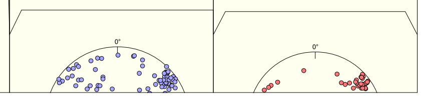
640.80

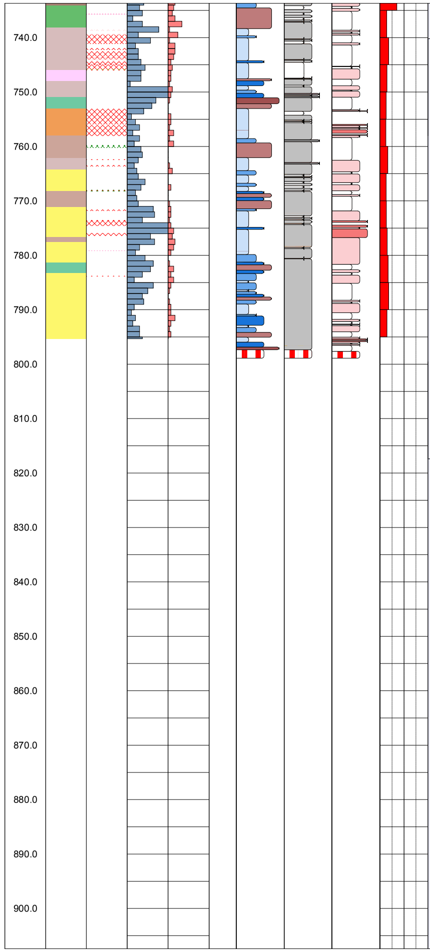
640.80

RU8
Medium-grained metagranite-granodiorite (101057), generally with intense ductile deformation, and with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017), fine- to medium-grained metagranitoid (101051) and felsic to intermediate metavolcanic rock (103076). These occurrences are somewhat thicker and occur together with quartz-bearing metadiorite (101033) and metatonalite-granodiorite (101054) in the lower part of the rock unit. Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. One crush-zone at 644 m. Confidence level = 3



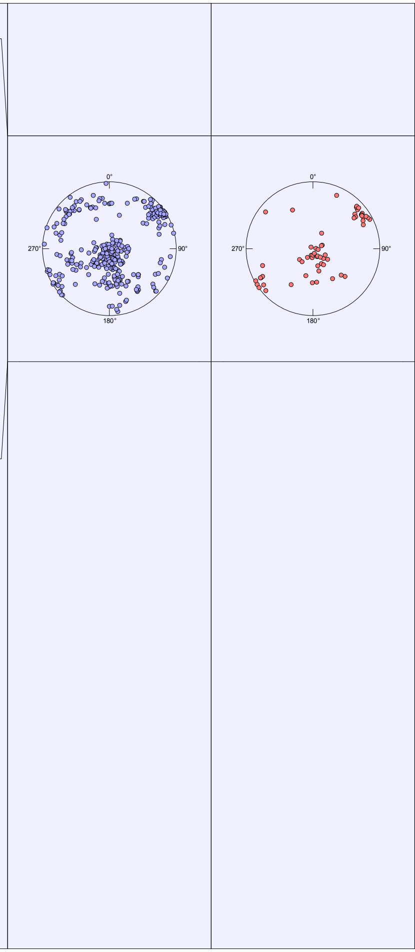
723.00
DZ4
Increased frequency of open fractures, sealed fractures and sealed fracture networks. No apertures in open fractures exceed 1 mm. Fractures show variable orientation. A conspicuous set strikes NW and dips steeply. Predominant fracture minerals are calcite, chlorite, laumontite, hematite, pyrite and clay minerals. Locally faint to medium oxidation. Geophysical anomaly with decreased resistivity





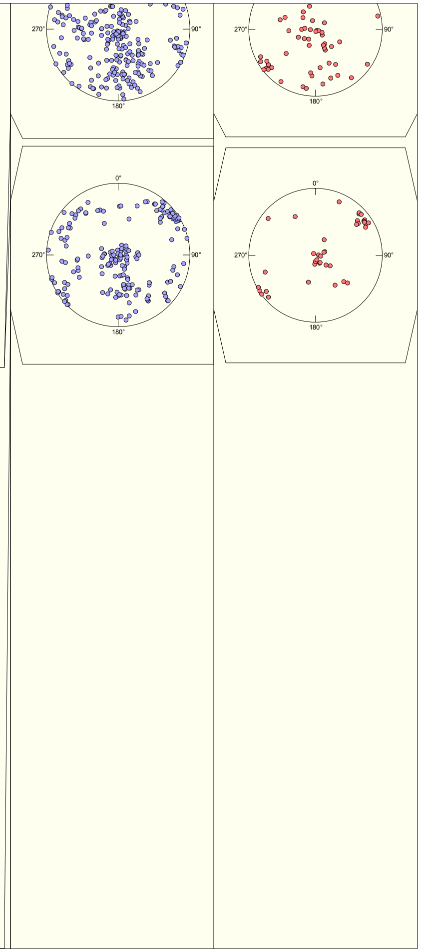
758.06

758.06
RU9
Felsic to intermediate metavolcanic rock (103076) with subordinate occurrences of metagranodiorite (101056), amphibolite (102017), metagranite-granodiorite (101057), metatonalite-granodiorite (101054) and fine- to medium-grained metagranitoid (101051). Virtually the whole borehole section has been affected by intense ductile deformation. Increased frequency of especially sealed fractures relative to the bedrock outside possible deformation zones in RU3, RU6 and RU7. Confidence level = 3
799.55



(730-750 m) and caliper anomalies. Low magnetic susceptibility between 743-746 m. Five radar reflectors of which one is oriented at 730 m (360/07). The zone consists of medium-grained metagranite-granodiorite (101057), with subordinate pegmatitic granite (101061), amphibolite (102017), quartz- bearing metadiorite (101033), fine- to medium-grained metagranitoid (101051), metatonalite-granodiorite (101054) and felsic to intermediate metavolcanic rock (103076). Confidence level = 3
754.00

770.00
DZ5
Increased frequency of sealed fractures and sealed fracture networks. No apertures in open fractures exceed 1 mm. Fractures show variable orientation. Conspicuous sets are gently dipping to subhorizontal and strike NW and are steeply dipping. Predominant fracture minerals are calcite, chlorite, quartz, laumontite, adularia and clay minerals. Locally faint to weak oxidation. Geophysical anomaly with decreased resistivity (778-788 m). Four radar reflectors of which one has an uncertain orientation at 784 m (313/84 or 044/14). Dominating rock type is felsic to intermediate metavolcanic rock (103076). Subordinate rock types are amphibolite (102017), metagranodiorite (101056) and fine- to medium-grained metagranitoid (101051). Confidence level = 3
790.00



Geological single-hole interpretation of KFM07B

Title	SINGLE HOLE INTERPRETATION KFM07B					
Site	FORSMARK	Inclination [°]	-53.70	Elevation [m.a.s.l.]	3.36	Signed data
Borehole	KFM07B	Date of mapping	2005-11-10 10:03:00	Drilling Start Date	2005-05-31 16:20:00	
Diameter [mm]	76	Coordinate System	RT90-RHB70	Drilling Stop Date	2005-10-18 10:24:00	
Length [m]	298.930	Northing [m]	6700123.62	Surveying Date		
Bearing [°]	134.35	Easting [m]	1631036.83	Plot Date	2006-09-20 21:10:12	

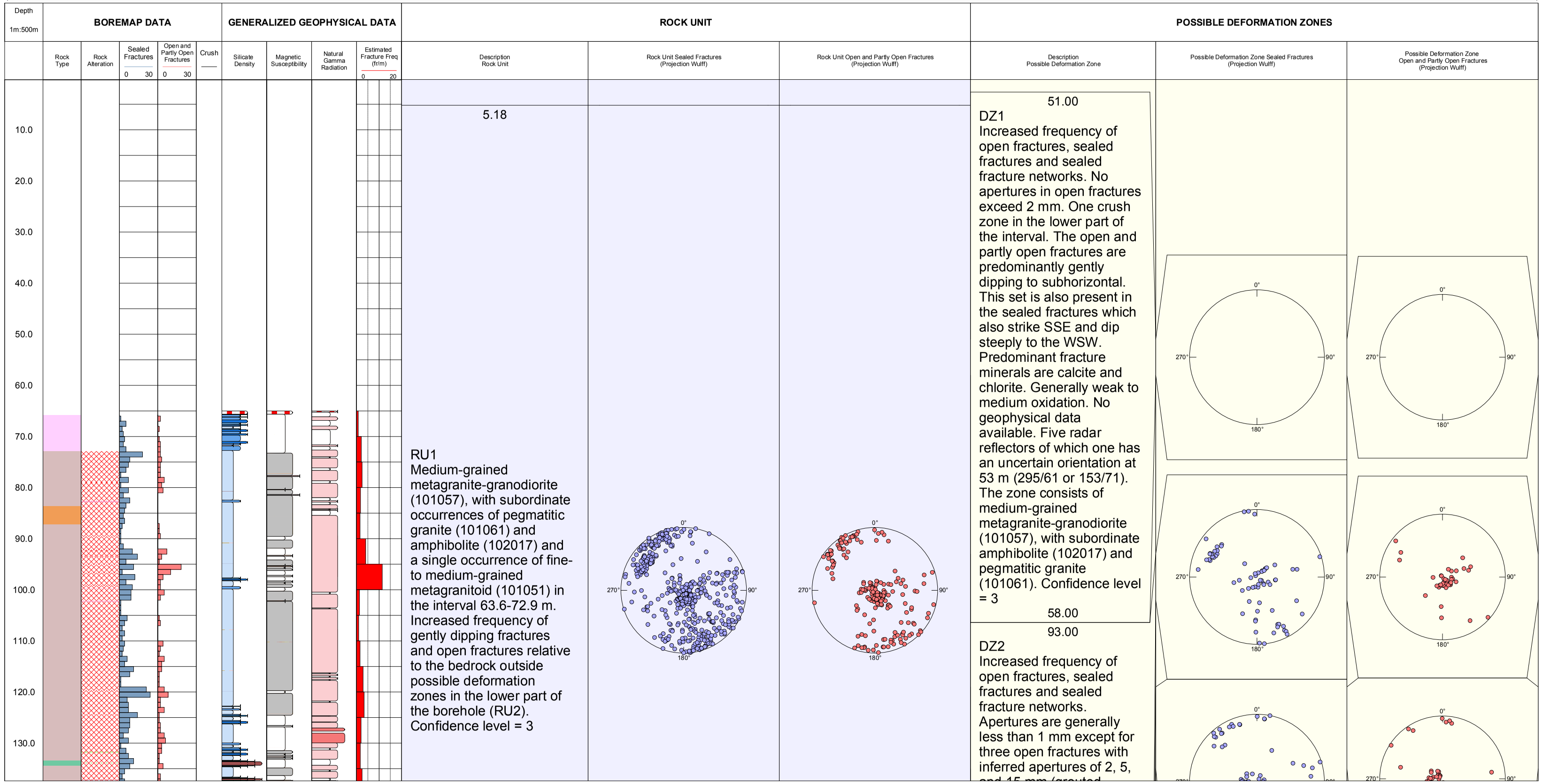
ROCKTYPE FORSMARK
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite

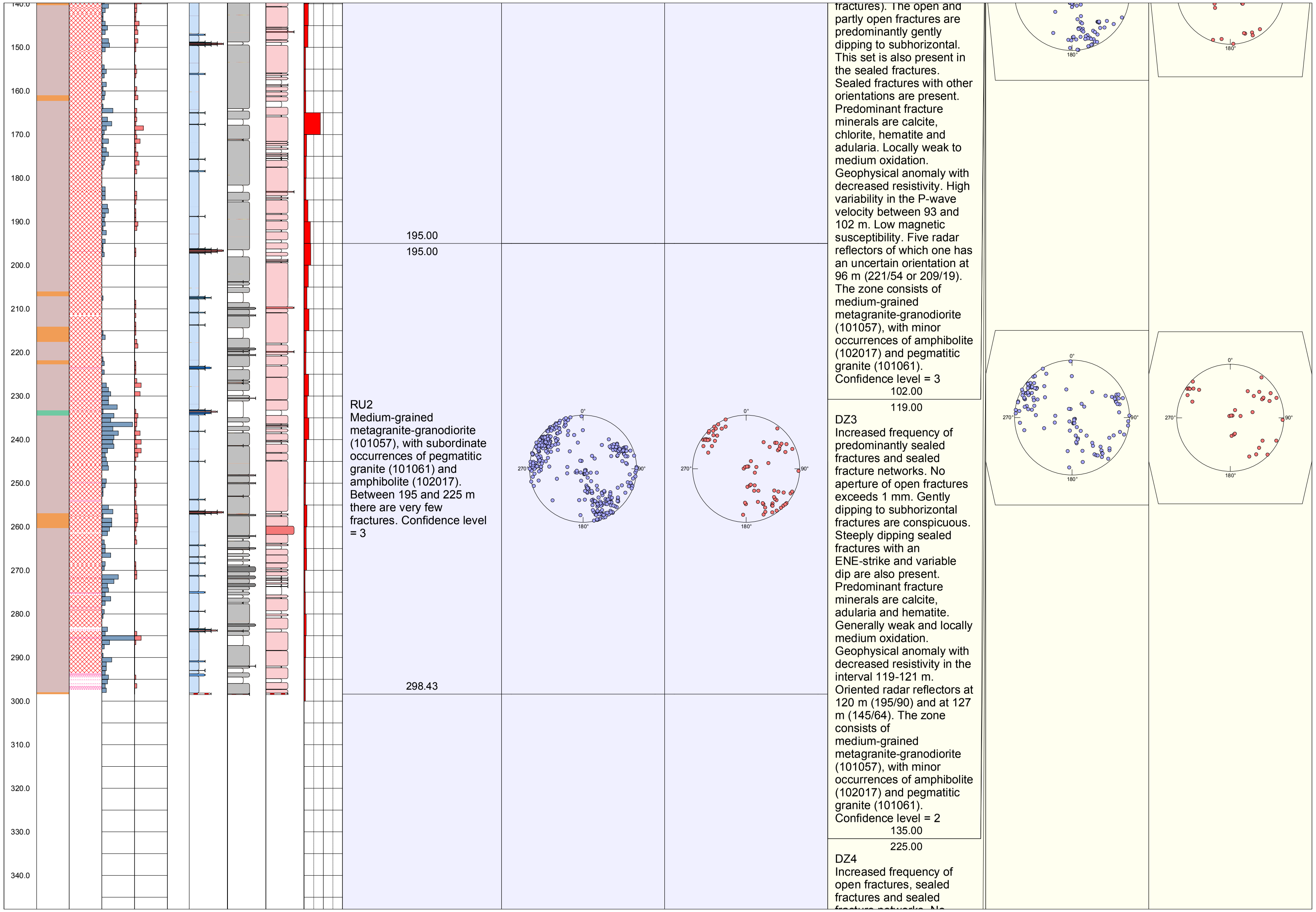
ROCK ALTERATION
- Oxidized
- Epidotisized
- Albitization

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

SUSCEPTIBILITET
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

NATURAL GAMMA
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53




140.0
150.0
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
195.00
195.00
RU2
Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Between 195 and 225 m there are very few fractures. Confidence level = 3
298.43
fractures). The open and partly open fractures are predominantly gently dipping to subhorizontal. This set is also present in the sealed fractures. Sealed fractures with other orientations are present. Predominant fracture minerals are calcite, chlorite, hematite and adularia. Locally weak to medium oxidation. Geophysical anomaly with decreased resistivity. High variability in the P-wave velocity between 93 and 102 m. Low magnetic susceptibility. Five radar reflectors of which one has an uncertain orientation at 96 m (221/54 or 209/19). The zone consists of medium-grained metagranite-granodiorite (101057), with minor occurrences of amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3
102.00
119.00
DZ3
Increased frequency of predominantly sealed fractures and sealed fracture networks. No aperture of open fractures exceeds 1 mm. Gently dipping to subhorizontal fractures are conspicuous. Steeply dipping sealed fractures with an ENE-strike and variable dip are also present. Predominant fracture minerals are calcite, adularia and hematite. Generally weak and locally medium oxidation. Geophysical anomaly with decreased resistivity in the interval 119-121 m. Oriented radar reflectors at 120 m (195/90) and at 127 m (145/64). The zone consists of medium-grained metagranite-granodiorite (101057), with minor occurrences of amphibolite (102017) and pegmatitic granite (101061). Confidence level = 2
135.00
225.00
DZ4
Increased frequency of open fractures, sealed fractures and sealed

350.0
360.0
370.0
380.0
390.0
400.0
410.0
420.0
430.0

fracture networks. No aperture of open fractures exceeds 1 mm. Steeply dipping fractures that strike SE to SSE as well as NE dominate. More gently dipping fractures are also present. Predominant fracture minerals are calcite, laumontite, adularia and chlorite. Weak to medium oxidation in the lower part of the interval. Geophysical anomaly with decreased resistivity in the interval 225-240 m. Caliper anomaly at 225 m and between 233-235 m. Seven radar reflectors of which one is oriented at 232 m (153/79). The zone consists of medium-grained metagranite-granodiorite (101057), with subordinate amphibolite (102017) and pegmatitic granite (101061). Confidence level = 3

245.00