P-06-135

Forsmark site investigation

Geological single-hole interpretation of KFM09B and KFM01C

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July 2006

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ISSN 1651-4416
SKB P-06-135

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Keywords: Forsmark, Geophysics, Geology, Borehole, Bedrock, Fractures, AP PF 400-06-022.

Abstract

This report presents geological single-hole interpretations of the cored boreholes KFM09B and KFM01C 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 four rock units (RU1–RU4) occur in KFM09B. However, the borehole can be divided into seven separate sections due to the repetition of RU1 (RU1a and RU1b), RU3 (RU3a and RU3b) and RU4 (RU4a and RU4b). Medium-grained metagranite-granodiorite (101057) dominates the borehole. Subordinate rock types in the different units are pegmatitic granite (101061), amphibolite (102017), fine- to medium-grained granite (111058) and calc-silicate rock (108019). A section with vuggy granite occurs in one rock unit. Five possible deformation zones of brittle character have been identified in KFM09B (DZ1–DZ5).

The geological single-hole interpretation shows that one rock unit (RU1) occurs in KFM01C. The borehole is dominated by medium-grained metagranite-granodiorite (101057). Subordinate rock types are pegmatitic granite (101061), amphibolite (102017), fine- to medium-grained metagranitoid (101051), felsic to intermediate metavolcanic rock (103076) and aplitic metagranite (101058). Three possible deformation zones of brittle character have been identified in KFM01C (DZ1–DZ3).

Sammanfattning

Denna rapport behandlar geologisk enhålstolkning av kärnborrhålen KFM09B och KFM01C 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 KFM09B finns fyra litologiska enheter (RU1–RU4). Baserat på repetition av enheten RU1 (RU1a och RU1b), RU3 (RU3a och RU3b) och RU4 (RU4a och RU4b) kan borrhålet delas in i sju sektioner. Medelkornig metagranit-granodiorit (101057) dominerar borrhålet. I mindre omfattning i de olika litologiska enheterna förekommer pegmatitisk granit (101061), amfibolit (102017), fin- till medelkornig metagranitoid (101051), fin- till medelkornig granit (111058) och kalksilikatbergart (108019). En sektion med porös granit förekommer i en av de litologiska enheterna. Fem möjliga deformationszoner som är spröda har identifierats i KFM09B (DZ1–DZ5).

Den geologiska enhålstolkningen visar att det finns en litologisk enhet (RU1) i KFM01C. Medelkornig metagranit-granodiorit (101057) dominerar borrhålet. I mindre omfattning förekommer pegmatitisk granit (101061), amfibolit (102017), fin- till medelkornig metagranitoid (101051), felsisk till intermediär metavulkanit (103076) och aplitisk granit (101058). Tre möjliga deformationszoner som är spröda har identifierats i KFM01C (DZ1–DZ3).

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 KFM09B and KFM01C in the Forsmark area. The horizontal projections of the boreholes in the candidate area are shown in Figure 1-1. The work was carried out in accordance with activity plan SKB PF 400-06-022. 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 400-06-022	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

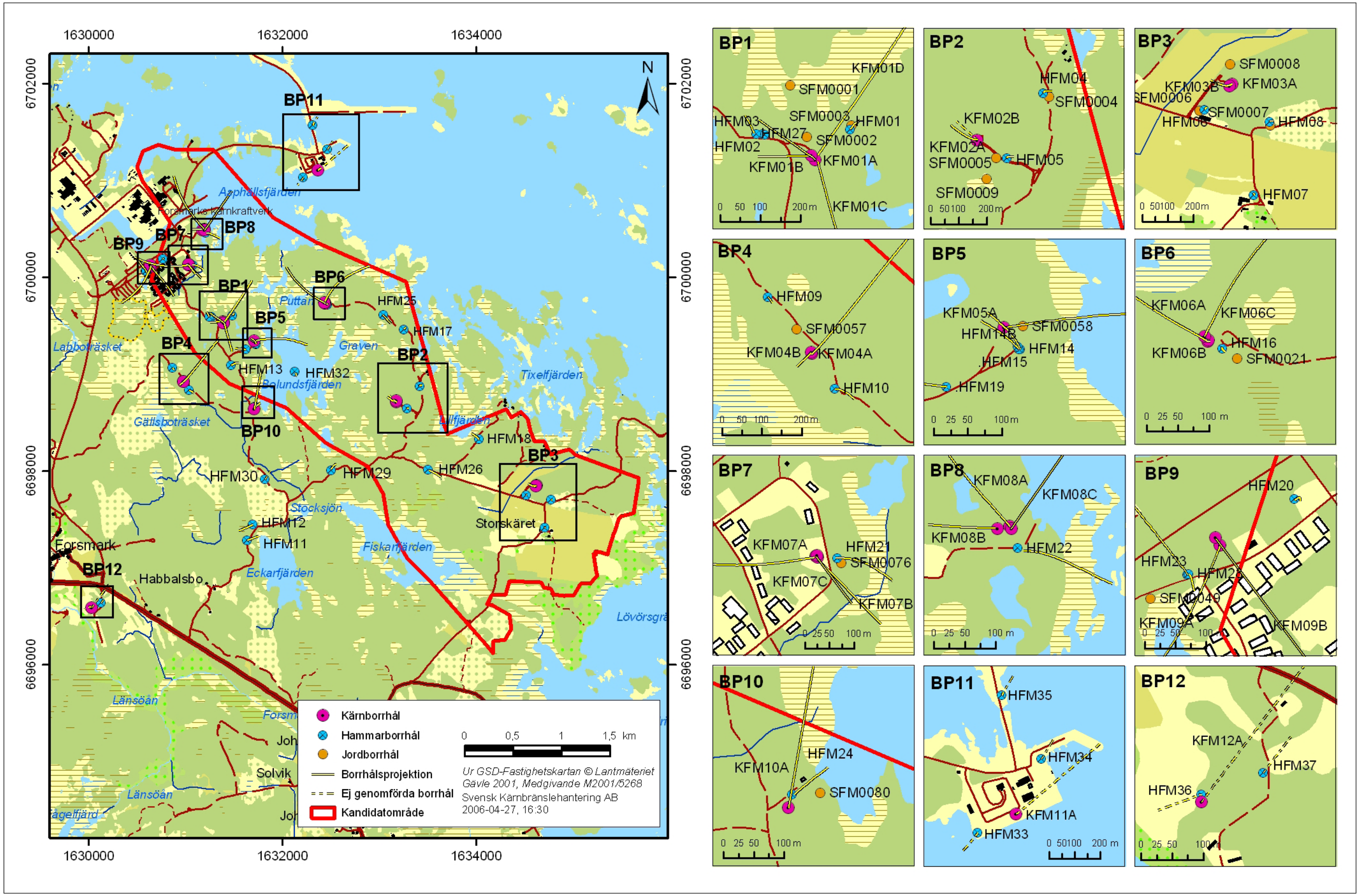


Figure 1-1. *Map showing position and horizontal projection of the boreholes in the candidate area including the cored boreholes KFM09B and KFM01C.*

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 KFM09B and KFM01C:

- Boremap data (including BIPS and geological mapping data) /1, 2/.
- Generalized geophysical logs and their interpretation /3/.
- Radar data and their interpretation /4, 5/.

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 /6/.

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.

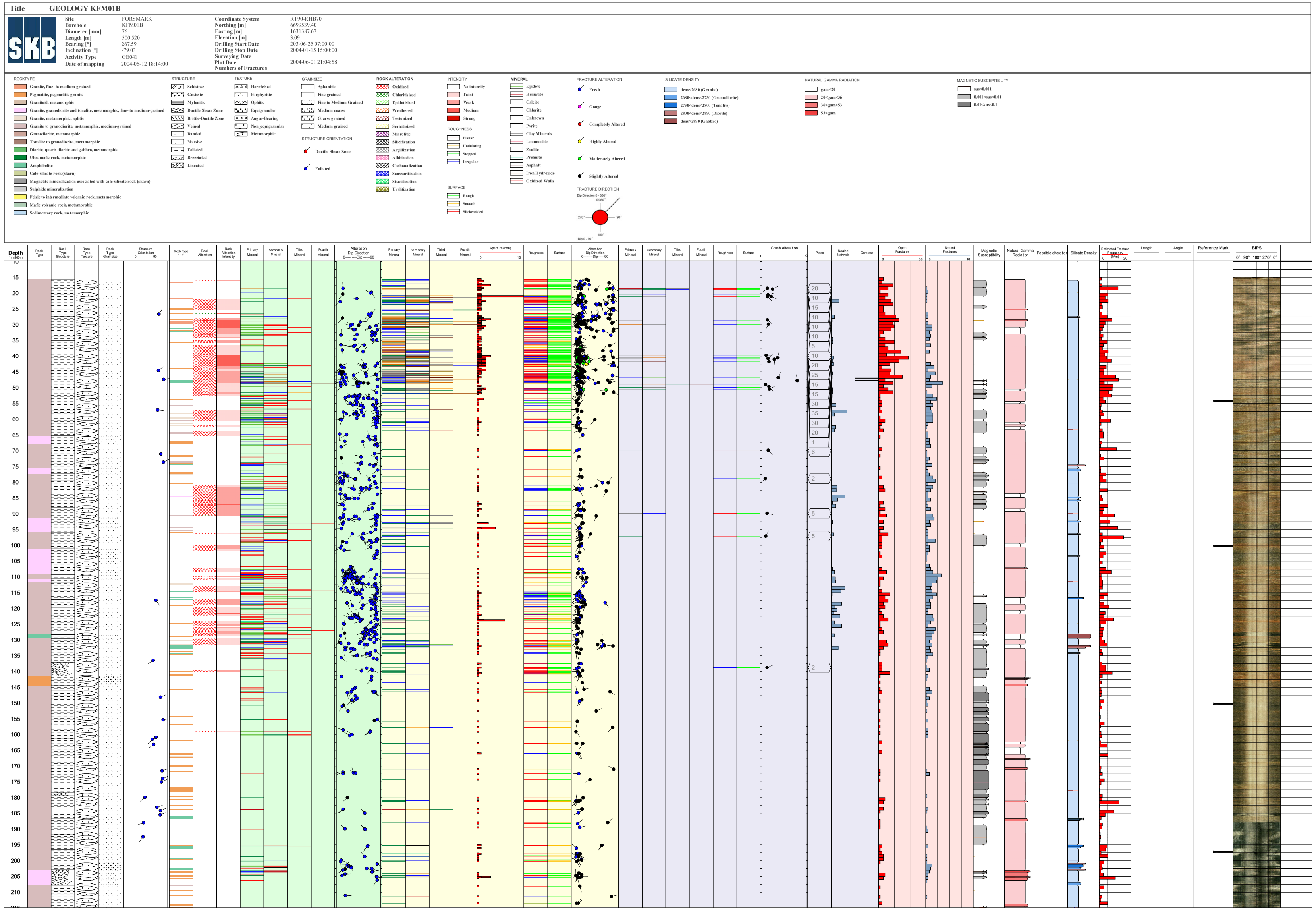


Figure 3-1. *Example of WellCad plot (from borehole KFM01B) used as a basis for the single-hole interpretation.*

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 Chapter 3) 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.

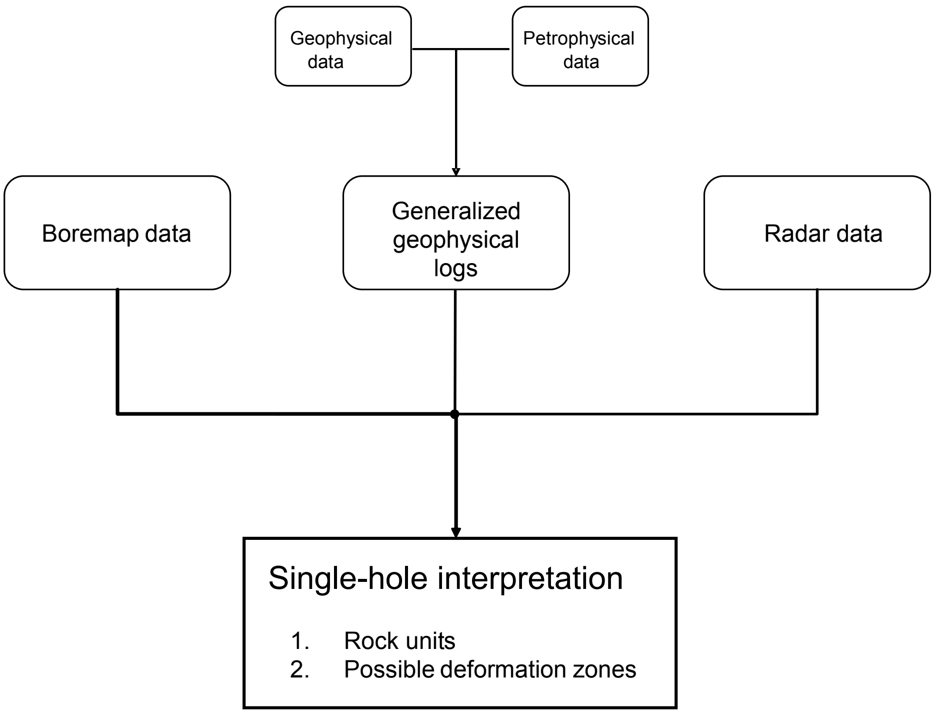


Figure 4-1. *Schematic chart that shows the procedure for the development of a geological single-hole interpretation.*

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 /7/. 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.

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 KFM09B and KFM01C (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.

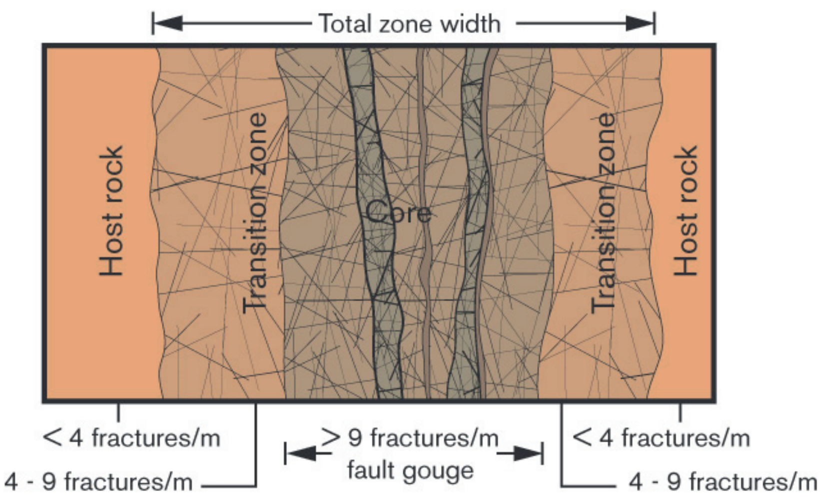


Figure 4-2. *Terminology for brittle deformation zones (after /7/).*

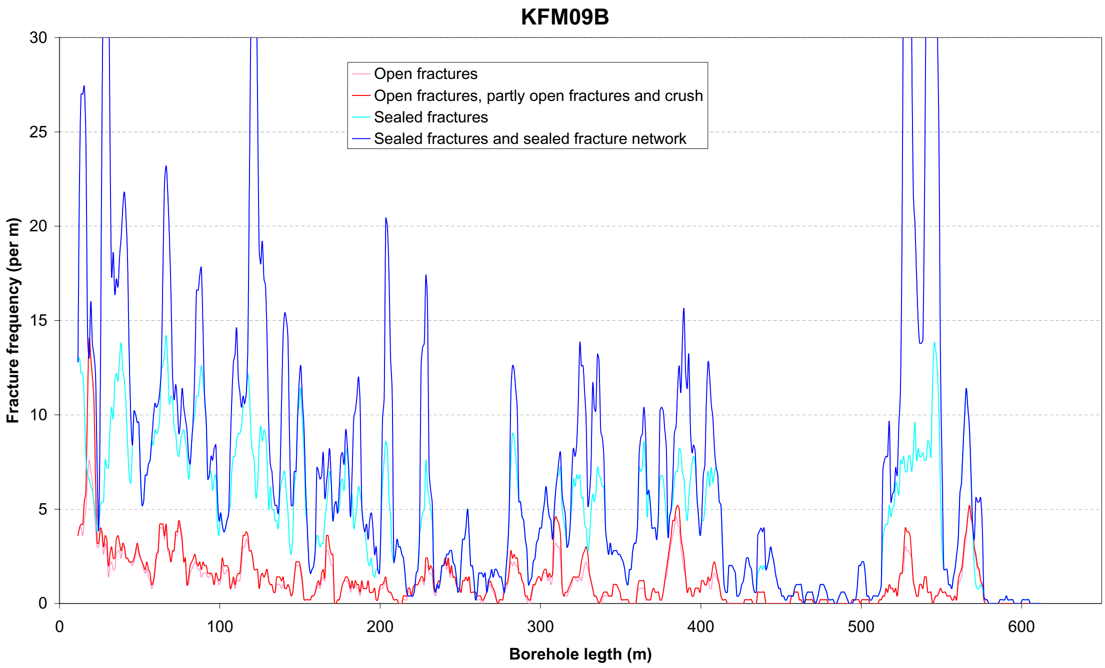


Figure 4-3. Fracture frequency plot for KFM09B. Moving average with a 5 m window and 1 m steps.

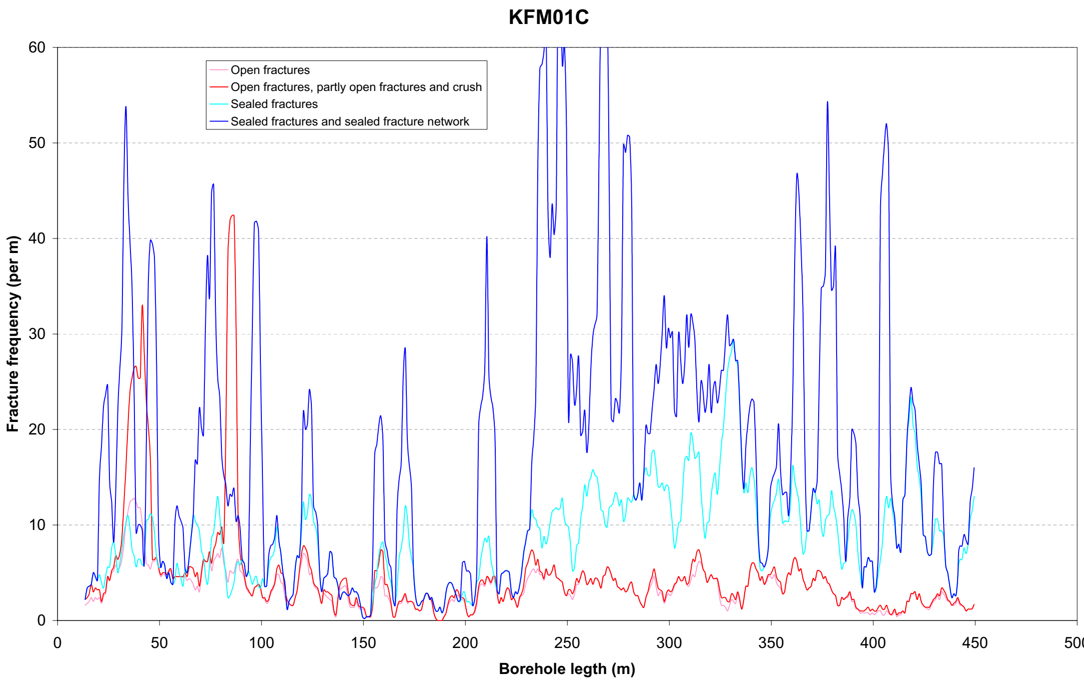


Figure 4-4. Fracture frequency plot for KFM01C. Moving average with a 5 m window and 1 m steps.

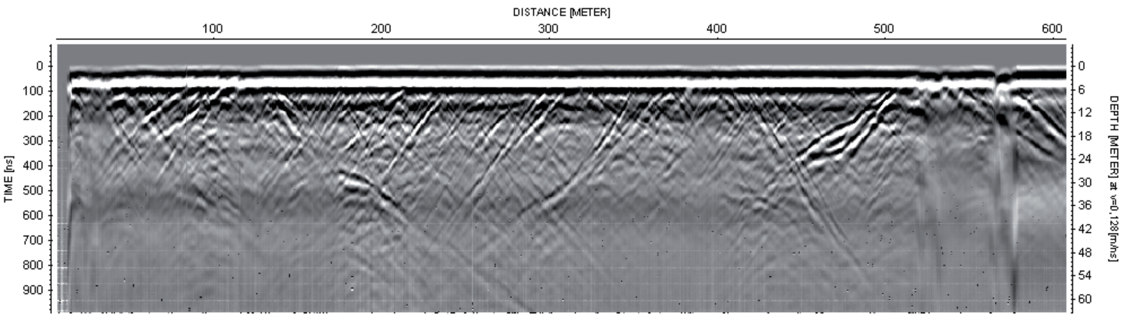


Figure 4-5. Overview (20 MHz data) of the borehole radar measurements in KFM09B.

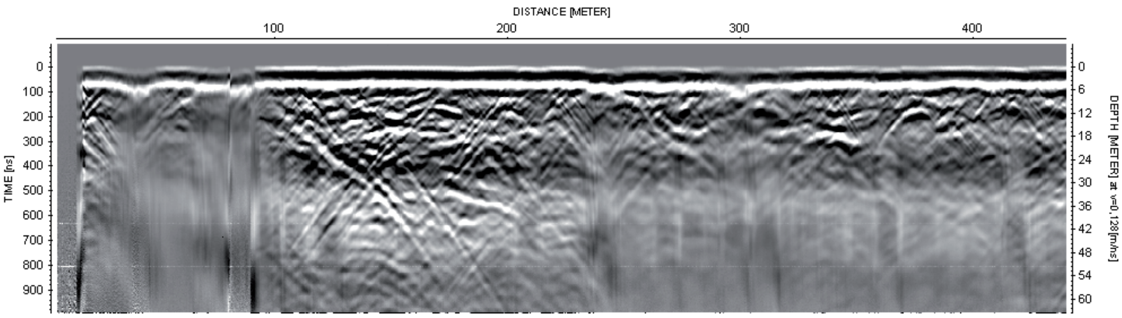


Figure 4-6. Overview (20 MHz data) of the borehole radar measurements in KFM01C.

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 measurements in KFM09B and KFM01C 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.

4.2 Nonconformities

The section 612–616.33 m in KFM09B was mapped without access to BIPS-image.

The section 441.73–449.92 m in KFM01C was mapped without access to BIPS-image.

Directional antenna was not logged in KFM01C.

Data from silicate density log is missing below 82 m borehole length in KFM01C.

Borehole KFM01C was shielded by a perforated metal plate at the section 84.31-86.27 m.

5 Results

The result of the geological single-hole interpretation is presented as print-outs from the software WellCad (Appendix 1 for KFM09B and Appendix 2 for KFM01C).

5.1 KFM09B

The borehole direction at the start is 140.8/–55.1.

Rock units

The borehole can be divided into four different rock units, RU1–RU4, all of which have been recognized with a high degree of confidence. Rock units RU1, RU3 and RU4 occur at two separate borehole intervals, respectively. These are distinguished using the identification codes RU1a, RU1b, RU3a, RU3b, RU4a and RU4b.

9.22–109.94 m

RU1a: Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Also one occurrence of fine- to medium-grained metagranitoid (101051) and one occurrence of fine- to medium-grained granite (111058). Confidence level = 3.

109.94–169.15 m

RU2: Pegmatitic granite (101061) with subordinate occurrences of medium-grained metagranite-granodiorite (101057). Also a few minor occurrences of amphibolite (102017). The medium-grained metagranite-granodiorite has been affected by faint albitization in the length interval 147–154 m. Locally high frequency of sealed fractures relative to lower half of the borehole outside possible deformation zones. Few fractures with apertures greater than 1 mm. Confidence level = 3.

169.15–258.93 m

RU1b: Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Locally high frequency of sealed fractures relative to lower half of the borehole outside possible deformation zones. Confidence level = 3.

258.93–317.58 m

RU3a: Medium-grained metagranite-granodiorite (101057) affected by faint to medium albitization. Low gamma radiation and partly low magnetic susceptibility characterize this alteration. Subordinate occurrences of pegmatitic granite (101061), calc-silicate rock (108019) and amphibolite (102017). Locally high frequency of sealed fractures relative to lower half of the borehole outside possible deformation zones. Confidence level = 3.

317.58–444.51 m

RU4a: Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061). Also a few minor occurrences of amphibolite (102017). Confidence level = 3.

444.51–480.48 m

RU3b: Medium-grained metagranite-granodiorite (101057) affected by faint to weak albitization. Low gamma radiation and partly low magnetic susceptibility characterize this alteration. Subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3.

480.48–616.33 m

RU4b: Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017), and one occurrence of fine- to medium-grained metagranitoid (101051). Pegmatitic granite in the interval 567–586 m shows high natural gamma radiation. Vuggy metagranite-granodiorite and pegmatitic granite as a result of quartz dissolution in the interval 569–573 m. This interval is characterized by radar wave attenuation, and low resistivity, P-wave velocity, magnetic susceptibility and density. See also DZ5. Confidence level = 3.

Possible deformation zones

Five possible deformation zones of brittle character that have been recognised with a high or medium degree of confidence are present in KFM09B:

9.2–132 m

DZ1: Increased frequency of sealed and open fractures and sealed fracture networks, especially in the upper (9.2–41 m) and lower (110–132 m) parts. Gently dipping to subhorizontal fractures and steeply dipping fractures with SW strike dominate. Some fractures also strike SSE and dip steeply westwards. Open fractures are predominantly gently dipping. Two, approximately 3 dm wide crush zones occur at 20 m borehole length. Apertures are typically less than 3 mm; one fracture aperture is up to 6 mm wide. Locally faint to weak oxidation. Low resistivity and low P-wave velocity in the intervals 14–43 m, 64–75 m and 112–132 m of which the uppermost interval also shows low magnetic susceptibility. 36 radar reflectors of which 5 are confidently oriented (235/70, 230/86, 009/38, 131/62, 148/69). One strong reflector (orientation 131/62) can be traced 18 m outside the borehole. Prominent radar wave attenuations in the intervals 14–22 m, 26–36 m and 120–124 m. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Zone situated in fine- to medium-grained granite, amphibolite and fine- to medium-grained metagranitoid. Confidence level = 3.

308–340 m

DZ2: Increased frequency of sealed and open fractures and sealed fracture networks. Steeply dipping fractures with NE strike as well as gently dipping fractures dominate. One 3 cm wide crush zone at 311 m. Apertures are typically less than 1 mm. No geophysical signature. 10 radar reflectors of which 2 are confidently oriented (094/16, 074/85). One radar reflector (orientation 094/16) is very strong and can be traced 30–40 m outside the borehole.

The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Zone situated in medium-grained metagranite-granodiorite which is affected by weak albitization in the uppermost part. Subordinate occurrences of pegmatitic granite. Confidence level = 2.

363–413 m

DZ3: Increased frequency of sealed and open fractures and sealed fracture networks. Steeply dipping fractures with NE strike as well as gently dipping fractures with variable strike dominate. Apertures are typically less than 1 mm, with a few ranging up to 5 mm. Locally faint to weak oxidation. Low resistivity and low P-wave velocity in the interval 379–411 m. Caliper anomaly at 390 m. 20 radar reflectors of which one is confidently oriented (154/65). Weak radar wave attenuation in the interval 380–390 m. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite and laumontite. Zone situated in medium-grained metagranite-granodiorite with minor occurrences of pegmatitic granite and amphibolite. Confidence level = 3.

520–550 m

DZ4: Increased frequency of sealed and open fractures and sealed fracture networks. Steeply dipping fractures with a strike that varies from NNW to ENE dominate. Apertures are 1 mm or less. Faint to weak oxidation. Low resistivity and low P-wave velocity in the interval 525–540 m. Low magnetic susceptibility in the whole zone. Caliper anomaly at 527 m. Eight radar reflectors of which two are confidently oriented (145/61, 122/58). One radar reflector (orientation 145/61) is very strong and can be traced 30–40 m outside the borehole. Prominent radar wave attenuation in the interval 522–530 m. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Zone situated in pegmatitic granite and medium-grained metagranite-granodiorite with subordinate occurrences of amphibolite. Confidence level = 3.

561–574 m

DZ5: Increased frequency of sealed and open fractures. Steeply dipping fractures dominate. One group strikes WSW and dips steeply northwards. A second group varies in strike from NNE to ENE. Fracture apertures are 1.5 mm or less. Faint to weak oxidation. Quartz dissolution occurs in the interval 569–573 m (see RU4b). Low resistivity, magnetic susceptibility and P-wave velocity in the whole zone. Two identified radar reflectors. Prominent radar wave attenuation in the interval (566–573 m). The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite and clay minerals. Zone situated in medium-grained metagranite-granodiorite with subordinate pegmatitic granite. Confidence level = 3.

5.2 KFM01C

The borehole direction at the start is 165.4/–49.6.

Rock units

The borehole consists of one rock unit, RU1, which have been recognized with a high degree of confidence.

11.88–449.92 m

RU1: Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017), fine- to medium-grained metagranitoid (101051), felsic to intermediate metavolcanic rock (103076) and aplitic metagranite (101058). Two wide sections of pegmatitic granite (161–172 m) and fine- to medium-grained metagranitoid (178–191 m). Oxidation, locally increased fracture frequency and a few fractures with apertures up to 9 mm occur in the rock unit also outside possible deformation zones. Subparallel radar reflector between 270 and 400 m occurs approximately 15–20 m from the borehole. Confidence level = 3.

Possible deformation zones

Three possible deformation zones of brittle character that have been recognised with a high degree of confidence are present in KFM01C:

23–48 m

DZ1: Increased frequency of open, partly open and sealed fractures and sealed fracture networks. Steeply dipping fractures that strike WSW and dip northwards as well as gently dipping to subhorizontal fractures dominate. Three crush zones between 40 and 45 m. Low resistivity, low P-wave velocity and low magnetic susceptibility. Three caliper anomalies. Geophysical anomalies are concentrated between 30 and 48 m which corresponds to a section with fracture apertures up to 4 mm and one up to 10 mm. Four non-oriented radar reflectors (angle to borehole axis 47–65°) and most prominent radar wave attenuation between 30 and 48 m. Weak to medium oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include clay minerals, hematite, chlorite, calcite, adularia and asphaltite. Zone situated in medium-grained metagranite-granodiorite. Pegmatitic granite occurs at the top of the zone. Confidence level = 3.

62–99 m

DZ2: Increased frequency of open fractures, sealed fractures and sealed fracture networks. Steeply dipping fractures that strike WSW and dip northwards as well as gently dipping to subhorizontal fractures dominate. One crush zone at 84.38–86.09 and core loss at 84.50–85.89 and 86.17–86.18 m. The borehole was shielded by a metal plate in the section 84.31–86.27. Fracture apertures are typically less than 1 mm, with a few up to 4 mm. Generally weak to medium oxidation. Low resistivity, low P-wave velocity and low magnetic susceptibility. Three caliper anomalies. Geophysical anomalies are concentrated between 70 and 89 m and between 96 to 99 m. Nine non-oriented radar reflectors (angle to borehole axis 30–56°) and most prominent radar wave attenuation between 68 and 80 m, possibly also lower down (borehole shielded). The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, clay minerals, hematite and asphaltite. Zone situated in medium-grained metagranite-granodiorite with subordinate pegmatitic granite and amphibolite. Confidence level = 3.

235–449.92 m

DZ3: Increased frequency of predominantly sealed fractures and sealed fracture networks. Steeply dipping fractures that strike WSW and dip northwards as well as gently dipping to subhorizontal fractures dominate. Steeply dipping fractures that strike NW are also present. Fracture apertures less than 1 mm, except for two fractures which are 1.5 mm and 4 mm at 352 m. The zone shows different characteristics in its upper and lower parts. The part of the zone between 235 and 343 m shows a generally high frequency of fractures and a more frequent occurrence of oxidation (weak to medium), while the part between 343 and 435 m shows a more variable fracture frequency with a concentration of fractures along narrower borehole intervals. Low resistivity anomalies in the intervals 235–245 m and 296–319 m. Slightly decreased bulk resistivity and magnetic susceptibility between 235 and 335 m. 49 non-oriented radar reflectors (angle to borehole axis 03–72°) and most prominent radar wave attenuation in the intervals 235–246 m, 295–299 m, 306–314 m, 362–366 m and 412–418 m. The most frequent fracture filling minerals in the order of decreasing abundance include laumontite, calcite and chlorite. Zone situated in medium-grained metagranite-granodiorite, with subordinate occurrences of amphibolite, pegmatitic granite, felsic to intermediate metavolcanic rock, aplitic metagranite and fine- to medium-grained metagranitoid. Confidence level = 3.

6 Comments

The results of the geological single-hole interpretations of KFM09B and KFM01C 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, Dalwigk I, Wängnerud A, Berglund J, 2006**. Forsmark site investigation. Boremap mapping of core drilled borehole KFM09B. SKB P-06-xx (in prep). Svensk Kärnbränslehantering AB.

/2/ **Döse C, Samuelsson E, 2006.** Forsmark Site Investigation. Boremap mapping of core drilled borehole KFM01C. SKB P-06-xxx (in prep). Svensk Kärnbränslehantering AB.

/3/ **Mattsson H, Keisu M, 2006.** Forsmark site investigation. Interpretation of geophysical borehole measurements from KFM01C, KFM09B, HFM07, HFM24, HFM26, HFM29 and HFM32. SKB P-06-xxx (in prep). Svensk Kärnbränslehantering AB.

/4/ **Gustafsson J, Gustafsson C, 2006.** Forsmark site investigation. RAMAC and BIPS logging in boreholes KFM09B, HFM24, HFM26, HFM27, HFM29 and HFM32. SKB P-06-64. Svensk Kärnbränslehantering AB.

/5/ **Gustafsson J, Gustafsson C, 2006.** Forsmark site investigation. RAMAC and BIPS logging in boreholes KFM01C and KFM01D. SKB P-06-98. Svensk Kärnbränslehantering AB.

/6/ **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.

/7/ **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.

Geological single-hole interpretation of KFM09B

Appendix 1

Title SINGLE HOLE INTERPRETATION KFM09B

Site	FORSMARK	**Inclination [°]**	-55.07	**Elevation [m.a.s.l.]**	4.30	**Signed data**
Borehole	KFM09B	**Date of mapping**	2006-02-05 10:35:00	**Drilling Start Date**	2005-11-15 00:00:00	
Diameter [mm]	77	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	2005-11-15 00:00:00	
Length [m]	616.450	**Northing [m]**	6700119.89	**Surveying Date**		
Bearing [°]	140.83	**Easting [m]**	1630638.78	**Plot Date**	2006-09-20 21:10:12	

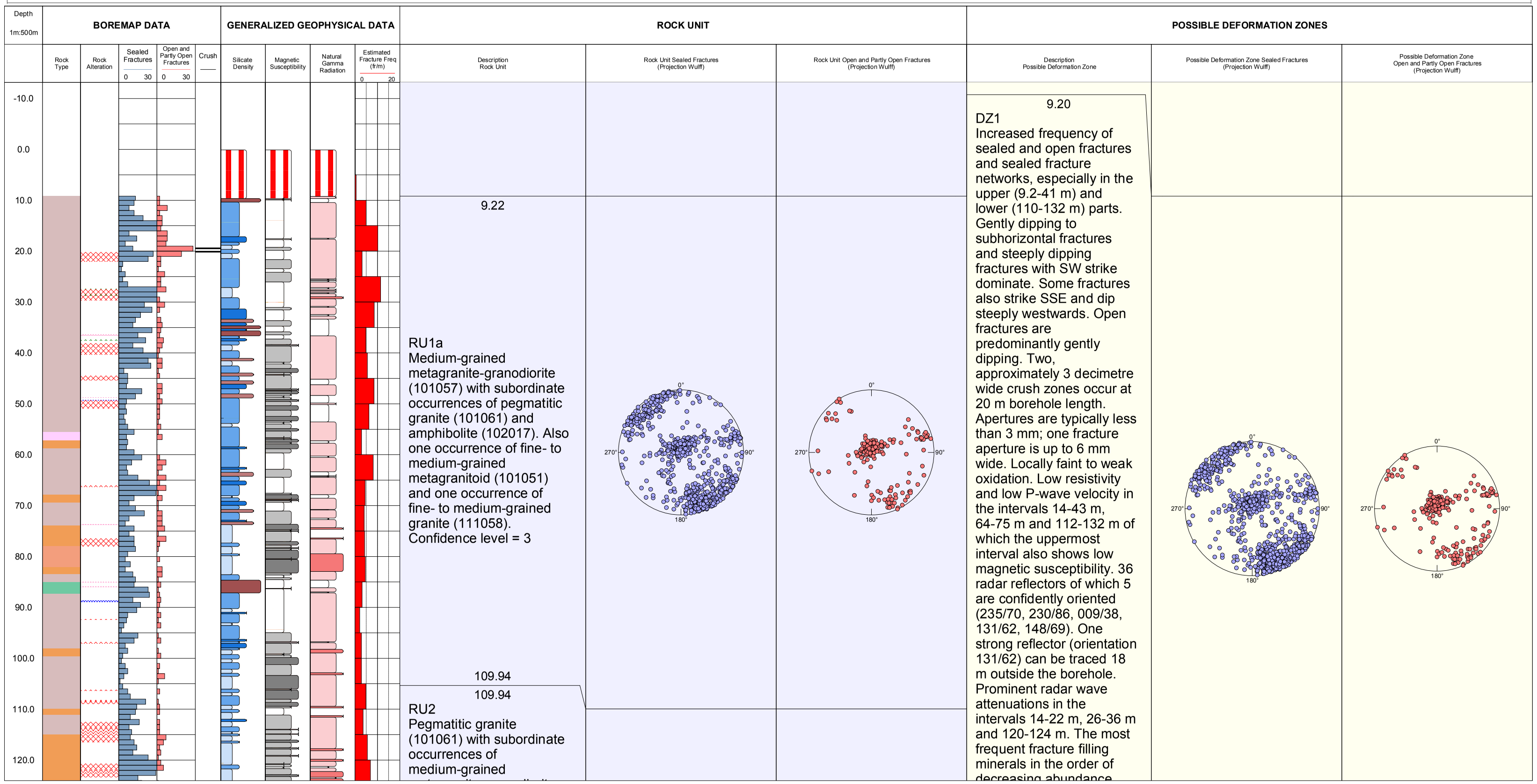
ROCKTYPE FORSMARK
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Calc-silicate rock (skarn)

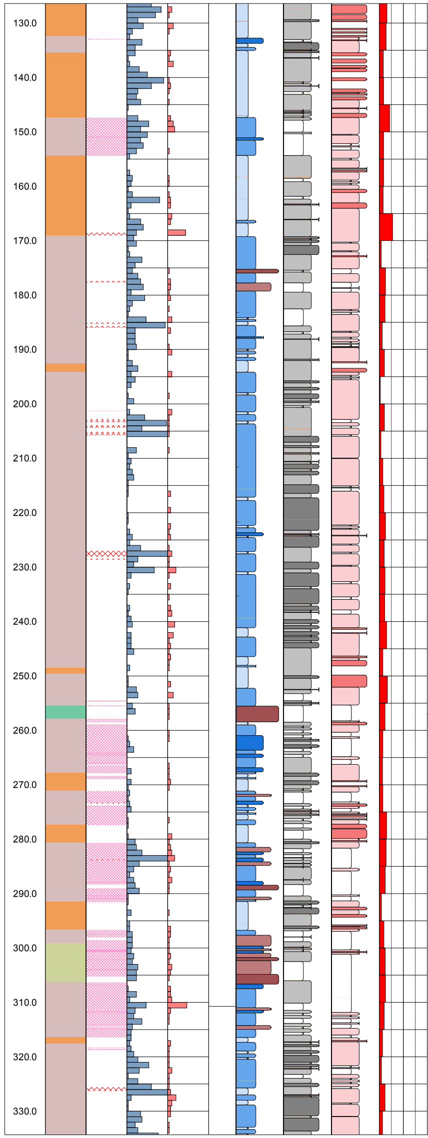
ROCK ALTERATION
- Oxidized
- Chloritisized
- Quartz dissolution
- Argillization
- Albitization
- Saussuritization
- Laumontitization

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





(101057). Also a few minor occurrences of amphibolite (102017). The medium-grained metagranite-granodiorite has been affected by faint albitization in the length interval 147-154 m. Locally high frequency of sealed fractures relative to lower half of the borehole outside possible deformation zones. Few fractures with apertures greater than 1 mm. Confidence level = 3

169.15

169.15

RU1b
Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Locally high frequency of sealed fractures relative to lower half of the borehole outside possible deformation zones. Confidence level = 3

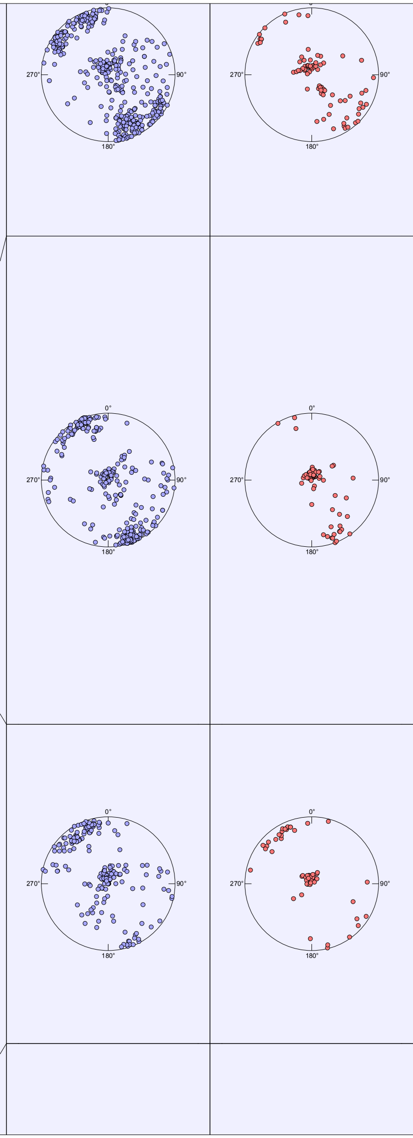
258.92

258.92

RU3a
Medium-grained metagranite-granodiorite (101057) affected by faint to medium albitization. Low gamma radiation and partly low magnetic susceptibility characterize this alteration. Subordinate occurrences of pegmatitic granite (101061), calc-silicate rock (108019) and amphibolite (102017). Locally high frequency of sealed fractures relative to lower half of the borehole outside possible deformation zones. Confidence level = 3

317.58

317.58

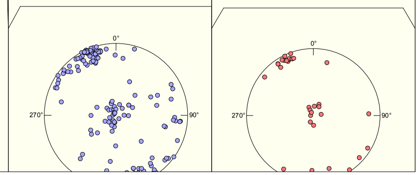


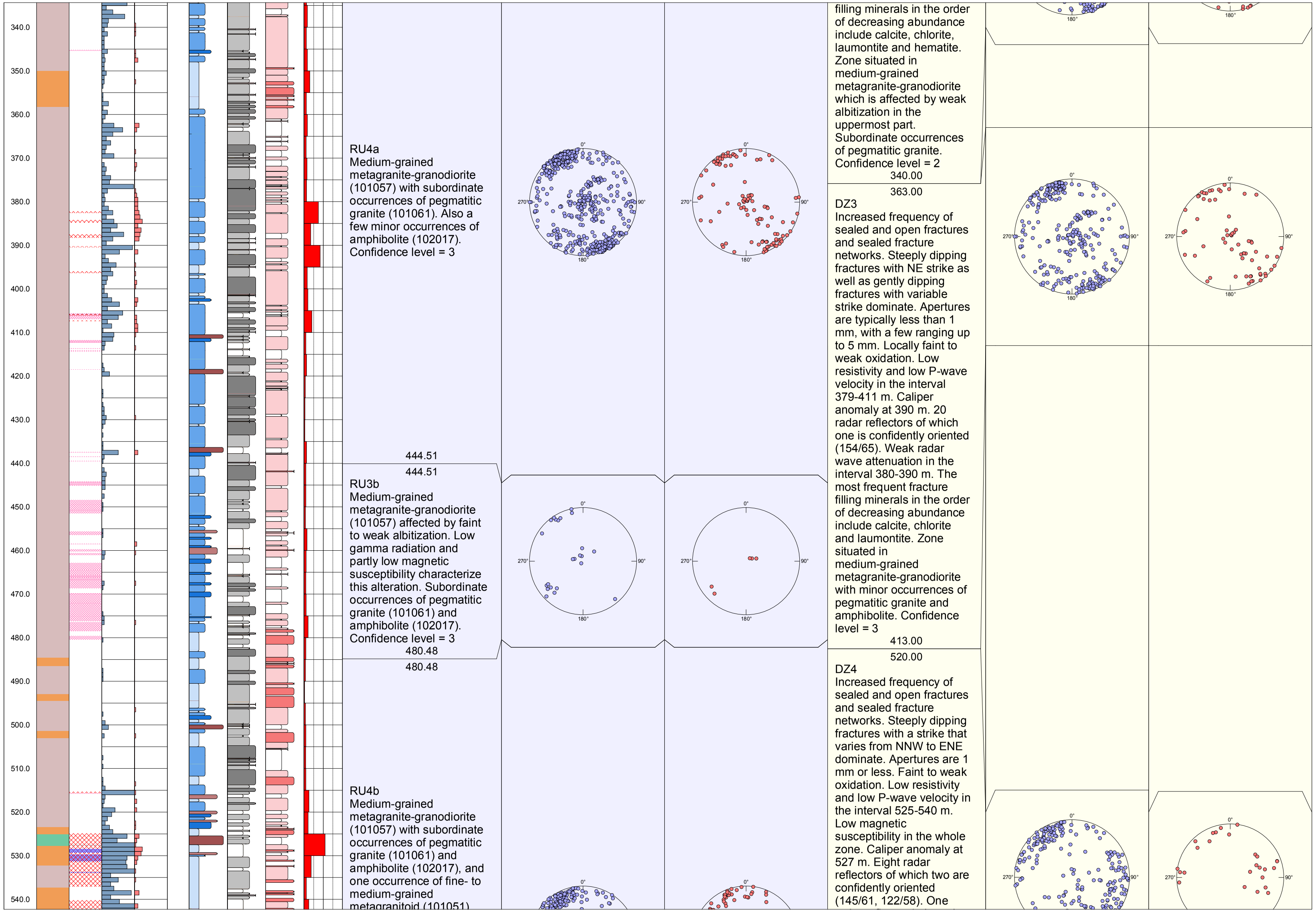
include calcite, chlorite, laumontite and hematite. Zone situated in fine- to medium-grained granite, amphibolite and fine- to medium-grained metagranitoid. Confidence level = 3

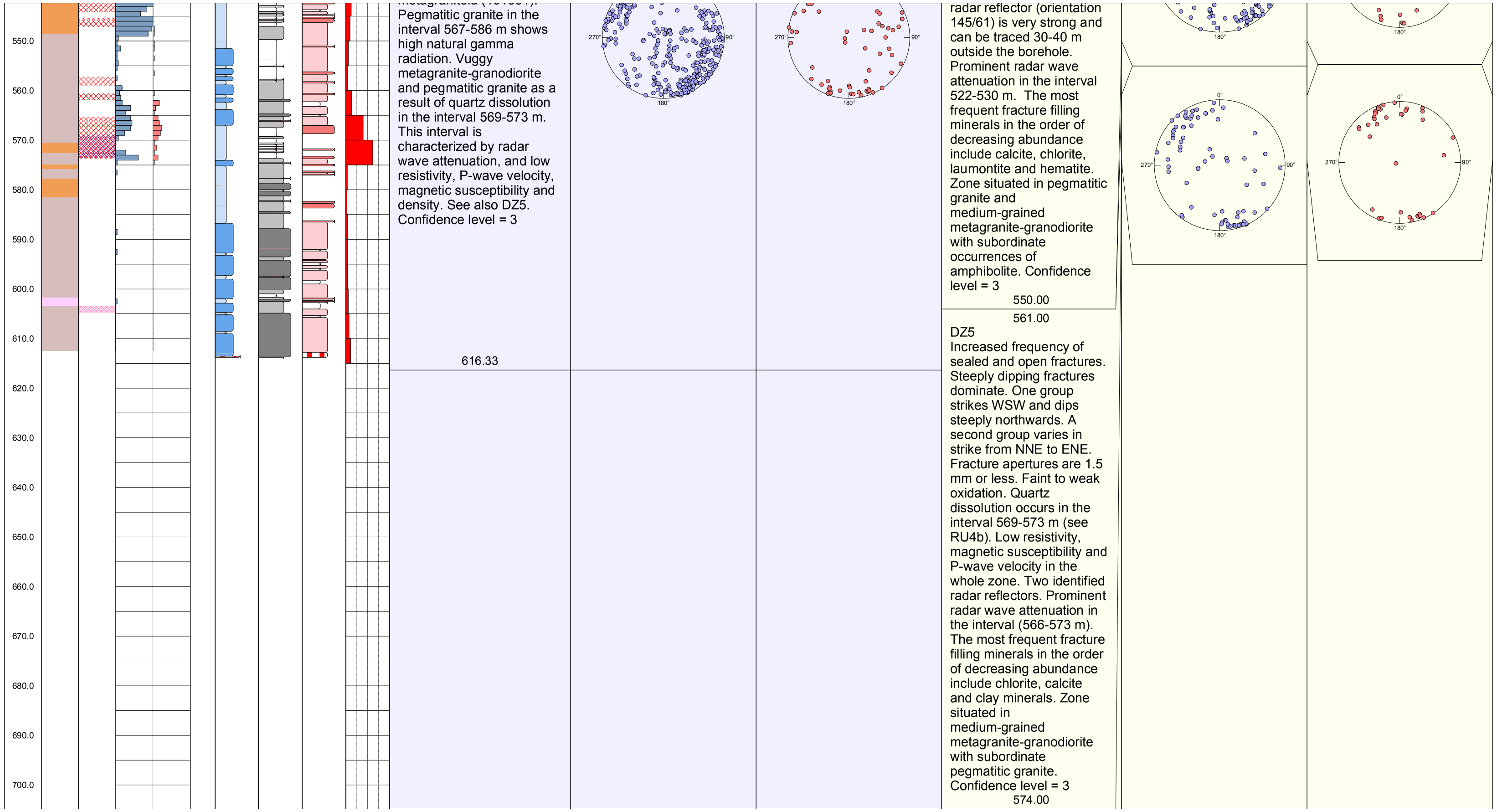
132.00

308.00

DZ2
Increased frequency of sealed and open fractures and sealed fracture networks. Steeply dipping fractures with NE strike as well as gently dipping fractures dominate. One 3 cm wide crush zone at 311 m. Apertures are typically less than 1 mm. No geophysical signature. 10 radar reflectors of which 2 are confidently oriented (094/16, 074/85). One radar reflector (orientation 094/16) is very strong and can be traced 30-40 m outside the borehole. The most frequent fracture




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
530.0
540.0
RU4a
Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061). Also a few minor occurrences of amphibolite (102017). Confidence level = 3
444.51
444.51
RU3b
Medium-grained metagranite-granodiorite (101057) affected by faint to weak albitization. Low gamma radiation and partly low magnetic susceptibility characterize this alteration. Subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Confidence level = 3
480.48
480.48
RU4b
Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017), and one occurrence of fine- to medium-grained metagranitoid (101051)
filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Zone situated in medium-grained metagranite-granodiorite which is affected by weak albitization in the uppermost part. Subordinate occurrences of pegmatitic granite. Confidence level = 2
340.00
363.00
DZ3
Increased frequency of sealed and open fractures and sealed fracture networks. Steeply dipping fractures with NE strike as well as gently dipping fractures with variable strike dominate. Apertures are typically less than 1 mm, with a few ranging up to 5 mm. Locally faint to weak oxidation. Low resistivity and low P-wave velocity in the interval 379-411 m. Caliper anomaly at 390 m. 20 radar reflectors of which one is confidently oriented (154/65). Weak radar wave attenuation in the interval 380-390 m. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite and laumontite. Zone situated in medium-grained metagranite-granodiorite with minor occurrences of pegmatitic granite and amphibolite. Confidence level = 3
413.00
520.00
DZ4
Increased frequency of sealed and open fractures and sealed fracture networks. Steeply dipping fractures with a strike that varies from NNW to ENE dominate. Apertures are 1 mm or less. Faint to weak oxidation. Low resistivity and low P-wave velocity in the interval 525-540 m. Low magnetic susceptibility in the whole zone. Caliper anomaly at 527 m. Eight radar reflectors of which two are confidently oriented (145/61, 122/58). One


550.0
560.0
570.0
580.0
590.0
600.0
610.0
620.0
630.0
640.0
650.0
660.0
670.0
680.0
690.0
700.0
Pegmatitic granite in the interval 567-586 m shows high natural gamma radiation. Vuggy metagranite-granodiorite and pegmatitic granite as a result of quartz dissolution in the interval 569-573 m. This interval is characterized by radar wave attenuation, and low resistivity, P-wave velocity, magnetic susceptibility and density. See also DZ5. Confidence level = 3
616.33
270°
90°
180°
0°
radar reflector (orientation 145/61) is very strong and can be traced 30-40 m outside the borehole. Prominent radar wave attenuation in the interval 522-530 m. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Zone situated in pegmatitic granite and medium-grained metagranite-granodiorite with subordinate occurrences of amphibolite. Confidence level = 3
550.00
561.00
DZ5
Increased frequency of sealed and open fractures. Steeply dipping fractures dominate. One group strikes WSW and dips steeply northwards. A second group varies in strike from NNE to ENE. Fracture apertures are 1.5 mm or less. Faint to weak oxidation. Quartz dissolution occurs in the interval 569-573 m (see RU4b). Low resistivity, magnetic susceptibility and P-wave velocity in the whole zone. Two identified radar reflectors. Prominent radar wave attenuation in the interval (566-573 m). The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite and clay minerals. Zone situated in medium-grained metagranite-granodiorite with subordinate pegmatitic granite. Confidence level = 3
574.00

Geological single-hole interpretation of KFM01C

Title SINGLE HOLE INTERPRETATION KFM01C

Site	FORSMARK	**Inclination [°]**	-49.60	**Elevation [m.a.s.l.]**	2.91	**Signed data**
Borehole	KFM01C	**Date of mapping**	2006-01-17 10:57:00	**Drilling Start Date**	2005-11-05 13:56:00	
Diameter [mm]	76	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	2005-11-29 13:52:00	
Length [m]	450.020	**Northing [m]**	6699526.14	**Surveying Date**		
Bearing [°]	165.35	**Easting [m]**	1631403.75	**Plot Date**	2006-09-20 21:10:12	

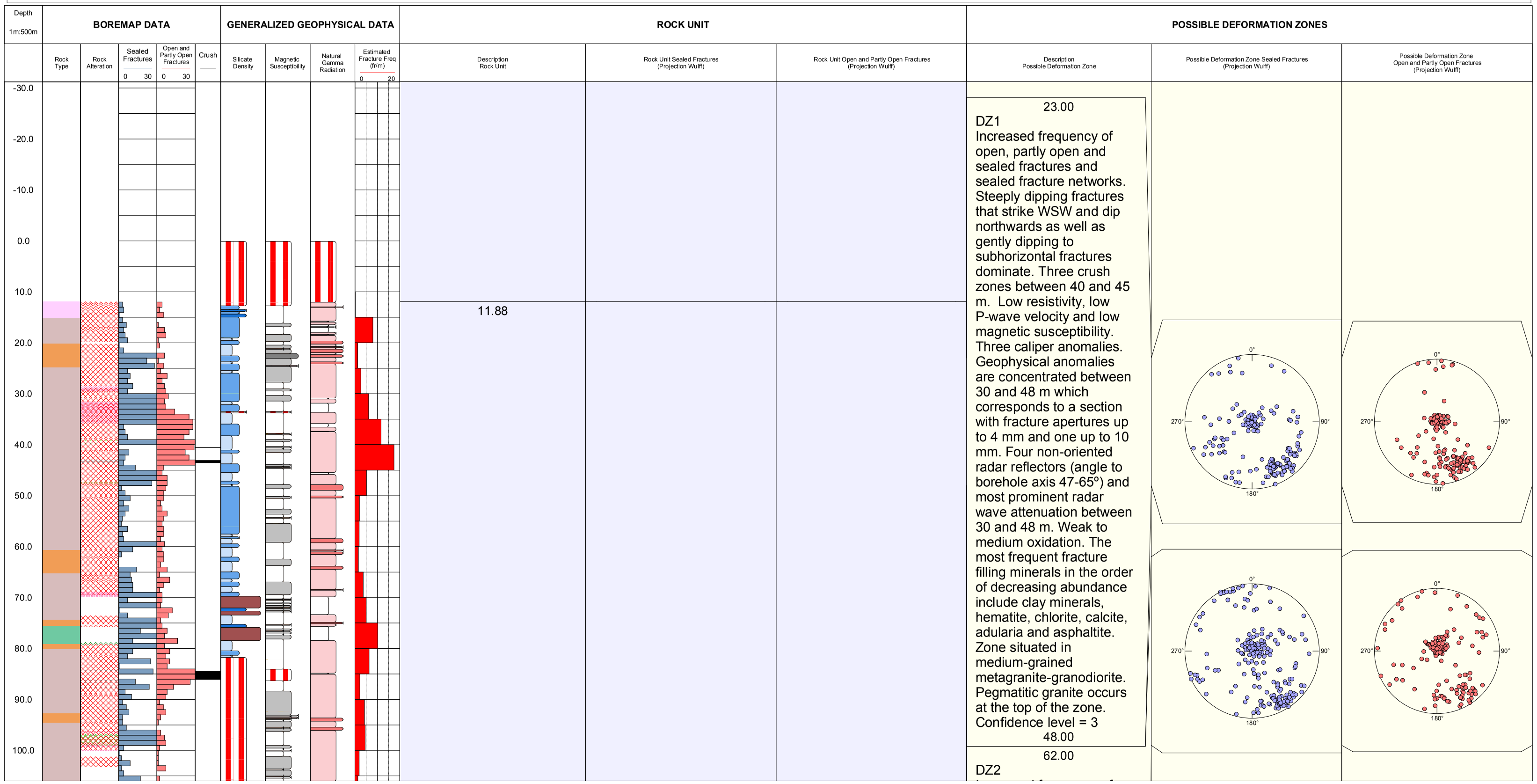
ROCKTYPE FORSMARK
- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock,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

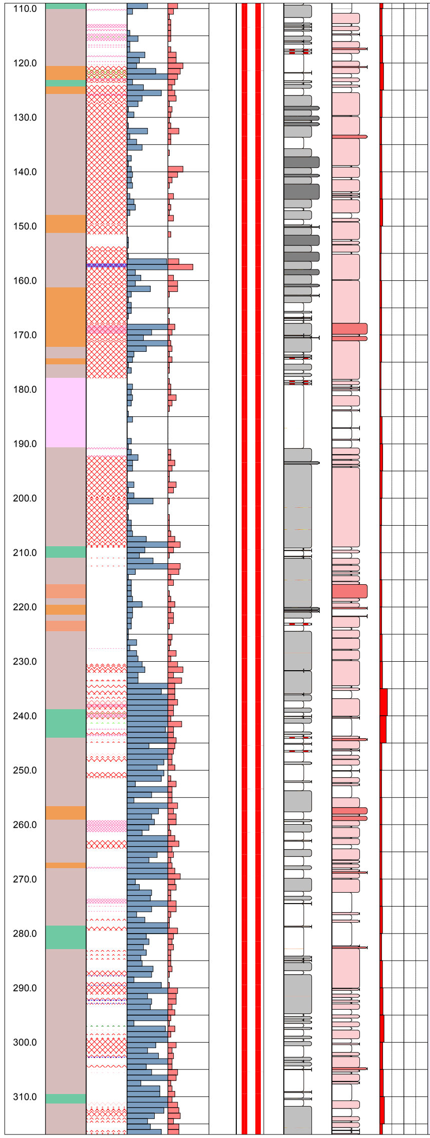
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Silicification
- Argillization
- Albitization
- Saussuritization
- Laumontitization

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

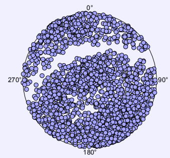
SUSCEPTIBILITET
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

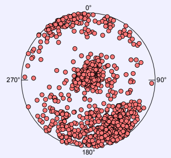
NATURAL GAMMA
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53





RU1
Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061), amphibolite (102017), fine- to medium-grained metagranitoid (101051), felsic to intermediate metavolcanic rock (103076) and aplitic metagranite (101058). Two wide sections of pegmatitic granite (161-172 m) and fine- to medium-grained metagranitoid (178-191 m). Oxidation, locally increased fracture frequency and a few fractures with apertures up to 9 mm occur in the rock unit also outside possible deformation zones. Subparallel radar reflector between 270 and 400 m occurs approximately 15-20 m from the borehole. Confidence level = 3



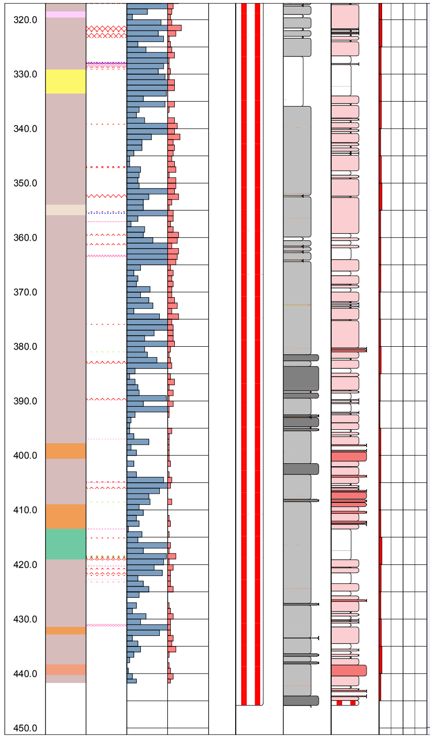


open fractures, sealed fractures and sealed fracture networks. Steeply dipping fractures that strike WSW and dip northwards as well as gently dipping to subhorizontal fractures dominate. One crush zone at 84.38-86.09 and core loss at 84.50-85.89 and 86.17-86.18 m. The borehole was shielded by a metal plate in the section 84.31-86.27. Fracture apertures are typically less than 1 mm, with a few up to 4 mm. Generally weak to medium oxidation. Low resistivity, low P-wave velocity and low magnetic susceptibility. Three caliper anomalies. Geophysical anomalies are concentrated between 70 and 89 m and between 96 to 99 m. Nine non-oriented radar reflectors (angle to borehole axis 30-56º) and most prominent radar wave attenuation between 68 and 80 m, possibly also lower down (borehole shielded). The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, clay minerals, hematite and asphaltite. Zone situated in medium-grained metagranite-granodiorite with subordinate pegmatitic granite and amphibolite. Confidence level = 3

99.00

235.00

DZ3
Increased frequency of predominantly sealed fractures and sealed fracture networks. Steeply dipping fractures that strike WSW and dip northwards as well as gently dipping to subhorizontal fractures dominate. Steeply dipping fractures that strike NW are also present. Fracture apertures less than 1 mm, except for two fractures which are 1.5 mm and 4 mm at 352 m. The zone shows different characteristics in its upper and lower parts. The part



449.92

of the zone between 235 and 343 m shows a generally high frequency of fractures and a more frequent occurrence of oxidation (weak to medium), while the part between 343 and 435 m shows a more variable fracture frequency with a concentration of fractures along narrower borehole intervals. Low resistivity anomalies in the intervals 235-245 m and 296-319 m. Slightly decreased bulk resistivity and magnetic susceptibility between 235 and 335 m. 49 non-oriented radar reflectors (angle to borehole axis 03-72°) and most prominent radar wave attenuation in the intervals 235-246 m, 295-299 m, 306-314 m, 362-366 m and 412-418 m. The most frequent fracture filling minerals in the order of decreasing abundance include laumontite, calcite and chlorite. Zone situated in medium-grained metagranite-granodiorite, with subordinate occurrences of amphibolite, pegmatitic granite, felsic to intermediate metavolcanic rock, aplitic metagranite and fine- to medium-grained metagranitoid. Confidence level = 3

449.92