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Geological single-hole interpretation of KFM08A, KFM08B and HFM22 (DS8)

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December 2005

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Keywords: Forsmark, Geophysics, Geology, Borehole, Bedrock, Fractures, AP-PF 400-05-029.

Reading instruction

For revision no. 1 of this report updated identification codes from rock units, in accordance with the revised method description for single-hole interpretation has been carried out. The term “confidence level” also replaces the term “uncertainty” in accordance with the revised method description.

The strike and dip of the oriented radar data are using the right-hand-rule method, e.g. 040/80 corresponds to a strike of N40°E and a dip of 80° to the SE.

Appendices 1, 2 and 3 are updated.

Abstract

This report contains geological single-hole interpretations of the cored boreholes KFM08A and KFM08B, and the percussion borehole HFM22 at Forsmark. Each interpretation combines the geological core mapping, interpreted geophysical logs and borehole radar measurements to interpret where rock units and possible deformation zones occur in the boreholes.

The geological single-hole interpretation shows that four rock units (RU1–RU4) occur in KFM08A. Medium-grained metagranite-granodiorite (101057) dominates the borehole. A biotite-rich variety of this rock occurs in the lower part of the borehole. Aplitic metagranite (101058) and a heterogeneous mixture of felsic to intermediate volcanic rock (103076) and amphibolite (102017) also occur in the borehole. Pegmatitic granite (101061) and fine- to medium-grained metagranitoid (101051) occur in shorter sections. A vuggy alteration rock with a metagranite-granodiorite (101057) protolith and pegmatitic granite (101061) occur in one section. Seven possible deformation zones that are brittle in character have been identified in KFM08A (DZ1–DZ7).

The borehole KFM08B is dominated by medium-grained metagranite-granodiorite (101057), which constitutes one rock unit (RU1). Pegmatitic granite (101061) and amphibolite (102017) occur in shorter sections. Two possible deformation zones that are brittle have been identified in KFM08B (DZ1–DZ2).

The percussion borehole HFM22 is dominated by medium-grained metagranite-granodiorite (101057), which constitutes one rock unit (RU1). Amphibolite (102017), pegmatitic granite (101061), and fine- to medium-grained metagranitoid (101051) occur in shorter sections. One possible deformation zone that is brittle has been identified in HFM22 (DZ1).

Sammanfattning

Denna rapport behandlar geologisk enhålstolkning av kärnborrhål KFM08A och KFM08B samt hammarborrhål HFM22 i Forsmark. Den geologiska enhålstolkningen syftar till att utifrån den geologiska karteringen, tolkade geofysiska loggar och borrhålsradarmätningar indikera olika litologiska enheters fördelning i borrhålen samt möjliga deformationszoners läge och utbredning.

Denna undersökning visar att det i KFM08A finns fyra litologiska enheter (RU1–RU4). Medelkornig metagranit-granodiorit (101057) förekommer i större delen av borrhålet. En biotitrik variant av denna finns i nedre delen av borrhålet. Aplitisk metagranit (101058) och en heterogen blandning av felsisk till intermediär vulkanisk bergart (103076) och amfibolit (102017) finns även i borrhålet. I mindre omfattning förekommer även pegmatitisk granit (101061) och fin- till medelkornig metagranitoid (101051). En porös omvandlingsbergart med metagranit-granodiorit (101057) som protolit samt pegmatitisk granit (101061) förekommer i en kort sektion av borrhålet. Sju möjliga deformationszoner som är spröda har identifierats i KFM08A (DZ1–DZ7).

Borrhål KFM08B domineras av medelkorning metagranit-granodiorit (101057), vilken utgör en litologisk enhet (RU1). I mindre omfattning förekommer pegmatitisk granit (101061) och amfibolit (102017). Två möjliga deformationszoner som är spröda har identifierats i KFM08B (DZ1–DZ2).

Hammarborrhål HFM22 domineras av medelkornig metagranit-granodiorit (101057), vilket utgör en enhet (RU1). I mindre omfattning förekommer amfibolit (102017), pegmatitisk granit (101061) och fin- till medelkorning metagranitoid (101051). En möjlig deformations-zon som är spröd har identifierats i HFM22 (DZ1).

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 system 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 KFM08A, KFM08B and HFM22 at and close to drill site 8 (DS8) in the Forsmark area. The horizontal projections of the boreholes in the candidate area and boreholes at DS8 are shown in Figure 1-1. The work was carried out in accordance with activity plan SKB PF 400-05-029. 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
Geologisk enhålstolkning av KFM08A, KFM08B och HFM22	AP PF 400-05-029	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	2.0

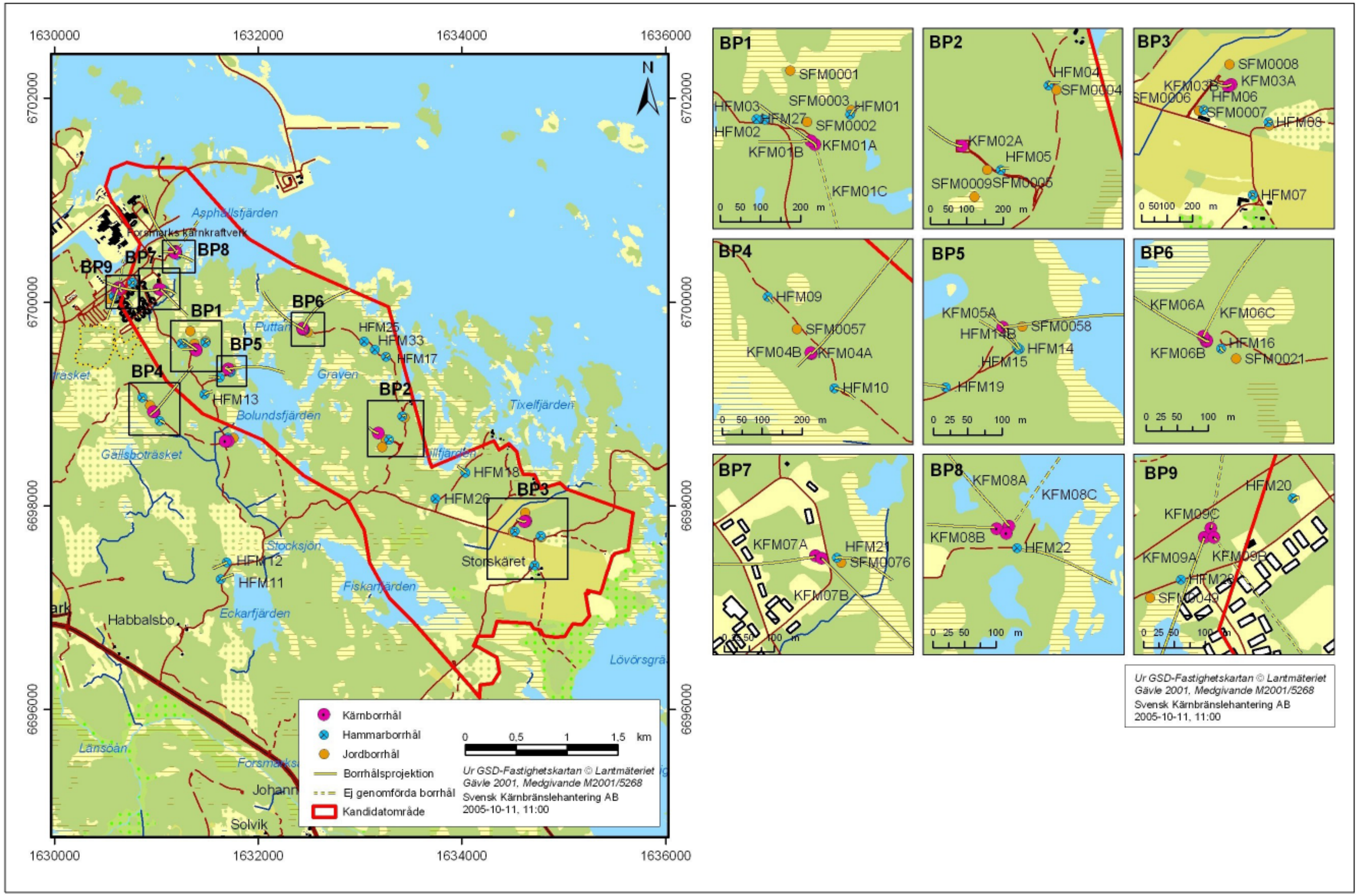

Figure 1-1. Map showing horizontal projection of the boreholes in the candidate area and the position of the cored boreholes KFM08A and KFM08B and the percussion drilled borehole HFM22 at DS8.

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).

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 KFM08A, KFM08B and HFM22:

- Boremap data (including BIPS and geological mapping data) /1 and 2/.
- Generalized geophysical logs and their interpretation /3, 4, 5 and 6/.
- Radar data and their interpretation /7, 8 and 9/.

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 the 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 /10/.

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, sonic 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.

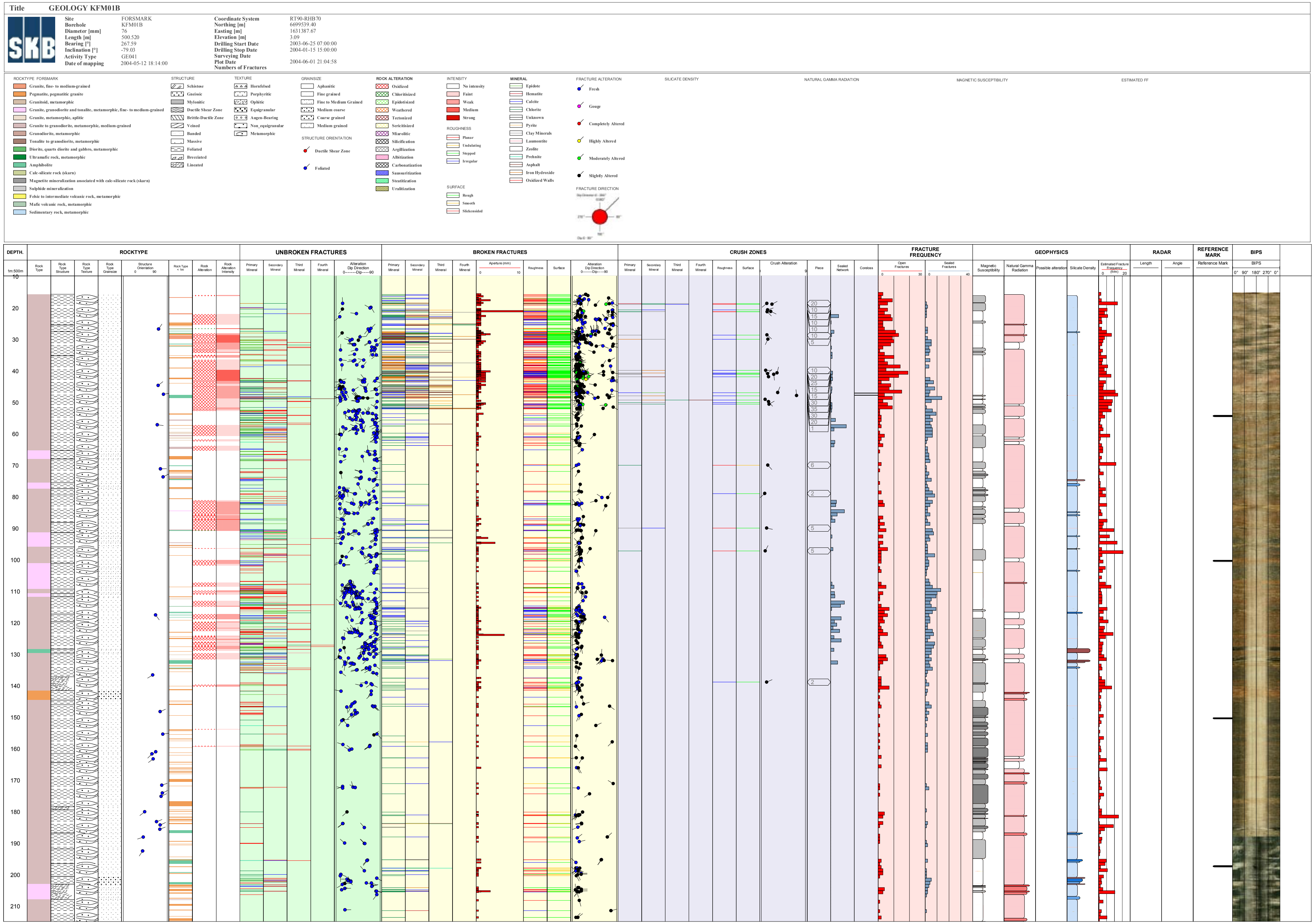

Figure 3-1. *Example of WellCad plot (from borehole KFM01B) used as a basis for the single-hole interpretation.*

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.

Stage 1 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 5–10 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.

Stage 2 in the working procedure is to identify 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 deformation zone 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 possible deformation zone is made on the following basis: 3 = high, 2 = medium, and 1 = low.

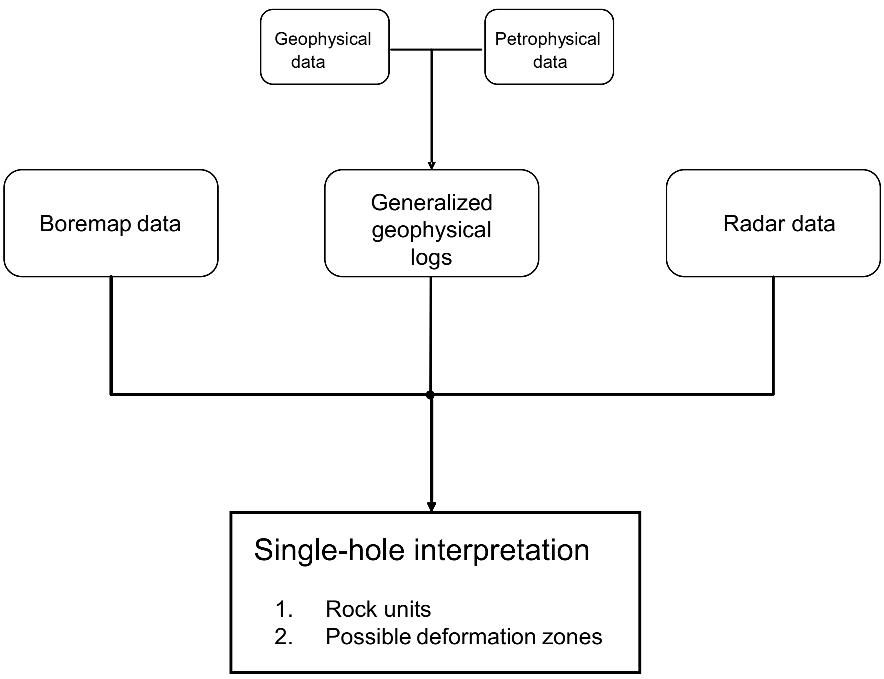

Figure 4-1. *Schematic chart that shows the procedure for the development of a geological single-hole interpretation.*

Inspection of BIPS images is carried out wherever it is judged necessary during the working procedure. Furthermore, following definition of rock units and deformation zones, with their respective confidence estimates, the cored boreholes 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.

Deformation zones that are brittle in character have been identified primarily on the basis of the frequency of fractures, according to the recommendations in /11/. Both the transitional part, with a fracture frequency in the range 4–9 fractures/m, and the cored 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, the inferred orientation of radar reflectors, and the resistivity, SPR, P-wave velocity, caliper and magnetic susceptibility logs have all assisted in the identification of the zones.

Since the frequency of fractures is of key importance for the definition of the possible deformation zones, a moving average plot for this parameter is shown for the cored boreholes KFM08A and KFM08B (Figure 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 this diagram.

4.2 Nonconformities

No interpreted geophysical log was available for KFM08B, only raw plots. Furthermore, no BIPS-images are present for the borehole interval below 950 m.

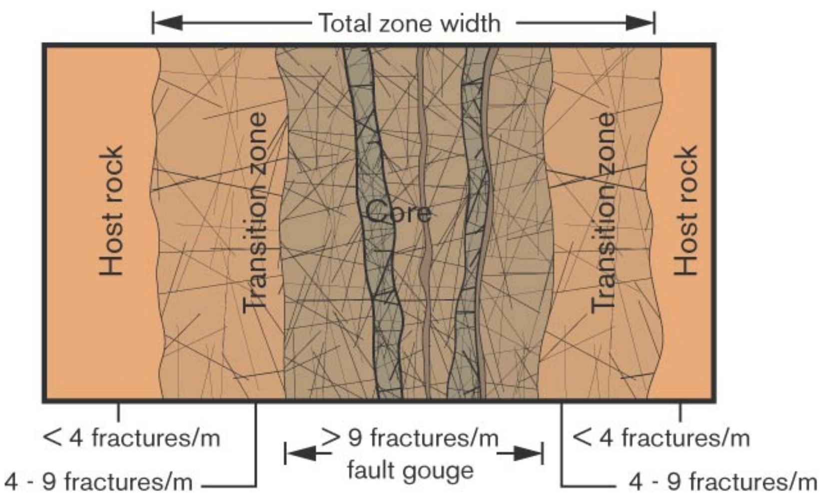

Figure 4-2. *Terminology for brittle deformation zones (after /11/).*

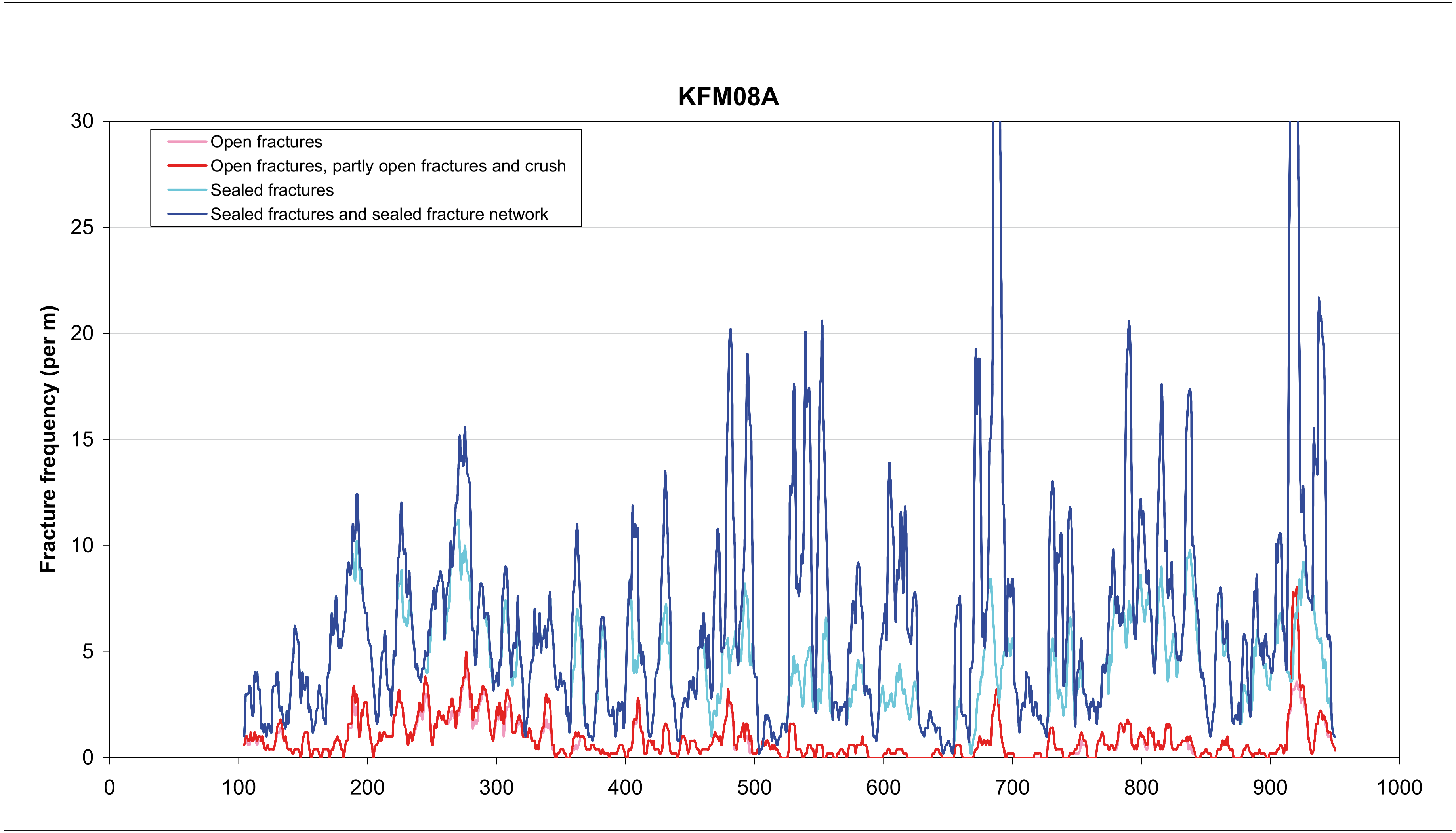

Figure 4-3. *Fracture frequency plot for KFM08A. Moving average with a 5 m window and 1 m steps.*

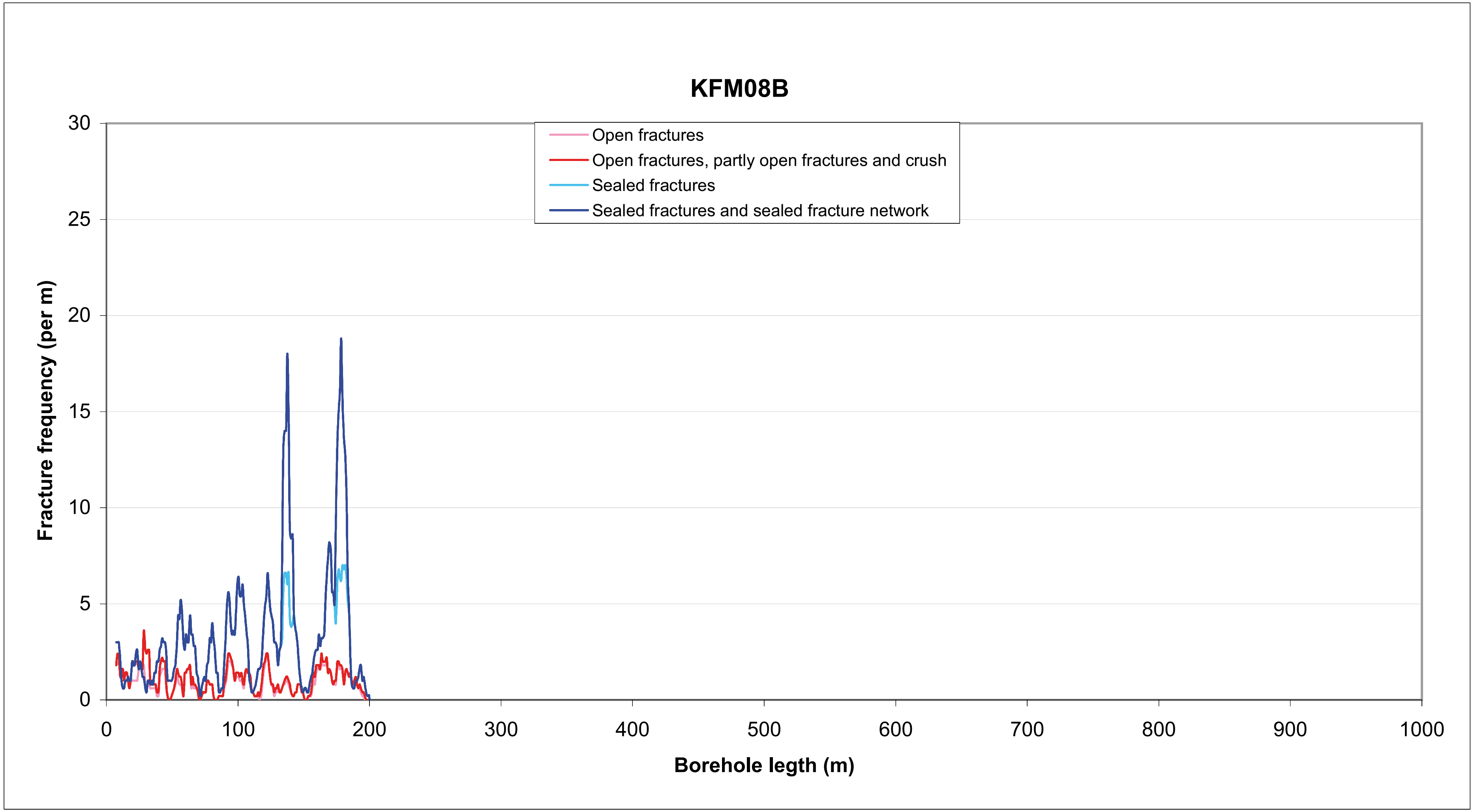

Figure 4-4. *Fracture frequency plot for KFM08B. Moving average with a 5 m window and 1 m steps.*

5 Results

The results of the geological single-hole interpretations are presented as print-outs from the software WellCad (Appendix 1 for KFM08A, Appendix 2 for KFM08B and Appendix 3 for HFM22).

5.1 KFM08A

The borehole direction at the start is 321.0/–60.9. The borehole can be divided into four different rock units, RU1–RU4:

102.466–780.605 m	RU1: Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Occurrences of fine- to medium-grained metagranitoid (101051) and felsic to intermediate metavolcanic rock (103076) in the interval 420–495 m. Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Section of vuggy metagranite-granodiorite (101057) and pegmatitic granite (101061) at 409.8–412.0 m. Low temperature ductile shear zone at 366.0–366.1 m. In the interval 320 to 355 m three very clear radar reflectors are identified in all three antenna frequencies, as well as one reflector at a depth of 410 m with the orientation 58/123. A number of reflectors subparallel to the borehole are seen down to 300 m (at a distance up to 45 m from the borehole), and also indications from 600 m and downwards (i.e. closer to the borehole wall). Confidence level = 3.
780.605–875.991m	RU2: Aplitic metagranite (101058), generally affected by faint to medium albitization, which in part corresponds to decreased natural gamma radiation. Subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Confidence level = 3.
875.991–925.377 m	RU3: Heterogeneous mixture of felsic to intermediate volcanic rock (103076) and amphibolite (102017). Subordinate occurrences of pegmatitic granite (101061) and aplitic metagranite (101058). The heterogeneity is also reflected in the variation in the silicate density, natural gamma radiation and magnetic susceptibility. Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Confidence level = 3.
925.377–1001.19 m	RU4: Biotite-rich metagranite-granodiorite (101057) that generally shows an increased content of muscovite. Subordinate occurrences of pegmatitic granite (101061), especially in the interval 952–962 m, felsic to intermediate metavolcanic rock (103076), amphibolite (102017) and fine- to medium-grained metagranitoid (101051). Confidence level = 3.

Seven deformation zones that are brittle in character and that have been recognised with a variable degree of confidence are present in KFM08A:

172–342 m DZ1: Increased frequency of sealed and open fractures, especially in the intervals 182–202, 221–295 and 335–345 m. Sealed fractures dominate. One 1 cm wide crush zone at 339.8 m. Steeply dipping fractures with NE-strike and subhorizontal fractures dominate. The intervals with an increased fracture frequency correspond to a general decrease in the bulk resistivity, as well as an increased occurrence of individual low resistivity anomalies. 49 radar reflectors have been identified in DZ1. In three intervals there are 11, 19 and 2 reflectors, respectively. 14 radar reflectors are oriented 62–81/050–076 (4), 39–76/332–354 (3), 51–80/002–014 (3) 42–43/122–124 (2), 5/319 and 36/172. In the interval 320 to 355 m occur three very clear radar reflectors, identified in all three dipole antenna frequencies. Locally faint to strong oxidation. Fracture apertures are typically less than 1 mm, with a few that ranges up to 8 mm. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite, adularia and pyrite. Confidence level = 3.

479–496 m DZ2: Increased frequency of sealed fractures, sealed fracture networks and open fractures. Sealed fractures dominate. One 4 cm wide crush zone at 495.3 m. There is a concentration of fractures that strike NS and dip to the east. Steeply dipping fractures with NE-strike and gently dipping fractures are also present. Some distinct low resistivity and low P-wave velocity anomalies. Nine non-oriented radar reflectors identified, intersection angle to the borehole axis is 25 to 64 degrees. One radar reflector at 495.5 m with the orientation 39/107. Locally faint to weak oxidation. Fracture apertures are typically less than 1 mm, with one 2 mm wide. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite and clay minerals. Confidence level = 3.

528–557 m DZ3: Increased frequency of sealed fractures and sealed fracture networks. Fracture orientations are variable. A few low resistivity anomalies and one distinct low P-wave velocity anomaly at 557 m. 13 radar reflectors identified, three of them are oriented, 50/111 (530.2 m), 65/102 (535.1 m) and 42/098 (544.1 m). Locally faint to medium oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, hematite and quartz. Confidence level = 2.

672–693 m DZ4: Increased frequency of sealed fractures, sealed fracture networks and open fractures. Sealed fractures dominate. Steeply dipping fractures that strike WNW and ENE as well as some gently dipping fractures are present. Open and partly open fractures are mostly gently dipping. Distinct low resistivity and low P-wave velocity anomalies at 686–689 m. Six radar reflectors identified, two of them are oriented, 20/072 (675.4 m) and 30/001 (686.1 m). One very clear reflector, identified in all three dipole antenna frequencies at a depth of 687 m. Fracture apertures are typically less than 1 mm, with one that is 7 mm. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, adularia and laumontite. Confidence level = 3.

775–840 m	DZ5: Increased frequency of sealed fractures, sealed fracture networks and open fractures. Sealed fractures dominate. Three sets of steeply dipping fractures are present as well as one gently dipping set. The steeply dipping fractures strike NE, WNW and NNW. A minor group of fractures that strikes NW and dips steeply to the SW is also present. The section 775–805 m is characterised by a general decrease in the bulk resistivity and partly decreased magnetic susceptibility. 15 radar reflectors identified, three of them are oriented, 84/149 (807.3 m), 50/127 (810.4 m) and 29/059 (812.5 m). Locally faint to medium oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, hematite, adularia and laumontite. Confidence level = 2.
915–946 m	DZ6: Increased frequency of sealed fractures, sealed fracture networks and open fractures, especially in the upper part (915–930 m). Sealed fractures dominate. Moderately to steeply dipping fractures that strike EW and dip to the S dominate. Steeply dipping fractures that strike WNW and dip to the NNE and strike NNE and dip WNW are also present. One 43 cm wide crush zone at 918.8–919.3 m. Distinct low resistivity, caliper and low P-wave velocity anomalies at 915–929 m. 8 non-oriented radar reflectors identified, intersection angle to borehole axis between 63 and 89 degrees. Locally faint oxidation. Fracture apertures are typically less than 1 mm, with one that is 2 mm at the base of the section. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, laumontite, adularia and clay minerals. Laumontite and clay minerals are more frequent in the upper part of the section. Confidence level = 3.
967–976 m	DZ7: Increased frequency of open and especially sealed fractures. Two ductile shear zones occur in the section. A few individual low resistivity anomalies. 4 non-oriented radar reflectors identified, intersection angle to borehole axis between 55 and 90 degrees. One very clear reflector, identified in all three dipole antenna frequencies at a depth of 972 m. Fracture apertures are typically less than 1 mm, with one that is 2 mm. The most frequent fracture filling minerals include chlorite and clay minerals (probably illite). Confidence level = 2.

5.2 KFM08B

The borehole direction at the start is 270.5/–58.8. The borehole consists of one rock unit:

5.731–200.055 m	RU1: Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Two crush zones that are 2 and 3 cm wide at 21.4 and 30.9 m, respectively. Several clear radar reflectors along the borehole, which have been identified with all three dipole antenna frequencies. Confidence level = 3.

Two possible deformation zones have been identified in KFM08B:

133–140 m	DZ1: Increased frequency of sealed fractures and sealed fracture networks. Fractures that strike NNW and dip steeply to the WSW are most conspicuous. A few minor resistivity anomalies. One radar reflector identified with the intersection angle 37 degrees to borehole axis. Locally faint to weak oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Confidence level = 2.
167–185 m	DZ2: Increased frequency of sealed fractures and sealed fracture networks. Fractures that strike NNW and dip steeply to the WSW as well as gently dipping to sub horizontal fractures are present. Several distinct low resistivity anomalies. Six non-oriented radar reflectors identified, intersection angle to borehole axis between 15 and 61 degrees. Locally faint to weak oxidation. Fracture apertures are typically less than 1 mm, with one that is 2 mm. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite and laumontite. Confidence level = 3.

5.3 HFM22

The borehole direction at the start is 090.0/–58.9. The borehole contains one rock unit:

12.340–215.870 m	RU1: Medium-grained metagranite-granodiorite (101057), with subordinate occurrences of pegmatitic granite (101061), aplitic metagranite (101058) and amphibolite (102017). One occurrence of fine- to medium-grained metagranitoid (101051) at 202–211 m, that corresponds to higher silicate density values. Two crush zones that are 4 and 4 cm wide at 62.2 and 85.2 m, respectively. These correspond to discrete well-defined geophysical anomalies. Very clear radar reflectors in the intervals 62–85 and 118–142, were reflectors can be identified with all three dipole antenna frequencies. Confidence level = 2.

One possible deformation zone is indicated in HFM22:

110–129 m	DZ1: Increased fracture frequency in the upper part and weak to medium oxidation in the entire section. Fractures that strike NE and are steeply dipping are prominent. Subhorizontal sealed fractures as well as open and partly open fractures that strike NNW and dip steeply to the ENE are also present. General decrease in the bulk resistivity and low P-wave velocity also in the upper part (c 112–120 m). Low magnetic susceptibility in the section 100–120 m. Five radar reflectors identified, intersection angle to borehole axis between 41 to 59 degrees. Fracture apertures are typically less than 1 mm, but some range up to 3 mm. Confidence level = 1.

6 Comments

The results from the geological single-hole interpretations of KFM08A, KFM08B and HFM22 are presented in WellCad plots (Appendix 1–3). The WellCad plots consist 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)

7 References

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/6/ **Mattsson H and Keisu M, 2005.** Interpretation of geophysical borehole measurements from KFM06A and HFM20, HFM21 and HFM22. SKB P-05-51, Svensk Kärnbränslehantering AB.

/7/ **Gustafsson J and Gustafsson C, 2005.** RAMAC and BIPS logging in borehole KFM08A. Forsmark site investigation. SKB P-05-158, Svensk Kärnbränslehantering AB.

/8/ **Gustafsson J and Gustafsson C, 2005.** RAMAC and BIPS logging in boreholes KFM06A and HFM22. Forsmark site investigation. SKB P-05-01, Svensk Kärnbränslehantering AB.

/9/ **Gustafsson J and Gustafsson C, 2005.** RAMAC and BIPS logging in borehole KFM08B. Forsmark site investigation. SKB P-05-58, Svensk Kärnbränslehantering AB.

/10/ **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.

/11/ **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 for KFM08A

Title	SINGLE HOLE INTERPRETATION KFM08A					
Site	FORSMARK	Inclination [°]	-60.88	Elevation [m.a.s.l.]	2.49	Signed data
Borehole	KFM08A	Date of mapping	2005-05-11 10:43:00	Drilling Start Date	2004-09-13 11:03:00	
Diameter [mm]	77	Coordinate System	RT90-RHB70	Drilling Stop Date	2004-09-27 11:30:00	
Length [m]	1001.190	Northing [m]	6700494.49	Surveying Date		
Bearing [°]	321.00	Easting [m]	1631197.06	Plot Date	2006-10-19 21:09:52	

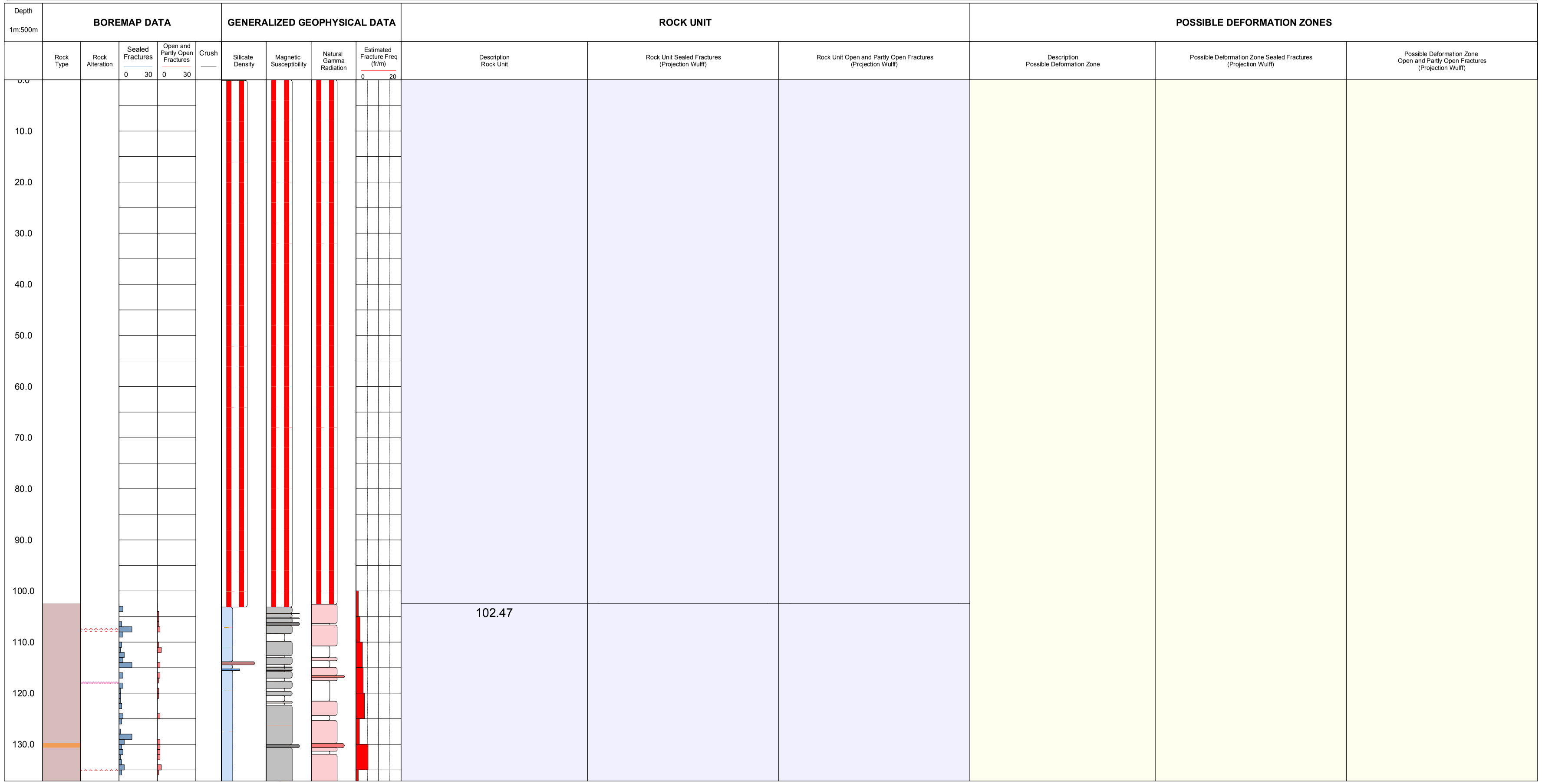
ROCKTYPE FORSMARK
- Pegmatite, pegmatitic granite
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite
- Felsic to intermediate volcanic rock, metamorphic

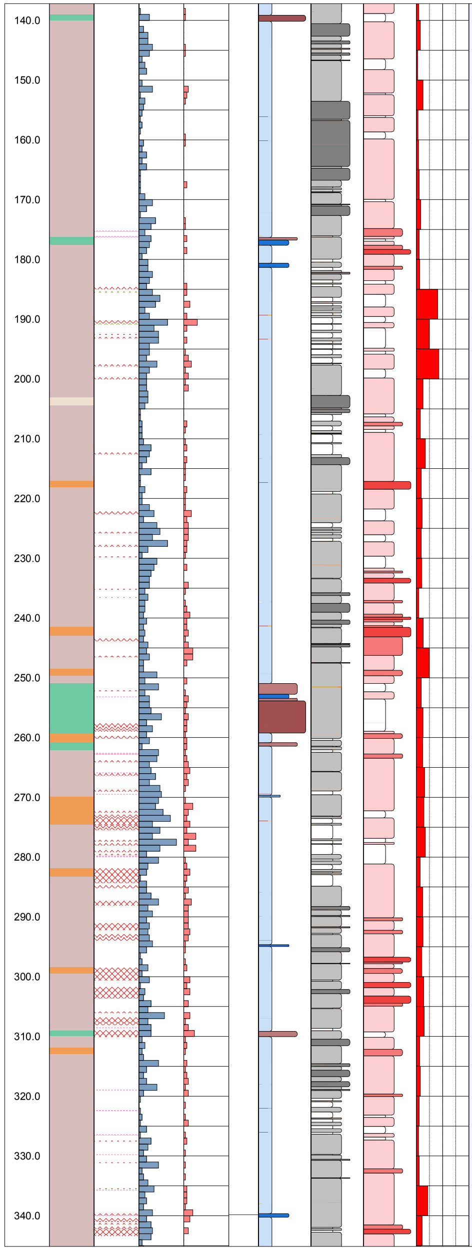
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Sericitisized
- Quartz dissolution
- Silicification
- Albitization
- Saussuritization

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
- gam<20
- 20<gam<36
- 36<gam<53

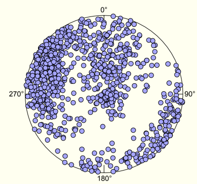


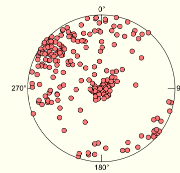


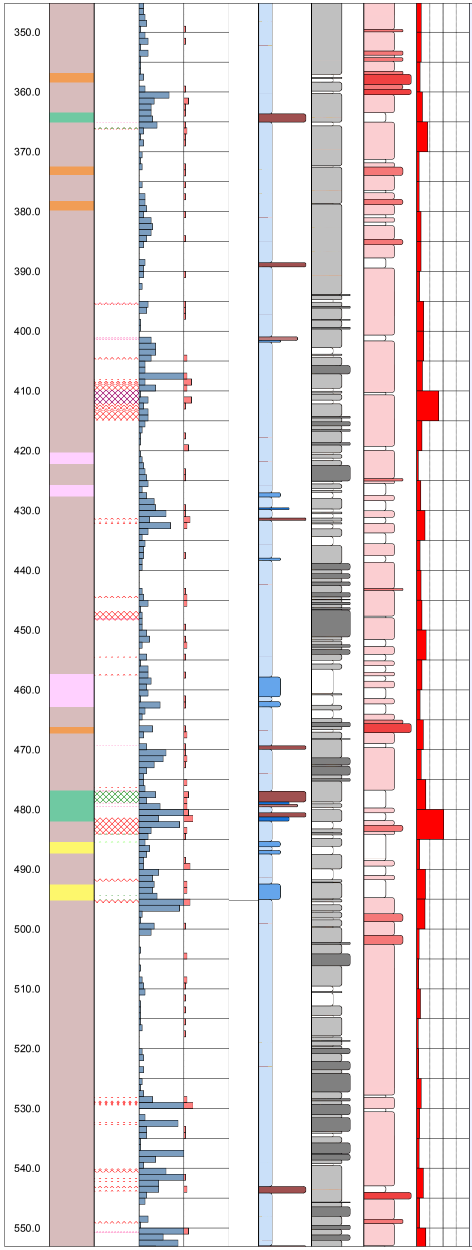
172.00

DZ1
Increased frequency of sealed and open fractures, especially in the intervals 182-202, 221-295 and 335-345 m. Sealed fractures dominate. One 1 cm wide crush zone at 339.8 m. Steeply dipping fractures with NE-strike and subhorizontal fractures dominate. The intervals with an increased fracture frequency correspond to a general decrease in the bulk resistivity, as well as an increased occurrence of individual low resistivity anomalies. 49 radar reflectors have been identified in DZ1. In three intervals there are 11, 19 and 2 reflectors, respectively. 14 radar reflectors are oriented 62-81/050-076 (4), 39-76/332-354 (3), 51-80/002-014 (3) 42-43/122-124 (2), 5/319 and 36/172. In the interval 320 to 355 m occur three very clear radar reflectors, identified in all three dipole antenna frequencies. Locally faint to strong oxidation. Fracture apertures are typically less than 1 mm, with a few that ranges up to 8 mm. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite, adularia and pyrite. Confidence level = 3.

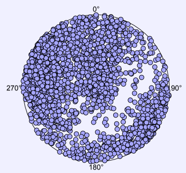
342.00

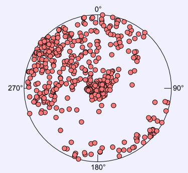




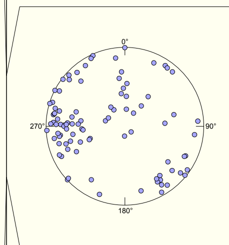


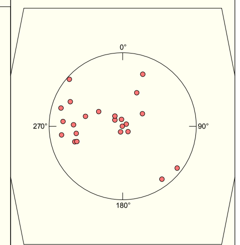
RU1
Medium-grained metagranite-granodiorite (101057) with subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Occurrences of fine- to medium-grained metagranitoid (101051) and felsic to intermediate metavolcanic rock (103076) in the interval 420-495 m. Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Section of vuggy metagranite-granodiorite (101057) and pegmatitic granite (101061) at 409.8-412.0 m. Low temperature ductile shear zone at 366.0-366.1 m. In the interval 320 to 355 m three very clear radar reflectors are identified in all three antenna frequencies, as well as one reflector at a depth of 410 m with the orientation 58/123. A number of reflectors subparallel to the borehole are seen down to 300 m (at a distance up to 45 m from the borehole), and also indications from 600 m and downwards (i.e. closer to the borehole wall). Confidence level = 3.



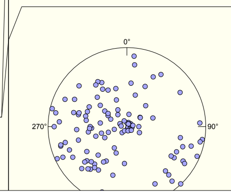


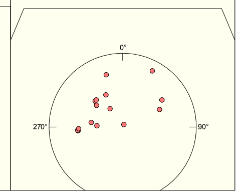
479.00
DZ2
Increased frequency of sealed fractures, sealed fracture networks and open fractures. Sealed fractures dominate. One 4 cm wide crush zone at 495.3 m. There is a concentration of fractures that strike NS and dip to the east. Steeply dipping fractures with NE-strike and gently dipping fractures are also present. Some distinct low resistivity and low P-wave velocity anomalies. Nine non-oriented radar reflectors identified, intersection angle to the borehole axis is 25 to 64 degrees. One radar reflector at 495.5 m with the orientation 39/107. Locally faint to weak oxidation. Fracture apertures are typically less than 1 mm, with one 2 mm wide. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite and clay minerals. Confidence level = 3.
496.00

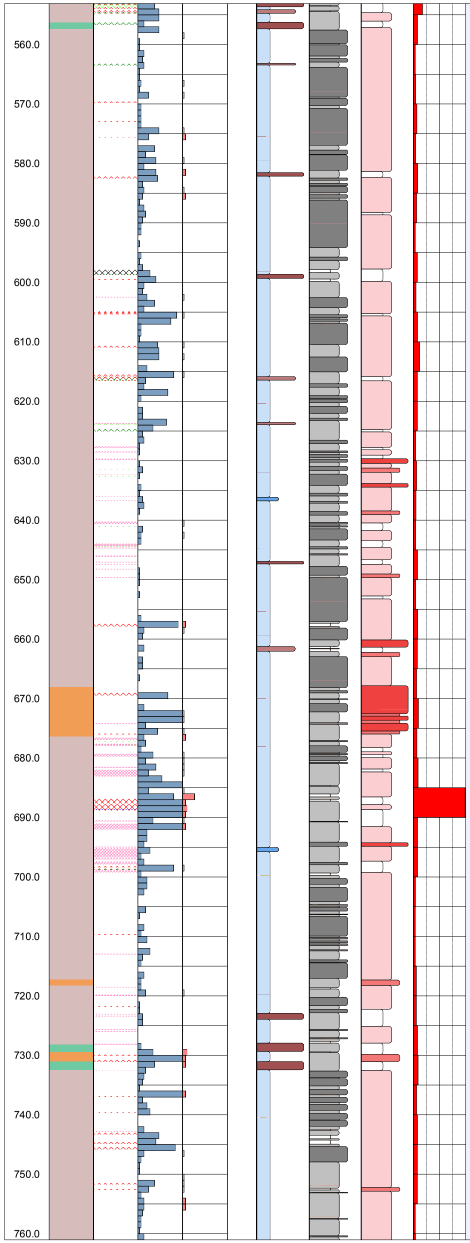




528.00
DZ3
Increased frequency of sealed fractures and

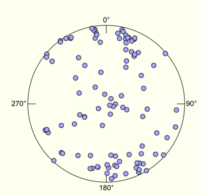


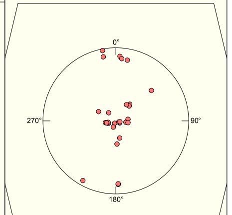




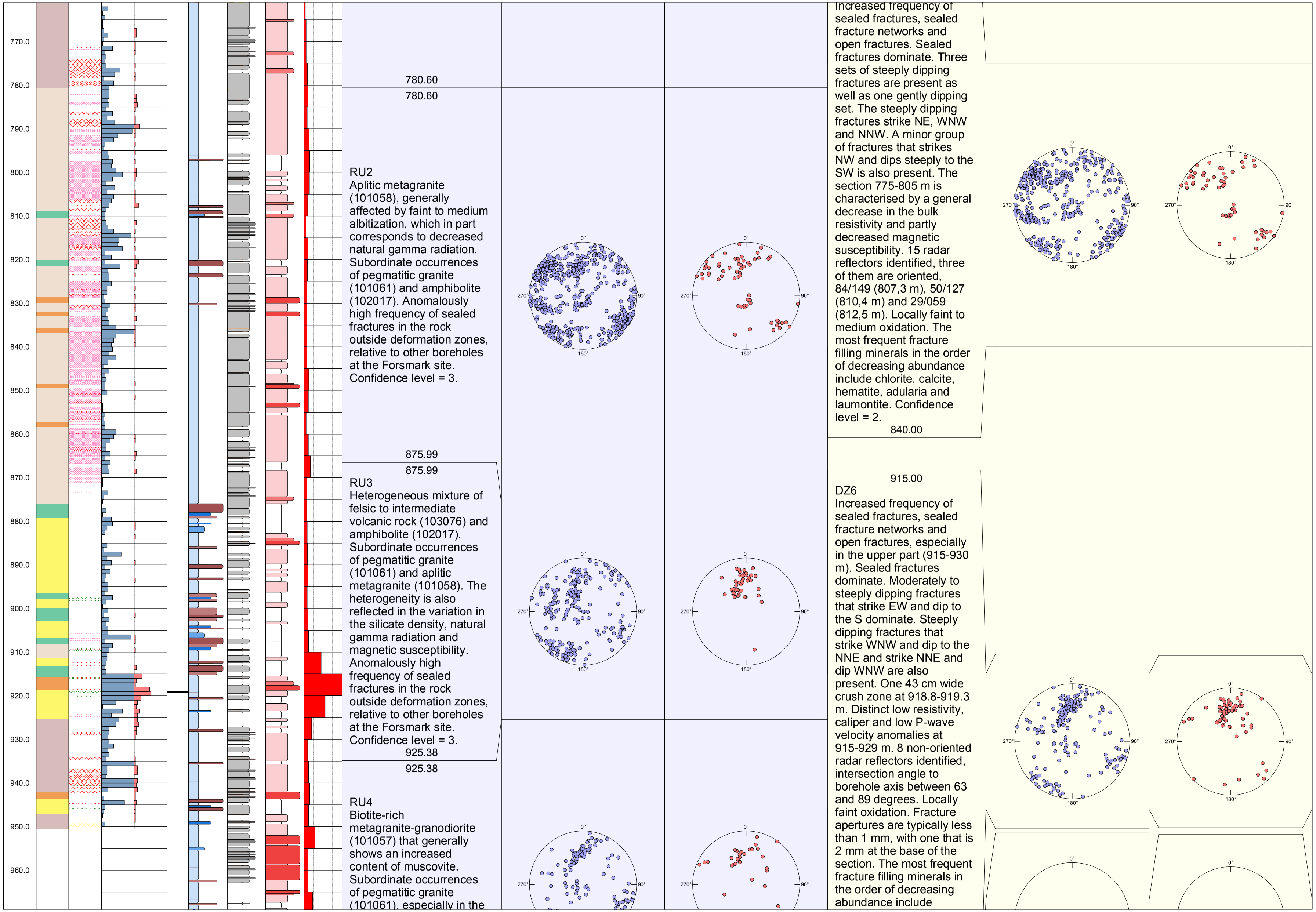
sealed fracture networks. Fracture orientations are variable. A few low resistivity anomalies and one distinct low P-wave velocity anomaly at 557 m. 13 radar reflectors identified, three of them are oriented, 50/111 (530,2 m), 65/102 (535,1 m) and 42/098 (543,1 m). Locally faint to medium oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, hematite and quartz. Confidence level = 2.
557.00

672.00
DZ4
Increased frequency of sealed fractures, sealed fracture networks and open fractures. Sealed fractures dominate. Steeply dipping fractures that strike WNW and ENE as well as some gently dipping fractures are present. Open and partly open fractures are mostly gently dipping. Distinct low resistivity and low P-wave velocity anomalies at 686-689 m. Six radar reflectors identified, two of them are oriented, 20/072 (675,4 m) and 30/001 (686,1 m). One very clear reflector, identified in all three dipole antenna frequencies at a depth of 687 m. Fracture apertures are typically less than 1 mm, with one that is 7 mm. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, adularia and laumontite. Confidence level = 3.
693.00





775.00
DZ5


770.0
780.0
790.0
800.0
810.0
820.0
830.0
840.0
850.0
860.0
870.0
880.0
890.0
900.0
910.0
920.0
930.0
940.0
950.0
960.0
780.60
780.60
RU2
Aplitic metagranite (101058), generally affected by faint to medium albitization, which in part corresponds to decreased natural gamma radiation. Subordinate occurrences of pegmatitic granite (101061) and amphibolite (102017). Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Confidence level = 3.
875.99
875.99
RU3
Heterogeneous mixture of felsic to intermediate volcanic rock (103076) and amphibolite (102017). Subordinate occurrences of pegmatitic granite (101061) and aplitic metagranite (101058). The heterogeneity is also reflected in the variation in the silicate density, natural gamma radiation and magnetic susceptibility. Anomalously high frequency of sealed fractures in the rock outside deformation zones, relative to other boreholes at the Forsmark site. Confidence level = 3.
925.38
925.38
RU4
Biotite-rich metagranite-granodiorite (101057) that generally shows an increased content of muscovite. Subordinate occurrences of pegmatitic granite (101061), especially in the
Increased frequency of sealed fractures, sealed fracture networks and open fractures. Sealed fractures dominate. Three sets of steeply dipping fractures are present as well as one gently dipping set. The steeply dipping fractures strike NE, WNW and NNW. A minor group of fractures that strikes NW and dips steeply to the SW is also present. The section 775-805 m is characterised by a general decrease in the bulk resistivity and partly decreased magnetic susceptibility. 15 radar reflectors identified, three of them are oriented, 84/149 (807,3 m), 50/127 (810,4 m) and 29/059 (812,5 m). Locally faint to medium oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include chlorite, calcite, hematite, adularia and laumontite. Confidence level = 2.
840.00
915.00
DZ6
Increased frequency of sealed fractures, sealed fracture networks and open fractures, especially in the upper part (915-930 m). Sealed fractures dominate. Moderately to steeply dipping fractures that strike EW and dip to the S dominate. Steeply dipping fractures that strike WNW and dip to the NNE and strike NNE and dip WNW are also present. One 43 cm wide crush zone at 918.8-919.3 m. Distinct low resistivity, caliper and low P-wave velocity anomalies at 915-929 m. 8 non-oriented radar reflectors identified, intersection angle to borehole axis between 63 and 89 degrees. Locally faint oxidation. Fracture apertures are typically less than 1 mm, with one that is 2 mm at the base of the section. The most frequent fracture filling minerals in the order of decreasing abundance include
0°
90°
180°
270°

Appendix 2

Geological single-hole interpretation for KFM08B

Title	SINGLE HOLE INTERPRETATION KFM08B							
Site	FORSMARK	Inclination [°]	-58.84	Elevation [m.a.s.l.]	2.25	Signed data		
Borehole	KFM08B	Date of mapping	2005-05-02 14:49:00	Drilling Start Date	2005-01-11 16:04:00			
Diameter [mm]	76	Coordinate System	RT90-RHB70	Drilling Stop Date	2005-01-26 14:51:00			
Length [m]	200.540	Northing [m]	6700492.75	Surveying Date				
Bearing [°]	270.45	Easting [m]	1631173.27	Plot Date	2006-10-12 21:59:42			

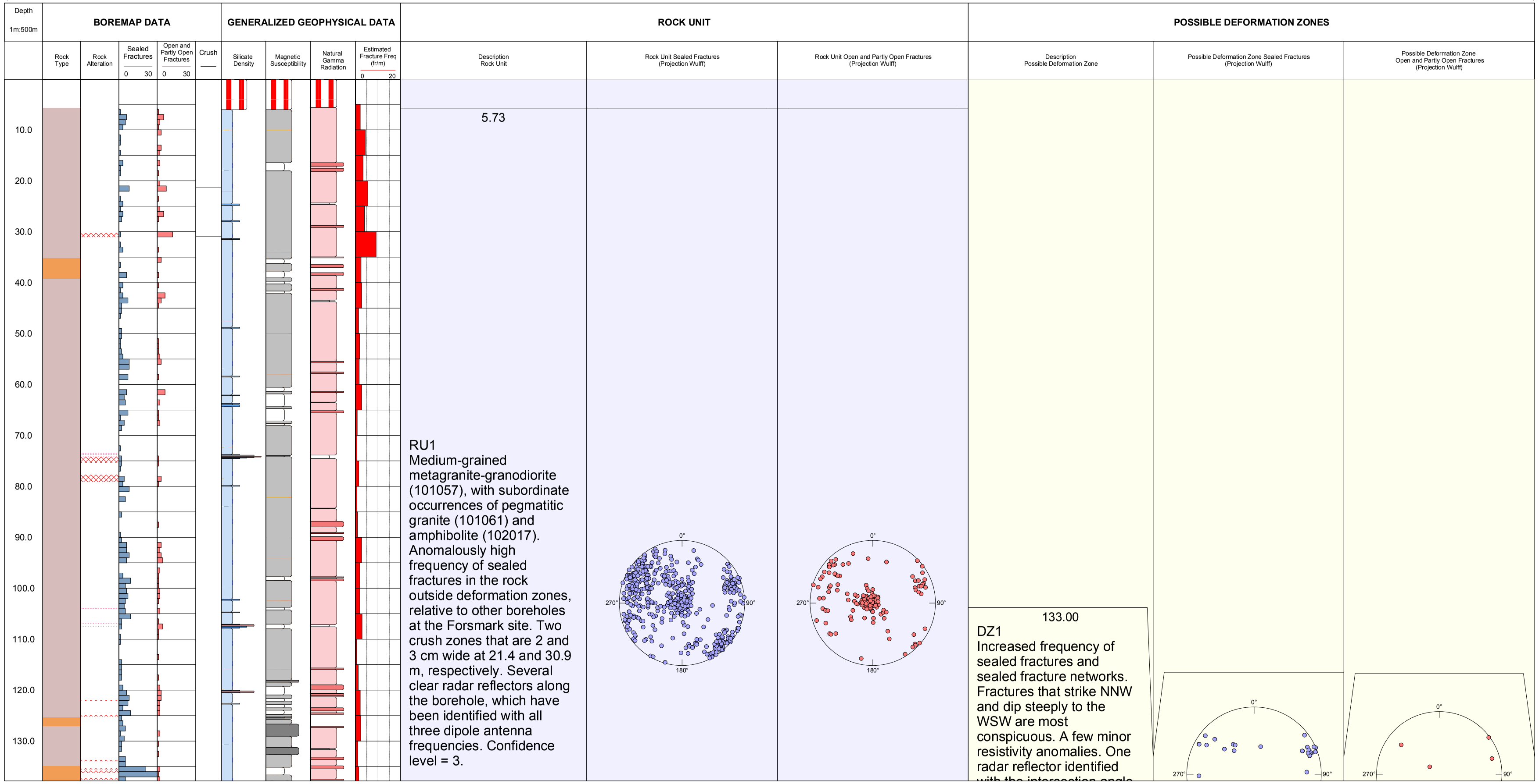
ROCKTYPE FORSMARK
- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained
- Amphibolite

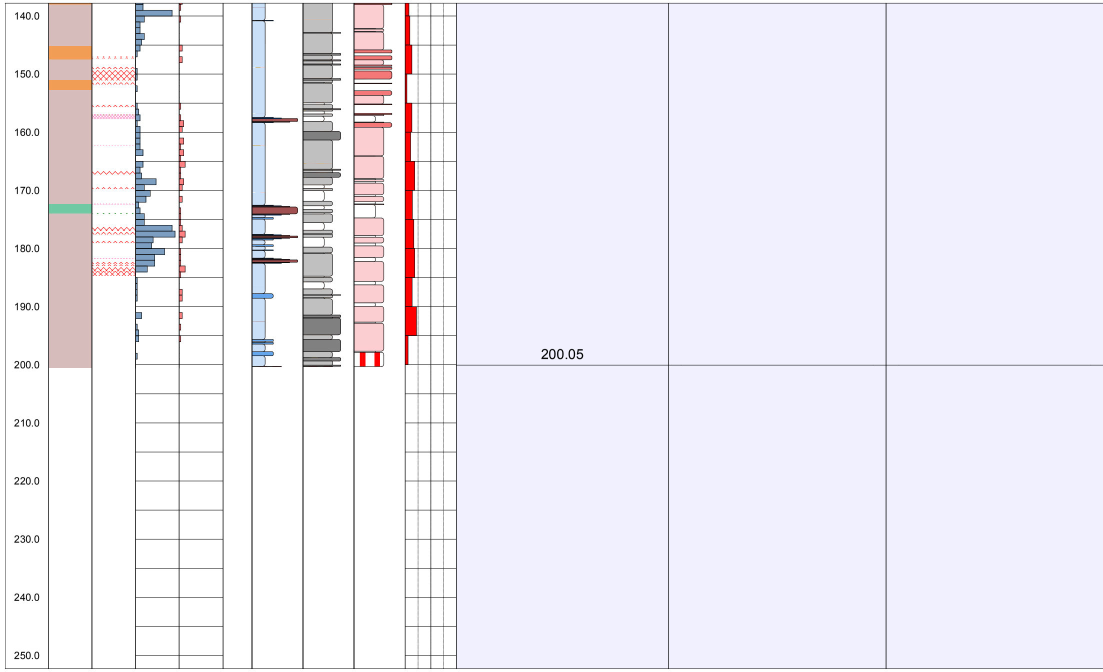
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Albitization

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

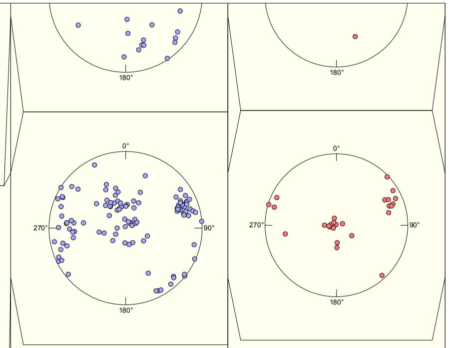
NATURAL GAMMA
- unclassified
- gam<20
- 20<gam<36
- 36<gam<53





with the intersection angle 37 degrees to borehole axis. Locally faint to weak oxidation. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite, laumontite and hematite. Confidence level = 2.
140.00

167.00
DZ2
Increased frequency of sealed fractures and sealed fracture networks. Fractures that strike NNW and dip steeply to the WSW as well as gently dipping to sub horizontal fractures are present. Several distinct low resistivity anomalies. Six non-oriented radar reflectors identified, intersection angle to borehole axis between 15 and 61 degrees. Locally faint to weak oxidation. Fracture apertures are typically less than 1 mm, with one that is 2 mm. The most frequent fracture filling minerals in the order of decreasing abundance include calcite, chlorite and laumontite. Confidence level = 3.
185.00



Appendix 3

Geological single-hole interpretation for HFM22

Title	SINGLE HOLE INTERPRETATION HFM22					
Site	FORSMARK	Inclination [°]	-58.84	Elevation [m.a.s.l.]	1.54	Signed data
Borehole	HFM22	Date of mapping	2005-06-09 13:24:00	Drilling Start Date	2004-09-07 12:00:00	
Diameter [mm]	136	Coordinate System	RT90-RHB70	Drilling Stop Date	2004-09-10 10:17:00	
Length [m]	222.000	Northing [m]	6700456.18	Surveying Date		
Bearing [°]	90.08	Easting [m]	1631217.64	Plot Date	2006-10-12 21:59:42	

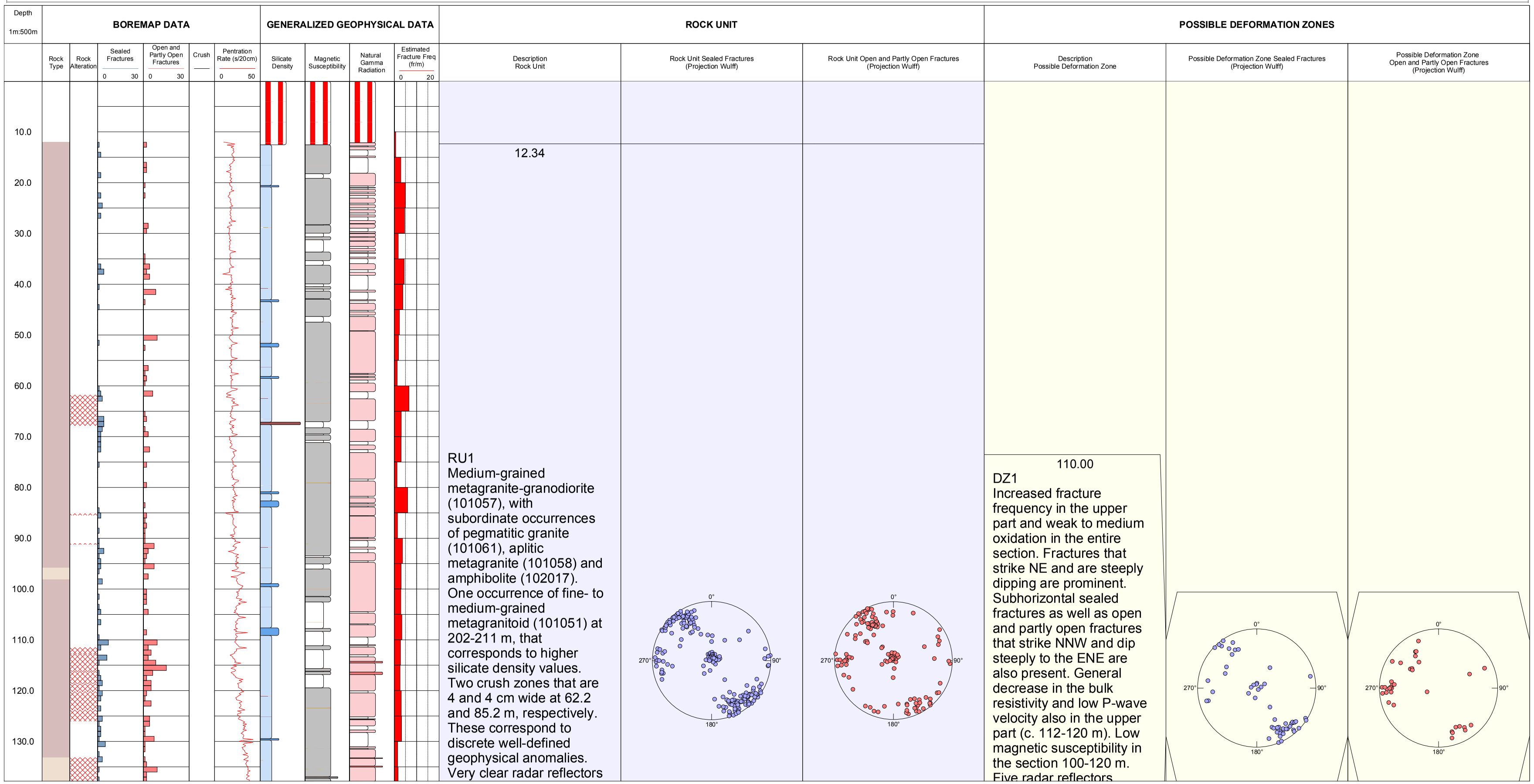
ROCKTYPE FORSMARK
- Granite, granodiorite and tonalite, metamorphic, fine- to medium-grained
- Granite, metamorphic, aplitic
- Granite to granodiorite, metamorphic, medium-grained

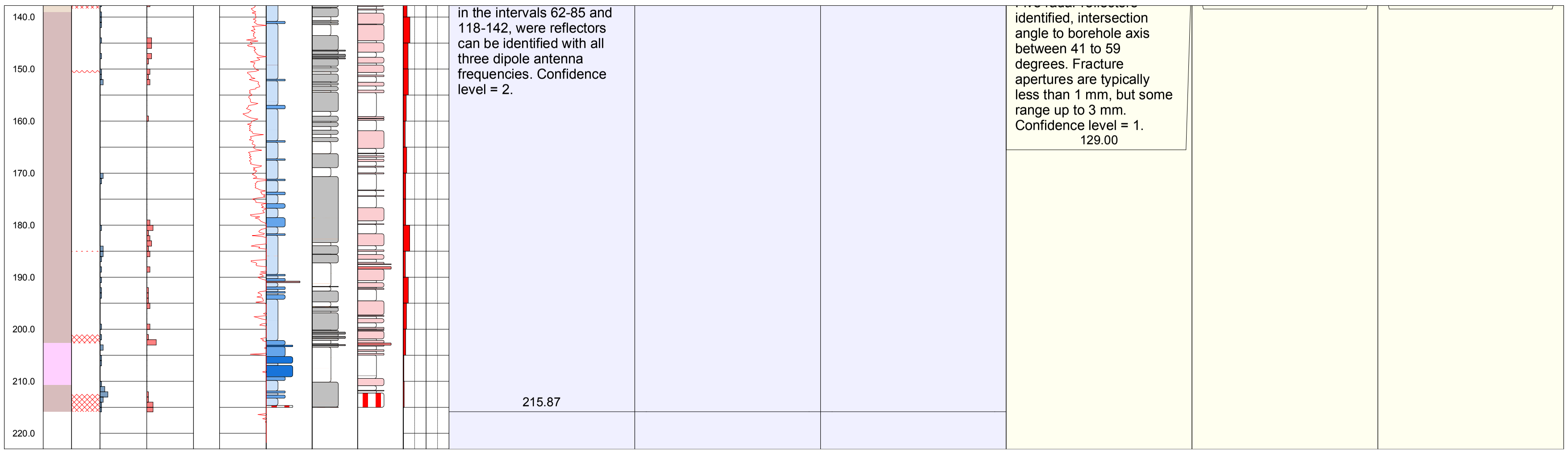
ROCK ALTERATION
- Oxidized

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
in the intervals 62-85 and 118-142, were reflectors can be identified with all three dipole antenna frequencies. Confidence level = 2.
215.87
identified, intersection angle to borehole axis between 41 to 59 degrees. Fracture apertures are typically less than 1 mm, but some range up to 3 mm. Confidence level = 1.
129.00