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Äspö Hard Rock Laboratory

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July 2013

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Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

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Abstract

This report contains geological single-hole interpretation of the cored boreholes KA2051A01 and KA3007A01which have been drilled underground from the Äspö tunnel. The interpretation combines the geological core mapping, interpreted geophysical logs, and borehole radar measurements to identify rock units and possible deformation zones in the boreholes.

The geological single-hole interpretation shows that borehole KA2051A01 is dominated by Äspö diorite (501037). A large section with Ävrö granodiorite (501056) occurs in the middle of the borehole. A section with gabbroid-dioritoid (508107) also occurs in the borehole. Fine-grained granite (511058) occurs in the beginning and in the end of the borehole. Subordinate rock types comprise occurrences of pegmatite (501061), hybrid rock (505105), and very sparse occurrence of breccia (508002). Five possible deformation zones are identified in KA2051A01 (DZ1–DZ5).

The geological single-hole interpretation shows that borehole KA3007A01 is dominated by Ävrö granodiorite (501056) and Äspö diorite (501037) which are alternating in the borehole. Two sections with gabbroid-dioritoid (508107) also occur in the middle of the borehole. Furthermore, two sections with fine-grained granite (511058) occur in the beginning of the borehole. Subordinate rock types comprise occurrences of pegmatite (501061) and hybrid rock (505105). Five possible deformation zones are identified in KA3007A01 (DZ1–DZ5).

Sammanfattning

Denna rapport behandlar geologisk enhålstolkning av kärnborrhålen KA2051A01 och KA3007A01 som har borrats under jord från Äspötunneln. Den geologiska enhålstolkningen syftar till att utifrån den geologiska karteringen, tolkade geofysiska loggar och borrhålsradarmätningar identifiera olika bergenheters fördelning i borrhålen samt möjliga deformationszoners läge och utbredning.

Den geologiska enhålstolkningen visar att kärnborrhålet KA2051A01 domineras av Äspödiorit (501037). En större sektion med Ävrögranodiorit (501056) förekommer i mellersta delen av borrhålet. En sektion med gabbroid-dioritoid (508107) förekommer även. Finkornig granit (511058) finns i borrhålets översta del och även i den undre delen av borrhålet. Underordnade bergarter utgörs av pegmatit (501061), hybridbergart (505105) och en mindre del med breccia (508002). Fem möjliga deformationszoner har identifierats i KA2051A01 (DZ1–DZ5).

Den geologiska enhålstolkningen visar att kärnborrhålet KA3007A01 domineras av Ävrögranodiorit (501056) och Äspödiorit (501037) vilka förekommer växelvis i borrhålet. Två sektioner med gabbroid-dioritoid (508107) förekommer i mellersta delen av borrhålet. Även två sektioner med finkornig granit (511058) finns i borrhålets översta del. Underordnade bergarter utgörs av pegmatit (501061) och hybridbergart (505105). Fem möjliga deformationszoner har identifierats i KA3007A01 (DZ1–DZ5).

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 integrated series of different loggings and accompanying descriptive documents (SKB MD 810.003 v.3.0, SKB internal controlling document).

This document reports the results gained by the geological single-hole interpretation of the cored boreholes KA2051A01 and KA3007A01, which is one of the activities performed within the work of upgrading the geological model of the Äspö HRL (Figure 1-1). The boreholes have been drilled underground from the Äspö tunnel for the expansion of the Äspö HRL.The work was carried out in accordance with activity plan AP TD TUDP002-11-055. The controlling documents for performing this activity are listed in Table 1-1. Rock type nomenclature (Table 1-2) that has been used is in accordance with method instruction SKB MD 132.004. The activity plan, method description and method instruction are SKB's internal controlling documents.

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

Activity plan	Number	Version
Äspö utbyggnad, DP1- karaktärisering-geologisk enhålstolkning av KA2051A01 och KA3007A01	AP TD TUDP002-11-055	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

Table 1-2. Rock type nomenclature for the Äspö SDM.

Rock type	Rock code	Rock description
Dolerite	501027	Dolerite
Fine-grained Götemar granite	531058	Granite, fine- to medium-grained, ("Götemar granite")
Coarse-grained Götemar granite	521058	Granite, coarse-grained, ("Götemar granite")
Fine-grained granite	511058	Granite, fine- to medium-grained
Pegmatite	501061	Pegmatite
Granite	501058	Granite, medium- to coarse-grained
Ävrö granite	501044	Granite to quartz monzodiorite, generally porphyritic
Ävrö granodiorite	501056	Granite to granodiorite, sparsely porphyritic to porphyritic
Ävrö quartz monzodiorite	501046	Quartz monzonite to quartz monzodiorite, generally porphyritic
Äspö diorite	501037	Quartz monzodiorite to granodiorite, porphyritic
Quartz monzodiorite	501036	Quartz monzonite to monzodiorite, equigranular to weakly porphyritic
Diorite-gabbro	501033	Diorite to gabbro
Fine-grained dioritoid	501030	Intermediate magmatic rock
Fine-grained diorite-gabbro	505102	Mafic rock, fine-grained
Gabbroid-dioritoid	508107	Mafic rock undifferentiated
Mylonite	508004	Mylonite
Sulphide mineralization	509010	Sulphide mineralization
Sandstone	506007	Sandstone
Quartz-dominated hydrothermal vein/segregation	508021	Quartz-dominated hydrothermal vein/segregation
Hybrid rock	505105	Hybrid rock
Breccia	508002	Breccia
Felsic volcanic rock	503076	Felsic volcanic rock

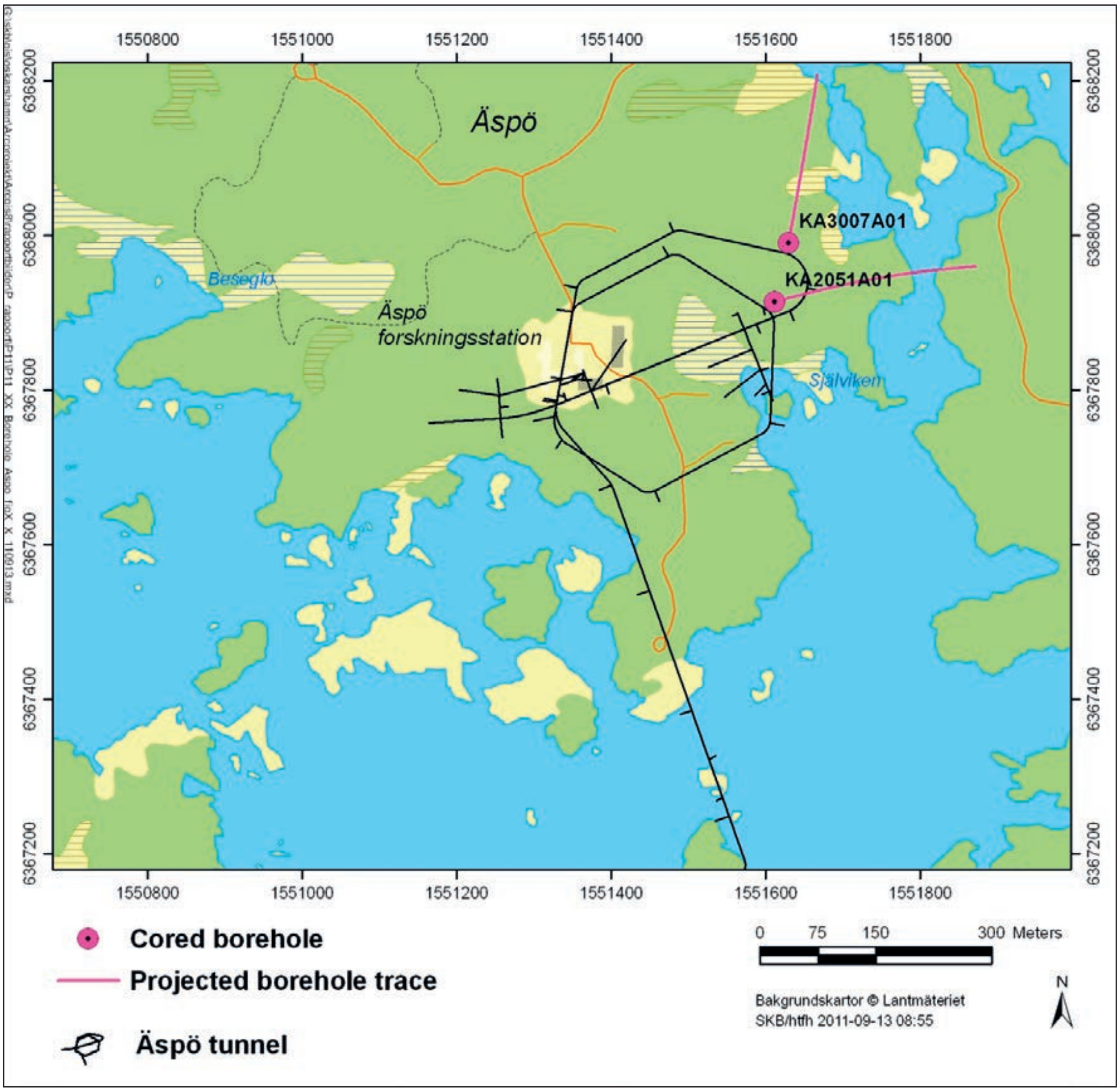

Figure 1-1. Map showing the position of the cored boreholes KA2051A01 and KA3007A01.

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 with the help of Petrocore which was converted into the Boremap system. The interpretations of the borehole geophysical and radar logs are available when the single-hole interpretation is performed.

The results from the geological single-hole interpretations are presented in WellCad plots (Appendix 1 and Appendix 2) and described in this report. The work reported here concerns stage 1 in the geological single-hole interpretation, as defined in the method description SKB MD 810.003.

3 Data used for the geological single-hole interpretation

The following data have been used in the single-hole interpretation of boreholes KA2051A01 and KA3007A01:

- Boremap data from geological mapping (Sigurdsson 2013)
- Generalized geophysical logs and their interpretation (Mattsson 2013)
- Radar data and their interpretation (Gustafsson 2013)
- The ocular observations as one important data source

As a basis for the geological single-hole interpretation a combined WellCad plot consisting of the above mentioned data sets were used. An example of a WellCad plot used during the geological single-hole interpretation is shown in Figure 3-1. The plot consists of seven main columns and several subordinate columns. Note that Figure 3-1 only serves as an example and that minor differences in the content of the columns between different boreholes might occur. The columns in Figure 3-1 include:

1: BH Length: Length along the borehole
2: Rock type
2.1: Rock type
2.2: Occurrence, Rock type < 1m
2.3: Rock type structure
2.4: Rock type texture
2.5: Rock type grain size
2.6: Structure orientation
2.7: Rock alteration
2.8: Rock alteration intensity
3: Fracture frequency
3.1: Open total
3.2: Sealed total
3.3: Fracture orientation open/sealed
3.4: Fracture orientation broken/unbroken
3.5: Total fractures
3.6: RQD
4: Fracture alteration orientation
4.1: Open alteration
4.2: Sealed alteration
4.3: Surface
5: Crush zones and core loss
5.1: Crush zone
5.2: Piece length (mm)
5.3: Core loss
6: Generalized geophysical data
6.1: Silicate density
6.2: Magnetic susceptibility
6.3: Natural gamma radiation
6.4: Estimated fracture frequency (fr/m)
7: Geophysics
7.1: Magnetic susceptibility
7.2: Sonic
7.3: Radar directional primary/radar dipole 1
7.4: Radar directional alternative

The geophysical logs are described below:

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

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

Natural gamma radiation: The bedrock 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 fine-grained granite or pegmatite.

Estimated fracture frequency: This parameter provides an estimate of the fracture frequency along 5 m sections, calculated from short, long and lateral resistivity (only KAS04), SPR, P-wave velocity and caliper data. 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.

Separate diagrams with moving averages for open fractures alone, sealed fractures alone, and total number of open and sealed fractures were available during the interpretation process.

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 or alpha angles of radar anomalies within the possible deformation zones are commented upon in the text that describes these zones.

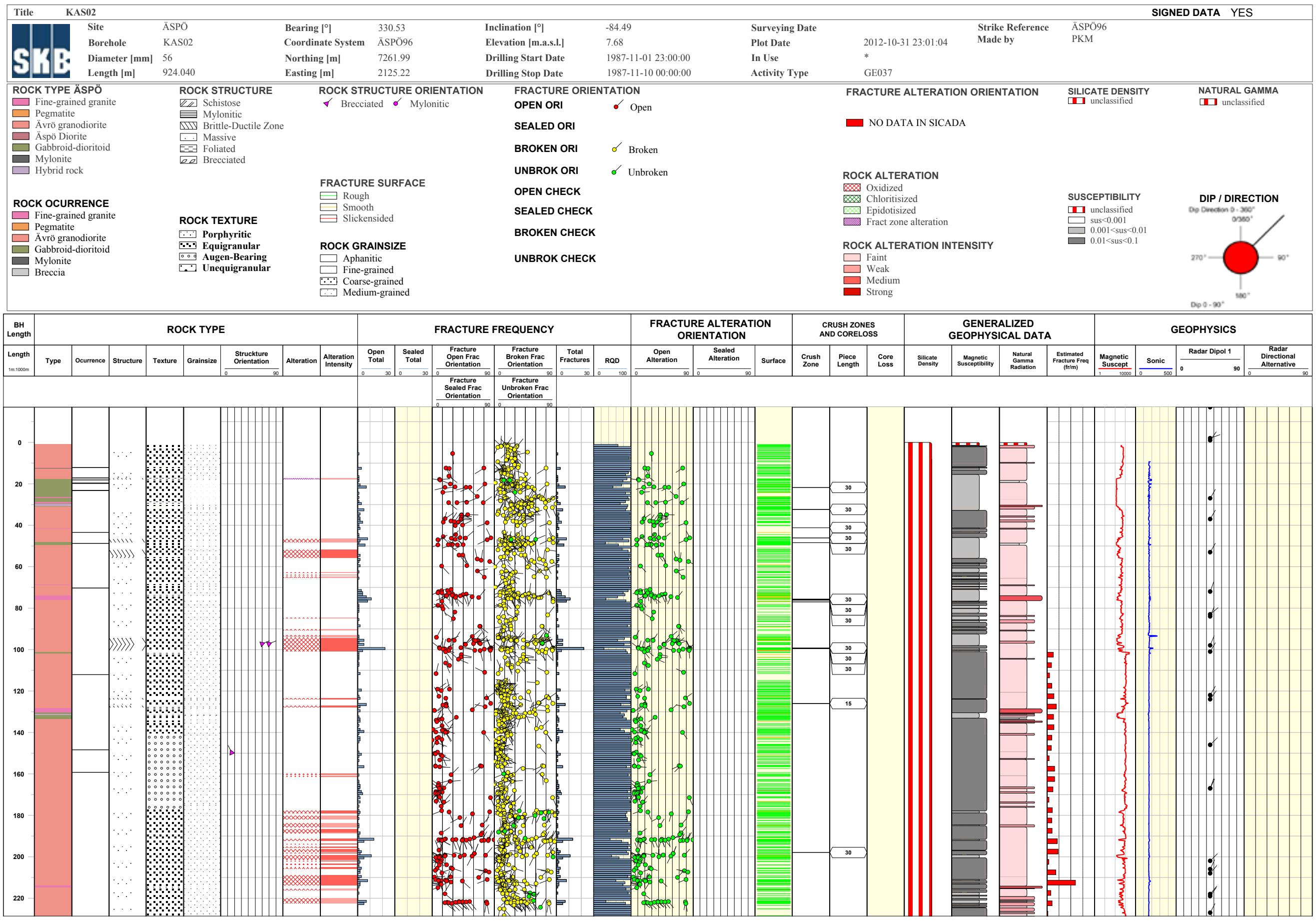

Figure 3-1. Example of WellCad plot (from borehole KAS02 at Äspö) used as a basis for the geological single-hole interpretation.

4 Execution

4.1 General

The geological and hydrogeological single-hole interpretation has been carried out by a group of geoscientists consisting of geologists and geophysicists. All data to be used (see Chapter 3) are visualized side by side in a borehole document made with the software WellCad. The working procedure is summarized in Figure 4-1 and in the text below.

The first step in the working procedure is to study all types of data related to the character of the rock type and to merge sections of similar rock types, or sections where one rock type is very dominant, into rock units (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. This includes a brief description of the rock types affected by the possible deformation zone. The confidence in the interpretation of a rock unit is made on the following basis: 3 = high, 2 = medium and 1 = low.

The second step in the working procedure is to identify possible deformation zones by visual inspection of the results of the geological mapping (fracture frequency, fracture mineral, 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. The confidence in the interpretation of a possible deformation zone is made on the following basis: 3 = high, 2 = medium and 1 = low.

Following definition of rock units and deformation zones, with their respective confidence estimates, the drillcores 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 ductile or brittle in character have been identified primarily on the basis of occurrence of protomylonitic to mylonitic foliation and fault rocks and frequency of fractures, respectively, according to the recommendations in Munier et al. (2003). Both the damaged zone and the core have been included in each zone (Figures 4-2 to 4-4). The fracture/m values in Figure 4-4 may serve only as examples. 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 and geophysical data, if available, have all assisted in the identification of primarily the brittle structures.

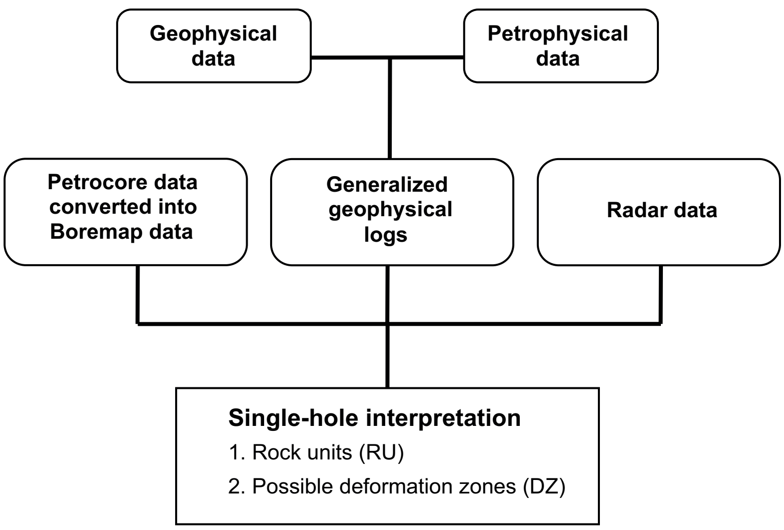

Figure 4-1. *Schematic block-scheme of single-hole interpretation.*

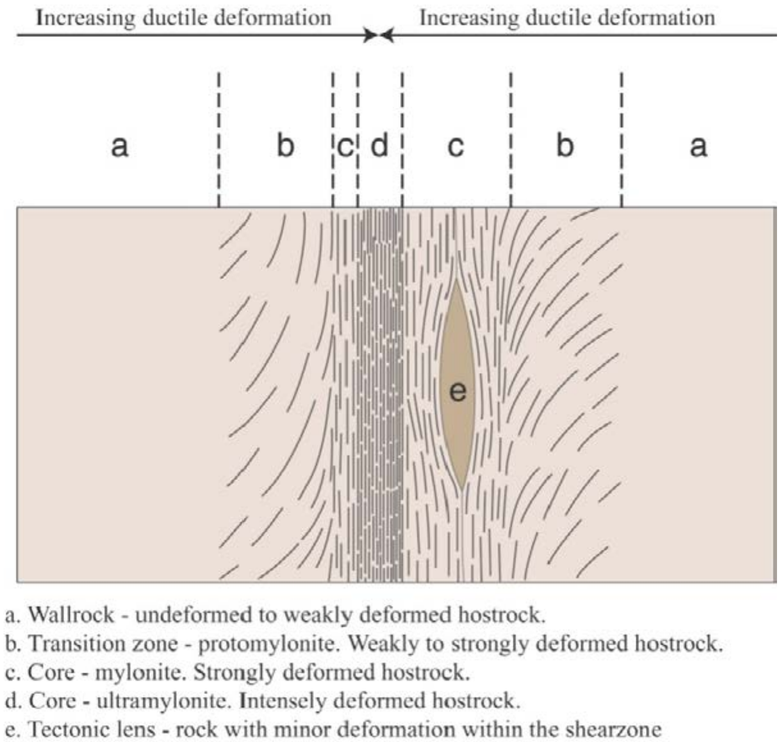

Figure 4-2. *Schematic example of a ductile shear zone. Homogeneous rock which is deformed under low- to medium-grade metamorphic conditions after Munier et al. (2003).*

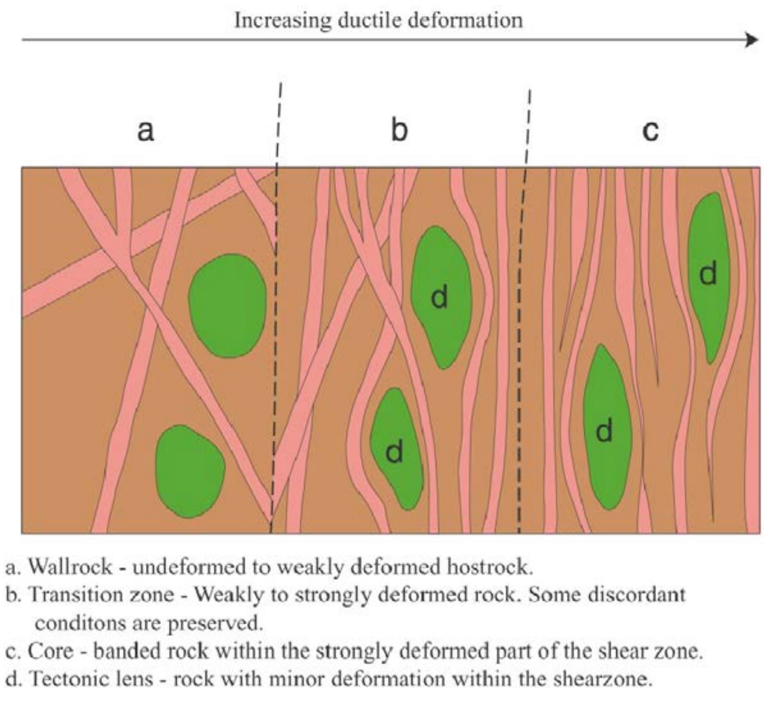

Figure 4-3. *Schematic example of a ductile shear zone. Heterogeneous rock which is deformed under low- to high-grade metamorphic conditions after Munier et al. (2003).*

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 KA2051A01 (Figure 4-5) and KA3007A01 (Figure 4-6). A 5 m window and 1 m steps have been used in the calculation procedure. The moving averages for open fractures alone, the sealed fractures alone, and the total number of open and sealed fractures are shown in diagrams.

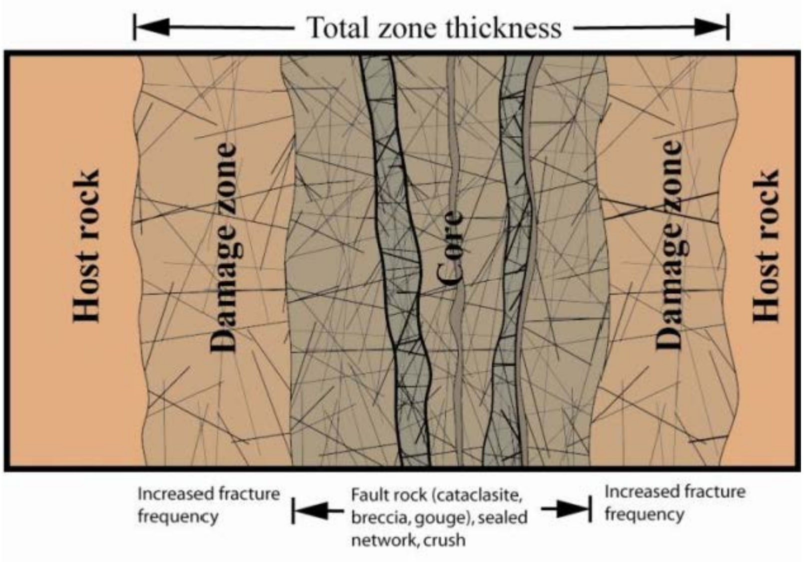

Figure 4-4. *Schematic example of a brittle deformation zone modified from Munier et al. (2003).*

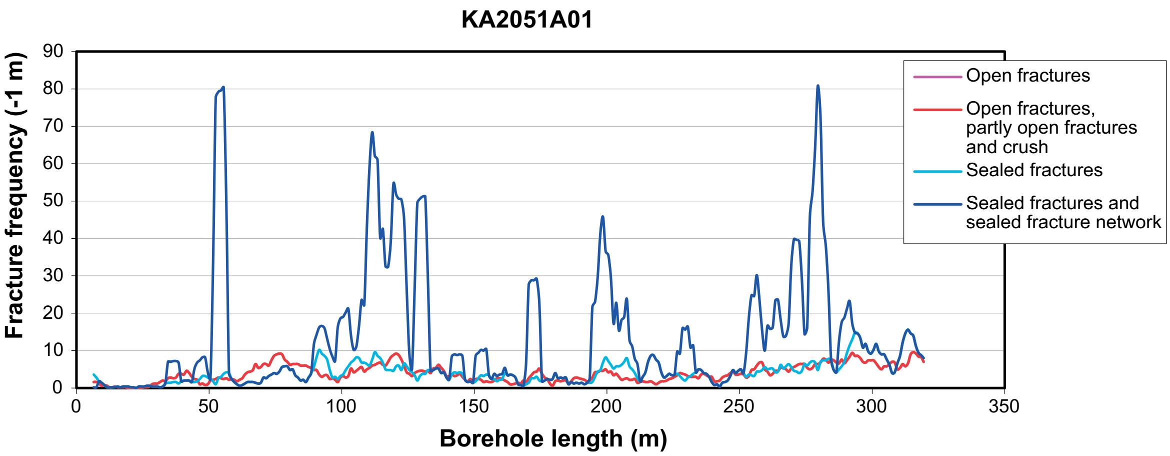

Figure 4-5. *Fracture frequency plot for KA2051A01. Moving average with a 5 m window and 1 m steps.*

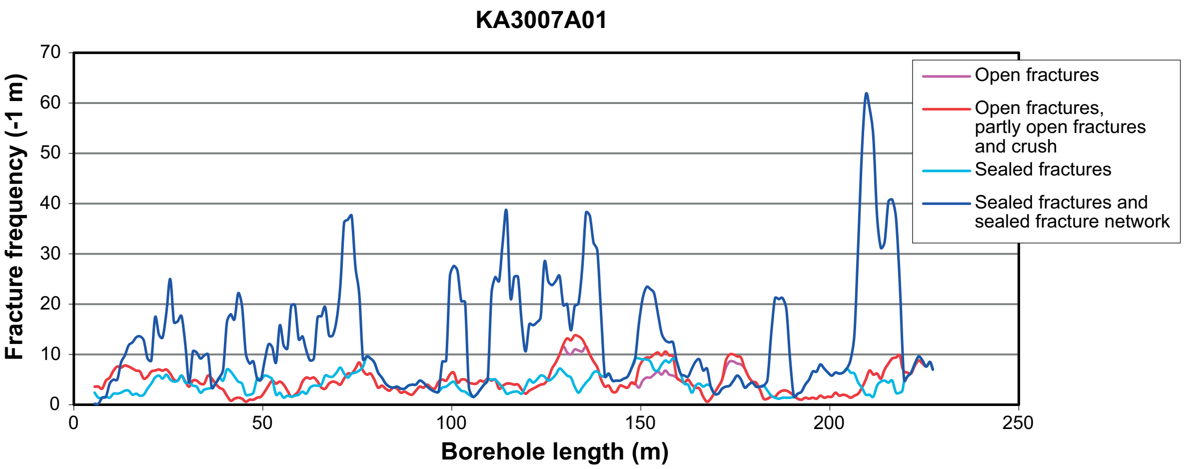

Figure 4-6. *Fracture frequency plot for KA3007A01. Moving average with a 5 m window and 1 m steps.*

The occurrence and orientation of radar anomalies have been adapted to the DZ afterwards. Overview of the borehole radar measurement in KA2051A01 is shown in Figure 4-7 and for KA3007A01 in Figure 4-8.

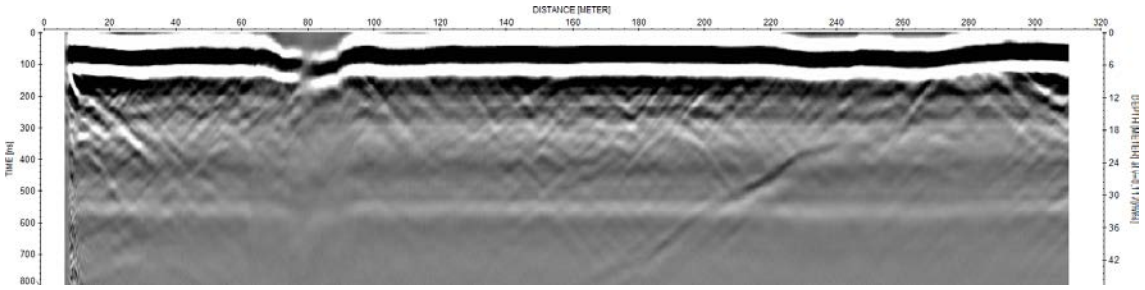

Figure 4-7. *Overview (20 MHz data) of the borehole radar measurement in KA2051A01.*

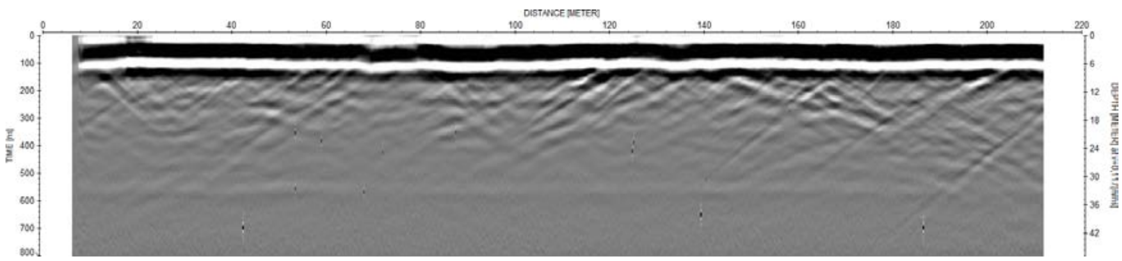

Figure 4-8. *Overview (20 MHz data) of the borehole radar measurement in KA3007A01.*

A conductive environment causes attenuation of the radar wave, which in turn decreases the penetration. The effect of strong attenuation can be observed at 64–92 m in KA2051A01. Attenuation can also be observed at 24–28 m, 104–108 m, 224–244 m and 258–272 m. However, only weak signs of attenuation can be observed at 72–82 m and 132–136 m in KA3007A01. The effect of attenuation varies between the different antenna frequencies (20 MHz and 60 MHz directional antenna). In some cases, alternative orientations for oriented radar reflectors are presented. One of the alternatives is considered to be correct, but due to uncertainty in the interpretation of radar data, a decision concerning which of the alternatives that represent the true orientation cannot be made.

Orientations from directional radar are presented as strike/dip using the right-hand-rule method, e.g. 040°/80° corresponds to a strike of N40°E and a dip of 80°to the SE. Strike is related to Äspö96 north.

4.2 Nonconformities

The upper section, the lower section and several sections along the borehole showed that uptakes and core pieces have been mixed and misplaced by the drilling staff during drilling of borehole KA3007A01. Attempts to adjust core pieces and uptakes were made by the mapping geologists.

BIPS-logging in KA3007A01 was performed to a borehole length of 219.386 m and the section to the end of the borehole (227.480 m) was therefore mapped only with drillcore and without access to BIPS-image.

Geophysical logging in KA3007A01was performed to c. 220 m.

Results from the borehole radar logging in KA2051A01 were not available during the time for the single-hole interpretation.

5 Results

The detailed result of the geological single-hole interpretations are presented as print-outs from the software WellCad (Appendix 1 for KA2051A01 and Appendix 2 for KA3007A01). Orientations are related to Äspö96 north.

5.1 KA2051A01

5.1.1 Rock units in KA2051A01

The borehole consists of four rock units (RU1–RU4). However, due to repetition of RU1 (RU1a and RU1b) and RU2 (RU2a, RU2b and RU2c) the borehole can be divided into seven sections.

2.780–7.819m

RU1a: Dominated by fine-grained granite (511058). Subordinate rock types comprise pegmatite (501061), hybrid rock (505105) and gabbroid-dioritoid (508107). Confidence level = 3.

7.819 –65.517 m

RU2a: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), pegmatite (501061) and gabbroid-dioritoid (508107). The Äspö diorite (501037) has a density in the range 2,700–2,830 kg/m^3. Confidence level = 3.

65.517–91.725 m

RU3: Totally dominated by diorite-gabbro (501033). Subordinate rock types comprise fine-grained granite (511058) and very sparse occurrence of pegmatite (501061). The major part of the rock unit is strongly hydrothermally altered (cf. DZ1). Note that the density in the rock unit varies in the range 2,800–3,100 kg/m^3. There is an indication that the density is increased in the sections with most intense hydrothermal alteration. In addition, there is a general increase in the gamma radiation in the rock unit which is interpreted to be genetically related to the hydrothermal alteration. Confidence level = 3.

91.725–134.248 m

RU2b: Dominated by Äspö diorite (501037). The Äspö diorite (501037) is texturally inhomogeneous and varies in texture from unequigranular to porphyritic (based on inspection of core during SHI). Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). The Äspö diorite (501037) has a density in the range 2,680–2,800 kg/m^3. Confidence level = 3.

134.248–224.409 m

RU4: Totally dominated by Ävrö granodiorite (501056). Subordinate rock types comprise sparse occurrences of fine-grained granite (511058), pegmatite (501061) and gabbroid-dioritoid (508107). The Ävrö granodiorite (501056) has a density in the range 2,660–2,720 kg/m^3. Confidence level = 3.

224.409–281.829 m

RU2c: Dominated by Äspö diorite (501037). Subordinate rock types comprise sparse occurrences of fine-grained granite (511058), pegmatite (501061), gabbroid-dioritoid (508107) and Ävrö granodiorite (501056). The Äspö diorite (501037) has a density in the range 2,780–2,840 kg/m^3. Confidence level = 3.

281.829–319.840 m

RU1b: Totally dominated by fine-grained granite (511058). Subordinate rock type comprises very sparse occurrence of breccia (508002). Confidence level = 3.

5.1.2 Possible deformation zones in KA2051A01

Five possible deformation zones have been recognized in KA2051A01 (DZ1–DZ5).

67.33–134.25 m

DZ1: Brittle deformation zone divided in a core and a damage zone.

67.33–91.70 m

Core: Primarily characterized by more or less strong hydrothermal alteration, increased frequency of open and sealed fractures and sparse occurrences of cataclasite and breccia. There are several distinct anomalies in the geophysical logging data, showing decreased resistivity, decreased p-wave velocity and caliper anomalies. The most prominent geophysical anomalies occur at c. 69.6 m and 84.5 m. There is also significantly increased density, partly increased natural gamma radiation and decreased magnetic susceptibility along the core section. The section 83.5–87.0 m is characterized by a significantly increased gamma radiation and decreased density, which is interpreted to be related to the hydrothermal alteration. At c. 66 m (just above the DZ) there is a significant anomaly in the borehole fluid temperature gradient. One non-oriented radar reflector occurs at 71.2 m with the angle 45° and one oriented radar reflector occurs at 76.3 m (alpha angle 49°) with the orientation 006°/85° or 142°/21°. Both reflectors are prominent in the radar map. The reflector at 71.2 m probably indicates a cataclasite at 71.962 m (alpha 43°). The reflector at 76.3 m probably indicates an open fracture at 76.41 m with the orientation 335°/81° (alpha 45°). Also, low radar amplitude occurs at 64–92 m, i.e. partly above the DZ. The host rock is dominated by hydrothermally altered diorite-gabbro (501033). Subordinate rock types comprise fine-grained granite (511058) and very sparse occurrence of pegmatite (501061). Confidence level = 3.

91.70–134.25 m

Damage zone: Characterized by inhomogeneous brittle deformation, particularly by increased frequency of sealed network and sealed fractures, increased frequency of open fractures compared to the bedrock outside the DZ, but decreased frequency of open fractures compared to the core section. Furthermore, increased degree of oxidation and saussuritization occurs. There is an increased occurrence of low resistivity and decreased p-wave velocity anomalies. The magnetic susceptibility is partly decreased and there are fairly large variations in the density. Decreased radar amplitude occurs at 104–108 m. The host rock is dominated by unequigranular to porphyritic Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). Confidence level = 3.

172.08–172.39 m

DZ2: Brittle deformation zone characterized by sealed network. In addition, cataclasite and some breccia occur (based on inspection of core during SHI). The geophysical logging data show decreased resistivity, p-wave velocity and magnetic susceptibility. The host rock is dominated by fine-grained granite (511058). Confidence level = 3.

195.40–201.40 m

DZ3: Brittle deformation zone characterized by increased frequency of open and sealed fractures, sealed network, oxidation and some cataclasite and sparse occurrence of breccia (based on inspection of core during SHI). The geophysical logging data show significantly decreased resistivity and partly decreased p-wave velocity. One oriented radar reflector occurs at 198.5 m with the orientation 212°/84° (alpha 53°). Best correlation with the reflector is an open fracture at 199.058 m with the orientation 353°/89° (alpha 55°), i.e. a subvertical fracture. The host rock is dominated by Ävrö granodiorite (501056). Subordinate rock type comprises pegmatite (501061). Confidence level = 2.

205.10–205.88 m

DZ4: Brittle deformation zone characterized by increased frequency of sealed fractures, sealed network and oxidation. The geophysical logging data show decreased resistivity (no other indications). The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 2.

271.84–281.91 m

DZ5: Inhomogeneous brittle deformation zone characterized by increased frequency of open and sealed fractures, sealed network, epidotization and oxidation. The geophysical logging data show a number of anomalies with decreased resistivity and p-wave velocity. The most prominent anomalies occur at c 281.2 m, and are spatially related to gradients in the density, magnetic susceptibility and natural gamma radiation caused by the contact between the Äspö diorite and fine-grained granite in the rock unit RU1b. Decreased radar amplitude occurs at 258–272 m, i.e. partly above the DZ. The host rock is dominated by Äspö diorite (501037). Subordinate rock types comprise pegmatite (501061), fine-grained granite (511058) and sparse occurrence of gabbroid-dioritoid (508107). Confidence level = 3.

5.2 KA3007A01

5.2.1 Rock units in KA3007A01

The borehole consists of six rock units (RU1–RU6). However, due to repetition of RU1 (RU1a, RU1b, RU1c and RU1d), RU4 (RU4a, RU4b, RU4c, RU4d and RU4e) and RU6 (RU6a and RU6b) the borehole can be divided into fourteen sections.

0.000–13.130 m

RU1a: Totally dominated by Ävrö granodiorite (501056). Subordinate rock types comprise gabbroid-dioritoid (508107), pegmatite (501061) and fine-grained granite (511058). The Ävrö granodiorite (501056) has a density in the range 2,670–2,720 kg/m^3. Confidence level = 3.

13.130–24.177 m

RU2: Totally dominated by fine-grained granite (511058). Subordinate rock types comprise Ävrö granodiorite (501056) and pegmatite (501061). Confidence level = 3.

24.177–45.640 m

RU1b: Totally dominated by Ävrö granodiorite (501056). Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). The Ävrö granodiorite (501056) has a density in the range 2,670–2,720 kg/m^3. Confidence level = 3.

45.640–79.860 m

RU3: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), Ävrö granodiorite (501056), pegmatite (501061) and hybrid rock (505105). The fine-grained granite (511058) is evenly distributed in the rock unit. The Äspö diorite (501037) has a density in the range 2,750–2,850 kg/m^3. Confidence level = 3.

79.860–120.384 m

RU4a: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), hybrid rock (505105), pegmatite (501061) and gabbroid-dioritoid (508107). The Äspö diorite (501037) has a density in the range 2,750–2,850 kg/m^3. Confidence level = 3.

120.384–133.241 m

RU5: Dominated by fine-grained granite (511058). Subordinate rock types comprise c. 1 m long sections of hybrid rock (505105) and gabbroid-dioritoid (508107). Furthermore, pegmatite (501061) and Äspö diorite (501037) occur. Confidence level = 3.

133.241–150.110 m

RU4b: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), hybrid rock (505105), pegmatite (501061) and gabbroid-dioritoid (508107). The Äspö diorite (501037) has a density in the range 2,730–2,850 kg/m^3. Confidence level = 3.

150.110–161.110 m

RU1c: Totally dominated by Ävrö granodiorite (501056). The Ävrö granodiorite (501056) has a density in the range 2,590–2,700 kg/m^3. Confidence level = 3.

161.110–165.218 m

RU6a: Dominated by gabbroid-dioritoid (508107). Subordinate rock types comprise c. 1 m long section of Ävrö granodiorite (501056). Furthermore, fine-grained granite (511058) and pegmatite (501061) occur. Confidence level = 3.

165.218–174.983 m

RU4c: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and Ävrö granodiorite (501056). The Äspö diorite (501037) has a density in the range 2,770–2,870 kg/m^3. Confidence level = 3.

174.983–182.393 m

RU6b: Totally dominated by gabbroid-dioritoid (508107). Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). Confidence level = 3.

182.393–191.744 m

RU4d: Dominated by Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107) and fine-grained granite (511058). The Äspö diorite (501037) has a density in the range 2,800–2,880 kg/m^3. Confidence level = 3.

191.744–197.798 m

RU1d: Totally dominated by Ävrö granodiorite (501056). Subordinate rock types comprise Äspö diorite (501037) and fine-grained granite (511058). The Ävrö granodiorite (501056) has a density in the range 2,680–2,730 kg/m^3. Confidence level = 3.

197.798–227.480 m

RU4e: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), Ävrö granodiorite (501056), pegmatite (501061) and gabbroid-dioritoid (508107). The Äspö diorite (501037) has a density in the range 2,750–2,880 kg/m^3. Confidence level = 3.

5.2.2 Possible deformation zones in KA3007A01

Five possible deformation zones have been recognized in KA3007A01 (DZ1–DZ5).

12.30–13.45 m

DZ1: Brittle deformation zone characterized by increased frequency of open fractures and slightly increased frequency sealed fractures, epidotization and minor brecciation. The geophysical logging data show significantly decreased resistivity and p-wave velocity. There is also a clear anomaly in the borehole diameter.The host rock is dominated by foliated gabbroid-dioritoid (508107) but fine-grained granite (511058) constitutes an important lithological component. Subordinate rock type comprises sparse occurrence of Ävrö granodiorite (501056). Confidence level = 3.

64.00–79.86 m

DZ2: Brittle deformation zone divided in a core and damage zones.

64.00–73.15 m

Damage zone: Characterized by inhomogeneous brittle deformation, particularly by slightly increased frequency of sealed fractures, sealed network, scattered cataclasites, oxidation and epidotization. There are no significant anomalies in the geophysical logging data along this section. One non-oriented radar reflector occurs at 63.6 m with the angle 49° to borehole axis. The interpreted intersection is just above the DZ. The host rock is dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058) and very sparse occurrence of pegmatite (501061). Confidence level = 3

73.15–74.77 m

Core: Characterized by increased frequency of open fractures, sealed network, brecciation, oxidation and epidotization. Along the section 73.5–75.5 m the geophysical logging data show significantly decreased resistivity and p-wave velocity, and there is also a clear anomaly in the caliper data. One oriented radar reflector occurs at 73.9 m with the orientation 294°/67° (alpha 51°). The reflector is prominent in the radar map and probably indicates the contact to Äspö diorite (501037) at 73.79 m with the orientation 296°/62° (alpha 45°) or the lower contact of afine-grained granite at 73.79 m with the orientation 296°/65° (alpha 53°). Weak signs of low radar amplitude occur at 72–82 m. The host rock is dominated by Äspö diorite (501037). Subordinate rock type comprises fine-grained granite (511058). Confidence level = 3.

74.77–79.86 m

Damage zone: Characterized by inhomogeneous brittle deformation, particularly by slightly increased frequency of open fractures, increased frequency of sealed fractures, oxidation. The damage zone is inhomogeneously foliated. Along the section 75.5–79.9 m there are no significant anomalies in the geophysical logging data. The host rock is dominated by Äspö diorite (501037) but fine-grained granite (511058) constitutes an important lithological component. Confidence level = 3.

119.50–137.70 m

DZ3: Brittle deformation zone divided in a core and damage zones.

119.50–131.60 m

Damage zone: Characterized by inhomogeneous brittle deformation, particularly by slightly increased frequency of open and sealed fractures, sealed network, oxidation and epidotization. The magnetic susceptibility is decreased along the entire section. However, there are no other significant anomalies. Two oriented radar reflectors occur at 123.6 m and 124.3 m with the orientation 044°/57° (alpha 30°) and 082°/49° (alpha 56°), respectively. The reflector at 124.3 m is considered prominent in the radar map, and probably indicates the lower contact at 124.86 m between hybrid rock and fine-grained granite 073°/46° (alpha 53°). The reflector at 123.6 m probably indicates the foliation measured at 124.08 m with the orientation 053°/58° (alpha 44°). The host rock is dominated by fine-grained granite (511058), but hybrid rock (505105) and gabbroid-dioritoid (508107) constitute important lithological components. Äspö diorite (501037) and pegmatite (501061) occur in minor amounts. Confidence level = 3.

131.60–133.30 m

Core: Characterized by slightly increased frequency of open fractures, sealed network, epidotization, oxidation, cataclastic to brittle-ductile deformation, some brecciation and one crush (131.901–132.540 m). The geophysical logging data show significantly decreased resistivity, p-wave velocity and magnetic susceptibility. Weak indication of low radar amplitude occurs at 132–136 m. The host rock is totally dominated by fine-grained granite (511058). Subordinate rock type comprises very sparse occurrence of Äspö diorite (501037). Confidence level = 3.

133.30–137.70 m

Damage zone: Characterized by increased frequency of open fractures, sealed network, oxidation and epidotization. The geophysical logging data show decreased magnetic susceptibility and partly decreased resistivity along the section. There are weak signs of low radar amplitude at 132–136 m. The host rock is dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). Confidence level = 3.

149.80–178.85 m

DZ4: Brittle deformation zone characterized by slightly increased frequency of open and sealed fractures, scattered minor occurrences of sealed network and cataclastic deformation, and epidotization. There are two short sections with significant anomalies in the geophysical logging data. In the section c. 152.0–153.0 m the resistivity and p-wave velocity are clearly decreased. Along the section c. 174.5–175.5 m decreased resistivity and p-wave velocity coincides with a significant anomaly in the fluid temperature data, which indicates the occurrence of in or out flow of water. One non-oriented radar reflector occurs at 149.4 m with the angle 31° to borehole axis. The interpreted intersection of the reflector at 149.4 m is just above the DZ. One oriented radar reflector occurs at 175.4 m with the orientation 136°/76° or 080°/78° (alpha 63°). The oriented reflector probably indicates a vein with fine-grained granite (511058) at 175.44 m with the orientation 075°/75° (alpha 67°) or a broken fracture at 175.6 m with the orientation 126°/73° (alpha 64°). The host rock is dominated by more or less equal amounts of Ävrö granodiorite (501056), Äspö diorite (501037) and gabbroid-dioritoid (508107). Subordinate rock type comprises fine-grained granite (511058). Confidence level = 2.

178.85–227.48 m

DZ5: The zone is characterized by inhomogeneously distributed shear foliation, sealed network, epidotization and oxidation. There are no significant anomalies in the geophysical logging data. However, at the very end of the section with collected geophysical data (c. 217 m), there are clear anomalies in the resistivity, p-wave velocity and fluid temperature data. One oriented radar reflector occurs at 209.7 m with the orientation 052°/60° (alpha 39°). The reflector is considered prominent in the radar map and probably indicates one or several subparallel open fractures at 209.11 m with the orientation 043°/75° (alpha 36°), at 210.20 m with the orientation 045°/48° (alpha 36°), and at 210.31 m with the orientation 051°/74° (alpha 44°). The reflector might also indicate a sealed fracture network at 209.04–211.62 m with sealed fracture orientation 067°/52°, 048°/68°, 163°/34° and 040°/79°. The host rock is dominated by Äspö diorite (501037), but Ävrö granodiorite (501056) and gabbroid-dioritoid (508107) constitute important lithological components. Subordinate rock types comprise fine-grained granite (511058) and sparse occurrence of pegmatite (501061). Confidence level = 2.

6 Comments

The results from the geological single-hole interpretations of KA2051A01 and KA3007A01 are presented in WellCAD plots (Appendix 1 and Appendix 2). The WellCAD plot consists of the following columns:

In data Boremap	1: Depth (Length along the borehole)
	2: Rock type
	3: Rock alteration
	4: Frequency of sealed fractures
	5: Frequency of open and partly open fractures
	6: Crush
In data Geophysics	7: Silicate density
	8: Magnetic susceptibility
	9: Natural gamma radiation
	10: Estimated fracture frequency
Interpretations	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

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

Gustafsson C, 2013. Äspö Hard Rock Laboratory. BIPS, Radar and Flexit in KA2051A01, KA3007A01, KJ0044F01 and KJ0050F01. SKB P-13-17, Svensk Kärnbränslehantering AB.

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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.

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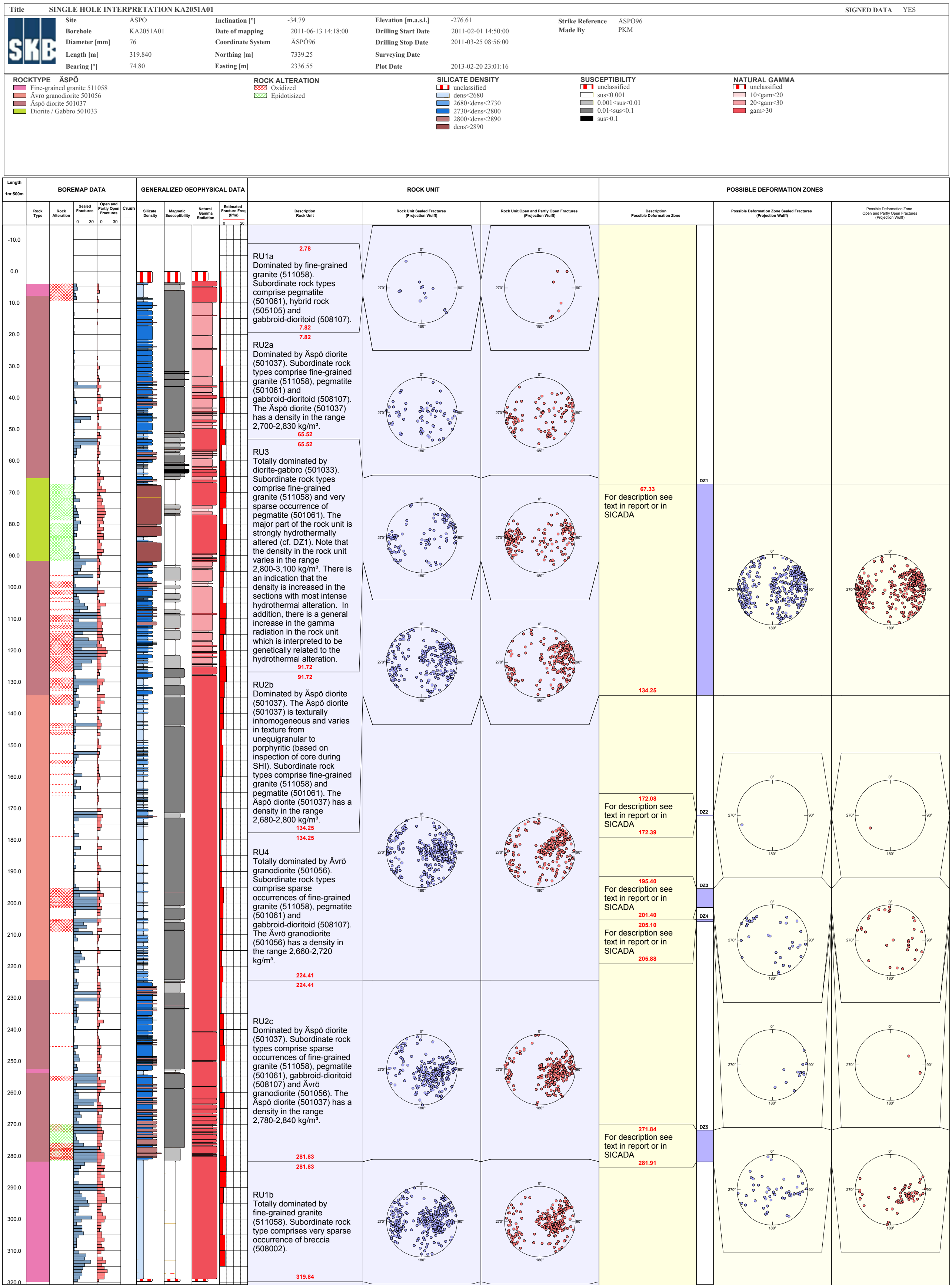
Appendix 1

Geological single-hole interpretation of KA2051A01



Geological single-hole interpretation of KA3007A01

Title SINGLE HOLE INTERPRETATION KA3007A01 — **SIGNED DATA** YES

Site	ÄSPÖ	Inclination [°]	-14.69	Elevation [m.a.s.l.]	-400.60	Strike Reference	ÄSPÖ96
Borehole	KA3007A01	Date of mapping	2011-08-15 13:58:00	Drilling Start Date	2011-04-13 10:00:00	Made By	PKM
Diameter [mm]	76	Coordinate System	ÄSPÖ96	Drilling Stop Date	2011-05-17 07:52:00		
Length [m]	227.760	Northing [m]	7410.09	Surveying Date			
Bearing [°]	10.43	Easting [m]	2369.57	Plot Date	2013-02-20 23:01:16		

ROCKTYPE ÄSPÖ
- Fine-grained granite 511058
- Ävrö granodiorite 501056
- Äspö diorite 501037
- Fine-grained diorite-gabbro 505102
- Gabbroid-dioritoid 508107
- Hybrid rock 505105

ROCK ALTERATION
- Oxidized
- Epidotisized

SILICATE DENSITY
- unclassified
- dens<2680
- 2680<dens<2730
- 2730<dens<2800
- 2800<dens<2890
- dens>2890

SUSCEPTIBILITY
- unclassified
- sus<0.001
- 0.001<sus<0.01
- 0.01<sus<0.1

NATURAL GAMMA
- unclassified
- gam<10
- 10<gam<20
- 20<gam<30
- gam>30