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Abstract

This report presents the outcome from geological single-hole interpretation of the core drilled boreholes KA2563A, KA2598A and KA3376B01 which have been drilled underground in the Äspö HRL tunnel. The geological single-hole interpretation (SHI) is part of the work for the Äspö Site descriptive model, Äspö SDM. The aim of the work is from data from geological core mapping and borehole radar measurements to identify different rock unit distribution in the boreholes and to identify the location and distribution of possible deformation zones in the borehole.

The geological mapping was initially made with the Petrocore system and the Petrocore data was later converted into the Boremap system in order to evaluate and present the geological data for the geological single-hole interpretation in a similar way as was performed during the Laxemar site investigation (SKB 2009). Due to the lack of borehole TV (BIPS)-images, inconclusiveness in the geological documentation and lack of certain parameters such as fracture frequency, a complete geological single-hole interpretation as was made in the Laxemar site investigation (SKB 2009) could not be performed.

The borehole radar measurements in KA2563A, KA2598A and KA3376B01 were performed with directional antenna and the evaluation of radar data was at that time performed more or less manually by using different programs for the different steps of evaluation.

The geological single-hole interpretation shows that the borehole KA2563A is dominated by Äspö diorite (501037). Fine-grained granite (511058) also occurs alternately in larger sections in the borehole. Subordinate rock types comprise occurrence of pegmatite (501061), gabbroiddioritoid (508107) and quartz-dominated hydrothermal vein/segregation (508021). Six possible deformation zones are identified in KA2563A (DZ1–DZ6).

The geological single-hole interpretation shows that the borehole KA2598A is dominated by Ävrö granodiorite (501056) in the middle part and Äspö diorite (501037) in the upper and lower part of the borehole. One large section with fine-grained granite (511058) also occurs in the borehole. Subordinate rock types comprise occurrence of gabbroid-dioritoid (508107), sparse occurrence of quartz-dominated hydrothermal vein/segregetation (508021) and very sparse occurrence of pegmatite (501061). Eight possible deformation zones are identified in KA2598A (DZ1–DZ8).

The geological single-hole interpretation shows that the borehole KA3376B01 is dominated by Äspö diorite (501037). Subordinate rock types comprise hybrid rock (505105), Ävrö granodiorite (501056), gabbroid-dioritoid (508107), pegmatite (501061) and very sparse occurrence of fine-grained granite (511058). One possible deformation zone is identified in KA3376B01 (DZ1). The sub-horizontal borehole is located close to the tunnel TASQ and is drilled in the NE direction (initially a core drilled borehole drilled as pilot borehole for tunnel TASQ). The borehole is drilled entirely inside a deformation zone (DZ).

Sammanfattning

Denna rapport presenterar resultatet av geologisk enhålstolkning av kärnborrhålen KA2563A, KA2598A och KA3376B01 vilka är belägna i Äspölaboratoriets tunnel. Den geologiska enhålstolkningen (SHI) utgör en del av arbetet med Äspö platsbeskrivande modell (SDM). Syftet är att utifrån den geologiska karteringen och borrhålsradarmätningar identifiera olika bergenheters fördelning i borrhålet samt att ange möjliga deformationszoners läge och utbredning i borrhålet.

Den geologiska borrkärnekarteringen genomfördes inledningsvis med Petrocore. Petrocoredata överfördes senare till Boremapsystemet för att kunna utvärdera och presentera geologiska data i form av geologisk enhålstolkning (geological single-hole interpretation (SHI)) på motsvarande sätt som genomfördes under platsundersökningarna i Laxemar (SKB 2009). I avsaknad av borrhåls-TV (BIPS), oklarheter i den geologiska dokumentationen, och avsaknad av parametrar som sprickfrekvens, genomfördes inte en komplett geologisk enhålstolkning på det sätt den genomfördes under platsundersökningarna i Laxemar (SKB 2009).

Borrhålsradar genomfördes i borrhålen KA2563A, KA2598A och KA3376B01 med radar riktantenn och utvärderingen och tolkningen av radardata genomfördes manuellt med fristående program och i olika steg.

Den geologiska enhålstolkningen visar att kärnborrhålet KA2563A domineras av Äspödiorit (501037). Finkornig granit (511058) förekommer växelvis i större sektioner i borrhålet. Underordnade bergarter utgörs av pegmatit (501061), gabbroid-dioritoid (508107) och kvartsdominerad hydrotermal ådra/segregation (508021). Sex möjliga deformationszoner har identifierats i KA2563A (DZ1–DZ3).

Den geologiska enhålstolkningen visar att kärnborrhålet KA2598A domineras av Ävrögranodiorit (501056) i den mellersta delen och av Äspödiorit (501037) i den övre respektive nedre delen av borrhålet. En större sektion med finkornig granit (511058) förekommer i borrhålet. Underordnade bergarter utgörs av gabbroid-dioritoid (508107), sparsam förekomst av kvartsdominerad hydrotermal ådra/segregation (508021) och mycket sparsam förekomst av pegmatit (501061). Åtta möjliga deformationszoner har identifierats i KA2598A (DZ1–DZ8).

Den geologiska enhålstolkningen visar att kärnborrhålet KA3376B01 domineras av Äspödiorit (501037). Underordnade bergarter utgörs av hybridbergart (505105), Ävrögranodiorit (501056), gabbroid-dioritoid (508107), pegmatit (501061) och mycket sparsam förekomst av finkornig granit (511058). En möjlig deformationszon har identifierats i KA3376B01 (DZ1). Borrhålet har borrats sub-horisontellt nära tunnel TASQ och är borrat i NE riktning (borrhålet var ett pilothål till tunnel TASQ). Borrhålet är i huvudsak borrat längs med en deformationszon (DZ).

Contents

1 Introduction

1.1 Background

To support predictions and planning of experiments performed at the Äspö Hard Rock Laboratory (Äspö HRL), a site descriptive model (SDM) is under development, Äspö SDM. The purpose is to present an integrated understanding of the Äspö area based on available information from the fields of geology, hydrogeology, hydrogeochemistry, rock mechanics and thermal properties. An essential part in the Äspö SDM project is to incorporate existing borehole data from the earlier investigations, as well from construction and operational phases of the Äspö HRL. This necessitates a reassessment of the available data together with a renewed examination of selected drill cores, along with the experiences from the preceding site investigations at Forsmark (SKB 2008) and Laxemar (SKB 2009), as well as the SFR (repository for low and medium activity waste in Forsmark) extension project.

A key input to the geological modelling during the site investigations at Forsmark (SKB 2008) and Laxemar (SKB 2009) has been the complete geological single-hole interpretation (SHI) of borehole data based also on a complete suite of geophysical logging data. The current methodology for geological single-hole interpretation provides an integrated synthesis of the geological and geophysical information in a borehole where the methodology is based on the modelling strategy by Munier et al. (2003). Important input data are the results from the borehole TV (BIPS) investigation of boreholes, which give the best possible location and true orientation (strike and dip) of the fractures intersecting the borehole and when the fractures also are visible in the core the orientation and grade of openness of the fractures can be estimated. However, due to lack of borehole TV (BIPS)-images, inconclusiveness in the geological documentation and lack of certain parameters such as fracture frequency, along with the fact that geophysical logging data are missing in the boreholes KA2563A, KA2598A and KA3376B01, complete input data for the geological single hole interpretation is not available as compared to the site investigations in Forsmark (SKB 2008) and Laxemar (SKB 2009).

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 modeling 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 boreholes KA2563A, KA2598A and KA3376B01 in the Äspö HRL tunnel (Figure 1-1), which is one of the activities performed within the work of upgrading the geological model of the Äspö Site Descriptive Model (SDM). The work was carried out in accordance with activity plan AP TD F140-10-031. The controlling documents for performing this activity are listed in Table 1-1. Rock type nomenclature (Table 1-2) has been used is in accordance with method instruction SKB MD 132.004. Activity plan, method descriptions and method instructions are SKB's internal controlling documents.

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

Activity plan	Number	Version
Geologisk enhålstolkning av KA2563A, KA2598A och KA3376B01	AP TD F140-10-031	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

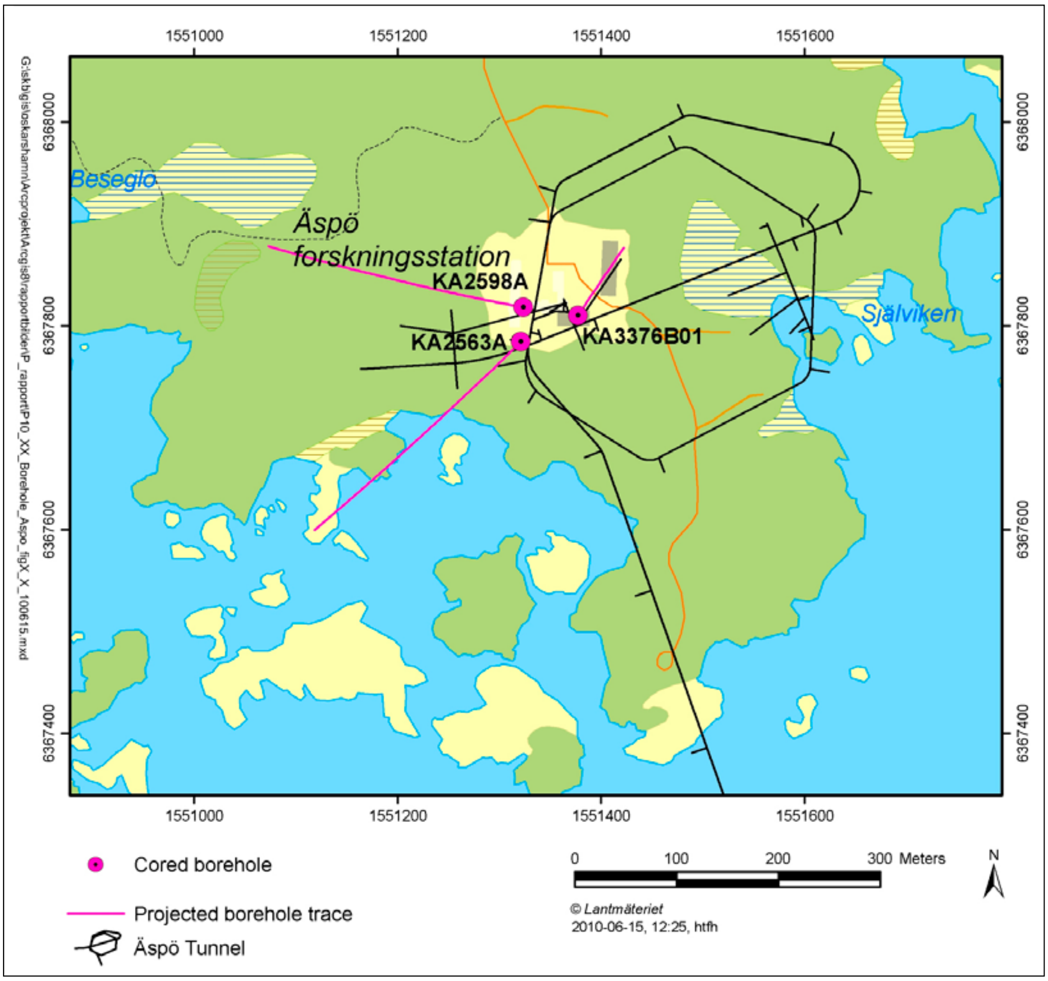


Figure 1-1. Map showing the position of the cored boreholes KA2563A, KA2598A and KA3376B01 in the Äspö tunnel.

Table 1-2. Rock type nomenclature for different rock types applied for 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

1.2 Objectives

This report presents the outcome from geological single-hole interpretation of the core drilled boreholes KA2563A, KA2598A and KA3376B01 located in the Äspö HRL tunnel. The geological single-hole interpretation (SHI) is part of the work for the Äspö Site descriptive model Äspö SDM. The aim of the work is to compile data from geological core mapping and borehole radar measurements to identify different rock unit distributions in the boreholes and as well as the location and distribution of possible deformation zones in the borehole.

The work involved an integrated interpretation of data from the geological mapping of the borehole which initially was performed with the Petrocore system which than was converted into the Boremap system. Borehole radar data were available for the core drilled boreholes KA2563A, KA2598A and KA3376B01. The methodology for geological single-hole interpretation has been developed during the site investigations at Forsmark (SKB 2008) and Laxemar (SKB 2009). 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 in a borehole.

The result from the geological single-hole interpretation is presented in WellCAD plots (Appendices 1 to 3) and is 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.

2 Methodology for the geological single-hole interpretation

2.1 Data used for the geological single-hole interpretation

The following data have been used in the single-hole interpretation of boreholes KA2563A, KA2598A and KA3376B01:

- Boremap data converted to Boremap from geological mapping initially performed in the Petrocore system, except for KA3376B01 which was mapped using the Boremap system.
- Radar data and their interpretation (Carlsten et al. 1995).

Note that geophysical logs as described in the example from borehole KAS02 (Figure 2-1) were not available in the boreholes KA2563A, KA2598A and KA3376B01.

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 2-1. The plot consists basically of seven main columns and several subordinate columns. Note that Figure 2-1 only serves as an example and that minor differences in the presentation within the columns between different boreholes might occur. The columns in Figure 2-1 as presented in Table 2-1 include:

Table 2-1. Headings in columns and sub-columns in the WellCAD plot in Figure 2-1.

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

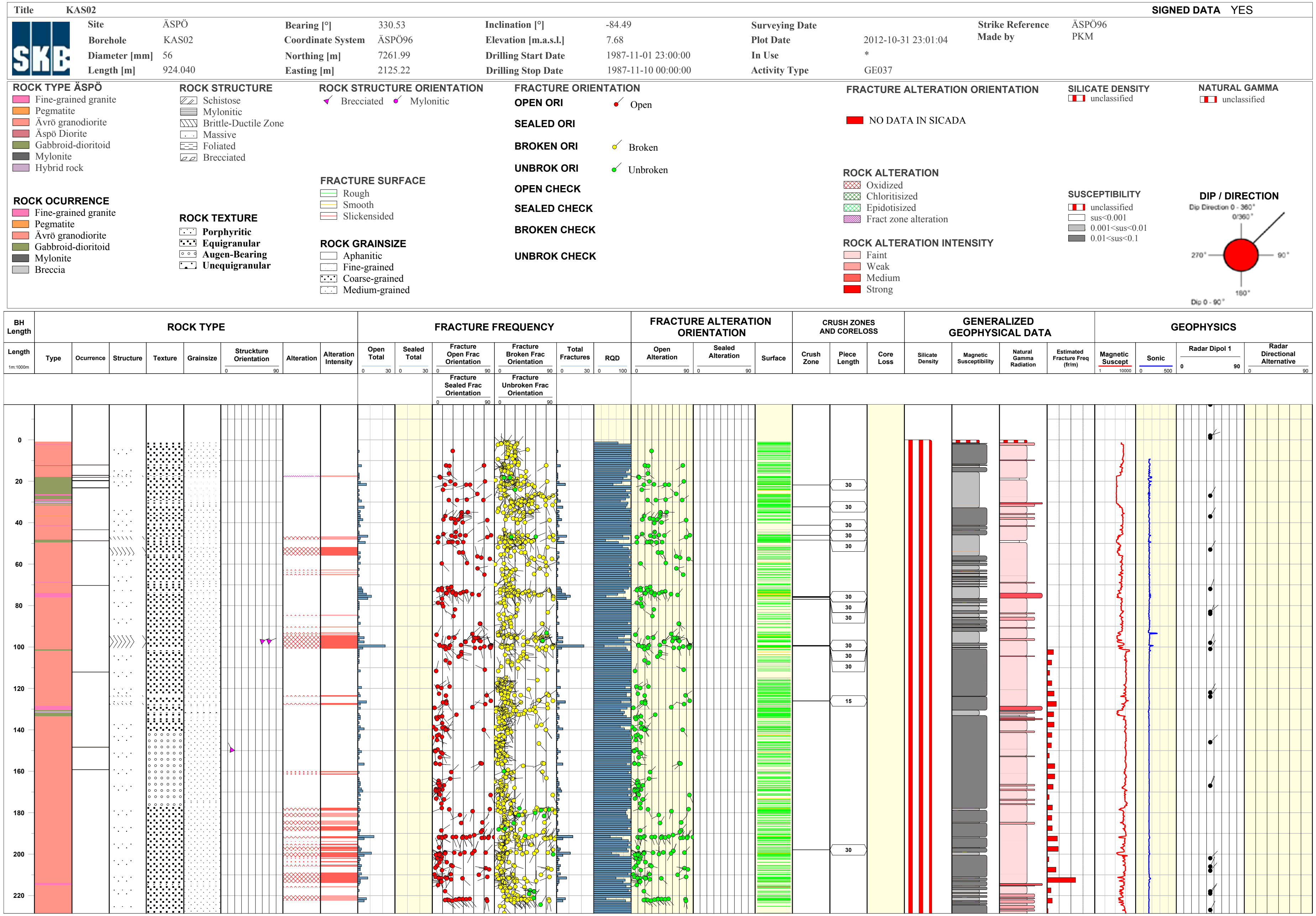


Figure 2-1. Example of WellCAD plot (from borehole KAS02 in Äspö) used as a basis for the single-hole interpretation. Note that no geophysical logging data exist for the boreholes KA2563A, KA2598A and KA3376B01.

The geophysical logs as described in the example from KAS02 (geophysical logs were not available in the boreholes KA2563A, KA2598A and KA3376B01) 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, 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.

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. Strike is related to Äspö96 North.

The data normally used for the geological single-hole interpretation is summarized in Figure 2-2.

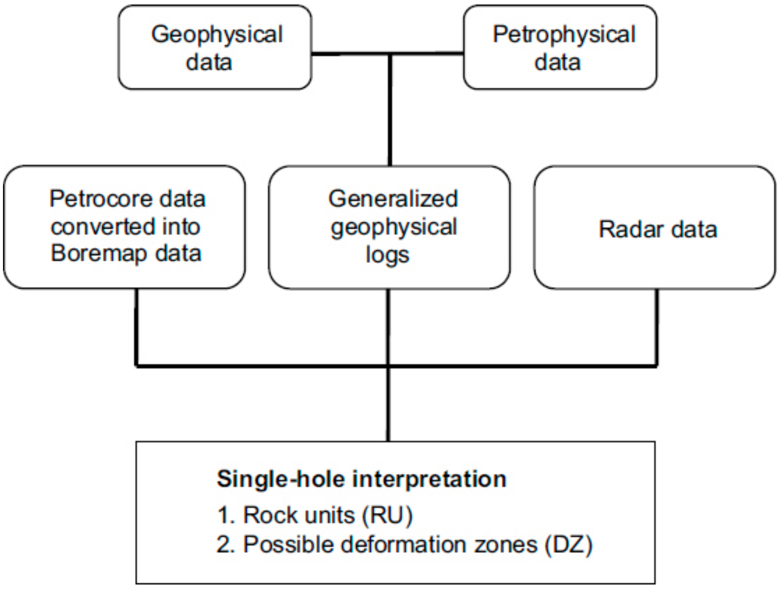


Figure 2-2. *Schematic block-scheme for data used in the geological single-hole interpretation.*

2.2 Geological single-hole interpretation

The working procedure is to study all available types of data related to the character of the rock types and to merge sections of similar geological character into rock units. All data to be used are presented side by side in a borehole document extracted from the software WellCAD. Geophysical density logs, when available, are very useful in the interpretation work, but such data were not available for these boreholes. A minimum length of about 5 m was used for definition of rock units in the geological single-hole interpretations during the site investigations at Forsmark (SKB 2008) and Laxemar (SKB 2009). This minimum length was also applied during the current work. The division into rock units was carried out by 2–3 geologists. Each rock unit is defined in terms of the borehole length interval and is provided with a brief description of the rock unit. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

The procedure to identify possible deformation zones is primarily based on inspection of the drill cores. By visual inspection of the geological mapping (fracture frequency, fracture mineral, aperture, alteration, etc.) in combination with the radar data and/or geophysical logs a possible deformation zone in the borehole is identified. The section of each identified possible deformation zone is defined in terms of the borehole length interval and the deformation zone unit is 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 the definition of rock units and deformation zones, with their respective confidence estimates, the drill cores were inspected in order to check the selection of the boundaries between these geological entities. If judged necessary, the location of these boundaries was 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). The damaged zone and the deformation zone core have been included in each deformation zone description (Figures 2-3 to 2-5). The frequencies of open and sealed fractures have been assessed in the identification procedure, and the character of the deformation zone has been described accordingly. Partly open fractures are included together with open fractures in the brief description of each deformation zone. The presence of bedrock alteration, the occurrence and, locally, inferred orientation of radar reflectors have all assisted in the identification of the deformation zones.

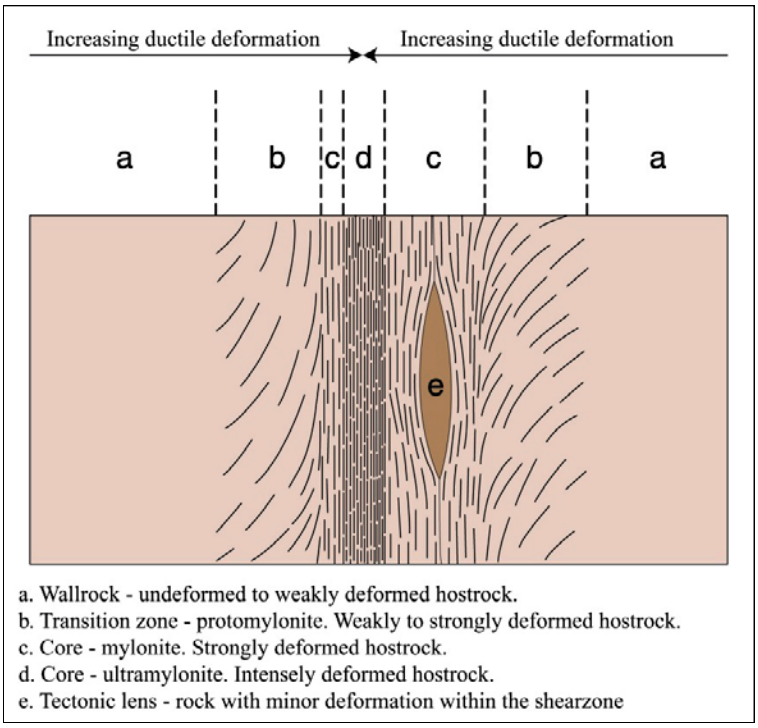


Figure 2-3. *Schematic example of a ductile shear zone. Homogeneous rock which is deformed under low- to medium-grade metamorphic conditions (after Munier et al. 2003).*

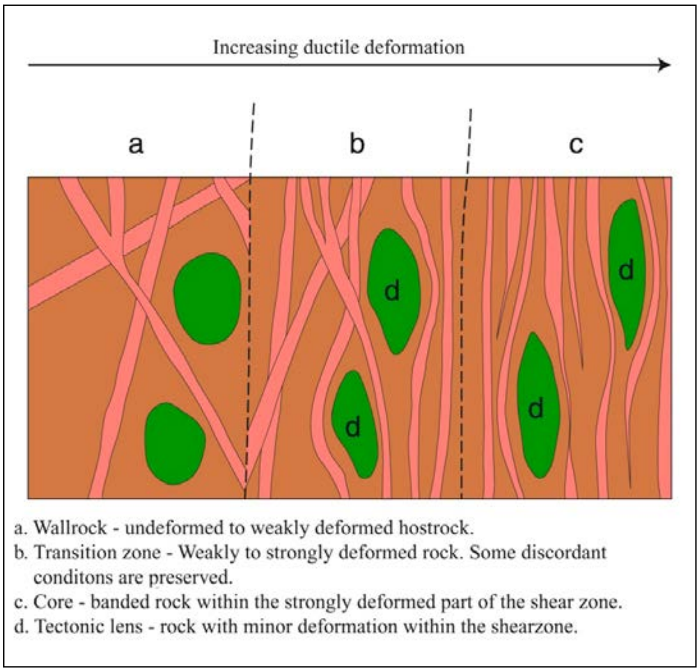


Figure 2-4. *Schematic example of a ductile shear zone. Heterogeneous rock which is deformed under low- to high-grade metamorphic conditions (after Munier et al. 2003).*

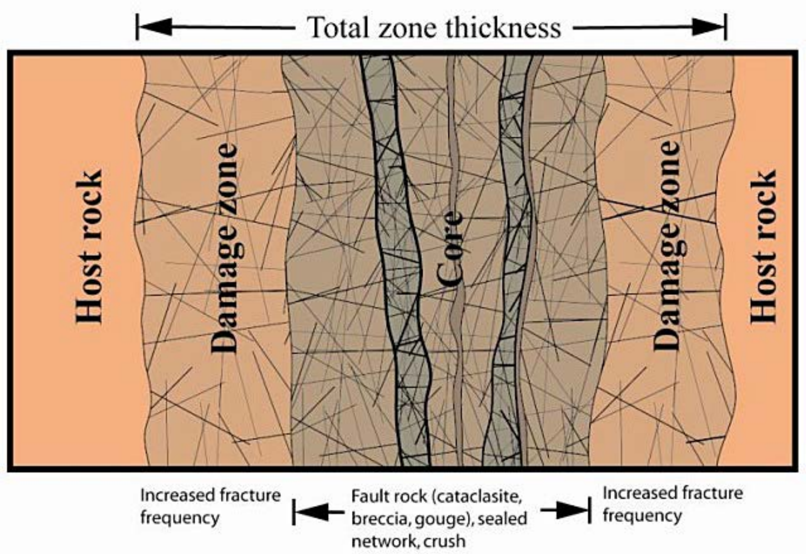


Figure 2-5. *Schematic example of a brittle deformation zone (modified from Munier et al. 2003).*

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 KA2563A, KA2598A and KA3376B01 (Figures 2-6 to 2-8). 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 the diagrams (Figures 2-6 to 2-8).

Observation of the occurrence of radar anomalies was used during the identification of possible deformation zones. 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.

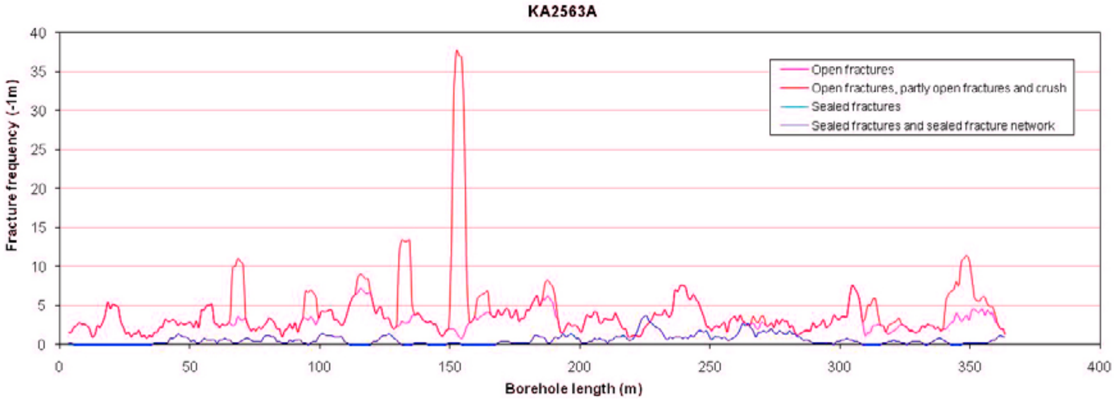


***Figure 2-6.** Fracture frequency plot for KA2563A. Moving average with a 5 m window and 1 m step is used. Open and partly open fractures, sealed fractures and sealed network are presented.*

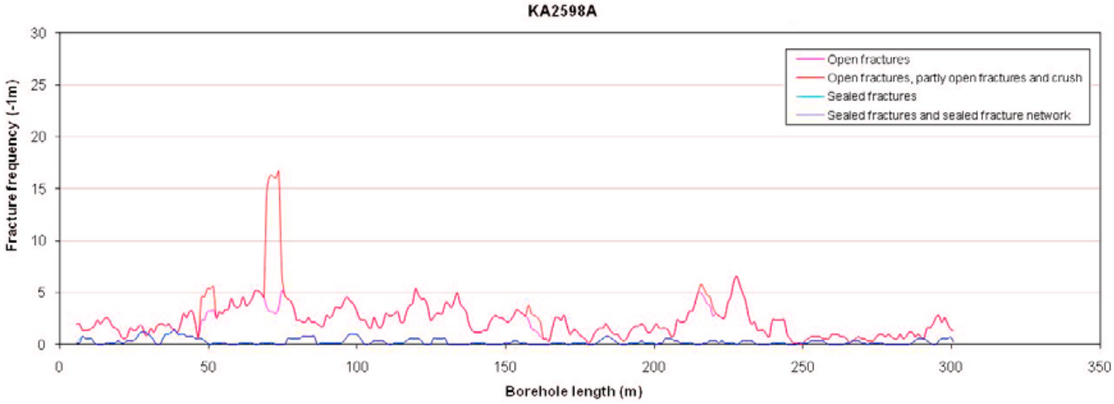


***Figure 2-7.** Fracture frequency plot for KA2598A. Moving average with a 5 m window and 1 m step is used. Open and partly open fractures, sealed fractures and sealed network are presented.*

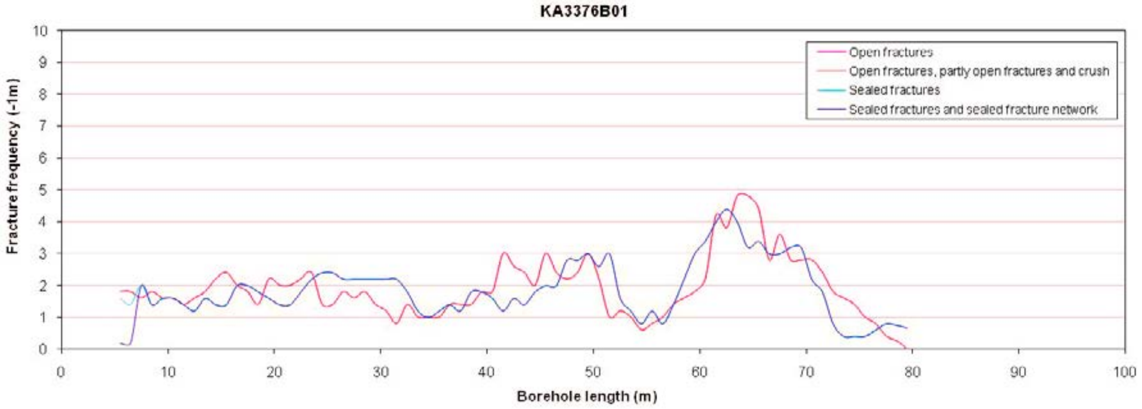


***Figure 2-8.** Fracture frequency plot for KA3376B01. Moving average with a 5 m window and 1 m step is used. Open and partly open fractures, sealed fractures and sealed network are presented.*

2.3 Nonconformities

The geological mapping was initially made with the Petrocore system. In order to evaluate and present the geological data in question for the Single-hole Geological Interpretation (SHI) in a similar way as was done during the Laxemar site investigation (SKB 2009), the Petrocore data was converted into Boremap, except for KA3376B01 which was mapped with Boremap system.

Fracture orientation was not available in the boreholes KA2563A and KA2598A due to lack of the borehole TV (BIPS). This is shown as blank sections in the columns *Open Frac Orientation /Sealed Frac Orientation* and *Broken Frac Orientation/Unbroken Frac Orientation* and as void stereograms in the Appendices. Due to the lack of borehole TV (BIPS) for KA2563A and KA2598A, the geological mapping was solely based on inspection of the drill core. However, borehole KA2563A was logged with BIPS during 1996 but at that time Boremap was not developed or available for mapping.

Geophysical logging was not performed in any of the boreholes KA2563A, KA2598A and KA3376B01.

The borehole radar measurements in KA2563A and KA2598A were made with directional antenna. The alternative orientations have been collected from Sicada and not from the reporting of the measurements. Strike is related to Äspö96 North. Evaluation of borehole radar measurements performed in borehole KA3376B01 has not been carried out. The interpretation of radar reflectors in the report for the boreholes was at that time focused on association with interpretation of deformation zones, i.e. interpretation was made only in selected sections of the borehole.

3 Results

The detailed result of the single-hole interpretation is presented as print-out from the software WellCAD (Appendix 1 for KA2563A, Appendix 2 for KA2598A and Appendix 3 for KA3376B01). Orientations are related to Äspö96 north.

3.1 KA2563A

3.1.1 Rock units

The borehole consists of three rock units (RU1–RU3). However, due to repetition of RU1 (RU1a, RU1b, RU1c, RU1d and RU1e), RU2 (RU2a and RU2b) and RU3 (RU3a and RU3b) the borehole can be divided into nine sections. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

0.00–88.67 m

RU1a: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), sparse occurrence of pegmatite (501061) and very sparse occurrence of gabbroid-dioritoid (508107). Confidence level = 3.

88.67–97.82 m

RU2a: Dominated by fine-grained granite (511058) and to a lesser extent gabbroid-dioritoid (508107). Subordinate rock types comprise Äspö diorite (501037) and very sparse occurrence of pegmatite (501061). Confidence level = 3.

97.82–108.53 m

RU1b: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). Confidence level = 3.

108.53–121.67 m

RU2b: Dominated by fine-grained granite (511058), and to a lesser extent Äspö diorite (501037) and gabbroid-dioritoid (508107). Subordinate rock type comprises sparse occurrence of quartz-dominated hydrothermal vein/segregation. Confidence level = 3.

121.67–288.79 m

RU1c: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), sparse occurrence of pegmatite (501061) and very sparse occurrence of gabbroid-dioritoid (508107). Small-scale, low-grade ductile structures which are oriented ENE-WSW/SE (i.e. sub-parallel to borehole axis) are inhomogeneously distributed along the rock unit. Furthermore, an inhomogeneously distributed foliation occurs. Confidence level = 3.

288.79–295.25 m

RU3a: Totally dominated by fine-grained granite (511058). Subordinate rock type comprises one sparse occurrence of Äspö diorite (501037). Confidence level = 3.

295.25–346.80 m

RU1d: Dominated by Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107) and pegmatite (501061). Confidence level = 3.

346.80–352.51 m

RU3b: Totally dominated by fine-grained granite (511058). Subordinate rock type comprises one thin pegmatite (501061). Confidence level = 3.

352.51–363.43 m

RU1e: Totally dominated by Äspö diorite (501037). Subordinate rock type comprises one very thin occurrence of pegmatite (501061). Confidence level = 3.

3.1.2 Possible deformation zones

Six possible deformation zones have been recognized in KA2563A (DZ1–DZ6). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

55.80–57.16 m

DZ1: Brittle deformation zone characterized by increased frequency of open fractures, sealed fractures (based on inspection of the drillcore during SHI) and oxidation. Low amplitude of direct radar pulse occurs at 55–59 m, i.e. partly outside the deformation zone (DZ). The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

67.88–69.72 m

DZ2: Brittle deformation zone characterized by slightly increased frequency of open fractures, oxidation and one crush at 67.93–69.00 m. One oriented weak and uncertain radar reflector occurs at 69 m with the orientation 166°/79° or 229°/16°. Low amplitude of direct radar pulse occurs at 62–72 m, i.e. partly outside the DZ. The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

108.60–121.62 m

DZ3: Deformation zone characterized by inhomogeneously distributed weak protomylonitic foliation (based on inspection of the drillcore during SHI), slightly increased frequency of open fractures, oxidation and one crush at 116.22–116.55 m. Two oriented radar reflectors of medium strength occur at 111 m and 114 m with the orientation 071°/26° or 124°/78° and 069°/25° or 125°/79°, respectively. Low amplitude of direct radar pulse occurs at 107–110 m, i.e. partly outside the deformation zone (DZ). The host rock is dominated by fine-grained granite (511058) and to a lesser extent by Äspö diorite (501037) and gabbroid-dioritoid (508107). Subordinate rock type comprises sparse occurrence of quartz-dominated hydrothermal vein/segregation.

110.77–112.54 m: Low-grade protomylonitic to mylonitic foliation.

113.50–113.80 m: Intense mylonitic foliation oriented in 046°/30° (according to control of the raw BIPS-data from 1996), direction converted into magnetic north) and 057°/25° according to radar data.

Confidence level = 3.

242.40–246.40 m

DZ4: Deformation zone characterized by inhomogeneously distributed weak to protomylonitic, ductile foliation (based on inspection of the drillcore during SHI), slightly increased frequency of open fractures and oxidation. One oriented radar reflector of medium strength occurs at 244 m with the orientation 041°/74° or 259°/74°. Low amplitude of direct radar pulse occurs at 245-246 m. The host rock is totally dominated by Äspö diorite. Subordinate rock type comprises very sparse occurrence of fine-grained granite (511058). Confidence level = 3.

306.56–318.90 m

DZ5: Low-grade ductile shear zone. The mylonitic foliation is oriented subparallel to borehole axis. One crush occurs at 311.68–312.16 m. One oriented radar reflector of medium strength occurs at 313 m with the orientation 036°/61° or 274°/74°. Low amplitude of direct radar pulse occurs at 301–310 m, i.e. partly outside the deformation zone (DZ). The host rock is dominated by Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107) and sparse occurrence of pegmatite (501061). Confidence level = 3.

342.00–357.43 m

DZ6: Inhomogeneous low-grade ductile shear zone including slightly increased frequency of open fractures. The mylonitic foliation is oriented subparallel to borehole axis. Four crush exist at 342.68–343.06 m, 347.35–348.81 m, 353.80–353.97 m and 357.30–357.40 m. One oriented weak and uncertain radar reflector occurs at 349 m with the orientation 067°/35° or 115°/79°. Low amplitude of direct radar pulse occurs at 343–356 m. The host rock is dominated by Äspö diorite (501037) and to a lesser extent fine-grained granite (511058). Subordinate rock types comprise gabbroid-dioritoid (508107) and very sparse occurrence of pegmatite (501061). Confidence level = 3.

3.2 KA2598A

3.2.1 Rock units

The borehole consists of three rock units (RU1–RU3). However, due to repetition of RU1 (RU1a and RU1b) the borehole can be divided into four sections. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

2.34–47.73 m

RU1a: Dominated by Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107), fine-grained granite (511058) and very sparse occurrence of pegmatite (501061). Confidence level = 3.

47.73–81.77 m

RU2: Dominated by fine-grained granite (511058). Subordinate rock types comprise gabbroid-dioritoid (508107) and sparse occurrence of quartz-dominated hydrothermal vein/segregation (508021). Confidence level = 3.

81.77–244.66 m

RU3: Dominated by Ävrö granodiorite (501056). Subordinate rock types comprise fine-grained granite (511058), sparse occurrence of gabbroid-dioritoid (508107) and very sparse occurrence of pegmatite (501061). The rock unit is inhomogeneously foliated of varying intensity. Confidence level = 3.

244.660–300.770 m

RU1b: Totally dominated by Äspö diorite (501037). Subordinate rock type comprises fine-grained granite (511058). The rock unit is inhomogeneously foliated with varying intensity. Confidence level = 3.

3.2.2 Possible deformation zones

Eight possible deformation zones have been recognized in KA2598A (DZ1–DZ8). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

14.30–14.63 m

DZ1: Brittle deformation zone characterized by increased frequency of open fractures and sealed network (based on inspection of the drillcore during SHI). The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

26.29–26.63 m

DZ2: Brittle-ductile shear zone including sealed network (based on inspection of the drillcore during SHI), slightly increased frequency of open fractures and epidotization. The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

49.20–81.77 m

DZ3: Deformation zone characterized by low-grade shear foliation of varying intensity, sealed network (based on inspection of the drillcore during SHI) and three crush located at 49.72–49.82 m, 71.03–71.58 m and 72.31–72.47 m. One oriented radar reflector of medium strength occurs at 74 m with the orientation 358°/84° or 067°/43°. The host rock is dominated by fine-grained granite (511058). Subordinate rock types comprise gabbroid-dioritoid (508107) and quartz-dominated hydrothermal vein/segregation (508021). Confidence level = 3.

118.40–121.05 m

DZ4: Deformation zone characterized by low-grade shear foliation of varying intensity, sealed network (based on inspection of the drillcore during SHI), slightly increased frequency of open fractures and oxidation. The host rock is dominated by Ävrö granodiorite (501056). Subordinate rock type comprises sparse occurrence of fine-grained granite (511058). Confidence level = 3.

202.07–202.43 m

DZ5: Deformation zone characterized by low-grade ductile to brittle-ductile deformation, slightly increased frequency of open fractures and oxidation. The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

212.83–215.50 m

DZ6: Brittle deformation zone characterized by sealed network (based on inspection of the drillcore during SHI), increased frequency of open fractures and epidotization. The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

228.35–228.95 m

DZ7: Deformation zone characterized by low-grade ductile deformation, increased frequency of open fractures and oxidation. The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

241.35–241.78 m

DZ8: Brittle deformation zone characterized by sealed network (based on inspection of the drillcore during SHI), increased frequency of open fractures and oxidation. The host rock is dominated by fine-grained granite (511058) and to a lesser extent Ävrö granodiorite (501056). Confidence level = 3.

3.3 KA3376B01

3.3.1 Rock units

The borehole consists of one rock unit (RU1). The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

2.28–79.88 m

RU1: Dominated by Äspödiorit (501037). Subordinate rock types comprise hybrid rock (505105), Ävrö granodiorite (501056), gabbroid-dioritoid (508107), pegmatite (501061) and very sparse occurrence of fine-grained granite (511058). Confidence level = 3.

3.3.2 Possible deformation zones

One possible deformation zone has been recognized in KA3376B01 (DZ1). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

2.28–77.85 m

DZ1: Brittle deformation zone characterized by continuous sealed network of varying intensity and weak to strong oxidation. Epidote is the dominant mineral in the sealed network, which locally grades into small-scale brecciation. Fractures filled with calcite are discordant to the sealed network. All the characteristics of the possible deformation zone are based on inspection of the drillcore during SHI. The sub-horizontal borehole is located close to the tunnel TASQ and is drilled in the NE direction (initially a core drilled borehole drilled as pilot borehole for tunnel TASQ). The borehole is drilled entirely inside a deformation zone (DZ).

The host rock is dominated by Äspödiorit (501037). Subordinate rock types comprise hybrid rock (505105), Ävrö granodiorite (501056), gabbroid-dioritoid (508107), pegmatite (501061) and very sparse occurrence of fine-grained granite (511058). Confidence level = 3.

4 Discussion

The geological mapping was initially performed by using the Petrocore system. The Petrocore data was then converted into the Boremap system in order to evaluate and present the geological data in question for the geological single-hole interpretation in a similar way as was performed during the Laxemar site investigation (SKB 2009).

Important input data to the interpretation are the results from the borehole TV (BIPS) measurements in the boreholes, which give the best possible location and true orientation (strike and dip) of fractures intersecting the core drilled borehole, and when fractures also are visible in the drill core a very good observation of the location and orientation of the fractures is given. However, lack of borehole TV (BIPS)-images in KA2563A and KA2598A, inconclusiveness in the geological documentation and lack of certain parameters such as fracture frequency, along with the fact that geophysical logging data did not exist for the boreholes KA2563A, KA2598A and KA3376B01, a full application of the established and complete SHI methodology could not be performed. When borehole TV (BIPS) were lacking the geological mapping was only based on inspection of the drill core.

The borehole radar measurements were performed with the radar directional antenna in boreholes KA2563A and KA2598A. The correlation between radar reflectors and geological structures has been studied elsewhere (see for example Carlsten et al. 1995).

References

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

Carlsten S, Stanfors R, Askling P, Annertz K, 1995. Comparison between borehole radar data and geological parameters from tunnel mapping. SKB HRL Progress Report 25-95-22, Svensk Kärnbränslehantering AB.

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.

SKB, 2008. Site description of Forsmark at completion of the site investigation phase. SDM-Site Forsmark. SKB TR-08-05, Svensk Kärnbränslehantering AB.

SKB, 2009. Site description of Laxemar at completion of the site investigation phase. SDM-Site Laxemar. SKB TR-09-01, Svensk Kärnbränslehantering AB.

Appendices

Geological single-hole interpretation of KA2563A, KA2598A and KA3376B01

The results from the geological single-hole interpretation of KA2563A, KA2598A and KA3376B01 are presented in WellCAD plots (Appendices 1–3). Note that geophysical logging data were not available for the boreholes mentioned above and as well no oriented data on fractures are not available due to that no BIPS measurement were obtained in the boreholes. The WellCAD plots consist of the following columns (Columns with no data is shown as well):

Boremap data	1: Length (length along the borehole).
	2: Rock type.
	3: Rock alteration.
	4: Sealed fractures (frequency).
	5: Open and partly open fractures (frequency).
	6: Crush.
Generalized geophysical data	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 (Wulff projection, blue symbols).
	13: Stereogram for open and partly open fractures in rock unit (Wulff projection, red symbols).
	14: Description: Possible deformation zone
	15: Stereogram for sealed fractures in possible deformation zone (Wulff projection, blue symbols).
	16: Stereogram for open and partly open fractures in possible deformation zone (Wulff projection, red symbols).

Geological single-hole interpretation of KA2563A

Appendix 1

Title SINGLE HOLE INTERPRETATION KA2563A

Site	ÄSPÖ	**Inclination [°]**		**Elevation [m.a.s.l.]**	-340.78
Borehole	KA2563A	**Date of mapping**	1996-08-18 00:00:00	**Drilling Start Date**	1996-08-11 14:33:00
Diameter [mm]	56	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	1996-09-24 15:40:00
Length [m]	363.430	**Northing [m]**	7271.54	**Surveying Date**	
Bearing [°]		**Easting [m]**	2025.57	**Plot Date**	2015-06-08 02:01:34

ROCKTYPE ÄSPÖ
- 🟥 Fine-grained granite 511058
- 🟥 Äspö diorite 501037
- 🟩 Gabbroid-dioritoid 508107

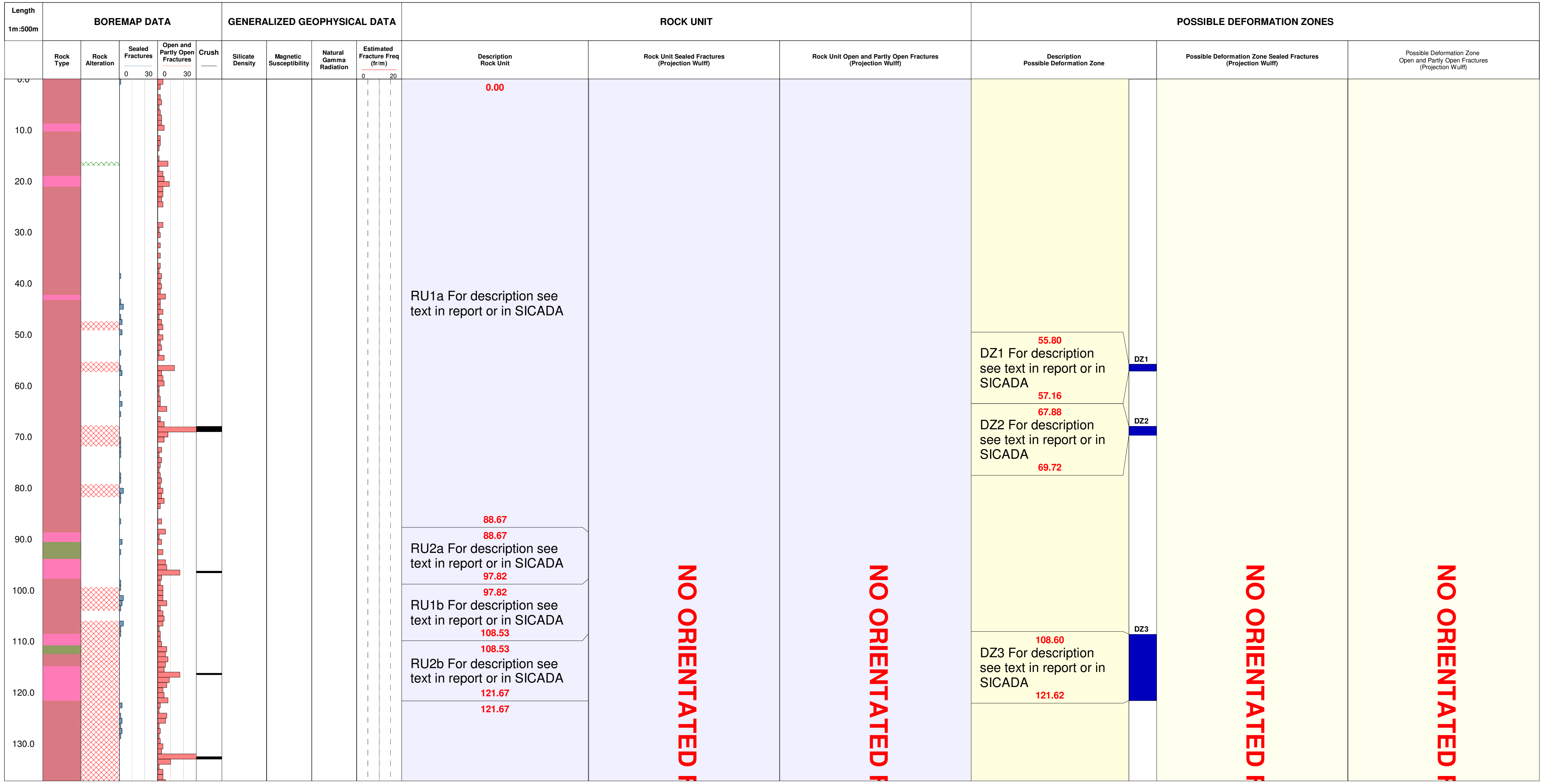
ROCK ALTERATION
- ▨ Oxidized
- ▨ Chloritisized

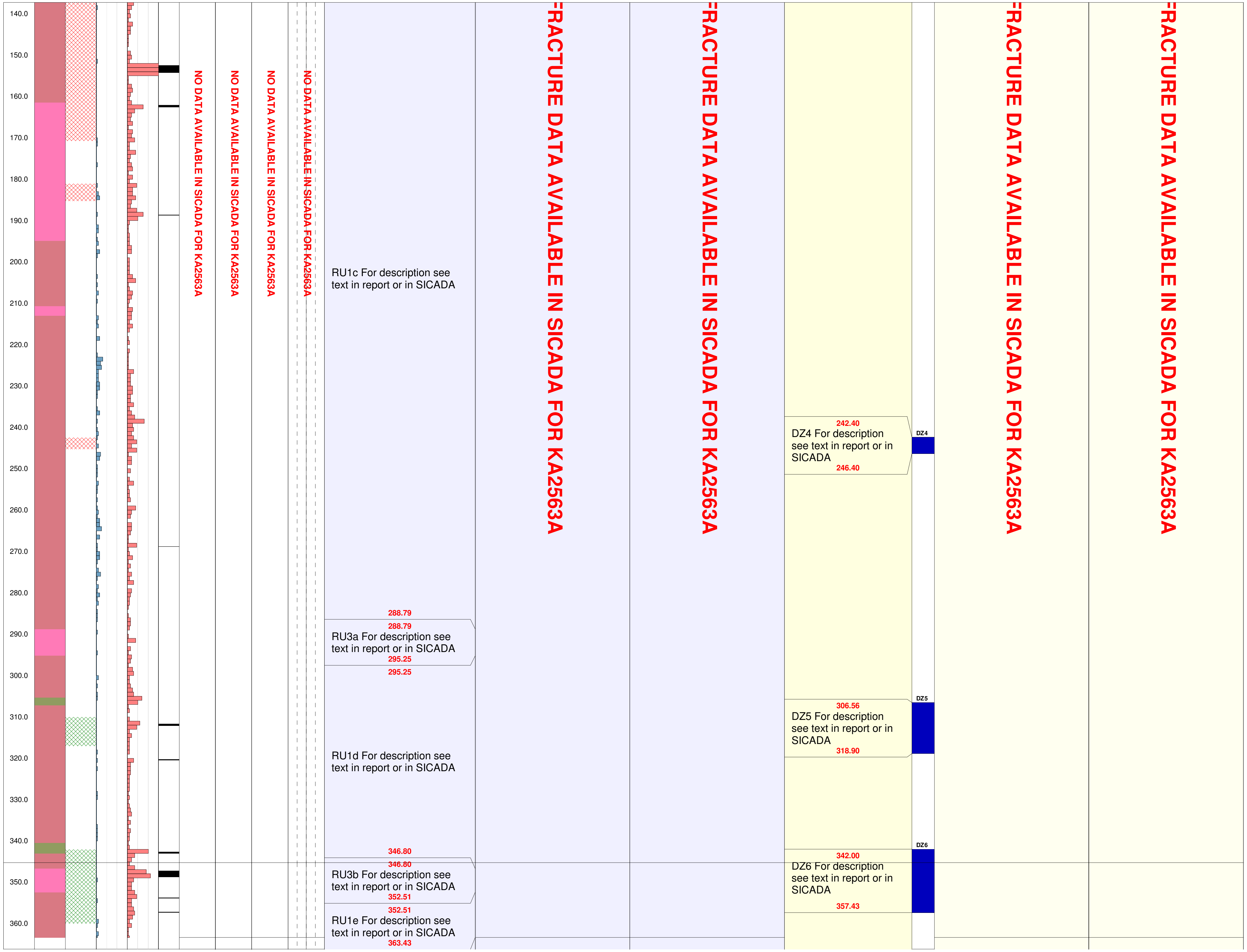
SILICATE DENSITY

SUSCEPTIBILITET

NATURAL GAMMA

DZ CONFIDENCE
- 🟦 Confidence 3

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320.0
330.0
340.0
350.0
360.0
NO DATA AVAILABLE IN SICADA FOR KA2563A
NO DATA AVAILABLE IN SICADA FOR KA2563A
NO DATA AVAILABLE IN SICADA FOR KA2563A
NO DATA AVAILABLE IN SICADA FOR KA2563A
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RU3a For description see text in report or in SICADA
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RU1e For description see text in report or in SICADA
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DZ4
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DZ5 For description see text in report or in SICADA
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DZ5
342.00
DZ6 For description see text in report or in SICADA
357.43
DZ6
FRACTURE DATA AVAILABLE IN SICADA FOR KA2563A
FRACTURE DATA AVAILABLE IN SICADA FOR KA2563A

Appendix 2

Geological single-hole interpretation of KA2598A

Title	SINGLE HOLE INTERPRETATION KA2598A							**SIGNED DATA**	YES
Site	ÄSPÖ	**Inclination [°]**	-32.14	**Elevation [m.a.s.l.]**	-342.36	**Strike Reference**	ÄSPÖ96		
Borehole	KA2598A	**Date of mapping**	1993-10-01 00:00:00	**Drilling Start Date**	1993-08-24 14:45:00	**Made By**	PKM		
Diameter [mm]	56	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	1993-09-28 17:42:00				
Length [m]	300.770	**Northing [m]**	7303.93	**Surveying Date**					
Bearing [°]	280.78	**Easting [m]**	2035.03	**Plot Date**	2014-04-29 02:01:10				

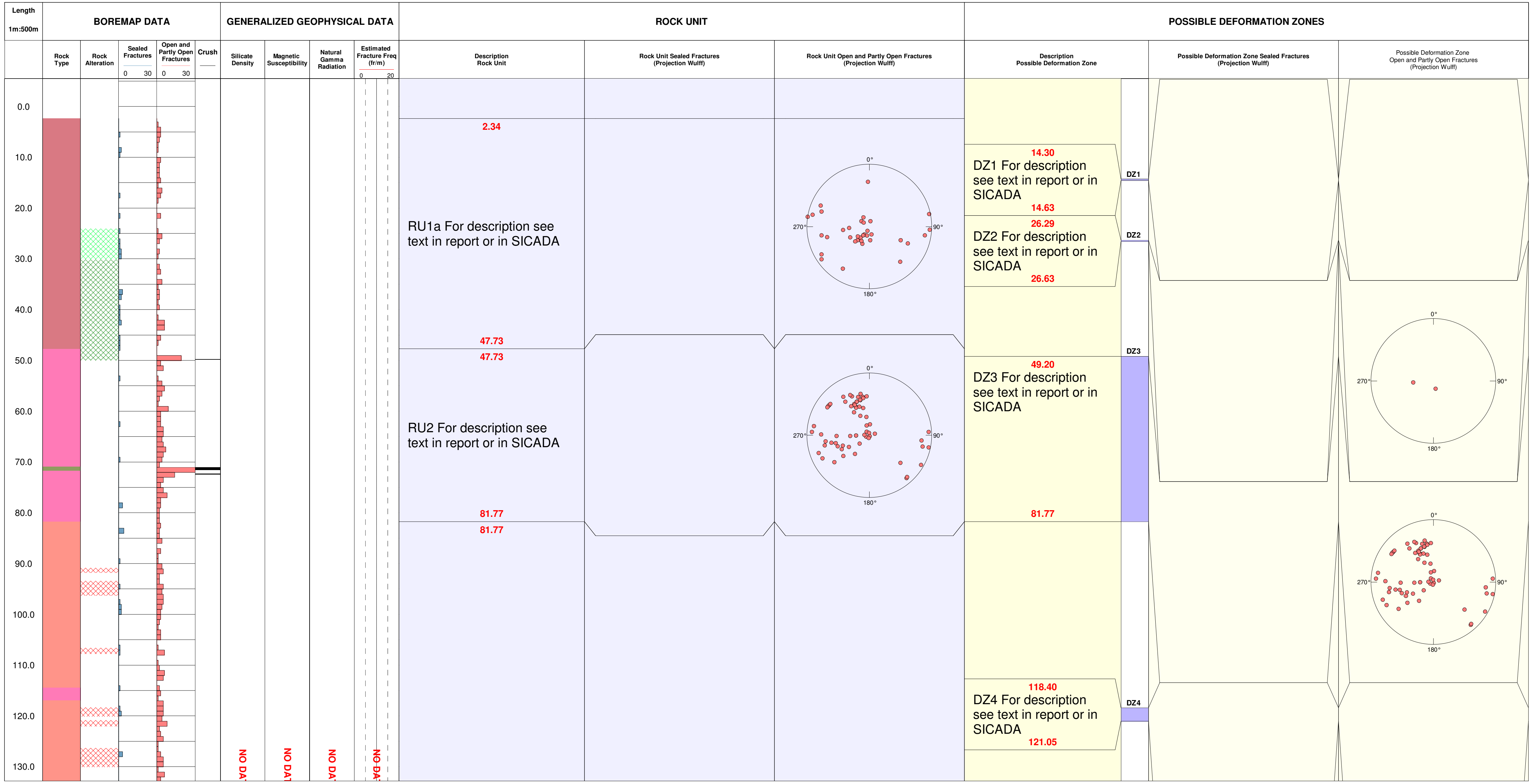
ROCKTYPE ÄSPÖ
- Fine-grained granite 511058
- Ävrö granodiorite 501056
- Äspö diorite 501037
- Gabbroid-dioritoid 508107

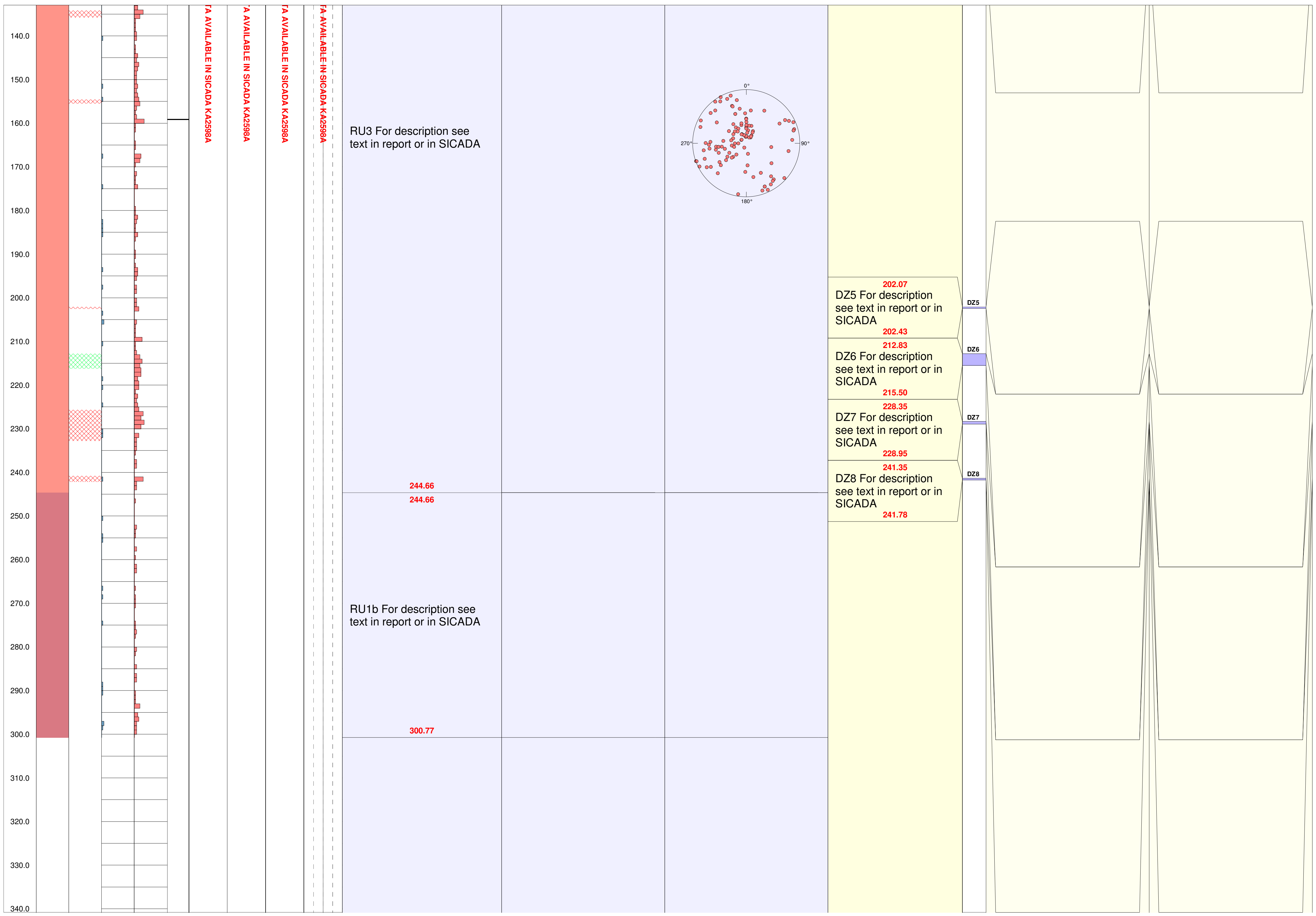
ROCK ALTERATION
- ▨ Oxidized
- ▨ Chloritisized
- ▨ Epidotisized

SILICATE DENSITY

SUSCEPTIBILITY

NATURAL GAMMA

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330.0
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TA AVAILABLE IN SICADA KA2598A
A AVAILABLE IN SICADA KA2598A
TA AVAILABLE IN SICADA KA2598A
TA AVAILABLE IN SICADA KA2598A
RU3 For description see text in report or in SICADA
244.66
244.66
RU1b For description see text in report or in SICADA
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90°
180°
270°
202.07
DZ5 For description see text in report or in SICADA
202.43
212.83
DZ6 For description see text in report or in SICADA
215.50
228.35
DZ7 For description see text in report or in SICADA
228.95
241.35
DZ8 For description see text in report or in SICADA
241.78
DZ5
DZ6
DZ7
DZ8

Appendix 3

Geological single-hole interpretation of KA3376B01

Title	SINGLE HOLE INTERPRETATION KA3376B01					**SIGNED DATA**	YES
Site	ÄSPÖ	**Inclination [°]**	-0.89	**Elevation [m.a.s.l.]**	-445.47	**Strike Reference**	ÄSPÖ96
Borehole	KA3376B01	**Date of mapping**	2002-12-13 00:00:00	**Drilling Start Date**	2002-11-08 15:22:00	**Made By**	PKM
Diameter [mm]	76	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	2002-11-26 15:39:00		
Length [m]	80.190	**Northing [m]**	6367810.22	**Surveying Date**			
Bearing [°]	33.72	**Easting [m]**	1551377.11	**Plot Date**	2014-02-02 03:03:40		

ROCKTYPE ÄSPÖ

🟥 Äspö diorite 501037

🟪 Hybrid rock 505105

ROCK ALTERATION

▨ Oxidized

SILICATE DENSITY

SUSCEPTIBILITY

NATURAL GAMMA