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Äspö site descriptive model

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Abstract

This report presents the outcome from geological single-hole interpretation of the core drilled boreholes KA2050A, KA2162B and KA2511A 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 boreholes.

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 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, in the boreholes KA2050A, KA2162B and KA2511A, a complete geological single-hole interpretation as was made in the Laxemar site investigations (SKB 2009) could not performed.

The borehole radar measurements in KA2050A, KA2162B and KA2511A 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 KA2050A in the Äspö HRL tunnel is dominated by Ävrö granodiorite (501056). Gabbroid-dioritoid (508107) and fine-grained granite (511058) occur also in larger sections in the borehole. Subordinate rock types comprise occurrence of pegmatite (501061), breccia (508002) and quartz-dominated hydrothermal vein/segregation (508021). Three possible deformation zones are identified in KA2050A (DZ1–DZ3).

The geological single-hole interpretation shows that the borehole KA2162B in the Äspö HRL tunnel is dominated by Äspö diorite (501037). One large section with fine-grained granite (511058) occur also in the borehole. Subordinate rock types comprise occurrence of pegmatite (501061), gabbroid-dioritoid (508107) and very sparse occurrence of quartz-dominated hydrothermal vein/segregation (508021). Five possible deformation zones are identified in KA2162B (DZ1–DZ5).

The geological single-hole interpretation shows that the borehole KA2511A in the Äspö HRL tunnel is dominated by Äspö diorite (501037). One large section with fine-grained granite (511058) occurs also in the borehole. Subordinate rock types comprise sparse occurrence of pegmatite (501061) and gabbroid-dioritoid (508107). Three possible deformation zones are identified in KA2511A (DZ1–DZ3).

Sammanfattning

Denna rapport behandlar geologisk enhålstolkning av kärnborrhålen KA2050A, KA2162B och KA2511A 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 i the borrhålen KA2050A, KA2162B and KA2511A, genomfördes inte en komplett geologisk enhålstolkning på det sätt den genomfördes under platsundersökningarna i Laxemar (SKB 2009).

Borrhålsradar genomfördes i borrhålen KA2050A, KA2162B och KA2511A med radar riktantenn och utvärderingen och tolkningen av radardata genomfördes manuellt med fristående program och i olika steg.

Den geologiska enhålstolkningen visar att kärnborrhålet KA2050A i Äspötunneln domineras av Ävrögranodiorit (501056). Gabbroid-dioritoid (508107) och finkornig granit (511058) förekommer i större sektioner i borrhålet. Underordnade bergarter utgörs av pegmatit (501061), breccia (508002) och kvartsdominerad hydrotermal gång/segregation (508021). Tre möjliga deformationszoner har identifierats i KA2050A (DZ1–DZ3).

Den geologiska enhålstolkningen visar att kärnborrhålet KA2162B i Äspötunneln domineras av Äspödiorit (501037). En större sektion med finkornig granit (511058) förekommer i borrhålet. Underordnade bergarter utgörs av pegmatit (501061), gabbroid-dioritoid (508107) och mycket sparsam förekomst av kvartsdominerad hydrotermal gång/segregation (508021). Fem möjliga deformationszoner har identifierats i KA2162B (DZ1–DZ5).

Den geologiska enhålstolkningen visar att kärnborrhålet KA2511A i Äspötunneln domineras av Äspödiorit (501037). En större sektion med finkornig granit (511058) förekommer i borrhålet. Underordnade bergarter utgörs av små förekomster av pegmatit (501061) och gabbroid-dioritoid (508107). Tre möjliga deformationszoner har identifierats i KA2511A (DZ1–DZ3).

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1 Introduction

1.1 Background

To support predictions and planning of experiments performed in 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 input from 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 the boreholes, which give the best possible location and true orientation (strike and dip) of the fractures intersecting the borehole and where the fractures are also visible in the core the orientation and grade of openness of the fractures can be estimated. However, due to the 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 KA2050A, KA2162B and KA2511A, complete input data for the geological single hole interpretation is not available as for 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 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 borehole radar data together with inspection of the available drill cores 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 KA2050A, KA2162B and KA2511A 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 F140-10-027. 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. 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
Geologisk enhålstolkning av KA2050A, KA2162B och KA2511A	AP TD F140-10-027	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 KA2050A, KA2162B and KA2511A in the Äspö HRL 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 KA2050A, KA2162B and KA2511A located in the Äspö HRL tunnel. The geological single-hole interpretation (SHI) is part of the work for the Äspö Site descriptive model SDM. The aim of the work is from data from geological core mapping and borehole radar measurements identify different rock unit distributions in the boreholes and to identify possible deformation zones location and distribution 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 KA2050A, KA2162B and KA2511A. The methodology for geological single-hole interpretation has been developed during the site investigations in 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 within 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 KA2050A, KA2162B and KA2511A:

- Boremap data converted to Boremap from geological mapping initially performed in Petrocore (SKB 1994).
- Radar data and their interpretation (Carlsten et al. 1995).

Note that geophysical logs as described in the example from KAS02 were not available in the boreholes KA2050A, KA2162B and KA2511A.

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 of seven main columns and several subordinate columns. Note that Figure 2-1 only serves as an example and that minor differences in the content of the columns between different boreholes might occur. The columns in Figure 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 < 1m	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

The geophysical logs as described in the example from KAS02 (were not available in the boreholes KA2050A, KA2162B and KA2511A) 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.

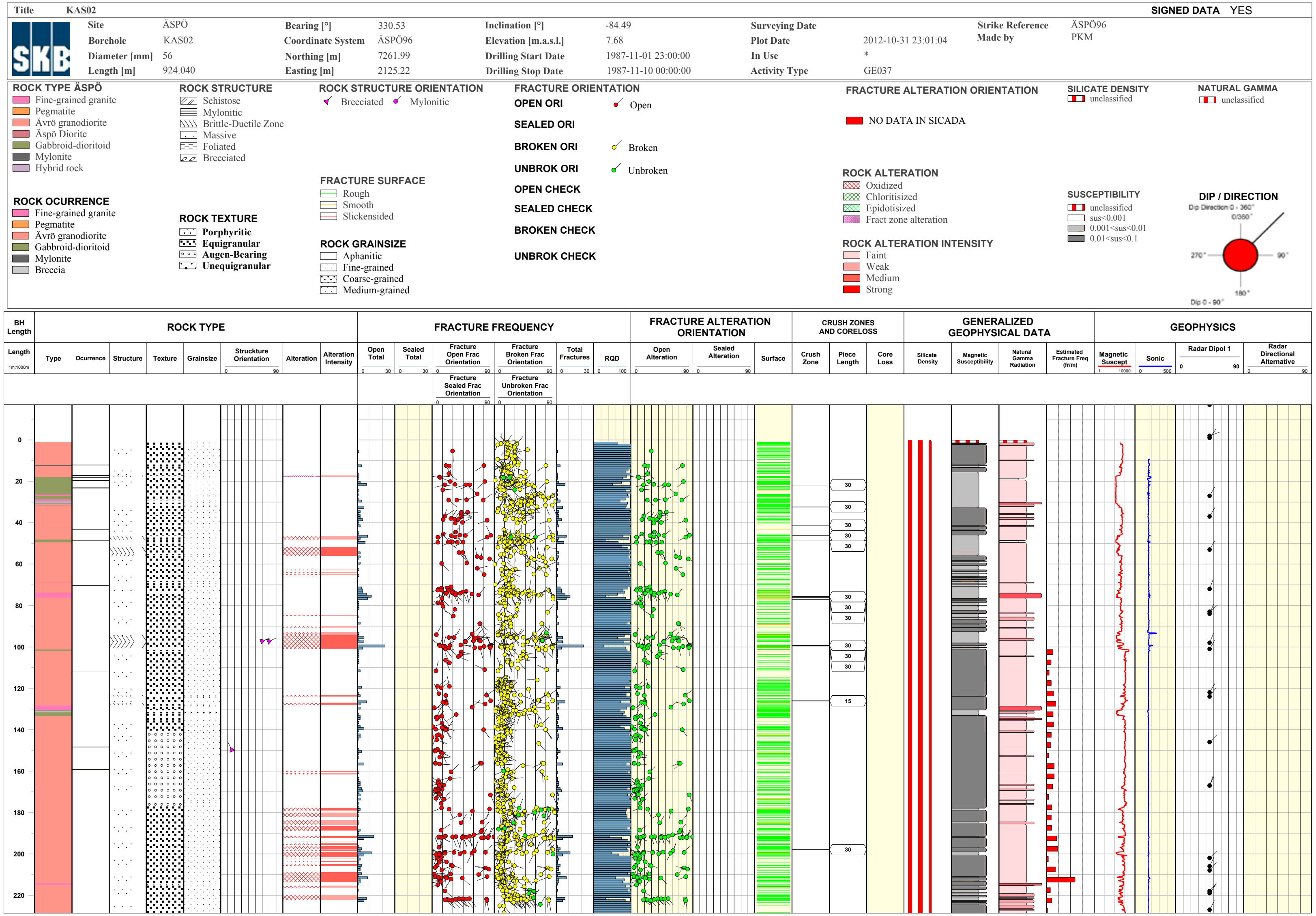

Figure 2-1. *Example of WellCAD plot (from borehole KAS02 at Äspö) used as a basis for the geological single-hole interpretation.*

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

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, were not available for the boreholes KA2050A, KA2162B and KA2511A. A minimum length of about 5 m was used for rock units in the geological single-hole interpretations during the site investigations at Forsmark (SKB 2008) and Laxemar (SKB 2009). This minimum length was generally 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 provided with a brief description. 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. Each identified possible deformation zone is performed by visual inspection of the results of the geological mapping (fracture frequency, fracture mineral, aperture, alteration, etc.) in combination with the 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 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.

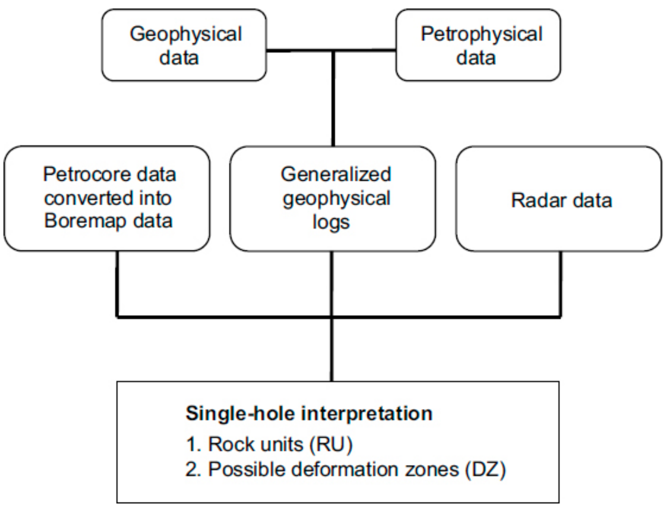

Figure 2-2. *Schematic block-scheme for data used in the geological single-hole interpretation.*

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 (Figures 2-3 to 2-5).

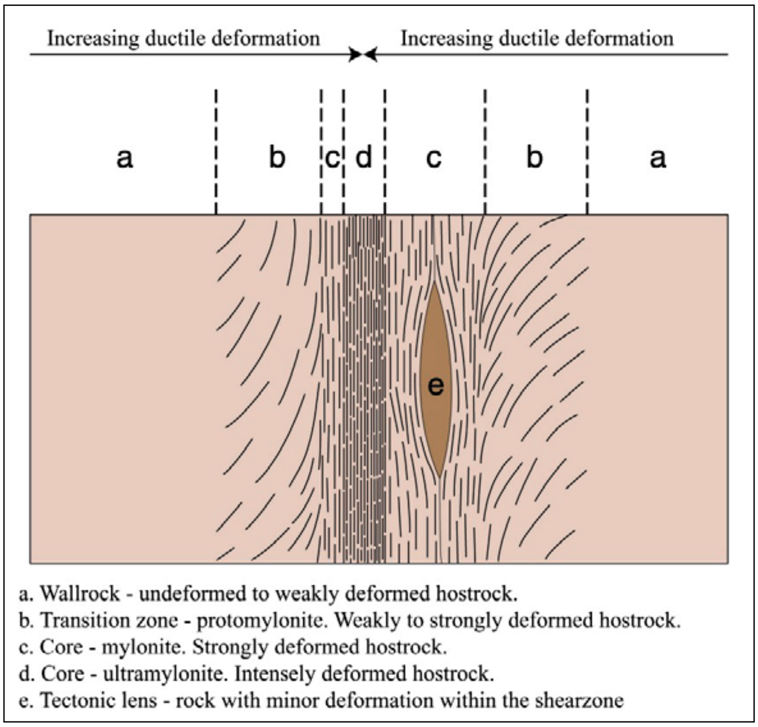

Figure 2-3. *Schematic example of a ductile shear zone. Homogeneous rock which is deformed under low- to medium-grade metamorphic conditions (after Munier et al. 2003).*

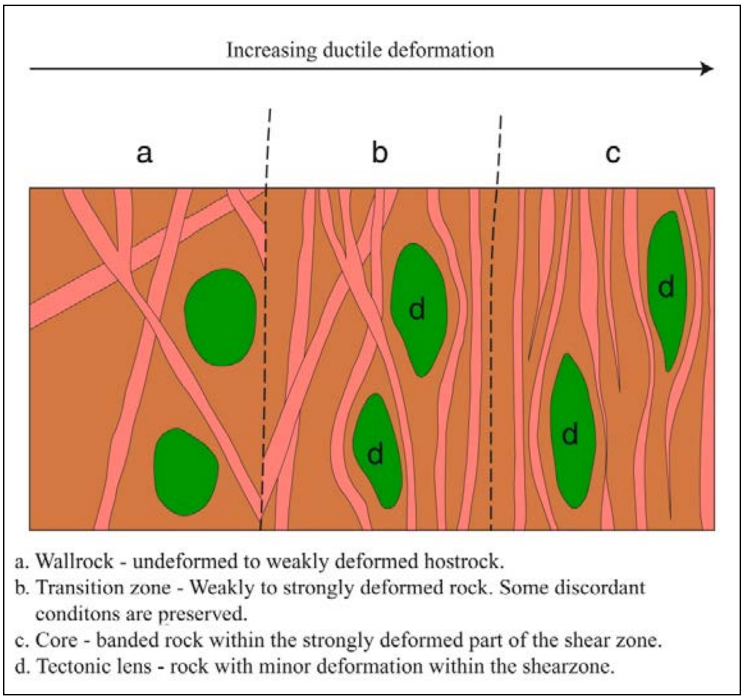

Figure 2-4. *Schematic example of a ductile shear zone. Heterogeneous rock which is deformed under low- to high-grade metamorphic conditions (after Munier et al. 2003).*

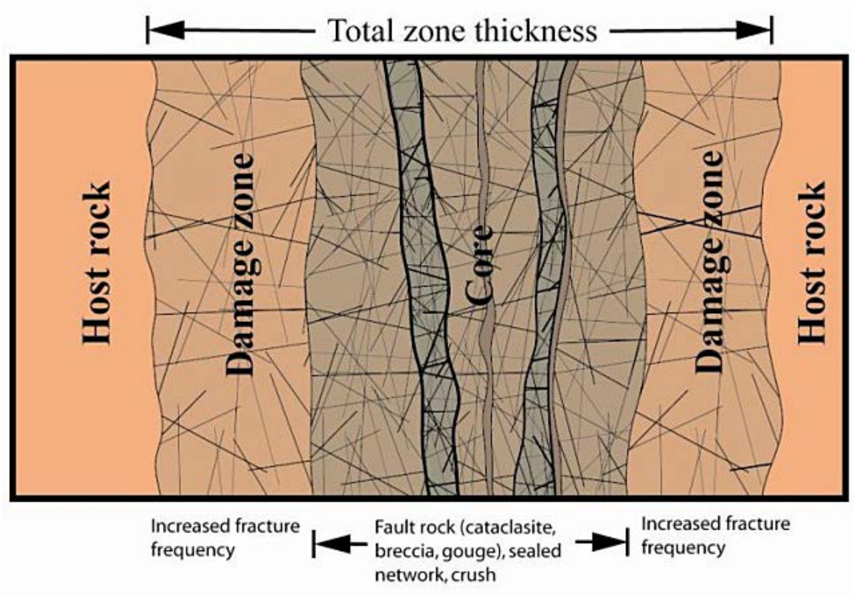

Figure 2-5. *Schematic example of a brittle deformation zone (modified from Munier et al. 2003).*

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.

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 KA2050A, KA2162B and KA2511A (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.

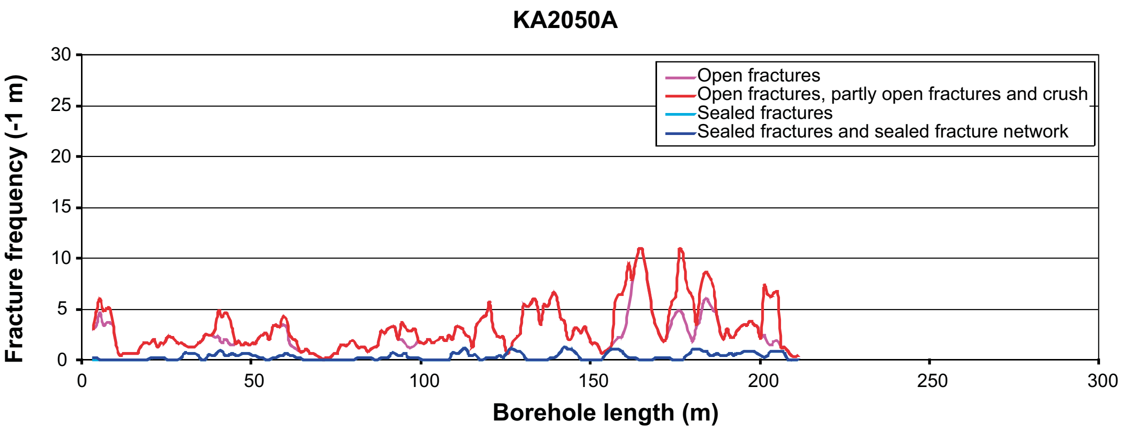

Figure 2-6. *Fracture frequency plot for KA2050A. Moving average with a 5 m window and 1 m steps.*

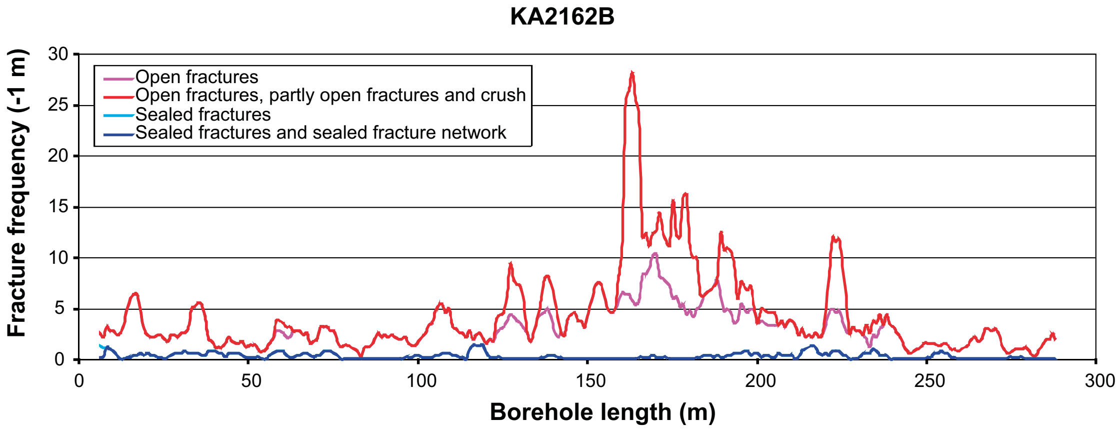

Figure 2-7. Fracture frequency plot for KA2162B. Moving average with a 5 m window and 1 m steps.

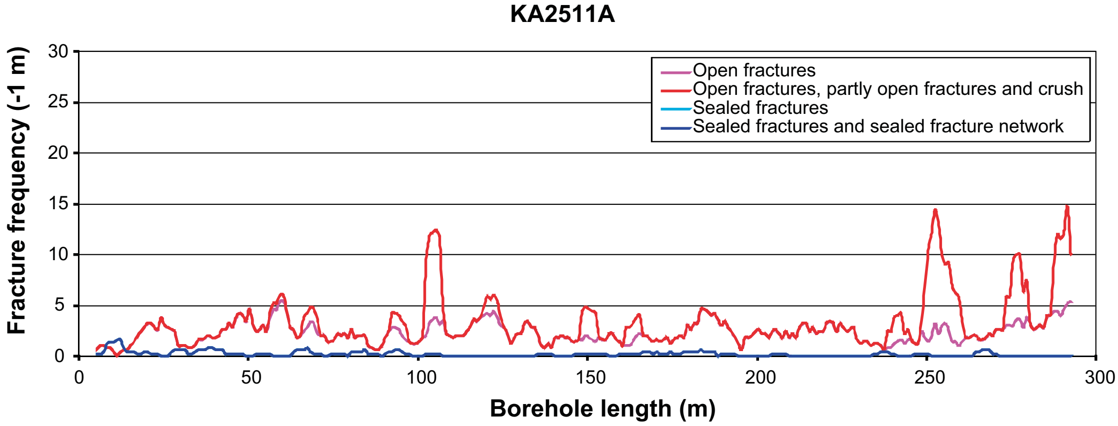

Figure 2-8. Fracture frequency plot for KA2511A. Moving average with a 5 m window and 1 m steps.

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 SHI in a similar way as during the Laxemar site investigation (SKB 2009), the Petrocore data was converted into Boremap.

Fracture orientation was not available in the boreholes KA2050A and KC0045F. 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.

Borehole TV (BIPS) was not available at the time for measurements of the boreholes, and therefore, the geological mapping was solely based on inspection of the drill core. However, borehole KA2511A was logged with BIPS during 1997 but at that time Boremap was not developed or available for mapping.

Geophysical logging was not performed in the underground boreholes KA2050A, KA2162B and KA2511A.

The borehole radar measurements in KA2050A, KA2162B and KA2511A were performed 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. 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 KA2050A, Appendix 2 for KA2162B and Appendix 3 for KA2511A). Orientations are related to Äspö96 North.

3.1 KA2050A

3.1.1 Rock units

The borehole consists of three rock units (RU1–RU3). However, due to repetition of RU1 (RU1a and RU1b), RU2 (RU2a, RU2b, RU2c and RU2d) and RU3 (RU3a and RU3b) the borehole can be divided into eight sections. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

0.00–7.37 m

RU1a: Totally dominated by fine-grained granite (511058). Subordinate rock type comprises one occurrence of pegmatite (501061). Confidence level = 3.

7.37–143.01 m

RU2a: Dominated by Ävrö granodiorite (501056). Subordinate rock types comprise fine-grained granite (511058), quartz-dominated hydrothermal vein/segregation (508021) and one thin pegmatite (501061) in the upper half of the rock unit. Confidence level = 3.

143.01–153.69 m

RU3a: Dominated by gabbroid-dioritoid (508107) and to a lesser extent fine-grained granite (511058). Subordinate rock type comprises sparse occurrence of quartz-dominated hydrothermal vein/segregation (508021). Confidence level = 3.

153.69–162.03 m

RU2b. Totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

162.03–169.86 m

RU1b: Totally dominated by fine-grained granite (511058). Confidence level = 3.

169.86–187.44 m

RU2c: Dominated by Ävrö granodiorite (501056). Subordinate rock type comprises gabbroid-dioritoid (508107) and breccia (508002). Confidence level = 3.

187.44–197.76 m

RU3b: Dominated by gabbroid-dioritoid (508107) and to a lesser extent Ävrö granodiorite (501056). Subordinate rock type comprises sparse occurrence of fine-grained granite (511058). Confidence level = 3.

197.76–211.57 m

RU2d: Totally dominated by Ävrö granodiorite (501056). Subordinate rock type comprises sparse occurrence of fine-grained granite (511058). Confidence level = 3.

3.1.2 Possible deformation zones

Three possible deformation zones have been recognized in KA2050A (DZ1–DZ3). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

109.50–109.88 m

DZ1: Low-grade ductile shear zone. The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

178.32–178.90 m

DZ2: Low-grade ductile shear zone with oxidation and overprinted by one crush at 178.32–178.73 m. One oriented weak radar reflector occurs at 178 m with the orientation 234°/45° or 100°/77°. Host rock is dominated by gabbroid-dioritoid (508107) and to a lesser extent Ävrö granodiorite (501056). Confidence level = 3.

183.25–186.60 m

DZ3: Brittle deformation zone characterized by increased frequency of open fractures, oxidation, breccia, inhomogeneously distributed sealed network (based on inspection of the drillcore during SHI) and one crush located at 183.96–184.58 m. One oriented weak radar reflector occurs at 187 m, which is immediately outside DZ3, with the orientation 237°/27° or 118°/76°. Host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

3.2 KA2162B

3.2.1 Rock units

The borehole consists of two rock units (RU1–RU2). However, due to repetition of RU1 (RU1a, RU1b and RU1c) 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.

3.60–12.08 m

RU1a: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise sparse occurrence of pegmatite (501061) and very sparse occurrence of gabbroid-dioritoid (508107). Confidence level = 3.

12.08–124.74 m

RU1b: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and pegmatite (501061). Confidence level = 3.

124.74–181.23 m

RU2: Totally dominated by fine-grained granite (511058). Confidence level = 3.

181.23–288.10 m

RU1c: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107), pegmatite (501061) and very sparse occurrence of quartz-dominated hydrothermal vein/segregation (508021). Confidence level = 3.

3.2.2 Possible deformation zones

Five possible deformation zones have been recognized in KA2162B (DZ1–DZ5). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

113.25–113.56 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.

128.91–129.24 m

DZ2: Brittle deformation zone characterized by one crush at 128.91–129.24 m. One oriented radar reflector of medium strength occurs at 129 m with the orientation 140°/68° or 063°/49°. The host rock is totally dominated by fine-grained granite (511058). Confidence level = 3.

161.10–200.96 m

DZ3: The deformation zone has been divided in two parts based on inspection of drillcore during SHI. Confidence level = 3.

161.10–181.23 m – damage zone: Increased frequency of open fractures, oxidation and nine crush which in total constitute 3.86 m. Two oriented radar reflectors of medium strength occur at 165 m and 171 m with the orientation 322°/14° or 198°/41° and 318°/87° or 053°/73°, respectively. Decreased radar amplitude occurs in the section 179–195 m. The host rock is totally dominated by fine-grained granite (511058).

181.23–200.96 m – core: Inhomogeneously distributed low-grade mylonitic foliation, increased frequency of open fractures, sealed network (based on inspection of the drillcore during SHI), oxidation and two crush located at 191.42–191.99 m and 196.08–196.39 m. The most intensely deformed section is 191.12–192.20 m and is characterized by low-grade mylonitic foliation. Three oriented weak radar reflectors occur, one reflector located at 182 m with the orientation 289°/48° or 239°/61°, one located at 186 m with the orientation 138°/76° or 061°/57° and another located at 190 m with the orientation 140°/77° or 058°/57°. One oriented strong radar reflector occurs at 198 m with the orientation 288°/48° or 240°/60°. Decreased radar amplitude occurs in the section 179–195 m. The host rock is dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and very sparse occurrence of quartz-dominated hydrothermal vein/segregation (508021).

223.72–224.48 m

DZ4: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and one crush at 223.82–224.33 m. The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

237.00–237.29 m

DZ5: Brittle deformation zone characterized by one crush at 237.00–237.29 m. The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

3.3 KA2511A

3.3.1 Rock units

The borehole consists of three rock units (RU1–RU3). The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

2.95–214.24 m

RU1: 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.

214.24–226.83 m

RU2: Totally dominated by fine-grained granite (511058). Subordinate rock type comprises gabbroid-dioritoid (508107). Confidence level = 3.

226.83–293.00 m

RU3: Dominated by Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107) in the section 250.100–253.610 m and sparse occurrence of pegmatite (501061). Confidence level = 3.

3.3.2 Possible deformation zones

Three possible deformation zones have been recognized in KA2511A (DZ1–DZ3). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

82.20–82.37 m

DZ1: Low-grade brittle-ductile shear zone with sealed network (based on inspection of the drillcore during SHI). The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

103.90–106.18 m

DZ2: Brittle deformation zone characterized by slightly increased frequency of open fractures and one crush at 104.31–105.15 m overprinting an inhomogeneous protomylonitic foliation. One oriented weak radar reflector occurs at 106 m with the orientation 165°/78° or 259°/22°. Host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

250.05–258.40 m

DZ3: Brittle deformation zone characterized by inhomogeneously distributed sealed network (based on inspection of the drillcore during SHI) and four crush located at 250.74–253.29 m, 254.51–254.63 m, 254.94–255.16 m and 257.47–258.40 m. One uncertain oriented radar reflector occurs at 259 m, i.e. outside, but very close to DZ3, with the orientation 352°/69° or 292°/50°. The host rock is slightly dominated by Äspö diorite (501037) but is composed of almost equal amount of gabbroid-dioritoid (508107). Confidence level = 3.

4 Discussion

The geological mapping was initially performed with the Petrocore system. The Petrocore data was 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 performed during the Laxemar site investigation (SKB 2009).

Important input data are the results from the borehole TV (BIPS) investigation of 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, 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 KA2050A, KA2162B and KA2511A, is too sparse to allow the full application of the established and complete SHI methodology. When borehole TV (BIPS) was not available the geological mapping was only based on inspection of the drill core.

The borehole radar measurements were performed with the directional antenna in boreholes KA2050A, KA2162B and KA2511A. 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.

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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 KA2050A, KA2162B and KA2511A

The results from the geological single-hole interpretation of KA2050A, KA2162B and KA2511A are presented in WellCAD plots (Appendices 1 to 3). The WellCAD plots consist of the following columns, note that geophysical logging data not were available for the boreholes KA2050A, KA2162B and KA2511A:

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 KA2050A

Appendix 1

Title SINGLE HOLE INTERPRETATION KA2050A

Site	ÄSPÖ	**Inclination [°]**	-53.49	**Elevation [m.a.s.l.]**	-275.78
Borehole	KA2050A	**Date of mapping**	1993-11-10 00:00:00	**Drilling Start Date**	1993-10-26 20:12:00
Diameter [mm]	56	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	1993-11-02 09:14:00
Length [m]	211.570	**Northing [m]**	7335.25	**Surveying Date**	
Bearing [°]	55.30	**Easting [m]**	2331.89	**Plot Date**	2015-06-08 02:01:34

ROCKTYPE ÄSPÖ
- Fine-grained granite 511058
- Ävrö granodiorite 501056
- Gabbroid-dioritoid 508107
- Breccia 508002

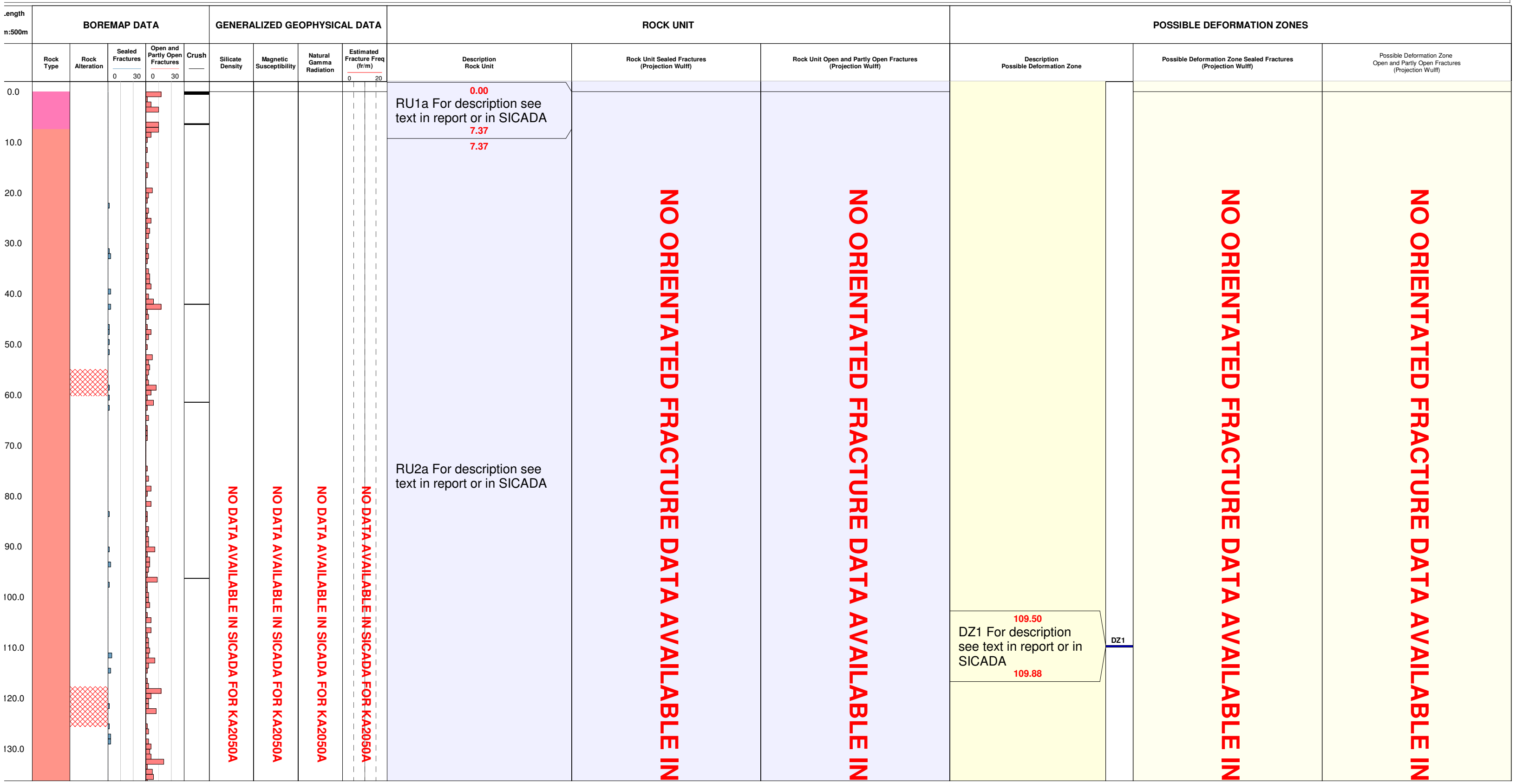
ROCK ALTERATION
- Oxidized

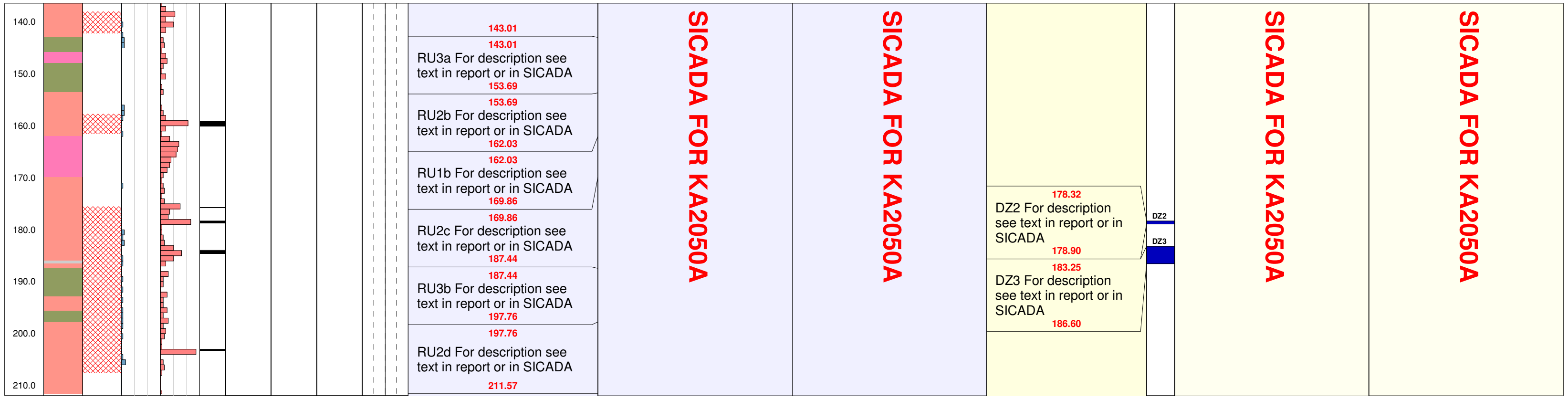
SILICATE DENSITY

SUSCEPTIBILITET

NATURAL GAMMA

DZ CONFIDENCE
- Confidence 3

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SICADA FOR KA2050A
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DZ3 For description see text in report or in SICADA
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DZ2
DZ3
SICADA FOR KA2050A
SICADA FOR KA2050A

Geological single-hole interpretation of KA2162B

Appendix 2

Title	**SINGLE HOLE INTERPRETATION KA2162B**				
Site	ÄSPÖ	**Inclination [°]**	-15.19	**Elevation [m.a.s.l.]**	-289.86
Borehole	KA2162B	**Date of mapping**	1995-04-04 00:00:00	**Drilling Start Date**	1993-03-13 21:51:00
Diameter [mm]	56	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	1993-04-01 15:01:00
Length [m]	288.100	**Northing [m]**	7225.04	**Surveying Date**	
Bearing [°]	272.20	**Easting [m]**	2296.40	**Plot Date**	2015-06-08 02:01:34

ROCKTYPE ÄSPÖ
- Fine-grained granite 511058
- Pegmatite 501061
- Äspö diorite 501037
- Gabbroid-dioritoid 508107

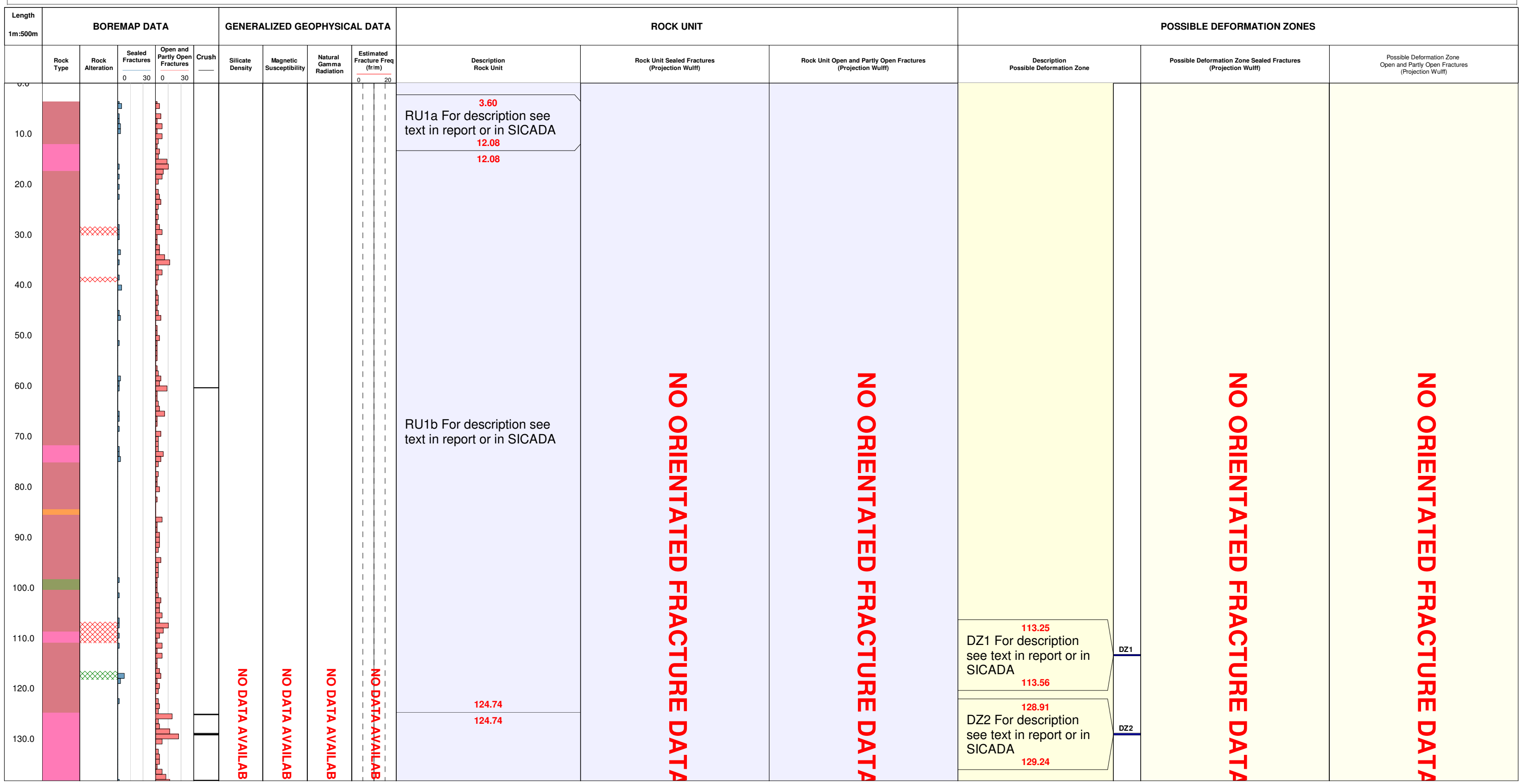
ROCK ALTERATION
- Oxidized
- Chloritisized

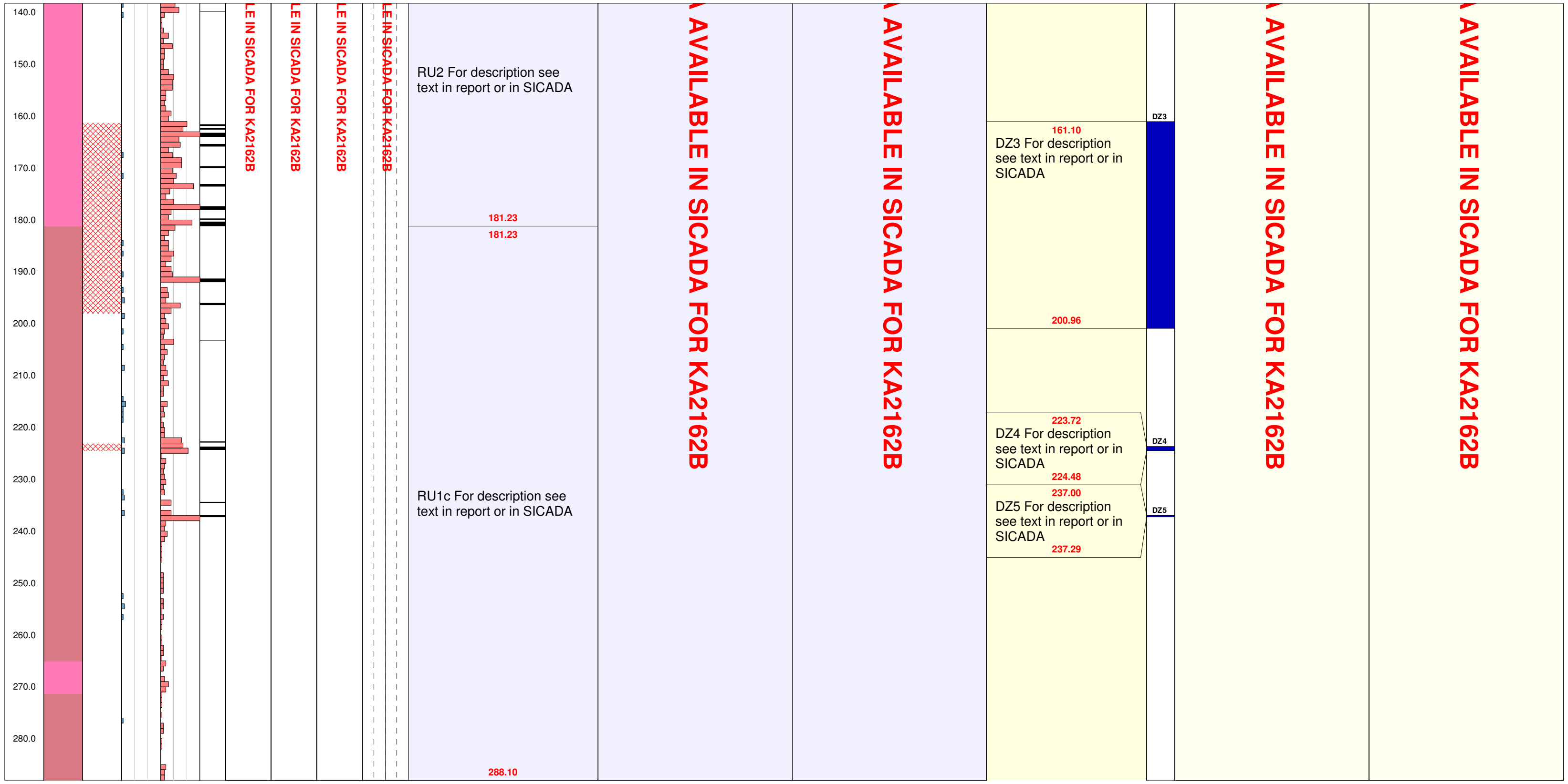
SILICATE DENSITY

SUSCEPTIBILITET

NATURAL GAMMA

DZ CONFIDENCE
- Confidence 3

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RU2 For description see text in report or in SICADA
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RU1c For description see text in report or in SICADA
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DZ4 For description see text in report or in SICADA
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DZ5 For description see text in report or in SICADA
237.29
DZ3
DZ4
DZ5
A AVAILABLE IN SICADA FOR KA2162B
A AVAILABLE IN SICADA FOR KA2162B

Geological single-hole interpretation of KA2511A

Appendix 3

Title SINGLE HOLE INTERPRETATION KA2511A

Site	ÄSPÖ	**Inclination [°]**	-33.26	**Elevation [m.a.s.l.]**	-335.87
Borehole	KA2511A	**Date of mapping**	1993-11-10 00:00:00	**Drilling Start Date**	1993-08-11 14:08:00
Diameter [mm]	56	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	1993-09-05 18:27:00
Length [m]	293.000	**Northing [m]**	7211.78	**Surveying Date**	
Bearing [°]	234.80	**Easting [m]**	2020.06	**Plot Date**	2015-06-08 02:01:34

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

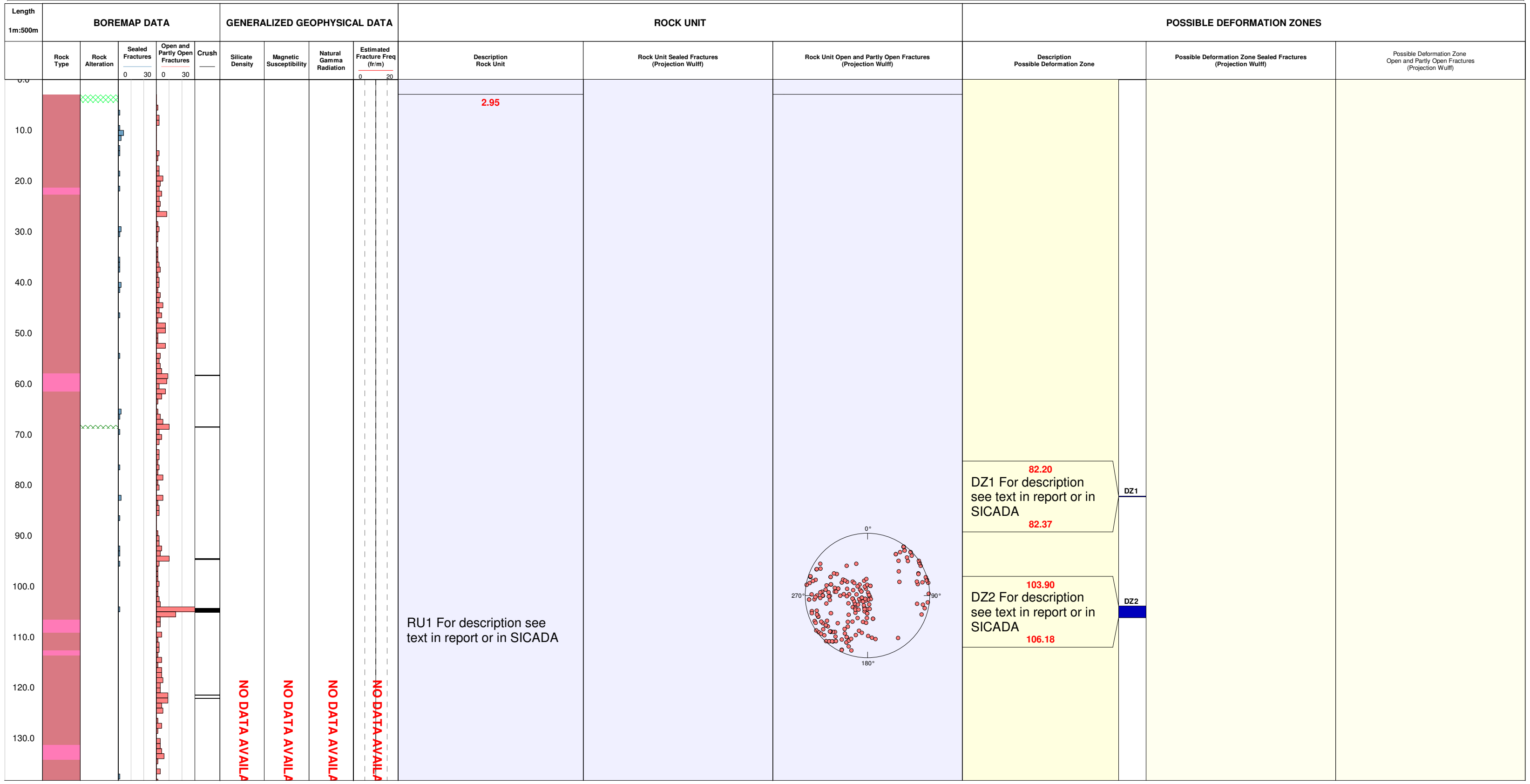
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized

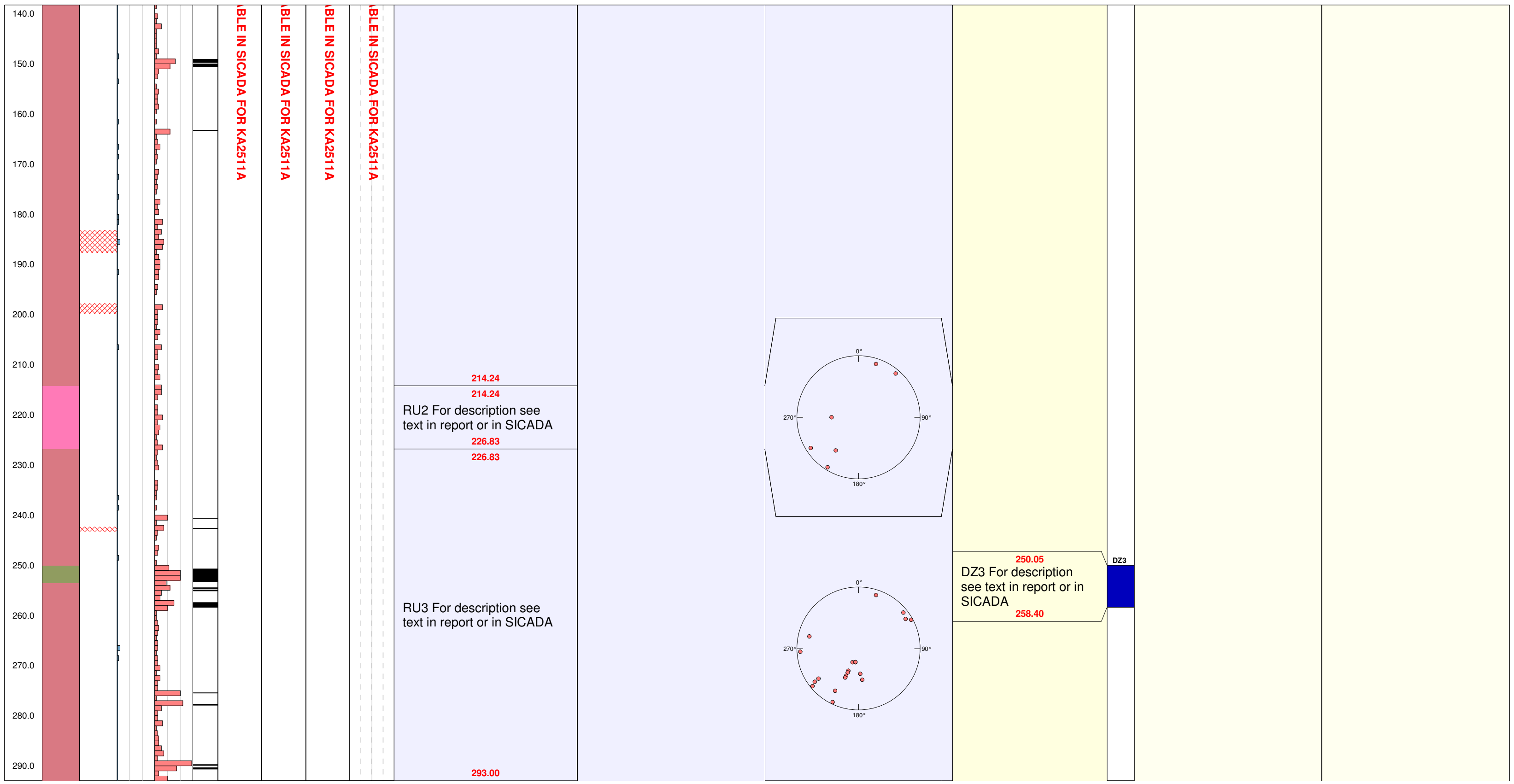
SILICATE DENSITY

SUSCEPTIBILITET

NATURAL GAMMA

DZ CONFIDENCE
- Confidence 3

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BLE IN SICADA FOR KA2511A
BLE IN SICADA FOR KA2511A
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RU2 For description see text in report or in SICADA
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RU3 For description see text in report or in SICADA
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DZ3 For description see text in report or in SICADA
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DZ3