P-14-15

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Seje Carlsten, Allan Stråhle
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Carl-Henric Wahlgren
Geological Survey of Sweden

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Svensk Kärnbränslehantering AB

Håkan Mattsson
GeoVista AB

March 2017

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-14-15
ID 1418216
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Keywords: Äspö, Geology, Geophysics, Radar, Rock unit, Deformation zone, Borehole, Interpretation, SHI.

Abstract

This report presents the outcome from geological single-hole interpretation of the core drilled boreholes KAS04, KAS06 and KAS08 located on Äspö. 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, interpreted geophysical logs, 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 performed 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, along with the fact that geophysical logging data only exist for some or in some parts of the boreholes KAS04, KAS06 and KAS08, a complete geological single-hole interpretation as was made in the Laxemar site investigations (SKB 2009) could not be performed.

The borehole radar measurements was performed with the first generation of radar equipment 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. Furthermore, the radar directional antenna was not available during the measurements in the boreholes. The correlation between radar reflectors and geological structures has been studied elsewhere (see for example Carlsten et al. 1995).

The geological single-hole interpretation of the borehole KAS04 shows that the upper part of the borehole is dominated by Ävrö granodiorite (501056). The lower part of the borehole is dominated by Äspö diorite (501037). Larger sections with fine-grained granite (511058) and gabbroid-dioritoid (508107) also occur in the borehole. Notable is the presence of dolerite (501027) in the beginning of the borehole. Subordinate rock types comprise occurrences of pegmatite (501061) and hybrid rock (505105). Six possible deformation zones are identified in KAS04 (DZ1–DZ6).

The geological single-hole interpretation of the borehole KAS06 shows that the borehole is dominated by Äspö diorite (501037). Larger sections with Ävrö granodiorite (501056), fine-grained granite (511058) and a mix of gabbroid-dioritoid (508107) and fine-grained granite (511058) also occur in the borehole. Subordinate rock type comprises occurrences of pegmatite (501061). Ten possible deformation zones are identified in KAS06 (DZ1–DZ10).

The geological single-hole interpretation of the borehole KAS08 shows that the borehole is dominated by Äspö diorite (501037). Larger sections with gabbroid-dioritoid (508107), Ävrö granodiorite (501056), fine-grained granite (511058) and a mix of gabbroid-dioritoid (508107) and fine-grained granite (511058) also occur in the borehole. Subordinate rock type comprises occurrences of pegmatite (501061). Five possible deformation zones are identified in KAS08 (DZ1–DZ5).

Sammanfattning

Denna rapport presenterar resultatet från geologisk enhålstolkning av kärnborrhålen KAS04, KAS06 och KAS08 belägna på Äspö. Den geologiska enhålstolkningen (SHI) utgör en del av arbetet med Äspö platsbeskrivande modell (SDM). Syftet är att utifrån den geologiska karteringen, tolkade geofysiska loggar 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, samt att vissa geofysiska loggar saknades till viss del i borrhålen KAS04, KAS06 och KAS08 genomfördes inte en komplett geologisk enhålstolkning på det sätt som den genomfördes under platsundersökningarna i Laxemar (SKB 2009).

Borrhålsradar genomfördes med den första generationen av radarantenner och utvärderingen och tolkningen av radardata genomfördes manuellt med fristående program och i olika steg. Radar riktantenn var inte heller tillgänglig vid tiden för undersökningarna. Korrelationen mellan orienteringen av radarreflektorer och geologiska strukturer har utvärderats tidigare av (Carlsten et al. 1995).

Den geologiska enhålstolkningen av kärnborrhålet KAS04 visar att den övre delen av kärnborrhålet domineras av Ävrögranodiorit (501056). Den nedre delen av borrhålet domineras av Äspödiorit (501037). Större sektioner med finkornig granit (511058) och gabbroid-dioritoid (508107) förekommer även. Noterbart är förekomsten av diabas (501027) i början av borrhålet. Underordnade bergarter utgörs av pegmatit (501061) och hybridbergart (505105). Sex möjliga deformationszoner har identifierats i KAS04 (DZ1–DZ6).

Den geologiska enhålstolkningen av kärnborrhålet KAS06 visar att kärnborrhålet domineras av Äspödiorit (501037). Större sektioner med Ävrögranodiorit (501056), finkornig granit (511058) och en blandning av gabbroid-dioritoid (508107) och finkornig granit (511058) förekommer i borrhålet. Underordnad bergart utgörs av pegmatit (501061). Tio möjliga deformationszoner har identifierats i KAS06 (DZ1–DZ10).

Den geologiska enhålstolkningen av kärnborrhålet KAS08 visar att kärnborrhålet domineras av Äspödiorit (501037). Större sektioner med gabbroid-dioritoid (508107) , Ävrögranodiorit (501056), finkornig granit (511058) samt en blandning av gabbroid-dioritoid (508107) och finkornig granit (511058) förekommer i borrhålet. Underordnad bergart utgörs av pegmatit (501061). Fem möjliga deformationszoner har identifierats i KAS08 (DZ1–DZ5).

Contents

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 when the fractures also are 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 only exist for some parts of the boreholes KAS04, KAS06 and KAS08, 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 different geophysical loggings and 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 KAS04, KAS06 and KAS08 at Äspö (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 TX F140-10-003. The controlling documents for performing this activity are listed in Table 1-1. The original lithological mapping and its used nomenclature was translated into an updated SKB nomenclature based on merging Äspö nomenclature with Laxemar-Simpevarp nomenclature and was converted into the Boremap system. The used rock Rock type nomenclature is presented in Table 1-2 that has been used is in accordance with method instruction SKB MD 132.004.

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

Activity plan	Number	Version
Geologisk enhålstolkning av KAS04, KAS06 och KAS08	AP TX F140-10-003	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

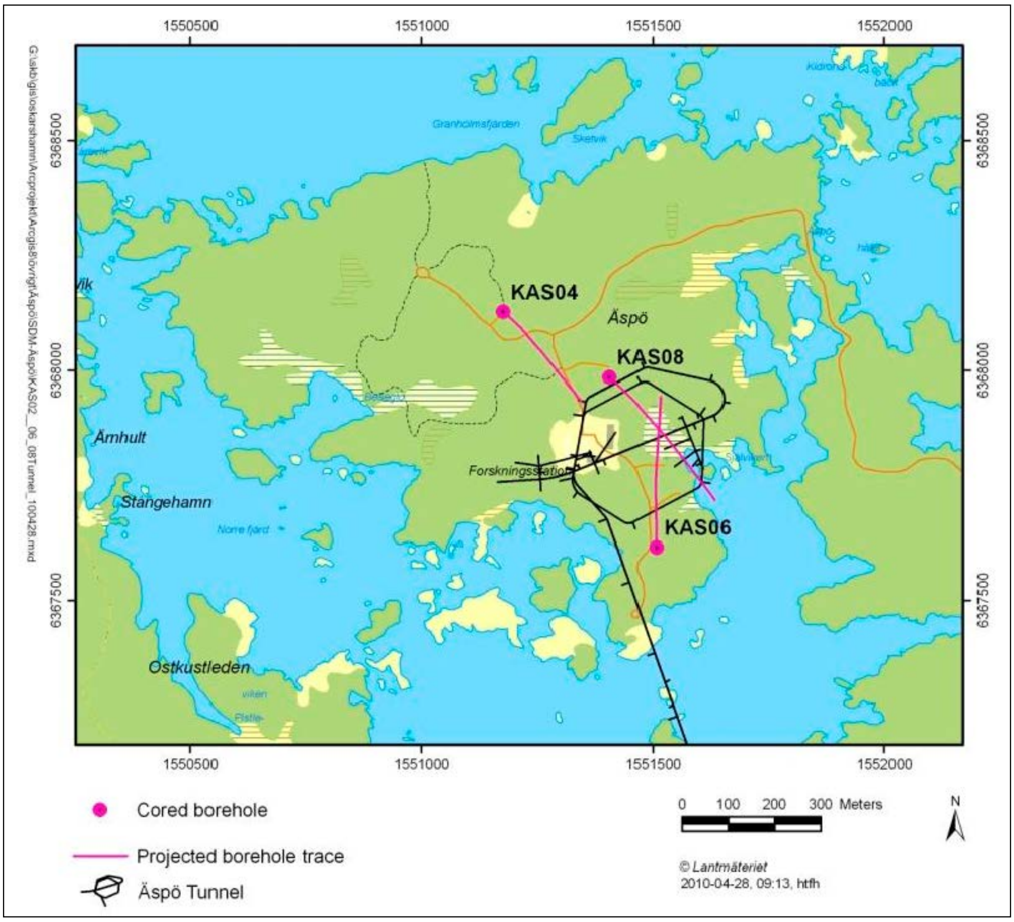


Figure 1-1. Map showing the position of the cored boreholes KAS04, KAS06 and KAS08.

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 KAS04, KAS06 and KAS08 located on Äspö. 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, interpreted geophysical logs, and borehole radar measurements in order to 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 KAS02, KAS06 and KAS08. 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 within a borehole. The interpretations of the borehole geophysical and radar logs were available when the single-hole interpretation is performed.

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 KAS04, KAS06 and KAS08:

- Boremap data converted from geological mapping performed in Petrocore (Stråhle 1989, Sehlstedt and Stråhle 1989).
- Generalized geophysical logs and their interpretation (Sehlstedt and Triumf 1988, Mattsson 2011).
- Radar data and their interpretation (Niva and Gabriel 1988, Carlsten 1989).

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 < 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

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.

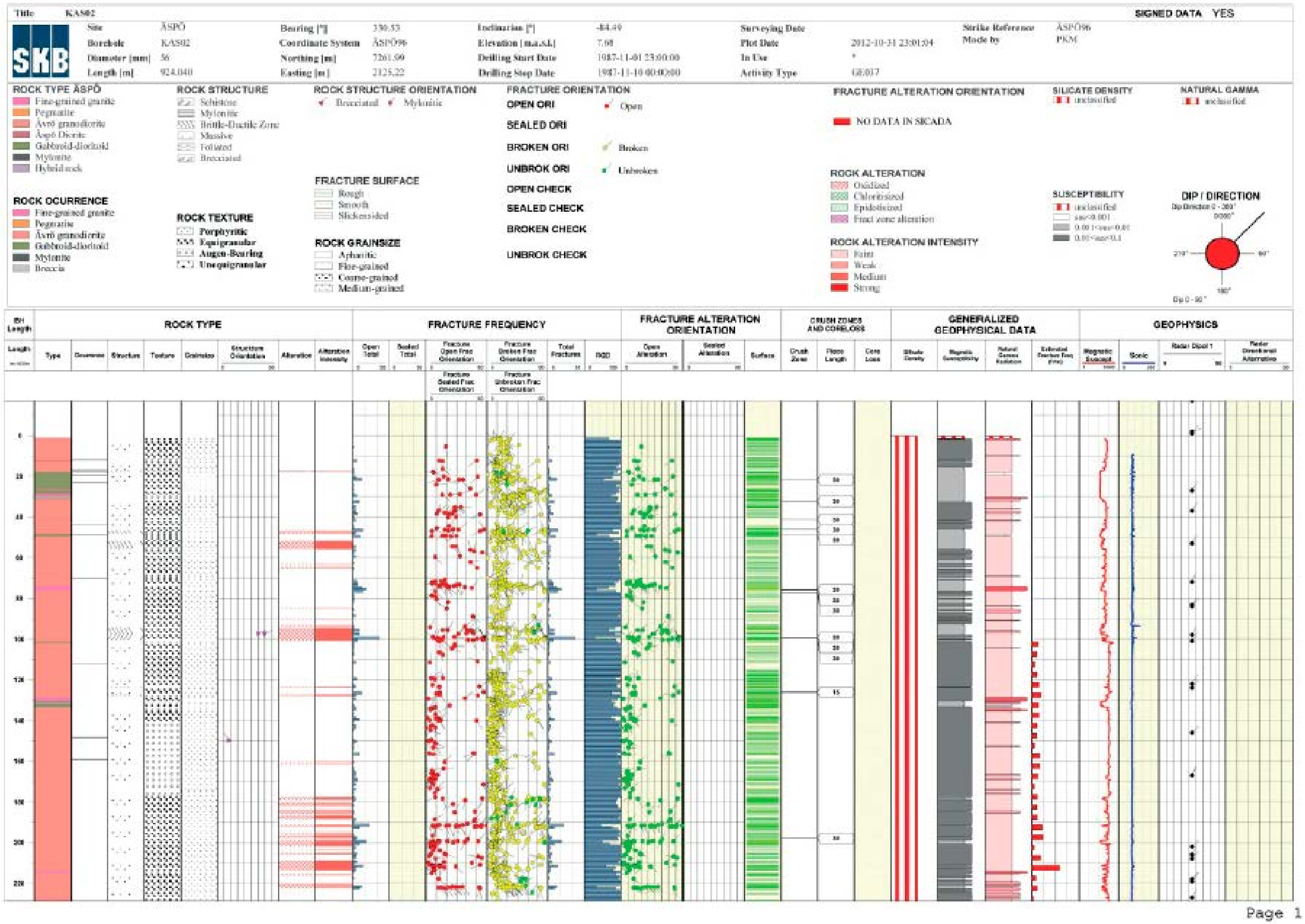


Figure 2-1. Example of WellCAD plot (from borehole KAS02 at Äspö) used as a basis for the geological single-hole interpretation.

Estimated fracture frequency: This parameter provides an estimate of the fracture frequency along 5 m sections, calculated from short, long and lateral resistivity (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.

Inspection of the borehole radar data was carried out during the interpretation process, especially during the identification of possible deformation zones. The occurrence of radar anomalies and the orientation of radar reflectors, e.g. their alpha angle against the borehole axis within the possible deformation zones were commented upon in the text that describes these deformation zones.

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, which represent important input for the work, were available for the boreholes. 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 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 the definition of rock units and deformation zones, with their respective confidence estimates, the drillcores 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 (Figures 2-3 to 2-5).

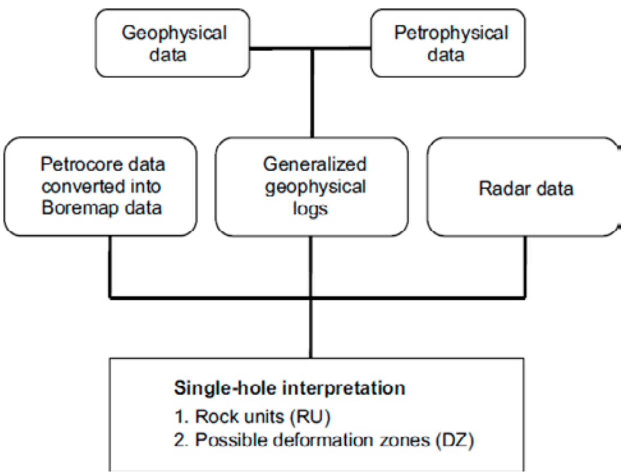


Figure 2-2. *Schematic block-scheme for data used in the geological single-hole interpretation.*

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 and geophysical data, if available, have all assisted in the identification of primarily the brittle structures.

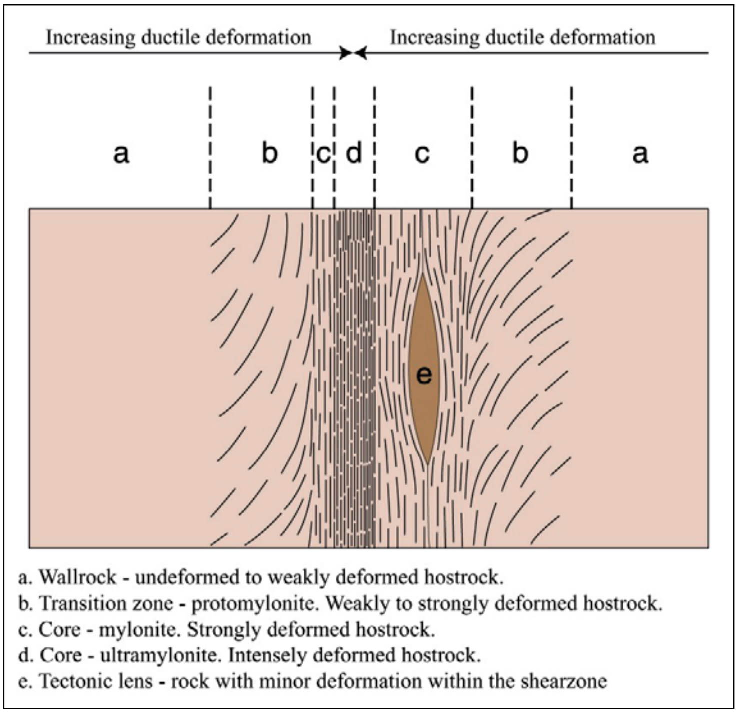


Figure 2-3. *Schematic example of a ductile shear zone. Homogeneous rock which is deformed under low- to medium-grade metamorphic conditions (after Munier et al. 2003).*

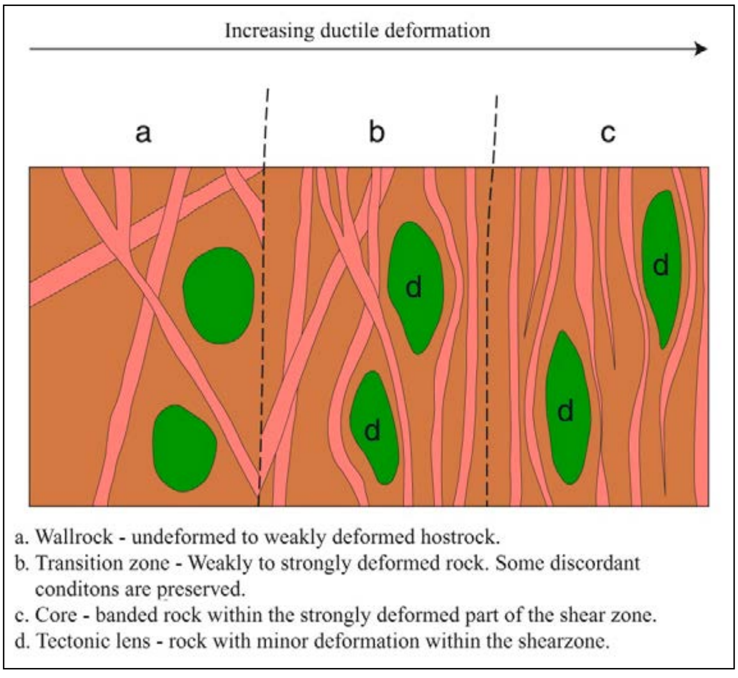


Figure 2-4. *Schematic example of a ductile shear zone. Heterogeneous rock which is deformed under low- to high-grade metamorphic conditions(after Munier et al. 2003).*

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 KAS04, KAS06 and KAS08 (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 diagrams (Figures 2-6 to 2-8).

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

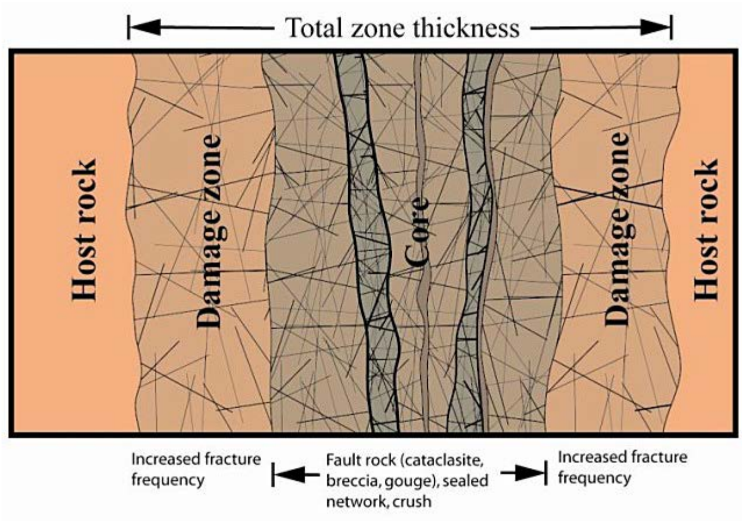


***Figure 2-5.** Schematic example of a brittle deformation zone (modified from Munier et al. 2003).*

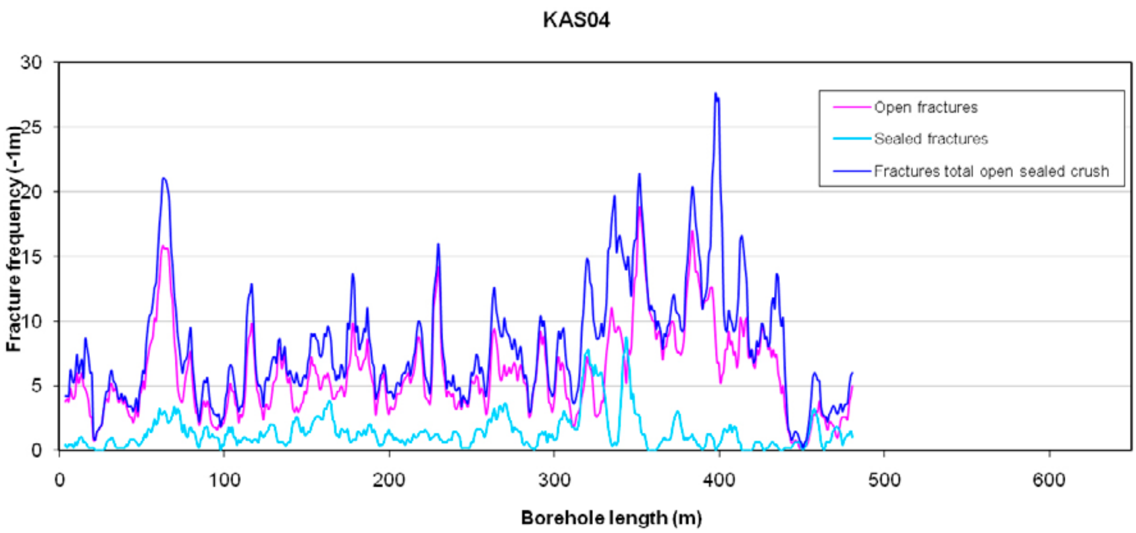


***Figure 2-6.** Fracture frequency plot for KAS04. Moving average with a 5 m window and 1 m steps.*

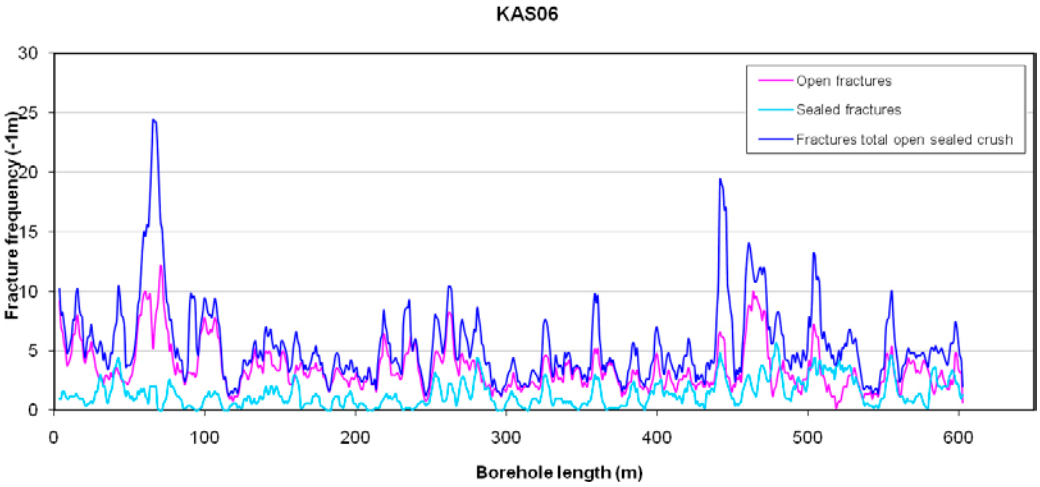


***Figure 2-7.** Fracture frequency plot for KAS06. Moving average with a 5 m window and 1 m steps.*

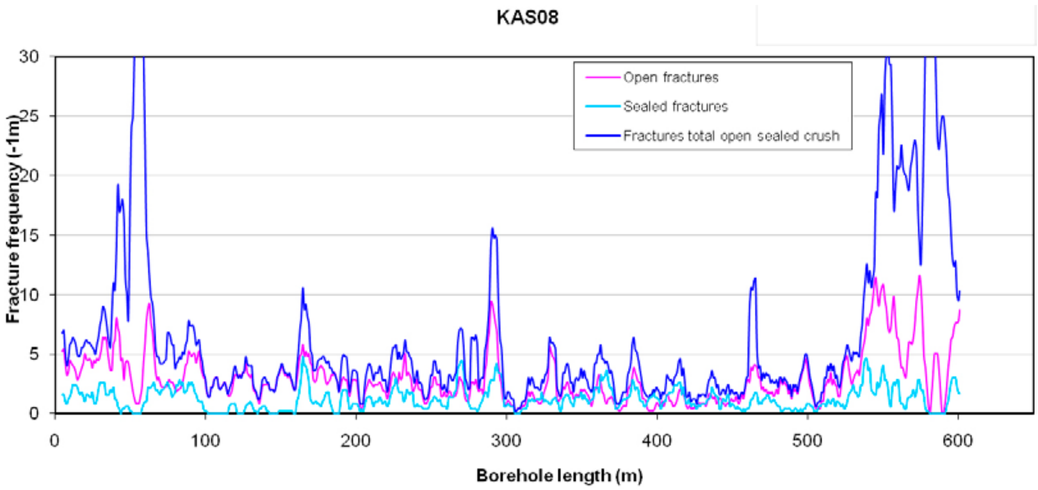


***Figure 2-8.** Fracture frequency plot for KAS08. Moving average with a 5 m window and 1 m steps.*

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 Single-hole Geological Interpretation (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 several sections in the boreholes KAS04 and KAS06, as well as in the entire borehole KAS08. 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 drillcore.

The geophysical logging measurements were performed after the reaming of the upper 100 m of KAS04, KAS06 and KAS08. The increased borehole diameter has caused decreased signal strength and decreased resolution in many of the measured parameters, which affects the result and interpretation of the logging data in the reamed part of the boreholes.

The borehole radar measurements were performed with the first generation of radar 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 the evaluation. Furthermore, directional antenna was not available during these measurements. The interpretation of radar reflectors in KAS06 and KAS08 was focused on association with interpretation of deformation zones, i.e. interpretation presented in the report comprises data for selected sections of the boreholes. However, remaining radar data have been collected from Sicada.

3 Results

The detailed result of the geological single-hole interpretation is presented as print-outs from the software WellCAD (Appendix 1 for KAS04, Appendix 2 for KAS06 and Appendix 3 for KAS08). Orientations are related to Äspö96 North.

3.1 KAS04

3.1.1 Rock units

The borehole consists of six rock units (RU1–RU6). However, due to repetition of RU3 (RU3a and RU3b), RU4 (RU4a, RU4b and RU4c), RU5 (RU5a, RU5b and RU5c) and RU6 (RU6a, RU6b and RU6c) the borehole can be divided into thirteen sections. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

0.10–17.52 m

RU1: Totally dominated by dolerite (501027). The rock type was originally mapped as gabbroid-dioritoid (508107), but was reinterpreted as dolerite based on inspection of the drillcore during SHI. The reinterpretation was supported by analytical data in Sicada (modal analyses of two rock samples). Subordinate rock type comprises a short section (0.56 m) of Äspö diorite (501037) in the central part of the rock unit. Confidence level = 3.

17.52–34.94 m

RU2: The rock unit is composed of Ävrö granodiorite (501056), Äspö diorite (501037) and gabbroid-dioritoid (508107) in three separate equally long sections. Subordinate rock types comprise fine-grained granite (511058) and pegmatite (501061). Confidence level = 3.

34.94–67.09 m

RU3a: Totally dominated by fine-grained granite (511058). Confidence level = 3.

67.09–131.30 m

RU4a: Dominated by Ävrö granodiorite (501056). Subordinate rock types comprise fine-grained granite (511058), hybrid rock (505105), and very sparse occurrence of pegmatite (501061). Confidence level = 3.

131.30–138.63 m

RU5a: Totally dominated by gabbroid-dioritoid (508107). Subordinate rock types comprise Ävrö granodiorite (501056), pegmatite (501061) and sparse occurrence of fine-grained granite (511058). Confidence level = 3.

138.63–262.10 m

RU4b: Dominated by Ävrö granodiorite (501056). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and pegmatite (501061). Confidence level = 3.

262.10–268.58 m

RU5b: Totally dominated by gabbroid-dioritoid (508107). Subordinate rock types comprise Ävrö granodiorite (501056), pegmatite (501061) and very sparse occurrence of fine-grained granite (511058). Confidence level = 3.

268.58–281.67 m

RU6a: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise pegmatite (501061) and very sparse occurrence of Ävrö granodiorite (501056). Confidence level = 3.

281.67–290.88 m

RU5c: Totally dominated by gabbroid-dioritoid (508107). Subordinate rock types comprise Ävrö granodiorite (501056), pegmatite (501061) and very sparse occurrence of fine-grained granite (511058). Confidence level = 3.

290.88–309.00 m

RU4c: Dominated by Ävrö granodiorite (501056). Subordinate rock types comprise Äspö diorite (501037) and fine-grained granite (511058). Confidence level = 3.

309.00–331.31 m

RU6b: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058) and very sparse occurrence of pegmatite (501061) and Ävrö granodiorite (501056). Confidence level = 3.

331.31–456.50 m

RU3b: Dominated by fine-grained granite (511058). Subordinate rock types comprise quartz-dominated hydrothermal vein/segregation (508021), Ävrö granodiorite (501056), particularly in the section 429.41–456.59 m (the assessment is based on inspection of drillcore during SHI, i.e. it deviates from data in Sicada where Ävrö granodiorite is reported as the dominant rock type in this section of the borehole), pegmatite (501061) and hybrid rock (505105). The section 431.54–437.42 m is composed of mylonite (508004), cf. DZ5. Confidence level = 3.

456.59–480.93 m

RU6c: Totally dominated by Äspö diorite (501037). Subordinate rock type comprises very sparse occurrence of pegmatite (501061). Confidence level = 3.

3.1.2 Possible deformation zones

Six possible deformation zones have been recognized in KAS04 (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.

17.40–18.15 m

DZ1: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and one crush at 17.53–17.68 m. There are no useful geophysical logging data in this section of the borehole. The host rock is dominated by Ävrö granodiorite (501056). Subordinate rock type comprises dolerite (501027). Confidence level = 3.

52.00–73.80 m

DZ2: Brittle deformation zone characterized by increased frequency of open fractures, sealed network (based on inspection of the drillcore during SHI), oxidation and five crush at 54.66–54.72 m, 60.50–60.62 m, 64.91–64.97 m, 65.27–65.31 m and at 72.93–73.00 m. The section 57.0–68.0 m is characterized by generally decreased p-wave velocity in combination with several distinct but narrow minima. There is also decreased bulk resistivity and decreased amplitude in the single point resistance (SPR). One non-oriented radar reflector of medium strength occurs at 62 m with an angle of 50° to the borehole axis. The host rock is dominated by fine-grained granite (511057) and to a lesser extent Ävrö granodiorite (501056). Subordinate rock type comprises very sparse occurrence of pegmatite (501061). Confidence level = 3.

114.23–117.35 m

DZ3: Brittle deformation zone characterized by increased frequency of open fractures and two crush at 114.86–114.96 m and 115.16–115.31 m. The entire section is characterized by decreased bulk resistivity and magnetic susceptibility. The single point resistance (SPR) amplitude is partly decreased. At 115.1 m there is a narrow but significant decrease in p-wave velocity. The host rock is totally dominated by gabbroid-dioritoid (508107) based on inspection of the drillcore during SHI, i.e. it deviates from data in Sicada where the rock is documented as hybrid rock (505105). Subordinate rock type comprise very sparse occurrence of fine-grained granite (511057). Confidence level = 3.

170.00–231.57 m

DZ4: Low-grade ductile deformation zone which is inhomogeneously overprinted by brittle deformation. It is characterized by protomylonitic to mylonitic foliation, increased frequency of open fractures, oxidation and four crush at 176.26–176.44 m, 178.83–178.91 m, 184.86–184.89 m and 231.51–231.56 m. Note that brecciated structure according to mapping results in Sicada is considered to be a misinterpretation based on inspection of the drillcore during SHI. The sonic data indicate a general increase in p-wave velocity along the entire section, which indicates a relative improvement of the mechanical properties of the rock along the DZ relative to the surrounding rocks. However, within the section there are five 0.3–1.0 m long intervals of decreased resistivity and p-wave velocity, occurring at the section coordinates c. 176.0 m, 187.4 m, 211.7 m, 218.4 m and 231.7 m. At c. 231 m there is a significant anomaly in the vertical temperature gradient data that indicates the occurrence of a water-bearing fracture. However, no hydraulic flow anomaly (HFA) is detected in the hydraulic measurements at 231 m. Three non-oriented strong radar reflectors occur at 170 m, 173 m and 202 m with angles of 45°, 22° and 10° towards the borehole axis, respectively. In addition, five radar reflectors of medium strength occur at 199 m, 201 m, 216 m, 218 m and 228 m with angles of 50°, 40°, 28°, 25° and 33° towards the borehole axis, respectively. The host rock is dominated by Ävrö granodiorite (501056). Subordinate rock types comprise gabbroid-dioritoid (508107), fine-grained granite (511057), mylonite (508004) and pegmatite (501061). Confidence level = 3.

317.00–440.00 m

DZ5: The upper section between 317.00–346.00 m and the lower section between 429.42–440.00 m are characterized by brittle-ductile to mylonitic foliation and overprinting brittle deformation, oxidation, eight crush in the upper section which in total constitute 1.28 m of this part of the deformation zone, and 4 crush in the lower section which in total constitute 0.47 m of this part of the deformation zone. This is in contrast to the section in between which is characterized by predominantly brittle deformation, which is based on higher frequency of open fractures, oxidation and 12 crush which in total constitute 3.15 m of this part of the deformation zone. Note that the Ävrö granodiorite (501056) in the section 413–414 m is characterized by protomylonitic to mylonitic foliation. The section 330–425 m is characterized by a major decrease in bulk resistivity and single point resistance (SPR) amplitude. Within this section the resistivity data also show several distinct minima. In the interval 333–353 m the p-wave velocity and magnetic susceptibility are significantly decreased. The lowest p-wave velocities occur at c. 335–345 m and in this interval the lowest resistivity amplitudes also occur. Four significant anomalies are identified in the vertical temperature gradient data. They occur at the approximate section coordinates 340 m, 355 m, 408 m and 418 m, and indicate the presence of water-bearing fractures. However, no hydraulic flow anomaly (HFA) is detected in the hydraulic measurements at c. 355, 408 and 418 m.

The host rock in the section 317.00–346.00 m is dominated by almost equal amounts of Äspö diorite (501037) and fine-grained granite (511058), and very subordinate amount of pegmatite (501061). The host rock in the section 346.00–429.42 m is dominated by fine-grained granite (511058) and subordinate amounts of Ävrö granodiorite (501056) and hybrid rock (505105). In the section 429.42–440.00 m, the host rock is dominated by almost equal amounts of mylonite (508004) and Ävrö granodiorite (501056). One non-oriented strong radar reflector occurs at 374 m with an angle of 34° to the borehole axis. Also, seven radar reflectors of medium strength occur at 333 m, 339 m, 376 m, 383 m, 387 m, 401 m and 436 m with an angle of 15°, 35°, 30°, 20°, 35°, 35° and 30° to borehole axis, respectively. Confidence level = 3.

466.75–468.40 m

DZ6: Ductile deformation zone characterized by protomylonitic foliation (based on inspection of the drillcore during SHI). There are no significant anomalies in the geophysical logging data. The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

3.2 KAS06

3.2.1 Rock units

The borehole consists of four rock units (RU1–RU4). However, due to repetition of RU1 (RU1a, RU1b, RU1c and RU1d) and RU2 (RU2a and RU2b) 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.

0.820–63.500 m

RU1a: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and pegmatite (501061). The lower part of the rock unit, from c. 40 m and downwards, is schistose (foliated). Confidence level = 3.

63.50–122.50 m

RU2a: Dominated by Ävrö granodiorite (501056), but with frequent up to 5 m long sections of fine-grained granite between 91.280 and 110.070 m. Subordinate rock types comprise Äspö diorite (501037), fine-grained granite (511058), gabbroid-dioritoid (508107) and pegmatite (501061). Confidence level = 3.

122.50–227.39 m

RU1b: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107), pegmatite (501061) and one thin occurrence of Ävrö granodiorite (501056). Confidence level = 3.

227.39–290.85 m

RU3: Mixture of gabbroid-dioritoid (508107) and fine-grained granite (511058). Gabbroid-dioritoid (508107) dominates in the upper part of the rock unit and fine-grained granite (511058) in the lower part. Subordinate rock types comprise Ävrö granodiorite (501056) and pegmatite (501061). Confidence level = 3.

290.85–435.50 m

RU1c: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107), pegmatite (501061) and Ävrö granodiorite (501056). Confidence level = 3.

435.50–459.21 m

RU2b: Totally dominated by Ävrö granodiorite (501056). Subordinate rock type comprises pegmatite (501061). Confidence level = 3.

459.21–535.61 m

RU4: Totally dominated by fine-grained granite (511058). Subordinate rock type comprises pegmatite (501061). Confidence level = 3.

535.61–602.23 m

RU1d: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), pegmatite (501061) and gabbroid-dioritoid (508107). Confidence level = 3.

3.2.2 Possible deformation zones

Ten possible deformation zones have been recognized in KAS06 (DZ1–DZ10). The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

44.35–44.53 m

DZ1: Brittle deformation zone characterized by one crush at 44.36–44.49 m and oxidation. The section is characterized by significantly decreased p-wave velocity, magnetic susceptibility (41.0–45.0 m) and partly decreased single point resistance (SPR) amplitude. Host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

59.80–76.00 m

DZ2: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and nine crush which in total constitute 3.06 m of the deformation zone. Furthermore, the section 64–68 m is characterized by brittle-ductile deformation and occurrence of mylonitic foliation. The section 64.5–70.5 m is characterized by significantly decreased p-wave velocity and partly decreased magnetic susceptibility and single point resistance (SPR) amplitude. There is also an anomaly in the vertical temperature gradient data that indicates the occurrence of a water-bearing fracture. Note that no hydraulic measurements have been carried out in the upper 100 m in KAS06. One non-oriented radar reflector of medium strength occurs at 68 m with an angle of 60° to the borehole axis. The direct radar pulse is reduced in the section 60–75 m. The host rock is dominated by Ävrö granodiorite and to a lesser extent Äspö diorite (501037), gabbroid-dioritoid (508107) and fine-grained granite (511058). Confidence level = 3.

91.30–92.30 m

DZ3: Brittle deformation zone characterized by one crush at 91.40–92.29 m. The section 89.0–94.0 m is characterized by several narrow but distinct anomalies of decreased p-wave velocity and also one anomaly in the vertical temperature gradient data that indicates the occurrence of a water-bearing fracture Note that no hydraulic measurements have been carried out in the upper 100 m in KAS06. Host rock is totally dominated by fine-grained granite (511058). Confidence level = 3.

151.98–152.58 m

DZ4: Low-grade ductile deformation zone and oxidation. There are no significant anomalies in the geophysical logging data. Host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

157.22–159.36 m

DZ5: Low-grade ductile deformation zone. There are no significant anomalies in the geophysical logging data. Host rock is dominated by gabbroid-dioritoid (508107) with subordinate Äspö diorite (501037). Confidence level = 3.

254.58–255.05 m

DZ6: Low-grade ductile deformation zone and oxidation. There are no significant anomalies in the geophysical logging data. Host rock is dominated by gabbroid-dioritoid (508107). Confidence level = 3.

441.79–444.10 m

DZ7: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and two crush at 441.80–441.93 m and 443.48–444.04. The geophysical logging data show partly decreased p-wave velocity and single point resistance (SPR) amplitude. The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

447.22–448.28 m

DZ8: Brittle deformation zone characterized by oxidation and one crush at 447.29–448.27 m. The geophysical logging data show partly decreased p-wave velocity and single point resistance (SPR) amplitude. The host rock is totally dominated by Ävrö granodiorite (501056). Confidence level = 3.

460.12–460.37 m

DZ9: Brittle deformation zone characterized by oxidation and one crush at 460.12–460.35 m. There are no significant anomalies in the geophysical logging data. The host rock is totally dominated by fine-grained granite (511058). Confidence level = 3.

466.75–470.00 m

DZ10: Brittle deformation zone characterized by increased frequency of open fractures, oxidation, narrow section with breccia and brittle-ductile foliation. The geophysical logging data show partly decreased p-wave velocity, magnetic susceptibility and single point resistance (SPR) amplitude. The host rock is totally dominated by fine-grained granite (511058). Confidence level = 3.

3.3 KAS08

3.3.1 Rock units

The borehole consists of four rock units (RU1–RU4). However, due to repetition of RU1 (RU1a, RU1b, RU1c, RU1d, RU1e and RU1f) and RU2 (RU2a, RU2b and RU2c) the borehole can be divided into eleven sections. The confidence in the interpretation of a rock unit is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

1.04–91.00 m

RU1a: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and very sparse occurrence of pegmatite (501061). The sections 1.04–7.590 m, 31.67–33.85 m, 34.40–39.00 m and 62.05–91.00 m are documented as brittle-ductile shear zone in Sicada, but are considered as misinterpretations (based on inspection of the drillcore during SHI). Confidence level = 3.

91.00–109.00 m

RU2a: Dominated by gabbroid-dioritoid (508107) but Äspö diorite (501037) constitutes an important lithological component. Subordinate rock types comprise fine-grained granite (511058) and very sparse occurrences of pegmatite (501061) and Ävrö granodiorite (501056). Confidence level = 3.

109.00–244.90 m

RU1b: Dominated by Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107), fine-grained granite (511058) and sparse occurrences of pegmatite (501061) and Ävrö granodiorite (501056). Confidence level = 3.

244.90–327.90 m

RU3: Dominated by Ävrö granodiorite (501056). Subordinate rock types comprise fine-grained granite (511058), Äspö diorite (501037), pegmatite (501061) and very sparse occurrence of gabbroid-dioritoid (508107). Confidence level = 3.

327.90–376.05 m

RU1c: Totally dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and pegmatite (501061). Confidence level = 3.

376.05–390.83 m

RU2b: Mixture of fine-grained granite (511058), gabbroid-dioritoid (508107) and Äspö diorite (501037). Subordinate rock types comprise pegmatite (501061) and Ävrö granodiorite (501056). Confidence level = 3.

390.83–468.50 m

RU1d: Dominated by Äspö diorite (501037). Subordinate rock types comprise Ävrö granodiorite (501056), fine-grained granite (511058), gabbroid-dioritoid (508107) and pegmatite (501061). Confidence level = 3.

468.50–499.94 m

RU2c: Dominated by gabbroid-dioritoid (508107). Subordinate rock types comprise fine-grained granite (511058), Äspö diorite (501037) and sparse occurrences of pegmatite (501061) and Ävrö granodiorite (501056). Confidence level = 3.

499.94–542.81 m

RU1e: Dominated by Äspö diorite (501037). Subordinate rock types comprise fine-grained granite (511058), gabbroid-dioritoid (508107) and sparse occurrence of pegmatite (501061). Confidence level = 3.

542.81–580.00 m

RU4: Totally dominated by fine-grained granite (511058). Subordinate rock types comprise pegmatite (501061), gabbroid-dioritoid (508107) and Ävrö granodiorite (501056). Confidence level = 3.

580.000–601.490 m

RU1f: Dominated by Äspö diorite (501037). Subordinate rock type comprises very sparse occurrence of fine-grained granite (511058). Confidence level = 3.

3.3.2 Possible deformation zones

Five possible deformation zones have been recognized in KAS08 (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.

39.00–62.05 m

DZ1: Brittle deformation zone characterized by slightly increased frequency of open fractures, occurrence of cataclasite and breccia, strong hydrothermal alteration and seven crush which in total constitute 8.66 m of the deformation zone. The section 39.40–57.44 m is documented as mylonite (508004) in Sicada, but is considered as a misinterpretation based on inspection of the drillcore during SHI. There are no geophysical logging data available along this section of the borehole. One non-oriented weak radar reflector occurs at 43 m with an angle of 30° to the borehole axis. The host rock is totally dominated by Äspö diorite (501037). Confidence level = 3.

290.59–292.12 m

DZ2: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and one crush at 291.88–292.12 m. The section 286.0–294.0 m is characterized by a general decrease in single point resistance (SPR) amplitude and magnetic susceptibility, and partly decreased p-wave velocity. There are also significant anomalies in the vertical temperature gradient data that indicate occurrence of water-bearing fractures. However, the hydraulic flow anomaly (HFA) in this interval has not been classified as a hydraulic conductive feature (HCF). The host rock is totally dominated by fine-grained granite (511058). Confidence level = 3.

330.05–330.85 m

DZ3: Brittle deformation zone characterized by strongly increased frequency of open fractures and oxidation. In the section 328.0–331.0 m there is a clear decrease in p-wave velocity and minor anomalies in the single point resistance (SPR) and magnetic susceptibility data. There is also one significant anomaly in the vertical temperature gradient data that indicates the occurrence of a water-bearing fracture. However, the hydraulic flow anomaly (HFA) in this interval has not been classified as a hydraulic conductive feature (HCF). The host rock is totally dominated by Äspö diorite (501037). Subordinate rock type comprises fine-grained granite (511058). Confidence level = 3.

462.90–464.60 m

DZ4: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and two crush at 463.28–463.58 m and 463.79–463.95 m. The section is characterized by decreased p-wave velocity, magnetic susceptibility and one distinct anomaly in the single point resistance (SPR) data. There is also a significant anomaly in the vertical temperature gradient data that indicates the occurrence of a water-bearing fracture. The host rock is totally dominated by fine-grained granite (511058). Subordinate rock type comprises Äspö diorite (501037). Confidence level = 3.

537.03–601.49 m

DZ5: Brittle deformation zone characterized by increased frequency of open fractures, oxidation and eleven crush which in total constitute 23.79 m of the deformation zone. The section 545.33–549.11 m is documented as mylonite (508004) in Sicada, but was considered as a misinterpretation based on inspection of the drillcore during SHI. Furthermore, the major part of the deformation zone has been documented as brittle-ductile shear zone in Sicada, but was also considered as a misinterpretation based on inspection of the drillcore during SHI. The entire section is characterized by a general decrease in the single point resistance (SPR) amplitude, decreased magnetic susceptibility and several low velocity intervals in the sonic data. There are also significant anomalies in the vertical temperature gradient data that indicate water-bearing fractures. The most significant anomalies in the geophysical logging data occur in the section 576.0–582.0 m, which suggests that the rock along this section has suffered from more intense deformation relative to the rocks in the other parts of the DZ. One non-oriented radar reflector of medium strength occurs at 555 m with an angle of 60° to the borehole axis and one weak radar reflector occurs at 580 m with an angle of 60° to the borehole axis. The direct radar pulse is reduced from 549 m and downwards in the borehole. The host rock is dominated by fine-grained granite (511058) and to a lesser extent Äspö diorite (501037). Subordinate rock types comprise gabbroid-dioritoid (508107), pegmatite (501061) and Ävrö granodiorite (501056). 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, o inconclusiveness in the geological documentation and lack of certain parameters such as fracture frequency, along with the fact that geophysical logging data only exist for some or in some parts of the boreholes KAS04, KAS06 and KAS08 is too sparse to allow the full application of the established and complete SHI methodology. When borehole TV (BIPS) were lacking the geological mapping was only based on inspection of the drill core.

The geophysical borehole logging measurements was performed after the reaming of the upper 100 m telescope drilled part of the core drilled boreholes KAS04, KAS06 and KAS08. The increased borehole diameter at the reamed part generates in a decreased geophysical signal strength and decreased resolution in many of the geophysical logging parameters, which affects the result and interpretation of the logging data in the reamed part of the borehole. Density logging (gamma-gamma) was not performed in KAS04.

The borehole radar measurements was performed with the first generation of radar equipment 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. Furthermore, the radar directional antenna was not available during the measurements in boreholes KAS04, KAS06 and KAS08. The occurrence of radar data is listed in the description of each deformation zone (DZ) unit in Section 3.1.2, 3.2.2 as well as in the Section 3.3.2. 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, 1989. Results from borehole radar measurements in KAS05, KAS06, KAS07 and KAS08 at Äspö – Interpretation of fracture zones by including radar measurements from KAS02 and KAS04. SKB HRL Progress Report 25-89-10, Svensk Kärnbränslehantering AB.

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.

Mattsson H, 2011. Interpretation of geophysical borehole measurements and petrophysical measurements from KAS02, KAS04, KAS06, KAS07 and KAS08. SKB P-11-07, 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.

Niva B, Gabriel G, 1988. Borehole radar measurements at Äspö and Laxemar – Boreholes KAS02, KAS03, KAS04, KLX01, HAS02, HAS03 and HAV07. SKB HRL Progress Report 25-88-03, Svensk Kärnbränslehantering AB.

Sehlstedt S, Stråhle A, 1989. Geological core mapping and geophysical borehole logging in the boreholes KAS05–KAS08 at Äspö. SKB HRL Progress Report 25-89-09, Svensk Kärnbränslehantering AB.

Sehlstedt S, Triumf C-A, 1988. Interpretation of geophysical logging data from KAS02–KAS04 and HAS08–HAS12 at Äspö and KLX01 at Laxemar. SKB HRL Progress Report 25-88-15, 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.

Stråhle A, 1989. Drillcore investigations in the Simpevarp area. Boreholes KAS02, KAS03, KAS04 and KLX01. SKB HRL Progress Report 25-88-07, Svensk Kärnbränslehantering AB

Appendices

Geological single-hole interpretation of KAS04, KAS06 and KAS08

The results from the geological single-hole interpretation of KAS04, KAS06 and KAS08 are presented in WellCAD plots (Appendices 1 to 3). 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).

Appendix 1

Geological single-hole interpretation of KAS04

Title	SINGLE HOLE INTERPRETATION KAS04				
Site	ÄSPÖ	Inclination [°]	-59.89	Elevation [m.a.s.l.]	11.66
Borehole	KAS04	Date of mapping	1988-04-12 00:00:00	Drilling Start Date	1988-04-01 01:00:00
Diameter [mm]	56	Coordinate System	ÄSPÖ96	Drilling Stop Date	1988-04-01 01:00:00
Length [m]	480.980	Northing [m]	7636.83	Surveying Date	
Bearing [°]	140.53	Easting [m]	1955.06	Plot Date	2015-06-08 02:01:34

ROCKTYPE ÄSPÖ
- Dolerite / Diabas 501027
- Fine-grained granite 511058
- Pegmatite 501061
- Ävrö granodiorite 501056
- Äspö diorite 501037
- Gabbroid-dioritoid 508107
- Mylonite 508004
- Quartz-dominated hydrothermal vein/segregation 508021
- Hybrid rock 505105

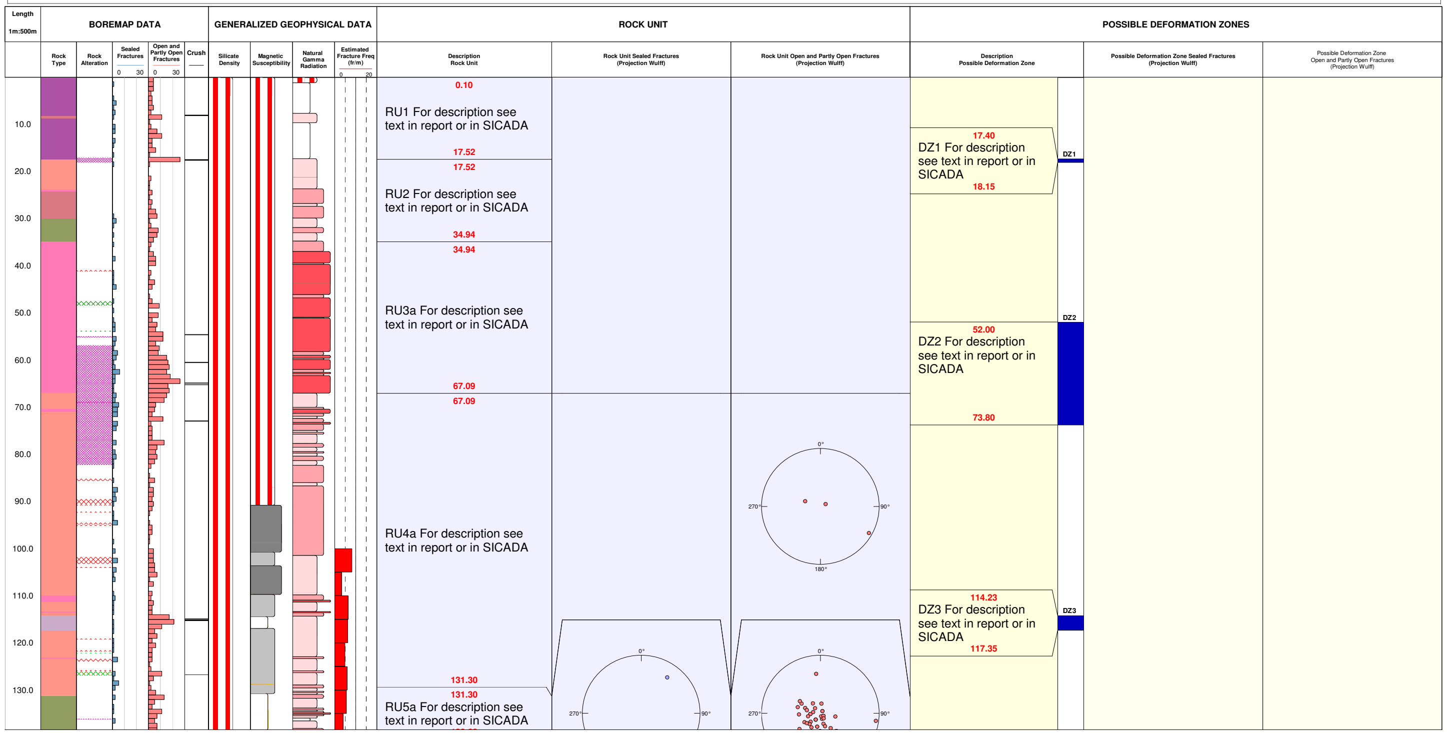
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Fract zone alteration

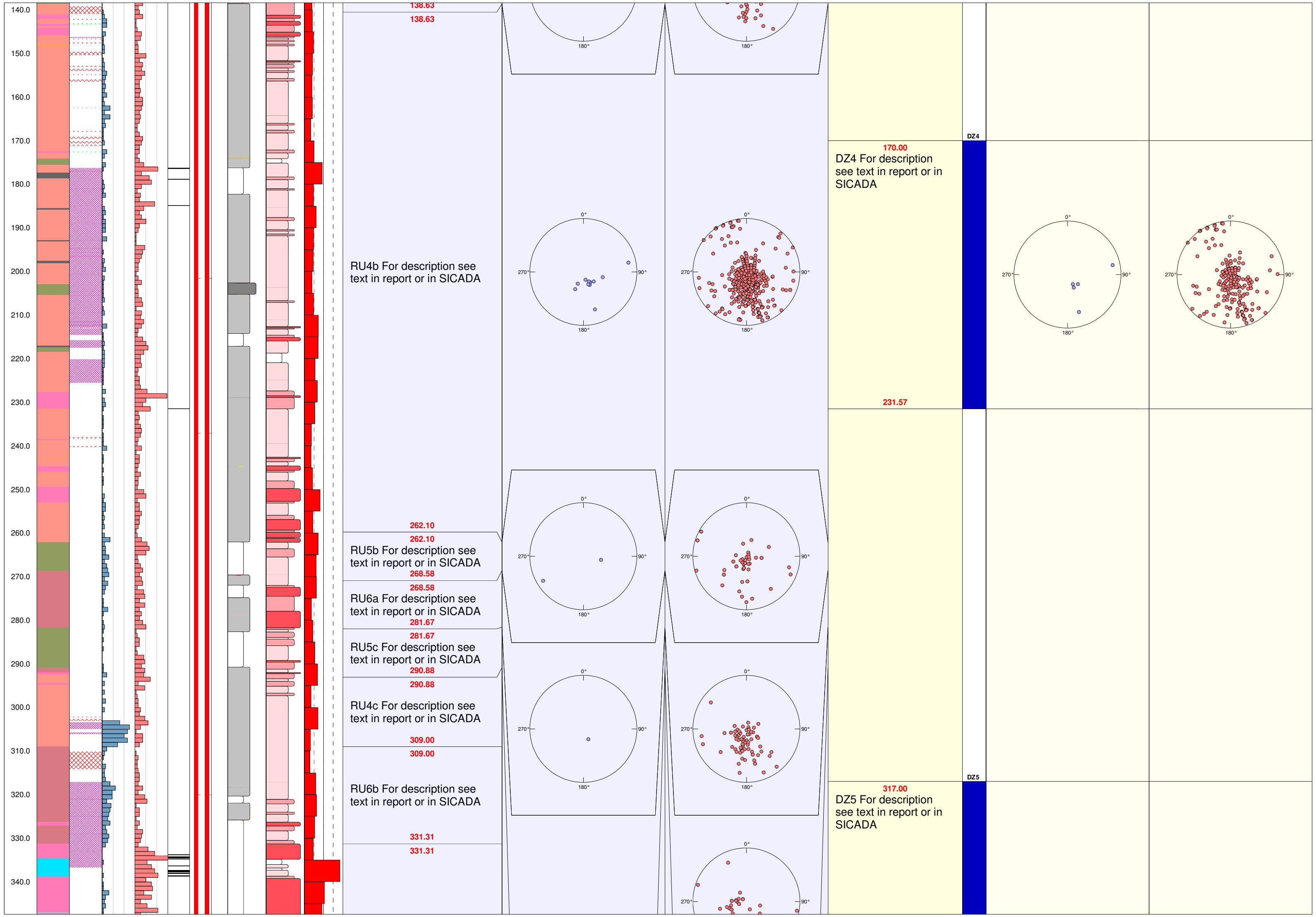
SILICATE DENSITY
- unclassified

SUSCEPTIBILITET
- 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

DZ CONFIDENCE
- Confidence 3

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290.0
300.0
310.0
320.0
330.0
340.0
138.63
138.63
RU4b For description see text in report or in SICADA
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262.10
RU5b For description see text in report or in SICADA
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268.58
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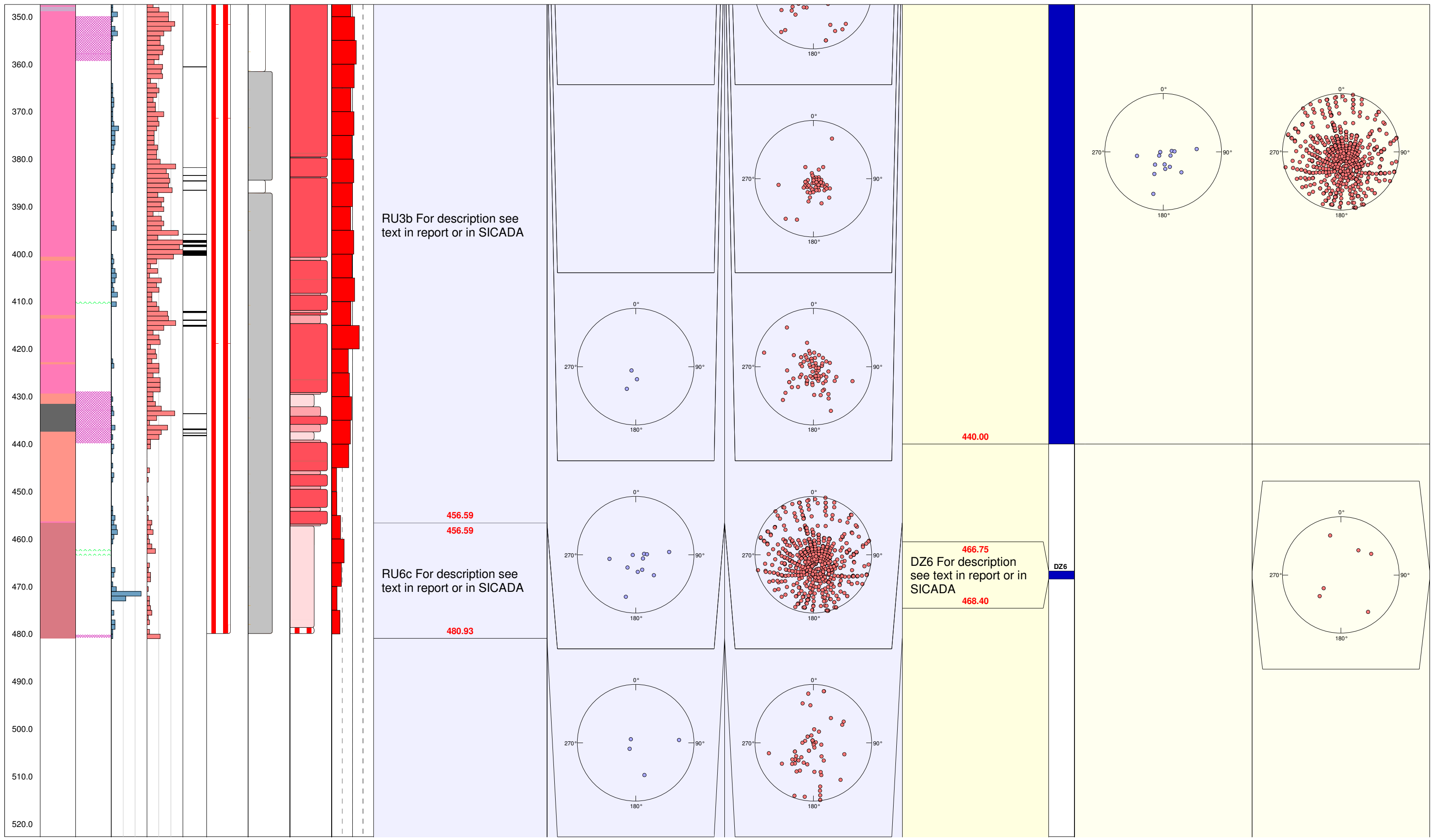
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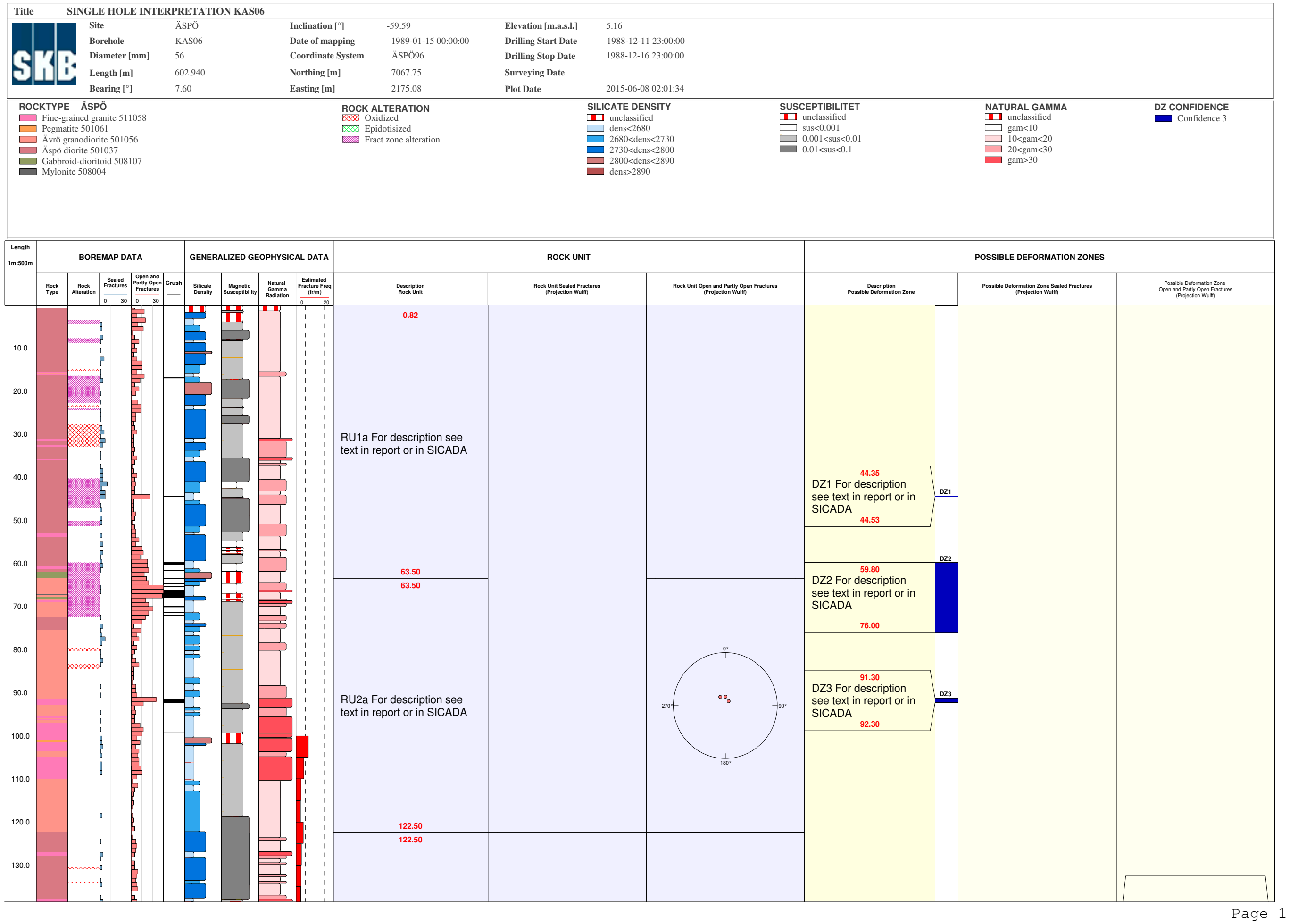
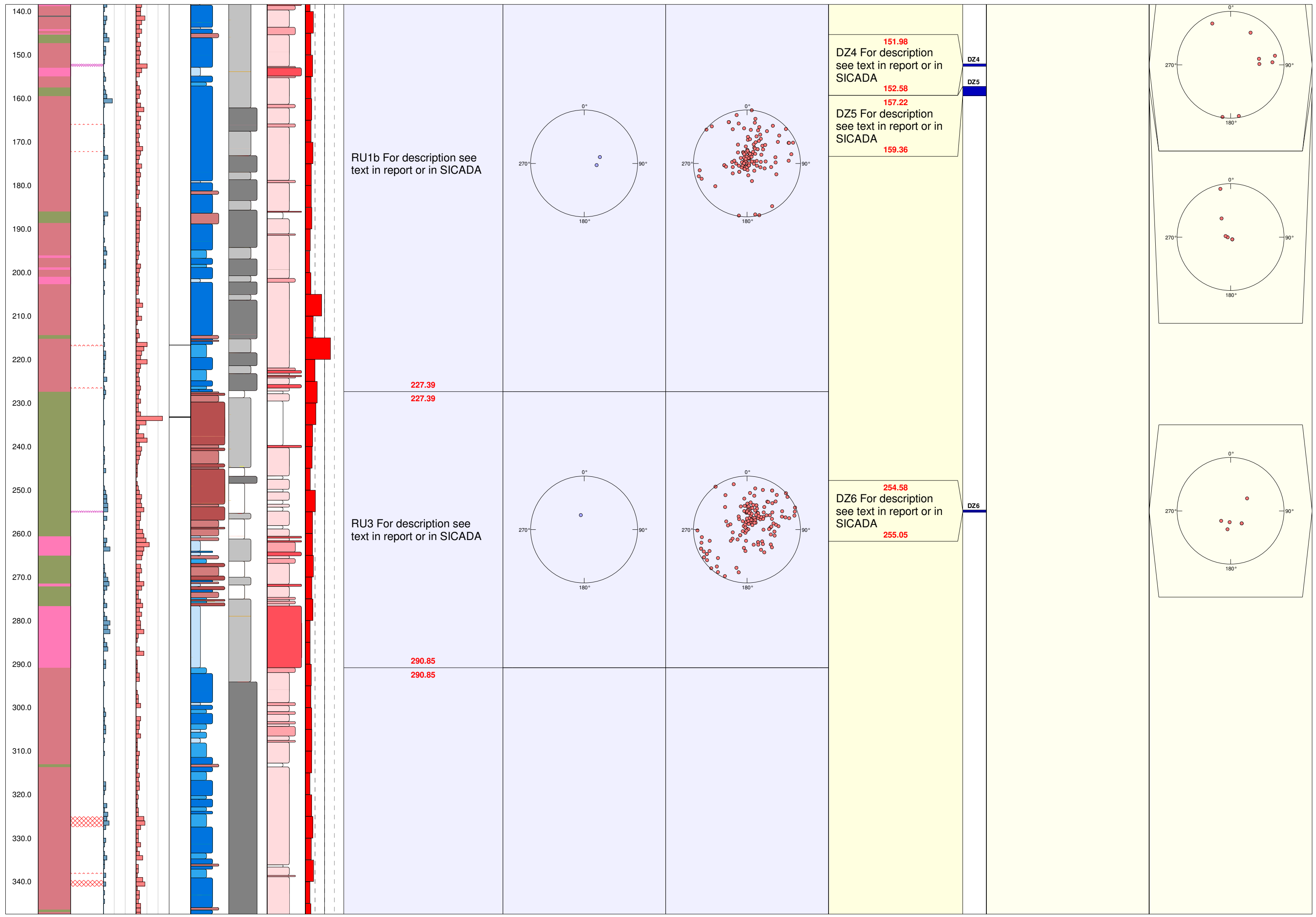
Appendix 2

Geological single-hole interpretation of KAS06

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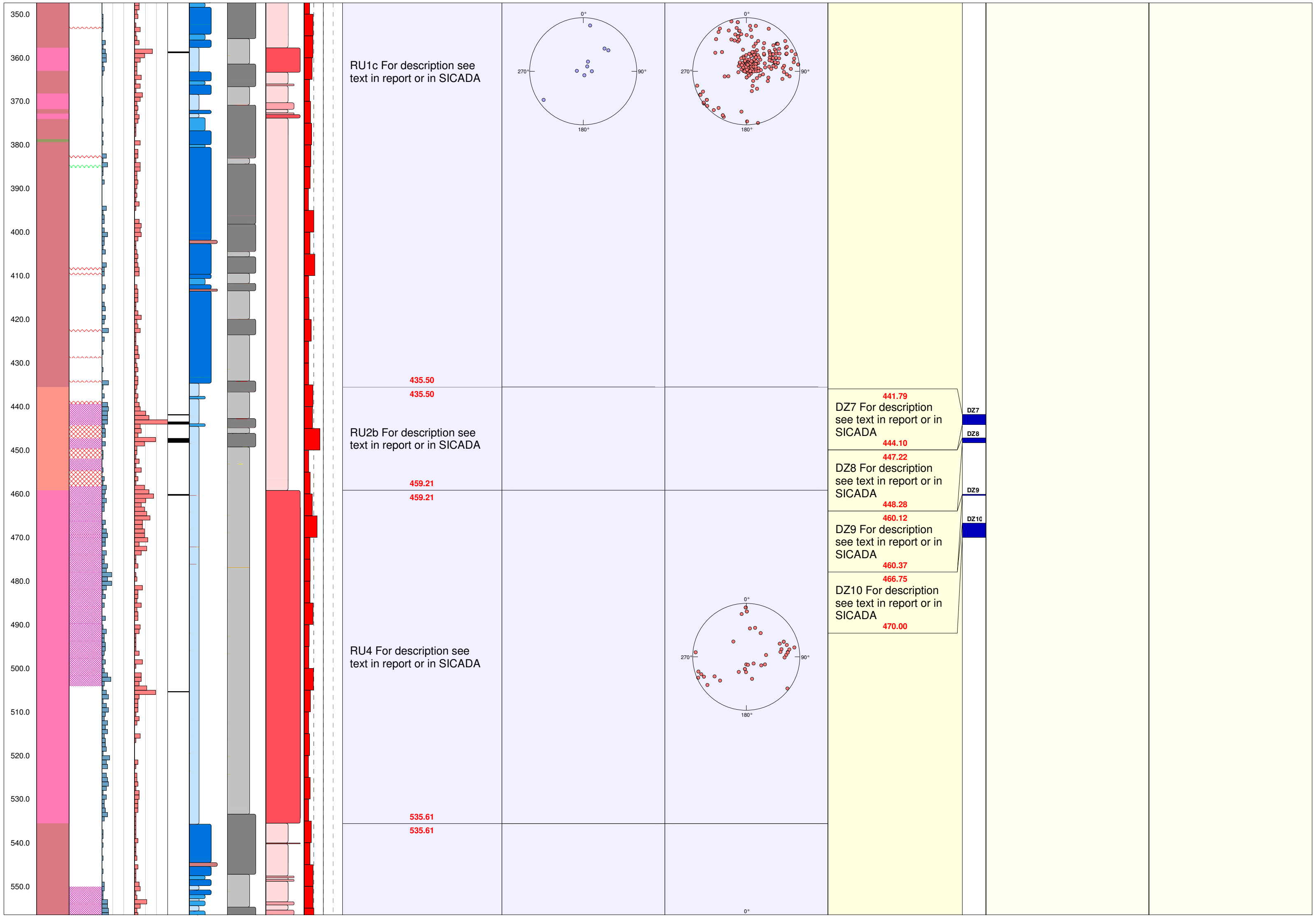
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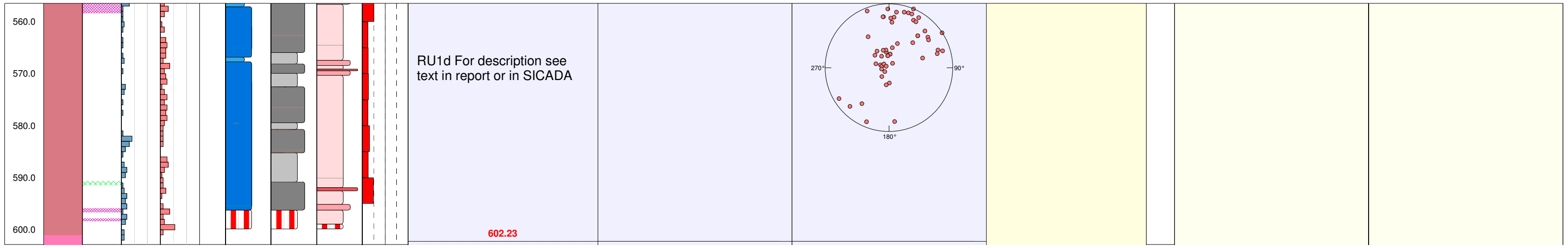
Page 3



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Appendix 3

Geological single-hole interpretation of KAS08

Title SINGLE HOLE INTERPRETATION KAS08

Site	ÄSPÖ	**Inclination [°]**	-58.99	**Elevation [m.a.s.l.]**	7.66
Borehole	KAS08	**Date of mapping**	1989-02-27 00:00:00	**Drilling Start Date**	1988-12-17 23:00:00
Diameter [mm]	56	**Coordinate System**	ÄSPÖ96	**Drilling Stop Date**	1988-12-17 23:00:00
Length [m]	601.490	**Northing [m]**	7451.05	**Surveying Date**	
Bearing [°]	145.60	**Easting [m]**	2150.44	**Plot Date**	2015-06-08 02:01:34

ROCKTYPE ÄSPÖ
- Fine-grained granite 511058
- Ävrö granodiorite 501056
- Äspö diorite 501037
- Gabbroid-dioritoid 508107
- Mylonite 508004

ROCK ALTERATION
- Oxidized
- Chloritisized
- Fract zone alteration

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

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

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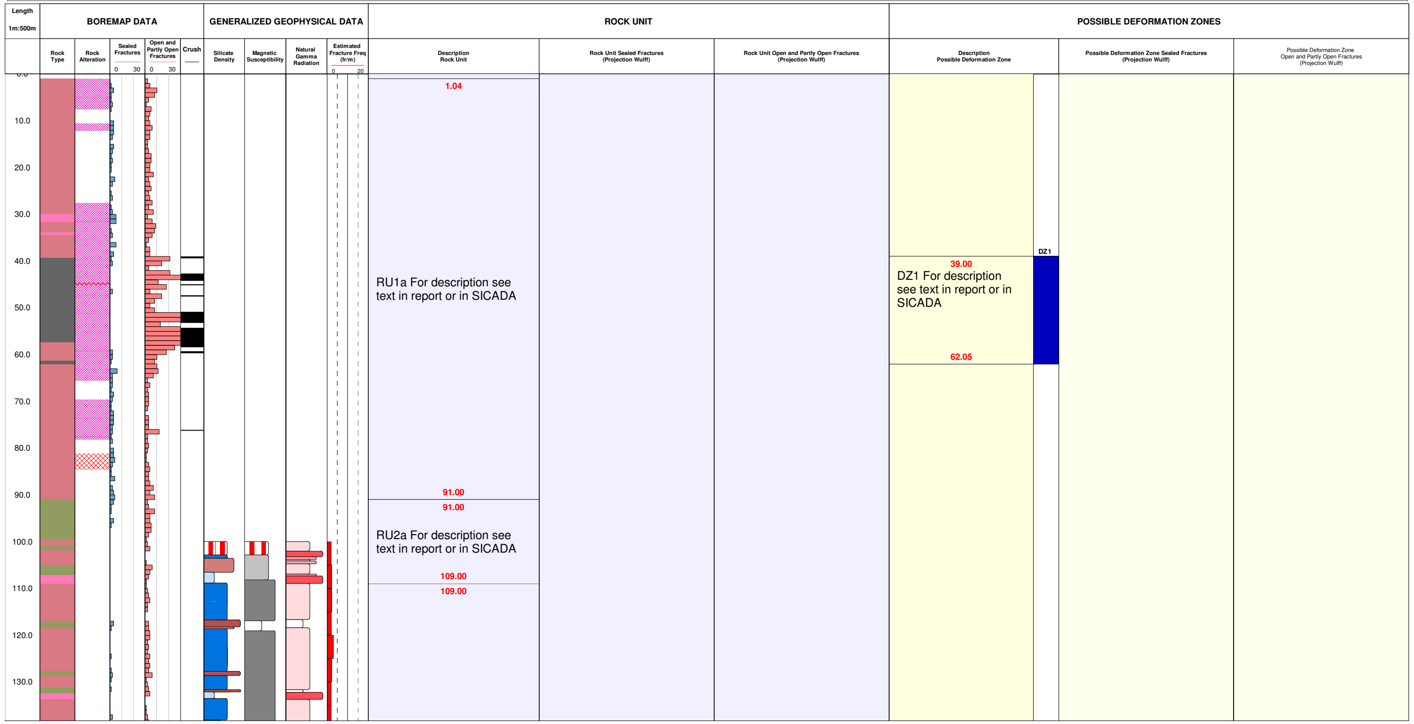
- gam<10
- 10<gam<20
- 20<gam<30
- gam>30

DZ CONFIDENCE
- Confidence 3



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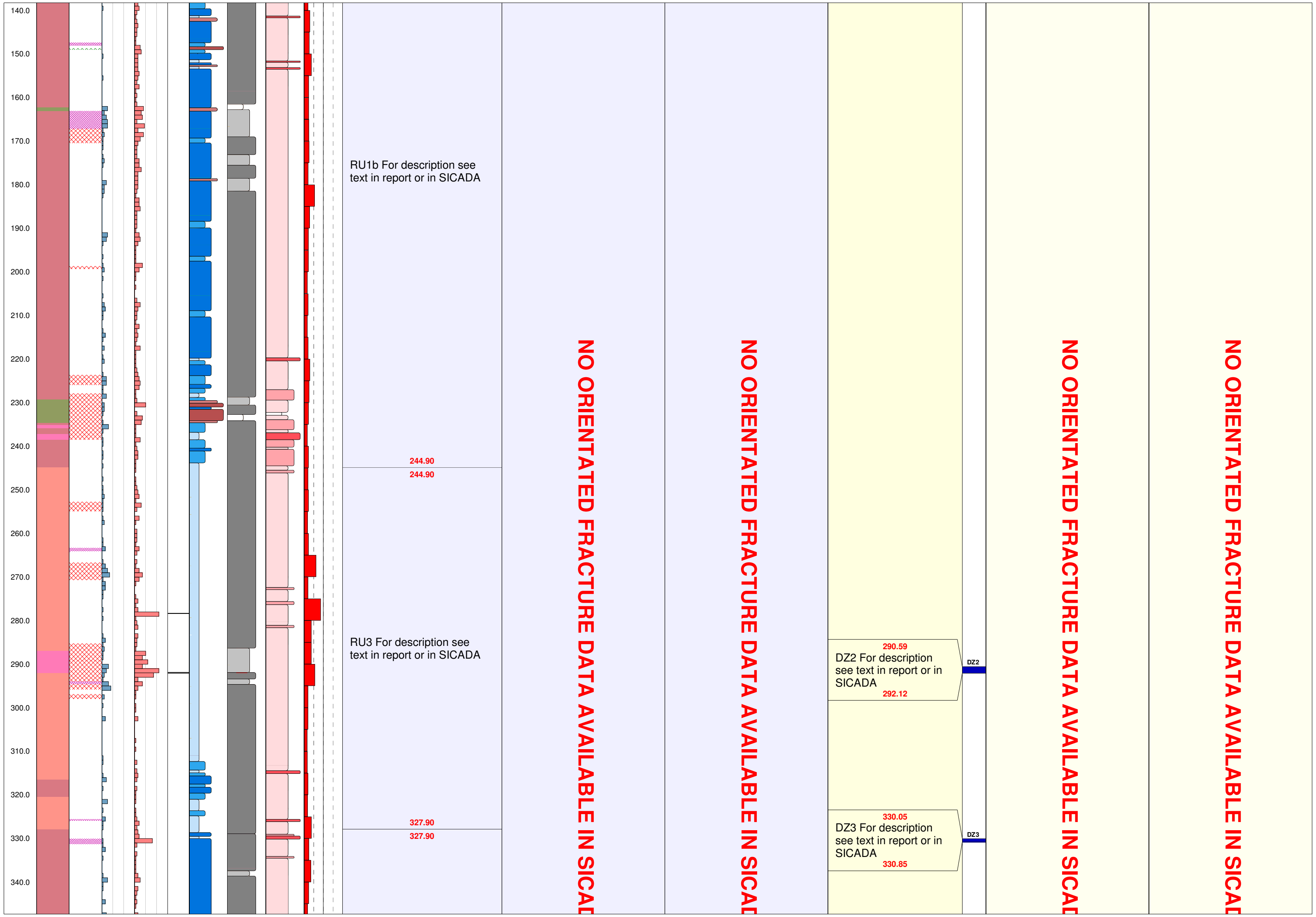
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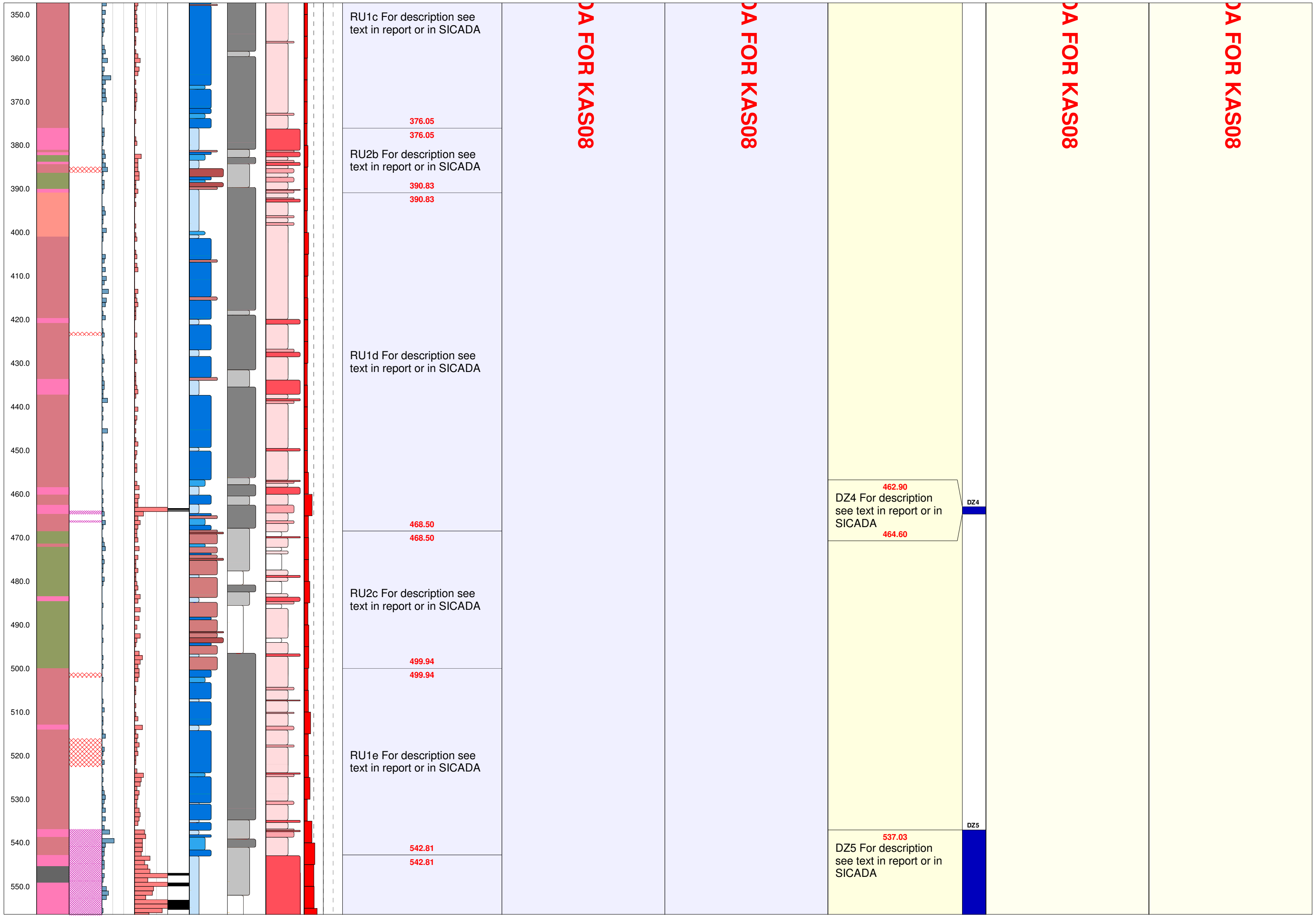
Page 2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DA FOR KAS08

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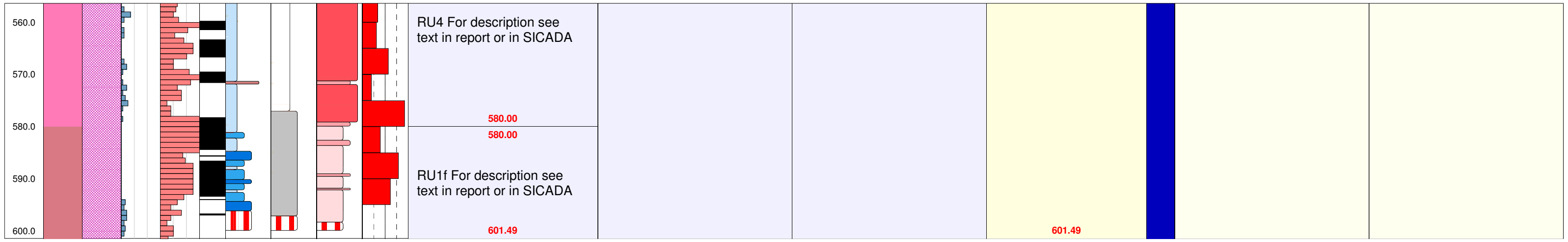
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