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Abstract

This report presents the outcome from a simplified geological single-hole interpretation (SHI) of three boreholes from the Äspö area (KA1061A, KA1131B and KBH02), which is one of the activities performed as part of the work for Äspö SDM. It also presents a revision of the rock type mapping for the boreholes.

The performed simplified geological single-hole interpretation deviates from the established SHI methodology of SKB, due to the fact that these older boreholes have an incomplete set of available input parameters, but follows the current nomenclature and methodology as far as possible and includes the following activities:

1. Merging sections of similar geological character along the drill core into rock units on the basis of lithological mapping and, when available, with support from density logs.
2. Identification of possible deformation zones based on inspection of the drill cores including characterization according to the criteria applied during the established SHI.

Most of the defined rock units are dominated by Äspö diorite (501037) or, less frequently, by Ävrö granodiorite (501056). Fine-grained granite (511058), gabbroid-dioritoid (508107) and diorite-gabbro (501033) typically occur as subordinate rock units. All rock units have been interpreted with a high degree of confidence.

In total, 20 possible deformation zones have been identified in the drill cores from the three boreholes, 18 with a high degree of confidence, one with a medium degree of confidence and one composite possible zone with both high and medium degrees of confidence. Ten of the possible deformation zones exceed 10 m in drill core length and the most extensive possible deformation zone occurs both in KA1131B and KBH02 at 102–203 and 155–253 m length, respectively. In addition to brittle deformation, ten of the possible deformation zones include sections of ductile and/or brittle-ductile deformation. The brittle component of the brittle-ductile deformation is typically characterized by epidote-sealed fracture networks.

Sammanfattning

Denna rapport presenterar resultaten från en förenklad geologisk enhålstolkning (SHI) utförd på tre borrhål från Äspöområdet (KA1061A, KA1131B och KBH02), som en delaktivitet i arbetet med den platsbeskrivande modelleringen av Äspö. I rapporten finns även en reviderad bergartskartering inkluderad.

Eftersom dokumentationen av de äldre borrhålen generellt är bristfällig avviker den förenklade geologiska enhålstolkningen från etablerad SHI metodik, men följer aktuell nomenklatur och metodik i möjligaste mån och inkluderar följande aktiviteter:

1. Sammanslagning av sektioner med likartad geologisk karaktär till bergenheter baserat på litologisk kartering, och i förekommande fall, med stöd av densitetsdata.
2. Identifiering av möjliga deformationszoner baserat på granskning av borrkärnorna och karaktärisering enligt kriterier som tillämpas vid etablerad SHI.

De flesta definierade bergenheterna domineras av Äspödiorit (501037) eller, mer sällan, Ävrö-granodiorit (501056). Underordnade bergenheter utgörs företrädelsevis av finkornig granit (511058), gabbroid-dioritoid (508107) och diorit-gabbro (501033). Alla bergenheter har tolkats med en hög konfidensgrad.

Totalt 20 möjliga deformationszoner har identifierats i borrkärnorna från de tre borrhålen, 18 med en hög konfidensgrad, en med en intermediär konfidensgrad och en sammansatt möjlig zon med både hög och intermediär konfidensgrad. Tio av de möjliga deformationszonerna överskrider 10 m i borrkärnelängd och den mest omfattande möjliga deformationszonen uppträder både i KA1131B och KBH02 vid 102–203 respektive 155–253 m längd. Utöver spröd deformation inkluderar tio av de möjliga deformationszonerna sektioner med plastisk och/eller spröd-plastisk deformation. Den spröda komponenten av den spröd-plastiska deformationen karaktäriseras generellt av epidotläkta spricknätverk.

Contents

1 Introduction

To support predictions and planning of experiments performed in the Äspö Hard Rock Laboratory (Äspö HRL), a site descriptive model (SDM) is under development. 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 SDM project is to incorporate existing borehole data from the earlier investigation, construction and operational phases of the Äspö HRL. This necessitates a reassessment of the data together with a renewed examination of selected drill cores, along with input from the experiences from the preceding site investigations at Forsmark and Laxemar-Simpevarp, as well as the SFR extension project.

A key input to the geological modelling during the site investigations at Forsmark and Laxemar-Simpevarp has been the geological single-hole interpretation (SHI) of borehole data. The established methodology provides an integrated synthesis of the geological and geophysical information in a borehole (SKB MD 810.003). Currently, borehole documentation from the older boreholes at Äspö is too sparse to allow the full application of the established SHI methodology, due to the lack of BIPS-images, obscurities in the geological documentation or lack of certain parameters such as fracture frequency, along with the fact that geophysical logs only exist for some of the boreholes.

During the modelling phase of the SFR extension project (Curtis et al. 2011), similar deficiencies in the borehole data were solved by the application of a *simplified* geological single-hole interpretation, which departs from the established SHI methodology, but follows the nomenclature and methodology of the current SHI procedure as far as possible (see Petersson et al. 2011). In this methodology, rock units consisting of sections of similar geological character were defined on the basis of available lithological mapping, which were translated into current SKB nomenclature. Possible deformation zones, on the other hand, were identified by visual inspection of the drill cores and characterized according to the criteria applied during the established SHI.

A first implementation of this simplified methodology for older borehole data from the Äspö HRL was made 2012, with the completion of totally 20 boreholes drilled during the period 1988–2002. The prime criterion for the selection of these boreholes was the expected crosscutting relationship with inferred deformation zones in the geological model established by Berglund et al. (2003) for Äspö. By the simplified SHI of these boreholes, the spatial coverage of the central part of the Äspö HRL is judged to be sufficient to allow facility scale modelling. However, there is still a lack of SHI data along the straight part of the Äspö tunnel, passing beneath the southernmost part of Äspö and Borholmsfjärden. Three of the longest, cored boreholes localized along this part of the tunnel were therefore selected for application of the simplified SHI technique.

The selected boreholes have a total length of approximately 1,117 m, confined to a minimum elevation of –210 m (RT90-RHB70). One of the boreholes, KBH02, is 706 m in length, whereas KA1061A is 203 m and KA1131B is 208 m in length, Figure 1-1 (Stanfors et al. 1997). Table 1-1 displays the drill core length, orientation and available geological and geophysical documentation of the boreholes. Drill cores were available for all three boreholes and have been mapped by the use of the Petrocore system.

This report outlines the results from the simplified geological single-hole interpretation of three boreholes drilled along the straight, upper part of the Äspö tunnel, which passes underneath the Borholmsfjärden, south of Äspö. It is one of the activities performed as part of the work for the Äspö SDM. The work was carried out in accordance with activity plan AP TD TDL-16-026, including reassessment of the existing rock type mapping for all three boreholes and photographing of drill cores from KBH02 in wet and dry conditions. In Table 1-2 the controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Table 1-1. Technical information and available geological/geophysical data for the three boreholes at Äspö which are included in the simplified geological single-hole interpretation.

Borehole ID	Drill core length (m)		Bearing[1] (°)	Inclination (°)	Mapping	BIPS	Geo-physics	New photos Drill core length (m)
	Sec_up	Sec_low						
KA1061A	0.00	208.50	337.78	0.57	Petrocore	–	X[2]	–
KA1131B	0.89	203.10	348.69	−12.90	Petrocore	–	X	–
KBH02	1.31	706.35	336.50	−44.99	Petrocore	–	–	0.00–706.35

[1)] RT90-RHB70.

[2)] Only radar.

Table 1-2. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Förenklad SHI av KBH02, KA1016A och KA1131B för Äspö platsbeskrivning	AP TD TDL-16-026	1.0
Method descriptions	**Number**	**Version**
Regler för bergarters benämningar för Laxemar-Simpevarpsområdet och för Äspölaboratoriet	SKB MD 132.004	3.0
Metodbeskrivning för Boremap-kartering	SKB MD 143.006	3.0
Instruktion för hantering och provtagning av borrkärna	SKB MD 143.007	3.0
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

Original data from the reported activity are stored in the primary database Sicada. Only data in SKB's databases are accepted for further interpretation and modelling work. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the associated P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

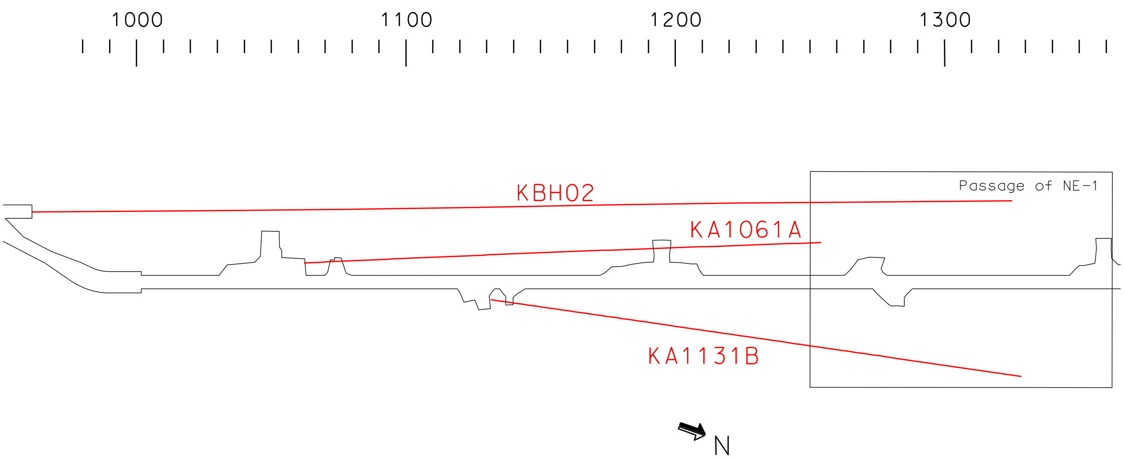

***Figure 1-1.** Location of bore holes KBH02, KA1061A and KA1131B. All three boreholes ends in the square denoted "Passage of NE-1". All three bore holes are colored red (Stanfors et al. 1997).*

1.1 Objective and scope

In order to facilitate the use of older borehole data in the development of a site descriptive model for the Äspö HRL, three boreholes drilled during the period 1990–1992 along the straight upper part of the Äspö tunnel have been subjected to a simplified geological single-hole interpretation (SHI) according to the methodology used by Petersson et al. (2011, 2017). This activity includes:

1. Merging sections of similar geological character into rock units on the basis of lithological mapping and, when available, with support from density logs.
2. Identification of possible deformation zones based on inspection of the drill cores including characterization according to the SHI criteria applied during the preceding site investigations at Forsmark and Laxemar-Simpevarp (i.e. SKB MD 810.003).

In those cases where borehole geophysical data are available, details have generally been included in the description of individual possible deformation zones. The results are presented both in Section 5.2 and in Appendix 1 as WellCAD plots.

A reassessment of the predominant rock types were performed for all three drill cores for decisions of possible revision of the former mapping.

These activities were complemented by photographing of the drill cores from KBH02 in wet and dry conditions.

1.2 Description of equipment/interpretation tools

The subdivision of the drill core into different rock units is initially based on a study of all the available geological data which are presented in a WellCAD log for a particular borehole. The log presents the results of the geological mapping, and if available, borehole geophysics.

The following equipment was used to facilitate the work with the drill cores: digital camera, folding rule, water sprayer and tap water.

2 Execution

2.1 General

During the identification of rock units and possible deformation zones, the drill cores were available in their full length on roller tables in the instrument storage building in Oskarshamn. The activity is solely based on ocular inspection of the drill core.

2.2 Reassessment of the predominant rock types

A reassessment of the predominant rock types were performed for all three drill cores as part of the SHI procedure. Decisions for revision of some intervals were exclusively based on ocular examination. Only rock types exceeding 1 m in drill core length were included in this work. Thus, the previously mapped alterations, fracture frequency and crushes were not subject to reassessment.

2.3 Photography of drill cores

The simplified geological SHI is complemented by photography of the drill cores in dry and wet conditions for KBH02, which lacked earlier documentation; photographs already existed for KA1061A and KA1131B. The activity follows SKB MD 143.007 and each photograph is named with borehole ID-code, box number and length interval.

2.4 Simplified geological single-hole interpretation

The available geological documentation does not comply with the SHI requirements of SKB MD 810.003, and therefore strict application of methodology has not been possible. However, it was decided to follow the nomenclature and methodology for the SHI procedure as far as possible and record all necessary deviations. Due to the deviations from the established methodology, the current activity described in this report has not been classified as a geological single-hole interpretation, but rather as a '*simplified* geological single-hole interpretation'. The methodology has previously been applied at older boreholes from both Äspö HRL (Petersson et al. 2017) and the construction of SFR in Forsmark (Petersson et al. 2011), but there is no specific method description available. The results are stored in the primary database Sicada as activity type GE299.

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. Density logs, which represent important input for the work, are only available for KA1131B (Table 1-1). A minimum length of about 5 m was used for rock units in the single-hole interpretations during the preceding site investigations at Forsmark and Laxemar-Simpevarp. 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. However, all rock units identified during the current work have been assigned a high confidence level.

The procedure to identify possible deformation zones is primarily based on inspection of the drill cores. Each identified possible deformation zone is defined in terms of the borehole length interval and provided with a brief description, which includes information of the rock types affected by the possible deformation zone, fracture character and frequency in general terms, as well as the existence of breccias, mylonites, cataclasites and bedrock alteration. A reassessment of each interval was done at the basis of the digital drill core images during the data compilation for this report. If judged necessary, the descriptions are adjusted. The confidence in the interpretation of a possible deformation zone is assigned according to three classes: 3 = high, 2 = medium and 1 = low.

Possible deformation zones may be brittle, ductile or combined brittle-ductile in character. In the latter case, the ductile or brittle-ductile component is typically concentrated to subsections of possible zones with an overall brittle character. Possible zones that are brittle in character have been identified primarily on the basis of the frequency of fractures, according to the concept presented in Munier et al. (2003). Brittle deformation zones defined by an increased frequency of extensional fractures (joints) or shear fractures (faults) are not distinguished. Both the damage zone (transition zone) and the core part of the deformation zone, with e.g. crushes, breccias and/or cataclasites, have been included in each zone (Figure 2-1). Zone core sections are generally identified wherever it has been possible. The presence of bedrock alteration has assisted in the identification procedure.

The borehole radar measurements in the surface boreholes were performed with the first generation of radar antenna and evaluation of radar data was at that time performed more or less manually by using different programs for the different steps of the evaluation. The interpretation of radar reflectors in KA1061A was focused on association with major fracture zones. However, directional antenna was available at the time for measuring the tunnel boreholes. Radar data have mostly been collected from Sicada and in some cases from radar reports. Orientations from radar data presented in this report are related to RT90. Generally, two alternatives for radar orientation are presented, firstly the radar directional primary and secondly the radar directional alternative. The direct radar pulse can be used as an indicator of the fracturing along the borehole wall, i.e. reduced direct radar pulse generally indicates increased fracturing.

2.5 Nonconformities

Methodology established during the preceding site investigations at Forsmark and Laxemar-Simpevarp has not been fully applied for the simplified geological single-hole interpretation. Table 2-1 presents the data limitations and deviations from SKB's method descriptions.

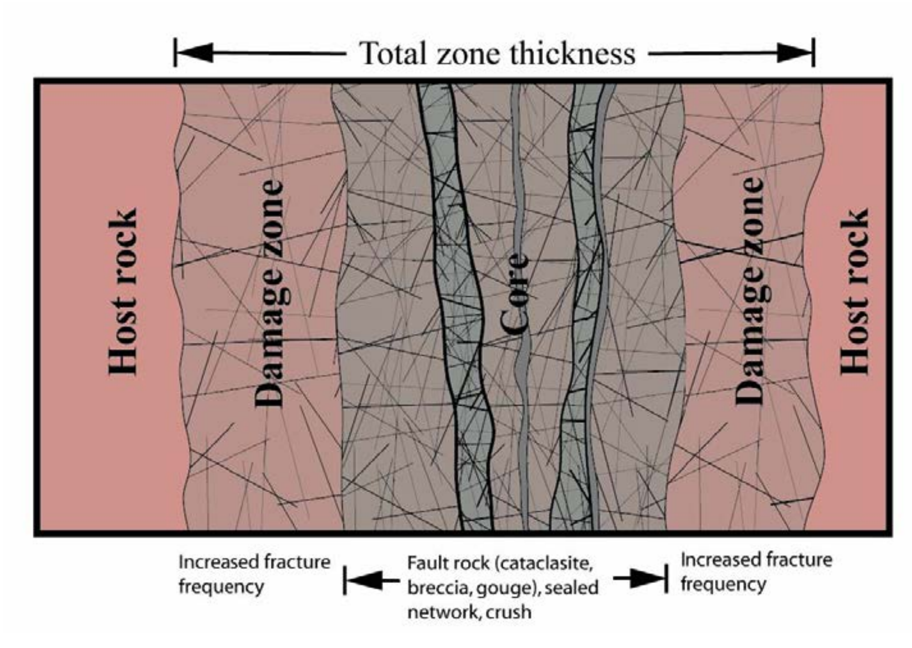

Figure 2-1. *Schematic illustration of the structure of a brittle deformation zone. Modified after Munier et al. (2003).*

Tabell 2-1. Deviations from SKB´s method description SKB MD 810.003 (v. 3.0) in the current work.

Included	Not included or specifically documented
Simplified geological single-hole interpretation (activity type GE299)	
Rock units (RU)	
Geological data with translated rock type nomenclature from Petrocore mapping	No BIPS- or TV-images are available
Geophysical logs: density, resistivity, magnetic susceptibility and natural gamma radiation are only available for KA1131B	Absence of geophysical information for KA1061A and KBH02
Possible deformation zones (PDZ)	
Identification was made based on direct drill core observations	Identification of possible deformation zones was performed despite lack of relevant data
Inspection of digital drill core images subsequent to the primary identification	

There are no geophysical logging data available for KBH02. For KA1061A the only geophysical data available are radar, directional antenna (frequency unknown). In KA1131B logging data were collected with most of the standard geophysical logging methods, including density, magnetic susceptibility, natural gamma radiation, resistivity and SPR. There are also radar data (directional antenna). However, no sonic, fluid temperature or caliper data are available. The density, magnetic susceptibility and natural gamma radiation data were length adjusted with reference to contacts between rock units identified in the geological mapping. No calibration of the geophysical data was carried out. The information from the geophysical borehole logging and radar measurements was attached after identification of possible deformation zones.

Since all three boreholes were mapped by the use of the Petrocore system, oriented fracture data are limited to some intervals in KA1061A (cf. WellCAD logs in Appendix 1).

3 Results

3.1 Reassessment of the predominant rock types

A major revision of the lithological mapping was prescribed by inaccuracies in rock type determinations as revealed during the SHI procedure. The changes made in the rock type mapping are summarized as follows:

- All intervals formerly inferred to be Ävrö granodiorite (501056) in KA1061A and KA1131B were converted to Äspö diorite (501037).
- Some of the intervals formerly inferred to be fine-grained granite (511058) in KA1061A and KA1131B are actually reddened (oxidized) Äspö diorite (501037) and has been changed accordingly.
- In KBH02, formerly mapped rock types in eleven intervals have been converted to Ävrö granodiorite (501056) and Äspö diorite (501037).

Further details of the rock type conversion are presented in Table 3-1, which include borehole length as well as former and current rock type name following SKB MD 132.004.

Tabell 3-1. Changes of the rock types mapping for KA1061A, KA1131B and KBH02. Note that none of the intervals converted from Ävrö granodiorite (501056) to Äspö diorite (501037) in KA1061A and KA1131B are included.

Borehole	Drill core length (m)		Former rock type		New rock type	
	Sec_up	Sec_low	ID code	Name	ID code	Name
KA1061A	48.17	51.60	511058	Fine-grained granite	501037	Äspö diorite
KA1061A	51.60	54.58	508004	Mylonite	501037	Äspö diorite
KA1061A	196.51	197.60	508002	Breccia	501037	Äspö diorite
KA1061A	197.60	198.35	508004	Mylonite	501037	Äspö diorite
KA1061A	198.35	199.73	508002	Breccia	501037	Äspö diorite
KA1061A	199.73	208.50	511058	Fine-grained granite	501037	Äspö diorite
KA1131B	170.43	172.97	511058	Fine-grained granite	501037	Äspö diorite
KBH02	42.65	53.76	501037	Äspö diorite	501056	Ävrö granodiorite
KBH02	55.45	69.65	501037	Äspö diorite	501056	Ävrö granodiorite
KBH02	374.30	385.62	511058	Fine-grained granite	501056	Ävrö granodiorite
KBH02	397.62	429.72	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	430.96	440.72	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	441.71	464.24	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	465.57	489.96	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	491.62	503.76	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	505.26	507.21	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	508.87	510.45	501056	Ävrö granodiorite	501037	Äspö diorite
KBH02	511.50	552.97	501056	Ävrö granodiorite	501037	Äspö diorite

3.2 Identification of rock units and possible deformation zones

The results of the identification of rock units and possible deformation zones in the three drill cores at Äspö are presented below and as print-outs from the software WellCAD in Appendix 1.

3.3 KA1061A

3.3.1 Rock units

The borehole can be divided into two different rock units, RU1–RU2. Rock unit 1 occurs in two separate intervals. Both rock units have been interpreted with a high degree of confidence.

RU1a (0.00–163.71 m)

Äspö diorite (501037) with several subordinate occurrences of fine-grained granite (511058) and a few minor of gabbroid-dioritoid (508107). Confidence level = 3.

RU2 (163.71–171.31 m)

Fine-grained granite (511058). Confidence level = 3.

RU1b (171.31–208.50 m)

Äspö diorite (501037) with several subordinate occurrences of fine-grained granite (511058). Confidence level = 3.

3.3.2 Possible deformation zones

Four possible deformation zones of brittle and, in some cases, brittle-ductile character have been identified in KA1061A, with a high degree of confidence.

DZ1 (46.00–55.60 m), brittle and ductile character

Increased frequency of fracture networks sealed by epidote and in the interval 51.4–54.5 m increased frequency of broken (open) fractures. The fractures are preferentially oriented parallel with the tectonic foliation in the Äspö diorite (501037). Predominant minerals in broken (open) fractures are chlorite and calcite. Intense ductile deformation (including grain-size reduction) parallel with the orientation of the tectonic foliation occurs in the interval 51.5–54.3 m. Oxidation and epidotization of weak to moderate, locally strong, intensity occur throughout the possible zone. Rock types: Äspö diorite (501037) and subordinate fine-grained granite (511058). Two radar reflectors intersect the borehole in this section, one at 51.90 m with orientation 128°/80° (or 187°/81°) and the other at 55.0 m with orientation 211°/78° (or 104°/78°). Confidence level = 3.

DZ2 (72.50–78.80 m), brittle and brittle-ductile character

Increased frequency of broken (open) fractures and sealed fracture networks. Several crushed intervals, especially at 73.9–74.5 m. Intense brittle-ductile deformation at 72.9–74.8 m. Predominant minerals in broken (open) fractures are Fe-oxyhydroxide, chlorite, quartz and calcite, and in unbroken (sealed) fractures, epidote. Moderate oxidation and epidotization throughout the possible zone. Rock types: Äspö diorite (501037) and subordinate fine-grained granite (511058). Two radar reflectors intersect the borehole in this section, one at 76.0 m with orientation 206°/69° (or 108°/70°) and the other at 77.0 m with orientation 236°/35° (or 81°/37°). Confidence level = 3.

DZ3 (163.00–172.50 m), brittle character

Highly increased frequency of broken (open) fractures, which are preferentially oriented parallel with the tectonic foliation in the fine grained granite (511058). Predominant minerals in broken (open) fractures are chlorite, calcite and locally fluorite. Moderate oxidation and in the Äspö diorite (501037) a weak to moderate epidotization. Rock types: Fine-grained granite (511058) and subordinate Äspö diorite (501037). No radar reflectors intersect the borehole in this section. Confidence level = 3.

DZ4 (194.50–208.50 m), brittle and brittle-ductile character

Increased frequency of broken (open) and unbroken (sealed) fractures occur. Several crushed intervals, especially at 204–208.5 m, and locally sealed fracture networks with partially sealed fractures and slight brecciation. Very locally, an intense brittle-ductile deformation occurs. Predominant minerals in broken (open) fractures are clay minerals, Fe-oxyhydroxide, chlorite, calcite and laumontite, and in unbroken (sealed) fractures, epidote and calcite. Moderate oxidation and weak chloritization throughout the possible zone. Rock types: Äspö diorite (501037) and subordinate fine-grained granite (511058). No radar reflectors intersect the borehole in this section. Confidence level = 3.

3.4 KA1131B

3.4.1 Rock units

The borehole can be divided into two different rock units, RU1–RU2. Rock unit 1 occurs in two separate intervals. Both rock units have been interpreted with a high degree of confidence.

RU1a (0.89–57.86 m)

Äspö diorite (501037) with several subordinate occurrences of fine-grained granite (511058) and a few minor of gabbroid-dioritoid (508107). The density averages at c. 2,800 kg/m^3. Confidence level = 3.

RU2 (57.86–65.87 m)

Fine-grained granite (511058). The average density is 2,600 kg/m^3, the natural gamma radiation is significantly increased and the magnetic susceptibility indicates no occurrences of magnetite. Confidence level = 3.

RU1b (65.87–203.10 m)

Äspö diorite (501037) with several subordinate occurrences of fine-grained granite (511058) and a few minor of gabbroid-dioritoid (508107). In the section 66–111 m the average density is c. 2,800 kg/m^3 and from 111 m to 199 m (end of survey) the average density is c. 2,775 kg/m^3. Confidence level = 3.

3.4.2 Possible deformation zones

Five possible deformation zones of brittle character have been identified in KA1131B, with a high degree of confidence, including one damage zone, which was assigned a medium confidence level.

DZ1 (0.89–16.10 m), brittle character

The possible zone consists of an inferred zone core at 13.1–16.1 m (confidence level = 3) and an associated damage zone at 0.89–13.1 m (confidence level = 2). The inferred zone core is characterized by the presence of crushed intervals, sealed fracture networks and an increased frequency of broken (open) and unbroken (sealed) fractures. The possible damage zone is distinguished by an increased frequency of epidote sealed fractures. Moderate oxidation and weak epidotization occur throughout the possible zone. Predominant minerals in broken (open) fractures are chlorite, calcite and locally fluorite. Rock types: Äspö diorite (501037) and fine-grained granite (511058). There are no geophysical data available in the section. No radar reflectors intersect the borehole in the section.

DZ2 (46.90–48.90 m), brittle character

Increased frequency of broken (open) and to some extent unbroken (sealed) fractures. Predominant minerals in broken (open) fractures are chlorite and calcite, and in unbroken (sealed) fractures, epidote. Weak to moderate oxidation occur in the Äspö diorite (501037). Rock types: Äspö diorite (501037) and subordinate gabbroid-dioritoid (508107). There is a clear decrease in the bulk resistivity and in the SPR along the entire section. One radar reflector intersects the borehole at 49.4 m, with orientation 227°/84° (or 115°/62°). Confidence level = 3.

DZ3 (57.70–66.00 m), brittle character

Increased frequency of broken (open) fractures, which coincides with an occurrence of fine-grained granite (511058). The fractures are generally fresh and appear to be sealed fractures that were reopened during the drilling. Predominant fracture minerals are calcite and chlorite, and locally fluorite. The fracture α-angle is typically ca 45°. Weak to moderate oxidation occur throughout the possible zone. Rock types: Fine-grained granite (511058). There is a clear decrease in the bulk resistivity and in the SPR along the entire section. One radar reflector intersects the borehole at 66.4 m, with orientation 107°/33° (or 241°/57°). Confidence level = 3.

DZ4 (87.70–88.90 m), brittle character

Increased frequency of broken (open) fractures, which coincides with an occurrence of fine-grained granite (511058). The fractures are generally fresh and appear to be sealed fractures that were reopened during the drilling. Predominant fracture minerals are calcite and chlorite, and locally fluorite. The fracture α-angle is typically ca 45°. Weak to moderate oxidation occur throughout the possible zone. Rock types: Fine-grained granite (511058). There are no significant anomalies in the geophysical logging data. One radar reflector intersects the borehole at 86.3 m, with orientation 79°/41° (or 259°/67°). Confidence level = 3.

DZ5 (101.8–203.10 m), brittle character

Brittle deformation of variable intensity, with the most intense fracturing in the interval 196.5–203.10 m, manifested by extensive, clay-bearing crushes. Also the interval 101.8–133.5 m is characterized by an increased frequency of broken (open) fractures and several crushed sections. Slightly increased frequency of unbroken (sealed) fractures, which locally forms sealed networks, and various degrees of oxidation (locally up to moderate or strong) occur throughout the possible zone. Predominant minerals in broken (open) fractures are, chlorite, calcite and Fe-oxyhydroxide, and in unbroken (sealed) fractures, epidote. Rock types: Äspö diorite (501037) and subordinate fine-grained granite (511058). No radar reflectors intersect the borehole in this section. Confidence level = 3.

3.5 KBH02

3.5.1 Rock units

The borehole can be divided into six different rock units, RU1–RU6. Rock unit 2 occurs in two separate intervals. All rock units have been interpreted with a high degree of confidence.

RU1 (1.31–18.48 m)

Diorite-gabbro (501033). Confidence level = 3.

RU2a (18.48–306.71 m)

Ävrö granodiorite (501056) with subordinate occurrences of fine-grained granite (511058). Confidence level = 3.

RU3 (306.71–374.30 m)

Fine-grained granite (511058) with subordinate occurrences of Ävrö granodiorite (501056). Confidence level = 3.

RU2b (374.30–385.62 m)

Ävrö granodiorite (501056) with minor occurrences of fine-grained granite (511058). Confidence level = 3.

RU4 (385.62–397.62 m)

Fine-grained granite (511058). Confidence level = 3.

RU5 (397.62–706.35 m)

Äspö diorite (501037) with subordinate occurrences of fine-grained granite (511058). Confidence level = 3.

3.5.2 Possible deformation zones

Elevenpossible deformation zones, whereof four of brittle character and seven of brittle-ductile character have been identified in KBH02, one with a medium degree of confidence and the other ten with a high degree of confidence.

DZ1 (13.20–13.90 m), brittle and ductile character

Increased frequency of broken (open) fractures preferentially oriented parallel with a precursor of intense ductile deformation with α-angle of approximately 45° to the drill core axis. Predominant fracture minerals are chlorite, calcite, Fe-oxyhydroxide and clay minerals. Oxidation of weak to moderate intensity occurs throughout the possible zone. Rock types: Diorite-gabbro (501033) and an unspecified granite. Confidence level = 2.

DZ2 (52.40–75.40 m), brittle and brittle-ductile character

Increased frequency of both broken (open) and unbroken (sealed) fractures. Locally epidote-sealed fracture networks, which in some cases exhibit ductile components. Predominant minerals in broken (open) fractures are, chlorite, calcite, Fe-oxyhydroxide and more rarely clay minerals, whereas the unbroken (sealed) fractures contain epidote and calcite. Oxidation of up to moderate intensity occurs. Local argillization occur also. Rock types: Ävrö granodiorite (501056). Confidence level = 3.

DZ3 (155.00–252.70 m), brittle and brittle-ductile character

Complex deformation of variable character, with a generally increased frequency of broken (open) fractures and several crushed intervals. More locally, an increased frequency of unbroken (sealed) fractures, sealed fracture networks and brittle-ductile deformation occur. Zone cores, characterized by crushes, sealed networks and locally brittle-ductile deformation, have been identified at 174.5–175.5, 188.4–193.0, 212.0–218.0 and 233.2–246.4 m. Predominant minerals in broken (open) fractures are, chlorite, calcite, Fe-oxyhydroxide and laumontite, whereas the unbroken (sealed) fractures mainly contain epidote. Varying degrees of oxidation occurs, from weak to strong intensity. Rock type: Ävrö granodiorite (501056). Confidence level = 3.

DZ4 (306.40–320.80 m), brittle character

Increased frequency of broken (open) fractures and some crushed intervals. Predominant fracture minerals are chlorite, Fe-oxyhydroxide, calcite and clay minerals. Moderate to strong oxidation occurs. Rock type: Fine-grained granite (511058). Confidence level = 3.

DZ5 (327.80–397.50 m), brittle character and brittle-ductile character

Brittle deformation of variable character with an increased frequency of unbroken (sealed) and especially broken (open) fractures. An interval of less intense fracturing occurs at 377–384 m. A zone core of brittle-ductile deformation has been identified at 359.5–361.5 m. Predominant minerals in broken (open) fractures are, chlorite, calcite, Fe-oxyhydroxide and locally clay minerals, whereas the unbroken (sealed) fractures mainly contain calcite and epidote. Oxidation of weak to strong intensity throughout the possible zone. Rock types: Fine-grained granite (511058) and Ävrö granodiorite (501056). Confidence level = 3.

DZ6 (470.00–473.20 m), brittle character

Increased frequency of broken (open) and unbroken (sealed) fractures. Locally epidote-sealed brecciation occurs. Predominant fracture minerals are chlorite, epidote, Fe-oxyhydroxide and calcite. Oxidation of weak to moderate intensity occurs throughout the possible zone. Rock type: Äspö diorite (501037). Confidence level = 3.

DZ7 (504.00–508.00 m), brittle and brittle-ductile character

Increased frequency of broken (open) and unbroken (sealed) fractures, generally with a brittle-ductile component. Predominant minerals in broken (open) fractures are chlorite and calcite, and in unbroken (sealed) fractures, epidote. Locally apertures in unbroken fractures occurs. Oxidation ranging up to strong intensity occurs also. Rock types: Äspö diorite (501037) and subordinate gabbroid-dioritoid (508107). Confidence level = 3.

DZ8 (619.60–634.70 m), brittle and brittle-ductile character

Increased frequency of broken (open) fractures, and in the fine-grained granite (511058), sealed fracture networks with brittle-ductile components and locally slight brecciation. A few fractures with low α-angles, but the majority of the α-angles is less than 45° relative to the drill core axis. Predominant minerals in broken (open) fractures are chlorite and calcite, and in unbroken (sealed) fractures, epidote. Oxidation of faint to moderate intensity occurs throughout the possible zone. Rock types: Äspö diorite (501037) and fine-grained granite (511058). Confidence level = 3.

DZ9 (650.00–652.50 m), brittle character

Epidote-sealed fracture network/breccia occurs in a crushed interval. Predominant minerals in broken (open) fractures are calcite, clay minerals and chlorite. Locally faint oxidation occurs. Rock types: Fine-grained variety of Äspö diorite (501037). Confidence level = 3.

DZ10 (660.70–671.20 m), brittle character

Increased frequency of broken (open) and unbroken (sealed) fractures. Predominant fracture minerals are chlorite, calcite and Fe-oxyhydroxide. Weak oxidation occurs. A zone core has been identified in the Äspö diorite (501037) at 668.3–670.1 m: moderate oxidation and epidote-sealed fracture network/breccia occur in a crushed interval. The inferred zone core intersects the drill core axis in a rather low angle ($\alpha < 45°$). Rock types: Äspö diorite (501037) and fine-grained granite (511058) with weak foliation. Confidence level = 3.

DZ11 (688.40–706.35 m), brittle and brittle-ductile character

Increased frequency of broken (open) fractures, which locally form crushed intervals. Also increased frequency of sealed fracture networks and slight brecciation, together with weak to moderate epidotization occur. Brittle-ductile deformation is concentrated to the following intervals: 692.2–692.6 and 694.3–696.1 m. Predominant fracture minerals are chlorite, Fe-oxyhydroxide, calcite and epidote. Oxidation ranging up to moderate intensity occurs throughout the possible zone. Rock types: Äspö diorite (501037) and subordinate fine-grained granite (511058) and minor quartz-rich pegmatite. Confidence level = 3.

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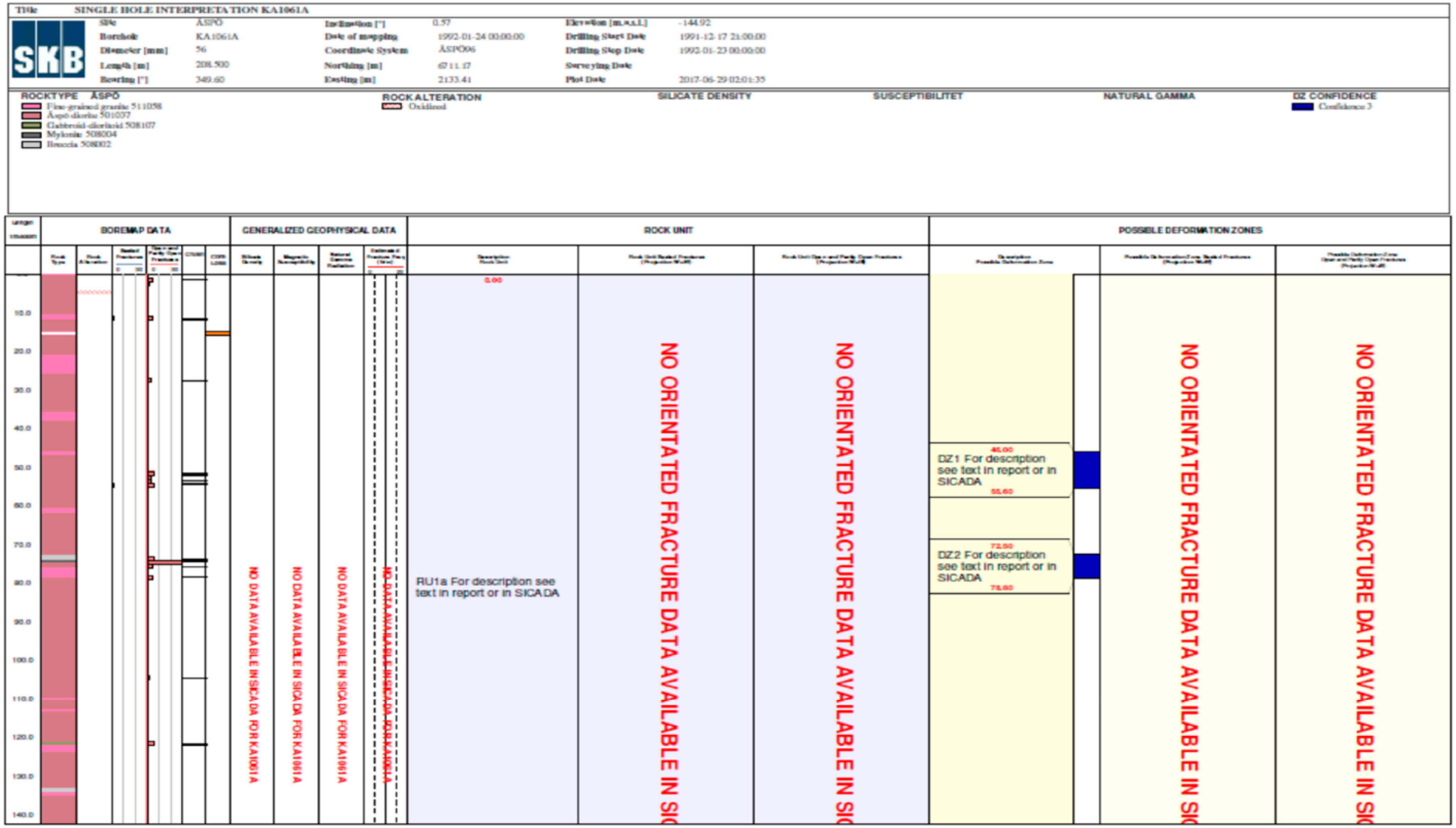
Appendix 1

Geological single-hole interpretation of KA1061A



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206.50
CADA FOR KA1061A
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163.71
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171.31
RU1b For description see text in report or in SICADA
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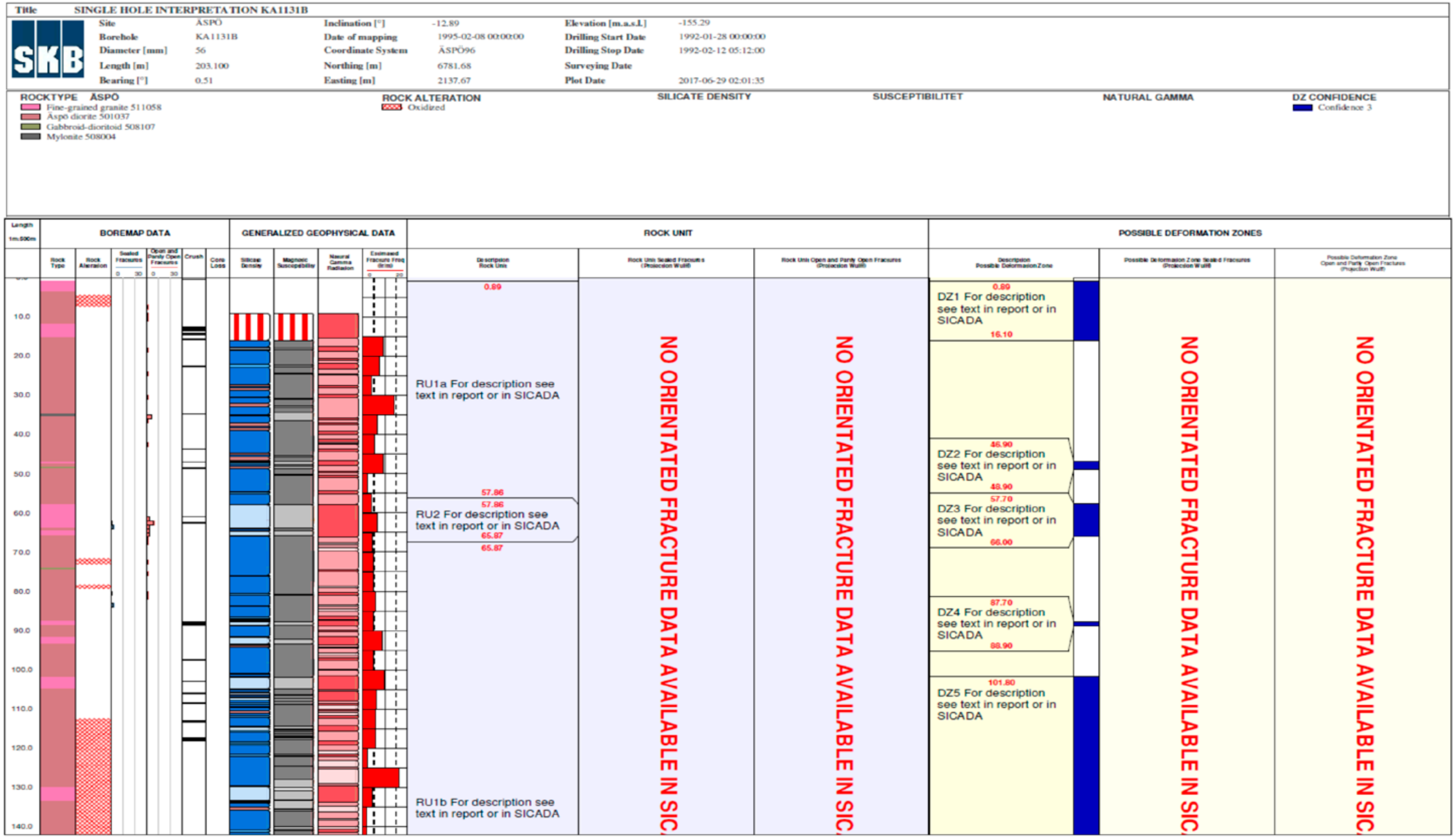
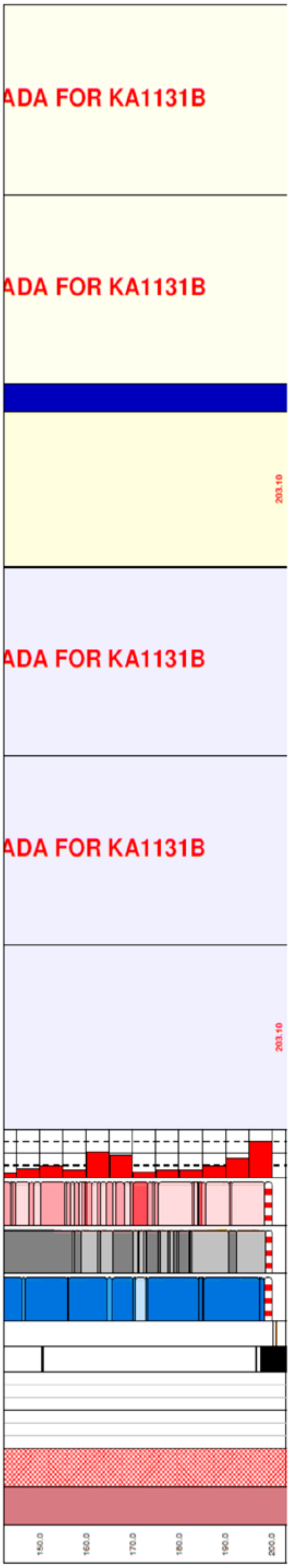
Appendix 2

Geological single-hole interpretation of KA1131B

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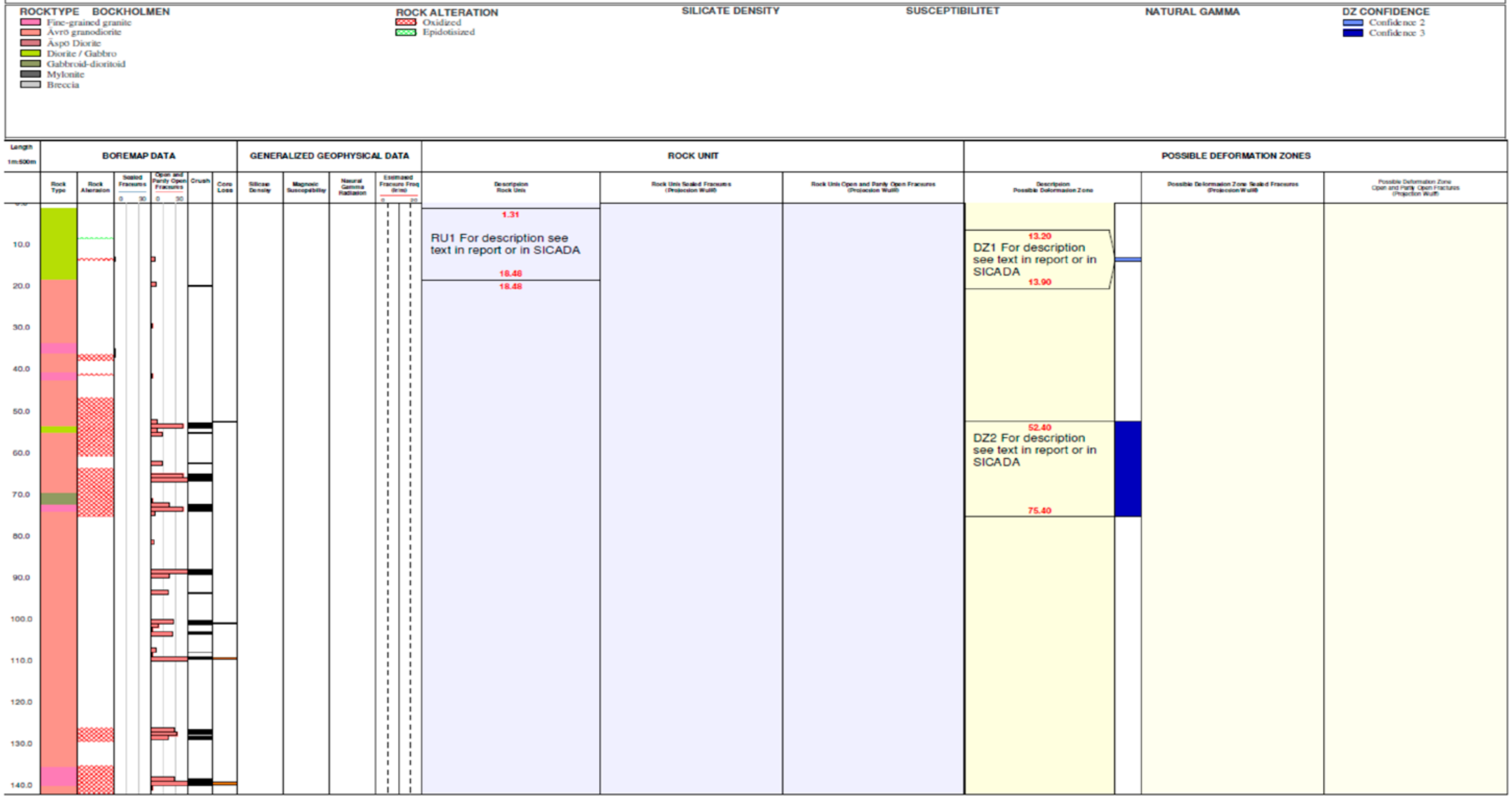
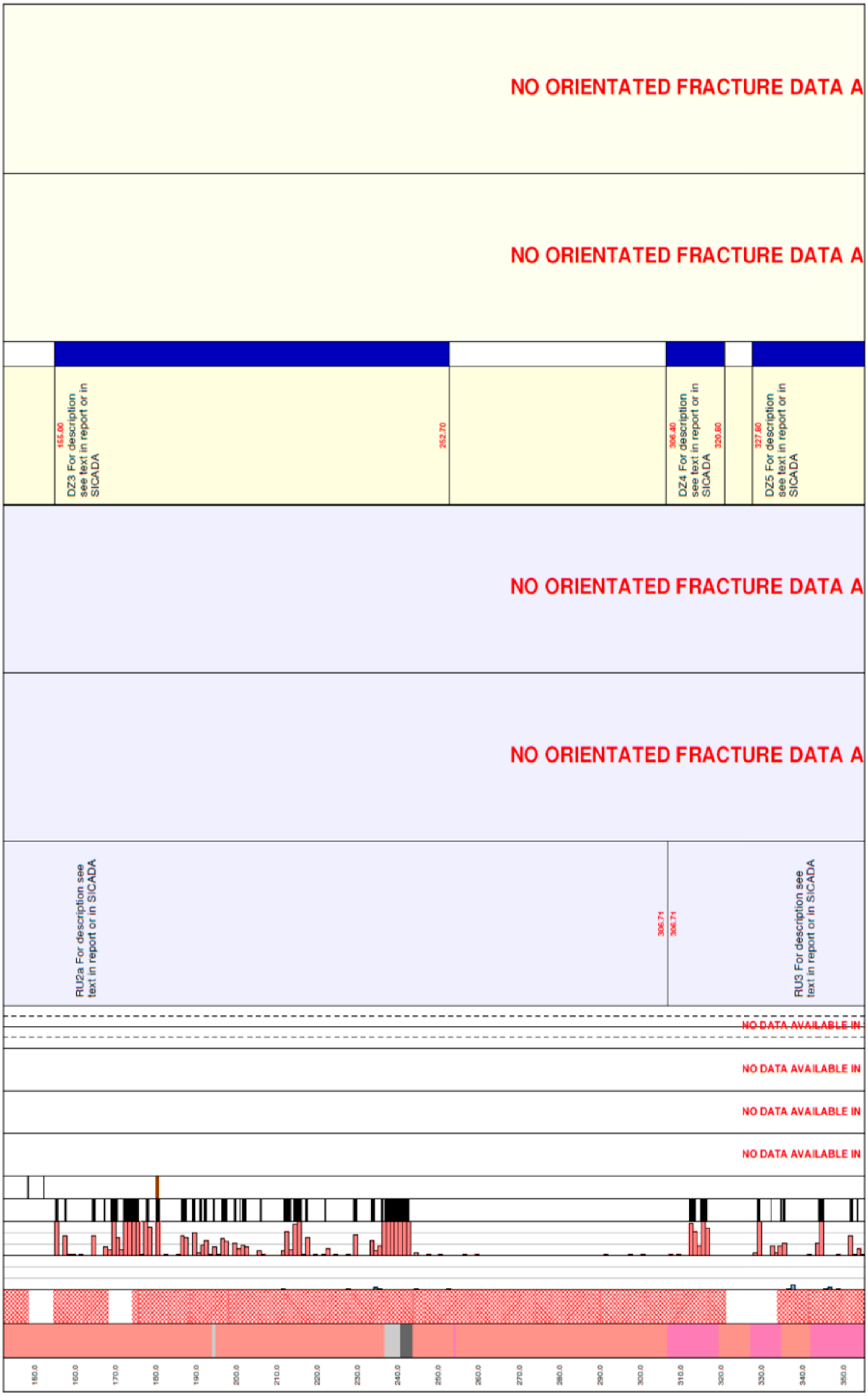
200.0

Appendix 3

Geological single-hole interpretation of KBH02

Title	SINGLE HOLE INTERPRETATION KBH02				
Site	BOCKHOLMEN	Inclination [°]	-44.99	Elevation [m.a.s.l.]	5.50
Borehole	KBH02	Date of mapping	1990-05-04 00:00:00	Drilling Start Date	1990-05-16 00:00:00
Diameter [mm]	56	Coordinate System	ÄSPÖ96	Drilling Stop Date	1990-05-17 00:00:00
Length [m]	706.350	Northing [m]	6313.83	Surveying Date	
Bearing [°]	348.32	Easting [m]	2170.59	Plot Date	2017-06-29 02:01:35

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DZ5 For description see text in report or in SICADA
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NO ORIENTATED FRACTURE DATA A
RU2a For description see text in report or in SICADA
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306.71
RU3 For description see text in report or in SICADA
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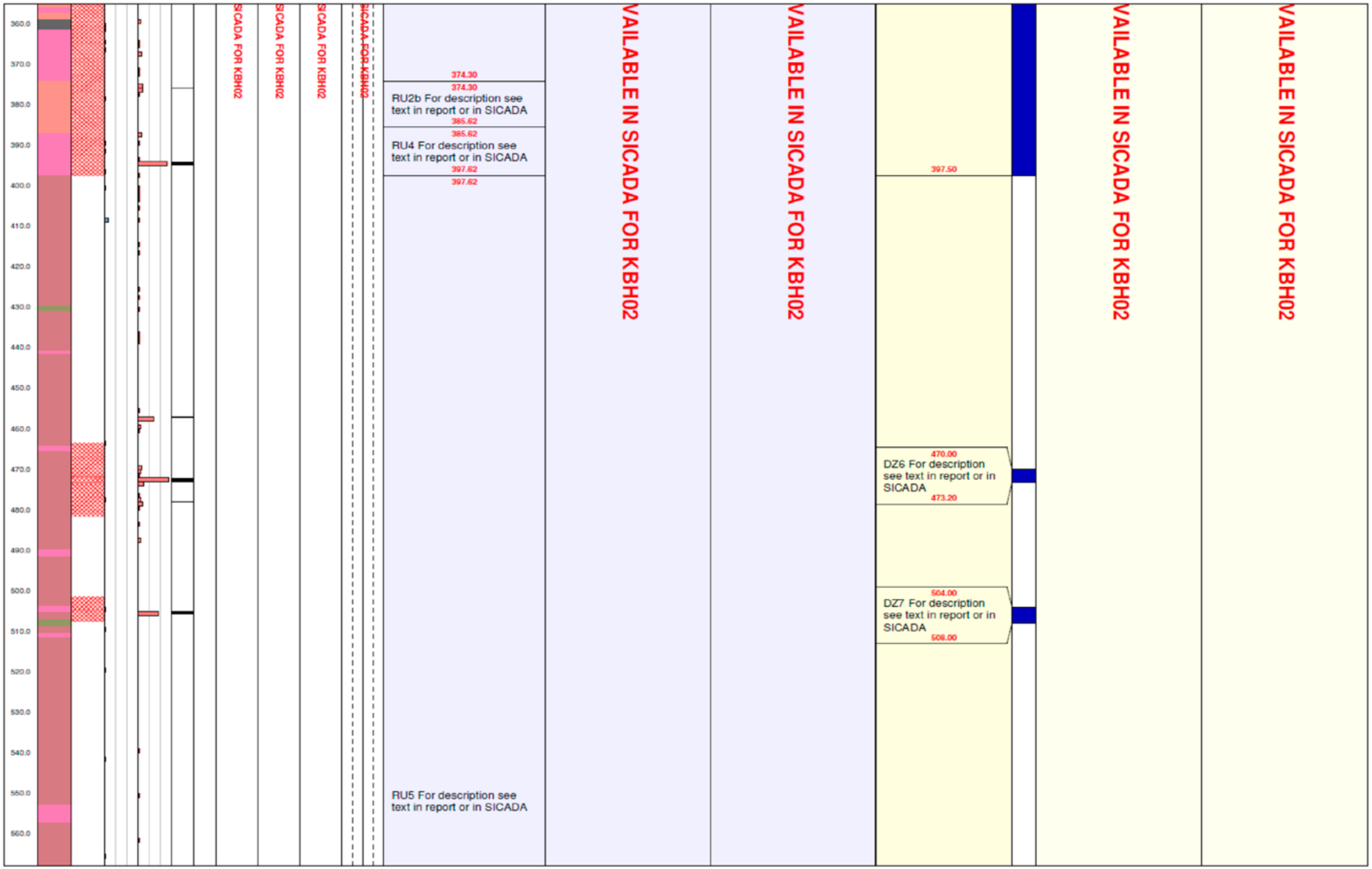
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SICADA FOR KBH02
SICADA FOR KBH02
SICADA FOR KBH02
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374.30
RU2b For description see text in report or in SICADA
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385.62
RU4 For description see text in report or in SICADA
397.62
397.62
RU5 For description see text in report or in SICADA
VAILABLE IN SICADA FOR KBH02
VAILABLE IN SICADA FOR KBH02
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DZ6 For description see text in report or in SICADA
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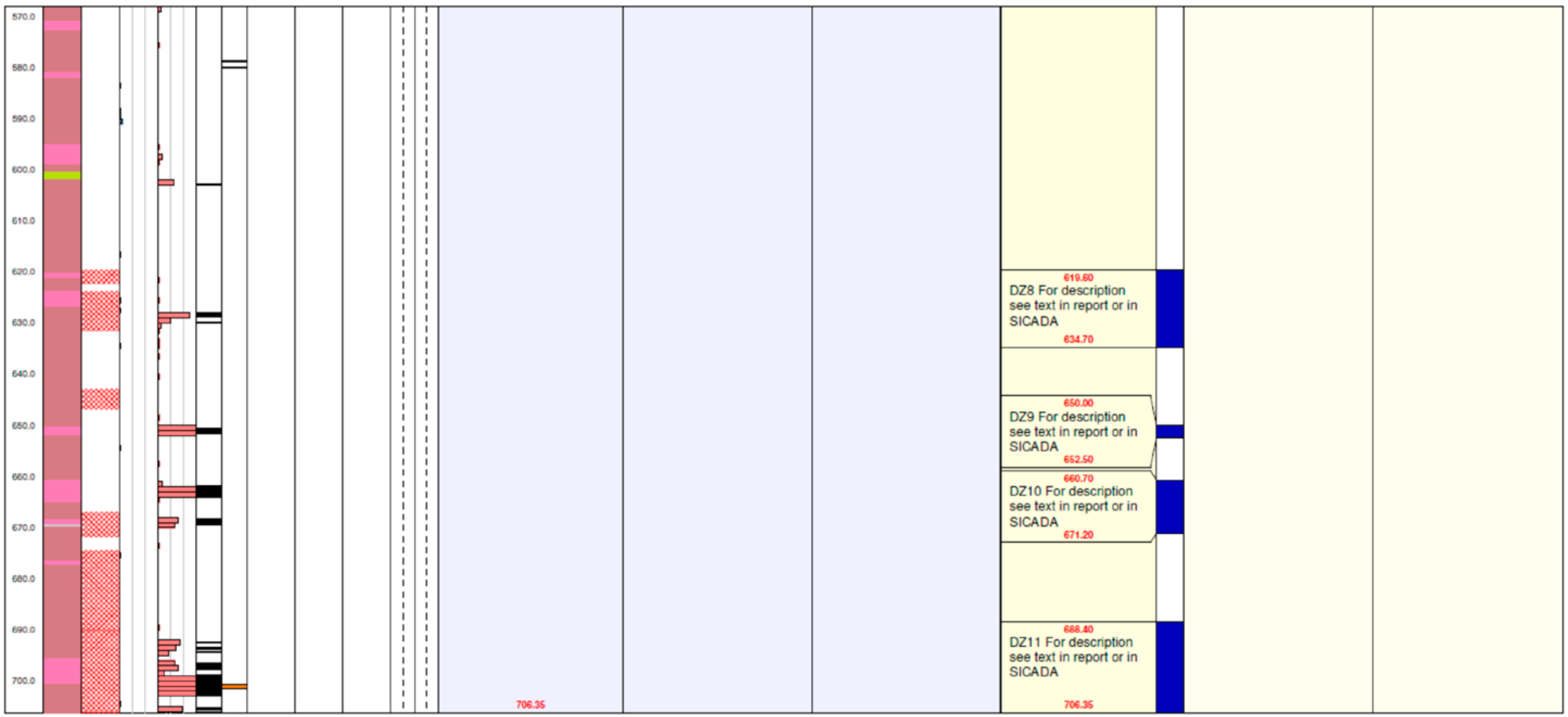
VAILABLE IN SICADA FOR KBH02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619.60
DZ8 For description see text in report or in SICADA
634.70
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671.20
688.40
DZ11 For description see text in report or in SICADA
706.35

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