P-04-32

Oskarshamn site investigation

Geological single-hole interpretation of KSH01A, KSH01B, HSH01, HSH02 and HSH03

Håkan Mattsson, GeoVista AB

Roy Stanfors, Roy Stanfors Consulting

Carl-Henric Wahlgren, Sveriges Geologiska Undersökning

Leif Stenberg, Peter Hultgren,
Svensk Kärnbränslehantering AB

March 2004

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-04-32

Oskarshamn site investigation

Geological single-hole interpretation of KSH01A, KSH01B, HSH01, HSH02 and HSH03

Håkan Mattsson, GeoVista AB

Roy Stanfors, Roy Stanfors Consulting

Carl-Henric Wahlgren, Sveriges Geologiska Undersökning

Leif Stenberg, Peter Hultgren,
Svensk Kärnbränslehantering AB

March 2004

Keywords: Geophysics, Geology, Borehole, Bedrock, Fractures.

Contents

1	**Introduction**	5
2	**Objective and scope**	7
3	**Data used for the single-hole interpretation**	9
3.1	Data used for method 1	9
3.2	Data used for method 2	9
3.3	Geophysical interpretation	9
4	**Execution of the single-hole interpretation**	11
5	**Results**	13
5.1	KSH01A	13
5.2	KSH01B	13
5.3	HSH01	13
5.4	HSH02	14
5.5	HSH03	14
6	**Discussion**	15
7	**Recommendation**	17
8	**References**	19
Appendix 1	Method 1. Results of the single-hole interpretations of KSH01A, KSH01B, HSH01, HSH02 and HSH03	21
Appendix 2	Method 2. Results of the single-hole interpretations of KSH01A and KSH01B	27

1 Introduction

Much of the primary geological and geophysical borehole data stored in the SKB database SICADA need to be integrated and synthesized before they can be used for modeling in RVS. The end result of this procedure is a geological single-hole interpretation, which consist of integrated series of different loggings and accompanying descriptive documents /1/.

The work was carried out in agreement with the instructions and guidelines from SKB (activity plan AP PS 400-03-038 and applicable parts of method description SKB MD 810.003, SKB internal controlling documents).

This document reports the geological single-hole interpretation, by the use of two methods, for the boreholes KSH01A, KSH01B, HSH01, HSH02 and HSH03 (Figure 1-1).

The methods are

1. Interpretation based on Boremap, geophysical loggings (raw data), interpretation of radar data and FZI.
2. Interpretation based on Boremap, pseudogeological loggings (statistically classified geophysical loggings), interpretation of radar data and FZI.

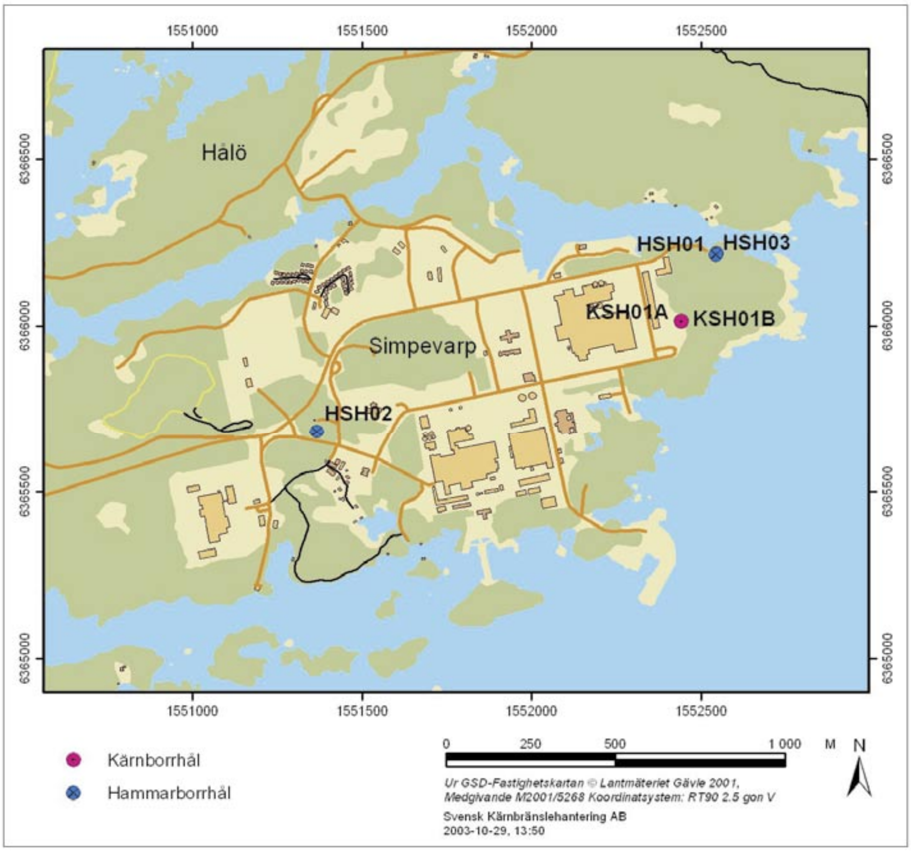


Figure 1-1. Map showing the position of the boreholes.

2 Objective and scope

The single-hole interpretation is performed in order to make a generalized classification of major lithological units and possible deformation zones within the borehole. The classification is performed manually by a combined interpretation of the different logging data. The results are presented as two comment-logs, one indicating the lithological unit (+ comments) at the corresponding depth co-ordinates and the other indicating the position and width of possible deformation zones (+ comments), see Figure 7-1 in Chapter 7 for an example of the presentation.

The main purpose of the work presented in this report is to perform and compare the single-hole interpretations for the boreholes KSH01A, KSH01B, HSH01, HSH02 and HSH03 based on two different methods. Based on this, we present our recommendation on how future single-hole interpretations should be performed. However, due to poor data quality of some of the geophysical loggings from the percussion drilled boreholes HSH01-HSH03 /2/, no single-hole interpretation is performed based on method 2 for these boreholes. Thus, a comparison between the two methods has only been performed for the cored boreholes KSH01A and KSH01B.

3 Data used for the single-hole interpretation

3.1 Data used for method 1

The data used for method 1 are:

- Boremap /3, 4/ (including BIPS and core mapping data).
- Geophysical loggings (raw data).
  For rock type identification: density, natural gamma and magn. susceptibility.
  For fracture identification: resistivity loggings, SPR, sonic and caliper.
- Interpreted radar data
- FZI (Fracture Zone Index, only used for KSH01A, KSH01B and HSH01) /5/.

3.2 Data used for method 2

The data used for method 2 are:

- Boremap (including BIPS and core mapping data).
- Pseudogeology, pseudofracture frequency and pseudoalteration (only used for KSH01A and KSH01A).
- Interpreted radar data.
- FZI (Fracture Zone Index, only used for KSH01A, KSH01B and HSH01).

3.3 Geophysical interpretation

The pseudogeology is the result of a maximum likelihood classification of rock types based on the methods gamma-gamma (density), natural gamma radiation and magnetic susceptibility /2/. The signatures of the different rock types have mainly been established by petrophysical measurements on core samples from KSH01A, KSH01B and partly also from a surface sampling /6/. The petrophysical database of core samples so far (2003-10-27) covers the rock types:

– quartz monzodiorite
– fine-grained dioritoid
– fine-grained granite
– granite (medium- to coarse-grained)
– fine-grained diorite to gabbro (only 2 samples)
– Ävrö granite (only 1 sample).

This means that the only possible rock types which may come out of the pseudogeological classification are the ones listed above. If the logging data do not fit any of the listed rock types the section is left unclassified. It is important to note that the petrophysical signatures of quartz monzodiorite and fine-grained dioritoid are very similar, which leads to the fact that these two rock types can not be significantly separated in the statistical classification.

Fractures are identified from the short normal resistivity, SPR, focused resistiviy (300 cm), caliper and sonic loggings. The position of fractures is calculated by applying a second derivative filter to the logging data and then locating maxima (or minima depending on the logging method) in the filtered logging. The estimated fracture frequency is calculated by applying a power function to the weighted sum of the maxima (minima) loggings. The power function is estimated by correlating the weighted sum to the true fracture frequency in one cored borehole (in our case KSH01A) /2/.

The investigation of geophysical logging data along sections of high intensity rock alteration zones in KSH01A indicates low density, low magnetic susceptibility and low natural gamma radiation along these sections. On basis of these data a "signature" of possible rock alteration was established which is used to create a logging of possible alteration zones within each of the investigated boreholes. The basic principle of the method is simply to identify sections where, simultaneously, the silicate density < 2800 kg/m^3, the magnetic susceptibility < 0.003 SI and the natural gamma radiation is < 20 μR/h.

4 Execution of the single-hole interpretation

The single-hole interpretation method is an integrated interpretation of the information from four sources, and these are the Boremap investigation, geophysical loggings, borehole radar data and FZI data. The interpretation is performed by a group of experts consisting of at least one geologist and one geophysicist. (Field notes: Simpevarp 12, Simpevarp 40, Simpevarp 43, Simpevarp 100 and Simpevarp 101, respectively.)

All data to be used (see above) are visualized side by side in a borehole document in the software WellCAD (see Appendices 1 and 2 for examples).

Step 1 is to manually (visually) go through the rock-type related logging data and merge sections of similar rock types, or sections where one rock type is very dominant, to a major lithological unit (minimum length of c 10 m). Four rock type descriptions (A-D) are representative for the bedrock in the investigated boreholes in the Simpevarp area.

Step 2 is to identify possible deformation zones by visual inspection of the fracture frequency loggings, alteration loggings, radar logging, FZI logging (only KSH01A and B) and the penetration rate logging (only HSH01-03). The section of each identified possible deformation zone is indicated and shortly described in text.

Two different methods on how to perform the single-hole interpretation are presented in this report. The two methods only differ in the way the geophysical loggings are presented. In method 1 (Figure 4-1) the raw data of 8 geophysical loggings are plotted and interpreted side by side. In method 2 (Figure 4-2) the 8 geophysical loggings are replaced by 3 pseudo-loggings, one displaying estimated lithology, one displaying possible alteration zones and the third shows an estimation of the fracture frequency.

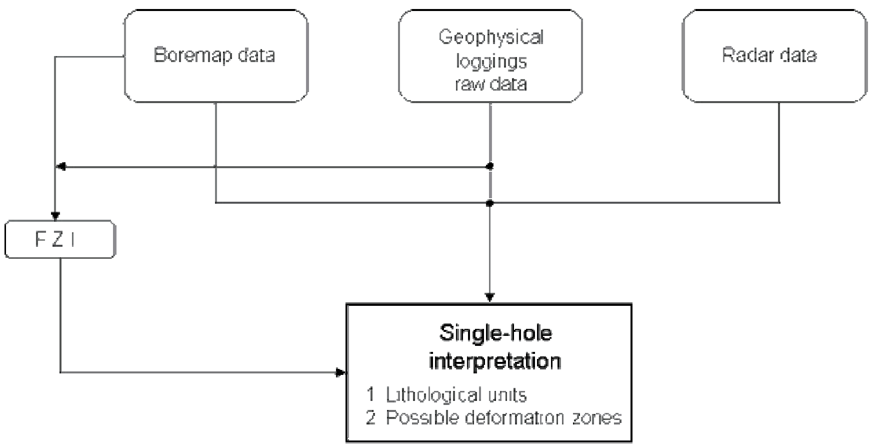


Figure 4-1. *Schematic block-scheme of single-hole interpretation, method 1.*

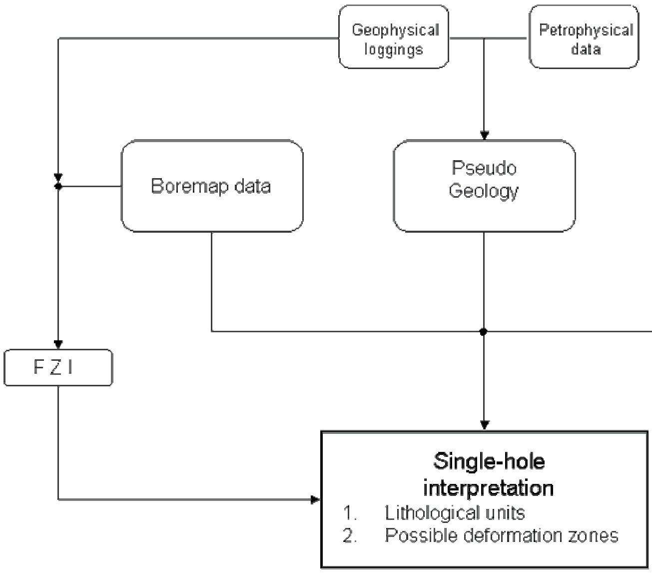


Figure 4-2. *Schematic block-scheme of single-hole interpretation, method 2.*

5 Results

The detailed results of the single-hole interpretations are presented as print-outs from the software WellCad (Appendices 1 and 2).

5.1 KSH01A

Method 1

The number of indicated lithological units is 7 and the number of indicated deformation zones is 13 (including low grade ductile zones). See Appendix 1 for a detailed presentation of the results.

Method 2

The number of indicated lithological units is 7 and the number of indicated deformation zones is 13 (including low grade ductile zones). See Appendix 2 for a detailed presentation of the results.

5.2 KSH01B

Method 1

The number of indicated lithological units is 1 and the number of indicated deformation zones is 0. See Appendix 1 for a detailed presentation of the results.

Method 2

The number of indicated lithological units is 1 and the number of indicated deformation zones is 0. See Appendix 2 for a detailed presentation of the results.

5.3 HSH01

Only method 1

The number of indicated lithological units is 2 and the number of indicated deformation zones is 2. See Appendix 1 for a detailed presentation of the results.

5.4 HSH02

Only method 1

The number of indicated lithological units is 2 and the number of indicated deformation zones is 4. See Appendix 1 for a detailed presentation of the results.

5.5 HSH03

Only method 1

The number of indicated lithological units is 3 and the number of indicated deformation zones is 1. See Appendix 1 for a detailed presentation of the results.

6 Discussion

A comparison between single-hole interpretation based on method 1 and method 2 shows good agreemen between the methods. There are two reasons for this. The first is that the Boremap data is given the most importance in both interpretations and thus give a strong influence on the results. Secondly, there is generally a good agreement between the Boremap data and the geophysical/pseudogeological data, both for lithological units and possible deformation zones.

The weakness of using geophysical raw data loggings (method 1) is fairly obvious. Even for a trained geophysicist it may be difficult, and time consuming, to simultaneously interpret eight different loggings. There is also an obvious risk of subjective influence on the results. To reduce the number of loggings and to create user friendly presentations we therefore suggest that different methods are combined. These are two reasons for the production of the pseudogeology loggings. For example, the pseudo fracture frequency combines five loggings into one, and the results so far look very promising (especially when considering the possible use of the technique in percussion drilled boreholes). A third reason for doing the pseudogeology loggings is that the results are based on independent measurements of physical properties and are therefore not biased by any subjective interpretation.

However, the pseudogeological "lithology" has been criticized for not managing to differ between rock types with similar petrophysical properties. The quartz monzodiorite and the fine-grained dioritoid have very similar physical properties and when comparing the boremap data and the pseudogeology, it is evident that large sections that are mapped as fine-grained dioritoid in boremap, are statistically classified by the pseudogeology as quartz monzodiorite, see Appendix 2.

To overcome this problem we therefore suggest that the pseudogeological lithology logging is replaced by simplified (generalized) versions of the three "rock-type-dependent" loggings silicate density, magnetic susceptibility and natural gamma radiation (see example in Figure 6-1 below). The pseudo fracture frequency is kept as it is, but we suggest that it is termed "estimated fracture frequency" instead. The pseudo alteration logging is also suggested to be kept as it is, but will be termed "possible alteration".

The generalized loggings take short time to produce. If the logging company can deliver data shortly after the completion of the measurements it is possible to produce the generalized logging well in time for the boremap investigation. In that case the geophysical loggings would be used in the single-hole interpretation and also serve as supportive information to the geologists during the boremap investigation. This has already been tried out for the mapping of KAV01, which immediately became much appreciated by the mapping crew.

In Chapter 7 below a recommendation on how to perform future single-hole interpretations is presented.

Figure 6-1. *Example of presentation of generalized geophysical loggings for KAV01, now in use as supportive information during the geological mapping.*

7 Recommendation

On basis of the results from this investigation we suggest the following procedure for future single-hole interpretations and treatment of geophysical logging data.

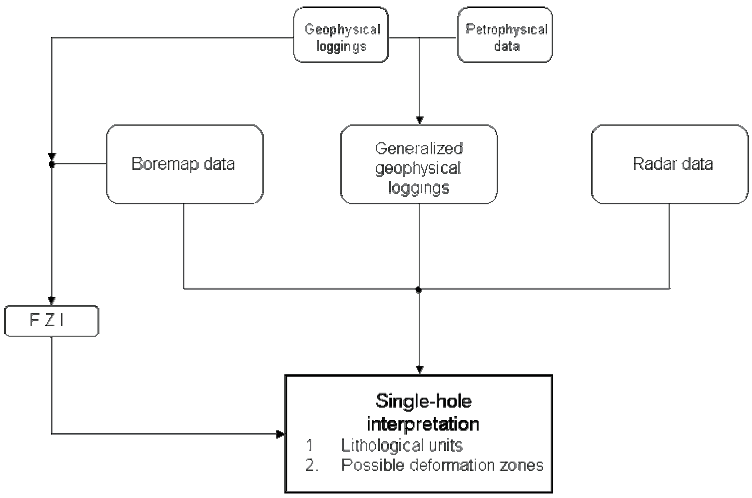
1. The logging company processes and delivers the geophysical logging data at the site, as soon as possible after (or during) the completion of the measurements. A quality control is performed on-line by a geophysicist, who controls the data quality and decides when the measurements are finished.

2. As soon as the logging data are approved, the production of the generalized loggings starts. The processed data is delivered to SKB to be used by the geologist performing the boremap investigation.

3. The boremap investigation is performed with support from the processed geophysical logging data. A short introduction (writing and/or oral) on how to use the geophysical data during mapping is given to the mapping crew by a geophysicist. Continuous communication between the mapping crew and the geophysicist is maintained through out the entire mapping procedure. A concise compilation of the petrophysical data of all known rock types in the area is placed at the mapping crew's disposal. If (when) new rock types are discovered these are sampled for petrophysical analyses, added to the data base, and their signatures can be identified in the geophysical logging data.

4. The single-hole interpretation is performed on basis of
   – Boremap
   – Generalized geophysical loggings
   – Interpreted radar data

   and it is performed according to the following scheme:



The FZI **can** be used during the single-hole interpretation, but may also be calculated at a later stage and used only in the RVS modeling work.

A new WellCAD script for the data is suggested to be used during the single-hole interpretation, see Figure 7-1 below for an example.

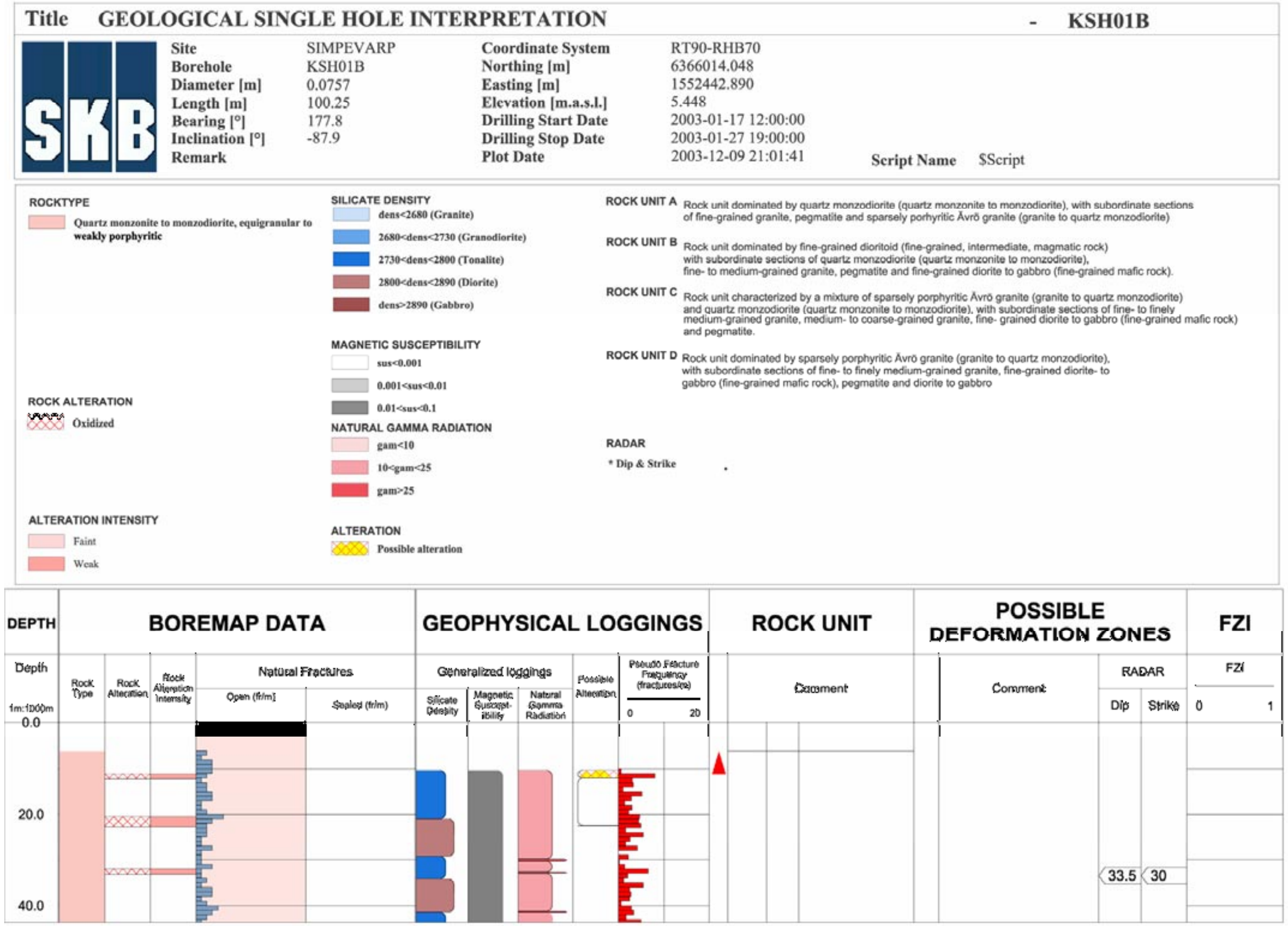


Figure 7-1. *Example from KSH01B of suggested presentation of single-hole interpretation layout.*

8 References

/1/ **SKB R-03-07.** Geological site descriptive model – a strategy for the model development during site investigations. Raymond Munier et al, 2003.

/2/ **SKB P-XX-XX.** Interpretation of geophysical borehole data from KSH01A, KSH01B, KSH02 (0-100 m), HSH01, HSH02 and HSH03, and compilation of petrophysical data from KSH01A and KSH01B. Håkan Mattsson and Hans Thunehed, GeoVista AB. In press.

/3/ **SKB P-04-01.** Boremap mapping of telescopic drilled boreholes KSH01A and KSH01B. Jan Ehrenborg and Vladislav Steiskal.

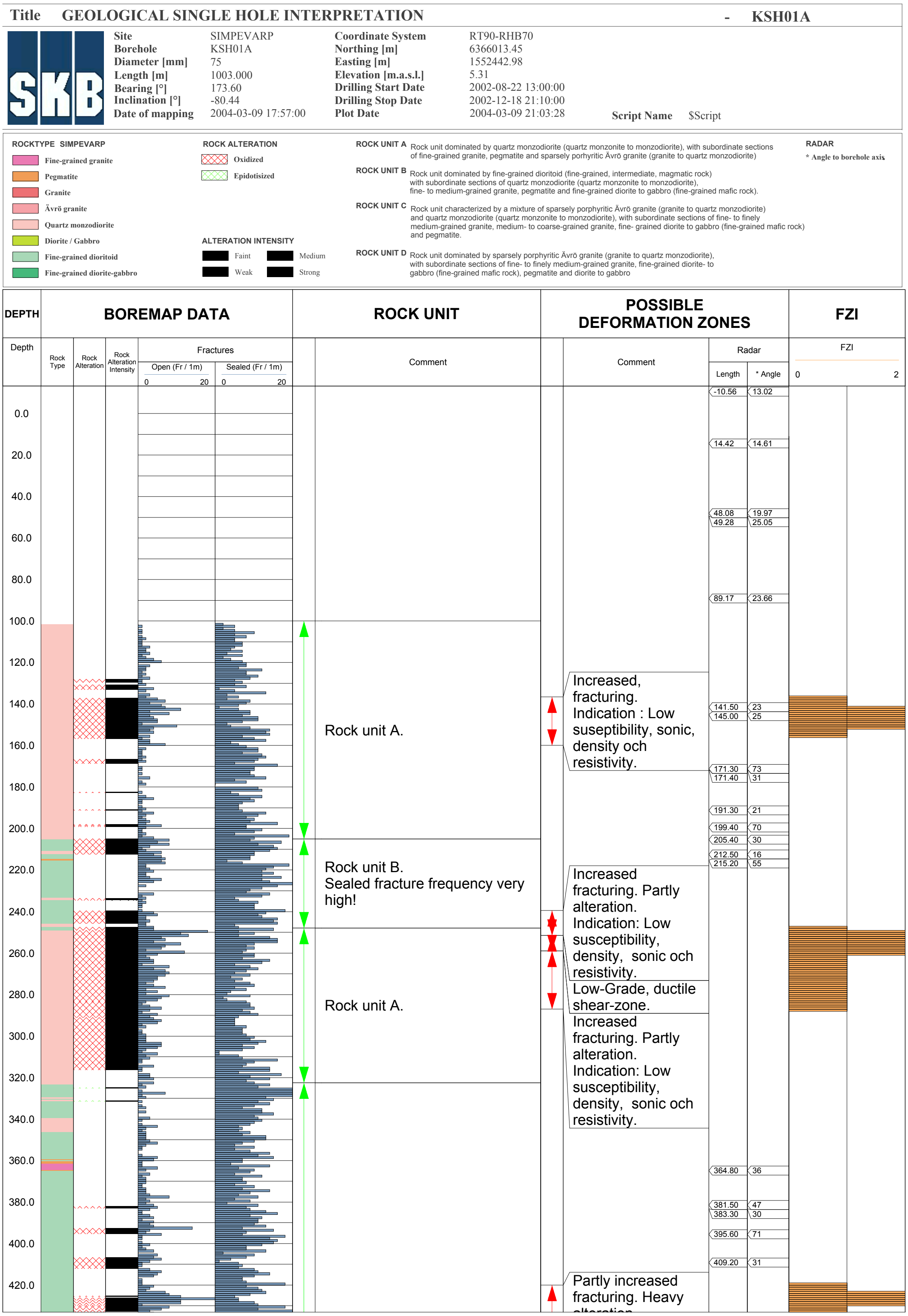
/4/ **SKB P-04-01.** Boremap mapping of percussion boreholes HSH01-03. Christin Nordman.

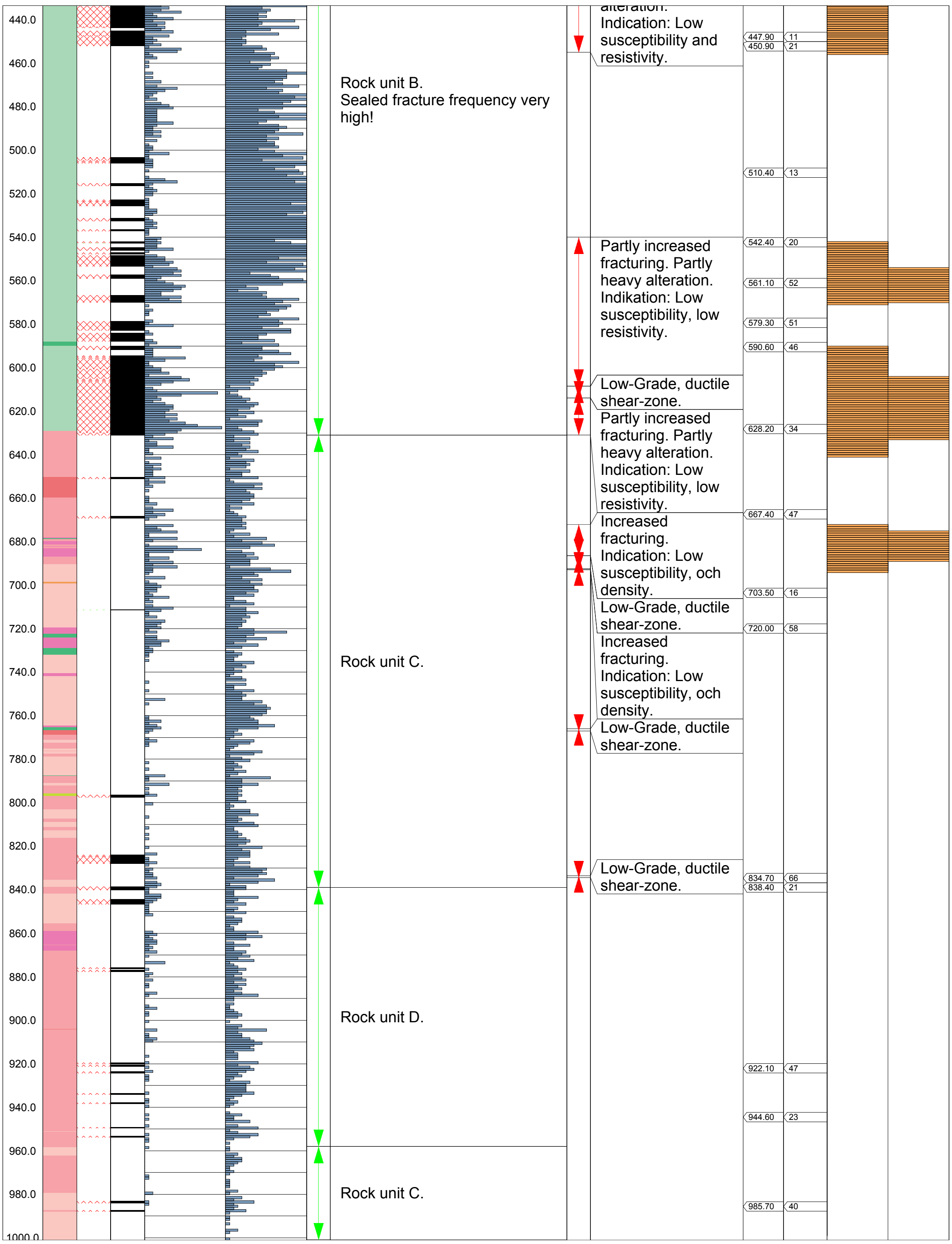
/5/ **SKB P-03-93.** Calculation of fracture zone index (FZI) for KSH01A. Lennart Lindqvist, Bergsten & Co i Värnamo AB, Hans Thunehed, GeoVista AB.

/6/ **SKB P-XX-XX.** Compilation of petrophysical data from rock samples and in situ gamma-ray spectrometry measurements Håkan Mattsson, Hans Thunehed and Carl-Axel Triumf, GeoVista AB. In press.

Appendix 1

Method 1. Results of the single-hole interpretations of KSH01A, KSH01B, HSH01, HSH02 and HSH03




440.0
460.0
480.0
500.0
520.0
540.0
560.0
580.0
600.0
620.0
640.0
660.0
680.0
700.0
720.0
740.0
760.0
780.0
800.0
820.0
840.0
860.0
880.0
900.0
920.0
940.0
960.0
980.0
1000.0
Rock unit B.
Sealed fracture frequency very high!
Rock unit C.
Rock unit D.
Rock unit C.
alteration. Indication: Low susceptibility and resistivity.
Partly increased fracturing. Partly heavy alteration. Indikation: Low susceptibility, low resistivity.
Low-Grade, ductile shear-zone.
Partly increased fracturing. Partly heavy alteration. Indication: Low susceptibility, low resistivity.
Increased fracturing. Indication: Low susceptibility, och density.
Low-Grade, ductile shear-zone.
Increased fracturing. Indication: Low susceptibility, och density.
Low-Grade, ductile shear-zone.
Low-Grade, ductile shear-zone.
447.90
450.90
510.40
542.40
561.10
579.30
590.60
628.20
667.40
703.50
720.00
834.70
838.40
922.10
944.60
985.70
11
21
13
20
52
51
46
34
47
16
58
66
21
47
23
40

Title	GEOLOGICAL SINGLE HOLE INTERPRETATION		- KSH01B
Site	SIMPEVARP	**Coordinate System**	RT90-RHB70
Borehole	KSH01B	**Northing [m]**	6366014.03
Diameter [mm]	75	**Easting [m]**	1552442.89
Length [m]	100.250	**Elevation [m.a.s.l.]**	5.20
Bearing [°]	177.76	**Drilling Start Date**	2003-01-17 12:00:00
Inclination [°]	-87.88	**Drilling Stop Date**	2003-01-27 19:00:00
Date of mapping	2003-03-13 14:46:00	**Plot Date**	2004-03-23 21:03:33

Script Name $Script

ROCKTYPE SIMPEVARP

Quartz monzodiorite

ROCK ALTERATION

Oxidized

ALTERATION INTENSITY

Faint

Weak

ROCK UNIT A Rock unit dominated by quartz monzodiorite (quartz monzonite to monzodiorite), with subordinate sections of fine-grained granite, pegmatite and sparsely porhyritic Ävrö granite (granite to quartz monzodiorite)

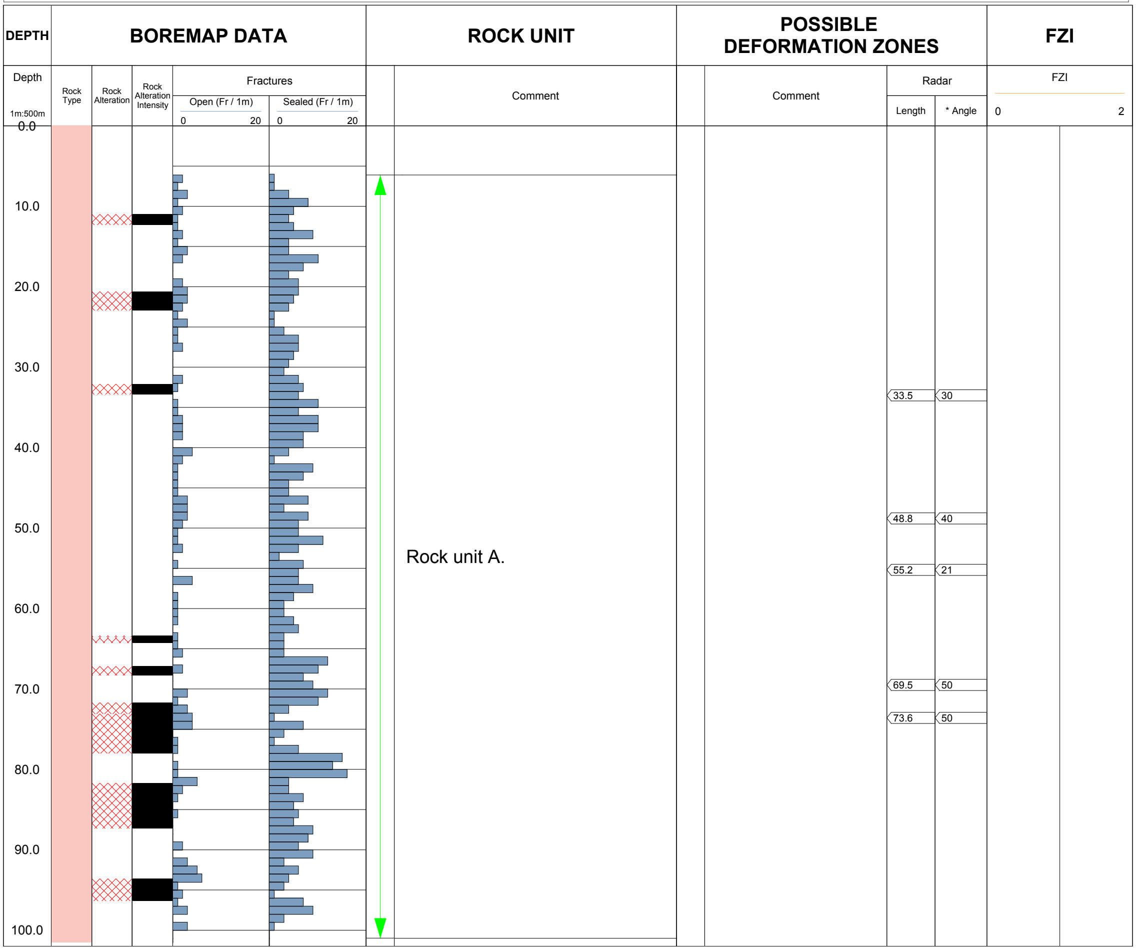
ROCK UNIT B Rock unit dominated by fine-grained dioritoid (fine-grained, intermediate, magmatic rock) with subordinate sections of quartz monzodiorite (quartz monzonite to monzodiorite), fine- to medium-grained granite, pegmatite and fine-grained diorite to gabbro (fine-grained mafic rock).

ROCK UNIT C Rock unit characterized by a mixture of sparsely porphyritic Ävrö granite (granite to quartz monzodiorite) and quartz monzodiorite (quartz monzonite to monzodiorite), with subordinate sections of fine- to finely medium-grained granite, medium- to coarse-grained granite, fine- grained diorite to gabbro (fine-grained mafic rock) and pegmatite.

ROCK UNIT D Rock unit dominated by sparsely porphyritic Ävrö granite (granite to quartz monzodiorite), with subordinate sections of fine- to finely medium-grained granite, fine-grained diorite- to gabbro (fine-grained mafic rock), pegmatite and diorite to gabbro

RADAR

* Angle to borehole axis



Title **GEOLOGICAL SINGLE HOLE INTERPRETATION HSH01**

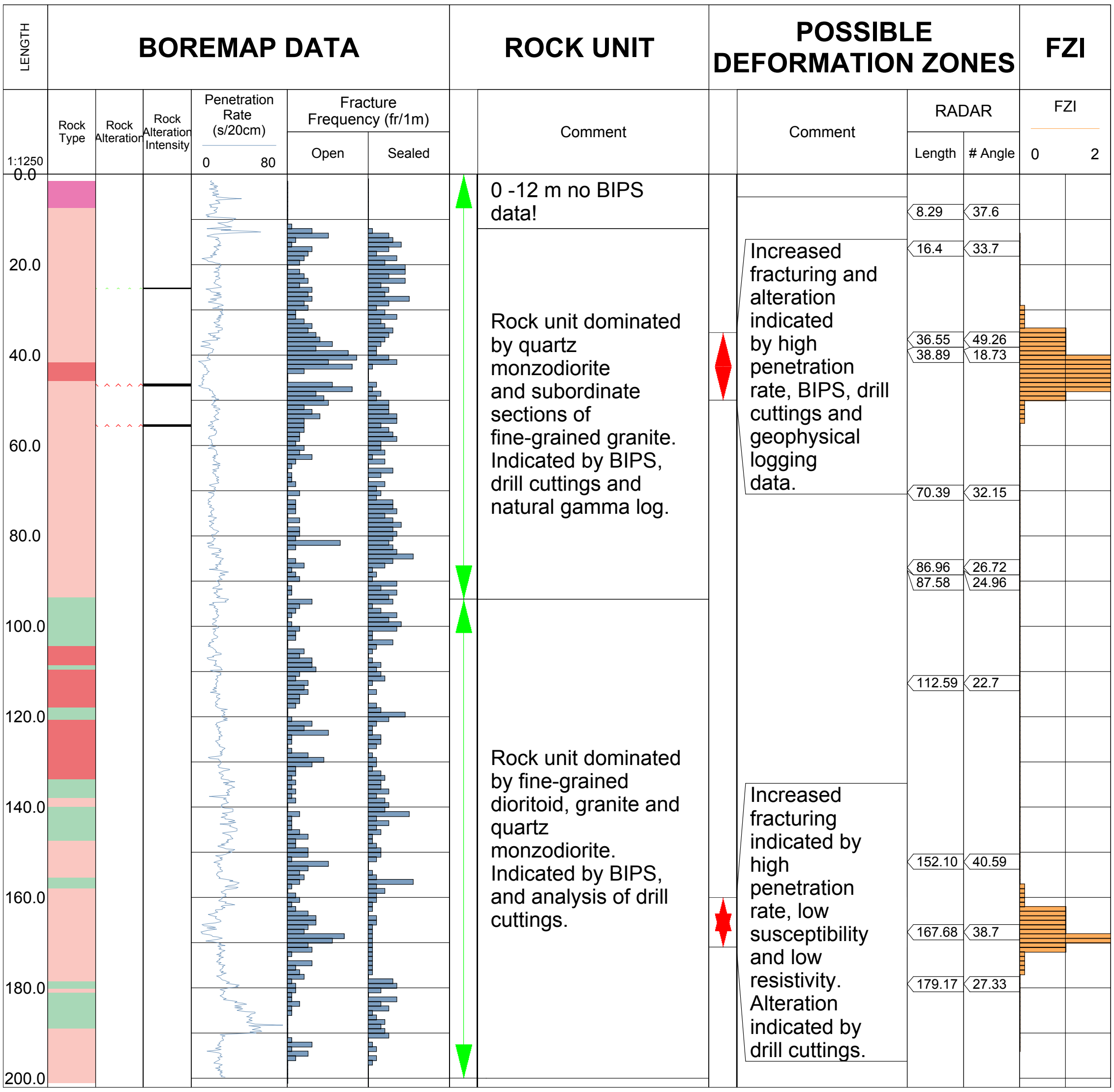
Site	SIMPEVARP	**Coordinate System**	RT90-RHB70
Borehole	HSH01	**Northing [m]**	6366217.77
Diameter [mm]	139	**Easting [m]**	1552545.71
Length [m]	200.000	**Elevation [m.a.s.l.]**	2.86
Bearing [°]	4.99	**Drilling Start Date**	2002-06-24 16:00:00
Inclination [°]	-69.99	**Drilling Stop Date**	2002-07-02 17:30:00
Date of mapping	2003-04-03 00:00:00	**Plot Date**	2004-03-24 21:03:42

ROCKTYPE
- Fine-grained granite
- Granite
- Quartz monzodiorite
- Fine-grained dioritoid

ROCK ALTERATION
- Oxidized
- Epidotisized

ALTERATION INTENSITY
- Weak
- Medium

RADAR
Angle to borehole axis



Title **GEOLOGICAL SINGLE HOLE INTERPRETATION HSH02**

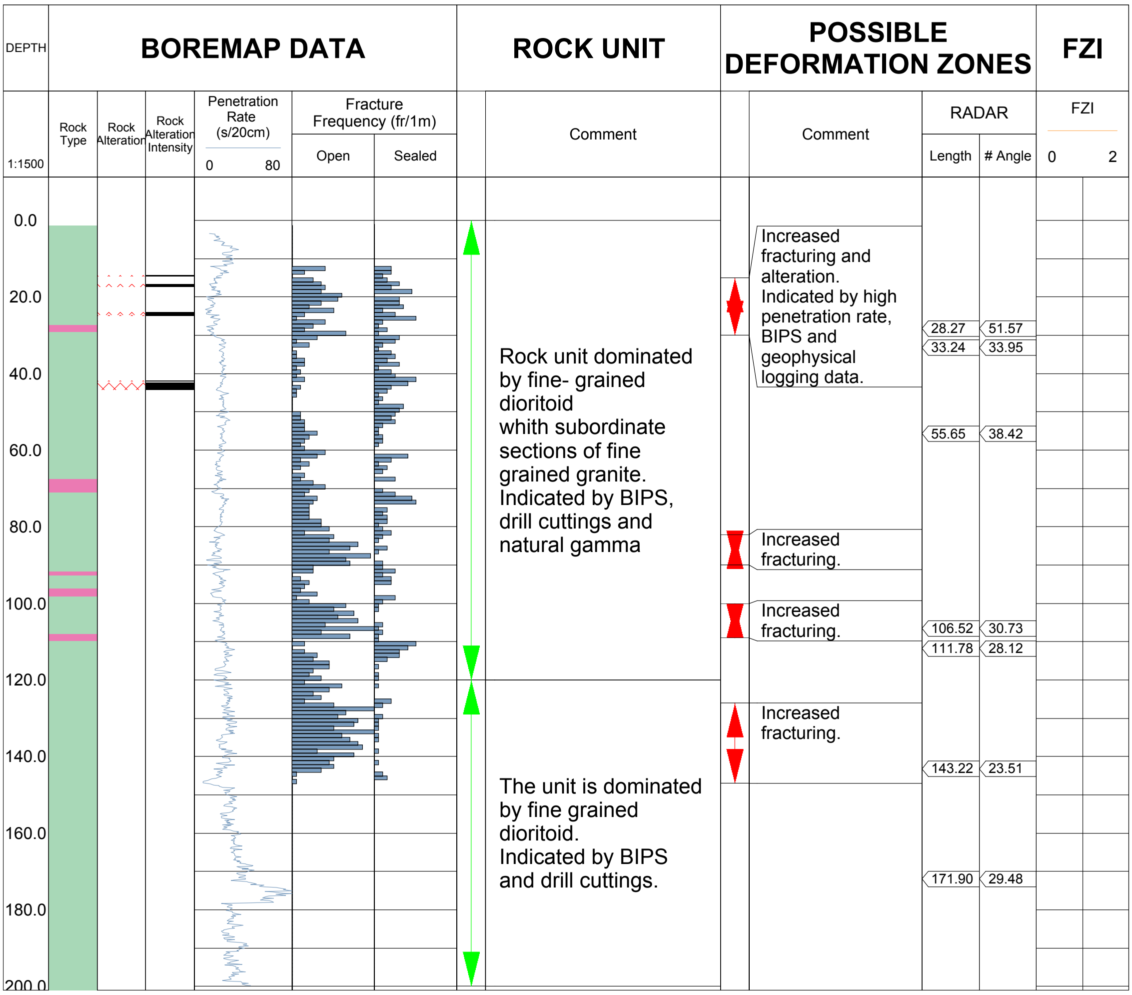
Site	SIMPEVARP	**Coordinate System**	RT90-RHB70
Borehole	HSH02	**Northing [m]**	6365682.89
Diameter [mm]	139	**Easting [m]**	1551368.33
Length [m]	200.000	**Elevation [m.a.s.l.]**	6.64
Bearing [°]	186.10	**Drilling Start Date**	2002-06-27 07:00:00
Inclination [°]	-80.08	**Drilling Stop Date**	2002-07-08 19:00:00
Date of mapping	2003-04-09 00:00:00	**Plot Date**	2004-03-24 21:03:42

ROCKTYPE
- Fine-grained granite
- Fine-grained dioritoid

ROCK ALTERATION
- Oxidized

ALTERATION INTENSITY
- Weak
- Medium

RADAR
- # Angle to borehole axis



Title	GEOLOGICAL SINGLE HOLE INTERPRETATION HSH03		
Site	SIMPEVARP	Coordinate System	RT90-RHB70
Borehole	HSH03	Northing [m]	6366213.94
Diameter [mm]	139	Easting [m]	1552544.52
Length [m]	201.000	Elevation [m.a.s.l.]	2.52
Bearing [°]	218.94	Drilling Start Date	2002-07-02 17:30:00
Inclination [°]	-79.49	Drilling Stop Date	2002-07-09 19:00:00
Date of mapping	2003-03-10 00:00:00	Plot Date	2004-03-24 21:03:42

ROCKTYPE

- Granite
- Ävrö granite
- Quartz monzodiorite

ROCK ALTERATION

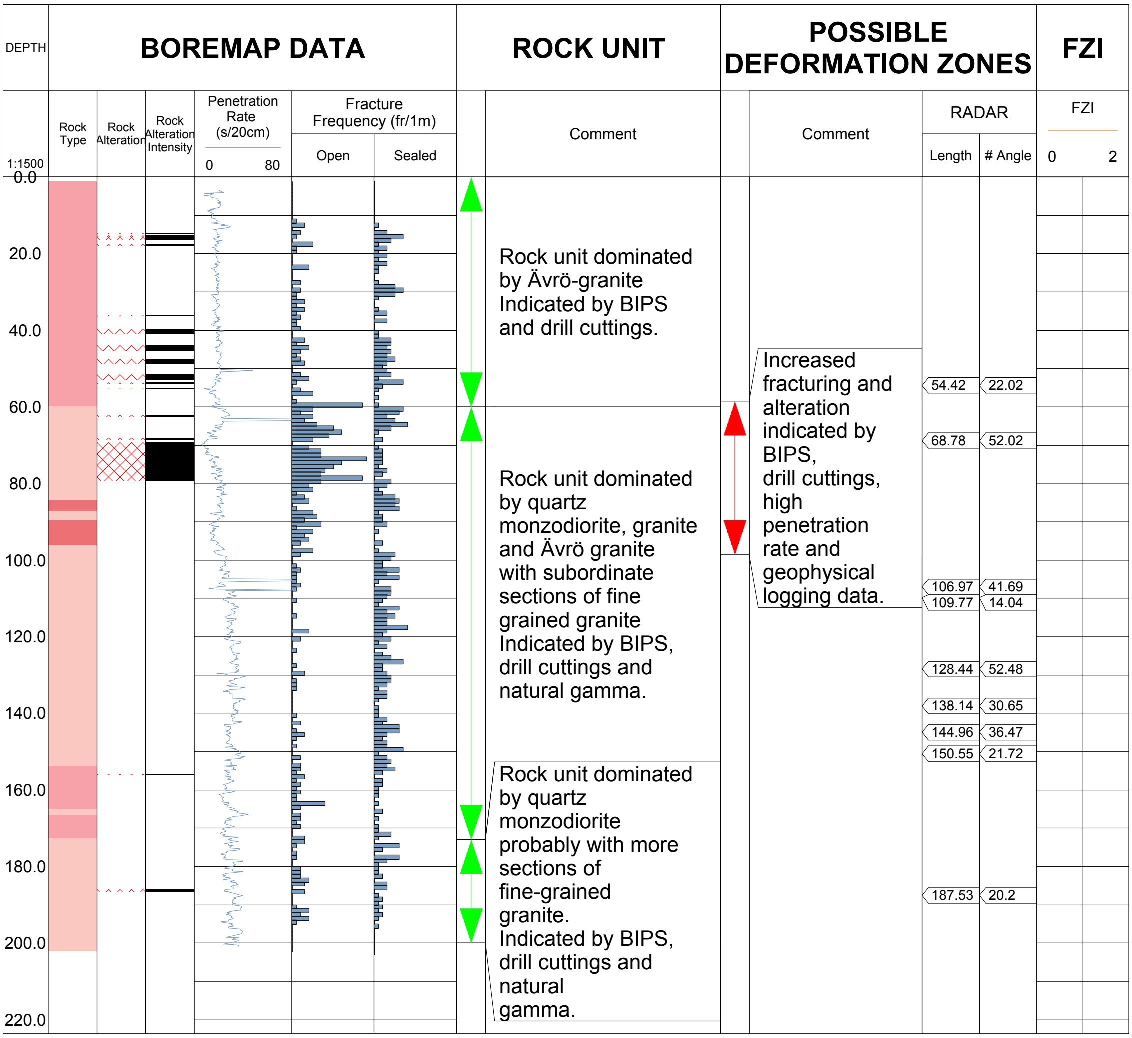
- Oxidized
- Epidotisized

ALTERATION INTENSITY

- Weak
- Strong
- Medium

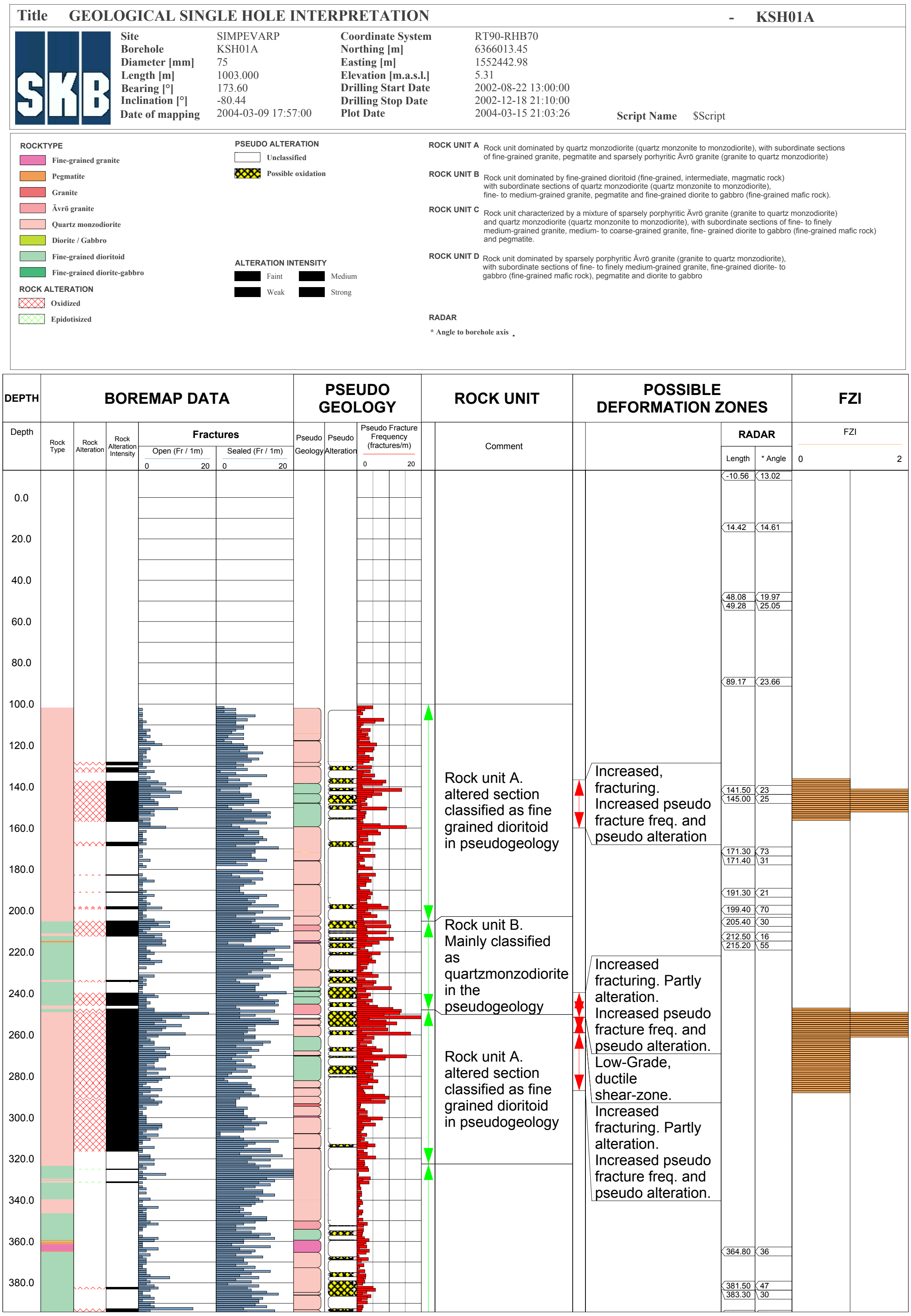
RADAR

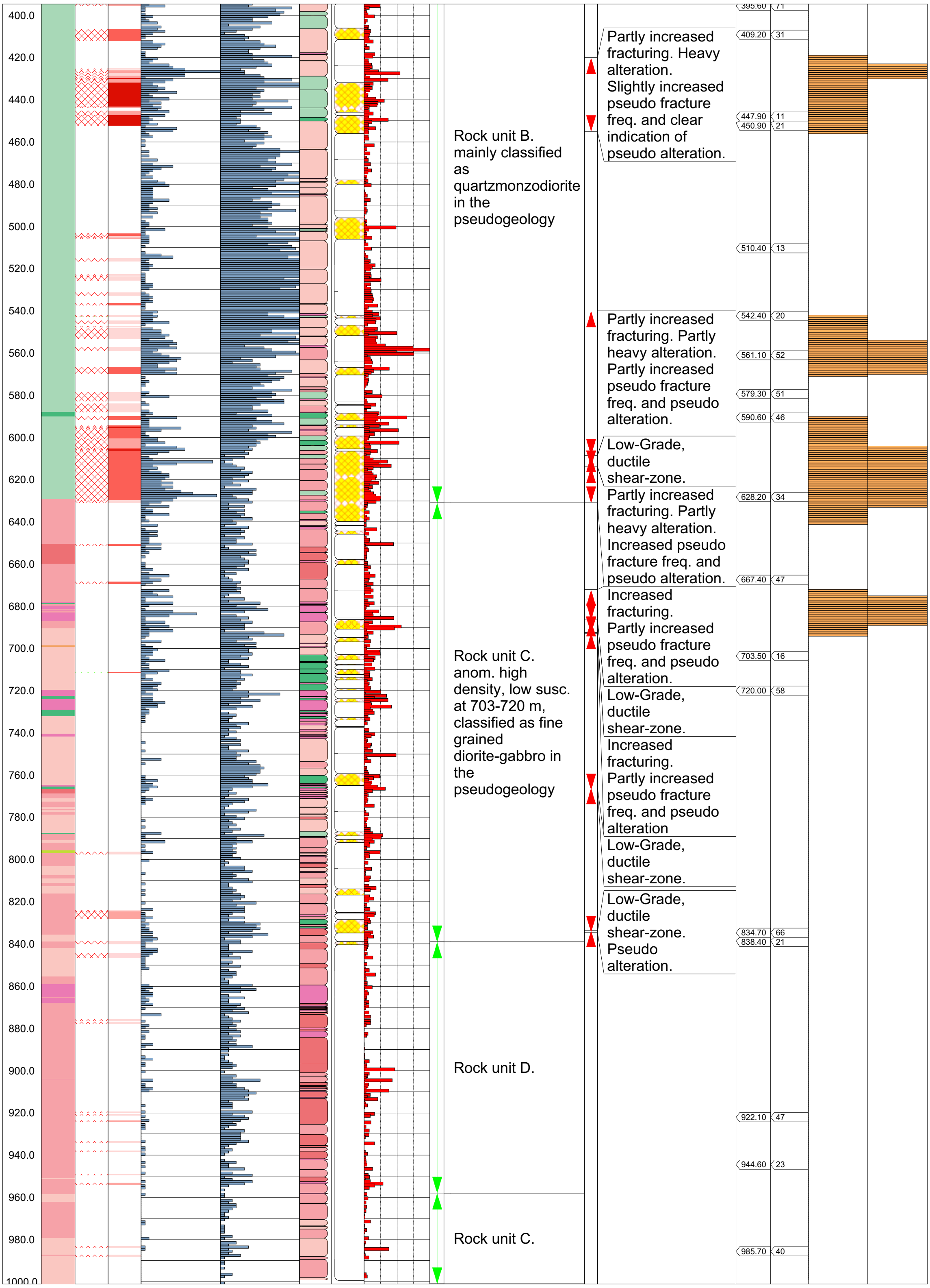
Angle to borehole axis



Appendix 2

Method 2. Results of the single-hole interpretations of KSH01A and KSH01B





400.0
420.0
440.0
460.0
480.0
500.0
520.0
540.0
560.0
580.0
600.0
620.0
640.0
660.0
680.0
700.0
720.0
740.0
760.0
780.0
800.0
820.0
840.0
860.0
880.0
900.0
920.0
940.0
960.0
980.0
1000.0
Rock unit B. mainly classified as quartzmonzodiorite in the pseudogeology
Rock unit C. anom. high density, low susc. at 703-720 m, classified as fine grained diorite-gabbro in the pseudogeology
Rock unit D.
Rock unit C.
Partly increased fracturing. Heavy alteration. Slightly increased pseudo fracture freq. and clear indication of pseudo alteration.
Partly increased fracturing. Partly heavy alteration. Partly increased pseudo fracture freq. and pseudo alteration.
Low-Grade, ductile shear-zone.
Partly increased fracturing. Partly heavy alteration. Increased pseudo fracture freq. and pseudo alteration.
Increased fracturing. Partly increased pseudo fracture freq. and pseudo alteration.
Low-Grade, ductile shear-zone.
Increased fracturing. Partly increased pseudo fracture freq. and pseudo alteration
Low-Grade, ductile shear-zone.
Low-Grade, ductile shear-zone. Pseudo alteration.
395.60 71
409.20 31
447.90 11
450.90 21
510.40 13
542.40 20
561.10 52
579.30 51
590.60 46
628.20 34
667.40 47
703.50 16
720.00 58
834.70 66
838.40 21
922.10 47
944.60 23
985.70 40

Title GEOLOGICAL SINGLE HOLE INTERPRETATION - **KSH01B**

Site	SIMPEVARP	**Coordinate System**	RT90-RHB70		
Borehole	KSH01B	**Northing [m]**	6366014.03		
Diameter [mm]	75	**Easting [m]**	1552442.89		
Length [m]	100.250	**Elevation [m.a.s.l.]**	5.20		
Bearing [°]	177.76	**Drilling Start Date**	2003-01-17 12:00:00		
Inclination [°]	-87.88	**Drilling Stop Date**	2003-01-27 19:00:00		
Date of mapping	2003-03-13 14:46:00	**Plot Date**	2004-03-15 21:03:26	**Script Name**	$Script

ROCKTYPE
Quartz monzodiorite

ROCK ALTERATION
Oxidized

PSEUDO ALTERATION
strong oxid thresh

ALTERATION INTENSITY
Faint
Weak

ROCK UNIT A Rock unit dominated by quartz monzodiorite (quartz monzonite to monzodiorite), with subordinate sections of fine-grained granite, pegmatite and sparsely porhyritic Ävrö granite (granite to quartz monzodiorite)

ROCK UNIT B Rock unit dominated by fine-grained dioritoid (fine-grained, intermediate, magmatic rock) with subordinate sections of quartz monzodiorite (quartz monzonite to monzodiorite), fine- to medium-grained granite, pegmatite and fine-grained diorite to gabbro (fine-grained mafic rock).

ROCK UNIT C Rock unit characterized by a mixture of sparsely porphyritic Ävrö granite (granite to quartz monzodiorite) and quartz monzodiorite (quartz monzonite to monzodiorite), with subordinate sections of fine- to finely medium-grained granite, medium- to coarse-grained granite, fine- grained diorite to gabbro (fine-grained mafic rock) and pegmatite.

ROCK UNIT D Rock unit dominated by sparsely porphyritic Ävrö granite (granite to quartz monzodiorite), with subordinate sections of fine- to finely medium-grained granite, fine-grained diorite- to gabbro (fine-grained mafic rock), pegmatite and diorite to gabbro

RADAR
* Angle to borehole axis