P-08-48

Oskarshamn site investigation

Geological single-hole interpretation of KLX27A

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Keywords: Geophysics, Rock unit, Borehole, Deformation zone, Fractures, Alteration.

Abstract

This report contains the geological single-hole interpretation of the cored borehole KLX27A at Laxemar. The interpretation combines the geological core mapping, interpreted geophysical logs and borehole radar measurements to identify rock units and possible deformation zones in the borehole.

The geological single-hole interpretation shows that the borehole KLX27A is dominated by quartz monzodiorite (501036) which constitutes one rock unit (RU1). Subordinate rock types comprise fine-grained granite (511058), fine-grained diorite-gabbro (505102),) and very sparse occurrences of granite (501058) and pegmatite (501061). Nine possible deformation zones are identified in KLX27A (DZ1–DZ9).

Sammanfattning

Denna rapport behandlar den geologiska enhålstolkning av kärnborrhål KLX27A i Laxemar. Den geologiska enhålstolkningen syftar till att utifrån den geologiska karteringen, tolkade geofysiska loggar och borrhålsradarmätningar identifiera olika litologiska enheters fördelning i borrhålet samt möjliga deformationszoners läge och utbredning.

Den geologiska enhålstolkningen visar att kärnborrhålet KLX27A domineras av kvartsmonzodiorit (501036) vilken utgör en bergartsenhet (RU1). Underordnade bergarter utgörs av finkornig granit (511058), finkornig diorit-gabbro (505102) och smärre förekomster av granit (501058) och pegmatit (501061). Nio möjliga deformationszoner har identifierats i KLX27A (DZ1–DZ9).

Contents

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 the 3D-CAD system Rock Visualization System (RVS). The end result of this procedure is a geological single-hole interpretation, which consists of integrated series of different loggings and accompanying descriptive documents (SKB MD 810.003 v.3.0, SKB internal controlling document).

This document reports the results gained by the geological single-hole interpretation of borehole KLX27A at Laxemar (Figure 1-1), which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-08-004. The controlling documents for performing this activity are listed in Table 1-1. Both activity plan and method description are SKB's internal controlling documents. Rock type nomenclature that has been used is shown in Table 1-2.

Figure 1-1. Map showing the position of the cored borehole KLX27A.

Table 1-2. Rock type nomenclature for the site investigation at Oskarshamn.

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
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
Sulphide mineralization	509010	Sulphide mineralization
Sandstone	506007	Sandstone

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

Activity plan	Number	Version
Geologisk enhålstolkning av KLX27A	AP PS 400-08-004	1.0
Method description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number (AP PS 400-08-004). Only data in SKB's databases are accepted for further interpretation and modelling. 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 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.

2 Objective and scope

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 work involves an integrated interpretation of data from the geological mapping of the borehole (Boremap), different borehole geophysical logs and borehole radar data. The geological mapping of the cored boreholes involves a documentation of the character of the bedrock in the drill core. This work component is carried out in combination with an inspection of the oriented image of the borehole walls that is obtained with the help of the Borehole Image Processing System (BIPS). The interpretations of the borehole geophysical and radar logs are available when the single-hole interpretation is performed. The result from the geological single-hole interpretation is presented in a WellCad plot. The work reported here concerns stage 1 in the single-hole interpretation, as defined in the method description.

3 Data used for the geological single-hole interpretation

The following data have been used in the single-hole interpretation of borehole KLX27A:

- Boremap data (including BIPS and geological mapping data) /2/.
- Generalized geophysical logs and their interpretation /3/.
- Radar data and their interpretation /4/.

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 3-1. The plot consists of nine main columns and several subordinate columns. These include:

1: Length along the borehole

2: Boremap data

- 2.1: Rock type
- 2.2: Rock type < 1 m
- 2.3: Rock type structure
- 2.4: Rock structure intensity
- 2.5: Rock type texture
- 2.6: Rock type grain size
- 2.7: Structure orientation
- 2.8: Rock alteration
- 2.9: Rock alteration intensity
- 2.10: Crush

3: Generalized geophysical data

- 3.1: Silicate density
- 3.2: Magnetic susceptibility
- 3.3: Natural gamma radiation
- 3.4: Estimated fracture frequency

4: Unbroken fractures

- 4.1: Primary mineral
- 4.2: Secondary mineral
- 4.3: Third mineral
- 4.4: Fourth mineral
- 4.5: Alteration, dip direction

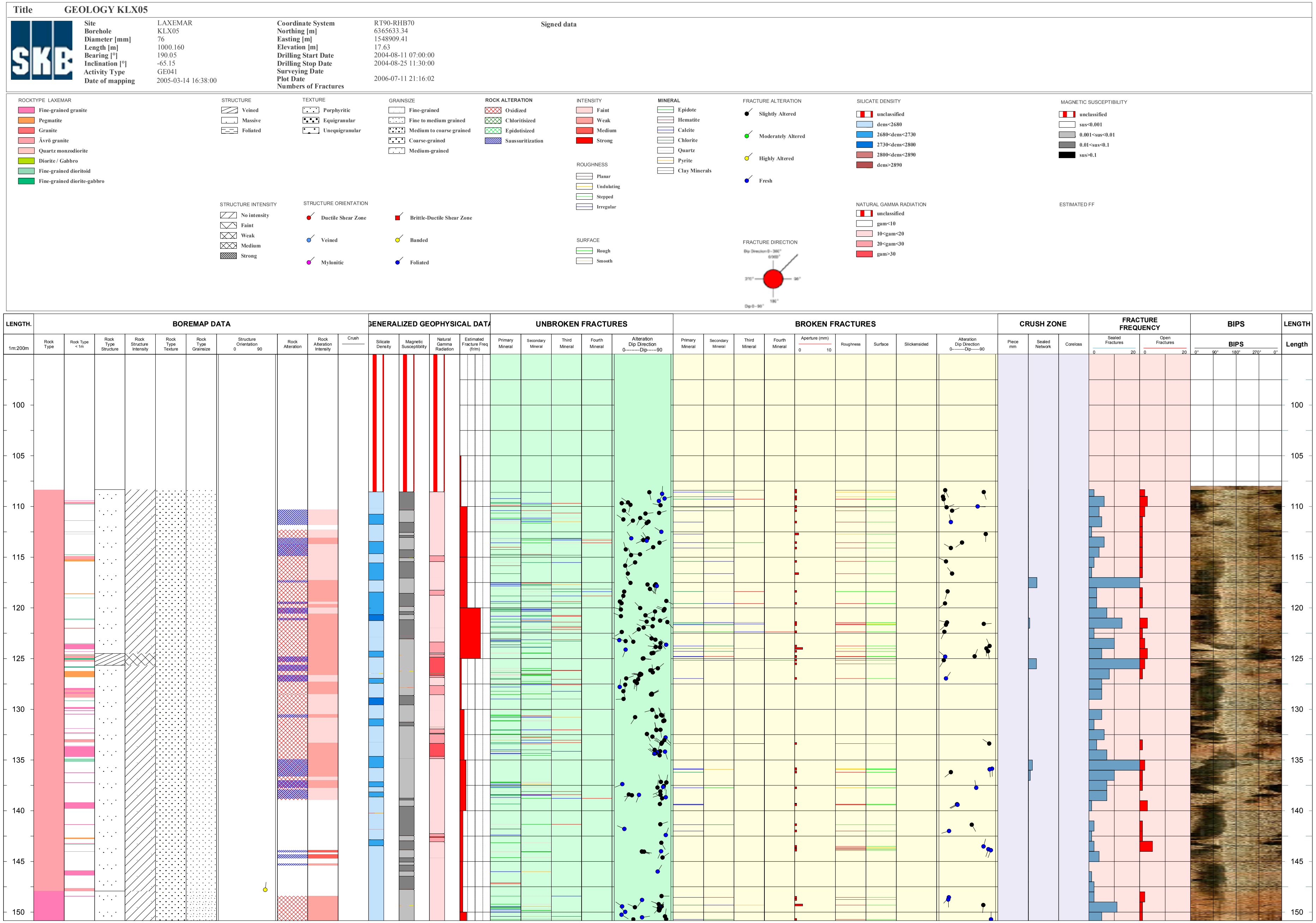

Figure 3-1. Example of WellCad plot (from borehole KLX05 in Laxemar) used as a basis for the single-hole interpretation.

5: Broken fractures
- 5.1: Primary mineral
- 5.2: Secondary mineral
- 5.3: Third mineral
- 5.4: Fourth mineral
- 5.5: Aperture (mm)
- 5.6: Roughness
- 5.7: Surface
- 5.8: Slickenside
- 5.9: Alteration, dip direction

6: Crush zones
- 6.1: Piece (mm)
- 6.2: Sealed network
- 6.3: Core loss

7: Fracture frequency
- 7.1: Sealed fractures
- 7.2: Open fractures

9: BIPS

The geophysical logs are described below:

Magnetic susceptibility: The rock 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 rock 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.

Possible alteration: This parameter has not been used in the geological single-hole interpretation in the area.

Silicate density: This parameter indicates the density of the rock after subtraction of the magnetic component. It provides general information on the mineral composition of the rock types, and serves as a support during classification of rock types.

Estimated fracture frequency: This parameter provides an estimate of the fracture frequency along 5 m sections, calculated from short and long normal resistivity, SPR, P-wave velocity as well as focused resistivity 140 and 300. 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.

Close inspection of the borehole radar data was carried out during the interpretation process, especially during the identification of possible deformation zones. The occurrence and orientation of radar anomalies within the possible deformation zones are commented upon in the text that describes these zones.

4 Execution

4.1 General

The geological single-hole interpretation has been carried out by a group of geoscientists consisting of both geologists and geophysicists. All data to be used (see Chapter 3) are visualized side by side in a borehole document extracted from the software WellCad. The working procedure is summarized in Figure 4-1 and in the text below.

The first step in the working procedure is to study all types of data (rock type, rock alteration, silicate density, natural gamma radiation, etc) related to the character of the rock type and to merge sections of similar rock types, or sections where one rock type is very dominant, into rock units (minimum length of c. 5 m). Each rock unit is defined in terms of the borehole length interval and provided with a brief description for inclusion in the WellCad plot. This includes a brief description of the rock types affected by the possible deformation zone. The confidence in the interpretation of a rock unit is made on the following basis: 3 = high, 2 = medium and 1 = low.

The second step in the working procedure is to identify possible deformation zones 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.

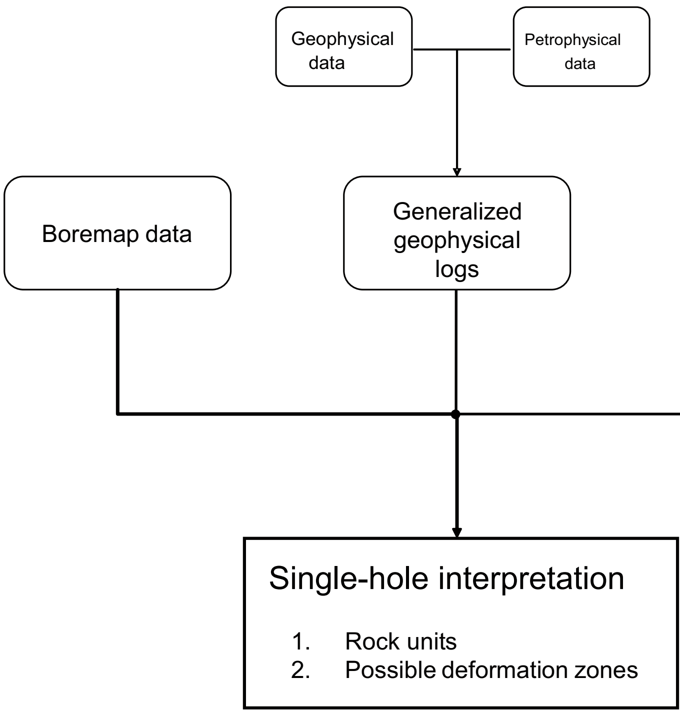

Figure 4-1. *Schematic block-scheme of single-hole interpretation.*

Inspection of BIPS images is carried out whenever it is judged necessary during the working procedure. Furthermore, following definition of rock units and deformation zones, with their respective confidence estimates, the drill cores are inspected in order to check the selection of the boundaries between these geological entities. If judged necessary, the location of these boundaries is 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 the frequency of fractures, respectively, according to the recommendations in /1/. Both the transitional parts and the core part have been included in each zone (Figures 4-2 to 4-4). The fracture/m values in Figure 4-4 may serve only as examples. The frequencies of open and sealed fractures have been assessed in the identification procedure, and the character of the zone has been described accordingly. Partly open fractures are included together with open fractures in the brief description of each zone. The presence of bedrock alteration, the occurrence and, locally, inferred orientation of radar reflectors, the resistivity, SPR, P-wave velocity, caliper and magnetic susceptibility logs have all assisted in the identification of primarily the brittle structures.

Since the frequency of fractures is of key importance for the definition of the possible deformation zones, a moving average plot for this parameter is shown for the cored borehole KLX27A (Figure 4-5). A 5 m window and 1 m steps have been used in the calculation procedure. The moving averages for open fractures alone, the total number of open fractures (open, partly open and crush), the sealed fractures alone, and the total number of sealed fractures (sealed and sealed fracture network) are shown in a diagram.

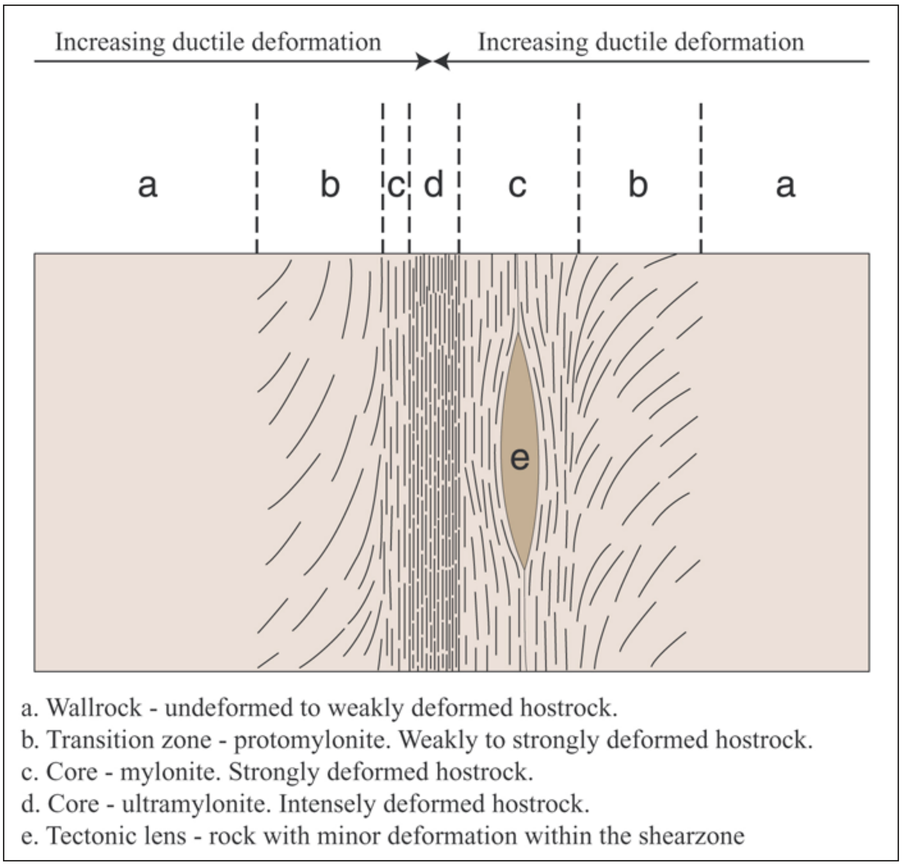

***Figure 4-2.** Schematic example of a ductile shear zone. Homogeneous rock which is deformed under low- to medium-grade metamorphic conditions (after /1/).*

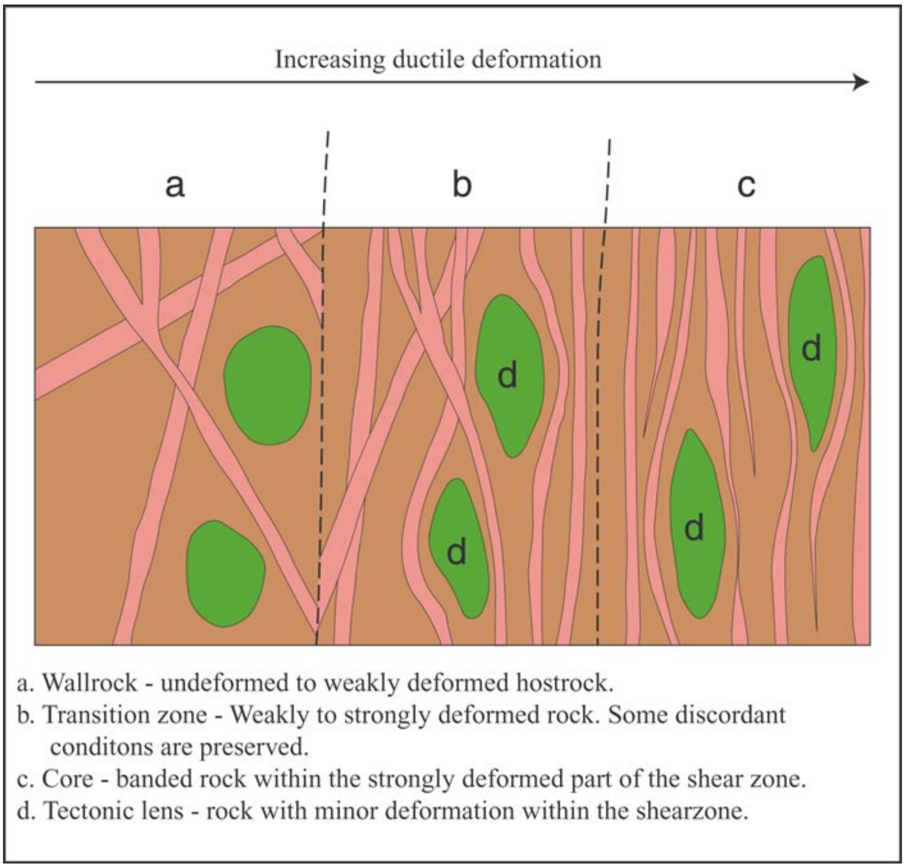

Figure 4-3. *Schematic example of a ductile shear zone. Heterogeneous rock which is deformed under low- to high-grade metamorphic conditions (after /1/).*

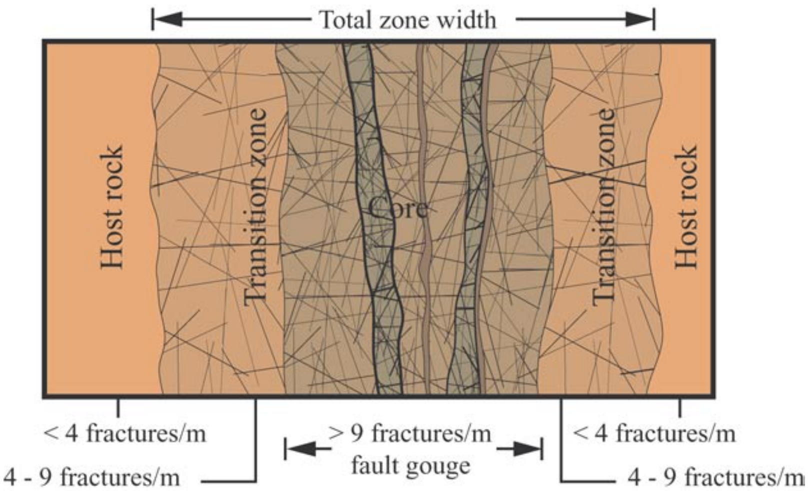

Figure 4-4. *Schematic example of a brittle deformation zone (after /1/).*

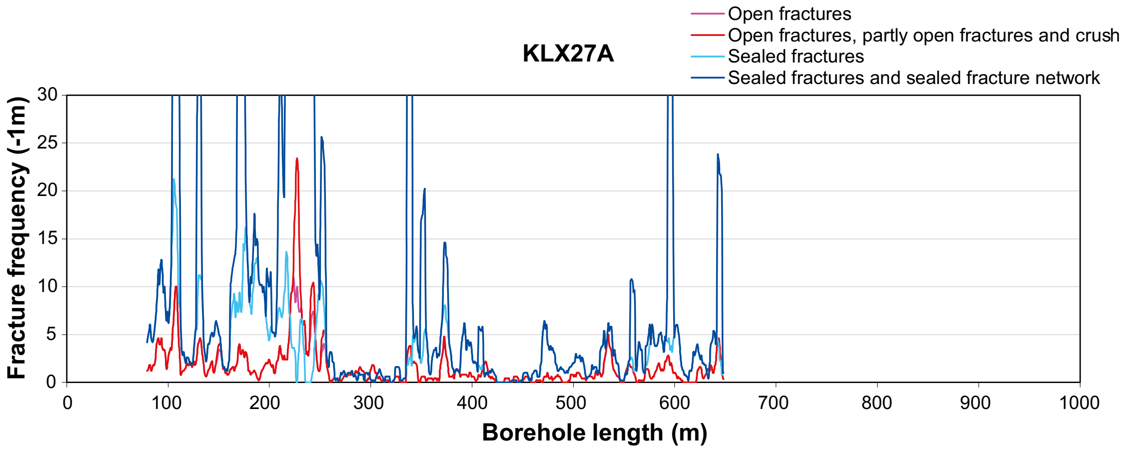

Figure 4-5. Fracture frequency plot for KLX27A. Moving average with a 5 m window and 1 m steps.

The occurrence and orientation of radar anomalies within these possible deformation zones are used during the identification of zones. Overviews of the borehole radar measurement in KLX27A is shown in Figure 4-6. A conductive environment causes attenuation of the radar wave, which in turn decreases the penetration. The effect of attenuation can be observed at 0–80 m (caused by larger borehole diameter) and at 220–240 m in borehole KLX27A. The effect of attenuation varies between the different antenna frequencies (20 MHz, 100 MHz, 250 MHz and 60 MHz directional antenna). In some cases, alternative orientations for oriented radar reflectors are presented. One of the alternatives is considered to be correct, but due to uncertainty in the interpretation of radar data, a decision concerning which of the alternatives that represent the true orientation cannot be made. Orientations from directional radar are presented as strike/dip using the right-hand-rule method, e.g. 040/80 corresponds to a strike of N40°E and a dip of 80° to the SE.

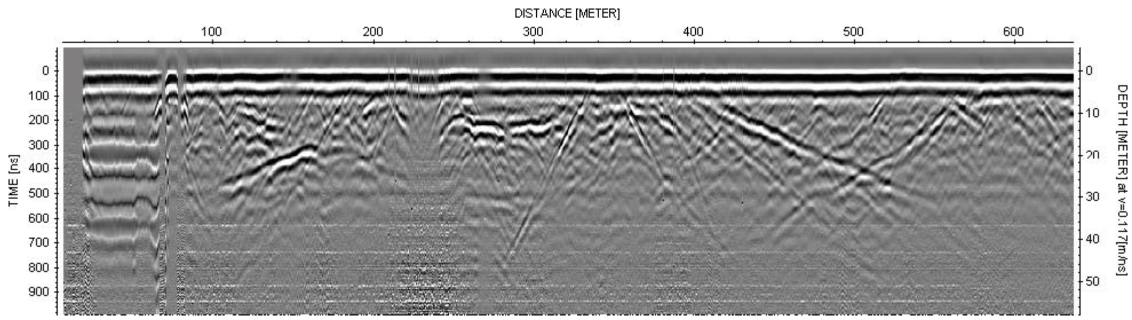

Figure 4-6. Overview (20 MHz data) of the borehole radar measurement in KLX27A.

5 Results

The detailed result of the single-hole interpretation is presented as print-out from the software WellCad (Appendix 1 for KLX27A).

5.1 KLX27A

Rock units

The borehole contains one rock unit, RU1. The rock unit has been recognized with a high degree of confidence.

76.13–648.69 m

RU1: Totally dominated by quartz monzodiorite (501036). Subordinate rock types comprise fine-grained granite (511058), fine-grained diorite-gabbro (505102), and very sparse occurrences of granite (501058) and pegmatite (501061). The major part of the rock unit is weakly foliated, although faintly foliated and massive sections also occur. In the section 76–110 m, the quartz monzodiorite (501036) has a density in the range 2,710–2,770 kg/m^3, and in the remaining part of the rock unit in the range 2,740–2,800 kg/m^3. Confidence level = 3.

Possible deformation zones

Nine possible deformation zones have been recognised in KLX27A. Eight have been recognised with a high degree of confidence and one with a medium degree of confidence (DZ1–DZ9).

105.90–109.80 m

DZ1: Minor brittle deformation zone in composite intrusion with increased frequency of sealed fractures, sealed network, breccia, faint to weak red staining, one slickenside, one crush and faint saussuritization. The resistivity and magnetic susceptibility are significantly decreased, whereas the P-wave velocity is partly decreased. Two non-oriented radar reflectors occur at 106.5 m and 108.5 m with the angle 54° and 78° to borehole axis, respectively. Low radar amplitude at 105–110 m. The host rock is dominated by fine-grained diorite-gabbro (505102) and fine-grained granite (511058) in the upper part. Confidence level = 3.

167.90–176.45 m

DZ2: Brittle deformation zone characterized by increased frequency of sealed fractures, sealed network, slight increase in open fractures, cataclasites, thin brittle-ductile shear zones, sparse brecciation, partly weak to strong red staining, sparse weak to strong epidotization and one slickenside. The magnetic susceptibility is significantly decreased; the resistivity and P-wave velocity only show minor anomalies. Two non-oriented radar reflectors occur at 168.0 m and 171.4 m with the angle 49° and 64° to borehole axis, respectively. One oriented radar reflector occurs at 173.5 m with the orientation 015/33 or 137/56. Low radar amplitude at 165–175 m. The host rock is dominated by quartz monzodiorite (501036) and fine-grained granite (511058) in the lower part. Confidence level = 3.

208.50–255.00 m

DZ3: Brittle deformation zone characterized by increased frequency of sealed and, partly, also open fractures, sealed network, six crush zones, cataclasites, gouge, core loss, weak to medium red staining and two slickensides. Brittle-ductile and ductile shear zones, overprinted by the brittle deformation, also occur. The most intensely deformed sections (cores) are 221.20–221.50 m, 225.17–229.90 m and 241.40–242.50 m. There are major anomalies in all geophysical logs. The most significant geophysical anomalies occur in the sections c. 225–230 m and 240–245 m. There are eleven non-oriented radar reflectors with an angle between 9° and 76° to borehole axis. The strongest of the non-oriented is reflector 61 at 223.1 m with the angle 63° to borehole axis. Three oriented reflectors occur, one at 215.4 m with the orientation 219/63, one at 241.8 m with the orientation 314/06 or 045/49, and one at 253.6 m with the orientation 044/34 or 023/17. Low radar amplitude occurs at 210 m, 225–230 m, and 240 m. The host rock is dominated by quartz monzodiorite (501036). Subordinate rock types comprise fine-grained diorite-gabbro (505102), fine-grained granite (511058) and very sparse occurrence of granite (501058). Confidence level = 3.

337.45–339.30 m

DZ4: Minor brittle deformation zone characterized by increased frequency of sealed and open fractures, sealed network, breccia and slickenside. The resistivity and magnetic susceptibility are significantly decreased, and there is also a distinct caliper anomaly. The P-wave velocity is partly decreased. Two non-oriented radar reflectors occur at 337.9 m and 338.0 m with the angle 20° and 65° to borehole axis, respectively. The former reflector can be observed to a distance of 16 m outside the borehole. Low radar amplitude occurs at 335–345 m, which is partly above and below the possible deformation zone. The host rock is dominated by fine-grained diorite-gabbro (505102). Subordinate rock type comprises quartz monzodiorite (501036). Confidence level = 3.

343.65–345.05 m

DZ5: Minor brittle deformation zone characterized by increased frequency of sealed and open fractures, faint and strong red staining. Slickenside, breccia and a thin brittle-ductile shear zone occur also. The resistivity and magnetic susceptibility are significantly decreased. The P-wave velocity is partly decreased. One oriented radar reflector occurs at 344.9 m with the orientation 006/54. One prominent non-oriented radar reflector occurs at 344.1 m. The non-oriented reflector can be observed to a distance of 25 m outside the borehole, and is interpreted to be part of a system of other radar reflectors intersecting at about the same borehole length. One of the included radar reflectors has the orientation 211/13 and is interpreted to intersect at 343.1 m, which is immediately above the possible deformation zone. Low radar amplitude occurs at 335–345 m, which is partly above the possible deformation zone. The host rock is totally dominated by quartz monzodiorite (501036). Confidence level = 3.

370.70–374.95 m

DZ6: Minor brittle deformation zone characterized by increased frequency of sealed and a slight increase in open fractures, weak to strong red staining, and also breccia, cataclasite, slickenside and brittle-ductile shear zones. The magnetic susceptibility is significantly decreased, but there are only minor anomalies in the other geophysical logs. One oriented radar reflector occurs at 374.5 m with the orientation 275/71. This reflector constitutes part of a system of very prominent reflectors intersecting close to the possible deformation zone. One of the included radar reflectors (reflector 89x at 368.3 m) can be observed to a distance of 36 m outside the borehole. Three non-oriented radar reflectors occur at 372.0 m, 373.0 m, and at 373.5 m with the angle 16°, 77° and 61° to borehole axis, respectively. Low radar amplitude occurs at 370 m. The host rock is dominated by quartz monzodiorite (501036). Subordinate rock type comprises fine-grained granite (511058). Confidence level = 3.

532.55–536.60 m

DZ7: Minor brittle deformation zone characterized by slight increase in open and sealed fractures and two thin breccias. The resistivity and magnetic susceptibility are significantly decreased. The P-wave velocity is partly decreased. Two oriented radar reflectors occur in the section, at 535.9 m with the orientation 249/42 or 246/87, and at 535.5 m with the orientation 051/84 or 215/36. The host rock is dominated by fine-grained granite (511058) and partly also by quartz monzodiorite (501036). Confidence level = 2.

595.02–596.54 m

DZ8: Minor ductile shear zone in composite intrusion which is dominated by fine-grained diorite-gabbro (505102). Overprinting sealed fractures and sealed network. The magnetic susceptibility is significantly decreased, but there are only minor anomalies in the other geophysical logs. One non-oriented radar reflector occurs at 596.5 m with the angle 68° to borehole axis. Confidence level = 3.

643.91–644.80 m

DZ9: Minor brittle deformation zone characterized by sealed fractures, sealed network and a slight increase in open fractures, strong red staining and thin brittle-ductile shear zones. The resistivity, magnetic susceptibility and P-wave are significantly decreased. The host rock is dominated by quartz monzodiorite (501036) and fine-grained granite (511058). Confidence level = 3.

6 Comments

The results from the geological single-hole interpretation of borehole KLX27A is presented in a WellCad plot (Appendix 1). The WellCad plot consists of the following columns:

In data Boremap	1: Depth (Length along the borehole).
	2: Rock type.
	3: Rock alteration.
	4: Frequency of sealed fractures.
	5: Frequency of open and partly open fractures.
	6: Crush zones.
In data Geophysics	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 (blue symbols).
	13: Stereogram for open and partly open fractures in rock unit (red symbols).
	14: Description: Possible deformation zone.
	15: Stereogram for sealed fractures in possible deformation zone (blue symbols).
	16: Stereogram for open and partly open fractures in possible deformation zone (red symbols).

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/2/ **Mattsson K-J, Eklund S, 2008.** Oskarshamn site investigation. Boremap mapping of telescopic drilled borehole KLX27A. SKB P-08-39, Svensk Kärnbränslehantering AB.

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/4/ **Gustafsson J, Gustafsson C, 2008.** Oskarshamn site investigation. RAMAC, BIPS and deviation logging in borehole KLX27A. SKB P-08-30, Svensk Kärnbränslehantering AB.

Appendix 1

Geological single-hole interpretation of KLX27A

Title	SINGLE HOLE INTERPRETATION KLX27A					
Site	LAXEMAR	Inclination [°]	-65.36	Elevation [m.a.s.l.]	16.91	Signed data
Borehole	KLX27A	Date of mapping	2007-12-12 09:03:00	Drilling Start Date	2007-08-15 07:00:00	
Diameter [mm]	76	Coordinate System	RT90-RHB70	Drilling Stop Date	2007-08-27 18:00:00	
Length [m]	650.560	Northing [m]	6365607.47	Surveying Date		
Bearing [°]	0.73	Easting [m]	1546742.68	Plot Date	2008-04-27 22:04:10	

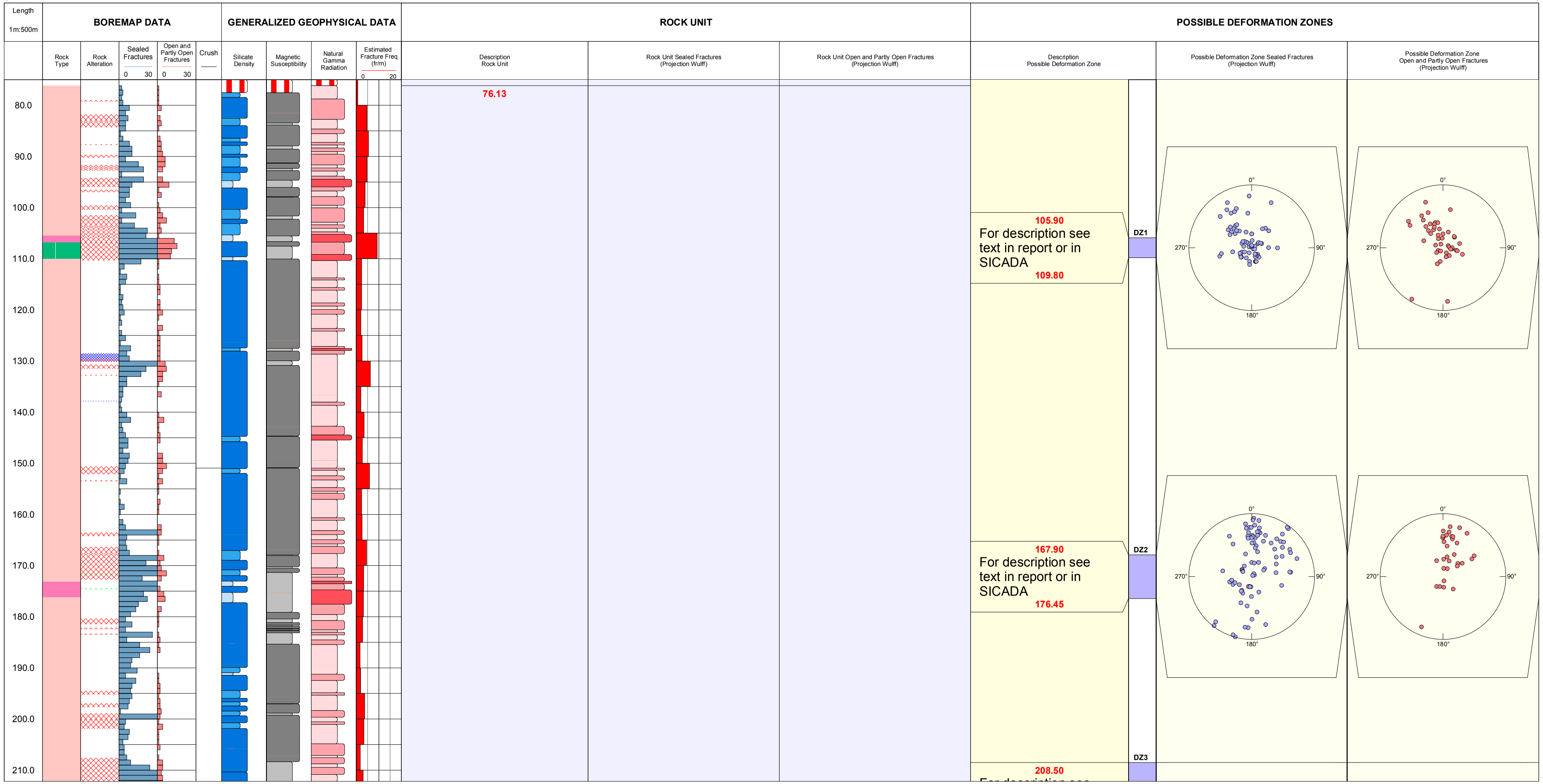
ROCKTYPE LAXEMAR
- Fine-grained granite
- Quartz monzodiorite
- Fine-grained diorite-gabbro

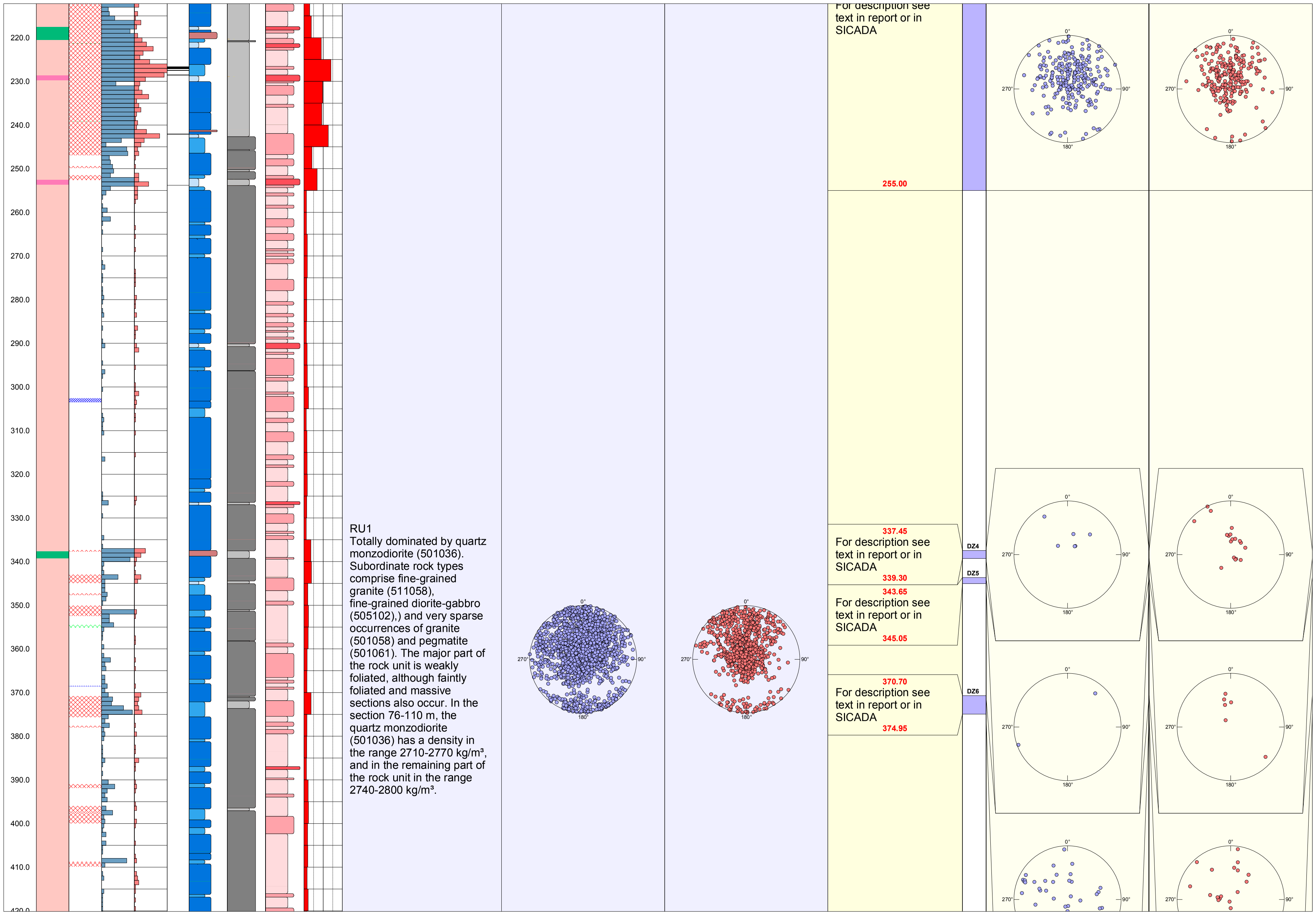
ROCK ALTERATION
- Oxidized
- Chloritisized
- Epidotisized
- Argillization
- Saussuritization

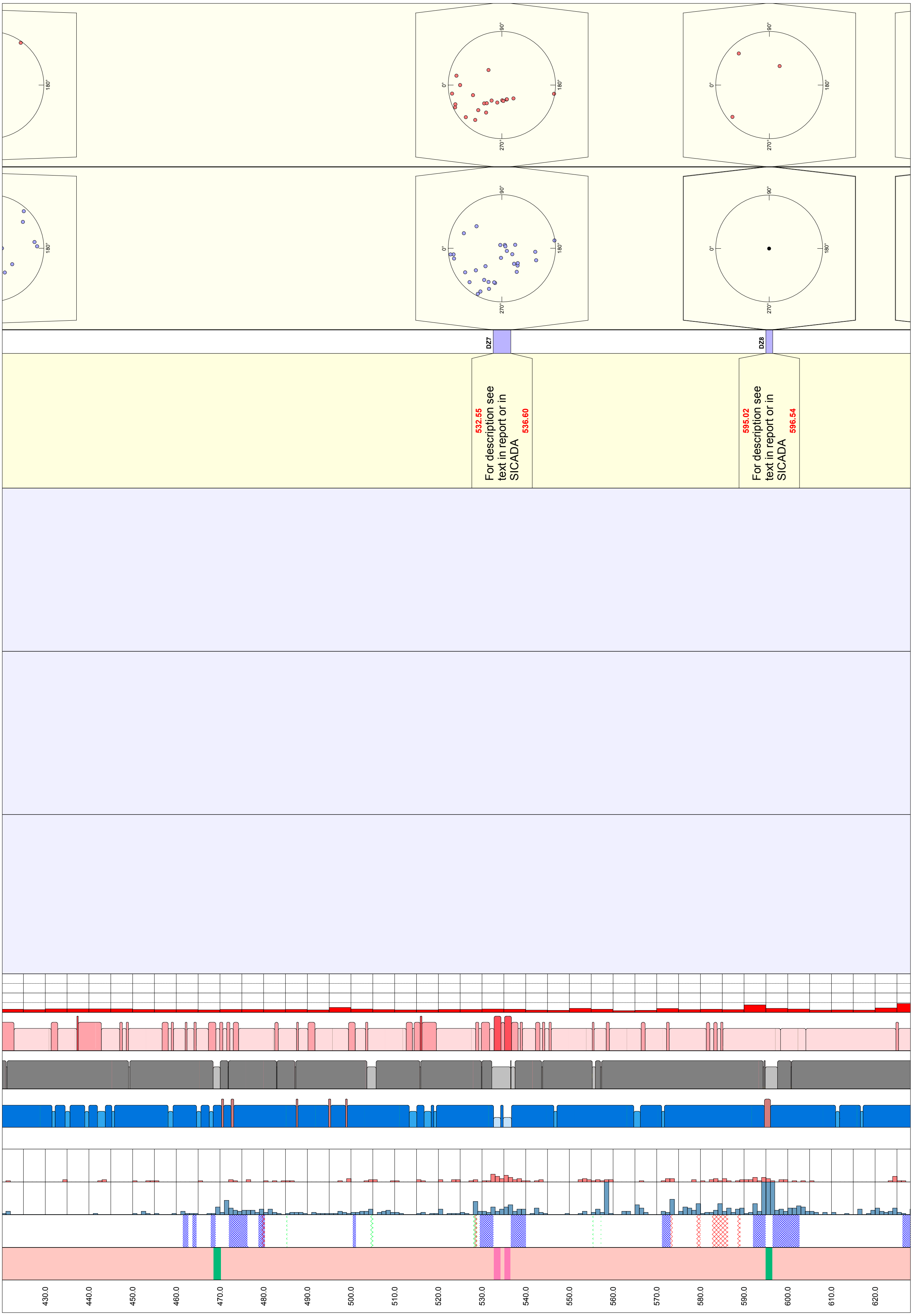
SILICATE DENSITY
- unclassified
- dens<2680
- 2680<dens<2730
- 2730<dens<2800
- 2800<dens<2890

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

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




220.0
230.0
240.0
250.0
260.0
270.0
280.0
290.0
300.0
310.0
320.0
330.0
340.0
350.0
360.0
370.0
380.0
390.0
400.0
410.0
420.0
RU1
Totally dominated by quartz monzodiorite (501036). Subordinate rock types comprise fine-grained granite (511058), fine-grained diorite-gabbro (505102),) and very sparse occurrences of granite (501058) and pegmatite (501061). The major part of the rock unit is weakly foliated, although faintly foliated and massive sections also occur. In the section 76-110 m, the quartz monzodiorite (501036) has a density in the range 2710-2770 kg/m³, and in the remaining part of the rock unit in the range 2740-2800 kg/m³.
For description see text in report or in SICADA
255.00
337.45
For description see text in report or in SICADA
339.30
343.65
For description see text in report or in SICADA
345.05
370.70
For description see text in report or in SICADA
374.95
DZ4
DZ5
DZ6
0°
90°
180°
270°


DZ7
532.55
For description see text in report or in SICADA
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460.0
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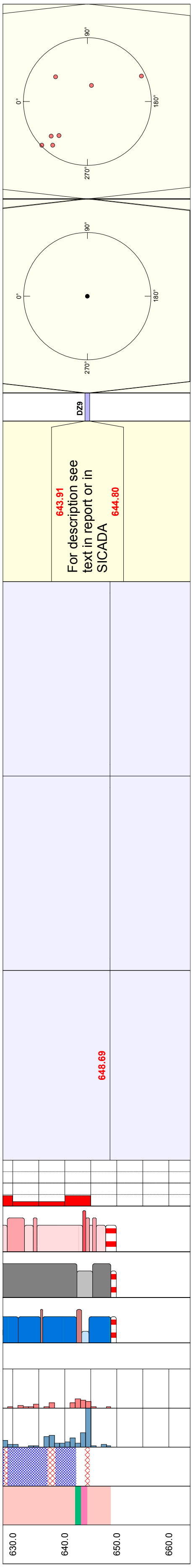
500.0
510.0
520.0
530.0
540.0
550.0
560.0
570.0
580.0
590.0
600.0
610.0
620.0



630.0
640.0
650.0
660.0
648.69
643.91
For description see text in report or in SICADA
644.80
DZ9
0°
90°
180°
270°