P-07-153

Oskarshamn site investigation

Geological single-hole interpretation of KLX28A and KLX29A

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

Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

A pdf version of this document can be downloaded from www.skb.se.

Abstract

This report contains geological single-hole interpretation of the cored boreholes KLX28A and KLX29A 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 boreholes.

The geological single-hole interpretation shows that one rock unit (RU1) occurs in KLX28A. In general, borehole KLX28A is dominated by Ävrö granite (501044). Subordinate rock types comprise occurrences of fine-grained granite (511058), fine-grained diorite-gabbro (505102), fine-grained dioritoid (501030), pegmatite (501061) and granite (501058). Two possible deformation zones are identified in KLX28A (DZ1–DZ2).

One rock unit (RU1) occurs in KLX29A. In general, the borehole KLX29A is dominated by Ävrö granite (501044). Subordinate rock types comprise occurrences of fine-grained diorite-gabbro (505102), fine-grained granite (511058), pegmatite (501061) and granite (501058). Two possible deformation zones are identified in KLX29A (DZ1–DZ2).

Sammanfattning

Denna rapport behandlar geologisk enhålstolkning av kärnborrhålen KLX28A och KLX29A i Laxemar. Den geologiska enhålstolkningen syftar till att utifrån den geologiska karteringen, tolkade geofysiska loggar och borrhålsradarmätningar identifiera olika litologiska enheters fördelning i borrhålen samt möjliga deformationszoners läge och utbredning.

Den geologiska enhålstolkningen visar att en litologisk enhet (RU1) förekommer i KLX28A. Generellt sett domineras borrhålet av Ävrögranit (501044). Finkornig granit (511058), finkornig diorit-gabbro (505102), finkornig dioritoid (501030), pegmatit (501061) och granit (501058) förekommer som underordnade bergarter. Två möjliga deformationszoner har identifierats i KLX28A (DZ1–DZ2).

En litologisk enhet (RU1) förekommer i KLX29A. Borrhålet domineras av Ävrögranit (501044). Finkornig diorit-gabbro (505102), finkornig granit (511058), pegmatit (501061) och granit (501058) förekommer som underordnade bergarter. Två möjliga deformationszoner har identifierats i KLX29A (DZ1–DZ2).

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 boreholes KLX28A and KLX29A 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 400-06-153. 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.

Original data from the reported activity are stored in the primary database SICADA, where they are traceable by the Activity Plan number (AP PS 400-06-153). 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.

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

Activity Plan	Number	Version
Geologisk enhålstolkning av KLX28A och KLX29A	AP PS 400-06-153	1.0
Method Description	**Number**	**Version**
Metodbeskrivning för geologisk enhålstolkning	SKB MD 810.003	3.0

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

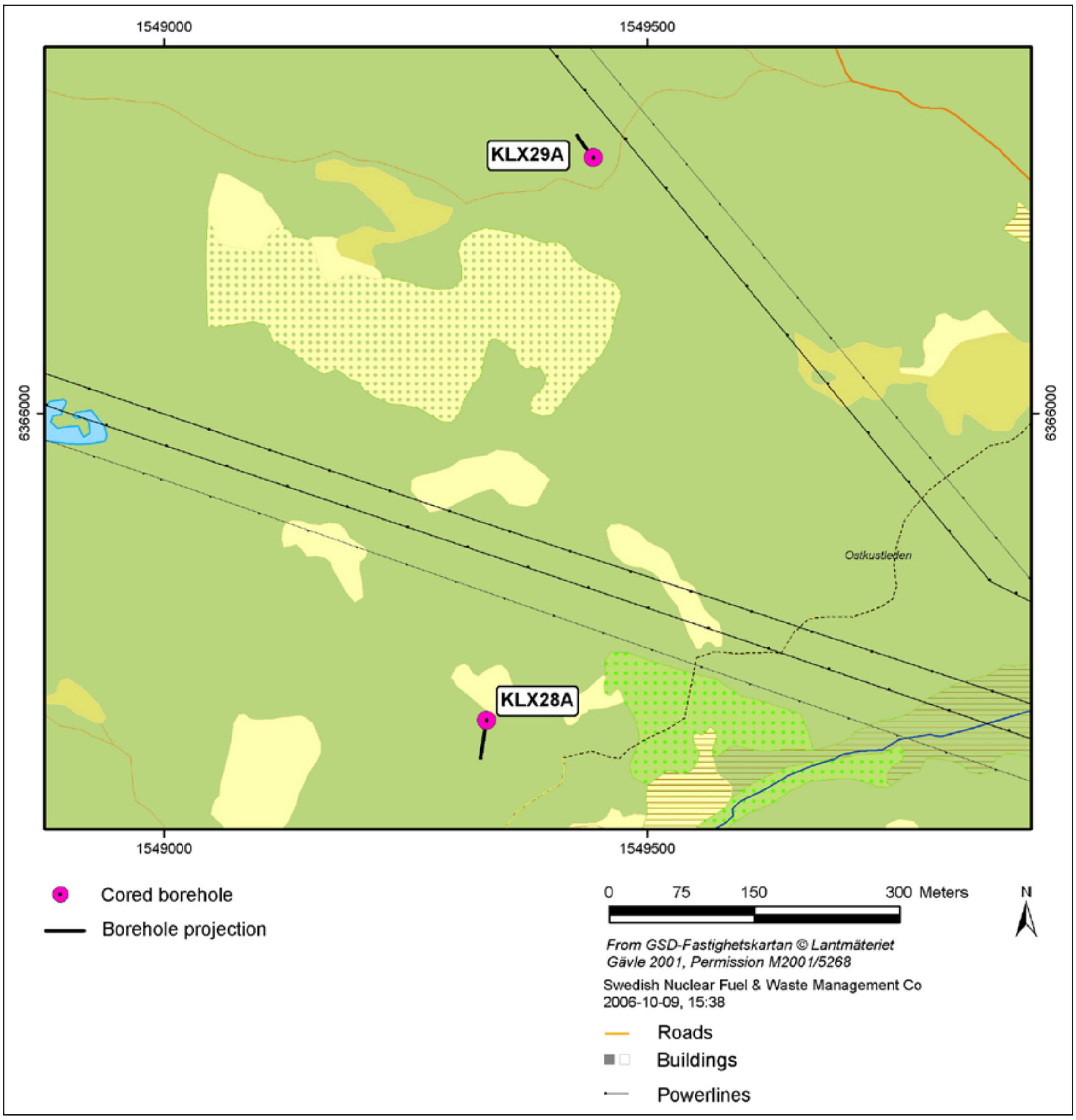


Figure 1-1. *Map showing the position of the cored boreholes KLX28A and KLX29A.*

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 *S*ystem (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 boreholes KLX28A and KLX29A:

- 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 nine main:

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

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

8: BIPS

9: Length along the borehole

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.

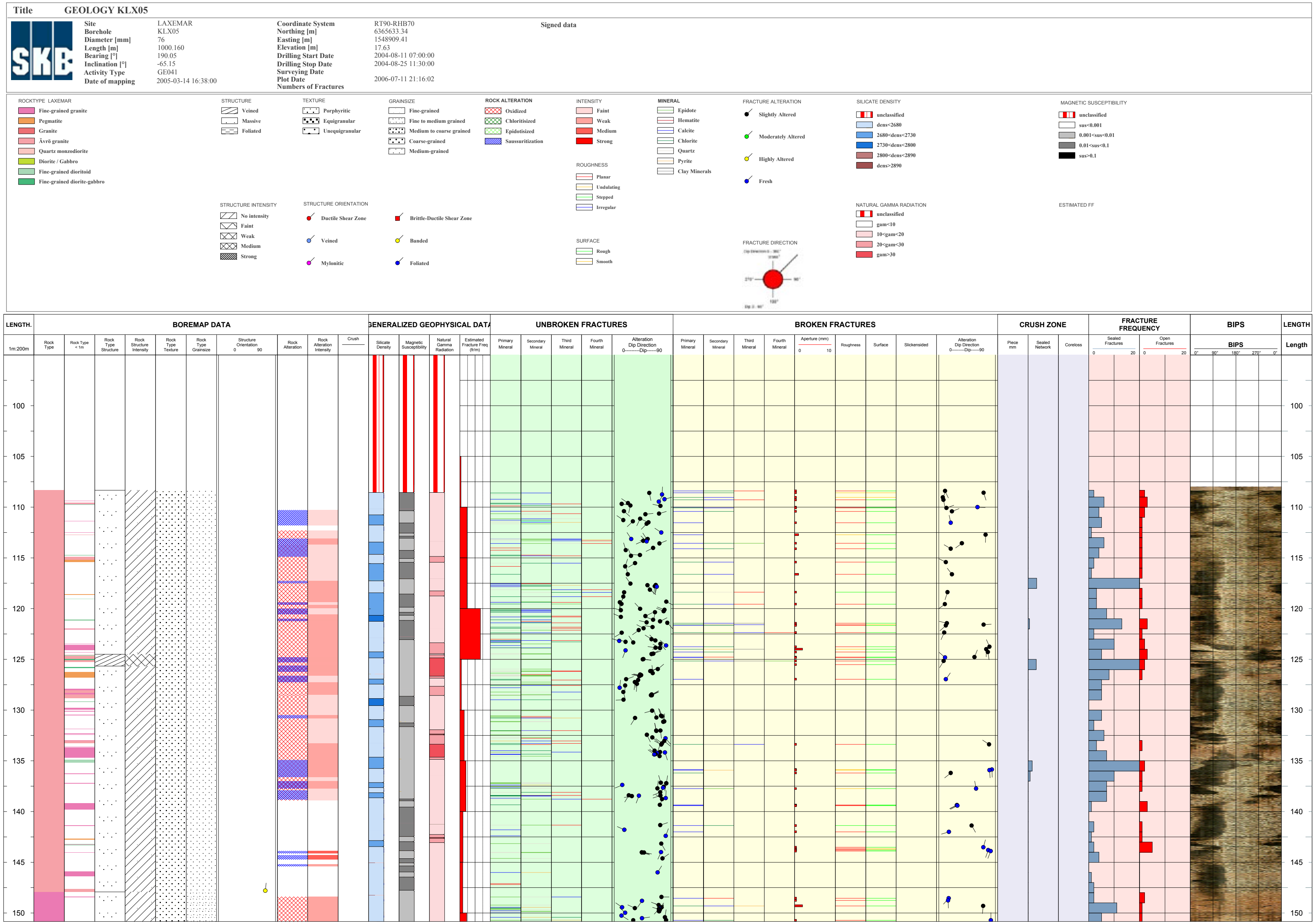


Figure 3-1. Example of WellCad plot (from borehole KLX05 in Laxemar) used as a basis for the single-hole interpretation.

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.

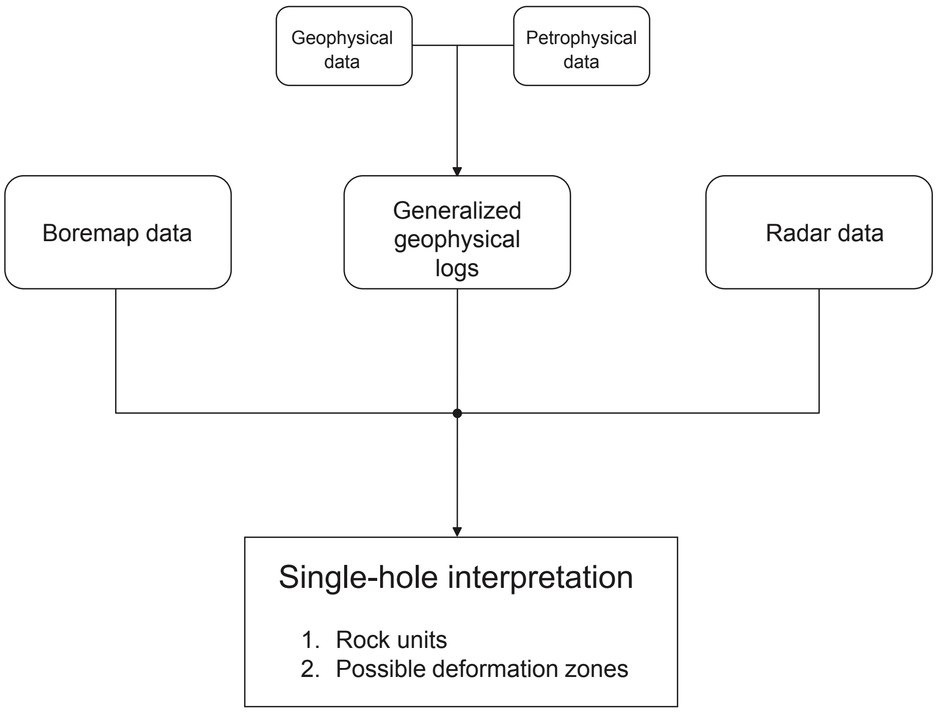
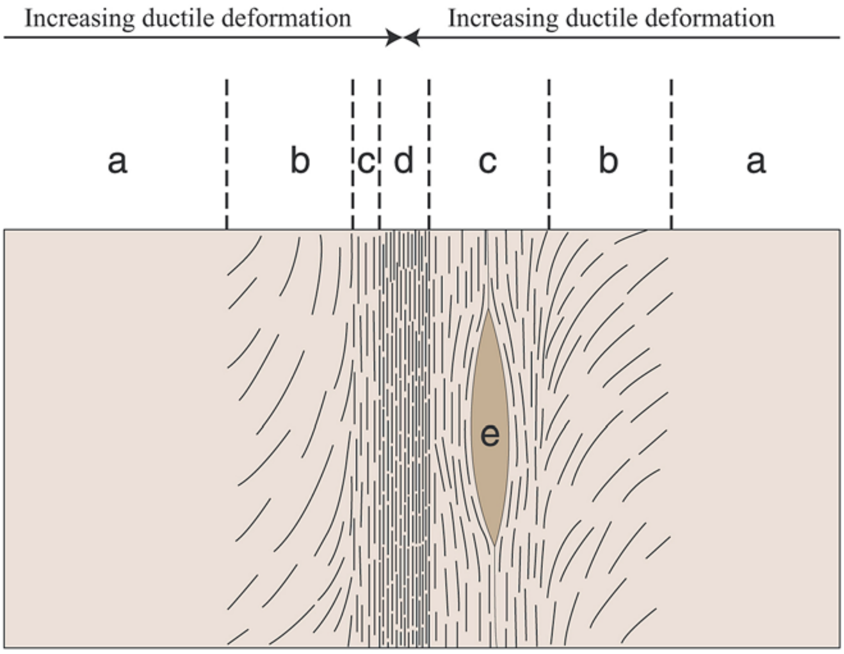


Figure 4-1. *Schematic block-scheme of single-hole interpretation.*

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.



a. Wallrock - undeformed to weakly deformed hostrock.
b. Transition zone - protomylonite. Weakly to strongly deformed hostrock.
c. Core - mylonite. Strongly deformed hostrock.
d. Core - ultramylonite. Intensely deformed hostrock.
e. Tectonic lens - rock with minor deformation within the shearzone

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

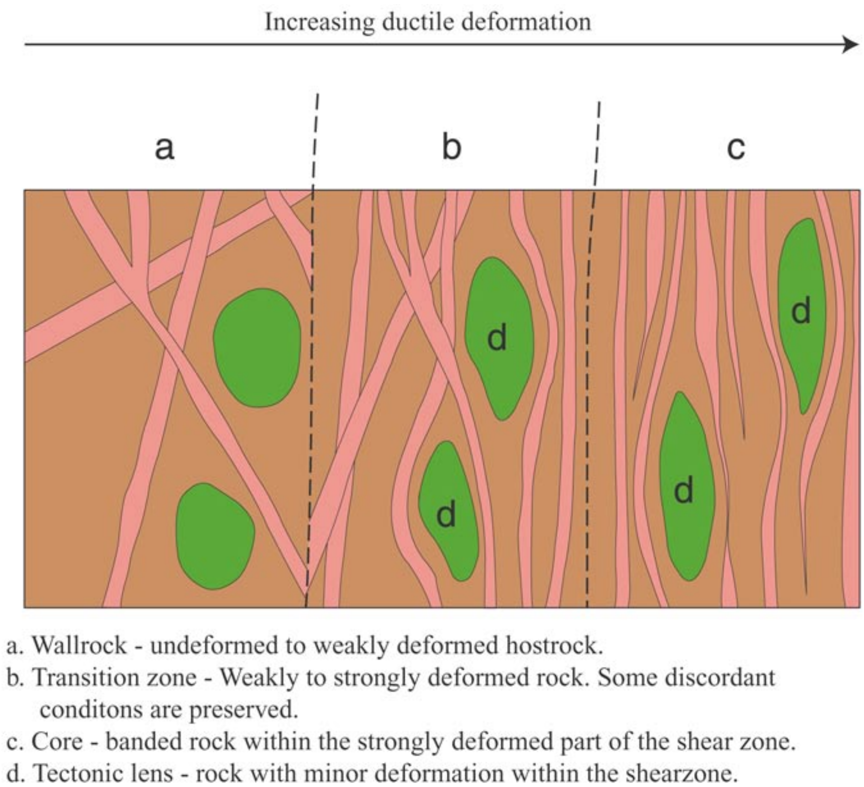


Figure 4-3. *Schematic example of a ductile shear zone. Heterogeneous rock which is deformed under low- to high-grade metamorphic conditions (after /1/).*

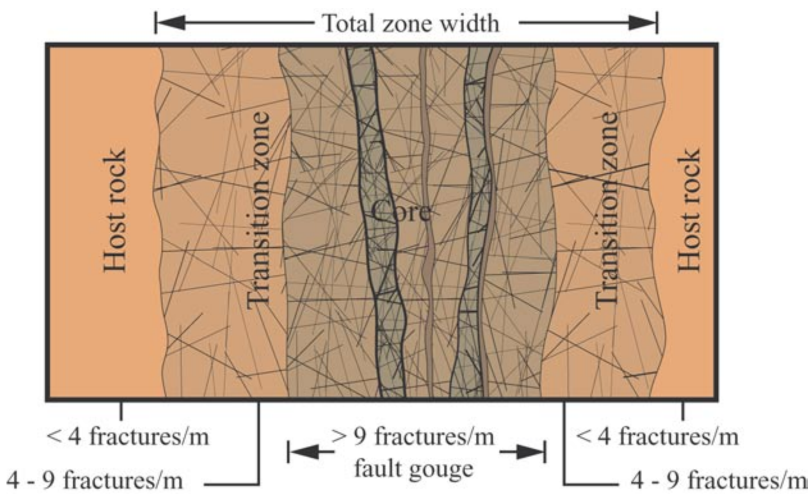


Figure 4-4. *Schematic example of a brittle deformation zone (after /1/).*

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 boreholes KLX28A and KLX29A (Figure 4-5 and 4-6). 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.

The occurrence and orientation of radar anomalies within these possible deformation zones are used during the identification of zones. Overview of the borehole radar measurement in KLX28A is shown in Figure 4-7 and for KLX29A in Figure 4-8. 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.

4.2 Nonconformities

No BIPS-image was available in the section 58.88–59.18 m in KLX29A.

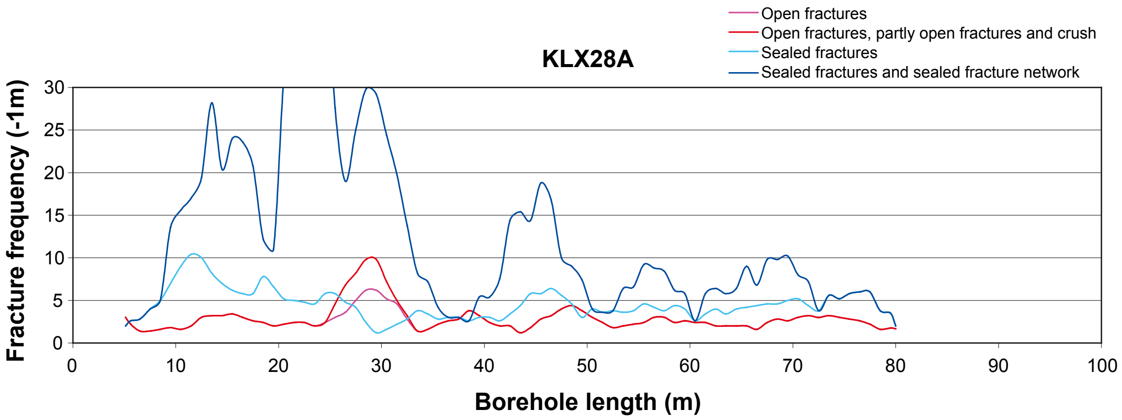


Figure 4-5. Fracture frequency plot for KLX28A. Moving average with a 5 m window and 1 m steps.

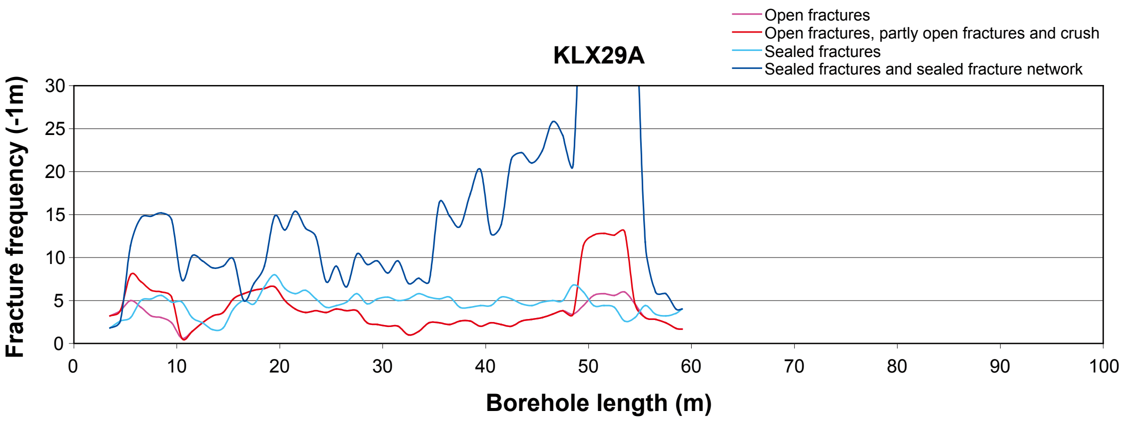


Figure 4-6. Fracture frequency plot for KLX29A. Moving average with a 5 m window and 1 m steps.

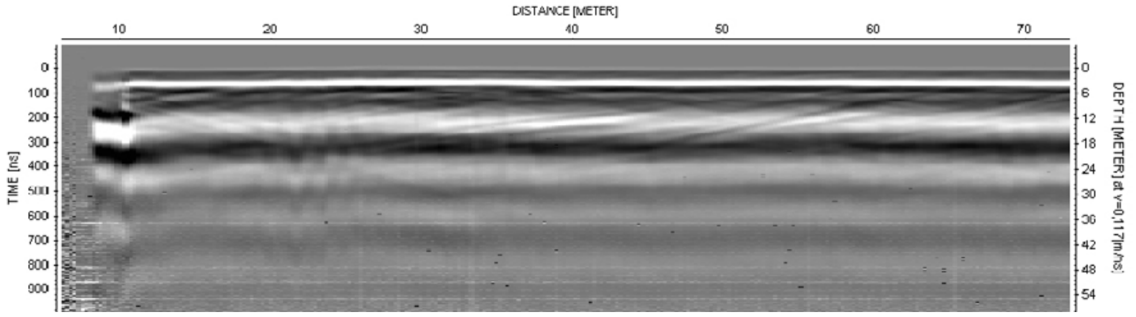


Figure 4-7. Overview (20 MHz data) of the borehole radar measurement in KLX28A.

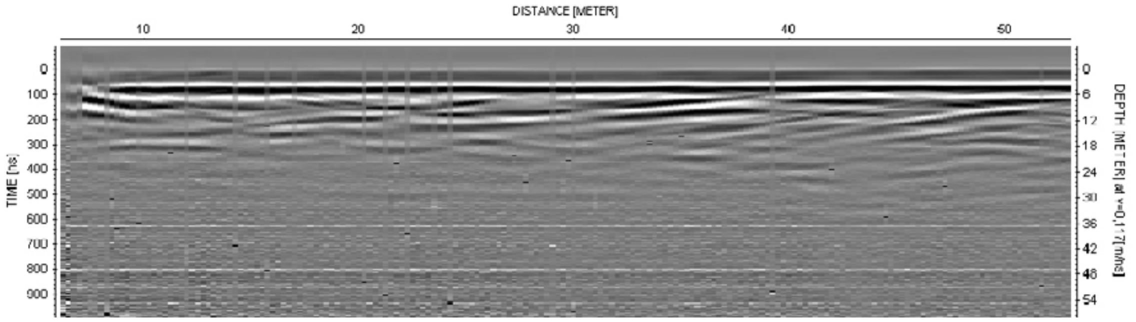


Figure 4-8. Overview (20 MHz data) of the borehole radar measurement in KLX29A.

5 Results

The detailed result of the single-hole interpretation is presented as print-out from the software WellCad (Appendix 1 for KLX28A and Appendix 2 for KLX29A).

5.1 KLX28A

Rock units

The borehole consists of one rock unit (RU1).

5.24–80.00 m

RU1: Totally dominated by Ävrö granite (501044). Subordinate rock types comprise fine-grained granite (511058), fine-grained diorite-gabbro (505102), fine-grained dioritoid (501030), and minor occurrences of pegmatite (501061) and granite (501058). The Ävrö granite (501044) has a density in the range 2,740–2,800 kg/m^3. Scattered ≤ c. 4 m long sections are faintly to weakly foliated between c. 5 m and 34 m borehole length. Confidence level = 3.

Possible deformation zones

Two possible deformation zones have been recognised in KLX28A.

14.40–33.10 m

DZ1: Inhomogeneous brittle-ductile deformation zone characterized by slightly increased frequency of open and sealed fractures, crush zones, cataclasite, slickensides and locally faint to weak red staining. The most intensely deformed part is the section 27.70–30.35 m, which is associated with fine-grained diorite-gabbro (505102). Several distinct low resistivity and decreased P-wave velocity anomalies in the entire section. The core is also characterized by caliper anomalies and decreased magnetic susceptibility. One oriented radar reflector occurs at 27.3 m (096/76) and five non-oriented radar reflectors occur with angle in the interval 43–69° to borehole axis. The oriented reflector can be observed to a distance of 8 m outside the borehole. Low radar amplitude at 13–21 m. The host rock is dominated by Ävrö granite (501044). Subordinate rock types comprise fine-grained granite (511058) and fine-grained diorite-gabbro (505102), and sparse occurrences of pegmatite (501061), granite (501058) and fine-grained dioritoid (501030). Confidence level = 3.

74.00–76.70 m

DZ2: Inhomogeneous brittle to ductile deformation zone with weak red staining. No significant anomalies in the geophysical logging data. One non-oriented radar reflector occurs at 76.9 m with the angle 28° to borehole axis. The reflector can be observed to a distance of 18 m outside the borehole. The host rock is dominated by Ävrö granite (501044) with subordinate occurrence of fine-grained granite (511058). Confidence level = 3.

5.2 KLX29A

Rock units

The borehole consists of one rock unit (RU1).

4.00–59.18 m

RU1: Totally dominated by Ävrö granite (501044). Subordinate rock types comprise fine-grained diorite-gabbro (505102), fine-grained granite (511058), and sparse occurrences of pegmatite (501061) and granite (501058). The Ävrö granite (501044) has a density in the range 2,730–2,790 kg/m^3. The mapping of the section 58.88–59.18 m is only based on the core (no BIPS-image). The section c. 38.75–42.50 m is faintly foliated. Scattered minor sections in the rock unit is characterized by red staining, increased frequency of open and sealed fractures, cataclasites, brittle-ductile and ductile deformation zones and breccias. Confidence level = 3.

Possible deformation zones

Two possible deformation zones have been recognised in KLX29A.

7.21–8.02 m

DZ1: Brittle deformation zone characterized by increased frequency of open and sealed fractures, minor core loss and crush, and medium to strong red staining. No geophysical logging data available. One non-oriented radar reflector occurs at 8.4 m with the angle 52° to borehole axis. The reflector can observed to a distance of 2 m outside the borehole. Low radar amplitude at 5–8 m. The host rock is dominated by Ävrö granite (501044) with subordinate occurrence of fine-grained granite (511058). Confidence level = 3.

44.05–52.40 m

DZ2: Inhomogeneous brittle deformation zone characterized by increased frequency of sealed fractures, sealed network, local increased frequency of open fractures, slickensides, minor crush, faint saussuritization, local weak red staining and local weak epidotization. The most intensely deformed parts are located to the sections 44.05–45.10 m and 51.44–52.40 m. The most intensely deformed sections are geophysically characterized by decreased resistivity and magnetic susceptibility; the lowermost also by a caliper anomaly. There are no significant geophysical anomalies outside the most intensely deformed sections. Two non-oriented radar reflectors occur at 44.9 m and 52.1 m with the angle 61° and 59° to borehole axis, respectively. The reflectors can be observed to a distance of 7 m and 6 m outside the borehole, respectively. The host rock is dominated by Ävrö granite (501044) with subordinate occurrence of fine-grained granite (511058). Confidence level = 3.

6 Comments

The results from the geological single-hole interpretation of KLX28A and KLX29A are presented in a WellCad plot (Appendices 1–2). 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).

7 References

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/4/ **Gustafsson J, Gustafsson C, 2007.** Oskarshamn site investigation. RAMAC, BIPS and deviation logging in boreholes KLX19A, KLX28A and KLX29A. SKB P-07-13, Svensk Kärnbränslehantering AB.

Geological single-hole interpretation of KLX28A

Title	SINGLE HOLE INTERPRETATION KLX28A					
Site	LAXEMAR	Inclination [°]	-60.05	Elevation [m.a.s.l.]	10.05	Signed data
Borehole	KLX28A	Date of mapping	2006-11-14 08:32:00	Drilling Start Date	2006-09-14 16:00:00	
Diameter [mm]	76	Coordinate System	RT90-RHB70	Drilling Stop Date	2006-09-20 08:55:00	
Length [m]	80.230	Northing [m]	6365682.22	Surveying Date		
Bearing [°]	189.70	Easting [m]	1549333.71	Plot Date	2007-10-14 22:03:05	

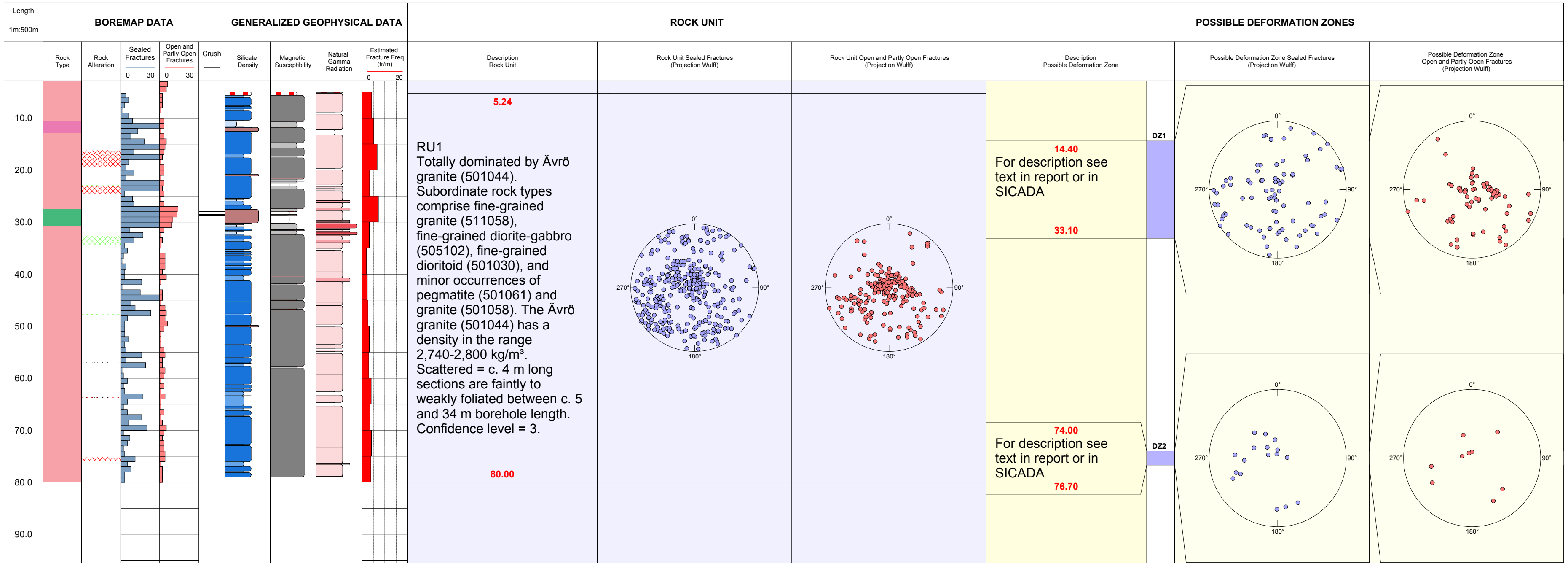
ROCKTYPE LAXEMAR
- Fine-grained granite
- Ävrö granite
- Fine-grained diorite-gabbro

ROCK ALTERATION
- Oxidized
- Epidotisized
- Silicification
- Saussuritization

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

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

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



Appendix 2

Geological single-hole interpretation of KLX29A

Title SINGLE HOLE INTERPRETATION KLX29A

Site	LAXEMAR	**Inclination [°]**	-60.90	**Elevation [m.a.s.l.]**	13.56	**Signed data**
Borehole	KLX29A	**Date of mapping**	2006-11-16 15:34:00	**Drilling Start Date**	2006-09-09 10:00:00	
Diameter [mm]	76	**Coordinate System**	RT90-RHB70	**Drilling Stop Date**	2006-09-13 11:40:00	
Length [m]	60.250	**Northing [m]**	6366263.72	**Surveying Date**		
Bearing [°]	321.21	**Easting [m]**	1549444.03	**Plot Date**	2007-10-14 22:03:05	

ROCKTYPE LAXEMAR
- Ävrö granite
- Fine-grained diorite-gabbro

ROCK ALTERATION
- Oxidized
- Epidotisized
- Saussuritization

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

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

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