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Identification and characterization of minor deformation zones based on lineament interpretation

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March 2007

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Keywords: Deformation zones, MDZ, Geology, Geophysics, Refraction seismics, Flow logging, Hydraulic testing, Lineaments.

Abstract

A number of linear features, lineaments, covering the site investigation area in Laxemar have been identified by interpretation of airborne geophysical and/or remote sensing data sets. Detailed ground geophysical investigations, including magnetic and resistivity methods were executed in the targeted area for the site investigation in order to obtain a better resolution.

Larger deformation zones (DZ), such as regional DZ and local major DZ will affect the available volumes for deposition areas whereas local minor DZ (MDZ) are expected only to affect individual canister positions. In order to localize and characterize the MDZs, a special study has been carried out. In total, 21 lineaments have been identified and further studied in this context in subarea Laxemar.

Detailed interpretation was made in three areas with focus on lineaments over exposed rock or with shallow soil cover. The identified lineaments were preliminary surveyed and some of the more interesting lineaments were selected for excavation in order to expose their character at the rock surface. The exposed area was mapped by the scan-line method and documented by photographic means.

Some of the lineaments that were regarded significant after the field reconnaissance were subsequently investigated by a shallow core-drilled borehole (50–150 m in length) in order to provide a basis to correlate the appearance of the DZ between the surface and the borehole. The siting of the boreholes was based on the existing surface information.

The main findings of the MDZ investigations are as follows:

- Less than c. 50 percent of the investigated lineaments with a length < 1,000 m are estimated to coincide with a MDZ or dykes of more or less practical importance. This result is in agreement with surface mapping along trenches in Laxemar.
- The most significant MDZs are characterized by brittle-ductile deformation, increased fracturing (open and sealed fractures) and sometimes also minor crush and mylonites.
- The most significant MDZs are also characterized by a significant transmissivity, $> 5 \cdot 10^{-7}$ m²/s.
- Many lineaments that have not been identified/studied are probably indications of minor ductile deformation, local rock alterations or dykes of i.e. fine-grained granite.
- It seems difficult to correlate a specific surface zone indication with a borehole indication at a depth of some tens of meters, especially if you do not have one or more unique geological signatures.
- Lineaments verified by refraction seismics appears to be more brittle in character with a higher degree of open fractures and also more transmissive.
- Spacing between deformation zones bordering blocks of more intact rock (Local Major DZ or MDZ) is in the order of 200–500 m.
- Spacing between deformation zones within the blocks are in the range 80–100 m.
- Estimated spacing between MDZs in boreholes is 50–100 m at shallow depth (< 150 m) and 120–200 m in boreholes at depth (in the 100 to 500 m depth interval).
- It appears as the dykes of fine-grained granite striking in NE are important water conduits with transmissivities well over $1 \cdot 10^{-6}$ m^2/s.

Sammanfattning

Ett flertal lineament baserat på flyggeofysiska och topografiska indikationer finns inom Laxemarområdet. Ett antal av dessa lineament motsvaras av deformationszoner av varierande storlek. För att förbättra detaljupplösningen har detaljerade geofysiska markmätningar (resistivitet och magnetiska mätningar) samt lasermätning av markytans topografi genomförts.

Större deformationszoner, exempelvis regionala deformationszoner samt lokala större deformationszoner avgränsar den bergvolym som kan användas för ett slutförvar. Mindre deformationszoner (MDZ) påverkar enbart enskilda deponeringstunnlar och deponeringsborrhål och är därför betydelsefulla för att bedöma det totala bortfallet av kapselpositioner. För att bättre förstå och att på ett tidigt stadium karaktärisera och bedöma dessa MDZ har en separat studie utförts inom ramen för platsundersökningarna i delområde Laxemar. Totalt har 21 lineament undersökts och dokumenterats.

Detaljundersökningar har utförts i tre delområden inom Laxemar med tonvikten på lineament i områden med mer blottat berg. Baserat på LIDAR och geofysiska indikationer utfördes en fältkontroll av ett antal lineament varav vissa avrymdes för att definiera deras karaktär på bergytan. De avrymda bergytorna karterades och fotodokumenterades. Sprickor längre än 20 cm mättes in och deras orientering dokumenterades.

Vissa av lineamenten bedömdes vara av intresse för en fördjupad undersökning och för dessa utfördes ett kärnborrhål (50–150 m långa) för att få uppfattning om zonens karaktär på något större djup och ge underlag för en korrelation mellan bergyta och borrhål. Borrhålens placering baserades på den tillgängliga informationen från ytundersökningen.

Undersökningarna av de mindre deformationszonerna (MDZ) kan sammanfattas enligt följande:

- Mindre än ca 50 procent av de undersökta mindre lineamenten (< 1 000 m) motsvaras av en zon som kan karaktäriseras som en MDZ eller bergartsgång som bedöms ha en praktisk betydelse för ett slutförvar. Detta överenstämmer med data som framkommit i samband med ytkartering längs avbanade stråk inom Laxemarområdet.
- De mest betydelsefulla MDZ karaktäriseras som spröd-duktila skjuvzoner med en ökad frekvens av öppna och slutna sprickor samt i vissa fall även krossat berg och mylonitisering.
- De mest betydelsefulla MDZ kan även karaktäriseras av en förhållandevis hög transmissivitet, $> 5 \cdot 10^{-7}$ m^2/s.
- Ett flertal av lineamenten utgör troligtvis endast indikationer på duktila mindre zoner, lokal omvandling eller bergartsgångar av främst finkornig granit.
- Det är svårt att med säkerhet korrelera en observation av en zon på ytan med ett borrhål på några totals meters djup, speciellt om entydiga geologiska signaturer saknas.
- Lineament som verifierats genom refraktionsseismik verkar generellt vara mer spröda med en högre andel öppna sprickor och ha en högre transmissivitet.
- Avståndet mellan deformationszoner som omger plintar av mer intakt berg (Lokala större deformationszoner eller MDZ) är i storleksordningen 200–500 m.
- Avståndet mellan mindre deformationszoner inom plintarna är normalt i storleksordningen 80–100 m.
- Bedömt avstånd mellan mer betydelsefulla MDZ i borrhål uppgår till 50–100 m i grunda borrhål (< 150 m) och 120–200 m i borrhål i djupintervallet 100–500 m.
- Mäktigare gångar av finkornig granit med en NE-lig strykning verkar utgöra betydelsefulla vattenledare i berggrunden med en transmissivitet som normalt är över $1 \cdot 10^{-6}$ m^2/s.

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Appendix A Excavations and photographs of excavations

Appendix B Scanline tables

Appendix C Geophysical indications

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Appendix E PFL anomalies

Appendix F Water injection tests

Appendix G Hydraulic characterization of MDZ in KLX10B

1 Introduction

1.1 General

SKB performs site investigations in order to evaluate the feasibility of locating a deep repository for high level radioactive waste in two Swedish municipalities: Östhammar and Oskarshamn. The execution of the investigations is basically controlled through a general programme /1, 2/ and a programme specifically for the Oskarshamn location /3/.

A number of linear features, lineaments, covering the site investigation area have been indicated by different geophysical methods and by remote sensing (LIDAR), primarily of topography /4–10/. Detailed ground geophysical investigations, including magnetic and resistivity methods were executed in the targeted area for the site investigation in order to obtain a better resolution.

Larger deformation zones, such as regional deformation zones (DZ) and local major DZs will affect the available volumes for deposition areas whereas local minor DZs are expected only to affect individual canister positions. In order to localize and characterize some of the Minor Deformation Zones (MDZ) and to obtain a better understanding of their importance for the geological and hydraulic pattern of the area, a special study has been carried out.

The work was carried out in accordance with activity plans AP PS 400-05-096 and AP PS 400-06-053. Reference is given in the activity plans to procedures in various Method Descriptions relevant for the study. Table 1-1 lists the controlling documents for performing this activity. Both activity plans and method descriptions are SKB internal controlling documents. The investigation areas used in the completed study is given in Figure 1-1.

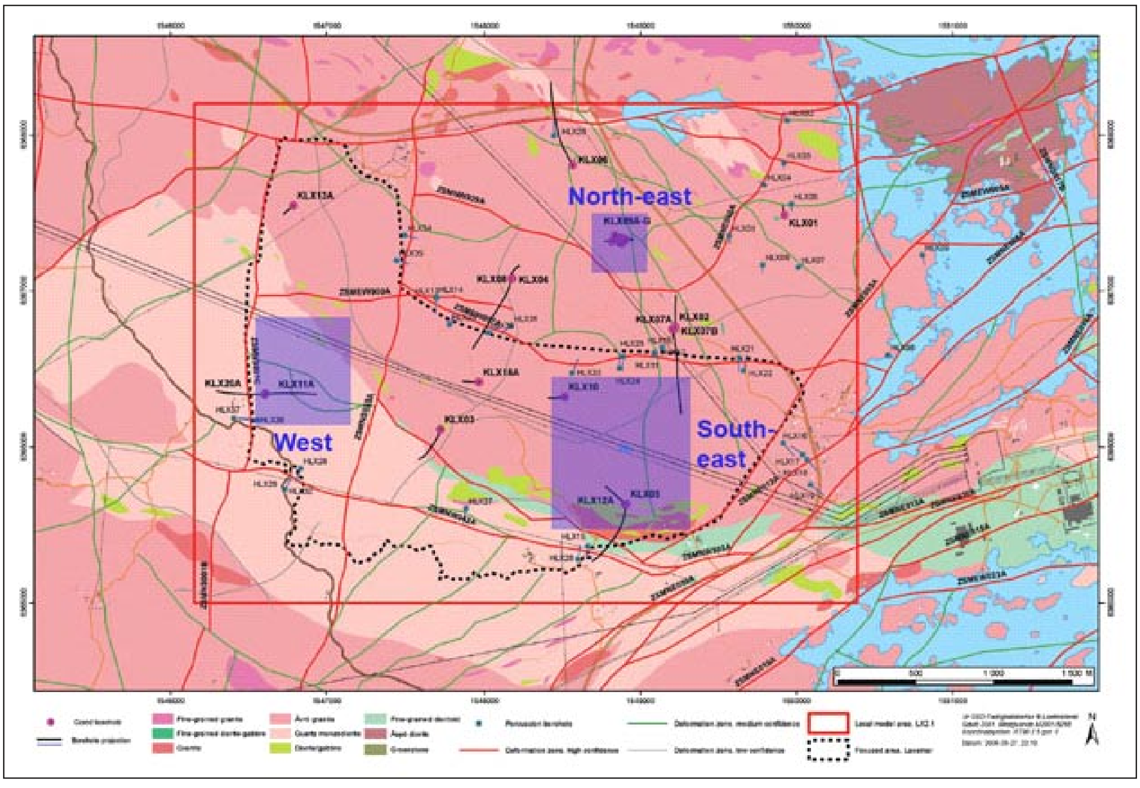


Figure 1-1. *Areas used for the investigations of MDZ in Laxemar /11/.*

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

Activity plan	Number	Version
Karaktärisering av mindre deformationzoner på delområde Laxemar.	AP PS 400-05-096	1.0
Karaktärisering av mindre deformationszoner, södra och sydvästra delen av Laxemar.	AP PS 400-06-053	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för lineamentstolkning baserad på topografiska data.	SKB MD 120.001	1.0
Metodbeskrivning för magnetometri.	SKB MD 212.004	1.0
Metodbeskrivning för resistivitetsmätning.	SKB MD 212.005	1.0

1.2 Terminology

For the site investigation the following terminology regarding classification and naming of deformation zones have been established, Table 1-2 /12/.

The term *fracture zone* has been changed to the more general term *deformation zone (DZ)*.

Table 1-2. Terminology regarding classification and naming of deformation zones.

Denotation	Length	Width	Assignment
Regional fracture zones	> 10 km	> 100 m	Deterministic
Local major fracture zones	1–10 km	5–100 m	Deterministic
Local minor fracture zones	10 m–1 km	0.1–5 m	Statistical (some deterministic)
Fractures	< 10 m	< 0.1 m	Statistical

1.3 Local Minor Deformation Zones

Regional Deformations Zones, such as ZSMEW002A and ZSMNE005A, appears not to be a major issue to utilize the Laxemar subarea for a deep repository for spent nuclear fuel. On the other hand, the existence of Local Major DZs (ZSMEW007A, ZSMNS059A and other zones with a length > 1,000 m), and Local Minor DZs may have an impact on the distribution and size of the rock volume available for the repository. This impact may be due to restrictions for deposition in the vicinity of major zones and in loss of individual deposition positions. In this context, the hydraulic and engineering characteristics of the zones will be of special interest. In SKB's Underground Design Premises (UDP) /13/, used as the guideline for the design of the repository, states that a deposition hole with an inflow above a certain threshold level should be cancelled. It is also probable that future versions of UDP will include demands for maximum acceptable inflow into the deposition tunnels in order to minimize the risk of erosion of the backfill. It is expected that the tunnel inflow will be restricted to the order of a few litres per minute and 100 m tunnel. This demand suggests that most, if not all water-bearing DZs (Local Major and Local Minor), need to be sealed by grouting in order to reduce the inflow.

1.4 Background data

The MDZ study is based on already existing investigations and supported by focused investigations on targeted lineaments. The existing investigations include:

- Detailed ground geophysic data from central Laxemar /6, 7/.
- Interpreted data, such as LIDAR-data, geophysical and topographical lineaments /5, 8, 9, 10, 16/.
- Geological maps /11, 37/.
- Borehole data (geology and hydrogeological data) /15/.

The MDZ investigation utilizes investigations executed according to separate Activity plans and reported separately in various P-reports. An overview of the various background data and the work flow is illustrated in Figure 1-2.

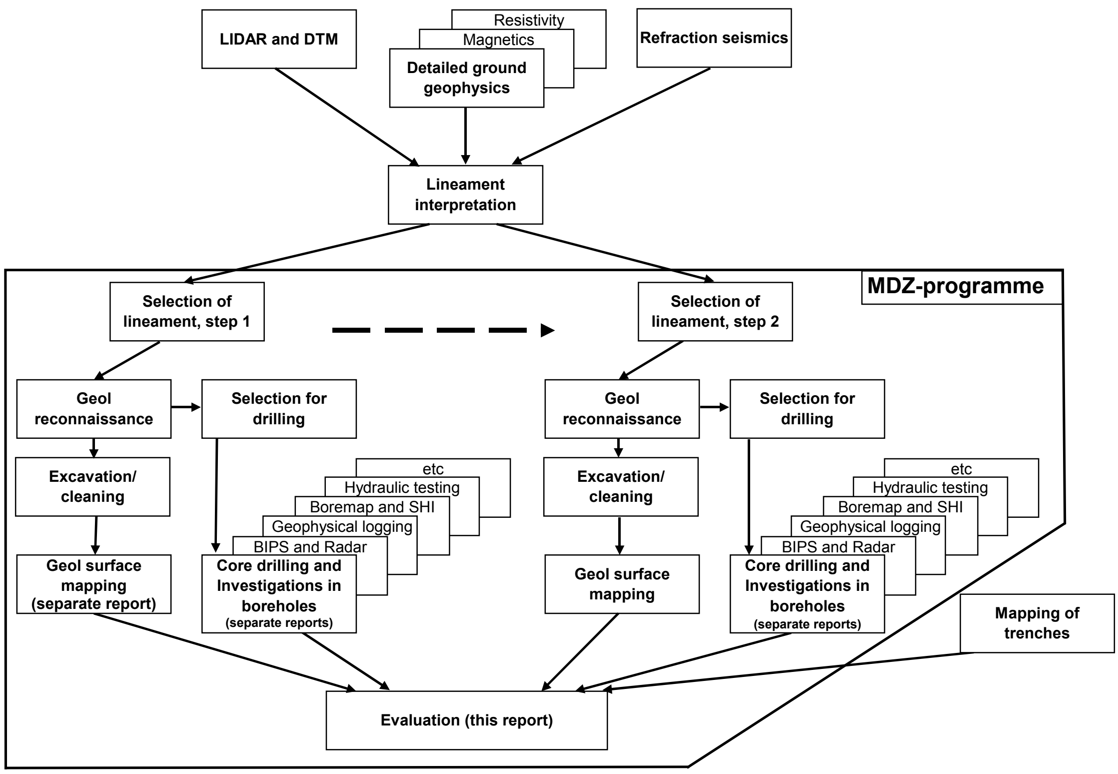


Figure 1-2. Background data and workflow for the MDZ study.

2 Objective and scope

This investigation programme for the MDZ study is carried out to obtain a better understanding of the properties of MDZs in the Laxemar subarea. Regional and local major deformation zones can be expected to influence the placement of repository and deposition areas, whereas MDZs only influence canister placement. The aim of this investigation is the identification and characterization of some MDZs in some of the well-exposed areas in the Laxemar investigation area.

The purposes of the investigation programme are:

- to try to locate and identify local minor deformation zones by comparative studies of geophysics and terrain models,
- to provide a basis for assessment of the frequency and orientation of local minor deformation zones,
- to characterize different types of local minor deformation zones, particularly with respect to the water-conducting properties of the zones,
- to devise a methodology for identification of local minor deformation zones in boreholes by comparative studies of BIPS, borehole geophysics, radar, difference flow logs and core mapping,
- to be able to carry out comparative studies of Äspö data regarding the occurrence and character of local minor deformation zones on rock surface, in boreholes and in tunnels.

The objective is to obtain better knowledge and understanding in the focussed site investigation area for assessment of hydraulic patterns, properties and the need for grouting by compiling the coupling of existing structures to geology, geophysical properties, rock stresses and groundwater conditions.

The objectives of an initial study was to identify local MDZs in the field adjacent to drill sites KLX09 and KLX10 by using geophysical data, aerial photographs and topographical information from laser scanning (LIDAR data) /14/.

3 Execution

3.1 General

The investigation has included the following activities:

- Combined interpretation of geophysical ground investigations and LIDAR data. This interpretation together with the lineament interpretation resulted in the identification of a number of possible MDZs which were chosen for more detailed investigation
- Field reconnaissance of identified lineaments in order to identify the possible MDZs at the rock surface. Selection of a limited number of objects for excavation and line mapping. The criterion for the selection was that the lineaments had an extension of at least 20 m and that the geometry at surface was well defined.
- Excavation and cleaning of the rock surface at some of the identified objects.
- Photo-documentation and scan-line mapping at the excavated lineaments.
- Core-drilling in order to verify or reject and characterize the zones at shallow depths.
- Investigations of the cored boreholes (radar, BIPS, geophysical logging, hydraulic testing).
- Core mapping using Boremap and single hole interpretation.
- Evaluation, a combined, integrated interpretation of data in order to verify or reject the lineaments as MDZs.

3.2 Execution of work

3.2.1 Combined interpretation of geophysical ground investigations and LIDAR

Detailed interpretation was made in three subareas with focus on lineaments over exposed rock or rock with shallow Quaternary cover. The lineaments initially interpreted from the geophysical ground investigations and LIDAR were re-assessed with the aim of identify possible MDZs, i.e. deformation zones less than 1 km in length. In addition, also the orientation of the lineaments was regarded as an issue in order to end up with MDZs in different directions. The lineament interpretations and background data are presented in /4–10, 16/. Also refraction seismic survey has been used /31, 33–36, 38/ as well as the geological mapping of the area /11, 37–38/.

The assignment in the geophysical interpretation in Appendix C is in accordance with the method statement, i.e. a five degree scale where 5 represents a high weight and 1 a low weight in the interpretation.

3.2.2 Field reconnaissance of identified lineaments

The identified lineaments were preliminary surveyed and some of the more interesting lineaments were selected for excavation in order to expose their character at the rock surface /14, 39/.

3.2.3 Excavation and cleaning

Over selected lineaments the soil cover and debris were removed in order to survey the daylighting of the possible MDZ. Not all of the selected lineaments were excavated due to practical reasons, such as too thick soil cover, difficult accessibility for necessary equipment and nature prevention. In total 12 lineaments were excavated and cleaned, although only minor excavation was made at some lineaments.

3.2.4 Photo-documentation and line mapping

The excavated areas were documented by photographic means (Appendix A). The exposed rock was mapped along scan-lines (Appendix B). Orientation of measured fractures longer than 20 cm were recorded in stereographic plots representing pole-to-planes, right-hand rule, lower hemisphere. In total, 9 lineaments were mapped, whereas the excavated area was too small at three of the lineaments to allow a reliable line mapping. The photo documentation is presented in Appendix A and the scan-line tables in Appendix B.

3.2.5 Core-drilling

Core-drilling was executed through selected lineaments using a small drill-rig. The boreholes have normally an inclination of 60° from the horizontal with length varying between 50 m and 150 m. In total, 13 core-drilled boreholes were made targeted at the MDZ study. In addition two boreholes, originally made for other purposes, were also used for the evaluation /17/.

3.2.6 Borehole investigations

Radar and BIPS measurements as well as geophysical logging were made in all core-drilled boreholes (Appendix C) /22–24, 26/. Hydraulic testing was made after completion using the Possiva flow-logging (PFL) equipment (Appendix E) /27–31/. The PFL anomalies are presented in Appendix E.

In addition, conventional water injection tests using single packer equipment (Lugeon test type) were made in most of the boreholes before the drill-rig was remobilized. These tests were made as single packer tests with duration of 3–5 minutes. The injection of water was made in two pressure steps, 0.2 and 0.5 MPa. The tests results are included in the drilling report /17/. The evaluation of the tests was made according to Moye's equation and is included as Appendix F. In one borehole, KLX10B, an open hole injection test were performed. The result is presented in Appendix G.

3.2.7 Core-logging and interpretation

Initially all cores were photographed (Appendix D). The logging of core was made according to the SKB standard procedure using the Boremap system /18/. A combined interpretation focussed on MDZ and based on the geophysical logging results and the detailed Boremap data completed the interpretation (SHI) /20, 21, 25/. Photographs of the cores are included as Appendix D.

The assignment of confidence for the deformation zones are in accordance with the single hole interpretation, i.e. the confidence in the interpretation of a possible deformation zone is made on the following basis: 3 = high, 2 = medium and 1 = low.

3.2.8 Evaluation

The final evaluation of lineaments XSM000001–XSM000021 is focused on the possibility to find a correlation between surface indications and borehole data especially concerning "geological signatures" such as mylonite, cataclasites, brecciation, alteration, host rock and fracture minerals. In order to correlate the orientation of a possible MDZ in boreholes with lineaments and zone orientation at surface it is important to compare fracture orientations at the surface and in the boreholes. Radar data can also be helpful.

The identified deformation zones from the SHI was also correlated to the results from the Posiva flow-logging in order to obtain a hydraulic signature.

Finally, an evaluation regarding the lineament's appearance at surface and in the borehole was defined stating its occurrence as a MDZ or not. The existence of a lineament is not necessarily a deformation zone, but may have other reasons as well. Also the MDZ's importance for design and construction was established in the concluding evaluation.

The evaluation of the lineaments as MDZs is made at three levels (a forth level contains structures not interpreted as a MDZ) depending on the structure's importance for design and construction:

A Verified MDZ of high importance.

B Possibly MDZ, but of minor importance.

C No or very weak indication of MDZ.

D Local major DZ or dyke.

Lineaments evaluated as MDZs, i.e. A or B have also been assigned a confidence level for its occurrence on the following where confidence level 1 indicate a low confidence and 3 high confidence of existence.

3.3 Data handling/post processing

Data handling was executed in the different steps outlined above according to the respective method description.

The results from the evaluation presented in this report are entered into Sicada as report files.

4 Results

The results are presented for lineaments identified in three sub-areas; West, Northeast and Southeast. The lineaments and core-drilled boreholes are shown in Figure 4-1. Below are each lineament described. Where excavations have been made, the surface mapping for each uncovered area is presented in figures, containing a map of the excavation, fracture orientation and photograph. Excavations have not been made at all lineaments due to various reasons. Thick Quaternary deposits restricts the possibility for excavation and so does the location of the lineament when access to the actual site is difficult. At some lineaments there were other restrictions, such as agreements with the land owners, environmental protected areas and so on.

At lineaments where core-drilling was made, a composite figure has been prepared which basically contains the following information:

1. Core-log with lithology, interpreted deformation zones and a geophysical log. At the schematic surface, potential surface indications are outlined.
2. Orientation map with the borehole, lineaments and other surface information.
3. Photographs of the core with indications of deformation zone.
4. Fracture orientation from the core.
5. Schematic sketch of the occurrence of the possible MDZ in the core with a brief description and transmissivity values.

The legend to the composite figures is given in Figure 4-2.

Some of the lineaments that were regarded significant after the field reconnaissance warranted a core-drilled borehole, the location of which was based on the existing surface information. The initial location of most of the boreholes was based on co-ordinated lineaments, version November 2005. A re-interpretation of the co-ordinated lineaments was made in spring 2006 which slightly changed the position of the lineaments. Both the preliminary interpretation (November 2005) and the final interpretation (May 2006) are presented for each lineament.

This report comprises information regarding the following core-drilled boreholes and the targeted MDZ. An overview of the boreholes and targeted lineaments are given in Table 4-1. The location of the boreholes is shown in Figure 4-1.

Complimentary information from the investigations are presented in a number of Appendices;

- Appendix A Excavations and photographs of the excavations.
- Appendix B Scan-line tables.
- Appendix C Geophysical indications.
- Appendix D Core photographs.
- Appendix E PFL Flow anomalies.
- Appendix F Water injection tests.
- Appendix G Open hole injections test in KLX10B.

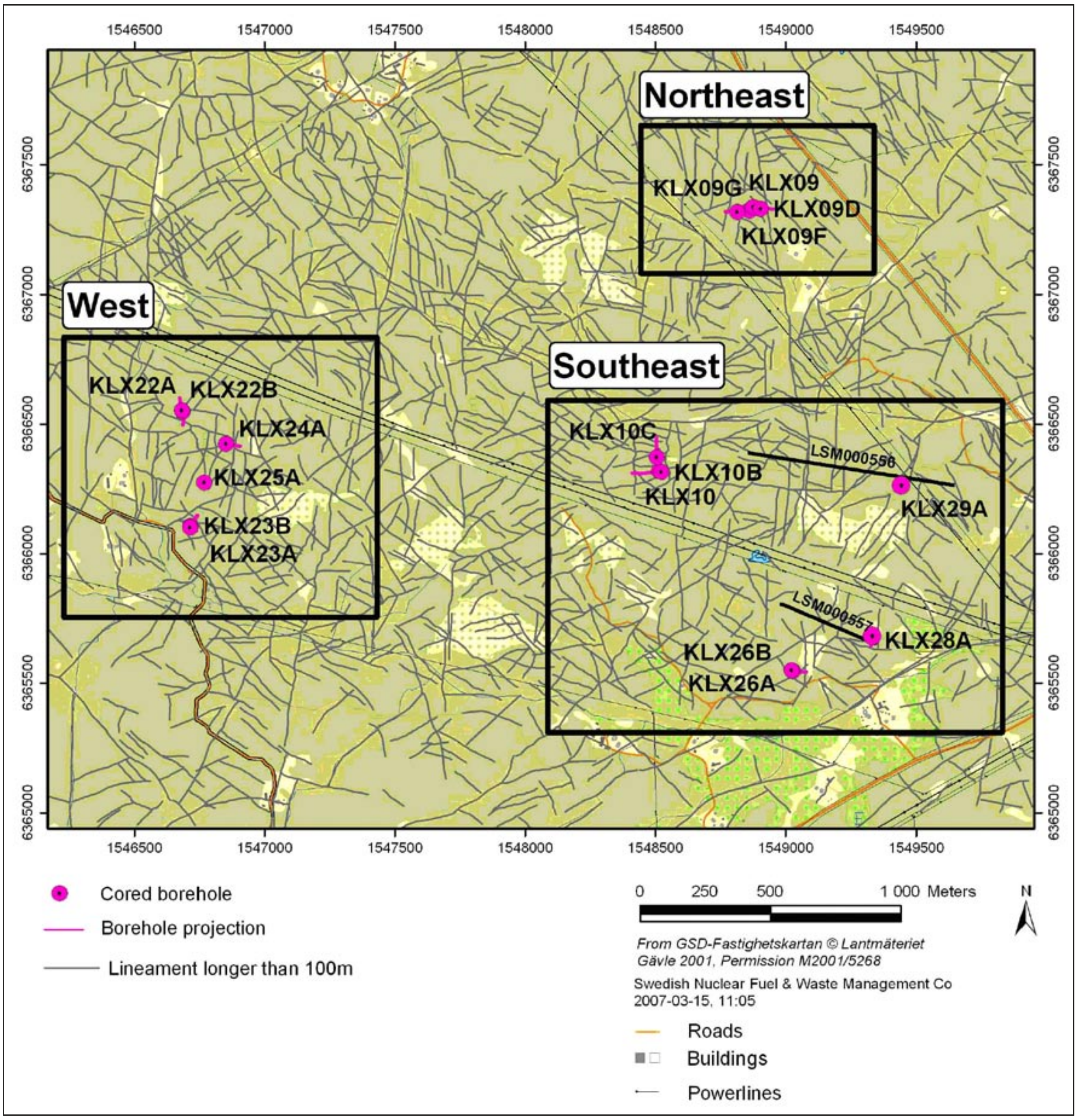


Figure 4-1. *Map of Laxemar showing co-ordinated lineaments, the investigated MDZ-areas in Laxemar, MDZ-boreholes as well as boreholes KLX09 and KLX10 and refraction seismic profiles (LSM000556 and -557) in area southeast.*

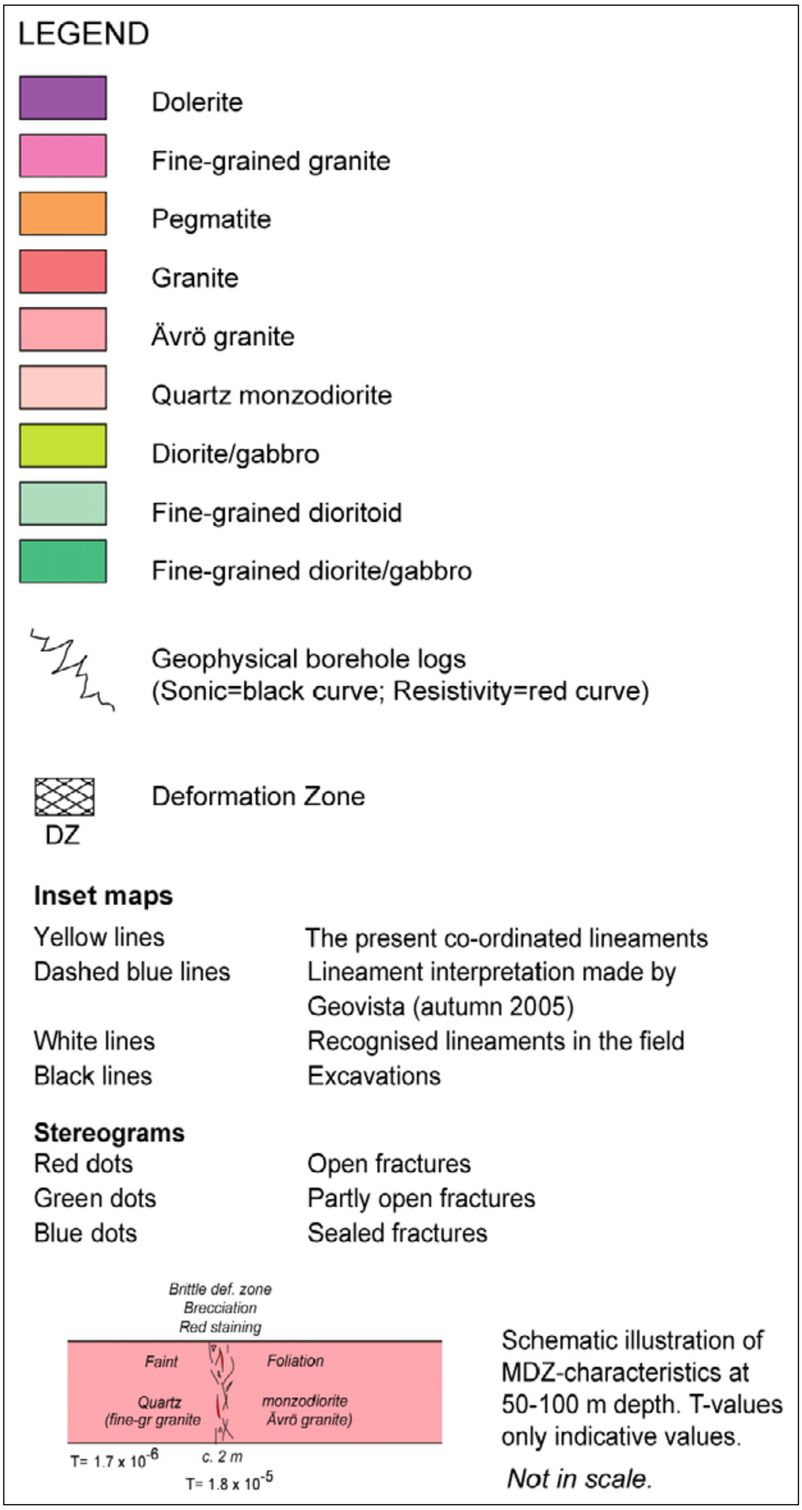


Figure 4-2. *Legend to the composite figures presented below for the core-drilled boreholes.*

Table 4-1. MDZ boreholes and targeted lineaments (single, non co-ordinated lineaments).

Sub-area	BH	Targeted lineament	Lineament characteristics / Comments
NE	KLX09D	N-S	Weak topographic lineament. Boreholes included in the DFN programme. Length 100 m.
NE	KLX09F	N-S	Weak topographic lineament. Boreholes included in the DFN programme. Length 100 m.
NE	KLX09G	NNW-SSE	Strong magnetic lineament. May coincide with ZSMNS046. Length > 500 m.
SE	KLX10B	NE-SW	Long and strong magnetic lineament. Length; discontinuous 250 m.
SE	KLX10C	E-W	Several parallel magnetic lineaments. Length 100 m.
W	KLX22A	WNW-ESE	Magnetic and topographic lineament. Length 344 m.
W	KLX22B	NE-SW	Magnetic and topographic lineament. Length 254 m.
W	KLX23A	E-W	Magnetic lineament. Length 250 m.
W	KLX23B	NE-SW	Magnetic lineament. Length 20 m.
W	KLX24A	N-S	Magnetic and topographic lineament. Length 350 m.
W	KLX25A	NE-SW	Magnetic and topographic lineament. Length 200 m.
SE	KLX26A	NE-SW N-S	Strong magnetic and topographic lineament. The NE-SW coincides with KLX26B, Length 180 m. The N-S lineament may coincide with NS046, Length 220 m.
SE	KLX26B	NE-SW	Magnetic lineament. Coincide with the NE-SW lineament targeted by KLX26A. Length 180 m.
SE	KLX28A	E-W	Magnetic, lineament also recorded by refraction seismics, Length 130 m.
SE	KLX29A	NE-SW	Magnetic and topographic lineament also recorded by refraction seismics, Length 180 m.

4.1 Area West

In total 9 lineaments were selected for investigations (XSM000001–XSM000009). In six of these core drilling and borehole investigations also were performed while three were rejected after field reconnaissance (XSM000005, XSM000006 and XSM000021), see Figure 4-3.

4.1.1 Lineament XSM000001 and XSM000002

Lineament description

The lineament XSM000001 is 250 m long and is indicated by topographic, magnetic and resistivity data with moderate weight (3). The primary co-ordinated lineaments have been reinterpreted and the extent and location of this lineament has changed. The target lineament strikes approximately 90° and the re-interpreted lineament in 100°.

The lineament XSM000002 is almost 250 m long. The rock at the site is filled with a shallow layer of till and the hills on either side are approximately 2–4 m high. No fractures along the depression were identified prior to uncovering.

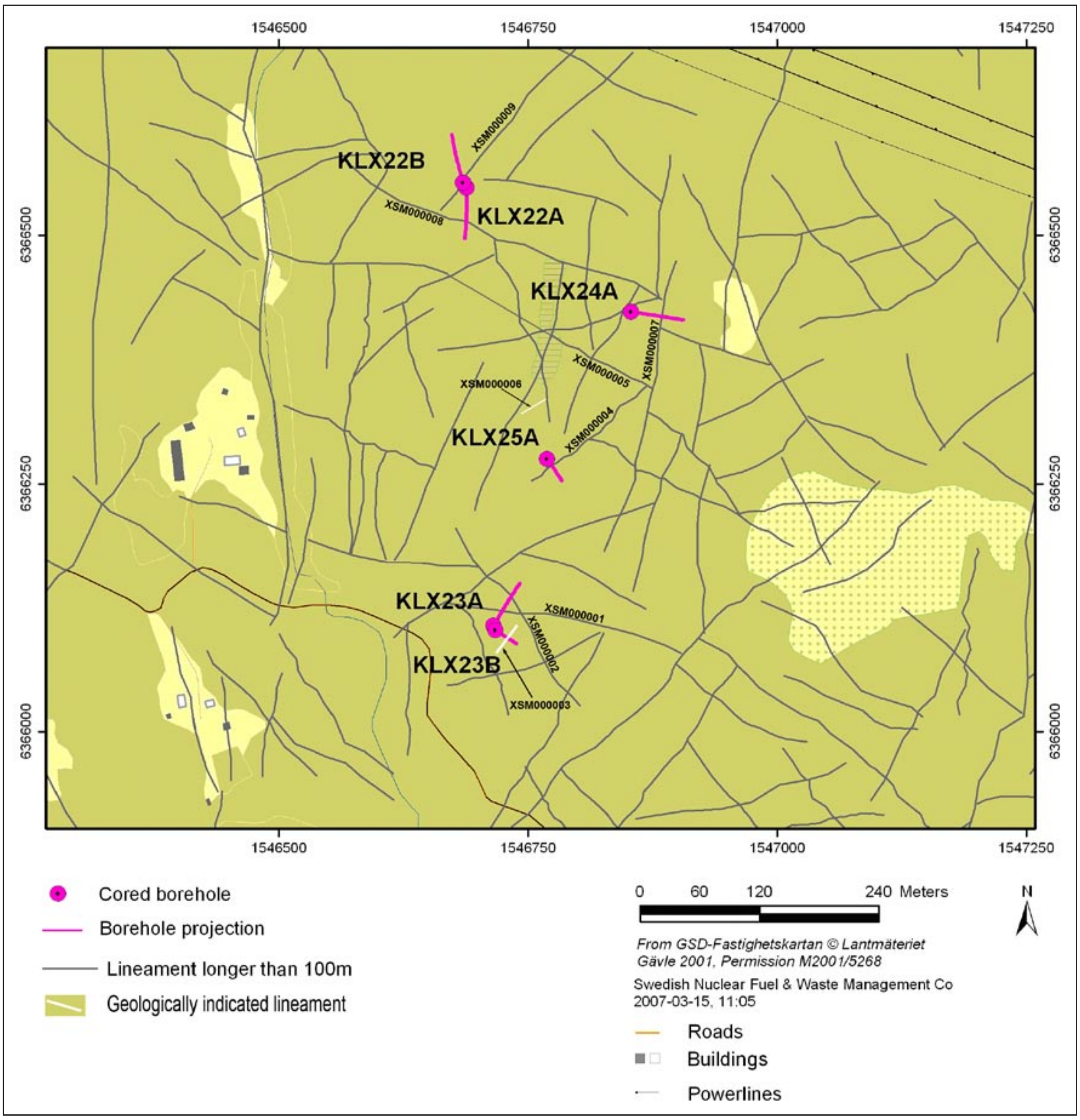


Figure 4-3. *Map showing lineaments and drillholes in the western area.*

Description of uncovered area

Uncovering was only made for lineament XSM000001. The uncovered area is approximately 13 m long (N-S) and 3 m wide (outcrop A6, Appendix B). Host rock is quartz-monzodiorite with minor fine-grained granite and pegmatite (Figure 4-4). The uncovered brittle-ductile deformation zone is c. 0.3 m thick and run along the lineament. Almost all fractures run parallel to the zone boundary. There is c. 1 fracture per cm in the zone (scan-line LSM000589). The ductile structure is diffuse.

No uncovering was made for XSM000002.

Lineament: XSM000001, scan-line: LSM000589 (outcrop A6)

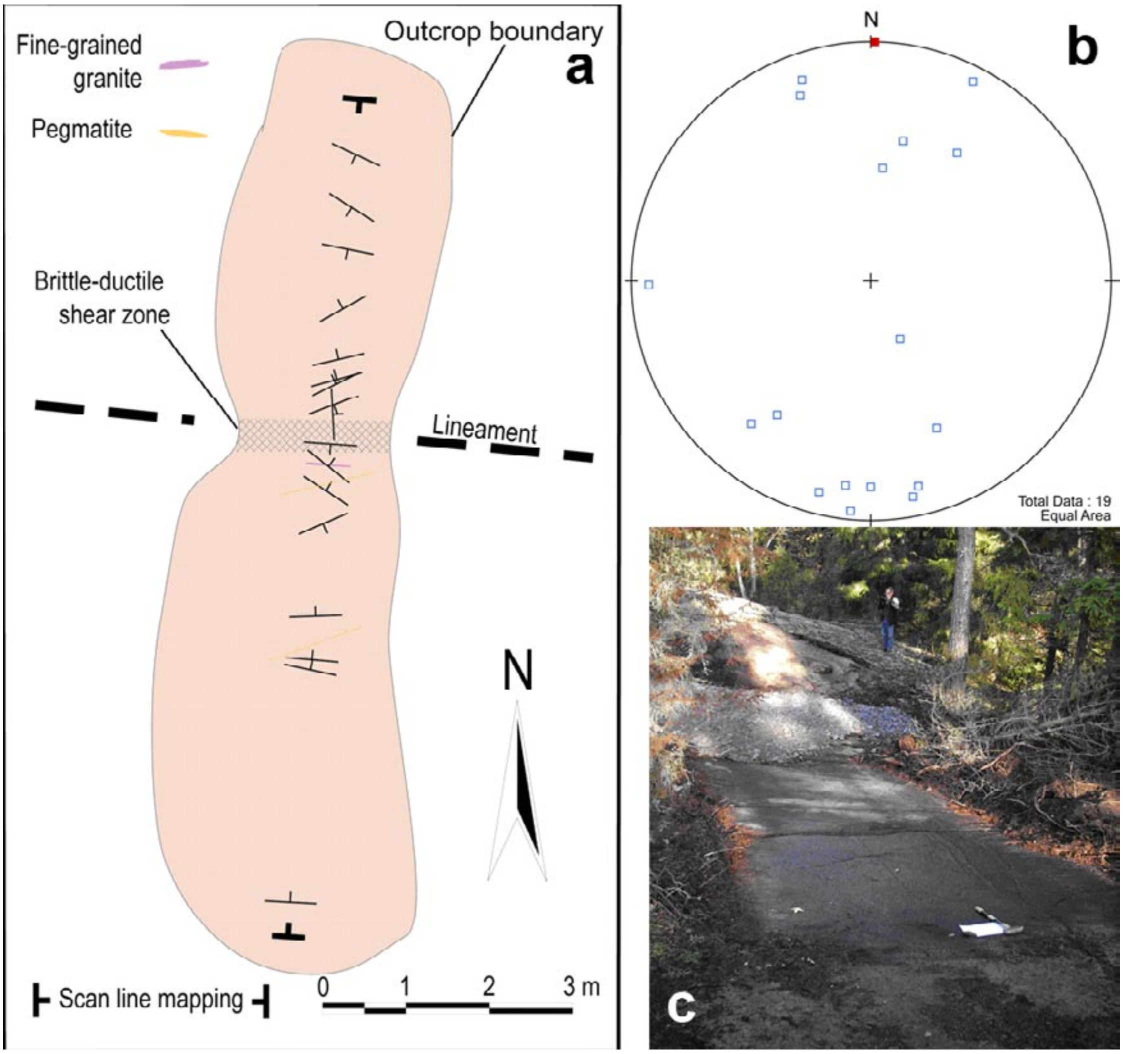


Figure 4-4. a) Sketch illustrating mapped structures and geology at scan-line LSM000589 (outcrop A6). The rock type at the outcrop is a quartz-monzodiorite. For location, see Figure 4-3 and Figure 4-5. The lineament across the outcrop is part of the co-ordinated lineaments in the area. The internal structures in the brittle–ductile deformation zone are primarily parallel to the zone (89/90). It is c. 30 cm thick and is located in the lowest part of the small depression along the lineament. b) Stereographic plot (lower hemisphere) of fracture orientations along the scan-line. Red dot represents the brittle-ductile deformation zone, and the fractures within it. c) Photograph taken towards the north of the uncovered outcrop A6. The brittle-ductile deformation zone is covered with gravel, which was not present during mapping, see Appendix A.

Description of borehole KLX23A /17/

The borehole site KLX23A was selected with the main aim to investigate the lineament XSM000001 having a close to E-W strike and possibly also the lineament XSM000002 striking NW-SE (Figure 4-5).

The cored borehole KLX23A was drilled towards the lineament XSM000001 t and entered the bedrock directly. Bearing = 28.73° Inclination = –61.35°.

The borehole length was chosen to reach lineament XSN000002 as well.

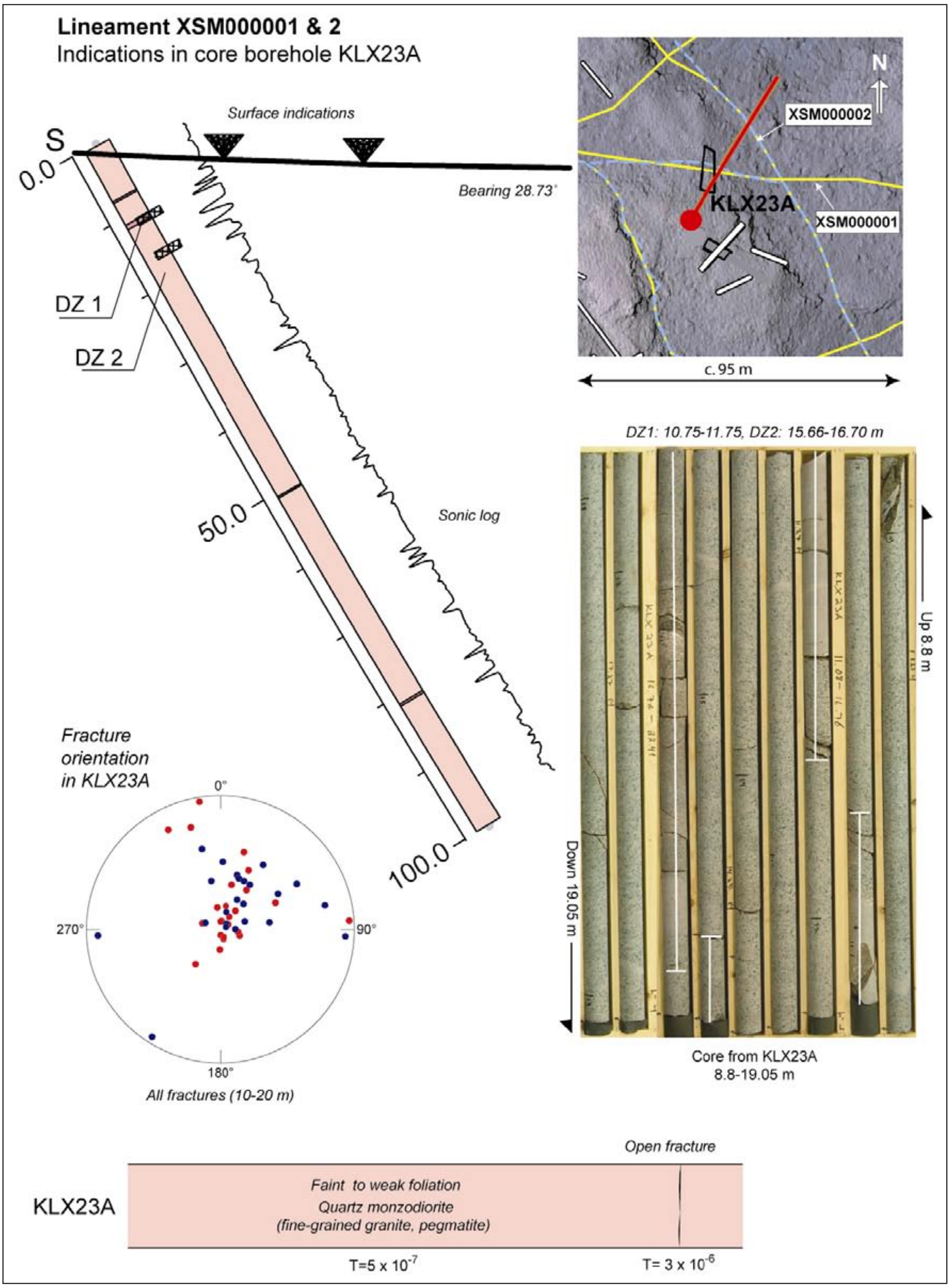


Figure 4-5. *Composite figure of KLX23A and the lineaments XSM000001 and XSM000002. A legend is given in Figure 4-2.*

Data from single hole interpretation /20/

Rock distributions

KLX23A is totally dominated by quartz-monzodiorite. Subordinate rock types comprise fine-grained granite and very sparse occurrence of pegmatite. The quartz-monzodiorite has a density in the range 2,720–2,770 kg/m^3, and a magnetic susceptibility in the range 0.020–0.030 SI. Scattered up to c. 15 m long sections, which make up c. 50% of the borehole, are characterized by faint and locally weak foliation. Confidence level = 3.

Possible deformation zones

DZ1: 10.75–11.75 m. Brittle deformation zone characterized by increased frequency of sealed fractures and a slight increase in open fractures and faint red staining. Low magnetic susceptibility. The host rock is dominated by quartz-monzodiorite and fine-grained granite. Two non-oriented radar reflectors occur within the section at 11.4 m with 61° to borehole axis and at 11.7 m with 77° to borehole axis. Confidence level = 3.

DZ2: 15.66–16.70 m. Brittle deformation zone characterized by increased frequency of sealed and open fractures and weak red staining. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by quartz-monzodiorite. Subordinate rock is fine-grained granite. No radar reflector occurs within the section. Confidence level = 3.

Hydrogeological description /17, 30/

None of the interpreted DZs are covered by the PFL measurements as they a located above the groundwater level during testing. The overall transmissivity from the PFL logging was estimated at $9\cdot10^{-6}$ m^2/s with the highest value being $3\cdot10^{-6}$ m^2/s at a length of 34.0 m. The transmissivity of the lowermost 50 m of the borehole from the water injection tests gives a transmissivity of $2.6\cdot10^{-6}$ m^2/s. The groundwater level during the water injection tests was 15.75 m along the borehole, and hence no information was obtained from the identified DZs.

Evaluation

XSM000001

An approximately 0.3 m thick brittle deformation zone surrounded by a 2 m thick zone with increased fracturing in parallel to the lineament.

Dominating rock in KLX23A is quartz-monzodiorite. Two c. 1 m long sections (DZ1 at about 11 m and DZ2 at about 16 m) occur with increased fracturing. No distinct resistivity is indicated for DZ1 whereas DZ2 is characterized by a resistivity anomaly. No oriented radar reflector is found. Rock contact and open fractures in BIPS /21/.

- Fracture orientation in borehole is dominated by a moderately dipping fracture set, moderately dipping fractures striking NW-SE and dipping to SW, and a steeply dipping in ENE. The latter could possibly be interpreted as coinciding with the surface data.
- The geological signatures in the borehole do not correspond to the surface indications.

Evaluation: **C**. It is unlikely that the lineament correspond to a MDZ.

XSM000002

No surface cleaning.

There are no indications in the borehole which can be correlated to the lineament XSM000002.

Evaluation: **C**. It is unlikely that the lineament correspond to a MDZ**.**

4.1.2 Lineament XSM000003

Lineament description

The lineament XSM000003 is c. 20 m long representing a narrow linear depression, identified by LIDAR (laser-scanning of topography) and a weak magnetic anomaly. Uncovering over the lineament was performed prior to drilling. The target lineament strike approximately 60°. The depression is partly filled with till, up to c. 1 m thick. Oxidation and several fractures along the depression were identified prior to the uncovering, but no actual zone.

Description of uncovered area

The uncovered area is c. 7 m long and 3 m wide (outcrop A5). Host rock is quartz-monzodiorite. The uncovered brittle-ductile deformation zone is 0.25–0.3 m thick and runs along the lineament. The major part of the fractures also runs parallel to the zone boundary, but fractures in c. 342/85 and 240/80 are also present (LSM000588). There are 2–3 fractures per cm in the zone (Figure 4-6).

Description of borehole KLX23B /17/

The cored borehole KLX23B was drilled towards the lineament XSM000003 and entered the bedrock directly (Figure 4-7). Bearing = 121.36°. Inclination = –60.54°.

Data from single hole interpretation /20/

Rock distributions

KLX23B is totally dominated by quartz-monzodiorite. Subordinate rock types comprise fine-grained granite, Ävrö granite and very sparse occurrence of granite. The quartz-monzodiorite has a density in the range 2,720–2,770 kg/m^3, and a magnetic susceptibility in the range 0.020–0.025 SI. Scattered up to c. 15 m long sections are characterized by faint foliation. Confidence level = 3.

Possible deformation zones

DZ1: 13.30–14.80 m. Brittle deformation zone characterized by increased frequency of sealed and open fractures, brecciation, apertures in open fractures and medium red staining and weak epidotization. Slickensides are documented. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by quartz-monzodiorite. Subordinate rock is fine-grained granite. One non-oriented radar reflector at 13.80 m has the angle 60° to borehole axis. Confidence level = 3.

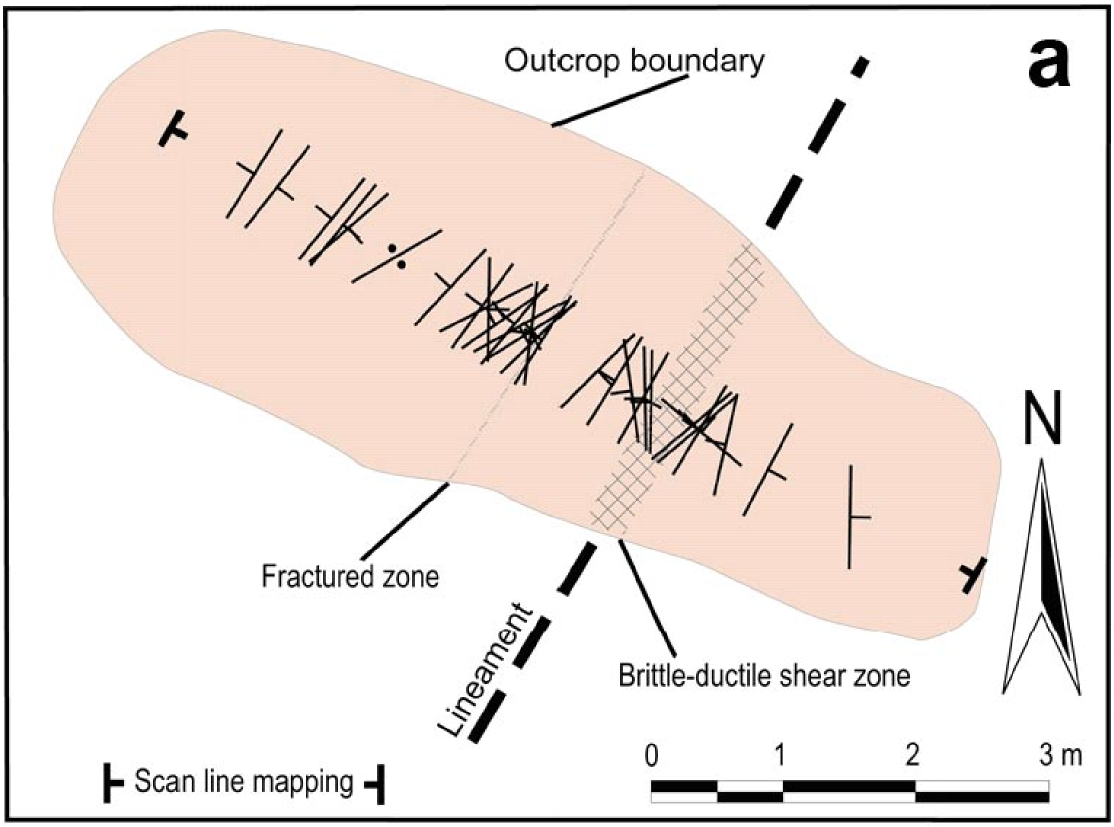
Hydrogeological description /17, 30/

The identified DZ from the single-hole interpretation occur at shallow depth, i.e. above the depth where the PFL logging indicates transmissive fractures. The overall transmissivity from the PFL logging was estimated at $7.5 \cdot 10^{-8}$ m^2/s which correspond to the highest value recorded at a borehole length of 41.5 m. The transmissivity of the entire borehole from the water injection tests gives a transmissivity of $2.6 \cdot 10^{-6}$ m^2/s which suggests that the identified superficial DZs may have a transmissivity in this order, i.e. significantly higher than the rest of the borehole. Consequently, the identified DZ1 may be of major importance as a water-bearing structure.

Evaluation

One c. 0.3 m thick ductile deformation zone runs along the lineament in the uncovered outcrop which is dominated by quartz-monzodiorite. Fracture orientation at the surface is almost parallel to the lineament.

Lineament: XSM000003, scan-line: LSM000588 (outcrop A5)



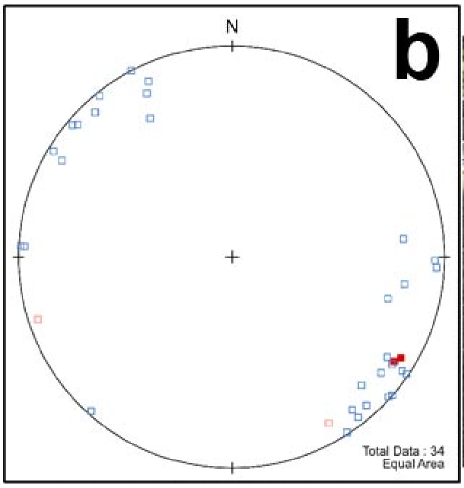


Figure 4-6. a) Sketch illustrating mapped structures and geology at scan-line LSM000588 (outcrop A5). The rock type at the outcrop is a quartz-monzodiorite. For location, see Figure 4-3 and Figure 4-7. The lineament across the outcrop is not part of the co-ordinated lineaments in the area but represents a short lineament interpreted from LIDAR data between the network of longer co-ordinated lineaments (see /14/) The internal structures in the brittle-ductile deformation zone is principally parallel to the zone (209/82). It is 25–30 cm thick and also contains fractures with the orientation 342/85 and 240/80. The narrow fractured zone (2 cm thick) has an orientation of 212/80. b) Stereographic plot (lower hemisphere) of fracture orientations along the scan-line. Red dots represent brittle-ductile deformation zone and fractured zone, and also the major part of the fractures within them, whereas pink symbols represent other fracture directions found in the brittle-ductile deformation zone. c) Photograph taken towards the east of the uncovered outcrop A5. The brittle-ductile deformation zone is covered with water, see Appendix A, which was removed before the scan-line mapping.

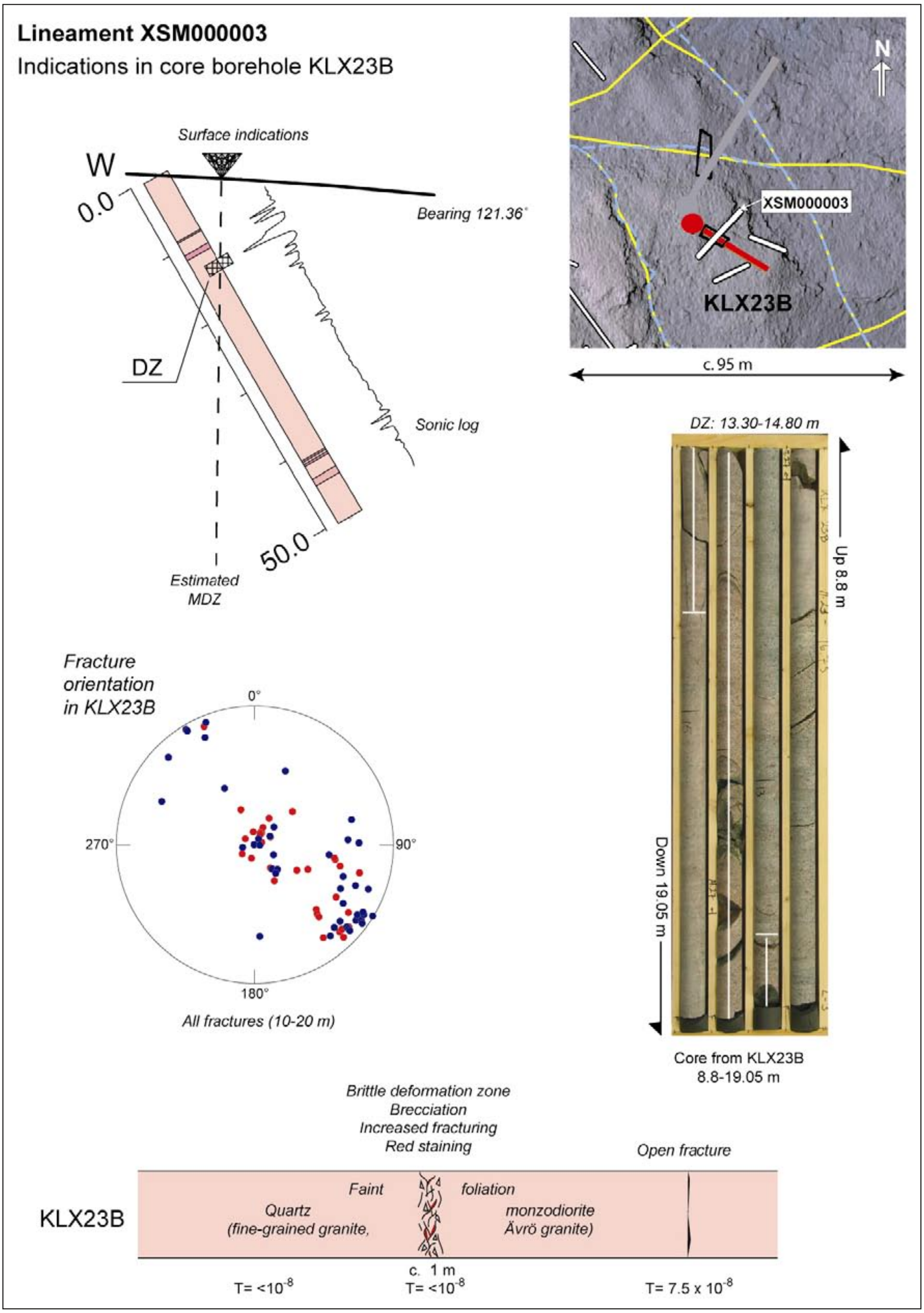


Figure 4-7. *Composite figure of KLX23B and the lineament XSM000003. A legend is given in Figure 4-2.*

The borehole KLX23B is dominated by quartz-monzodiorite. The section 13.30–14.80 m in the borehole KLX23B is characterized by increased fracturing, red staining, brecciation, low magnetic and resistivity indications. No oriented radar reflectors. About 1.5 m long section in BIPS with high frequency of open and sealed fractures corresponding to the fractured borehole section /21/.

- Fracture orientation in borehole shows a good correlation with the surface fractures.
- The hydraulic tests suggest that DZ1 is of significance.
- As there is a probable correlation between the surface zone indication and the fractured, red stained section at c. 14 m in the borehole, the indications are estimated to be a part of a MDZ with a thickness of c. 0.5 m, dipping approximately 70°.

Evaluation: **A.** The MDZ is likely to affect the siting of deposition hole.

4.1.3 Lineament XSM000004

Lineament description

The lineament XSM000004 was topographically and magnetically identified by LIDAR and detailed ground geophysical measurements. No resistivity indication. Geological field control was made before drilling. The lineament is c. 200 m long and represents locally a shallow depression covered by soil and till. A few fractures along the depression were identified prior to the uncovering.

Description of uncovered area

The uncovered area is approximately 6 m long and 2 m wide (outcrop A4, Appendix B), Figure 4-8. The dominating rock is quartz-monzodiorite. Some cm-thick brittle-ductile oxidized deformation-zone runs close to and parallel to the lineament. There is increased fracturing close to the lineament with most fractures approximately parallel to the lineament (scan-line LSM000587).

Description of borehole KLX25A /17/

The cored borehole KLX25A was drilled towards the lineament XSM000004 and entered the bedrock directly (Figure 4-9). Bearing = 145.73°. Inclination = –59.46°.

Data from single hole interpretation /20/

Rock distributions

KLX25A is totally dominated by quartz-monzodiorite. Subordinate rock types comprise fine-grained granite, and very sparse occurrences of pegmatite and fine-grained diorite to gabbro. The quartz-monzodiorite has a density in the range 2,740–2,790 kg/m^3, and a magnetic susceptibility in the range 0.015–0.025 SI. A few minor sections are characterized by faint to moderate foliation. Confidence level = 3

Lineament: XSM000004, scan-line: LSM000587 (outcrop A4)

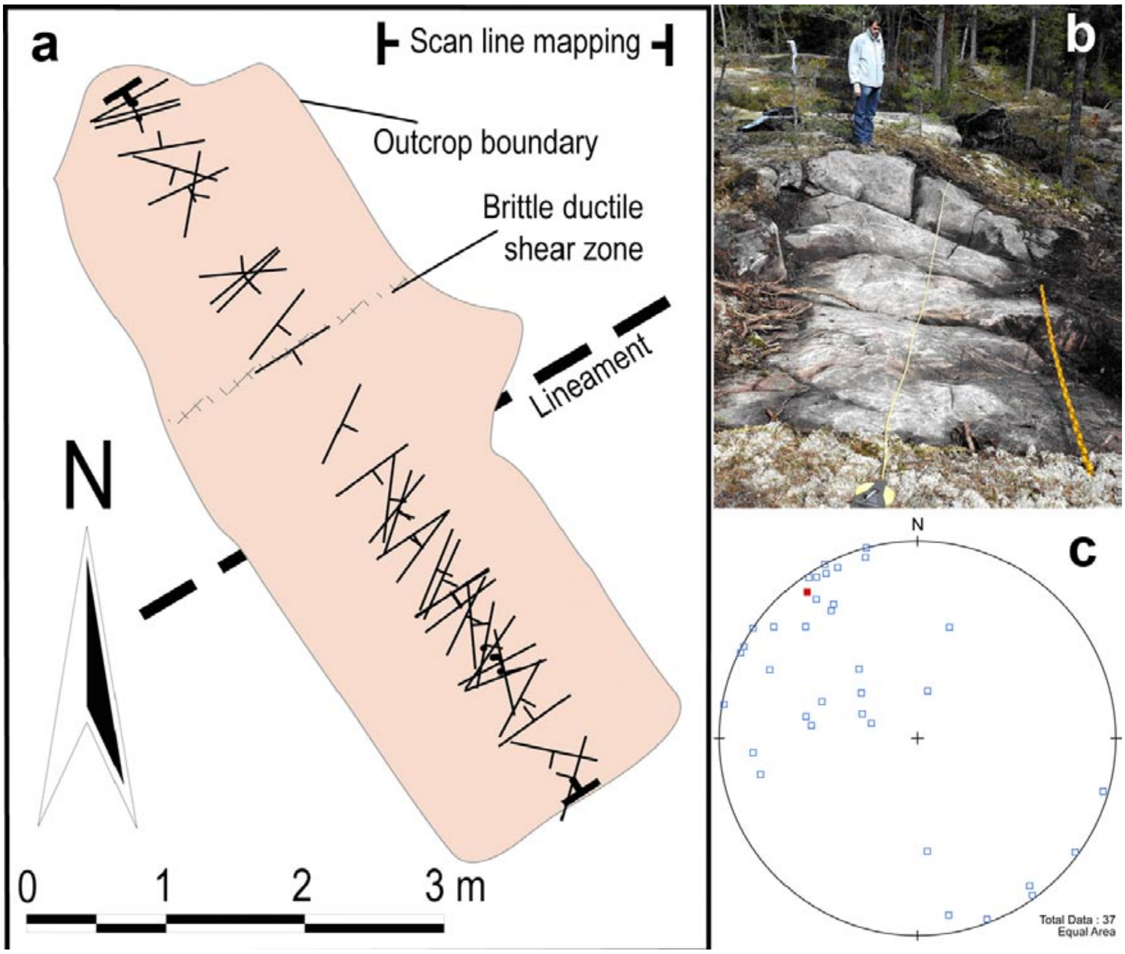


Figure 4-8. *a) Sketch illustrating mapped structures and geology at scan-line LSM000587 (outcrop A4). The rock type at the outcrop is a quartz-monzodiorite. For location, see Figure 4-3 and Figure 4-9. The lineament across the outcrop is part of the co-ordinated lineaments. b) Photograph taken towards the northwest of the uncovered outcrop at LSM000587 (A4, see Appendix A). c) Stereographic plot (lower hemisphere) of fracture orientations along the scan-line. Red dot represent the brittle-ductile deformation zone and the fractures within it.*

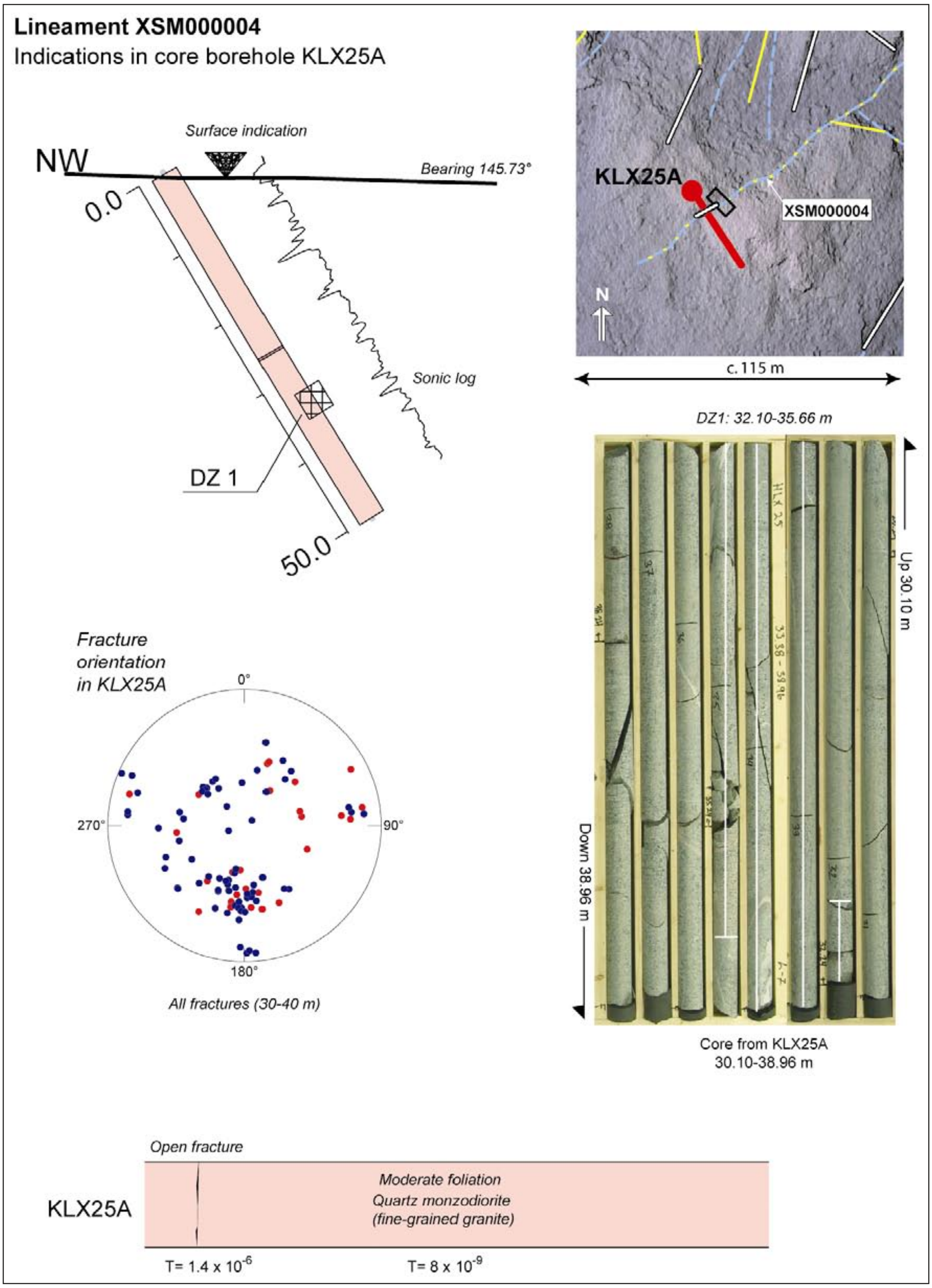


Figure 4-9. *Composite figure of KLX25A and the lineament XSM000004. A legend is given in Figure 4-2.*

Possible deformation zones

DZ1: 32.10–35.66 m. Brittle-ductile deformation zone, moderately foliated with increased frequency of sealed and open fractures, faint to weak red staining and weak carbonatization. Low magnetic susceptibility. The host rock is dominated by quartz-monzodiorite. Subordinate rock type is fine-grained granite. One non-oriented radar reflector at 34.3 m has the angle 61° to borehole axis. Confidence level = 3.

Hydrogeological description /17, 30/

The identified DZ1 at 32.10–35.66 has 3 recorded flow anomalies with low transmissivities, the integrated transmissivity being $8 \cdot 10^{-9}$ m^2/s. The overall transmissivity from the PFL logging was estimated at $1.7 \cdot 10^{-6}$ m^2/s with the maximum at a borehole length of 23.3 m. The transmissivity of the entire borehole from the water injection tests gives a transmissivity of $9.6 \cdot 10^{-6}$ m^2/s. Consequently, the identified DZ1 is of low importance as a water-bearing structure.

Evaluation

The uncovered area is dominated by quartz-monzodiorite. Cm-thick ductile-brittle deformation zones and increased fracturing is mapped close to the lineament. Most fractures have an orientation parallel to the lineament.

The borehole KLX25A is dominated by quartz-monzodiorite. DZ1 at about 32–36 m is low magnetic and characterized as a brittle-ductile deformation zone, sealed and open fractures. No oriented radar reflectors. Inhomogeneous rock with open and sealed fractures in BIPS /21/.

- The correlation in fracture orientation between the borehole and the surface is poor.
- The identified DZs have no significant water flow. The transmissivity is only $8 \cdot 10^{-9}$ m^2/s.
- There is no clear correlation between surface zone indications and DZ1 in the borehole.

Evaluation: **C.** It is unlikely that the lineament represents to a MDZ.

4.1.4 Lineament XSM000005

Lineament description

This site was selected with the aim to investigate the NW-trending lineament XSM000005 (Figure 4-10).

The lineament is 250 m long and belongs to the lineaments in the first delivery. Since then the co-ordinated lineaments have been reinterpreted and the exact location have partly changed. In this particular case the target lineament has been discarded and a lineament with another orientation runs across the uncovered area. The target lineament strikes approximately 120°, whereas the reinterpreted lineament strikes in 80°. The target lineament represents a shallow depression covered by peat bog and till. A few fractures along the depression were identified prior to the uncovering, but no actual zone.

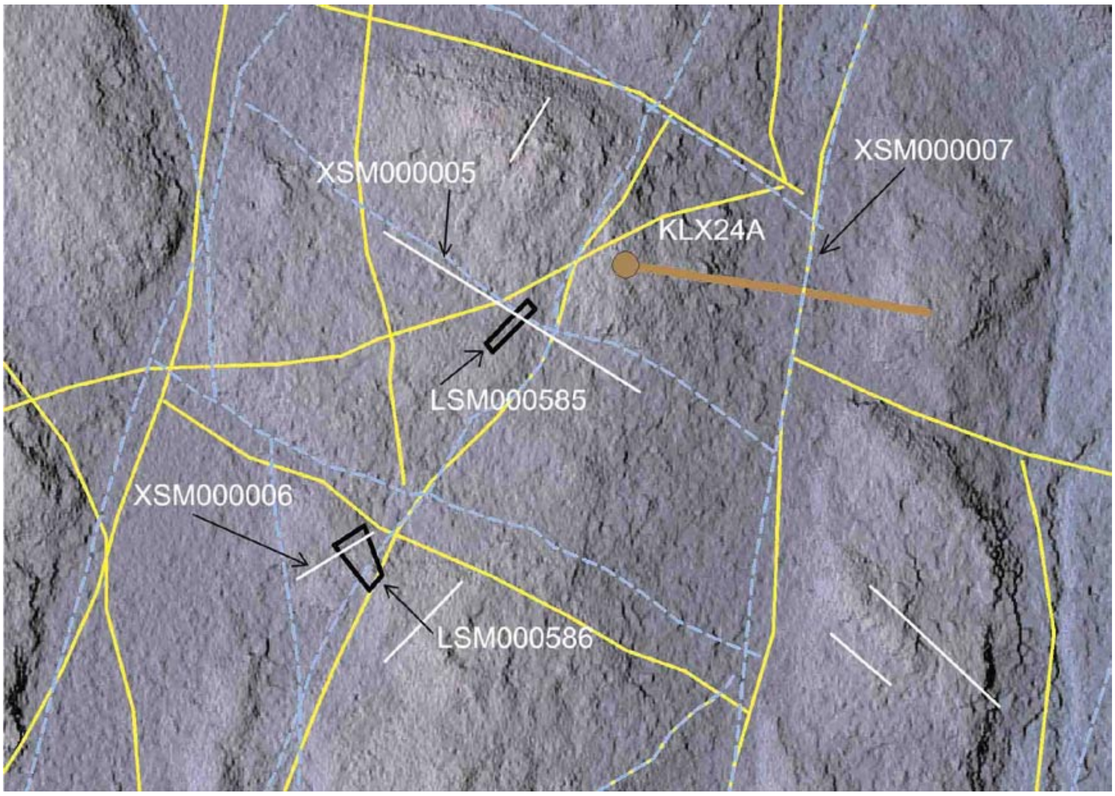


Figure 4-10. *Location of uncovered areas A2 and A3 with scan-lines LSM00585 and LSM000586, respectively. Location of KLX24A as well as the three actual lineaments (XSM000005, XSM000006 and XSM000007) is also shown. Yellow lines show the latest version of co-ordinated lineaments, blue lines the version before that and the white lines show lineaments recognised in the field.*

Description of uncovered area

The uncovered area (outcrop A2) is approximately 10 m long and 2 m wide. 40 fractures (> 0.2 m long) have been mapped along the scan-line (LSM000585). Most of the fractures strike N-NW. A c. 3 cm thick sinistral brittle-ductile deformation zone was found parallel to the target lineament. Host rock is quartz-monzodiorite (Figure 4-11).

Evaluation

The uncovered area is dominated by quartz-monzodiorite. Very narrow (some cm thick) ductile deformation zone runs parallel to the lineament direction. Most of the mapped fractures are not parallel to the lineament.

Due to weak surface indications drilling was not performed.

Evaluation: **C**. No MDZ.

4.1.5 Lineament XSM000006

Lineament description

The site was selected in order to collect field information from a minor lineament recognized in the LIDAR data, having a northeast-southwest strike (Figure 4-10).

The lineament is > 150 m long and represents a narrow linear depression in the bedrock. The target lineament strikes approximately 60°. The depression is partly filled with till, up to c. 1 m thick. A few fractures along the depression were identified prior to the uncovering, but no actual zone was found.

Lineament: XSM00005, scan-line: LSM000585 (outcrop A2)

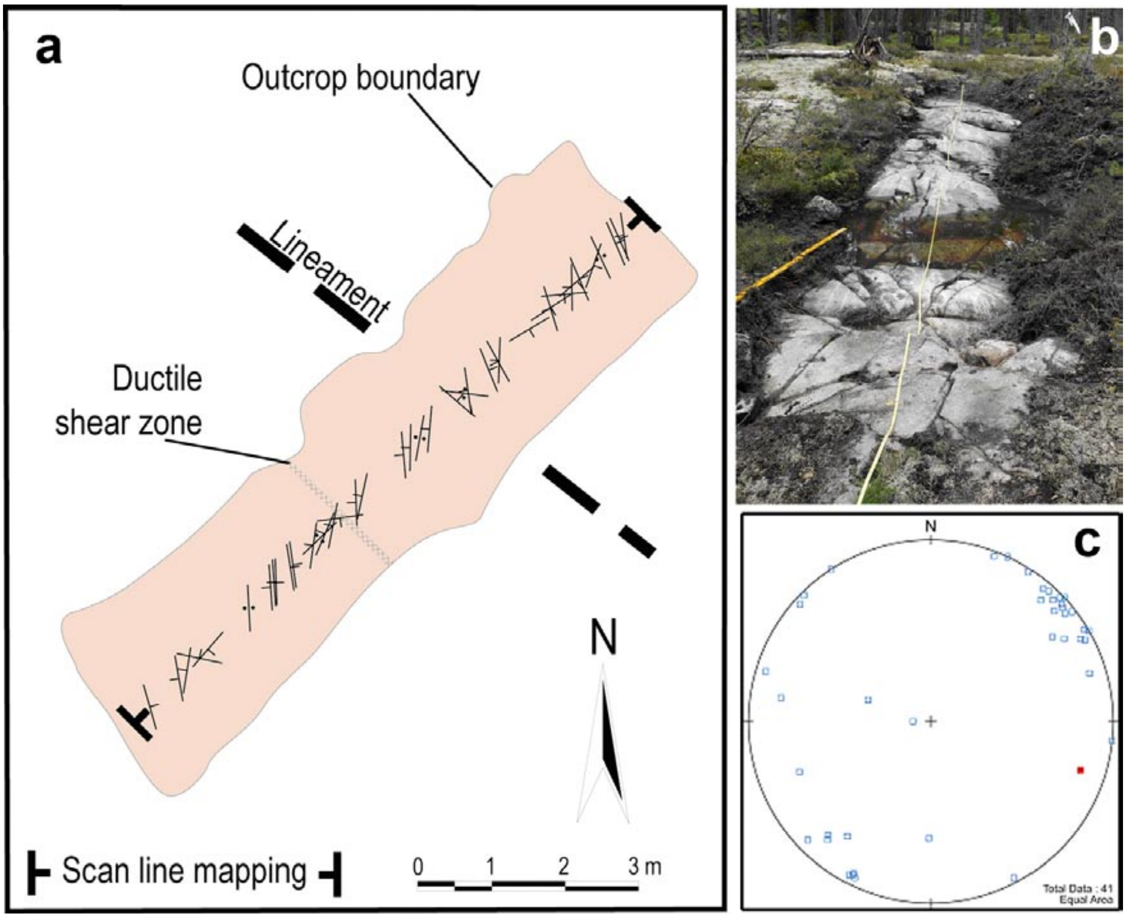


Figure 4-11. *a) Sketch illustrating mapped structures and geology at scan-line LSM000585 (outcrop A2). The rock type at the outcrop is a quartz-monzodiorite. For location, see Figure 4-3 and Figure 4-10. The lineament across the outcrop does not belong to the latest version of co-ordinated lineaments. b) Photograph of the uncovered rock at LSM000585, see Appendix A. The photo is taken towards the south. c) Stereographic plot (lower hemisphere) of fracture orientations along the scan-line. Red dot represent brittle-ductile deformation zone.*

Description of uncovered area

The uncovered area (outcrop A3) is approximately 10 m long and 4 m wide. 25 fractures (> 0.2 m long) were mapped along the scan-line LSM000586. Most of them are almost parallel to the target lineament. Host rock is quartz-monzodiorite (Figure 4-12).

Evaluation

Due to weak indications at surface (mapping of uncovered area) of a possible DZ, drilling was not performed at this site.

Evaluation: **C**. No distinct MDZ.

4.1.6 Lineament XSM000007

Lineament description

The lineament is 350 m long and topographically and magnetically identified by LIDAR and detailed geophysical measurements (weight 3), respectively. Geological field controls were made before drilling (Figure 4-10).

Lineament: XSM000006, scan-line: LSM000586 (outcrop A3)

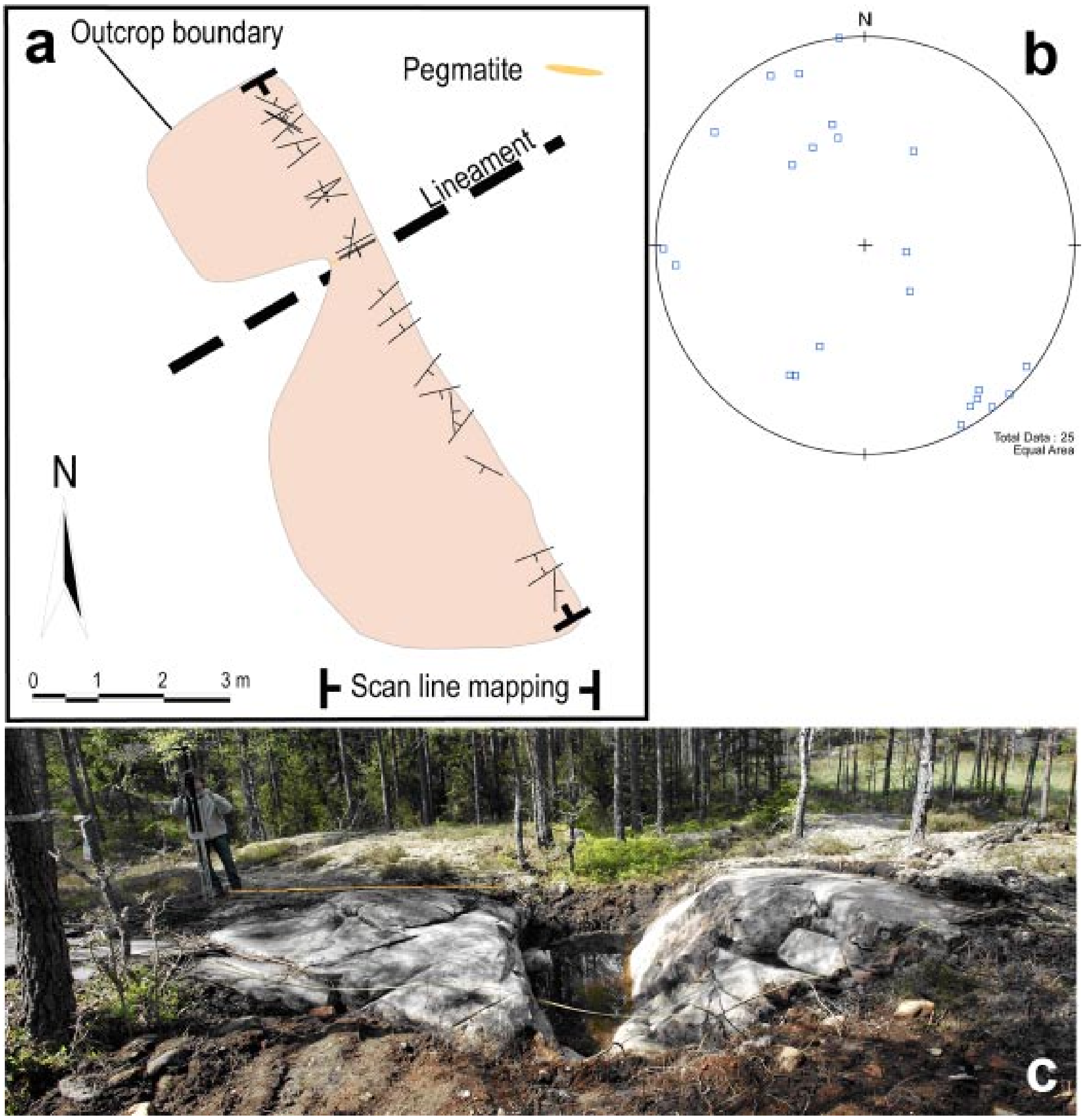


Figure 4-12. a) Sketch illustrating mapped structures and geology at scan-line LSM000586 (outcrop A3). The rock type at the outcrop is a quartz-monzodiorite. For location, see Figure 4-3 and Figure 4-10. The lineament across the outcrop does not belong to the co-ordinated lineaments, but is one of the short lineaments interpreted from the LIDAR data between existing larger scale co-ordinated lineaments (see /14/). b) Stereographic plot (lower hemisphere) of fracture orientations along the scan-line. c) Photograph of the uncovered outcrop A3. The photo is taken towards the southwest. The lineament runs along the small water-filled depression.

Description of uncovered area

Due to thick overburden in the lineament valley, uncovering was not possible.

Description of borehole KLX24A /17/

The core borehole KLX24A was drilled towards the lineament XSM000007 and entered the bedrock directly (Figure 4-13). Bearing = 98.41°. Inclination = –59.15°.

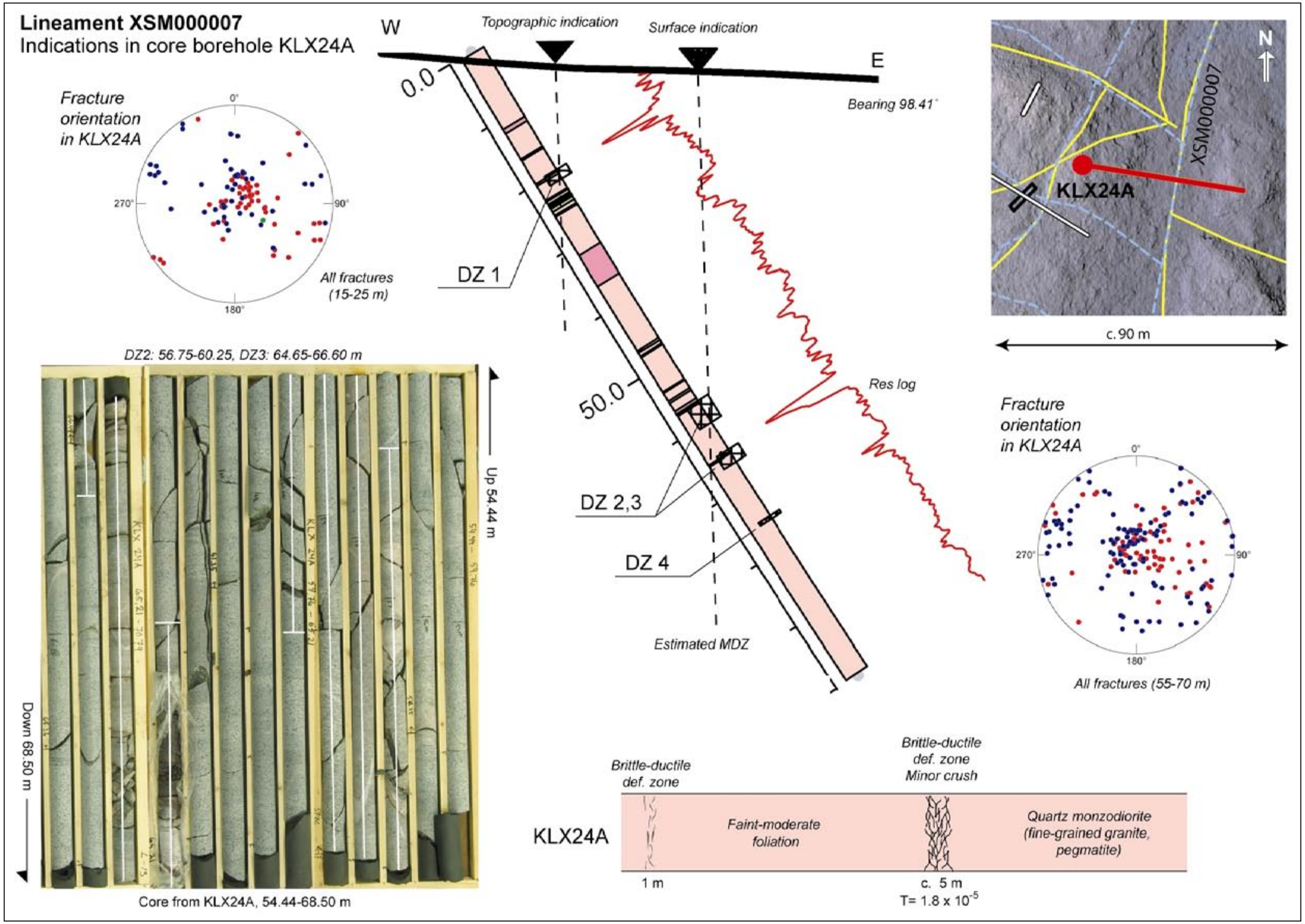


Figure 4-13. *Composite figure of KLX24A and the lineament XSM000007. A legend is given in Figure 4-2.*

Data from single hole interpretation /20/

Rock distributions

KLX24A is totally dominated by quartz-monzodiorite. Subordinate rock types comprise fine-grained granite, particularly in the section c. 31–36 m, pegmatite, diorite to gabbro, and very sparse occurrences of granite and sandstone. The quartz-monzodiorite has a density in the range 2,750–2,800 kg/m^3, and a magnetic susceptibility in the range 0.020–0.040 SI. Scattered minor sections are characterized by faint to moderate foliation, particularly the fine-grained granite in the section c. 31–36 m. Confidence level = 3.

Possible deformation zones

DZ1: 19.75–21.20 m. Brittle deformation zone characterized by increased frequency of sealed and open fractures, faint red staining, minor crush and slickensides. Low magnetic susceptibility, resistivity and P-wave velocity as well as two caliper anomalies. The host rock is dominated by quartz-monzodiorite. Subordinate rock types are pegmatite and fine-grained granite. Two non-oriented radar reflectors at 20.2 and 21.4 m have the angle 18° and 63° respectively to borehole axis. Confidence level = 3.

DZ2: 56.75–60.25 m. Ductile deformation zone with increased frequency of sealed and open fractures, weak red staining and saussuritization, and slickensides. Low magnetic susceptibility. The host rock is dominated by quartz-monzodiorite. Subordinate rock types are pegmatite and fine-grained granite. One non-oriented radar reflector at 56.7 m has the angle 47° to borehole axis. Confidence level = 3.

DZ3: 64.65–66.60 m. Brittle-ductile deformation zone with increased frequency of both sealed and open fractures, minor crush and core loss, weak red staining and slickensides. Low magnetic susceptibility, resistivity and P-wave velocity, one caliper anomaly. The host rock is dominated by quartz-monzodiorite. Subordinate rock types are pegmatite and fine-grained granite. Two radar reflectors occur in the section. One oriented at 64.1 m (191/17) and one non-oriented at 65.6 m has the angle 82° to borehole axis. Confidence level = 3.

DZ4: 75.25–75.75 m. Brittle deformation zone, brecciated with increased frequency of sealed fractures, apertures in some open fractures and weak red staining. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by quartz-monzodiorite. Subordinate rock type is pegmatite. Three radar reflectors in the section. One oriented at 74.4 m (224/50) and two non-oriented at 73.4 and 75.3 m have the angles 26° and 45° respectively, to the borehole axis. Confidence level = 3.

Hydrogeological description /17, 30/

Several flow anomalies were recorded in KLX24A, some of coincide with identified DZs. The uppermost DZ1 is located above the depth where the PFL logging indicates transmissive features. DZ2 coincide with 4 flow anomalies with a total transmissivity of $6.2 \cdot 10^{-8}$ m^2/s and DZ3 coincide with 2 flow anomalies with a total transmissivity of $1.8 \cdot 10^{-5}$ m^2/s, which is by far the highest transmissivity recorded in KLX24A. DZ4 coincide with one flow anomaly with a transmissivity of $2.7 \cdot 10^{-8}$ m^2/s.

The overall transmissivity from the PFL logging was estimated at $2.0 \cdot 10^{-5}$ m^2/s suggest that DZ2 dominates the borehole. The transmissivity of the entire borehole from the water injection tests gives a transmissivity of $2.3 \cdot 10^{-5}$ m^2/s, i.e. in the same order as the PFL-measurements. This suggests that the contribution from DZ1 to the borehole transmissivity is limited.

Evaluation

No uncovered area.

The borehole KLX24A is dominated by quartz-monzodiorite. A number of DZs appear at c. 21 m (DZ1), 57 m (DZ2), 65 m (DZ3) and 75 m (DZ4). Directional radar at 64 m coincides with the lineament orientation. Inhomogeneous rock with high frequency of open and sealed fractures in BIPS /21/.

- Some correlation in fracture orientation between one fracture set in borehole and lineament orientation.
- Significant transmissivity in DZ3, $1.8 \cdot 10^{-5}$ from the PFL measurement.
- The DZs in the borehole probably represent a complex, rather thick DZ (local major DZ) which correspond to the wide lineament valley. Due to lack of uncovered surface it is very uncertain to estimate DZ1 (19.75–21.20 m) as a part of a separate minor zone.

DZ1 at c. 20–21 m can be correlated to a topographic indication. DZ2 and DZ3 at about 56.7–66.7 m is probably a part of a local major zone.

Evaluation: **D.** Local Major DZ.

4.1.7 Lineament XSM000008

Lineament description

The site was selected in order to investigate the WNW-trending lineament XSM000008 (Figure 4-15).

The co-ordinated lineament is c. 350 m long and identified by LIDAR and ground geophysical measurements. The major part of the lineament in question represents a valley that varies in width between c. 15 and 20 m. The hills on either side are c. 10 m high and have a large proportion of outcropping rock. Very few outcrops of rock are found in the valley, where most of the ground is peat and till. Fracturing along the valley was identified prior to the uncovering, but no actual zone was found.

Description of uncovered area

The uncovered area (outcrop area A1) is approximately 18 m long and 4 m wide. 34 fractures and a fracture zone where mapped along the scan-line LSM000584. The fracture zone is c. 2 dm thick, strikes 260° and have a gentle (15°) northerly dip. The host rock is quartz-monzodiorite with minor pegmatite and fine-grained granite (Figure 4-14).

Description of borehole KLX22A /17/

The core borehole KLX22A was drilled towards the lineament XSM000008 and entered the bedrock directly and drilled towards the lineament. Bearing = 179.19°. Inclination = –59.93°.

Data from single hole interpretation /20/

Rock distributions

KLX22A is totally dominated by quartz-monzodiorite. Subordinate rock types comprise fine-grained granite, particularly in the section 64–69 m, and fine-grained diorite to gabbro, particularly in the section c. 69–74 m. The quartz-monzodiorite has a density in the range 2,750–2,800 kg/m^3, and a magnetic susceptibility in the range 0.015–0.025 SI. A major part of the rock unit is characterized by faint to moderate foliation. Confidence level = 3.

Lineament: XSM000008, scan-line: LSM000584 (outcrop A1)

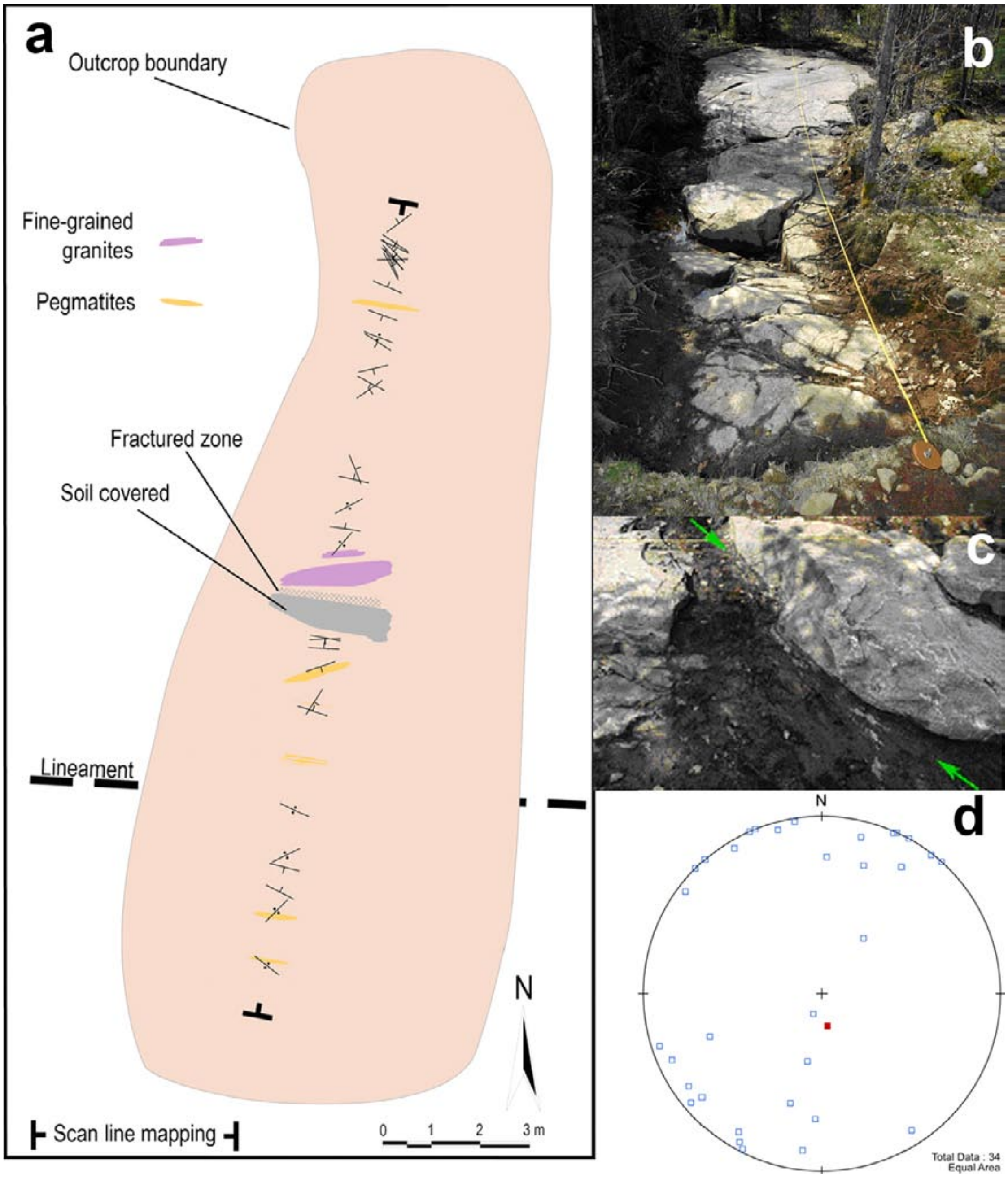


Figure 4-14. a) Sketch illustrating mapped structures and geology at scan-line LSM000584 (outcrop A1). The major rock type at the outcrop is a quartz-monzodiorite. For location, see Figure 4-3 and Figure 4-15. A small brook is located in the lowest part of the valley and the co-ordinated lineament interpreted along the valley crosses the outcrop in its southernmost part. The fractured zone consists of an undulating network of 10–20 fractures sub-parallel to the zone itself, all with an approximate orientation of 260/15 (i.e. dipping gently to the north). The rock between fractures is rather fresh. b) Photo taken towards south on outcrop A1, Appendix A. c) Close-up photo taken towards west of the fractured zone in the central part of LSM000584. d) Stereographic plot (lower hemisphere) of fracture orientations (as poles to planes) along the scan-line. Red dot represent fractured zone and the fractures within it.

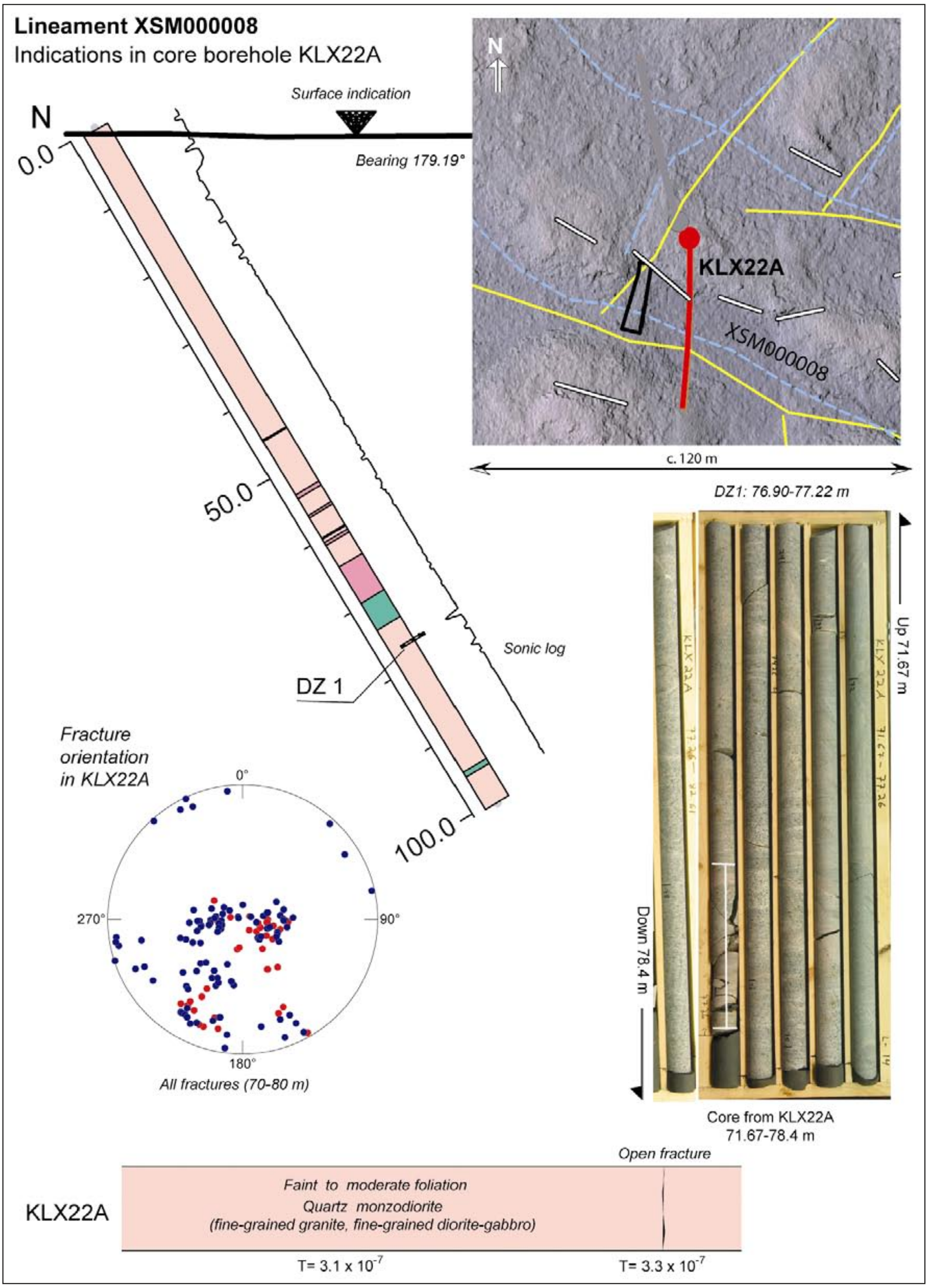


Figure 4-15. *Composite figure of KLX22A and the lineament XSM000008. A legend is given in Figure 4-2.*

Possible deformation zones

DZ1: 76.90–77.22. Minor ductile to brittle-ductile deformation zone with increased frequency of sealed fractures, medium red staining and saussuritization and aperture of open fractures. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by quartz-monzodiorite. Subordinate rock types are fine-grained granite. No radar reflectors occur within the section. Confidence level = 3.

Hydrogeological description /17, 30/

The identified DZ1 coincide with one flow anomaly from the PFL-logging with a transmissivity of $3.1 \cdot 10^{-7}$ m^2/s at 77.10 m. The most prominent water-bearing feature occur outside the identified DZs, at 79.3 m with a transmissivity of $8.3 \cdot 10^{-6}$ m^2/s.

The overall transmissivity from the PFL logging was estimated at $1.3 \cdot 10^{-5}$ m^2/s which suggests that the feature at 79.3 m dominates the borehole. The transmissivity of the entire borehole from the water injection tests gives a transmissivity of $1.5 \cdot 10^{-5}$ m^2/s, i.e. in the same order as the PFL-measurements.

Evaluation

One 0.2 m thick fracture zone occurs in the quartz-monzodiorite. Fracture orientation is about 260/15 and almost parallel to the fracture zone.

The borehole KLX22A is dominated by quartz-monzodiorite with one DZ at about 77 m (increased fracturing in a ductile to brittle ductile deformation zone). Open and sealed fractures but no distinct "zone" in BIPS /21/. No directional radar reflectors occur.

- Fracture orientation correlates reasonably well between borehole and surface.
- The hydraulic tests shows a small zone at about 77.1 m with a transmissivity of $3.1 \cdot 10^{-7}$ m^2/s and open fracture at 79.3 m with a transmissivity of $8.3 \cdot 10^{-6}$ m^2/s.
- It appears as this lineament coincides with a minor fracture zone at surface which has decreased to individual open fractures in the borehole.

Evaluation: **C.** It is unlikely that the lineament corresponds to a MDZ**.**

4.1.8 Lineament XSM000009

Lineament description

The site was selected with the aim to investigate the NE-trending lineament XSM000009 (Figure 4-16).

The co-ordinated lineament is c. 250 m long and identified by LIDAR and ground geophysical measurements (weight = 4).

Description of uncovered area

No uncovering due to practical reasons.

Description of borehole KLX22B /17/

The core borehole KLX22B was drilled towards the lineament XSM000009 and entered the bedrock directly. Bearing = 343.96°. Inclination = –61.24°.

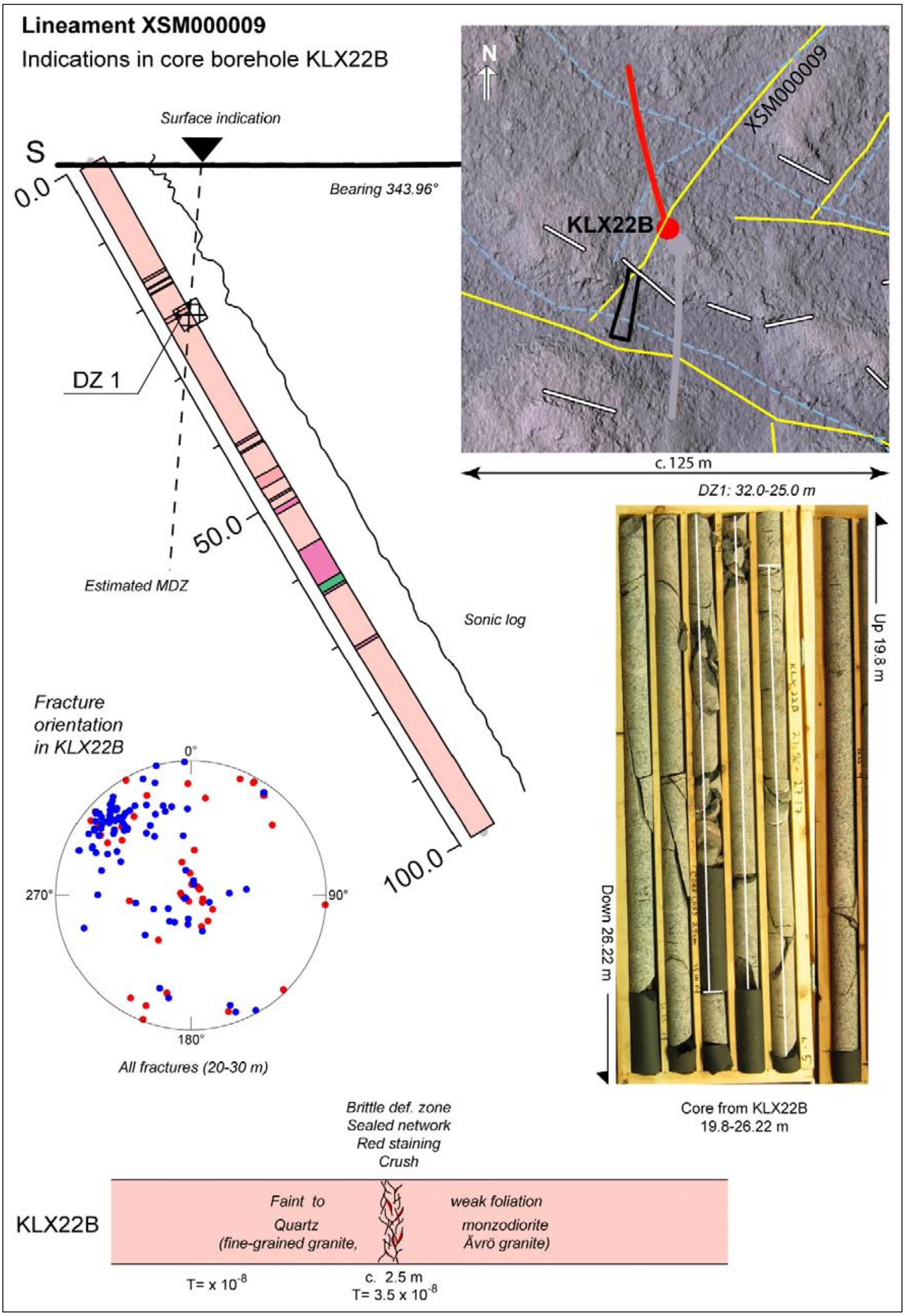


Figure 4-16. *Composite graph of KLX22B and the lineament XSM000009. A legend is given in Figure 4-2.*

Data from single hole interpretation /20/

Rock distributions

KLX22B is totally dominated by quartz-monzodiorite. Subordinate rock types comprise fine-grained granite, particularly in the section 57–62 m, fine-grained diorite to gabbro, particularly in the section c. 62–63 m, Ävrö granite, and very sparse occurrence of diorite to gabbro, pegmatite and presumed sandstone. The quartz-monzodiorite has a density in the range 2,750–2,800 kg/m^3, and a magnetic susceptibility in the range 0.015–0.025 SI. Scattered up to c. 20 m long sections are characterized by faint to weak foliation. Confidence level = 3.

Possible deformation zones

DZ1: 22.00–25.00 m. Brittle deformation zone characterized by increased frequency of open and sealed fractures, sealed network, minor core loss and crush, and weak to medium red staining, epidotization and saussuritization. Slickensides are documented. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by quartz-monzodiorite. Two radar reflectors occur within the section. One with the orientation 241/31 at 25.3 m and one non-oriented at 22.6 m has the angle 32° to borehole axis. Confidence level = 3.

Hydrogeological description /17, 30/

The identified DZ1 coincide with one flow anomaly from the PFL-logging with a transmissivity of $3.5 \cdot 10^{-8}$ m^2/s at 24.80 m. The most prominent water-bearing feature according to the PFL-logging occur at 58.2 m with a transmissivity of $2.0 \cdot 10^{-7}$ m^2/s. Also the length interval 16–20 m appears to have high transmissivity (about $1.0 \cdot 10^{-5}$ m^2/s) according to the two injection tests made in this borehole.

The overall transmissivity from the PFL logging was estimated at $8.2 \cdot 10^{-7}$ m^2/s. The transmissivity of the entire borehole from the water injection tests gives a transmissivity of $2.5 \cdot 10^{-6}$ m^2/s, i.e. three times higher than the PFL-measurements.

Evaluation

The borehole KLX22B is dominated by quartz-monzodiorite and fine-grained granite. DZ1 at 22–25 m is characterized by brittle deformation – crush, core loss, open and sealed fractures. Directional radar reflector at 25 m coincides with lineament direction. Inhomogeneous rock, open and sealed fractures in BIPS /21/.

- Fracture orientation from the borehole is dominated by steeply dipping fractures striking in NE which agrees with the lineament orientation.
- The transmissivity of the zone is $3.5 \cdot 10^{-8}$, m^2/s according to the PFL-measurements, but is probably higher according to the injection tests.
- Based on parameters as strong lineament indications, radar coincidence and DZ at 22–25 m it seems probable to presume a MDZ with a 1–2 m thick core surrounded by a few metres of more fractured rock

Evaluation: **B.** Probably a MDZ, but with only limited importance as a controlling feature for deposition holes.

4.2 Area Southeast

In total there are nine lineaments (XSM000010–XSM000018) investigated by boreholes in the south eastern area as indicated in Figure 4-17.

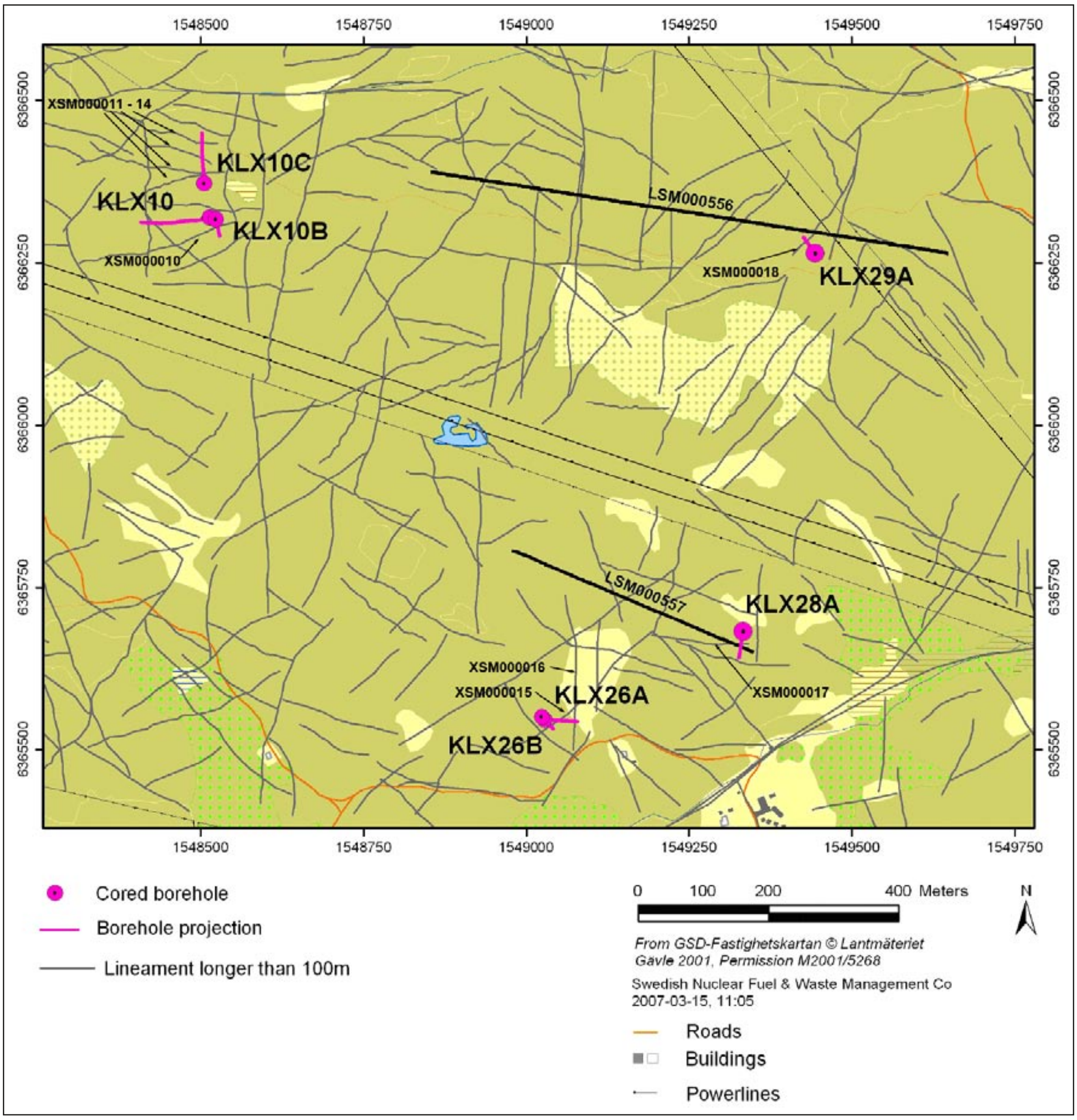


Figure 4-17. *Map over area SE showing lineaments, boreholes and seismic refraction lines LSM000556 and -557.*

4.2.1 Lineament XSM000010

Lineament description

The borehole site KLX10B was selected in order to investigate the ENE-trending lineament XSM000010 (Figure 4-19).

The lineament XSM000010 is 250 m long and indicated by magnetic, resistivity and LIDAR data with the highest weight (5). A dyke of fine-grained granite is mapped along the lineament.

Description of uncovered area

No uncovering but a dyke of fine-grained granite can be followed along parts of the lineament, outcrop (A8, Appendix A) in Figure 4-18.

Description of borehole KLX10B /17/

The core borehole KLX10B was drilled towards the lineament XSM000010 and entered the bedrock directly. Bearing = 170.33°. Inclination = –59.65°.

Figure 4-18. *Along the existing NE-SW lineament passing just south of KLX10, fine-grained granite outcrops (A8). It is several metres thick and not particularity deformed in the outcrop. The granite has been penetrated by KLX10B. The same kind of granite, a bit more deformed, has also been found c. 200 m to the NE, following the same set of lineament.*

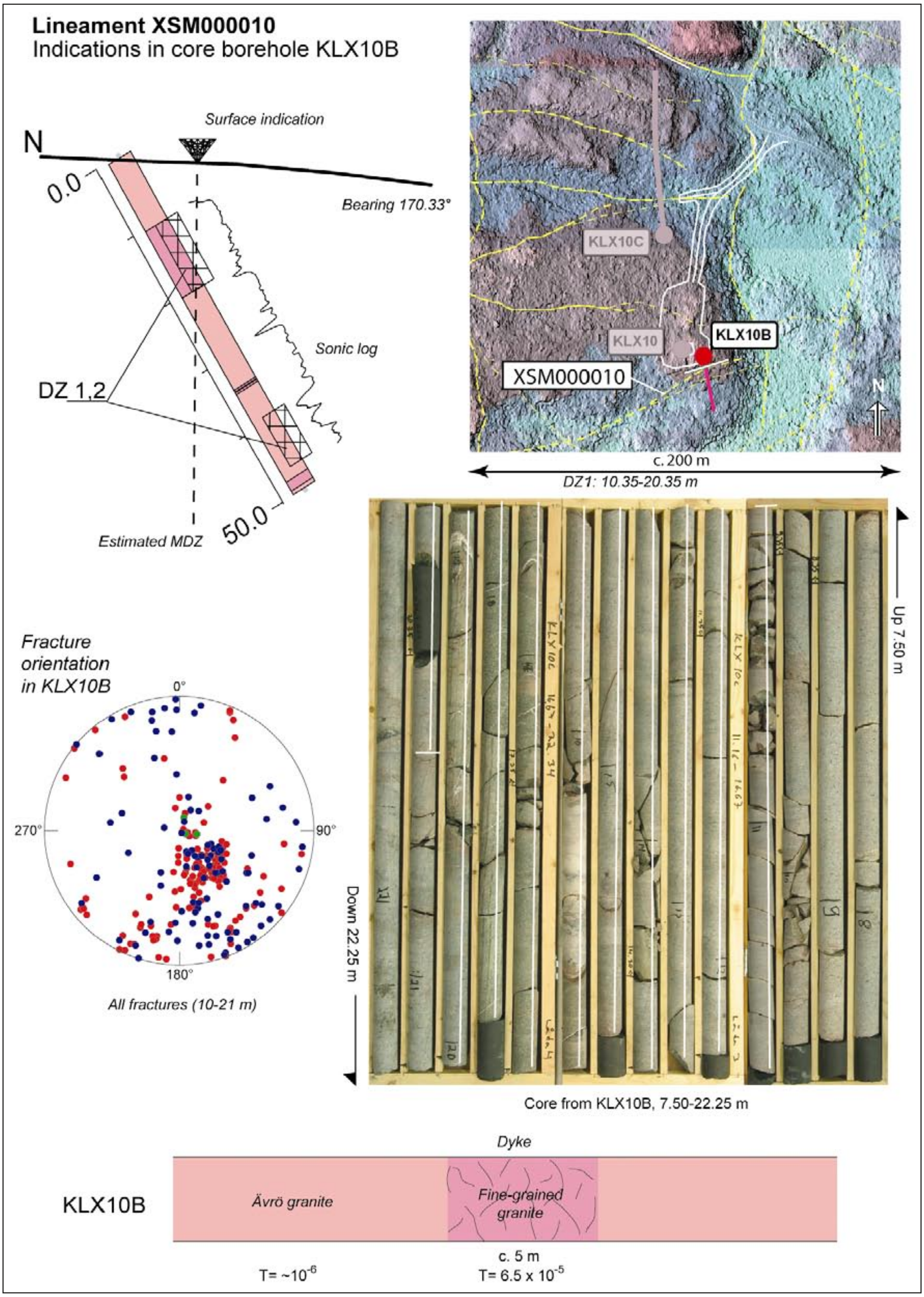


Figure 4-19. *Composite figure of KLX10B and the lineament XSM000010. A legend is given in Figure 4-2.*

Data from single hole interpretation /19/

Rock distributions

The borehole is dominated by Ävrö granite with a density in the range 2,730–2,750 kg/m^3. Gamma radiation is in the range 20–25 μR/h. Subordinate rock types comprise fine-grained granite, particularly between 10.35 and 20.35 m, and minor occurrences of fine-grained diorite-gabbro and granite. The occurrence of fine-grained granite at 10.35–20.35 m coincides with decreased density (2,630 kg/m^3) and the natural gamma radiation is in the range 35–50 μR/h. Confidence level = 3.

Possible deformation zones

Two possible deformation zones have been recognized in KLX10B.

DZ1 = 10.35–20.35 m. Dominated by fine-grained granite. In the section 19.63–20.35 m, gradually increased degree of foliation. Increased frequency of open fractures, faint red staining. There are no significant anomalies in the geophysical logging data along the section. Two non-oriented radar reflectors at 13.6 m and 16.4 m with the angle to borehole axis 58° and 47°, respectively. The host rock is dominated by fine-grained granite. Subordinate rock types are Ävrö granite and granite. Confidence level = 3.

DZ2 = 39.20–46.60 m. Increased frequency of open fractures, partly with large apertures. Low frequency of sealed fractures. Most intense part in between 39.96–40.32 m. At c. 40.4 m there is one distinct caliper anomaly that coincides with decreased resistivity and decreased P-wave velocity. One non-oriented radar reflector at 39.9 m with the angle 51° to borehole axis. Two radar reflectors, one at 41.0 m with the orientation 274/72 or 125/15 and one at 43.6 m with the orientation 131/30. The host rock is dominated by Ävrö granite. Confidence level = 3.

Hydrogeological description /27/

The identified DZ1 occur at shallow depth, i.e. above the depth where the PFL logging indicates transmissive fracture. An open hole injection test was made in order to test DZ1. The result was a transmissivity of $6.5 \cdot 10^{-5}$ m^2/s for DZ1, which is higher than the overall transmissivity obtained from the PFL-logging.

The overall transmissivity from the PFL logging was estimated at $3.5 \cdot 10^{-5}$ m^2/s with the highest value being $1.9 \cdot 10^{-5}$ m^2/s at 27.4 m. No water injection tests have been made of the entire borehole.

Evaluation

No uncovering was performed.

The borehole KLX10B is dominated by Ävrö granite and fine-grained granite (about 10–20 m). DZ1 is dominated by fine-grained granite with increased fracturing. Directional radar coincident with lineament (dyke) direction. Very high frequency of sealed fractures in BIPS /23/.

- Fracture orientation in the core is dominated by medium steep and steep fractures striking in NE, i.e. parallel to the lineament
- The hydraulic tests indicate a transmissivity in the order of $6.5 \cdot 10^{-5}$ m^2/s.
- Good correspondence between surface indicated fine grained granite and the same type of fractured granite in DZ1.

Evaluation: **C**. Dyke of fine-grained granite. No MDZ.

4.2.2 Lineament XSM000011, XSM000012, XSM000013 and XSM000014

Lineament description

The borehole site KLX10C was selected in order to investigate four almost parallel EW trending lineaments (XSM000011, XSM000012, XSM000013 and XSM000014) (Figure 4-21).

The three lineaments XSM000011, XSM000012 and XSM000013 are c. 100 m long and all geophysically (magnetic and resistivity) and LIDAR detected with high weight (4, 5, 4). Lineament XSM000014 is only magnetically indicated with low weight (1) and regarded very uncertain.

Description of uncovered area

The uncovered area is about 30 m long and 5 m wide (A9, Appendix A) and is shown in Figure 4-20.

Description of borehole KLX10C /17/

The core borehole KLX10C was drilled towards the lineaments XSM000011, XSM000012, XSM000013 and XSM000014 and entered the bedrock directly. Bearing = 352.43°. Inclination = –60.15°.

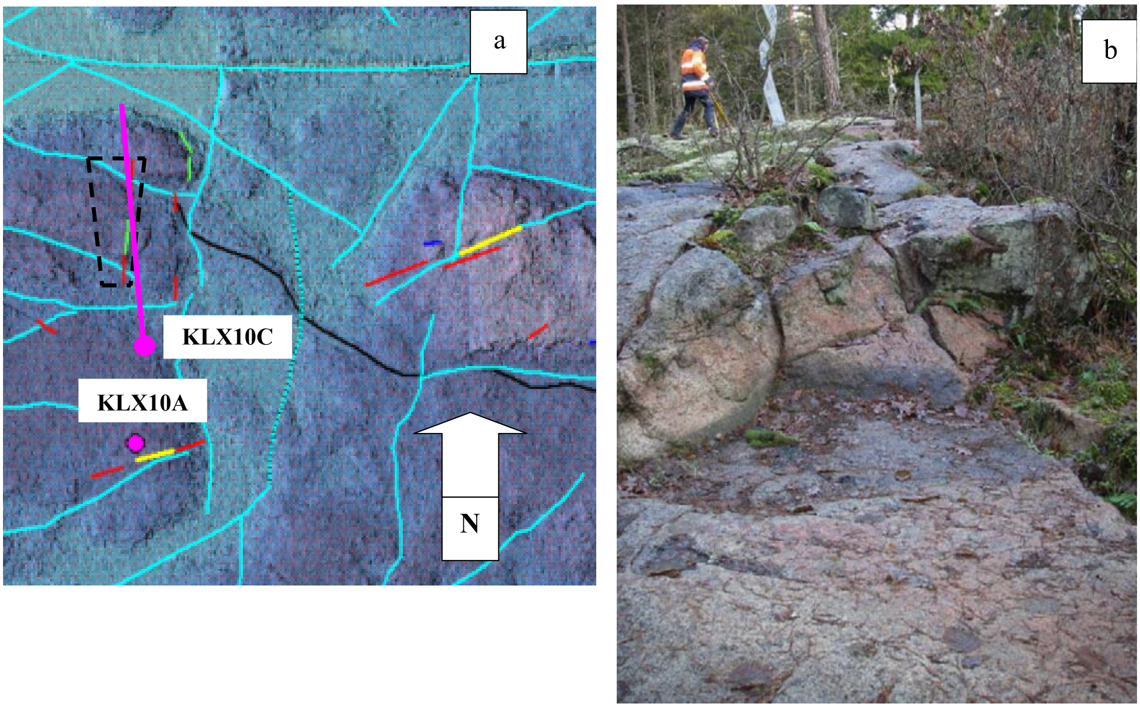


***Figure 4-20.** a) LIDAR figure showing approximate position of uncovered area A9 as black dashed lines. Blue lines representthe first interpretation of co-ordinated lineament, red lines represent identified lineaments included during the interpretation, green lines are lineaments verified as geological features, Dark blue lines represent lineaments classified in the field as individual fractures or a cluster of a few parallel fractures and yellow lines represent lineaments classified as fine-grained granite. b) Figure taken north of KLX10C, towards the north showing uncovered area A9, Appendix A, (c. 30 m long and 5 m wide).*

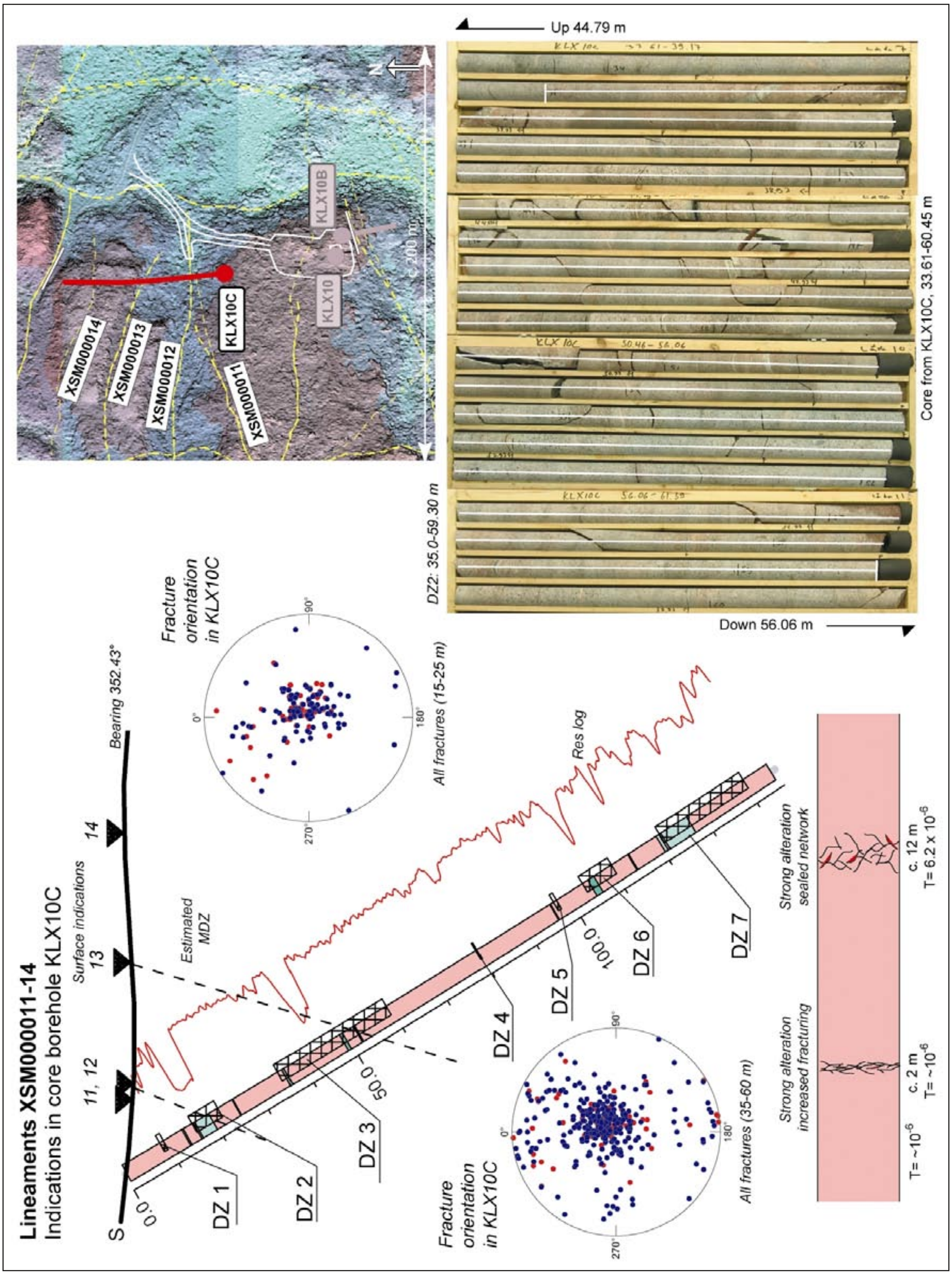


Figure 4-21. *Composite figure of KLX10C and the lineaments XSM0000011–XSM000014. A legend is given in Figure 4-2.*

Data from single hole interpretation /19/

Rock distributions

Totally dominated by Ävrö granite. Subordinate rock types comprise fine-grained dioritoid, minor occurrence of fine-grained diorite-gabbro, fine-grained granite, and very sparse occurrence of pegmatite and granite. Ävrö granite has a density in the range 2,750–2,800 kg/m^3 in the section c. 9–60 m, and mainly 2,690–2,730 kg/m^3 in the remaining part of the borehole. Scattered sections are foliated. Confidence level = 2.

Possible deformation zones

Seven possible deformation zones have been recognized in KLX10C.

DZ1 = 8.65–9.50 m. Brittle deformation zone, red staining. Increased frequency of open fractures. Section is above BIPS image and geophysical logging data, apart from the caliper log that does not show any anomalies. The host rock is dominated by Ävrö granite. No radar reflector. Confidence level = 2.

DZ2 = 15.90–21.60 m. The most intense sections are at 17.18–17.35 m and 18.92–19.60 m. Deformation characterized by medium to strong alteration (chloritization and red staining) and increased frequency of sealed and open fractures. The entire section is characterized by a major decrease in the bulk resistivity, significantly decreased P-wave velocity and magnetic susceptibility and also caliper anomalies. Two very strong and persistent non-oriented radar reflectors at 16.7 m and 19.4 m with the angle to borehole axis 58° and 55°, respectively. Low radar amplitude at 15–21 m. The host rock is dominated by a mixture of fine-grained dioritoid and Ävrö granite. Subordinate rock types are pegmatite and fine-grained diorite-gabbro. Confidence level = 3.

DZ3 = 35.00–59.30 m. Inhomogeneous deformation zone. Characterized by increased alteration (red staining) and increased frequency of sealed network, and partly also open fractures. Partly decreased magnetic susceptibility along the entire section. Decreased P-wave velocity and low resistivity anomalies in the section 42–47 m. Two non-oriented radar reflectors at 41.2 m and 44.3 m with the angle to borehole axis 8° and 6°, respectively. The host rock is dominated by Ävrö granite. Subordinate rock types are fine-grained diorite-gabbro and fine-grained granite. Confidence level = 3.

DZ4 = 79.45–79.70 m. Characterized by sealed network. Partly decreased P-wave velocity in the interval 79.2–80.7 m and sharp low resistivity anomaly at c. 80.0 m. The host rock is dominated by Ävrö granite. No radar reflector occur. Confidence level = 3.

DZ5 = 96.90–97.60 m. Characterized by sealed fracture network. The interval 97.17–97.26 m is the most intense section. Red staining. No anomalies in the geophysical logs. The host rock is dominated by Ävrö granite. Subordinate rock type is fine-grained granite. No radar reflector occur. Confidence level = 2.

DZ6 = 103.50–110.10 m. Inhomogeneous deformation zone. Characterized by sealed fracture network and open fractures. The most intense sections are between 105.50–105.74 m and 106.10–106.27 m depth. Significant decrease in P-wave velocity and in resistivity along the section 105.5–107.1 m, which coincides with decreased magnetic susceptibility, natural gamma radiation and increased density. One strong and persistent radar reflector at 104.7 m with the orientation 193/25 or 060/71. Two non-oriented radar reflectors at 103.9 m and 105.6 m with the angle to borehole axis 78° and 52°, respectively. Low radar amplitude at 105–108 m. The host rock is dominated by Ävrö granite. Subordinate rock types are fine-grained diorite-gabbro and fine-grained granite. Confidence level = 3.

DZ7 = 121.00–140.00 m. Increased frequency of sealed fractures and partly open fractures. Partly also medium red staining. Partly decreased magnetic susceptibility in the section 127.7–140.0 m. Only minor negative anomalies in the P-wave velocity and resistivity logging data along the section of the DZ. Two radar reflectors, one at 125.0 m with the orientation 187/32 and one at 134.52 m with the orientation 060/33 or 114/34. Two non-oriented radar reflectors at 123.4 m and 125.6 m with the angle to borehole axis 29° and 52°, respectively. The host rock is dominated by Ävrö granite. Subordinate rock types are fine-grained dioritoid and fine-grained granite. Confidence level = 3.

Hydrogeological description /27/

Several flow anomalies were recorded in KLX10C, some of coincide with identified DZ's. The uppermost DZ1 is located above the depth where the PFL logging indicates transmissive and neither DZ1 nor DZ2 have any valid flow logging records.

DZ3 coincide with five flow anomalies with a total transmissivity of $6.2 \cdot 10^{-6}$ m^2/s. No flow anomaly coincides with DZ4 and DZ5. DZ6 coincide with one flow anomalies with a transmissivity of $7.7 \cdot 10^{-9}$ m^2/s at 110.10 m and DZ7 coincide with four anomalies with a total transmissivity of $8.5 \cdot 10^{-7}$ m^2/s. The most prominent anomaly has a transmissivity $6.0 \cdot 10^{-6}$ m^2/s at 44.60 m, i.e. within DZ3.

The overall transmissivity of the borehole is $7.5 \cdot 10^{-6}$ m^2/s.

Evaluation

Uncovered area is dominated by oxidized Ävrö granite. No distinct zone indications – only some south dipping major fractures.

The borehole KLX10C is dominated by Ävrö granite with two main zones of interest for correlation with surface indications – DZ2 at 16–21 m and DZ3 at 35–59 m in the borehole. Open fractures in BIPS at about 16–20 m and at 44.6 m in DZ3 /23/. No oriented radar refector occur.

- The fracture orientation for DZ1 and DZ2 is dominated by subhorizontal fractures. Also DZ3 is dominated by horizontal fractures but also a large number of E-W fractures are found, i.e. parallel to the E-W trending lineament.
- The hydraulic testing suggests a transmissivity for DZ1 and DZ2 in the order of $1 \cdot 10^{-7}$ m^2/s, and for DZ3 $6.2 \cdot 10^{-6}$ m^2/s. Average for rock has a transmissivity of $1 \cdot 10^{-8}$ m^2/s.
- Possibly can lineament XSM000011 and XSM000012 be correlated to DZ2 and XSM000013 to DZ3.
- XSM000014 is regarded too uncertain to correlate with any DZ in the borehole.

XSM000011

Evaluation: **B**. Uncertain MDZ, may be a local superficial feature. May affect the siting of deposition holes.

XSM000012

Evaluation: **B**. Uncertain MDZ, may be a local superficial feature. May affect the siting of deposition holes.

XSM000013

Evaluation: **A.** Likely MDZ with significant transmissivity. Will probably affect the siting of deposition holes.

XSM000014

Evaluation: **C**. Unlikely MDZ.

4.2.3 Lineament XSM000015

Lineament description

The lineament XSM000015 is 180 m long and is also interpreted in the latest version of co-ordinated lineaments. It locally represents fine-grained granite, severely deformed by brittle-ductile deformation. Both the deformation within the zone and the fine-grained granite were identified prior to the uncovering. Lineament XSM000015 is magnetically detected (weight 2).

Description of uncovered area

The uncovered area is approximately 13 m long and 5 m wide (outcrop A7, Appendix A). The uncovered brittle-ductile deformation zone is approximately 2 m thick and runs along the lineament XSM000015 and in the fine-grained granite. At this location most expressions of the ductile deformation is located south of the brittle components, but it has been noted nearby that this is not always the case. The major part of the fractures also runs sub-parallel to the zone boundary (scan-line LSM000590) (Figure 4-22).

Description of borehole KLX26A /17/

The borehole site KLX26A was selected with the main aim to investigate the NE-trending lineament XSM000015. KLX26A was also intended to investigate the NS trending lineament XSM000016.

The core borehole KLX26A and KLX26B were both drilled towards the lineament XSM000015. KLX26A entered the bedrock directly. Bearing = 93.47°. Inclination = –60.45°.

Data from single hole interpretation /20/

Rock distributions

4.00–26.43 m: Totally dominated by diorite to gabbro. Subordinate rock types comprise Ävrö granite, fine-grained granite and minor occurrences of pegmatite and granite. The diorite to gabbro has a density in the range 2,920–3,020 kg/m^3, and a magnetic susceptibility in the range 0.005–0.120 SI. Confidence level = 3.

26.43–45.69: Totally dominated by fine-grained granite. Subordinate rock types comprise Ävrö granite, pegmatite and diorite to gabbro. The rock unit is characterized by weak foliation and increased frequency of open fractures. Confidence level = 3.

45.69–99.93: Totally dominated by diorite to gabbro. Subordinate rock types comprise quartz-monzodiorite, Ävrö granite, fine-grained diorite to gabbro, particularly in the lower part of the rock unit, fine-grained granite. The diorite to gabbro has a density in the range 2,920–3,100 kg/m^3, and a magnetic susceptibility in the range 0.005–0.120 SI. Confidence level = 3.

Possible deformation zones

DZ1: 17.45–18.10 m. Brittle-ductile deformation zone, brecciated, with increased frequency of open and sealed fractures, weak epidotization. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by diorite to gabbro. Subordinate rock type is pegmatite. One oriented radar reflector, 121/69, occurs at 18.6 m. Confidence level = 3.

DZ2: 42.60–54.80 m. Inhomogeneous brittle-ductile deformation zone, partly weakly foliated, with increased frequency of sealed and open fractures, faint red staining and weak epidotization. Low magnetic susceptibility and frequent minor resistivity anomalies. The host rock is dominated by diorite to gabbro and fine-grained granite. Subordinate rock types are pegmatite, fine-grained granite and very sparse quartz-monzodiorite. Two oriented radar reflectors occur

Lineament: XSM000015, Scan-line: LSM000590 (outcrop A7)

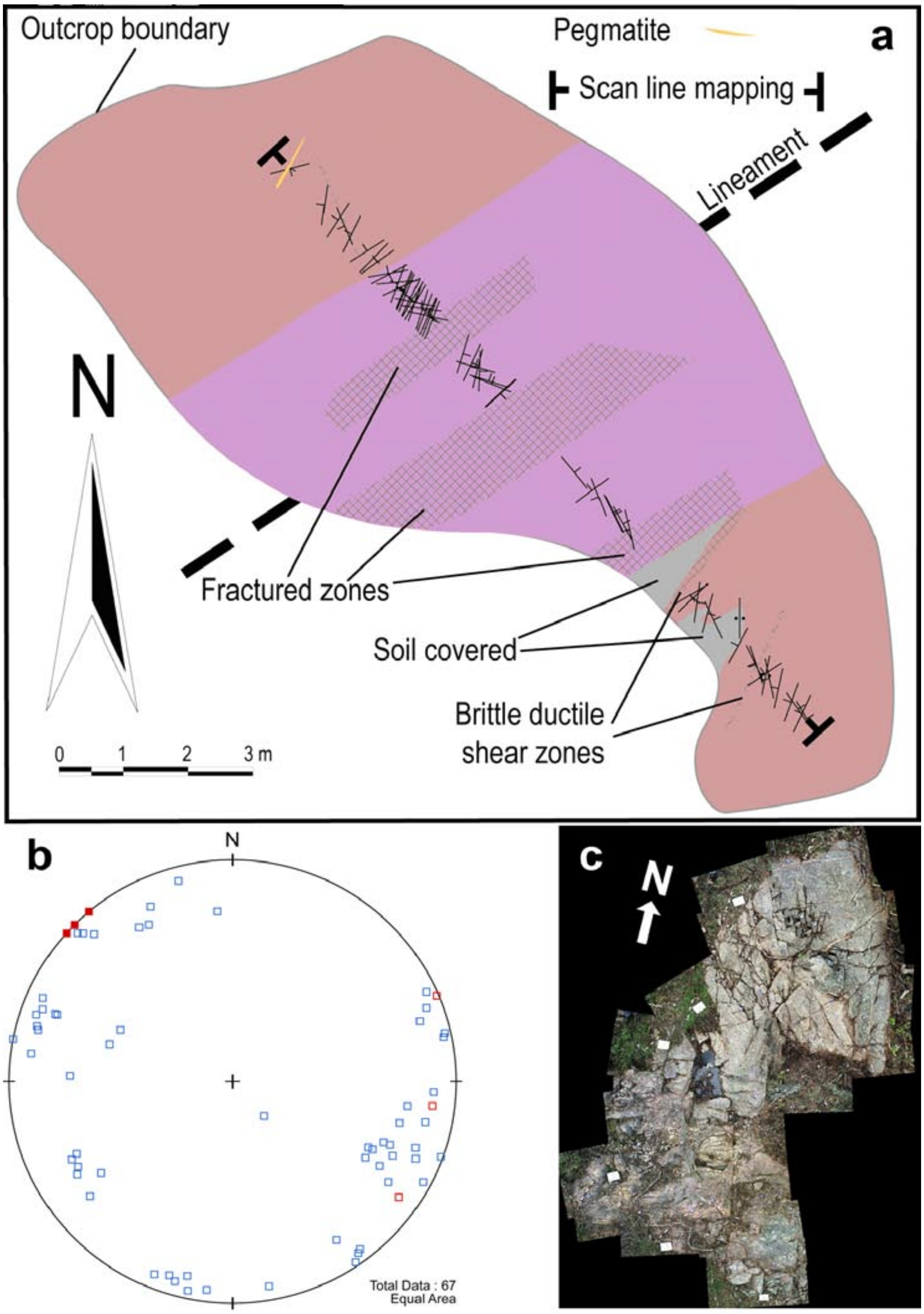


Figure 4-22. *a) Sketch illustrating mapped structures and geology at scan-line LSM000589 (outcrop A7, Appendix A). The major rock type at the outcrop is Ävrö granite, with diorite/gabbro in the north-eastern most part. It is cut by fine-grained granite, which has a dyke- parallel foliation. The ductile and brittle deformation in the dyke is normally so strong that it can be regarded as a brittle-ductile deformation zone. For location, see Figure 4-17 and Figure 4-23. The lineament along the dyke is interpreted on LIDAR data, but it is parallel to a nearby co-ordinated lineament. b) Stereographic plot (lower hemisphere) of fracture orientations along the scan-line. Red dots represent fractured zones, where the fractures are so closely spaced that measuring individual fractures was not possible. Most fractures in the zones are sub parallel with the zone. The brittle-ductile deformation zones are represented with red open squares. c) Photograph of the uncovered outcrop A7 at LSM000590, Appendix A. Up in the photo is towards the south-southeast.*

within the section. One with orientation 122/17 at 42.2 m and one at 47.4 m with orientation 103/73. Four non-oriented radar reflectors at 45.2 m, 46.5 m, 46.8 m and 50.5 m have the angles 66°, 26°, 40° and 52° respectively. Confidence level = 3.

DZ3:72.30–73.95 m. Brittle-ductile deformation zone, brecciated, with increased frequency of open and sealed fractures, weak epidotization and crush. Low magnetic susceptibility, resistivity and P-wave velocity, and one caliper anomaly. The host rock is dominated by diorite to gabbro. Subordinate rock type is fine-grained granite. One radar reflector with the orientation 104/32 occurs at 73.6 m. Confidence level = 3.

DZ4:97.30–99.80 m. Ductile deformation zone with increased frequency of open and sealed fracture and minor crush. Low magnetic susceptibility, resistivity and P-wave velocity. The host rock is dominated by fine-grained diorite to gabbro. Subordinate rock types are quartz-monzodiorite and Ävrö granite. One non-oriented radar reflector has the angle 43° to borehole axis. Confidence level = 3.

Description of borehole KLX26B /17/

The borehole site KLX26B was selected in order to investigate lineament XSM000015 (Figure 4-23 and 4-24).

The core borehole KLX26B was drilled towards the lineament XSM000015 and entered the bedrock directly. Bearing = 137.42°. Inclination = –60.01°.

Data from single hole interpretation /20/

Rock distributions

4.00–27.49 m: Totally dominated by diorite to gabbro. Subordinate rock types comprise fine-grained granite and pegmatite. The diorite to gabbro has a density in the range 2,920–2,990 kg/m^3, and a magnetic susceptibility in the range 0.005–0.030 SI. Confidence level = 3.

27.49–44.86 m: Totally dominated by fine-grained granite. The rock unit is characterized by faint foliation and increased frequency of open and sealed fractures. Confidence level = 3.

44.86–50.30 m: Totally dominated by diorite to gabbro. Subordinate rock types comprise fine-grained granite and pegmatite. The diorite to gabbro has a density in the range 2,920–3,080 kg/m^3, and a magnetic susceptibility in the range 0.020–0.100 SI. Confidence level = 3.

No possible deformation zone was indicated.

Hydrogeological description /17, 30/

KLX26A

One flow anomaly was noted in DZ1 at a depth of 17.60 m with a transmissivity of $3.51 \cdot 10^{-9}$ m^2/s. DZ2 is manifested by 4 flow anomalies with an integrated transmissivity of $3.4 \cdot 10^{-8}$ m^2/s. One anomaly coincide DZ3 which has a transmissivity of $1.5 \cdot 10^{-8}$ m^2/s. No measurable flow was detected in DZ4.

The borehole section 26.43–45.69, which is made up by a dyke of fine-grained granite includes 17 flow anomalies with an integrated transmissivity of $1.3 \cdot 10^{-6}$ m^2/s. This figure could be compared with the transmissivity of the entire borehole which is $1.5 \cdot 10^{-6}$ m^2/s.

Two water injection tests have been made in this borehole, one with the packer at 29 m and the bottom at 44.16 m, and one at full depth (101.14 m) with the packer at 2.80 m in the borehole. The result suggests that the dominant part of the transmissivity emanates from the section between 29 m and 44.16 m.

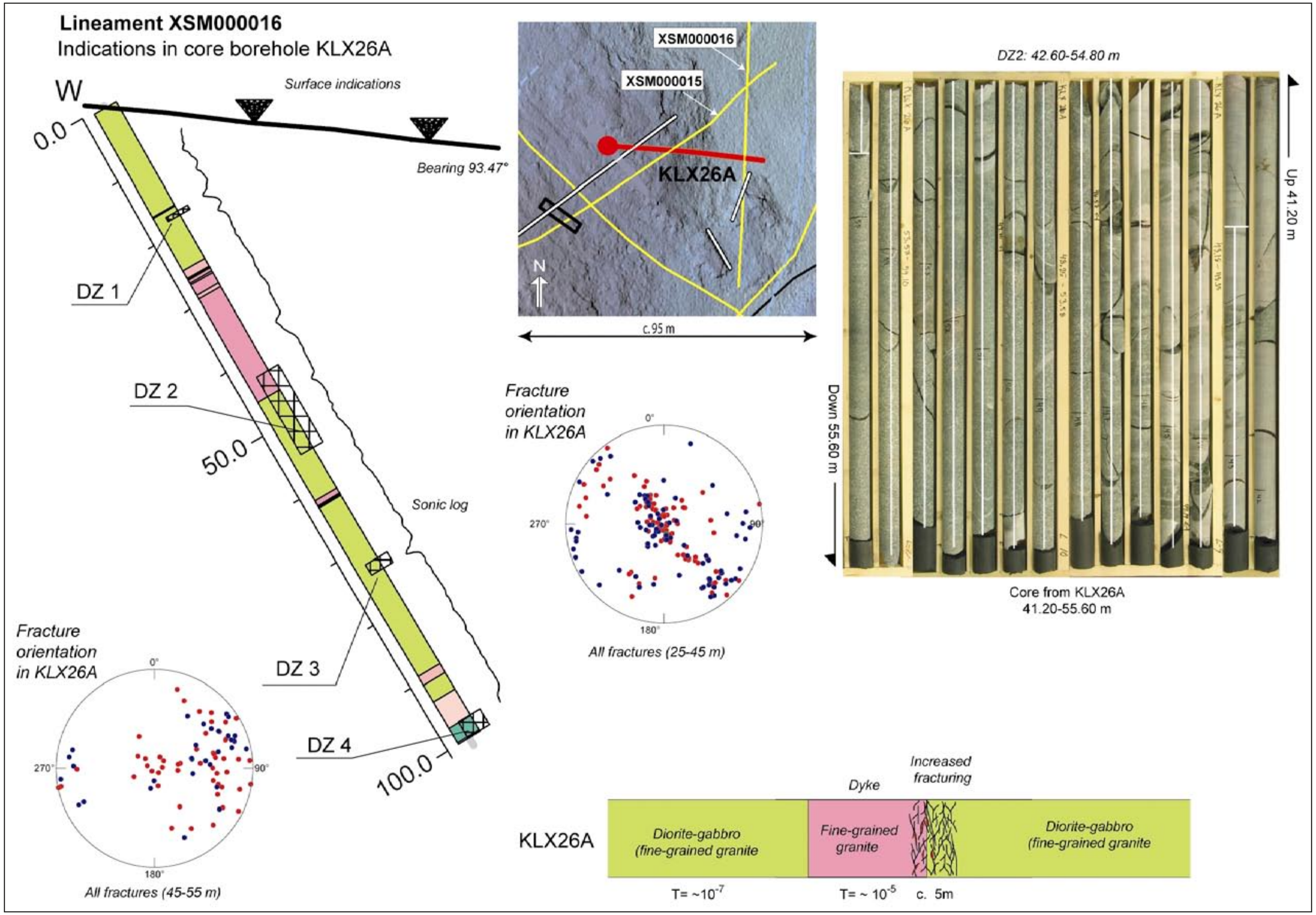


Figure 4-23. *Composite figure of KLX26A and the lineament XSM000016. A legend is given in Figure 4-2.*

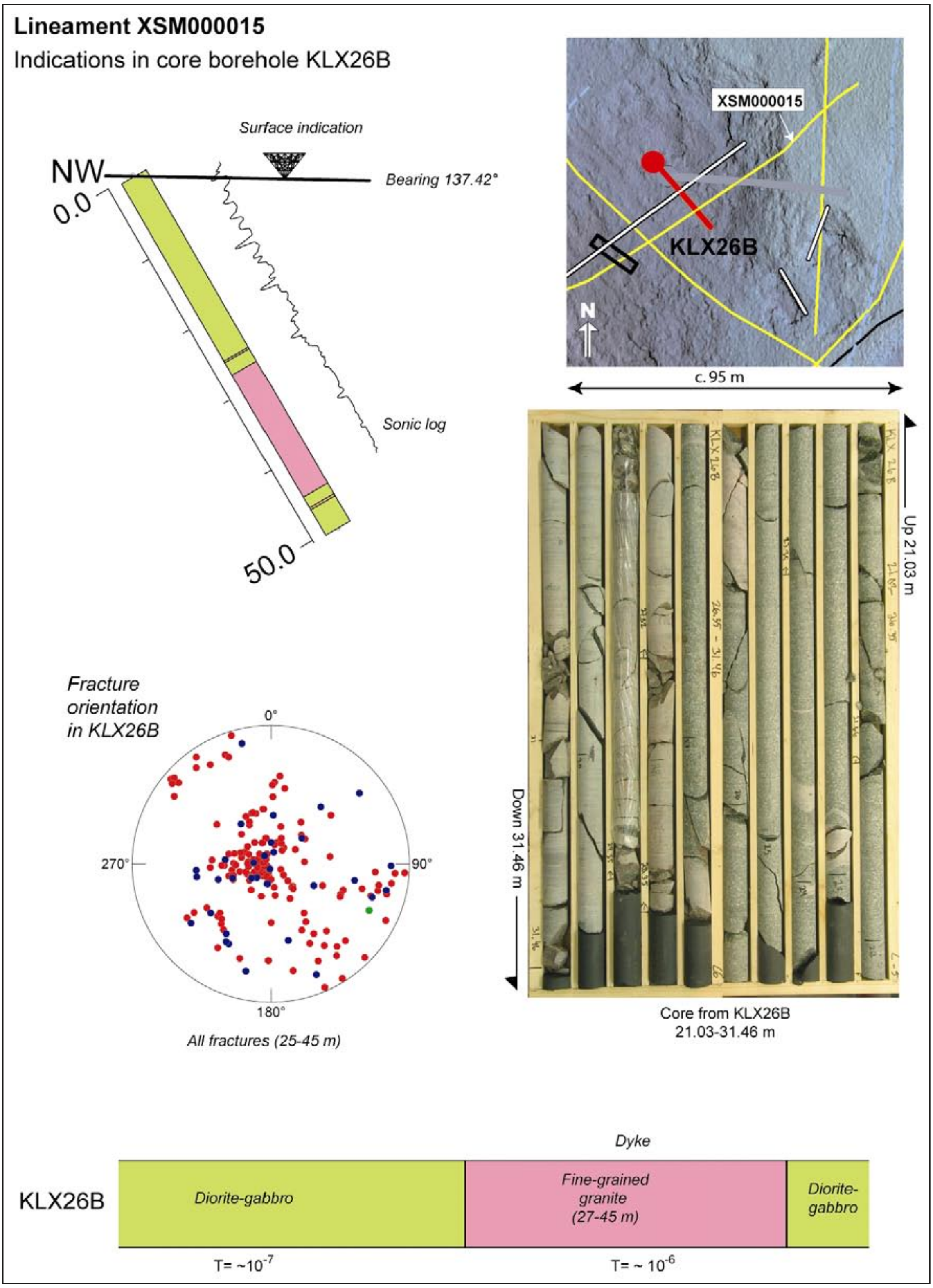


Figure 4-24. *Composite figure of KLX26B and the lineament XSM000015. A legend is given in Figure 4-2.*

KLX26B

KLX26B is penetrating the dyke of fine-grained granite at section 27.49–44.86 m. This section contains 11 flow anomalies with an integrated transmissivity of $2.3 \cdot 10^{-6}$ m^2/s, compared to the entire hole which has a transmissivity of $2.4 \cdot 10^{-6}$ m^2/s.

Water injection tests made for the entire borehole gave a transmissivity of $2.2 \cdot 10^{-5}$ m^2/s.

Evaluation

A 2 m thick brittle-ductile deformation zone runs along the lineament in a dyke of fine-grained granite. Most of the fractures are oriented subparallel to zone and the dyke.

Open and sealed fractures in inhomogeneous rock is the most important DZ in KLX26A according to BIPS /21/. Orientated radar indicates structures at 18.6 m (121/69), at 42.2 m (122/17) and at 47.4 m (103/73). No DZ in KLX26B, but a dyke of fine-grained granite occur at about 27–45 m.

- Subhorizontal and steeply dipping fractures in NE dominate in both KLX26A and KLX26B.
- The hydraulic tests show that the dyke of fine-grained granite is the dominant hydraulic conductor in both boreholes. The transmissivity of the dyke is in both boreholes just above 10^{-6} m^2/s.
- The fine-grained granite in KLX26A is partly highly fractured but not in KLX26B.
- The borehole indications can be correlated to the mapped dyke at surface.

Evaluation: **D.** Dyke of fine-grained granite. No MDZ.

4.2.4 Lineament XSM000016

Lineament description

Lineament XSM000016 is 220 m long and represents a topographic depression which is detected by LIDAR and resistivity (weight = 2).

Description of uncovered area

The lineament XSM000016 is not uncovered due to thick overburden.

Description of boreholes KLX26A and KLX26B

KLX26A and KLX26B are described in connection to XSM000015 (Figure 4-23).

Evaluation

No uncovering was performed – but distinct topographic depression occur.

A DZ in the outermost part of KLX26A (97.30–99.80 m) in very inhomogeneous rock.
No oriented radar occur. Increased sealed fracturing in BIPS is visible /21/.

- The fracture orientation in KLX26A show mainly fractures in NS, steeply dipping towards W. The NS strike coincide with the direction of the lineament
- Only very low transmissivities have been recorded.
- The DZ at 97–99 m can possibly be correlated to the lineament XSM000016 but is in this case rather a local major zone than a MDZ.

Evaluation: **D.** Local Major DZ**.**

4.2.5 Lineament XSM000017

Lineament description

The lineament XSM000017 is 130 m long which coincides with a refraction seismic low-velocity section from profile LSM000557 /36/. The lineament is recognized by LIDAR and detailed ground geophysical measurements.

Description of uncovered area

There was no uncovering of this lineament due to practical reasons.

Description of borehole KLX28A /17/

The core borehole KLX28A was drilled towards the lineament XSM000017 and entered the bedrock directly (Figure 4-25). Bearing = 180.70°. Inclination = –59.23°.

Data from single hole interpretation */24/*

Rock distributions

KLX28A is totally dominated by Ävrö granite. Subordinate rock types comprise fine-grained granite, fine-grained diorite-gabbro, fine-grained dioritoid, and minor occurrences of pegmatite and granite. The Ävrö granite 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 and 34 m borehole length. Confidence level = 3.

Possible deformation zones: Two possible deformation zones have been recognised in KLX28A.

DZ1 (14.40–33.10 m): Inhomogeneous brittle-ductile deformation zone characterized by slightly increased frequency of open and sealed fractures, crush zones, cataclastite, 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. 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 occur at 13–21 m. The host rock is dominated by Ävrö granite. Subordinate rock types comprise fine-grained granite and fine-grained diorite-gabbro, and sparse occurrences of pegmatite, granite and fine-grained dioritoid. Confidence level = 3.

DZ2 (74.00–76.70 m): 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 with subordinate occurrence of fine-grained granite. Confidence level = 3.

Hydrogeological description */17, 28/*

Several flow anomalies were recorded in KLX28A, some of coincide with identified DZs. The uppermost part of DZ1 is located above the depth where the PFL logging indicates transmissive fractures. In total 8 flow anomalies were found within DZ1 where the highest were recorded at $4.7 \cdot 10^{-7}$ m^2/s at a length of 28 m. The overall transmissivity of DZ1 amounts to $8.1 \cdot 10^{-7}$ m^2/s according to the PFL-logging.

DZ2 coincide with two flow anomalies with a total transmissivity of $7.0 \cdot 10^{-9}$ m^2/s.

The overall transmissivity of the borehole is $3.2 \cdot 10^{-6}$ m^2/s according to the water injection tests and $1.8 \cdot 10^{-6}$ m^2/s according to the PFL logging.

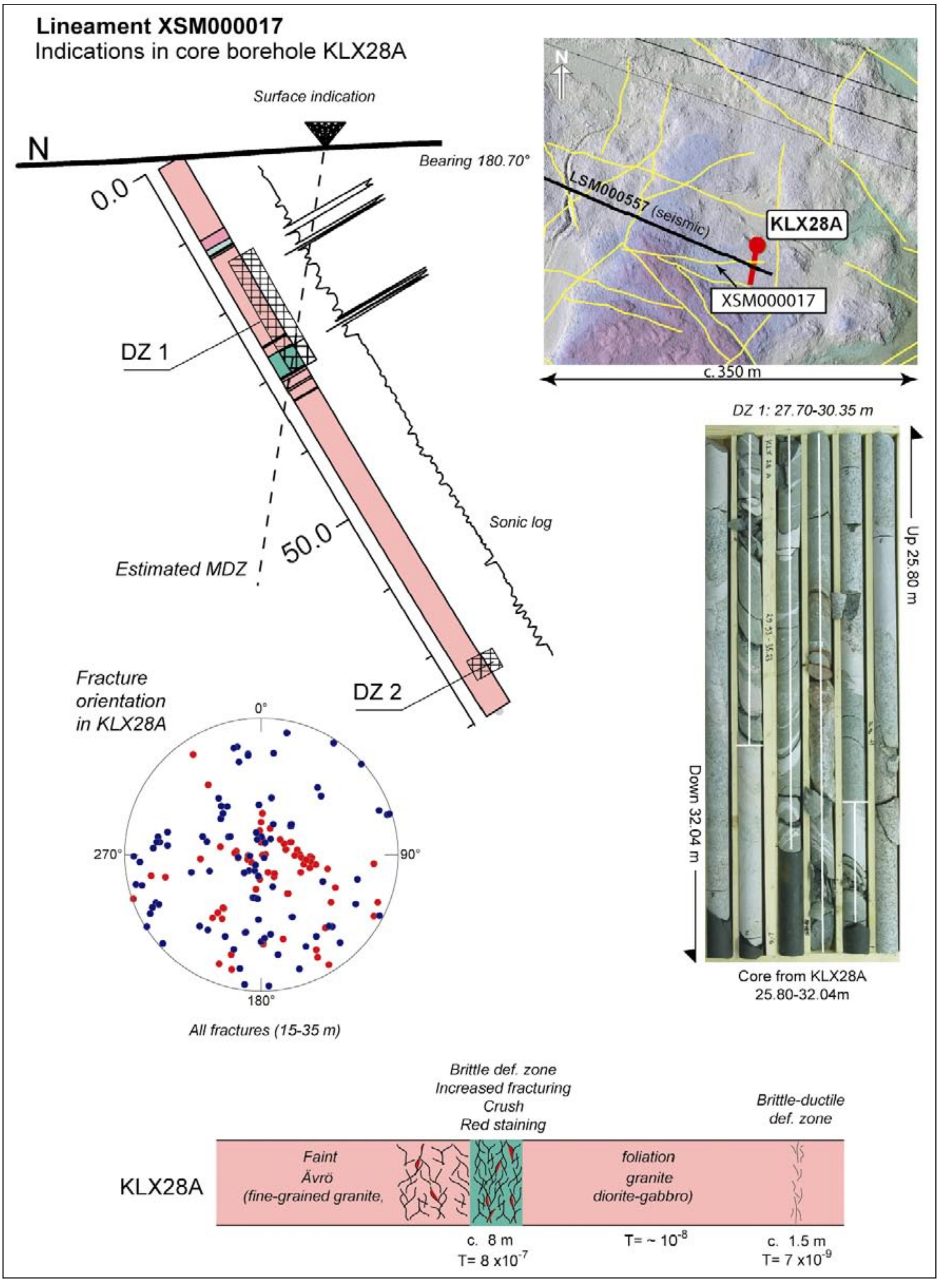


Figure 4-25. *Composite figure of KLX28A and the lineament XSM000017. A legend is given in Figure 4-2.*

Evaluation

No uncovering but seismic refraction indications at surface. Two DZ in KLX28A which is dominated by Ävrö granite. Brittle-ductile zones in inhomogeneous rock about 27–30 m and at 74–76 m. Directional radar at 27.3 m (096/76). Inhomogeneous rock and sealed fracturing at c. 27–30 m in BIPS /25/. No BIPS indication at 74–76 m.

- Fracture orientation gives a very scattered view and no clear fracture sets may be seen.
- The hydraulic tests suggest that DZ1 have a transmissivity approaching $1 \cdot 10^{-6}$ m^2/s.
- It seems probable to correlate DZ1 at 27–30 m in KLX28A with the seismic indication at surface.

Evaluation: **A (B).** Likely MDZ with moderate transmissivity. May probably affect the siting of deposition holes.

4.2.6 Lineament XSM000018

Lineament description

The lineament XSM000018 is 180 m long and detected by LIDAR and detailed ground geophysics. The lineament coincides with a low-velocity section in the refraction seismic profile LSM000556 /36/.

Description of uncovered area

There was no uncovering in this area due to thick Quaternary deposits and difficult access, but the lineament is topographically visible in field.

Description of borehole KLX29A /17/

The borehole site KLX29A was selected with the aim to investigate the NE-trending lineament XSM000018, Figure 4-26.

The core borehole KLX29A was drilled towards the lineament XSM000018 and entered the bedrock directly. Bearing = 321.21°. Inclination = –60.35°.

Data from single hole interpretation /24/

Rock distributions

KLX29A is totally dominated by Ävrö granite. Subordinate rock types comprise fine-grained diorite-gabbro, fine-grained granite, and sparse occurrences of pegmatite and granite. The Ävrö granite 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, cataclastites, brittle-ductile and ductile deformation zones and breccias. Confidence level = 3.

Possible deformation zones: Two possible deformation zones have been recognised in KLX29A.

DZ1 (7.21–8.02 m): 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 be observed to a distance of 2 m outside the borehole. Low radar amplitude occur at 5–8 m. The host rock is dominated by Ävrö granite with subordinate occurrence of fine-grained granite. Confidence level = 3.

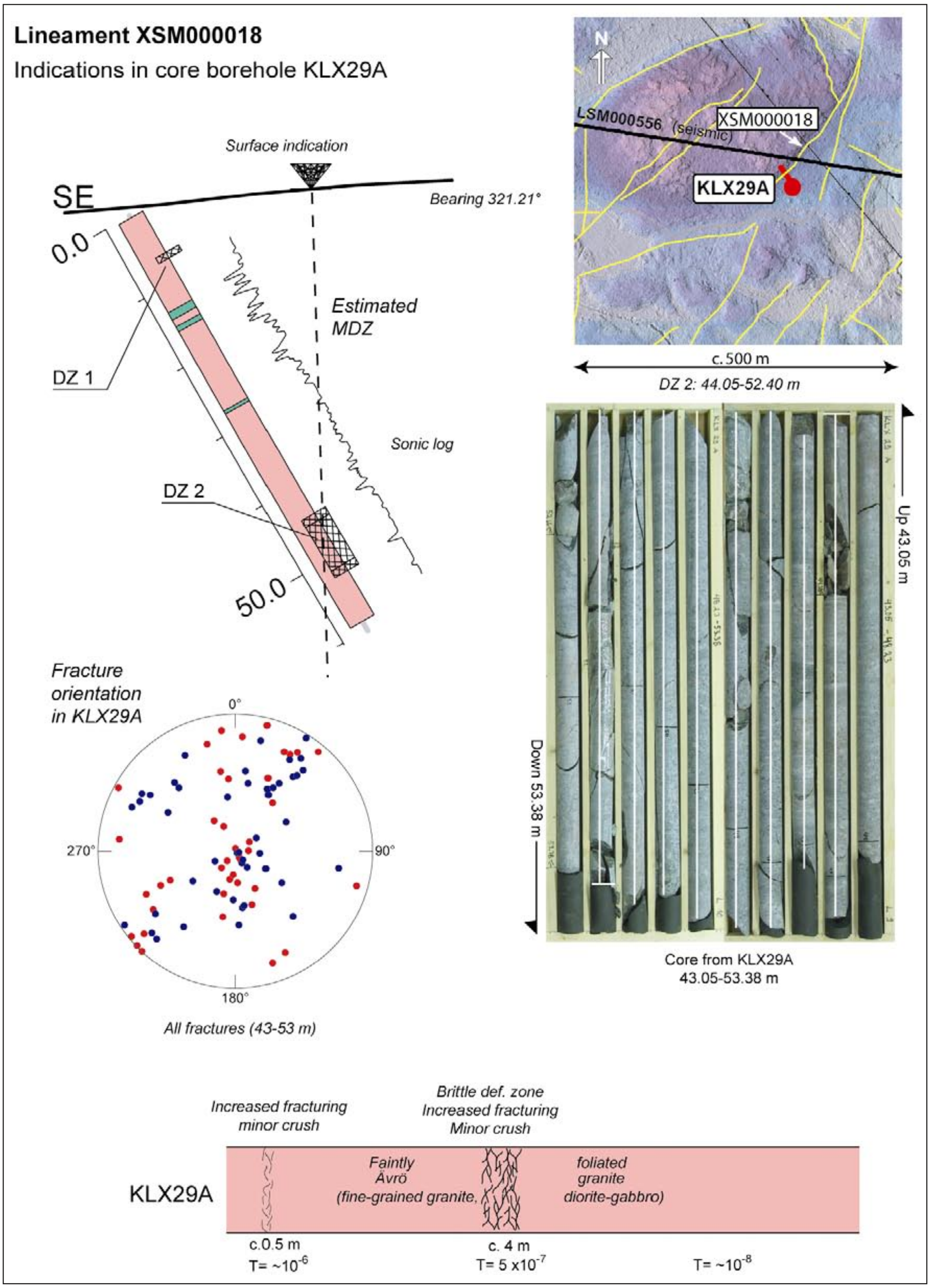


Figure 4-26. *Composite figure of KLX29A and the lineament XSM000018. A legend is given in Figure 4-2.*

DZ2 (44.05–52.40 m): 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 are also characterized 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 with subordinate occurrence of fine-grained granite. Confidence level = 3.

Hydrogeological description */17, 28/*

The identified DZ1 occur at shallow depth, i.e. above the depth where the PFL logging indicates transmissive fracture. Hence no PFL data exist for DZ1.

In total six flow anomalies were found within DZ2 where the highest flow anomaly was recorded at $3.7 \cdot 10^{-7}$ m^2/s at a length of 49.1 m. The overall transmissivity of DZ2 amounts to $5.4 \cdot 10^{-7}$ m^2/s according to the PFL-logging.

The overall transmissivity of the borehole is $3.4 \cdot 10^{-5}$ m^2/s according to the water injection tests and $3.5 \cdot 10^{-6}$ m^2/s according to the PFL logging. This suggests that the identified DZ1 may be a significant water conduit.

Evaluation

The dominating rock in KLX29A is Ävrö granite with DZ1 at about 8 m (core loss, crush, increased fracturing) and DZ2 at 44–52 m (increased fracturing, sealed network and minor crush). A section in the borehole at about 12–18 m is indicated by low resistivity log. Non-oriented radar reflectors exist. Inhomogeneous rock and sealed fractures at the interval 8–18 m in BIPS /25/.

No uncovering but a seismic low velocity at surface can probably be correlated with the fractured and altered rock in the borehole at c. 8–18 m.

- There are a weak correlation for one fracture set and the lineament orientation.
- The hydraulic tests indicate that the transmissivity in DZ1 may be high, in the order of $1 \cdot 10^{-5}$ m^2/s.

Evaluation: **A.** Likely MDZ with significant transmissivity. Will probably affect the siting of deposition holes.

4.3 Area Northeast

In total there are two lineaments (XSM000019–XSM000020) investigated by three boreholes in the NE area as indicated in Figure 4-27. In addition, one other lineament was investigated (XSM000021) but regarded as too complicated to investigate further.

4.3.1 Lineament XSM000019

Lineament description

The lineament XSM000019 is 100 m long structure identified by geological mapping with no geophysical indication.

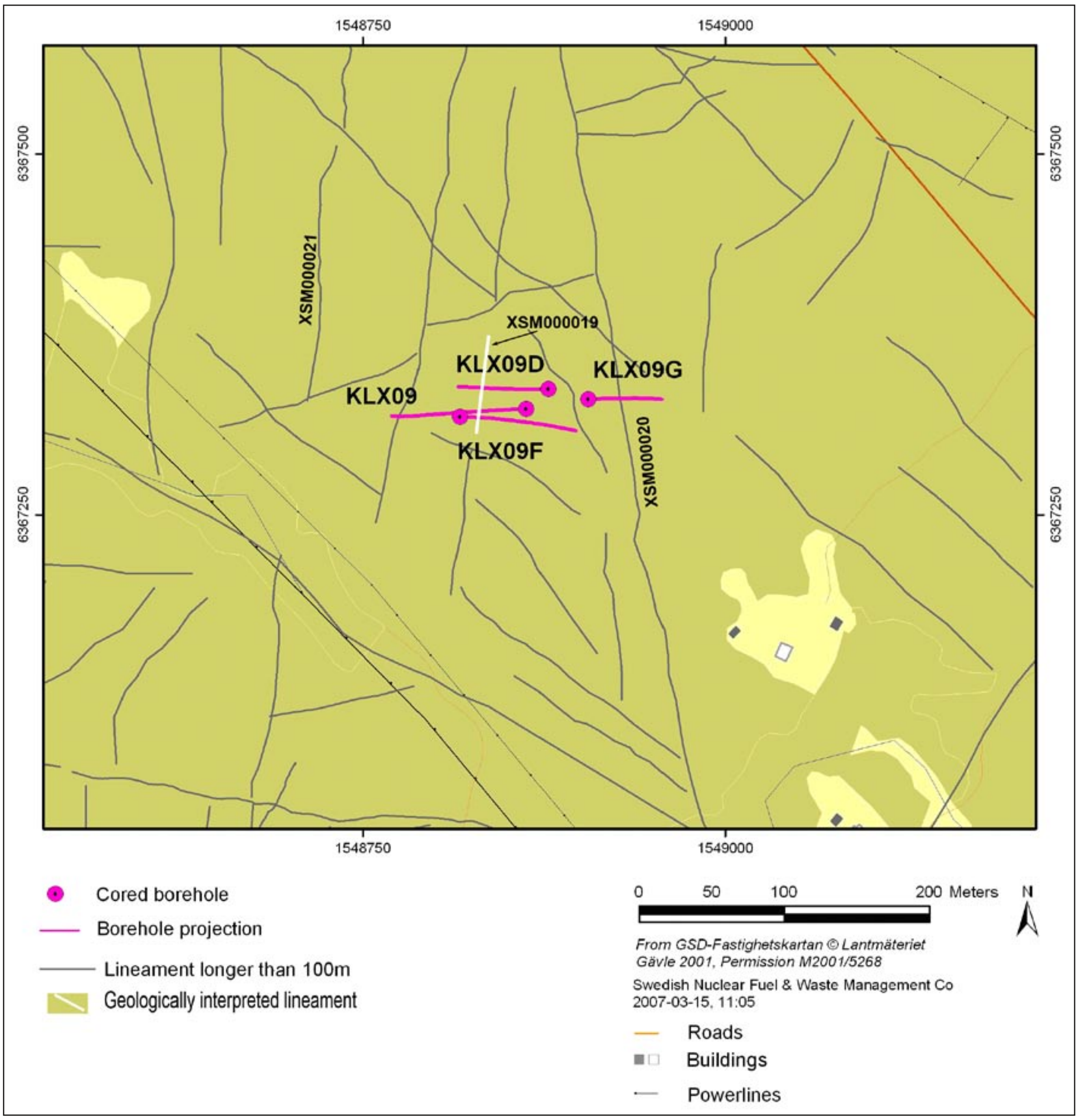


Figure 4-27. *Map over area northeast, showing lineaments and boreholes. White lineament was identified during the field reconnaissance.*

Description of uncovered area

The lineament XSM000019 was uncovered along a c. 20 m long and 4 m wide trench (outcrop A10). Photo documentation and detailed geological mapping was performed along the trench (Figure 4-28 and Appendix A). A central 178/86 trending persistent fault is the dominating structure in the trench. Mylonite, fault gouge and increased fracturing are mapped along the southern part of the trench east of the main fault. It is interesting to note the changes in thickness and character along this lineament.

Description of boreholes KLX09D and KLX09F

The core borehole KLX09D was drilled towards the lineament XSM000019 and entered the bedrock directly. Bearing = 270.1°. Inclination = –59.6°. The core borehole KLX09F was drilled towards the lineament XSM000019 and entered the bedrock directly. Bearing = 91.0°. Inclination = –59.0° (Figure 4-29 and 4-30).

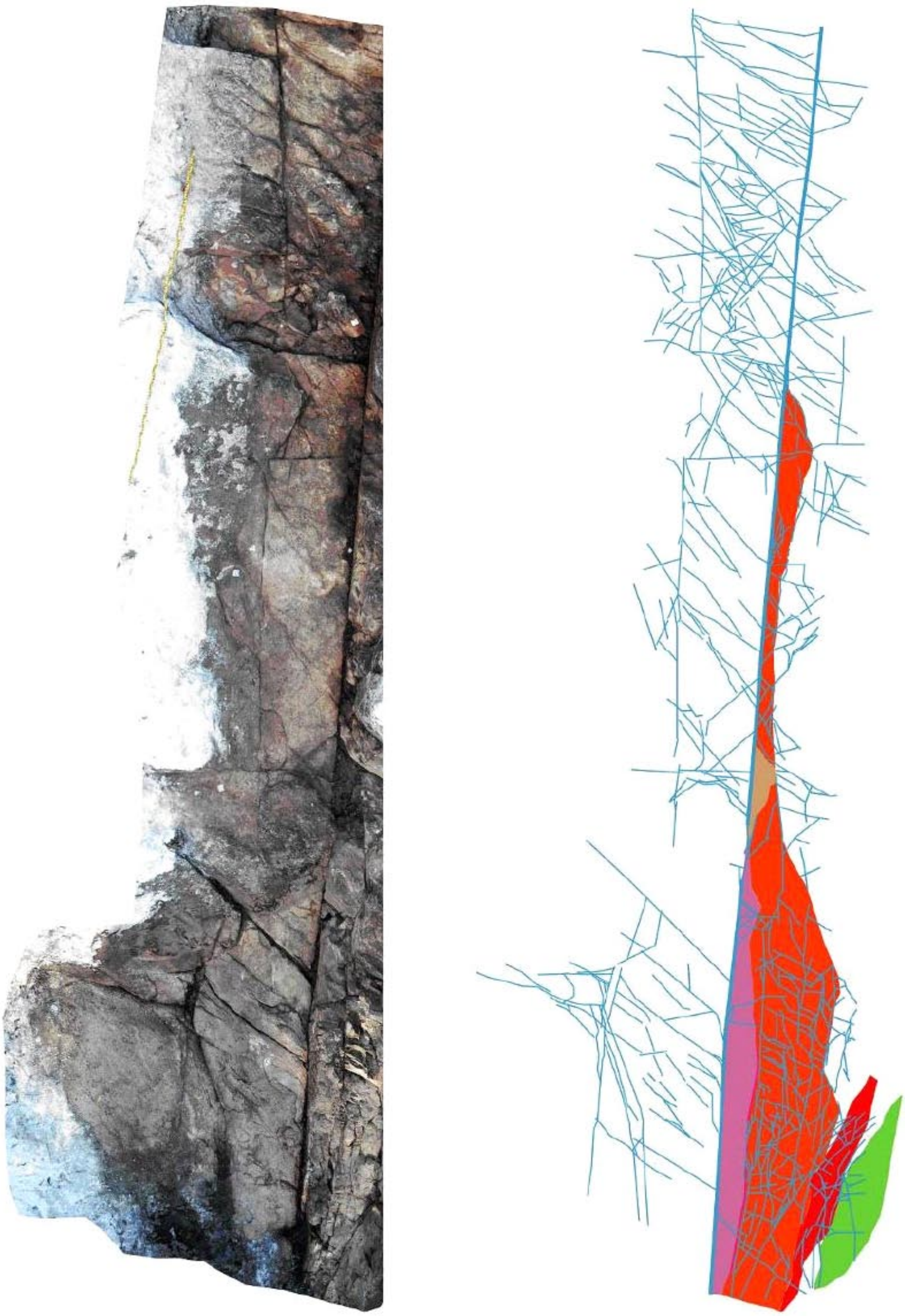


***Figure 4-28.** Documentation and interpretation of the excavated zone (outctop A10) close to KLX09, Appendix A. North is up in the figure and the width of the outcrop is approximately 4 metres. On the left a high-resolution photographic image, that that has been transformed to a close-range orthophoto. To the right a geologic map (schematic) showing fractures as blue lines and the rock type in various colours (orange = fine-grained granite, red = pegmatite, green = mafic rock, purple = cataclastic rock, white = Ävrö granite).*

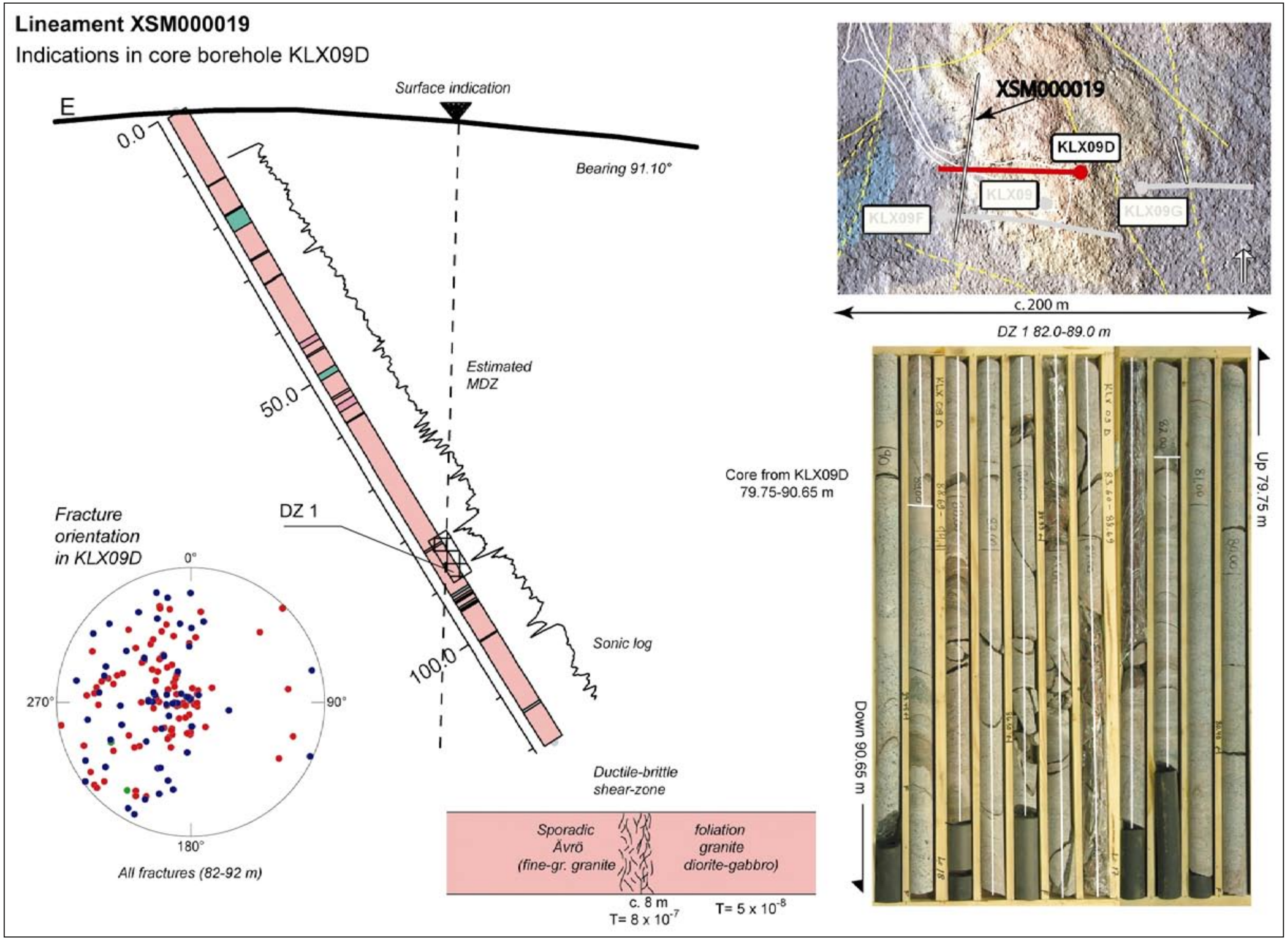


Figure 4-29. Composite figure of KLX09D and the lineament XSM000019. A legend is given in Figure 4-2.

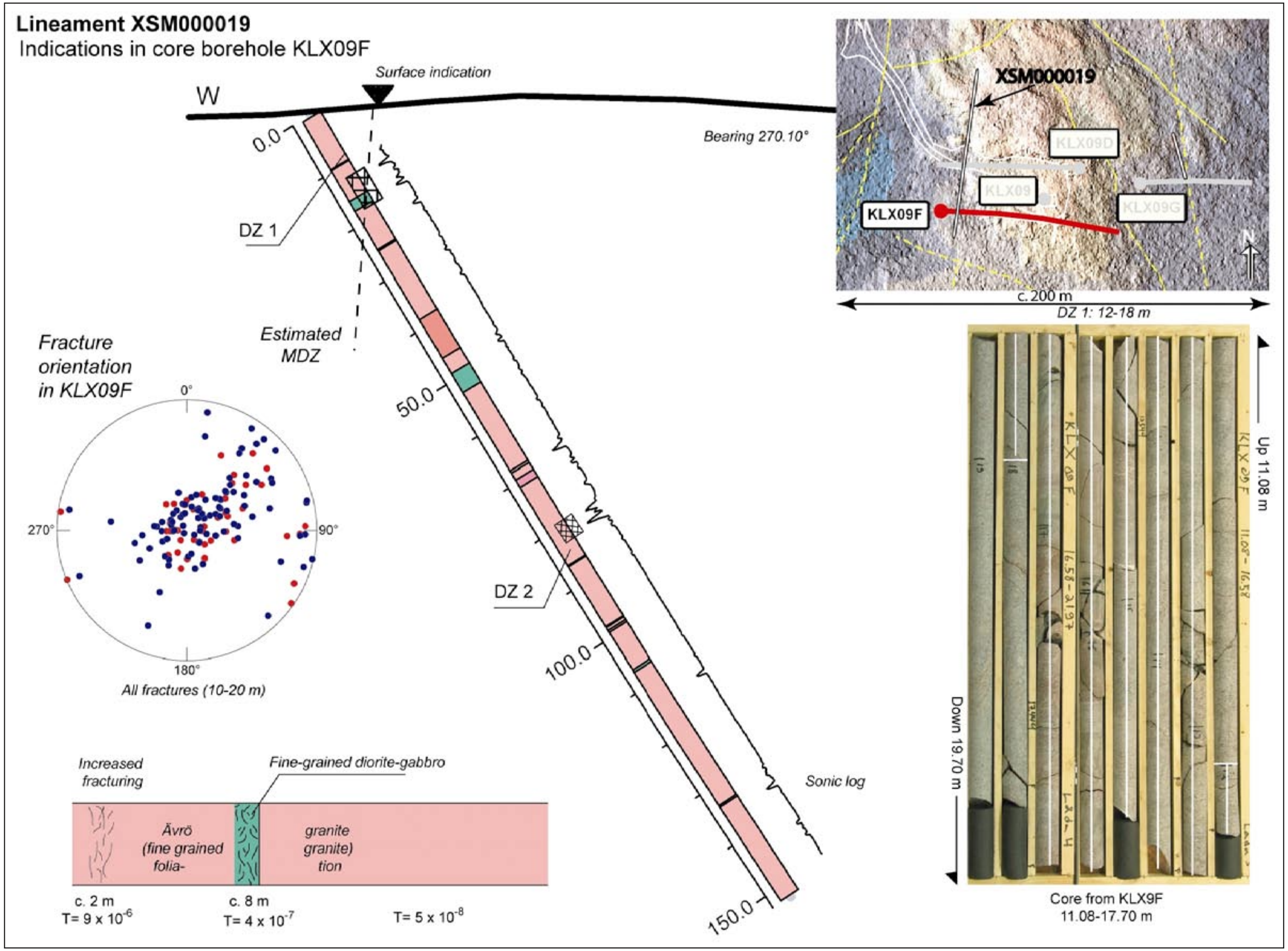


Figure 4-30. Composite figure of KLX09F and the lineament XSM000019. A legend is given in Figure 4-2.

Data from single hole interpretation

KLX09D

Rock distribution

Totally dominated by Ävrö granite. Subordinate rock types comprise fine-grained granite, and fine-grained diorite-gabbro. The major part of the core is foliated.

Possible deformation zones

One possible deformation zone has been recognized in KLX09D.

DZ1 (c. 82.00–89.00 m): Characterized by high frequency of open and sealed fractures, some with large aperture visible in BIPS. The most intense deformation is between c. 82.50–85.00 m (ductile to brittle ductile deformation zone), showing low resistivity and magnetic indications. One radar reflector occurs at 88.10 m with the orientation 017/44. Five non-oriented reflectors at 65.6 m, 69.0 m, 83.5 m, 84.0 m and 89.9 (mostly weak) have the angles 44°, 44°, 59°, 26° and 14° respectively to borehole axis.

KLX09F

Rock distribution

Totally dominated by Ävrö granite. Subordinate rock types comprise fine-grained granite, fine-grained diorite-gabbro and granite. Some sections of the core are foliated.

Possible deformation zones

Two possible deformation zones have been recognized in KLX09F.

DZ1 (c. 12–18 m): Characterized by increased frequency of sealed and open fractures – some with large aperture, visible in BIPS, they are oxidized and partly mylonitic. Distinct indications in geophysical logs. One non-oriented radar reflector at 14.9 m with the angle 56° to the borehole axis.

DZ2 (c. 80–83.5 m): Characterized by high frequency of sealed and open fractures – some with large apertures. Visible in BIPS. Oxidized brittle-ductile deformation zone. Core loss. Low magnetic and resistivity indications. One very strong radar indication at 82.7 m with the angle 55° to borehole axis.

Hydrogeological description */26/*

KLX09D

In total, seven flow anomalies were recorded in KLX09D at the interpreted DZ. The integrated transmissivity over the DZ according to the PFL logging amounts to $7.6 \cdot 10^{-7}$ m^2/s. The highest transmissivity value within the DZ were recorded at $3.2 \cdot 10^{-7}$ m^2/s at a length of 84.9 m.

The overall transmissivity of the borehole is $3.91 \cdot 0^{-5}$ m^2/s according to the PFL logging with the highest being $1.6 \cdot 10^{-5}$ m^2/s at a length of 65.7 m.

KLX09F

Only one flow anomaly have been recorded in DZ1 with a transmissivity of $3.6 \cdot 10^{-7}$ m^2/s at a borehole length of 12.90 m. The overall transmissivity of DZ2 amounts to $8.7 \cdot 10^{-6}$ m^2/s. The maximum transmissivity in the borehole is $6.5 \cdot 10^{-5}$ m^2/s at a length of 113.3 m.

Evaluation

A fault zone in Ävrö granite with mylonite, fault gouge and increased fracturing is mapped at surface.

KLX09D and KLX09F are both dominated by Ävrö granite. DZ1 in KLX09D (82–89 m) with large aperture, visible in BIPS /22/, deformation zone at c. 83 m. A radar reflector oriented 017/44 occur at 88 m.

DZ1 in KLX09F (12–18 m) with increased fracturing – some with large aperture, visible in BIPS /22/. DZ2 (80–83 m), is a deformation-zone with increased fracturing (large apertures) visible in BIPS /22/.

- There is some correlation between one fracture set and the DZ at surface.
- The hydraulic tests gave a transmissivity in the range 10^{-7} to 10^{-6} m^2/s.
- It seems possible to correlate DZ1 in KLX09F with surface indications of XSM000019, as this borehole was started close to the lineament. DZ1 in KLX09D at c. 85 m is probably also a part of the same DZ at depth.

Evaluation: **A.** Likely MDZ with significant transmissivity. May probably affect the siting of deposition holes.

4.3.2 Lineament XSM000020

Lineament description

The lineament XSM000020 is > 500 m long and very distinct, both magnetically (weight = 4) and LIDAR indicated.

Description of uncovered area

Due to practical reasons uncovering (Outcrop A11) was not large enough to map the total width of the lineament. Only photo documentation (Figure 4-31 and Appendix A).

Description of boreholes KLX09G

The borehole site KLX09G was selected in order to investigate the NNW-trending lineament XSM000020 (Figure 4-32).

The core borehole KLX09G was drilled towards the lineament XSM000020 and entered the bedrock directly. Bearing = 85.41°. Inclination = –60.96°.

Data from single hole interpretation */19/*

Rock distribution

9.31–99.63 m. Totally dominated by Ävrö granite. Subordinate rock types comprise fine-grained granite, fine-grained diorite-gabbro, granite, pegmatite and fine-grained dioritoid. The Ävrö granite has a density in the range 2,750–2,790 kg/m^3. The major part of the section is foliated. Confidence level = 3.

Possible deformation zone

DZ1 (40.02–67.52 m): Characterized by high frequency of open and sealed fractures, with partly large aperture. Increased frequency of sealed network in the lower part. Most intense deformation between 40.38–41.50 m (low grade ductile to brittle ductile deformation zone) and 53.40–56.15 m (low grade ductile to brittle-ductile deformation zone). In the section c.40–44 m

Figure 4-31. *At outcrop A11 part of the deformation zone width was uncovered in two locations a few metres apart, Appendix A. The rock is here strongly affected by cataclastic deformation, in what is best described as a brittle-ductile deformation zone. The deformed rock seems to be primarily granite, but extensive intrusion of brecciating quartz and intensive alteration and fracturing make it difficult to exclude that other rock types also are involved. As can be seen in the image, the fracture frequency is high. Since the full zone width is not exposed the fracture geometries and zone geometry has not been examined.*

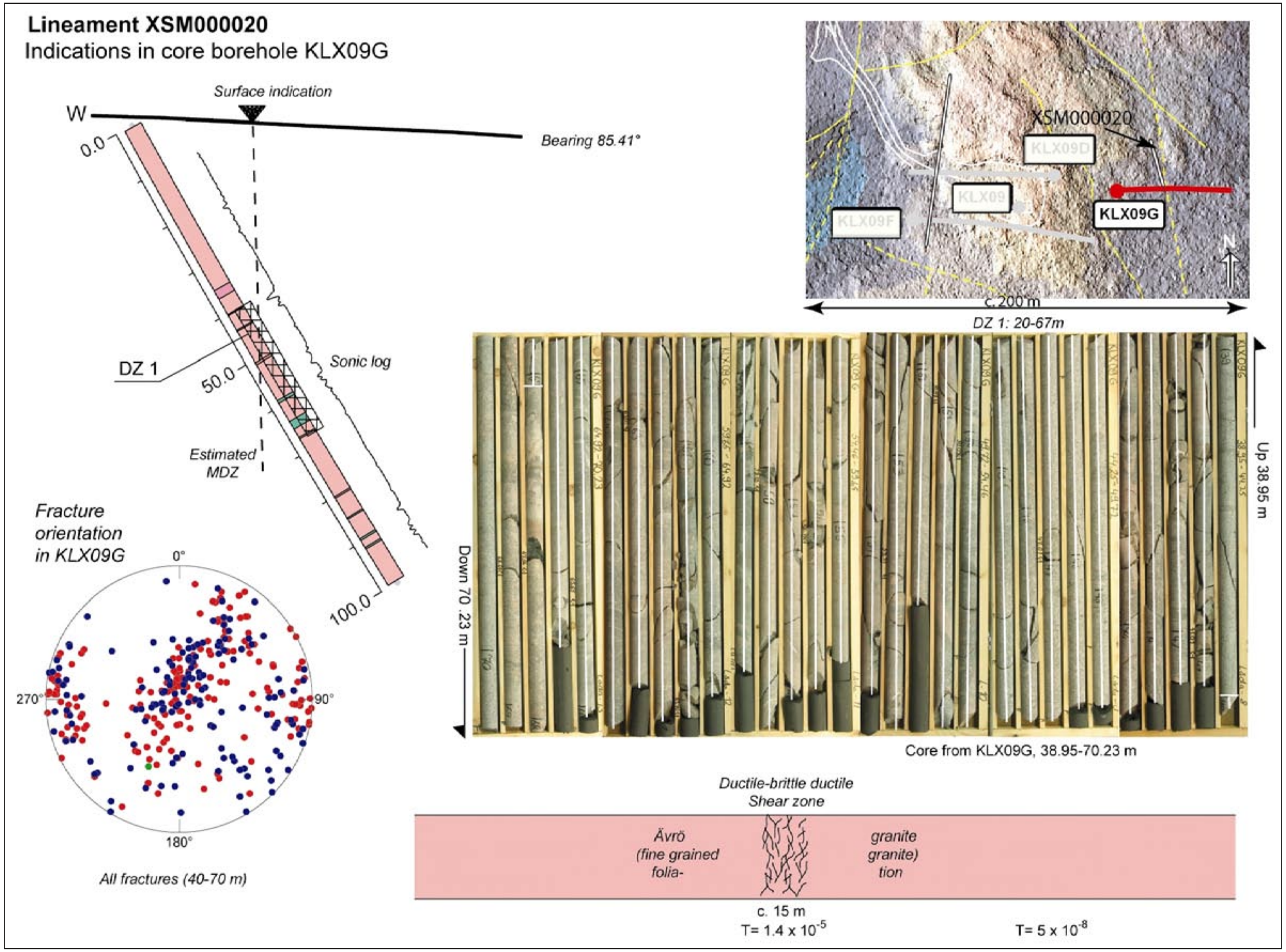


Figure 4-32. *Composite figure of KLX09G and the lineament XSM000020. A legend is given in Figure 4-2.*

there is partly decreased resistivity, decreased P-wave velocity and a caliper anomaly. Three radar reflectors occur; at 41.9 m with the orientation 004/29, at 42.9 m with the orientation 146/68 or 273/25, and at 52.8 m with the orientation 330/16 or 167/77. Five non-oriented radar reflectors with angle to borehole axis are located between 20° and 49°. Low radar amplitude occur at 40–41 m and 55–56 m. The host rock is dominated by Ävrö granite. Subordinate rock types are fine-grained diorite-gabbro, granite, fine-grained granite and pegmatite. Confidence level = 3.

Hydrogeological description /17, 27/

Several flow anomalies were recorded in KLX09G within DZ1. The total transmissivity within DZ1 according to the PFL logging amounts to $1.4 \cdot 10^{-5}$ m^2/s. The highest individual value with the DZ is $9.77 \cdot 10^{-6}$ m^2/s 43.50 m in the borehole.

The overall transmissivity of the borehole is $1.5 \cdot 10^{-5}$ m^2/s according to the PFL logging.

Evaluation

The granitic rock in the partly uncovered lineament is brecciated and highly fractured/altered. KLX09G is dominated by Ävrö granite and DZ1 at c. 40–67 m has high frequency of open and sealed fractures and narrow brittle-ductile deformation zones. Oriented radar reflectors with orientations of 004/29, 146/68 and 330/16. BIPS indication at c. 41–67 m (inhomogeneous rock and sealed/open fractures) /22/.

- Fracture orientation correlates with lineament direction.
- The hydraulic tests show a significant transmissivity, i.e. above 10^{-5} m^2/s.
- It seems possible to correlate DZ1 at c. 40–67 m in KLX09G with surface indication in parts of XSM000020. This lineament corresponds to the local major zone ZSMNS046A.

Evaluation: **D.** Local Major DZ.

4.3.3 Lineament XSM000021

The NNW-trending lineament XSM000021 was partly uncovered in order to find optimal position for core drilling.

Lineament description /16/

The lineament XSM000021 is a more than 300 m long co-ordinated lineament – LIDAR indicated, supposed by field mapping to represent a possible brittle or brittle-ductile DZ.

Description of uncovered area

The primary intention was to uncover a part of the NNW striking main lineament but due to practical reasons (large soil depth) it was not possible. The aim of the uncovered area (outcrop A12) east and close to the main lineament, was to investigate some topographically indicated E-W trending splays, but this area was found to be structurally very complex, with no distinct zone character, Appendix A. Due to these circumstances no drilling was performed (Figure 4-33).

Evaluation

There are no clear indications of a MDZ in the uncovered area. It seems more probable that XSM000021 coincide with a DZ to the west of the uncovered area.

Evaluation: **C**. Probably no MDZ.

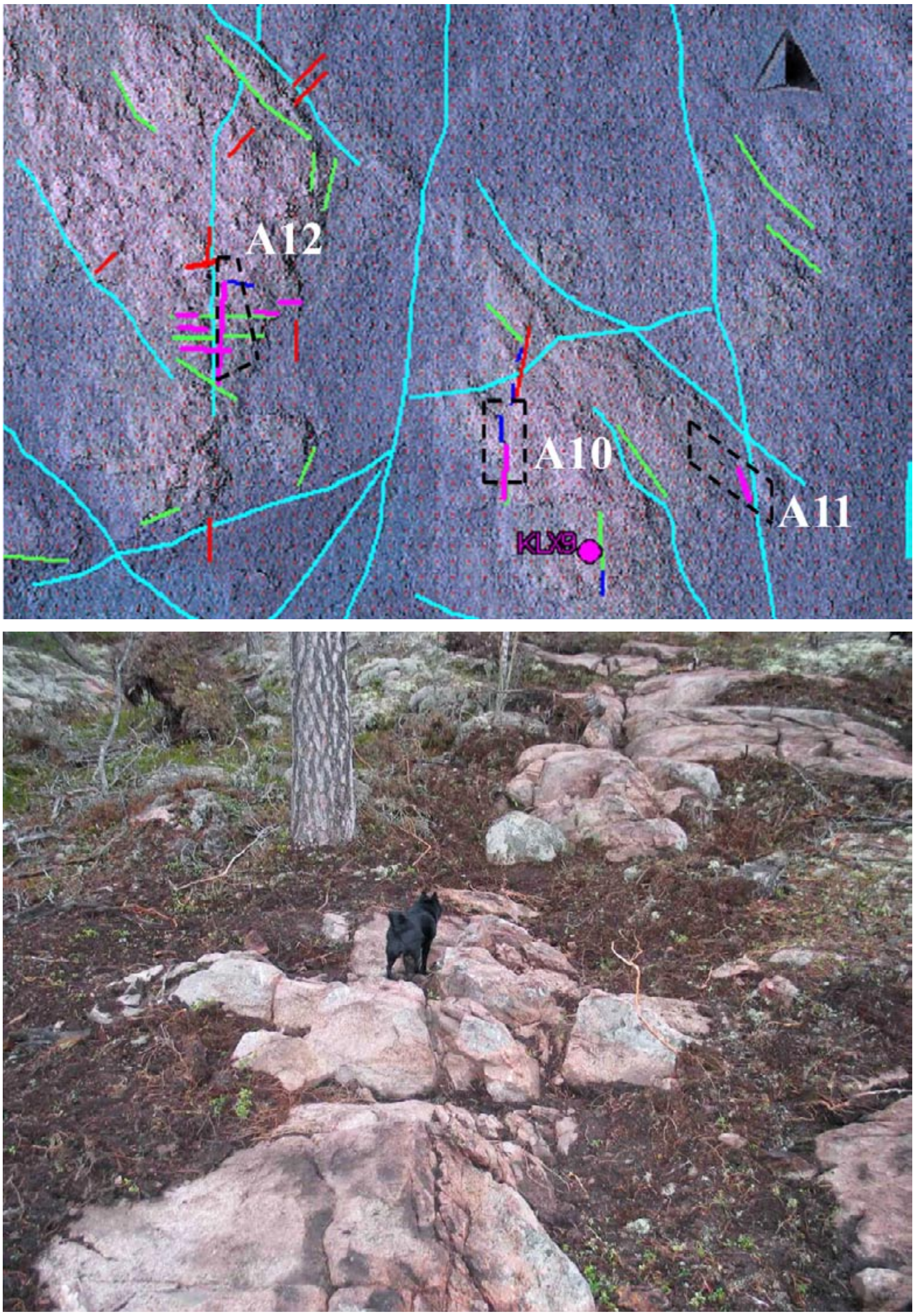


Figure 4-33. *Location of outcrops at drillsite KLX09. At outcrop A12 the deformation zone was not uncovered in its full width, although the zone boundary is a bit difficult to delineate. The zone is marked by a central, brittle-ductile deformation zone, with a slight en echelon character. The zone has a varying width from only millimetres, up to 2–3 dm. Fracture mineralogy is often hard to recognize, but epidote is common. The zone, but also large parts of the surrounding rock is oxidized, which is recognized by a red staining of the rock. At least part of the oxidation in surrounding rock can be related crosscutting fractures and small fracture zones. A10 and A11 are discussed in the description of lineaments XSM000019 and XSM000020.*

5 Discussion and conclusions

5.1 Characterization of investigated lineaments

In total, 21 lineaments, mostly < 350 long, have been investigated. Three of the targeted lineaments were rejected directly after the field reconnaissance, i.e. XSM000005, XSM000006 and XSM000021. The main reason for the rejection was that the lineaments were very weak or even non-existing at the uncovered surface. The 18 lineaments remaining as potential MDZs were further investigated by means of shallow core drilled boreholes. 13 holes were sited to penetrate the potential MDZs at a predefined depth. In addition, two core-drilled boreholes primarily made for other purposes have also been used for the MDZ characterization.

Three boreholes were sited to penetrate two or more lineaments, i.e. KLX10C (XSM000011, XSM000012, XSM000013 and XSM000014), KLX23A (XSM000001 and XSM000002) and KLX26A (XSM000015 and XSM000016).

The same lineament was penetrated by two boreholes at two different drill-sites, i.e. XSM000019 by boreholes KLX09D and KLX09F, and XSM000015 by boreholes KLX26A and KLX26B.

The investigated lineaments with length and lineament indicators (topography and/or geophysical) as well as estimated indicators of the lineaments being MDZs based on surface geology, core drilling and hydraulic tests are presented i Table 5-1.

The criterion used to define weather the investigated lineament should be regarded as a MDZ of importance for design and construction was based on an integrated evaluation of the surface and borehole information according to the following sequence:

- A positive correlation between surface data and interpreted DZs from the single hole interpretation in the borehole.
- Width of zone in the core should be > 0.1 m.
- Significant transmissivity of the encountered zone ($> 1 \cdot 10^{-7}$ m^2/s).

Each interpreted MDZ have also been assigned a level of confidence which is further discussed later on in this chapter.

5.2 Defined MDZs

5.2.1 Importance of the MDZs

The characterization has been made in two steps:

1. Define the MDZ's importance for design and construction, where A implies a verified MDZ of high importance, B Possibly MDZ of less importance, C Probably no MDZ and D Local major DZ or dyke.
2. For MDZs which are defined as A or B the confidence for the interpretation have been assigned. Confidence level 1 indicate a low confidence and 3 high confidence of existence.

The result is summarized in Table 5-2. Of the table it can be seen that only five lineaments have been assigned high importance whereas 8 have been assigned to be of no importance mainly due to geological and hydraulic signatures in the borehole. Another three have been assigned to be of less importance and five are either regarded as Local major DZs or lithological units (dykes). Consequently out of the 21 lineaments only eight are regarded as MDZs of high or less importance, i.e. less than 40%, and less than 25% are regarded as being of high importance for design and construction. In addition, three local major DZs and two dykes were found, which are of importance, although no MDZ.

Table 5-1. Investigated lineaments with length and lineament indicators (topography and/or geophysical). Indicators on MDZ from surface geology, core drilling and hydrogeological tests.

Lineament		Topography	Geophysics			Estimated zone indication									Comments
			Weight 1–5			Surface geology			Core drilling					Hydrogeology	
ID	Length (m)		M	R	S	Uncovered areas	Width of zone (m)		Borehole	Width of zone (m)		Directional radar		+ (+) –	
XSM000001	250	+	3	–	–	A6	+	0.3	KLX23A	+	< 0.1	–		–	
XSM000002	250	(+)	3	3	–	–	–		KLX23A	–		–		–	
XSM000003	20	+	1	–	–	A5	+	0.25–0.3	KLX23B	+	1.5	–		+	
XSM000004	200	+	2	–	–	A4	+	< 0.1	KLX25A	+	< 0.1	–		–	
XSM000005	250	+	–	–	–	A2	+	< 0.1	–	–		–			Rejected after reconnaissance
XSM000006	> 150	+	?	–	–	A3	+	0.5	–	–		–			Rejected after reconnaissance
XSM000007	350	+	3	–	–	–	–		KLX24A	+	10	+	DZ4	+	Interpreted as local major DZ
XSM000008	350	+	4	4	–	A1	+	0.5	KLX22A	–		–		(+)	
XSM000009	250	+	4	4	–	–	–		KLX22B	+	3	+	DZ1	–	
XSM000010	250	+	5	5	–	A8			KLX10B	+	10	+	DZ2	+	Dyke (fine-grained granite)
XSM000011	110	+	4	4	–				KLX10C	+	5	+	DZ1	(+)	
XSM000012	100	+	5	5	–				KLX10C						
XSM000013	100	+	4	4	–	A9	+		KLX10C	+	20	–		+	
XSM000014	100	+	1	–	–	A9			KLX10C	–		–		–	
XSM000015	180	+	2	–	–	A7	+	0.5–1.5	KLX26A+B	–	10	+	DZ2	+	Dyke (fine-grained granite)
XSM000016	220	+	–	2	–	–	–		KLX26A	+	6	–		–	Interpreted as local major DZ
XSM000017	130	+	2	–	4	–	–		KLX28A	+	3	+	DZ1	+	
XSM000018	180	+	–	–	4	–	–		KLX29A	+	8	–		(+)	
XSM000019	100	+	1	–	–	A10	+	1.0	KLX09D	+	8	+	DZ1	(+)	
									KLX09F	+	6	+	DZ1	(+)	
XSM000020	> 500	+	4	–	–	A11	+	2.0	KLX09G	+	26	+	DZ1	+	Interpreted as local major DZ
XSM000021	> 300	(+)	–	–	–	A12	–		–	–		–			Rejected after reconnaissance
Topography Distinct = + Less distinct = (+)			Magnetic = M Resistivity = R Seismic = S			Outcrop no = A1–A12	+ = zone – = no zone			+ = zone – = no zone		+ or – = coincidental or not with lineament DZ = Deformation Zone		+ = strong (+) = uncertain – = none	

Table 5-2. Assignment of the different lineaments as MDZ of importance for design and construction.

Lineament	Direction	A	B	C	D	Confidence*	MDZ	Transmissivity	Comments	Cored borehole
XSM000001	WNW			X		–		No data	No correlation	KLX23A
XSM000002	NW			X		–		$< 10^{-9}$	No correlation	KLX23A
XSM000003	NNE	**X**				2	ZSMNE703A	$2 \cdot 10^{-6}$ (Inj)		KLX23B
XSM000004	NE			X		–		$8 \cdot 10^{-9}$ (PFL)		KLX25A
XSM000005	NW			X		–		–	No drilling	–
XSM000006	NE			X		–		–	No drilling	–
XSM000007	N-S				X		ZSMNS707A	$1 \cdot 10^{-5}$ (PFL)	Local major DZ	KLX24A
XSM000008	WNW			X		–		$3 \cdot 10^{-7}$ (PFL)	Weak in core, low T	KLX22A
XSM000009	NE		X			3	ZSMNE709A	$3 \cdot 10^{-8}$ (PFL)		KLX22B
XSM000010	ENE				X		ZSMNE943A	$1 \cdot 10^{-4}$ (Inj)	Fine-grained granite	KLX10B
XSM000011	E-W		X			2	ZSMEW711A	No data	Uncertain hydro	KLX10C
XSM000012	E-W		X			2	ZSMEW712A	$6 \cdot 10^{-6}$ (PFL, DZ3)		KLX10C
XSM000013	E-W	**X**				2	ZSMEW713A	$8 \cdot 10^{-7}$ (PFL DZ7)		KLX10C
XSM000014	E-W			X		–		$7 \cdot 10^{-9}$ (PFL)		KLX10C
XSM000015	NE				**X**	–		$2 \cdot 10^{-6}$ (PFL)	Fine-grained granite	KLX26A KLX26B
XSM000016	N-S				X			$5 \cdot 10^{-8}$ (PFL)	Local major DZ	KLX26A
XSM000017	E-W	**X**	(x)			2	ZSMEW717A	$8 \cdot 10^{-7}$ (PFL)		KLX28A
XSM000018	NE	**X**				3	ZSMNE718A	$5 \cdot 10^{-7}$ (PFL)		KLX29A
XSM000019	N-S	**X**	(x)			3	ZSMNS719A	$7 \cdot 10^{-7}$ (PFL) $4 \cdot 10^{-7}$ (PFL)		KLX09D KLX09F
XSM000020	NNE				X		ZSMNS046A	$1 \cdot 10^{-5}$ (PFL)	Local major DZ	KLX09G
XSM000021	NNW			X				–	No distinct MDZ	–
Total		5	3	8	5					

* Reflects the interpreters confidence in assigning the lineament as a MDZ based on existence and properties.

5.2.2 Orientation indications

The total number of observation is too small to permit a more thorough analysis of the variations of MDZs in different directions. However, some general patterns may be distinguished. A distribution of the classification in relation to orientation is given in Table 5-3.

- It appears as the most prominent MDZs (A) have a predominant orientation of EW towards NE. All MDZs of A-category falls within this range of orientation.
- Dykes of fine-grained granite have a predominant orientation of NE-ENE /37/.
- It appears as MDZs with a more WNW to NNWorientation have a lower importance.

5.3 Estimated frequency of MDZs in the Laxemar area

5.3.1 LIDAR and geophysical indications

Spacing between lineaments (longer than 100 m), indicated by LIDAR and geophysics, seems to be in the order of about 100 m with no significant preference to orientation /16/. These lineaments and also some lineaments 10–100 m in length are mostly estimated to be indications of brittle-ductile deformation zones (possibly water-bearing), local rock alteration or low-magnetic dykes i.e. fine-grained granite within blocks of generally good quality.

5.3.2 Refraction seismic indications

Refraction seismic profiling executed in the Laxemar area /33, 35, 36/ with a geophone distance of 5 m demonstrates that zones with reduced seismic velocity (< 4,000 m/s) appear on average with a distance of 200–500 m, cf. Table 5-4. Seismic low velocity sections mostly indicate highly fractured rock (possibly water-bearing) or local rock alteration. The result from the seismic survey does also reveal the existence of local blocks with generally high velocity (> 5,000 m/s) and no significant discontinuities, i.e. rock of generally good quality. The lineaments surrounding the blocks are likely to be indications of local major or minor zones, whereas the seismic low-velocity zones, with a mean spacing of approximately 80–100 m, probably indicate narrow structures (MDZ) within the blocks, Table 5-4. It can be noticed that a mapping study along a N-S profile on Äspö indicated 60–75 m spacing between minor fracture zones /35/.

Seismic profiles, with 5 m geophone spacing, mainly indicate brittle zones with a width of 5 m ore more. Most of these zones are also indicated by co-ordinated lineaments but the latter probably also indicate a number of ductile and altered zones, and perhaps some low-magnetic dykes, Table 5-4. However, it should be noted that, whereas the seismic survey detected

Table 5-3. Distribution of different classification for lineaments with different orientation.

Orientation	Observations	A	B	C	Dyke	Local major DZ
E-W	5	2	2	1	–	–
WNW	2	–	–	2	–	–
NW	2	–	–	2	–	–
NNW	1	–	–	1	–	–
N-S	3	1	–	–	–	2
NNE	2	1	–	–	–	1
NE	5	1	1	2	1	–
ENE	1	–	–	–	1	–

Table 5-4. Seismic refraction in Laxemar. 5 m between geophones. Estimated spacing between low-velocity zones approximately 200–500 m /33, 35, 36/, of which less than 40% is estimated to be brittle zones.

Profile no	Length (m)	Direction	No of sections (< 4,000 m/s)	Number of co-ordinated lineaments	Coincided
LSM000276	505	N-S	2	5	2
LSM000277	500	N-S	1	5	1
LSM000278	400	E-W	3	5	3
LSM000279	370	N-S	3	4	3
LSM000280	570	N-S	3	7	3–2
LSM000281	4,750	N-S	1	3	1
LSM000282	350	N-W	1	2	1
LSM000283	720	N-W	1	7	1
LSM000504	430	N-S	2	7	2
LSM000505	405	N-S	3	6	2
LSM000506	660	N-S	3	6	3
LSM000507	770	N-S	2	8	2
LSM000508	650	N-S	4	4	3

29 low-velocity zones of which 27 coincided with co-ordinated lineaments. The total number of interpreted co-ordinated lineaments transversed by the seismic profiles was as many as 69. Thus, only about 40% of the interpreted lineaments were detected by the refraction seismic survey.

The same comparison may be done for seismic profiles with 2.5 m geophone distance /36/. From Table 5-5 it is evident that only c. 50% of the seismic low velocity zones with 2.5 m geophone spacing coincide with co-ordinated lineaments probably due to the fact that magnetic and resistivity measurements do not pick up narrow (less than c. 3 m thick) brittle zones. The c. 50% of co-ordinated lineaments which do not coincide with seismic indications probably represents indications such as low-magnetic altered rock, topographic effects and to some extent low-magnetic dykes.

Table 5-5. Seismic refraction in Laxemar. 2.5 m between geophones. Estimated spacing between low-velocity zones approximately 80 m /36/, c. 50% of the low-velocity sections coincide with co-ordinated lineaments.

Profile no	Length (m)	Direction	No of sections (< 4,000 m/s)	Number of co-ordinated lineaments	Coincided
LSM000556	800	E-W	6	10	3
LSM000557	400	E-W	4	3	2
LSM000558	200	N-S	1	4	0
LSM000559	450	N-E	7	8	5
LSM000560	300	N-E	5	3	3
LSM000561	200	N-W	6	4	2
LSM000562	200	N-W	3	3	2
LSM000563	200	E-W	4	4	2
LSM000564	400	N-S	4	6	3
LSM000565	250	N-W	4	2	2
LSM000566	200	N-W	2	1	1
LSM000567	200	N-S	3	5	2
LSM000568	300	N-S	3	5	2

Measurements made on southern Äspö show increased values for sections up to a few metres thick in red stained zones close to low-magnetic features, probably due to oxidation of magnetite in bedrock /35/. Assuming that these results roughly represent the actual Laxemar area it seems reasonable to expect that less than about 50% of all co-ordinated lineaments (major DZ excluded) represent brittle, highly fractured possible water-bearing MDZ.

5.3.3 Trench mapping in western Laxemar

The distance between MDZs may also be deduced from data gained during detailed fracture and bedrock mapping on a number of cleaned trenches and outcrops in the Laxemar area /38/. The total length of the 10 mapped strips (ASM000114–ASM000123) each c. 30–100 m long is approximately 580 m.

Three of the longer E-W trending trenches, close to a power line, which probably affect the geophysical results are not crossed by any co-ordinated lineament, probably due to the location of the trenches on outcrops between major lineaments. Three altered sections, 1–4 m thick, are mapped but not geophysically/topographically indicated as lineaments longer than 100 m. Mapped dykes of fine-grained granite are only c. 1 to 20 cm in width. There is no detailed geophysics in this area.

Five of the seven trenches close to KLX11A in an area with detailed ground geophysics are crossed by a number of co-ordinated lineaments. In the trench ASM000117 there is a correlation between a NS trending lineament and a c. 5 m thick dyke of fine-grained granite and between a section with increased fracturing and another NS trending lineament. In the other trenches there is no clear correlation between two crossing lineaments and mapping data. Dykes of fine-grained granite or altered rock sections thicker than c. 1 m are not documented. Perhaps can susceptibility variation in rock and locally intensity of fracturing explain some of the lineaments but the results strengthen the assumption that all lineaments are not coincident with deformation zones.

Several of the lineaments crossed by the trenches were not verified by the surface mapping.

5.3.4 Shallow core-drilled boreholes

Spacing between possible MDZ indications in 14 shallow (< 150 m) core drilled boreholes is estimated to be in the order of 50–100 m.

5.3.5 Deep core-drilled boreholes

Mean spacing between possible MDZ indications, in the 100–500 m interval is estimated to be 120–200 m based on data from 5 deep boreholes.

It appears as MDZ indications are more frequent at shallow depth, and that the frequency becomes significantly lower at depth. The difference in inclination between shallow and deep boreholes may be one reason, but it does not explain the significant difference between indications near surface and at depth. There are also geological reasons for the difference due to i.e. differences in hydrothermal circulation during an early deformation phase.

5.3.6 Comparison with Äspö data

The pre-investigations for the Äspö HRL involved extensive field measurements aimed to characterize the rock formations with regard to geology, geohydrology, ground water chemistry and rock mechanics /32/. In a separate study /35/, data from the Äspö HRL have been re-evaluated with the aim of study the MDZs with respect to their appearance at surface, in boreholes and in excavated openings within the Äspö HRL.

During construction of the Äspö HRL water inflow was the most important problem. In order to limit the water inflow pre-grouting was performed along many sections of the access tunnel. Passage of the major deformation zones NE-1, NE-3 and NE-4 caused the main problems. These deformation zones which were identified prior to the construction consumed about 45% of the total grout volume, but it is important to note that minor deformation zones, only partly indicated, consumed more than 50% of the total grout volume.

One question of importance is whether there is a correlation between water-bearing MDZs mapped on surface, in boreholes and in the tunnel regarding frequency and spacing? Based on data from different studies distance between MDZs mapped on surface is in the order of 40–100 m with variation linked to orientation. In the deep boreholes the equivalent distance is 75–200 m with great variation between different boreholes.

In the tunnel the distance is approximately 75–100 m between highly conductive MDZs (often pre-grouted) and 25–35 m between less conductive structures. However, there is great variation between different sections of the tunnel. In the section c. 700–1,300 m – between the major deformation zones – there is an increased frequency of MDZs.

The feasibility of identifying conductive MDZs and their properties is dependent of the geological structural model, the number of interference tests, the number of pressure observation sections in boreholes and the complexity of the major conductive structures.

Field data – geological and geophysical – gave the first indications of NNW–NNE trending swarm of MDZs. Fractures in this swarm are often red-stained or filled with quartz.

Interference hydraulic tests in boreholes on southern Äspö revealed their hydraulic importance. During excavation of the tunnel, this kind of MDZ have been mapped and indicated and some found by drilling. This type of hydraulically significant zones is complex to describe deterministically by means of geological and geophysical investigations. Possibly they are rather common in what is considered to be "rock blocks within major fracture zones" but the exact position and orientation of sub-vertical MDZs at depth seem to be almost impossible to determine within reasonable efforts.

Summarized there is a good correlation between surface – borehole data regarding frequency and spacing and conditions at depth of 400–450 m but it is important to perform detailed geological and geophysical surface investigations complemented with borehole data from BIPS, Boremap, geophysical logging, borehole radar and hydrogeological flowlogging.

5.4 Conclusions

- Less than c. 50 percent of the investigated lineaments < 1,000 m are estimated to coincide with a MDZ or a dyke of more or less practical importance. This result is in agreement with surface mapping in Laxemar.
- The important MDZs are characterized by brittle-ductile deformation zones, increased fracturing (open and sealed fractures) and sometimes also minor crush and mylonites.
- The important MDZs are also characterized by a significant transmissivity, > $5 \cdot 10^{-7}$ m^2/s.
- Many lineaments are probably indications of minor ductile deformation zones, local rock alteration or dyke of i.e. fine-grained granite.
- It seems to difficult to correlate a specific surface zone indication with a borehole indication at a depth of some tens of meters, especially if you do not have one or more unique geological signatures.
- Lineaments verified by refraction seismics appears to be more brittle with a higher degree of open fractures and also more transmissive.

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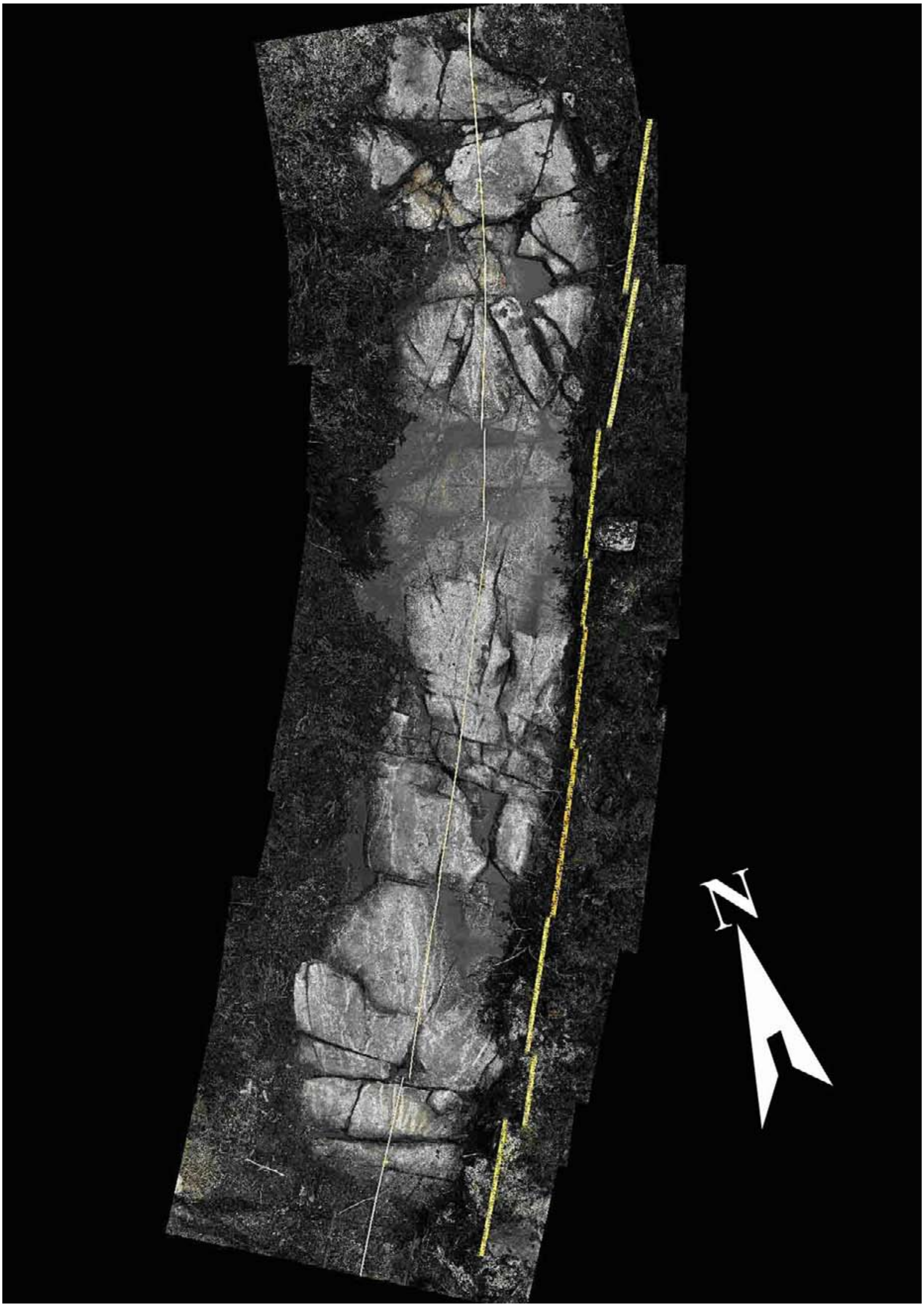
Appendix A

Excavations and Photographs of Excavations

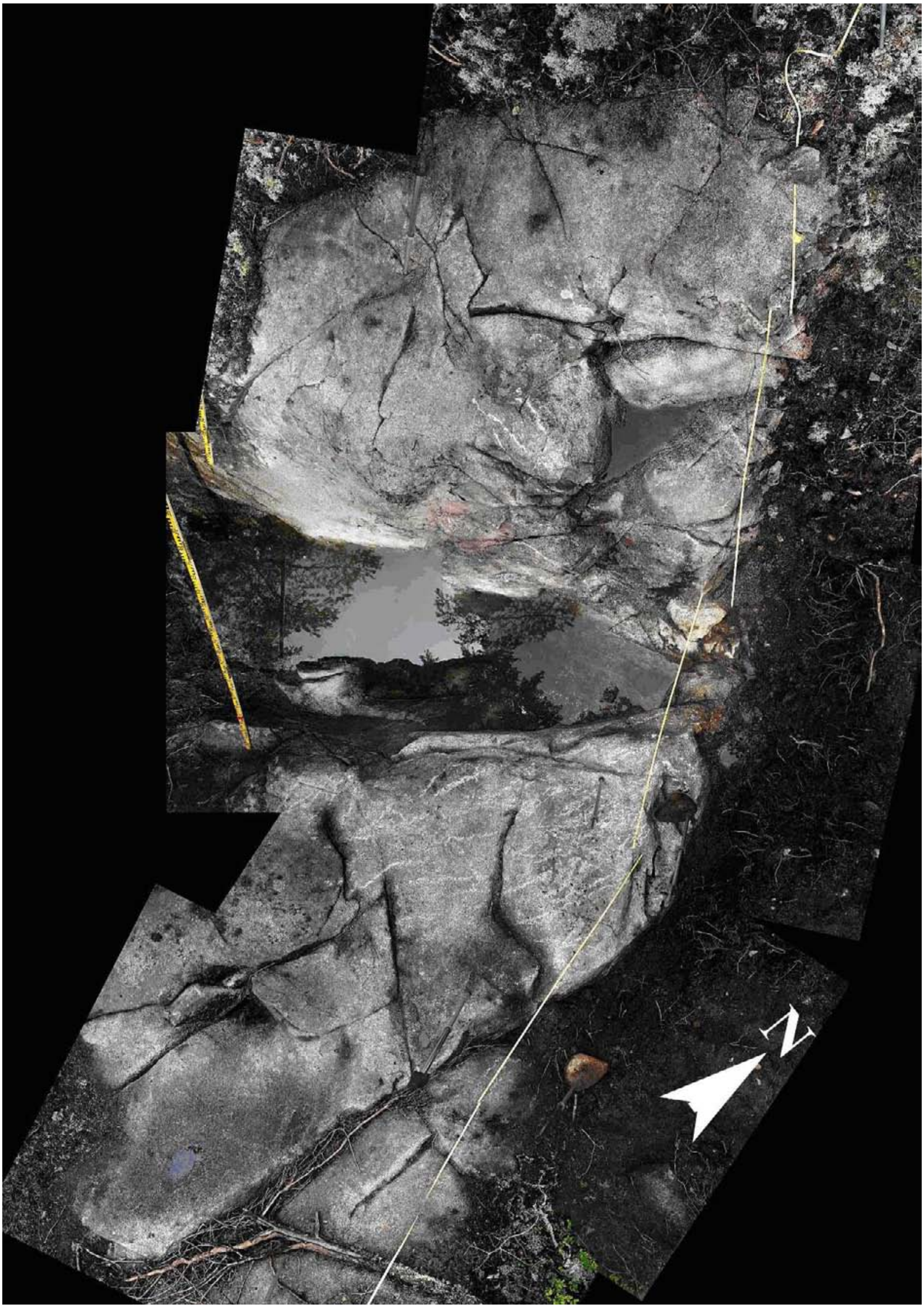
Photo, Photograf C-R Lindqvist

OUTCROP A1

OUTCROP A2



OUTCROP A3



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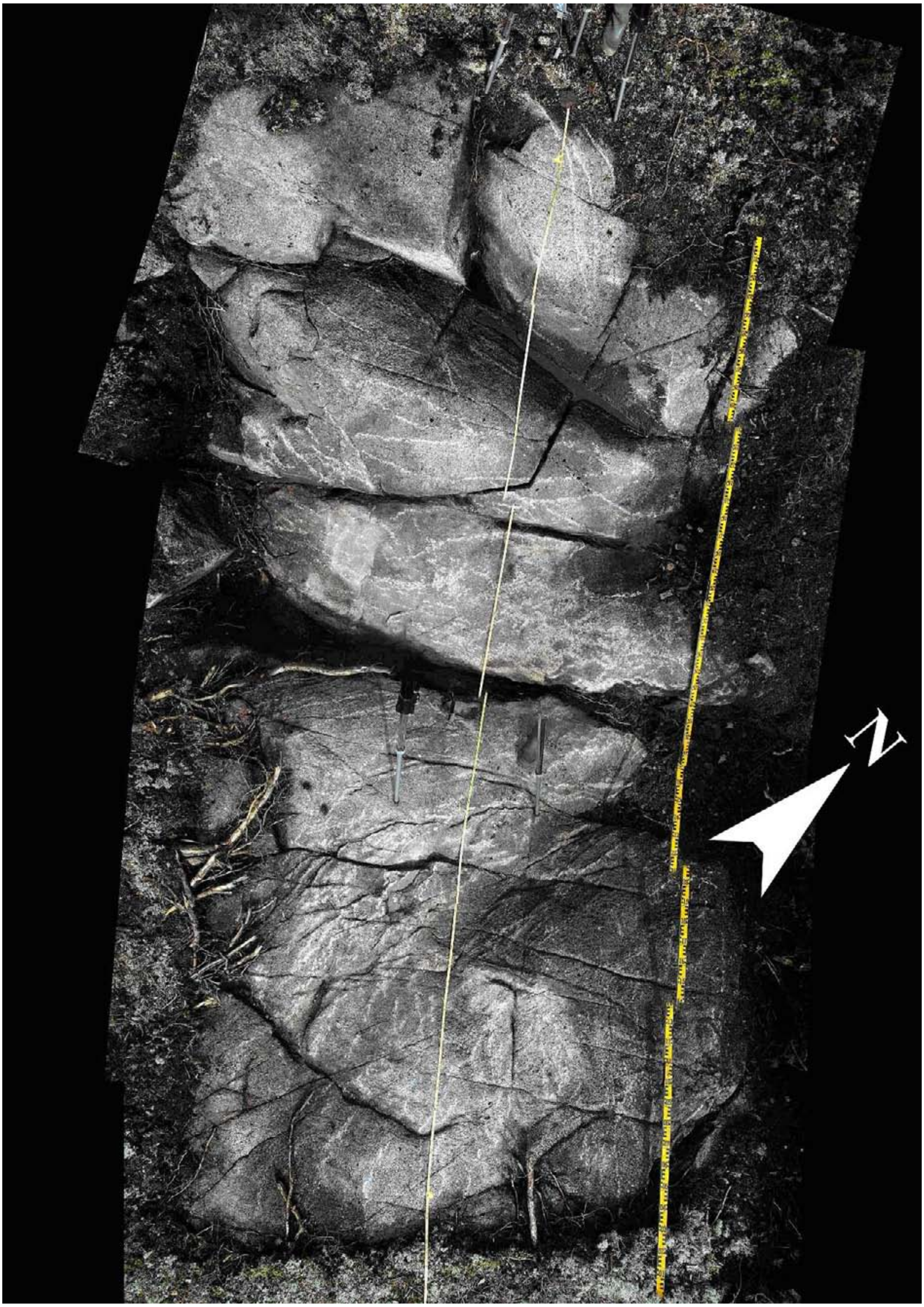
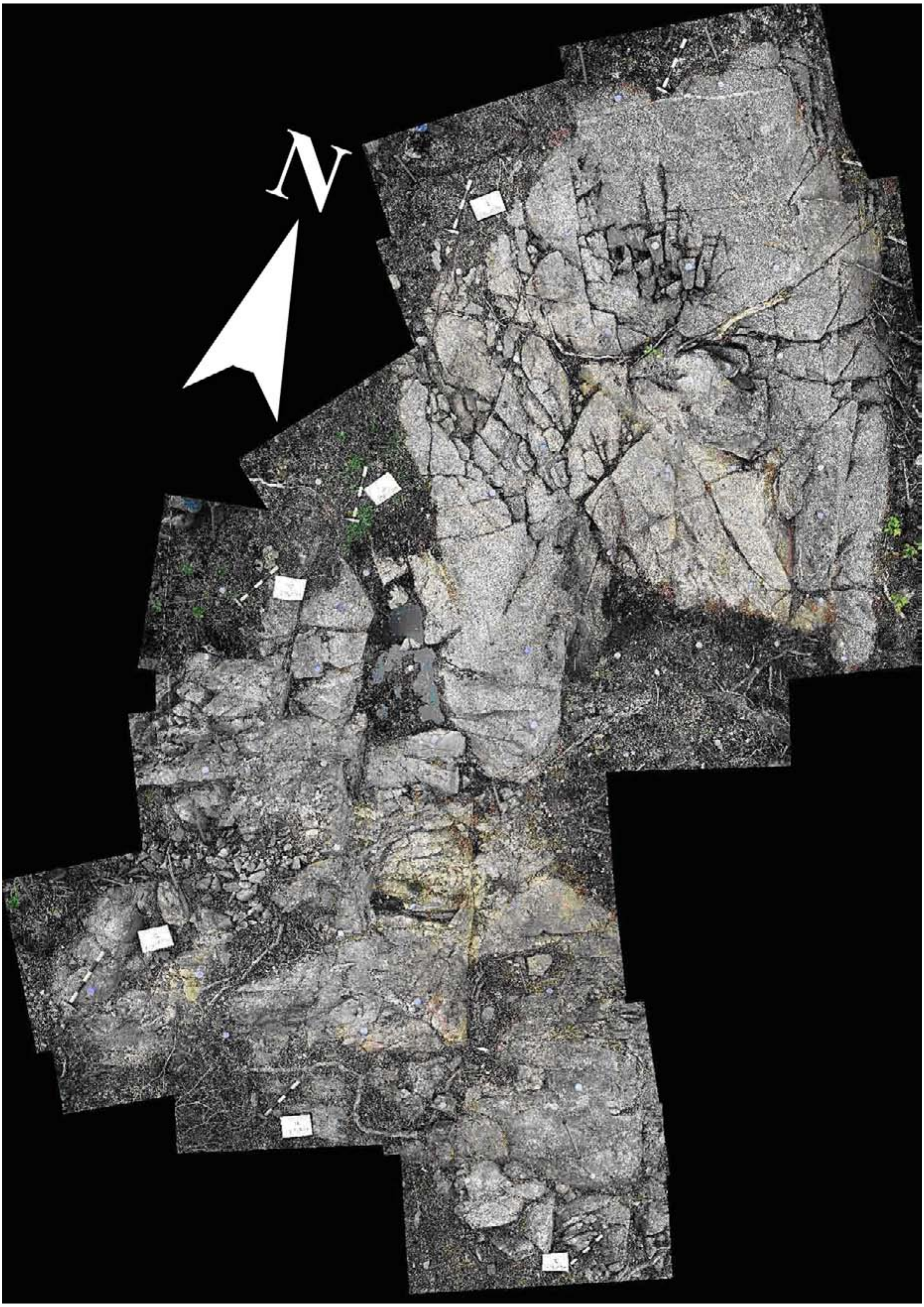


OUTCROP A5

OUTCROP A6

OUTCROP A7



OUTCROP A8

View facing north. KLX10B at the concrete cylinder.

OUTCROP A9

View facing north. Lineaments crossing the outcrop ahead.

OUTCROP A10

OUTCROP A11

OUTCROP A12

View facing north, southern part of outcrop

View facing north, northern part of outcrop

Appendix B

Scanline Tables

Johan Berglund, Vattenfall Power Consultants

Appendix B
Scanline Tables

Field-name of excavation	LSM-number	Proximal boreholes	Comments
A1	LSM000584	KLX22A	
A2	LSM000585	KLX24A	
A3	LSM000586	-	
A4	LSM000587	KLX25A	
A5	LSM000588	KLX23B	
A6	LSM000589	KLX23A	
A7	LSM000590	KLX26A & KLX26B	
A8	-	KLX10B	No excavation
A9	LSM000583	KLX10C	
A10	-	KLX09D & KLX09F	
A11	-	KLX09G	No mapping
A12	LSM000581	-	Northern profile
	LSM000582	-	Southern profile

LEGEND

Fracture endings:

o The fracture termination is not visible.

p The fracture is terminated in a point, but not against any discontinuity in the rock.

t The fracture terminates against another fracture.

Appendix B
Scanline Tables

A1

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
108-114	pegmatite
195-210	pegmatite, hornblende-rich
518-520	pegmatite
522-527	pegmatite
530-533	pegmatite
643-645	pegmatite
700-720	pegmatite
800-860	soil covered
890-935	red, fine-grained granite
951-966	red, fine-grained granite
1470-1482	dyke, granite

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000584	A1	1546673	6366527	10	16,49	34 + fracture zone

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	100	128	90	pp	3,80	
2	215	45	90	oo	7,20	
3	257	297	80	pt	2,60	
4	307	104	65	pt	1,15	
5	330	64	90	pt	4,80	
6	425	115	90	pl	1,20	
7	632	289	10	pp	1,00	
8	650	33	85	pp	1,10	
9	725	71	85	pl	0,70	
10	763	273	78	pt	1,70	
11	781	88	66	op	1,50	
12	783	100	80	ot	0,30	
13	800-860					soil covered
14	860-875	260	15	oo		fracture zone
15	980	41	90	pp	2,10	dextral fault
16	1011	278	32	oo	2,30	soil covered, 2 cm
17	1059	62	90	tt	0,60	
18	1115	282	54	oo	2,40	soil covered, 3 cm
19	1137	338	85	pt	0,70	
20	1301	55	85	ot	3,80	soil covered, 3 cm
21	1314	118	73	oo	2,10	soil covered, 1 cm
22	1345	77	88	oo	1,20	
23	1400	123	32	ot	3,10	
24	1410	111	90	oo	1,40	
25	1456	110	89	ot	1,00	
26	1516	293	88	oo	1,50	soil covered, 2,5 cm

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
27	1559	332	81	ot	0,80	
28	1565	335	57	ot	0,30	
29	1572	269	60	tt	1,80	
30	1573	315	78	ot	1,90	
31	1578	321	80	oo	1,90	
32	1590	316	85	oo	1,70	
33	1600	295	85	ot	1,90	
34	1606	124	89	pt	1,10	
35	1649	233	81	ot	0,60	

A2

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
-	no other rock detected

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000585	A2	1546834	6366414	30	9,29	40 + shear zone

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	0,20	304	67	oo	1,55	soil covered, 2 cm
2	0,76	128	85	oo	1,50	soil covered, 1 cm
3	0,91	147	88	ot	1,55	
4	1,15	240	87	tt	1,45	
5	1,31	359	8	pt	1,00	
6	2,11	135	90	op	1,20	
7	2,52	134	88	op	1,20	
8	2,60	314	83	oo	1,20	
9	2,62	136	86	oo	1,20	
10	2,90	309	75	pp	0,30	
11	2,94	310	73	pt	0,50	
12	3,32	146	75	pp	0,80	
13	3,45	184	90	to	1,50	
14	3,55	161	80	ot	1,00	
15	3,70	149	83	op	0,90	
16	3,85	40	86	oo	1,50	
17	3,85-3,92	198	75	oo		sinistral, ductile shear zone, 3 cm wide
18	4,15	136	80	ot	1,10	
19	4,27	150	85	oo	0,75	
20	5,06	133	84	op	1,20	
21	5,20	139	84	ot	1,40	
22	5,39	148	90	pt	1,10	
23	5,57	143	70	op	1,30	
24	6,10	269	54	op	0,40	
25	6,23	55	90	tt	0,25	
26	6,30	130	79	op	1,25	
27	6,70	296	85	oo	0,50	
28	6,87	109	87	ot	0,70	
29	6,89	140	88	ot	0,55	
30	7,49	17	30	pt	0,70	
31	7,89	121	88	oo	1,30	
32	7,90	15	84	op	1,90	
33	8,15	43	88	tt	0,30	

Appendix B
Scanline Tables

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
34	8,29	137	85	ot	0,70	
35	8,40	7	72	tt	1,50	
36	8,45	295	83	oo	1,20	soil covered, 1 cm
37	8,71	337	66	pt	0,60	
38	8,85	113	90	tt	0,20	
39	9,13	295	84	ot	0,50	
40	9,21	294	85	oo	0,45	
41	9,29	130	86	pp	0,75	

A3

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
646-655	pegmatite

Line id:	Outcrop id	Start co-ordinates: Easting	Start co-ordinates: Northing	Line azimuth (degrees)	Line length (m)	Number of fractures
LSM000586	A3	1546812	6366372	325	9,01	25

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	0,43	357	86	pt	0,85	
2	0,74	235	81	tt	1,05	
3	1,09	67	77	op	1,30	parallel to 3 mm wide pegmatite
4	2,64	115	42	ot	0,55	
5	3,35	215	86	ot	0,30	
6	3,60	352	80	oo	4,50	soil covered, 1 cm
7	3,97	74	44	op	0,60	
8	4,33	35	79	pt	0,85	
9	5,03	230	88	op	1,30	
10	5,32	232	80	pt	0,70	
11	5,66	224	89	op	1,90	
12	6,46	60	44	oo	0,90	
13	6,48	60	44	oo	0,90	
14	6,55	60	44	oo	5,00	
15	6,67	187	16	op	1,70	
16	7,40	81	90	tt	0,60	undulating
17	7,45	224	25	pt	0,40	
18	7,56	240	87	op	0,85	
19	8,11	230	77	op	0,30	
20	8,33	73	50	op	0,45	
21	8,60	46	43	op	0,70	
22	8,70	298	61	op	0,55	undulating
23	8,75	296	60	op	1,30	undulating
24	8,85	59	82	op	1,30	
25	9,01	292	44	pp	0,35	

A4

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
-	no other rock detected

Line id:	Outcrop id	Start co-ordinates: Easting	Northing	Line azimuth (degrees)	Line length (m)	Number of fractures
LSM000587	A4	1546776	6366266	320	5,84	35 + shear zone

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	0,02	59	85	pp	0,25	
2	0,10	73	90	op	0,25	
3	0,12	72	85	op	0,90	
4	0,42	258	80	pp	0,50	
5	0,60	104	49	ot	1,30	
6	0,78	63	85	pp	0,25	
7	0,82	8	89	pp	0,95	
8	1,50	263	48	oo	3,00	
9	1,51	48	38	pt	0,40	
10	1,59	43	69	pt	0,70	
11	1,94	36	81	tt	0,70	
12	2,17	56	69	oo	2,40	2 mm wide
13	2,16-2,18	49	82	oo	2,40	brittle-ductile shear zone, w/a.o. oxidation & epidotization. FeOH.
14	2,80	23	71	pp	1,60	
15	3,20	52	76	oo	3,00	soil covered, 2 cm
16	3,43	5	45	tt	0,65	undulating
17	3,52	37	30	pt	1,80	
18	3,55	16	20	pp	0,30	
19	3,75	54	67	pp	0,65	
20	3,84	214	88	pt	0,30	
21	4,04	19	43	oo	2,30	
22	4,12	22	25	pp	0,40	undulating
23	4,27	56	86	pp	0,45	
24	4,28	54	88	oo	2,90	
25	4,35	231	83	pt	1,10	
26	4,45	24	89	pp	0,65	
27	4,51	353	72	pt	0,50	undulating
28	4,70	9	48	tt	0,50	undulating
29	4,77	32	90	pp	0,75	
30	4,87	60	90	pt	1,10	

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
31	4,95	247	88	pp	0,45	
32	4,95	345	70	tt	0,55	
33	5,17	26	89	op	2,25	
34	5,37	232	88	pp	0,60	
35	5,61	100	20	op	1,45	undulating
36	5,84	194	87	op	0,95	

A5

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
-	no other rock detected

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000588	A5	1546726	6366096	120	5,16	31 + two deformation zones

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	97	1	89	oo	2,60	
2	155	28	81	po	2,50	
3	185	193	65	tt	0,80	
4	202	310	88	pt	0,40	
5	204	211	76	oo	1,00	
6	206	230	86	pt	0,45	
7	210	230	81	pt	0,40	
8	211-237	209	82	oo	1,00	brittle-ductile shear zone
9	238	181	86	pt	0,55	
10	242	179	85	pt	0,25	
11	243	29	87	pt	0,30	
12	251	172	70	pt	0,50	
13	264	212	86	pt	0,70	
14	276	45	83	oo	1,10	
15	313	212	80	oo	1,10	fracture zone, 2 cm
16	317	226	84	pt	0,45	
17	321	187	71	pt	0,25	
18	321,5	58	65	po	0,75	
19	329	61	76	tt	0,50	
20	333	220	89	tt	1,15	
21	340	235	89	po	1,10	
22	350	1	87	tt	0,35	
23	351	63	81	to	1,70	
24	356	216	78	oo	2,20	
25	378	223	75	pt	1,30	
26	414	60	90	po	2,10	
27	449	49	88	po	2,00	
28	452	39	85	pp	0,55	
29	461	219	90	pt	1,05	
30	499	38	87	to	2,05	
31	516	212	89	to	1,70	

A6

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
355-356	pegmatite
546-547	pegmatite
564-566	fine-grained granite

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000589	A6	1546712	6366114	5	9,40	17 + shear zone

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	38	273	86	oo	2,70	
2	318	282	80	oo	2,20	
3	330	275	75	oo	2,30	undulating
4	383	268	75	oo	2,80	undulating
5	494	67	72	po	1,55	
6	534	303	58	pt	1,90	
7	563	308	67	tt	1,10	
8	590	94	39	oo	2,30	
9	590-650	89	90	oo	2,30	brittle-ductile shear zone
10	627	357	82	pt	0,55	
11	638	69	78	tt	1,10	
12	664	244	57	pt	1,25	
13	670	255	77	tt	0,30	
14	694	257	81	tt	0,45	
15	756	241	22	Po	0,80	
16	827	101	50	pp	0,45	
17	877	122	54	tt	1,40	
18	940	115	83	pt	0,65	

A7

Lenght along line (cm)	Rock type Host rock: quartz monzodiorite
351-975	fine-grained granite
1184-1185.5	pegmatite

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000590	A7	1549073	6365516	315	11,85	62 + four deformation zones

Line mapping - fractures (>0,2 m), Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (cm)	Comment
1	10	327	70	to		
2	21	203	68	oo		
3	30	323	61	tt		
4	45	198	76	pt		
5	74	190	77	tt		
6	78	181	79	to		
7	95	166	86	pt		
8	102	9	90	pt		
9	102,5	234	88	po		
10	124	185	79	to		in the centre of a 2 cm wide, faintly developed brittle-ductile shear zone
11	125	160	77	pt		
12	128	153	85	po		
13	166	206	86	to		
14	166-222					soil covered
15	222	333	66	to	90	
16	235	13	79	to	30	
17	238-246					soil covered
18	260	6	80	to	35	
19	269	43	84	pp	120	
20	274	57	70	to	40	
21	283-298	213	80	oo	200	brittle-ductile shear zone
22	298-351					soil covered
23	351-415	50				fracture zone
24	414	165	87	pp		
25	427	329	68	pt		
26	446	332	69	po		
27	450	332	69	pp		
28	482	157	82	pp		
29	498	231	84	po		
30	536	319	71	pp		
31	580-696	43				fracture zone
32	704	45	80	pp		

Appendix B
Scanline Tables

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (cm)	Comment
33	705	226	17	to		
34	725	290	83	tt		
35	741	286	81	pt		
36	753	360	62	po		
37	758	192	66	pp		
38	761	284	83	pp		
39	770	23	46	to		
40	790	15	48	po		
41	800-860	40				fracture zone
42	860	19	74	po	50	
43	865	19	73	pp	55	
44	869	22	82	pt	45	
45	870	281	79	tt	40	
46	876	19	80	pt	20	
47	882	14	80	po	25	
48	884	275	84	to	35	
49	884-898					soil covered
50	898	17	82	to	35	
51	898	280	86	tt	20	
52	899	208	65	pt	65	
53	904	208	58	to	55	
54	909	204	59	to	60	
55	919	200	65	po	65	
56	922	201	78	pp	50	
57	924	200	62	pt	40	
58	930	63	76	pp	25	
59	939	198	89	pp	70	
60	940	83	66	po	85	
61	957	60	69	pt	55	
62	960	258	83	tt	35	
63	984	232	85	po	115	
64	991	42	86	pt	45	
65	1009	235	74	po	160	
66	1043	204	57	pp	85	
67	1060	155	89	to	350	epidote, in the centre of a 1-2 cm wide brittle-ductile shear zone
68	1084	211	72	pt	80	
69	1105	186	68	to	380	
70	1182	73	83	po	40	

A9

Lenght along line (cm)	Rock type Host rock: Ävrö granite
-	no other rock detected

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000583	A9	1548509	6366449		1,55	

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	11	125	40	oo		
2	71	117	37	oo		

A12 Northern profile (LSM000581)

Lenght along line (cm)	Rock type Host rock: Ävrö granite
-	no other rock detected

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000581	A12	1548830	6367370		3	

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
	0,50	136	31	pt		
	0,94	173	89	to		
	1,13	14	81	tt		
	1,15	123	78	tt		
	1,80	112	80	tt		
	1,86	109	80	pp		
	2,30	359	89	oo		

A12 Southern profile (LSM000582)

Lenght along line (cm)	Rock type Host rock: Ävrö granite
-	no other rock detected

Line id:	Outcrop id	Start co-ordinates:		Line azimuth (degrees)	Line length (m)	Number of fractures
		Easting	Northing			
LSM000582	A12	1548829,3	6367356,5		4,1	32

Line mapping - fractures (>0.2 m). Length is along line starting in south or west

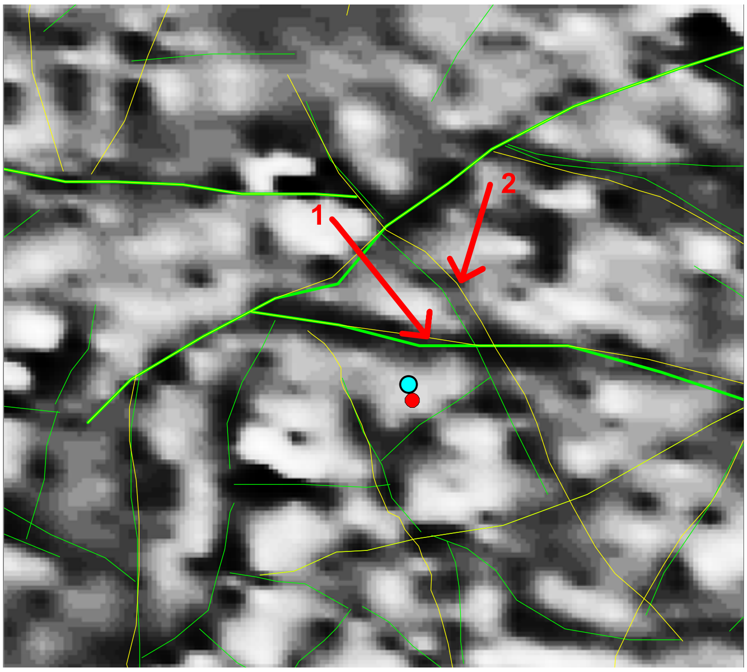
Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
1	8	197	85	pp		
2	10	53	85	po		
3	16	139	78	pp		En échelon
4	97	186	90	to		
5	115	126	66	tt		
6	126	160	44	tt		1 cm wide cataclastic rock
7	130	169	41	tt		
8	141	20	18	to		
9	175	178	86	oo		Soil covered, 3 cm wide
10	185	125	90	tt		Gouge, 3 mm wide
11	188	209	85	tt		Gouge, 1 mm wide
12	194	164	88	tt		Gouge+epidote, 2 mm wide
13	196	188	76	tt		Gouge, 3-5 mm wide
14	204	187	82	pp		
15	211	188	81	pt		
16	220	107	73	tt		En échelon
17	226	165	76	pp		
18	234	179	86	pt		
19	239	174	86	pp		
20	255	169	78	pp		
21	265	186	82	pt		
22	290	181	79	pp		
23	300	204	73	pt		
24	320	166	90	pt		
25	340	31	87	oo		Contact to pegmatite
26	341	23	90	tt		
27	344	329	58	pt		
28	348	338	73	to		
29	360	232	76	tt		

Fracture no:	Length along line (cm)	Strike (degrees)	Dip (degrees)	Fracture endings*	Fracture length (m)	Comment
30	364	234	73	to		
31	380	230	82	pt		
32	397	30	80	oo		Contact to metabasite

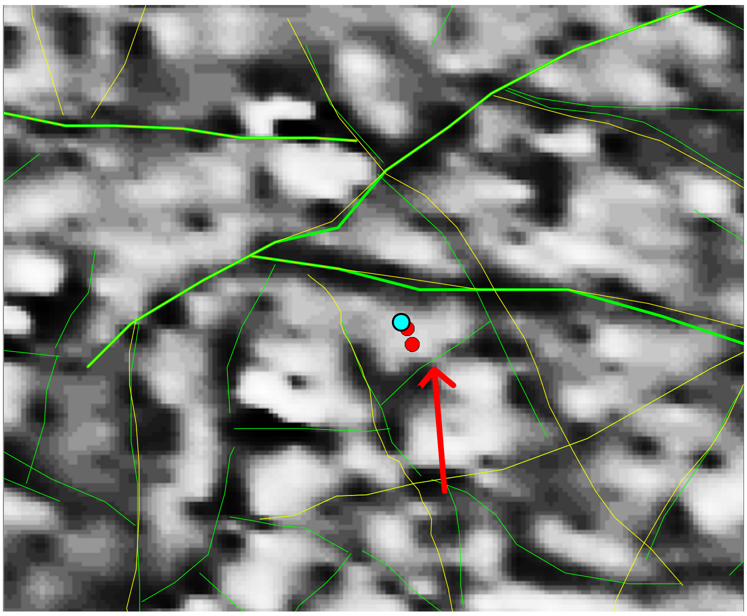
Appendix C

Geophysical Indications

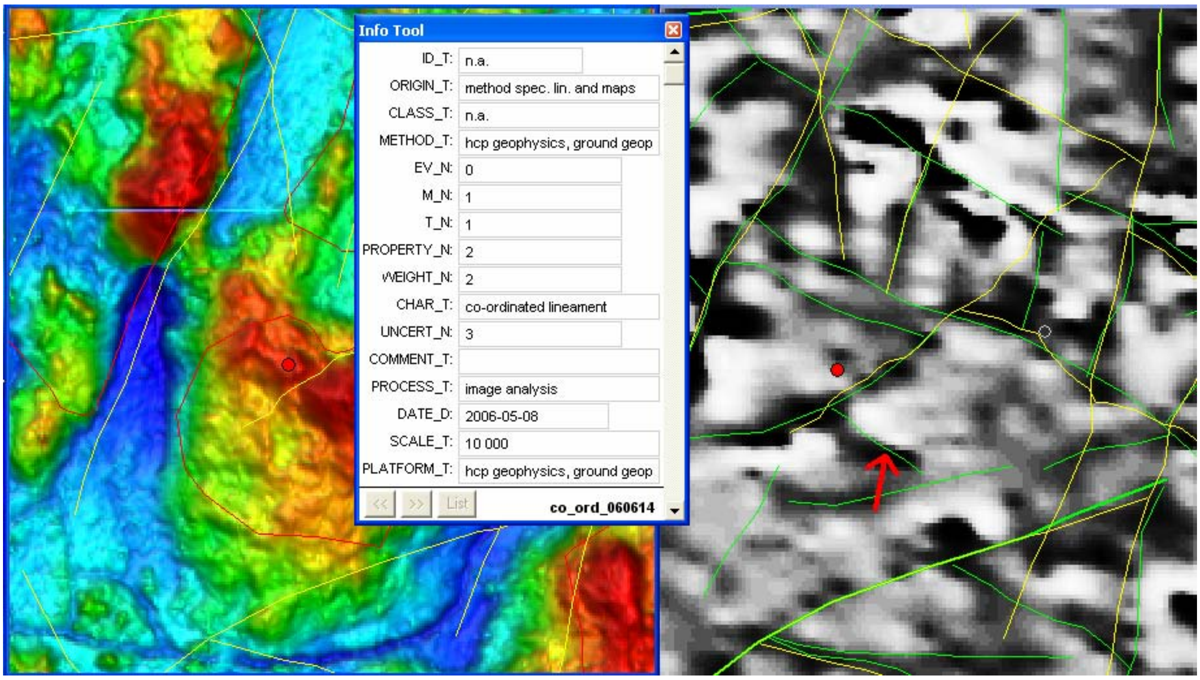
Carl-Axel Triumf, Geovista AB



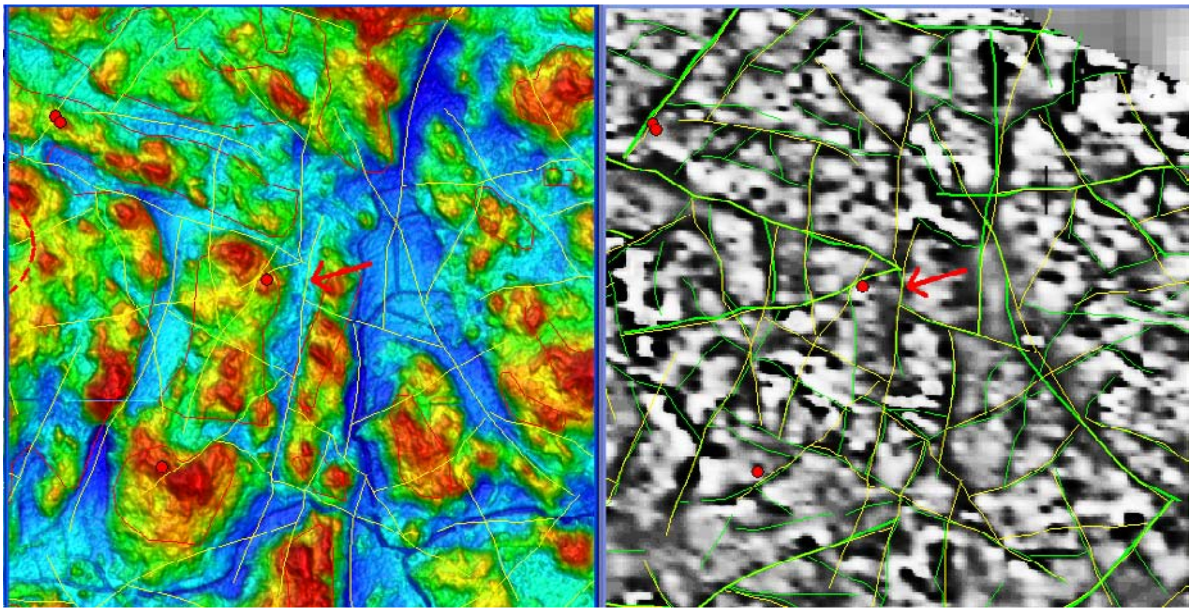
Lineament XSM000001 (and XSM000002), borehole KLX23A (marked with blue dot, drilled towards the northeast). *The red arrows point at the two lineaments which borehole KLX23A was aimed at. Lineament 1(XSM000001) is detected in the ground model as well as the magnetic total field and has a medium weight (weight = 3). Lineament 2 (XSM000002) is weakly detected in the ground model, magnetic data as well as resistivity data and has a medium weight (weight = 3). Greyscale magnetic figure (black=low and white=high). Green lines are interpreted magnetic lineaments, yellow lines are coordinated lineaments >100 m long.*



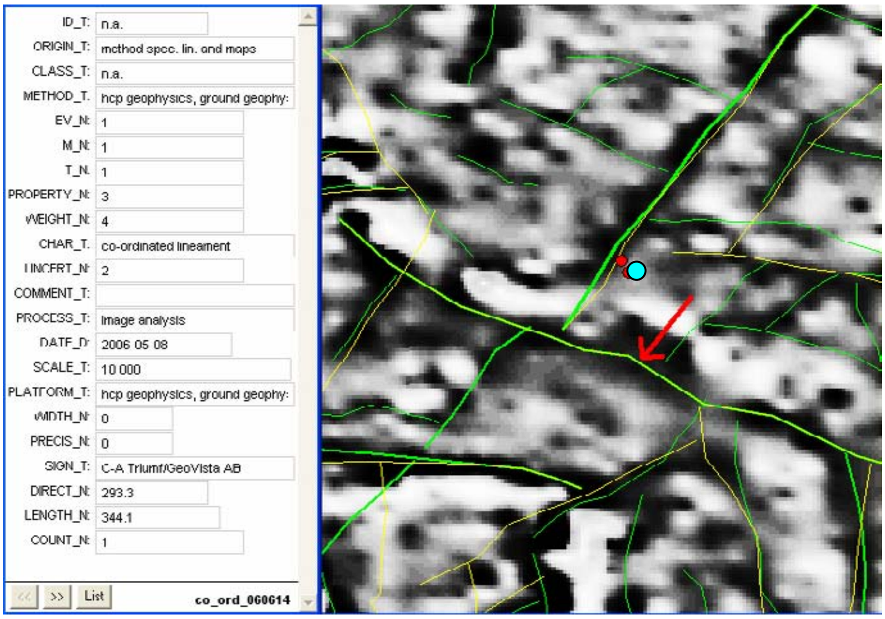
Lineament XSM000003, borehole KLX23B (red dot, drilled towards the southeast). *The red arrow points at the magnetically indicated short and uncertain lineament (XSM000003, lowest weight) that borehole KLX23B is meant to cross.*



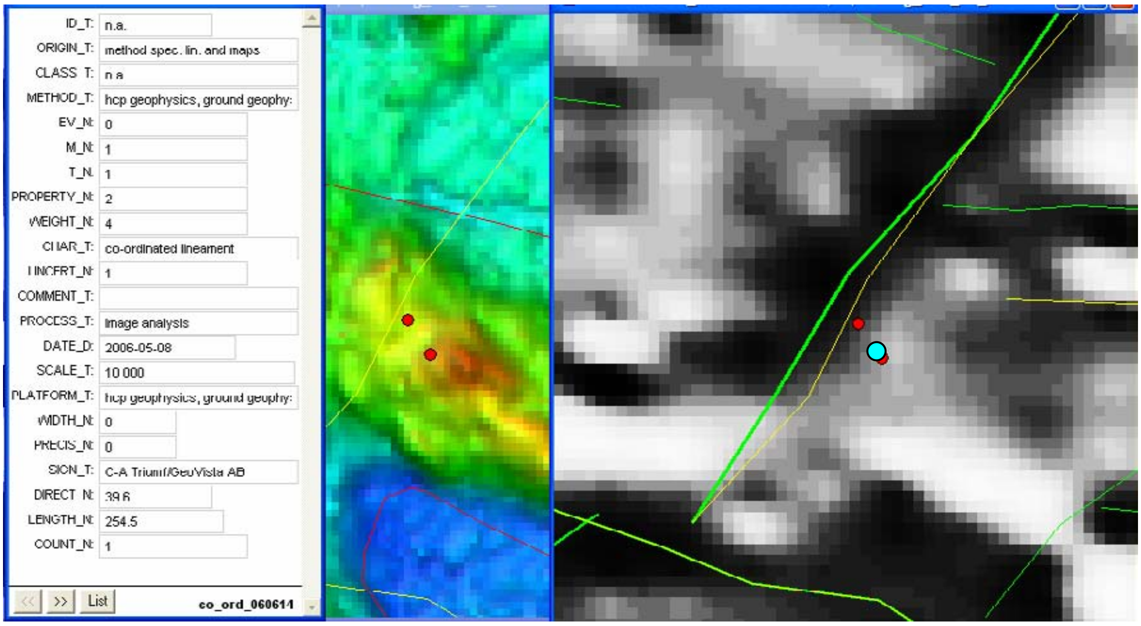
***Lineament XSM000004, borehole KLX25A (drilled towards the southeast).** The red arrow points at a WNW-ESE-striking structure which could be the reason for the low magnetic zone between c. 30-37 m in the borehole. The probable reason for the lineament that the borehole was meant to cross occurs in the low magnetic section which starts at c. 18 m in the borehole. Figure to the right is a coloured topographic model (blue low, red high) and the figure to the right is a greyscale magnetic figure.*



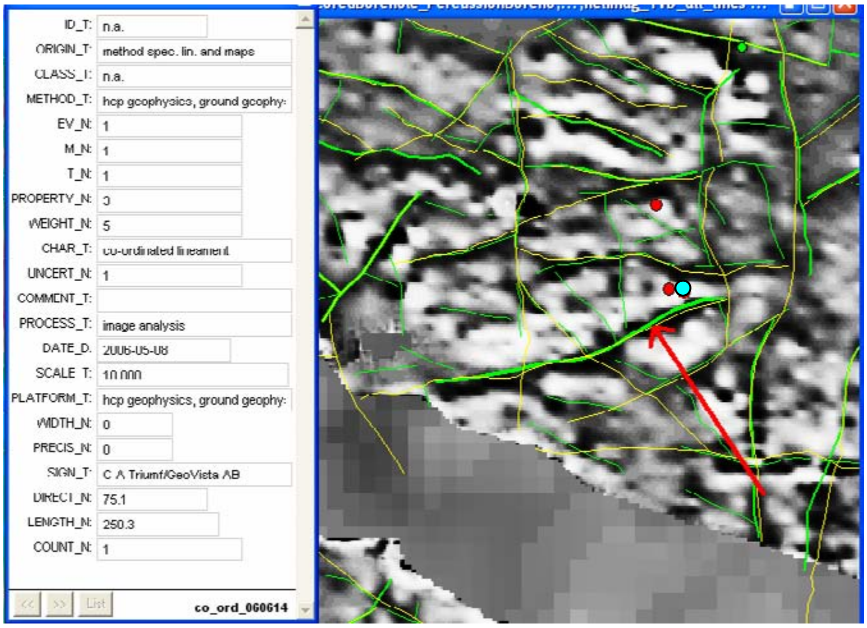
***Lineament XSM000007, borehole KLX24A (drilled towards the east).** Red arrow points at the aimed for lineament, which is detected in magnetic data and in the terrain model. It has a weight=3 because it can not be detected in electric data and is magnetically somewhat unclear in its southern part. In the area where the borehole is meant to penetrate the lineament, it is more obvious and should have a higher weight (perhaps 4) at the point of intersection.*



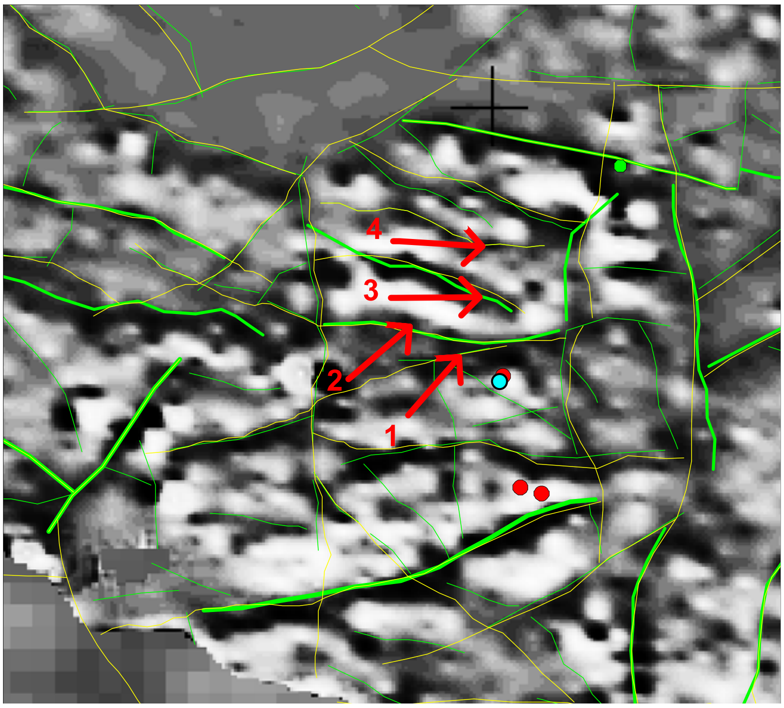
Lineament XSM000008, borehole KLX22A (marked with blue dot, drilled towards the south). *The red arrow points at the lineament which borehole KLX22A is aimed at. The arrow points at an area of generally low magnetic susceptibility which partly coincides with a lineament. In the borehole a typical low magnetic section occurs which could coincide with one or the other, or both. KLX22B is only a few meters to the north-west (red dot) and drilled towards NW.*



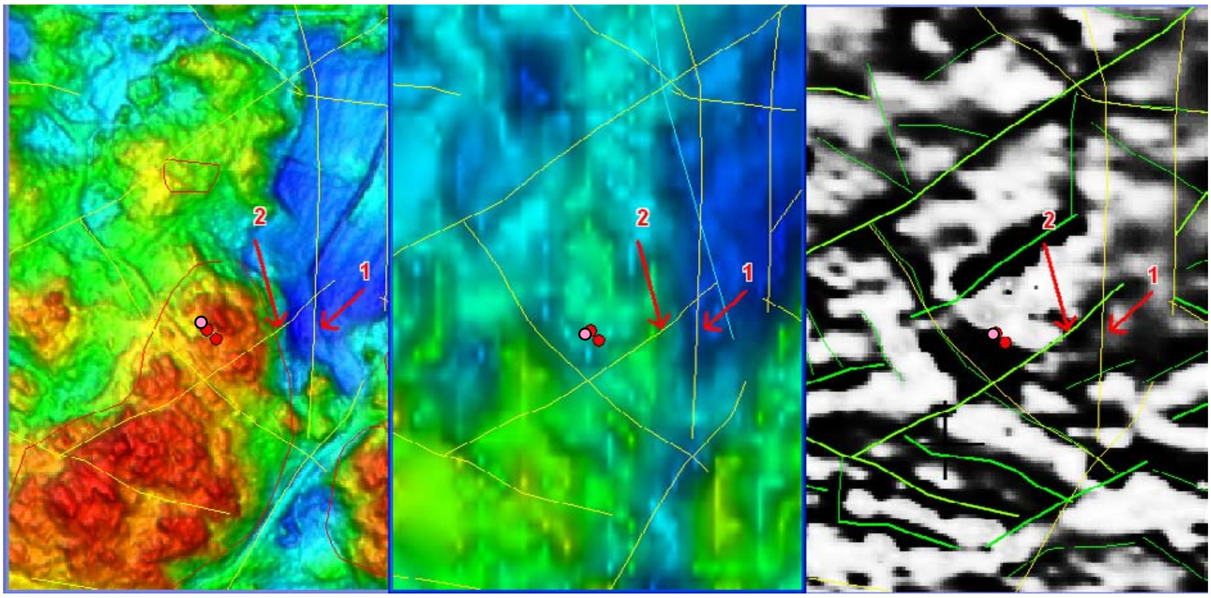
Lineament XSM000009, borehole KLX22B (red dot, drilled towardsNW. "*The coordinated lineament longer than 100 m" (yellow) is detected in magnetic data and terrain model and has high weight (weight=4). The table "Info Tool" lists the properties of the lineament. The borehole KLX22A is only a few meters to the south east (marked with blue dot) and drilled to the south.*



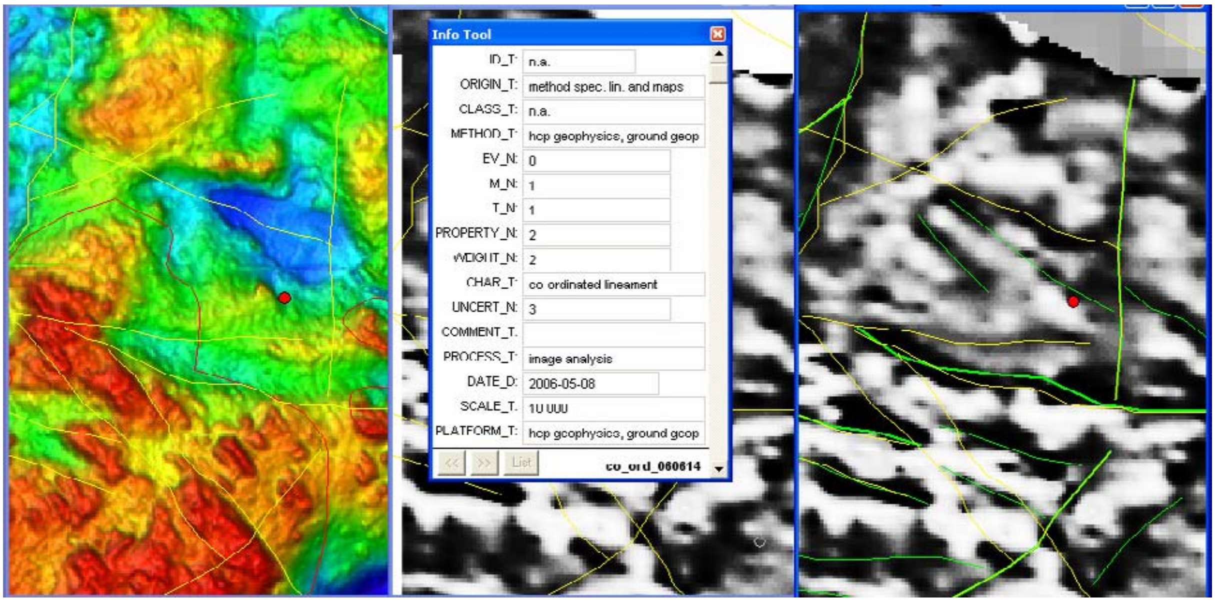
Lineament XSM000010, borehole KLX10B (marked with blue dot). *The borehole is drilled towards the south, red arrow points at the lineament which is cut by KLX10B. In the table "Info Tool" the properties of the lineament is listed. It has the highest weight (Weight=5) and is clear. The lineament is detected in topographic data as well as data over the magnetic total field and resistivity.*



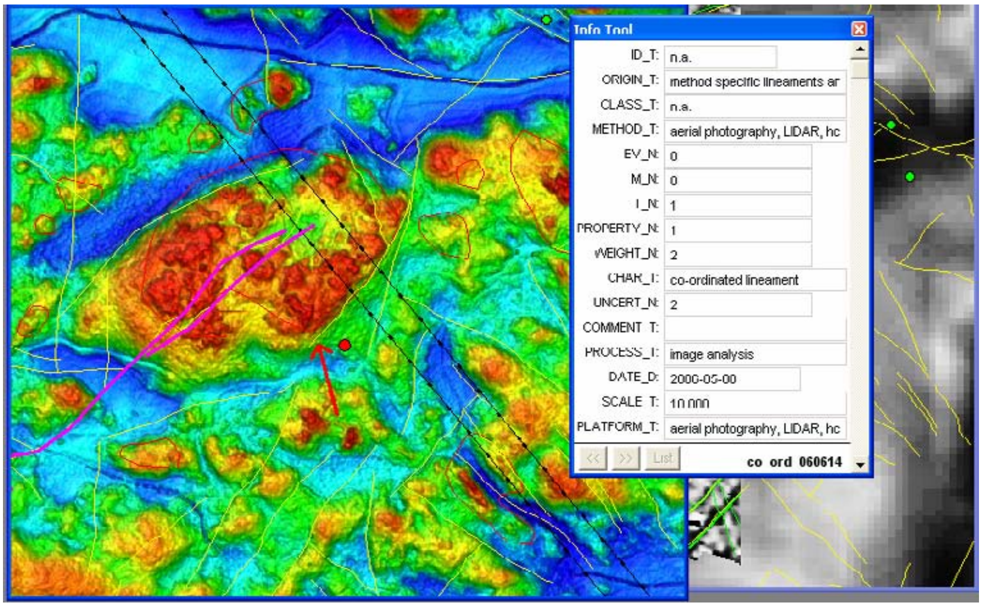
Lineament XSM000011, XSM000012, XSM000013 and XSM000014, borehole KLX10C (marked with blue dot, drilled towards the north). *The red arrows point at the four lineaments which can be cut by KLX10C supposing that the lineaments dip is vertical to sub vertical. The lineaments 1, 2 and 3 have high weight (4, 5 and 4 respectively), i.e. they are clear. Lineament 4 is uncertain and has the lowest weight class, Weight=1.*



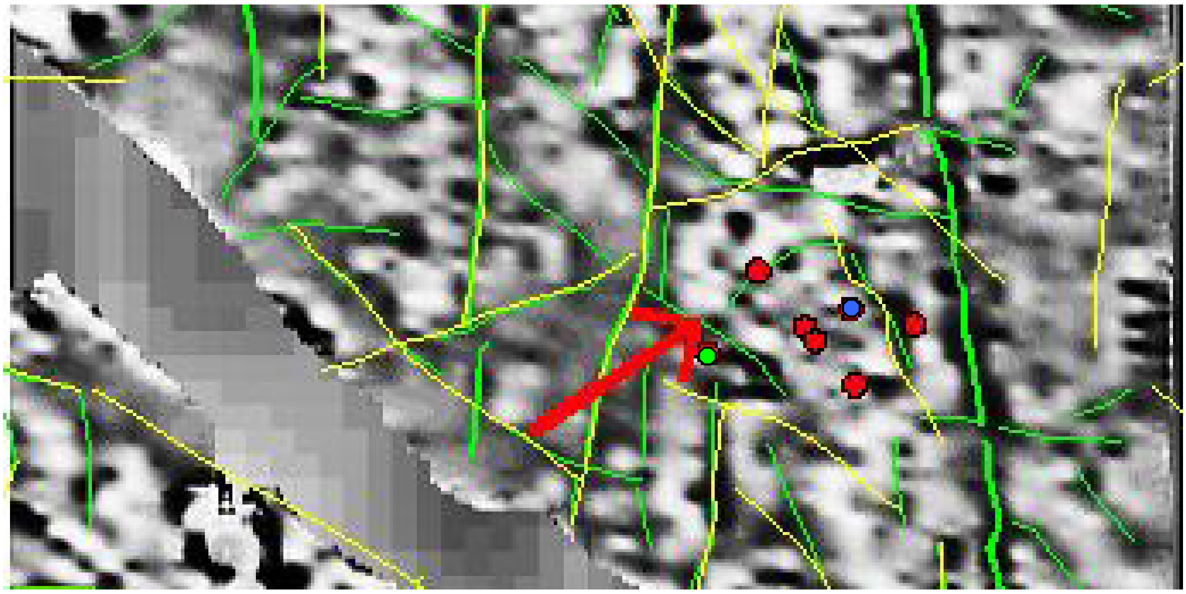
Lineament XSM000015 and XSM000016, borehole KLX26A (marked with pink dot, drilled towards the east) and KLX26B (red dot, drilled towards the southeast). *Borehole KLX26B only aims to cross the NE-SW striking lineament (no 2 in the figure, XSM000015). It should be a low magnetic source to the lineament. In the borehole the same fine-grained granite as in KLX26A occurs which should be the source. Within it a number of thin resistivity anomalies occur which indicates that it is somewhat fractured. Borehole KLX26A aims at two lineaments, the one closest to the borehole strikes NE-SW (no 2 in the figure, XSM000015), the other strikes N-S (marked 1 in the figure, XSM000016). Figure to the left DEM from LIDAR, in the middle resistivity inversion and to the right magnetic gradient. No 2 is detectable in DEM and magnetic, no 1 only in resistivity, although it is possible to see a weak indication of no 2 in the resistivity when the figure is studied closely.*



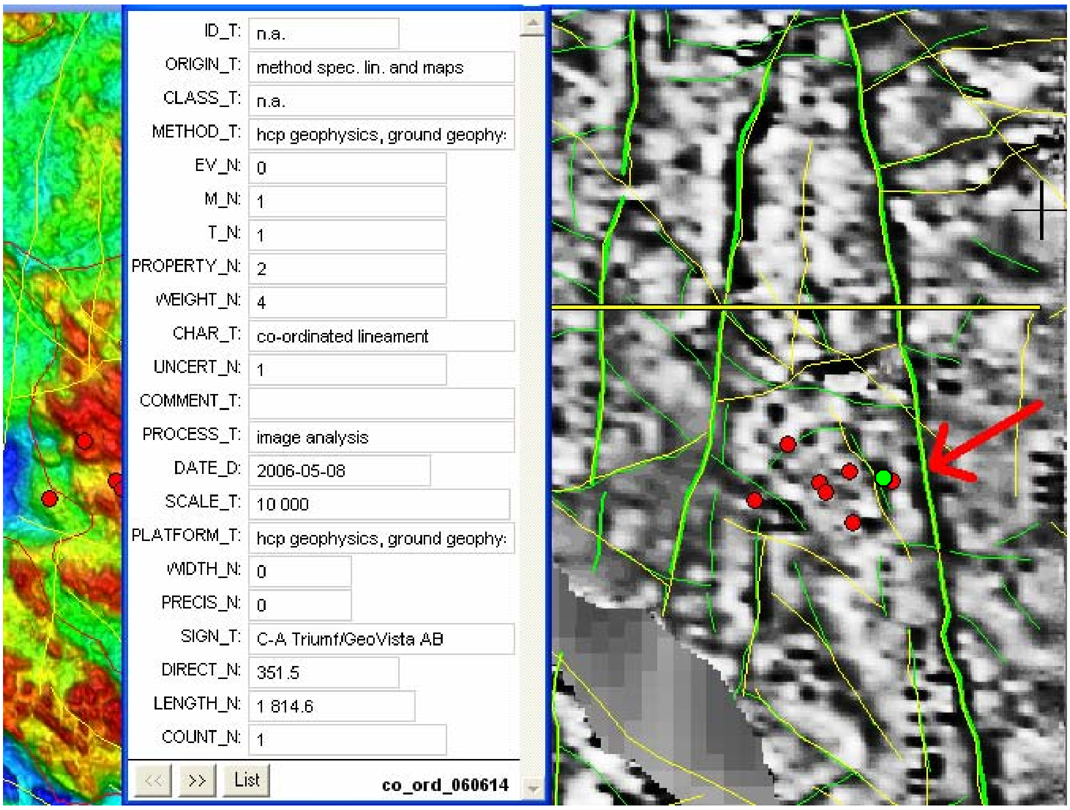
Lineament XSM000017, borehole KLX28A (red dot, drilled towards the south). *Borehole KLX28A mainly aims at a low magnetic lineament which is also weakly indicated in DEM. Its weight is relatively low, only 2, because the lineament is unclear.*



Lineament XSM000018, borehole KLX29A (red dot, drilled towards the north-west). *The red arrow points at the lineament which is indicated in DEM (surface covering magnetic measurements on the ground are not available). In the position for the lineament there occurs a low velocity zone in the refraction seismic profile which runs over the lineament.*



Lineament XSM000019, borehole KLX09D (marked with blue dot, drilled towards the west) and KLX09F (marked with green dot, drilled towards the east). *Red arrow marks a NW-striking short lineament shown on the ground magnetometry which could possibly by crossed over by the end of borehole KLX09D and the start of borehole KLX09F. In general no other lineaments longer than 100 m exists here that could be cut by these boreholes.*

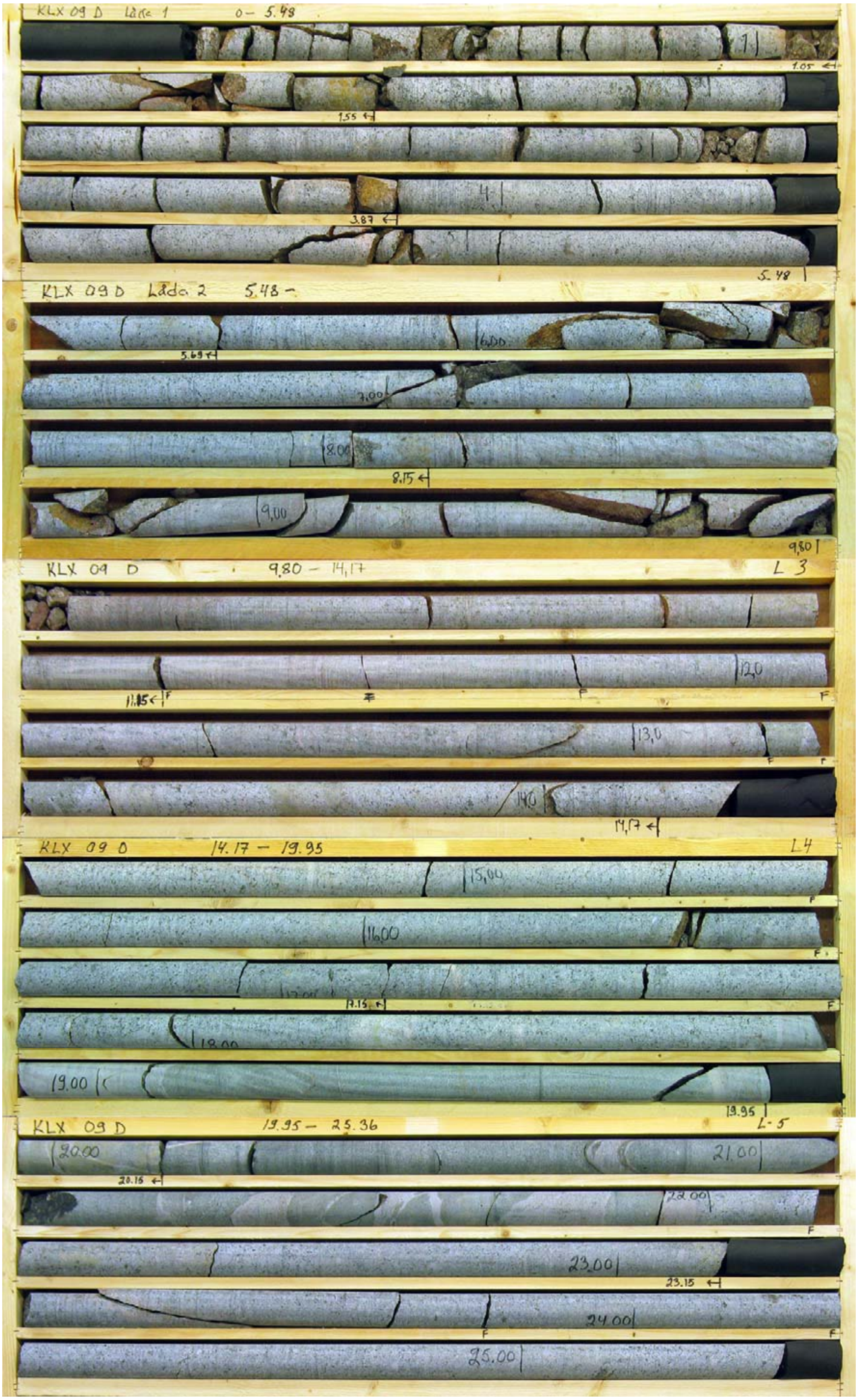


Lineament XSM000020, borehole KLX09G (marked with green dot). *It is drilled towards the east, the red arrow points at the lineament which most probably is cut by KLX09G. In the tabel the specifications of the lineament are listed.*

Appendix D

Core Photographs

Photo, Thomas Kisiel SKB

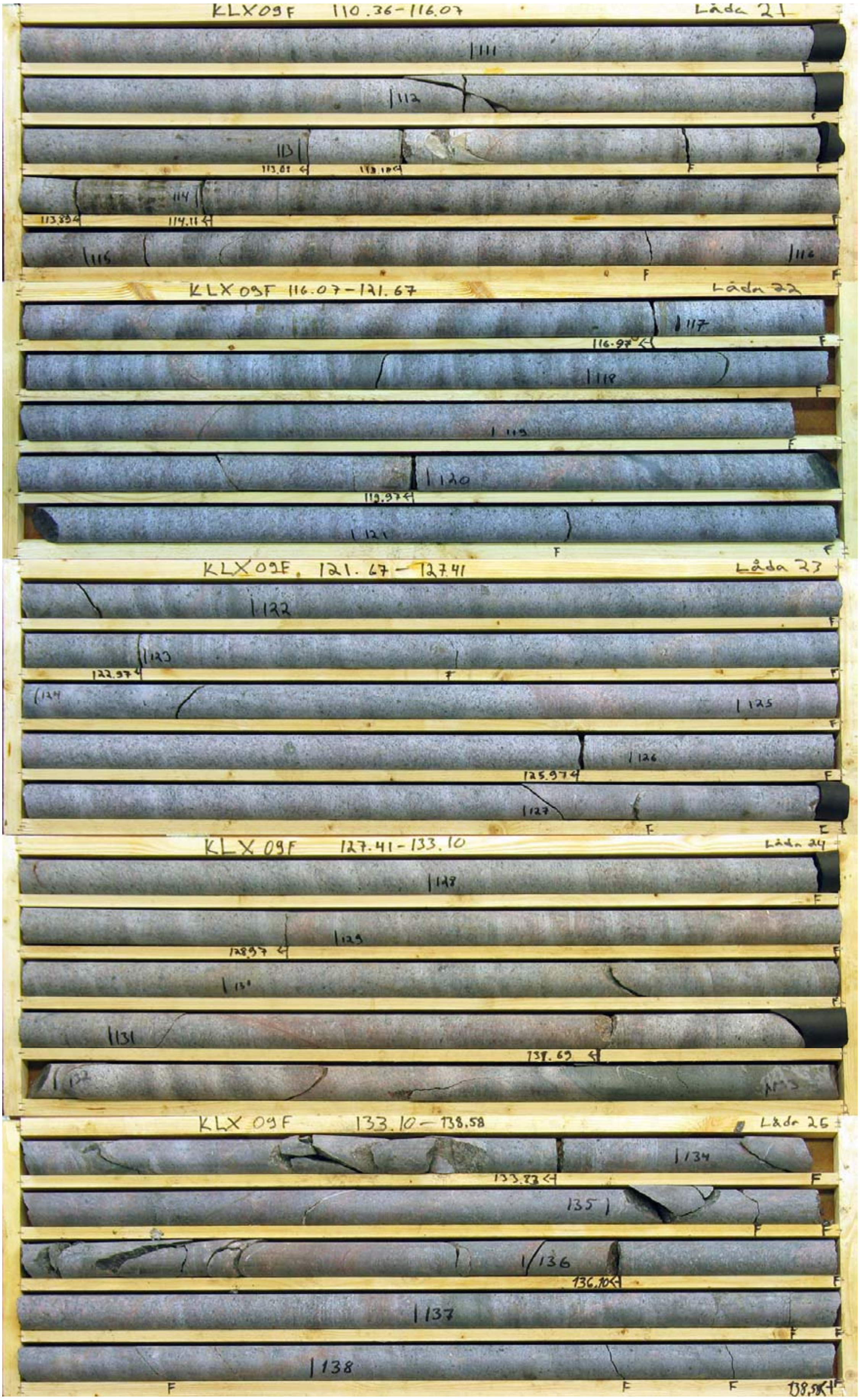

KLX 09 D Låda 1 0 – 5.48
1.05
1.55
3.87
5.48
KLX 09 D Låda 2 5.48 –
5.69
6,00
7,00
8,00
8,15
9,00
9,80
KLX 09 D 9,80 – 14,17
L 3
11,15
12,0
13,0
14,0
14,17
KLX 09 D 14.17 – 19.95
L4
15,00
16,00
17,15
18,00
19.00
19.95
KLX 09 D 19.95 – 25.36
L-5
20.00
20.15
21.00
22.00
23.00
23.15
24.00
25.00

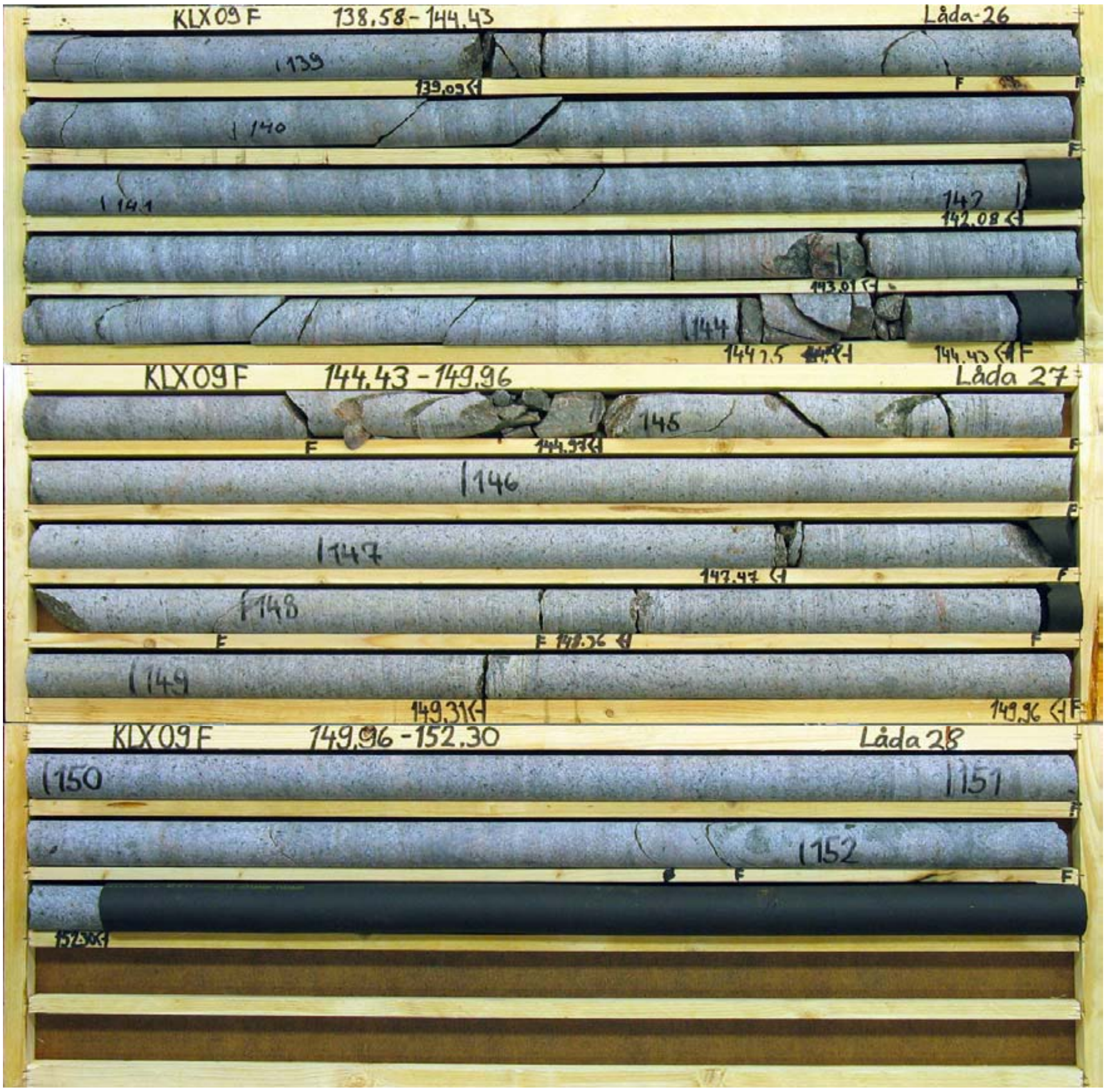

KLX 09 D 51.34 – 56.58 L-11
KLX-09 D 56.58 – 61.92 L-12
KLX 09 D 61.92 – 67.56 L-13
KLX 09 D 67.56 – 72.96 L-14
KLX 09 D 72.96 – 78.44 L-15

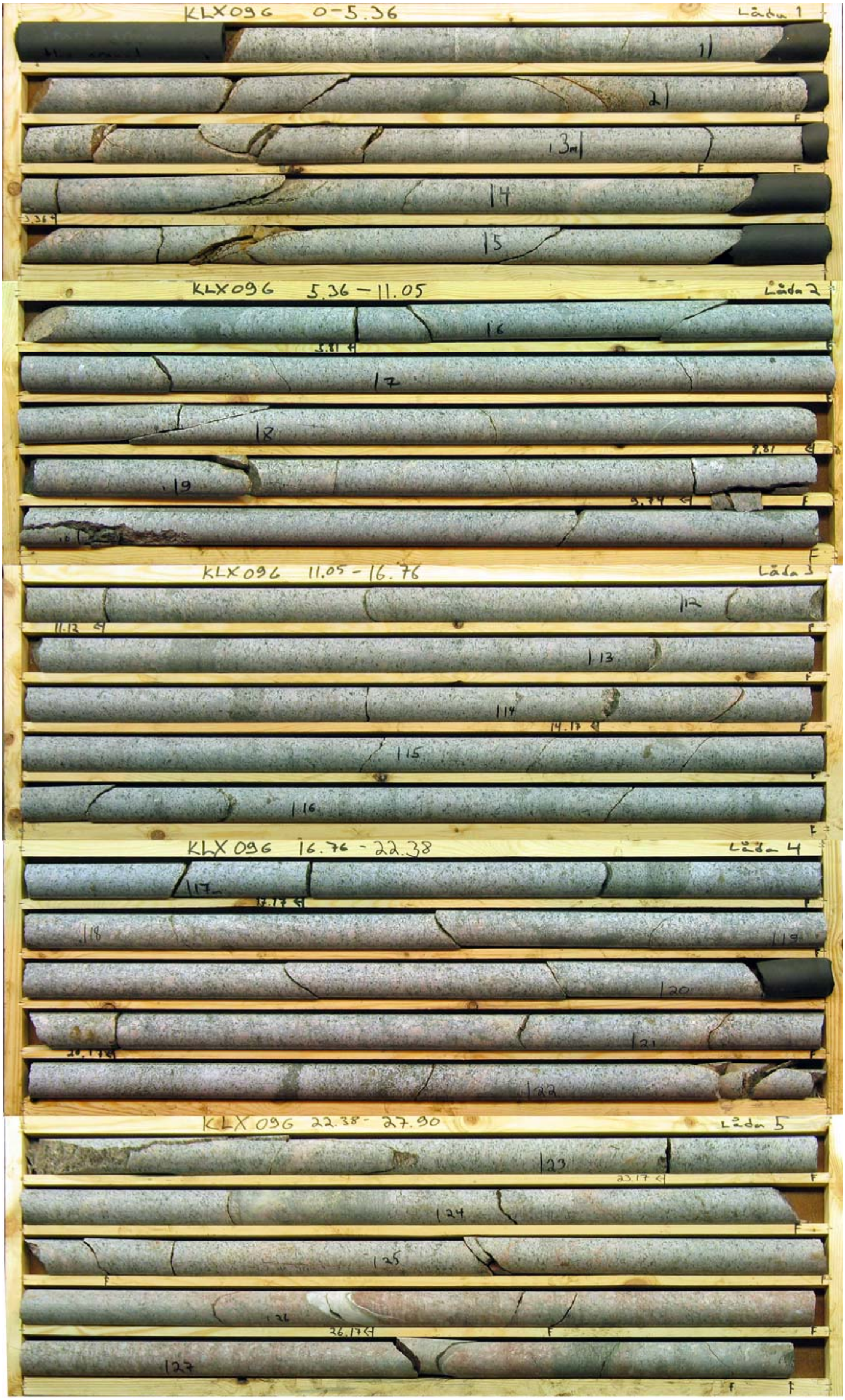

KLX09F 27.38 – 32.56
Låda 6
KLX09F 32.56 – 37.98
Låda 7
KLX09F 37.98 – 43.62
Låda 8
KLX09F 43.62 – 49.27
Låda 9
KLX09F 49.27 – 54.86
Låda 10


KLX09F 54.86 – 60.42
Låda 11
KLX09F 60.42 – 65.97
Låda 12
KLX09F 65.97 – 71.30
Låda 13
KLX09F 71.30 – 76.67
Låda 14
KLX09F 76.67 – 82.20
L 15


KLX 09F 82.20– 87.78
Låda 16
KLX09F 87.78 - 93.46
Låda 17
KLX 09 F 93.46 – 99.18
Låda 18
KLX09F 99.18 – 104.73
Låda 19
KLX09F 104.73 - 110.36
Låda 20


KLX09F 110.36-116.07
Låda 21
KLX09F 116.07-121.67
Låda 22
KLX09F 121.67-127.41
Låda 23
KLX09F 127.41-133.10
Låda 24
KLX09F 133.10-138.58
Låda 25

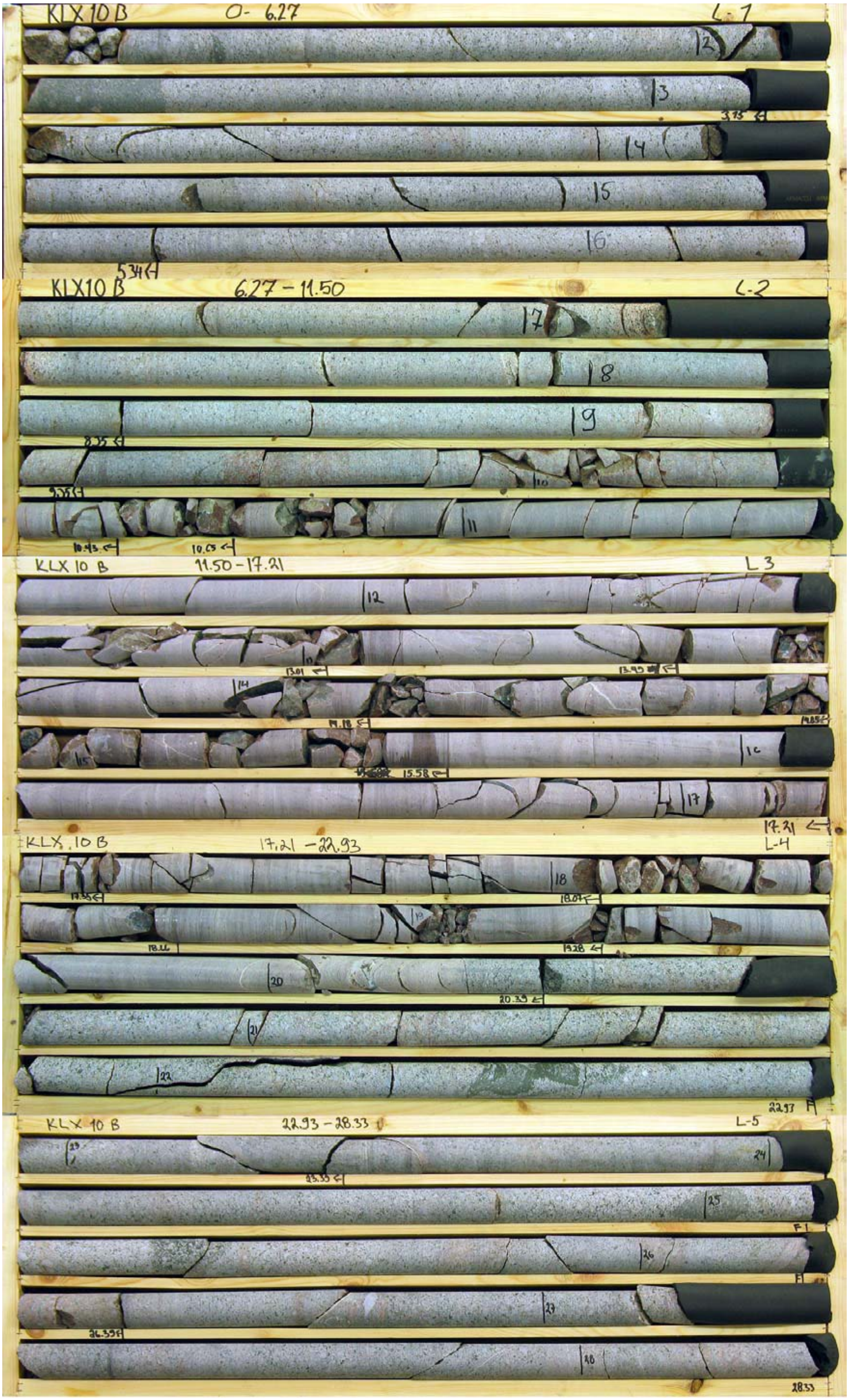

KLX09F
138,58-144,43
Låda-26
139,09
142,08
143,01
144,43
KLX09F
144,43-149,96
Låda 27
144,93
147,47
148,36
149,31
149,96
KLX09F
149,96-152,30
Låda 28

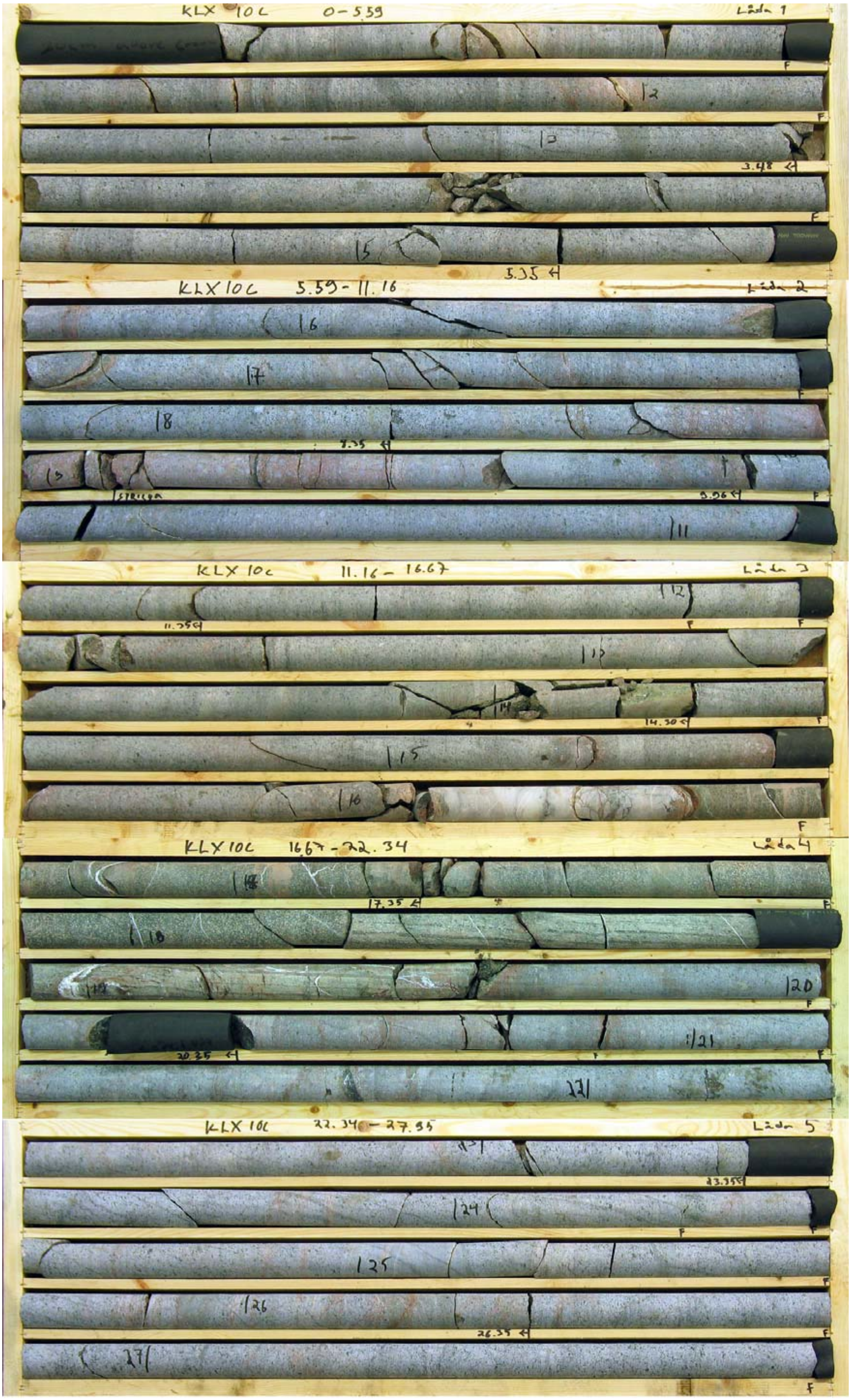

KLX09G 0–5.36
Låda 1
KLX09G 5.36 – 11.05
Låda 2
KLX09G 11.05 – 16.76
Låda 3
KLX09G 16.76 - 22.38
Låda 4
KLX09G 22.38 - 27.90
Låda 5


KLX09G 38.95 - 44.25
Låda-8
KLX09G 44.25-49.72
Låda-9
KLX09G 49.72- 54.46
L-10


KLX09G 54.46 - 59.65 Låda - 11
KLX09G 59.65 - 64.92 Låda - 12
KLX09G 64.92 - 70.23 Låda - 13
KLX09G 70.23 - 75.69 Låda - 14
KLX09G 75.69 - 81.19 L - 15


KLX09G
81.19 - 86.59
Låda - 16
KLX 09 G
86.59 - 92.17
KLX09G
92.17 - 97.75
Låda - 18
KLX09G
97.75
Låda - 19


KLX 10 B
0- 6.27
L-1
KLX 10 B
6.27 – 11.50
L-2
KLX 10 B
11.50 – 17.21
L 3
KLX 10 B
17.21 – 22.93
L-4
KLX 10 B
22.93 – 28.33
L-5




KLX10C 27.95 - 33.61
Låda 6
KLX 10C 33.61 - 39.17
Låda 7
KLX 10C 39.17 - 44.79
Låda 8
KLX 10C 44.79 - 50.46
Låda 9
KLX 10C 50.46 - 56.06
Låda 10


KLX10C 56.06 - 61.59
KLX10C 61.59 - 67.33
KLX10C 67.33 - 72.85
KLX 10C 72.85 - 78.30
KLX10C 78.30 - 83.93


KLX10C 139.22 – 144.82
KLX10C 144.82 – 146.25 m


KLX22A 0 – 5.43
L-1
KLX 22A 5.43 – 11.11
L-2
KLX 22A 11.11 – 16.61
L-3
KLX 22A 16.61 – 22.07
L-4
KLX 22A 22.07 – 27.64
L-5


KLX 22A 27.64 – 33.13
KLX 22A 33.13 – 38.63
KLX 22 A 38.63 – 44.00
KLX 22A 44.00 – 49.55
KLX 22 A 49.55 – 55.12


KLX 22A 55.12 – 60.73
L-11
KLX 22A 60.73 – 66.26
L-12
KLX 22A 66.26 – 71.67
L-13
KLX 22A 71.67 – 77.26
L-14
KLX 22A 77.26 – 82.61
L-15


KLX 22A 82.61- 88.20
L- 16
KLX 22A 88.20 - 93.56
L. 17
KLX 22A 93.56 - 99.08
L- 18
KLX 22A 99.08 - 100.45
L- 19


KLX22B 0-5.54
L-1
KLX 22 B 5.54-11.02
L-2
KLX 22B 11.02-16.67
L-3
KLX 22B 16.67-21.96
L-4
KLX 22B 21.96-27.17
L-5
CORE LOSS 25cm


KLX 22B 27.17 – 32.53
L-6
KLX 22 B 32.53 – 38.03
L-7
KLX 22B 38.03 - 43.68
L-8
KLX 22B 43.68 – 49.18
L-9
KLX22B 49.18 - 54.77
L-10


KLX22B 54.77– 60.20
L-11
KLX 22B 60.20 – 65.70
L-12
KLX22B 65.70– 71.22
KLX 22 B 71.22- 76.75
L-14
76.75 – 82.46
L-15

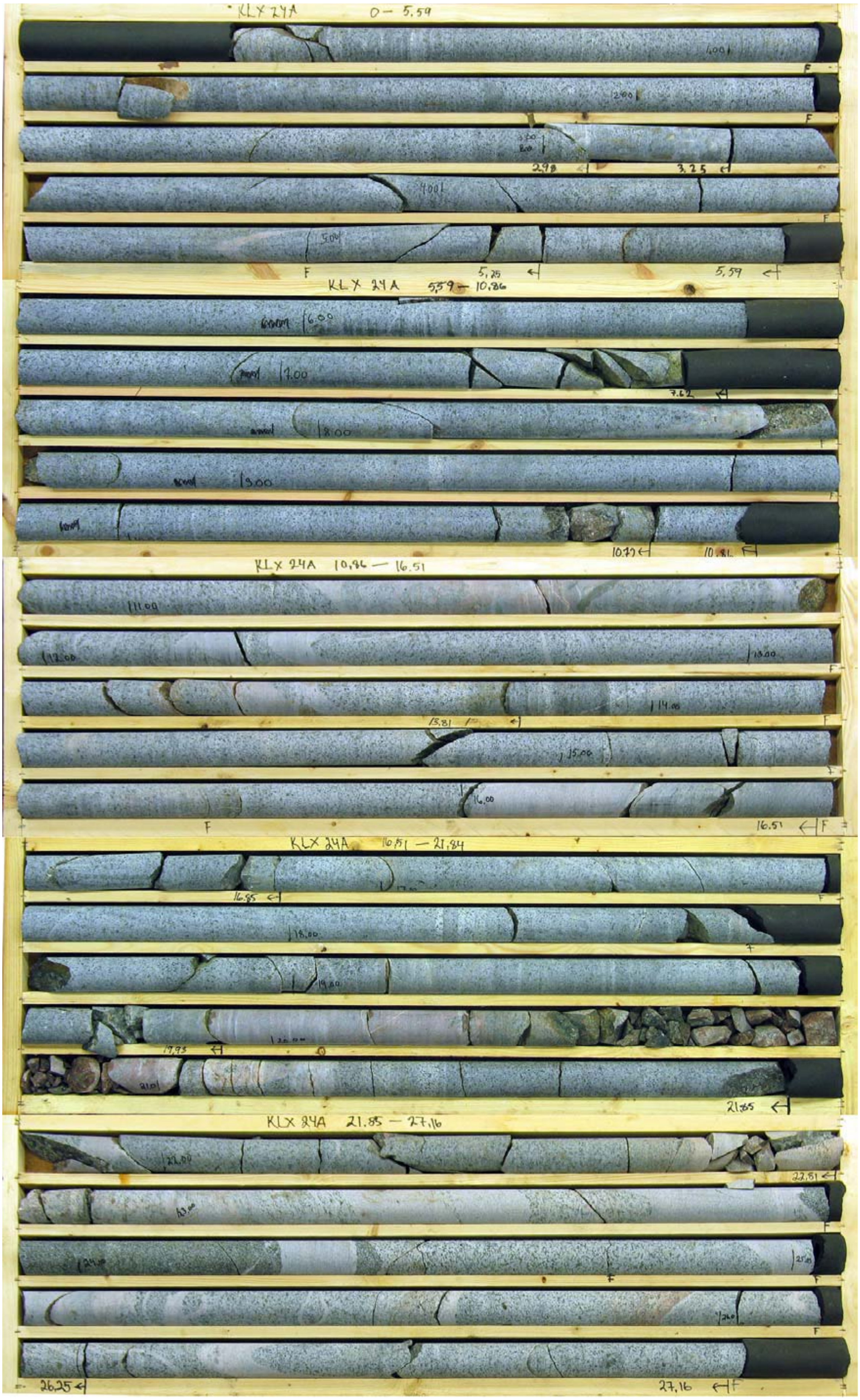

KLX 22B 82.46 – 88.08
L-16
KLX 22B 88.08 – 93.51
KLX 22B 93.51 – 99.06
L-18
KLX 22B 99.06 – 100.25
L-19


KLX 23A 0– 5.57
L-1
KLX 23A 5.57 - 11.08
L-2
KLX 23A 11.08– 16.76
L-3
KLX 23A 16.76 – 22.41
L-4
KLX 23A 22.41 – 28.10
L-5

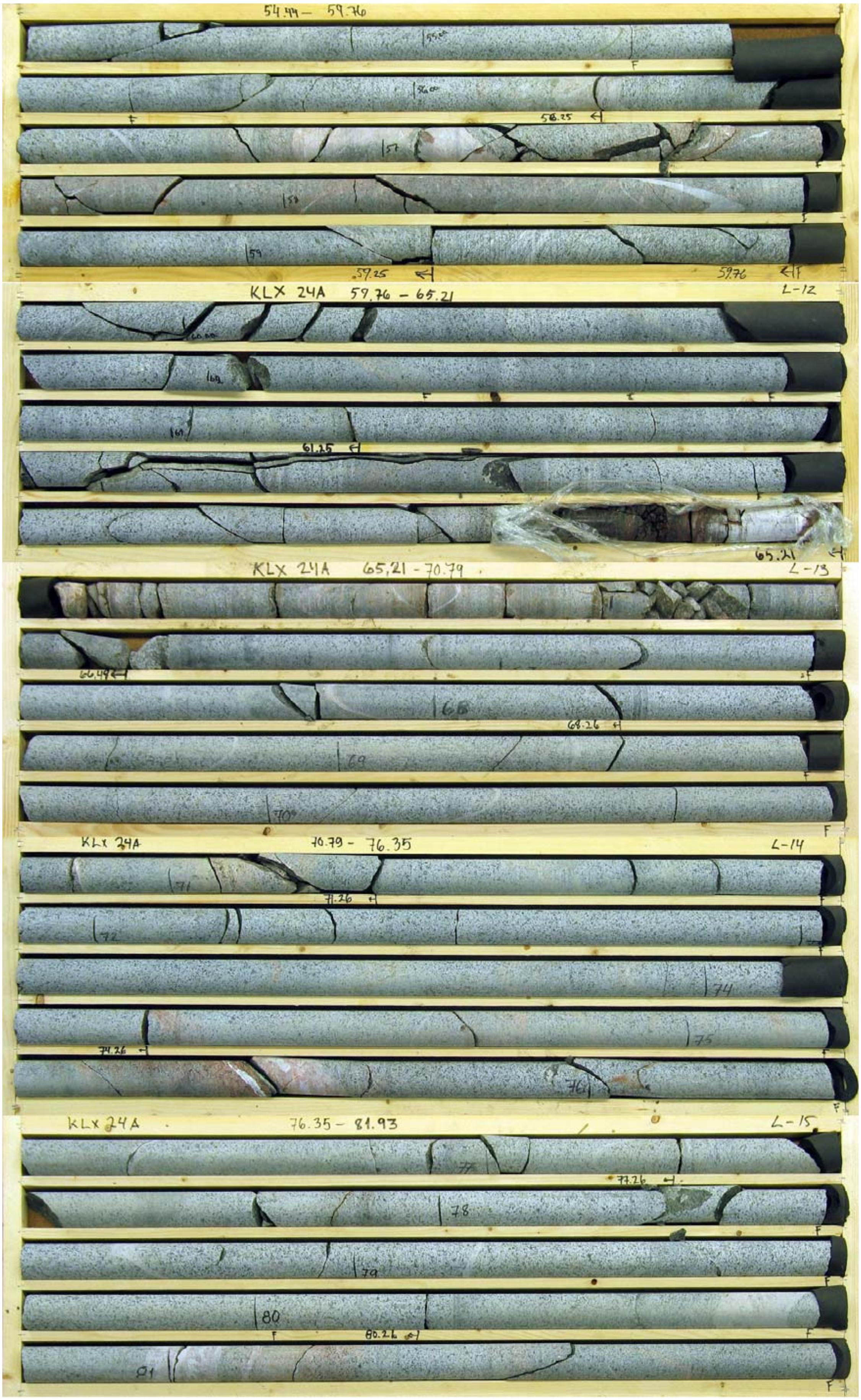

KLX 23A
56.09 - 61.74
L-11
KLX 23A
61.74 - 67.38
L-12
KLX 23A
67.38 - 72.99
L-13
KLX 23A
72.99 - 78.66
L-14
KLX 23A
78.66 - 84.28
L-15


KLX 23B
0 – 5.62
L-1
KLX 23B
5.62 – 11.23
L-2
KLX 23B
11.23 – 16.75
L-3
KLX 23B
16.75 – 22.38
L-4
KLX 23B
22.38 – 27.85
L-5

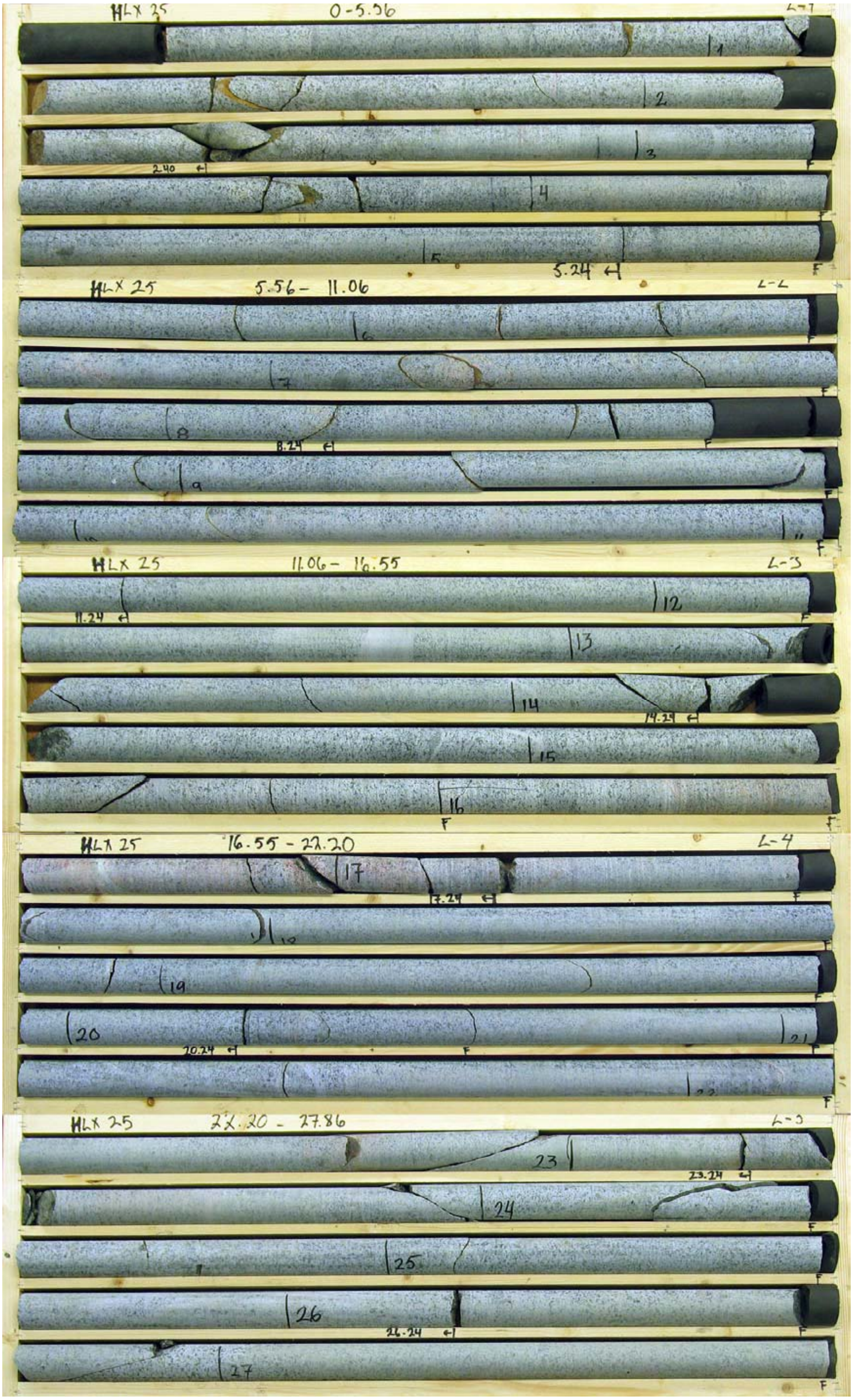

KLX 23B
29.27
KLX 23B
35.27
38.27
KLX 23B
41.27
44.27
KLX 23B
44.69 –
47.27
50.27

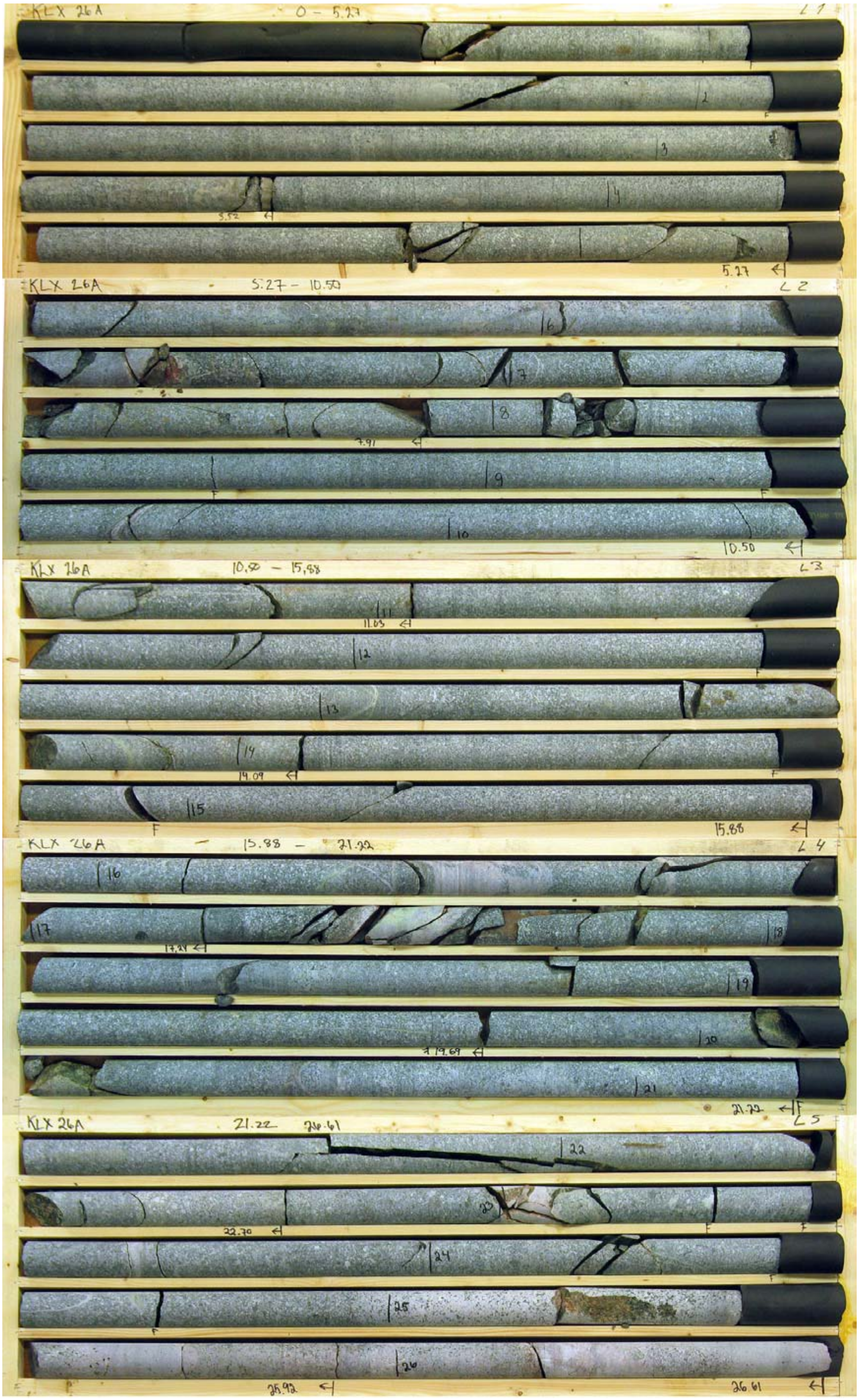


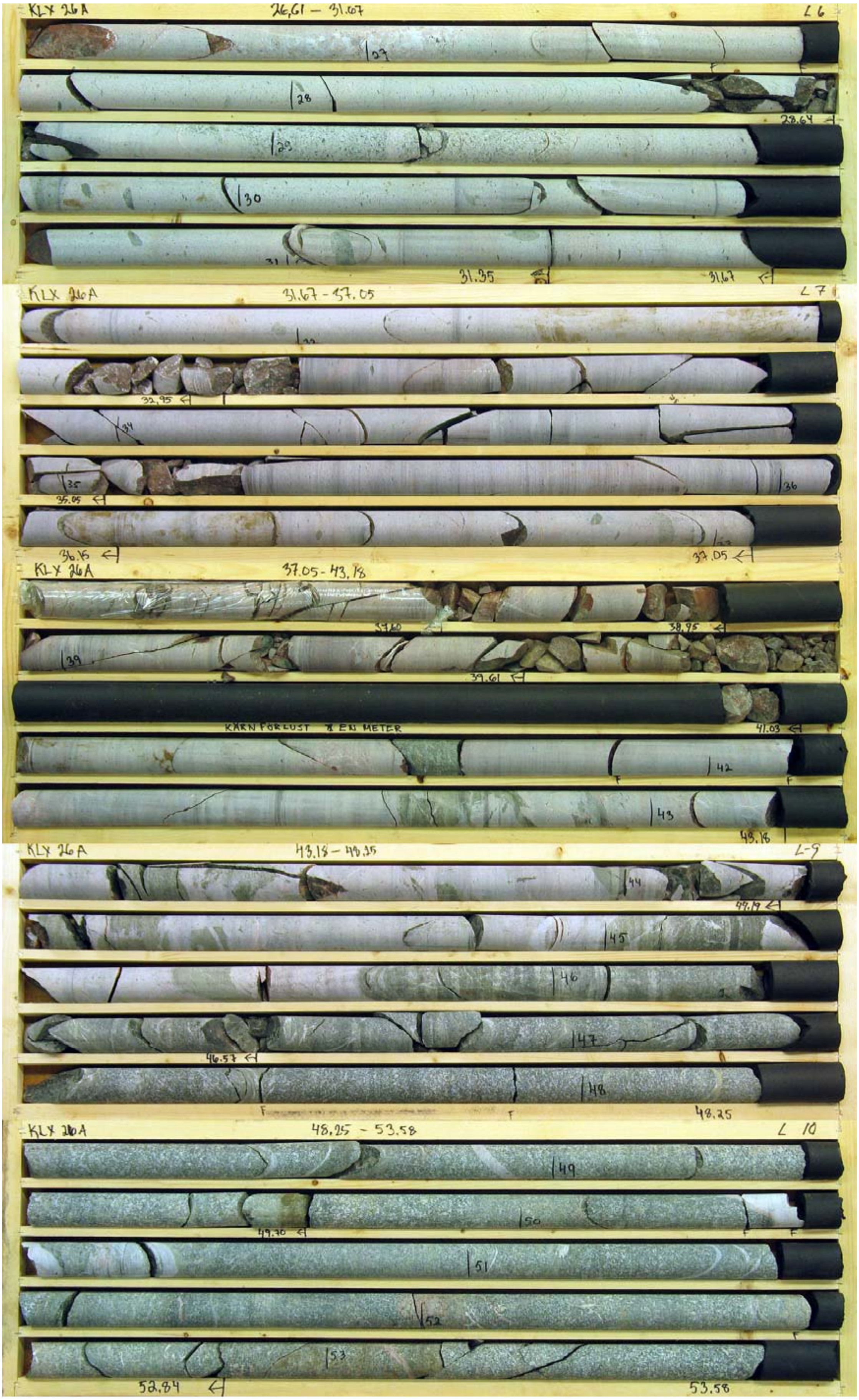

KLX 24A 27,16 – 32,62
29,25
32,25
32.62
KLX 24A – 32,62
35,25
38,17
KLX 24A 38,17 – 43,72
38,25
41,25
43,72
KLX 24A 43,72 – 48,86
44,25
47,25
48.86
KLX 24A 48.86 – 54.44
50.25
53.25
54.44

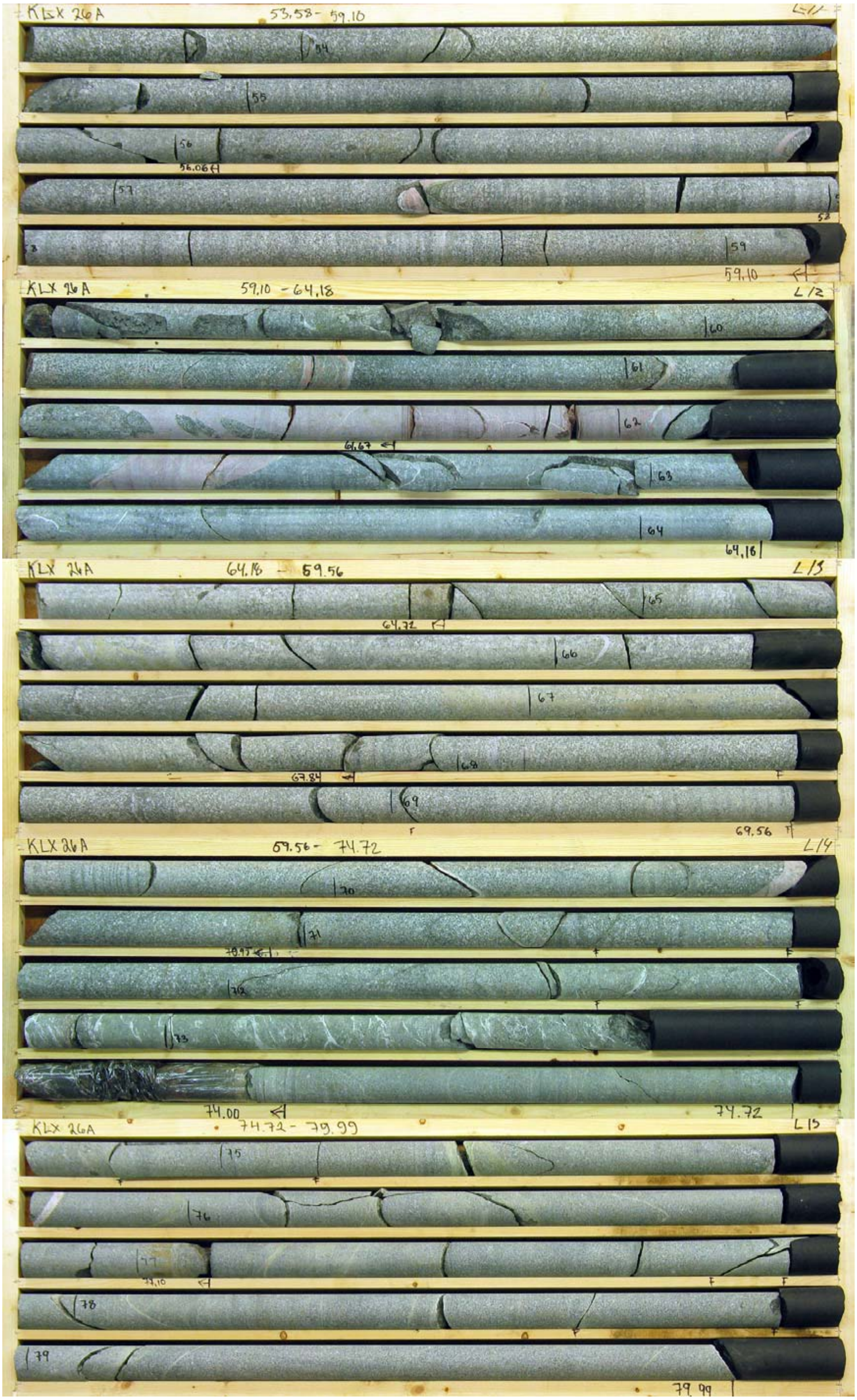

54.44 – 59.76
KLX 24A 59.76 – 65.21
L-12
KLX 24A 65.21 – 70.79
L-13
KLX 24A 70.79 – 76.35
L-14
KLX 24A 76.35 – 81.93
L-15

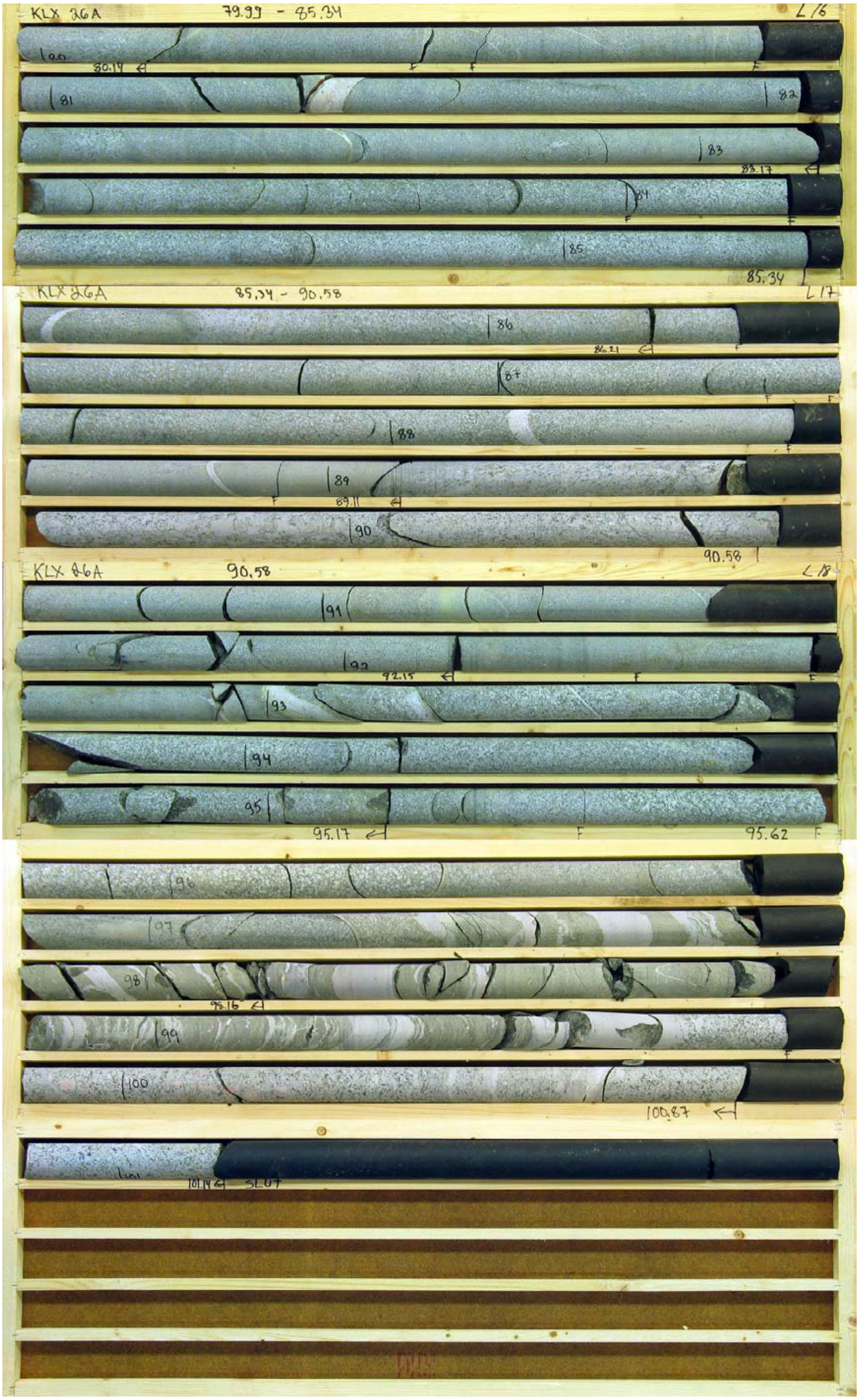

KLX 24A
81.93 – 87.65
L-16
83.26
86
86.26
KLX 24A
87.65 – 93.22
L-17
88
89
89.26
91
92
91.72
KLX 24A
93.22 – 98.75
L-18
94
94.78
96
97
97.81
KLX 24A
98.75 – 100.17
L-19
99
100
100.17

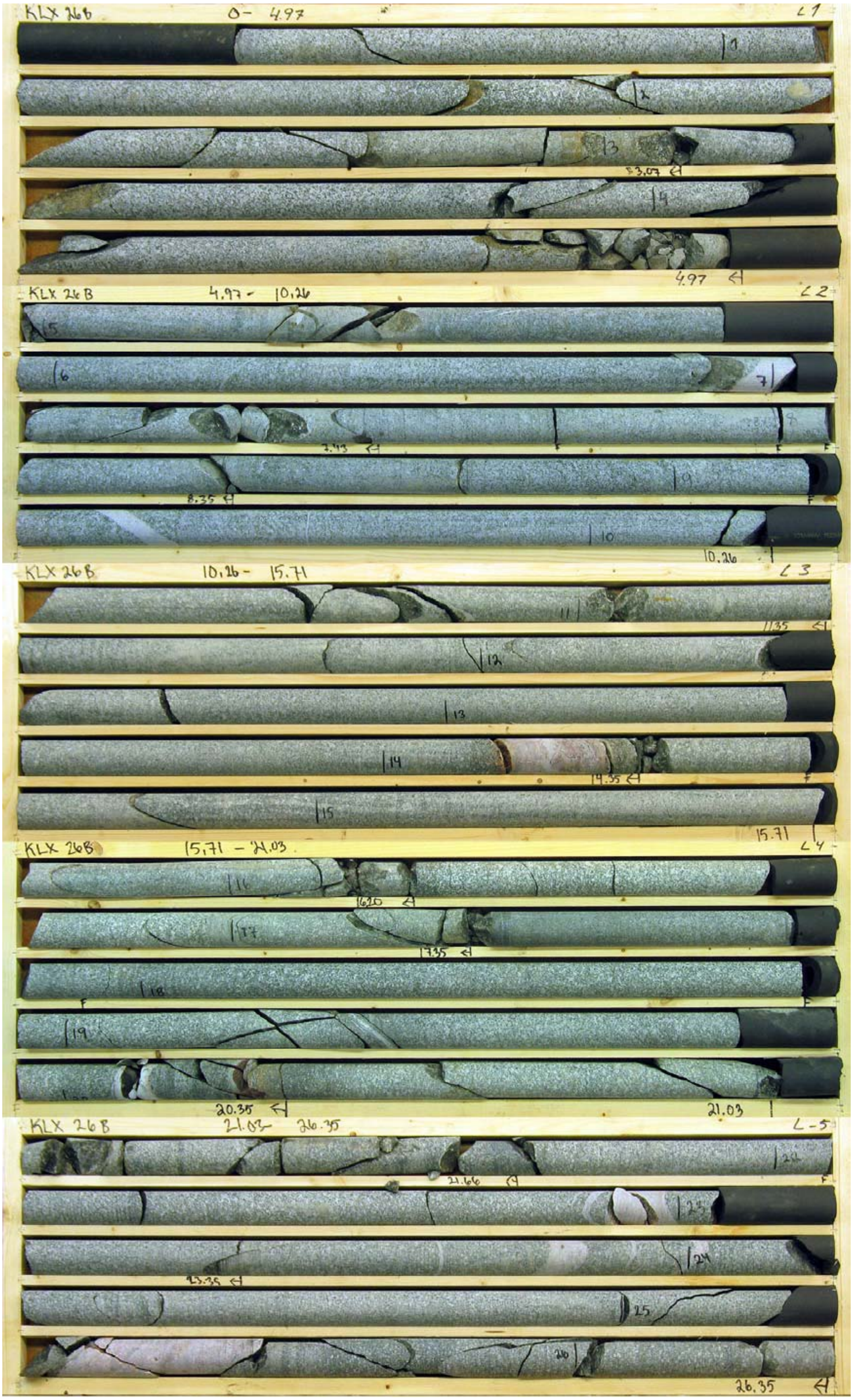


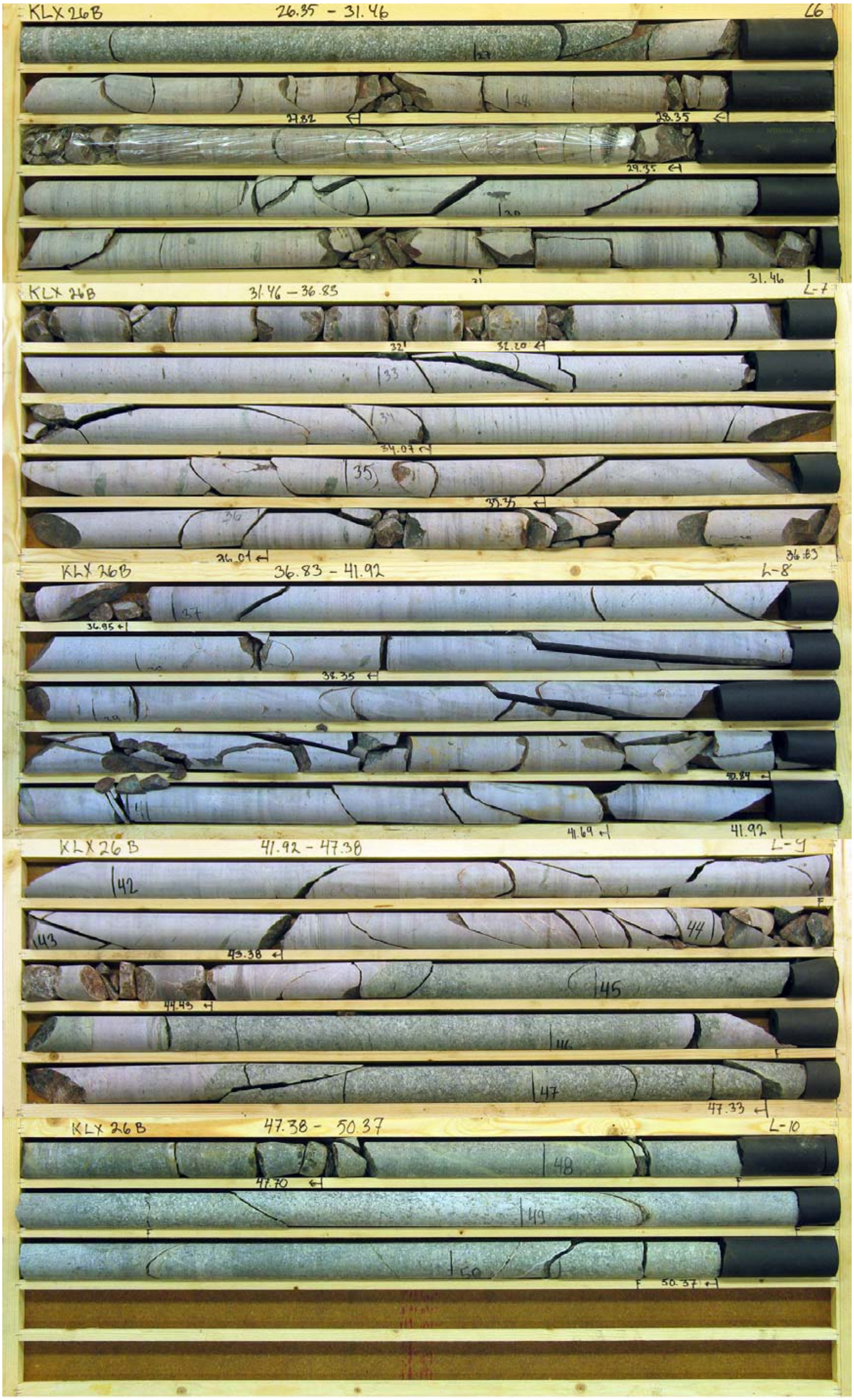


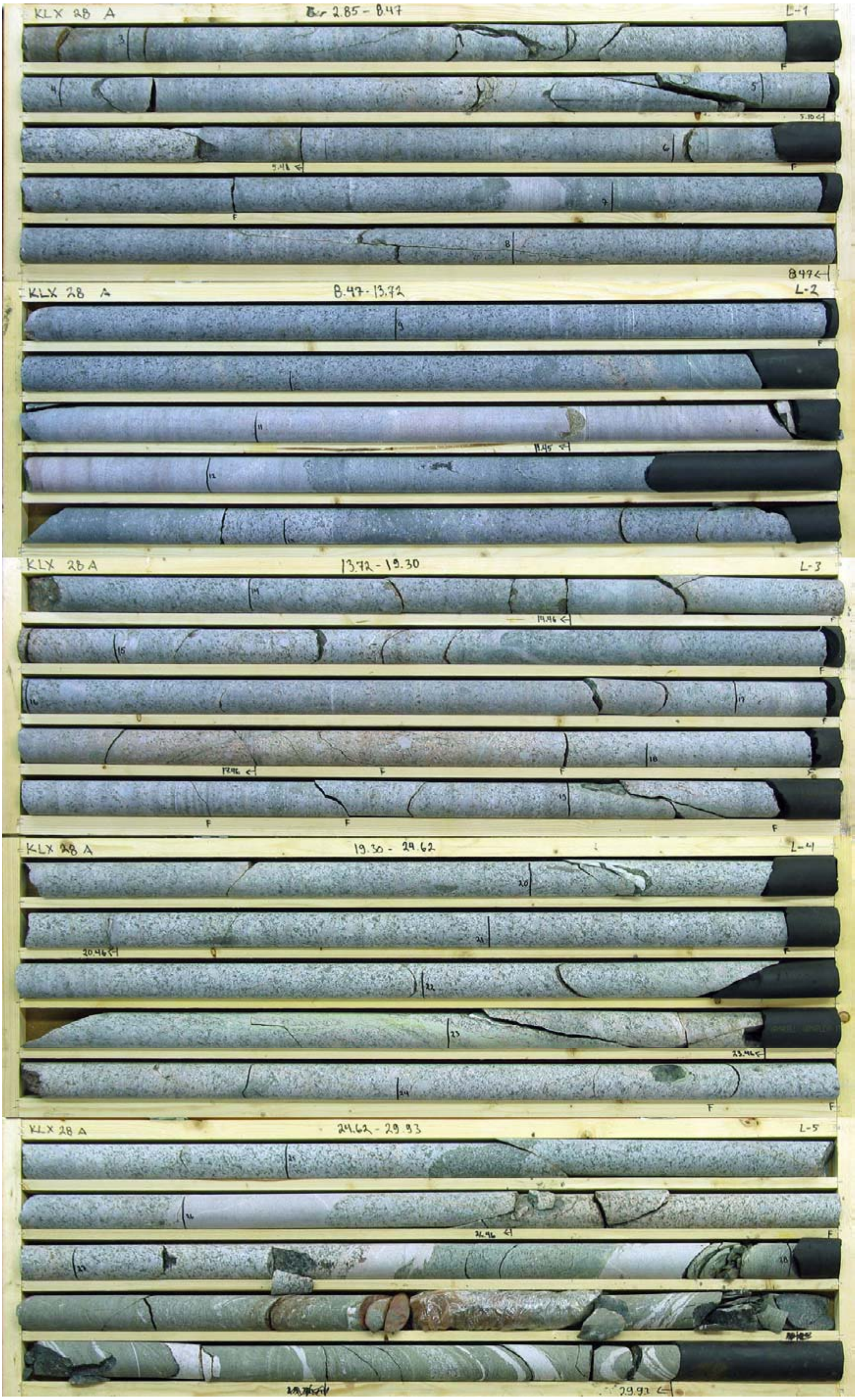

KLX 26A
26,61 – 31,67
L 6
KLX 26A
31,67 – 37,05
L 7
KLX 26A
37,05 – 43,18
KÄRNFÖRLUST ≈ EN METER
KLX 26A
43,18 – 48,25
L 9
KLX 26A
48,25 – 53,58
L 10

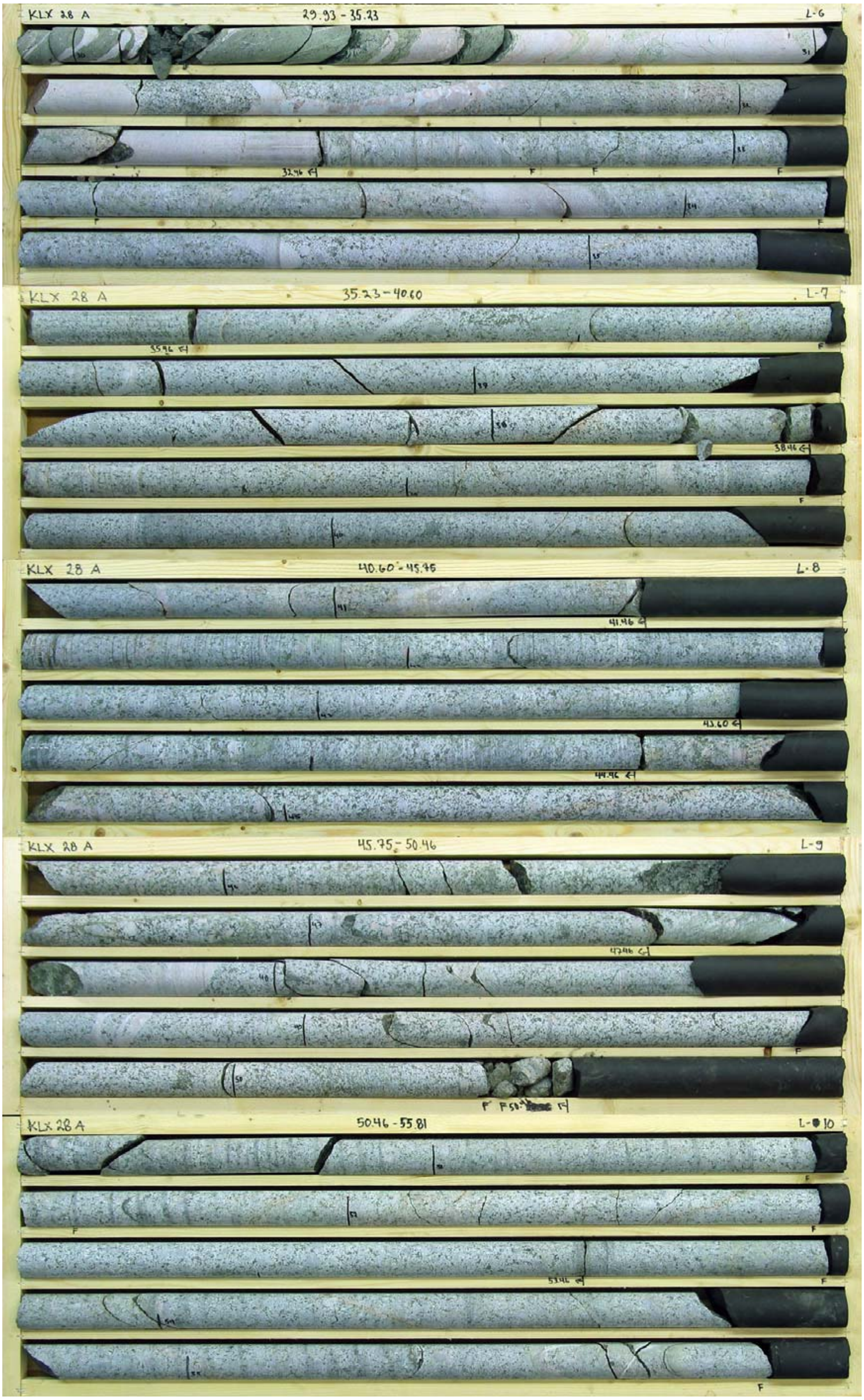

KLX 26A
53.58 - 59.10
59.10
KLX 26A
59.10 - 64.18
61.67
64.18
64.72
67.84
69.56
KLX 26A
74.00
74.72
KLX 26A
74.72 - 79.99
79.99

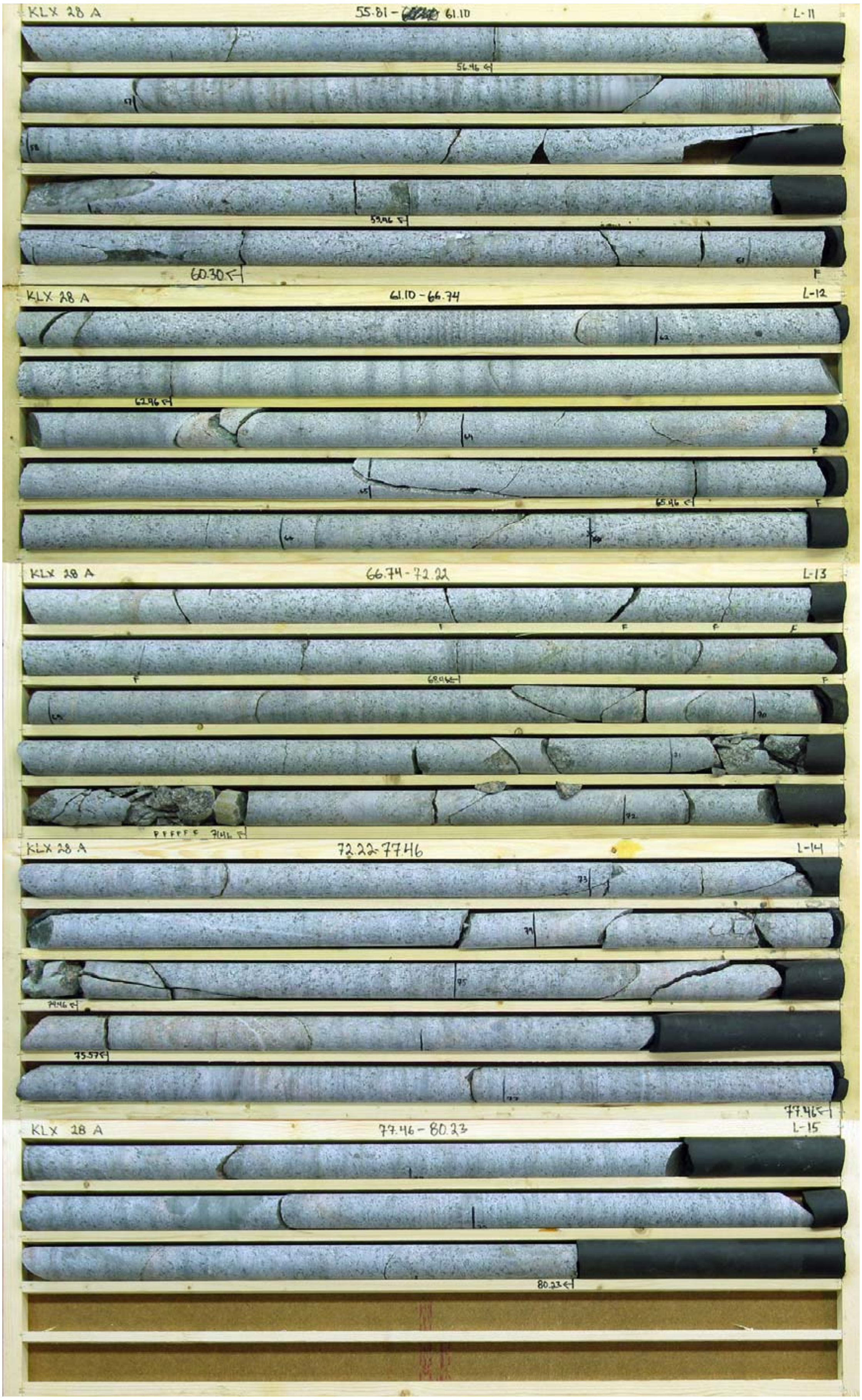


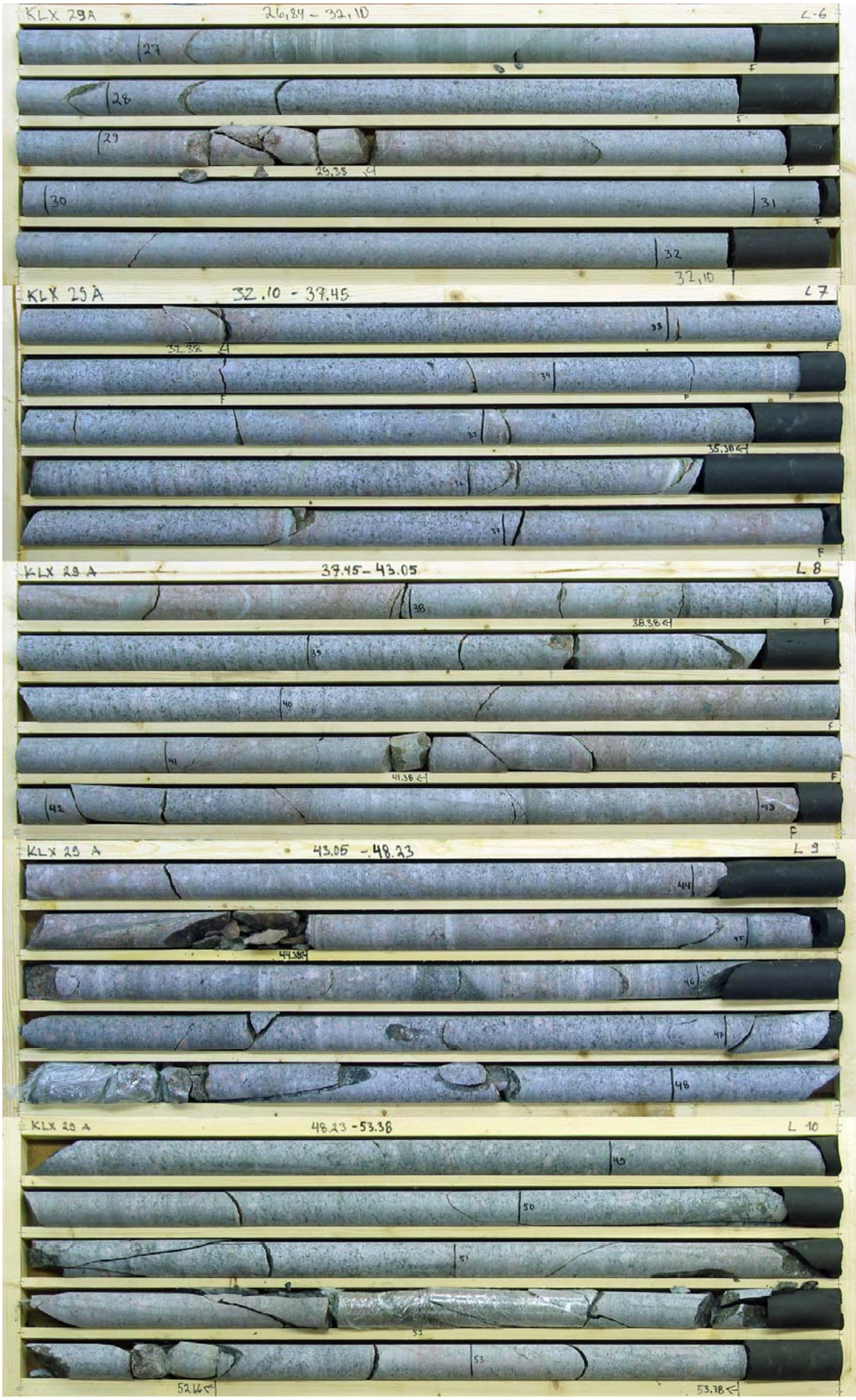





KLX 28 A
2.85 – 8.47
L-1
KLX 28 A
8.47 - 13.72
L-2
KLX 28 A
13.72 - 19.30
L-3
KLX 28 A
19.30 - 24.62
L-4
KLX 28 A
24.62 - 29.93
L-5


KLX 28 A
29.93 - 35.23
L-6
KLX 28 A
35.23 - 40.60
L-7
KLX 28 A
40.60 - 45.75
L-8
KLX 28 A
45.75 - 50.46
L-9
KLX 28 A
50.46 - 55.81



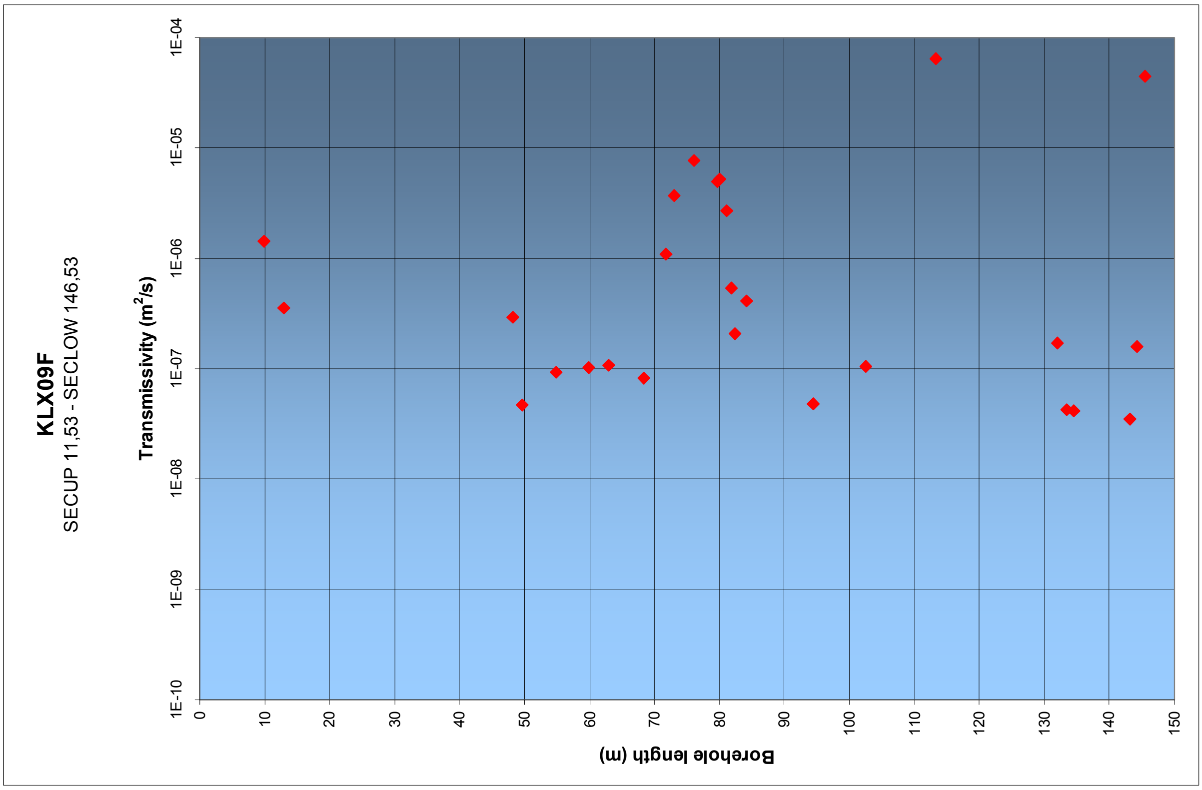

KLX 29A 26,24 – 32,10 L-6
KLX 29A 32.10 – 37.45 L7
KLX 29 A 37.45 – 43.05 L 8
KLX 29 A 43.05 – 48.23 L 9
KLX 29 A 48.23 – 53.38 L 10

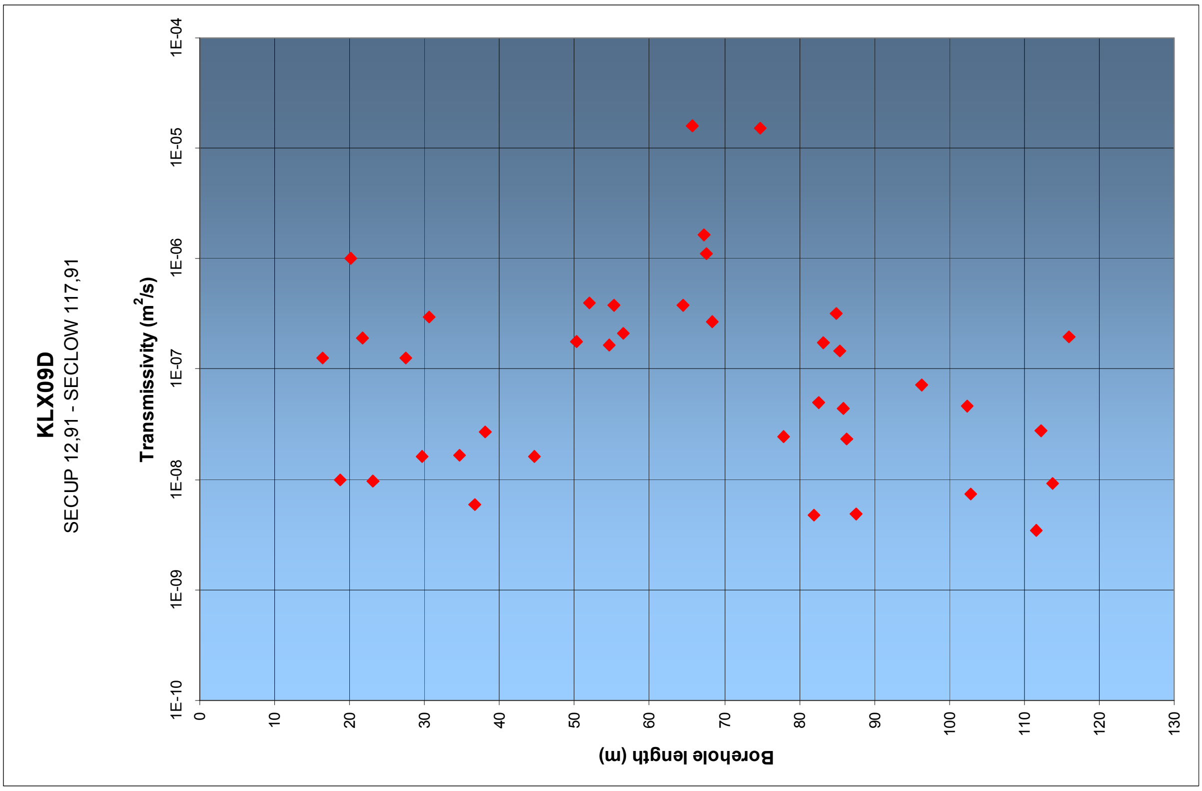

KLX 29 A
53.38 - 58.60
L 11
KLX 29 A
58.60 - 60.25
L 12

Appendix E

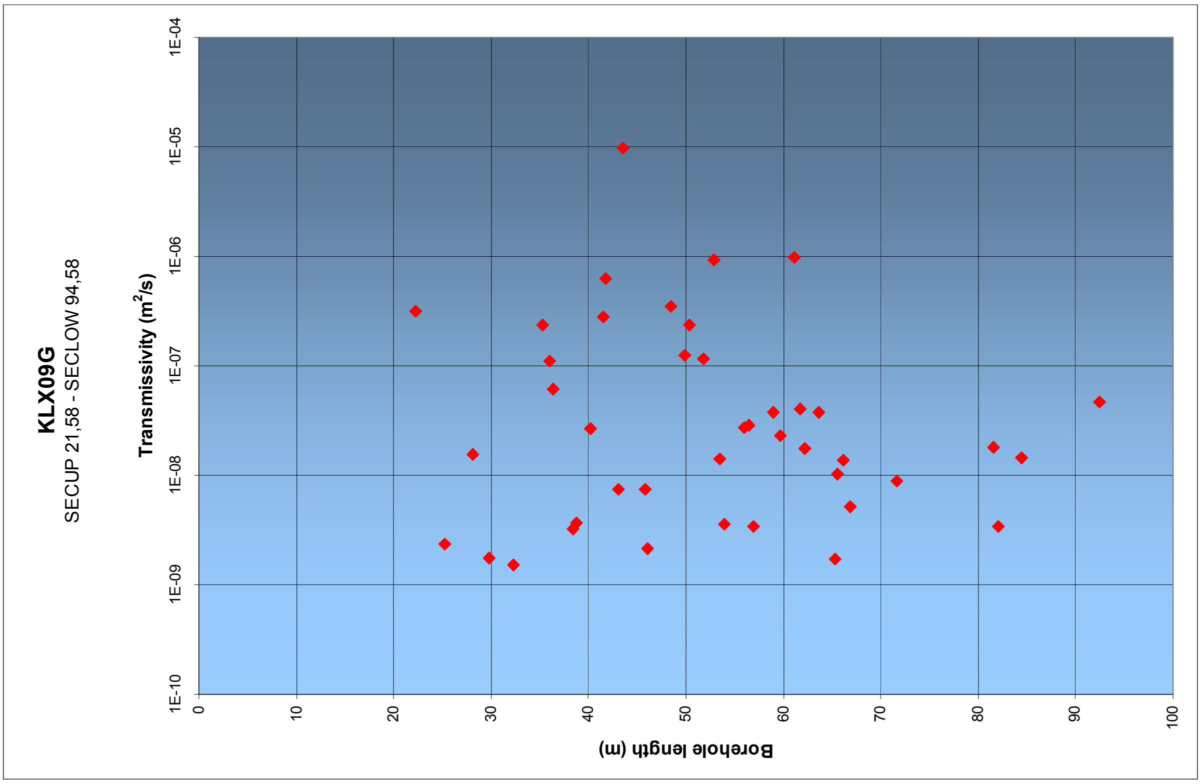
PFL Flow Anomalies

Posiva OY

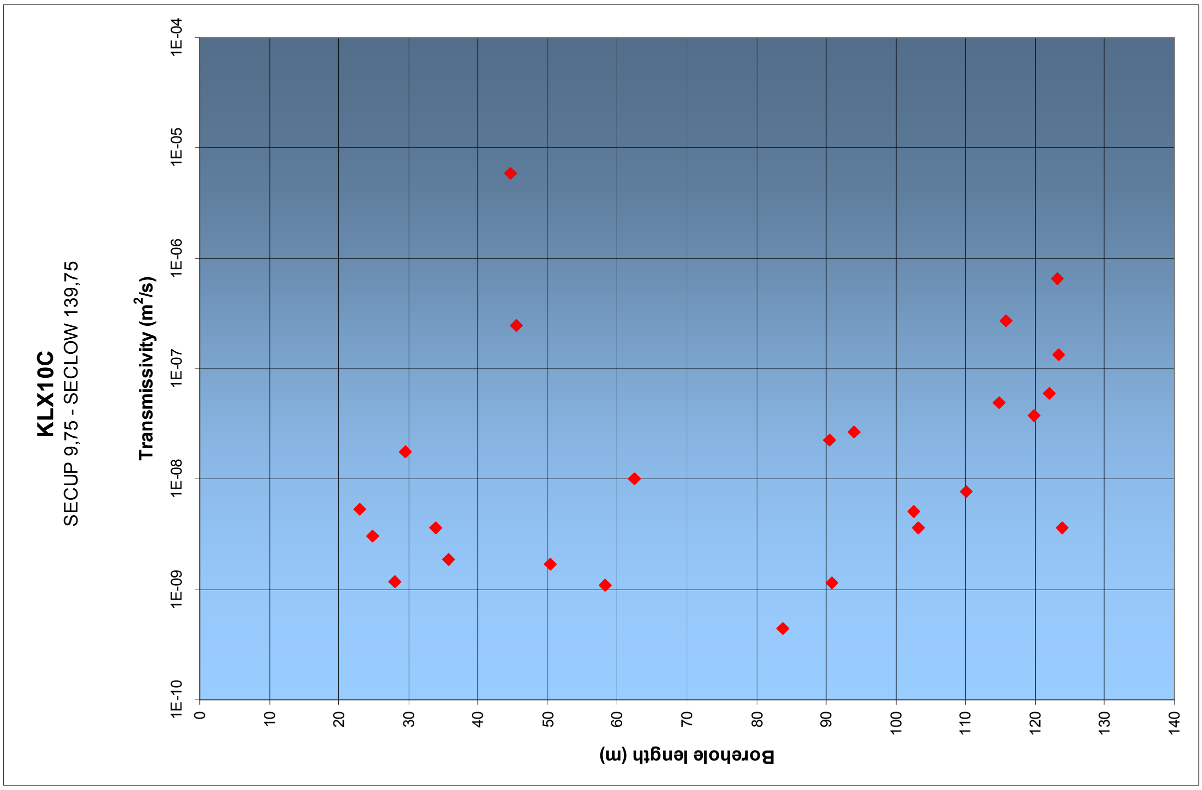

KLX09F
SECUP 11,53 - SECLOW 146,53
Transmissivity (m^2/s)
Borehole length (m)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

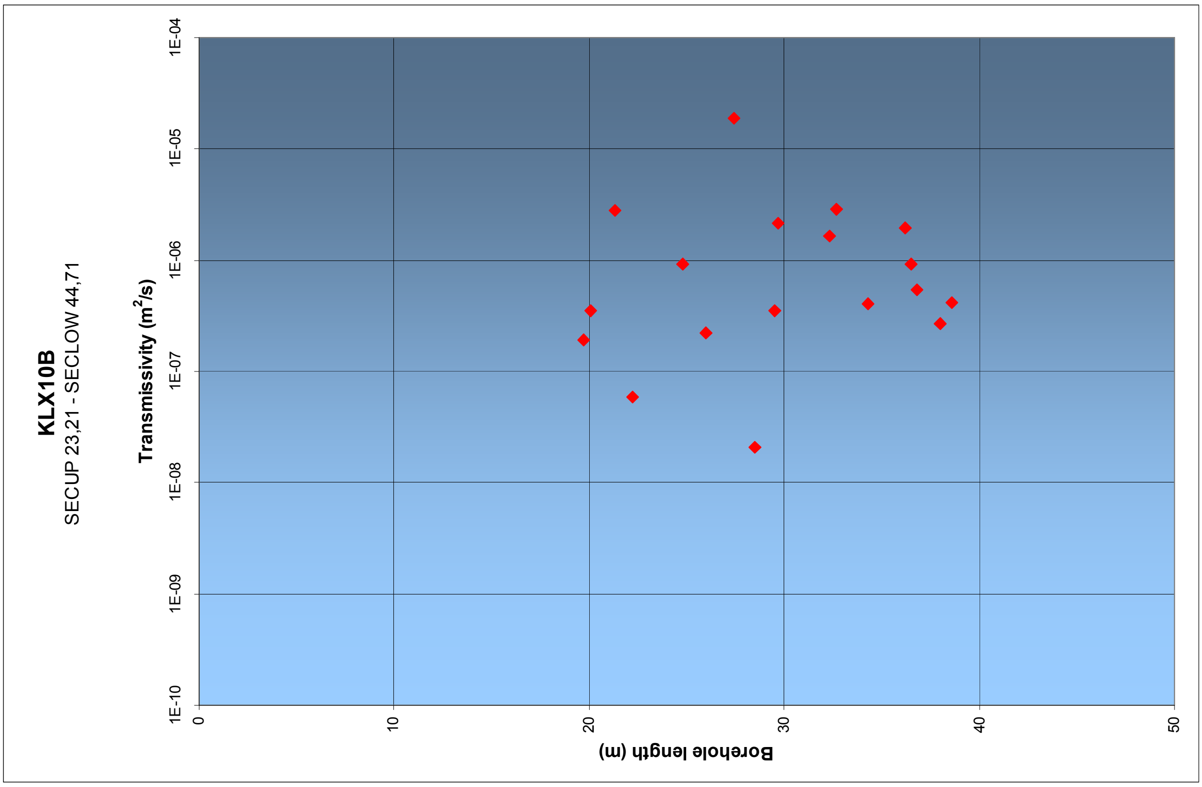

KLX09D
SECUP 12,91 - SECLOW 117,91
Transmissivity (m^2/s)
Borehole length (m)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
0
10
20
30
40
50
60
70
80
90
100
110
120
130

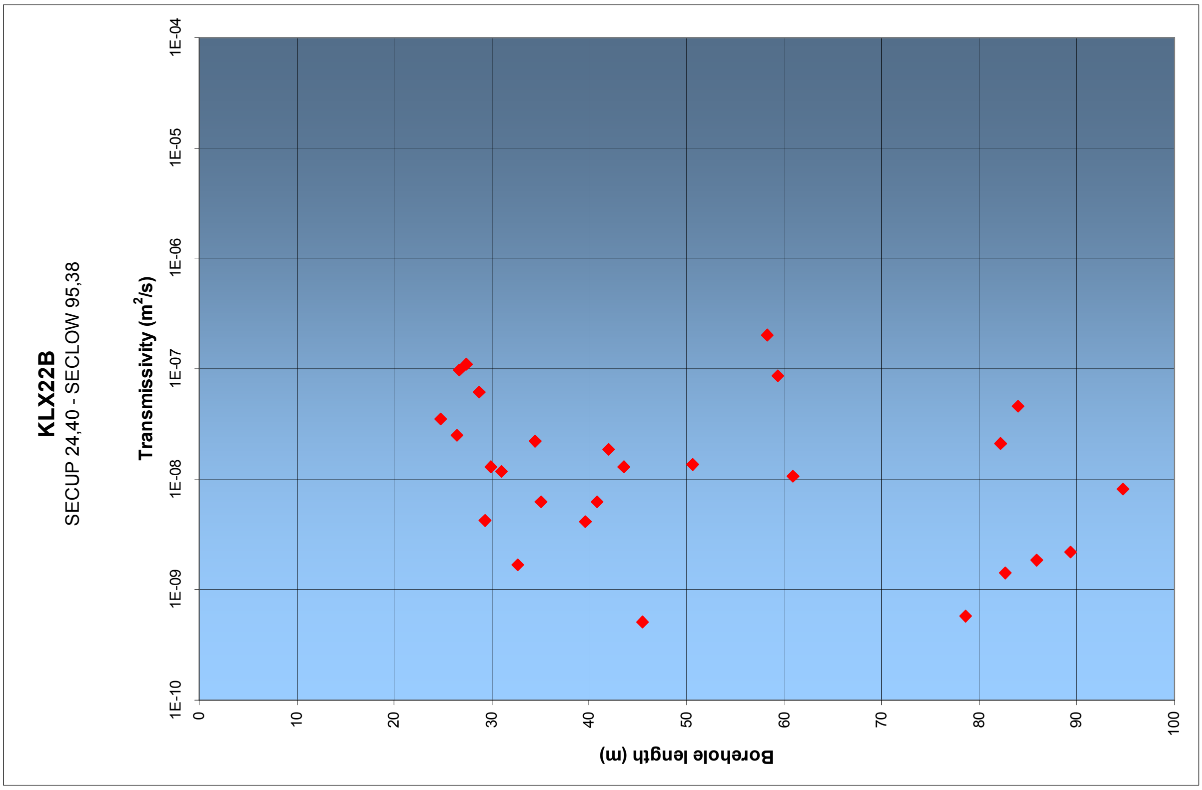
Appendix E
Flow anomalies PFL



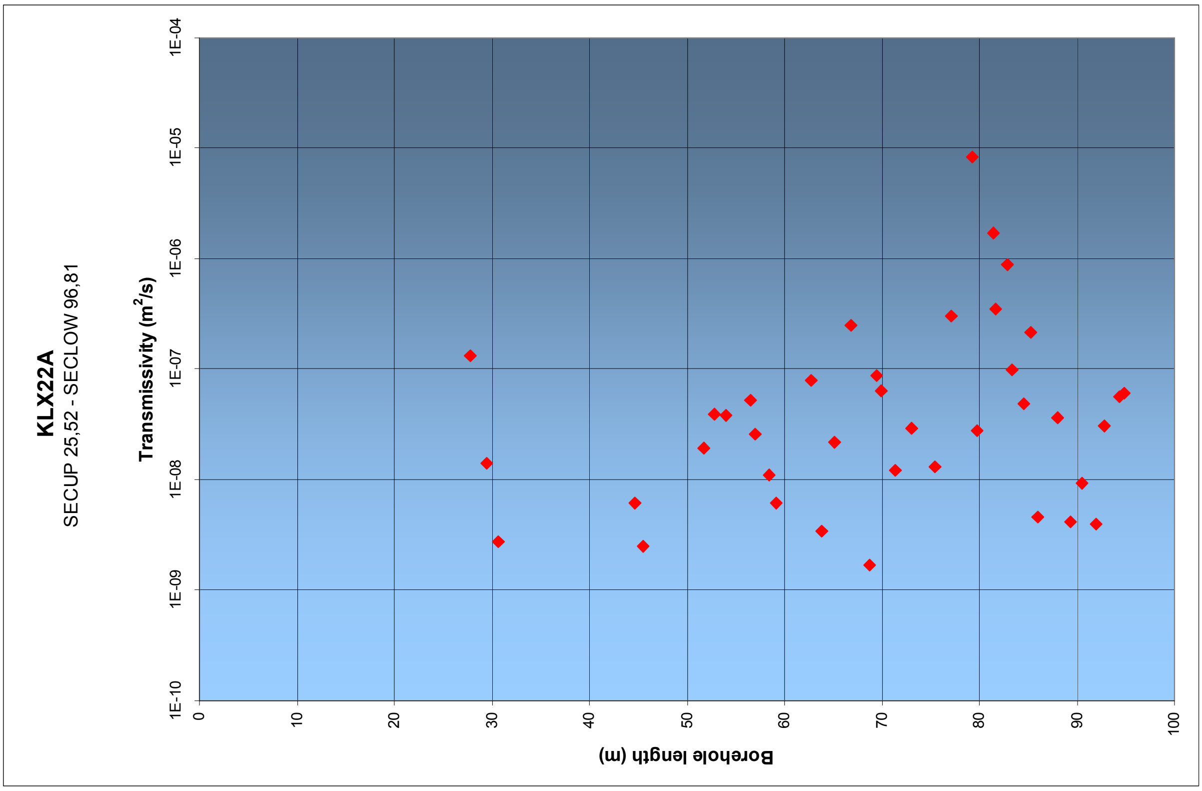
Appendix E
Flow anomalies PFL



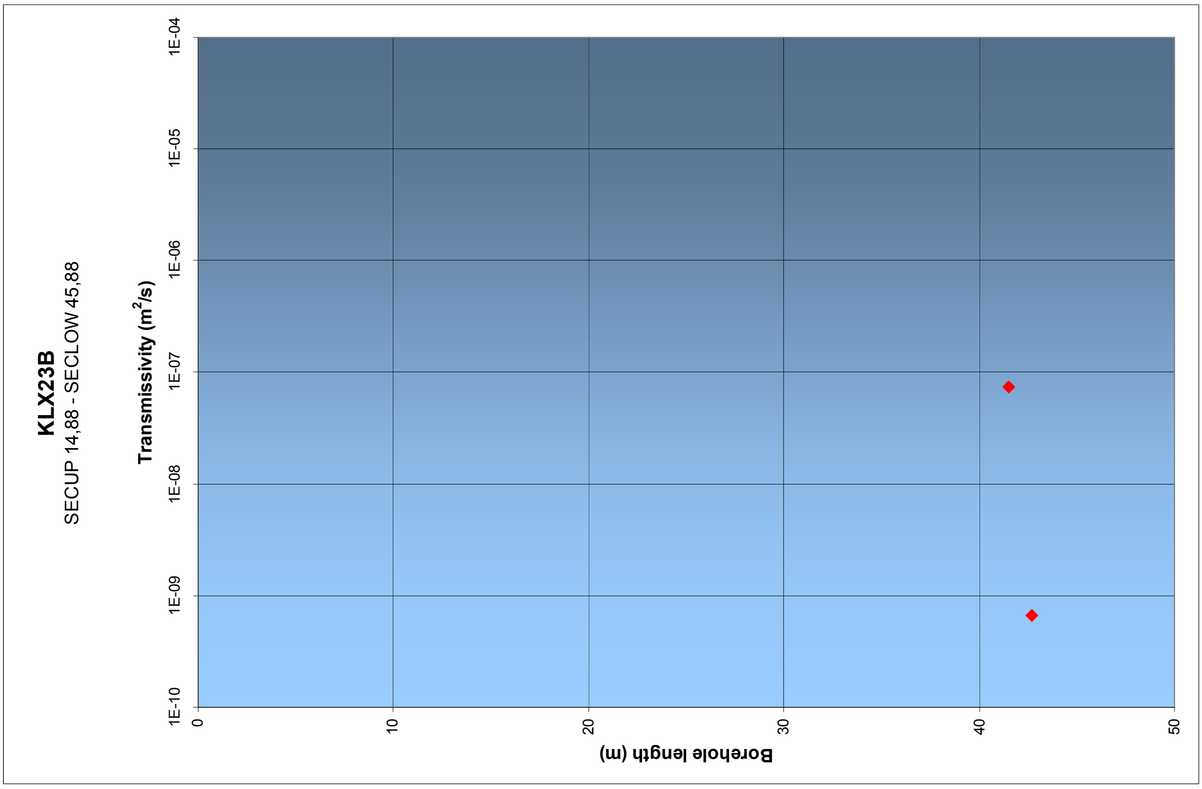


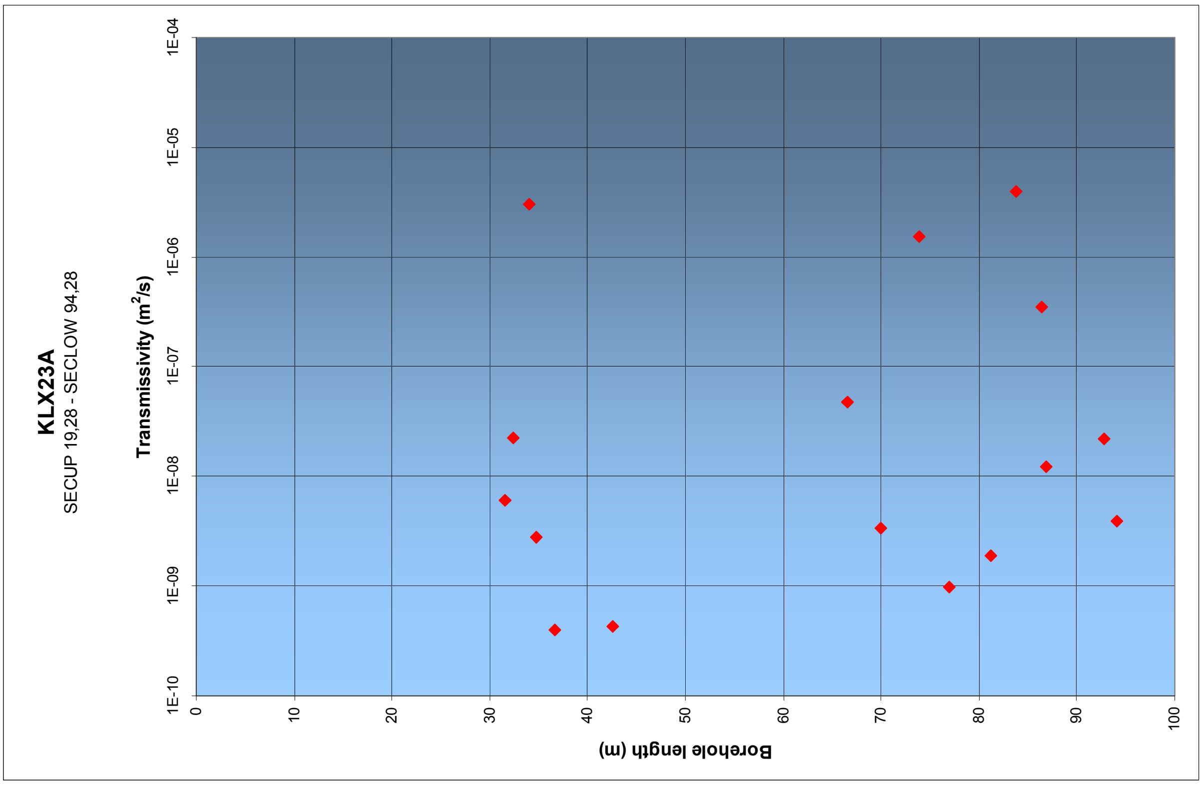


KLX22B
SECUP 24,40 - SECLOW 95,38
Transmissivity (m2/s)
Borehole length (m)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
0
10
20
30
40
50
60
70
80
90
100

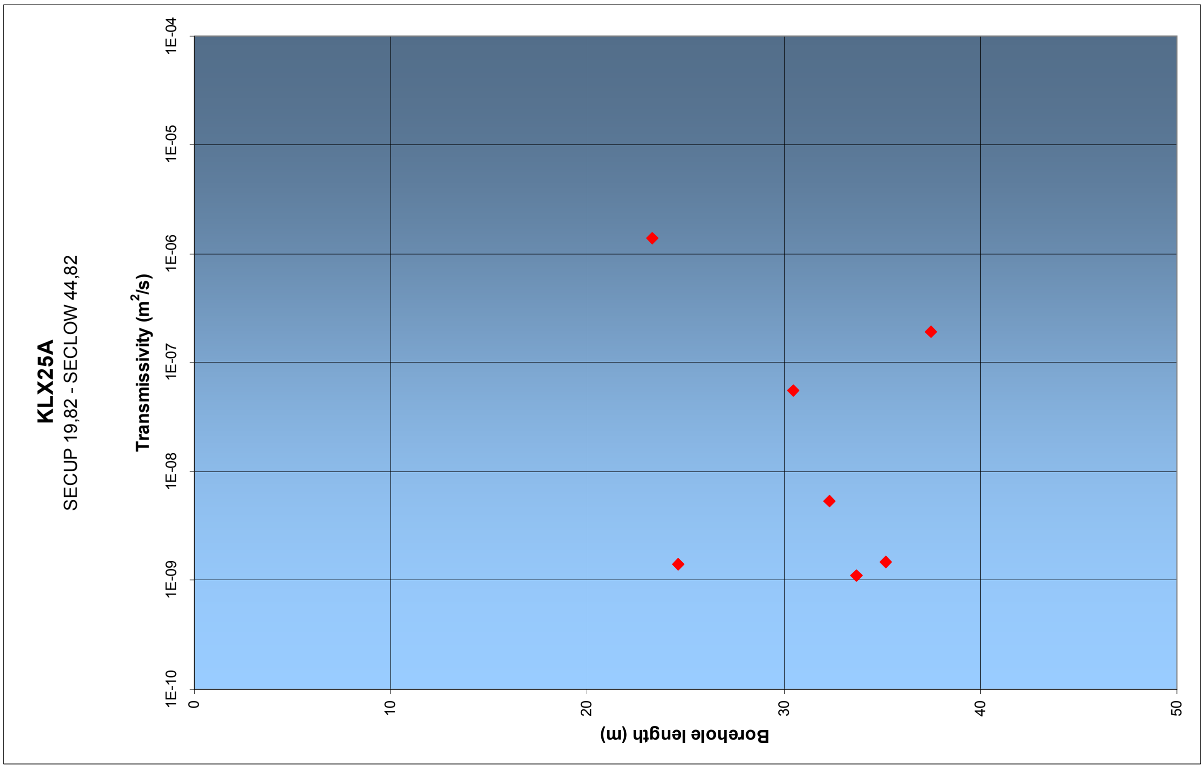


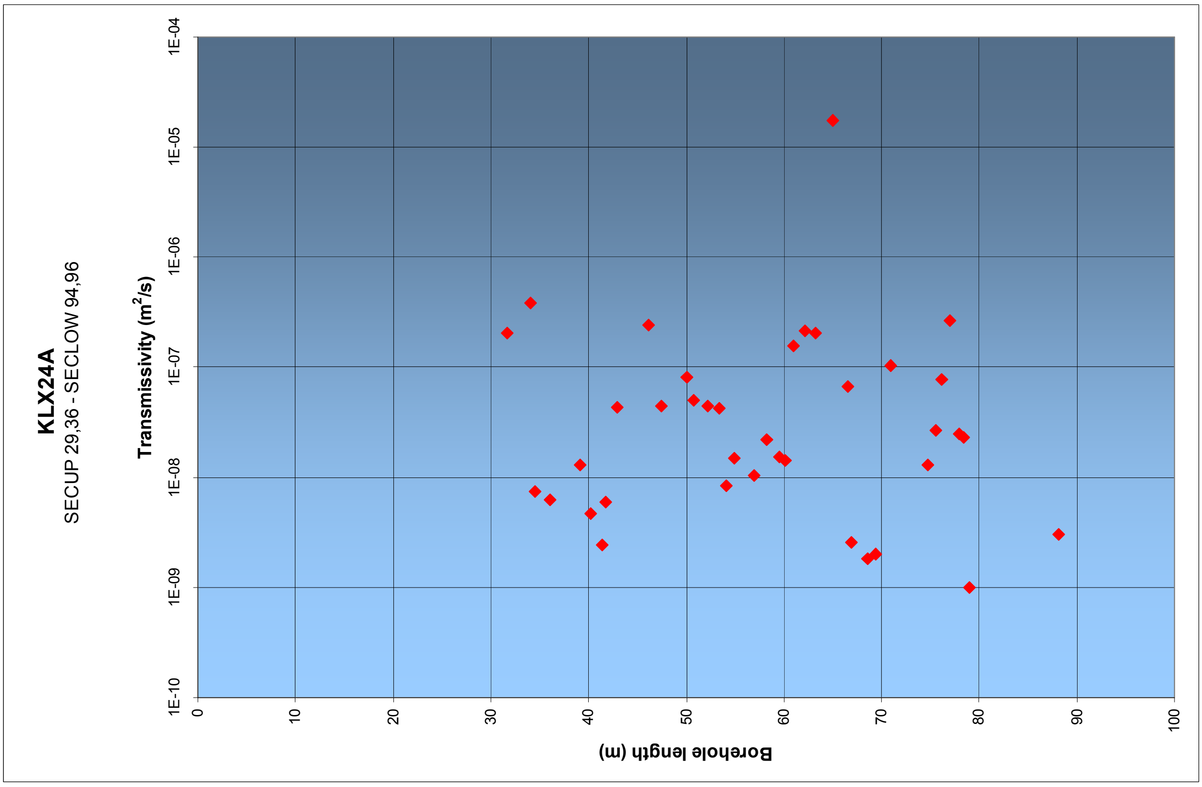
KLX22A
SECUP 25,52 - SECLOW 96,81
Transmissivity (m2/s)
Borehole length (m)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
0
10
20
30
40
50
60
70
80
90
100

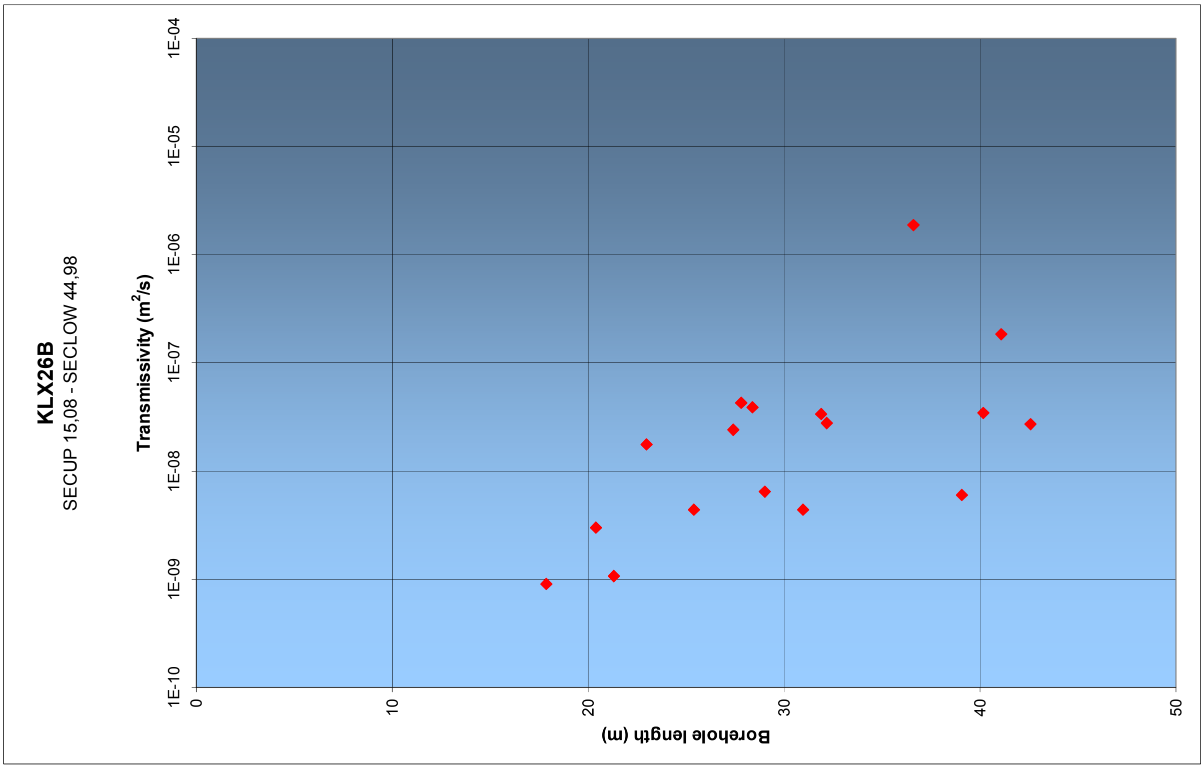

KLX23B
SECUP 14,88 - SECLOW 45,88
Transmissivity (m²/s)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
Borehole length (m)
0
10
20
30
40
50


KLX23A
SECUP 19,28 - SECLOW 94,28
Transmissivity (m²/s)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
Borehole length (m)
0
10
20
30
40
50
60
70
80
90
100

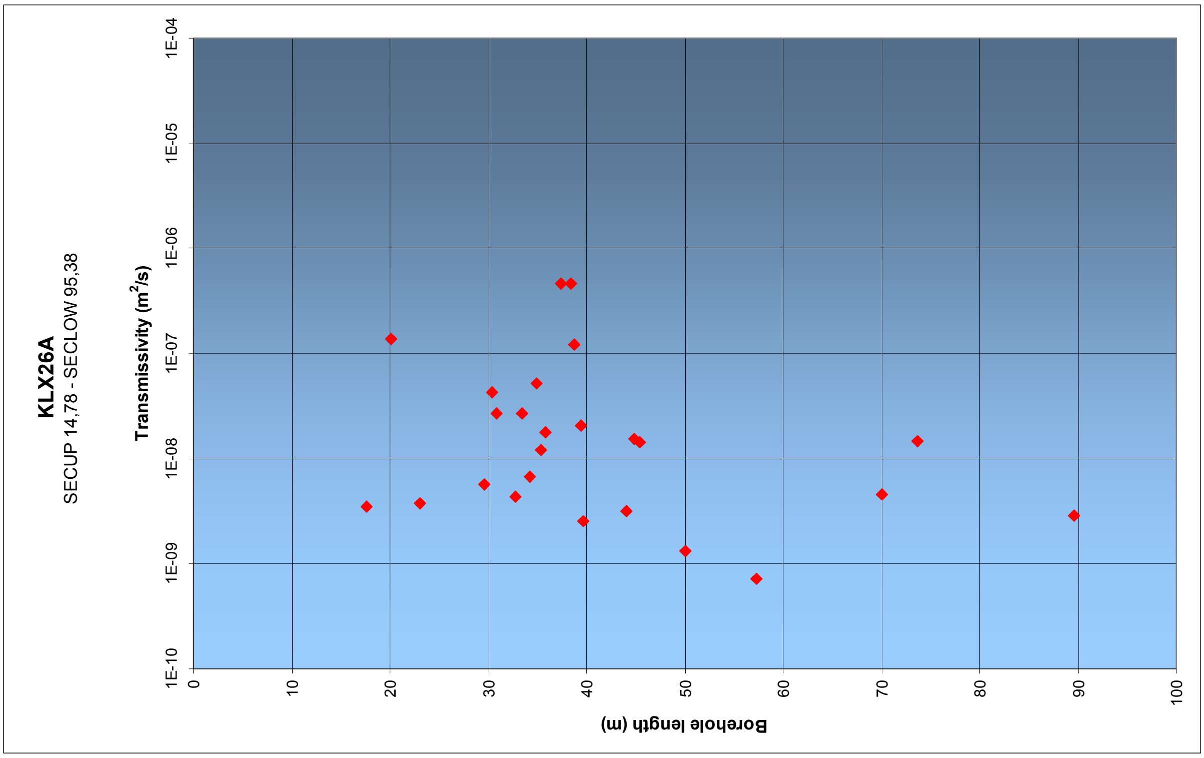
Appendix E
Flow anomalies PFL



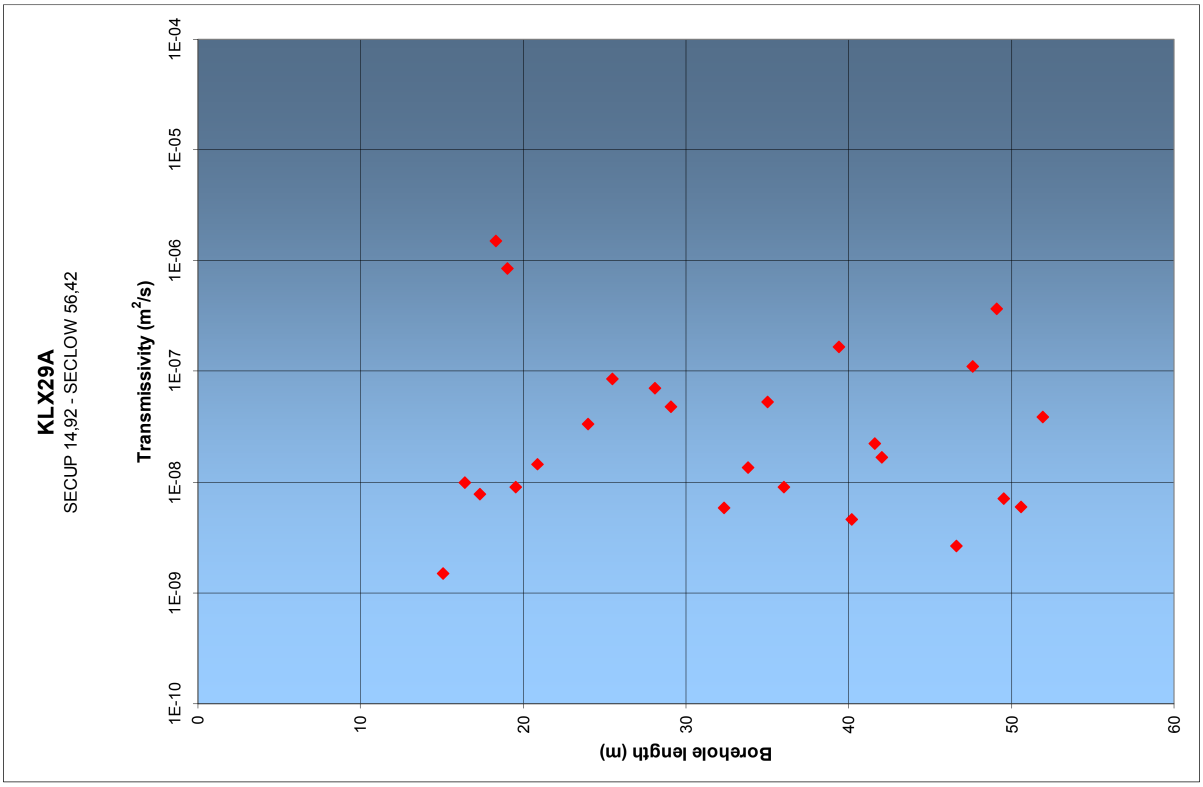


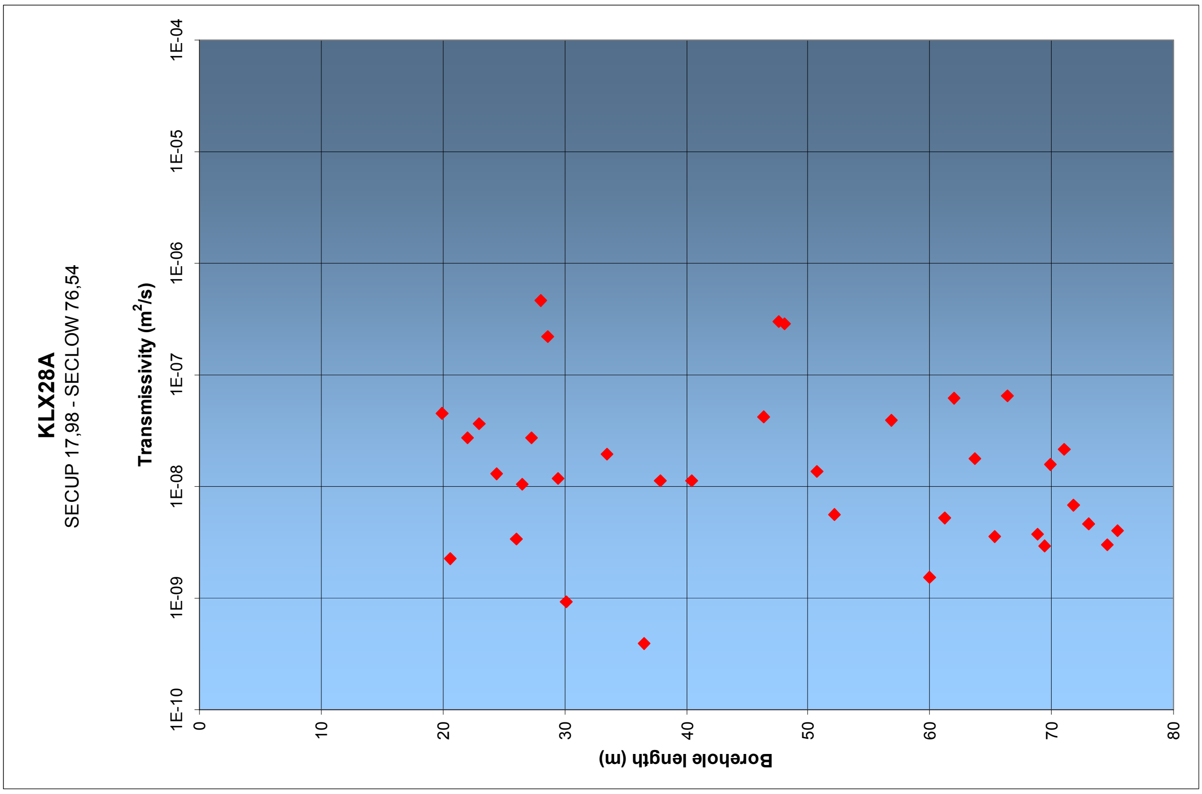


KLX26B
SECUP 15,08 - SECLOW 44,98
Transmissivity (m2/s)
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-10
0
10
20
30
40
50
Borehole length (m)



KLX26A
SECUP 14,78 - SECLOW 95,38
Transmissivity (m2/s)
1E-04
1E-05
1E-06
1E-07
1E-08
1E-09
1E-10
0
10
20
30
40
50
60
70
80
90
100
Borehole length (m)


KLX29A
SECUP 14,92 - SECLOW 56,42
Transmissivity (m^2/s)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
0
10
20
30
40
50
60
Borehole length (m)


KLX28A
SECUP 17,98 - SECLOW 76,54
Transmissivity (m^2/s)
1E-10
1E-09
1E-08
1E-07
1E-06
1E-05
1E-04
0
10
20
30
40
50
60
70
80
Borehole length (m)

Appendix F

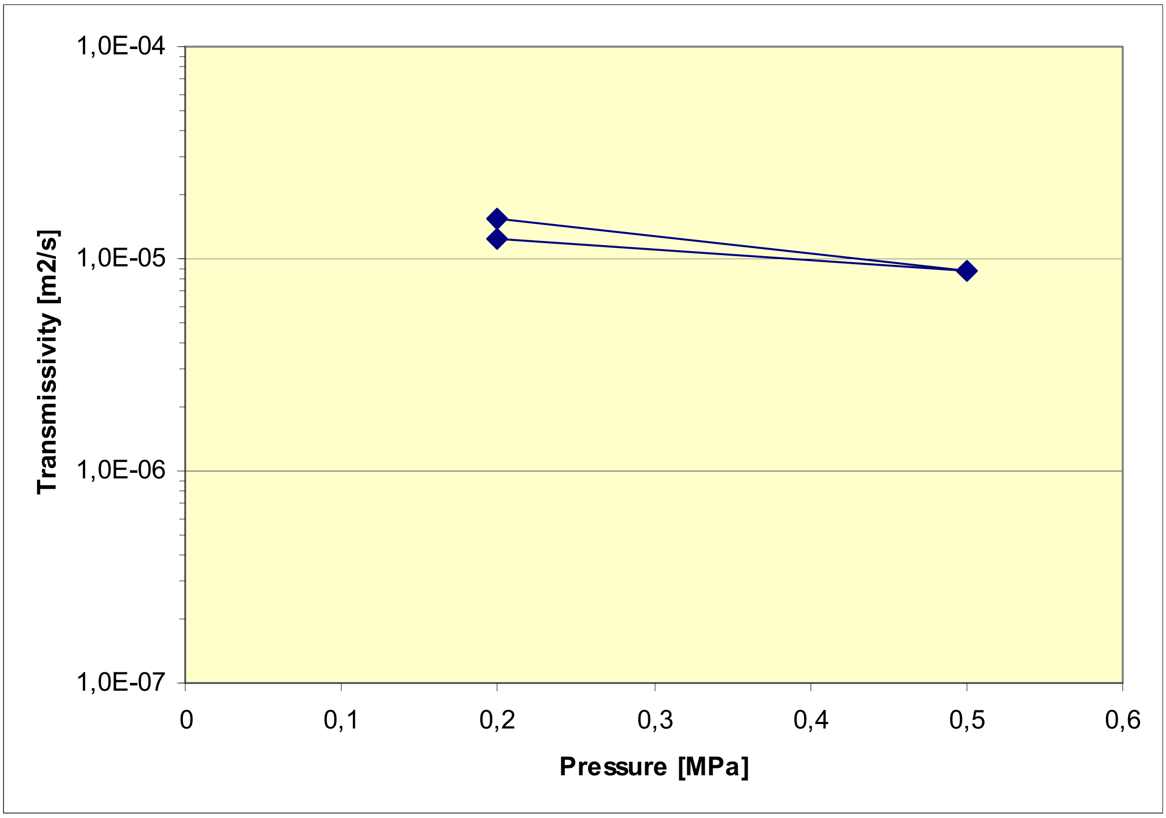
Water Injection Tests

Drillcon AB

KLX22A

Water Loss Measurements		**Packer Interval**		**63-100,45 m**
MDZ Drillholes				
	Pressure steps [Mpa]			
	0,2	0,5	0,2	
Q [l]	48,2	69	39,4	
t [min]	3	3	3	
t [sec]	180	180	180	
L [m]	37,45	37,45	37,45	
P [Mpa]	0,2	0,5	0,2	
T	**1,5E-05**	**8,8E-06**	**1,3E-05**	
K	**4,1E-07**	**2,3E-07**	**3,4E-07**	

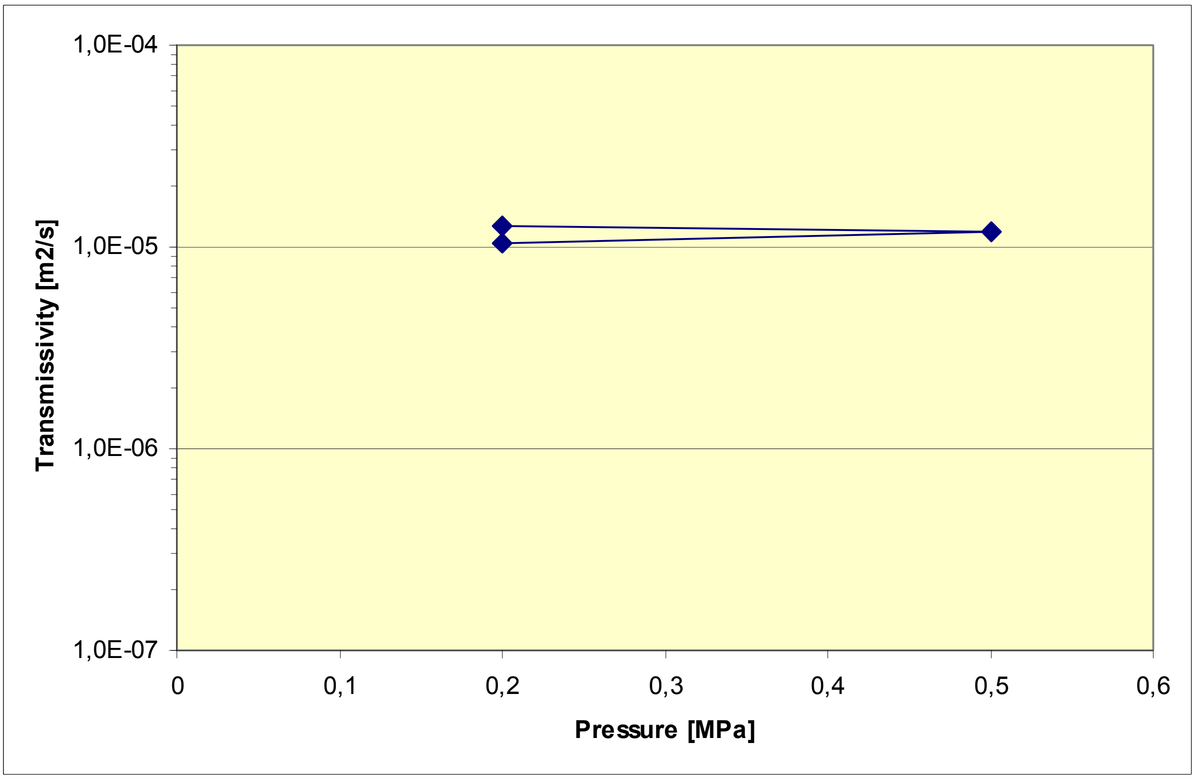
$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$



KLX22B

Water Loss Measurements		**Packer Interval**		**16-100,25 m**
MDZ Drillholes				
	Pressure steps [Mpa]			
	0,2	0,5	0,2	
Q [l]	29,2	83,3	36	
t [min]	3	3	3	
t [sec]	180	180	180	
L [m]	84,25	84,25	84,25	
P [Mpa]	0,2	0,5	0,2	
T	**1,0E-05**	**1,2E-05**	**1,3E-05**	
K	**1,2E-07**	**1,4E-07**	**1,5E-07**	

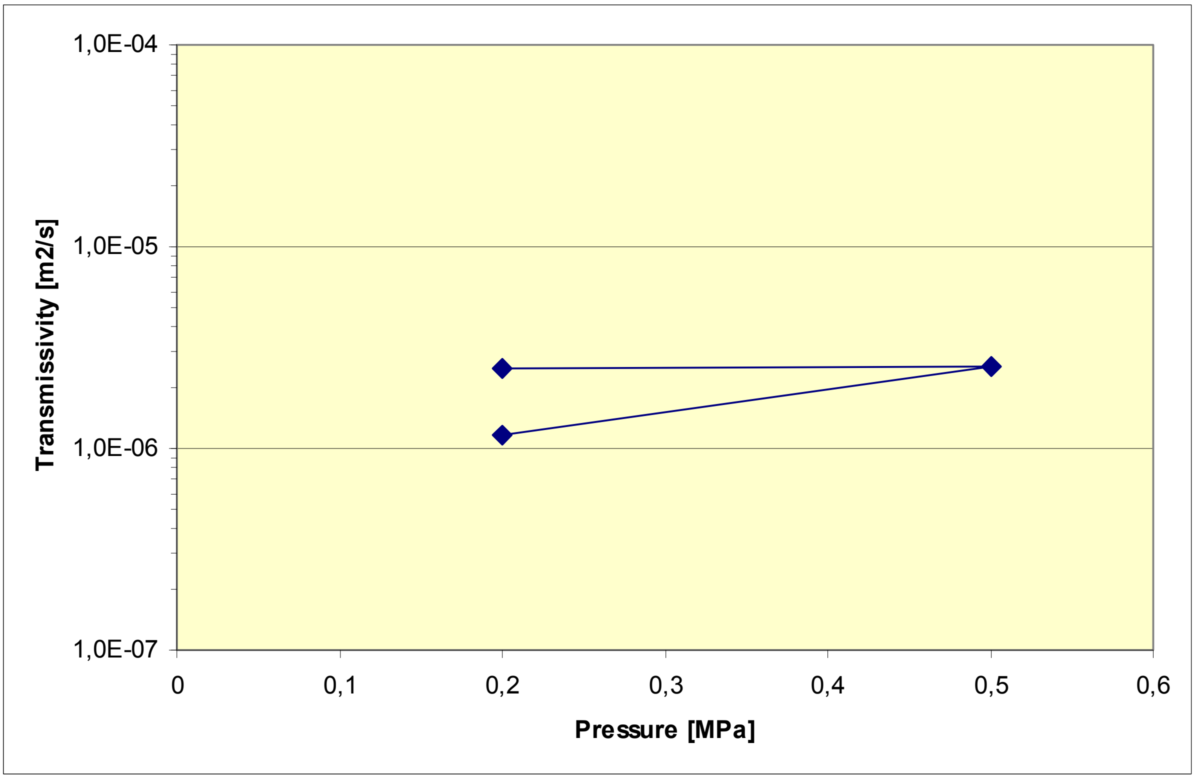
$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi}\right]$$



KLX22B

Water Loss Measurements		**Packer Interval**		**20-100,25 m**
MDZ Drillholes				
	Pressure steps [Mpa]			
	0,2	0,5	0,2	
Q [l]	7	18,2	3,3	
t [min]	3	3	3	
t [sec]	180	180	180	
L [m]	80,25	80,25	80,25	
P [Mpa]	0,2	0,5	0,2	
T	**2,5E-06**	**2,6E-06**	**1,2E-06**	
K	**3,1E-08**	**3,2E-08**	**1,4E-08**	

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

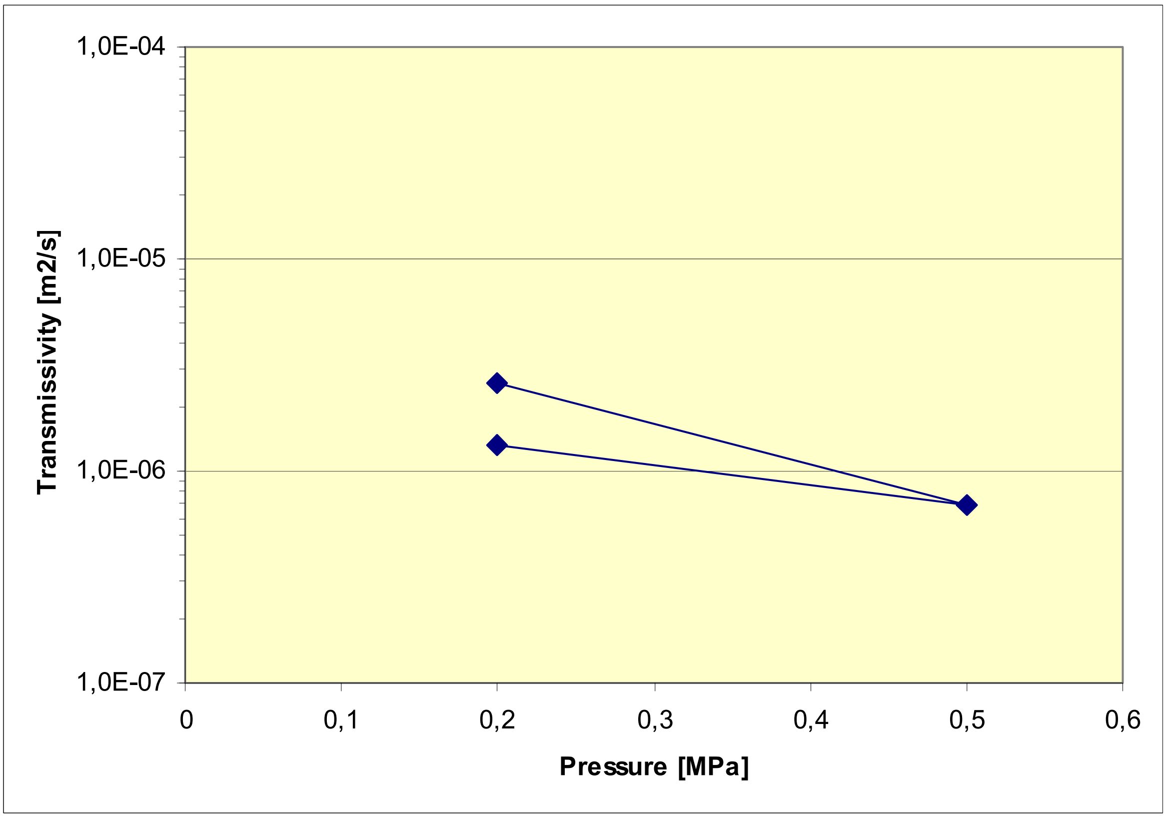


KLX23A

Water Loss Measurements **Packer Interval** **50-100,15 m**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	7,9	5,2	4
t [min]	3	3	3
t [sec]	180	180	180
L [m]	50,15	50,15	50,15
P [Mpa]	0,2	0,5	0,2
T	**2,6E-06**	**6,9E-07**	**1,3E-06**
K	**5,2E-08**	**1,4E-08**	**2,6E-08**

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

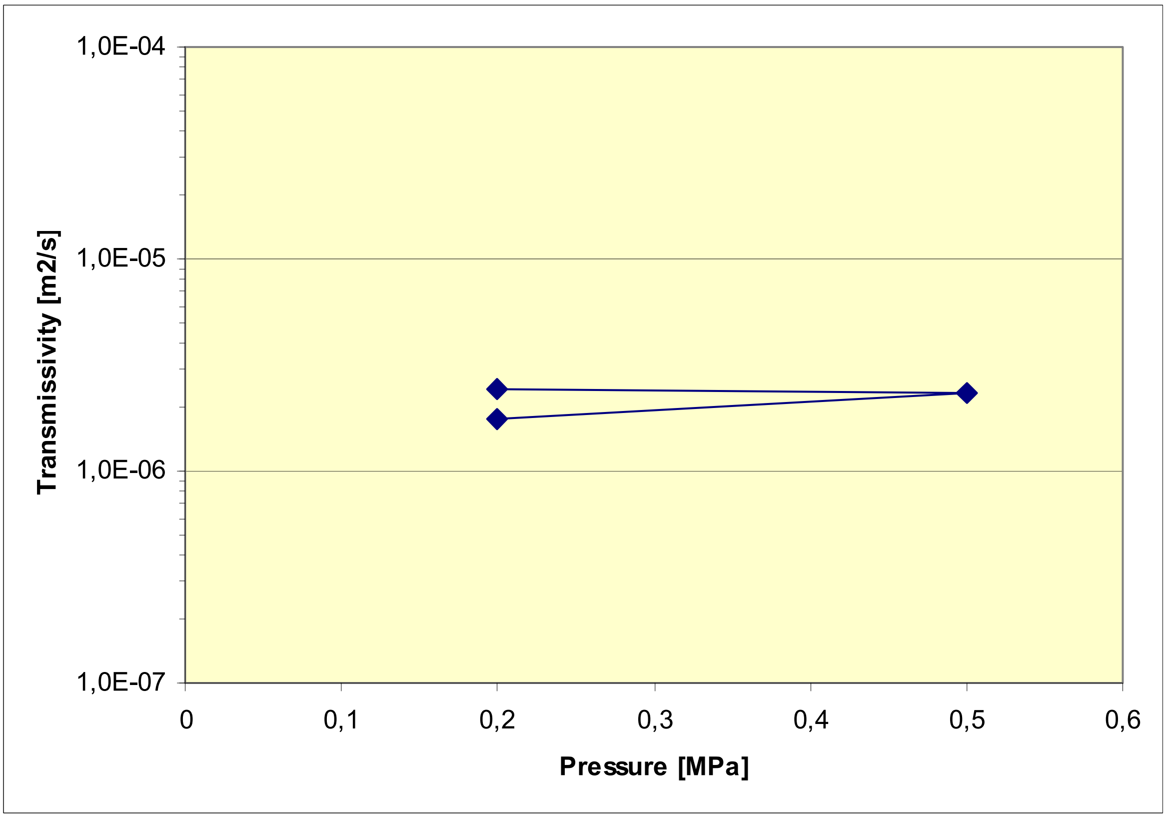


KLX23B

Water Loss Measurements **Packer Interval** **2,5-50,27 m**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	7,4	17,6	5,3
t [min]	3	3	3
t [sec]	180	180	180
L [m]	47,77	47,77	47,77
P [Mpa]	0,2	0,5	0,2
T	**2,4E-06**	**2,3E-06**	**1,7E-06**
K	**5,1E-08**	**4,9E-08**	**3,7E-08**

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

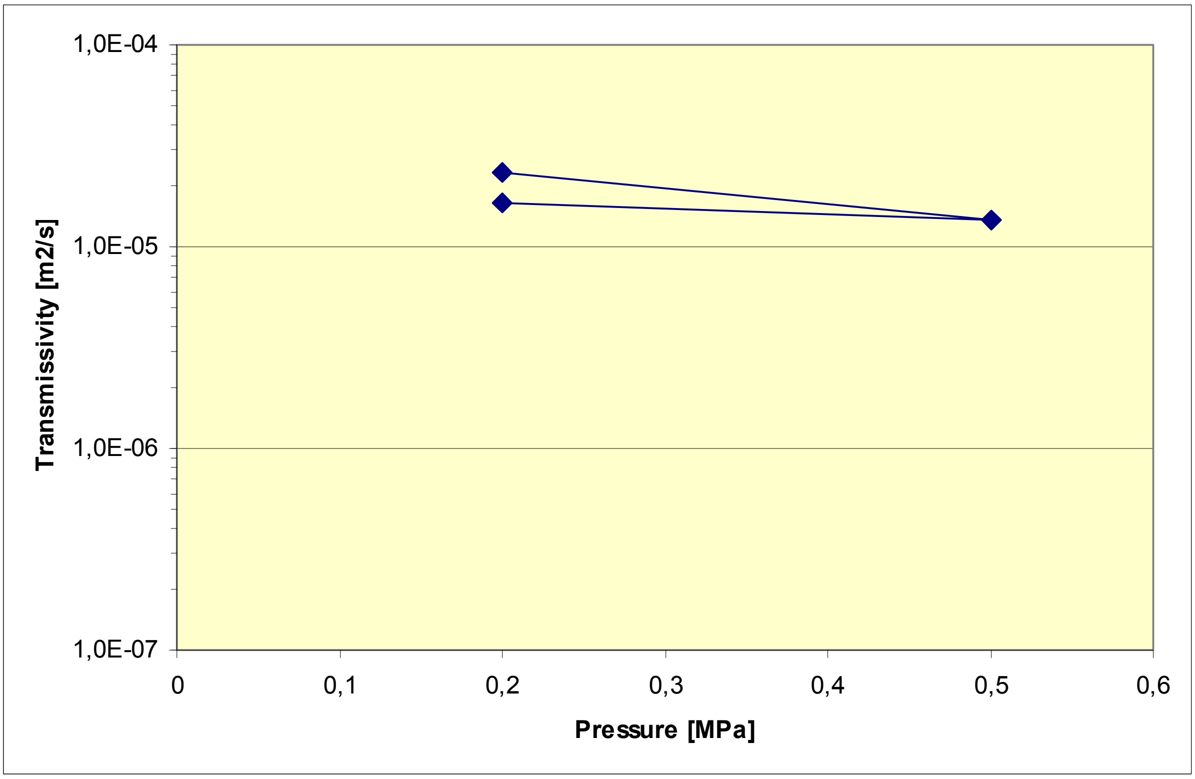


KLX24A

Water Loss Measurements **Packer Interval** **2,70-100,17 m**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	65	94	46
t [min]	3	3	3
t [sec]	180	180	180
L [m]	97,47	97,47	97,47
P [Mpa]	0,2	0,5	0,2
T	**2,3E-05**	**1,4E-05**	**1,7E-05**
K	**2,4E-07**	**1,4E-07**	**1,7E-07**

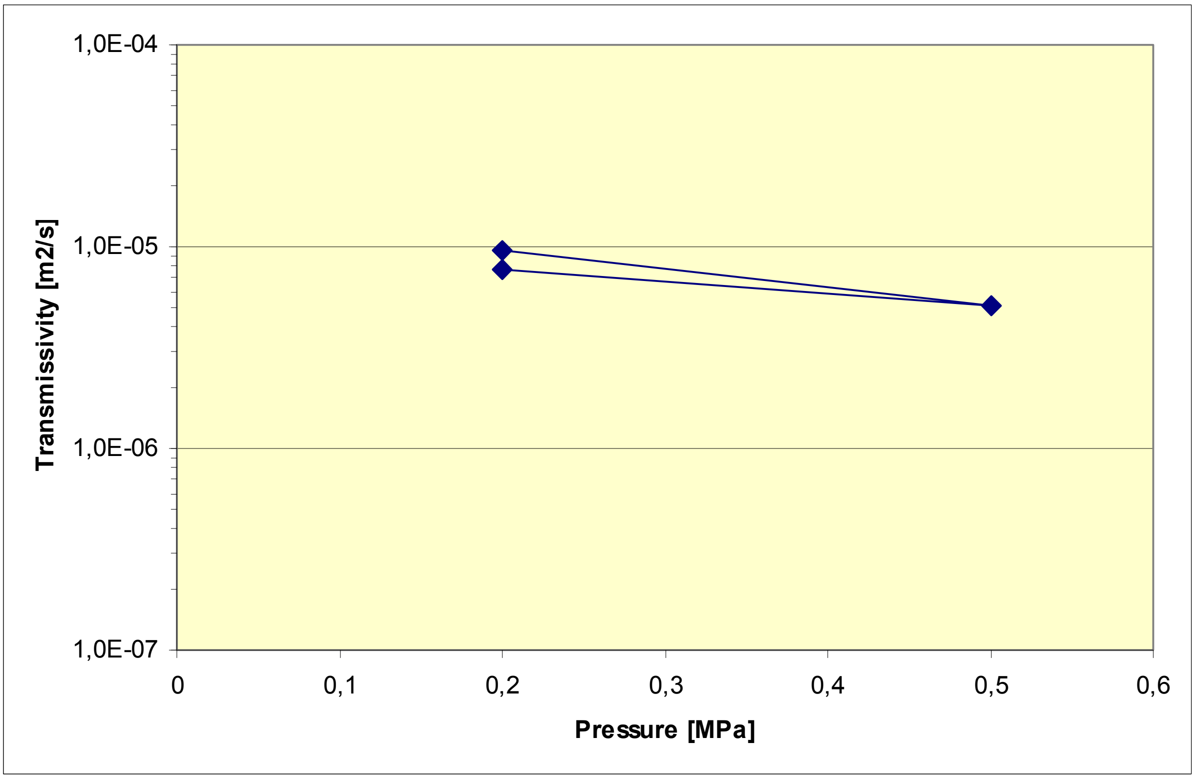
$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$



KLX25A

Water Loss Measurements		**Packer Interval**		**3,50-50,24 m**
MDZ Drillholes				
	Pressure steps [Mpa]			
	0,2	0,5	0,2	
Q [l]	26,7	35,7	21,4	
t [min]	3	3	3	
t [sec]	180	180	180	
L [m]	97,47	97,47	97,47	
P [Mpa]	0,2	0,5	0,2	
T	**9,6E-06**	**5,2E-06**	**7,7E-06**	
K	**9,9E-08**	**5,3E-08**	**7,9E-08**	

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

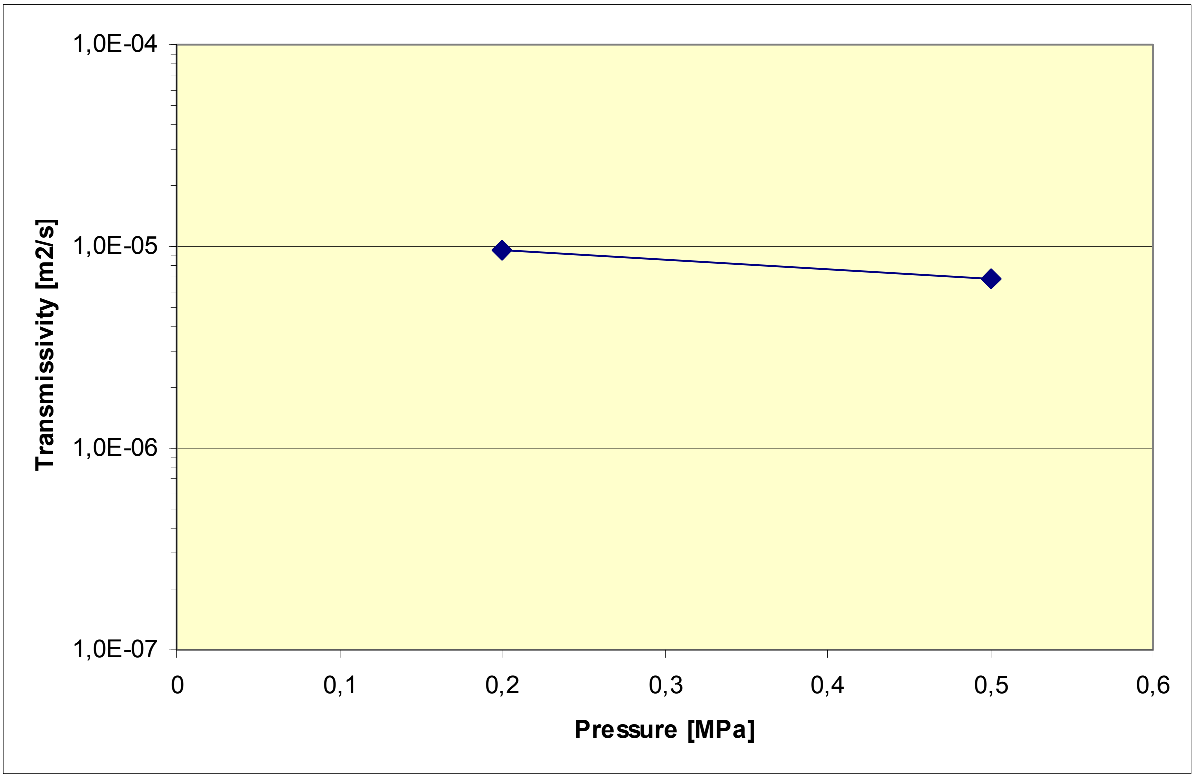


KLX26A

Water Loss Measurements **Packer Interval** **29-44,16 m**
MDZ Drillholes

	Pressure steps [Mpa]	
	0,2	0,5
Q [l]	115	208
t [min]	10	10
t [sec]	600	600
L [m]	15,16	15,16
P [Mpa]	0,2	0,5
T	**9,6E-06**	**7,0E-06**
K	**6,3E-07**	**4,6E-07**

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

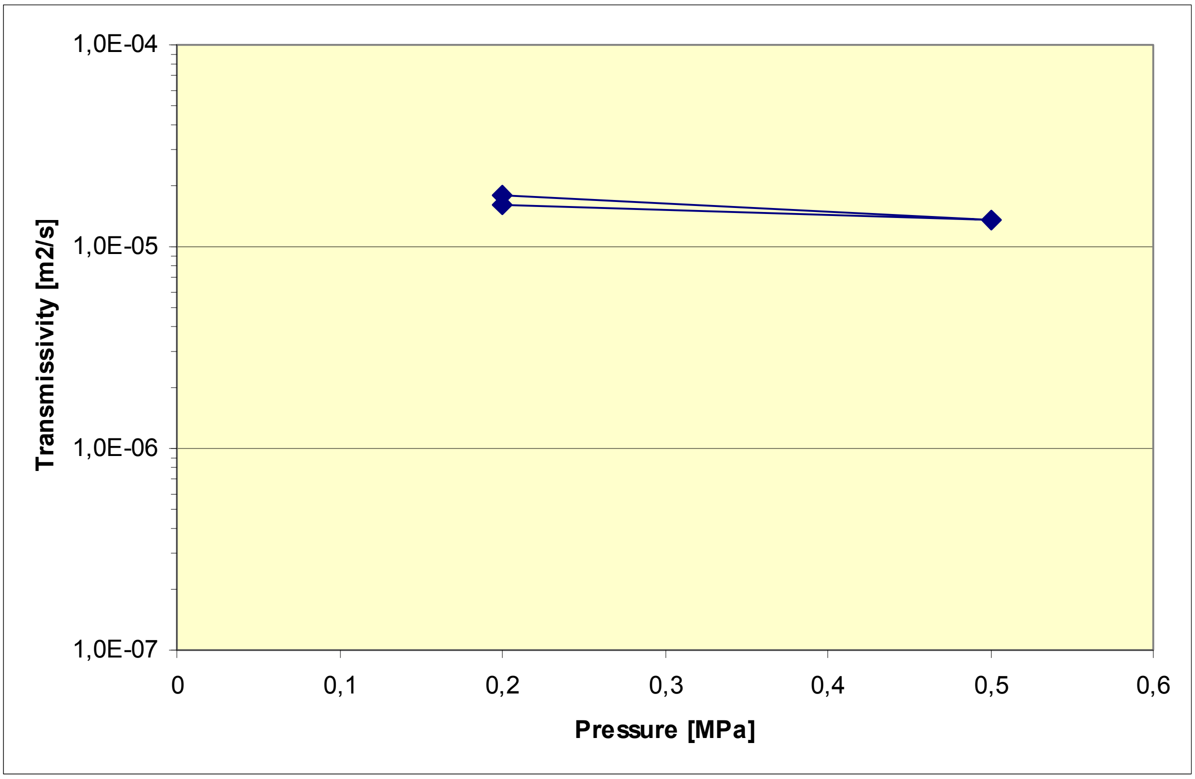


KLX26A

Water Loss Measurements **Packer Interval** **2,80-101,14 m**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	45	93	50
t [min]	3	3	3
t [sec]	180	180	180
L [m]	98,34	97,47	97,47
P [Mpa]	0,2	0,5	0,2
T	**1,6E-05**	**1,3E-05**	**1,8E-05**
K	**1,7E-07**	**1,4E-07**	**1,9E-07**

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

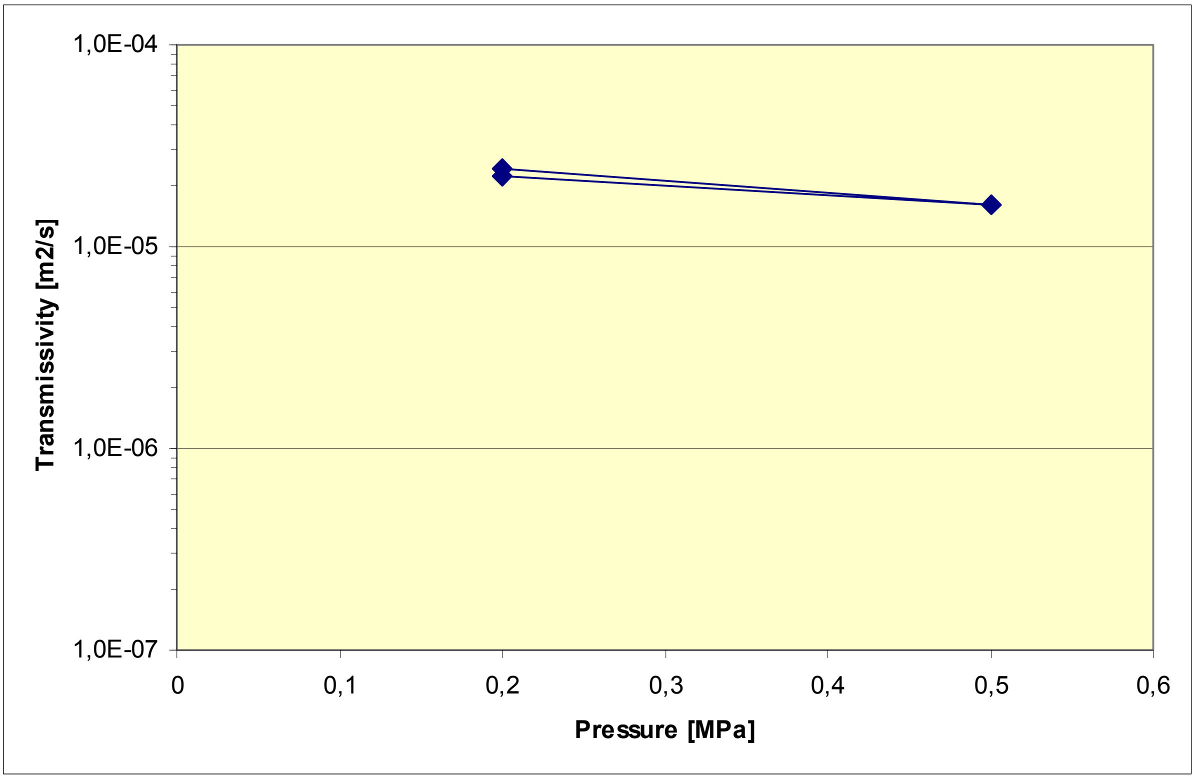


KLX26B

Water Loss Measurements **Packer Interval** **2,60-50,37 m**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	68	111	67
t [min]	3	3	3
t [sec]	180	180	180
L [m]	47,77	97,47	97,47
P [Mpa]	0,2	0,5	0,2
T	**2,2E-05**	**1,6E-05**	**2,4E-05**
K	**4,7E-07**	**1,6E-07**	**2,5E-07**

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

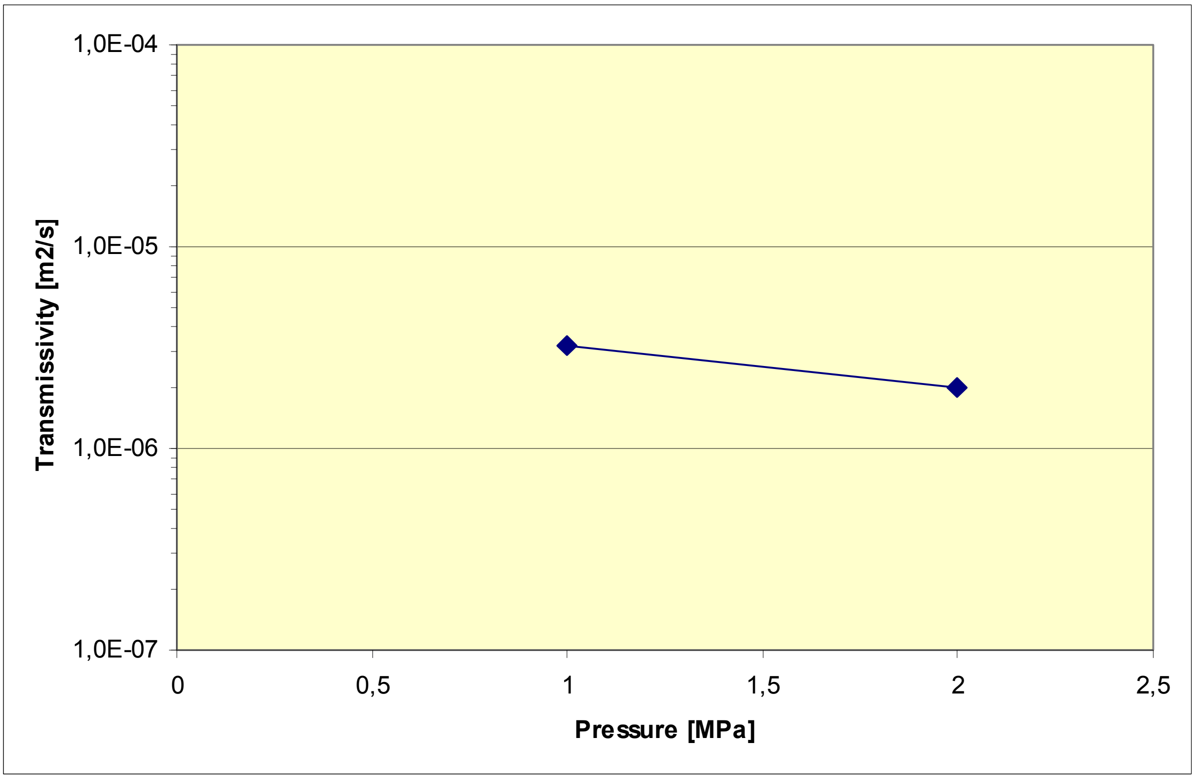


KLX28A

Water Loss Measurements **Packer Interval** **5,80-80,23**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	31	48	
t [min]	10	10	
t [sec]	600	600	
L [m]	74,43	74,43	
P [Mpa]	0,2	0,5	
T	**3,2E-06**	**2,0E-06**	
K	**4,4E-08**	**2,7E-08**	

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$

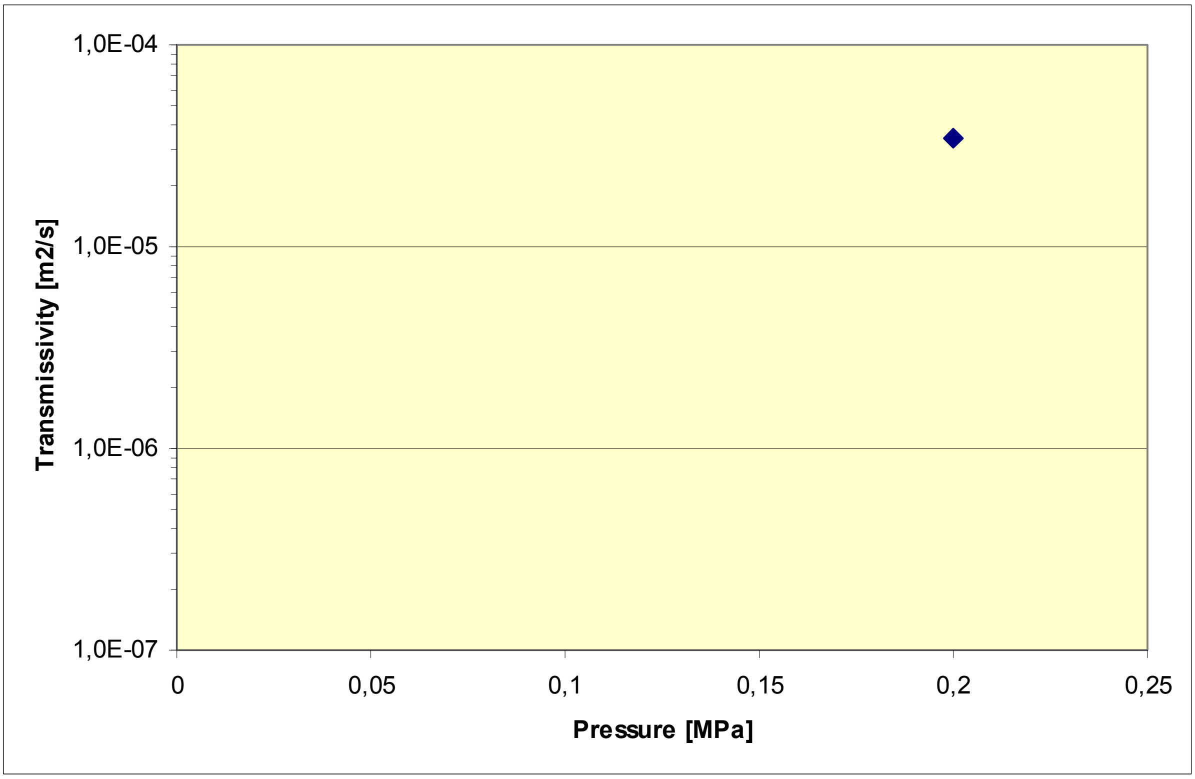


KLX29B

Water Loss Measurements **Packer Interval** **11-60,25 m**
MDZ Drillholes

	Pressure steps [Mpa]		
	0,2	0,5	0,2
Q [l]	347		
t [min]	10		
t [sec]	600		
L [m]	49,25		
P [Mpa]	0,2		
T	**3,4E-05**		
K	**7,0E-07**		

$$K = \frac{Q}{PtL} \cdot \left[\frac{1 + \ln(L/d)}{2\pi} \right]$$



Appendix G

Open hole injections test in KLX10B

Mansueto Morosini, SKB

DISTRIBUTION
Tommy Olsson, Roy Stanfors

Hydraulic characterization of MDZ in KLX10B

Background

From the detailed geological mapping the inferred local minor deformation zone (MDZ) is situated at 11-20m borehole length. This part of the borehole is to a large extent the position of the drawdown cone generated during the PFL. Hence, it was not possible to measure inflow from this part of the borehole during the PFL, appendix 2.

Objective and scope

The objective is to characterise the MDZ in terms of its hydraulic properties, in particular the transmissivity. This MDZ is coincident with the fine grained granite, appendix 1.

This done through a constant head injection and recovery test (CHir) where head is maintained constant at the top of casing. The test consist of two phases a) injection and b) recovery. Such measurement will yield a transmissivity for the whole borehole which in conjunction with the results from the PFL being below the MDZ will allow to calculate the transmissivity of the rock in the interval 9-20m, appendix 2.

The test was conducted on 2006-12-14.

Analysis

During the injection phase steady state condiditon were eventually obtained. This allows the calculation of transmissivity with the steady state relation of Moye and with the transient relation of Jacob. The recovery phase was analysed with the transient relation of Jacob.

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Corp id SE556175201401 *Seat* Stockholm

Results

Derived transmissivites from various tests are compiled in table 1.

	Secup (m)	Seclow (m)	Transmissivity (m^2/s)	
Chi-Jacob	9	50	$1.2 \cdot 10^{-4}$	
Chi-Moye	9	50	$9.5 \cdot 10^{-5}$	
CHr-Jacob	9	50	$1.3 \cdot 10^{-4}$	
PFL borehole	16	50	$5.5 \cdot 10^{-5}$	
PFLsum anom	16	50	$3.5 \cdot 10^{-5}$	Zero balance with pumped flow!

From the above table we can conclude that

a) a consistent transmissivity of c.$1.0 \cdot 10^{-4}$ m^2/s is obtained from the injection testing
b) a consistent transmissivity of c. $4.5 \cdot 10^{-5}$ m^2/s is obtained from the PFL testing

The pumped flow during the PFL was accounted for completely by the sum of the inflow anomalies. The anomalies were encountered in the interval 19-45m. Hence, during the PFL measurements the part of the borehole 9-19m was not characterized. This part is largely covered by the MDZ.

Conclusion

The difference in transmissivity account for the interval 9-19m i e $1.0 \cdot 10^{-4} - 4.5 \cdot 10^{-5} = 6.5 \cdot 10^{-5}$ m^2/s, by and large coincident with the MDZ.

It can not, however, be argued that $6.5 \cdot 10^{-5}$ m^2/s is the T of the MDZ exclusively. But it is certainly from or close to the MDZ, the discrepancy being the distance from the casing (9m) to the upper boundary of the MDZ (11m).

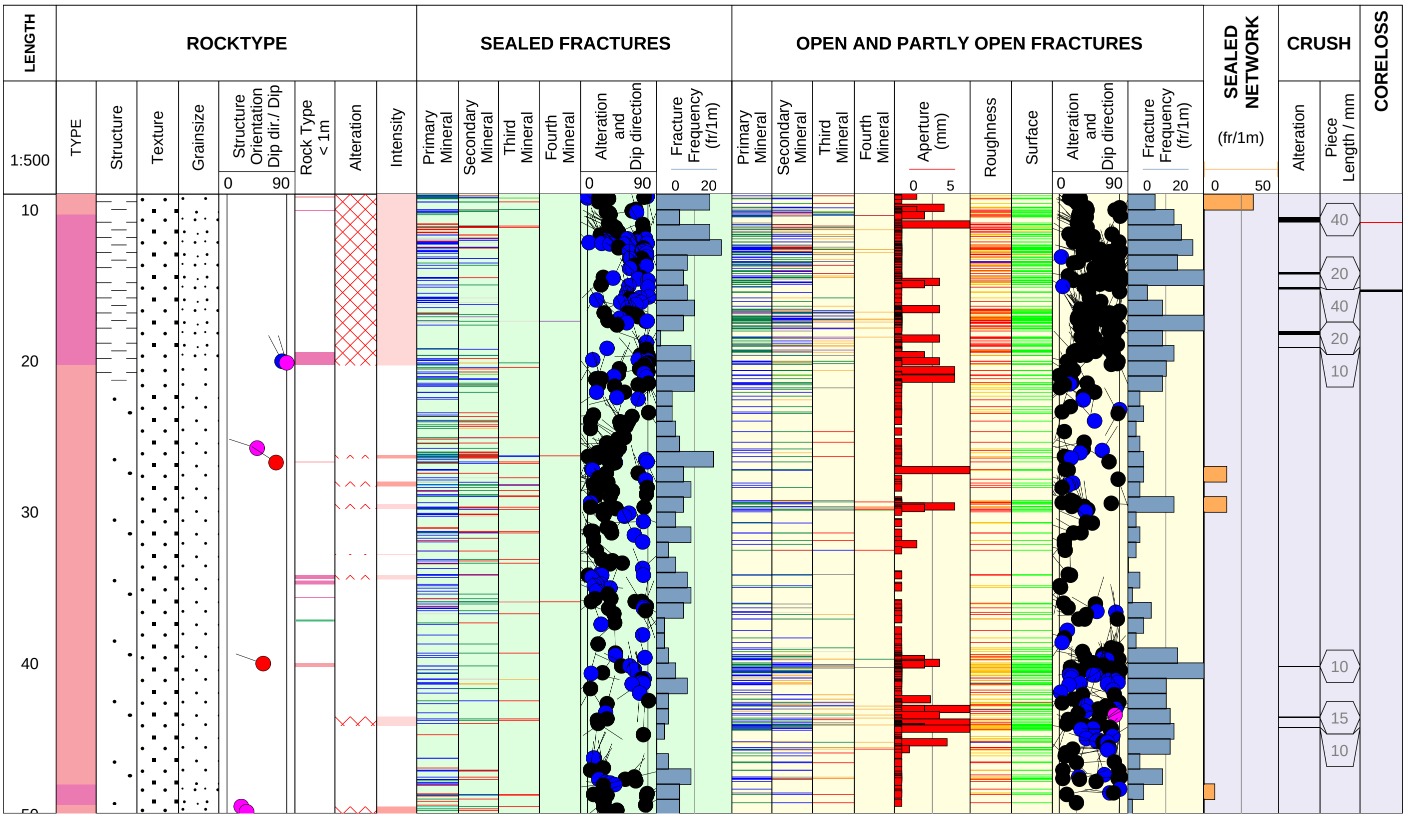
/mm

Attachements
1. Detailed geology log
2. PFL flow anomaly log
3. Injection test results

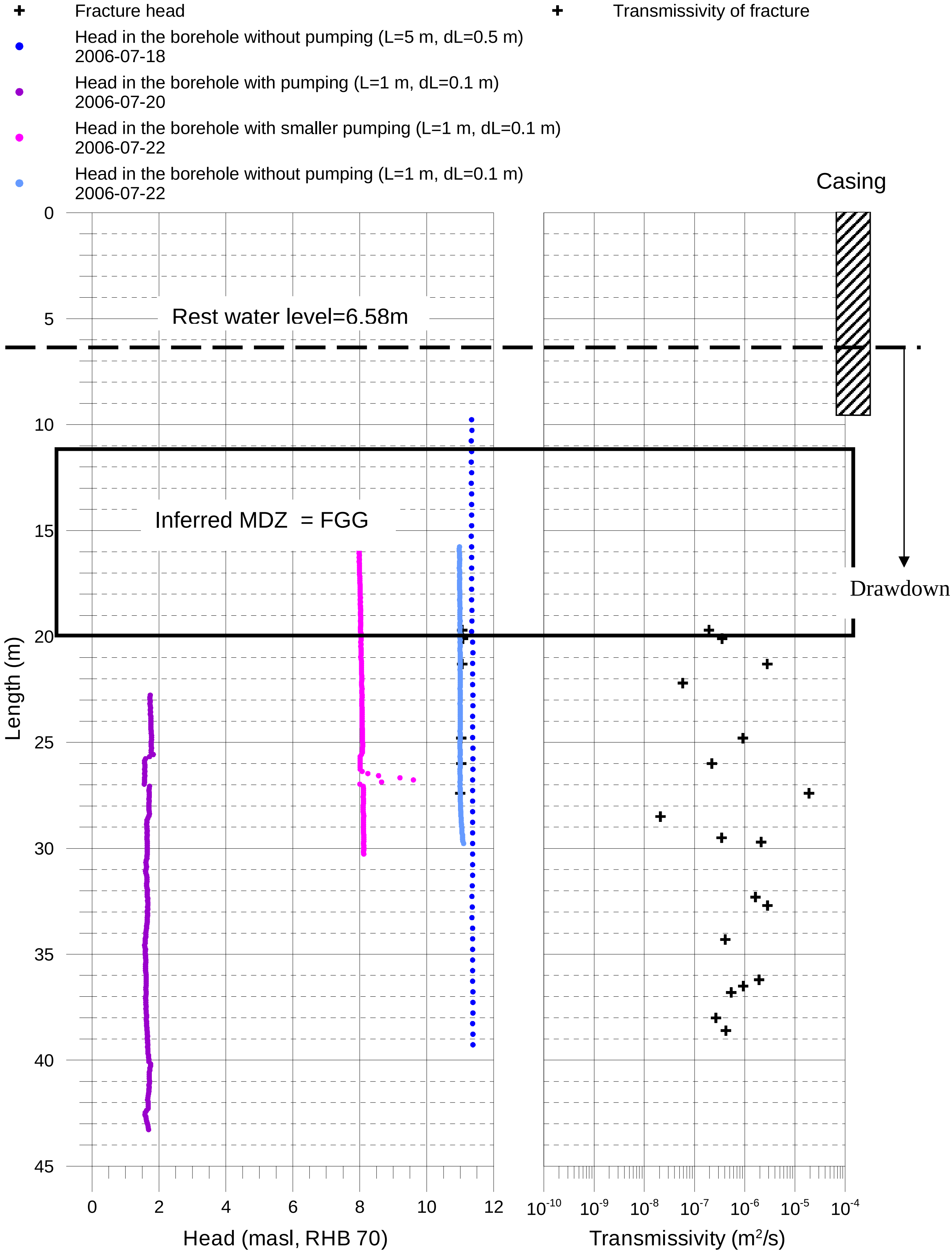
Title GEOLOGY IN KLX10B

Appendix:

Site	LAXEMAR	**Coordinate System**	RT90-RHB70
Borehole	KLX10B	**Northing [m]**	6366315.67
Diameter [mm]	76	**Easting [m]**	1548525.20
Length [m]	50.250	**Elevation [m.a.s.l.]**	18.08
Bearing [°]	170.33	**Drilling Start Date**	2006-02-08 16:35:00
Inclination [°]	-59.64	**Drilling Stop Date**	2006-02-14 06:55:00
Date of coremapping	2006-04-12 17:24:00	**Plot Date**	2006-05-01 21:13:07
Rocktype data from	p_rock	**Signed data**	



Laxemar, borehole KLX10B
Transmissivity and head of detected fractures



Main Results	Injektionsfas
Company: Svensk Kärnbränslehantering AB	Field: Laxemar
Well: KLX10B	Test Name / #: Injection test in KLX10B for MDZ

Test date / time	2006-12-14 10:00
Formation interval	9 - 50m
Perforated interval	9 - 50m
Gauge type / #	Mitec
Gauge depth	13m b toc borehole length
Field crew	Andersson, Hagman, Henriksson
Analysis by	Mansueto Morosini, SKB
TEST TYPE	Standard
Porosity Phi (%)	10
Well Radius rw	0.0379 m
Pay Zone h	41 m
Water Salt (ppm)	10000
Form. compr.	4.35113E-10 Pa-1
Reservoir T	10 °C
Reservoir P	500 kPa
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	1E-8 Pa-1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	0.117 [sec]-1
PMatch	2.02 [kPa]-1
C	6.32E-7 m3/Pa
Total Skin	2
T	1.16E-4 m2/s
K	2.82E-6 m/s
Pi	56 kPa

Model Parameters

Well & Wellbore parameters (KLX10B)

C	6.32E-7 m3/Pa
Skin	2

Reservoir & Boundary parameters

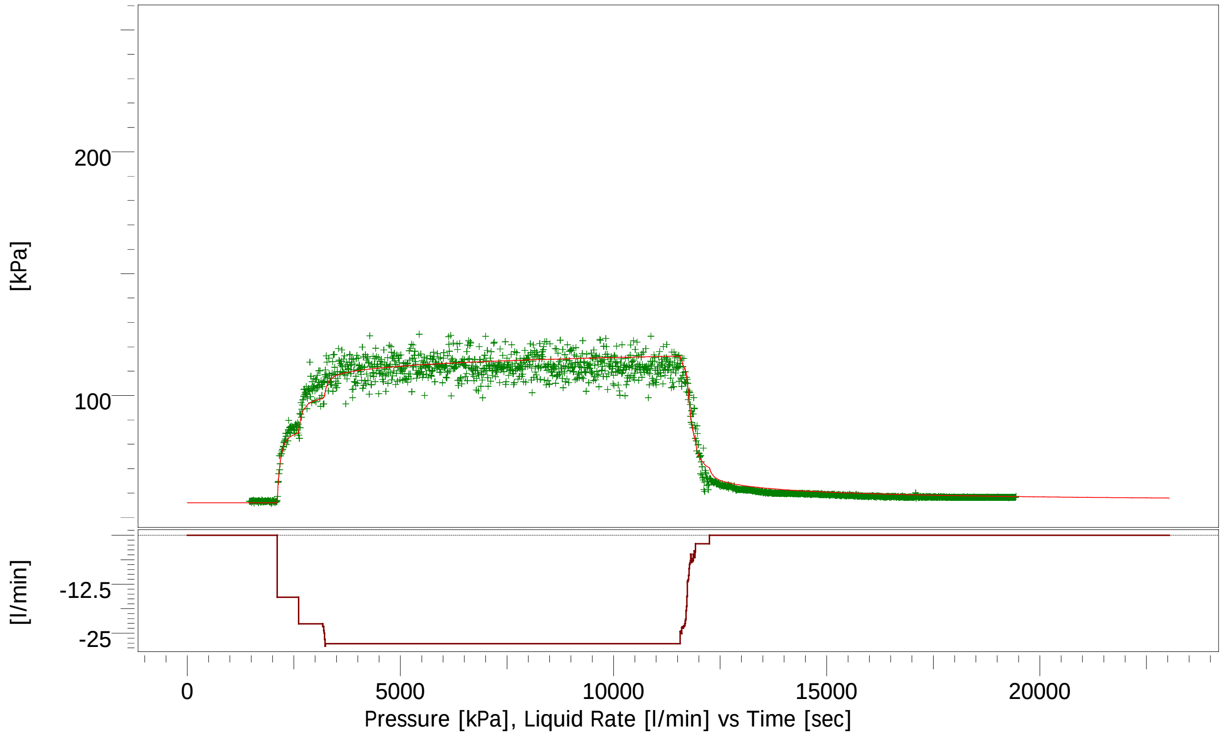
Pi	56 kPa
T	1.16E-4 m2/s
K	2.82E-6 m/s

Derived & Secondary Parameters

P @ dt=0	57.2 kPa
Rinv	95.8 m
Test. Vol.	0.118198 MMm3
Delta P (Total Skin)	0.991808 kPa
Delta P Ratio (Total Skin)	0.0691314 Fraction

History plot	Injektionsfas

Company Svensk Kärnbränslehantering AB — Field Laxemar
Well KLX10B — Test Name / # Injection test in KLX10B for MDZ



KLX10B injektionstest 061214_Q & p (mitec) injection #1

Rate	-2.19 l/min
Rate change	2.19 l/min
P@dt=0	57.224 kPa
Pi	56 kPa
Smoothing	0.5

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	0.117 [sec]-1
PMatch	2.02 [kPa]-1
C	6.32E-7 m3/Pa
Total Skin	2
T	1.16E-4 m2/s
K	2.82E-6 m/s
Pi	56 kPa

Model Parameters

Well & Wellbore parameters (KLX10B)

C	6.32E-7 m3/Pa
Skin	2

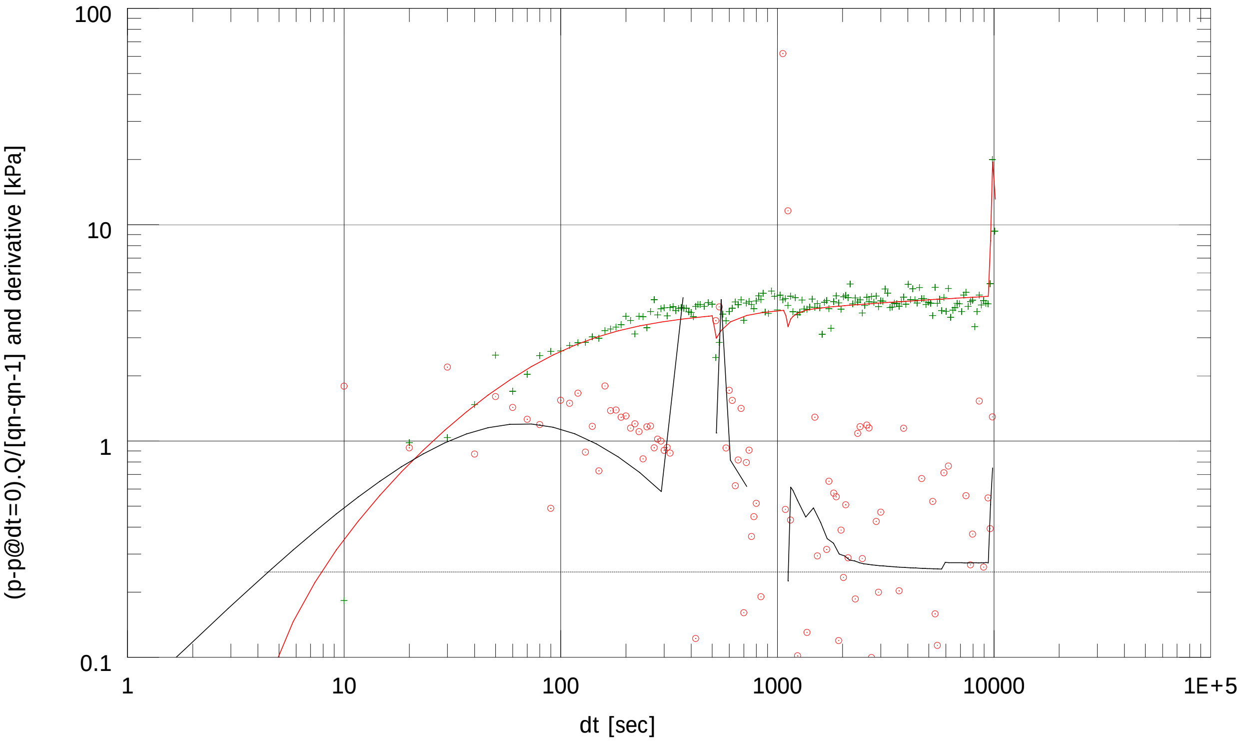
Reservoir & Boundary parameters

Pi	56 kPa
T	1.16E-4 m2/s
K	2.82E-6 m/s

Derived & Secondary Parameters

P @ dt=0	57.2 kPa
Rinv	95.8 m
Test. Vol.	0.118198 MMm3
Delta P (Total Skin)	0.991808 kPa
Delta P Ratio (Total Skin)	0.0691314 Fraction

Log-Log plot	Injektionsfas
Company Svensk Kärnbränslehantering AB Well KLX10B	Field Laxemar Test Name / # Injection test in KLX10B for MDZ



KLX10B injektionstest 061214_Q & p (mitec) injection #1

Rate	-2.19 l/min
Rate change	2.19 l/min
P@dt=0	57.224 kPa
Pi	56 kPa
Smoothing	0.5

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	0.117 [sec]-1
PMatch	2.02 [kPa]-1
C	6.32E-7 m3/Pa
Total Skin	2
T	1.16E-4 m2/s
K	2.82E-6 m/s
Pi	56 kPa

Model Parameters

Well & Wellbore parameters (KLX10B)

C	6.32E-7 m3/Pa
Skin	2

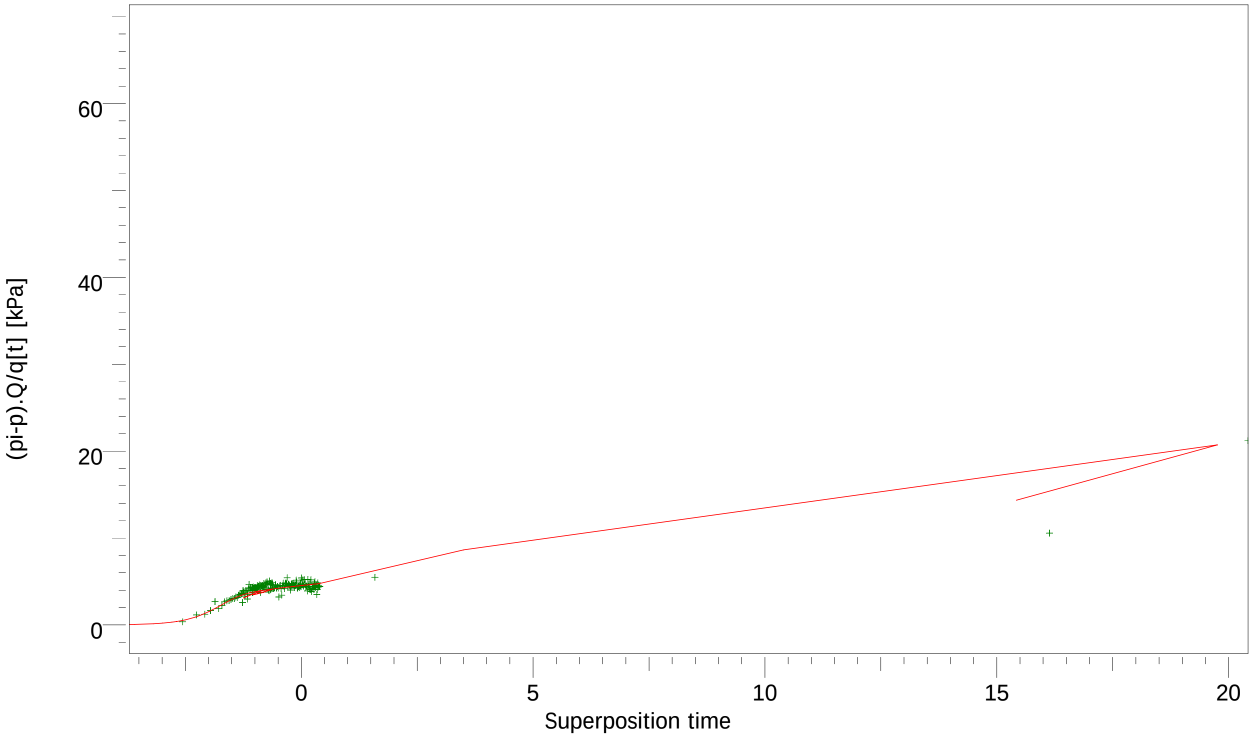
Reservoir & Boundary parameters

Pi	56 kPa
T	1.16E-4 m2/s
K	2.82E-6 m/s

Derived & Secondary Parameters

P @ dt=0	57.2 kPa
Rinv	95.8 m
Test. Vol.	0.118198 MMm3
Delta P (Total Skin)	0.991808 kPa
Delta P Ratio (Total Skin)	0.0691314 Fraction

Semi-Log plot	Injektionsfas
Company Svensk Kärnbränslehantering AB Well KLX10B	Field Laxemar Test Name / # Injection test in KLX10B for MDZ



KLX10B injektionstest 061214_Q & p (mitec) injection #1

Rate	-2.19 l/min
Rate change	2.19 l/min
P@dt=0	57.224 kPa
Pi	56 kPa
Smoothing	0.5

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	0.117 [sec]-1
PMatch	2.02 [kPa]-1
C	6.32E-7 m3/Pa
Total Skin	2
T	1.16E-4 m2/s
K	2.82E-6 m/s
Pi	56 kPa

Model Parameters

Well & Wellbore parameters (KLX10B)

C	6.32E-7 m3/Pa
Skin	2

Reservoir & Boundary parameters

Pi	56 kPa
T	1.16E-4 m2/s
K	2.82E-6 m/s

Derived & Secondary Parameters

P @ dt=0	57.2 kPa
Rinv	95.8 m
Test. Vol.	0.118198 MMm3
Delta P (Total Skin)	0.991808 kPa
Delta P Ratio (Total Skin)	0.0691314 Fraction

Test date / time	2006-12-14 10:00
Formation interval	9 - 50m
Perforated interval	9 - 50m
Gauge type / #	Mitec
Gauge depth	13m b toc borehole length
Field crew	Andersson, Hagman, Henriksson
Analysis by	Mansueto Morosini, SKB
TEST TYPE	Standard
Porosity Phi (%)	10
Well Radius rw	0.0379 m
Pay Zone h	41 m
Water Salt (ppm)	10000
Form. compr.	4.35113E-10 Pa-1
Reservoir T	10 °C
Reservoir P	500 kPa
FLUID TYPE	Water
Volume Factor B	1 B/STB
Viscosity	1E-3 Pa.sec
Total Compr. ct	1E-8 Pa-1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	0.595 [sec]-1
PMatch	2.21 [kPa]-1
C	1.36E-7 m3/Pa
Total Skin	2.01
T	1.27E-4 m2/s
K	3.1E-6 m/s
Pi	56 kPa

Model Parameters

Well & Wellbore parameters (KLX10B)

C	1.36E-7 m3/Pa
Skin	2.01

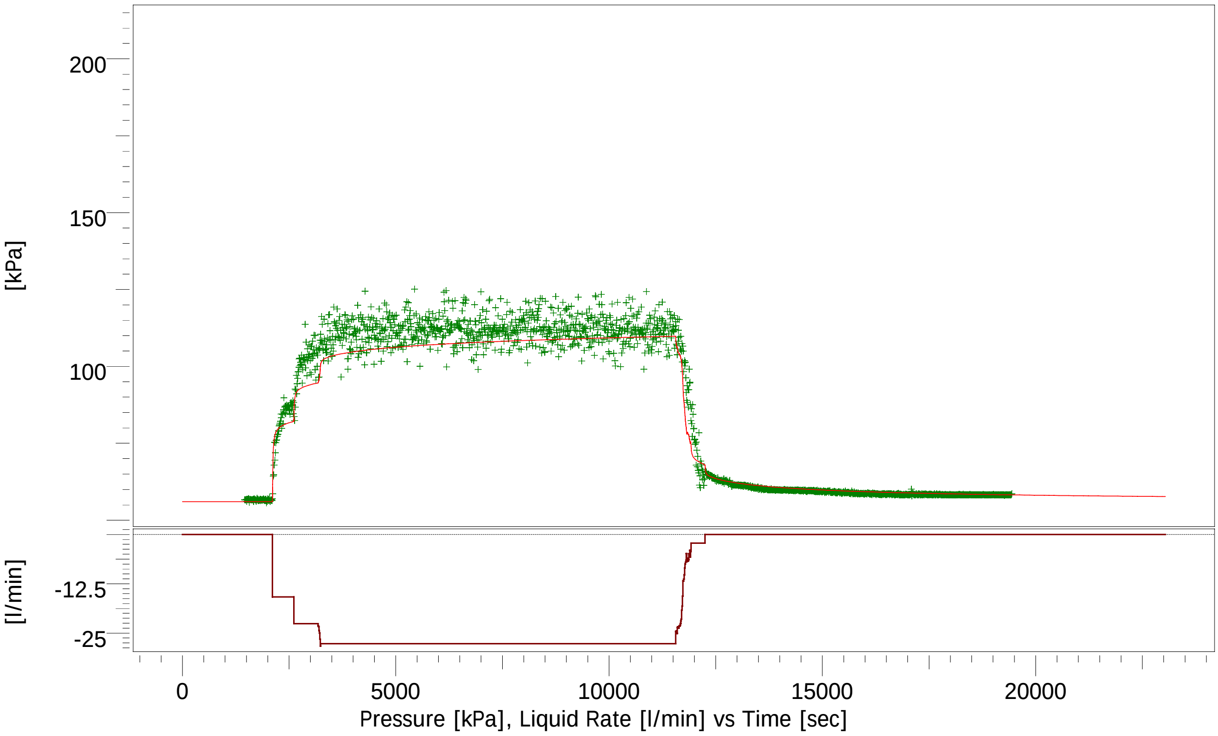
Reservoir & Boundary parameters

Pi	56 kPa
T	1.27E-4 m2/s
K	3.1E-6 m/s

Derived & Secondary Parameters

P @ dt=0	63.9 kPa
Rinv	84.8 m
Test. Vol.	0.092543 MMm3
Delta P (Total Skin)	0.909135 kPa
Delta P Ratio (Total Skin)	0.0880093 Fraction

History plot	Återhämtningsfas
Company Svensk Kärnbränslehantering AB Well KLX10B	Field Laxemar Test Name / # Injection test in KLX10B for MDZ



KLX10B injektionstest 061214_Q & p (mitec) fall-off #1

Rate	0 l/min
Rate change	2.19 l/min
P@dt=0	63.912 kPa
Pi	56 kPa
Smoothing	0.1

Selected Model

Model Option	Standard Model
Well	Vertical
Reservoir	Homogeneous
Boundary	Infinite

Main Model Parameters

TMatch	0.595 [sec]-1
PMatch	2.21 [kPa]-1
C	1.36E-7 m3/Pa
Total Skin	2.01
T	1.27E-4 m2/s
K	3.1E-6 m/s
Pi	56 kPa

Model Parameters

Well & Wellbore parameters (KLX10B)

C	1.36E-7 m3/Pa
Skin	2.01

Reservoir & Boundary parameters

Pi	56 kPa
T	1.27E-4 m2/s
K	3.1E-6 m/s

Derived & Secondary Parameters

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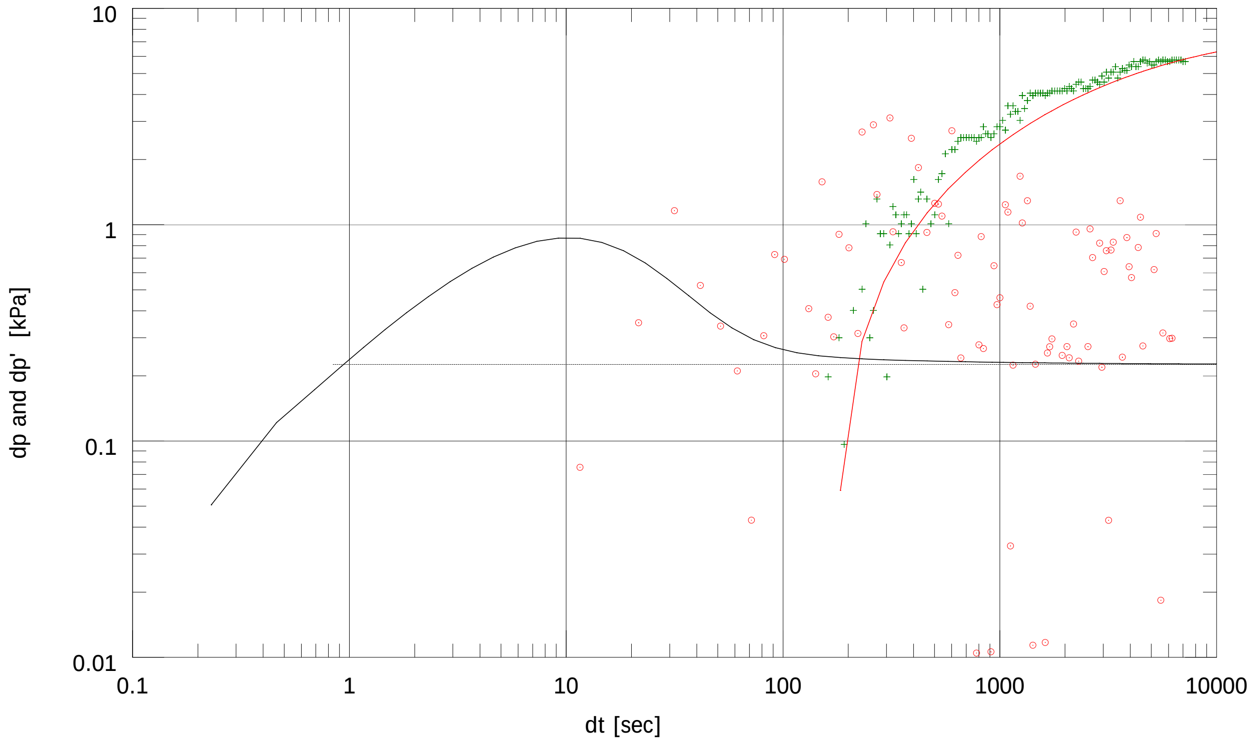
Rinv	84.8 m
Test. Vol.	0.092543 MMm3
Delta P (Total Skin)	0.909135 kPa
Delta P Ratio (Total Skin)	0.0880093 Fraction

Log-Log plot	Återhämtningsfas
Company Svensk Kärnbränslehantering AB Well KLX10B	Field Laxemar Test Name / # Injection test in KLX10B for MDZ



KLX10B injektionstest 061214_Q & p (mitec) fall-off #1

Rate	0 l/min
Rate change	2.19 l/min
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Pi	56 kPa
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Selected Model

Model Option	Standard Model
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Boundary	Infinite

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TMatch	0.595 [sec]-1
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Skin	2.01

Reservoir & Boundary parameters

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K	3.1E-6 m/s

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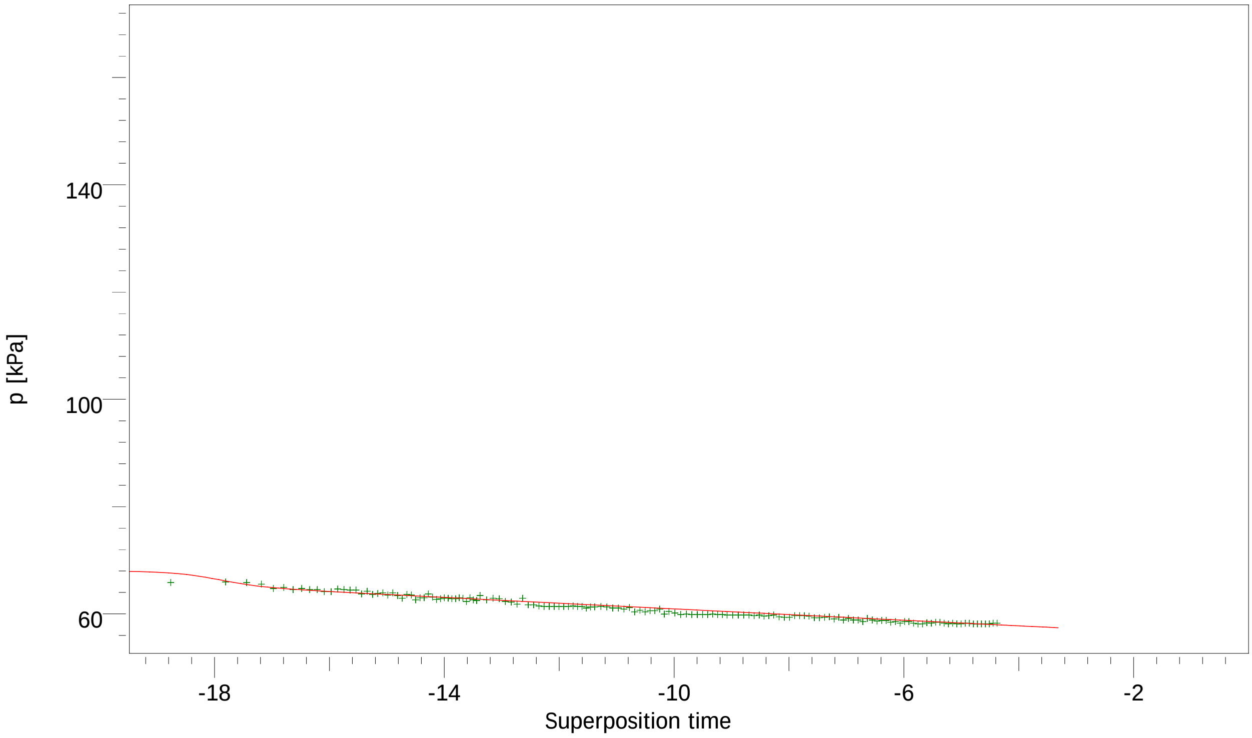
Test. Vol.	0.092543 MMm3
Delta P (Total Skin)	0.909135 kPa
Delta P Ratio (Total Skin)	0.0880093 Fraction

Semi-Log plot	Återhämtningsfas

Company Svensk Kärnbränslehantering AB — Well KLX10B

Field Laxemar — Test Name / # Injection test in KLX10B for MDZ



KLX10B injektionstest 061214_Q & p (mitec) fall-off #1

Rate	0 l/min
Rate change	2.19 l/min
P@dt=0	63.912 kPa
Pi	56 kPa
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Selected Model

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