P-05-269

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December 2007

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ISSN 1651-4416
SKB P-05-269

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Keywords: Outcrop, Fracture, Lithology, Drill site 7, Scan-line, Quaternary deposits, Ground penetrating radar, Sheet joints, AP PF 400-05-074.

Abstract

SKB performs site investigations in Forsmark and Oskarshamn for location of a deep repository for high radioactive waste.

This document reports the data gained during detailed bedrock mapping and subsequent detailed fracture mapping of the bedrock on an excavated rock surface, outcrop AFM001264 located in the candidate area at Forsmark. In addition, a detailed mapping of a fracture zone in a trench AFM001265 was carried out.

The aim of mapping was to collect data for statistical analyses of fractures for the DFN model. The DFN model aims to stochastically model the fracture network.

Fracture trace geometry and rock contacts were surveyed by a total station, with the survey points along the fracture traces adapted to fracture geometry. Survey points varied from two, for a straight trace on a flat surface, to several points along an undulating fracture trace or an irregular rock surface. All fractures with a length more than 0.5 m were surveyed. All surveyed data have been converted to the RT90 2.5 gon V, RHB70 survey system.

Strike, dip and other properties such as rock type, termination of fracture, rock type contact relationships, aperture, shape, roughness, indications of movement, mineral fillings and alteration, were registered manually. Detailed bedrock mapping, including magnetic susceptibility measurements, were carried out by SwedPower AB.

The outcrop AFM001264 has an area of 275 m^2, part of which features more or less loose blocks. Due to this, detailed fracture mapping covers an area of 184 m^2. In total 322 fractures were mapped, resulting in a fracture frequency of 1.7 fractures/m^2.

On the outcrop AFM001264, scan line mapping was carried out along two lines, each with a length of 10 metres. The trend of the lines was approximately East-West and North-South, respectively. Truncation of the fracture trace in the scan lines was 0.2 metres.

In the fracture zone in Trench AFM001265, a total of 139 fractures were mapped. Truncation of the fracture trace was 0.2 metres.

A comparison was made between surveyed points and manually recorded data, mainly concerning fracture host rock and fracture strike in order to detect errors due to miswriting, compass misreading, magnetic disturbance, etc.

The dominating rock type on the exposure is medium-grained metagranite with granitic to granodioritic composition and a fine-grained amphibolite, the latter occurring as deformed and boudinaged dikes. Minor pegmatite and quartz veins are also present.

A study of the Quaternary deposits was performed to describe the spatial distribution and properties of the regolith as studied in the excavated outcrop AFM001264. Furthermore, Ground Penetrating Radar measurements were carried out at the outcrop. The purpose of the measurements was to study the possibility of mapping sheet joints.

Sammanfattning

SKB utför platsundersökningar i Forsmark och Oskarshamn för att finna en plats att djupförvara använt kärnbränsle.

Denna rapport beskriver en detaljkartering av sprickor och bergarter på en avrymd berghäll, AFM001264, som ligger inom kandidatområdet i Forsmark i anslutning till borrplats 7. Dessutom redovisas resultaten från den detaljkartering av en sprickzon som utfördes i dike AFM001265.

Ändamålet för insamlande av sprickdata är att samla information för diskret sprickmodellering (DFN) och statistisk sprickanalys.

Sprickornas geometri har karterats med en totalstation, där ett antal punkter uppmätts längs sprickspåret på hällen. Om sprickan är rak och hällens topografi jämn har endast de två ändpunkterna uppmätts. Ifall sprickan är undulerande eller om topografin varierar har mätpunkter etablerats på lämpliga ställen, såsom brytpunkter utmed sprickspåret. Samtliga sprickor med ett sprickspår längre än 0,5 m har karterats.

På hällen utfördes även linjekartering längs två ca 10 m långa linjer i nord-sydlig respektive öst-västlig riktning, där samtliga sprickor med sprickspårslängd längre än 0,2 m har karterats. Alla inmätta geometriska data har konverterats till RT90 2.5 gon V, RHB70-systemet.

Sprickornas strykning, stupning och övriga geologiska egenskaper har karterats för hand. För varje spricka beskrivs sprickavslut, relation till bergartsgränser, vidd, form, strävhet, rörelseindikationer, sprickmineral och vittring. En detaljerad bergartskartering, inklusive bestämning av magnetisk susceptibilitet på hällen utfördes av SwedPower AB.

Hällen AFM001264 har totalt en yta på 275 m^2, varav 184 m^2 karterats i detalj eftersom resterande häll bestod av lösa block. Sammanlagt identifierades och karterades 322 sprickor över trunkeringslängden 0,5 m, vilket ger en sprickfrekvens på 1,7 sprickor per m^2.

Den del av hällen som inte karterades utgörs inte fast berg, utan är separerad från detta med sedimentfyllda, flackt lutande sprickplan och uppbruten i lösa block. Ett mindre parti av den karterade delen av hällen – ca 2 m^2 – utgörs också av lösa block skilda åt av sedimentfyllda eller tomma öppna sprickor.

Kompletterande detaljerad sprickkartering gjordes på sprickzonen i diket AFM001265. Totalt karterades 139 sprickor, med en minsta längd av 0,2 m.

För att spåra felaktigheter eller inkonsekvenser i data, har jämförelser gjorts mellan data inmätta med totalstation och manuellt mätta data.

Den dominerande bergarten på hällen AFM001264 utgörs av medelkornig granit-granodiorit och finkornig amfibolit. Den senare uppträder som deformerade och boudinerade gångar. Underordnat uppträder pegmatit och kvartsgångar.

I samband med jordavrymningen av AFM001264 utfördes också en studie av de kvartära sedimenten för att beskriva deras stratigrafi och egenskaper. Dessutom utfördes mätningar med markradar på hällytan för att studera eventuell förekomst av bankningssprickor.

Contents

1 Introduction

SKB performs site investigations in Forsmark and Oskarshamn for location of a deep repository for high radioactive waste. This document reports data gained during detailed fracture and bed-rock mapping of an outcrop within the candidate area at Forsmark. The outcrop, AFM001264, was mapped in early September 2005. Detailed fracture mapping of a deformation zone in a nearby trench, AFM001265, was also carried out.

The detailed fracture mapping, the detailed geological mapping and the study of the study of the Quaternary deposits were conducted according to Activity Plan PF 400-05-074, and SKB internal controlling documents; SKB MD 132.003, SKB MD 132.001 and SKB MD 131.001, respectively.

The location of the investigated outcrops is demonstrated in Figure 1-1. The outcrop has been excavated and cleaned from soil cover prior to mapping. The outcrop AFM001264 has an area of 275 m^2, part of which features more or less loose blocks. Due to this, the detailed fracture mapping covers an area of 184 m^2. In total 322 fractures were mapped, resulting in a frequency of 1.7 fractures per m^2.

The detailed fracture mapping of the deformation zone in the trench AFM001265, resulted in 139 mapped fractures.

The detailed geological mapping of the outcrop surface, the study of the Quaternary deposits and the additional measurements with the ground penetrating radar (GPR) are presented in Appendix A, Appendix B and Appendix C. respectively.

In Table 1-1, controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Original data from the reported activity are stored in the primary database Sicada, where they are traceable by the Activity Plan number AP PF 400-05-074. Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data.Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

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

Activity plan	Number	Version
Detaljerad sprickkartering vid borrplats 7, 2005	PF 400-05-074	1.0
Method descriptions	**Number**	**Version**
Method description for detailed fracture mapping of rock outcrops	SKB MD 132.003e (draft 2)	1.1
Instruktioner för inmätning och avvägning av objekt	SKB MD 110.001	1.0
Metod för berggrundskartering	SKB MD 132.001	1.0
Metodbeskrivning för jordartskartering	SKB MD 131.001	1.0
Metodbeskrivning för markradar	SKB MD 231.003	1.0

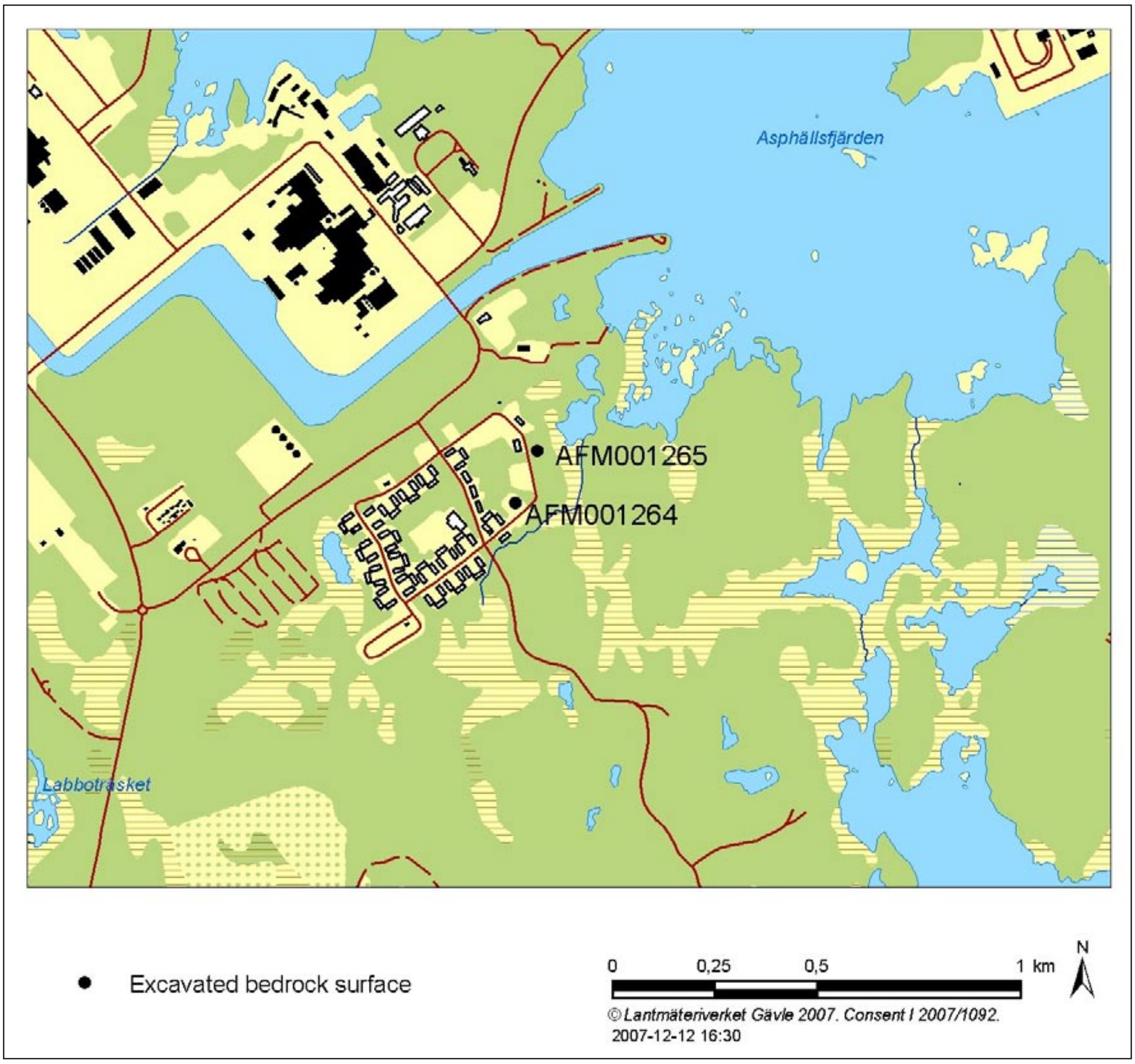

Figure 1-1. Location of AFM001264 and AFM001265.

2 Objective and scope

The activity aimed at collecting detailed fracture data at allocation within the candidate area at Forsmark. The data will be used in discrete fracture network modelling (DFN). The area mapping is expected to indicate the geometric properties for open and sealed fractures within the trace length interval between 0.5 m to approximately 10 m. The results are indicative of the properties of the local fracture network. The variability and properties of the fractures may also depend on rock type and the present structures, presented in appendix A.

The line mapping aims at giving some information about the truncation effect in areas with rock classified as "very good" with respect to rock design, since it has a lower truncation limit of 0.2 m.

3 Equipment

3.1 Description of equipment

The fracture trace geometry and contacts between rock types was measured with a Geodimeter 640S Total Station. Theoretically the survey instrument gives an error of the position (x, y and z) of less than 3 mm. However, this accuracy is based on the assumption that the measuring lath is held in a perfectly vertical position. Since this is not always possible to achieve in typical field conditions, the error is larger. Each measurement is therefore estimated to be performed with an x, y accuracy better than 2 cm. The elevation error is estimated to be less than 0.5 cm.

The number of points measured along each fracture trace varies. The minimum is 2 points, but more points are needed as the complexity of the fracture trace and rock surface increases. The number of points along a contact between rock types varies between a few, up to more than a hundred. More measurements result in a better definition of the extent of the fracture trace or contacts between rock types. However, an increasing number of measurements slow down the survey substantially. The work was performed such that there was a balance between mapping speed and degree of detail of the mapped fracture traces.

The orientation and most of the other fracture parameters were mapped by hand in the field. Fracture length and fracture host rock, was computed in Excel and ArcView after the field work, based on the geodetic data from the bedrock and the fracture survey.

4 Execution

4.1 General

The mapping was performed using standard protocols following the methods described in the method descriptions for detailed fracture mapping at outcrops (SKB MD 132.003e) and for bedrock mapping (SKB MD 132.001) respectively.

4.2 Preparations

The survey instrument was positioned outside the outcrop and was calibrated against five fix points located around the outcrop. The fix points, listed in Table 4-1, were positioned by SKB prior to the fracture mapping. The survey instrument was calibrated against three fix points at the beginning and at the end of each working session. The survey results were converted to the RT90 2.5 gon V, RHB70 system after each completed survey.

4.3 Execution of work

4.3.1 Field work

Site establishment involved the following activities.

1. The SKB activity leader introduced the staff to the outcrop, and the fix points around the outcrop. Part of the outcrop was separated from the bedrock by sediment-filled fractures and considered not to be within the scope of work for this mapping.
2. The survey instrument was calibrated against known and appointed fix points in the vicinity to the outcrop.
3. The compass was adjusted to the regional deviation of 3.5° east. Control of magnetic disturbance was carried out by compass-walking four tracks on the outcrop, two of which in northerly direction and two westerly, approximately. No disturbances were observed.
4. A grid of approximately 5×5 m squares of plastic tape was not applied to this outcrop. The reason for this deviation from the usual procedure, formerly applied, was that the fractures and rock boundaries formed a "natural grid" and that the grid is only used to keep track of fracture marking and has no imprint on the collected data.
5. The complete extent of the cleaned outcrop and the mapped area was measured with the total station.

Table 4-1. Fix points for the outcrop AFM001264 in RT90 2.5 gon V, RHB70.

Pnr	Northing	Easting	Elevation
7101	6700163.793	1631046.839	3.705
7102	6700083.102	1631067.893	3.155
7103	6700052.651	1631037.158	2.596
20101	6700170.621	1630848.589	2.569
86112	6700089.493	1630885.785	2.688

The methodology of the lithological mapping follows the SKB controlling document SKB MD 132.001. Specifically the work was carried out as follows:

1. The lithological boundaries of the outcrop was identified and marked with crayons by staff from SwedPower AB.
2. The lithological boundaries were registered with a required number of measurements with the survey instrument in cooperation with staff from SwedPower AB.
3. The survey data were extracted and digitally converted to RT90 2.5 gon V, RHB70 coordinates. The measurements were opened in a CAD software and a lithological draft map was printed.
4. The draft map was controlled on the outcrop by staff from SwedPower AB, and complementary notes and corrections were marked on the map or measured with the survey instrument.

The methodology for mapping fractures follows the method presented in SKB MD 132.003 (SKB internal controlling document). The work process was conducted as follows:

1. Each fracture trace was marked with a metal marker at its start (A) and end (B) point on the outcrop to keep track of measured fractures. The used truncation length for mapping fracture traces was 0.5 m. The direction from start to end was defined as approximate strike according to the right hand rule.
2. Each fracture location and length was surveyed with two or more points with the survey instrument. The number of survey points on each fracture was dependent of the complexity of the structure. At the end of each day the data were extracted from the survey instrument. A digital conversion of survey instrument data to RT90 2.5 gon V, RHB70 coordinate data was conducted and the measurements of the day where opened in a CAD software. The reasonability of the traces was checked.
3. Each fracture was mapped with respect to the given geological parameters outlined in SKB MD 132.003, also given in Tables 5-1 and 5-2.
4. Scan line measurements were performed along two 10 m long, approximately orthogonal scan lines established in an approximate NS and EW orientation on a part of the outcrop, classified by the field staff as “very good” with respect to rock design. The truncation length was 0.2 m. The same parameters as for the surface mapping were collected, plus length and position along the scan line.

4.3.2 Post processing

Off field activities conducted:

1. Construction of ArcMap shape files of fracture traces, lithologic features, outcrop grid and boundary.
2. Calculation of fracture lengths from the fracture survey data.
3. Spatial calculation of fracture host rock was derived from fracture and lithology survey data.
4. Quality control of all data.
5. Report production.

4.4 Consistency check of orientation data and rock boundary relation data

On completion of field work, collected orientation data (strike/dip) were checked against survey data in order to find and evaluate simple miswriting or compass reading errors in the field log. Consistency check was carried out by comparison of strike calculated from survey data with compass readings. Two alternative methods for orientation calculation were used, based on conditions, as demonstrated in Table 4-2.

Strike and dip calculated with Method II replaced field measured values in 37 cases with a dip in the interval 1–35°. This method is regarded as giving a better orientation accuracy than does a compass reading for gently dipping fractures with an irregular surface. This may also apply to certain steeper fractures, provided the fracture surface is sufficiently well exposed. For this outcrop, however, all steep fractures (58° to vertical) were calculated with Method I.

Strike calculated with Method I was compared to field notes of compass readings. In case of deviation of 10° or more, the compass reading notes were further checked. This check revealed that two sequences of fractures (Nos. 105–120 and 125 to 140) had swapped ID numbers during fieldwork. The errors due to this was corrected, whereafter the computer check was repeated and measured strike replaced with calculated strike for 39 fractures. For three of these, deviation was 30° and over, two within 20–29°, six within 15–19°, and the remaining 28 between 10 and 14°. For all of these, in-field measured strike was replaced with calculated strike. Deviation values over 20° are regarded to be due to miswriting, while the others are assessed to be due mainly to inclined rock surfaces. For the fracture zone data, four strike deviations over 15° were replaced in the Sicada data file.

Intersection of each fracture with rock boundaries was checked by comparison of Sicada data with GIS data. In data where deviation occurred (112 cases), further check of the field notes and the GIS map was carried out, and corrections in the Sicada data were made. In 68 cases, the fracture termination was very close to a rock boundary, for which reason the field notes were regarded to be correct, while remaining data were replaced with GIS derived data.

4.5 Data handling and deliveries

A complete registry of the delivered documents is given in Tables 4-3 to 4-5.

Table 4-2. Methods for calculation of fracture orientation.

Method	Criteria	Input	Output
I	The fracture exposure practically forms a line (trace). Usually steeply dipping fractures.	At least 2 Survey points on trace and clinometer measured dip.	Strike
II	The fracture ”trace” forms a well exposed surface rather than a line. Usually gently dipping fractures.	At least 3 Survey points on the fracture surface.	Strike and dip

Table 4-3. Field notes.

Description	Name	Format
Field mapping protocols	Blankett sprickkartering	Hard copy
Calibration notes	Compass_check	.xls
Start meeting protocol	AFM001264_Startmöten.doc	.doc
Daily log	Aktivitetsdagbok V2.0.1	Hard copy

Table 4-4. Primary data.

Folders	Files	Description	Gis format
AFM001264_ Bedrock_GIS	AFM001264_Bedrock.shp	Bedrock lithology.	Polygon
	AFM001264_StructOrient.shp	Structure orientation in bedrock.	Point
	AFM001264_Deformation-zone.shp	Deformation zones.	Polygon
	AFM001264_Shear_zone.shp	Shear zones.	Polygon
	AFM001264_Bedrock.jpg	Map displaying the GIS-layers.	
AFM001264_ Fractures_GIS	AFM001264_Fractures.shp	Fracture traces. Contains all fractures having any part within the mapped area.	Line
	AFM001264_Fractures.jpg	Map displaying the fracture layers.	
AFM001264_ Site_GIS	AFM001264_outcrop_mapped.shp	Mapped extent of the outcrop.	Polygon
	AFM001264_topography.shp	Complete extent of the outcrop.	Polygon
	LFM000909_LFM000910_ Scanlines.shp	The lines along which the line mapping was executed.	Line
	AFM001264_outcrop.jpg	Map displaying the outcrop descriptive layers.	
Each shape file is a combination of several file;, such as a database file, different binary files, sometimes a layout (lyr) file and an xls -metadata file.			
AFM001264_ CAD&xls	AFM001264_ outcrop_mapped.dgn	The boundary of the washed outcrop.	
	AFM001264_ Scanlines.dgn	The lines along which scan line mapping was executed. Scan line mapping file only contains the fractures between the truncation limit of 0.5 and 0.2 m.	
	AFM001264_ Fractures.dgn	The mapped fracture traces from the outcrop in Cad format.	
	AFM001264_ topography.dgn	Extra topographic points needed to sample the 3D form of the outcrop.	
	AFM001264_Suscept.xls	Susceptibility measurement locations.	
	AFM001264_ Fractures.xls	Fracture coordinates and length.	
AFM001264_ pictures	jpg-files as listed in the folders named “frac_20-50cm” and “surface”.		
AFM001264_ Sicada	EG165_AFM001264_Area_ surveying.xls	Coordinates of a mapped extent of the outcrop in a Sicada template.	
	EG170_Line_surveying_ LFM000909_LFM000910.xls	Coordinates of the scanlines in a Sicada template.	
	GE076_Detailed_fracture_ mapping_surface_AFM001264.xls	Parameters of the mapped fractures on the outcrop. Contains each fracture that has any part within the area limitation and is longer than the truncation length of 0.5 m.	
	GE075_Detailed_fracture_ mapping_line_ LFM000909_ LFM000910.xls	Parameters of all fractures longer than the truncation limit of 0.2 m crossing two scan lines.	
AFM001265_zon _Fractures_GIS	AFM001265_zon_ Fractures.shp	Fracture traces. Contains all fractures having any part within the mapped area.	
	AFM001265_zon_ Fractures.jpg	Map displaying the fracture layers.	
AFM001265_zon _CAD&xls	AFM001265_zon_ outcrop_ mapped.dgn	The boundary of the mapped area.	
	AFM001265_zon_ Fractures.dgn	The mapped fracture traces from the outcrop in Cad format.	
	AFM001265_zon_ Fractures.xls	Fracture coordinates and length.	
AFM001265_zon _Sicada	EG165_AFM001265_zon_Area_ surveying.xls	Coordinates of a mapped extent of the outcrop in a Sicada template.	
	GE076 - Detailed fracture mapping - surface_AFM001265_zon.xls	Parameters of the mapped fractures on the outcrop. Contains each fracture that has any part within the area limitation and is longer than the truncation length of 0.2 m.	

Table 4-5. Documentation.

Description	File name
Report	Report-ForsmarkDrillsite 7_0510113.doc
Folder with jpg files for report print original	Figures
QA-protocol	Granskning&kvalitet.doc

5 Results

5.1 Detailed fracture mapping

The results of the outcrop mapping include data tables, Cad files and ArcMap shape files including:

- Outcrop lithology and shape.
- Area fracture mapping.
- Focused Area fracture mapping of the minor deformation zone.
- Scan line fracture mapping.

Based on experience from work in crystalline basement outcrops, it was prior to the field investigation estimated that there would be approximately two fractures (over the truncation trace length of 0.5 m) in each m^2 of the outcrop. AFM001264 contained 322 fractures which represent approximately 1.7 fractures per m^2. This is somewhat less fractures compared to the previously mapped outcrops at Forsmark.

The scan line mapping was performed along two 10 m long lines on outcrop AFM001264, one trending approximately north-south (LFM000910) and one trending approximately east-west (LFM000909), crosswise the former. Truncation length for the fracture traces in the scan line survey was 0.2 m. The fracture frequency along the north-south trending line and the east-west trending line was 2.1 and 1.9 fractures per metre, respectively.

All fractures were controlled by comparing compass reading with strike calculated from all survey points and measured dip.

Table 5-1 and Table 5-2 present the codes for the geological parameters. The parameters have been coded according to a specified system that is appropriate for retrieving from Sicada.

Figure 5-1 shows the outcrop with scan line traces at site, and Figure 5-2 demonstrates the fracture trace map of the outcrop.

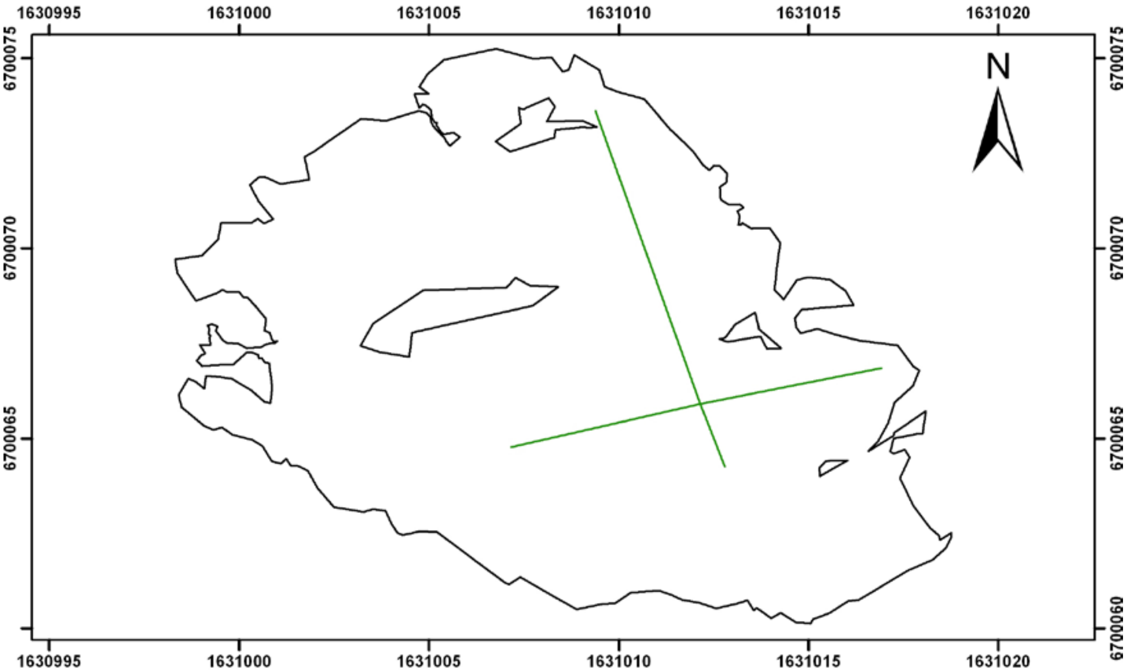

Figure 5-1. *Outcrop AFM001264. Outcrop contour and scan line traces LFM000909 and LFM000910.*

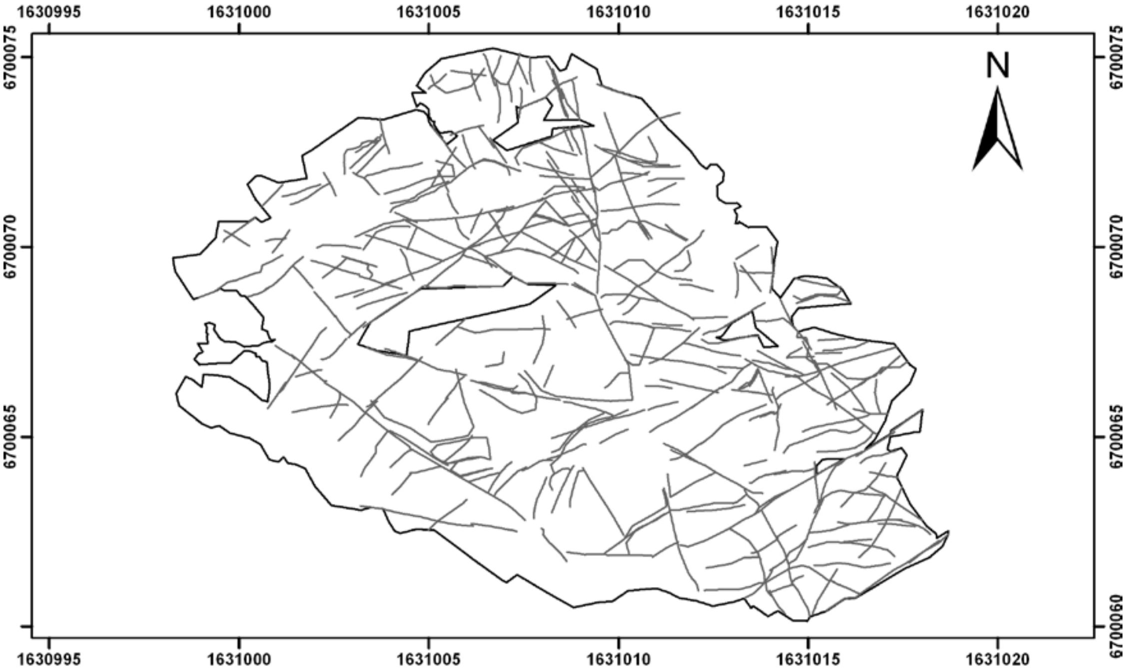

Figure 5-2. Fracture trace map of the AFM001264 outcrop.

Table 5-1. Bedrock codes and description. SKB code system has been used to describe rock, structure, grain size and colour.

code	Rock type (two first digits relate to the Forsmark site)
101057	Granite to granodiorite, metamorphic, medium-grained
101058	Granite, metamorphic, aplitic
102017	Amphibolite
101061	Pegmatite, pegmatite granite, metamorphic
code	**Structure**
20	gneissic
98	metamorphic, unspecified
30	massive
code	**grain-size of matrix**
2	fine-grained
9	medium-grained
4	coarse-grained
code	**Colour**
12	pinkish red
28	reddish grey
18	reddish grey
59	greenish black
	Orientation (terminology applied on all structures in bedrock)
	Strike/dip (used for all planar structures)
	Bearing/plunge (used for all linear structures)

Table 5-2. Fracture character codes.

Parameter	Codes	
Fracture termination (see Figure A2-1)	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.
	y	The fracture ends independently on the rock but in several splays. Some of these splays could connect to other fractures.
	x	The fracture terminates against a lithological boundary.
Relation to lithology	a	No lithological boundary is crossed.
	b	One lithological boundary is crossed.
	c	More than one lithological boundary is crossed.
	d	The fracture coincides with a lithological boundary.
Fracture type	o	Open fracture. This needs to be open at depth. Many fractures give the impression of being open due to increased erosion at surface.
	c	Closed fracture, c is considered default, i.e. write c if the aperture cannot be seen or detected.
Fracture shape/ Waviness (See Figure A2-2)	t	The fracture is stepped if it is composed of several segments with a lateral offset, and the segments are connected with smaller perpendicular or close to perpendicular segments. If the offset is great or no connecting fracture is found, the segments should be mapped separately.
	u	The fracture is undulating (wavy).
	p	The fracture is planar or close to planar. A planar fracture with a bend or splay in the end is still considered planar.
Roughness/ unevenness (See Figure A2-2)	r	The fracture plane is rough. This is the normal case when movement has not taken place along a fracture. r can be considered default value, i.e. write r if the fracture walls cannot be seen.
	s	The fracture plane is smooth, either due to a mineral filling or due to grinding activity between the fracture walls
	h	Slickenside (Harnesk). Grinding has taken place in a visible direction.
Indication of movement	0	There are indications that no movement has taken place.
	s	Sinistral; Standing on one side of the fracture facing the other, the opposite side should have moved relatively to the left.
	d	Dextral. Standing on one side of the fracture facing the other, the opposite side should have moved relatively to the right.
	1	The fracture has indications of movement but direction cannot be determined.
	-	Nothing can be said about the movement.
Alteration	0	No alteration (equivalent to ISRM** weathering class I)
	1	Change of colour in the host rock, other than red (ISRM weathering class II).
	2	Change of mineral composition in host rock. The mineral durability is reduced. (ISRM weathering class III).
	r or rr	The host rock around the fracture is red or strongly red coloured. This can be combined with the above digit codes 2 and 3.
	-	Nothing can be said about alteration due to soil infill etc.
Fracture filling		No visible fracture filling.
	code	Codes according to SKB standard (as defined on Sicada delivery template).
	-	Nothing can be said about fracture filling due to soil infill etc.

Fracture mineral codes are explained in SKB's Sicada templates used for delivery.

Figure 5-3 is showing the mapped area and a trace map of trench AFM001265. The description of the detailed geological mapping is presented in /1/.

Figure 5-3. *Fracture trace map of the fracture zone in the AFM001265 trench.*

6 Reference

/1/ **Petersson J, Skogsmo G, Vestgård J, Albrecht J, Hedenström A, Gustavsson J, 2007.** Forsmark site investigation. Bedrock mapping and magnetic susceptibility measurements, Quaternary investigations and GPR measurements in trench AFM001265. SKB P-06-136, Svensk Kärnbränslehantering AB.

Appendix A

Detailed bedrock mapping

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SwedPower AB

The bedrock surface has been uncovered in an area south of drill site 7 in order to obtain fracture data from the roof zone of a potential deep repository in the Forsmark site investigation area. The excavation, referred to as AFM001264, has a soil cover that ranges from about 0.6 to more than 5 m. The dimensions of the exposed bedrock in the bottom are c. 17×20 m, and the total area amounts to 275 m^2. However, a WNW–ESE striking trench separates the exposure into a 85 m^2 southern area and a 184 m^2 northern area. The southern area is more intensely fractured as a result of inferred glaciotectonic activity.

A detailed bedrock mapping has been carried out in AFM001264. The mapping focused mainly on rock types, contact relations, ductile deformational structures and fracture minerals. All mapping was done in accordance with activity plan AP PF 400-05-074 (SKB internal document) following the SKB method description for bedrock mapping, SKB MD 132.001 (v. 1.0; SKB internal document). The spatial distribution and contacts of different rock types were measured with a Geodimeter 640S Total Station (see the methodology section).

A.1 Lithology

The exposed bedrock in AFM001264 consists of a medium-grained metagranite (rock code 101057) with several dyke-like occurrences of amphibolite (rock code 102017) (Figure A-1). The geometry of these amphibolites is apparently the result of an intense ductile deformation, where 'dykes' that strike roughly perpendicular to the inferred maximum stress direction have undergone stretching and more oblique occurrences have suffered shortening, as indicated by intrafolial folding. Other rock units are sparse and include a few occurrences of pegmatitic granite (rock code 101061), a vein-like occurrence of aplitic metagranite (rock code 101058) and some quartz-dominated metamorphic segregations (rock code 8021). None of these occurrences are more than a few decimetres in width. Except for some late, discordant dykes of pegmatitic granite and quartz veins, all rocks have experienced Svecofennian metamorphism under amphibolite facies conditions.

The medium-grained metagranite (101057) is typically greyish red to reddish grey, locally with a tendency to be slightly granodioritic. Texturally, the rock is rather equigranular with a distinct planar mineral fabric defined by elongated aggregates of quartz and feldspar as well as a preferred orientation of biotite.

Ambhibolites (102017) occupy 13% of the exposed bedrock in AFM001264. The largest, continuous body of amphibolite forms a roughly metre-wide, NNW striking 'dyke' along the eastern part of the excavation (Figure A-2a). Other occurrences are more irregular, exhibiting cuspate-lobate contacts, ruptures and foliation-parallel stretching (Figure A-2b). The amphibolites are always fine-grained, on the verge of being finely medium-grained, with equigranular texture. Most of them are rather biotite-rich, in extreme cases with biotite contents exceeding 25–30 vol.%. Some occurrences are surrounded by up to a few centimetres wide rims of whitened or bleached wall rock. This 'bleaching' is obviously metasomatic and inferred to be the result of albitization.

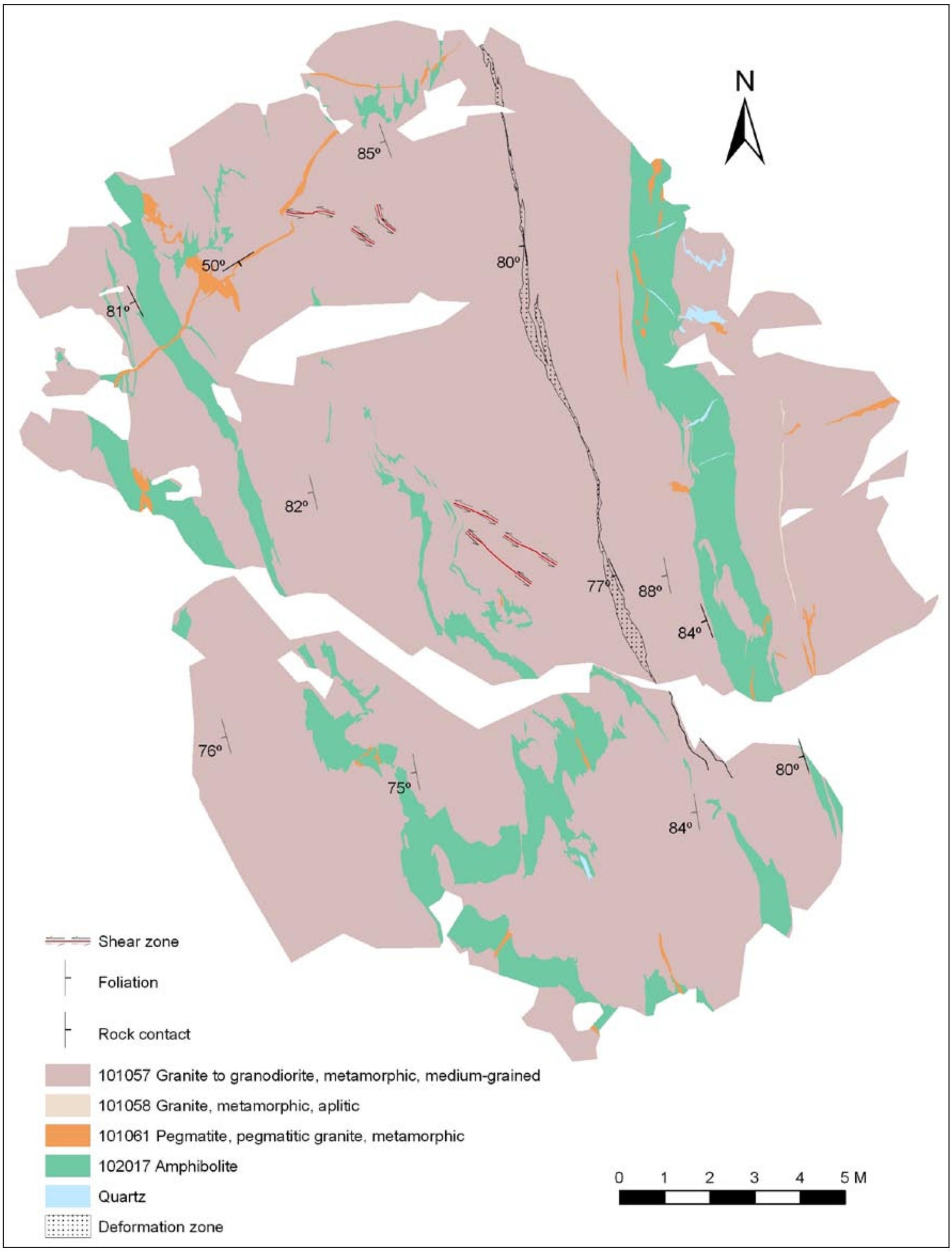

Figure A-1. *Geological map of AFM001264.*

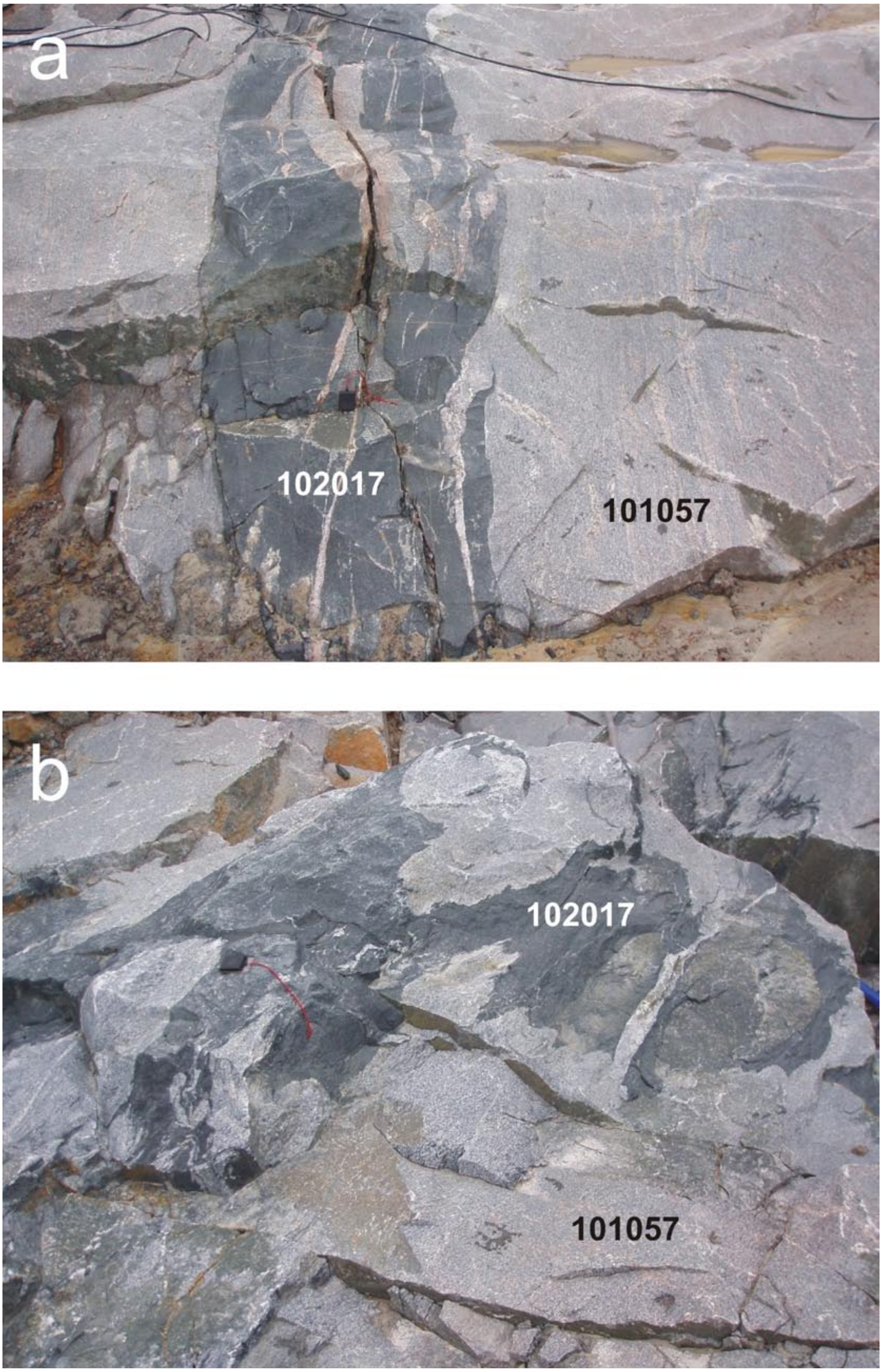

Figure A-2. *Photographs of two amphibolite (102017) occurrences that suffered from intense ductile deformation. (a) A NNW striking, dyke-like occurrence and (b) a more irregular with cuspate-lobate contacts towards the surrounding medium-grained metagranite (101057). Size of the compass used as scale is 6.4×10 cm.*

Pegmatitic granite (101061) occurs as (1) minor segregations intimately associated with amphibolite (102017), (2) vein-like occurrences parallel with the tectonic foliation, and (3) up to decimetre-wide, discordant dykes. The first variety occurs typically as metamorphic segregations in low stress regions within or adjacent to amphibolites. Some of them are quartz-dominated and have been mapped as 'quartz-dominated metamorphic segregations' (8021). The discordant dykes are all massive and one of them is garnet-bearing. Except for one of the dykes, they are all NNE striking and appear to dip moderately towards south.

The presence of aplitic metagranite (101058) is limited to an up to four centimetres wide, concordant vein in the easternmost part of the exposure. It is fine-grained, equigranular and greyish red in colour. In addition, there are four, up to 3 centimetres wide quartz filled tension gashes in the NNW striking amphibolite 'dyke' in the eastern part of the excavation. The orientation of these are from north to south as follows: 072°/?, 127°/?, 060°/50° and 070°/52°.

A.2 Ductile structures

All exposed rocks, except for the late pegmatitic granite and quartz veins, show a distinct tectonic foliation with a general orientation of 160–171°/75–88°. The intensity of this ductile strain is typically strong, though streaks of less intense foliation are frequent.

Several localized shear zones have been found in two areas of the exposure, one in the central part and a second in the north central part. They are all restricted to the medium-grained metagranite (101057), and striking between 290–310°. Individual zones are up to two metres long with a central, centimetre-wide zone of recrystallisation. Five of the six zones show a clear sinistral movement (Figure A-3a), whereas the sixth is more obscure, but probably dextral.

In addition, there is a SSE striking brittle-ductile deformation zone that runs across the exposure. However, the continuation south of the WNW–ESE striking trench is not obvious, but it appears eventually to disappear as two brittle structures. Generally, it dips 77–80° towards west. The northern part of the zone consists mainly of pegmatitic granite with streaks of biotite-rich, amphibolite-like material, locally rich in quarts. The southern part is quartz-dominated with a more brittle character. The width of the zone ranges up to 1.5 decimetre, though the contact with the wall rock is not always sharp. Individual fractures in the zone are typically up to one millimetre wide and filled by calcite and chlorite. Based on the asymmetry of the internal foliation planes it is suggested that the zone is mainly dextral (Figure A-3b).

A.3 Fracture fillings

The fracture orientations vary considerably throughout the exposure, though at least three distinct fracture sets can be distinguished on the basis of the fracture orientation and mineralogy. These fracture sets are found at both sides of the WNW–ESE striking trench that separate the exposure. The most apparent difference is that fractures south of the trench typically are coated by rust. The *first* set consists of gently dipping fractures, oriented 233–260°/13–18°. Some of them are part of the glacially polished surface of the excavation. The most frequent infilling minerals in these fractures are calcite and chlorite. One fracture surface contains also epidote. Virtually all fractures in this set exhibit oxidized walls. The other two fracture sets are vertical to sub-vertical and comprise fractures oriented 45–70°/65–90° and 117–120°/84–86°. The typical mineral assemblage in both these fracture sets is chlorite + calcite ± clay minerals.

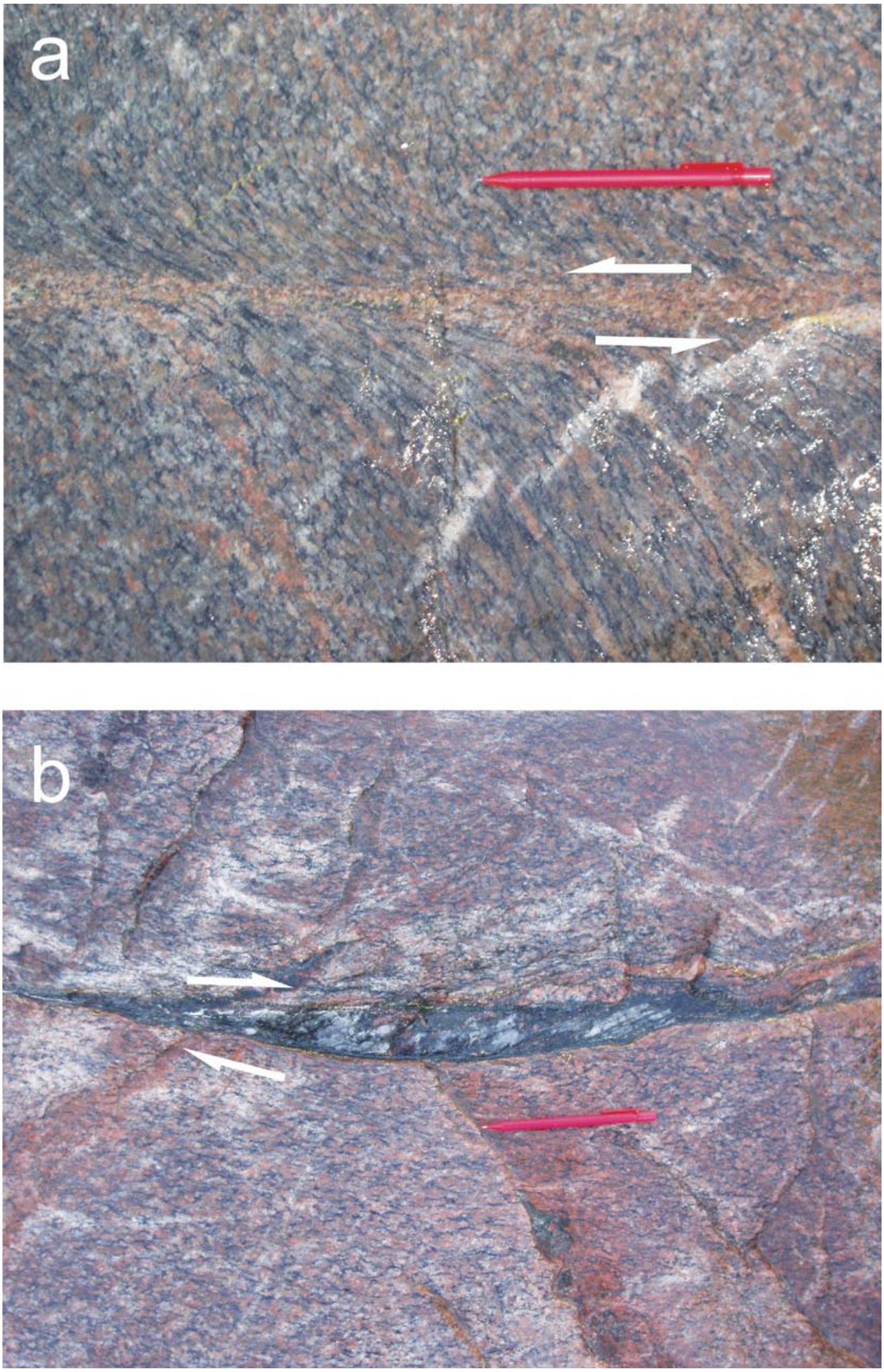

Figure A-3. *Photographs of (a) a localized sinistral shear zone in the medium-grained metagranite (101057), and (b) a well-defined section of a brittle-ductile deformation zone; note the internal foliation planes, indicating a dextral movement. Length of the pencil used as scale is 14 cm.*

Appendix B

Quaternary investigations in the excavated area AFM001264

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Geological Survey of Sweden

Introduction

This appendix reports the results gained by the investigation *Quaternary investigations in the excavated area AFM001264*, which is one of the activities performed within the site investigation at Forsmark. The work presented in this appendix was carried out in accordance with the methods in SKB MD 131.001, Table B-1.

The work was conducted in August–September 2005 in connection with detailed mapping of fractures and bedrock geology in trench AFM001264 (see the main report). In order to study the bedrock surface, the Quaternary deposits were removed. This sub-activity aims at describing the spatial distribution and properties of the Quaternary sediments as studied in the trenches.

Unique id-codes were assigned to the sites for the documentation of the Quaternary deposits (PFM-series). All geological data are stored in SGU's database (Jorddagboken 5.4.3), exported to Excel-files and delivered to SKB primary database (Sicada).

Results

General description and interpretation

The excavation measures about 16×22 m and extends in 160–340° (Figure B-1 and Sketch I, II, III). The upper surface was flat before excavation, levelled by artificial filling material. The total soil thickness varies between 0.5 m and 5 m.

The bedrock consists of grey and red granite cut by up to 50 cm wide mafic dykes. These dykes are deformed and in places cut by quartz-filled fractures. Detailed descriptions of the bedrock and fractures are presented in this main report and Appendix A, respectively.

A one to two metres wide inferred fracture zone runs diagonally (WNW-ESE) through the excavated area (Figure B-1). Bedrock fragments in this zone were removed partly by glacial activity and partly by the excavator. The bedrock at the bottom of the resulting trench is heavily fractured. Many of the fractures are filled with sediments, mainly silt (Figures B-2 and B-3).

South of the trench, two or three sub-horizontal (dip direction to the S) fractures occur, which are approximately 20 cm wide and filled with sediment (Figure B-2). Vertical fractures are abundant, but narrower and not always sediment-filled. Fracture fillings consist mainly of silt, fine sand and diamicton, but also sharp-edged bedrock fragments (Figure B-3). In general the sedimentary lamination within the open fractures is undisturbed. However, in connection to vertical fractures small-scaled graben structures occur, which probably are caused by water percolating through the fractures (Figure B-4).

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

Activity plan	Number	Version
Detaljerad sprickkartering vid borrplats 7, 2005	PF 400-05-074	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för jordartskartering	SKB MD 131.001	1.0

Figure B-1. *View of the excavated area from the east. Note the difference in the fracture pattern N and S of the trench, respectively.*

Figure B-2. *Heavily fractured bedrock. Two subhorizontal sediment-filled fractures can be distinguished.*

Figure B-3. *Sandy and silty sediment-fill in one of the sub-horizontal fractures. To the right sharp-edged bedrock fragments.*

Figure B-4. *Small-scale collapse structures within the sediment-fill. These graben structures are probably caused by percolating water in nearby fractures.*

Generally, the fracturing is interpreted as result of glacial tectonics and was likely enabled by a pre-existing fracture system and further enhanced by the bedrock topography. However, the bedrock close to the surface may have undergone fracturing by frost and roots. Even blasting may have occurred, since electrical cables, fresh water and waste water pipes are situated in narrow trenches in the bedrock.

In the northern part of the excavated area, the bedrock is almost free of glacially induced fractures, except from a chunk of bedrock, which has been lifted up and dislocated approximately 20 cm (Figure B-5).

The bedrock surface exposes a distinct glacial polish. The last glaciation has only polished the highest parts of the surface (Figure B-6). The ice movement direction has been determined by glacial striae, stoss and lee sides to between 0 and 20°. The lower parts of the bedrock surface show several other striation patterns, which may at least partly originate from the excavator (Figure B-7). The most prominent directions are 50° and 290°. Unpolished surfaces have been observed in the lowest parts of the trench, especially on south-facing walls, but also on other south-facing slopes in the northern part of the outcrop, where fracture-fill minerals like epidote and chlorite are preserved.

The Quaternary sediments, investigated at log PFM006609, are made up by six different units, numbered 1 through 6 from youngest to oldest (Sketch IV). The oldest (unit 6) is a hard, compact (over-consolidated) diamicton, which contains remarkably much Paleozoic limestone clasts. Its upper surface appears like a stone pavement, which is interpreted as erosional lag. This diamicton is only preserved in small pockets in the bedrock surface. It is interpreted as lodgement till, belonging to an older glacial stage. Due to the lack of sufficient material, fabric analysis has not been carried out.

Unit 5 is a 10 to 20 cm thick intercalation of silt, fine sand and diamicton, which probably represents the gliding layer between the bed rock (alternatively older sediments) and the glacier sole.

Figure B-5. *A chunk of bedrock has been lifted and rotated by a moving ice sheet.*

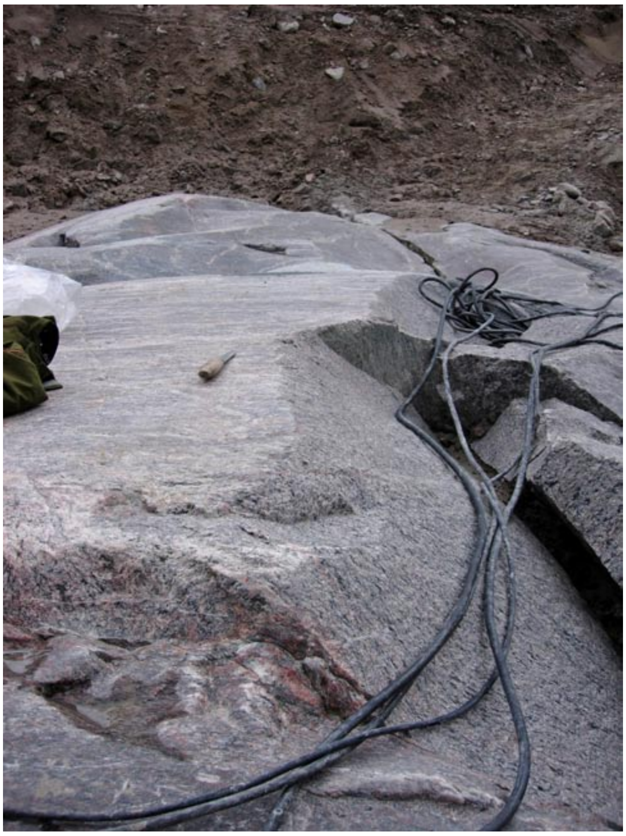


Figure B-6. *Polished and striated bedrock surface. Note the distinct lee-side edge.*

Figure B-7. *Striation pattern at lower parts of the bedrock surface. Several directions can be distinguished. The striation may at least partly originate from construction work and excavation of the bedrock.*

Unit 4 is a grey sandy-silty (occasionally silty) diamicton, which is interpreted as till. Limestone clasts are abundant. This sediment has due to its high silt content a high water-bearing capability, but also extremely low material strength. Slopes tend to flow out and fabric analyses are impossible to carry out.

Unit 3 is a brown to greyish-brown sandy (sometimes sandy-silty) diamicton, which contains remarkably many large clasts. Single sand streaks occur. This sediment is interpreted as melt-out till. Fabric analysis conducted in the lower part of the sediment indicates an ice movement direction from the NNE, i.e. similar to the glacial striae (Figure B-8, Table B-2).

Unit 2 is a 20 cm thick dark brown layer containing cables and drainpipes. Probably this unit corresponds to the soil surface before the artificial fill was deposited on the top.

The uppermost unit (unit 1) is a diamicton similar to unit 3 in grain size and rock composition, but containing cables and drainpipes and represents thus excavated material. In some places, where fresh water and waste water pipes have been placed, this unit reaches down to the bedrock surface (Sketch II).

Table B-2. Eigenvalue (V_1) and strength (S_1) of the fabric analysis.

Fabric analysis	Eigen vector V1 (Strike/Dip)	Strength S1
PFM006609_5	10°/11°	0.725

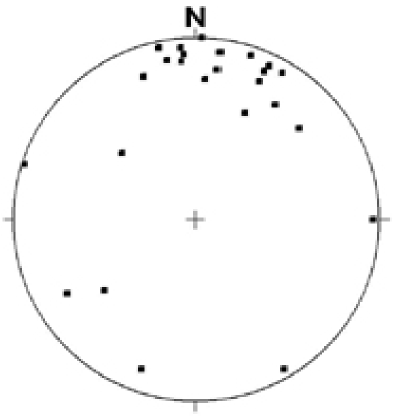
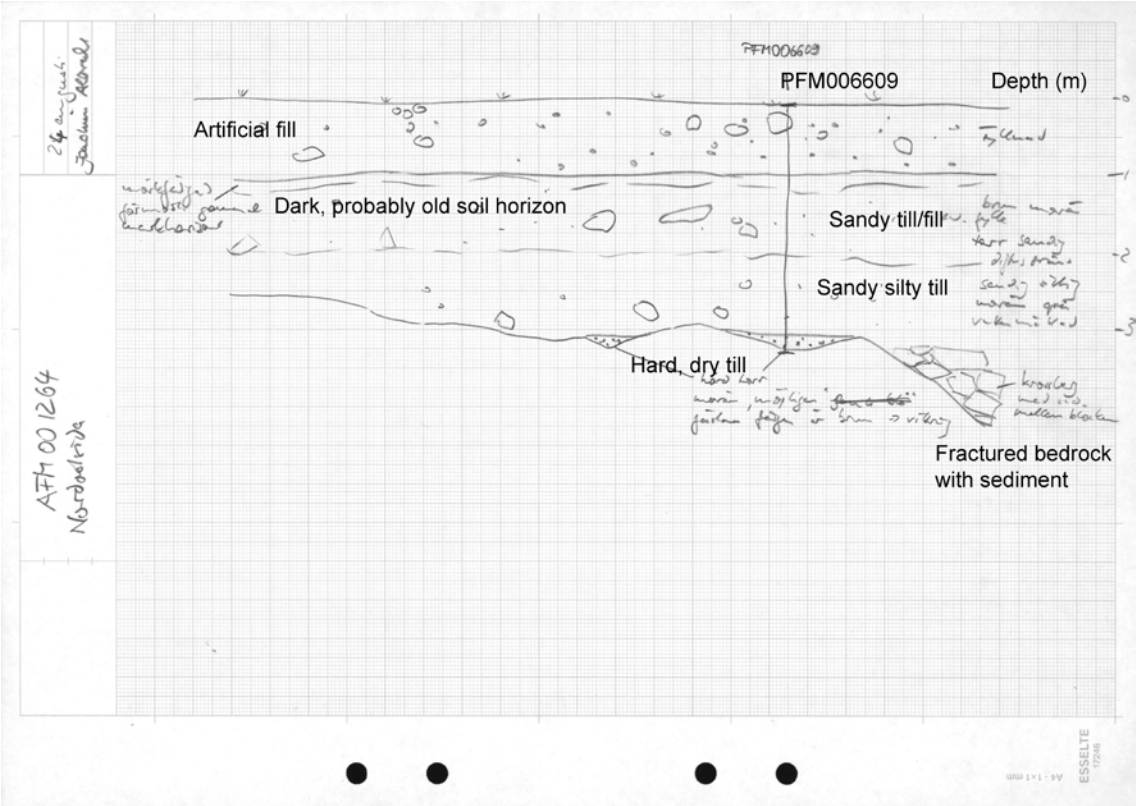
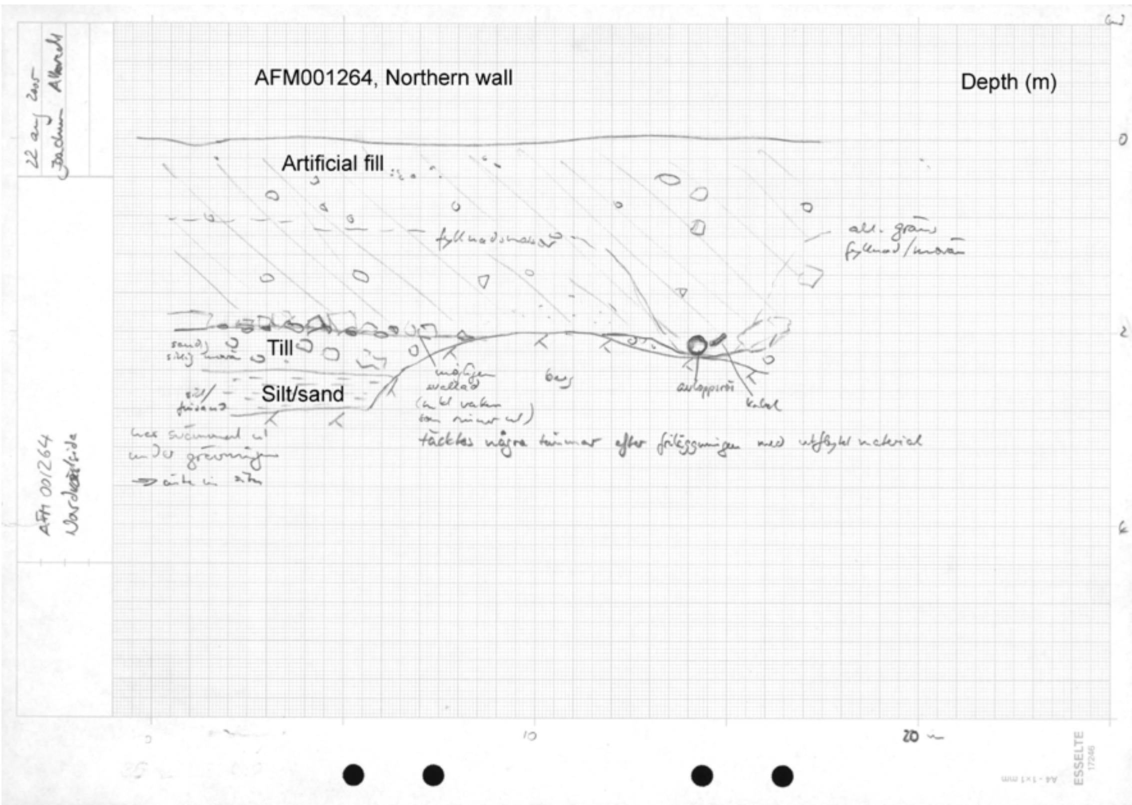


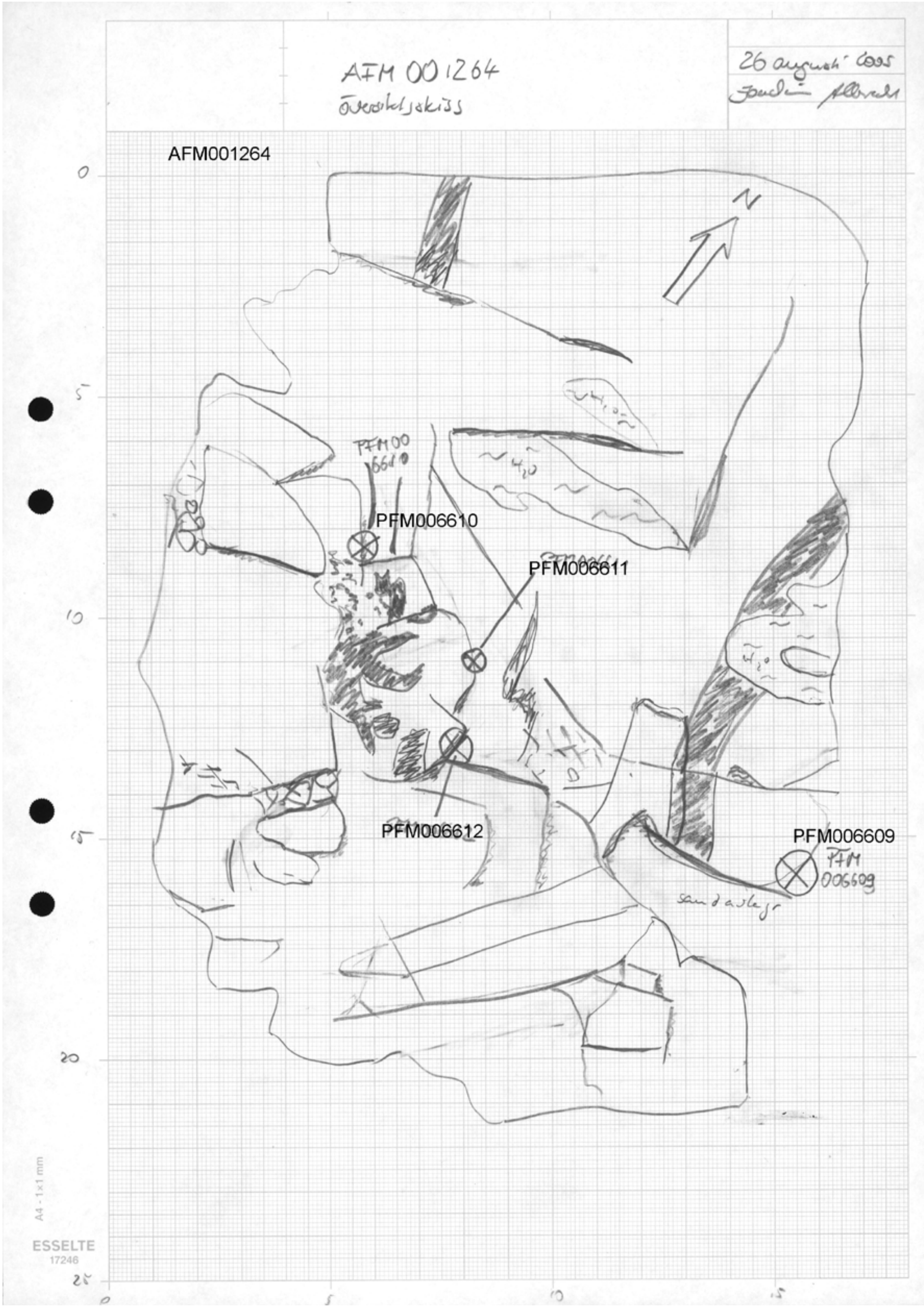
Figure B-8. Fabric pattern of unit 3, PFM006609 at 2 m depth. The inherited ice flow direction is from the NNE.



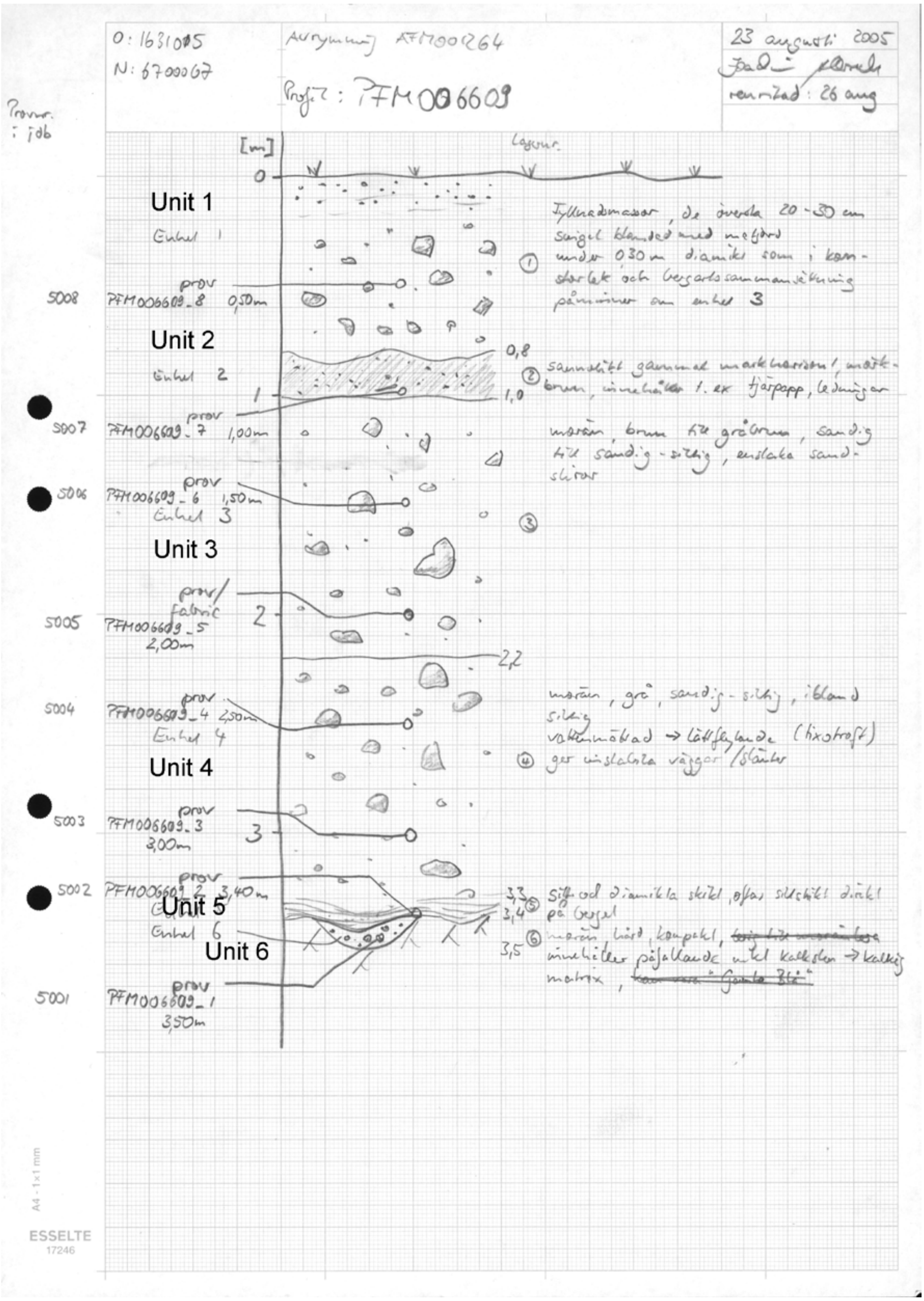
Sketch I. *Cross section of the Quaternary deposits towards north in AFM001264.*



Sketch II. *Cross section of the Quaternary deposits in the northern wall at AFM001264.*



Sketch III. *Simplified overview of the excavated area and the location of the individual point observations.*



Sketch IV. *Log showing the lithostratigraphy at PFM006609.*

Appendix C

GPR measurements at AFM001264, drill site 7, Forsmark

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Malå GeoScience AB

Ground Penetrating Radar measurements were carried out 2005-09-14 at the excavated outcrop AFM001264 at drill site 7, Forsmark. The purpose of the measurements was to study the possibility of mapping sheet joints.

Execution

Three different profiles were measured directly on the bedrock, see Figure C-1. All measurements were carried out with a 100 MHz RAMAC X3M system manufactured by Malå GeoScience AB. The measurements were performed according to SKB internal controlling document MB 251.003.

According to a velocity analysis in the current data and /1/ the velocity was set to 128 m/ns to calculate the correct depth of the identified structures.

The measured profiles correspond to the following locations (Figure C-1, Table C-1).

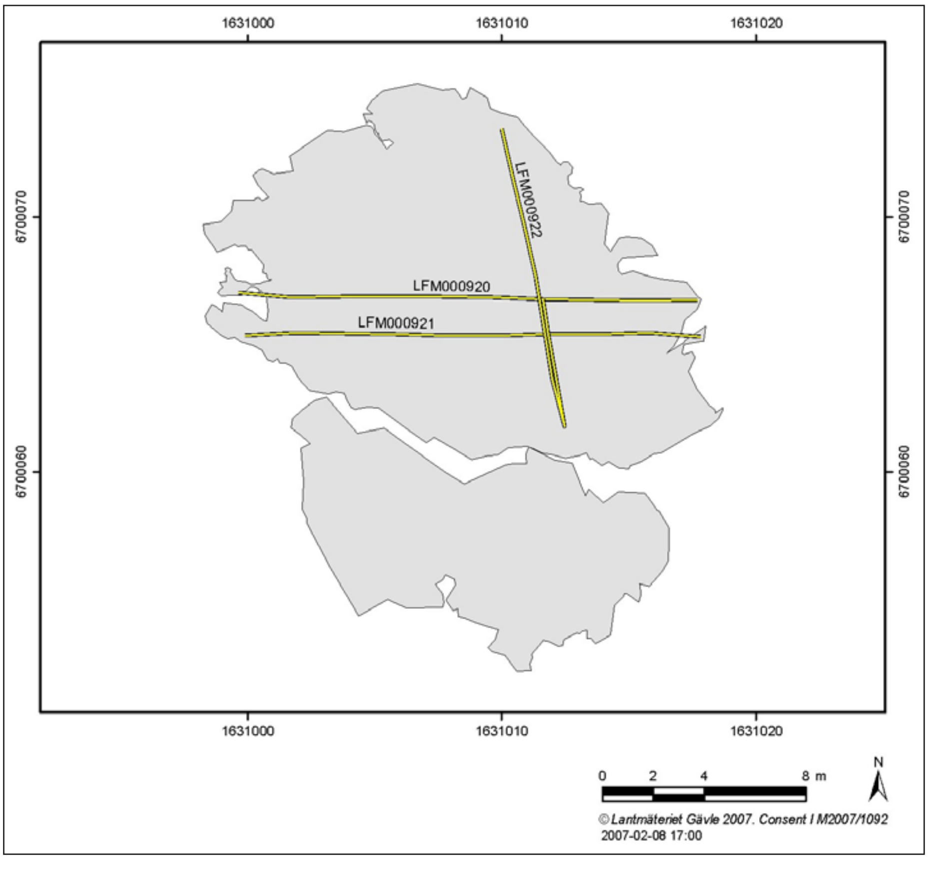

Figure C-1. Outline of the area AFM001264 at drill site 7, Forsmark. The measurements were conducted along the three profiles, indicated by symbols and numbers.

Table C-1. Coordinates for the measured radar profiles (RT90 2.5 gon V, RHB70).

Profile ID	Location	Start	Stop
LFM000920	From R1 to R10	6700066.758 1631017.690	6700067.034 1630999.636
LFM000921	From R11 to R20	6700065.300 1631017.812	6700065.356 1630999.900
LFM000922	From R21 to 26	6700061.763 1631012.450	6700073.472 1631009.985

Results

In the profile LFM000920 (see Figure C-2) a reflector is clearly identified at a depth of approximately 5 to 6 m. This is most likely corresponding to an expected sheet joint in the area. As seen at the start of the profile, the plane most probably consists of several parallel structures. At the end of the profile a deeper laying structure is also identified, but not as clear as those close to

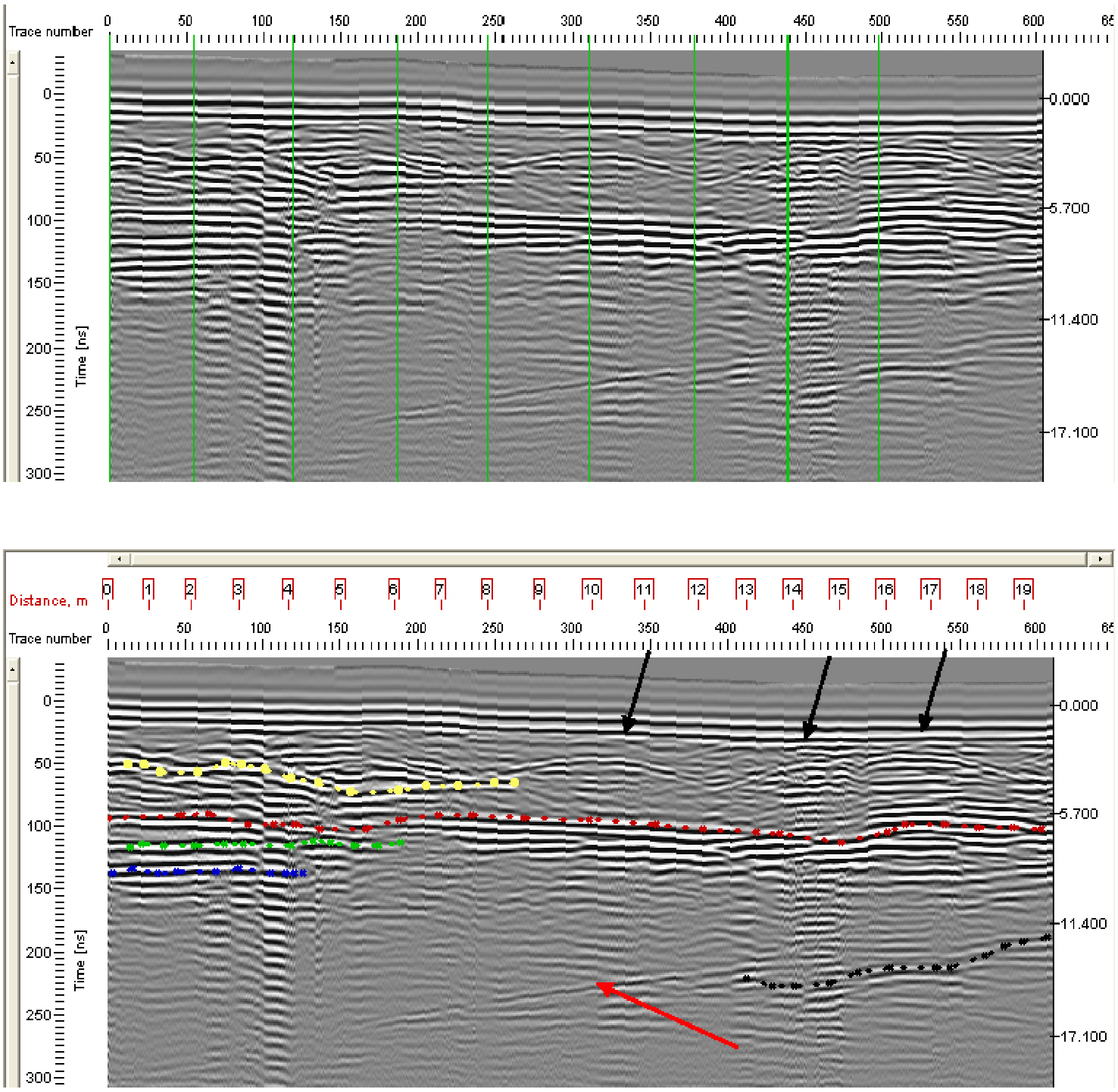

Figure C-2. The results from LFM000920 (from R1 to R10), 100 MHz data without interpretation (upper radargram) and with interpretation (lower radargram).

the surface. Several single hyperbolas are also seen, marked with arrows in Figure C-2. These are most probably representing fractures in the upper part of the bedrock. The straight leaning structure marked with a red arrow is, after a velocity analyse, considered as a disturbance due to airwaves.

The profile LFM000921 is parallel to LFM000920, and the results are quite similar, see Figure C-3. A strong reflector is seen at a depth of 5 to 6 meters, and above and below that reflector there are some weaker reflectors. Observe that not all structures are marked in the radargram in Figure C-3. Also in this profile some hyperbolas can be identified (marked in Figure C-3). The pattern, seen as large hyperbolas between 13 and 17 m are obvious here as well as in LFM000920, Figure C-2. Probably they are representing a section with more superficial fracture planes?

In the profile LFM000922 several reflectors are seen at a depth of 5 to 6 m (see Figure C-4). Weaker reflectors can also be identified. In this profile a quite strong reflector is also identified at approximately 16 m depth.

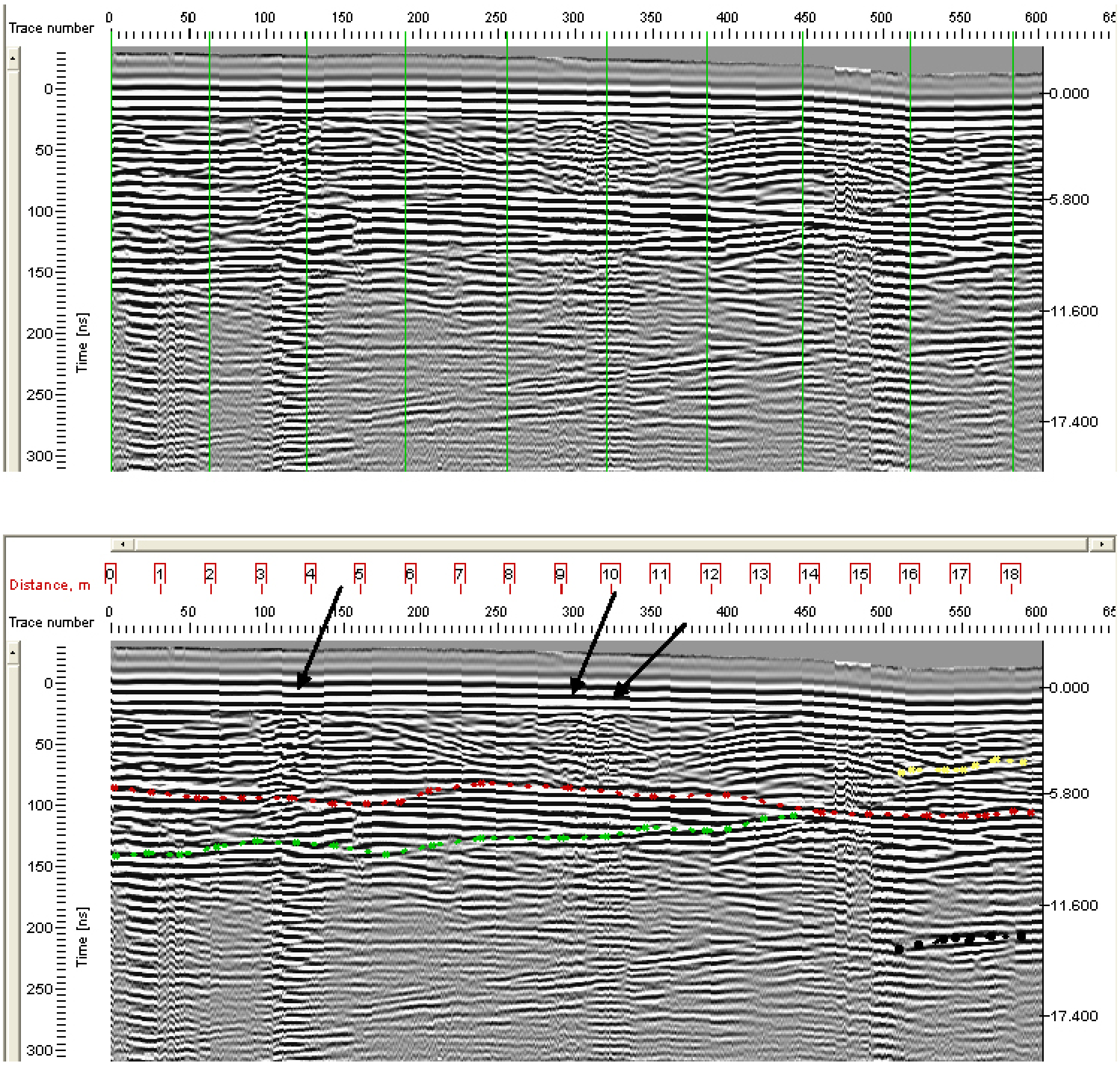

__Figure C-3.__ The results from LFM000921 (from R11 to R20), 100 MHz data without interpretation (upper radargram) and with interpretation (lower radargram).

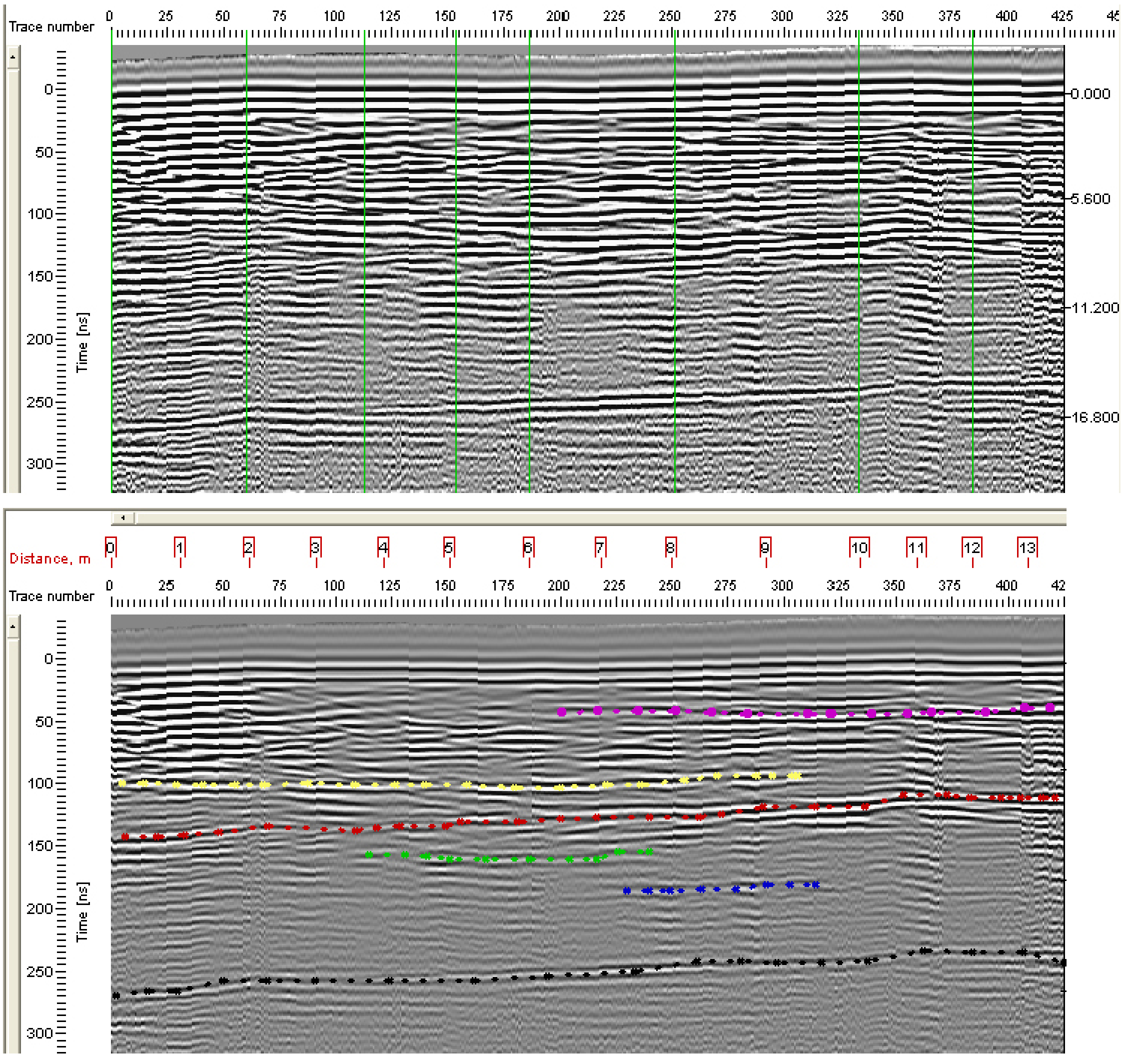

Figure C-4. *The results from LFM000922 (from R21 to R26), 100 MHz data without interpretation (upper radargram) and with interpretation (lower radargram).*

Finally, in Figure C-5, two views of the profiles measured on the outcrop AFM001264 are shown. The sheet joint is clearly seen and can be followed between the cross-sections.

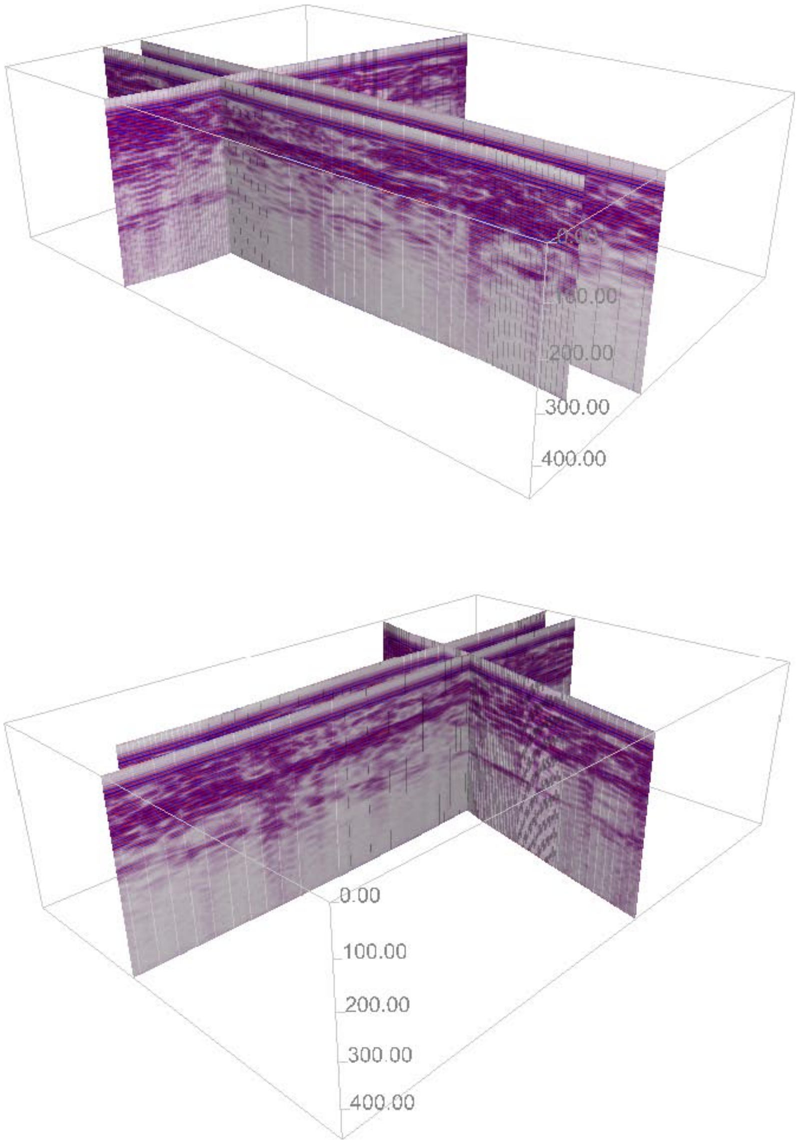

Figure C-5. Combined visualisation of the profiles LFM000920, LFM000921 and LFM000922.

Reference

/1/ **Gustafsson C, Nilsson P, 2003.** Geophysical Radar and BIPS logging in borehole HFM01, HFM02, HFM03 and the percussion drilled part of KFM01A. SKB P-03-39, Svensk Kärnbränslehantering AB.