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Forsmark site investigation

Bedrock mapping and magnetic susceptibility measurements, Quaternary investigations and GPR measurements in trench AFM001265

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December 2007

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Keywords: AFM001265, XFM0159A0, Geology, Deformation zone, Lineament, Fractures, Forsmark, Quaternary deposits, Ground penetrating radar, Sheet joints, AP PF 400-05-075.

Abstract

This report presents the results form the bedrock mapping of trench AFM001265, which is located just northeast of drill site 7, in the northern part of the Forsmark site candidate area. The trench was excavated perpendicular across a lineament, referred to as XFM0159A0, to investigate if it is related to any geological feature, such as a deformation zone or dyke. A conventional lithological mapping of the trench was complemented by (1) a profile of magnetic susceptibility measurements, and (2) characterization of the outcrop area, with highly increased fracture frequency. The length of the trench is 41 metres, and the total area amounts to 95 m^2.

More than 95% of the exposed surface in the trench consists of medium-grained metagranite. Other rock units include a few thin, often highly discordant, dykes and veins of pegmatitic granite, one dyke of fine- to finely medium-grained granite, some minor, foliation-parallel streaks of aplitic metagranite and a single, foliation-parallel occurrence of biotite/chlorite-rich amphibolite.

An about ten metres wide interval of highly increased fracture frequency occurs near the centre of the trench. The predominant fracture set within this interval consists of vertical to sub-vertical fractures that strike 243–250°. A second, less conspicuous fracture set comprises vertical to sub-vertical, NNE–SSW trending fractures. A few decimetres wide breccia zone occurs in the centre of this interval. Individual fractures are typically up to 1–2 mm in width, with a few reaching up to 7 mm. The distinguishable fracture sealing includes calcite, chlorite, epidote and red coloured adularia. Most fractures exhibit oxidized walls, and the highly fractured, central zone shows a continuous oxidation of weak to medium intensity.

Magnetic susceptibility was only measured at the predominant medium-grained metagranite. Generally, the susceptibility decreases with an increasing intensity of oxidation. Thus, there is a distinct susceptibility drop in the area with increased frequency of NE–SW and NNE–SSW trending fractures. However, the exposed surface of this highly fractured area largely corresponds to pre-existing fracture planes, which are variably affected by oxidation.

A study of the Quaternary deposits was performed to describe the spatial distribution and properties of the unconsolidated sediments as studied in the excavated outcrop. 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

Föreliggande rapport redovisar resultaten från berggrundskarteringen av avrymningsdike AFM001265, vilket är beläget strax nordost om borrplats 7, i den norra delen av undersökningsområde Forsmark. Avrymningsdiket grävdes i rät vinkel över ett lineament med beteckningen XFM0159A0 för att undersöka om det har sin orsak i någon geologisk struktur, så som en deformationszon, bergartsgång, etc. En konventionell litologisk kartering av avrymningsdiket kompletterades med (1) mätningar av magnetisk susceptibilitet längs en profil och (2) karaktärisering ett område med kraftigt förhöjd sprickfrekvens.

Över 95 % av den blottlagda berggrunden i avrymningsdiket består av medelkornig metagranit. Andra förekommande bergarter inkluderar ett fåtal tunna, ofta kraftigt diskordanta, gångar eller ådror av pegmatitisk granit, en gång av fint- till fint medelkornig granit, några mindre, foliationsparallella stråk av aplitisk metagranit och en konkordant förekomst av biotit-/kloritrik amfibolit.

Ett ungefär tio meter brett intervall med kraftigt förhöjd sprickfrekvens nära centrum av avrymningsdiket. Den förhärskande sprickgruppen i intervallet utgörs av vertikala till subvertikala sprickor som stryker 243–250°. En andra, mindre framträdande sprickgrupp utgörs av vertikala till subvertikala, NNO–SSV strykande sprickor. En några decimeter bred breccia zon förekommer i den centrala delen av intervallet. Enskilda sprickor är vanligtvis upp till 1–2 mm, och några få upp till 7 mm breda. De makroskopiskt urskiljbara sprickmineralen omfattas av kalcit, klorit, epidot och rödfärgad adularia. De flesta sprickor omges av oxiderat sidoberg och den kraftigt uppspruckna centrala zonen uppvisar sammanhängande oxidation av varierande intensitet.

Magnetisk susceptibilitet uppmättes endast för den dominerande medelkorniga metagraniten. Susceptibiliteten minskar generellt med ökande oxidationsintensitet. Området med förhöjd frekvens av sprickor som stryker NO–SV och NNO–SSV uppvisar således en markant negativ susceptibilitetsanomali. Blottningens överyta sammanfaller dock till stora delar med flacka sprickplan som i varierande utsträckning oxiderats.

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

Contents

1 Introduction

Since 2002, SKB investigates two potential sites at Forsmark and Oskarshamn for a deep repository in the Swedish Precambrian basement. An important part in this work is the examination of inferred lineaments, in order to confirm their possible relation to various geological structures, such as dykes and fracture zones. The most direct method to do this is by uncovering the soil somewhere along the lineament.

In order to investigate two inferred lineaments, as indicated by topography, bathymetry and airborne magnetic data in the Forsmark area, SKB has decided to uncover one trench across each of the lineaments. The two lineaments, referred to as XFM0159A0 and LL0018, are located in the north central part of the site investigation area, the most prioritized area for a potential deep repository in Forsmark. XFM0159A0 is a typical representative of the NE–SW trending lineaments in the area, whereas LL0018 is a curved lineament with mainly NNW–SSE strike (Figure 1-1). A ca 40 metres long trench, referred to as AFM001265, was dug perpendicular across XFM0159A0, just northeast of drill site 7, with the main purpose to investigate the magnetic component of the lineament. The uncovering of a second trench, referred to as AFM001266, across LL0018, was hampered by the constant inflow of water-saturated soil. Because of this, the digging was interrupted and AFM001266 was refilled. No further documentation of this trench was, therefore, possible.

This document reports the results gained by the bedrock mapping of trench AFM001265, one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with Activity Plan AP PF 400-05-075. In Table 1-1 controlling documents for 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 400-05-075. Only data in SKB's databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor data revisions are normally presented as supplements, available at www.skb.se.

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

Activity Plan	Number	Version
Undersökning av diken för verifiering lineament	AP PF 400-05-075	1.0
Method Descriptions	**Number**	**Version**
Metodbeskrivning för berggrundskartering	SKB MD 132.001	1.0
Instruktioner för inmätning och avvägning av objekt	SKB MD 110.001	1.0
Metodbeskrivning för detaljerad sprickundersökning på häll	SKB MD 132.003	1.0
Metodbeskrivning för jordartskartering	SKB MD 131.001	1.0
Metodbeskrivning för markradar	SKB MD 231.003	1.0

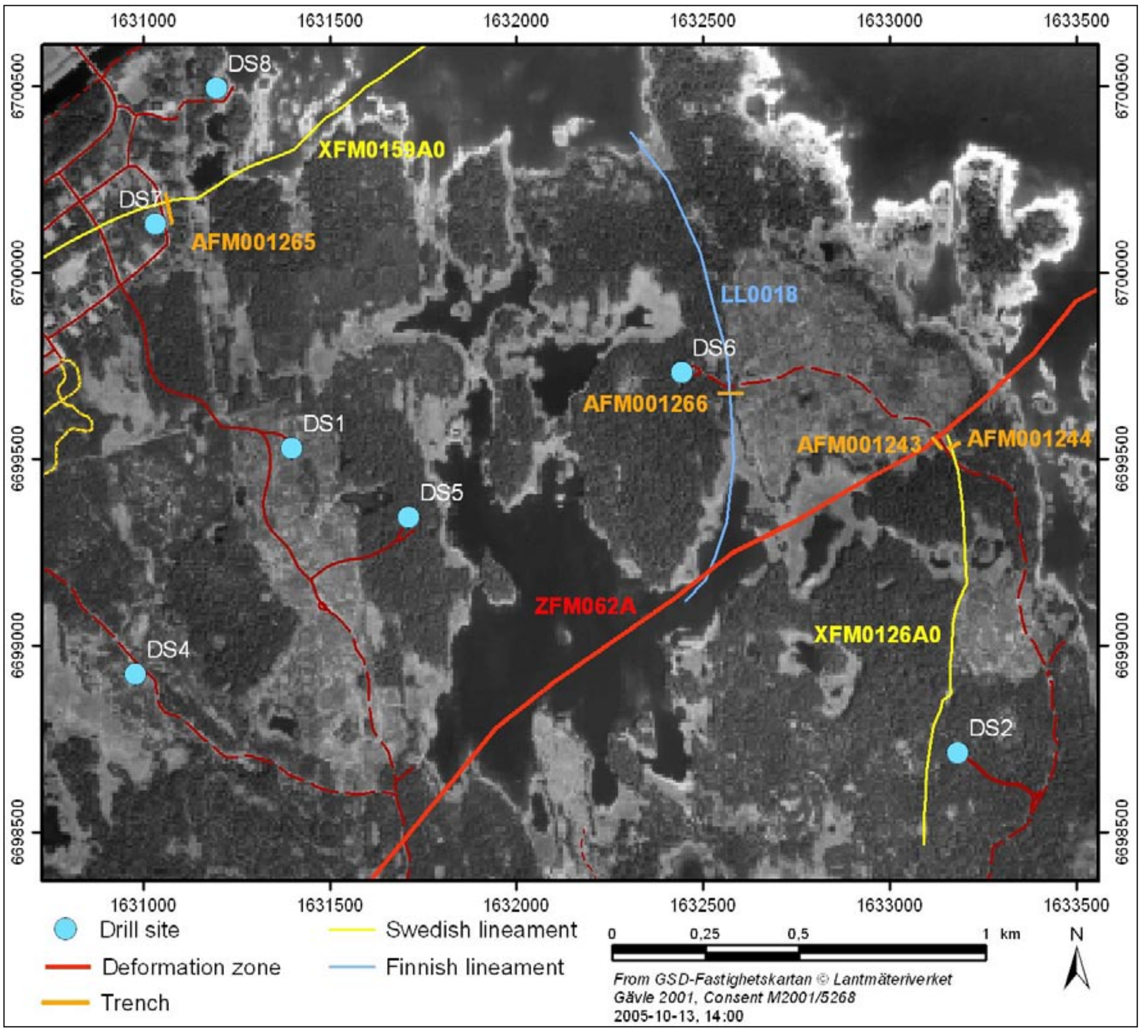


Figure 1-1. *Aerial photograph showing inferred lineaments in the north central part of the Forsmark site investigation area. Also shown are the locations of the two trenches, AFM001265 and AFM001266, and their relation to drill sites and other trenches.*

2 Objective and scope

The dimension of the exposed bedrock in the bottom of trench AFM001265 is c. 3×41 m, and the total area amounts to 95 m^2. The soil cover ranges generally from 2.5 to 4.2 m and the normal groundwater inflow over a day is more or less negligible.

The aim of the bedrock mapping of AFM001265 is to find out if lineament XFM0159A0 is connected to any geological feature, such as a deformation zone or dyke. To obtain a more integrated geological picture of the exposed area, the conventional lithological mapping was complemented by (1) a profile of magnetic susceptibility measurements along the centre of the trench and (2) characterization of one or more deformation zones, which were expected to be found in the trench. The latter includes documentation of fracture frequency, main fracture orientations, fracture filling minerals and the general character.

3 Equipment

The following equipment was used to facilitate the geological mapping of AFM001265: Silva compass, hand lens, folding rule, chalks, tap water and concentrated hydrochloric acid diluted with three parts of water.

The instrument used to measure susceptibility is a SM-20 magnetic susceptibility meter (GF instruments, Czech Republic) with sensitivity of 10^{-6} SI units (see www.gfinstruments.cz for more details).

The geometry of fractures, lithological contacts and the exposure was measured with a Geodimeter 640S Total Station. In theory, the survey instrument gives an accuracy 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. This is of course not always possible. Each measurement is, therefore, estimated to be performed with a northing and easting accuracy of 1 cm. Elevation accuracy is estimated at less than 5 mm.

4 Execution

4.1 General

The fieldwork includes generally three parts: (1) detailed bedrock mapping, (2) magnetic susceptibility measurements and (3) measurement of all objects trace geometry. The work has been conducted by a group of people, where Jesper Petersson (SwedPower AB) was responsible for the geological mapping, Göran Skogsmo (SwedPower AB) for the susceptibility analysis, and Jon Vestgård (Golder Associates AB), with assistance from Göran Skogsmo and Jesper Petersson, for measuring in the trace geometries.

The bedrock mapping, susceptibility measurements, spatial analysis and the study of the Quaternary deposits were performed according to Activity Plan AP PF 400-05-075 (SKB internal document) following the SKB Method Descriptions/instructions for bedrock mapping (SKB MD 132.001, v. 1.0), measuring in and levelling of objects (SKB MD 110.001, v. 1.0) and descriptions/instructions mapping Quaternary deposits.

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

4.2 Preparations

The necessary calibration of the SM-20 magnetic susceptibility meter was conducted by the Swedish Geological Survey (SGU) before the field season 2005.

The geodimeter was positioned outside the trench and measurements were made against three fix points related to the regional coordinate survey established by SKB (Table 4-1). These measurements were done in the beginning and at the end of each fieldwork session. The instrument calibration was checked before and after the fieldwork.

4.3 Data handling

The storage capacity of the SM-20 magnetic susceptibility meter is 100 readings. The total number of readings along the profile is 328 (i.e. 8×41). Since no portable PC was available all readings were written down manually, and later fed into Microsoft Excel. The digital data and the original protocol were checked twice for consistency, and after delivery exported to the SKB database Sicada.

The geodimeter instrument data were achieved in RT90 2.5 gon V, RHB70 coordinate data. These were subsequently converted to an AutoCAD DWG file. Quality control of the geodimeter data was made both by the surveyor and a second person. The calculations were checked and the data were compared with the map. All data were finally delivered for export to SKB's database Sicada.

Table 4-1. Fix points for trench AFM001265. RT90 2.5 gon, RHB70.

SKB ID	X (northing)	Y (easting)	Z (elevation)
7101	6 700 163.793	1 631 046.839	3.705
7102	6 700 083.102	1 631 067.893	3.155
7103	6 700 052.651	1 631 037.158	2.596

4.4 Execution of fieldwork

All lithological descriptions and identification of fracture minerals are based on ocular inspection. The orientation of ductile structures, lithological contacts and fractures were measured by using a Silva compass with inclinometer. To give the general characteristics of the more highly fractured area in the central part of the trench, it was decided that the fracture documentation here should be restricted to measuring in trace geometries of major fractures (truncation length of about one metre), orientation measurements for some major fractures and fracture frequency estimates along a 15 metres scan line (truncation length of about 0.5 metre). The documentation does, therefore, deliberately not follow the SKB Method Description for detailed fracture mapping (SKB MD 132.003, v. 1.0).

Magnetic susceptibility measurements were done with about one-metre intervals along a central profile in AFM001265. Each measurement represents the mean of eight instrument readings within an area with a radius less than about 0.5 m. Special care has been taken to avoid composite measurements comprising readings from more than one rock type. Totally, the profile in AFM001265 comprises 41 measurement areas (Appendix A2).

To facilitate the geodimeter measurements of trace geometries, all lithological contacts, fractures and susceptibility measurement areas were marked by chalk on the rock surface. The frequency of measuring points registered along each object depends on the geometrical complexity of the trace and the rock surface. More measurements result in a more well-defined trace. However, an increasing number of measured points substantially slow down the survey. The work was, therefore, performed in such a way that there was a balance between speed and degree of trace complexity.

5 Results

5.1 Lithology

A geological map of AFM001265 is given in Appendix A1. More than 95% of the exposed surface in the trench consists of medium-grained metagranite (rock code 101057). Other rock types include a few narrow dykes and veins of pegmatitic granite (rock code 101061), one dyke of fine- to finely medium-grained granite (111058), some minor, foliation-parallel streaks of aplitic metagranite (rock code 101058) and a single, foliation-parallel occurrence of biotite/chlorite-rich amphibolite (rock code 102017) (Figure 5-1). None of these occurrences are more than a few decimetres in width. Except for most pegmatitic granite and the fine- to finely medium-grained granite, 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.

Dykes and veins of pegmatitic granite (101061) occupy about 2% of the exposed bedrock. Most of them are rather persistent in the strike direction, and only a few centimetres wide. Except for a few minor, foliation-parallel veins in the southern part of the exposure, all these dykes and veins are discordant to the tectonic foliation in the wall rock. Discordant dykes and veins generally strike from 55° to 95°, and dip moderately to the south. One, up to two decimetres wide, discordant dyke of massive, fine- to finely medium-grained granite (111058) occurs in the northern part of the exposure. Parts of the dyke are slightly pegmatitic. Aplitic metagranite (101058) occurs as a few minor, foliation-parallel veins in the central part of the exposure. It is fine-grained, equigranular and red in colour.

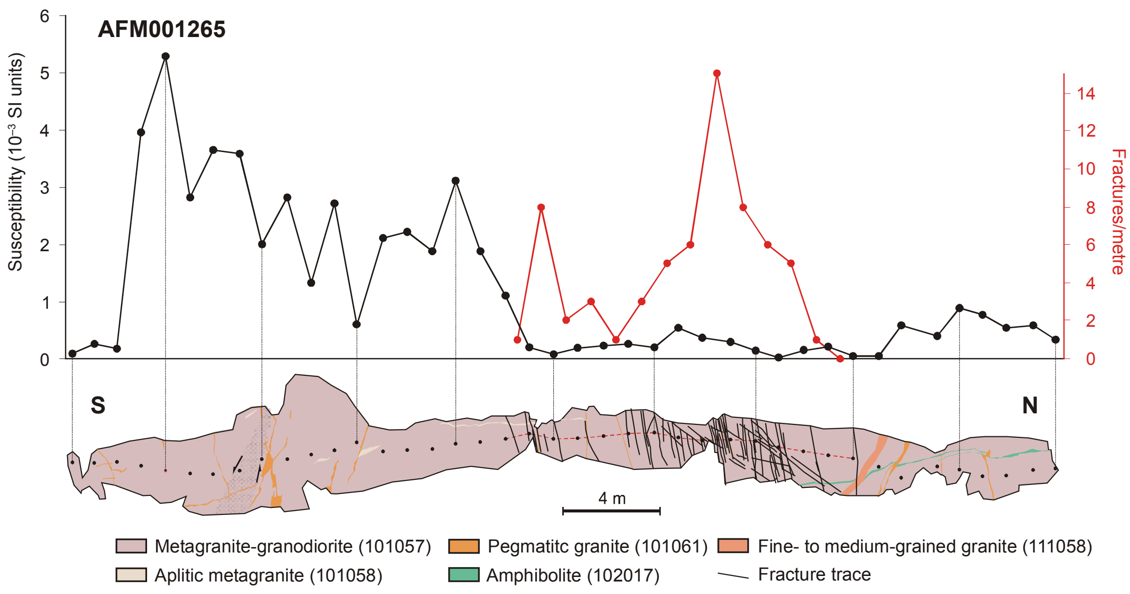


__Figure 5-1.__ Magnetic susceptibility and fracture frequency profiles along AFM001265. Exact locations of susceptibility measurement areas are indicated by dots on the geological map. Scan lines for fracture frequency estimates are marked by red on the geological map. Fracture truncation level is 0.5 metre.

The presence of amphibolite (102017) is limited to an intensely stretched, concordant 'dyke' in the northern part of the exposure. The maximum width of the occurrence is five centimetres. It is very biotite/chlorite-rich and exhibits a rather strong tectonic foliation.

5.2 Ductile structures

All exposed rocks, except for the discordant dykes and veins of pegmatitic granite and fine- to finely medium-grained granite, show a distinct tectonic foliation with an orientation of 135–161°/54–75°. The intensity of this ductile strain is typically medium, though streaks of more intense foliation occur locally.

In addition, there is an E–W trending, vaguely defined ductile shear zone in the southern part of the exposure. The zone is roughly metre-wide with a weak, but prevalent sinistral component.

5.3 Fractures

The vast majority of the fractures in the trench belong to a well-defined, sub-vertical fracture set that strikes 243–250°. These NE–SW striking fractures are found throughout the exposure, though the fracture frequency increases dramatically in a several metres wide zone in the central part of the trench (see Appendix A1 and Figure 5-1). Another conspicuous fracture set in this interval consists of vertical to sub-vertical, NNE–SSW striking fractures. Also the number of minor fractures (typically a few decimetres in length) with variable orientation increases in this interval. A 20–30 cm wide breccia, primarily defined by NNE–SSW striking fractures, occurs in the centre of the zone (Figure 5-2a).

The NE–SW striking fractures are typically up to 1–2 mm in width, with a few reaching up to 7 mm. The distinguishable fracture sealing includes calcite, chlorite, red coloured adularia, and epidote. However, the central zone, in which the breccia occurs, is dominated by chlorite, calcite and locally, epidote. Most fractures exhibit oxidized walls, and the highly fractured, central zone shows a continuous oxidation of weak to medium intensity.

The exposed surface of the more fractured interval corresponds largely to pre-existing, flat-lying fracture planes, with relict coatings of calcite and chlorite (Figure 5-2b). The surface has, moreover, generally been affected by varying degrees of oxidation.

Detailed fracture mapping of a deformation zone in a nearby trench, AFM001265, was also carried out. The results are presented in /1/.

5.4 Magnetic susceptibility

Magnetic susceptibility was only measured at the predominant medium-grained metagranite (101057), since most of the other rock units are too thin to yield reliable data. Typically, the metagranite exhibits a rather low susceptibility averaging at c. 1.2×10^{-3}. However, the susceptibility does, even in decimetre scale, vary considerably, from 3.5×10^{-5} to 5.3×10^{-3} SI (Appendix A2). Generally, the susceptibility decreases with an increasing intensity of oxidation. Thus, there is a distinct susceptibility drop in the area with increased frequency of NE–SW and NNE–SSW trending fractures (Figure 5-1). However, it must be emphasized that the exposed surface of this highly fractured area largely corresponds to pre-existing fracture planes, which are variably affected by oxidation. For this reason it is not obvious how much of the susceptibility drop that is related to these gently dipping fracture planes. Also the southernmost part of the trench yields anomalously low susceptibility values. There is no obvious reason for this drop. The rock shows no evidence of oxidation or any other alterations. To check the reliability of the data, we re-measured the anomalous areas. However, the results were broadly consistent with the first measurements.

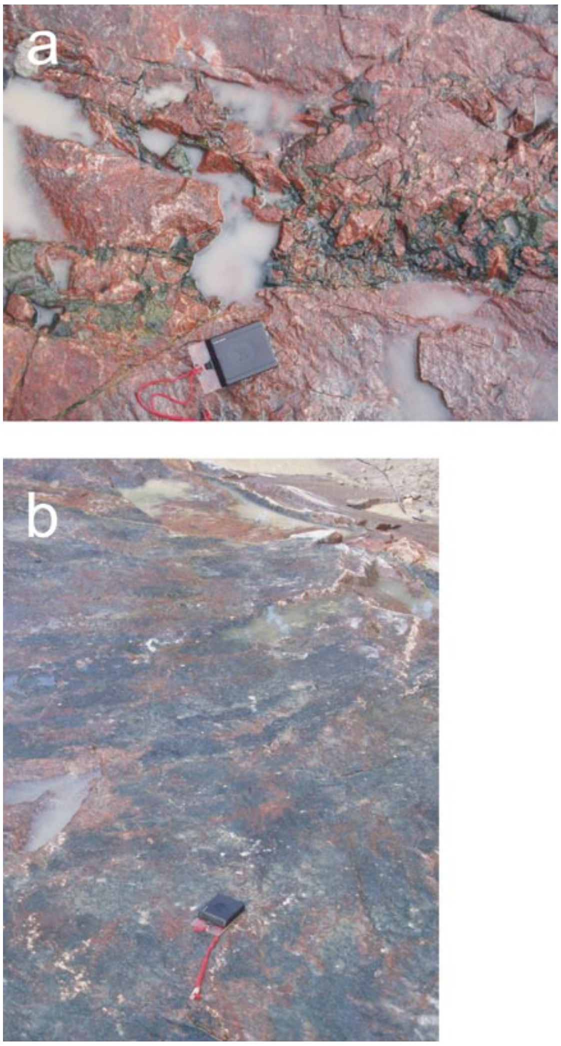


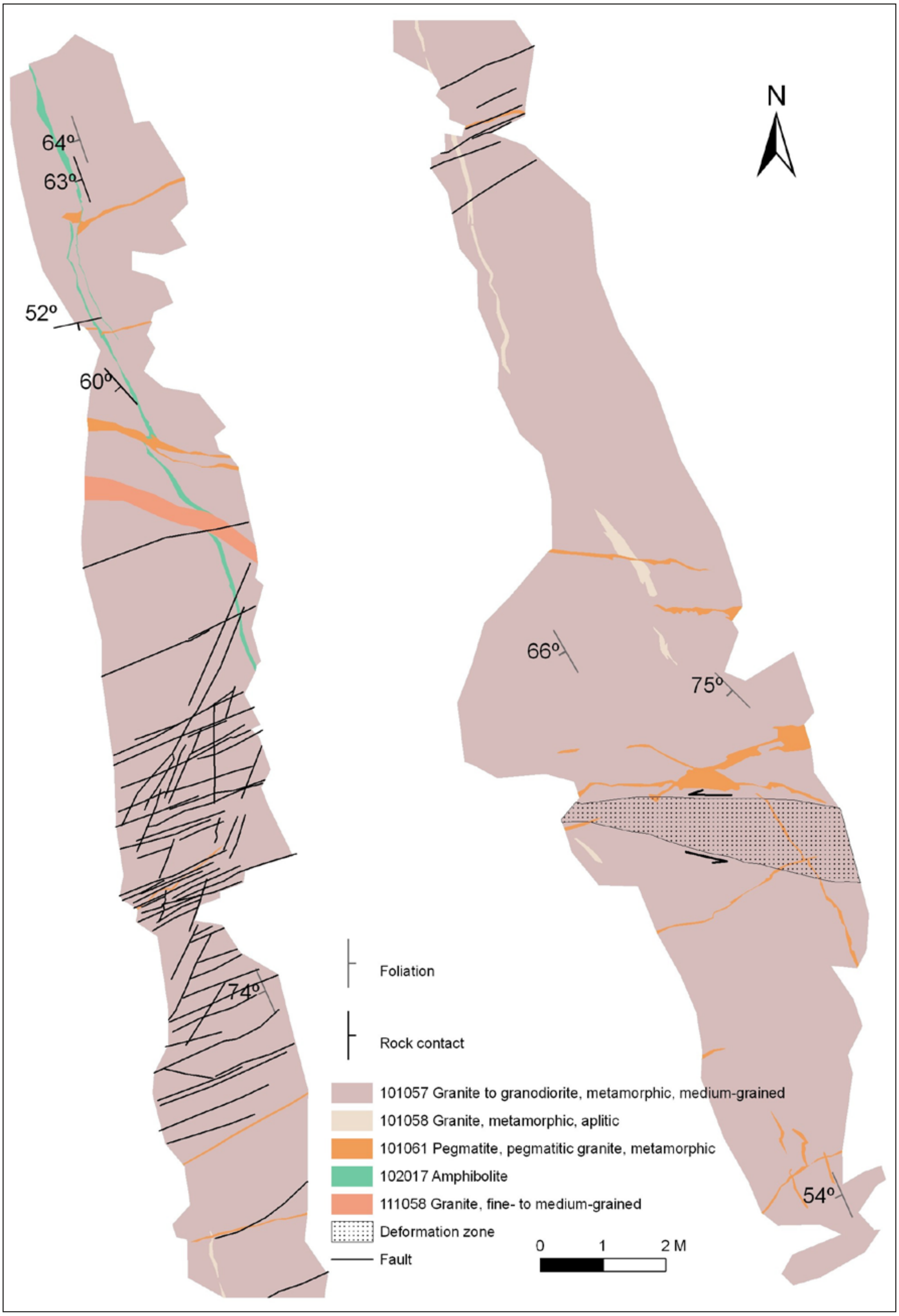
Figure 5-2. *Photographs of various brittle structures in AFM001265. (a) Chlorite and epidote sealed breccia in the intersection between the NNE–SSW and NE–SW trending fracture sets. (b) Flat-lying fracture surface with relict coatings of calcite and chlorite, as well as oxidized walls. Size of the compass used as scale is 6.4×10 cm.*

6 References

/1/ **Forssberg O, Hansen L M, Koyi S, Vestgård J, Öhman J, Petersson J, Albrecht J, Hedenström A, Gustavsson J, 2007.** Forsmark site investigation. Detailed fracture and bedrock mapping, Quaternary investigations and GPR measurements at excavated outcrop AFM001264. SKB P-05-269. Svensk Kärnbränslehantering AB.

Appendix A

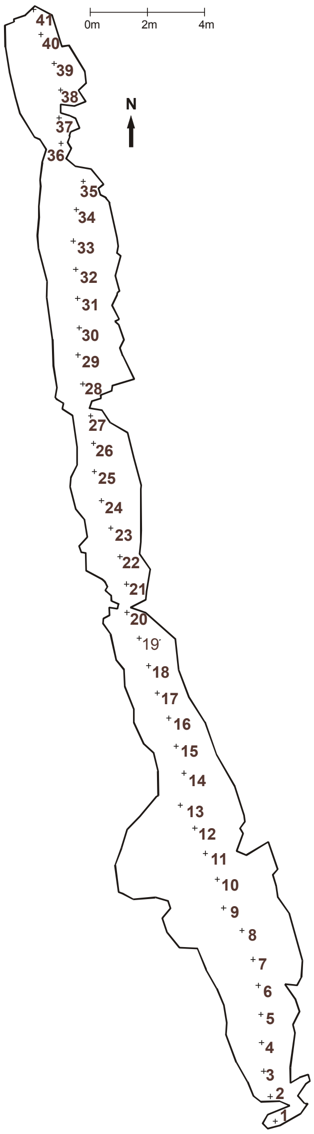
1. Lithological map of AFM001265



2. Magnetic susceptibility measurements along AFM001265

Area*	Readings								Mean
	1	2	3	4	5	6	7	8	
1	0.026	0.050	0.084	0.117	0.119	0.147	0.147	0.101	**0.0989**
2	0.096	0.081	0.062	0.132	0.106	0.139	0.107	1.44	**0.270**
3	0.150	0.191	0.129	0.240	0.056	0.35	0.216	0.164	**0.187**
4	5.38	4.40	0.350	7.67	0.268	6.82	0.080	6.76	**3.97**
5	10.5	1.54	2.65	4.40	3.96	9.60	3.51	6.17	**5.29**
6	1.62	3.36	1.81	2.89	6.65	4.95	0.812	0.497	**2.82**
7	3.94	5.08	4.91	2.13	2.70	4.43	2.53	3.53	**3.66**
8	2.41	7.72	1.96	4.79	1.74	2.68	1.06	6.35	**3.59**
9	1.77	7.85	1.34	2.33	1.16	0.271	1.10	0.261	**2.01**
10	4.34	5.92	3.92	2.77	1.33	1.41	1.55	1.44	**2.84**
11	1.57	0.941	1.79	0.973	1.94	1.18	0.44	1.85	**1.34**
12	3.83	3.00	5.23	3.28	1.92	0.934	1.29	2.26	**2.72**
13	0.646	0.893	0.608	0.875	0.286	0.445	0.275	0.861	**0.611**
14	2.03	3.31	0.634	2.13	5.07	0.914	0.589	2.25	**2.12**
15	2.26	2.22	1.99	5.47	1.74	2.11	0.648	1.36	**2.22**
16	1.56	1.69	2.98	3.46	0.653	1.65	1.59	1.55	**1.89**
17	5.35	6.20	4.15	3.42	0.644	2.68	1.20	1.34	**3.12**
18	1.29	2.27	1.51	1.02	0.671	1.86	4.74	1.80	**1.90**
19	0.396	1.05	1.22	0.36	2.15	1.18	1.72	0.838	**1.11**
20	0.144	0.133	0.267	0.271	0.02	0.332	0.413	0.094	**0.209**
21	0.070	0.063	0.146	0.055	0.110	0.060	0.069	0.126	**0.087**
22	0.582	0.113	0.154	0.275	0.087	0.073	0.136	0.184	**0.200**
23	0.158	0.350	0.182	0.163	0.333	0.388	0.08	0.315	**0.246**
24	0.089	0.269	0.125	0.208	0.464	0.79	0.196	0.109	**0.281**
25	0.273	0.203	0.156	0.255	0.195	0.248	0.304	0.076	**0.214**
26	0.443	0.059	1.82	0.206	0.080	0.253	1.26	0.282	**0.550**
27	0.010	0.769	0.044	1.63	0.046	0.336	0.003	0.185	**0.378**
28	0.716	0.202	0.762	0.121	0.274	0.041	0.178	0.137	**0.304**
29	0.124	0.046	0.074	0.061	0.603	0.188	0.066	0.051	**0.152**
30	0.029	0.020	0.055	0.029	0.030	0.056	0.026	0.033	**0.035**
31	0.234	0.055	0.18	0.123	0.445	0.081	0.174	0.029	**0.165**
32	0.207	0.378	0.506	0.191	0.122	0.161	0.113	0.091	**0.221**
33	0.097	0.052	0.047	0.093	0.037	0.043	0.014	0.081	**0.058**
34	0.058	0.013	0.028	0.05	0.046	0.284	0.003	0.020	**0.063**
35	0.163	0.877	0.405	1.02	0.032	0.055	0.272	1.94	**0.596**
36	0.641	0.196	0.569	0.346	0.020	0.746	0.495	0.282	**0.412**
37	1.20	1.02	0.869	1.63	0.030	0.967	0.832	0.619	**0.896**
38	2.97	0.758	0.612	0.431	0.353	0.405	0.451	0.264	**0.780**
39	0.867	0.191	0.219	1.01	0.780	0.136	0.623	0.572	**0.550**
40	0.446	2.34	0.443	0.389	0.174	0.238	0.393	0.240	**0.583**
41	0.831	0.513	0.117	0.172	0.121	0.115	0.571	0.321	**0.345**

* The numbers refer to the measurement areas marked in the map right of the table.



Appendix B

Quaternary investigations in machine-cut trenches

Joachim Albrecht, Anna Hedenström
Geological Survey of Sweden

Introduction

This appendix reports the results gained by the investigation *Quaternary investigations in machine cut trenches*, 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 bedrock mapping and magnetic susceptibility measurements in trench AFM001265 and AFM001266 for verification of lineament XFM0159A0 (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 unconsolidated 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

AFM001265 General description and interpretation

The excavated trench is about 60 m long and extends in NNW-SSE direction. The upper soil surface was flat before excavation, levelled by artificial filling material. The soil thickness varies between 1.8 and 3.5 m (Figure B-1, Sketch I and II).

The bedrock consists mainly of greyish and red granite. Minor fractures induced by glacial activity occur. Detailed description of the bedrock and fractures are presented in this main report and Appendix A. Large sub-horizontal sediment-filled fractures (cf. AFM001264, /1/) do not occur, although the western trench wall exposes several large blocks which are separated from the bedrock by 10 to 20 cm thick laminated sand, silt and diamicton (Figure B-2). This feature shows a striking similarity to the sub-horizontal fractures at AFM001264 and drill site 5, /2/. Only the highest parts of the bedrock surface show glacial striation, the most prominent indicating an ice movement direction from 360°. A younger, more faintly developed striation suggests an ice movement direction from 295° (Figure B-3). Large parts of the lower bedrock surface are unpolished.

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

Method Descriptions	Number	Version
Metodbeskrivning för jordartskartering	SKB MD 131.001	1.0

Figure B-1. *The excavated trench at AFM001265, view to the S.*

Figure B-2. *Laminated sediment between the bedrock surface and large short-transported boulders.*

Figure B-3. *Striation pattern at the site. The dominating direction is from the N (360°). The compass illustrates a younger direction from 295°.*

The sedimentary succession, which was examined in three sedimentary logs, consists of seven units (Sketch III, IV and V). The lowermost and oldest (unit 7) is an inhomogeneous and complex sediment, mainly consisting of sandy, relatively clast-poor diamicton with an occasional tectonically formed stratification (Figure B-4 and Sketch V). In places, especially at the rock/sediment interface, the diamicton appears sandy-silty. A crudely stratified sand inclusion occurs, which shows signs of glacio-tectonization (Figure B-5). Fabric analysis in the diamicton at PFM006615 yielded a very weakly developed preferred orientation of 240° (Figure B-6 and Table B-2), which should not be used for ice movement reconstructions. This unit occurs in the northern half of the trench where it represents the major part of the litho-stratigraphy. The unit is interpreted as deformation till.

Unit 6 replaces unit 7 in the southern part of the trench (Sketch II, III and IV). Unit 6 is a grey, hard, sandy and over-consolidated diamicton (Figure B). Especially the upper part of the unit is very rich in stones and boulders and appears almost clast-supported. Clasts of Palaeozoic limestone are abundant. A cobble 'pavement' occurs at the top. Fabric analyses have been carried out at two levels (Figure B6 and Table B-2). The lower level, 20 cm above the bedrock, indicates an ice movement direction from NNE. The fabric strength of the upper level, 1.3 m above bedrock, is too weak for any conclusions about ice flow directions. This diamicton is interpreted as lodgement till, with an eroded upper part, and with an uncertain chronological and spatial relationship to unit 7. This diamicton is either contemporary or younger than unit 7.

Table B-2. Eigenvalue (V1) and strength (S1) of the fabric analyses.

Fabric analysis	Eigen vector V1 (Strike/Dip)	Strength S1
PFM006614_1	9°/9°	0.751
PFM006614_2	14°/12°	0.588
PFM006615_4	239°/22°	0.511

Figure B-4. *The inhomogeneous sediments of unit 7. Sand dominates in the lower part, a tectonically stratified diamicton the upper part.*

Figure B-5. *Deformation structures in a sand lens in unit 7 (dislocation top to the right).*

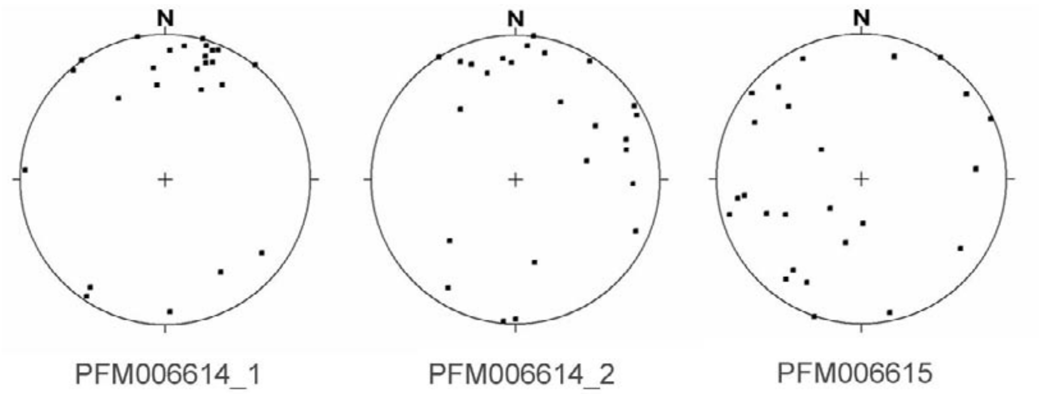


Figure B-6. *Fabric patterns of the till units. Only the lowest parts show strong orientation (PFM006614_1), suggesting an ice flow from the NNE.*

Unit 5, situated above units 6 and 7 is a brown, sandy and clast-rich diamicton (Figure B-7). Paleozoic limestone clasts are abundant. Single sand lenses occur. Fabric analysis has not been carried out. This unit is interpreted as melt-out till.

Units 4 through 1 are situated at a depression in the central part of the trench. Unit 4 is represented by greyish clay with brown patches. The clay contains sand-rich lenses, several gravel-sized clasts and single cobbles (Figure B-8). The occurrence of pyrite suggests reducing environment. The unit was deposited during de-glaciation. Input of sand and larger clasts occurred by grain-fall from melting winter ice and by wash-out and subsequent gravity currents.

Unit 3 is yellowish brown, crudely stratified medium sand. The sand is well-sorted, although several out-sized clasts are observed (Figure B-9). Many large clasts are observed at the bottom of the unit. The sand is interpreted as wave-washed sediment in a shallow bay of the Bothnian Sea. Out-sized clasts were probably transported and deposited by currents on the bottom of the Bothnian Sea.

Unit 2 is a dark brown peat containing single sand and gravel clasts. The peat was formed at the final stage of a very small pond and subsequently a fen.

Unit 1 is a brown, sandy, clast-rich diamicton, which contains cables, waste water pipes etc. Unit 1 is interpreted as excavated material, which was used to level depressions before the construction of the buildings nearby.

AFM001266

Severe problems with slope stability and high ground water flow caused termination of the planned excavation and prevented detailed studies (Figure B-10). The unfinished trench revealed two units. The lower, a silty to sandy-silty diamicton, is interpreted as till. The physical properties of this sediment gave rise to slope instability (cf. AFM001264, /1/).

The upper unit, a sandy, clast-rich diamicton, resembles unit 5 at AFM001265 and is accordingly interpreted as meltout till.

Figure B-7. *Units 6 and 5 at PFM006614. Unit 6 appears dense and hard while unit 5 is sandy and loose.*

Figure B-8. *Left – detail from Unit 4. The clay contains drop-stones and sandy horizons, which have a grainy appearance in this picture. Right – shows the section from SW. The person is standing at the transition between Unit 5 and Unit 4, holding his hand at the level for Unit 3. The dark unit on top of the sand is Unit 2, a highly humified layer of peat.*

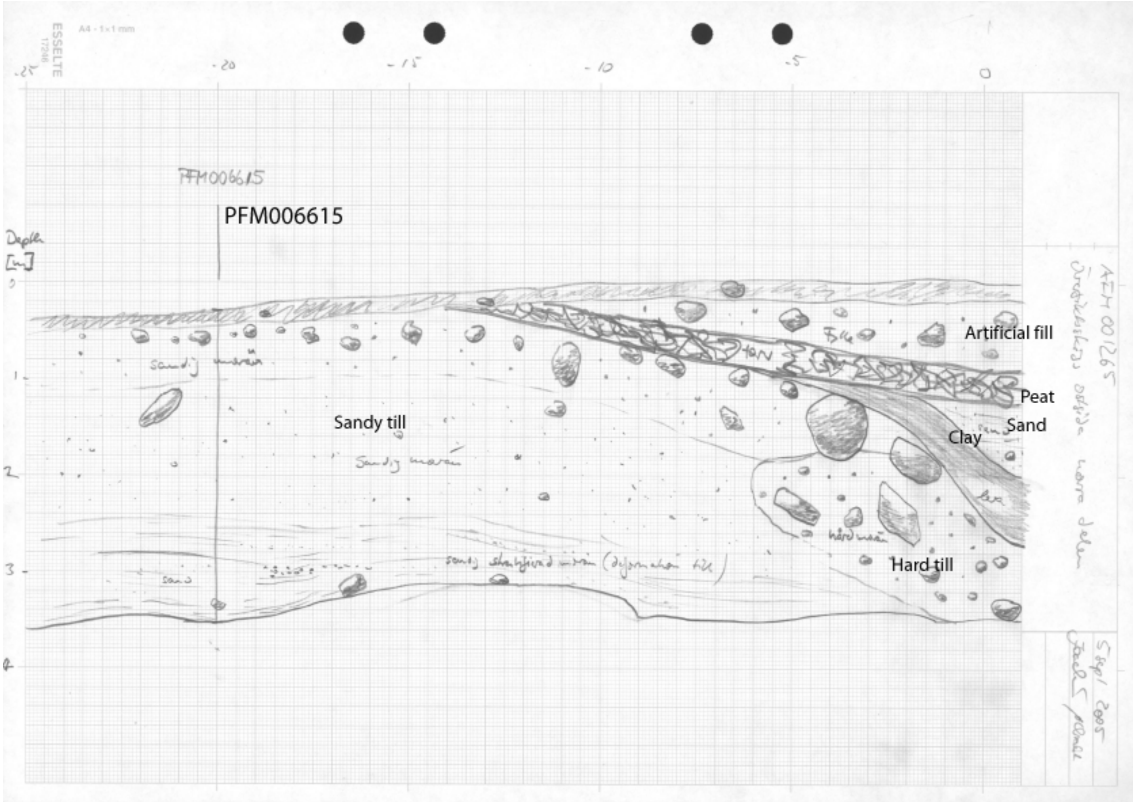
Figure B-9. *Sand with stones from Unit 3. Note the downward bending lamination below and the upward bending lamination above the stone.*

Figure B-10. *High groundwater flow and unstable water saturated slopes prevented detailed investigations at site AFM001266.*

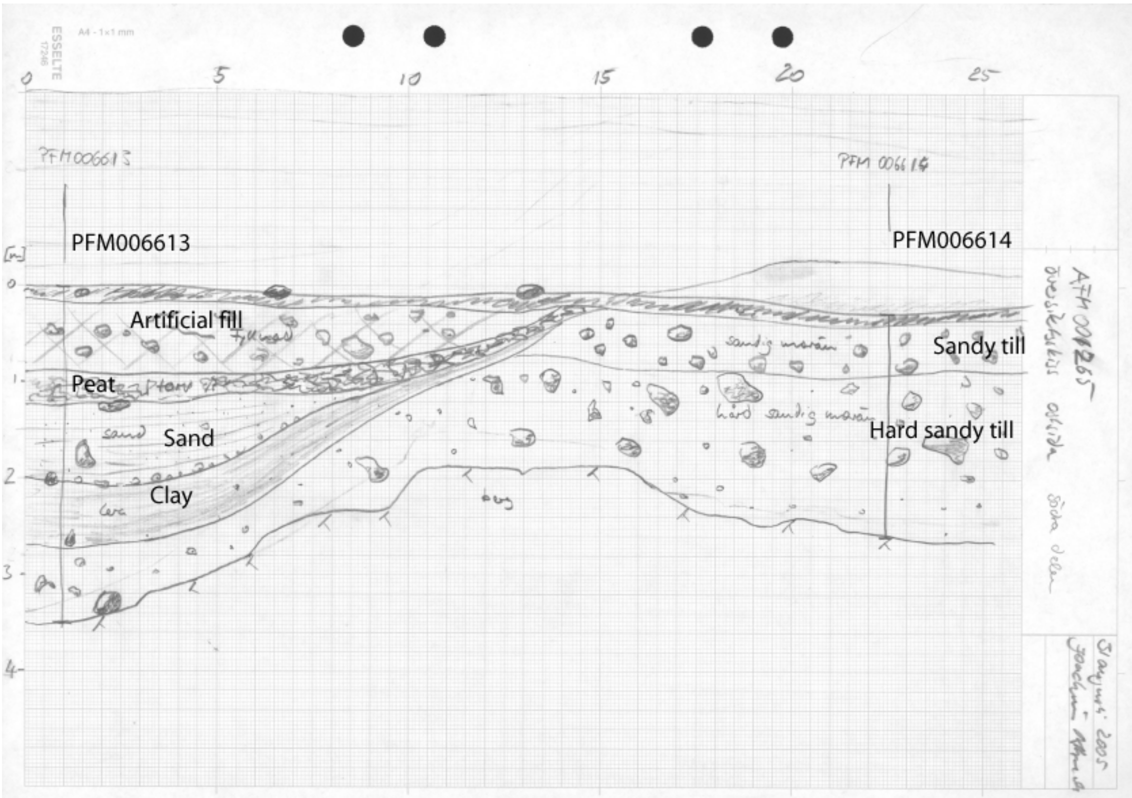
References

/1/ **Forssberg O, Hansen L M, Koyi S, Vestgård J, Öhman J, Petersson J, Albrecht J, Hedenström A, Gustavsson J, 2007.** Forsmark site investigation. Detailed fracture and bedrock mapping, Quaternary investigations and GPR measurements at excavated outcrop AFM001264. SKB P-05-269. Svensk Kärnbränslehantering AB.

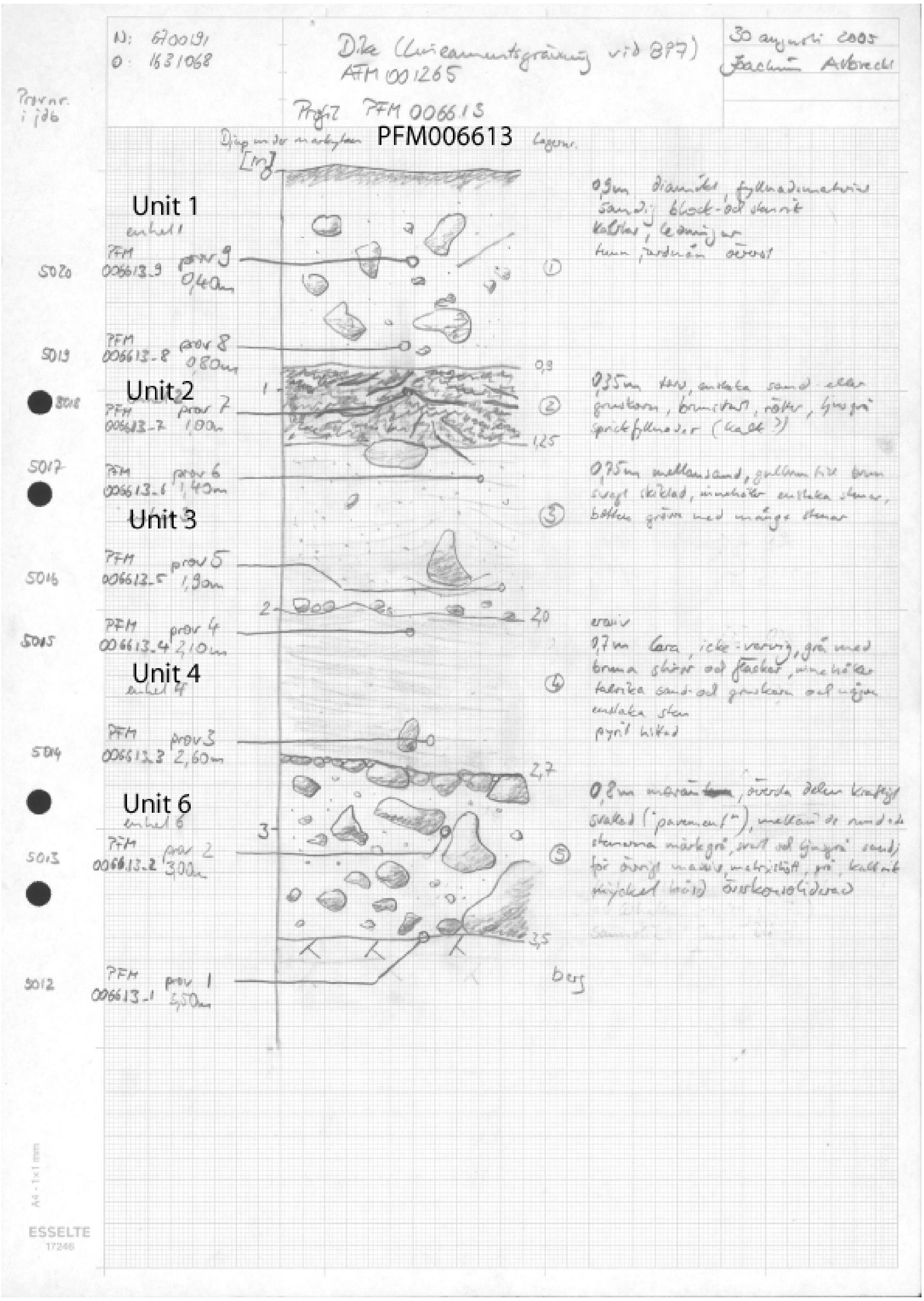
/2/ **Leijon B (ed) 2005.** Investigations of superficial fracturing and block displacements at drill site 5. Forsmark site investigation**.** SKB P-05-199. Svensk Kärnbränslehantering AB.



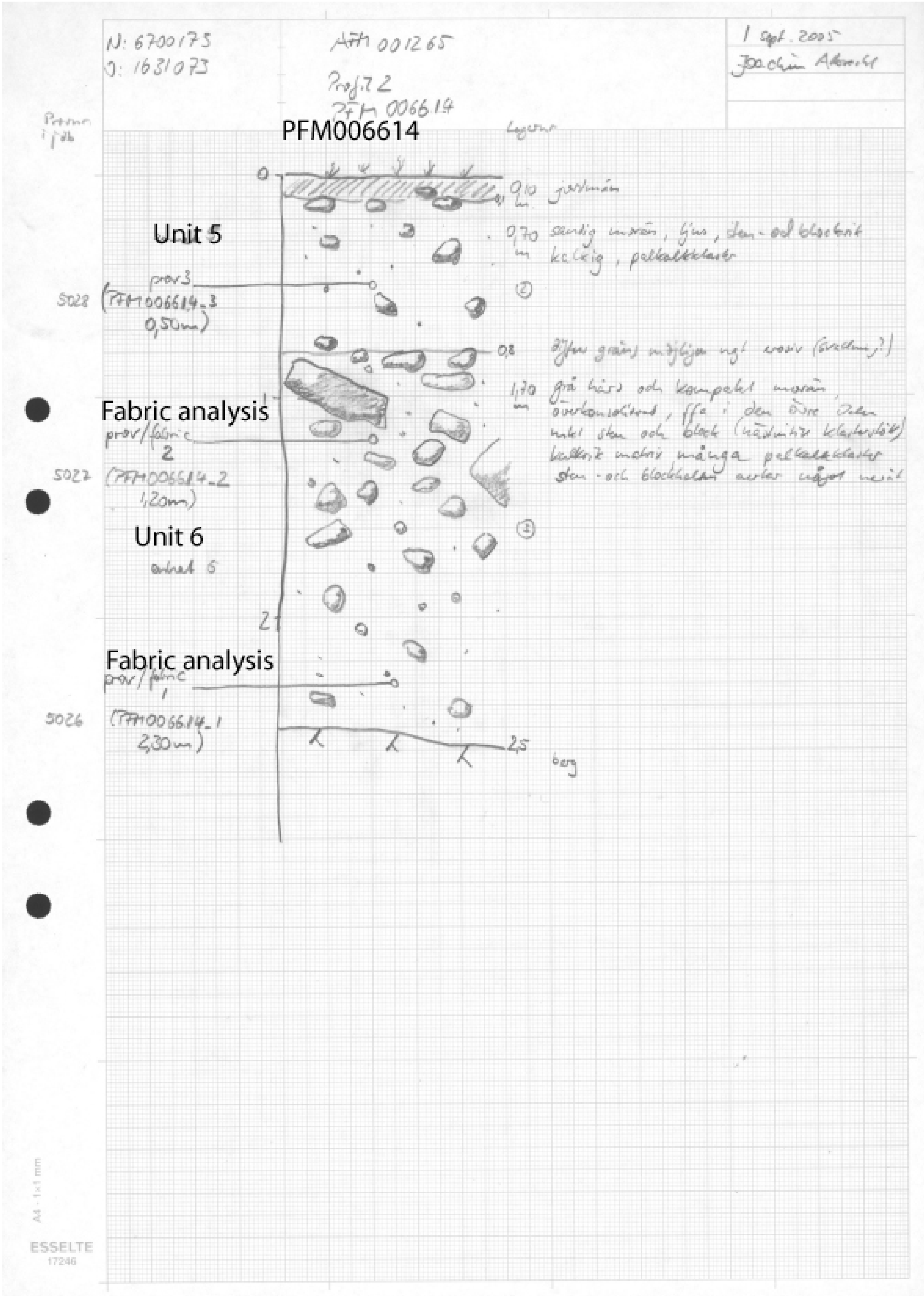
Sketch I. *Cross section through the northern part of the Quaternary sediments at AFM001265.*



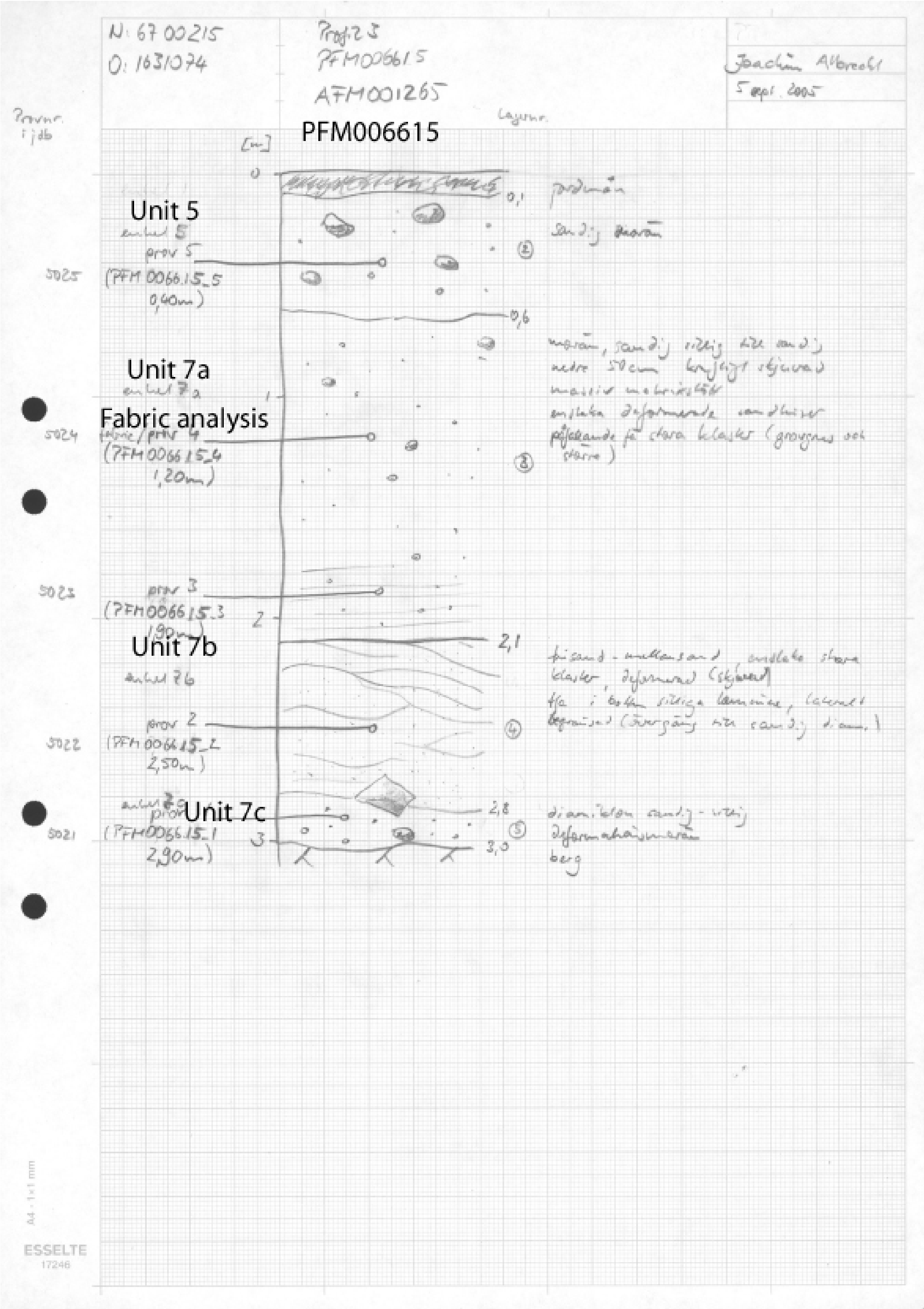
Sketch II. *Cross section through the southern part of the Quaternary sediments at AFM001265.*



Sketch III. *Log showing the lithostratigraphy at PFM006613.*



Sketch IV. *Log showing the lithostratigraphy at PFM006614.*



Sketch Sketch V. *Log showing the lithostratigraphy at PFM006615.*

Appendix C

GPR measurements at AFM001265, 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 AFM001265 at drill site 7, Forsmark. The purpose of the measurements was to study the possibility of detecting sheet joints.

Execution

The profile LFM000923 is located along the ditch AFM001265, and the measurements were conducted directly on the exposed bedrock surface (Figure C-1). The measurements were carried out with a RAMAC X3M system, manufactured by Malå GeoScience AB, and the antenna frequencies were 100 MHz and 500 MHz. The measurements where carried out 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 profile LFM000923 corresponds to the following start- and end-coordinates (RT90 2.5 gon; RHB70) (Table C-1).

Results

Figure C2 displays the data conducted with the 100 MHz antenna. A clear reflector, most probably a sheet joint, is identified at approximately 3 m depth. Several other structures are also identified at greater depths, see Figure C-2. Two narrow sections, at 1 m and 28 m, appear to be somewhat disturbed, probably due to metallic objects close to the profile.

Figure C-3 displays the data from the profile measured with a 500 MHz antenna. The structures identified with the 100 MHz antenna (Figure C-2) are clearly seen also in Figure C-3. The resulting radargram however gives more details at the cost of a more limited penetration depth due to the higher antenna frequency used. A number of hyperbolas can be identified, e.g. directly beneath the yellow reflector in Figure C-3. A possible explanation to these hyperbolas is a fragmentation of the reflector. Observe that not all structures are marked in the radargram in Figure C-3, e.g. the dipping structure at the end of the profile.

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

Profile ID	Location	Start	End
LFM000923	From 1 to 41	6700172.898 1631072.301	6700211.922 1631063.858

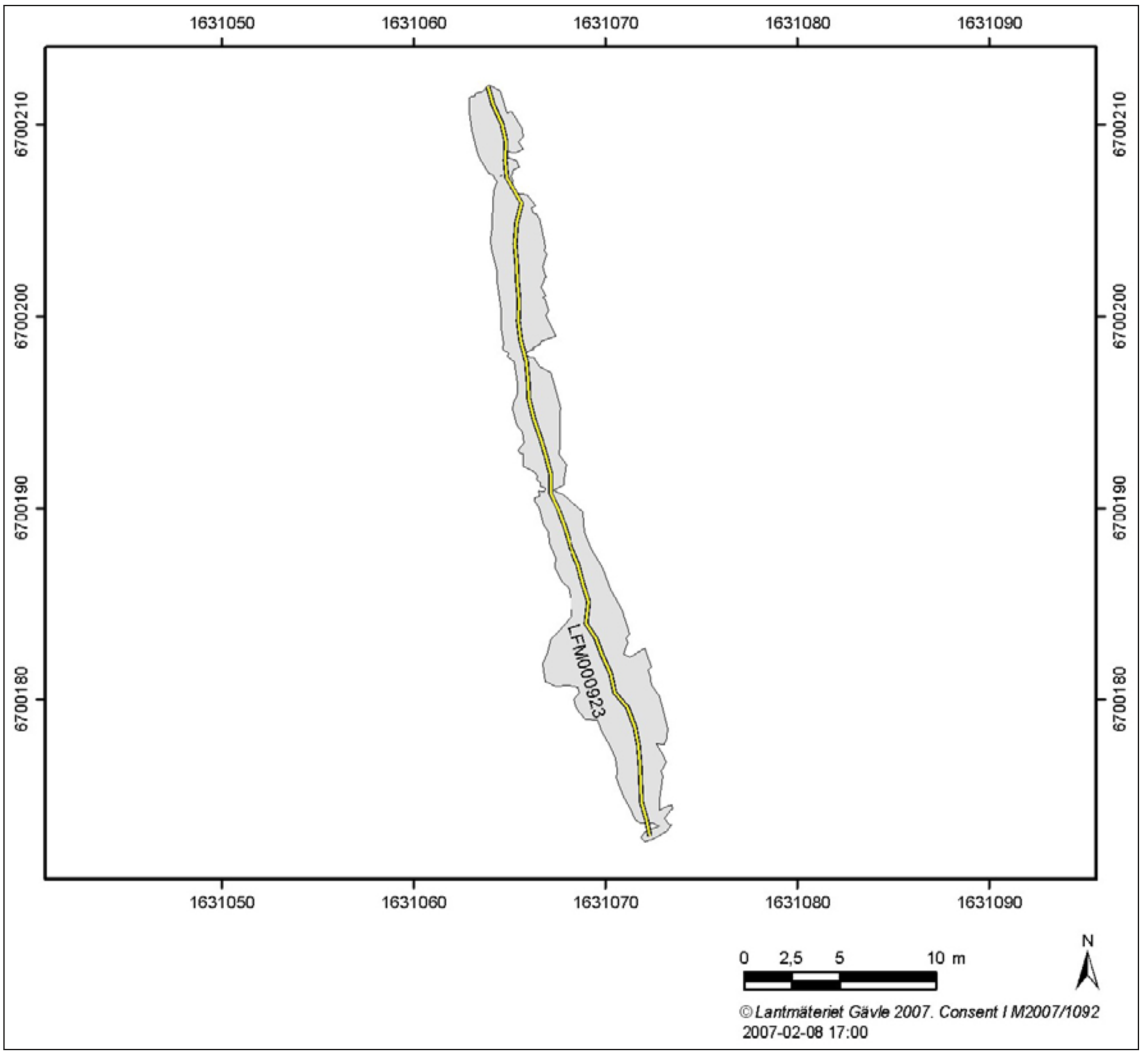

Figure C-1. *Outline of the area AFM001265 at drill site 7, Forsmark. The measurements were conducted along the profile, indicated by symbols and numbers from 1 to 41.*

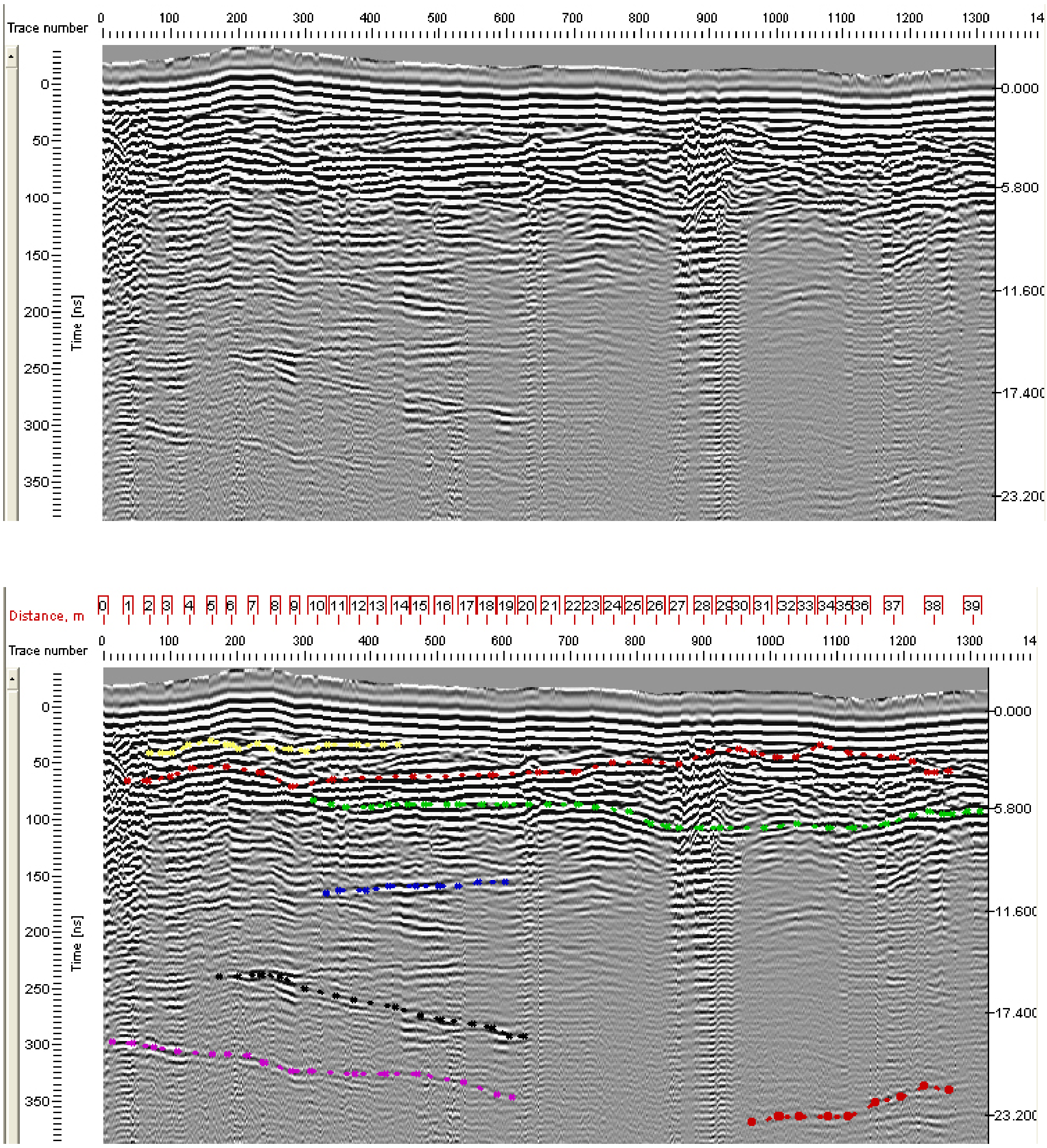

Figure C-2. *The results from profile LFM000923 (from 1 to 41), 100 MHz data without interpretation (upper radargram) and with interpretation (lower radargram).*

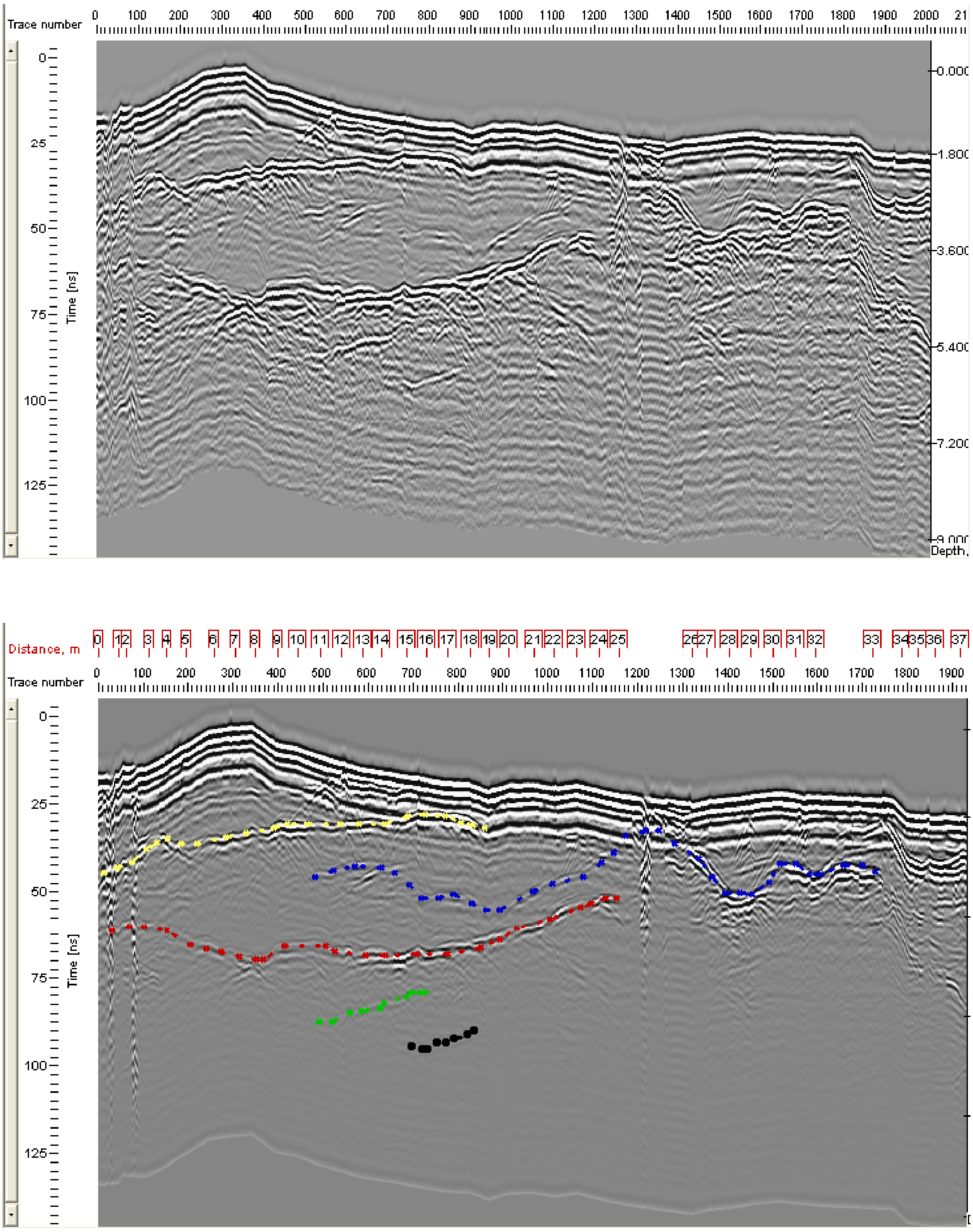

Figure C-3. *The results from profile LFM000923 (from 1 to 41), 500 MHz data without interpretation lines (upper radargram), and with interpretation lines applied (lower radargram).*

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.