P-05-138

Forsmark site investigation

Study of Quaternary sediments in connection with investigations of bedrock lineaments

Joachim Albrecht
Sveriges Geologiska Undersökning

June 2005

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Keywords: Glacial sediment, Till stratigraphy, Quaternary geology, Till fabric, CaCO3-content, Grain size distribution, Forsmark AP PF 400-04-97.

Abstract

The Quaternary sediments in two trenches within the Forsmark candidate area were investigated. Three till units were distinguished, of which the two upper probably belong to the same glacial event. The uppermost till unit is eroded by wave action and overlain by gravelly sand. The possibly youngest regional ice movement direction was from the N through NNW. The lowermost till was deposited by an ice advancing from the ENE.

The bedrock surface is fractured, probably by glaciotectonical stress. Water percolated through the open fractures and washed out fine-grained material from the adjacent sediment.

Sammanfattning

De kvartära sedimenten i två maskingrävda diken inom kandidatområdet i Forsmark har undersökts. Tre olika moränbäddar har kunnat urskiljas, varav de två övre sannolikt hör till en och samma glaciala händelse. Den översta moränen är svallad och överlagras av svallsand. Den förmodligen yngsta isrörelseriktningen finns dokumenterad i räffelmönstret och är från mellan N och NNV. Den understa moränen är avsatt av en is som rörde sig från ONO.

Berggrunden visar spår av glacialtektonisk stress i form av små öppna sprickor. Vatten har rört sig i dessa sprickor och sköljt ur de fina fraktionerna.

Contents

1 Introduction

This document reports the results gained by the study of Quaternary sediments in connection with investigations of bedrock lineaments, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-04-97. In Table 1-1 controlling documents for performing this activity are listed. Both the activity plan and method descriptions are SKB's internal controlling documents. The location of the two investigated trenches is shown in Figure 1-1.

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

Activity Plan	**Number**	**Version**
Kvartärgeologiska undersökningar i samband med lineamentsgrävningar, hösten 2004	AP PF 400-04-97	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för jordartskartering	SKB MD 131.001	1.0

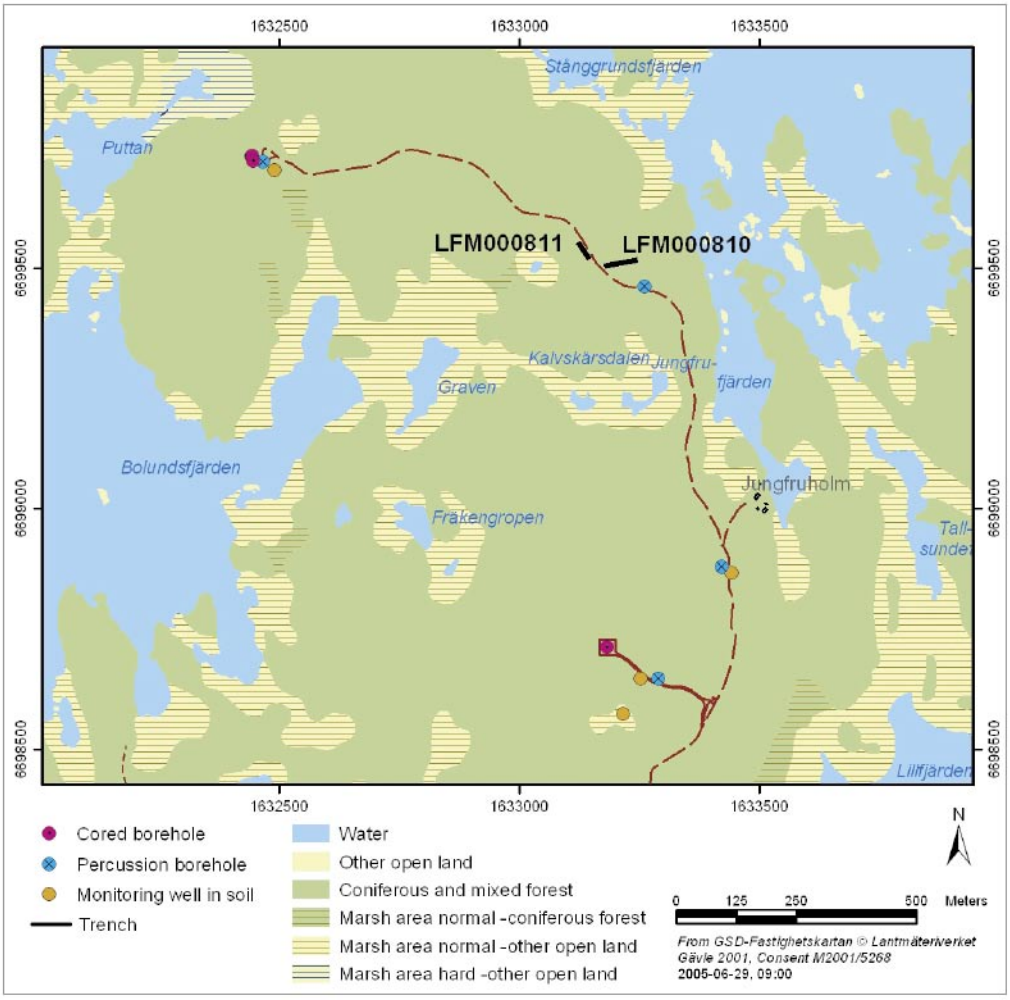

Figure 1-1. *Map showing the location of the two investigated trenches.*

2 Objective and scope

This study aims at gaining additional information on glacial stratigraphy in the Forsmark area and on the physical properties of the glacial sediments. Special interest is attached to till stratigraphy, till composition and ice flow directions. The investigations were carried out on three days between September 28 and October 4, 2004.

The work was conducted in two machine-cut trenches (Figure 1-1), which had been excavated in order to gain information on lineament structures in the bedrock.

At each site, the stratigraphical succession was documented and clast fabric analyses were carried out in selected till units. Samples were collected for laboratory analyses of grain size composition and $CaCO_3$-content. The physical properties of the sediment are important for hydrogeological modelling. Some hydraulic properties were calculated from the grain size distribution.

Other activities performed at, or close to, the trenches are:

Vegetation mapping and soil type inventory (AP PF 400-04-99).

Detailed fracture mapping and bedrock mapping and ground penetrating radar measurements (AP PF 400-04-81).

Refraction seismics (AP PF 400-04-77).

Sampling and analyses of near surface groundwater (performed as described in AP PF 400-04-90).

3 Equipment

3.1 Description of equipment/interpretation tools

The trenches were first cut by an excavator. Then the trench walls were cleaned manually by using shovel and scraper and were then documented in sketches and digital photographs.

A 360° mirror compass was used for clast fabric measurements.

Analyses of grain size and $CaCO_3$-content were carried out at SWECO Geolab according to /2, 3, 5 /.

4 Execution

4.1 General

The methods used are described in SKB MD 131.001 (SKB internal document).

The sections were cleaned manually by using shovels and scrapers and documented in hand-drawn sediment logs and sketches (see Appendix 1), as well as in photographs.

Clast fabric analyses in tills were performed at one location (PFM004454_1.20 m) in trench LFM000810 and at two locations (PFM004460_1.00 m and PFM004459_3.00 m) in trench LFM000811, see Appendix 1 for location.

Sediment samples were taken by using a scraper or knife.

4.2 Data handling/post processing

Unique id-codes were assigned to the trenches (LFM-series) and to observation points (PFM-series). All geological data are stored in SGU's database (Jorddagboken 5.4.3), exported to Excel-files and delivered to SKB. Data from till analysis (grain size composition, $CaCO_3$-content and hydraulic K-values) are stored in the SICADA database.

4.3 Analyses and interpretations

Three types of analyses were carried out on the sediments: fabric analysis (i.e. analysis of clast orientation), grain size analysis and analysis of $CaCO_3$-content. Fabric analysis is carried out on tills directly in the sections, where trend and plunge of the a-axes of elongated gravel-sized particles are measured. Generally, a-axes are aligned more or less parallel to the former ice movement direction and dipping upstream. Thus, a sufficient number of measurements (commonly 25 or more) provide a statistical tool for the reconstruction of ice flow directions.

Grain size analyses and analyses of $CaCO_3$-content were carried out at SWECO Geolab on representative samples. Sand and gravel fractions are analysed by sieving, whereas silt and clay fractions are analysed with the hydrometer method, where grain size parameters are calculated from sedimentation rates /2, 3/. The results are used for stratigraphical interpretations.

4.4 Nonconformities

Due to rainy weather during several weeks prior to the investigations, a high groundwater level combined with water-saturated soil above the groundwater level proved to be a problem, especially in trench LFM000811. To prevent this trench to become entirely water-filled, a submersible pump had to be installed, which drained over 50 l/s at peak levels.

The walls in the deepest part of the trench were unstable and too dangerous, for which reason they were only summarily documented.

Certain till units, especially those with high silt and fine sand content, tended to become mobilised and to flow out (tixotrophic behaviour), which made it impossible to carry out fabric analyses.

5 Results

The bedrock surface exposes distinct stoss and lee sides, as well as indications of glaciotectonical stress, such as millimetre-wide open fractures and dislocated and occasionally fractured bedrock blocks. In connection to these fractures the sediment appears to be depleted in fines, which is interpreted as an effect of percolating water.

Four different units could be determined. The results from the analyses are shown in Table 5-1. Grain size data and geological sketches are presented in Appendix 1. All data are stored in the SICADA database.

Table 5-1. Results from the grain size, $CaCO_3$ analyses and calculated hydraulic conductivity. The reference levels for the depth values are the ground level for the samples where the depth has one decimal whereas the samples with two decimals are measured from the upper surface of the mineral soil.

Trench	ID-code/ Sample number	Lithol unit	Depth (m)	Quaternary deposit (Swedish)	$CaCO_3$ (%)	Hydr cond (m/s)
LFM000810	PFM004454/1	C	1.2	Clayey sandy till (Lerig sandig morän)	25	6.1 E–07
LFM000810	PFM004455/2	D	0.1–0.15	Gravelly sand (Grusig sand)	0	1.2E–04
LFM000810	PFM004455/3	C	0.2–0.25	Sandy till (Sandig morän)	9	1.0E–06
LFM000810	PFM004455/4	C	0.5–0.55	Sandy till (Sandig morän)	25	5.2E–07
LFM000810	PFM004455/5	C	0.80–0.85	Sandy till (Sandig morän)	25	6.4E–07
LFM000810	PFM004455/6	C	1.20–1.25	Sandy till (Sandig morän)	25	5.3E–07
LFM000810	PFM004455/7	C	1.70–1.75	Sandy till (Sandig morän)	21	2.8E–07
LFM000810	PFM004455/8	B	2.50–2.55	Clayey sandy till (Lerig sandig morän)	27	6.6E–08
LFM000810	PFM004455/1	B	2.5	Clayey sandy silty till (Lerig sandig-siltig morän)	27	5.5 E–07
LFM000810	PFM004456/1	B	2.2	Clayey sandy silty till (Lerig sandig-siltig morän)	24	4.3 E–07
LFM000811	PFM004458/1	-	0.05–0.10	Sandy till (Sandig morän)	19	3.3E–06
LFM000811	PFM004458/2	-	0.20–0.25	Sandy till (Sandig morän)	20	3.2E–06
LFM000811	PFM004458/3	-	0.50–0.55	Sandy till (Sandig morän)	21	2.9E–06
LFM000811	PFM004458/4	-	0.80–0.85	Gravelly till (Grusig morän)	20	5.5E–06
LFM000811	PFM004458/5	-	1.20–1.25	Gravelly till (Grusig morän)	24	4.7E–06
LFM000811	PFM004458/6	-	1.70–1.75	Sandy till (Sandig morän)	26	5.6E–07
LFM000811	PFM004458/7	-	2.50–2.55	Sandy till (Sandig morän)	28	7.2E–07
LFM000811	PFM004459/1	A	3.5	Boulder clay (Moränlera)	23	3.9 E–07
LFM000811	PFM004459/2	A	3.5	Clayey sandy silty till (Lerig sandig-siltig morän)	26	1.0E–08
LFM000811	PFM004460/5	D	0.05–0.10	Gravelly sand (Grusig sand)	0	2.0E–04
LFM000811	PFM004460/6	-	0.20–0.25	Boulder clay (Moränlera)	17	6.1E–09
LFM000811	PFM004460/7	C	0.50–0.55	Sandy till (Sandig morän)	24	5.4E–07
LFM000811	PFM004460/8	C	0.80–0.85	Sandy till (Sandig morän)	25	4.2E–07
LFM000811	PFM004460/9	B	1.20–1.25	Sandy till (Sandig morän)	24	4.9E–07
LFM000811	PFM004460/10	B	1.70–1.75	Sandy till (Sandig morän)	25	4.0E–07
LFM000811	PFM004460/1	D	0.5	Gravelly sand (Grusig sand)	< 0.1	7.3 E–05
LFM000811	PFM004460/2	C	1.0	Clayey sandy till (Lerig sandig morän)	23	4.2 E–07
LFM000811	PFM004460/3	B	1.5	Clayey sandy till (Lerig sandig morän)	30	1.5 E–07
LFM000811	PFM004460/4	B	2.2	Clayey sandy silty till (Lerig sandig-siltig morän)	25	2.3 E–07

The lowermost unit, here named Unit A, is a diamicton and occurs only in the deepest part of trench LFM000811. It is dark grey in colour and at most 1.5 m thick (Figure 5-1). Its main characteristics are its hardness, its high clay content (15.7%) and its high content of Palaeozoic limestone in the gravel fraction. The sediment is interpreted as subglacial overconsolidated till ("Boulder clay").

Unit A is concordantly overlain by two diamictic units, Unit B and C, two and one metre thick, respectively. Unit B appears greyish and is characterised by a high content of fines (clay and silt). Fines amount up to 60%, which makes the sediment prone to mobilisation. Clay, silt and fine sand occur in streaks and lenses in an otherwise unsorted matrix. The lenses show indistinct signs of deformation during deposition. Unit B is interpreted as a basal deformation till. The transition to the overlying Unit C is indistinct. Unit C itself is grey with brown patches. It appears somewhat more homogeneous and less deformed than Unit B and the content of fines is lower (appr 30%). Unit C is interpreted as basal till and corresponds probably to the same glacial event as Unit B.

Figure 5-1. *Photograph showing the trench LFM000811. The dark clayey till, Unit A, is located in the bottom of the trench.*

Figure 5-2. *The deepest part of the trench LFM000810. The grey sediment in the bottom represents Unit B, clayey sandy silty till, overlain by the brown till representing Unit C.*

In LFM000810, Unit C is overlain by 10 to 20 cm gravelly sand (Unit D). This sediment is well sorted and lacks silt and clay. Clasts are rounded to well rounded. The sand is interpreted as residual sediment deposited due to erosion of the till by wave action.

The $CaCO_3$-content in the three diamicton units amounts to between 23 and 30%. The gravelly sand (Unit D) lacks $CaCO_3$, which might be a result of postglacial weathering. Information on ice movement directions is provided by glacial striae and clast fabrics (Figure 5-3). The dominating striation on the bedrock surface indicates an ice flow direction from NNW (340 through 350°), which also corresponds roughly to the direction implied by the bedrock morphology (stoss and lee sides). However, the striation is faint and coincides with the direction of the mineral lineation of the rock. An older direction, a fine lineation (360°), was measured on a horizontal surface close to a small vertical rock wall. However, this wall can have influenced the direction of ice flow locally. Clast fabric analysis in Unit A indicates an ice movement direction from the east north east. Analyses in Units B and C yielded a random pattern of clast orientation, maybe due to tixotrophic behaviour of the sediment, and do thus not provide any information of ice flow directions.

The northern ice flow direction is in agreement with other investigations carried out in the Forsmark area /4/ whereas an ice flow direction from the ENE is rather unusual (cf /1/). Usually, the hard clayey till shows fabric orientation patterns indicating ice flow directions from the N. Bedrock topography can however cause local variations of ice flow directions.

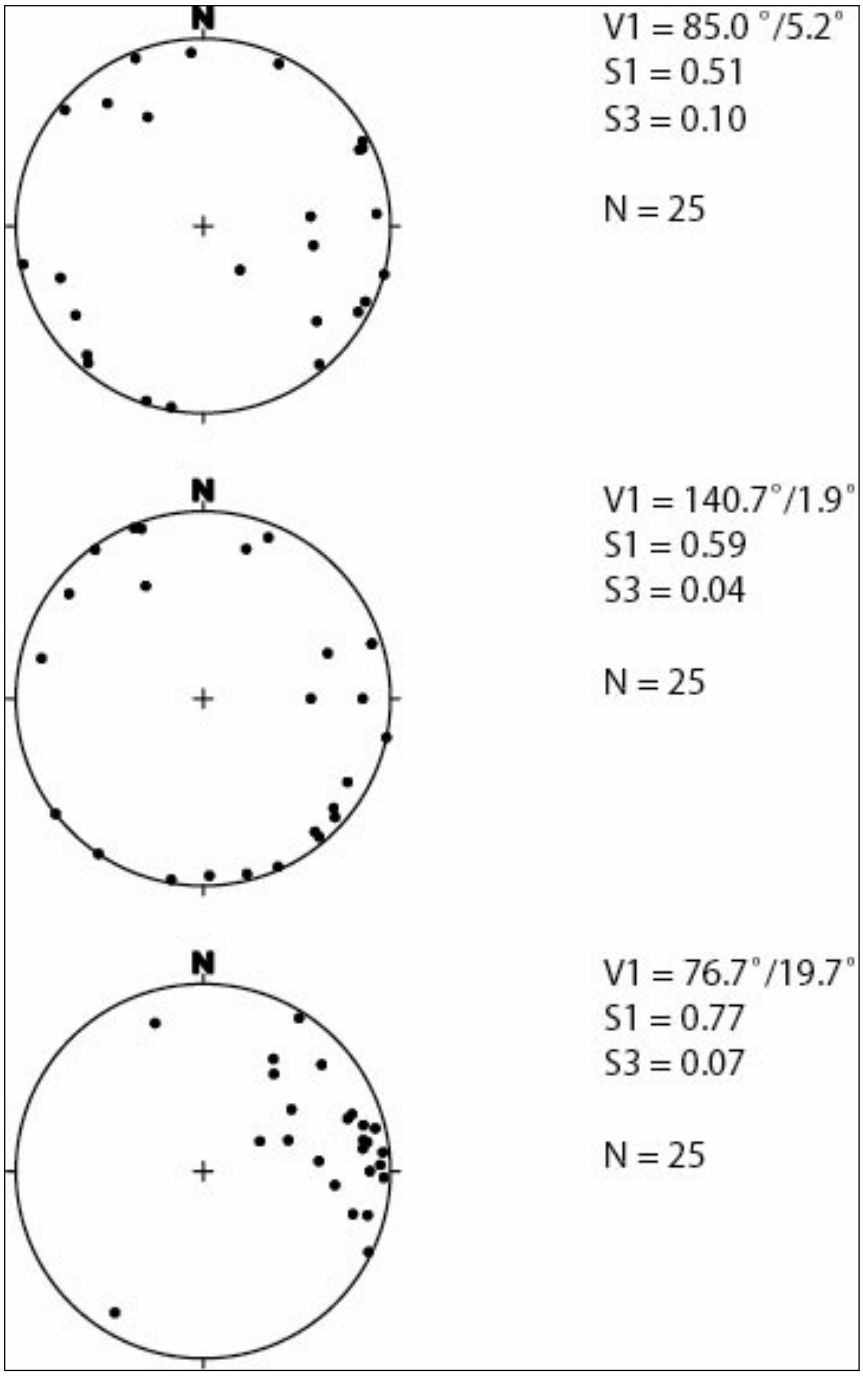

Figure 5-3. *The results of the fabric analyses. From top to bottom: Unit B showing random orientation (LFM000810). Unit B indicating random orientation (LFM000811). Unit A showing deposition from the east north east (LFM000811).*

References

/1/ **Björnbom S, 1979.** The clayey basal till in central and northern Sweden. A deposit from an old phase of the Würm glaciation. SGU C 753.

/2/ **Standardiseringskommissionen i Sverige (SIS), 1992a.** Geotekniska provtagningsmetoder – Kornfördelning – Siktning. Svensk Standard, SS 02 71 23, 4 pp.

/3/ **Standardiseringskommissionen i Sverige (SIS), 1992b.** Geotekniska provtagningsmetoder – Kornfördelning – Sedimentering. hydrometermetoden. Svensk Standard, SS 02 71 24, 74 pp.

/4/ **Sundh M, Sohlenius G, Hedenström A, 2004.** Forsmark site investigation. Stratigraphical investigation of till in machine cut trenches, SKB P-04-34. Svensk Kärnbränslehantering AB.

/5/ **Talme O, Almén K-E, 1975.** Jordartsanalys. Laboratorieanvisningar, del 1. Department of Quaternary Research. Stockholm University, 133 pp.

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Box 670
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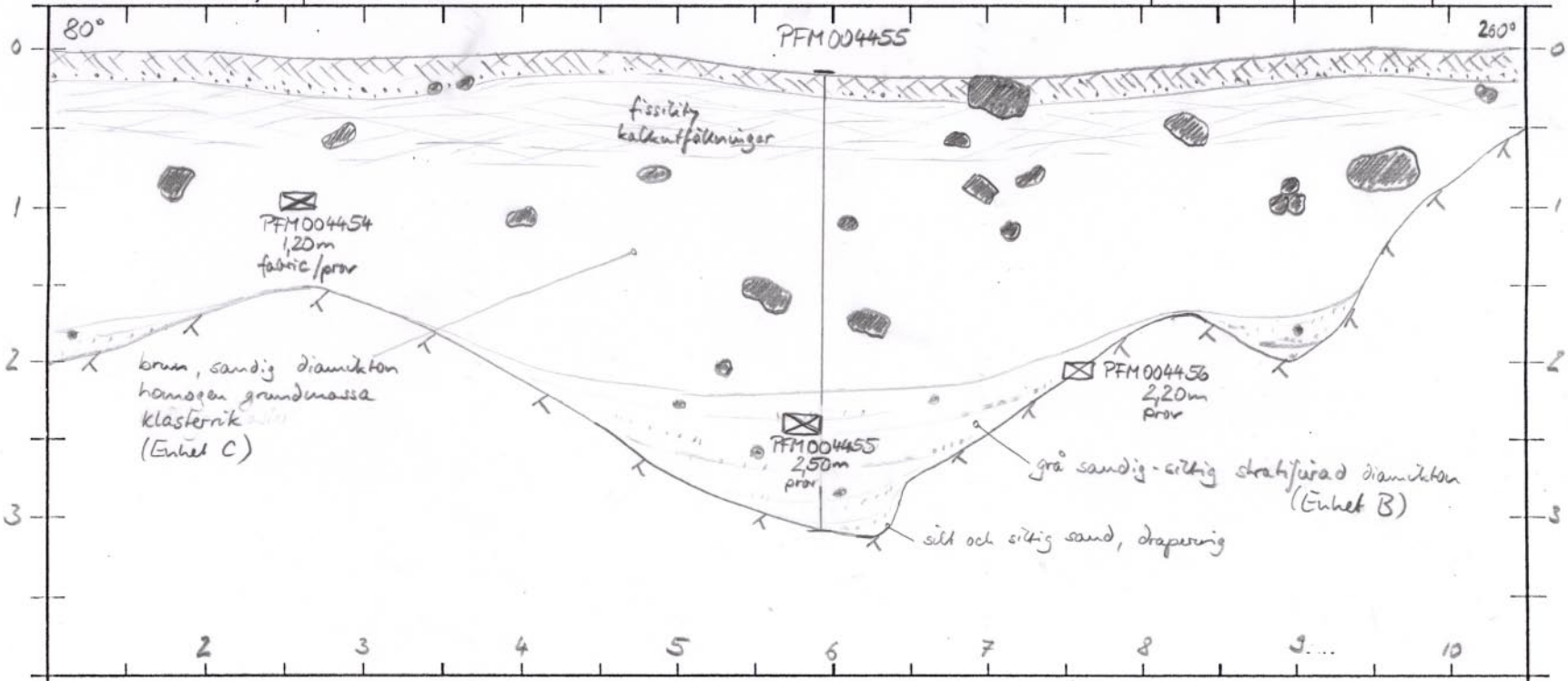
Jordlagerföljd

ID-nr: LFM000810

Kartblad	Ruta	Gula kartan	Rikets nät	Höjd ö h	Lokal namn
12I	3G		N: O:	ca. 5 m	Forsmark

Typ av avlagring, ytform: skogsmark, ingen ytform
Uppgiftslämnare: Joachim Albrecht
Grundv yta: m u my
Övrigt
Maskingrävd grop ☒ Bygge, anläggning ☐
Täkt ☐ Vägskärning ☐ Naturlig skärning ☐
Annat ☐
Täkt nr | Schaktbarhet | Dom. mtrl



Detta är den djupaste delen av hela diket, som är 75m lång. För övrigt är jorddjupet sällan större än 1m.

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Box 670
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Jordlagerföljd

PFM004455

Kartblad	Ruta	Gula kartan	Rikets nät	Höjd ö h	Lokal namn
12 I	9G		N: 6699514 O: 163324	4 m	Forsmark

Maskingrävd grop ☒ Bygge, anläggning ☐ Täkt ☐ Vägskärning ☐ Naturlig skärning ☐ Annat ☐

Typ av avlagring, ytform: Skogsmark, ingen utpräglad utform
Uppgiftslämnare: Joachim Albrecht
Grundv yta: m u my
Övrigt: Jordlagerföljd i dike LFM000810
Täkt nr | Schaktbarhet | Dom. mtrl

Prover Analyser: PFM0044 | Jordmån gvy | djup dm Umb | 80° ← 260° →

lager nr	Jordartssymbol	Kornstorlek Prim./Sekund.	Ange 1-5 So	Bl	St	K	Ru	Övrigt (färg, struktur m m)
1								
2	S △	grusig sand	4	1	2	1	4	tunt, osammanhängande, rötter, humus
3	∧	sandig diamikton	1	2	3	3	2	brun, homogen, översta metern uppvisar tydlig fissurity med kalkutfällningar på sprickytorna något högre silthalt i övre delen kalkig paleozoisk kalksten
4	△	sandig till sandig-siltig diamikton	2	1	1	3	2	grå, svag antydan till deformationsstrukturer (diktila: öppna veck, flexurer) sand- och siltskikt, nedersta ett par mm silt-draperung på berget; kalkig
5								röd medelkornig granit

3m ← 54_1,20 PO ME
ME 56_2,20 → 2m
ME 55_2,50

D
10
C
20
B
30
40
50
60

Part. orient.= PO. Mekanisk analys=ME. Kemisk-mineralogisk analys= KE. Mikrofossilanalys= MI

So=sorteringsgrad: 1=ingen, 2=viss, 3=ofullst., 4=god, 5=mkt god sortering. Bl=blockhalt: 1=inga, el. nästan inga, 2=ett fåtal, 3=spridda, 4=rikligt förekommande, 5=nästan bara block. St=stenhalt. Se blockhalt. K=kompaktion: 1=helt okonsoliderad, 2=svagt konsol., 3=normalt konsol. (morän), 4=hårt, svårgrävt, 5=mkt hårt, m l m ogrävbart. Ru=rundningsgrad: 1=skarpkantigt, 2=kantigt, 3=kantavrundat, 4=rundat, 5=väl rundat.

Vänd ☐

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Jordlagerföljd

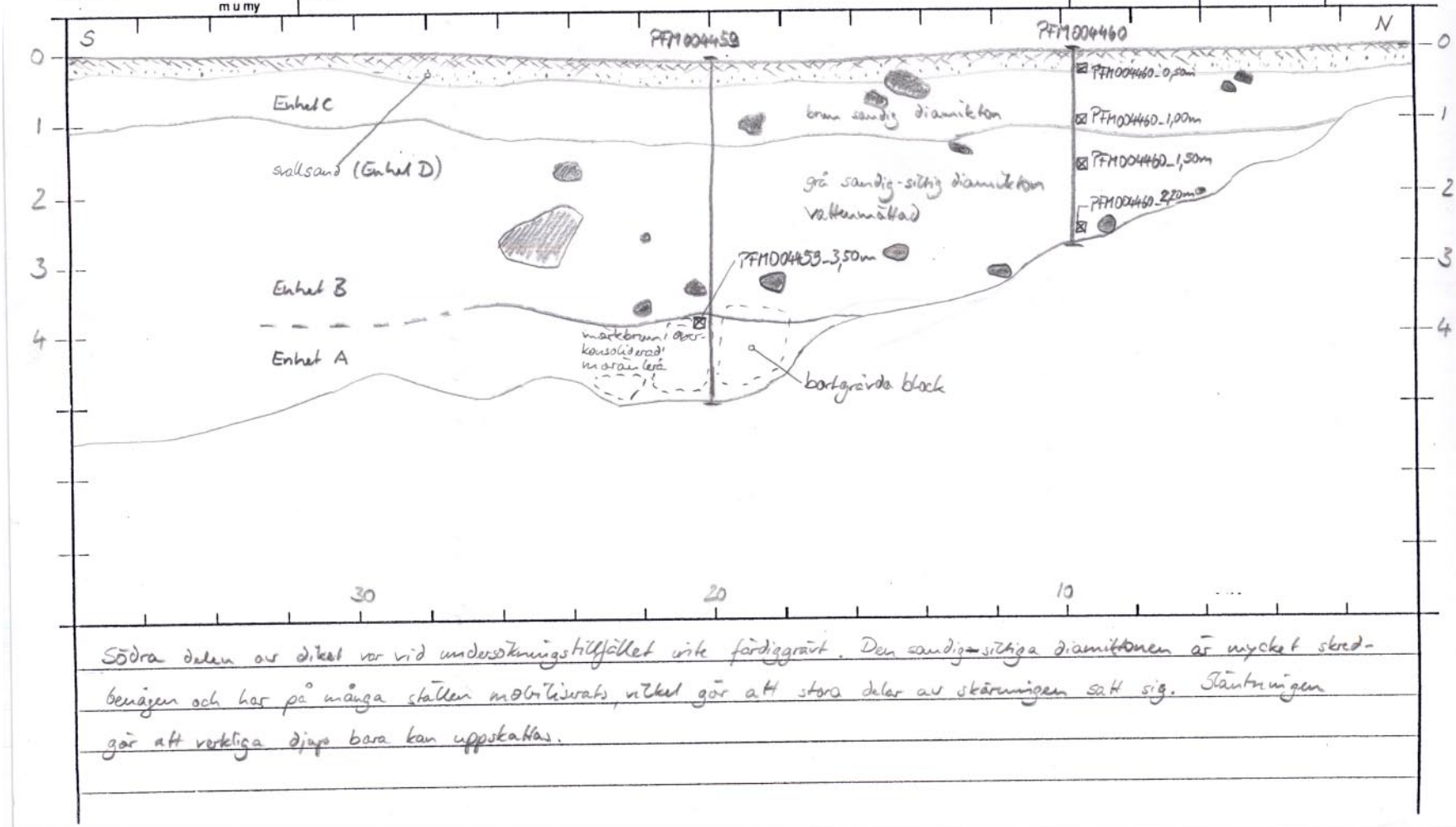
ID-nr LFM000811

Kartblad	Ruta	Gula kartan	Rikets nät	Höjd ö h	Lokal namn
12I	9G		N: O:	ca 5m	Forsmark

Maskingrävd grop ☒ Bygge, anläggning ☐
Täkt ☐ Vägskärning ☐ Naturlig skärning ☐
Annat ☐

Typ av avlagring, ytform: skogsmark, ingen ytform
Uppgiftslämnare: Joachim Albrecht

Grundv yta m u my | Övrigt | Täkt nr | Schaktbarhet | Dom. mtrl



Södra delen av diket var vid undersökningstillfället inte färdiggrävt. Den sandiga-siltiga diamiktonen är mycket skredbenägen och har på många ställen mobiliserats, vilket gör att stora delar av skärningen satt sig. Släntstrigen gör att verkliga djup bara kan uppskattas.

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Jordlagerföljd

PFM 004459

Kartblad	Ruta	Gula kartan	Rikets nät	Höjd ö h	Lokal namn	Maskingrävd grop ☒	Bygge, anläggning ☐
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Typ av avlagring, ytform: Skogsmark, ingen utpräglad ytform					Uppgiftslämnare: Joachim Albrecht	Annat ☐	
Grundvyta m u my	Övrigt: jordlagerföljd, dike LFM000811					Täkt nr	Schaktbarhet	Dom. mtrl

Prover Analyser	Jordmån gvy	djup dm	lager nr	Jordartssymbol	Kornstorlek Prim./Sekund.	Ange 1-5 So	Bl	St	K	Ru	Övrigt (färg, struktur m m)
PFM004459			1								mörkbrun, humus, gödmån
		D	2	△ S	grusig sand	4	2	3	1	4	svallsand/svallad morän enstaka rötter
		C 10	3	∧	sandig diamikton Dmm	1	2	4	3	2	brun, enstaka grå eller mörkbruna klaster bestående av lera, siltig morän och moränlera klasterrik sandig kalkig
		B 20	4	∧ △	sandig-siltig diamikton Dms	2	2	3	3	2	grå, vattenmättad, tixotrop, inhomogen skikt och stråk med silt och finsand
PO	59_300	30	5	λ	lerig diamikton till diamikt grovlera	1	2	2	5	3/4	mörkbrun, kompakt brantstående silt- och finsandstråk (gråvita) påfallande mycket paleozoisk kalksten
	59_350	A 40	6								röd medelkornig granit öppna sprickor (<4 mm breda)
		50									
		60									

OBS: Delar av profilen har karterats nedan grävning pågick. Väggen (främst lager 3 och 4) är extremt skredbenägen.

Part. orient.= PO. Mekanisk analys=ME. Kemisk-mineralogisk analys= KE. Mikrofossilanalys= MI

So=sorteringsgrad: 1=ingen, 2=viss, 3=ofullst., 4=god, 5=mkt god sortering. Bl=blockhalt: 1=inga, el. nästan inga, 2=ett fåtal, 3=spridda, 4=rikligt förekommande, 5=nästan bara block. St=stenhalt. Se blockhalt. K=kompaktion: 1=helt okonsoliderad, 2=svagt konsol., 3=normalt konsol. (morän), 4=hårt, svårgrävt, 5=mkt hårt, m l m ogrävbart. Ru=rundningsgrad: 1=skarpkantigt, 2=kantigt, 3=kantavrundat, 4=rundat, 5=väl rundat.

Vänd ☐

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Jordlagerföljd

PFM 004460

Kartblad	Ruta	Gula kartan	Rikets nät	Höjd ö h	Lokal namn
12I	9G		N: 6639536 O: 1633126	4	Forsmark

Typ av avlagring, ytform: ingen ytform
Uppgiftslämnare: Joachim Albrecht
Grundv yta: m u my
Övrigt: jordlagerföljd i dike LFM000811

Maskingrävd grop ☒ Bygge, anläggning ☐ Täkt ☐ Vägskärning ☐ Naturlig skärning ☐ Annat ☐

Täkt nr	Schaktbarhet	Dom. mtrl

Prover Analyser	Jordmån gyy	djup dm Unit	lager nr	Jordartssymbol	Kornstorlek Prim./Sekund.	So	Bl	St	K	Ru	Övrigt (färg, struktur m m)
PFM004460			1								jordmån
ME 0,5m		D	2	^ ≤	grusig sand	4	1	2	1	5	grovsand med enstaka stenar, rötter
PO/ME 1,0m		10 C	3	∧	sandig diamikton Dmm	1	2	3	3	2	brun, homogen grundmassa, bortsett från enstaka ler- och moränlerklaster fissrikt i översta delen kalkig
ME 1,5m		20	4	∧/∧	sandig till sandig-siltig diamikton Dms	2	2	3	3	2	grå, vattenmättad (⇒ skredbenägen, därför ingen fabricanalys) "brylépudding" nedre delen, främst i fickor i berggrytan, hårt packad silt och finsand
ME 2,2m		30 B									röd medelkornig granit öppna sprickor
		40									
		50									
		60									

Part. orient.= PO. Mekanisk analys=ME. Kemisk-mineralogisk analys= KE. Mikrofossilanalys= MI

So=sorteringsgrad: 1=ingen, 2=viss, 3=ofullst., 4=god, 5=mkt god sortering. Bl=blockhalt: 1=inga, el. nästan inga, 2=ett fåtal, 3=spridda, 4=rikligt förekommande, 5=nästan bara block. St=stenhalt. Se blockhalt. K=kompaktion: 1=helt okonsoliderad, 2=svagt konsol., 3=normalt konsol. (morän), 4=hårt, svårgrävt, 5=mkt hårt, m l m ogrävbart. Ru=rundningsgrad: 1=skarpkantigt, 2=kantigt, 3=kantavrundat, 4=rundat, 5=väl rundat.

Vänd ☐