P-03-43

Forsmark site investigation

Ground penetrating radar and resistivity measurements for overburden investigations

Johan Nissen, Malå Geoscience AB

April 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-03-43

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Keywords: Ground penetrating radar, GPS, resistivity measurements, CVES, overburden investigations

Contents

1 Introduction

This document reports data gained from ground penetrating radar (GPR) and resistivity (CVES) measurements in the Forsmark site investigation area (Figure 1-1). The first attempt to interpret the data obtained is also presented as well as an evaluation of the methods with respect to their applicability to overburden investigations.

The project was carried out according to activity plan AP PF 400-02-28 (SKB internal controlling document).

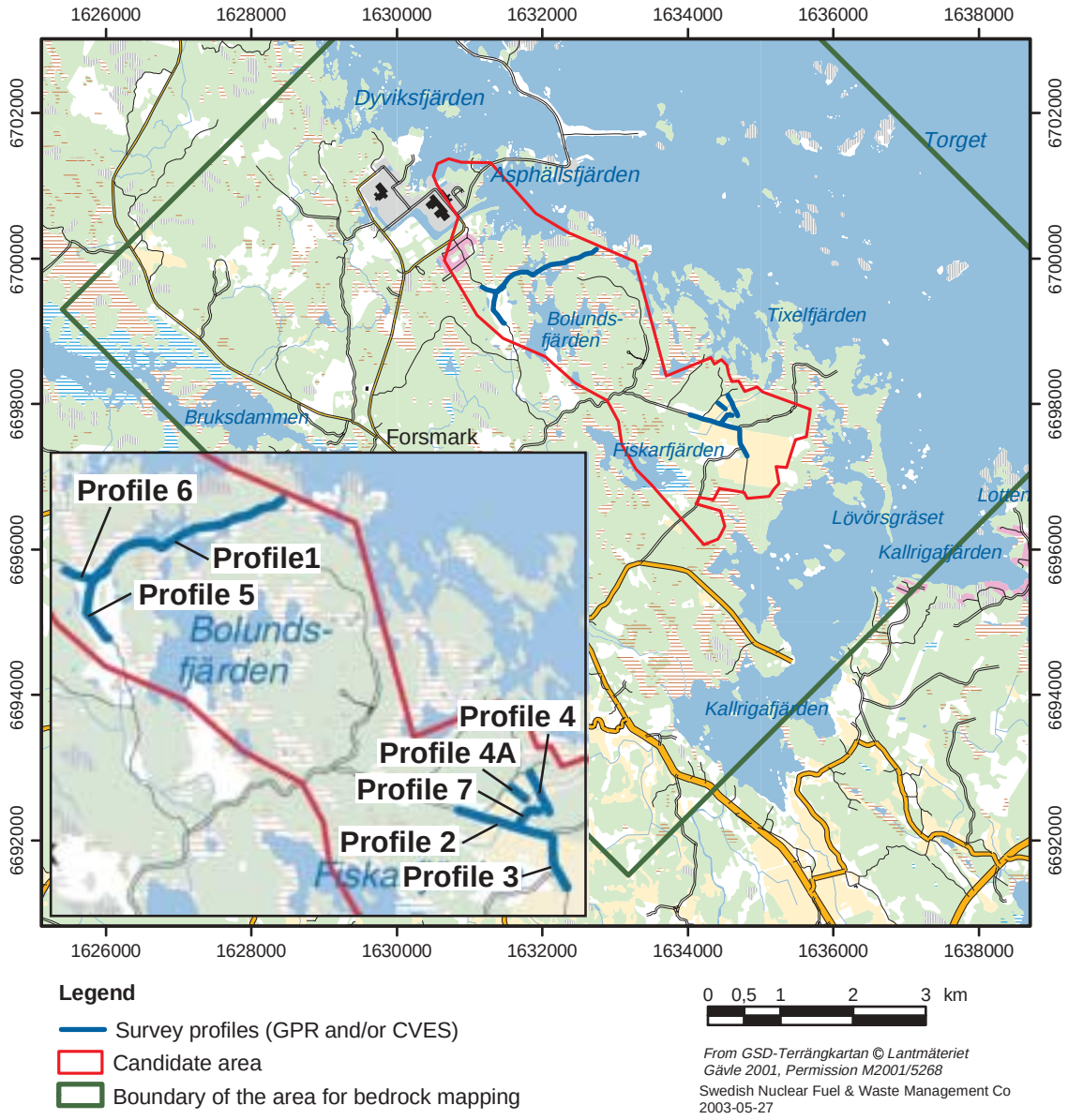

Figure 1-1. *General overview of the Forsmark site investigation area.*

2 Objective and scope

The objective of the survey was to perform test measurements with two geophysical methods, which were considered to have a potential for future application to overburden investigations in the Forsmark area.

The measurements were carried out during October 2002–January 2003 along eight profiles (Figure 1-1). Three profiles were investigated with both methods, one with CVES only and four with GPR only.

3 Measuring procedure and equipment

The profiles measured have been denoted Profile 1 to Profile 7 and these denotations are consequently used in the raw data files. The corresponding SKB ID-codes are as follows:

Profile	1	LFM000568	(CVES, GPR(minor part))
	2	LFM000569	(CVES, GPR)
	3	LFM000570	(CVES, GPR)
	4	LFM000571	(CVES)
	4A	LFM000572	(GPR)
	5	LFM000573	(GPR)
	6	LFM000574	(GPR)
	7	LFM000575	(GPR)

In this report, the “field names” (Profile 1–7) are used, frequently complemented by the SKB ID-codes.

3.1 Resistivity measurements

Measurements with CVES (Continuous Vertical Electrical Sounding) were conducted with 5 m electrode separations along the Profiles 1–3 and with 2 m electrode separations along Profile 4 (Figure 1-1).

The data was collected with the following equipment:

Profile 1,2,3	ABEM Terrameter SAS 4000, S/N 2982231	Cable system, 5 m
Profile 4	ABEM Terrameter SAS 1000, S/N 2020281	Cable system, 2 m

For all readings, the equipment was set to perform a maximum of 4 stackings, with the condition that if the deviation between the first two readings was below 1% the stacking procedure was stopped. The error displayed is the deviation in percent between the two readings. If more than two stackings are performed, the resulting error is calculated as the standard deviation.

Along all profiles, the data quality was good. In Figure 3-1, the error distribution for all 1809 readings from Profile 1 is demonstrated. As can be seen, the typical error is in the interval 0.1%–0.2%. 95% of all readings has a standard deviation less than 0.3%.

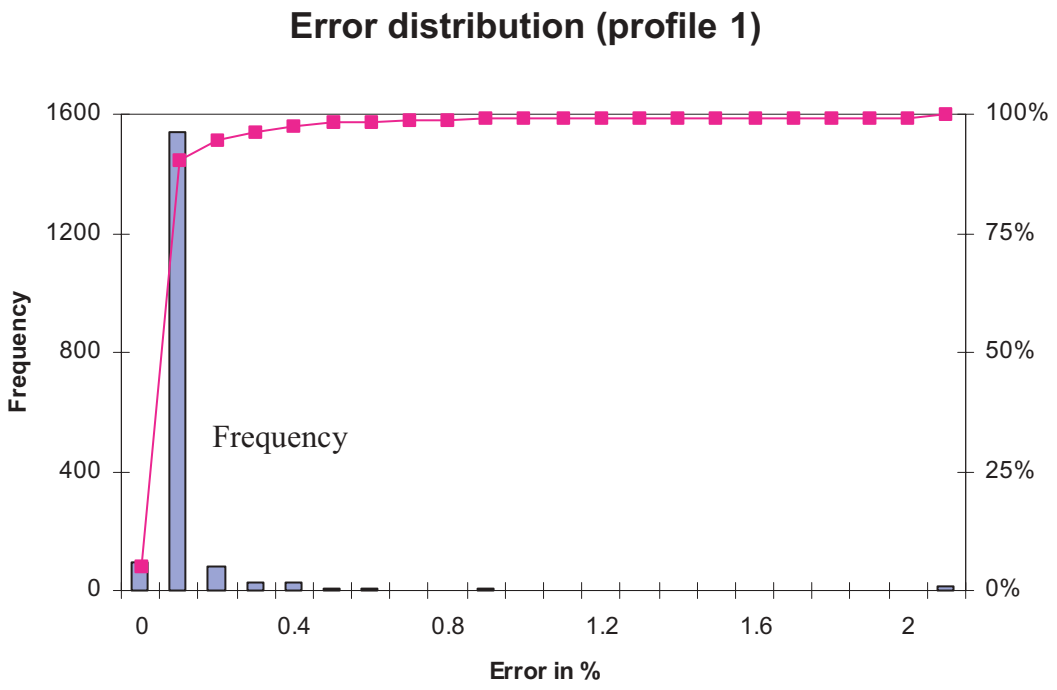

Figure 3-1. *Distribution of error in CVES measurements, Profile 1.*

3.2 Positioning

A GPS reading was taken at each cable joint (i.e. for each 100 m in Profile 1–3 and each 40 m in Profile 4). The GPS instrument was checked on four local fix points in the area. Table 3-1 comprises the checks. It is seen that the deviation is within a few metres.

Table 3-1. GPS readings at four local fix points, and the corresponding reference values from GEOCON /1/.

ID	Measured position	GEOCON
1102	16313336699422	16313336699418
1105	16346536697860	16346526697858
1106	16345676697872	16345656697871
1107	16344116698013	16344126698014

3.3 Radar measurements

All radar measurements were conducted with the Malå Geoscience RAMAC unshielded 50 MHz antennas and a CUII control unit. The data presented in this report is processed by means of the program REFLEXW, and the following processing steps were made:

1. Adjust time zero.
2. Remove DC shift.
3. Band pass filtering (Butterworth) 25–100 MHz.
4. Gain adjustment for display.

4 Results and data delivery

The obtained results from the investigation are presented below. The raw and processed/ interpreted data have been delivered on a CD to SKB. Information on the activity has been inserted in the SICADA database, whereas the delivered CD has been archived. It is foreseen that further interpretation, including input data from e.g. drilling, will be made in several steps. These future interpretations will be inserted in SICADA.

The SICADA reference to the present activity is Field note Forsmark 108.

4.1 Resistivity measurements

4.1.1 Profile 1 (LFM000568)

Profile 1 was measured from east to west along the existing path of a seismic line, see Figure 4-1. At each cable joint (every 100 m) the position corresponding to the existing seismic line was noted. These positions are indicated in the interpretation. The positions of all cable joints are given in Appendix 1.

The CVES-data (Figure 4-2 a,b) is presented after an inversion procedure with the program RES2DINV, version 3.4. Topography data from the seismic survey is included in the interpretation.

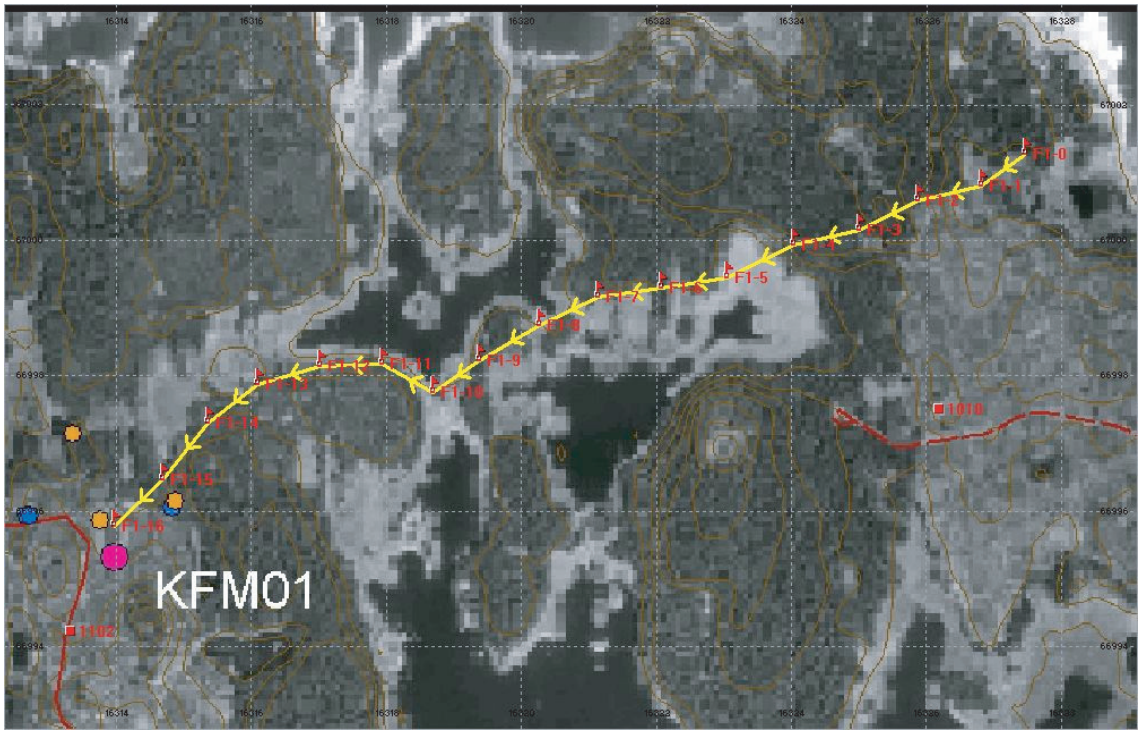

Figure 4-1. *Profile 1 (LFM000568). The yellow arrows show the route from the GPS readings.*

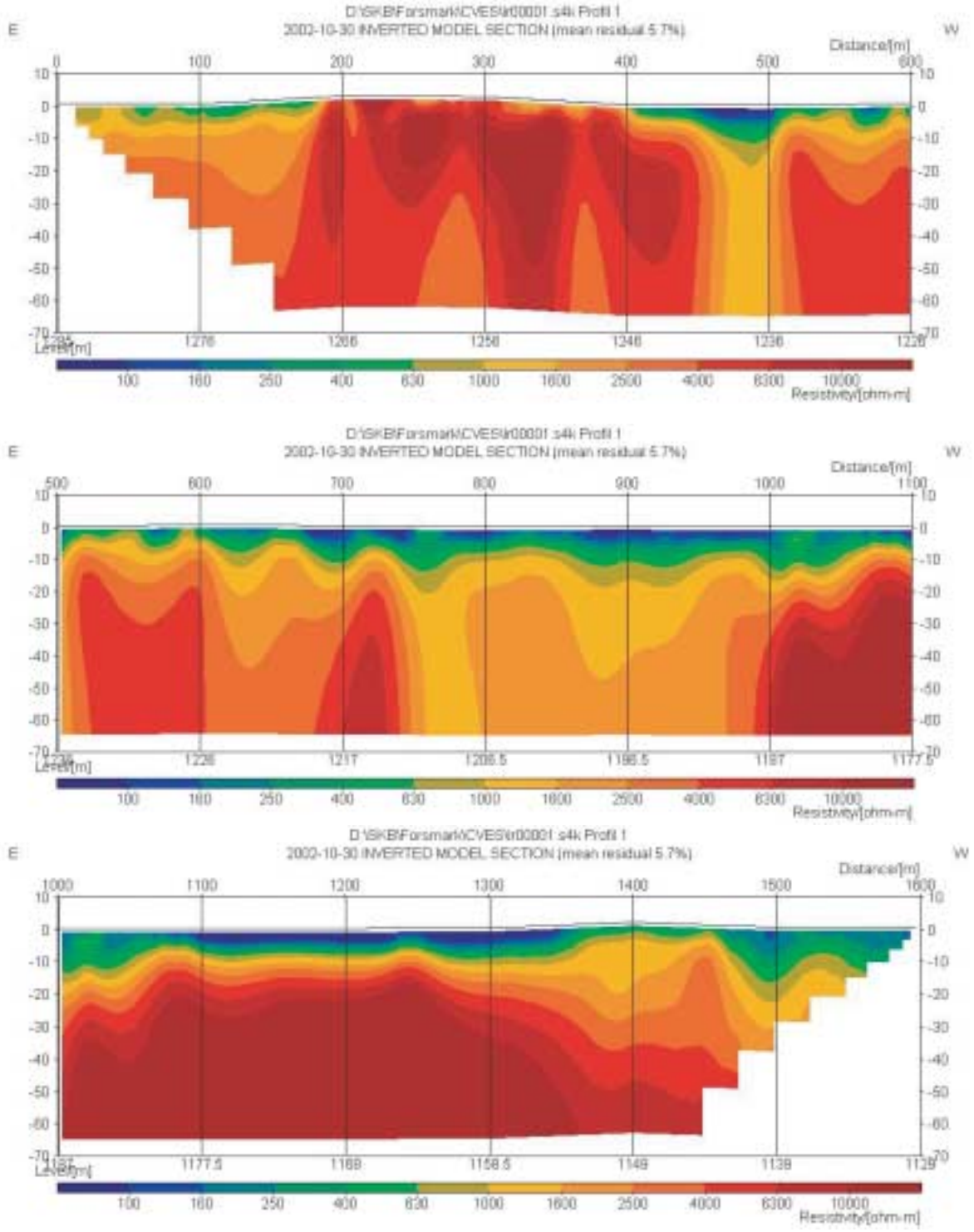

Figure 4-2a. *Profile 1 (LFM000568). Resistivity sections.*

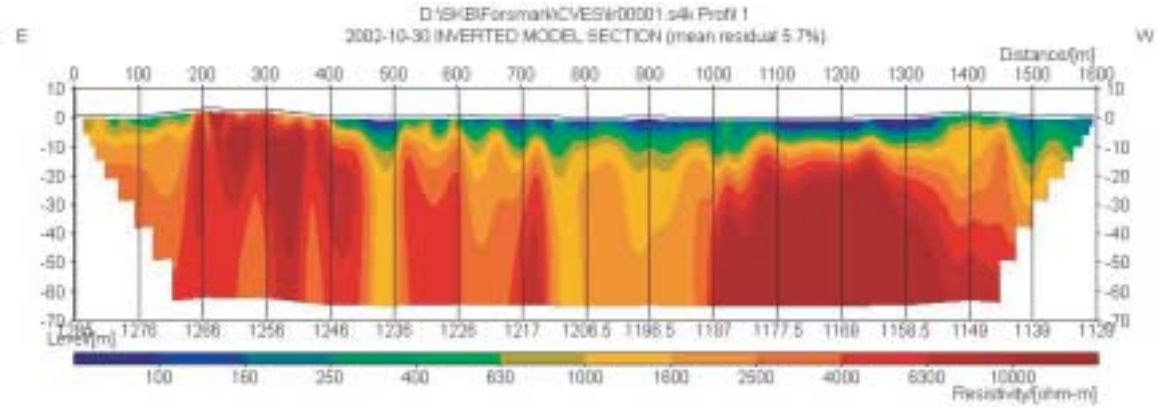

Figure 4-2b. *Profile 1 (LFM000568). Resistivity section (entire profile).*

Comments on the interpretation of Profile 1 (LFM000568):

- The resistivity of the overburden (soil) is in the range of 100–300 Ohm-m.
- The resistivity of the metagranitoid rock exceeds 10000 Ohm-m.
- A transition zone with intermediate resistivity values in the upper part of the rock probably exists. However, the border between a low-resistive overburden and a high-resistive rock is difficult to resolve due to inherent limitations in the resistivity method.
- The overburden thickness is at most approximately 15 m.
- Between 190 m and 400 m (position 1268 to 1246) the granitoid rock is extending to the ground surface, with only a thin cover. The resistivity values at depth indicated intermediate rock quality.
- Between 460 m and 500 m (position 1240 to 1236) a possible fracture zone with low resistivity values manifest itself. The zone extends to at least 65 m depth.
- Between 500 m and 750 m (position 1236 to 1212) intermediate resistivity values in the range 2500–5000 Ohm-m are observed. This is probably caused by water filled fractures.
- Between 750 m and 980 m (position 1212 to 1189) a wide zone with comparatively low resistivity values (1000–2500 Ohm-m) is observed. This is probably caused by water filled fractures. The borders correspond to lineaments indicated on the geological map.
- Between 980 m and 1600 m (position 1189 to 1145) the rock resistivity is high, indicating rock of good quality.

For all resistivity profiles a build-in bedrock edge detection algorithm (depth corresponding to a certain resistivity value /2/) is applied. In all cases, a resistivity value of 2000 Ohm-m for the detection of the bedrock surface has been used (Figure 4-3). However, this value has to be estimated by use of borehole data. If e.g. a value of 1500 Ohm-m is used, the result will be a shallower estimate of the bedrock surface.

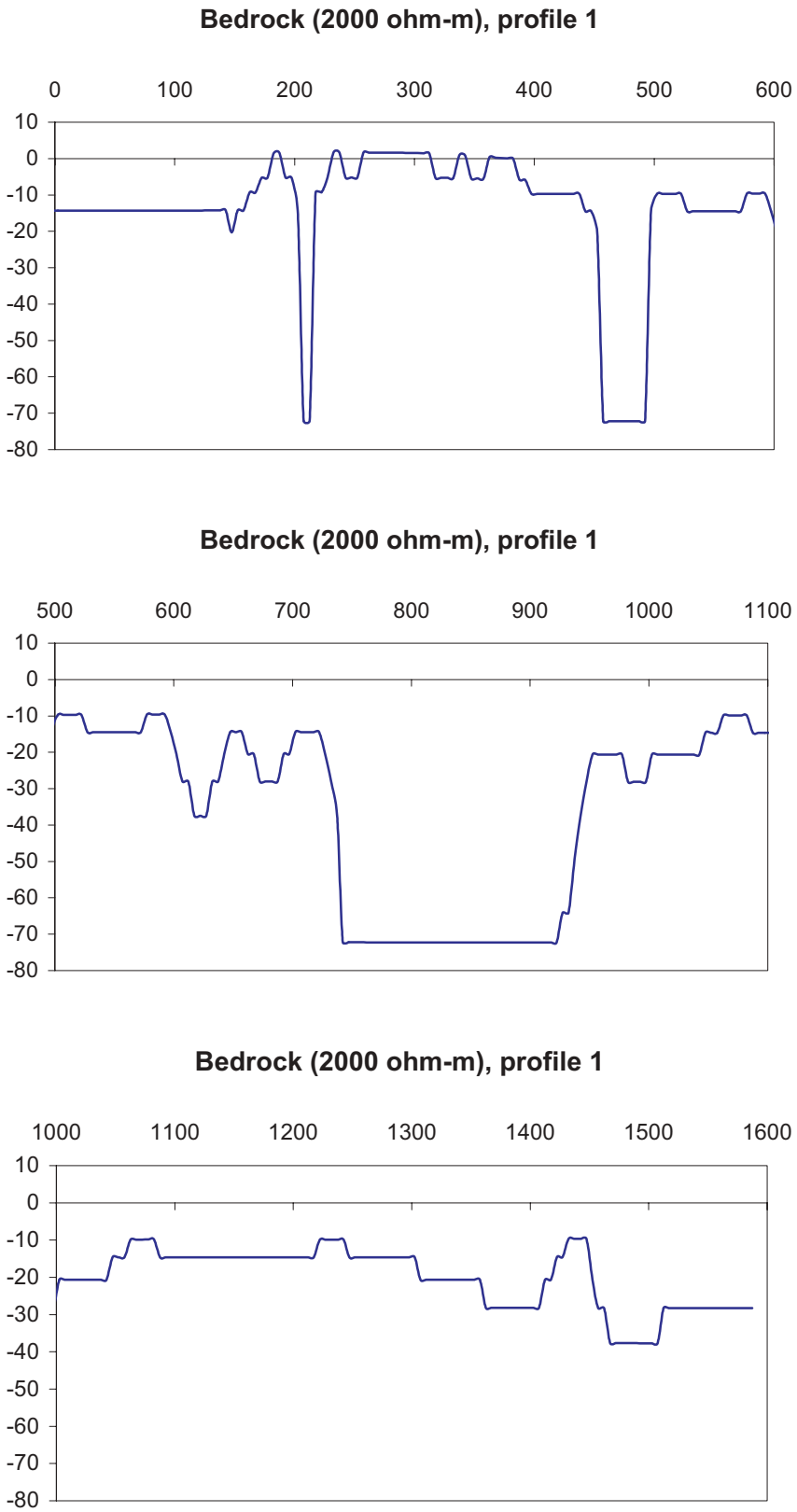

Figure 4-3. *Detected bedrock along Profile 1 (LFM000568). The depth scale is corrected for topography. The line corresponds to a resistivity level of 2000 Ohm-m.*

4.1.2 Profiles 2, 3 and 4 (LFM000569, 570 and 571)

The Profiles 2, 3 and 4 are located at Storskäret in the south-eastern part of the Forsmark area (Figures 1-1 and 4-4).

Profile 2 (Figure 4-4) starts at the intersection and follows the northern side of the road westwards. At position 500 m the border of the farmland is passed. Profile 3 (Figure 4-4) starts at the intersection and follows the eastern side of the road southwards. Profile 4 (Figure 4-4) starts at the road and follows the power line southwards. This profile is measured with 2 m electrode separation, thereby giving a depth penetration down to approximately 25 metres as compared to the other profiles which are measured with 5 m separation, penetrating approximately 60 metres.

The results are presented in Figures 4-5 to 4-10.

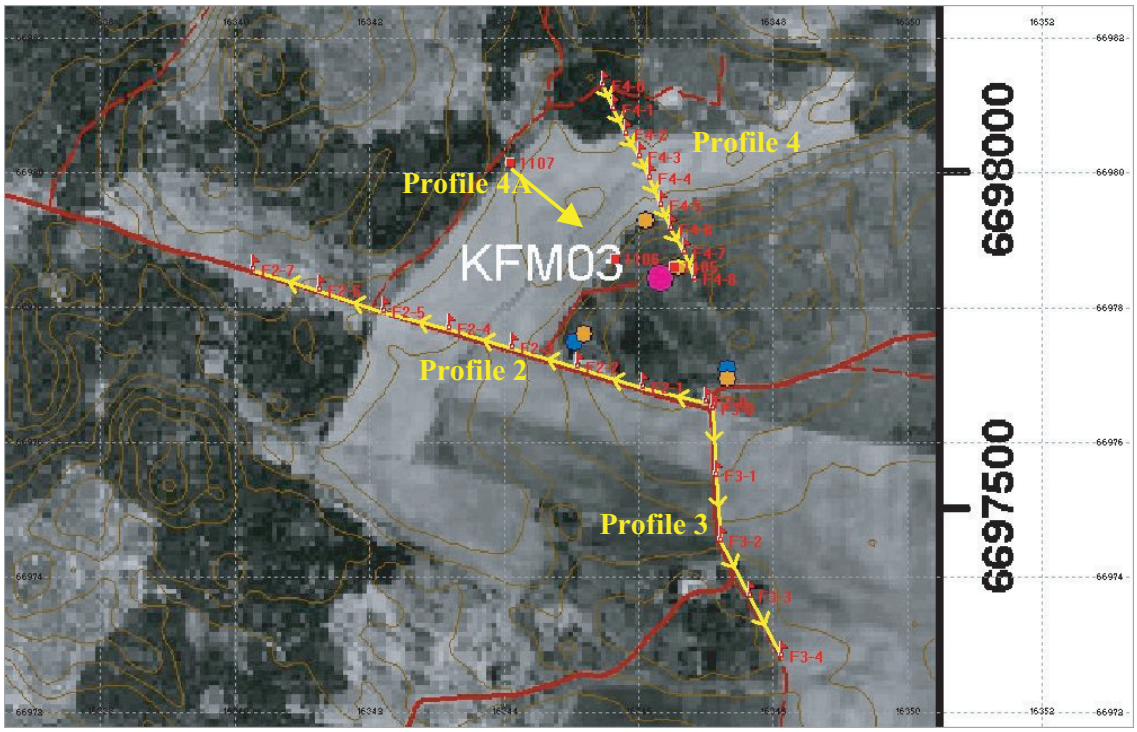

Figure 4-4. *Location of the Profiles 2,3,4 and 4A (LFM000569-572) at Storskäret.*

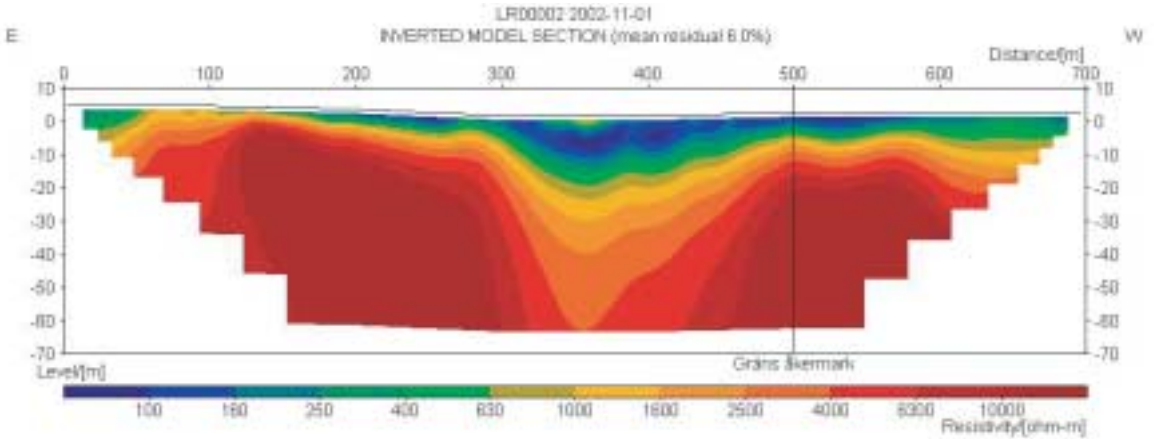

Figure 4-5. *Profile 2 (LFM000569). Resistivity section.*

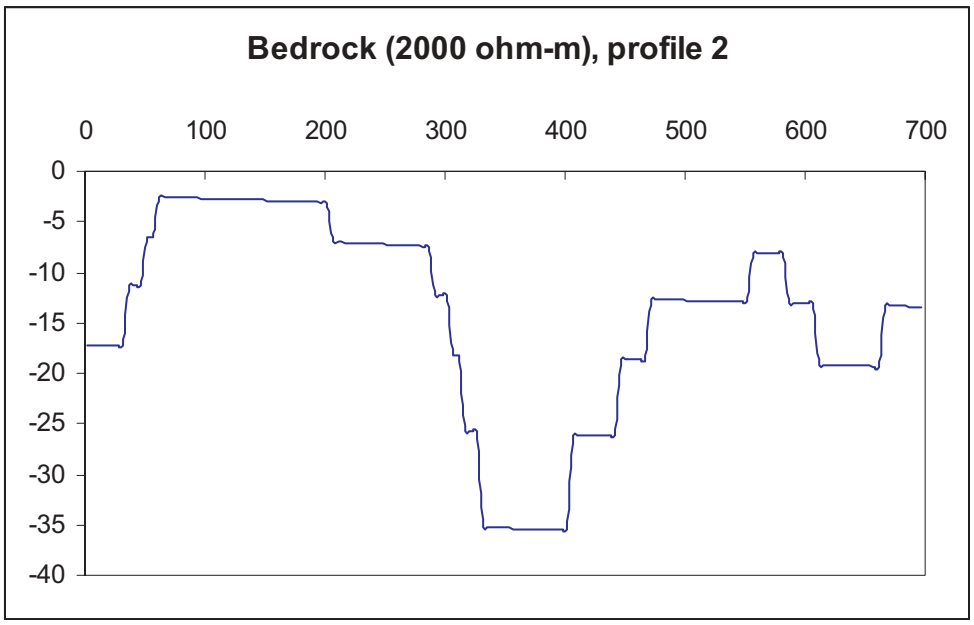

Figure 4-6. *Detected bedrock in Profile 2 (LFM000569). The depth scale is corrected for topography. The line corresponds to a resistivity level of 2000 Ohm-m.*

Comments on the interpretation of Profile 2 (LFM000569):

- The overburden thickness varies from 2–3 m (at position 130 m) to at least 20 m (at position 350 m).
- Between 310 m and 450 m a low-resistivity zone, probably a fracture zone, is observed.
- In general the rock resistivity values are high, indicating rock without fractures or fissures.

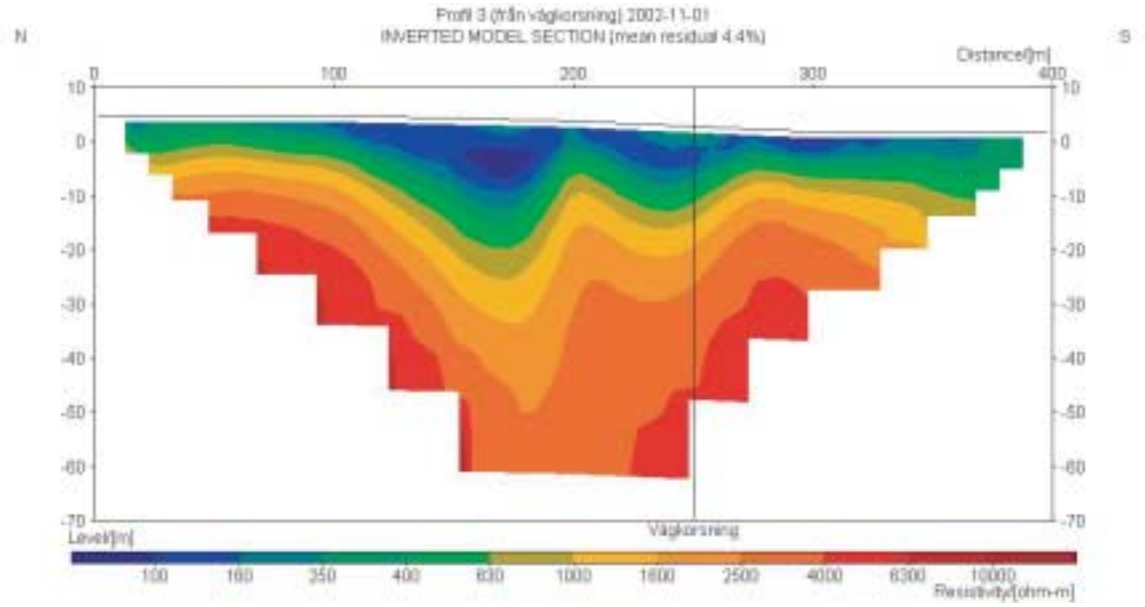

Figure 4-7. *Profile 3 (LFM000570). Resistivity section.*

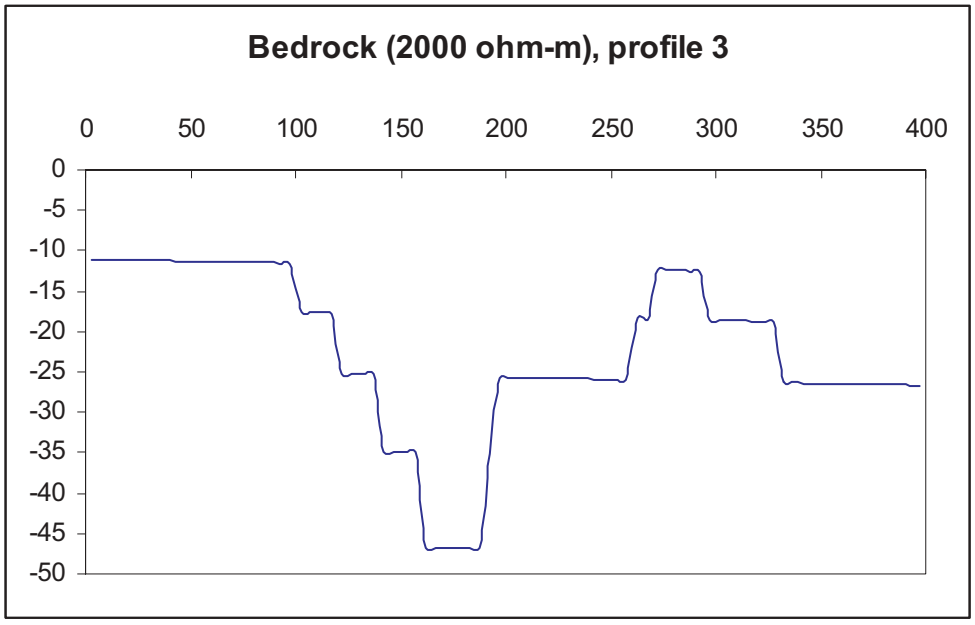

Figure 4-8. *Detected bedrock in Profile 3 (LFM000570). The depth scale is corrected for topography. The line corresponds to a resistivity level of 2000 Ohm-m.*

Comments on the interpretation of Profile 3 (LFM000570):

An area of low resistivity is observed between 150 m and 250 m. This may indicate a section of fractured bedrock. However, the profile is rather short for making definite conclusions.

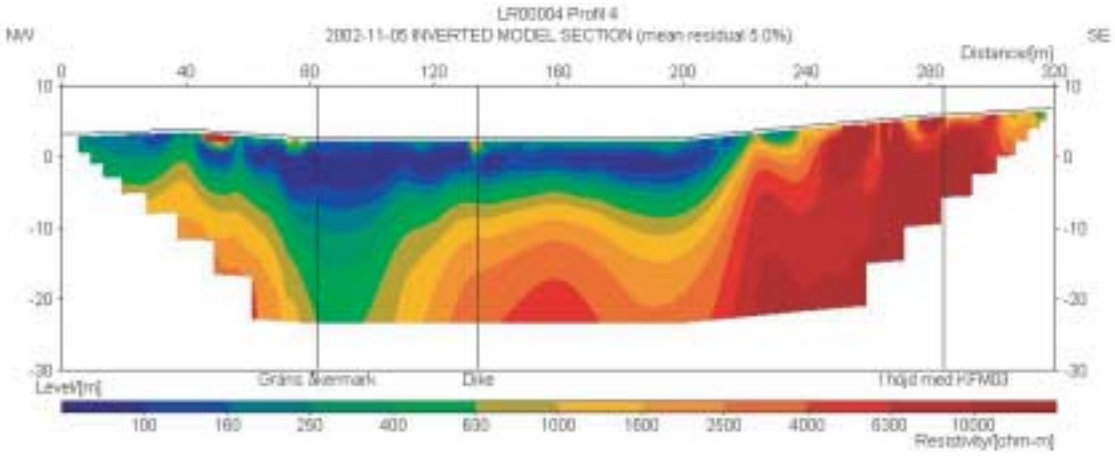

Figure 4-9. *Profile 4 (LFM000571). Resistivity section.*

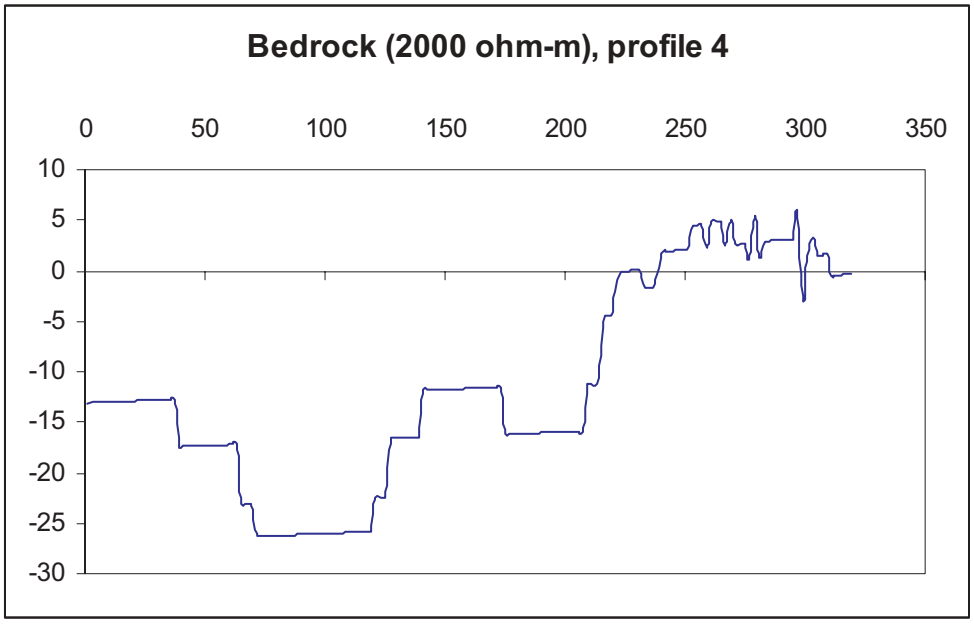

Figure 4-10. *Detected bedrock in Profile 4 (LFM000571). The depth scale is corrected for topography. The line corresponds to a resistivity level of 2000 Ohm-m.*

Comments on the interpretation of Profile 4 (LFM000571):

- A zone with low resistivity readings is observed from position 70 m to 120 m. This is probably a fracture zone. In general the overburden thickness is approximately 10–15 m within the agricultural area.
- From 220 m to 320 m, the high resistivity readings indicate homogeneous rock of good quality.

4.2 Radar measurements

4.2.1 Profile 1 (LFM000568)

In order to conduct radar measurements with the existing equipment, the survey lines need to be cleared from obstacles (spinney, thickets, etc). Due to the actual conditions along Profile 1, it was not possible to carry out measurements according to plan (i.e. along the entire profile).

In Figure 4-11 a short section (130 m) of Profile 1 between position 1129 and 1139 (close to KFM01) is presented. The yellow arrows show the bedrock surface. Also a number of boulders on the bedrock surface can be observed.

This example indicates that the radar method is suitable for detecting the bedrock surface.

4.2.2 Profiles 2, 3, 4A and 7 (LFM000569, 570, 572 and 575)

For location of the Profiles 2, 3 and 4A, see Figure 4-4. Profile 4A was measured instead of Profile 4 in order to avoid disturbances from the power line along the latter profile.

Profile 2 (Figures 4-12 and 4-13) is typical for all measured profiles in the Storskäret area. The penetration is very limited, only a few metres. This is due to conductive soil in the uppermost 10–30 cm, probably caused by dust binding chemicals on the roads and/or fertilizers. Figures 4-14 and 4-15 show similar results from Profiles 3 and 4A.

Repeated measurements of the above profiles were performed in January 2003 with identical results. At the same time, a new profile, Profile 7 (LFM000575, Figures 1-1 and 4-16), was measured at Storskäret along with additional measurements, Profiles 5 and 6, in the vicinity of borehole KFM01A (see section 4.2.3).

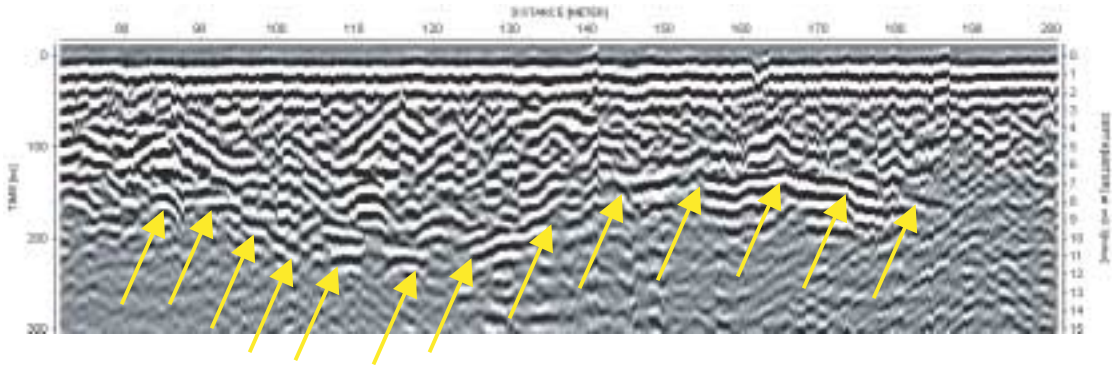

Figure 4-11. *Part of Profile 1 (LFM000568). Yellow arrows indicate the bedrock surface.*

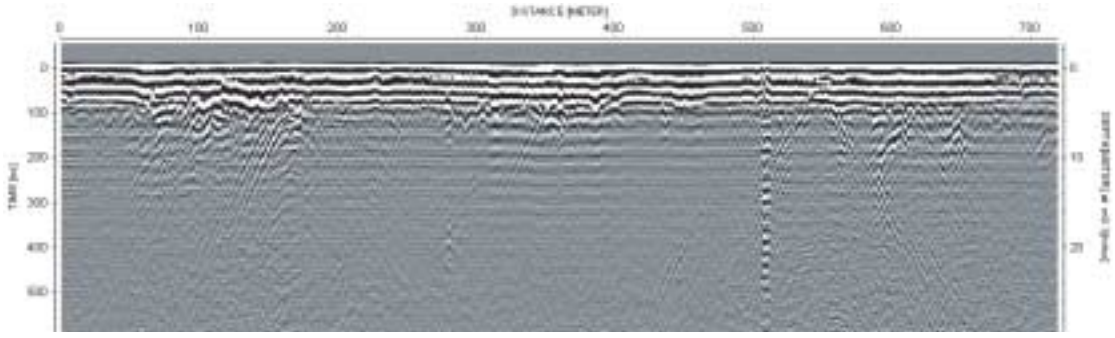

Figure 4-12. *Radar data from Profile 2 (LFM000569). The hyperbolic signatures are caused by air reflections from trees and a building.*

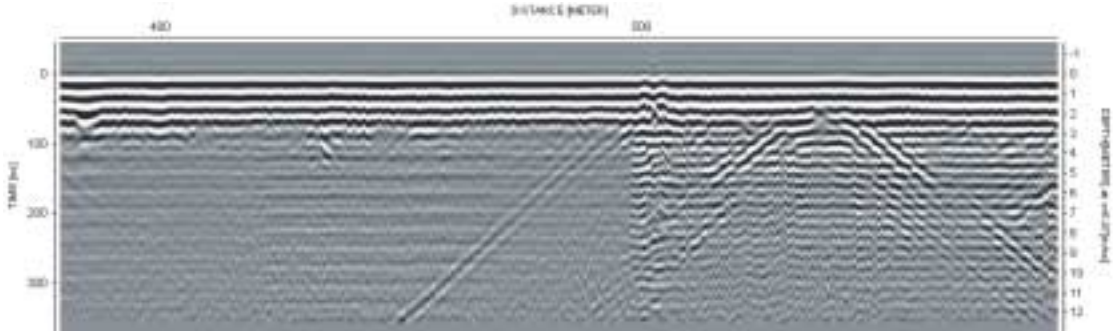

Figure 4-13. *Enhanced view of a section of Profile 2 (LFM000569). The end of the agricultural area is at position 500 m. It is seen that there is essentially no penetration. The hyperbolic structures correspond to air-reflections from a fence and from trees.*

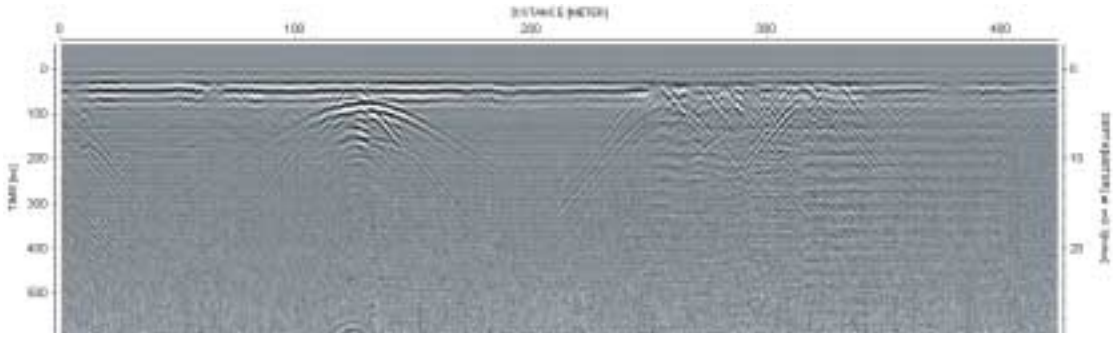

Figure 4-14. *Profile 3 (LFM000570). The hyperbolic signatures are caused by air reflections from trees, power lines and buildings.*

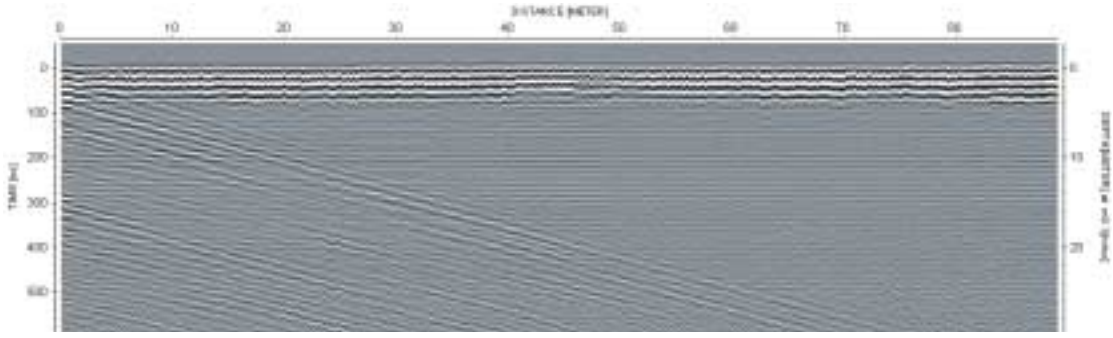

Figure 4-15. *Profile 4A (LFM000572) from fix point 1107 towards KFM03. The profile ends at a ditch.*

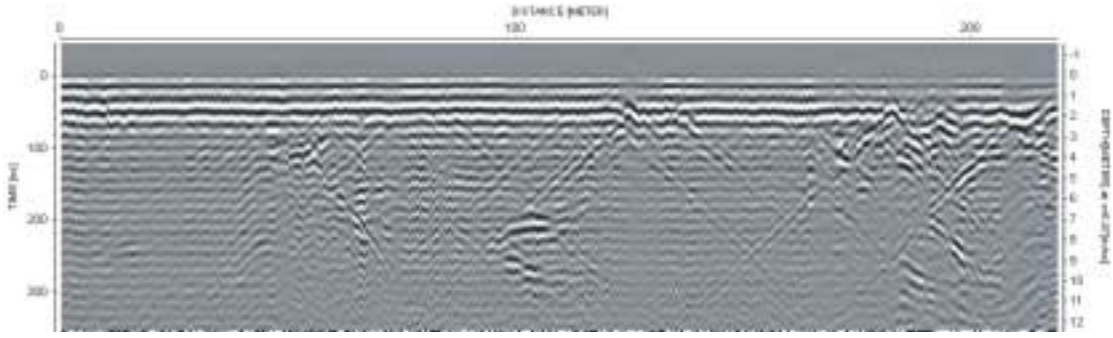

Figure 4-16. *Profile 7 (LFM000575) at Storskäret, from the barn along a new road to the entrance of the fence at KFM03. The gate is at position 46 m.*

4.2.3 Profiles 5 and 6 (LFM000573 and 574)

Figure 4-17 shows the location of the Profiles 5 and 6, see also Figure 1-1.

Figures 4-18 a–c present the results from Profile 5 along the road, starting at the fence at KFM01, passing the road crossing at 62 m and extending southwards. The red line in the figures corresponds to the interpreted bedrock surface.

Figure 4-19 presents the results from Profile 6 (LFM000574) measured along the road nearby KFM01. The profile starts at the power line, passes KFM01 and extends along a small road to SFM0003. It is seen that the filling material on the new road from KFM01 to SFM0003 screens the radar-wave.

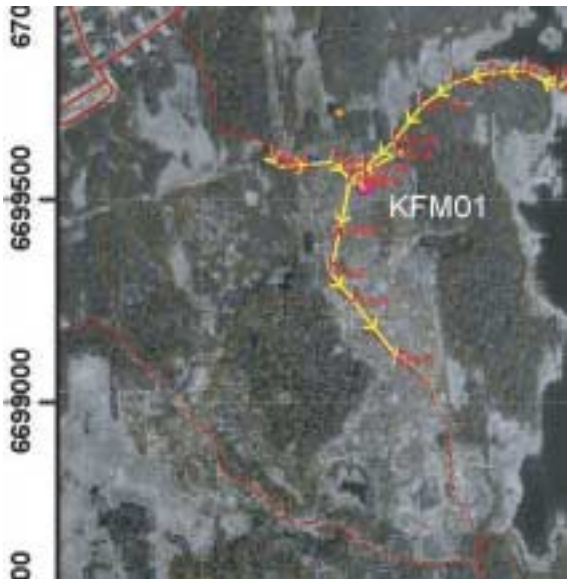

Figure 4-17. *The location of radar Profiles 5 and 6 (LFM000573, 574).*

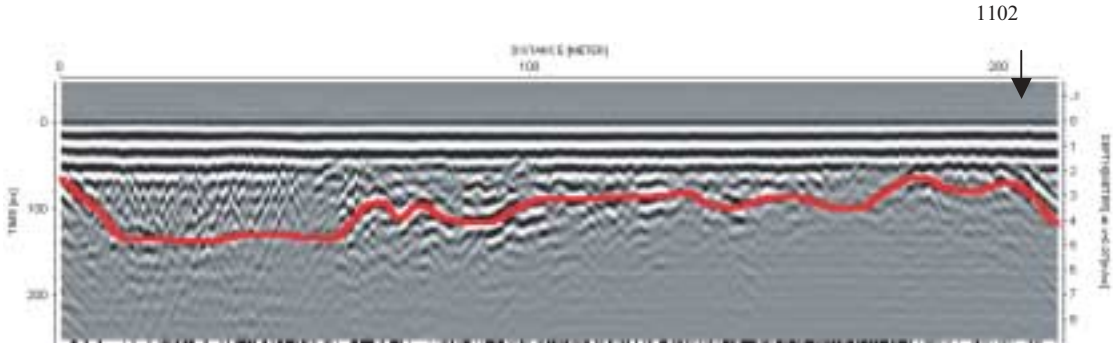

Figure 4-18a. *First 200 m of Profile 5 (LFM000573) from KFM01. Road crossing at 62 m. Fix point 1102 at position 206 m. The interpreted bedrock surface is indicated by a red line.*

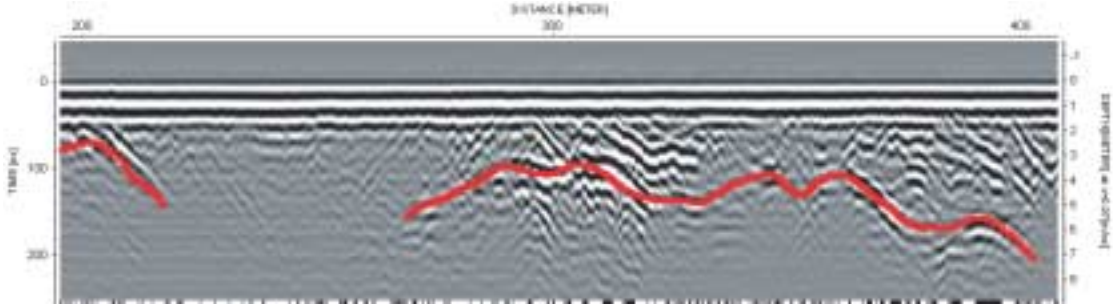

Figure 4-18b. *Profile 5(LFM000573) southwards along the road at KFM01. Fix point 1102 at position 206 m. The interpreted bedrock surface is indicated by a red line.*

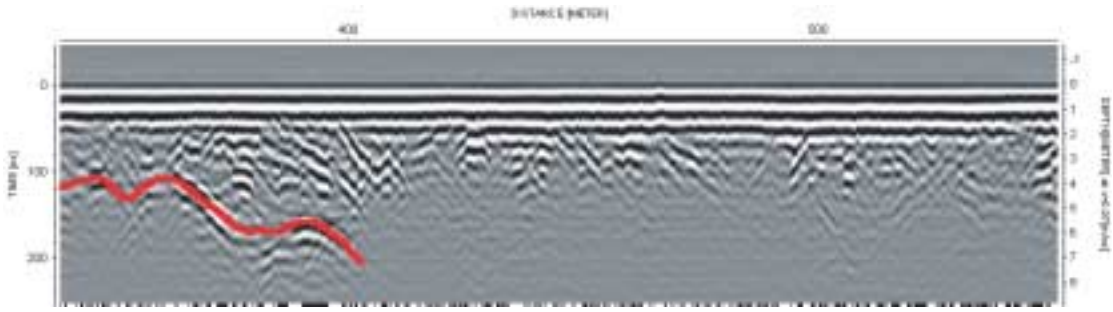

Figure 4-18c. *Last part of Profile 5 (LFM000573), ending at the turnaround at position 550 m. The interpreted bedrock surface is indicated by a red line.*

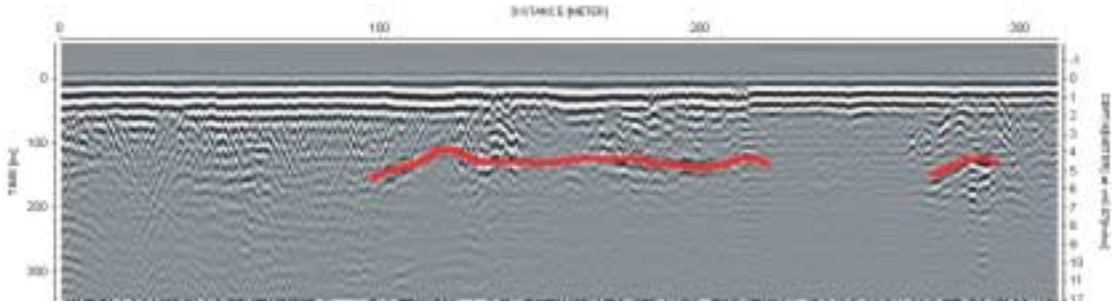

Figure 4-19. *Profile 6 (LFM000574) along road, starting at power line, passing KFM01, extending along small road. Stop at SFM0003. Passing road intersection at 135 m and passing KFM01 at 195 m. The interpreted bedrock surface is indicated by a red line.*

4.3 Conclusions

The present study has demonstrated that CVES measurements may give a good picture of the structure of the overburden and the upper part of the bedrock. It was also demonstrated that it is possible to achieve data of very good quality. An inherent disadvantage of the resistivity method is, however, its limited resolution of the depth to a resistive basement.

According to the CVES measurements, the overall resistivity of the overburden is around 100 Ohm-m, which indicates that it should be possible to conduct successful radar measurements. This is also clearly demonstrated from the very short radar section of Profile 1 and from the profiles close to KFM01. The radar method is seen to be well suited mainly for mapping the overburden thickness.

However, in the arable land around Storskäret many decades of farming have most probably created a zone of low resistivity near the surface, which makes radar measurements more or less impossible. Similarly, the use of dust-binding chemicals causes the conductivity to increase, thus making it difficult to perform radar measurements along the roads.

5 References

/1/ GEOCON, 2002. Stomnätsmätning i plan och höjd vid PLU Forsmark. Rapport S1020.

/2/ GEOTOMO Software, 2003. RES2DINV ver 3.51 Reference Manual.

Appendix 1

Coordinates along Profile 1 (LFM000568).
The distance between each joint is 100 m.

ID	Easting	Northing
F1-0	1632746	6700127
F1-1	1632681	6700081
F1-2	1632588	6700058
F1-3	1632501	6700015
F1-4	1632403	6699993
F1-5	1632304	6699944
F1-6	1632207	6699930
F1-7	1632114	6699916
F1-8	1632027	6699874
F1-9	1631938	6699822
F1-10	1631869	6699776
F1-11	1631794	6699817
F1-12	1631701	6699814
F1-13	1631610	6699788
F1-14	1631536	6699731
F1-15	1631469	6699646
F1-16	1631397	6699578

Coordinates along Profile 2 (LFM000569).
The distance between each joint is 100 m.

ID	Easting	Northing
F2-0	1634700	6697658
F2-1	1634606	6697681
F2-2	1634510	6697710
F2-3	1634413	6697739
F2-4	1634318	6697767
F2-5	1634221	6697793
F2-6	1634126	6697825
F2-7	1634028	6697854

Coordinates along Profile 3 (LFM000570).
The distance between each joint is 100 m.

ID	Easting	Northing
F3-0	1634711	6697649
F3-1	1634716	6697550
F3-2	1634723	6697453
F3-3	1634765	6697371
F3-4	1634813	6697282

Coordinates along Profile 4 (LFM000671).
The distance between each joint is 40 m.

ID	Easting	Northing
F4-0	1634548	6698128
F4-1	1634563	6698093
F4-2	1634582	6698056
F4-3	1634601	6698022
F4-4	1634617	6697990
F4-5	1634633	6697950
F4-6	1634649	6697915
F4-7	1634669	6697879
F4-8	1634684	6697841

Coordinates along Profile 4A (LFM000672).

ID	Easting	Northing
F4A-0	1634412	6698014
F4A-1	1634517	6697931

Coordinates along Profile 5 (LFM000673).

ID	Easting	Northing
F5-0	1631381	6699542
F5-1	1631349	6699541
F5-2	1631357	6699496
F5-3	1631333	6699418
F5-4	1631319	6699295
F5-5	1631384	6699224
F5-6	1631457	6699117
F5-7	1631481	6699107

Coordinates along Profile 6 (LFM000674).

ID	Easting	Northing
F6-0	1631173	6699607
F6-1	1631230	6699575
F6-2	1631340	6699550
F6-3	1631385	6699554
F6-4	1631434	6699580
F5-5	1631474	6699616

Coordinates along Profile 7 (LFM000675).

ID	Easting	Northing
F7-0	1634455	6697734
F7-1	1634544	6697850
F7-2	1634607	6697845