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Forsmark site investigation

Soils in two large trenches

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Abstract

The Swedish Nuclear Fuel and Waste Management Company (SKB) carries out site investigation in the Forsmark area. One important part of the investigation is to clarify the connections between bedrock, soils and ground surface ecosystems to understand flow conditions between bedrock to the ground surface. Special bedrock investigations were carried out in fall 2004 through trench excavations when the regolith was removed and the bedrock surface cleared. The excavations furnished possibilities for in-depth studies along the trenches.

Determinations in the large trenches included investigations of ground vegetation, surface organic layer and stoniness conditions over the trenches. Further studies involved rooting depth, soil profile development, soil physical conditions of the regolith as well as chemical properties including pH, C, N, base cations and phosphorus. Five profiles were totally included but determinations of variables varied between the profiles.

The two large trenches investigated were located adjacent to each other on a distance of on average 75 m. The elongation of the trenches was almost perpendicular, i.e. with an angel of 120 degrees. In spite of the relative closeness, the two trenches exhibited rather different conditions regarding hydrology and soil depth with rather deep soils at trench 3 compared to number 4, where bedrock almost reached the ground surface at a few spots.

The soil profile type was mainly Regosol. Rooting depth in trench 4 reached at the most 57 cm depth. Soil physical conditions at the trench sites coincided fairly well with properties found in natural till soils above the highest coastline. A considerable stone and boulder content together with high bulk densities provided low porosities, especially in the deeper soil layers. Water retentions were high with small amounts of free water. Only in the top soil layers higher porosities existed. Hydraulic conductivity demonstrated the common pattern with relatively high conductivities in the top soil layers and very low in deep soil layers.

Chemical conditions revealed the content of $CaCO_3$ almost through the entire regolith, providing high pH values, often over 6. Calcium, magnesium, potassium, carbon and nitrogen values were similar to the soil site inventory of the Forsmark area.

Sammanfattning

Svensk Kärnbränslehantering AB (SKB) genomför platsundersökningar i Forsmarksområdet. En viktig del i dessa är att klarlägga kopplingar mellan berggrund, jordlager och ytekosystem för att förstå transportmekanismer mellan berggrunden och ytsystemen. I samband med berggrundsundersökningar under hösten 2004 grävdes två schakt där de lösa jordlagren avlägsnades så att berggrundsytan skulle kunna studeras. Dessa schakt medförde möjligheter att undersöka även markprofiler längs schakten.

Genomförda inventeringar och bestämningar i markprofilerna inkluderade vegetation, organiskt marktäcke, stenighet, rotutbredning, jordmån, markfysikaliska egenskaper och markkemi med variablerna pH, C, N, baskatjoner och fosfor. Totalt ingick fem profiler i studierna men några egenskaper studerades enbart i en del av dessa profiler.

De två schakten med dimensionerna 6 m bredd och 51 m respektive 72 m längd fanns på ett avstånd av ca 75 m från varandra. De var orienterade i ca 120 graders vinkel mot varandra. Trots närheten förevisade schakten lite olika förhållanden, bl a var fuktighetsförhållandena något olika. Djupet till berggrunden var också större vid schakt 3 än 4, där berget ställvis gick nära markytan. Jordmånsutvecklingen var mer enhetlig i schakt 3 med 87 % regosol och 13 % podsol, medan schakt 4 uppvisade större variation med 82 % regosol, 8 % leptosol, 7 % podsol och även 3 % histosol.

De markfysikaliska förhållandena karaktäriserades av egenskaper liknande de som finns i opåverkad moränmark över högsta kustlinjen. Ett ganska stort innehåll av sten och block tillsammans med förhållandevis hög skrymdensitet medförde relativt liten porositet, åtminstone i profilernas djupare nivåer. En hög vattenhållande förmåga medförde också liten volym lättrörligt vatten. Låg hydraulisk konduktivitet noterades också. Endast i ytlagren förekom högre porositet och konduktivitet.

Ett viktigt förhållande som präglar markkemin var förekomsten av kalciumkarbonat med vilket följer högt kalciuminnehåll och höga pH-värden, i regel över 6 utom i de organiska markskikten. Halterna av magnesium och kalium var tämligen normala eller möjligen något lägre än vad som är vanligt i svensk skogsmark. Kol och kväveinnehållet överensstämmer ganska väl med tidigare markinventering i Forsmarksområdet och ligger i nivå med andra svenska markförhållanden.

Contents

1 Introduction, objectives and scope

This document reports the data gained by the soil investigations in two large trenches in Forsmark, 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 400-04-99 (SKB's internal controlling document), see Table 1-1. All data from the investigation have been stored in the database SICADA and are traceable by the activity plan number. The chemical data presented in this report constitute a subset of the complete dataset.

The soil conditions of the regolith are of great significance in the transfer of water and elements from the bedrock to the surface ecosystems and vice versa. Information on the spatial variations with horizontal distances as well as with soil depth contributes in clarification of pathways and transfer in the regolith. The cleared trenches provide at least a two dimensional, if not even three dimensional, view of the regolith, adding spatial knowledge of soil physical and chemical prerequisites for transport between bedrock and ground surface. Prevailing soil thicknesses vary considerably as there was a strong small-scale topographical contour of the bedrock relief together with the almost flat ground surface. This implied the regolith thickness to differ very much only within short distances. Special investigations were therefore attributed to the bedrock trench excavations for lineament studies which took place in autumn 2004.

This special investigation is part of the large-scale project under the auspice of the Swedish Nuclear Fuel and Waste Management Company (SKB) to find prerequisites and conditions for long-term storage of nuclear waste. Ecosystem functions are crucial in this management, and the scope includes intensive investigations in the biosphere, hydrosphere, regolith and bedrock. The interface between deep bedrock and surface systems, i.e. the soils, are given special attention. As a complement to the investigations in soil and site types /Lundin et al. 2004/, the Department of Forest Soils, Swedish University of Agricultural sciences, carried out special regolith investigations in large trenches having the main focus on bedrock lineaments. The methods used were mainly based on the instructions to the Swedish Forest Soil Inventory /RIS, 2004/.

Determinations included in the investigations embraced vegetation, humus layer, stoniness, root depth, soil profile development and sampling for soil physical and chemical conditions.

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

- Study of Quaternary sediments (AP PF 400-04-97),
- 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).

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

Activity plan	Number	Version
Jordmånsinventering I schakt 2004	AP PF 400-04-99	1.0

1.1 Investigation area

The trench investigations were located to the site investigation area of Forsmark in the eastern part of central Sweden. The Forsmark area is located on the southwest Bothnian sea coastline (Figure 1-1). In the area a special candidate sub-area is selected for special and intensive investigations. The area is located approximately at N 60°22' and E 18°13', southwest of the Forsmark nuclear power plant. The altitudes in the larger area range from coastal sea shoreline to c 15 m above sea level. The site for the large trenches was located fairly low at only a few metres above the sea level. The main land cover is forest on till soils underlain by a granitic bedrock. Also partly open land and wet soils, i.e. peatlands, exist.

The climate of the region is characterised by a snow-covered winter period during four months in 80% of the years, ranging approximately from first of December to beginning of April, c 125 days. Average maximum snow depth is 50 cm. The vegetation period extends over 180 days, mainly May to September. Hydrology is characterised by fairly dry summers, autumn rain with increasing runoff and a spring snowmelt period, also with relatively high streamwater discharges. Annual precipitation amounts to c 650 mm and evapotranspiration reaches c 400 mm, resulting in a runoff of c 250 mm. The mean annual temperature is c +5°C.

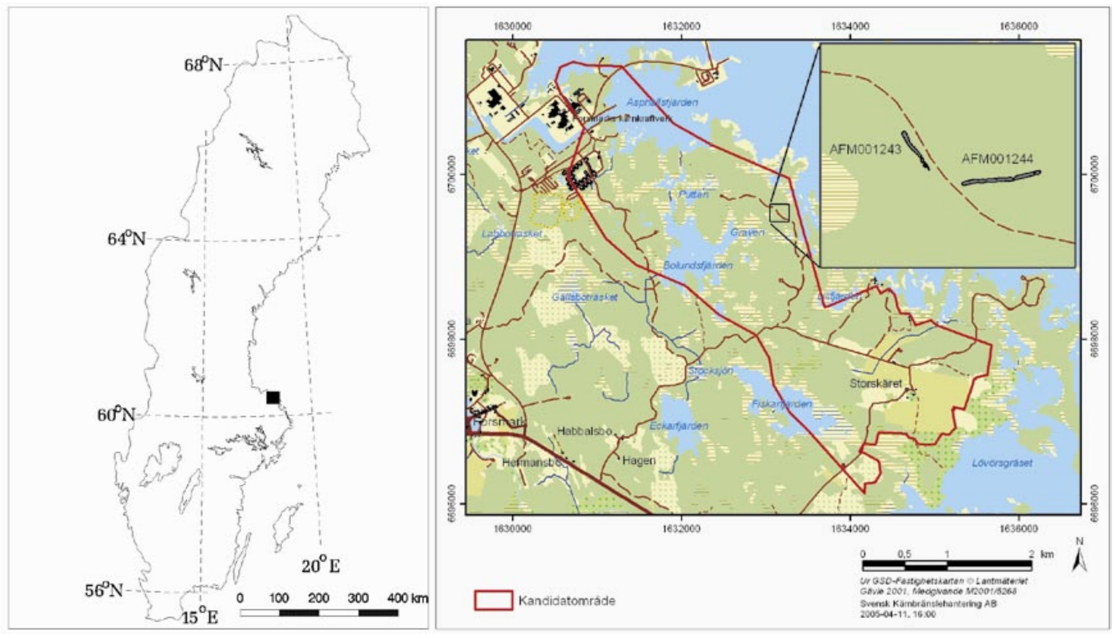

Figure 1-1. *Geographical location of the Forsmark area in the eastern part of central Sweden and the trench sites close to the sea.*

The soils of the Forsmark area are very young; in most of the area, the soils are less than 1,500 years. The soil material is of till origin, which has been affected by the action of sea waves during the transgression of the Baltic Sea. This redistribution of soil material has left course wave washed till in large parts and in higher locations thin soils and bare bedrock. Elsewhere, in depressions the redistributed fine material has been deposited as sorted sediments. During the land upheaval, bays have been cut off and now form inland lakes. Many of these lakes are slowly being turned into swamps and peatlands with shallow peat cover, which is also a characteristic feature of the area. A detailed description of the Quaternary deposits in the Forsmark area has been presented /Sohlenius et al. 2002/.

At the sites of the deep excavations, the two trenches were opened in two directions, trench 3 (AFM001243, LFM00811 (different kind of id-codes have been used for different parameters)), in a NNW – SSE elongation with end coordinates 6699555; 1633122 and 6699520, 1633145, having a length of 51 m. The other trench, number 4 (AFM001244, LFM00810), that extends in a WSW – ENE direction with the end coordinates 6699518; 1633246 and 6699506, 1633175, had a length of 72 m (Figure 1-2). A geographical standard point (6699508.538; 1633146.214) was identified for proper determination of coordinates. Depth of the regolith in the two trenches varied between almost zero and up to almost five metres. Trench 3 was the deeper one and was also influenced by water furnishing a rather moist site. Trench 4 was less deep and the site was also less moist, mainly being of fresh moisture type. The regolith in the deeper parts of trench 4 reached c 2.6 m depth but only in short sections of the trench.

Sampling and some of the other investigations performed were concentrated to profiles, three in trench 3 and two in trench 4, see Figure 1-2.

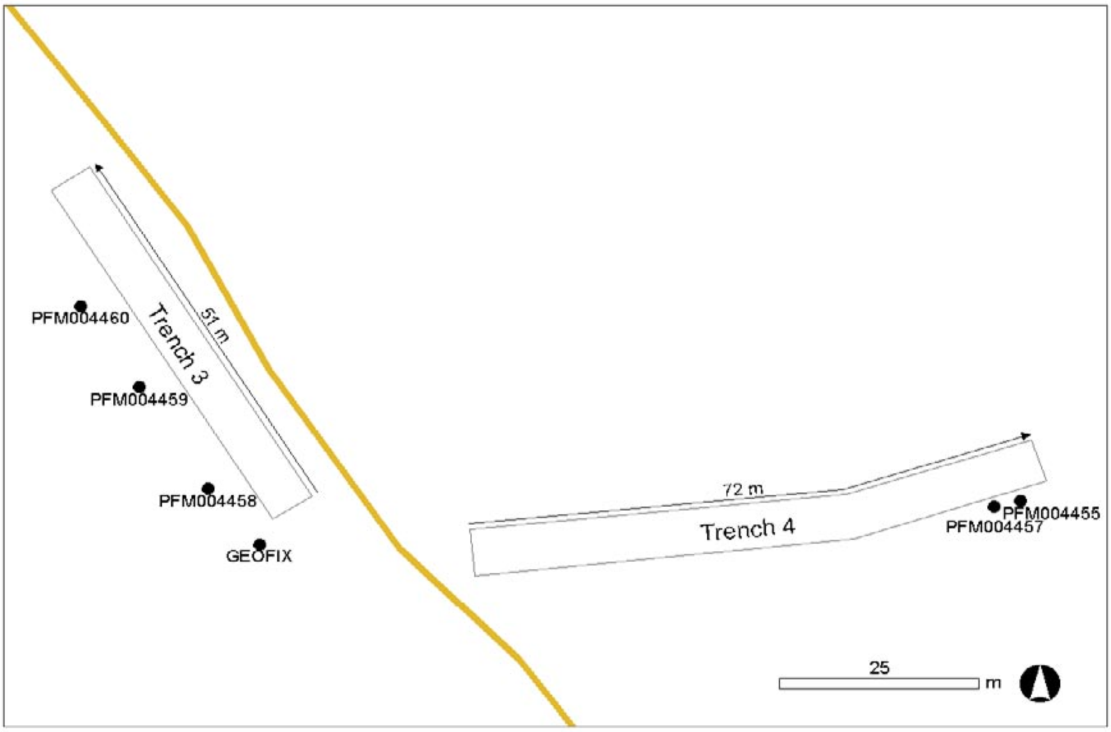

Figure 1-2. *The trench sites with a small road passing in-between. Location of the profiles indicated by SICADA identification numbers. The profiles were located in the wall of the trenches at a half metre distance from the trench side (in trench 3 the distances seem larger but this depends on a sloping trench side wall). The geographical standard point (GEOFIX) has coordinates 6699508.538 and 1633146.214.*

2 Execution

2.1 Investigation content

The investigation included vegetation inventory, humus layer thickness, stoniness, root depth, soil profile development, sampling for soil physical conditions such as porosity, bulk and compact densities, soil water retention and hydraulic conductivity. Further, sampling for chemical analyses of pH, C, N, exchangeable base cations, extractable potassium and phosphorus, and also determinations of presence of $CaCO_3$ were performed.

The investigations were carried out according to Activity Plan SKB AP PF 400-04-99 (SKB internal control document). The data have been incorporated in the database SICADA.

Most determinations followed the instructions for Swedish Forest Soil Inventory /RIS, 2004/. Vegetation inventory was made in one trench, trench 3, and root depth only in trench 4. Other determinations included both trenches with sampling for soil physical analysis in three profiles and a special four sample comparison at the similar and close-by points at c 3.5 m depth. Sampling for chemical determinations were made in three profiles at trench 3 and two profiles in trench 4 (Figure 1-2).

2.2 Site survey methods

At each of the trenches a site description was made including type of field and bottom layer vegetation, hydrology, frequency of stones and boulders, thickness of the humus layer, root depth and soil type distributions.

2.2.1 Vegetation

Vegetation types and dominating species within the list of species used in the "The Swedish National Inventory of Forests" /RIS, 2004/ and percentage of coverage were determined.

Vegetation types included in the bottom layer:

1 Lichen type.

2 Lichen-moss type.

3 Lichen rich type.

4 *Sphagnum* type.

5 Wet moss type.

6 Mesic moss type.

Field layer:

1 Tall herbs without shrubs.

2 Tall herbs with shrubs/bilberry.

3 Tall herb type with shrubs/vitis-idea.

4 Low herbs without shrubs.

5 Low herbs with shrubs/bilberry.

6 Low herbs with shrubs/vitis-idea.

7 Without field layer.

8 Broad leaved grass.

9 Narrow leaved grass.

10 Tall sedge.

11 Low sedge.

12 Horse tail type.

13 Bilberry type.

14 Vitis-idea/whortleberry, marsh rosemary type.

15 Crowberry/heather type.

16 Poor shrubs type.

2.2.2 Site hydrology – Soil moisture class

This variable reflects the average distance from the ground surface to the groundwater table during the vegetation period. Estimations are made from geophysiographical conditions, i.e. local topography and hydrological features, etc.

1 Dry.

2 Fresh.

3 Fresh/moist.

4 Moist.

5 Wet.

2.2.3 Regolith thickness

Estimations were made according to the classes of regolith depth to bare bedrock according to the inventory classes.

1 Considerable thickness.

2 Rather thin regolith.

3 Thin regolith.

4 Considerable variation in regolith thickness.

2.2.4 Stoniness – Stones and boulders

Statement was posed on possibility to perform the stoniness inventory /Viro, 1958/. The special determination means pushing a 10 mm steel rod into the soil until a stone or boulder is hit within a maximum depth of 30 cm. This was made in 36 points over the 30×30 m plot. At the same locations also the thickness of the humus layer was measured. The average stoniness depth is used in a function to estimate the volumetric content of stones and boulders in the soil. The values were compared with actual measurements on the trench wall.

0 measurements not possible to make,

1 measurement made.

The equation used in the calculations was: $Y = 65.7 - 2.22\ X$

Y: stoniness in vol-%;

X: rod penetration depth.

2.2.5 Root depth

The root extension depth was determined with the mineral soil surface as the upper boundary. Depths were measured for fine and coarse roots, separated on the two classes at a diameter of 5 mm.

2.2.6 Soil type

Classification on soil types refers to the international World References Base system (WRB) /WRB, 1998/. The system used is a simplified version including the appropriate types for Sweden and with field determinations, which actually is not totally correct because a thorough classification needs chemical analysis. However, the simplified determination would reflect an almost correct classification.

1 Histosol.

2 Leptosol.

3 Gleysol.

4 Podzol.

5 Umbrisol.

6 Cambisol.

7 Arenosol.

8 Regosol.

9 Unclassified (could be caused by too much water, etc).

2.2.7 Additional features in the soil profile

There are a number of specific features of decisive interest in the soil profile and some of these have been determined. Most special for the Forsmark area is the presence of $CaCO_3$, which deviates from large parts of Sweden. Appearances of $CaCO_3$ were determined by flushing with 9% HCl in the profile and observe the reaction. Layers of the $CaCO_3$ occurrence were determined.

2.2.8 Sampling and analysis of soil physical properties

Volumetric mineral soil samples were taken to determine dry bulk density, porosity, water retention and hydraulic conductivity. Three profiles were sampled, if possible, at the depths: 5–10, 20–25, 50–55, 80–85, 120–125, 170–175 and 250–255 cm. In one profile four samples from the same 350 cm layer were collected. Sampling was made using steel cylinders. The sizes of these were a height of 5 cm and a radius of 3.6 cm. Two replicates were taken in each layer.

Analysis of retention was made using porous suction beds and of hydraulic conductivity in permeameters with constant head. Suction steps used were 10, 50, 100 and 500 cm water pressure. Conductivity values were determined after one hour flow and after 24 hours flow. Time for measurements varied between 5 and c 60 minutes.

Analyses of grain size distribution was performed on samples collected from the same lithological units /Albrecht, 2005/.

2.2.9 Soil sampling for chemistry

Soil was sampled from the profiles and were classified both according to the system for international conditions and the traditional Swedish system to give the possibility to compare with the ongoing Swedish "Forest Soil Inventory".

The humus layer was sampled separately and mineral soils mainly in relevant layers down to regolith depth (Figure 2-1).

Mineral soil layers: 0–10 (H10 sample under mull and mull like moder), 10–20 and 55–65 cm.

In Podzols the layer 0–5 in the B-horizon was added. Deeper layers were sampled at fixed depths, i.e. 1.0 m, 1.5 m, 2.0 m, 2.5 m 3.0 m and 3.5 m if sufficient soil depth.

Chemical analysis included pH, C, N, exchangeable Ca, Mg and K in 1 M NH_4Ac at pH 7, extractable K and P in ammonium-acetate (AL) and 2 M hydrochloric acid (HCl).

2.3 Nonconformities

The activity was performed according to the plans (no nonconformities).

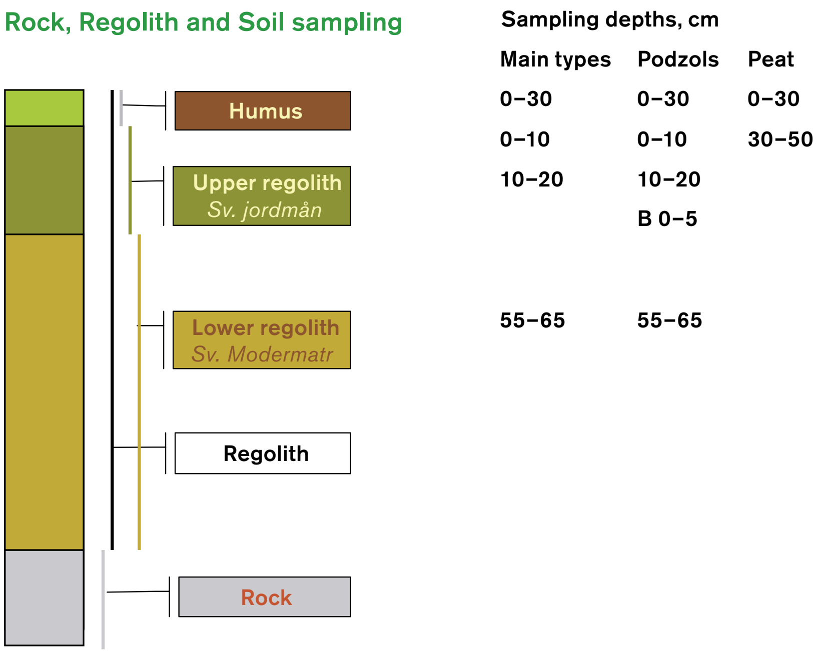

Figure 2-1. *The regolith over the bedrock with soil sampling depths in three categories of soils.*

3 Results

3.1 Site conditions and vegetation

Despite the short distance (on average 75 m) between the two trenches (Figure 1-2), there were differences in the site conditions. Regolith depth was greater at trench 3 with a more wet soil moisture class being mainly fresh-moist or even partly moist, while trench 4 was comparably drier with mainly a fresh soil moisture class and also more shallow regolith varying from almost zero to almost three metres depth.

The soil and site type class, related to the soil classification of the Forsmark area (Lundin et al. 2004), would mainly be the RG/GL: Regosol/Gleysol type found in upslope locations with fresh soil moisture class. The Regosol soil, which dominates the class, is formed on unconsolidated course textured parent material and are characterised by a minimal soil profile development as a consequence of young age. Partly, the site also showed similarities to the Leptosol type. Humus forms would be mor or moder. The mixed coniferous forests are dominated by spruce with herbs in the field layer.

Vegetation conditions in both trenches showed fresh mosses in the bottom layer, low herbs or bilberry type in the field layer and trees embracing pine, spruce, birch and, at least at trench 3, alder. In trench 4 a more detailed vegetation inventory was made showing the dominant bottom layer species *Hylocomium splendens* and *Pleurozium Schreberi* and in the field layer the low herb indicators *Geum rivale*, *Hepatica nobilis* and *Oxalis acetosella* dominated. Site conditions, vegetation type and plant species were determined in sections of 10 m width, starting with the first section in the south-east part of the trench (data presented in Appendix Ia–e).

Sampling of plants was made at trench 3 where common species were collected and sub-divided in different parts, i.e. stem, branches and last year shoots. The stem samples were taken from low, middle and top parts. These are archive samples stored in a freezer at SKB. The sampled species were:

Bottom layer species: *Hylocomium splendens* and *Pleurozium schreberi*.

Field layer species: *Vaccinium myrtillus*, *Filipendula ulmaria*, *Rubus saxatilis*, *Vaccinium vitis-idaea*, *Deschampsia flexuosa*, *Tussilago farfara*, *Calamagrostis canescens* and *Geum rivale*.

Tree layer species: *Picea Abies*, *Alnus glutinosa*, *Pinus silvestris* and *Betula pendula*.

3.2 Humus layer thickness

The thicknesses of the humus layer were determined in grid nets over the trenches with 33 locations in trench 3 and 51 in trench 4. In trench 3 organic soil mor layer appeared at 15 locations and the humus form mull at 18 spots, while mor layer type was found over the whole of trench 4. The thicknesses of the organic soil layer were on average 7.2 cm and 10.7 cm in the two trenches, respectively, but varied in trench 3 from 0–26 cm and in trench 4 from 0–35 cm (Table 3-1).

In trench 3 it was not meaningful to present the spatial distribution of the organic soil layer thickness, because the humus form varied between mor and mull. In trench 4, however, the average thickness along the trench varied from 8 cm to 17 cm (Figure 3-1).

3.3 Stoniness

Content of stones and boulders in the soil have a significant influence on soil hydrology and soil chemistry. Information on such content is difficult to obtain. In the trench investigations, two methods were used. One was based on the rod penetration method /Viro, 1958/ and the other being actual measurements on the soil profile wall.

A problem with the rod method is a fairly poor validation to actual contents, which resulted in somewhat uncertain values of 37% and 49% in trench 3 and 4, respectively (Figure 3-2). Uncertainties could also depend on few numbers of penetrations.

The soil profile wall determinations were made on each dm depth from the mineral soil surface to 0.5 m depth. Probably, the contents in the top soil layers (0.1 m) would best resemble the rod method giving fairly similar results, i.e. 55% and 48% for trench 3 and 4, respectively. In trench 4 this value coincided fairly well with the rod method while deviations existed for trench 3. This could be explained by two specific conditions, i.e. first the total trench 3 could not be measured on the wall because of working hazards,

Table 3-1. Thicknesses of the organic soil layer in the two trenches 3 and 4.

	Mean thickness, cm	95% conf. interval, cm	N
Trench 3, LFM000811	7.2	2.0–11.4	15
Trench 4, LFM000810	10.7	9.8–11.6	50

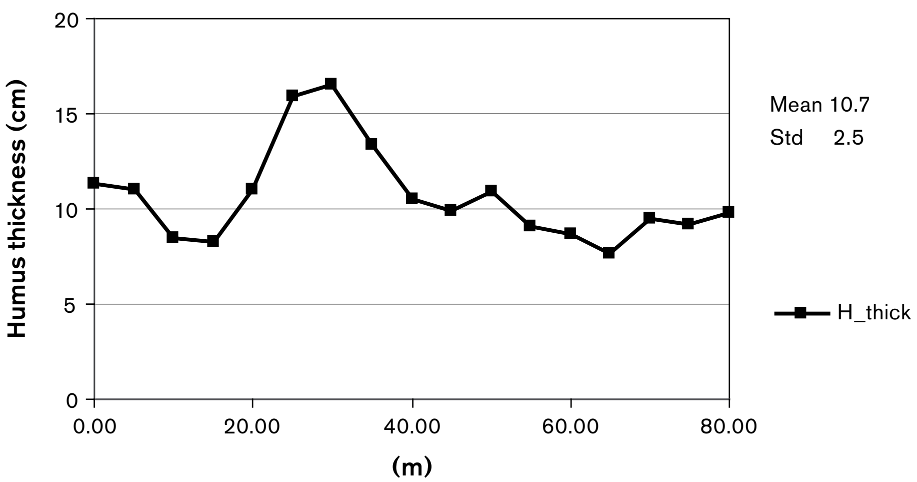

Figure 3-1. Average humus layer thickness in trench 4, LFM000810. Values calculated as floating means over 10 m length, and at each 5 m section three determinations across the trench are included.

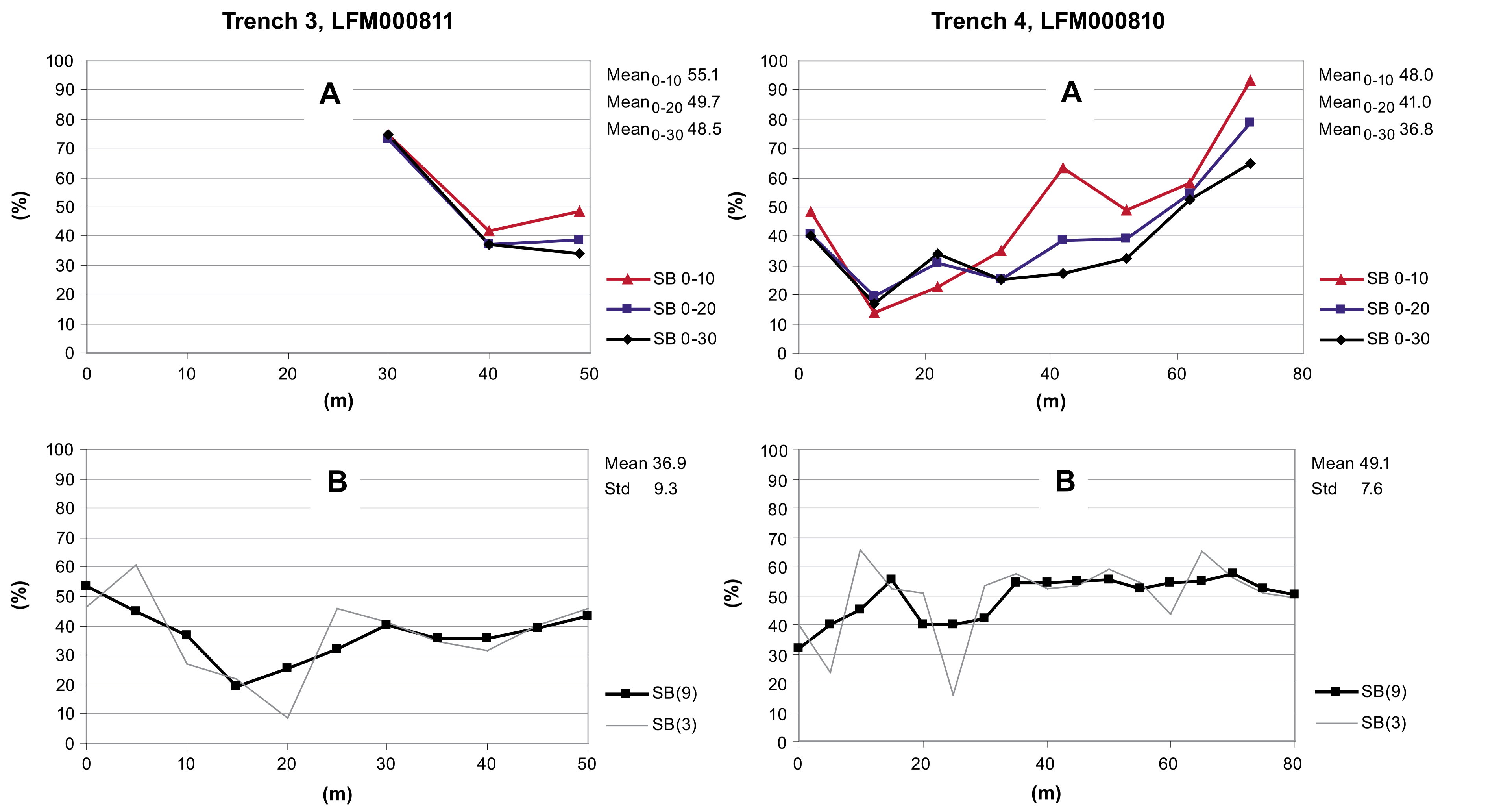

Figure 3-2. *Estimated stoniness in trench 3 and 4 by A. measurements on the trench wall, and B. by Viro's rod penetration method. SB(3) and SB(9) denote estimations of mean penetration depth from 3 or 9 values.*

entailing that the total stoniness value for the whole trench by the rod method was compared with wall determinations on a shorter part of the trench. Secondly, one section in the wall determination deviated strongly from the two others, being those showing similar values for the two methods. In conclusion, the stoniness values are rather uncertain and could be estimated as being between 40% and 50% (Figure 3-2).

A stratification in stoniness with soil depth was also observed showing high values in the 0.2 m surface layer (50–60%) and lower values in deeper layers (20–40%). In trench 4 the corresponding value was below 20% at 0.5 m depth (Figure 3-3). For comparison, the stoniness in the profiles down to bedrock was documented in geological sketches /Albrecht, 2005/.

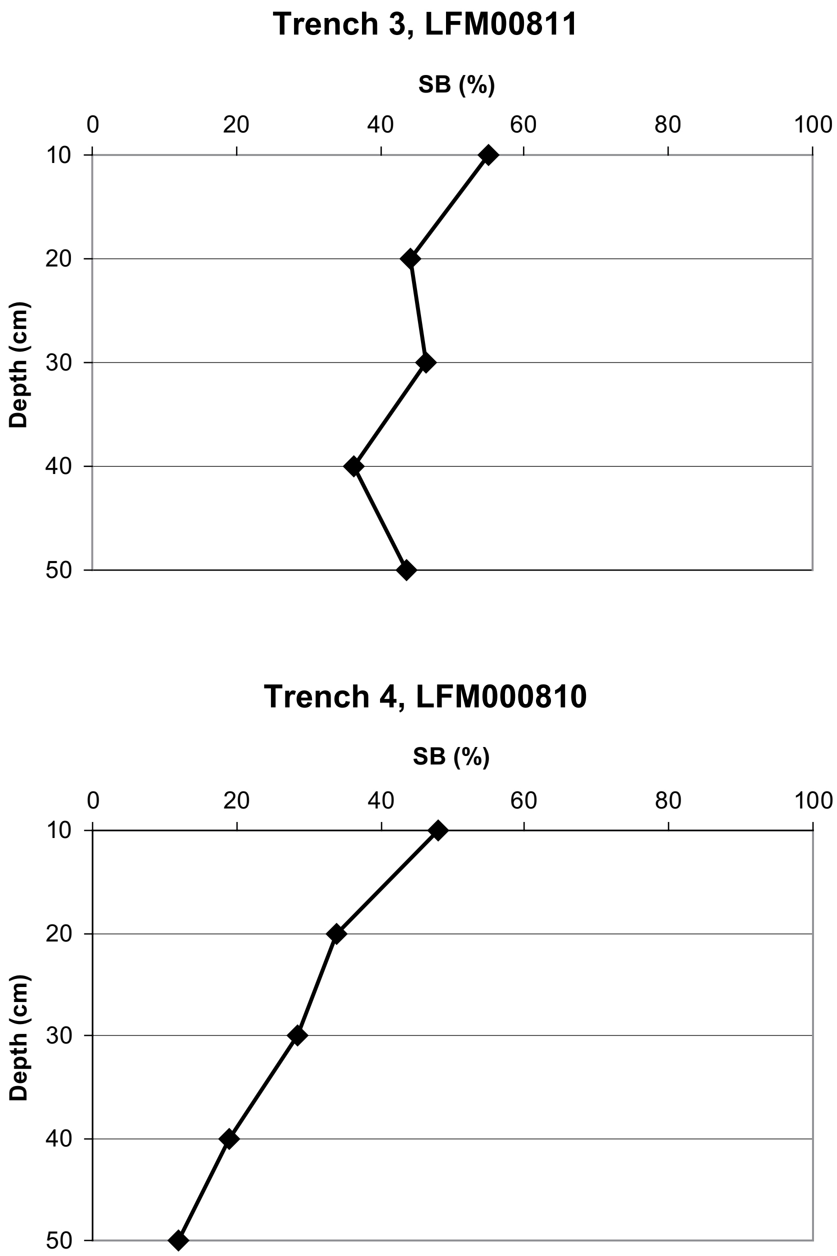

Figure 3-3. Distribution of stone and boulder content versus depth in trench 3 and 4 from measurements on the trench walls.

3.4 Root depth

The depth of fine and coarse roots was investigated in trench 4. Determinations were made in each two metre section along the trench. Fine roots were found in most locations and the depth varied from 3 cm to 57 cm. On two locations there were bedrock without roots. Most of the roots reached between 10 cm and 40 cm with an average of 25 cm. Coarse roots were observed at 19 locations with the deepest root reaching 25 cm but on average the depth was 10 cm (Figure 3-4).

3.5 Soil type

In both trenches, the soil types were determined and the long trench wall provided possibilities to get a continuous semi-quantitative distribution of the soils. These, being young in the Forsmark area, mainly had not developed to mature soils. Therefore, Regosols dominated the sites with 87% in trench 3 but with a larger variation in trench 4 where Regosol made up 82% (Figure 3-5). Compared to the earlier soil inventory of the Forsmark area, the trench sites provided much more of the Regosol type, comprising 28% in the total area. One reason for this was the selection of a fairly well-drained site avoiding the wetter sites with Histosols and Gleysols constituting 53% of the Forsmark area /Lundin et al. 2004/. Other soil types noted at the trench sites were Histosol, Leptosol and Podzol (Table 3-2).

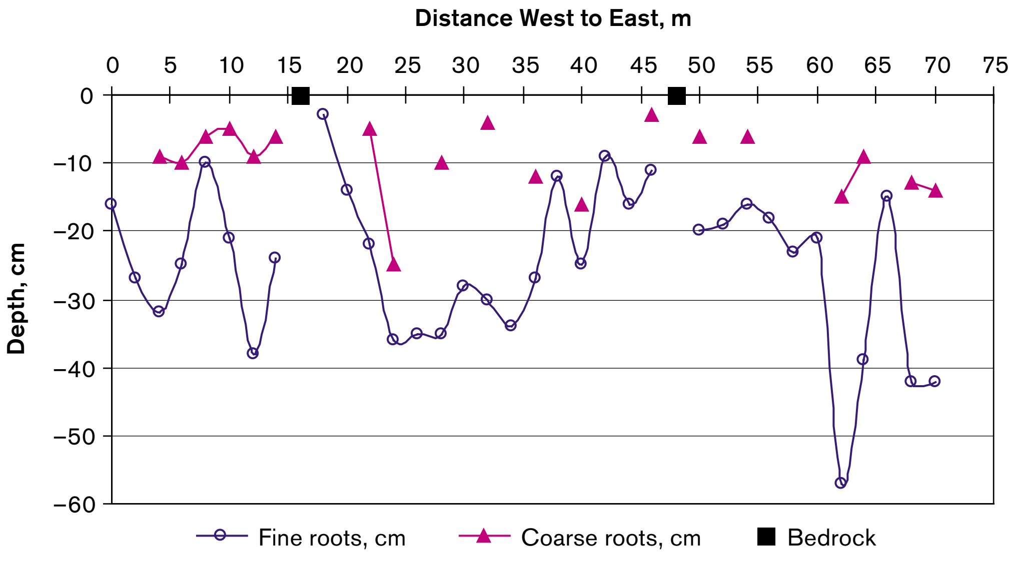

Figure 3-4. *Depths of fine and coarse roots in the Forsmark area trench 4, LFM000810.*

Table 3-2. Soil type distributions in trenches 3 (LFM000811) and 4 (LFM000810) of the Forsmark area.

Site	Length of the trench, m	Soil type, %			
		Histosol	Leptosol	Podzol	Regosol
Trench 3, LFM000811	51	0.0	0	13.1	86.9
Trench 4, LFM000810	72	3.3	8	7.1	81.8

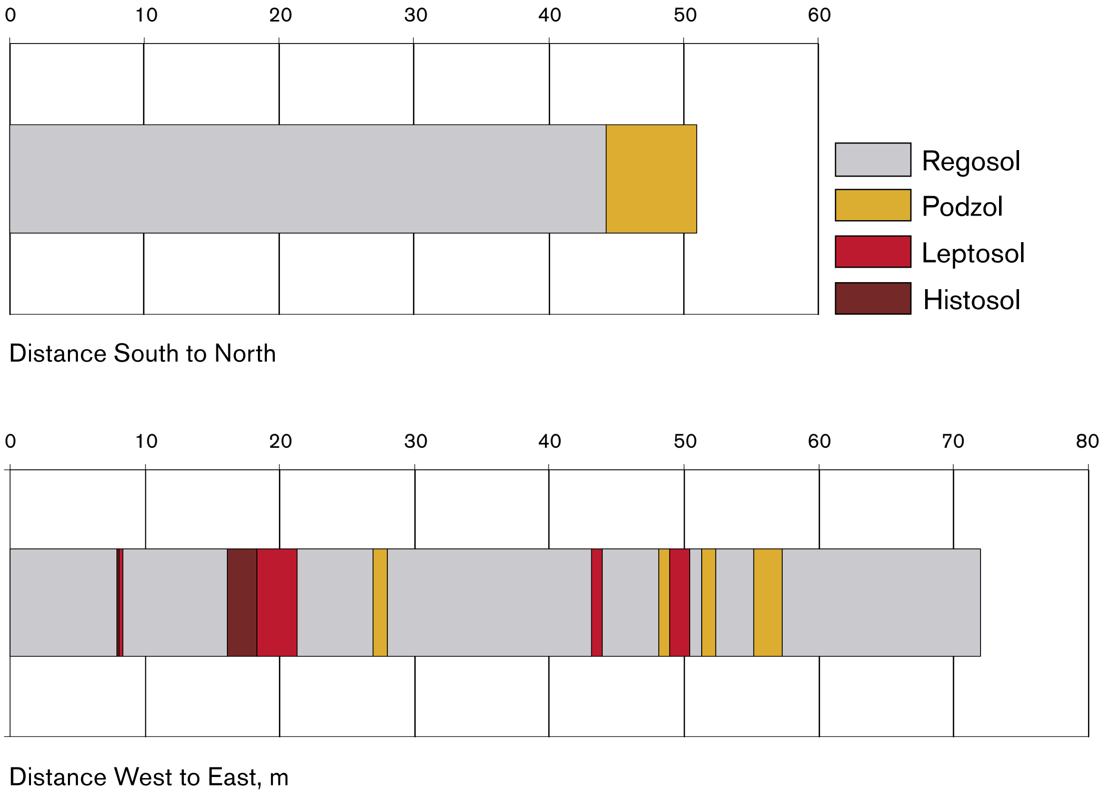

Figure 3-5. Soil type distributions in the two trenches, no 3 (LFM000811) above and no 4 (LFM000810) below. The rather black illustration at c 8 m is a 0.2 m Histosol.

3.6 Calcium carbonate

Presence of calcium-carbonate was determined in the five profiles, see Figure 1-2, and existences were observed in all. In two of the profiles (PFM004458 and 4459) occurrence was found up to the top mineral soil surface while in the other three $CaCO_3$ was present from 15 cm depth.

3.7 Density, porosity and soil moisture content

The compact density in the profiles was somewhat increased with values often of 2.7 g/cm^3 to be compared with the ordinary silica material being 2.65 g/cm^3. However, deviations were small (Appendix II).

Dry bulk densities were slightly lower in the top soil layers with values between 1.5–2.0 g/cm^3 as compared to the deep layers with densities between 1.9 g/cm^3 and 2.3 g/cm^3 (Figure 3-6 and Appendix II). Such values were also found in forested till soils in region Bergslagen but there the highest densities up to 2.3 g/cm^3 were not observed /Lundin, 1982/.

Porosities could be considered slightly low with values in the upper soil layers of 30–40%, decreasing with depth to 10–20% in layers at 2–3 m depth (Figure 3-6 and Appendix II). These values coincide fairly well with ordinary porosities in till soils without wave-washing /Lundin, 1982/.

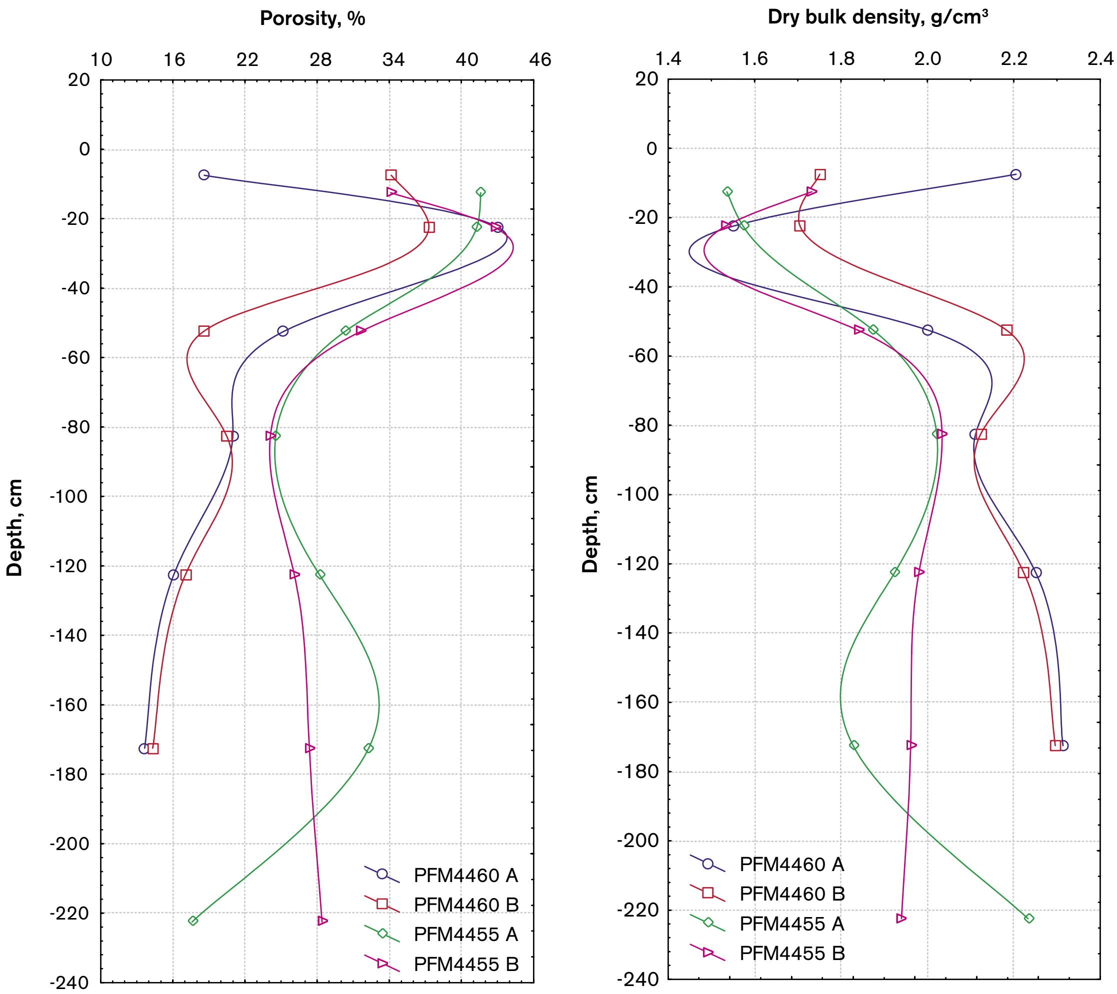

Figure 3-6. *Porosity (left) and dry bulk density (right) in the profiles PFM004455 and PFM004460 in trench 4 and 3, respectively. The depth zero (0) level is the mineral soil surface.*

3.8 Water retention conditions and soil moisture content

At the time for soil sampling, soil moisture content was low, in the top layers of profile PFM004455 below 10 vol-%. Otherwise, moisture contents were between 10 and 20 vol-% with the exception of the layer 0.20–0.25 m in profile PFM004460 where contents of 30–40 vol-% were observed (Appendix II).

Water content in relation to retentions showed similar patterns with higher total water contents and stronger decrease with suction in the upper soil layers compared to deeper ones. In profile PFM004455, trench 4, the content of water at saturation was 30–40 vol-% in the top 0.2 m decreasing to less than 20 vol-% at 2.5 m depth (Figure 3-7). The “free” water content in the top 0.10–0.15 m layer was 26 vol-%, at 0.20–0.25 m depth it was 23 vol-% and in the 2.5–2.55 m layer it was only 4 vol-% (Appendix II).

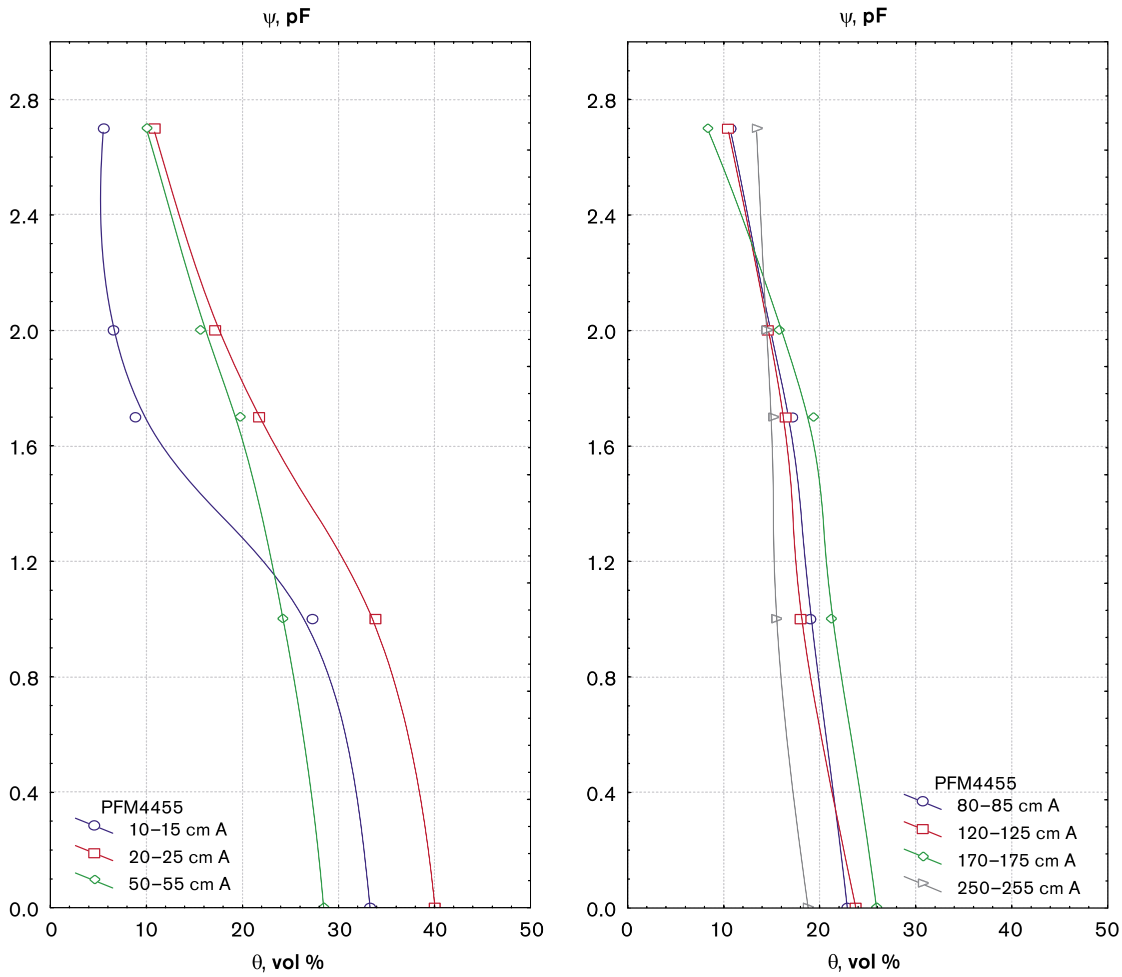

Figure 3-7. *Soil water retention curves for seven layers in the PFM004455 profile of trench 4. (pF values are the negative logarithm of water suction in cm water pressure).*

Similar patterns were found in the other investigated profiles, but in profile PFM004460 of trench 3, the top 0.05–0.10 m layer provided lower water contents at saturation, on average 29 vol-%, as compared to the deeper layer 0.20–0.25 m depth where the total water content was on average 46 vol-% (Figure 3-8 and Appendix II). The higher water content also coincided with higher porosity in this layer. Mainly the two replicate samples showed good agreements but in the top layer of profile PFM004460 deviations were observed.

In deeper layers as for 0.8 m and 1.7 m the retention curves were very similar showing water saturation values around 20 vol-% and fairly high retention capacities (Figure 3-8). Such conditions were earlier found for till soils above the highest coastline /Lundin, 1982/.

In one of the deeper profiles, i.e. PFM004459 in trench 3, four replicate samples were collected from c 3.5 m depth. Water contents were fairly similar between the samples with only 1.8 vol-% range at saturation of on average 25 vol-%, ±3.5% amplitude. At higher retentions, the range was slightly larger with 2.1 vol-% making up an amplitude of ±6% at the average water content of 18 vol-% (water content at pF 2.7) (Appendix IIc).

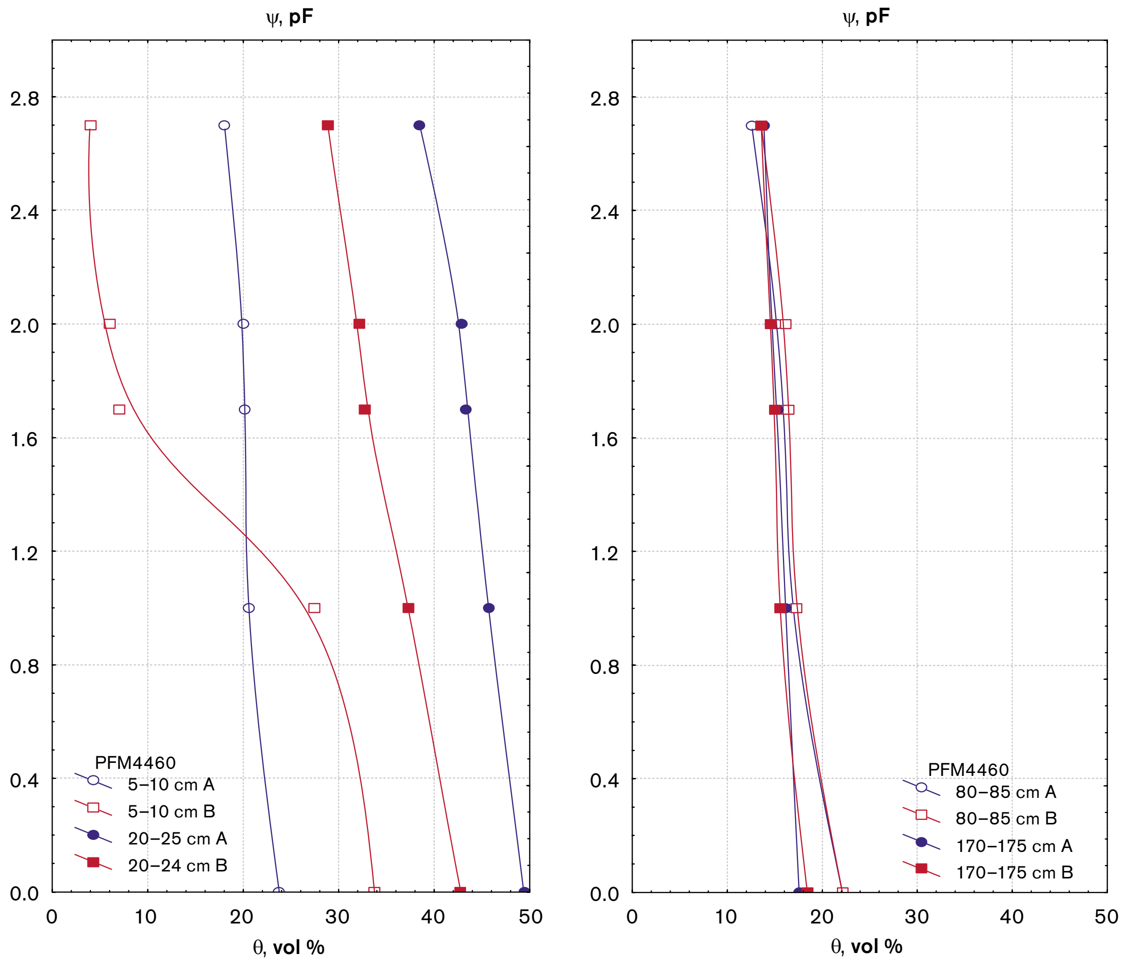

Figure 3-8. *Water holding relationships in profile PFM004460 at trench 3 showing the two sample replicates at four layers.*

3.9 Hydraulic conductivity

The hydraulic conductivity provides information on the possibilities for water to flow through soil and bedrock materials. With knowledge of the hydraulic conductivity it is possible to calculate water and element flows. Investigations on hydraulic conductivity have mainly been carried out on water-bearing formations where flows are considerable, such as glaciofluvial deposits. In such geological formations rather high conductivity values have been measured. In till soils, such as those in the trenches of the Forsmark area, lower values could be expected. A small number of investigations have been made in till soils and resulted in values being relatively high in the top soil layers with 10^{-5}–10^{-4} m/s and a strong stratification with soil depth to reach values on 10^{-8}–10^{-7} in the deep layers at 2–3 m /Lundin, 1982; Lind and Lundin, 1990/.

In the Forsmark investigations knowledge also of the deep layer hydraulic conductivity is crucial in the determinations of element transport from the bedrock to the surface water systems. Therefore, special determinations were made in the trench profiles and conductivity measured on the undisturbed samples taken. One special study was made at a depth of c 3.5 m with four replicates in profile PFM004459, trench 3. At this stratigraphical position an over-consolidated boulder clay was identified /Albrecht, 2005/. The conductivity values showed considerable variation within short distances, 0.07–0.6×10^{-7} m/s but also with large differences between measurements at the two time intervals (one and 24 hours) used in the analysis, 0.08–0.3×10^{-7} m/s (Table 3-3).

The hydraulic conductivity of the profiles in the trenches of the Forsmark area showed mainly the ordinary pattern for till soils with relatively high conductivities in the upper soil layers (2–4×10^{-5} m/s) and with a considerable decrease with depth to values below 10^{-7} m/s already at 0.5 m depth (Figure 3-10). Profile PFM004458 was slightly deviating from this with comparably low values in the top layers but higher value in layers down to 1.2 m, i.e. 2–10×10^{-7} m/s (Figure 3-9, Appendix III).

Table 3-3. Hydraulic conductivities of profile PFM004459 in trench 3 at c 3.5 m depth, four replicates. Measurements after one hour and 24 hours throughflow.

Sample	Measurement after 1 hour 10^{-7}, m/s	Measurements after 24 hours 10^{-7}, m/s
PFM004459 A	0.58	0.00
PFM004459 B	0.00	0.07
PFM004459 C	0.46	0.23
PFM004459 D	0.07	0.03
Average	0.28	0.08

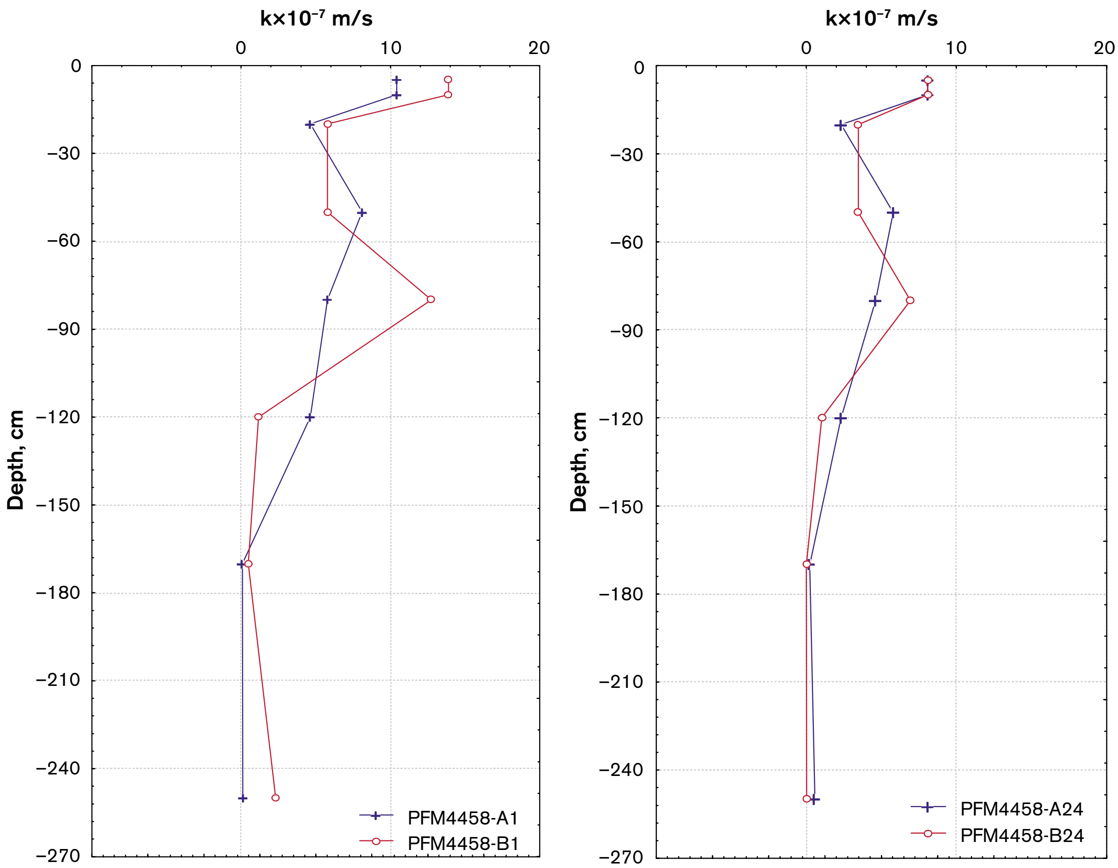

Figure 3-9. *Hydraulic conductivity in profile PFM004458, trench 3. The two replicate samples showed left and the two measurements on each sample, right. Observe the scale on the conductivity axis.*

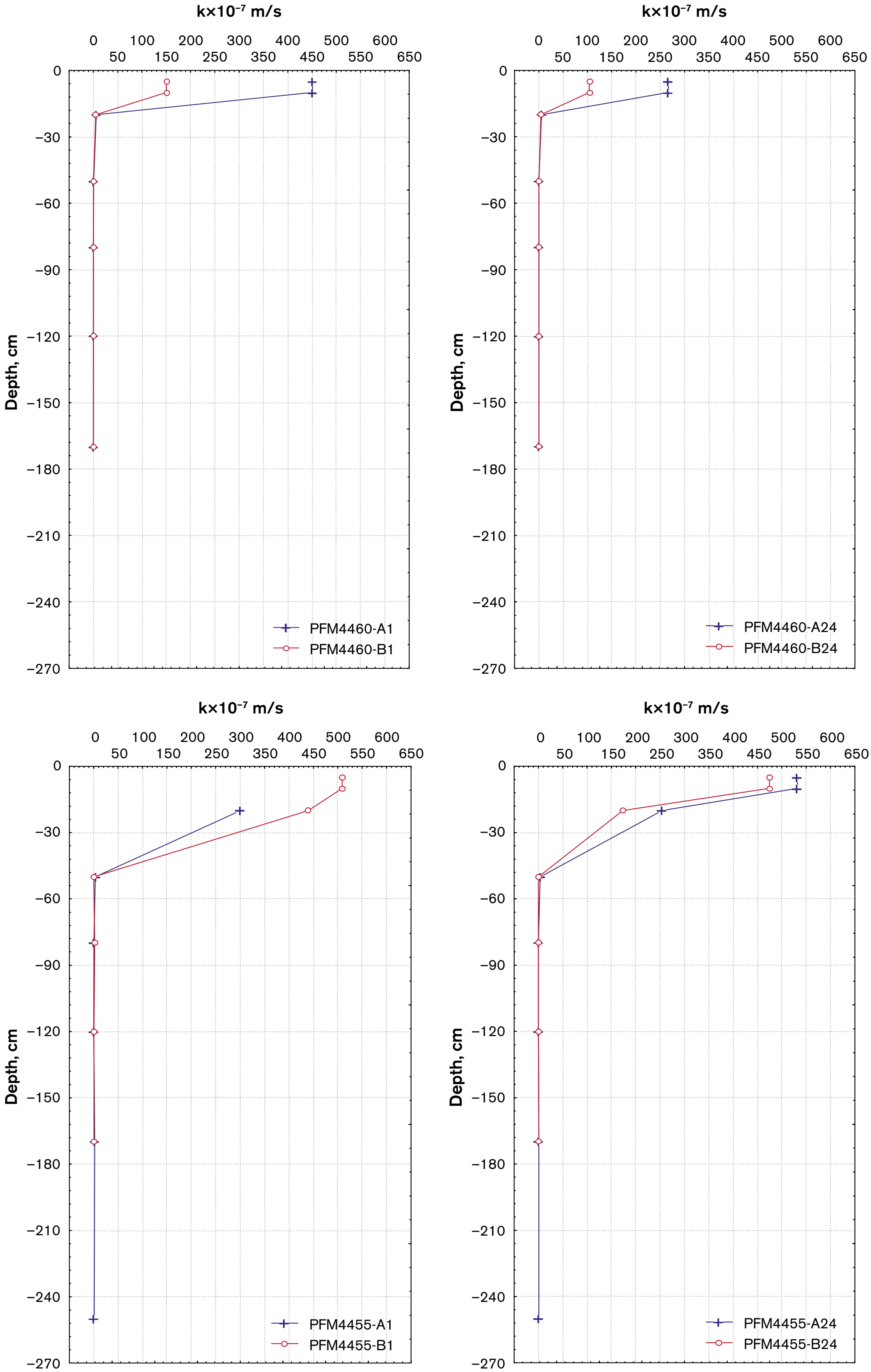

Figure 3-10. *Hydraulic conductivity in profiles PFM004455, trench 4, and PFM004460, trench 3. The two replicate samples showed left and the two measurements on each sample, right. Observe the scale on the conductivity axis.*

3.10 Soil chemistry

3.10.1 pH

Mainly, the pattern for pH in the soil of the trenches showed comparably high values between 5 and 8. However, in the O-horizon of the two profiles in trench 4 low values (3.6–3.7) were found (Figure 3-11). These values coincide with the lowest values found in the soil type investigation for the Forsmark area /Lundin et al. 2004/. In trench 4, however, with mainly a mor humus form, that would provide lower pH values compared to the richer moder or mull types partly found in trench 3, pH in the top soil was 5.6–7.3 (Figure 3-11).

In general the stratification of pH values with depth follows the ordinary pattern with increasing values. In deep layers, pH reaches 8, a value occurring already at 0.2 m to 1.0 m in profiles PFM004459 and PFM004460, respectively (Figure 3-11). Otherwise, the pH in the upper mineral soil layers are mainly between 5 and 7, which coincides with the earlier soil inventory values of 6.5–6.7 /Lundin et al. 2004/. Values in deeper layers were not determined in the earlier study but are in the trench sites mainly between 7 and 8 (Appendix IV).

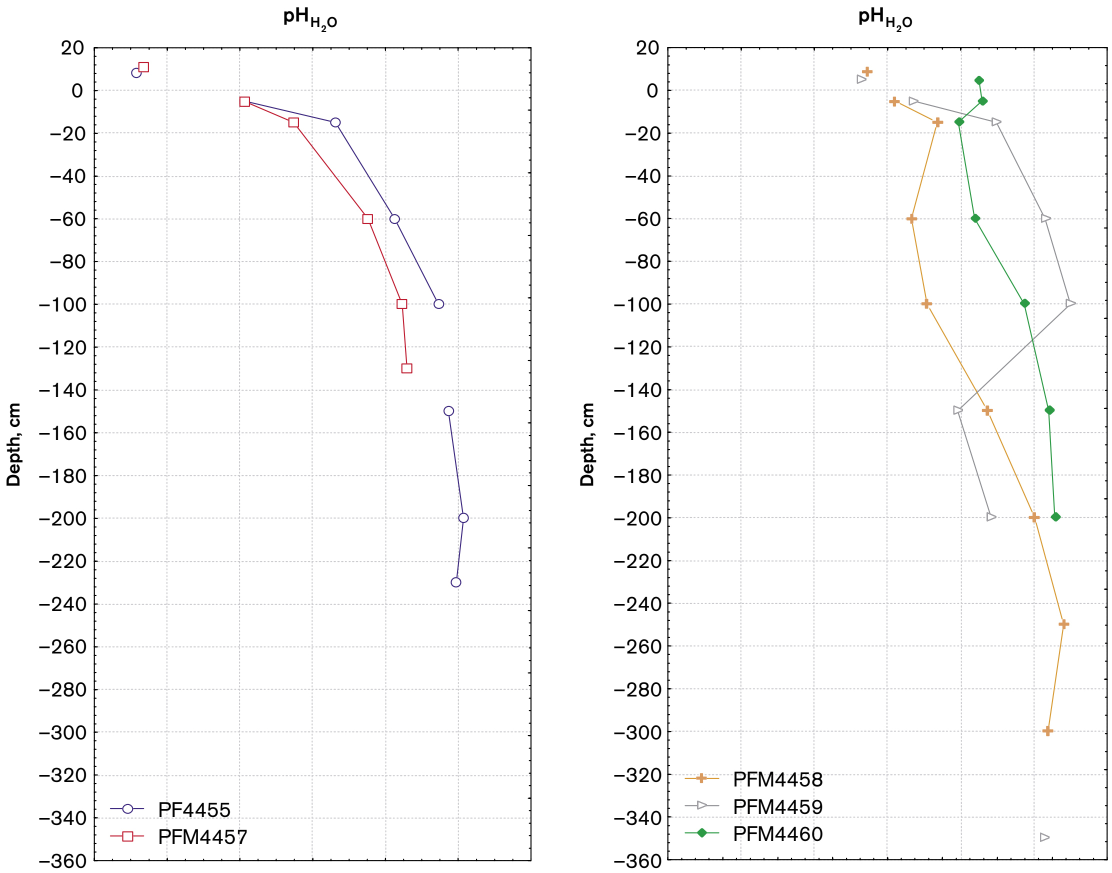

Figure 3-11. *Profiles of pH values in trench 4 (left) and trench 3 (right) in the Forsmark area 2004, (no line means incomplete profile data).*

3.10.2 Organic carbon

Carbon contents in the organic layer varied considerably between profiles with a low content of 15% in PFM004460 to fairly ordinary at PFM004458 and PFM004459 with c 39% and as high values as 56% in profiles PFM004455 and PFM004457 (Figure 3-12). The latter values indicate total organic matter of high decomposition or a probable influence of fire.

In the mineral soil values are lower, mainly between 1% and 2% but in profiles PFM004457 and PFM004460 as low as 0.2–0.4% in the top 0.1–0.2 m and in PFM004455 0.8%. In the layer below, with some accumulation of iron-organic substances slightly higher contents (c 2%) occurred. Deeper in the profile similar values on 1.5% to 2.1% were found (Figure 3-12 and Appendix IV). Such contents agreed with those found in the earlier Forsmark soil investigation /Lundin et al. 2004/.

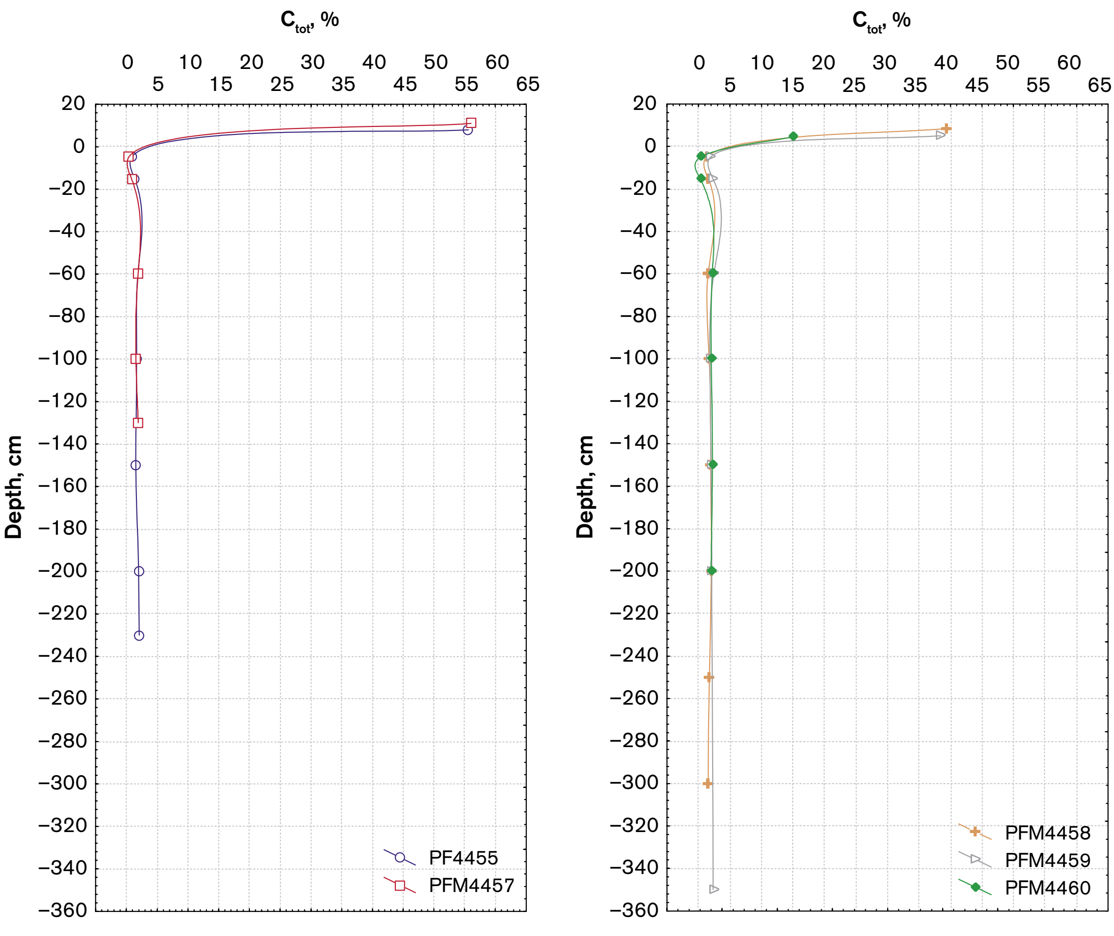

Figure 3-12. *Carbon concentration stratification versus soil depth in the trench profiles at the Forsmark area 2004.*

3.10.3 Nitrogen

The nitrogen content in the humus layer agreed fairly well with the earlier soil investigation /Lundin et al. 2004/ with values between 0.9% and 2.0% (Figure 3-13). Mainly the contents were higher at the trench sites where profile PFM004460 provided the lowest value, however not being lower compared to the earlier inventory. In relation to other parts of Sweden the contents coincided rather well, mainly being higher than values for Sweden as a whole.

In the mineral soil, nitrogen contents were lower with concentrations between 0.01% and 0.06%. The higher values occurred in the upper soil layers (0.1–0.2 m) especially in profiles PFM004455 and PFM004457. In the very top mineral soil layer, 0–0.1 m, lower values were observed, coinciding also with less organic matter as indicated by the carbon content. In the deeper layers of the profiles rather stable contents occurred, being between 0.01% and 0.02% (Figure 3-13). Compared to the earlier soil investigation, the concentrations were slightly lower at the trench sites.

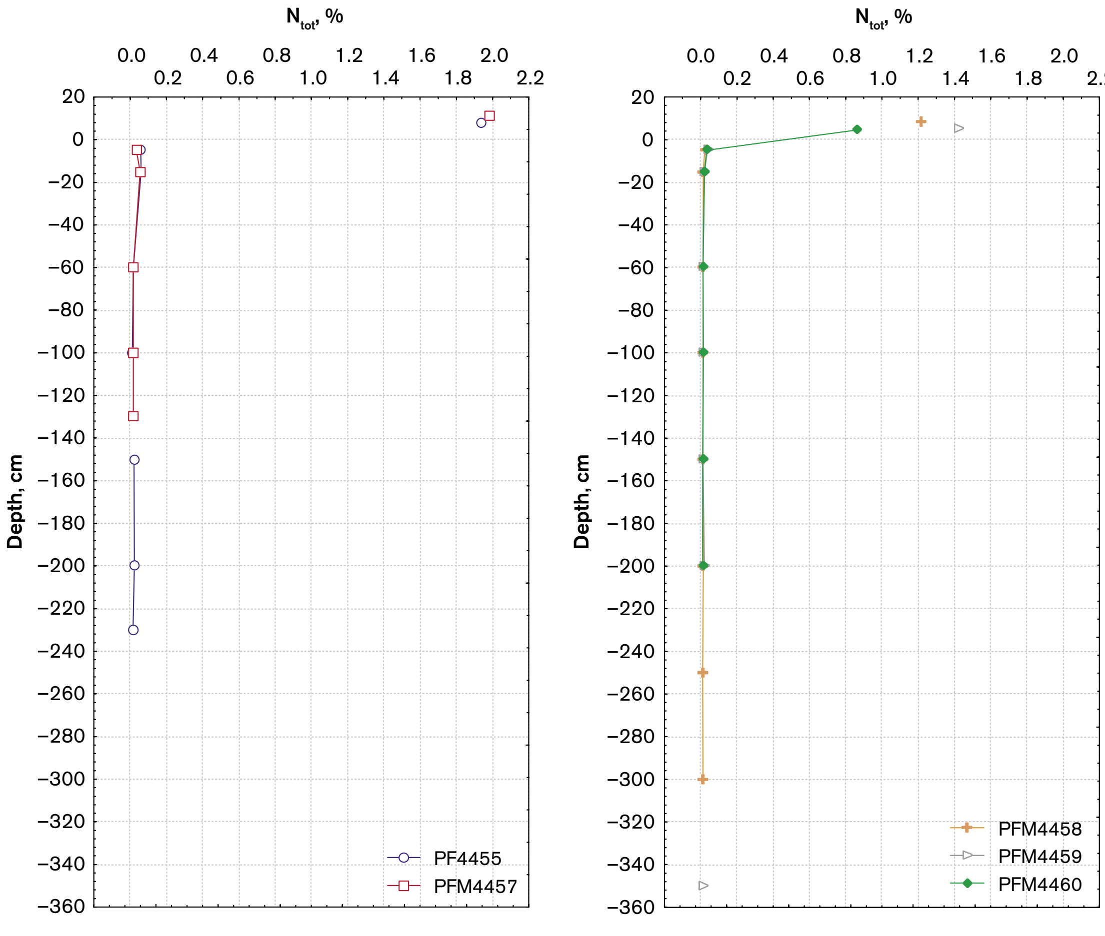

Figure 3-13. Nitrogen content stratification versus soil depth in the trench site profiles of the Forsmark area 2004, (no line means incomplete profile data).

3.10.4 Base cations

Exchangeable contents of Ca, Mg and K were determined. The distribution pattern of the profiles were rather similar with high concentrations in the organic horizon, low in the very top mineral soil, higher in the top soil layer below and further down in the soil almost no stratification with depth.

Calcium

Calcium content levels were comparably high as compared to ordinary forest soils. In the organic layer the concentration range was 20–80 $mmol_c$/100 g. Contents in ordinary Swedish forest soils with a Podzol profile could be 5–10 $mmol_c$/100 g and in Cambisol c 20 $mmol_c$/100 g. In the very top mineral soil layers where Ca had been leached, the values could be 1–3 $mmol_c$/100 g but immediately below with some Ca accumulation higher values up to 12 $mmol_c$/100 g occurred. In ordinary Swedish forest podzolic soils values below 1 $mmol_c$/100 g were found in the bleached horizon and up to 1 $mmol_c$/100 g in the underlying B-horizon. Further down values between 0.01–0.4 $mmol_c$/100 g could occur. This could be compared with the concentration in deep layers at the trench sites of the Forsmark area where values of c 10 $mmol_c$/100 g were common (Figure 3-14 and Appendix IV).

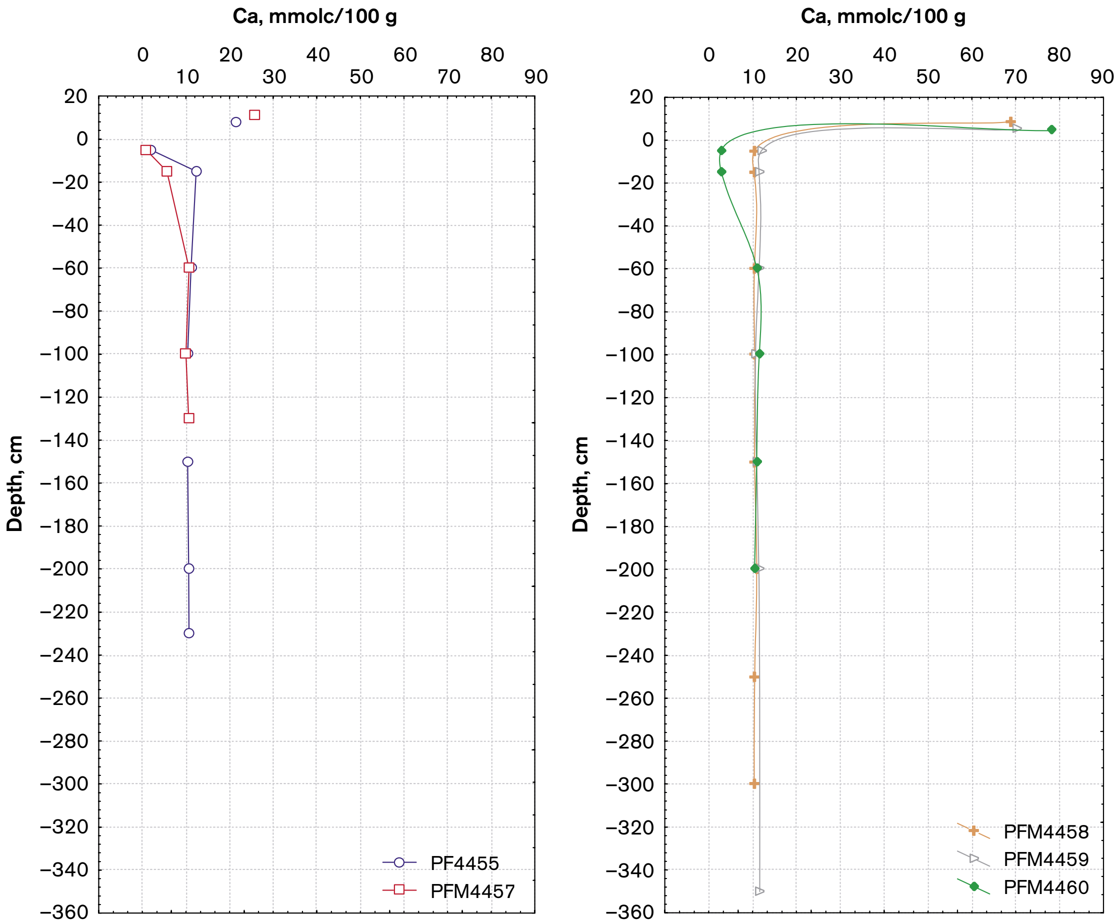

***Figure 3-14.** Calcium content stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).*

Magnesium

Exchangeable magnesium mainly demonstrating a similar pattern as for Ca had contents in the O-horizon of 2.6 $mmol_c$/100 g to 4.3 $mmol_c$/100 g which is comparable to podzolic forest soils in Sweden but lower than compared to some Cambisols. The low concentrations found in the very top mineral soil were c 0.1 $mmol_c$/100 g with slightly higher values below at 0.2–0.3 $mmol_c$/100 g (Appendix IV). These values could be compared with Swedish forest soil values of 0.2 $mmol_c$/100 g in both top mineral horizons and in Cambisols 0.1–2 $mmol_c$/100 g with the high values in geologically rich soils. In the deeper soil layers values for the trench profiles were 0.1–0.2 $mmol_c$/100 g with the profile PFM004459 deviating at c 0.7 $mmol_c$/100 g (Figure 3-15) being very high for podzolic soils, and only reached in Mg rich soils.

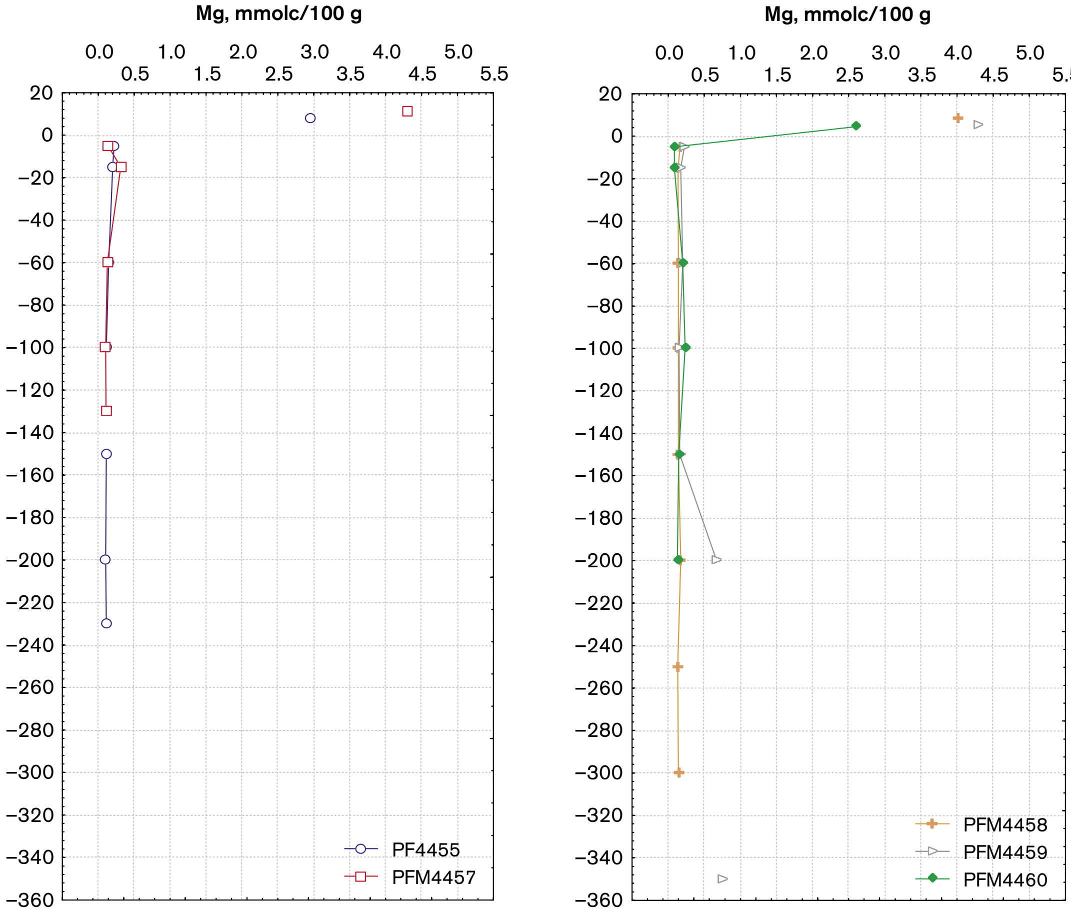

Figure 3-15. *Magnesium content stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).*

Potassium

Exchangeable potassium also revealed similar patterns as for Ca and Mg but perhaps with a more pronounced increase in the B-horizon and with the same discrepancy in deep soil layers in profile PFM004459 as for Mg. Organic soil concentrations were 1–1.3 $mmol_c$/100 g but with profile PFM004460 at lower values (0.3 $mmol_c$/100 g) (Appendix IV). In the upper mineral soil the contents were 0.02–0.05 $mmol_c$/100 g and in deeper mineral soil layers 0.03–0.08 $mmol_c$/100 g. However, profile PFM004460 deviated with values of c 0.25 $mmol_c$/100 g (Figure 3-16).

Comparable contents in Swedish forest podzolic soils showed stratification from c 2 $mmol_c$/100 g in the O-horizon, 0.05–0.1 $mmol_c$/100 g in the upper mineral soil layers and 0.01–0.05 $mmol_c$/100 g in the C-horizon. Corresponding values in Cambisols were 0.3–1.5 $mmol_c$/100 g and 0.1–0.2 $mmol_c$/100 g in the mineral soil.

Potassium extracted with AL (ammoniumlactate) showing easily accessible K, provided similar values as for NH_4Ac extracts and provided almost the same stratification pattern (Figure 3-17).

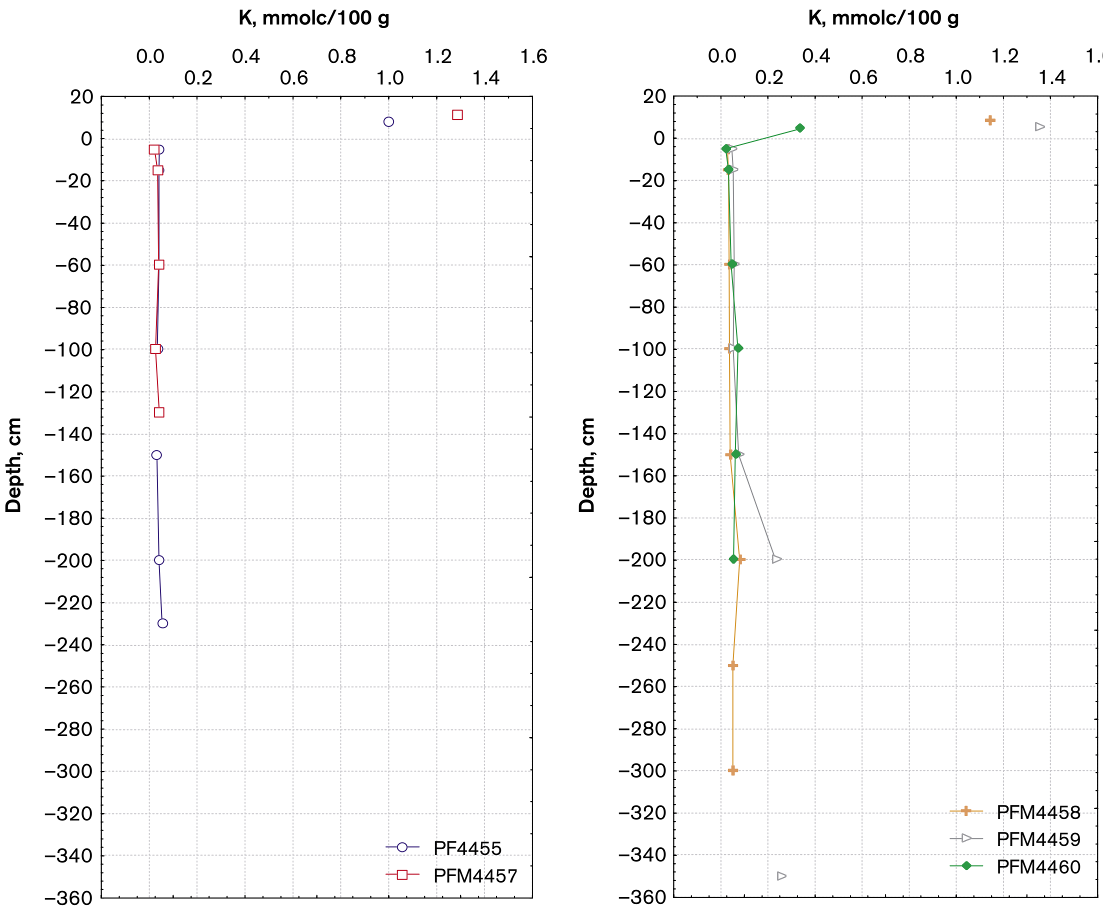

Figure 3-16. *Potassium content (NH_4Ac extracted) stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).*

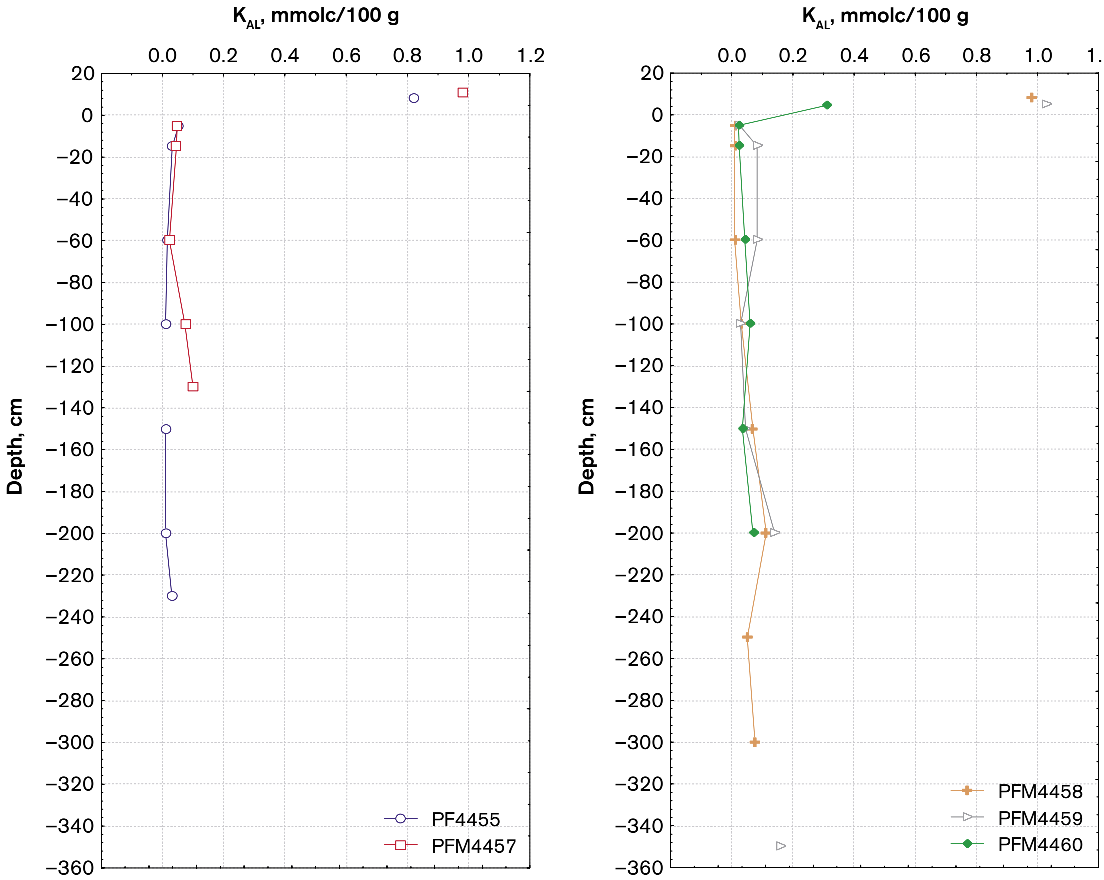

Figure 3-17. *Extractable potassium (K_{AL}) content stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).*

Potassium was also extracted with a stronger agent (HCl) indicating potential plant available K. These values were obviously higher and another stratification could be observed (Figure 3-18). Profile contents differed considerably with relatively low contents in the O-horizon (1.0–1.5 $mmol_c$/100 g) but mostly even lower values in the very top mineral soil (0.7–1.1 $mmol_c$/100 g). In the mineral horizon just below the top layer comparably high contents occurred (1.6–2 $mmol_c$/100 g). Deeper in the profile large variations were observed with both low and higher values and a range between c 1 $mmol_c$/100 g and 2.4 $mmol_c$/100 g (Figure 3-18 and Appendix IV). The very highest value coincided with the high deep soil values for Ca and Mg in profile PFM004460.

3.10.5 Extractable phosphorus

Phosphorus being a very important plant nutrient besides nitrogen could be strongly bound to mineral soils, especially Ca-rich soils such as the ones in the Forsmark area. Easily accessible P, reflecting mainly organically bound P, could be determined in AL-extracts and concentrations in the organic soil horizon were 2–10 mg/100 g. Stronger bound but potentially available P were determined in HCl extraction and these values were considerably higher, i.e. 29–35 mg/100 g. Compared to ordinary Swedish forest soils with values in the organic layer at 5–15 mg P_{AL}/100 g and 30–60 mg P_{HCl}/100 g, the trench values were somewhat low. In the mineral soil values of P_{AL} were in the range 1–2 mg/100 g and of P_{HCl} in the range 30–40 mg/100 g but with slightly lower values in the very top mineral soil layers being below 1 mg/100 g and 10 mg/100 g for P_{AL} and P_{HCl}, respectively (Figure 3-19). Comparable values in forest soils could be 4–5 mgP_{AL}/100 g and 50–100 mgP_{HCl}/100 g implying also rather low concentrations in these layers.

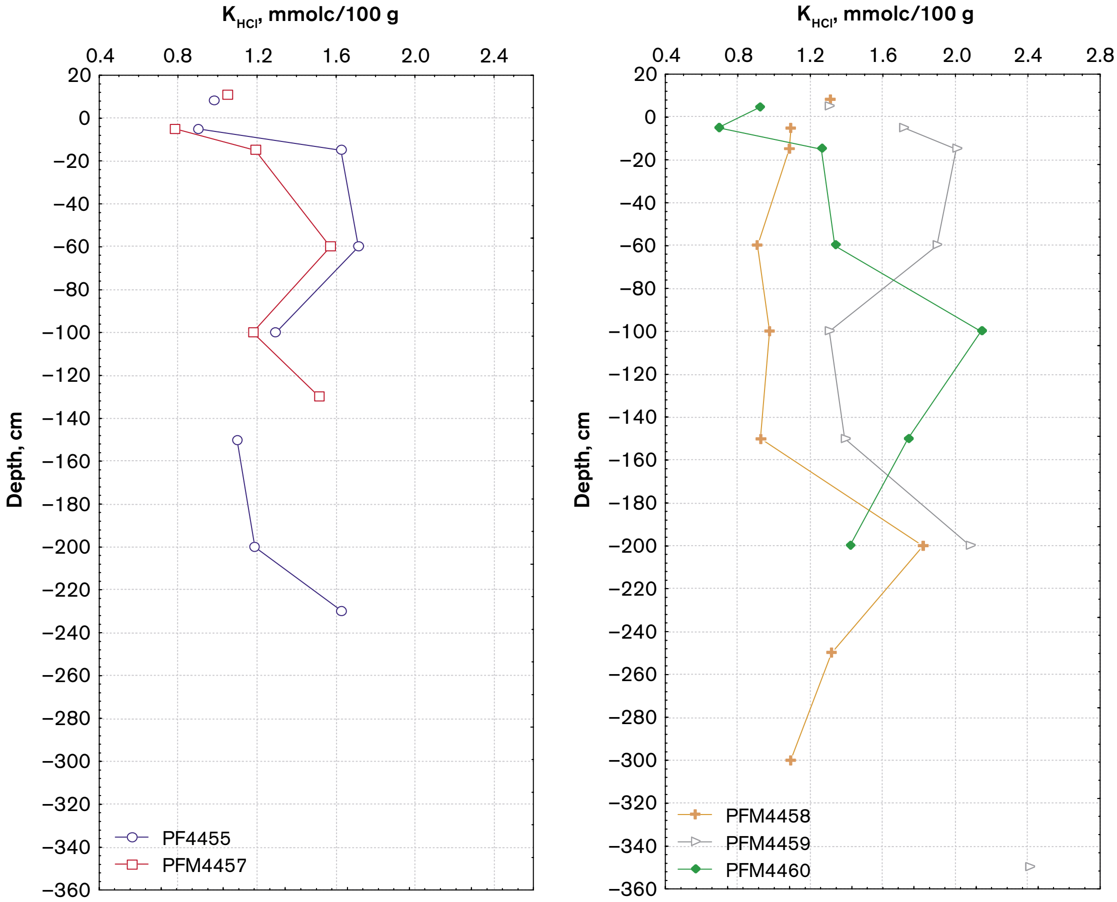

Figure 3-18. Extractable potassium (K_{HCl}) content stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).

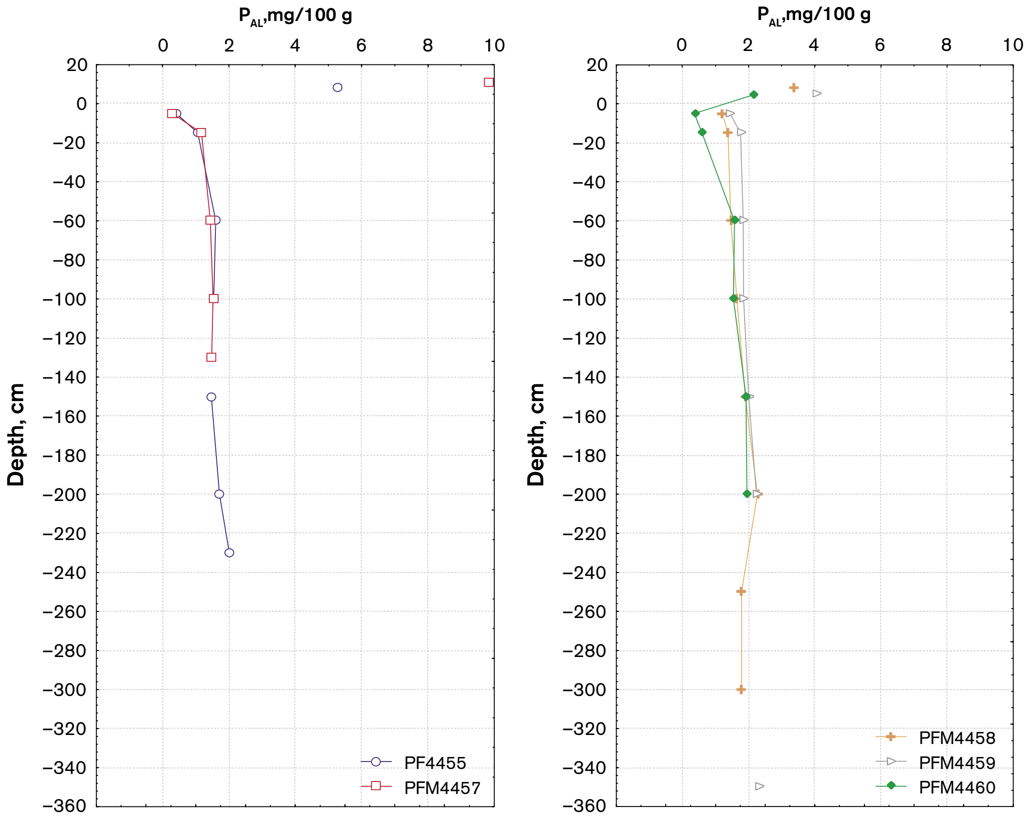

***Figure 3-19.** Extractable phosphorus (P_{AL}) content stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).*

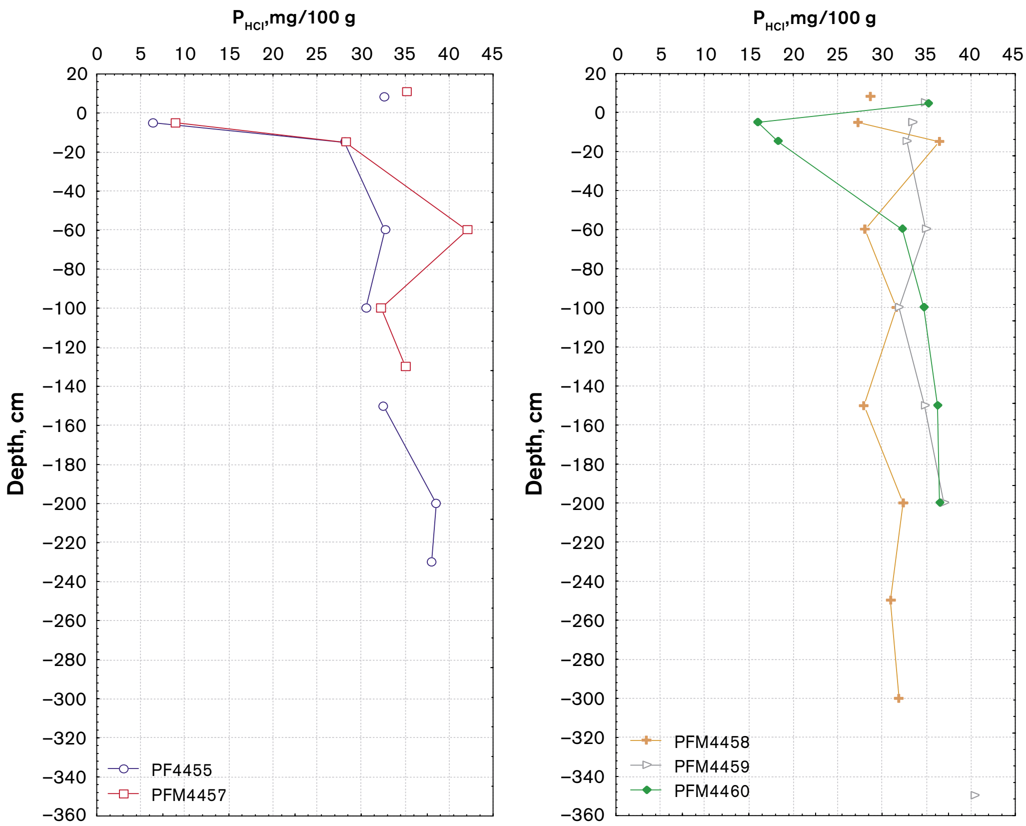

***Figure 3-20.** Extractable phosphorus (P_{HCl}) content stratification versus soil depth in the trench profiles at the Forsmark area 2004, (no line means incomplete profile data).*

4 Summary

Ecosystem investigations are made by the Swedish Nuclear Fuel and Waste Management Company (SKB) to find out properties and processes relevant for transport of elements from the bedrock to ground surface systems. This includes intensive investigations of the biosphere, hydrosphere, regolith and bedrock. In connection with special bedrock investigations, two large trenches were cleared from the regolith soil deposits. This furnished suitable conditions for spatial soil studies and deep profile determinations. Properties of the regolith are of significance to clarify prerequisites for element flow conditions in the interface between bedrock and the ground surface systems. Special investigations in two trenches were therefore made in autumn 2004.

The present study in the large trenches included investigations of ground vegetation, surface organic layer and stoniness conditions over the trenches. Further studies involved rooting depth, soil profile development, soil physical conditions as well as chemical properties including pH, C, N, base cations and phosphorus. Five profiles were investigated in the two trenches but determinations of variables varied between the profiles.

The two large trenches investigated, number 3, 51 m long, and number 4, 72 m long, were located rather closely to each other with elongated directions nearly perpendicular to each other, i.e. with an angel of c 120 degrees. The average distance was c 75 m. Despite this, the two trenches furnished rather different conditions with number 3 being moist to fresh-moist and trench 4 on fresh soils. The depth differed also being larger in trench 3 compared to number 4, where bedrock almost reached the ground surface at a few spots.

The soil profile type was mainly Regosol together, with in trench 3, 13% Podzol. In trench 4 Regosol made up 82% but also Podzol 7%, Leptosol 8% and Histosol 3% occurred. Rooting depth in trench 4 reached at the most 57 cm depth.

Soil physical conditions at the trench sites coincided fairly well with properties found in natural till soils above the highest coastline. Such conditions have also been found in not wave washed tills below the highest coastline. A considerable stone and boulder content together with high bulk densities provided low porosities, especially in the deeper soil layers. Water retentions were high with small amounts of free water. Only in the top soil layers higher porosities existed. Hydraulic conductivity demonstrated the common pattern with relatively high conductivities in the top soil layers but very low in deep soil layers.

$CaCO_3$ content influenced the chemical conditions almost through the entire profiles. This provided high pH values, often exceeding 6. Only in the top soil of two profiles and in the humus layer low values were found. These conditions were also reflected in the calcium content in the soil. Magnesium and potassium showed ordinary or partly low contents as compared to Swedish forest soil conditions. The carbon and nitrogen values were similar to the soil site inventory of the Forsmark area and agreed reasonably well with other part of Sweden.

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Appendix Ia

Site characteristics and vegetation in trench 3 (AFM001243) section 1 0–10 m from SSE

Trench	Section	Soil depth	Soil wetness	Ground-layer vegetation type	Ground-layer vegetation missing, %	Bottom layer species	Field layer type	Field layer species	Tree-bush species
3	0–10	Deep	Fresh-Moist	Mesic mosses	<5	*Dicranum scoprium (sD),* *Hylocomium splendens (D)* *Mnium spp.(P)* *Pleurozium Schreberi (D)* *Rhytidiadelphus triquetrus (sD)*	Low herbs with shrubs/ lingonberry	*Calamagrostis canescens* *Carex nigra* *Convallaria majalis* *Deschampsia caespitosa* *Deschampsia flexuosa* *Galium boreale* *Geum rivale (LH)* *Hepatica nobilis (LH)* *Luzula pilosa* *Lycopodium annotinum* *Lysimachia vulgaris* *Maianthemum bifolium (LHs)* *Oxalis acetosella (LH)* *Phalaris arundinacea* *Platanthera spp* *Potentilla anserina* *Potentilla erecta* *Pyrola rotundifolia* *Rubus idaeus* *Rubus saxatilis (LHs)* *Solidago spp.* *Tussilago Farfara* *Vaccinium myrtillus* *Vaccinium vitis-idaea*	*Alnus glutinosa* *Berberis vulgaris* *Betula alba* *Corylus Avellana* *Faxinus excelsior* *Juniperus communis* *Lonicera xylosteum* *Picea Abies* *Pinus silvestris* *Rosa spp.* *Salix spp.* *Sorbus aucuparia* *Viburnum opulus*

Appendix Ib

Site characteristics and vegetation in trench 3 (AFM001243) section 2 10–20 m from SSE

Trench	Section	Soil depth	Soil wetness	Ground-layer vegetation type	Ground-layer vegetation missing,%	Bottom layer species	Field layer type	Field layer species	Tree-bush species
3	10–20	Deep	Fresh-Moist	Mesic mosses	30	*Dicranum scoprium (P)* *Hylocomium splendens (D)* *Pleurozium Schreberi (D)* *Pleurozium Schreberi (P)* *Rhytidiadelphus triquetrus (sD)*	Tall herbs without shrubs	*Aquilegia vulgaris* *Calamagrostis canescens* *Carex nigra* *Carex panacea* *Cirsium oleraceum (TH)* *Comarum palustre* *Deschampsia caespitosa* *Deschampsia flexuosa* *Drypteris carthusiana* *Filipendula ulmaria (TH)* *Galeopsis tetrahit+G.bifida* *Galium boreale* *Geum rivale* *Juncus articulatus* *Luzula pilosa* *Lycopus europaeus* *Lysimachia vulgaris* *Oxalis acetosella* *Peucedanum palustre* *Phalaris arundinacea* *Potentilla anserine* *Potentilla erecta* *Ranunculus Flammula* *Rubus saxatilis* *Stellaria palustris* *Tussilago Farfara* *Vaccinium myrtillus* *Viola palustris*	*Alnus glutinosa* *Betula alba* *Faxinus excelsior* *Juniperus communis* *Picea Abies* *Pinus silvestris* *Rhamnus frangula* *Rosa spp.* *Sorbus aucuparia*

Appendix Ic

Site characteristics and vegetation in trench 3 (AFM001243) section 3 20–30 m from SSE

Trench	Section	Soil depth	Soil wetness	Ground-layer vegetation type	Ground-layer vegetation missing,%	Bottom layer species	Field layer type	Field layer species	Tree-bush species
3	20–30	Deep	Fresh-Moist	Mesic mosses	<5	*Cladiona spp. (P)* *Climacium dendroides (P)* *Dicranum scoprium (sD)* *Hylocomium splendens (D)* *Pleurozium Schreberi (D)* *Rhytidiadelphus triquetrus*	Low herbs without shrubs	*Calamagrostis arundinacea* *Calamagrostis canescens* *Carex nigra* *Carex panacea* *Cirsium oleraceum* *Comarum palustre* *Convallaria majalis* *Dactylis glomerata* *Deschampsia caespitosa* *Deschampsia flexuosa* *Epilobium angustifolium* *Equisetum palustre* *Filipendula ulmaria* *Fragaria vesca (LHs)* *Geum rivale (LH)* *Hepatica nobilis (LH)* *Hieracium silvaticum* *Luzula pilosa* *Maianthemum bifolium (LHs)* *Melica nutans* *Mentha spp.* *Oxalis acetosella (LH)* *Peucedanum palustre* *Phragmites australis* *Potentilla erecta* *Ramischia secunda* *Rubus idaeus* *Rubus saxatilis (LHs)* *Scirpus silvaticus* *Solidago spp.* *Taraxacum vulgare* *Trientalis eurpaea* *Tussilago Farfara* *Vaccinium myrtillus* *Viola palustris*	*Alnus glutinosa* *Berberis vulgaris* *Betula alba* *Faxinus excelsior* *Lonicera xylosteum* *Picea Abies* *Pinus silvestris* *Rosa spp.* *Salix spp.* *Sorbus aucuparia*

Appendix Id

Site characteristics and vegetation in trench 3 (AFM001243) section 4 30–40 m from SSE

Trench	Section	Soil depth	Soil wetness	Ground-layer vegetation		Bottom layer species	Field layer type	Field layer species	Tree-bush species
				type	missing,%				
3	30–40	Deep	Fresh	Mesic mosses	<5	*Cladonia spp.(exept Cladina spp.) (P)* *Dicranum scoprium (sD)* *Hylocomium splendens (D)* *Pleurozium Schreberi (D)* *Rhytidiadelphus triquetrus (sD)* *Sphagnum spp. (P)*	Low herbs without shrubs	*Agrostis tenuis* *Calamagrostis canescens* *Carex nigra* *Carex panacea* *Cirsium oleraceum* *Convallaria majalis* *Deschampsia caespitosa* *Deschampsia flexuosa* *Drypteris carthusiana* *Equisetum arvense* *Eupatorium cannabinum* *Filipendula ulmaria* *Fragaria vesca (LHs)* *Galium boreale* *Geum rivale (LH)* *Gymnocarpium dryopteris (LH)* *Hepatica nobilis (LH)* *Hieracium silvaticum* *Luzula pilosa* *Lycopodium annotinum* *Maianthemum bifolium (LHs)* *Melica nutans* *Phragmites australis* *Polygonatum odoratum* *Potentilla erecta* *Rubus saxatilis (LHs)* *Solidago spp.* *Taraxacum vulgare* *Trientalis eurpaea* *Trifolium pretense* *Tussilago Farfara* *Vaccinium myrtillus* *Vaccinium vitis-idaea* *Viola Riviniana (LHs)*	*Berberis vulgaris* *Betula alba* *Corylus Avellana* *Faxinus excelsior* *Juniperus communis* *Picea Abies* *Pinus silvestris* *Ribes alpinum* *Rosa spp.* *Sorbus aucuparia* *Viburnum opulus*

Appendix Ie

Site characteristics and vegetation in trench 3 (AFM001243) section 5 40–50 m from SSE

Trench	Section	Soil depth	Soil wetness	Ground-layer vegetation type	Ground-layer vegetation missing,%	Bottom layer species	Field layer type	Field layer species	Tree-bush species
3	40–50	Deep	Fresh	Mesic mosses	<5	*Cladiona spp. (P)* *Hylocomium splendens (D)* *Pleurozium Schreberi (D)* *Rhytidiadelphus triquetrus (sD)* *Sphagnum spp. (P))*	Tall herbs without shrubs	*Briza media* *Calamagrostis canescens* *Carex panacea* *Cirsium oleraceum (TH)* *Convallaria majalis* *Deschampsia flexuosa* *Drypteris carthusiana* *Equisetum arvense* *Filipendula ulmaria (TH)* *Fragaria vesca* *Galium boreale* *Geum rivale* *Gymnocarpium dryopteris* *Hepatica nobilis* *Hieracium silvaticum* *Luzula pilosa* *Lycopodium annotinum* *Maianthemum bifolium* *Melica nutans* *Myosotis palustris* *Paris quadrifolia (TH)* *Phragmites australis* *Plantago lanceolata* *Potentilla erecta* *Ramischia secunda* *Rubus saxatilis* *Solidago spp.* *Tussilago Farfara* *Vaccinium myrtillus* *Vaccinium vitis-idaea* *Viola Riviniana*	*Berberis vulgaris* *Betula alba* *Faxinus excelsior* *Juniperus communis* *Picea Abies* *Pinus silvestris* *Ribes alpinum* *Salix spp.* *Sorbus aucuparia* *Viburnum opulus*

Appendix IIa

Water retention, porosity and density in profile PFM004455

Site, level, cm	Volume, vol %		Water retention, % suction, cm					Water content, %	Density g/cm³	Dry bulk density g/cm³
	material	pore	0	10	50	100	500			
PFM004455										
10–15 cm A	58.4	41.6	33.3	27.2	8.9	6.6	5.6	4.5	2.6	1.5
10–15 cm B	65.9	34.1	24.8	20.7	5.6	4.1	3.5	2.8	2.6	1.7
Average	62.1	37.9	29.0	24.0	7.2	5.4	4.5	3.6	2.6	1.6
20–25 cm A	58.7	41.3	40.0	33.9	21.7	17.2	10.8	9.1	2.7	1.6
20–25 cm B	57.2	42.8	39.7	27.5	17.9	14.2	9.8	7.4	2.7	1.5
Average	58.0	42.0	39.9	30.7	19.8	15.7	10.3	8.3	2.7	1.6
50–55 cm A	69.7	30.3	28.5	24.2	19.8	15.5	10.0	7.6	2.7	1.9
50–55 cm B	68.4	31.6	25.0	17.7	15.9	13.7	9.7	7.1	2.7	1.8
Average	69.0	31.0	26.7	20.9	17.8	14.6	9.9	7.4	2.7	1.9
80–85 cm A	75.4	24.6	22.9	19.0	17.1	14.5	10.7	10.2	2.7	2.0
80–85 cm B	75.9	24.1	23.8	19.3	17.5	15.2	10.9	10.6	2.7	2.0
Average	75.7	24.3	23.3	19.2	17.3	14.9	10.8	10.4	2.7	2.0
120–125 cm A	71.8	28.2	23.8	18.0	16.5	14.5	10.4	11.5	2.7	1.9
120–125 cm B	73.9	26.1	21.8	18.0	16.8	13.9	10.2	11.8	2.7	2.0
Average	72.9	27.1	22.8	18.0	16.7	14.2	10.3	11.7	2.7	2.0
170–175 cm A	67.7	32.3	25.9	21.2	19.2	15.7	8.3	15.3	2.7	1.8
170–175 cm B	72.6	27.4	25.5	22.3	21.2	18.0	9.8	18.8	2.7	2.0
Average	70.2	29.8	25.7	21.8	20.2	16.8	9.0	17.1	2.7	1.9
250–255 cm A	82.4	17.6	18.8	15.4	15.1	14.4	13.4	14.3	2.7	2.2
250–255 cm B	71.6	28.4	26.0	18.1	16.8	15.7	14.4	14.6	2.7	1.9
Average	77.0	23.0	22.4	16.8	15.9	15.1	13.9	14.4	2.7	2.1

Appendix IIb

Water retention, porosity and density in profile PFM004458

Site, level, cm	Volume, vol %		Water retention, %					Water content, %	Density g/cm³	Dry bulk density g/cm³
	material	pore	suction, cm							
			0	10	50	100	500			
PFM004458										
5–10 cm A	72.9	27.1	26.6	24.4	19.3	15.8	9.5	16.7	2.7	1.9
5–10 cm B	75.1	24.9	26.3	23.3	17.8	14.5	8.9	14.6	2.7	2.0
Average	74.0	26.0	26.5	23.8	18.6	15.1	9.2	15.7	2.7	2.0
20–25 cm A	74.0	26.0	26.3	21.9	17.5	14.1	8.0	14.2	2.7	2.0
20–25 cm B	71.4	28.6	24.8	20.4	15.6	12.3	7.3	12.5	2.7	1.9
Average	72.7	27.3	25.6	21.1	16.6	13.2	7.6	13.4	2.7	1.9
50–55 cm A	75.4	24.6	24.1	20.1	17.0	13.8	7.4	15.0	2.7	2.0
50–55 cm B	79.3	20.7	23.7	20.1	17.6	14.8	8.7	16.1	2.7	2.1
Average	77.4	22.6	23.9	20.1	17.3	14.3	8.0	15.6	2.7	2.1
80–85 cm A	79.6	20.4	20.9	18.7	14.9	12.8	7.6	16.0	2.7	2.1
80–85 cm B	76.0	24.0	24.0	19.9	15.0	12.3	6.7	14.6	2.7	2.0
Average	77.8	22.2	22.5	19.3	14.9	12.6	7.1	15.3	2.7	2.1
120–125 cm A	80.8	19.2	19.5	17.5	15.5	12.9	6.7	16.0	2.7	2.1
120–125 cm B	82.7	17.3	18.8	15.7	14.5	12.9	6.5	13.8	2.7	2.2
Average	81.7	18.3	19.1	16.6	15.0	12.9	6.6	14.9	2.7	2.2
170–175 cm A	83.1	16.9	18.2	15.9	15.0	14.3	9.2	14.0	2.7	2.2
170–175 cm B	84.3	15.7	19.1	16.8	16.0	15.6	12.9	16.2	2.7	2.3
Average	83.7	16.3	18.7	16.3	15.5	14.9	11.0	15.1	2.7	2.2
250–255 cm A	84.2	15.8	20.0	16.7	15.8	15.2	9.3	14.4	2.7	2.3
250–255 cm B	81.8	18.2	18.8	15.6	14.6	13.8	10.8	12.1	2.7	2.2
Average	83.0	17.0	19.4	16.2	15.2	14.5	10.0	13.3	2.7	2.2

Appendix IIc

Water retention, porosity and density in profile PFM004459 and PFM004460

Site, level, cm	Volume, vol %		Water retention, %					Water content, %	Density, g/cm³	Dry bulk density g/cm³
	Material	pore	suction, cm							
			0	10	50	100	500			
PFM004459										
c 350 cm A	81.2	18.8	24.6	19.4	17.0	16.9	15.7	16.3	2.71	2.2
c 350 cm B	79.1	20.9	26.4	21.8	21.7	21.2	19.8	21.6	2.71	2.1
c 350 cm C	81.2	18.8	24.6	19.4	17.0	16.9	15.7	16.3	2.71	2.2
c 350 cm D	79.1	20.9	26.4	21.8	21.7	21.2	19.8	21.6	2.71	2.1
Average	80.2	19.8	25.5	20.6	19.3	19.1	17.8	18.9	2.7	2.2
PFM004460										
5–10 cm A	81.4	18.6	23.8	20.5	20.1	20.1	18.0	19.5	2.66	2.2
5–10 cm B	65.8	34.2	33.7	27.4	7.0	6.0	4.0	7.2	2.66	1.8
Average	73.6	26.4	28.7	23.9	13.5	13.0	11.0	13.4	2.7	2.0
20–25 cm A	56.9	43.1	49.4	45.7	43.2	42.9	38.5	42.2	2.7	1.5
20–25 cm B	62.7	37.3	42.8	37.3	32.7	32.2	28.8	32.0	2.7	1.7
Average	59.8	40.2	46.1	41.5	38.0	37.6	33.6	37.1	2.7	1.6
50–55 cm A	74.8	25.2	25.2	19.7	17.6	16.5	12.4	14.7	2.7	2.0
50–55 cm B	81.5	18.5	21.4	18.6	16.9	16.2	12.8	15.1	2.7	2.2
Average	78.1	21.9	23.3	19.1	17.2	16.3	12.6	14.9	2.7	2.1
80–85 cm A	79.0	21.0	22.1	16.8	15.9	15.4	12.6	15.2	2.7	2.1
80–85 cm B	79.5	20.5	22.1	17.3	16.4	16.1	13.6	16.7	2.7	2.1
Average	79.3	20.7	22.1	17.0	16.2	15.7	13.1	16.0	2.7	2.1
120–125 cm A	83.9	16.1	19.9	16.4	16.2	15.7	14.7	17.0	2.7	2.3
120–125 cm B	83.0	17.0	19.9	16.5	16.3	15.6	14.2	16.6	2.7	2.2
Average	83.4	16.6	19.9	16.5	16.3	15.7	14.5	16.8	2.7	2.2
170–175 cm A	86.3	13.7	17.6	16.1	15.3	14.6	13.9	15.8	2.7	2.3
170–175 cm B	85.7	14.3	18.4	15.5	15.0	14.5	13.6	16.1	2.7	2.3
Average	86.0	14.0	18.0	15.8	15.2	14.6	13.7	15.9	2.7	2.3

Appendix III

Hydraulic conductivity

Level, cm	Conductivity, k×10^{-7}, m/s					
	PFM004460		PFM004455		PFM004458	
	After 1 hour	After 24 hours	After 1 hour	After 24 hours	After 1 hour	After 24 hours
5–10 cm A	451	266			10.4	8.10
5–10 cm B	150	104			13.9	8.10
Average	301	185			12.7	8.10
10–15 cm A			660	532		
10–15 cm B			509	475		
Average			584	503		
20–25 cm A	5.79	5.79	301	255	4.63	2.31
20–25 cm B	4.63	4.63	440	174	5.79	3.47
Average	4.63	4.63	370	208	4.63	3.47
50–55 cm A	0.463	0.463	3.47	3.47	8.10	5.79
50–55 cm B	0.116	0.231	0.347	0.000	5.79	3.47
Average	0.347	0.347	1.91	2.31	6.94	4.63
80–85 cm A	0.000	0.116	0.694	0.000	5.79	4.63
80–85 cm B	0.347	0.069	2.31	0.000	12.7	6.94
Average	0.231	0.093	1.16	0.000	9.26	5.79
120–125 cm A	0.231	0.000	0.000	0.000	4.63	2.31
120–125 cm B	0.035	0.000	0.463	0.035	1.16	1.04
Average	0.116	0.000	0.231	0.012	2.31	2.31
170–175 cm A	0.104	0.000	2.31	1.16	0.069	0.231
170–175 cm B	0.069	0.347	0.463	0.694	0.463	0.000
Average	0.081	0.116	1.16	1.16	0.231	0.093
250–255 cm A			0.926	1.04	0.116	0.579
250–255 cm B					2.31	0.035
Average					1.04	0.347

Appendix IVa

Soil chemistry in profiles PFM004455, PFM004457 and PFM004458

Ca, Mg and K extracted in 1 M NH4Ac, at pH 7

Trench ID	Horizon ID	Depth, cm	Chemical element									
			pH_{H_2O}	C_{tot}, %	N_{tot}, %	Mg, mmolc/100 g	Ca, mmolc/100 g	K, mmolc/100 g	K_{AL}, mmolc/100 g	K_{HCl}, mmolc/100 g	P_{AL}, mg/100 g	P_{HCl}, mg/100 g
PFM004455	H30	8	3.58	55.6	1.93	2.95	21.4	1.00	0.82	0.98	5.27	32.7
	M010	–5	5.07	0.838	0.059	0.22	2.0	0.04	0.05	0.90	0.40	6.4
	M020	–15	6.31	1.32	0.060	0.20	12.3	0.04	0.03	1.63	1.06	28.1
	M065	–60	7.13	1.85	0.017	0.15	11.1	0.04	0.02	1.71	1.60	32.7
	M100	–100	7.73	1.67	0.012	0.12	10.4	0.03	<0.01	1.30	1.54	30.5
	M150	–150	7.87	1.51	0.022	0.11	10.4	0.03	<0.01	1.10	1.47	32.5
	M200	–200	8.08	1.98	0.023	0.11	10.6	0.04	<0.01	1.19	1.71	38.5
	M230	–230	7.98	2.06	0.016	0.12	10.7	0.05	0.03	1.63	2.02	38.0
PFM004457	H30	11	3.69	56.0	1.98	4.31	25.8	1.29	0.98	1.05	9.82	35.2
	M010	–5	5.06	0.359	0.035	0.14	0.9	0.02	0.05	0.78	0.29	9.0
	M020	–15	5.74	0.828	0.055	0.32	5.6	0.03	0.05	1.19	1.17	28.3
	M065	–60	6.76	1.89	0.017	0.13	10.7	0.04	0.02	1.57	1.44	42.0
	M100	–100	7.23	1.54	0.018	0.11	10.0	0.03	0.07	1.18	1.53	32.3
	M130	–130	7.30	1.91	0.018	0.11	10.6	0.04	0.10	1.52	1.49	35.1
PFM004458	H30	8.5	5.73	39.4	1.22	4.01	68.8	1.15	1.06	1.42	3.37	28.7
	M010	–5	6.10	1.25	0.023	0.16	10.4	0.03	<0.01	1.09	1.21	27.2
	M020	–15	6.68	1.54	0.015	0.14	10.3	0.03	<0.01	1.08	1.38	36.4
	M065	–60	6.33	1.54	0.013	0.14	10.4	0.04	<0.01	0.91	1.46	28.1
	M100	–100	6.54	1.71	0.013	0.14	10.5	0.04	0.03	0.98	1.65	31.6
	M150	–150	7.37	1.94	0.013	0.14	10.4	0.04	0.07	0.92	1.90	28.0
	M200	–200	8.01	2.05	0.015	0.17	10.9	0.08	0.11	1.82	2.27	32.4
	M250	–250	8.41	1.72	0.011	0.13	10.5	0.05	0.05	1.32	1.79	30.9
	M300	–300	8.19	1.54	0.014	0.14	10.4	0.05	0.08	1.09	1.79	31.9

Soil chemistry in profiles PFM004459 and PFM004460

Ca, Mg and K extracted in 1 M NH4Ac at pH 7

Trench ID	Horizon ID	Depth, cm	Chemical element									
			pH_{H_2O}	C_{tot}, %	N_{tot}, %	Mg, mmolc/100 g	Ca, mmolc/100 g	K, mmolc/100 g	K_{AL}, mmolc/100 g	K_{HCl}, mmolc/100 g	P_{AL}, mg/100 g	P_{HCl}, mg/100 g
PFM004459	H30	5	5.64	38.4	1.42	4.29	70.1	1.36	1.11	1.42	4.05	34.8
	M010	–5	6.35	1.90	0.037	0.23	12.0	0.05	0.03	1.72	1.44	33.5
	M020	–15	7.49	2.30	0.022	0.18	11.4	0.05	0.08	2.00	1.76	32.8
	M065	–60	8.15	2.44	0.013	0.20	11.5	0.06	0.08	1.90	1.84	34.9
	M100	–100	8.50	1.81	0.015	0.15	10.7	0.05	0.03	1.30	1.85	31.9
	M150	–150	6.96	2.01	0.013	0.16	10.9	0.08	0.05	1.39	2.00	34.8
	M200	–200	7.42	2.11	0.020	0.67	11.4	0.23	0.14	2.08	2.24	37.0
	M350	–350	8.14	2.35	0.016	0.75	11.6	0.26	0.16	2.41	2.30	40.4
PFM004460	H30	4.5	7.25	15.0	0.861	2.60	78.1	0.33	0.32	0.98	2.14	35.2
	M010	–5	7.29	0.304	0.034	0.08	2.8	0.02	0.02	0.69	0.37	16.0
	M020	–15	6.97	0.242	0.021	0.09	2.9	0.03	0.02	1.26	0.60	18.3
	M065	–60	7.19	2.20	0.012	0.20	11.0	0.04	0.04	1.33	1.58	32.3
	M100	–100	7.87	2.02	0.014	0.24	11.5	0.07	0.06	2.14	1.54	34.7
	M150	–150	8.20	2.22	0.012	0.15	10.9	0.06	0.03	1.74	1.92	36.2
	M200	–200	8.29	1.99	0.012	0.13	10.4	0.05	0.070	1.42	1.95	36.5