R-08-04

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Site descriptive modelling SDM-Site Forsmark

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Geological Survey of Sweden (SGU)

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Preface

The Swedish Nuclear Fuel and Waste Management Company (SKB) has undertaken site characterisation at two different locations, the Forsmark and Laxemar-Simpevarp areas, with the objective being to site a geological repository for spent nuclear fuel. The site investigations began in 2002 and were completed in 2007. The analysis and modelling of data from the site investigations provide a foundation for the development of an integrated, multidisciplinary Site Descriptive Model (SDM) for each of the two sites. A SDM constitutes a description of the site and its regional setting, covering the current state of the geosphere and the biosphere, as well as those natural processes that affect or have affected their long-term development. The site descriptions shall serve the needs of both Repository Engineering and Safety Assessment with respect to repository layout and construction, and its long-term performance. The descriptions shall also provide a basis for the Environmental Impact Assessment.

The surface system consists of a number of disciplines that have been organised and worked together within the project group SurfaceNet. The disciplines involved in the description are:

- hydrogeology, surface hydrology and oceanography,
- bedrock- and Quaternary geology and soil-science,
- hydrogeochemistry and surface water chemistry,
- system- and landscape ecology,
- nature- and human geography.

Besides serving as a general description of site conditions, focus has also been to support and answer a few overall questions, such as:

- What types of ecosystems are present and how do they function in terms of transport and accumulation of matter on a local and regional scale?
- How has the site developed over time?
- Can we find evidence for deep groundwater discharge, and describe the processes involved?

Previous versions of these site descriptions have been published for both Forsmark and Laxemar-Simpevarp. The latest version of the overall concluding site description, SDM-Site, is found in the SDM report (/SKB 2008/, TR-08-05). Further, more comprehensive overall surface system descriptions of Forsmark and Laxemar-Simpevarp are found in two surface system reports: (Lindborg T. (ed.) 2008a. Surface System Forsmark, Site Descriptive Modelling, SDM-Site Forsmark, R-08-11, Svensk Kärnbränslehantering AB; Lindborg T. (ed.) 2008b. Surface System Laxemar-Simpevarp, Site Descriptive Modelling, SDM-Site Laxemar-Simpevarp, R-09-01, Svensk Kärnbränslehantering AB.)

The report you are about to read comprises a final description of the regolith at the Forsmark site. The description includes the spatial distribution of the Quaternary Deposits (QD) and soil types, together with the physical and chemical properties of the deposits.

Tobias Lindborg

Project leader, SurfaceNet

Summary

This report contains a compilation of the available information regarding the regolith in the Forsmark regional model area. Regolith refers to the unconsolidated deposits overlying the bedrock. In the Forsmark area, the regolith was deposited during the Quaternary period and is often referred to as Quaternary deposits (QD). In the terrestrial areas, the upper part of the regolith that has been affected by climate and vegetation is referred to as the soil.

The Forsmark site is located in northern Uppland within the municipality of Östhammar, about 120 km north of Stockholm. The area is characterized by smallscale topographic variations and is almost entirely located at altitudes less than 25 metres above sea level. The Forsmark site has been completely below water for most of the Holocene and the first areas emerged from the Bothnian Sea as late as c.1000 BC. The flat topography of the land surface, together with a relatively fast land upheavel, has resulted in a rapid growth of the terrestrial areas and a very young terrestrial system.

There is no conclusive evidence of deposits older than the latest glaciation in the Forsmark area. The bedrock outcrops in the model area are characterised by glacial abrasion with a dominating ice movement from the north and sub-dominant (older) from the northwest. During excavations, the surficial bedrock has displayed horizontal to sub-horizontal fractures. Boulders and uplifted blocks of bedrock have been observed under covering layers of till in the western part of the investigated area. The uplifted blocks were partly underlaid by silty laminated sediments.

Till is the overall dominating QD that fills small-scale crevasses in the granite-dominated bedrock, leaving a flat upper surface. The oldest observed regolith is a lithological unit consisting of hard, clayey till that has been recorded under a younger till unit at several sites within the Forsmark regional model area. The exact age of this till unit is not known, but most probably it was deposited during a stage of the Weichselian glaciation, c 75,000–60,000 years ago.The till at Forsmark has been separated into three local domains, Till Area I, II and III. Till Area I, representing the major part of the terrestrial area, is dominated by sandy and silty till. Till Area II, located around Storskäret, is dominated by clayey till and boulder clay, whereas Till Area III consists of the area close to the Börstilåsen Esker with high concentrations of large boulders on the surface. Characteristic for almost all till material at Forsmark is the occurrence of calcium carbonate ($CaCO_3$) in the fine fraction. Furthermore, the high clay content in Till Area II has resulted in that the agriculture land at Forsmark is located almost entirely on till. It has been shown that the majority of the till material in the area has been deposited by ice moving from the north-west, although at some locations, the uppermost and youngest till unit have been deposited from the north.

Glaciofluvial sediments at Forsmark are concentrated to one small esker, the Börstilåsen Esker. The majority of the esker is found south of the regional model area. The part of the esker that passes through the south-eastern part of the model area is dominated by gravel that rests directly on the bedrock. The distribution of fine-grained, water-laid sediments mainly follows the large scale bedrock morphology. The greatest amount of clay is found in depressions in the marine area and under the present lakes. Glacial clay is the oldest fine-grained sediment, deposited in relatively deep water during the latest deglaciation, c 8800 BC. Postglacial gravel and sand frequently superimpose glacial clay, interpreted to represent mainly deposition after erosion and transport by currents at the sea floor. Typical for the Forsmark area is that postglacial sediments are generally thin and are mainly recorded in the deeper marine areas or sheltered shallow basins and lakes. Postglacial clay, including clay gyttja, is predominantly found in the deeper parts of the sea floor. The surface distribution of organic deposits in the terrestrial area has been divided into two general domains, one representing areas above 5 m altitude and one representing organic deposits located in areas below 5 m altitude. Actual peatlands are only found in areas with elevations higher than 5 m altitude where the basins have been above sea lavel long enough

for peat to form. Bogs do occur, but are few in number and are still young, while rich fens are the dominating type. Clay gyttja is common at the surface of the wetlands located at low altitudes, e.g. along the shores of Lake Fiskarfjärden and Lake Gällsboträsket. The vegetation in the wetlands is influenced by the high pH value in the surrounding QD and surface water. Gyttja is presently formed in lakes and consists mainly of remnants from algae that have grown in the lake. In areas with calcareous soils such as the Forsmark area, calcareous gyttja forms when calcium carbonate precipitates in the lake. The lakes are generally quite shallow with thin sedimentary layers and many of them will soon be filled-in with sediments and transformed into wetlands.

There are two areas with artificial filling material within the Forsmark regional model area. The largest one is the area around the Forsmark nuclear power plants where the filling material consists mainly of blasted rocks and QD excavated from the sea bottom. The second area of artificial filling material is located in the distal part of the regional model area at Johannisfors. This deposit consists of calcareous waste material from an old pulp mill.

The soil types in the Forsmark area are typically immature, poorly developed soils on till or sedimentary parent material, which are highly influenced by the calcareous material. The dominating soil types are Regosols, Gleysols and Histosols. Typical soils for Sweden are Podsols, but this soil type has not yet developed at Forsmark.

The distribution of QD at Forsmark is in accordance with the general distribution of QD in areas situated below the highest coastline in central Sweden. The knowledge of the distribution of the QD at the site is reflected in the construction of the conceptual model used for the geometrical regolith depth model. According to the distribution of the different QD in the Forsmark area, this depth model was divided into domains representing geological units with different properties. The present summary report presents physical and chemical properties for the different domains of the regolith depth model.

The most common QD types were analysed for calcium carbonate ($CaCO_3$) content. The minerogenic QD have been analysed with respect to grain size distribution, porosity and density. The water-laid sediments were characterised regarding water content, density, carbon (C), nitrogen (N), phosphorus (P) and sulphur (S). The total chemical composition of the different QD is presented. The contents of elements in the till from the Forsmark area are close to the Swedish averages with the major exception of calcium (Ca) and, to some extent strontium (Sr), which occurs in higher levels than average. The ash from peat samples at Forsmark showed higher contents of zinc (Zn) and lead (Pb) compared to Swedish averages. The petrographical and mineralogical composition of the till reflects that of the local bedrock, with the exception of a relatively high content of Palaeozoic limestones whereas Illite is the dominating clay mineral in both the fine fraction of the till and clay samples from Forsmark.

Sammanfattning

Denna rapport presenterar en sammanställning av information om regoliten i Frosmarks regionala modellområde. Med regolit menas de lösa avlagringar som överlagrar berggrunden. Regoliten i Forsmark har bildats under Kvartärtiden och kallas därför ofta kvartära avlagringar eller jordart. Närmast markytan har jordarternas egenskaper påverkats av bland annat klimat och vegetation. I landområdena kallas denna övre del av regoliten för jordmån.

Forsmark är beläget vid kusten i Östhammars kommun i Norduppland, ungefär 120 km norr om Stockholm. Området karaktäriseras av småskalig topografisk variation och är nästan uteslutande beläget lägre än 25 meter över havsytan. Det undersökta området har legat under Östersjöns yta under under huvuddelen av Holocen, de första öarna komm upp så sent som på 1 000-talet före kristus. Den platta markytan, i kombination med snabb landhöjning, har medfört att nya landytor snabbt växer till och att de terrestra ekosystemen är mycket unga.

Den senaste inlandsisen rörde sig från norr i slutskedet men en äldre isrörelseriktning från nordväst är också vanlig. Berggrunden visar tydliga spår av glacial slipning, huvudsakligen i form av isräfflor som har bildats från norr men också äldre räfflor från nord väst. När regoliten grävts bort har det ytliga berget även visat sig vara uppsprucket i stora block som delvis lyfts upp och underlagrats av laminerade sediment. Morän är den dominerande jordarten och den fyller ut småskaliga variationer i berggrunden och lämnar en platt markyta. De kvartära avlagringarna i Forsmarksområdet har troligen helt avsatts under eller efter den senaste nedisningen. Den äldsta jordarten som påträffats i Forsmark utgörs av en mycket hård, lerig morän som påträffats under yngre jordarter. Det är troligt att den hårda moränen avsatts under ett tidigare skede av den senaste nedisningen för ca 75 000–60 000 år sedan. Moränen har delats in i tre lokala domäner, moränområde I, II och III. Moränområde I representerar huvddelen av den terrestra delen av det regionala modellområdet och är dominerat av sandig och siltig morän. Moränområde II är området med lerig morän och moränlera runt Storskäret medans moränområde III utgörs av det stor- och rikblockiga området utmed Börstilåsen. Karaktäristiskt för nästan allt moränmaterial i Forsmark är att det innehåller kalciumkarbonat.

Isälvssedimenten i Forsmark utgörs av den nordligaste delen av en rullstensås, Börstilåsen. Den del av åsen som passerar modellområdet domineras av grus och sten som ligger direkt på berggrunden. Utbredningen av finkorniga, vattenavsatta sediment, följer huvudsakligen den storskaliga berggrundsmorfologin. Huvuddelen lera finns i djuphålor på havsbotten och i sjöarna. Glaciallera bildades i samband med deglaciationen, ca 8800 f kr och är den äldsta finkorniga jordarten. Postglacialt grus och sand ligger ofta direkt på glacialleran och representerar resterna efter erosion och transport på havsbotten. Utmärkande för de postglaciala sedimenten är att de generellt är tunna och att de framför allt återfinns i sjöar, skyddade vikar och i de djupare maria områdena. Fördelningen av organiska jordarter på land har delats in i två domäner beroende på om de är belägna högre eller lägre än 5 meter över havet. Torvmarker återfinns i områden högre än 5 meter över havet eftersom dessa varit över havsytan tillräckligt länge för torv att bildas. Enstaka mossar förekommer men torvmarkenrna domineras av näringsrika kärr. Våtmarker med lergyttja i ytan är vanliga i låglänta områden, till exempel utmed Fiskarfjärden och Gällsboträskets stränder. Vegetationen i våtmarkerna är rik och reflekterar det höga pH värdet i de underlagrande minerogena jordarterna och i det ytliga grundvattnet. Sjöarna i Forsmark är generellt grunda och har tunna sediment. Gyttja bildas av orgainskt material som sedimenterar till botten. Typiskt för Forsmarkssjöarna är att det kalkhaltiga grundvattnet ger upphov till att kalkgyttja bildas.

I Forsmarks regionala modellområde finns två ytor med fyllnadsmaterial. Den största ytan utgör området runt Forsmarks kärnkraftverk, där sprängsten och jordarter som grävts bort från havsbotten har använts som utfyllnad. Det andra området ligger vid Johannisfors i utkanten av det regionala modellområdet och utgörs av kalkhaltigt avfall från ett sedan länge nedlagt pappersmassabruk.

Jordmånerna i Forsmark karaktäriseras av att de är mycket unga och med svag jordmånsutveckling, på morän eller vattenavsatta sediment. Jordmånerna är till mycket stor del påverkade av den höga kalkhalten. De dominerande jordmånerna är regosol, glaycsol och histosol. Den för Sverige vanliga jormånen podsol har ännu inte hunnit utvecklas i Forsmarks unga jordar.

Utbredningen av jordarterna inom Forsmakrsområdet följer det normala mönstret för områden under högsta kustlinjen i syd-södra Sverige. Jordarternas fördelning har använts för att framställa en jorddjupsmodell över hela modellområdet. Med utgångspunkt från jordarternas utbredning har jorddjupsmodellen delats in i domäner med jordarter som har olika egenskaper. I denna rapport presenteras fysikaliska och kemiska egenskaper för de olika domänerna i jorddjupsmodellen.

De vanligaste jordarterna har analyserat med avseende på kornstorleksfördeling och kalkhalt. Morän har även karaktäriserats med avseende på porositet, densitet och hydraulisk konduktivitet. Vattenavsatta sediment har analyserats med avseende på vattenhalt, densitet, kol, kväve, fosfor och svavel. Den totala kemiska sammansättningen på de vanligaste jordarterna har analyserats. Moränen Forsmark har en kemisk sammansättning som liknar riksgenomsnittet, med undantag av förhöjda halter av kalcium och strontium medan aska från torvmarker visade förhöjda halter av zink och bly. Bergartsinnehållet i morän återspeglar den lokala berggrunden, med undantag för förekomster av paleosoisk kalksten som härrör från Gävlebukten. Lermineralanalyser visade att illit är det vanligaste lermineralet i både morän och glaciallera.

Contents

1 Introduction

1.1 Background

Radioactive waste from nuclear power plants is managed by the Swedish Nuclear Fuel and Waste Management Co., SKB. The Swedish program for geological disposal of spent nuclear fuel is approaching major milestones in the form of permit applications for an encapsulation plant and a deep geologic repository. For siting of the geological repository, SKB has undertaken site characterisation at two different locations, Forsmark and Laxemar-Simpevarp (Figure 1-1). The site investigations have been conducted in campaigns, punctuated by data freezes. After each data freeze, the site data have been analysed and modelling has been carried out with the overall purpose being to develop a Site Descriptive Model (SDM). SDM is an integrated model of geology, rock mechanics, thermal properties, hydrogeology, hydrogeochemistry and bedrock transport properties, as well as a description of the surface system.

The surface system section of the site descriptive model includes hydrology, Quaternary deposits (QD), chemistry, vegetation, animals, human population and land use, and is compiled in an integrated report /Lindborg (ed.) 2008a/. The geological and evolutionary development of the Forsmark and Laxemar-Simpevarp areas are presented in a Level II report /Söderbäck (ed.) 2008/. The present report is one of the background reports at Level III in the overall Site Description (Figure 1-2).

The main background references for this report are the following: Mapping of unconsolidated Quaternary deposits 2002-2003, map description /Sohlenius et al. 2004/, Shore displacement in Uppland during the last 6,500 calender years /Hedenström and Risberg 2003/, Soils and site types in the Forsmark area /Lundin et al. 2004/, Searching for evidence of late- and postglacial faulting in the Forsmark region /Lagerbäck et al 2005/, Element composition of a deep sediment core from Lake Stocksjön in the Forsmark area /Strömgren and Brunberg 2006/, Chemical characteristics of surface systems in the Forsmark area /Tröjbom and Söderbäck 2006/ and Depth and stratigraphy of regolith at Forsmark /Hedenström et al. 2008/.

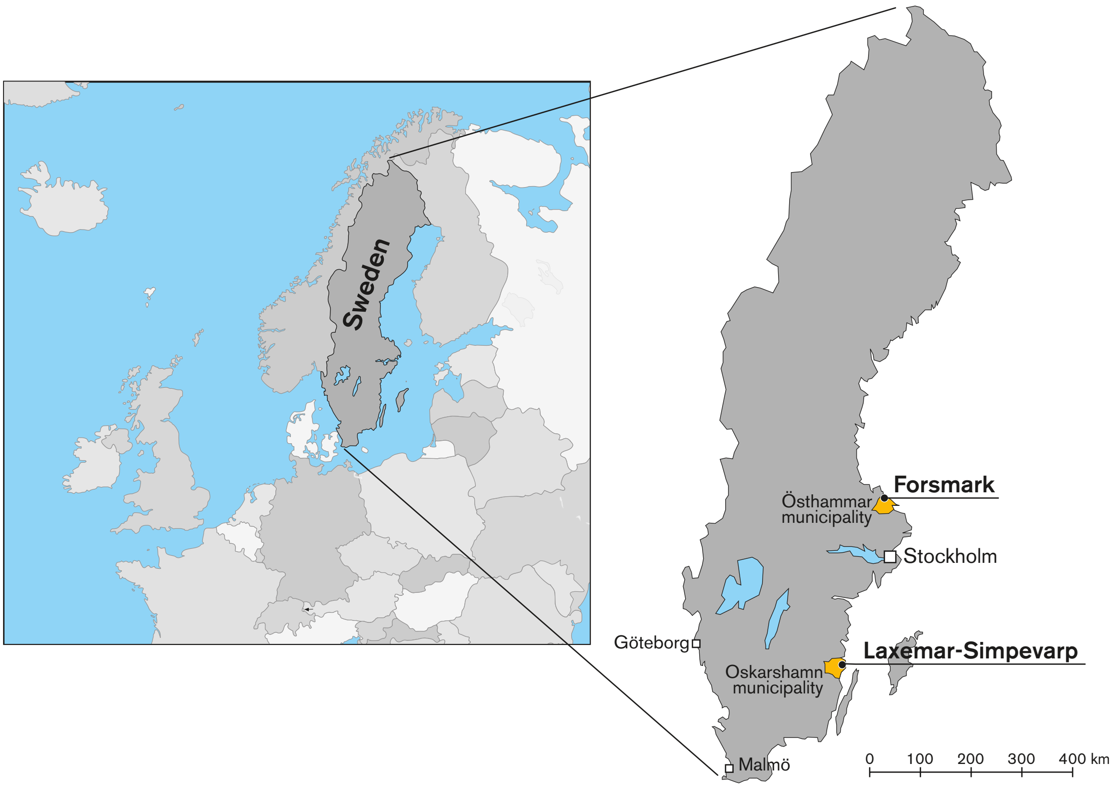


***Figure 1-1.** Map showing the location of the two sites Forsmark and Laxemar-Simpevarp.*

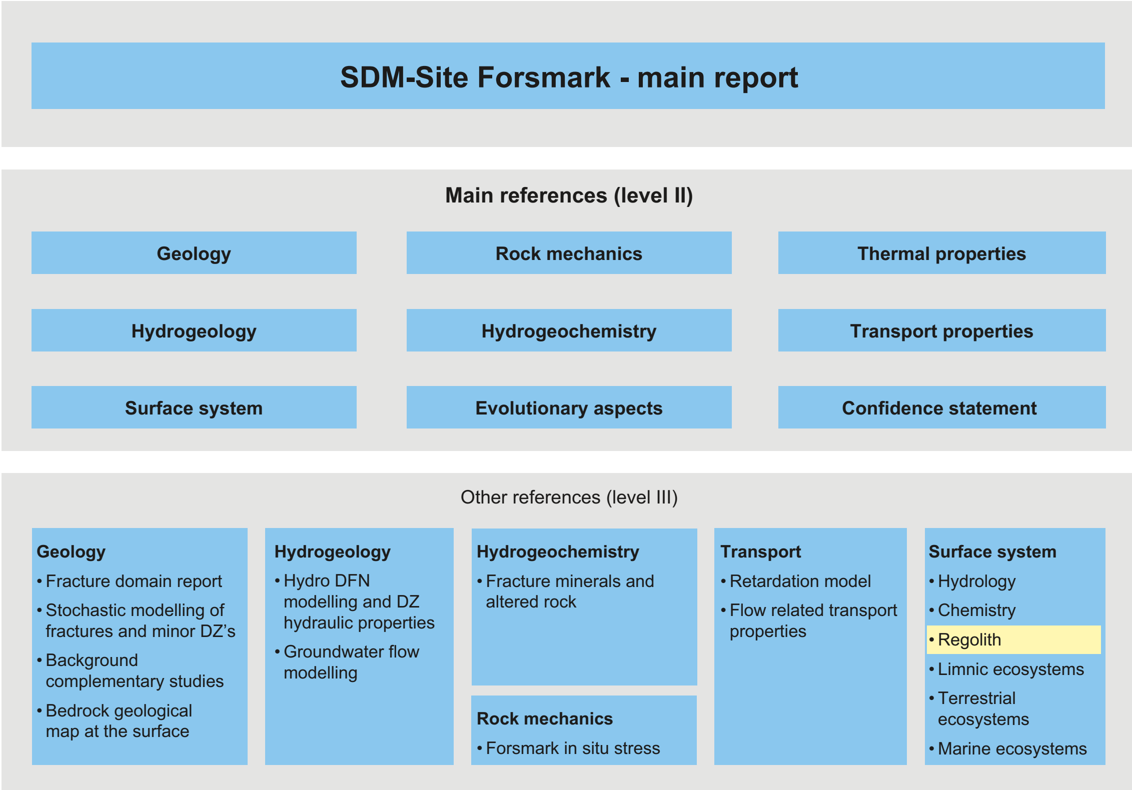


Figure 1-2. *SDM-Site main report and background reports on different levels produced during modelling stages 2.2 and 2.3. The present report is a background report on level III, highlighted in the lower right hand corner.*

1.2 This report

This summary report contains information on the regolith in the Forsmark area. Chapter 2 presents the available data and evaluates the quality of the different data sets, while Chapter 3 contains an overview of the late Quaternary history of the Forsmark area. Chapter 4 presents the conceptual models used for the descriptive and geometrical modelling and the results are then presented in Chapter 5. The main part of the report is the description of the spatial distribution of the deposits containing both surface- and stratigraphical distribution. The properties of the most common QD found in the Forsmark area have been quantified. Additionally, the model area has been separated into sub-domains which are described with respect to the spatial distribution of the deposits and their properties. Chapter 6 contains a discussion of the uncertainties identified in the data sets and models and Chapter 7 presents the resulting description of the distribution and properties of the regolith at the Forsmark site.

In this report, the term Quaternary deposit (QD) is often used since all known regolith in the Forsmark area was formed during the Quaternary period (the last 2.6 million years). The regolith includes all types of unconsolidated QD, both glacial deposits such as till, glaciofluvial sediment and clay, and postglacial deposits such as marine and lacustrine sediment and peat. Regolith also includes other unconsolidated deposits such as artificial filling and physically weathered bedrock. The upper part of the regolith is referred to as soil. Soils are formed as a result of the interactions among the soil-forming factors, i.e. geology, topography, climate, biota and time. Different types of soils are characterised by diagnostic horizons with different chemical and physical properties.

The information of the distribution and composition of QD in the Forsmark regional model area comprises primary data compiled in connection with the Östhammar feasibility study /Bergman et al. 1996/, together with the results from the site investigations at Forsmark. The data density is highest in the central part of the regional model area, where a detailed map of QD has been produced and a majority of the stratigraphical investigations has been undertaken.

The models of the regolith are both descriptive/conceptual and quantitative. The 3-dimensional distribution of regolith is used as a geometrical input for modelling of near-surface hydrogeology /Johansson (ed.) 2008/. The 2-dimensional distributions of QD and soil types are used in quantitative modelling of e.g. carbon (C) budget for the Forsmark regional model area. The descriptive models are essential for the understanding of the Late Quaternary history of the Forsmark site.

A previous version of this report was critically reviewed by Rune Johansson (SGU), Per Arne Melkerud (SLU), Björn Söderbäck (SKB) and Sten Berglund (SKB). Björn Bergman (SGU) was consulted regarding the section on geophysical investigations. They have all contributed comments that improved the manuscript.

Figure 1-3. *Map showing the areas described in this report: the regional model area, the Forsmark candidate area and the central part of the Forsmark candidate area. The hatched area is the model area for the Regolith Depth Model.*

2 Input data

The scope of the present description of the regolith in the Forsmark area is to include all information obtained during the site investigations, as well as to include the foregoing knowledge from the area. This summary is based on the data available at the Forsmark Data-Freeze 2.3, March 2007. Table 2-1 summarises the maps (2D models), stratigraphical information and analytical data included.

The following data were added to the previously existing data set (Data Freeze 1.2) and are valid as new input for this version of the site description:

- Quaternary geological map for the shallow areas along the coastline.
- Interpreted map of Quaternary deposits (QD) below the lakes and in very shallow areas off shore.
- Updated soil type map.
- Additional stratigraphical and analytical data from auger drillings, corings and excavations.
- Chemical analyses and radiometric datings of sediments and peat.
- Stratigraphical investigation of a marine sediment core.
- Petrographical analyses of boulders and gravel in till.
- Additional estimations of bedrock topography and regolith thickness along refraction seismic profiles.

Table 2-1. Available data from the regolith and their handling in the Forsmark Model Version 2.3.

Available site data Data specification	Ref. SKB report series	Usage in 2.3 Analysis/Modelling	Comments
Geometrical and topographical data			
Geometry, topography, bathymetry, Digital Elevation Model (DEM).	P-04-25 P-04-125 R-04-70 R-08-62	Basic input to flow and transport models, 20-m DEM used as input to Regolith Depth Model (RDM).	
Geological data			
Surface data			
Geological maps, QD, descriptions.	SGU Ae 73 SGU Ae 86 P-03-11 R-04-39 P-03-101 P-06-88 R-08-04 SKB GIS	Conceptual model, distribution of QD, 2D model and input to 3D RDM.	
Petrographical analysis of gravels and boulders.	P-06-87	Glacial history, petrographical composition of regolith.	
Soil type map.	R-04-08, updated 2006, SKB GIS	Conceptual and quantitative model, input to historical/evolutionary model.	No reference is available to an updated soil type map, which is only available in SKB GIS.
Stratigraphical and analytical data			
Stratigraphical and analytical data from boreholes (HFM, SFM, PFM).	P-03-14 P-03-64 P-04-111 P-04-138 P-04-139 P-04-140 P-04-148 P-06-89 P-06-92 P-07-01	Stratigraphical distribution and characterisation of QD. Depth to bedrock. Input to 3D RDM.	

Available site data Data specification	Ref. SKB report series	Usage in 2.3 Analysis/Modelling	Comments
Stratigraphy and spatial distribution of marine and lacustrine sediments and peat.	R-01-12 P-03-24 R-03-26 TR-03-17 P-04-86 P-04-127 P-05-139 P-06-88 P-06-89 P-06-92 P-06-220 P-06-301 P-07-196	Conceptual model. Description of stratigraphical distribution and properties of sediment in lakes and mires. Chemical properties and distribution of organic deposits in mires. Input to 3D RDM.	
Stratigraphical data from machine-cut trenches.	P-04-34 P-04-111 P-05-138 P-05-166 P-05-269 P-06-136 P-06-199 P-06-45	Depth and stratigraphical distribution of QD. Conceptual model, input to 3D regolith-depth model. Physical properties of QD.	
Investigation of evidence of neotectonic movements.	P-03-76 P-04-123 R-05-51 P-05-199	Conceptual understanding. Depth and stratigraphy of QD.	
Physical properties of sediment and peat, textural composition.	P-03-14 P-04-34 P-04-86 P-04-111 P-04-148 R-04-08 P-05-138 P-05-139 P-05-166 P-06-88 P-06-92 P-07-196	Conceptual model, input to quantitative modelling of hydraulic properties. Dominated by textural composition, but also water content for determination of the accumulation rate of sediments and peat.	
Chemical analyses and radiometric datings of glacial and post-glacial sediments.	P-03-14 TR-03-17 P-03-118 P-04-34 P-04-86 P-04-111 P-04-148 R-04-08 P-05-139 R-06-96 P-06-220 P-06-301 P-07-40	Conceptual model, input to quantitative model of chemical properties.	
Chemical analyses of peat.	P-04-127 P-06-301		
Microfossil composition in glacial sediments.	P-04-110 P-05-199	Conceptual understanding, dating of sediments, glacial/interglacial history.	
Geophysical data			
Ground penetrating radar.	P-04-78 P-04-156	Depth to bedrock. Conceptual model and 3D model of regolith depth.	
Refraction seismics.	P-04-81 P-05-12 P-06-138 P-06-45	Depth to bedrock. Conceptual model and 3D model of regolith depth.	
Reflection seismics.	P-04-99 P-04-158	Depth to bedrock. Conceptual model and 3D model of regolith depth.	
Helicopter-borne survey.	P-03-41 P-04-157 P-04-282	Depth of regolith.	Only used in (RDM) version 2.2.

The methods used to investigate the distribution, genesis and properties of the QD are summarised below, together with evaluation for each data set. The data has been grouped into two main groups: *Spatial distribution* (horizontal and vertical) and *Properties* (physical and chemical).

2.1 Surface distribution of Quaternary deposits and soils

2.1.1 Maps of Quaternary deposits

The QD map presented in the 2.3 model version covers the regional model area, i.e. terrestrial, limnic and marine areas. The resulting map is a compilation of six different data sources, initially produced with different methods and adjusted for presentation on different scales. A majority of the geological maps has been constructed using standard or modified standard methods from the Geological Survey of Sweden (SGU). Additionally, geological maps have been constructed for the remaining areas, i.e. under lakes and in the shallow marine area. Altogether, six sets of geological maps are presented and in this final description the maps are joined together into a continuous geological map covering the terrestrial, limnic and marine part of the model area. A short description of the data sets follows below.

The map generally shows the QD at a depth of 0.5 m below ground surface, as well as areas with bedrock exposures. Thin layers of e.g. sand or peat are also displayed on parts of the map, as well as the superficial boulder frequency of the till. Other information included in the terrestrial section of the map is the direction of glacial striae on the bedrock outcrops, which provides information on the direction of the ice movements during the latest ice age. The legend used for displaying the different QD is presented in Figure 2-2.

The distribution of unconsolidated QD in the Forsmark regional model area was initially mapped by the SGU /Persson 1985, 1986/. These maps give a good overview of the relative distribution of QD and bedrock outcrops in a 1:50000 scale (Area 2 in Figure 2-1). The geological maps present a generalised 2-dimensional model where geological objects > 50×50 m are presented. Compared with the most detailed map (Area 1), the generalisation for presentation at a scale of 1:50000 has resulted in generally larger areas with bare bedrock, represented by fewer outcrops. These maps and their descriptions were the main input used for prior knowledge of the Quaternary geology of the Forsmark region. From the central part of the regional model area, a detailed map that can be presented using a scale of 1:10000 was produced within the initial site investigations /Sohlenius et al. 2004/. The detailed map includes bedrock exposures and QD with an area larger than 10×10 m (Area 1 in Figure 2-1). The methods used for the geological inventory are similar in Areas 1 and 2 following standard SGU methodology.

The distribution of exposed bedrock was first interpreted from infrared aerial photos taken from a height of 2,300 m and later checked in the field /Stephens et al. 2003/. The field inventory took place during the summer months of 2002 and 2003 /Sohlenius et al. 2003, 2004/. The uppermost deposits were investigated using a spade and a hand-driven probe (Figure 2-3). Orientation and positioning were based on hand-held GPS and detailed aerial infrared photographs plotted at a scale of 1:5000. A mirror compass was used to measure the direction of the glacial striae. The occurrences of different QD were directly marked on the aerial photographs during the field mapping. All QD that could be separated from other deposits and had an area larger than 10×10 m were marked on the map as separate areas.

Samples were collected during the mapping process in order to characterise the different geological units and, in some cases, to enhance the geological classification.

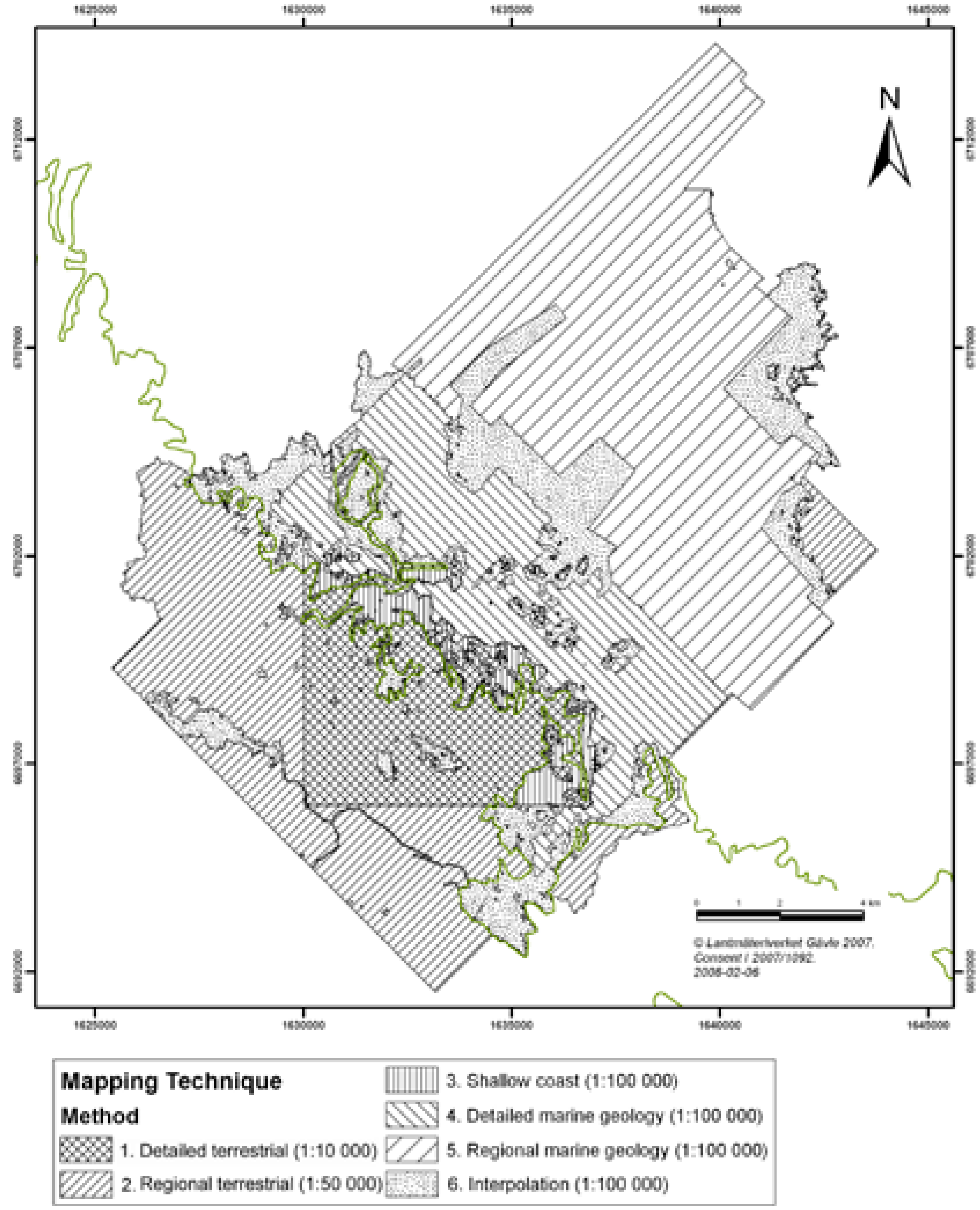


Figure 2-1. *The different sets of mapping methods used to compile the final map of QD. Area 1 represents the most detailed investigation /Sohlenius et al. 2004/. Area 2 is based on a geological map from SGU /Persson 1985, 1986/. Area 3 is based on interpretations of point observations in shallow coastal areas /Ising 2006/. Areas 4 and 5 are based on marine geological investigations using standard mapping techniques /Elhammer and Sandkvist 2005/. Area 6 is an interpretation based on the conceptual model of the area, together with information from the DEM /Strömgren and Brydsten 2008/ and extrapolation to the QD from the neighbouring areas.*

Figure 2-2. *The legend used for the map of QD in this report.*

Data from a marine geological survey gave information regarding the horizontal and vertical distribution of QD and bedrock outcrops on the sea bottoms located at water depths greater than 3 m /Elhammer and Sandkvist 2005/. This information was presented on a geological map of the sea floor (scale 1:100000). The data was collected by boat (the S/V Ocean Surveyor in the deeper area and a smaller boat in areas with water depths of 3–6 m). The mapping followed survey lines with a spacing of 100 m in the detailed area and a spacing of 1 km further out in Öregrundsgrepen. Some information gained during the marine geological survey contains details regarding bathymetry. This information is classified for military defence reasons by the Swedish Maritime Administration and cannot be presented in resolutions higher than 20×20 m pixels.

The geological mapping of the sea floor (Areas 4 and 5 in Figure 2-1) was performed by detailed hydro-acoustic mapping. The investigations comprised approximately 410 km survey lines. The survey includes echo-sounding, sediment echo-sounding, reflection seismics and side scan sonar. Forty-seven bottom inspections with video camera were conducted and, where possible, sediment sampling was done at these locations. The samples were taken with 1- and 6-m corers to verify the interpretation from the acoustic measurements. Soft bottoms (clay) were sampled with the corers and coarser deposits with a grab sampler. The results were used to produce a map showing the distribution of QD at a depth from approximately 0.5 m below the regolith-water interface (the same as on land). Thin surface layers of sand and gravel were also presented on the map.

Figure 2-3. A) *The equipment used during detailed mapping of QD in the terrestrial area (Area 1 and 2 in Figure 2-1). Localization was made using a hand-held GPS and high-resolution IR photos.* ***B)*** *The geological observations were made in spade-dug holes or, more frequently, using a hand-held probe.*

In the shallow bays along the coastline, where not even the small survey boat could enter, the distribution of QD was investigated through a large number of point observations (Area 3 in Figure 2-1). In February 2005, coring samples were taken from the ice in all areas where possible due to ice quality. The remaining areas were investigated in August 2005 using a probe from a small boat /Ising 2006/. The investigations were performed along profiles separated by approximately 200 m. The distance between the coring or probing points along these profiles varied between 100 m and 200 m (Figure 2-4). The point observations were analysed together with information on the bottom substrate taken from diving profiles and the bathymetry. This method adapts the precision of the map to a presentation scale of 1:50000 and no areas less than 50×50 m are displayed on the final map. The construction of the QD map in the coastal area was based mainly on the many point-observations of bottom substrate and stratigraphical information obtained from coring and probing. To extrapolate the information and extend the contour lines, additional information was gained from the mapping of benthic vegetation in shallow bays /Borgiel 2004/, where the bottom substrate was mapped along profiles. Additionally, the bathymetry from the Digital Elevation Model, DEM for the area /Brydsten and Strömgren 2004/ was consulted. Furthermore, the final map was matched to correspond to the map of QD in the terrestrial and marine areas /Sohlenius et al. 2004, Elhammer and Sandkvist 2005/.

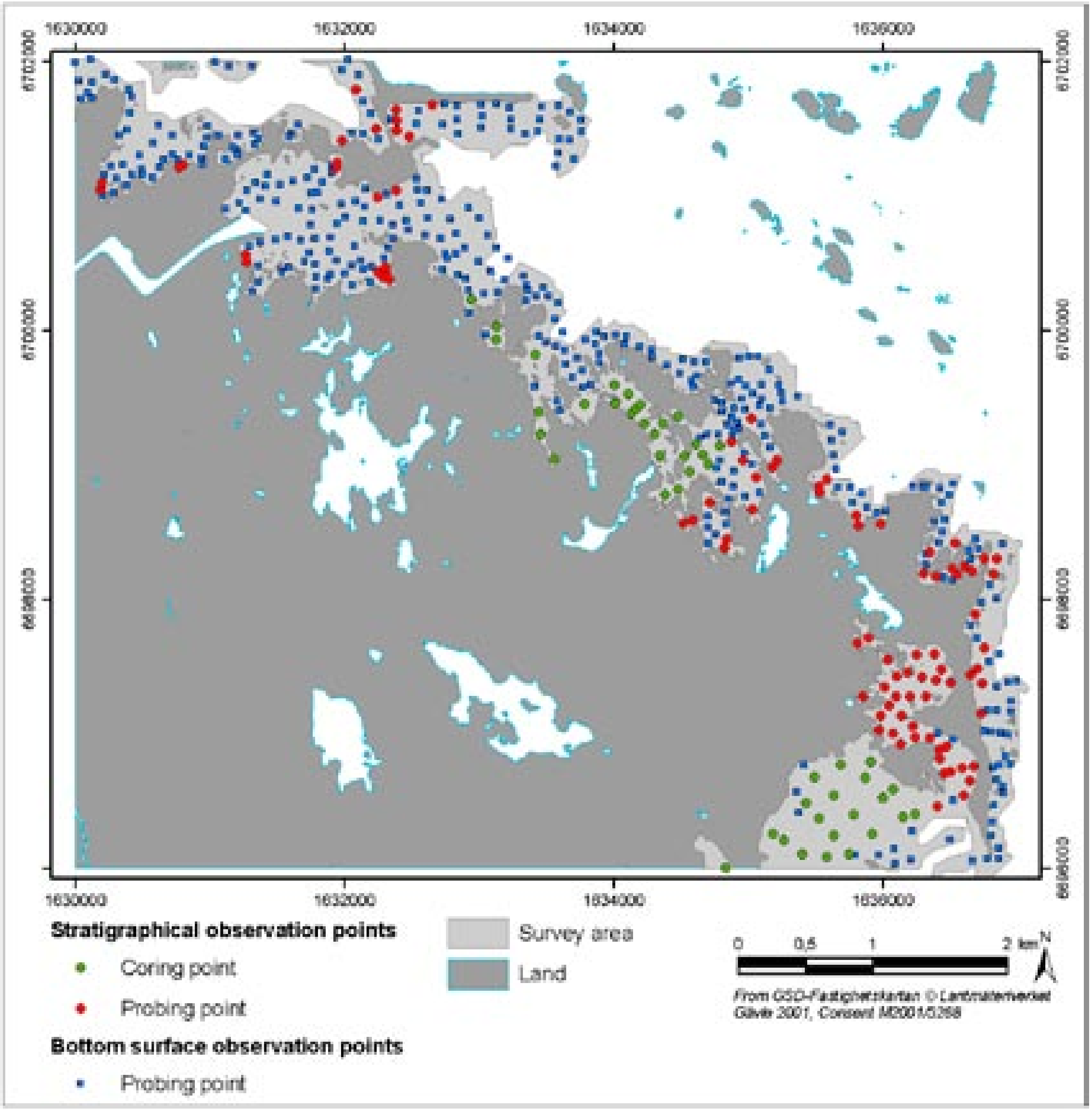


__Figure 2-4.__ The coring and probing points used as input to construct the QD geological map for the shallow coastal area /from Ising 2006/.

Finally, some areas under water in the terrestrial areas (under lakes and rivers) and in the very shallow coastal areas mainly close to the islands remained unclassified after the above-described geological mapping (Area 6 in Figure 2-1). This lack of information was a problem for the hydrogeological modelling in these areas. An interpretation and classification was therefore performed to produce a geological map for these areas. The resulting map is based on the DEM, surrounding QD and the conceptual geological knowledge of the area. Within the terrestrial part of the model area, the areas presently covered by water, i.e. lakes, ponds and the Forsmark River, have been classified in a similar manner. The stratigraphical investigation performed during the site investigations was used in conjunction with the DEM describing the bathymetry for the lakes. In areas without QD data, extrapolation and interpretation were based on the surrounding deposits. After this final interpretation and construction, the resulting model presents a QD map covering the entire model area. However, the differing quality of the data sets should be kept in mind by the user!

2.1.2 Soil type map

Soils in the present discussion refer to the upper part of the regolith that is affected by soil-forming processes, e.g. bioturbation, frost action and chemical weathering. Soils from eight different land types were studied within the Forsmark regional model area /Lundin et al. 2004/. The land types were defined based on vegetation, land use and wetness. Classifications of soil type and the parent material of QD were conducted in spade-dug profiles at two sites from each land type.

Soil studies of the land type “rock outcrops” refers to sites which have a thin cover of regolith and are situated close to rock exposures. Glacial till is the most common deposit at these sites. The soil type investigation did not have the same total spatial coverage as did the mapping of QD. Instead, the spatial distribution of the soil types in the area was determined from a secondary GIS-based inventory that included information on vegetation types, distribution of QD and a topography-based hydrological index. The properties of the QD have a large influence on the soil-forming processes. A first version of a soil map, delivered to SKB and published in /Lundin et al. 2004/ was based partly on the old map of QD (SGU series Ae, 1:50000). However, a new, more detailed map of QD has been published since that first version /Sohlenius et al. 2004/. In order to improve the soil type map and to make the maps in the SKB geographical database concurrent, the soil map was updated based on the new map of QD.

The aim of the soil classification is to define soils with special properties, which can then be compared with soils from other areas. The soils were classified according to /WRB 1998/. For chemical characterisation, samples were collected from the 2–3 uppermost soil horizons and analysed for pH values, calcium carbonate ($CaCO_3$), organic carbon (C) and nitrogen (N). The extrapolation of the chemical analyses into maps was conducted using the initial version of the soil type map /Lundin et al. 2004/.

2.2 Stratigraphical data

Stratigraphical data comprises information on the spatial distribution of the different layers of QD. The information was derived from the large number of drillings, machine-cut trenches, hand-driven corings in sediment and peat, and stratigraphical observations from the geological mapping (Table 2-1). Information on the depth to bedrock, but generally not on the individual layers, was obtained from different geophysical investigations. In the marine area, however, the geophysical investigations of QD have been interpreted with respect to the different sedimentary layers and used for stratigraphical information, as well as for the evaluation of total depth to the bedrock.

2.2.1 Drillings and excavations

Soil-rock drillings were conducted within the site investigations with a primary purpose to obtain information on the bedrock or to monitor hydrogeology. In a majority of the soil-rock drillings, a Quaternary geologist was present at the drill site to classify the QD directly in the field /e.g. Sohlenius and Rudmark 2003, Hedenström 2004b, Hedenström et al. 2004, Lokrantz and Hedenström 2006/. However, at certain sites, the samples collected were inspected later by a Quaternary geologist and classified into lithological units /Sohlenius and Rudmark 2003, Albrecht 2007/. The coring methods used were percussion corings or auger drillings. A majority of the drillings performed by percussion coring were HFM-sites, whereas auger drillings mainly constituted SFM-sites. Generally, the sediments retrieved from percussion coring acquired more damage compared to the samples obtained through auger drillings (Figure 2-5) since the samples derived from percussion bore holes are taken from the corer using a flushing method. These samples therefore can sometimes contain crushed fragments of bedrock or boulders. Furthermore, the fine fractions may be washed out from the samples, thus the stratigraphical descriptions from these sites may sometimes be of poor quality.

A large data set with information regarding the stratigraphy of the QD was obtained from the installation of groundwater monitoring wells (SFM-sites). A total number of 74 groundwater wells (SFM sites) have been installed in the regolith (69 monitoring wells and 5 pumping wells). Graphs showing the stratigraphical profiles based on geotechnical classifications and the location of samples collected are presented by /Johansson 2003, Werner et al. 2004, Werner and Lundholm 2004, Werner et al. 2006/. Stratigraphical descriptions based on field observations and grain size distribution are described by /Hedenström et al. 2004, Lokrantz and Hedenström 2006/.

***Figure 2-5.** **A)** A majority of the HFM-corings were performed using percussion coring. The samples retrieved were often crushed and included bedrock fragments. **B)** Corings were performed using an auger drill during installation of groundwater monitoring wells (SFM-sites). The corings resulted in higher quality samples than those from the percussion corer. The photo shows clayey till obtained from a 4-m depth at Storskäret. Note the detail in the bottom right-hand corner showing the sediment after the cleaning of the sample.*

Machine-cut trenches were dug at 22 sites within the Forsmark model area /Sundh et al. 2004/ (Figure 2-6) in order to investigate the physical properties of the till and, where possible, the stratigraphical relations between the different till beds. The trenches were dug down to the bedrock if possible or to a maximum depth of c 5 m (Figure 2-7). Clast fabric analyses were performed in the different till beds and glacial striae were measured at the bottom of the trenches so that information on ice flow direction at the different phases of the glaciation could be obtained /Sundh et al. 2004/. Additional stratigraphical investigations were made at open sections where trenches had been cut for purposes other than to primarily investigate till stratigraphy /Albrecht 2005, Leijon (ed.) 2005, Forssberg et al. 2007, Petersson et al. 2007/.

A regional investigation in the search for traces of postglacial faulting included excavations in connection to glaciofluvial deposits was made outside the regional model area in the north-eastern part of Uppland /Lagerbäck et al. 2005/. The information gained from these excavations on the distribution of Quaternary sediments has, however, been evaluated and included in the descriptive model and the conceptual understanding of the model area.

Stratigraphical investigations of sediment and peat in lakes, ponds, shallow coastal areas and mires were performed using a hand-driven Russian peat corer /Bergström 2001, Hedenström 2003, Bergkvist et al. 2003, Fredriksson 2004, Ising 2006, Lokrantz and Hedenström 2006,

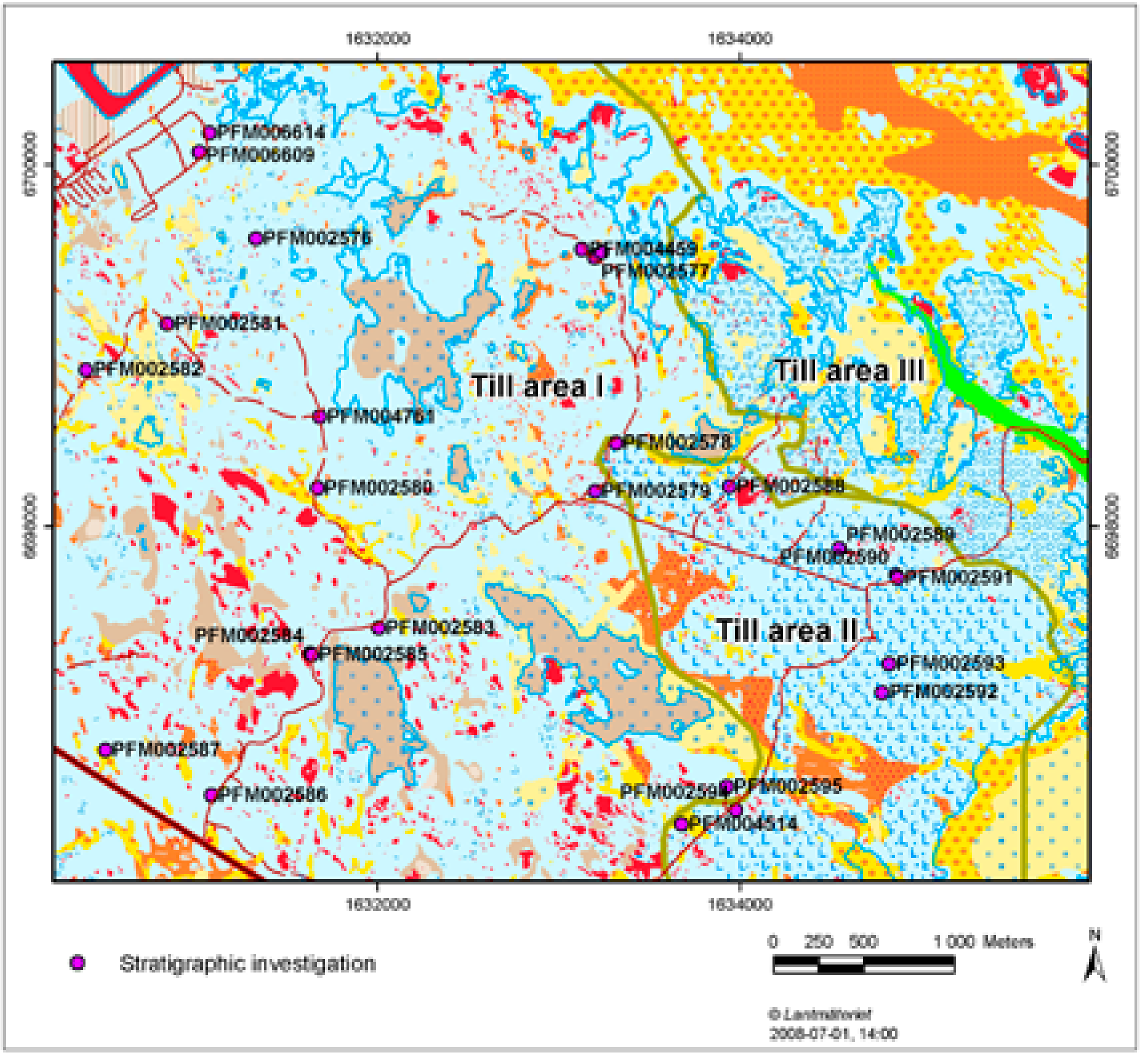


Figure 2-6. *The location of the sites where the stratigraphical relations of the till beds were studied in machine-cut trenches /Sundh et al. 2004, Albrecht 2005, Petersson et al. 2007, Forssberg et al. 2007/. Fabric analyses and direction of glacial striae were measured and used in the development of a glacio-geological model for the area.*

Sternbeck et al. 2006/. The corer derived almost undisturbed 1 or 0.5-m long samples /Jowsey 1966/ (Figure 2-8), which were classified and described directly in the field with respect to lithostratigrapy. Stratigraphical information from water-laid sediment and peat comprised lithological profiles, lithological descriptions and physical and chemical analyses /Hedenström 2003, 2004a, Fredriksson 2004, Lokrantz and Hedenström 2006/. At two sites (Tixelfjärden and Kallrigafjärden), the uppermost sediments were sampled using a modified Kajak corer /Sternbeck et al. 2006/. These samples were used for radiometric dating in order to estimate the accumulation rate in sub-recent time.

Figure 2-7. *Stratigraphical investigations of the till were performed in machine-cut trenches. The walls were classified into lithological units. Samples were collected for grain size analysis and till fabric analysis was performed.*

Besides lithological classification and stratigraphical description, samples were collected for analysis of e.g. grain size distribution and calcium carbonate ($CaCO_3$) content. Some samples were used for geochemical analysis /Sohlenius and Rudmark 2003, Nilsson 2003/, while others were subject to microfossil analysis under microscope /Robertsson 2004/.

2.2.2 Geophysical methods

The geophysical surveys include seismic, ground-penetrating radar and resistivity measurements. For the marine area, the results were used to interpret the stratigraphical distribution of the individual layers of QD. For the terrestrial areas, the geophysical measurements were used to estimate the total depth to bedrock and, in some cases, to also investigate the properties, e.g. fracture frequency, of the upper part of the bedrock.

Refraction seismics is generally the most affordable method for estimating regolith depth and determining the properties of the superficial bedrock, for example, detecting surface fractures. In the north-western part of the candidate area, refraction seismic investigations predominantly along profiles perpendicular to lineaments were included in the analysis of the depth to bedrock /Toresson 2005, 2006, Mören and Nyström 2006/. A large number of refraction seismic measurements were performed prior to the construction of the Forsmark power plants. The regolith depth from these measurements have been delivered to the SICADA database /Keisu and Isaksson 2004/. It should be noted that these measurements present the depth to bedrock before the excavation and construction of the power plants.

__Figure 2-8.__ The equipment used for the investigations of sediment and peat. The corer collects a 1-m long sequence that is inspected and described in the field. The colours of the sediments are classified according to Munsell soil colour charts (Munsell 1975). The corer is hand-driven and used in soft deposits such as gyttja, clay and peat, but cannot be used to sample coarse-grained deposits such as till.

The total thickness of the regolith in the terrestrial area was also estimated through first-arrival seismic tomography analysis of data from reflection seismic profiles /Bergman et al. 2004, Juhlin and Bergman 2004/. Approximately 16 km of high-resolution seismic data distributed along 5 profiles within the regional model area was analysed. First-arrival seismic tomography uses the travel times of only the first-arriving seismic waves from the sources that reach the receivers. These seismic waves travel at relatively shallow depths from the source to the receivers and are not reflected in the bedrock. The travel times depend on the distance between the source and the receiver, the seismic wave velocities in the bedrock and the thickness of regolith. A method was used in the study that separates the travel times the seismic waves spend in bedrock from the times spent in the regolith. For a detailed description of the methods used, see /Bergman 2005/.

A Ground Penetrating Radar (GPR) survey was conducted during the initial site investigations /Marek 2004a/. Data from a survey of 64 km was collected and interpreted in order to obtain the depth to bedrock /Marek 2004b/. The data from the GPR was compared with drillings and surface geology to produce QD-depth sections. The GPR method is an electro-magnetic method that is frequently used to detect subsurface objects and structures at depths of approximately 0–10 m. The depth penetration and resolution of the method depend on the frequency used, strength of the signal, and the dielectrical properties of the ground. A low frequency can “see” deeper than a higher frequency, whereas a high frequency gives a higher resolution. A dry and well-sorted material transmits the signal better than a water-saturated, fine-grained or poorly sorted material. For a detailed description of the methods used, see /Marek 2004ab/.

Electric soundings were performed to investigate the electric properties of the ground as a function of depth /Thunehed and Pitkänen 2003/. The data were then used to calibrate the results gained from inversion of helicopter-borne electromagnetic measurements in the Forsmark area /Thunehed 2005/. Comparisons between the depth to bedrock obtained from the helicopter-born measurements and data from e.g. trenching showed that this data set created great uncertainty, especially in the coastal areas (Appendix 2 in /Hedenström et al. 2008/). Therefore, the measurements taken from the helicopter were not used to estimate the regolith depth.

The depth to bedrock information obtained from the seismic and GPR surveys was used as input data for a model of the depth of the regolith /Hedenström et al. 2008/.

2.3 Analytical methods and sampling program

In order to characterise QD, samples were collected within the wide range of activities described above. The majority of the minerogenic samples analysed were glacial till. The standard analyses used to characterise the physical properties of the minerogenic deposits were grain size distribution and content of calcium carbonate ($CaCO_3$).

Additional analyses comprise geochemical analyses, such as elemental composition, isotopes and clay mineral analyses, as well as microfossil analyses of till and sediments. Porosity and density were measured on till samples from excavations. In the soil type inventory, texture, pH values, carbon (C) and nitrogen (N) at the different horizons in each soil class were analysed. Porosity and hydraulic conductivity were calculated from the grain size distribution curves on a large number of samples. A compilation of the analyses performed on unconsolidated deposits is presented in (Table 2-2).

Table 2-2. Analyses performed to characterise the physical and chemical properties of QD during the site investigations at Forsmark.

Parameter analysed	Number of samples or sites/ Description and geological assessment	References
Grain size distribution and calcium carbonate ($CaCO_3$) content	433 and 259 samples respectively /Minerogenic deposits mainly from the terrestrial part of the regional model area and sediments in lakes.	Sohlenius and Rudmark 2003, Lundin et al. 2004, Hedenström, 2004ab, Hedenström et al. 2004, Sundh et al. 2004, Albrecht 2005, Risberg 2005, Lundin et al. 2005, Ising 2006, Lokrantz and Hedenström 2006
Water retention, porosity and density* from minerogenic deposits in trenches.	26*+5 sites/Mostly till from different horizons in the upper 60 cm of the soil profile.	Lundin et al. 2004* Lundin et al. 2005
Theoretical hydraulic parameters	75 samples/Calculated from grain size distribution curves of minerogenic deposits	Albrecht 2005, Ising 2006, Lokrantz and Hedenström 2006
Field measured hydraulic parameters	Slugtests in soil monitoring wells at different levels including the upper bedrock	Johansson 2003, Werner et al. 2006
Chemical composition	45 sites/Geochemical analysis of till, sediment and peat	Sohlenius and Rudmark 2003, Nilsson 2003 Hannu and Karlsson 2006, Strömgren and Brunberg 2006 Baxter et al. 2007
Carbon (C), Nitrogen (N), Sulphur (S) and Phosphorous (P) analysis of sediments	8 sites/sediment sequences from Kallrigafjärden, Eckarfjärden, Fiskarfjärden, Puttan, Lake 5, Stocksjön Tixelfjärden, Rönningarna	Bergkvist et al. 2003, Hedenström and Risberg 2003, Hedenström, 2004a, Hannu and Karlsson 2006, Sternbeck et al. 2006
Age of sediment and peat	5 sites/carbon 14 (^{14}C) and lead 210 (^{210}Pb) datings of peat and sediments	Hedenström and Risberg 2003, Risberg 2005, Sternbeck et al. 2006
Clay mineralogy	12 samples/till and clay	Sohlenius and Rudmark 2003, Hedenström 2004a
Chemical analysis of peat and sediments in mires	3 sites/Organic carbon, ash content, and $CaCO_3$ elemental analysis	Fredriksson 2004, Lokrantz and Hedenström 2006, Hannu and Karlsson 2006, Sternbeck et al. 2006
Microfossil analysis of sediment	3 sites/Sediment sequences from Kallrigafjärden, Lake Eckarfjärden and off shore Forsmark	Bergkvist et al. 2003, Hedenström and Risberg 2003, Risberg 2005
Microfossil analysis of till	13 samples/Redeposited microfossils in minerogenic, glacial deposits	Robertsson 2004, Leijon (ed.) 2005
Soil profile chemistry (Organic carbon, Nitrogen, Base cations, Extractable phosphorus, pH values)	21 sites/different horizons of 8 soil-types	Lundin et al. 2004 Lundin et al. 2005

2.3.1 Physical properties

The grain size distribution of material (0.063–20 mm) was analysed using sieving and the finer fraction (< 0.063 mm) was analysed using sedimentation measurement using a hydrometer. The analytical methods used are national standard methods /Standardiseringskomissionen i Sverige 1992ab/. Altogether, 265 sieve analyses and 253 sedimentation analyses have been performed on samples from the Forsmark regional model area.

Water content of peat and sediments was analysed and is expressed as water loss after drying at 105°C as weight percentage of wet sample /Borgiel 2004, Hannu and Karlsson 2006, Sternbeck et al. 2006, Nordén 2007/. The water content was used to determine the porosity and bulk density of the deposits. For these calculations, the average mineral grain density of 2.65 g/cm^3 and a density for the organic matter of 1 g/cm^3 were used.

Wet bulk density and porosity for water-laid sediments were calculated from the contents of organic carbon and water. It was assumed that water and organic matter have a density of 1 g/cm^3 and that the mineral particles have a density of 2.65 g/cm^3 /Talme and Almén 1975/. The organic content was calculated as 1.7 times the carbon (C) content, based on the van Bemmelen factor /Jackson 1958/.

The frequency of stones in the upper 30 cm of the soil was determined along one traverse /Lundin et al. 2005/. A 10-mm steel rod was pushed into the soil until a boulder or stone was hit /Viro 1958/. This was done at 36 different points within a 30×30 m area. The thickness of the humus layer was also measured at these sites. The average penetration depth was used as a function to estimate the volumetric content of stones and boulders in the soil. The values were compared with observations of stones from the trench wall. Stoniness was also classified in a five-grade scale in the machine-cut trenches studied by /Sundh et al. 2004/.

Samples were collected in two machine-cut trenches for analysis of physical parameters such as dry bulk density, porosity, water retention and hydraulic conductivity /Lundin et al. 2005/. Analysis of retention was done using porous suction plates and analysis 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 1-hour flow and after 24-hours flow. Measurement time varied mainly between 1 and 60 minutes, but extended up to 14 hours for one sample.

In order to obtain a large data set with hydraulic properties for the different lithological units, grain size distribution curves were used to estimate the hydraulic conductivity using two different methods: the equations presented by Hazen and Gustafson /Andersson et al. 1984/, and the Fair-Hatch equation /Freeze and Cherry 1979/.

2.3.2 Chemical and mineralogical properties

The chemical and mineralogical analyses cover the most commonly-occurring QD and soils in the Forsmark area. Samples of QD have been collected within several investigations (Figure 2-9). Details on the sampling techniques, descriptions of local conditions and stratigraphy of the sampling sites are found in the reports cited in Table 2-2. At some sites, sub-samples of till were collected at different depths in the stratigraphical column and the chemical composition of these samples was analyzed /Sohlenius and Rudmark 2003/. These samples are either handled as separate observations or compiled as mean values in the following presentations.

Chemical characterisation was performed on representative samples in order to characterise the most commonly occurring QD (Chemistry 3 in Figure 2-9).

The regolith samples are represented by till, peat, gyttja and clay gyttja and clay. Elements, oxides, loss on ignition (LOI), dry substance (DS), ash content and macro elements were analysed for each QD type /see Hannu and Karlsson 2006/. The QD samples were freeze-dried and then leached with nitric acid (HNO_3) and a small amount of hydrofluoric acid (HF) in a closed Teflon vessel in a microwave oven (analytical package M7). The elements arsenic (As), cadmium (Cd), mercury (Hg), copper (Cu) and sulphur (S,) were leached with seven mol nitric acid (HNO_3) in a closed Teflon vessel in a microwave oven. Concentrations have been reported on a dry weight (105°C) basis. The samples for bromine (Br), chlorine (Cl) and iodine (I) were leached in highly purified water. The other elements were determined after fusion with lithium metaborate followed by dissolution in diluted HNO_3 (analytical package MG1). Analytical package MG3 was applied for organic sediments. The samples were dried at 50°C. The samples for the elements As, Cd, Hg, Cu and S, the samples were leached in HNO_3 and hydrogen peroxide

(H_2O_2) in a closed Teflon vessel in a microwave oven. Concentrations have been reported on a dry weight (105°C) basis. For Br, Cl and I, the samples were leached in highly purified water. The other elements were determined after ashing at 550°C, followed by fusion with lithium metaborate and dissolution in diluted HNO_3. The macro elements were analysed according to standard methods. Analysis of total carbon (C) and total organic carbon (TOC), were conducted according to standard method DIN ISO 10694, Soil Quality – Determination of Organic and Total Carbon after Dry Combustion (elementary analysis). Analysis of total nitrogen (N) and organic nitrogen were conducted according to standard method DIN ISO 11261, Soil Quality – Determination of Total Nitrogen – Modified Kjeldahl Method. Phosphate (PO_4) was determined with standard method DIN EN ISO 15681-2, Water Quality – Determination of Orthophosphate and Total Phosphorus Contents by Flow Analysis (FIA and CFA) – Part 2: Method by Continuous Flow Analysis (CFA). This method was used after the sample had been extracted in calcium-lactate.

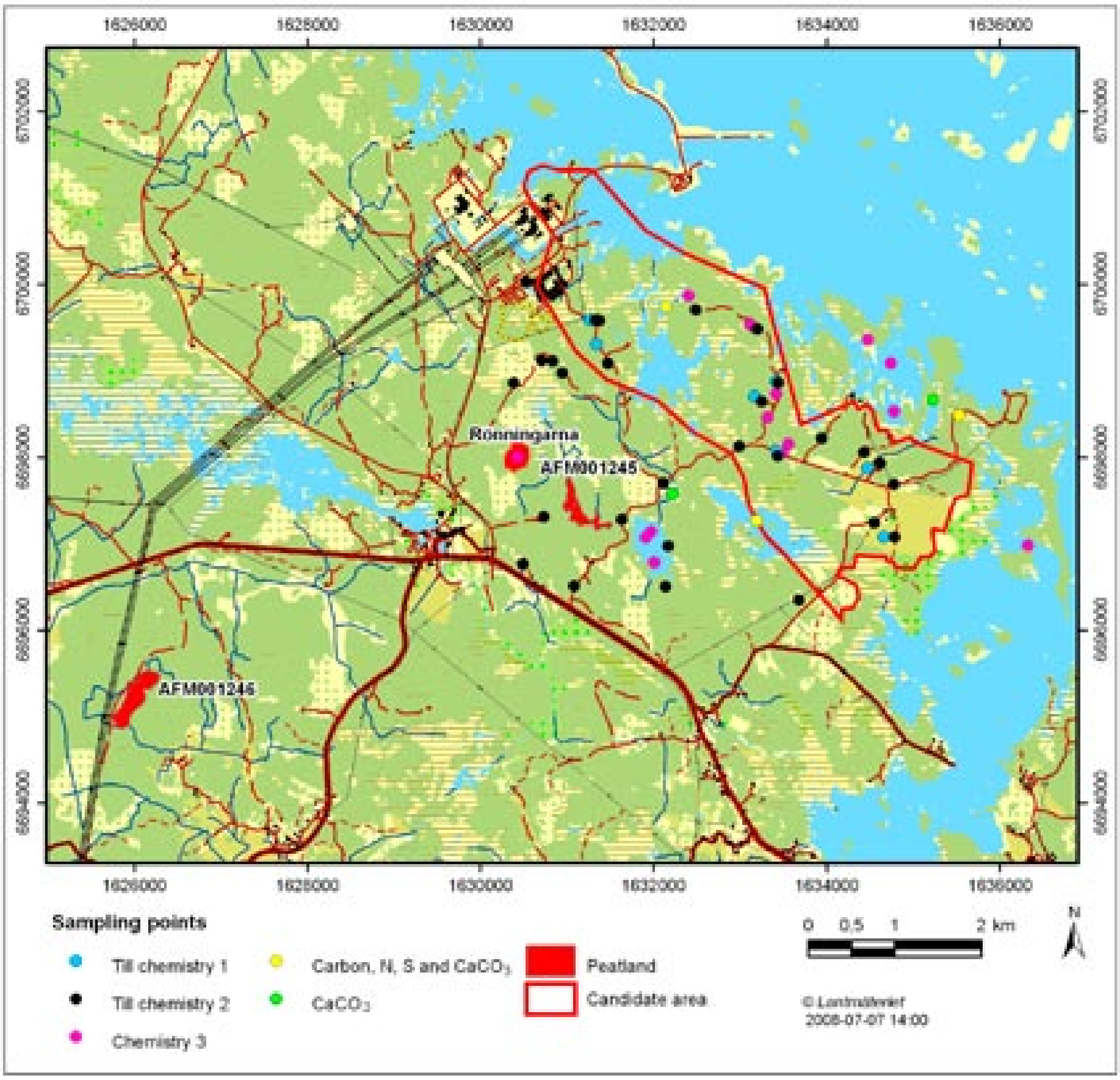


Figure 2-9. *Sites where the chemical composition of the till has been analysed are marked with black /Nilsson 2003/ and blue /Sohlenius and Rudmark 2003/. Sites where the chemical composition of sediments has been analysed are marked with yellow, green or red /Hedenström and Risberg 2003, Hedenström 2004a, Strömgren and Brunberg 2006, Baxter et al. 2007/. The peatlands investigated are marked with red /Fredriksson 2004, Lokrantz and Hedenström 2006/. Sites used for radiometric datings and analysis of carbon (C), nitrogen (N) and phosphorous (P) /Sternbeck et al. 2006/ and sites used for the chemical characterisation of common deposits and soils are marked with white dots included in Chemistry 3 /Hannu and Karlsson 2006/.*

The content of calcium carbonate ($CaCo_3$) in the fine fraction (material < 0.063 mm) has been a standard analysis for the majority of the regolith samples collected at Forsmark. The analysis of $CaCO_3$ has been performed using a volumetric method, i.e. the Passons apparatus /Wahnschaffe and Schucht 1924/. The content of $CaCO_3$ has a large impact on the physical properties of the regolith and the chemical properties of e.g. the surficial ground water. In agricultural land, calcite enhances the formation of aggregates, which in turn is favourable for preserving pH values of around seven7.

The characterisation of the marine and lacustrine sediments is based on analyses from different depth intervals from the cores. The content of organic carbon (C) has been analysed in marine and lacustrine sediments /Bergkvist et al. 2003, Hedenström and Risberg 2003, Hedenström 2004a/. In addition, the total contents of nitrogen (N) and sulphur (S) were analysed in sediments from three of these lakes at Forsmark. The analyses of elemental C, N and S was carried out by means of a LECO elemental analyser according to /SIS 1996/.

A 55-cm long sediment core from Lake Stocksjön was analysed for elemental composition. A total of 55 elements were analysed. The results are presented as main elements, heavy metals and trace elements, for details see /Strömgren and Brunberg 2006/.

The chemical composition of ash content of peat was analysed in three samples consisting of a large number of pooled sub-samples. Two different depth intervals were analysed separately at Lersättermyran /Fredriksson 2004/.

Soil sampling was conducted in diagnostic soil horizons representing the soiltypes /Lundin et al. 2004, 2005/. During the soil survey, /Lundin et al. 2004/ took samples of the upper regolith from eight site types. The samples were analysed for pH, carbon (C) and nitrogen (N). In the minerogenic soils, the uppermost organic layer was sampled separately. Beneath the organic layer, three samples were taken: 0–10 cm, 10–20 and 55–65 cm below the organic layer. In Podsol soils, the upper 5 cm in the B horizon was also sampled. Soil samples from the same levels were also taken in the machine-cut trenches studied by /Lundin et al. 2005/.

In the work to characterise the soils in the Forsmark area, data were collected to calculate the carbon stocks for each dominant soil class. The soil carbon pools for each soil layer were calculated and added together using the following formula:

$$C_{pool} = \sum_{i=\text{soil layer}} (C_{conc}/100) \times BD \times DEPTH_i \times \left(1 - C_{stone}/100\right)$$

, where C_{pool} is the carbon pool (kg m^{-2}), C_{conc} is the carbon concentration (%), *BD* is the bulk density (kg m^{-3}), *DEPTH* is the layer depth (m), and C_{stone} is the stone content (%).

Bulk geochemical analyses were carried out on parallel till samples from eight locations (Till Chemistry 1 in Figure 2-9) /Sohlenius and Rudmark 2003/. Two grain size fractions, < 63 µm and < 2 mm respectively, were analysed with ICP-MS (at SGU in Uppsala) after leaching with 7M (HNO_3). An total of 43 till samples (material < 0.063 mm) from 28 sites (Till Chemistry 2 in Figure 2-9) were digested in Aqua Regia and then analysed by ICP-MS [35 elements including gold (Au)] /Nilsson 2003/. The precision of the Au analysis is low, since the content of that element is low in the area. The results from the ICP-MS analyses were presented in colour-shaded maps. These maps were produced from gridding with the Kriging Method of Spherical Variogram model. The result from each site is also presented as a circle proportional to the content of the element. The method used for Till Chemistry 1 dissolves a smaller fraction of the samples compared to the method used for Till Chemistry 2.

The calcium carbonate ($CaCO_3$) concentration was measured on the sediment from Lake Eckarfjärden /Hedenström and Risberg 2003/. The sediment from Lake Eckarfjärden was analysed by means of ELTRA CS 500 and combusted at both 550°C and 1,200°C. The organic carbon (C) content was subtracted from the total C content, i.e. the $CaCO_3$ was calculated from the differences in total and organic carbon and the ratio of the molar weight of $CaCO_3$ and C as:

$$[C\%_{(1{,}200°C)} - C\%_{(550°C)}] \times (60/12)$$

The total carbon (C) content includes C from both organic material and carbonates. Earlier studies have shown that both the glacial and postglacial fine-grained sediments contained calcium carbonate ($CaCO_3$) /Hedenström and Risberg 2003/. The $CaCO_3$ content in sediments from five different lakes was analysed.

The content of elemental silicon (Si) was analysed using ICP-SFMS on several samples representing different QD from one sediment core from Lake Eckarfjärden and one sample each from Lake Puttan and the mire Rönningarna /Baxter et al. 2007/. The concentration of biogenic silica (Si_{bio}) was calculated using the total concentrations of silicon (Si_{tot}) and aluminium (Al_{tot}) in the sediment samples and the aluminium/silicon ratio ($R_{Si,Al}$) in glacial clay (average value from the two samples):

$$Si_{bio} = Si_{tot} - Al_{tot} \times R_{Si,Al}$$

A sediment sequence containing peat and water-laid sediments from Rönningarna was included in the characterisation of QD by /Hannu and Karlsson 2006/. The mire Stenrösmossen (AFM001245, Figure 2-9) was selected as a representative peatland of the slightly more elevated section of the Forsmark area. An additional peatland west of the mire Lersättermyran (AFM001246) was selected to represent an older and more developed mire. Peat samples from these two mires were dried and mixed into three general samples. Stenrösmossen is represented by one such sample representing the uppermost metre of peat. AFM001246 is represented by two samples, one from the uppermost metre of peat and the other from 1–2 m. The three samples were ignited at 550°C and the ash content was analysed according to /SIS 1984/. The ash was then analysed for major and trace elements with ICP-MS at Analytica laboratory. The results have been compared with the arithmetic mean and median values for Swedish peatlands /Fredriksson 1984/.

The surface sediment from one off shore sediment core from the marine area representing off shore environment, was analysed for element and isotope content. The organic carbon (C) and calcium carbonate ($CaCO_3$) content was analysed on a 6-m long core from another sediment core, representing a deep part of the model area /Risberg 2005/. Sediments from two sites at the bay Tixelfjärden were included in the characterisation of QD by /Hannu and Karlsson 2006/.

Clay mineralogy of till samples (material < 2 μm) was qualitatively analysed using "oriented" samples /Drever 1973/. The analyses were performed at SGU on four samples using X-ray diffraction (XRD). Further-more, quantitative X-ray diffraction was carried out according to /Środoń et al. 2001/. The mineralogy of eight till samples was analysed with XRD on randomly-oriented bulk material < 2 mm.

Clay mineralogy in lake sediments was also analysed using XRD. The mineralogy was determined by means of a Siemens D5000 (theta-theta) diffractometer (CuKa). The X-ray generator operated at 50 kV and 40 mA. The minerals were identified using the Bruker/Siemens software DIFFRACPLUS (version 2.2), including a database for mineral identification. Clay minerals were determined using data from /Brindley and Brown 1984/.

The petrographical composition of boulders and gravel in till has been studied (Figure 2-10). The aim was to determine whether or not the mineralogical composition of the till reflects that of the local bedrock /Bergman and Hedenström 2006/. The bedrock composition of till boulders was studied in the field along three traverses perpendicular to the dominating ice movement direction, representing the documented till types of the area /Sohlenius et al. 2004/. The mineralogical composition of gravel from till was studied using a stereo microscope.

2.3.3 Radiometric datings and accumulation rates

Radiometric datings were used to determine the ages and accumulation rates of sediment and peat. The uppermost deposits were lead 210 (^{210}Pb) dated. The deeper and older deposits were dated with carbon 14 (^{14}C) /Sternbeck et al. 2006, Hedenström and Risberg 2003, Risberg 2005/. The accumulation rates were used to calculate the annual accumulation of e.g. organic carbon (C), nitrogen (N) and phosphorous (P).

In order to determine the isolation age of Lake Eckarfjärden, four carbon 14 (^{14}C) (AMS) dates were carried out on macrofossils and sediments /Hedenström and Risberg 2003/. The results were also used to estimate the rate of sediment accumulation. /Risberg 2005/ used ^{14}C datings of sediment at various depths in a c 6-m long sediment core collected offshore (PFM004396). The ^{14}C ages were calibrated to calendar years BP (before present, i.e. 1950). In order to calibrate the ^{14}C ages, the ages were first corrected for reservoir effect. For example, the sediments deposited in the Littorina Sea was corrected with –400 years before calibration /cf Hedenström and Possnert 2001/. In this text, the ages are presented as AD/BC years.

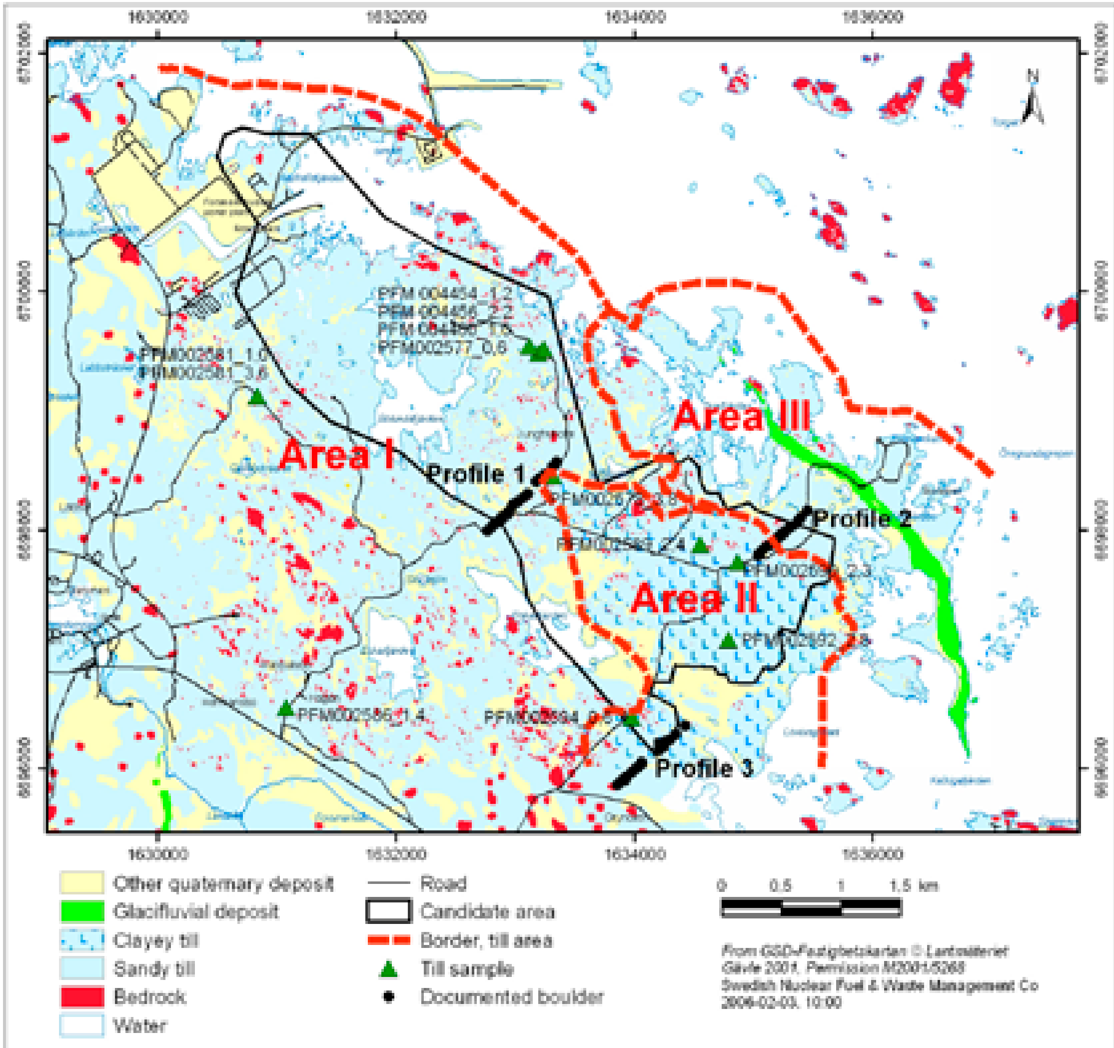


Figure 2-10. The sampling sites for petrographical analysis of gravel and boulders /from Bergman and Hedenström 2006/.

2.3.4 Analysis of microfossils

Diatoms were extracted from the sediments mainly by following the standard procedure compiled by /Battarbee 1986/.The ecological classification of the diatoms mainly follow the checklist containing 500 diatom taxa described by /Snoeijs et al. 1993–1998/, where the species are grouped into classes according to their salinity preferences and the recent distribution in the Baltic Sea.

The sediments from Lake Eckarfjärden were analysed with respect to diatoms in order to reconstruct the aquatic environment and to identify the isolation event /Hedenström and Risberg 2003/. In a sediment core (PFM004396) collected off-shore of Forsmark, stratigraphical analysis of siliceous microfossils was performed to reconstruct the postglacial development of the site (Figure 2-11). One sediment core collected in the bay Kallrigafjärden was analysed with respect to pollen and diatom distribution /Bergkvist et al. 2003/.

In order to test if reworked microfossils in till and glacial sediment could contribute to the relative dating of glacial sediment, 13 samples were collected (Figure 2-12). The microfossils were concentrated from the sediments and analysed under microscope /Robertsson 2004/.

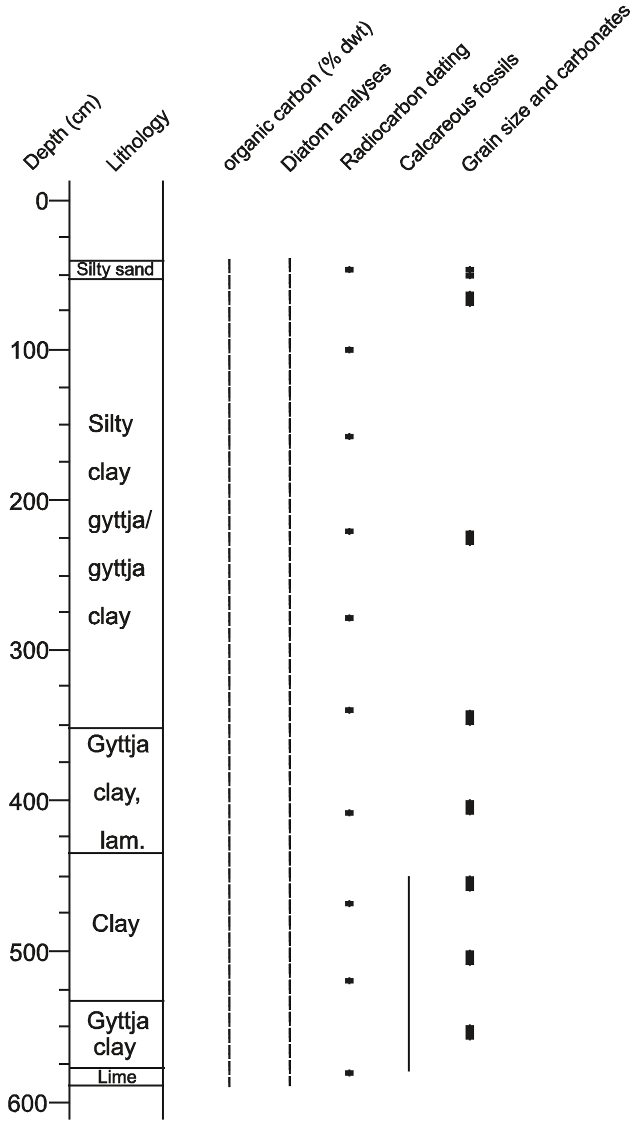


Figure 2-11. Summary of the samples collected from the marine sediment core collected at PFM004396. The depths are from the sediment surface. Lime referrers to clasts of limestone present in the sediment /from Risberg 2005/.

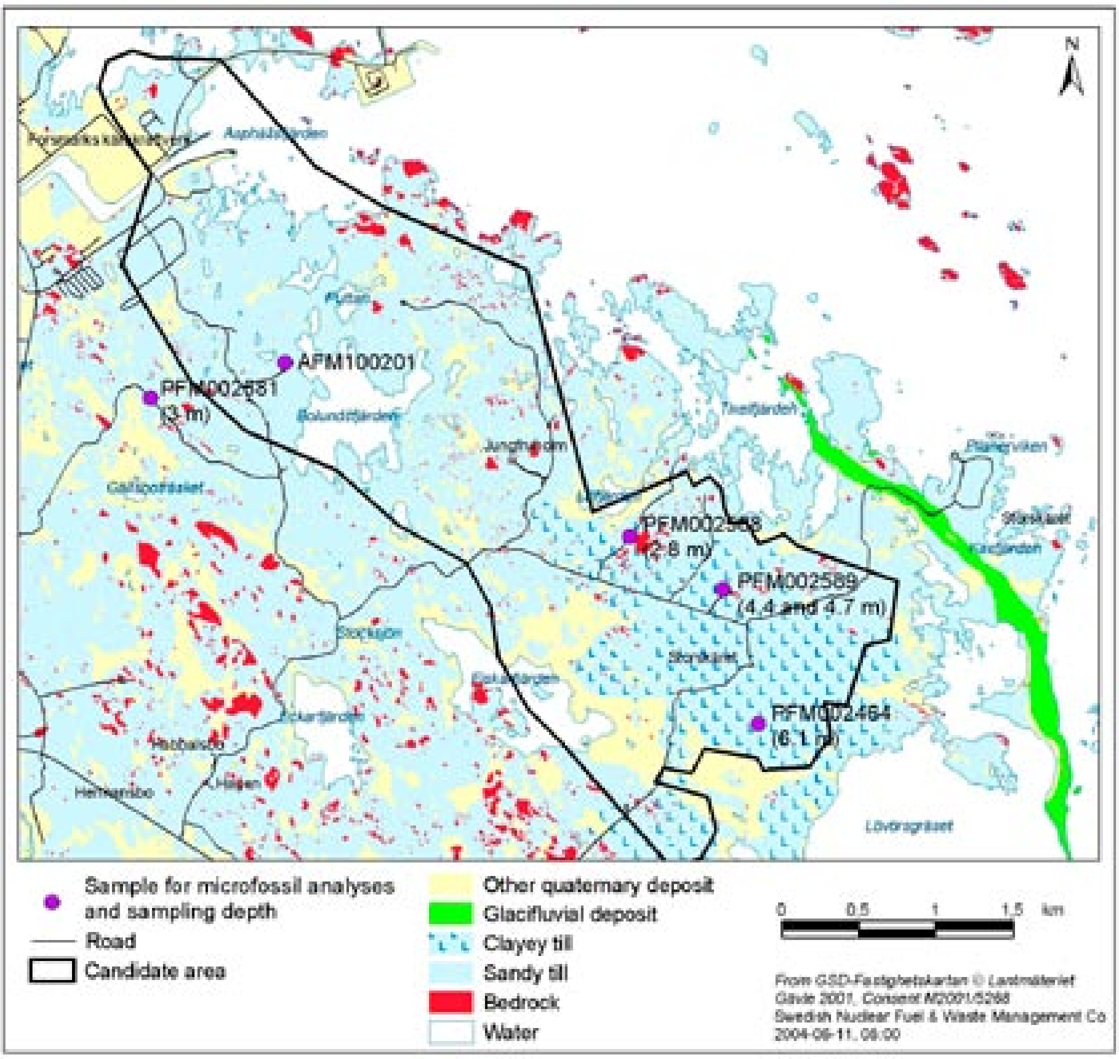


Figure 2-12. Map showing the location of the samples collected for analysis of reworked microfossils /from Robertsson 2004/.

3 Overview of the Quaternary history of the Forsmark area

This chapter gives a review of the Quaternary history of the Forsmark area. A comprehensive description of the geological evolution, palaeoclimate and historic development of the Forsmark and Laxemar-Simpevarp areas is presented in /Söderbäck (ed.) 2008/.

The Quaternary is the present geological period, which started 2.6 million years ago and is subdivided into two epochs: the Pleistocene and the Holocene. The latter represents the present interglacial, which began c 9500 years BC. The Quaternary climate is considerably colder than the previous Tertiary period. The Quaternary climate is also characterised by large, sometimes fast, changes in global temperature. In Sweden and in other areas situated at high and low latitudes, the climate during the Quaternary has been switching between cold glacial and warm interglacial stages. The glacial stages are further subdivided into cold phases called stadials, and relatively warm phases called interstadials. The repeated glaciations have had a major impact on the distribution of the regolith and the morphology of the landscape. This in turn has affected the near surface hydrology and the local distribution of soils and vegetation /e.g. Berglund et al. 1996/.

Studies from other parts of the world suggest as many as fifty glacial/interglacial cycles during the Quaternary Period /Shackleton et al. 1990/. The climate during the past c 700,000 years has been colder than the earlier part of the Quaternary and has been characterised by 100,000 year-long glacial periods interrupted by interglacials lasting approximately 10,000–15,000 years. The absolute number of glaciers covering the Forsmark area is unknown, but end moraines from three glaciations are known from northern Poland and Germany /e.g. Andersen and Borns 1997/. It can therefore be concluded that the Forsmark area has been glaciated at least three times during the Quaternary Period.

Preserved deposits older than the latest glacial phase are rare in Sweden, hence very little is known about the duration and extent of the early Quaternary glaciations. During the two glaciations preceding the latest glacial cycle, the ice cap reached into northern Poland and Germany, which means that the Forsmark area was covered by ice at least during the Elster and Saale glaciations. A large number of excavations in glacial sediments has been performed in north-eastern Uppland /Lagerbäck et al. 2004, 2005/ and in the Forsmark candidate area /Sundh et al. 2004/. However, no traces of sediments preserved from the Holstein interglacial (c 230,000 years ago) or the Eemian were observed in the Forsmark region. During the latest interglacial, called the Eemian (130,000–115,000 years ago), the Baltic Sea level was higher than at present and it is therefore likely that the Forsmark area was covered with brackish water during a large part of that interglacial /Robertsson et al. 1997/.

The latest glaciation, the Weichselian, started c 115,000 years ago and there is geological evidence of at least two periods thereafter when a large part of Sweden was free of ice. Several authors have suggested that most of Fennoscandia was free of ice during these early Weichselian interstadials /e.g. Lundqvist 1992/. The northern parts of Fennoscandia were probably covered by ice during the Early Weichselian stadials. It has been generally suggested that a large part of Fennoscandia was covered by ice from the beginning of the Mid-Weichsel (70,000 years ago) until the latest deglaciation. The models presented by e.g. /Lundqvist 1992/ and /Fredén 2002/ are often used to illustrate the evolution of the Weichsel (Figure 3-1). The Forsmark area was probably free of ice during the Early Weichselian stadials and interstadials (Figure 3-1). It has been assumed that tundra conditions prevailed during these stadials /Fredén 2002/. The vegetation during the first Weichselian interstadial was probably dominated by coniferous forest, whereas the second interstadial was colder, with sparse forest dominated by *Betula* (birch). The ice advanced southward and reached the Forsmark area first during the Mid-Weichselian (c. 70,000 years ago). Since a large part of Sweden may have been free of ice during parts of the Mid-Weichsel, the total time of ice coverage in the Forsmark area may have been considerably shorter than shown in (Figure 3-1). The greatest extent of the Weichselian ice sheet, LGM, was reached c 16,000 BC /Fredén 2002/. According to mathematical and glaciological models, the maximum thickness of the ice cover in the Forsmark region was up to c 3 km during LGM /Näslund 2006/.

At Forsmark, till that may have been deposited during the third Weichselian stadial have been found during excavations within the candidate area /Sundh et al. 2004/. A hard clayey till was revealed under a sandy-silty till at a depth of 1.9 m. The contact between the two till beds is sharp and erosive. This till unit, as well as a unit of similar properties observed during the construction of the Forsmark nuclear power plant /Agrell and Björnbom 1978/, is tentatively correlated with a unit consisting of a dark clayey till observed at several sites in central and northern Sweden /Björnbom 1979, Robertsson et al. 2005/. The most recent interpretation of the age of the dark clayey till is that it was deposited c 75,000–60,000 years ago /cf. Robertsson et al. 2005/.

Glacial striae on bedrock outcrops and till fabric are formed at different stages of the glaciations, and several generations of ice movement direction may be identified. The oldest glacial striae observed in the region of north-eastern Uppland oriented from the north-west, a younger system

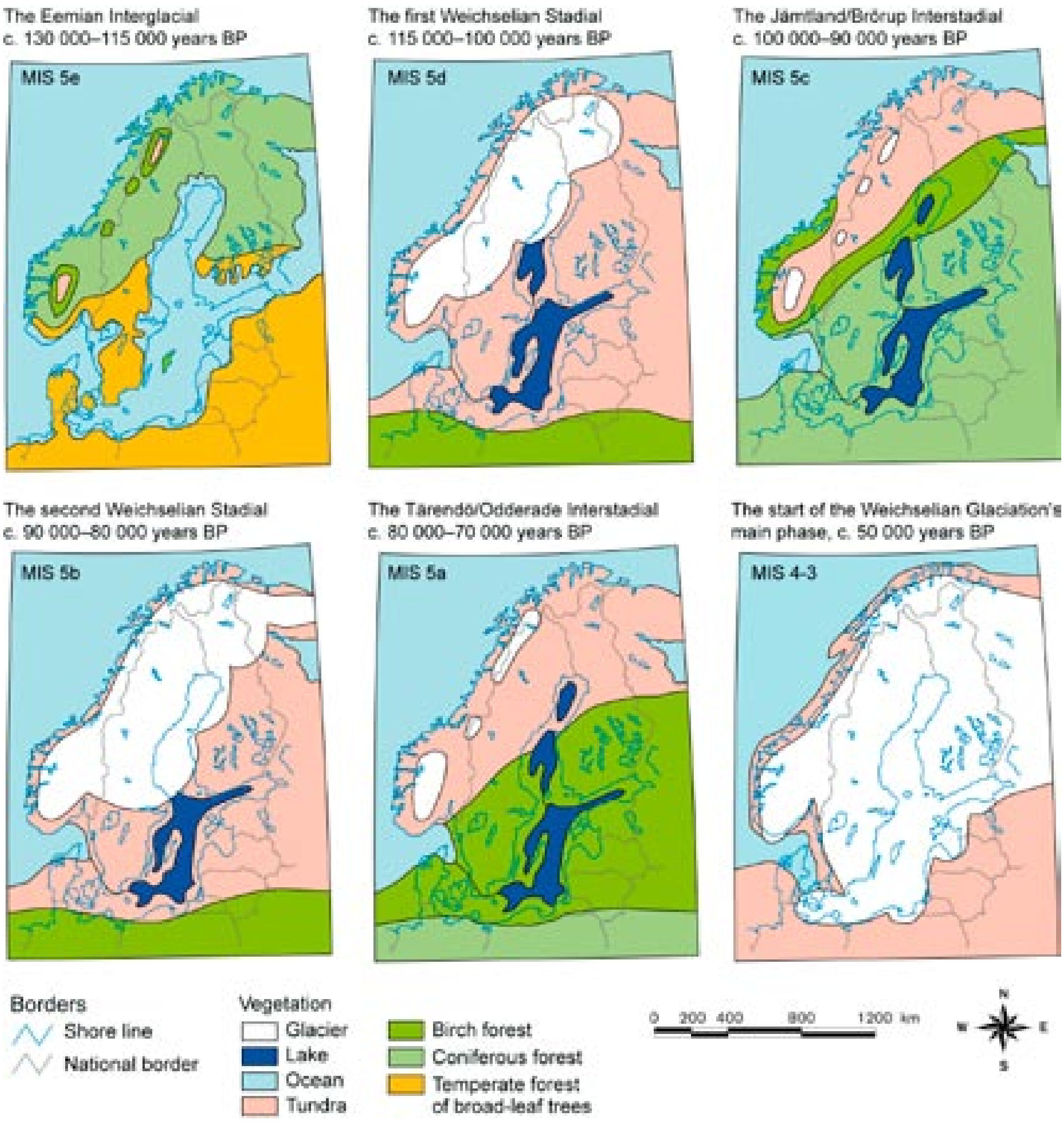


Figure 3-1. The development of vegetation and ice cover in northern Europe during the latest interglacial (Eem) and the first half of the latest glaciation (Weichsel). The maps should be regarded as hypothetical due to the lack of accurately-dated deposits from the different stages /from Fredén 2002/.

approximately from the north and the youngest from an ice sheet moving from approximately the north or north-east /Persson 1992/. At Forsmark, a northerly direction is recorded both in the oldest glacial striae and the oldest documented directional transport of the till material as recorded in clast fabric analysis /Sundh et al. 2004/. At one site, the oldest till fabric direction recorded was from the east to north-east /Albrecht 2005/. However, the overall dominating system shows transport and deposition from the north-west /Sohlenius et al. 2004/. Boulders and the gravel fraction from till samples were analysed with regard to petrographical distribution and compared to the local bedrock /Bergman and Hedenström 2006/. It was concluded that the majority of the boulders consisted of local rock types with a suggested dominant transport direction from the north-west. However, a high percentage of Ordovician limestone in the gravel fraction suggests that these grains may originate from the bottom of the Bothnian Sea /Bergman and Hedenström 2006/.

During a later stage of the latest glaciation, or during deglaciation, the environment beneath the ice sheet was favourable for the deposition of laminated, fine-grained sediments under uplifted slabs of bedrock. These spectacular, sediment-filled open fractures in the upper part of the bedrock were identified below till during the site investigations at Forsmark /Leijon (ed.) 2005/, as well as during the construction of the Forsmark power plants /Stephansson and Ericsson 1975, Carlsson 1979/. The sediment-filled fractures are interpreted as having been formed during a late stage of the glacial phase, when large amounts of sediment-loaded melt water accumulated beneath and inside the retreating ice /cf. Stephansson and Ericsson 1975, Leijon (ed.) 2005/.

After the Last Glacial Maximum, LGM, the deglaciation started with the melting of the ice cap. The front of the melting ice reached Forsmark c 8800 BC /Strömberg 1989, Persson 1992, Fredén 2002/, during the Preboreal climatic stage. The ice front was in the order of 300-m thick, retreating sub aquatically by c 300–350 m annually during the freshwater phase of the Yoldia Sea.

The development of the Baltic Sea since the latest deglaciation is characterised by changes in salinity, which have been caused by variations in the relative sea level. This history has been divided in four main stages /Björck 1995, Fredén 2002/, which are summarised in Table 3-1 and Figure 3-2.

Freshwater conditions prevailed in the Baltic basin during most of the deglaciation of Sweden. The brackish water phase of the Yoldia Sea lasted c 120 years /Wastegård et al. 1995/. The salinity was between 10‰ and 15‰ in the central Yoldia Sea /Schoning et al. 2001/. The short duration of the brackish phase, in combination with the late deglaciation of the Forsmark area and the freshwater supply from the melting ice, resulted in only minor, if any, influence of saline water in north-eastern Uppland during this stage. The Yoldia Sea stage was followed by the Ancylus Lake, characterised by freshwater conditions until the onset of the Littorina Sea around 9,500 years ago /Fredén 2002, Berglund et al. 2005/. In Uppland, the Littorina Sea stage includes an initial phase (the Mastogloia Sea Stage) when the salinity was low and stable. This stage lasted for approximately 1,000 years. The salinity started to increase at c 6500 years BC /Hedenström 2001/. Salinity variations since the onset of the Littorina Sea have been summarised by /Westman et al. 1999/ and are presented in Figure 3-3. The most saline period occurred between 4000 and 3000 years BC when the surface water salinity in the Baltic proper (south of Åland) was approximately 10–15‰ compared to c 6‰ in the surface water today /Westman et al. 1999/.

Table 3-1. The four main stages the Baltic Sea has experienced since the latest deglaciation. The Littorina Sea here includes the entire period from the first influences of brackish water 7500 years BC to the present Baltic Sea.

Baltic stage	Calendar years BC	Salinity
Baltic Ice Lake	13,000–9500	Glacio-lacustrine
Yoldia Sea	9500–8800	Lacustrine/Brackish/Lacustrine
Ancylus Lake	8800–7500	Lacustrine
Littorina Sea, Sensu lato	7500–present	Brackish

Figure 3-2. The four main stages of the Baltic Sea since the latest deglaciation. ***A)*** *the Baltic Ice Lake* ***B)*** *the Yoldia Sea,* ***C)*** *the Ancylus Lake and* ***D)*** *the Littorina Sea. Fresh water is displayed as dark blue and marine/brackish water with pale blue /from Fredén 2002/.*

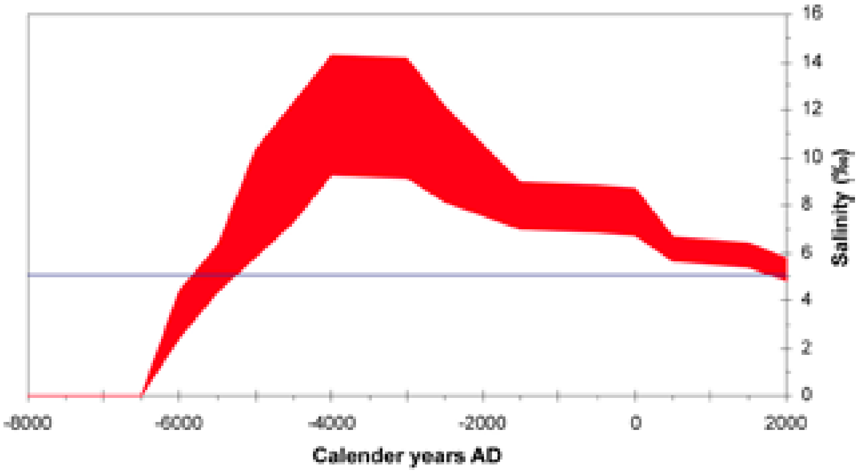


Figure 3-3. Salinity variations in the open Bothnian Sea during the past c 9000 years /from Westman et al. 1999/.

In north-eastern Uppland, the highest Holocene shoreline was reached in conjunction with the deglaciation during the Yoldia Sea stage of the Baltic. The closest shore/land area at that time was situated c 100 km west of Forsmark, where the highest shoreline has been identified at c 190 m above sea level (Figure 3-4). The Forsmark area was initially covered by approximately 150–190 m of glacio-lacustrine water.

The Holocene shoreline displacement in northern Uppland has been studied using stratigraphical methods by /Robertsson and Persson 1989/ and /Hedenström and Risberg 2003/. The methods are based on diatom stratigraphy of lake sediments for the identification of the isolation event of the basin, together with radiocarbon dating and determination of the elevation of the isolation threshold of the basins. Since there are no elevated (and old) areas close to Forsmark, the stratigraphical investigations cover only the last 6,500 years. A mathematical modelling of the post glacial shoreline displacement in Fennoscandia has been presented by /Påsse 2001/.

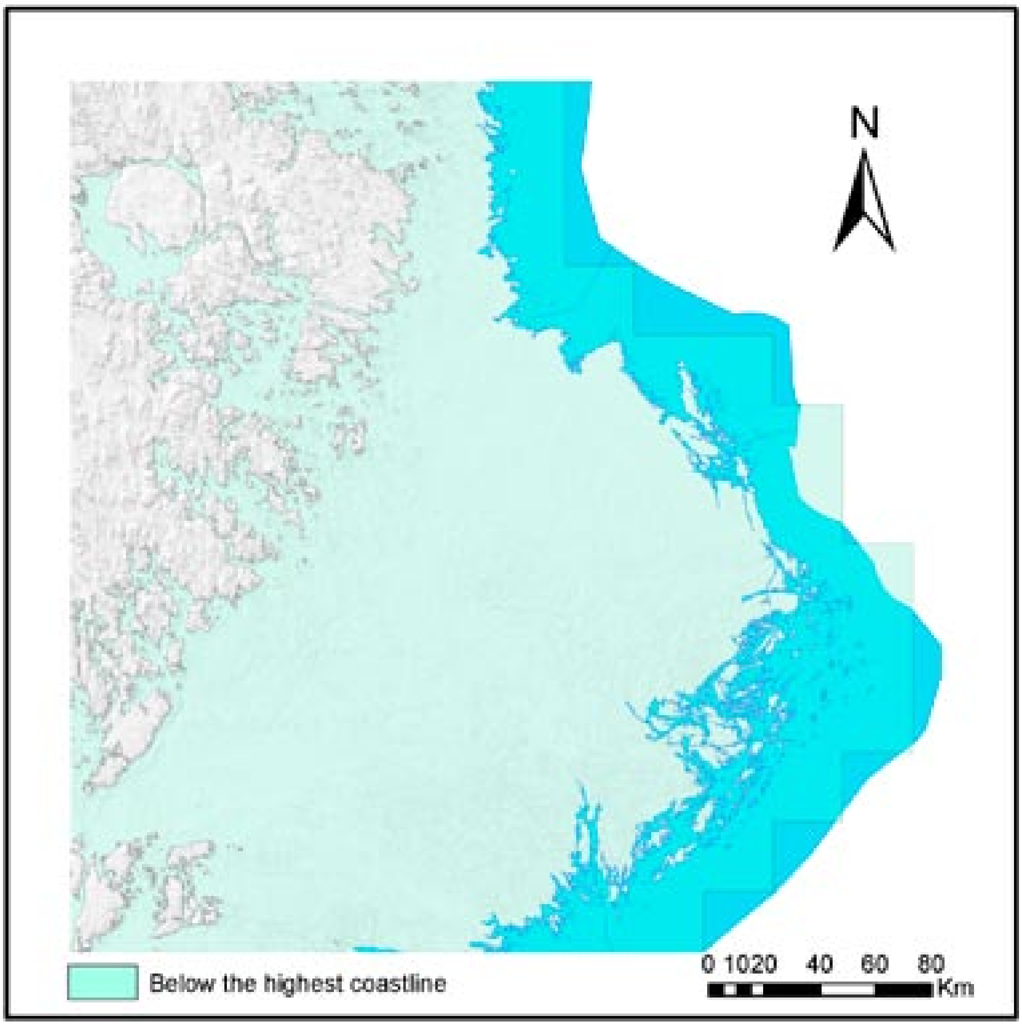


Figure 3-4. *Palaeogeographical map showing the areas located above (white) the highest coastline in the region of Eastern Svealand /based on Påsse and Andersson 2005/.*

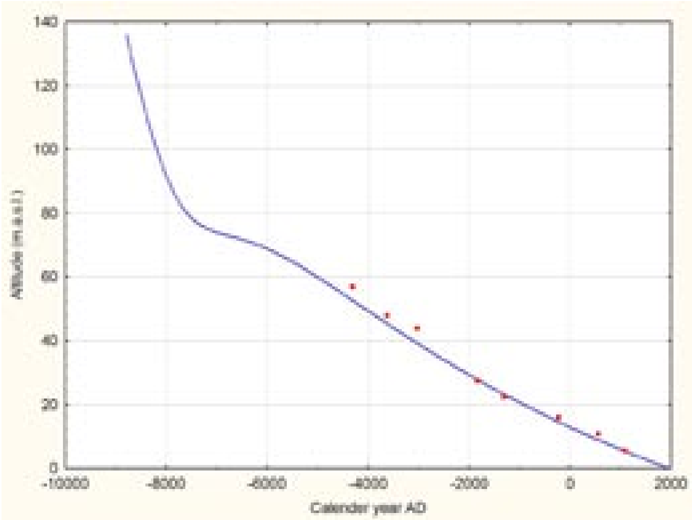


Figure 3-5. *Shoreline displacement curve for the Forsmark area after the latest deglaciation. The red symbols depict dating of the isolation events of lakes and mires /Hedenström and Risberg 2003/. The blue solid curve was calculated using a mathematical model /Påsse 2001/.*

In contrast to the southern parts of the Swedish coast, where the relative sea level was both transgressive and regressive during the Holocene, the shoreline in Forsmark and further north /Berglund 2005/ has been continuously regressive since the deglaciation (Figure 3-5). The average regression rate was initially around 3.5 m/100 years during the Yoldia Sea and Ancylus Lake stages of the Baltic.

In northern Uppland, the first land areas emerged c 6,500 years ago /Hedenström and Risberg, 2003, Risberg et al. 2005/, during the most saline phase of the Littorina Sea, which coincides well with the Holocene climatic optimum during the Atlantic climatic stage /Westman et al. 1999/. At Forsmark, however, it was not until c 500 BC that the first islands started to form. The flat topography, in combination with the relatively rapid land uplift (presently 6 mm/year /Ekman, 1996/), resulted in the rapid growth of new land areas and major geographical changes over time. One effect of the continuous regressive shoreline displacement is that the new land areas and lakes have not re-flooded once they became isolated from the Baltic. For a description of the development of the landscape and the vegetation, see Chapter 6 in /Söderbäck (ed.) 2008/.

The ongoing change in the distribution of land and sea continues with the emergence of new land areas, forming new and larger islands. The physical and chemical properties of minerogenic Quaternary Deposits (QD) are affected by soil-forming processes at the surface, but no major redistribution of the regolith has taken place since the area emerged from the Baltic. The most notable change will be observed in the distribution of organic deposits, for example, the sedimentation of gyttja in the lakes and the formation of peat in the wetlands.

Regarding the vegetation history of the area, sub-fossil pollen records are used to reconstruct the immigration and succession of terrestrial plants. Pollen-analytical levels recorded in northern Uppland are the Elm decline, c 3250 BC (5200 cal years BP), and the spread of spruce at c 1450–750 BC (3400–2700 cal years BP) /Robertsson and Persson 1989/. At the Hållnäs peninsula, located c 35 km north of the regional model area, biostratigraphical investigations have been performed in connection to archaeological investigations /Ranheden 1989/. Settlements from the Viking age and medieval period were identified in the fossil record, i.e. humans have been successively occupying the archipelago since new land emerged from the Baltic. A survey of the pollen distribution in sediment collected in the Kallrigafjärden indicated that parts of the area was used for agriculture shortly after its emergence from the Baltic /Bergkvist et al. 2003/.

4 Conceptual models

4.1 The bedrock

The inorganic Quaternary Deposits (QD) consists of more or less altered fragments of bedrock. Depending on the parent material and transport processes, the grain sizes of the minerogenic fraction of the till varies from clay particles up to large boulders with a volume of several m^3. The chemical and mineralogical composition of the QD can be expected to reflect the composition of the local, or regional, bedrock. The sensitivity for chemical weathering is of importance for soil-pH values and concentrations of nutrients available for plants. A high percentage of easily weathered minerals, such as calcite, will be favourable for vegetation. The bedrock in the Forsmark regional model area is dominated by igneous rocks, formed during the Svecofennian Orogenese, c 1,850 million years ago. Sedimentary Palaeozoic limestones, shales and sandstones are located north and north-east of the model area at the bottom of the Bothnian Sea /Axberg 1980/.

4.2 The Quaternary deposits

All regolith in the Forsmark area was formed during the Quaternary period and is therefore referred to as QD. The majority of the QD were formed during or after the final phase of the latest glaciation, i.e. during the last c 115,000 years. In the Forsmark area, the latest deglaciation occurred c 9000 years BC /Fredén 2002/. Due to the pressure from the ice sheet, the bedrock was submerged and the Forsmark area was initially covered by c 150–190 m lacustrine water of the Baltic basin. The highest altitude covered by water is referred to as the highest coastline. The highest level covered by the brackish water of the Littorina Sea is referred to as the marine limit. To get an overview of the QD and deglaciation history from the Östhammar region, readers are referred to the earlier investigations in the area (SGU Ser. Ae, scale 1:50000) /Persson 1985, 1986, 1992, Strömberg 1989/.

The QD are divided into two main categories according to the environment in which they were formed: *glacial* and *postglacial* deposits. This is a Swedish national standard classification used in the geological maps presented in this report, as well as in a majority of the descriptions of maps of unconsolidated QD.

The typical stratigraphical distribution of QD in areas located below the highest coastline is presented in (Figure 4-1). The general distribution of the QD at Forsmark are probably distributed in the same order, however not all of the units are necessarily present at all sites. For example, the depth of the glaciofluvial esker within the Forsmark regional model area is less than what is presented in the generalized profile in (Figure 4-1) whereas the till layer is thicker.

Glacial deposits are deposited either directly from the continental ice sheet or from water derived from the melting ice. A majority of the QD covering the bedrock were deposited during the Weichselian. A characteristic of the glacial deposits is that they are minerogenic in composition, i.e. they contain very little (or no) organic matter.

Glacial till consists of bedrock fragments and older deposits incorporated, transported and later deposited by the ice sheet. Generally, till is characterised by poor sorting, which results in grain size composition including grain sizes ranging from clay particles to large boulders. Till is the most common type of QD in Sweden, covering approximately 70% of the land areas /Fredén 2002/. In the geological classification, till is divided according to the grain size distribution of the matrix (i.e. fractions < 20 mm) together with the boulder frequency at the surface. These factors are determined by e.g. the properties of the original bedrock material and the processes

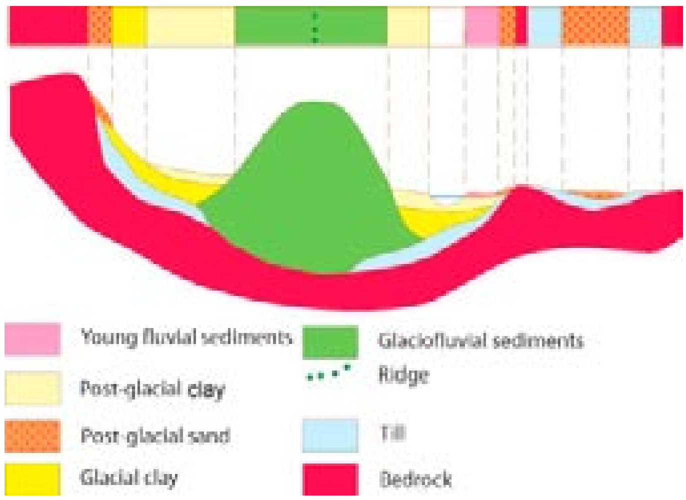


Figure 4-1. *Schematic stratigraphical distribution of QD in areas below the highest coastline (© Geological Survey of Sweden). The results from Forsmark suggest that the general distribution of the QD have a similar stratigraphy.*

during transportation and deposition from the ice. In areas with crystalline bedrock, sandy till with normal boulder frequency occurs commonly, whereas in areas with sedimentary bedrock, the till often contains clay. Clayey till contains between 5% and 15% clay particles and boulder clay contains > 15% clay. Sandy till is predominantly covered by forests, whereas clayey till is frequently used for agriculture.

During the deglaciation, large quantities of melt water from the ice were produced. The melt water was concentrated to tunnels under the ice and to fractures on the ice surface seeking their way to the ice front. Rock material was transported, sorted and rounded by the melt water and deposited in cavities within the ice or at the ice margin. Glaciofluvial deposits are characterised by well-sorted sediments, often forming eskers of sand and gravel. The glaciofluvial deposits are often deposited directly on the bedrock or on top of the till. Glaciofluvial sediments generally have a high hydraulic conductivity and are often used as groundwater resources.

The finest particles, clay and silt, were transported with the melt water and deposited in deep and calm water further from the ice margin. Glacial clay and silt are often characterised by varves, i.e. layers representing summer and winter accumulation. Glacial clay and silt often occurs as flat fields below the highest coastline, frequently used for agriculture.

Postglacial deposits were formed after the ice sheet had melted and retreated from an area. Postglacial sediment and peat forms the youngest group of regolith. In general, they overlie till and glacial clay or rest directly upon crystalline bedrock. The postglacial deposits often contain organic sediment and re-deposited, wave-washed clay, sand and gravel. Processes forming postglacial deposits have continuously been active since the latest deglaciation. The re-deposition of sediment often has a levelling effect on the topography since the fine-grained sediments are concentrated to local depressions.

Postglacial clay was deposited after erosion and re-deposition of some of the previously deposited sediments, such as glacial clay. The postglacial clay can often be found in the deeper parts of valleys below the highest coastline. Postglacial clay often contains organic material and is then referred to as gyttja clay (2–6% organic matter), clay gyttja (6–20% organic matter) or gyttja (> 20% organic matter).

Postglacial sand and gravel have been eroded from glacial deposits and transported by streams and waves and subsequently deposited at more sheltered positions, predominantly below the highest shoreline.

Gyttja sediments containing > 20% organic matter formed in lakes and consisted mainly of remnants from plants that had grown in the lake. In areas with calcareous soils, such as the Forsmark area, calcareous gyttja will form when calcium carbonate precipitates in the lake.

Peat consists of remnants of dead plants, which are preserved in areas (mires) where the prevailing wet conditions prevent the breakdown of the organic material. In the geological map, peatlands are often subdivided into fens and bogs. The vegetation in the fens gains nutrients from the groundwater, whereas a bog mainly gains nutrient from precipitation. The bogs are therefore poor in nutrients and are characterised by a coherent cover of Sphagnum species.

In general, the distribution of QD is related to the bedrock morphology. The most elevated areas are characterised by bedrock outcrops, till and peatlands. The lower parts of the model area are characterised by fine-grained sediments. The distribution of the QD in different areas of Forsmark has been used to distinguish subareas where it is possible to generalise the depth and stratigraphy.

4.3 Regolith Depth Model (RDM)

A geometrical model of the regolith depth and stratigraphy has been constructed for the Forsmark area /Hedenström et al. 2008/. The model is based on evaluation of drillings and corings, excavations and geophysical investigations. Furthermore, the map of QD was used to define different sub-domains where average depth values were used when other information was lacking. The model describes the total regolith depth, subdivided into seven layers (Z1–Z6) and three lake sediment lenses (L1–L3) (Figure 4-2). The layers and lenses in the model are purely geometrical and were constructed according to the conceptual understanding of the site, hence properties of the layers and lake sediment lenses should be assigned by the user. For example, the upper layer Z1 can have different properties in different areas through connection to e.g. maps of QD or soil types.

The model presents the geometry of the lower level for each layer, presented as elevation above sea level (RH 70) with a spatial resolution of 20×20 m. The resulting interpolated surfaces are presented in a GIS-environment. The model area is a modified Forsmark regional model area which includes present and future catchment areas (Figure 4-3). The total area modelled is 155 km^2 and includes all surfaces (land, sea and lakes).

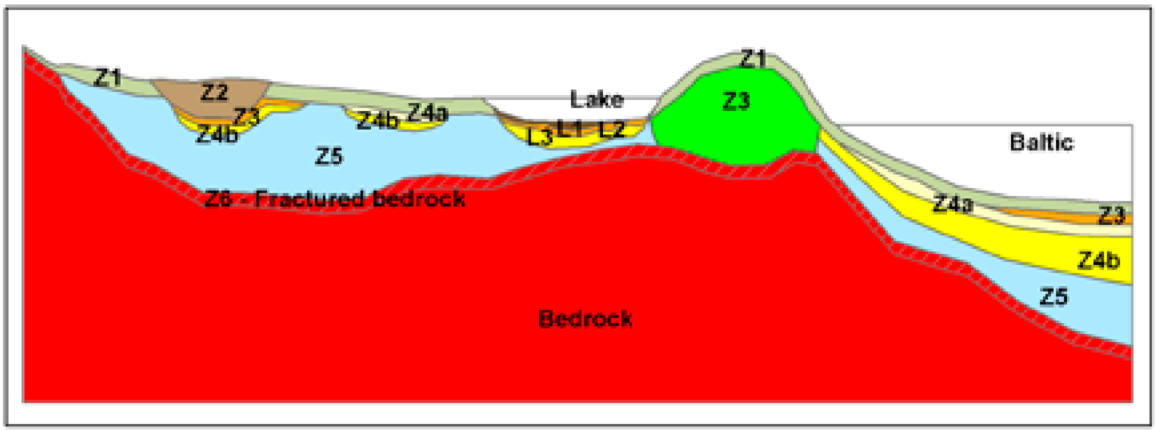


Figure 4-2. *Conceptual model used for the RDM /from Hedenström et al. 2008/. See Table 4-1 for a layer description of the spatial distribution of the seven layers and the three lake sediment lenses modelled.*

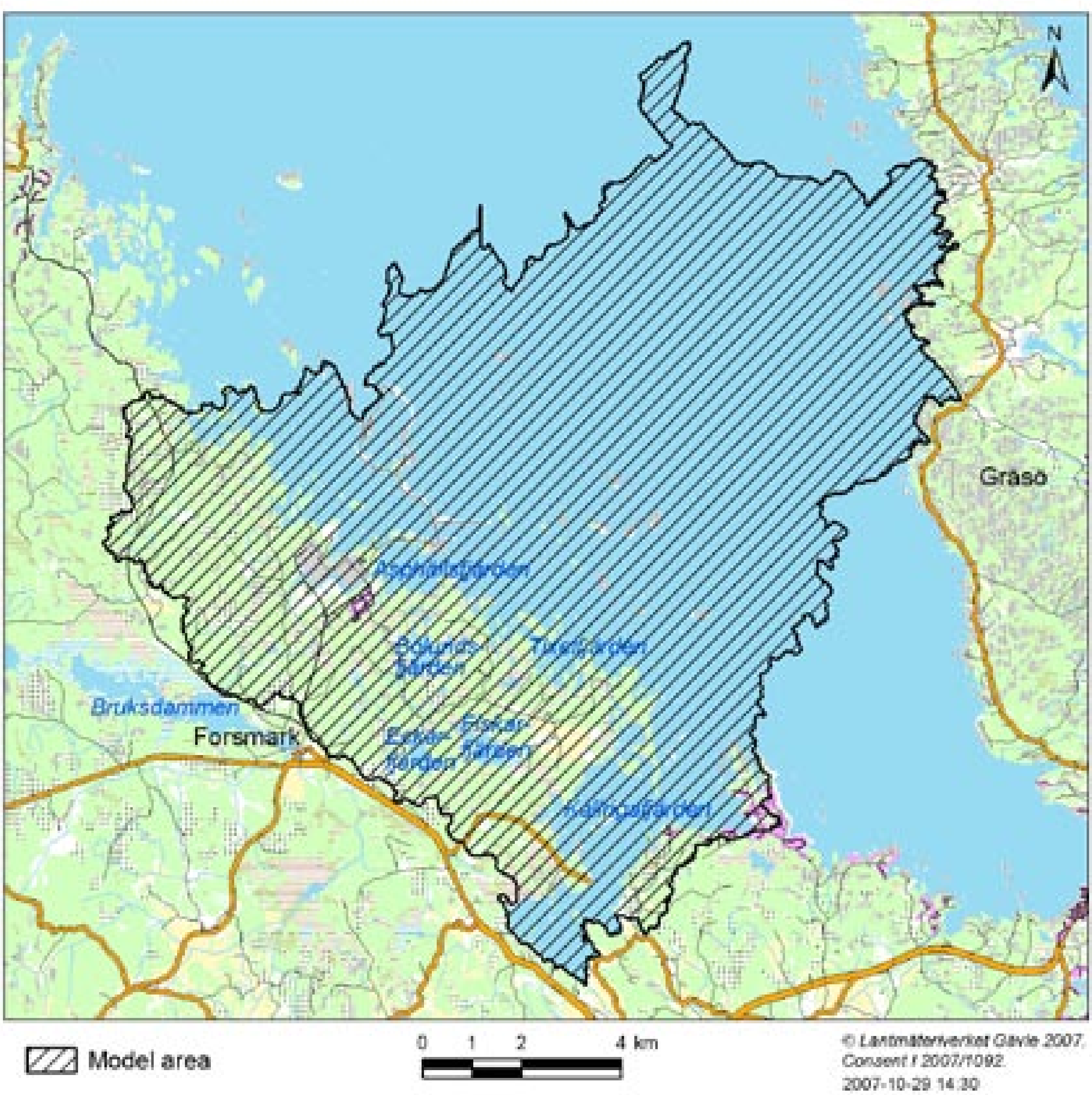


Figure 4-3. *Area for modelling of regolith depth in the Forsmark area /from Hedenström et al. 2008/.*

Table 4-1. Data used for the construction of the bedrock surface (Z5) in the RDM at Forsmark /Hedenström et al. 2008/.

Data	No of points
Average QD depth values	283,529
Seismic and sediment echo sounding data (detailed area)	128,296
Seismic and sediment echo sounding data (regional area)	18,855
Bedrock outcrops	88,945
Observation points reaching bedrock	8,119
Observation points not reaching bedrock	3
Total no of points	**527,747**

The lower level for Z5 is interpolated from available regolith depth data, including bedrock outcrops and average depth values, thus Z5 represents the bedrock surface regardless of whether it is covered by regolith or not. The layers in the model are summarised and explained below (Table 4-2).

Table 4-2. Description of the layers used in the Forsmark RDM /from Hedenström et al. 2008/.

Description of layer/lens	Simplified Code	Description/Occurrence
Gyttja (algal gyttja, calcareous gyttja, clay gyttja-gyttja clay), Peat	L1	Present inside the boundary of lakes. Peat is included in the L1 lens when it is present as a surface layer within the lake area. The sediment in L1 and Z4a consists partly of the same geological units.
Postglacial sand and/or gravel	L2	Present inside the boundary of lakes. The sediments in L2 and Z3 consist of the same geological unit.
Clay (glacial and postglacial)	L3	Present inside the boundary of the lakes. The sediments in L3 and Z4a and Z4b consist of the same geological unit.
Surface layer	Z1	The layer is affected by surface processes, e.g. soil-forming processes in the terrestrial parts or sedimentation/transport/erosion in the limnic/marine parts. This layer is present within the entire modelled area, except where the surface is covered by peat or where the model has a lens (under some of the lakes). The layer is 0.1-m thick on bedrock outcrops and 0.6 m in other areas. If the total modelled regolith depth is less than 0.6 m, Z1 will be the only layer. The layer can be connected to a GIS application such as the map of QD or soil type map and assigned properties in accordance with the properties of the deposits.
Peat	Z2	This layer is only present where peat is presented on the QD map. Calculated average depths are used for the layer since too few observations are available for interpolating. The average depth is used for peat above and below the 5 m above sea level. contour line, 1.4 m and 0.4 m respectively. Postglacial sand (Z3) always underlies Z2. If peat is intersecting glacial clay or sand on the QD map, Z4b underlie Z3.
Postglacial sand/gravel, glaciofluvial sediment and artificial fill	Z3	The layer is only present where the surface layer consists of postglacial sand/gravel, glaciofluvial sediment or artificial fill or under Z2 when peat is intersecting glacial clay or sand on the QD map. The layer geometry is interpolated from input data and average values. This may result in a discrepancy between the modelled Z3 and the marine geological map. In the terrestrial parts, Z3 is assigned average depth values for postglacial sand and artificial fill and glaciofluvial sediment. The glaciofluvial sediment and artificial fill are modelled to always be situated directly on bedrock. Z3 as sand is always present under peat (Z2).
Postglacial clay including gyttja clay	Z4a	Z4a is present in the marine area where postglacial clay is the surface layer. In the marine areas, the layer geometry is interpolated from input data and average values. This may result in a discrepancy between the modelled Z4a and the marine geological map. When average values are used, Z4a is always underlain by Z4b.
Glacial clay	Z4b	Z4b is present where glacial clay is the surface layer. Additionally, Z4b is present under Z3 when peat is located next to sand or glacial clay and when sand is located next to glacial clay. In the marine area, the layer geometry is based on interpolation from input data and average values. In the terrestrial area, the layers are assigned calculated average depth values. In the marine area, interpolated Z4b values > 0.5 m are rejected in areas where the geological map shows till or glaciofluvial sediment. This may result in a discrepancy between the modelled Z4b and the marine geological map.
Till	Z5	This layer is present in a major part of the model area. The thickness of the layer is based on interpolation from input data and average values. Z5 is of zero thickness at bedrock outcrops if the total QD depth is < 0.6 m or if the layers/lenses are located directly on the bedrock surface. The lower limit of Z5 represents the bedrock surface, i.e. Z5 represents a DEM for the bedrock surface.
Fractured bedrock	Z6	This layer has a constant depth of 0.6 m and represents the bedrock upper part, calculated from the interpolated Z5. The layer represents a zone with high hydraulic conductivity that has been observed in many of the hydraulic tests within Forsmark.

Since there are large parts of the model area with a low density of input data, the model is mostly built using average values of different deposits calculated from input data. The average values are then assigned to the different domains in the model in relation to the map of QD according to the conceptual model and overall stratigraphical understanding of the Forsmark area. The input data was ranked according to accuracy in the determination of the regolith depth. Observations with lower rank were excluded using a buffering distance of 30 m or 100 m, thus all the observations are not used in the final model. The thickness of the regolith varies within the model area. The RDM is divided into nine sub-domains where the depth and stratigraphy of the deposits are similar. For details regarding the modelling methodology, see /Hedenström et al. 2008/.

4.4 The soils

The upper part of the overburden is referred to as *the soil*. Soils are characterised by diagnostic horizons with certain physical and chemical properties. The soil type developed is a result of the interaction between several parameters, such as the parent material (QD), climate, topography, biota and time. In Sweden, the soil-forming processes have been active since the latest deglaciation. In areas below the highest shoreline, these processes have been active from the time the area emerged from the sea. At Forsmark, the soils are generally quite young and immature since the area has only been above sea level for less than 2,500 years. At several sites, calcite occurs from the ground surface and downwards /Sohlenius and Rudmark 2003/. A study from northern Uppland showed that the depth of the carbonate-free zone increases at higher altitudes /Ingmar and Moreborg 1976/. The high calcite content is reflected e.g. in the pH values of the surface water /Tröjbom et al. 2007/ and in the composition of the flora /Löfgren (ed.) 2008/. The results from the soil type classification and description of the distribution and character of the soil types in the Forsmark area were described and analysed by /Lundin et al. 2004/.

The following soil horizons are used, from the ground surface:

The O horizon is the organic surface layer, which is dominated by the presence of large amounts of organic material in varying stages of decomposition.

The A horizon may be darker in colour than the deeper layers and contain more organic material. In some soils, the lowermost A horizon has been subject to intense weathering and leaching and has a lighter colour than the underlying horizons.

The B horizon is enriched in elements that have been eluviated from overlying horizons. This horizon is often enriched in amorphous iron oxides with or without aluminium compounds.

The C horizon is unaffected by soil-forming processes and referred to as parent material for soil formation.

The soils are classified according to properties /WRB 1998/, which can then be compared with soils from other areas. The predominant soil classes of the Forsmark area are briefly summarised below:

Histosol (HI) – peatland and open mires as well as forested peatland with at least 40 cm peat depth. In the Forsmark area, the Histosol soil is typically covered by a sparse tree layer of birch, pine and alder. Histosols also include the reed areas surrounding many of the lakes.

Leptosol (LP) – shallow soils with less than 25 cm overburden overlaying the bedrock. Leptosols are predominant in local high altitudes in the landscape. This soil type also includes bedrock outcrops.

Gleysol (GL) – moist soils that are periodically saturated with water. This soil type can be found in wetlands not covered by peat, but instead by different types of clay sediments such as gyttja clay.

Gleysol/Cambisol (GL/CM) – fertile forest soils on fine-textured parent material, often located in local depressions in the landscape. The Cambisol is a young soil that develops on fine textured material. The tree layer is dominated by deciduous trees.

Arenosol/Gleysol (AR/GL) – soils along the sea shoreline on sandy sediments.

Regosol/Gleysol (RG/GL) – poorly developed profiles on coarse-grained parent material and characterised by a weak soil profile development as a consequence of its young age. The tree layer is dominated by mixed coniferous forests.

Regosol/Gleysol on arable land (RG/GL-a) – poorly developed profiles on sediment and clayey till soils of the Cambisol type. The soil type covers arable land, pasture and abandoned arable land.

Regosol (RG) – less developed soil on coarse glaciofluvial material found on the Börstilåsen Esker in the eastern part of the area.

5 Results

The description of the regolith at Forsmark is presented in the map of the Quaternary Deposits (QD), the soil type map, and a Regolith Depth Model (RDM), together with results from stratigraphical and analytical investigations. The most detailed description of the surface distribution of QD comes from the central part of the regional model area, where the majority of the site investigations has been carried out. Detailed geological mapping and stratigraphical investigations have been performed within this area /e.g. Sohlenius et al. 2004, Sundh et al. 2004, Hedenström et al. 2004, Ising 2006/.

The presentation below starts with the bedrock and glacial deposits and continues with the postglacial sediments and peat. The surface distribution and the direction of glacial transport are described in the first part of the chapter; thereafter total depth and stratigraphy are discussed. Finally, the physical and chemical properties are described at the end of the chapter. Some features are described separately, i.e. the till stratigraphy near the lakes and wetlands, and the occurrence of a hard, clayey till unit observed at several sites within the investigated area.

In a regional perspective, the Forsmark area is dominated by till in the western part and clay in the central, deepest areas (Figures 5-1 and 5-2). The highest topographical areas are located in the western part of the model area, dominated by till. The Forsmark area is part of a regional occurrence of till with high clay content following the coast from Forsmark southward. Further more, in the county of Uppland there are several large glaciofluvial deposits, mostly eskers, which have a north-south main direction. One of these deposits, the Börstilåsen esker, passes through the Forsmark area along the coast. Figure 5-1 and Figure 5-2 provides an overview of the distribution of QD in terrestrial and marine areas in the Forsmark region.

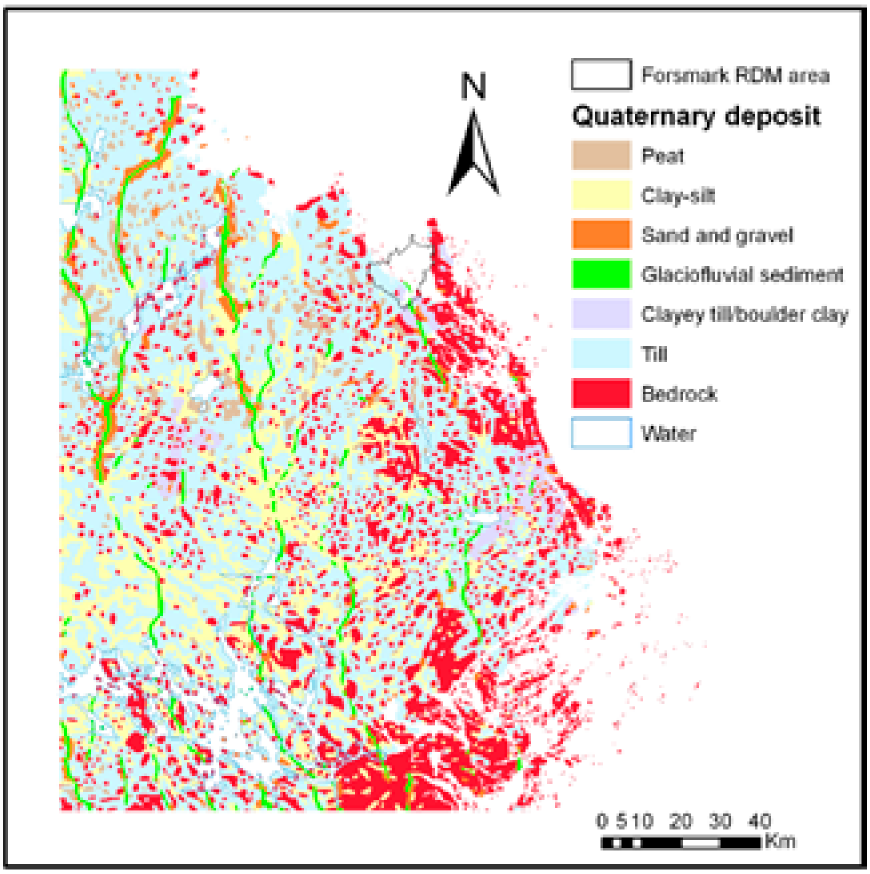


***Figure 5-1.** Map showing the distribution of the QD in central Sweden.*

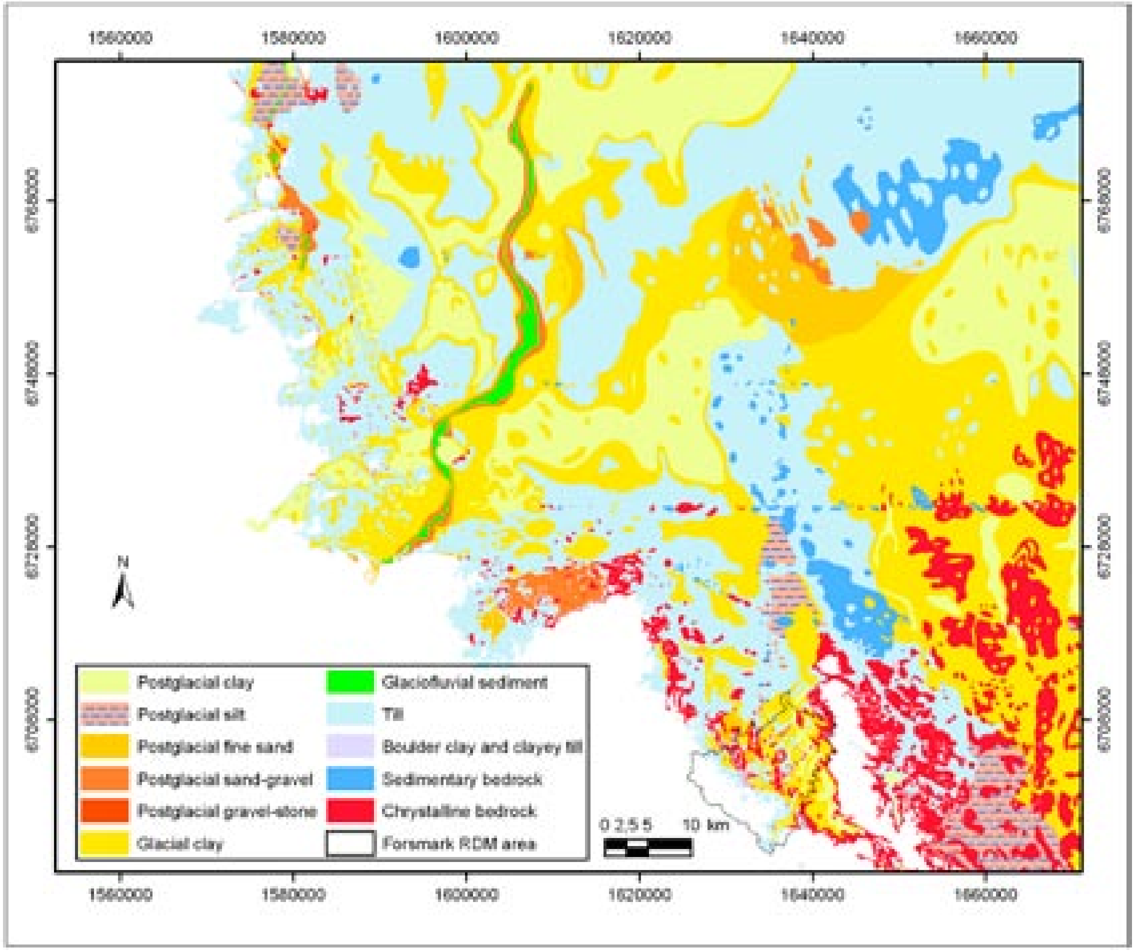


Figure 5-2. *Regional map showing the distribution of QD and bedrock in the marine area.*

5.1 Surface distribution

5.1.1 Bedrock and glacial striae

The bedrock morphology in northern Uppland is characterised by a peneplain, which dips gently towards the north-east /Lidmar-Bergström in Fredén 2002/. A small-scale undulating surface with a few marked lineaments of regional scale characterise the bedrock surface. The highest area lies in the south-west, reaching c 25 m above sea level. The deepest parts are located in the northern part of the model area west of Gräsö, where the water depth is c 40 m. The Digital Elevation Model (DEM) for the Forsmark area is presented in (Figure 5-3).

The composition of the bedrock has been described in detail /Stephens et al. 2007/. The bedrock geological map (Figure 5-4) shows the distribution of different rock types in the Forsmark area. Reddish-grey metamorphic granite (metagranite) is the dominating rock type in the candidate area, and metamorphic tonalite and pegmatite are found towards the south-east. Small bodies of amphibolite are common, however are too small to be included on this map. The bedrock is heterogeneous outside the candidate area. Beside metamorphic granite, granodiorite and tonalite, there are also rocks of volcanic origin present that sometimes contain small iron mineralizations. South-west of the candidate area, dark basic (quartz-poor) rocks, such as metamorphic diorite and gabbro, and ultramafite are common. The age of the granite in the candidate area is 1,865 million years, making it slightly younger than the oldest rocks in central Sweden. Datings also show that between 1,793 and 1,834 million years ago the rock had cooled to about 500°C. There was little ductile deformation after that and the predominant deformation was instead brittle.

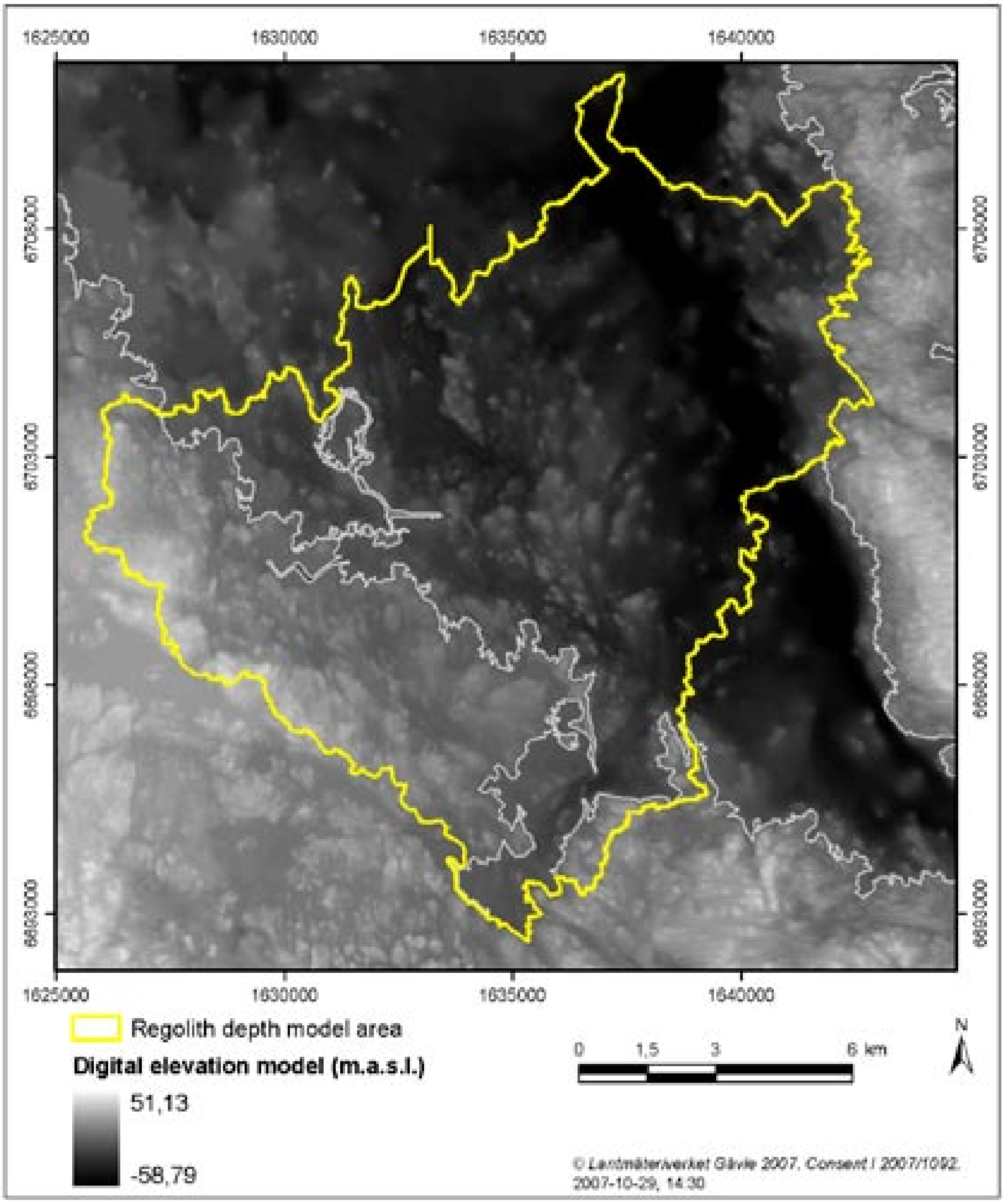


Figure 5-3. *DEM for the Forsmark area /Strömgren and Brydsten 2008/. The highest area lies in the south-west, whereas the lowest part is found in the marine area.*

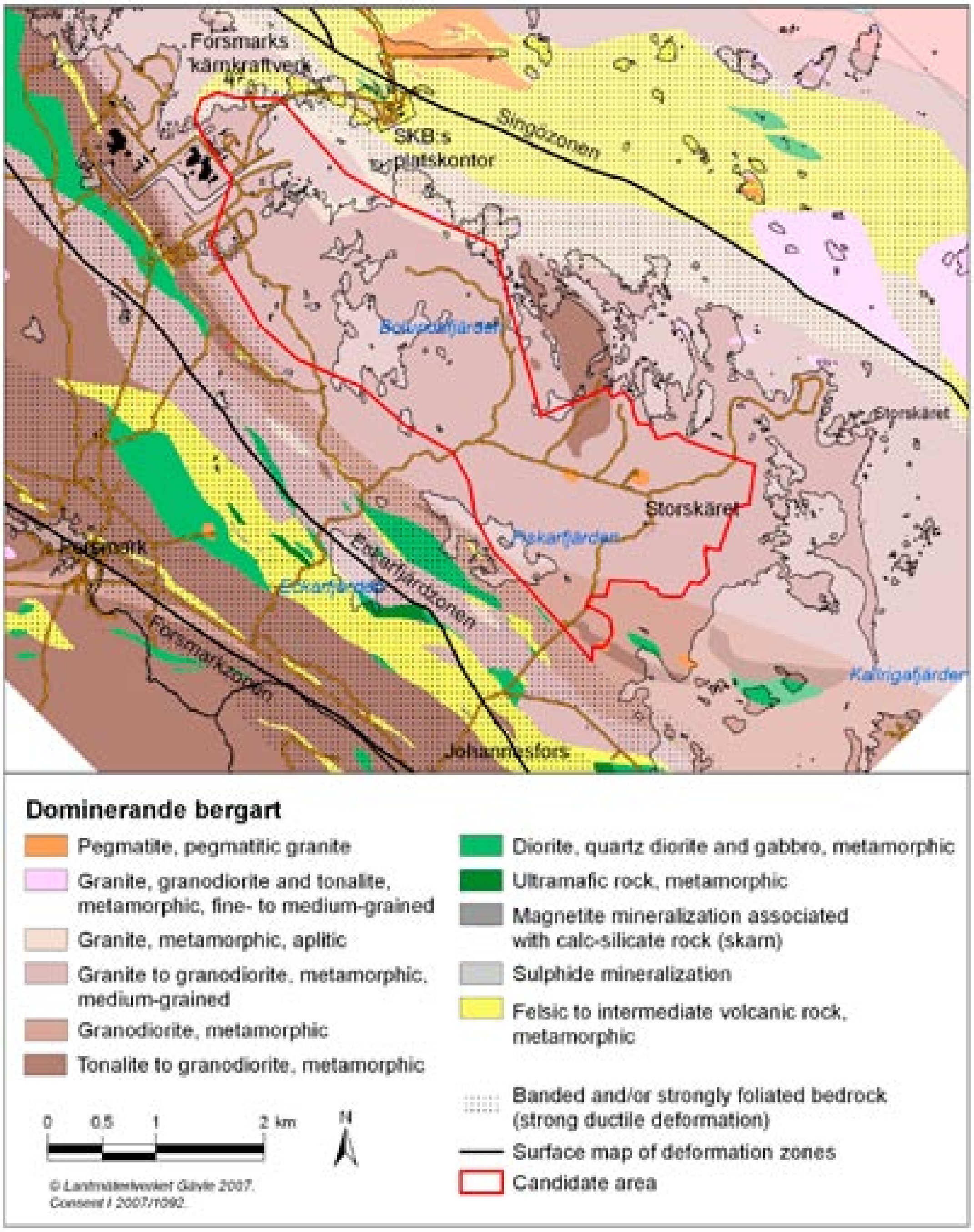


Figure 5-4. *The distribution of the different rock types in the Forsmark candidate area.*

Sedimentary Palaeozoic bedrock is present north of Forsmark on the floor of the Bothnian Sea (Figure 5-2). Fragments of limestone have been transported by glaciers and can be traced in the glacial deposits along the coast of Uppland. Hence, even if this rock type is not observed in outcrops within the investigated area, the Palaeozoic limestone has a large impact on the chemical properties of the regolith, surface water and vegetation in the Forsmark area /cf. Tröjbom et al. 2007/. For a comprehensive description of the geological evolution, see /Söderbäck (ed.) 2008/.

Exposed bedrock or bedrock with only a thin Quaternary cover (< 0.5 m) occupies c 13% of the land area in the regional model area and c 5% of the central part. Areas with low frequency of outcrops are e.g. the eastern part of the investigated area at Storskäret and west of Lake Bolundsfjärden (Figure 5-5). Areas with a high frequency of bedrock outcrops are e.g. the south-western and north-eastern parts of the regional model, e.g. the island of Gräsö. Exposed bedrock occurs frequently along the present shoreline and on several small islands (Figure 5-6). Many of the outcrops were formed by glacial erosion, with smooth, abraded northern sides and rough, steep lees or plucking sides towards the south (Figure 5-7). In the areas close to the present sea level, the bedrock surface is typically unaffected by chemical weathering, hence glacial abrasion is evident on the outcrops. Observations of striae, crescentic fractures and crescentic gouges indicate that ice moving from the north (350–360°) formed the majority of these features. An older ice movement, forming a system of striae from the north-west, is preserved on lee side positions.

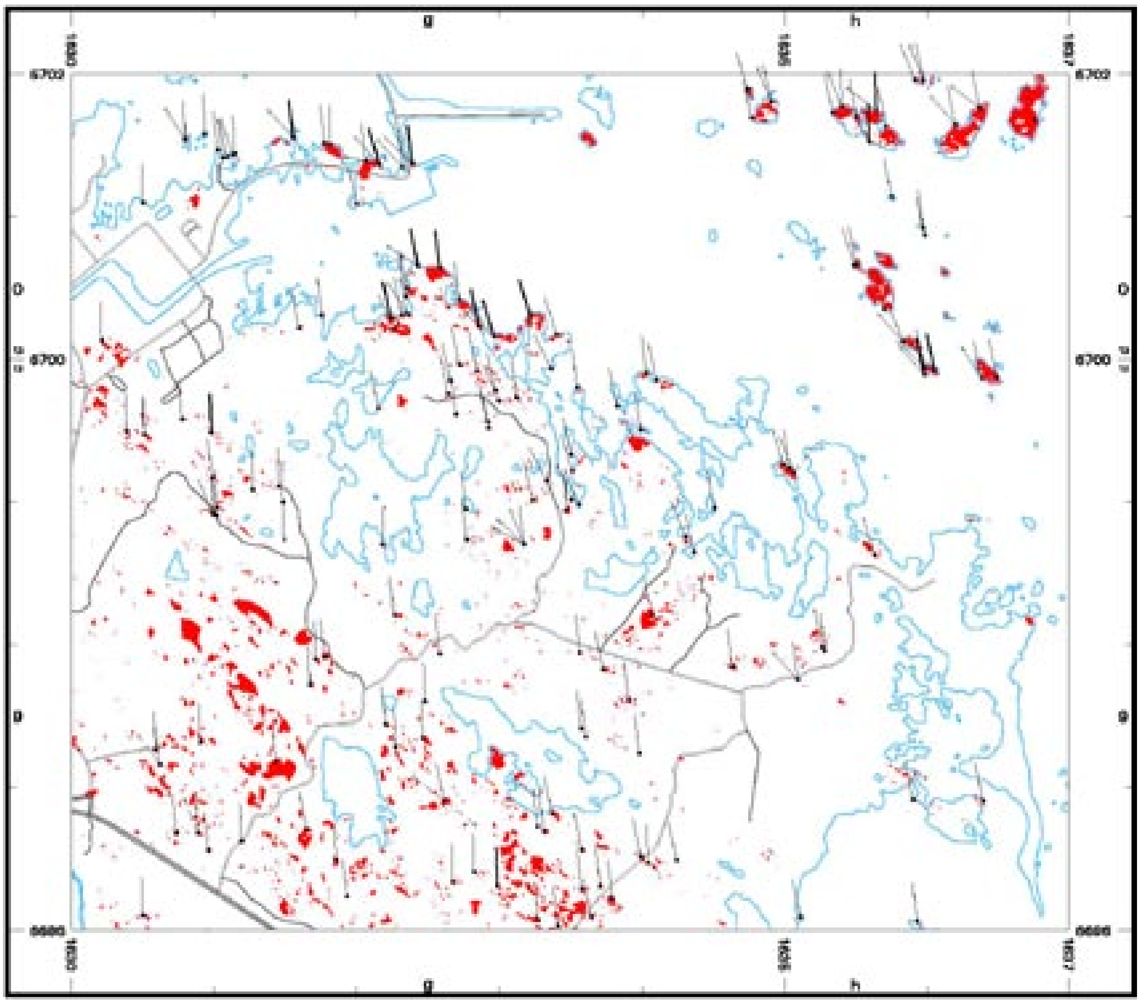


__Figure 5-5.__ Bedrock outcrops (red) and direction of glacial striae in the area of detailed geological mapping. More than one direction of striae has been identified at several sites, representing different directions and generations of ice movements. The youngest striae are marked with a black line and the older striae have one vertical stripe and the even older striae have two or three vertical stripes /Sohlenius et al. 2004/.

Figure 5-6. *A 100×300 m large bedrock exposure at Mickelsbådan (PFM 002753).*

Figure 5-7. *One example of glacial erosion of a bedrock outcrop. A smooth abraded northern side and a rough, steep, plucking side facing the south. Ice moving from the north (350°) formed the striae on the outcrop, from the right in the picture. The site is situated at Mickelsbådan south of the bay Asphällsfjärden (PFM002754).*

In contrast to the solid bedrock outcrops, a different surface appearance was observed at some excavations. Excavation of the Quaternary cover during preparation of Drill Site 5 revealed freshly fractured bedrock with displacement of bedrock blocks and the occurrence of several fractures filled by glacial sediment (Figure 5-8). These features strongly resemble those identified in the superficial rock mass close to the Forsmark nuclear power plant, where vertical displacements near the ground surface of up to nearly one m have been documented /Carlsson 1979/. A preliminary evaluation suggested that the fracturing at Drill Site 5 was a result of the formation and/or reactivation of fractures during glacial time and that the observations at the drill site may be important from a safety assessment viewpoint. For this reason, it was decided to conduct a series of more detailed investigations at Drill Site 5, so that additional information on the character and possibly the origin of these structures could be provided /Leijon (ed.) 2005/. These investigations addressed the Quaternary cover sequence, the bedrock at the ground surface, and the subsurface bedrock down to a depth of c 130 m.

Detailed mapping of the bedrock surface verified the occurrence of a high frequency of open fractures when compared with other areas at Forsmark. Most of these open fractures exhibit signs of either formation or reactivation under late-glacial conditions, although in many cases, judgements in this respect were uncertain. The most prominent features documented were a number of fractures that strike north-east to south-west and dip gently to the south-east. These fractures had apertures ranging up to about 0.20 m and were typically filled with unconsolidated sediment (Figure 5-8b). The bedrock in the hanging wall to these fractures was uplifted and, in some cases, slightly rotated relative to the bedrock in the footwall. Investigations of grain size distribution and reworked microfossils in the filling material revealed a composition resembling that observed in the covering till. It has been inferred that sediment-loaded water flowed into the fractures and was followed by calm sedimentation of the material.

Drillings and ground penetrative radar surveys were carried out to determine whether the disturbances observed at the surface persisted at depth. The presence of anomalous, wide and sediment-filled fractures was verified down to a maximum depth of 10 m. There were no signs of conditions that deviate from those typically encountered within the tectonic lens at Forsmark below this depth. Based on these observations, it was concluded that the observed disturbances are surface-related phenomena concentrated to the superficial rock mass and are not related to faults deeper down in the crust (see also /Carlsson 1979/). The relationship between fractures, glacial striation, fracture-filling and glacial sediment indicate that the fracturing occurred during a late stage of the local deglaciation /Lagerbäck et al. 2005/.

Figure 5-8. *Character of the bedrock surface at Drill Site 5, Forsmark.* ***(a)*** *Glacially-smoothed and striated bedrock. Freshly fractured bedrock is common along the exposed surface. The major fracture in the foreground, which lacks signs of glacial abrasion, was filled with laminated, silty sandy sediment.* ***(b)*** *Laminated silt in an open fracture in the north-western part of the excavated area at Drill Site 5. The site was originally covered by till that has been removed /from Leijon (ed.) 2005/.*

The regolith thickness at Drill Site 5 varied from almost zero to c 5 m. In contrast to the rugged surface morphology of the underlying bedrock, the overburden surface was flat and almost horizontal. Investigations of the north-eastern wall cut revealed two major till units (Figure 5-9). The lower unit is described as a deformation till formed by sedimentation of debris flow, as well as sorted material that was subsequently deformed by moving ice. The upper unit is interpreted as a basal till, most likely deposited by ice movement from the north. It is

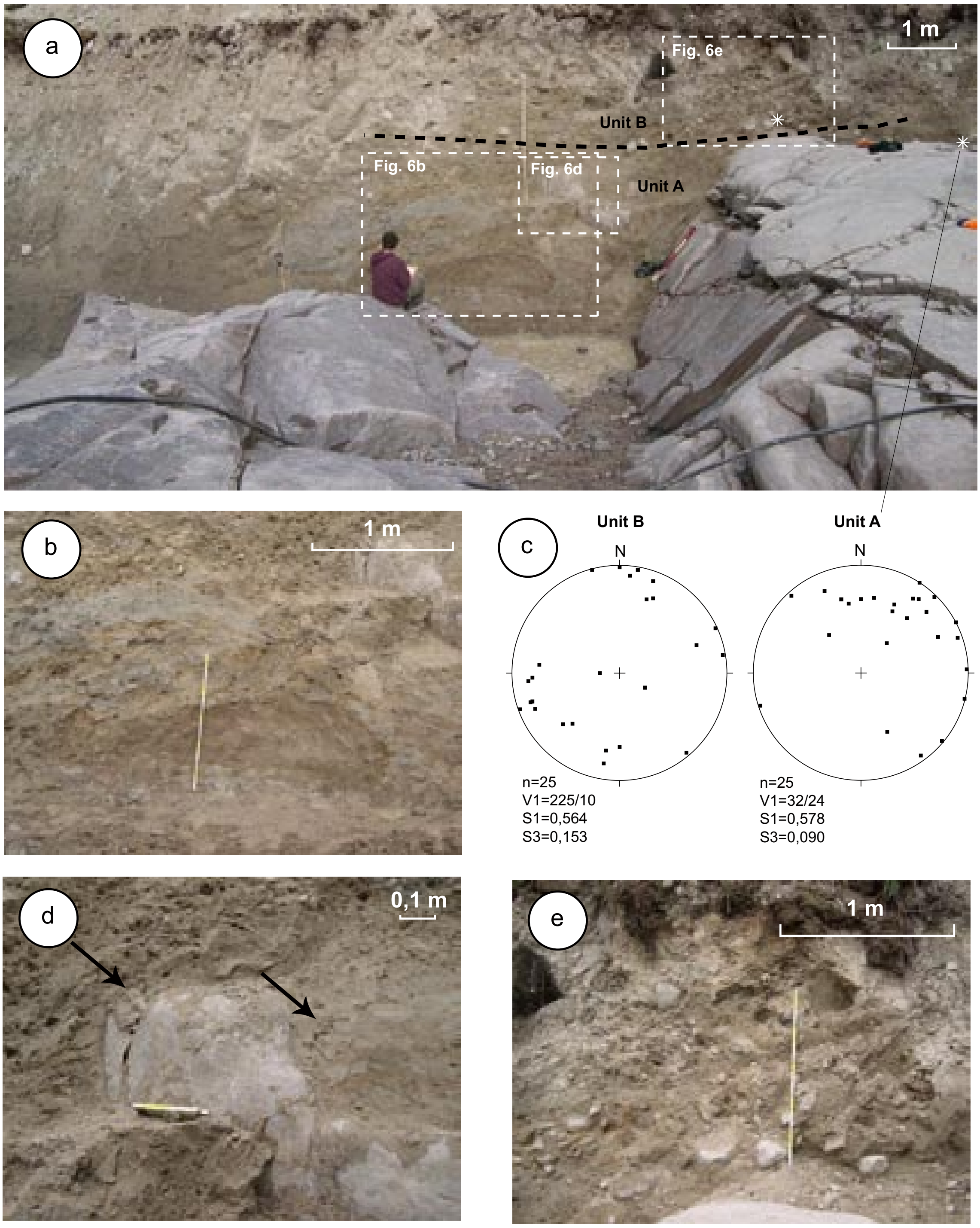


Figure 5-9. *Till in the western wall at the excavations at Drill Site 5.* ***a)*** *Sites for till fabric measurements are marked with *.* ***b)*** *Sandy diamicton with inclusions of silt and sand, Unit A.* ***c)*** *Schmitt stereographic plot (lower hemisphere) of till fabric measurements from Units A and B. V1=eigenvector orientation, S1/S3=eigenvalues.* ***d)*** *Stringers of sand in connection with fractures in the bedrock.* ***e)*** *Sandy till with stones, Unit B /from Leijon (ed.) 2005/.*

likely that both units were deposited during the same glaciation. An attempt to obtain a relative dating of the fractures, the timing and the processes for deposition of the laminated silt and the age of the covering till was made through analysis of reworked microfossils. Samples of laminated sediment collected in the open fractures showed the same pollen signature as the till situated above /Robertsson in Leijon (ed.) 2005/. Pollen analysis of samples from the sediments suggested an original pollen deposition under interglacial conditions, most probably the Eemian. Neither the composition and structure of the sediments nor the pollen flora show any notable deviations from what may be described as typical conditions in the Forsmark area. All samples analysed were rich in pre-Quaternary palynomorphs, suggesting incorporation and transport of material from Palaeozoic bedrock in the Bothnian Sea north of Forsmark, i.e. corresponding to the latest known ice-movement direction of the late Weichselian.

It should be noted that water-laid sediments under uplifted bedrock blocks were not observed during the site investigations of glacial stratigraphy in 21 machine-cut trenches /Sundh et al. 2004/ and may have been overlooked during coring. Additional sites with open fractures and dislocated bedrock blocks, similar to those observed at Drill Site 5, were found after excavating the QD from the central part of the candidate area /Albrecht 2005, Forssberg et al. 2007/. Furthermore, /Lokrantz 2004/ describes similar phenomena that was discovered during construction of a new highway (E4) c 40 km north of Uppsala. Thus, even if the phenomenon is not frequently observed during the Forsmark site investigations, it is plausible that bedrock with a similar appearance to that of Drill Site 5 occurs under the regolith at Forsmark.

5.1.2 Distribution of Quaternary deposits

The proportions of the spatial distribution of different types of deposits are presented in Table (5-1). Altogether, QD cover c 84% of the land area in the regional model area and 3% is covered by artificial fill. Based on comparison with a national database covering 85,000 km^2 in southern Sweden, which in turn is based on geological mapping by SGU (Ser Ae), the distribution of QD at Forsmark shows two significant differences. The Forsmark area has less clay and silt (8% compared to 20%) and more till (65% compared to 41%) as compared with the national averages. A comparison with the surface coverage in the Simpevarp area shows a significantly higher proportion of bedrock outcrops in Simpevarp compared to Forsmark, as well as to national values (Table 5-2). Artificial fill is present in two areas; one around the Forsmark nuclear power plants and one area close to Johannisfors' former pulp mill in the south-eastern part of the model area.

Table 5-1. The spatial coverage (%) of the different types of QD and bedrock exposures from the mapping of the subareas (Figure 2-1). The first column (Area 1–6) gives the proportion within the entire model area, the second column (Areas 1 and 2) represents the terrestrial areas, excluding lakes. The third column (Area 2) gives the distribution from the central part, where detailed mapping has been performed. The right-hand columns (Areas 4 and 5) give the proportion of QD at sea.

	Area 1–6	Area 1 and 2	Area 2	Area 4 and 5
Bedrock exposures	9	13	5	6
Glacial clay	25	4	4	41
Postglacial clay (including gyttja clay and gyttja)	11	4	4	17
Postglacial sand and gravel	4	2	4	6
Till (sandy/clayey)	48.5 (46/2.5)	65 (58/7)	74 (63/11)	30
Glaciofluvial sediment	0.5	1	2	0
Peat	1	8	3	–
Artificial fill	1	3	4	–

Table 5-2. The spatial coverage in % of QD and bedrock exposures in areas covered by SGU geological maps (Ser Ae, scale 1:50000) compared to the terrestrial part of Forsmark (Areas 1 and 2) and the Simpevarp-Laxemar area.

Quaternary deposit	National mean* (SGU Ae)	Forsmark	Simpevarp-Laxemar
Peat and gyttja	9	8	8
Clay and silt	20	8	5
Postglacial sand and gravel	6	2	4
Glaciofluvial deposits	6	1	3
Till	41	65	43
Thin coverage of QD	3		–
Bedrock	15	13	35
Artificial fill	–	3	1
Other deposits	–	–	

* Southern Sweden, predominantly below the highest shoreline.

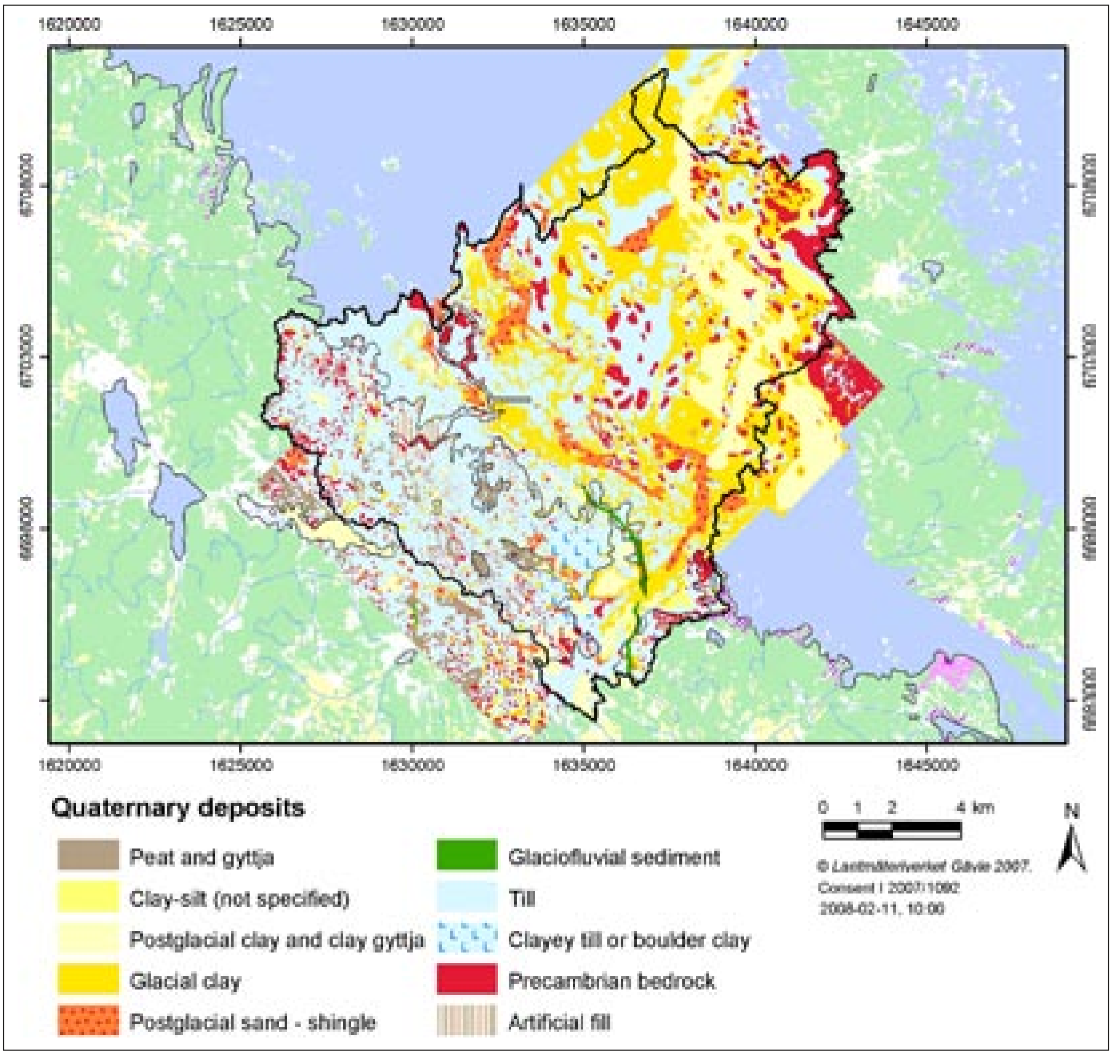


Figure 5-10. The map of QD at the Forsmark area. The map is compiled from six different maps, initially presented at different scales (cf. Figure 2-1).

Till

Glacial till is the dominating QD in the Forsmark regional model area, covering c 65% of the terrestrial areas and 30% of the marine area (Figure 5-10, Table 5-1). The results from corings, excavations and geophysical investigations indicate that the till fills depressions and small-scale crevasses in the bedrock, resulting in a flat ground surface. Only a few morphological features in the form of small moraine ridges (a few metres high) have been identified in the area (Figure 5-12).

Two main characteristics of the till in the Forsmark area are 1) the occurrence of clayey till/boulder clay with a low frequency of boulders in the eastern part and 2) the generally high content of calcium carbonate ($CaCO_3$) in the fine- and gravel fractions of the till.

The clayey till present in the eastern part of the investigated area is part of a regional occurrence of clayey till along the northern coast of Uppland (purple areas in Figure 5-1). Till with a grain size distribution more typical for areas with crystalline bedrock, i.e. sandy and silty till, dominates in the western and central parts of the area. A high content of calcium carbonate ($CaCO_3$) is recorded in a majority of the glacial deposits in the area /e.g. Sohlenius and Rudmark 2003, Hedenström et al. 2004, Hedenström 2004b/. The $CaCO_3$ in the till material has its origin from Palaeozoic limestone bedrock /Axberg 1980/ on the bottom of the Bothnian Sea north of Forsmark, eroded, incorporated and deposited by glaciers /Persson 1992/.

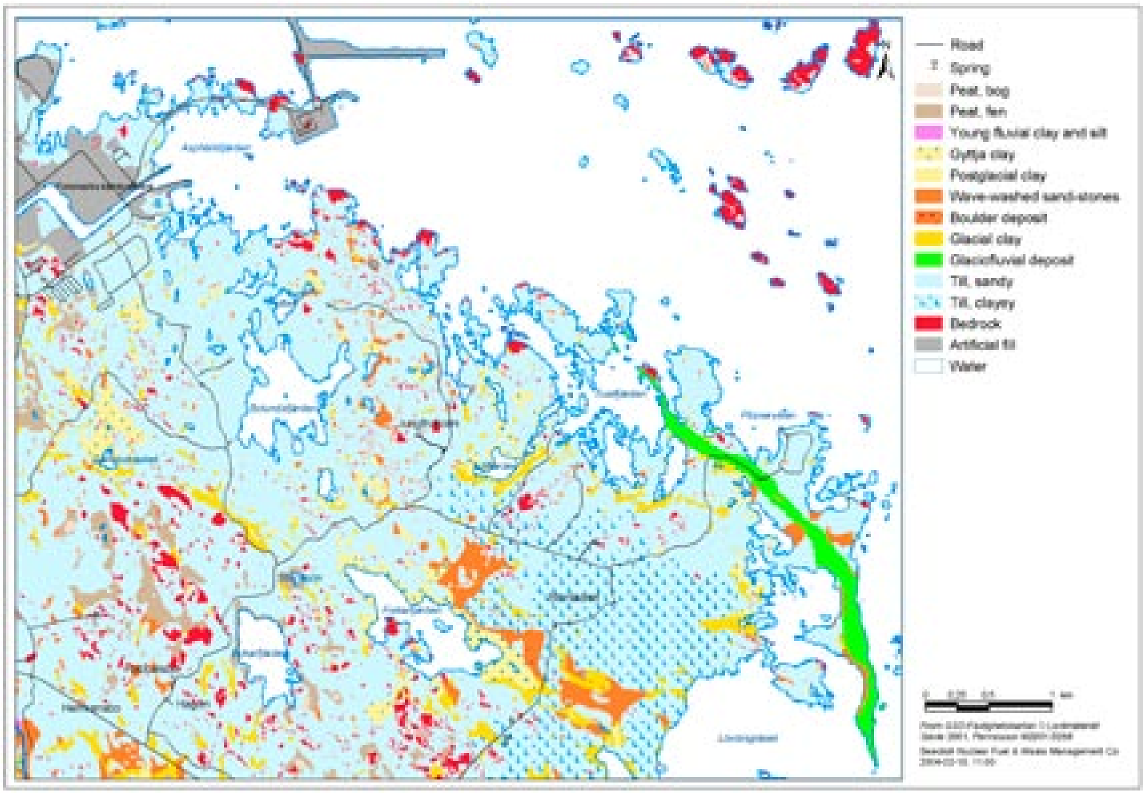


Figure 5-11. The distribution of QD in the central part of the Forsmark area (Area 2 in Figure 2-1), from /Sohlenius et al. 2004/.

Figure 5-12. *Map showing morphological features in the till /from Sohlenius et al. 2004/.*

The complex composition of the till types makes it necessary to perform some generalisations for the Forsmark area. Based on the composition of the surface layer, the till in the terrestrial part of Forsmark has been divided into three areas, Till Areas I, II and III (Figure 5-13). Till Area I consist of sandy and silty till with a medium frequency of superficial boulders. Till Area II consists of clayey till and boulder clay with a low frequency of superficial boulders, whereas Till Area III is dominated by till with a high frequency of large boulders in the surface layer. The spatial distribution of the till areas are based on the surface layers identified during the field investigations and presented on the map of QD /Sohlenius et al. 2004/. The stratigraphic distribution between Units I and II is complex and is not fully understood /Sundh et al. 2004/. In the surface layer, the contact between Till Areas I and II gives the impression of being undulating with small patches of clayey till situated within the area of sandy till. The different till types were especially observed to be mixed in the contact zones. The major part of Till Area III is situated within the Kallriga Nature Reserve and in the coastal marine area, hence no excavating or coring has been performed. In the marine area, the grain size distribution of the till matrix has not been analysed, thus Till Areas I and II have not been extended off shore. The boulder frequency, however, was analysed for the near shore area, thus Till Area III continues off shore (Figure 5-13).

Till Area I constitutes the major part of the Forsmark area, especially in the western and southern parts of the model area. This area is dominated by sandy till with a medium frequency of superficial boulders (Figure 5-14). Areas with a high frequency of superficial boulders, e.g. south-east and north-west of Lake Bolundsfjärden, do occur, but these do not characterise

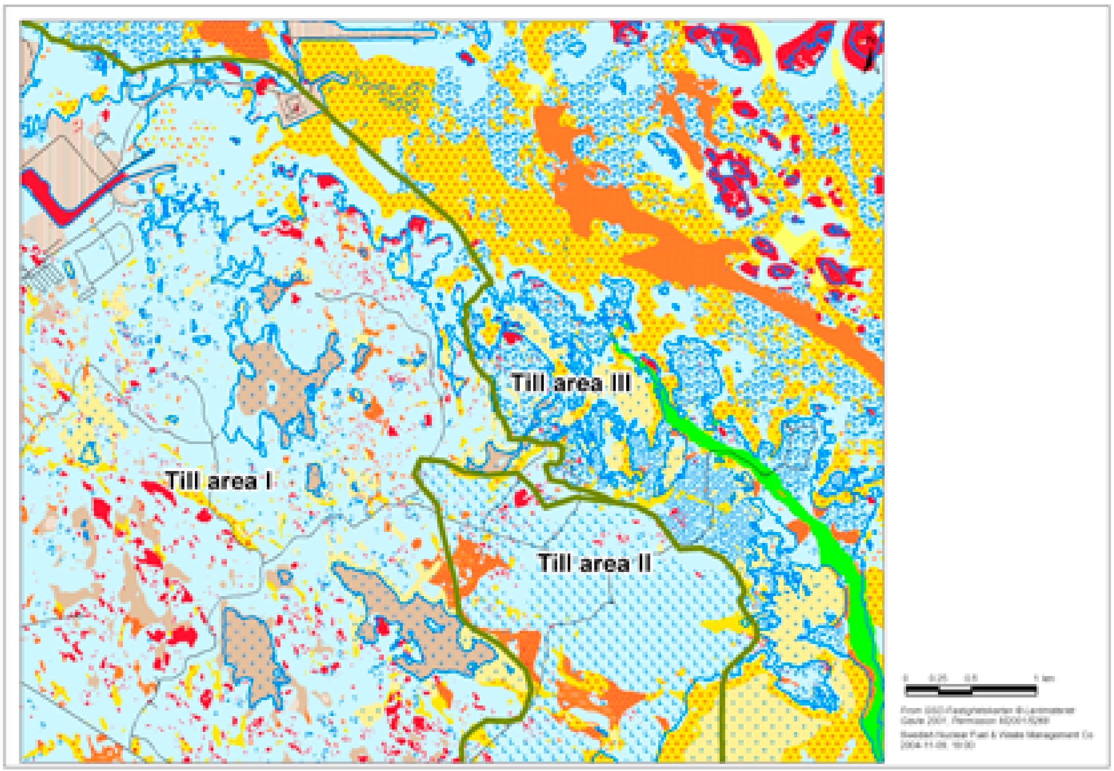


Figure 5-13. The superficial distribution of the three till types identified at Forsmark.

Figure 5-14. Till Area I consists of sandy to sandy silty till. The vegetation is predominantly forest.

the area. Additionally, boulders are often concentrated on the southern side of outcropping bedrock. The volume of the boulders within Area I is often smaller than 1 m^3. The topography is generally flat and gently undulating with numerous, often small, bedrock outcrops at the highest altitudes in the south-western part of the model area and close to the coast. Some small moraine ridges were identified in the vicinity of Lake Bolundsfjärden and Lake Gällsboträsket. These ridges have a few metres relative elevation and are predominantly orientated from north to south (Figure 5-12). There are observations of till classified as sandy-silty till within Till Area I, however, these are not separated on the generalised map. There are also several observations of silty and clayey till located under the sandy till within Till Area I, e.g. at SFM0016, SFM0017 and PFM002581 (see further section 5.2). The petrographical composition of the boulders at the surface of this till area is dominated by metagranite typical for the area around Lake Bolundsfjärden.

Till Area II. The till type in this subarea is dominated by clayey till and boulder clay, i.e. a clay content higher than 5% of the matrix. Clayey till dominates in the eastern part of the model area at Storskäret and on Gräsö Island. The major part of the arable land at Forsmark is located within this area at Storskäret. The frequency of bedrock outcrops is low in areas with clayey till. The boulder frequency is generally low, but stones have frequently been removed from the arable areas and gathered into heaps. The stones are of equal size and notably rounded (Figure 5-15). Within Till Area II, minor areas with a normal boulder frequency occur, exhibiting a various collection of rock types from the Forsmark area. Clay-rich till is generally not common in Sweden. However, on a regional scale, clayey till occurs in north-eastern Uppland from Gräsö Island down to the Norrtälje area (Figure 5-1). Other areas with clay-rich till are found close to sedimentary bedrock, e.g. in the provinces of Jämtland and Skåne.

Till Area III. In the eastern part of the investigated area close to the glaciofluvial Börstilåsen Esker, the till is characterised by a high frequency of large boulders with a volume often exeeding1 m^3 (Figure 5-16). The frequency of exposed bedrock outcrops is low within Till Area III. The boulder frequency in the shallow marine area is high, thus Till Area III was extended off shore. In the deeper marine area, neither boulder frequency nor the composition of the matrix was analysed.

The frequency of bedrock outcrops is low within Till Area III, however the petrographical composition of the boulders, dominated by metagranite, is to a high degree similar to that of the local bedrock /Bergman and Hedenström 2006/. At some sites, there are joints in the exposed bedrock which sometimes make it difficult to distinguish the angular boulders from fractured bedrock outcrops. Areas completely covered by boulders were identified at the islands of Dundersborg, Lill-Tixlan and Stor-Tixlan. The boulder fields are located close to bedrock exposures on the south-western slope of these islands. It is suggested that the boulder fields have been transported a short distance from the original bedrock outcrop (Figure 5-17). Lagerbäck points out the deficit of bedrock outcrops in boulder-rich areas in Uppland and suggests a short transport for the boulders /Lagerbäck et al. 2005/. Till Area III is part of a regional zone of till with a high frequency of boulders following the coast south to Östhammar and then continuing further south /Persson 1998/. Stratigraphical investigations in boulder-rich areas have shown that most boulders are situated close to the ground surface and that they have only been transported a short distance from the original bedrock outcrop /e.g. Bergman and Hedenström 2006/. These boulder fields probably represent an intermediate stage of a process of local, late glacial rupturing and quarrying, while the fractured uplifted bedrock found at BP5 represents an initial stage of the process.

Figure 5-15. *a) Heaps of rounded stones in the arable area at Storskäret. b) Arable land at Storskäret. The frequency of boulders is low, but stones commonly occur in the clayey till.*

Figure 5-16. *Concentration of large boulders in the area close to the glaciofluvial Börstilåsen Esker in Till Area III.*

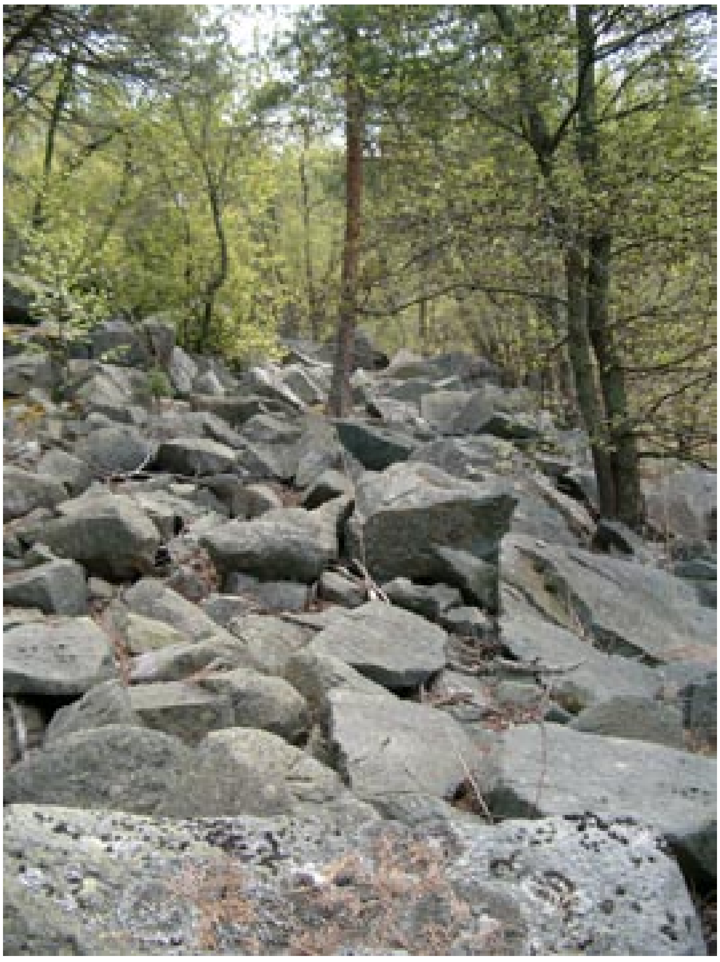


Figure 5-17. *Angular boulders cover the surface at Dundersborg (PFM002907).*

Glaciofluvial sediment

Only 1% of the land area at Forsmark is covered by glaciofluvial sediments (Table 5-1, Figure 5-1). This area is predominantly represented by the small Börstilåsen Esker, which passes through the south-eastern part of the model area. The Börstilåsen Esker is the largest glaciofluvial deposit in the Östhammar region and can be followed from Harg, situated c 30 km south of Forsmark (Figure 5-18). In comparison with other eskers found further south and west around Lake Mälaren, the Börstil esker is small. The crest of the esker is affected by wave-washing in the southern parts, resulting in a flat, sandy surface. The part of the esker located within the Forsmark model area has a distinct crest. Wave-washing has resulted in a raised shingle shoreline consisting of well-rounded stones in the surface (Figure 5-19). In the south-western part of the area designated for detailed mapping, a very small area was observed that consisted of glaciofluvial sand and represented the final tip of the Stockholm esker (Figure 5-11).

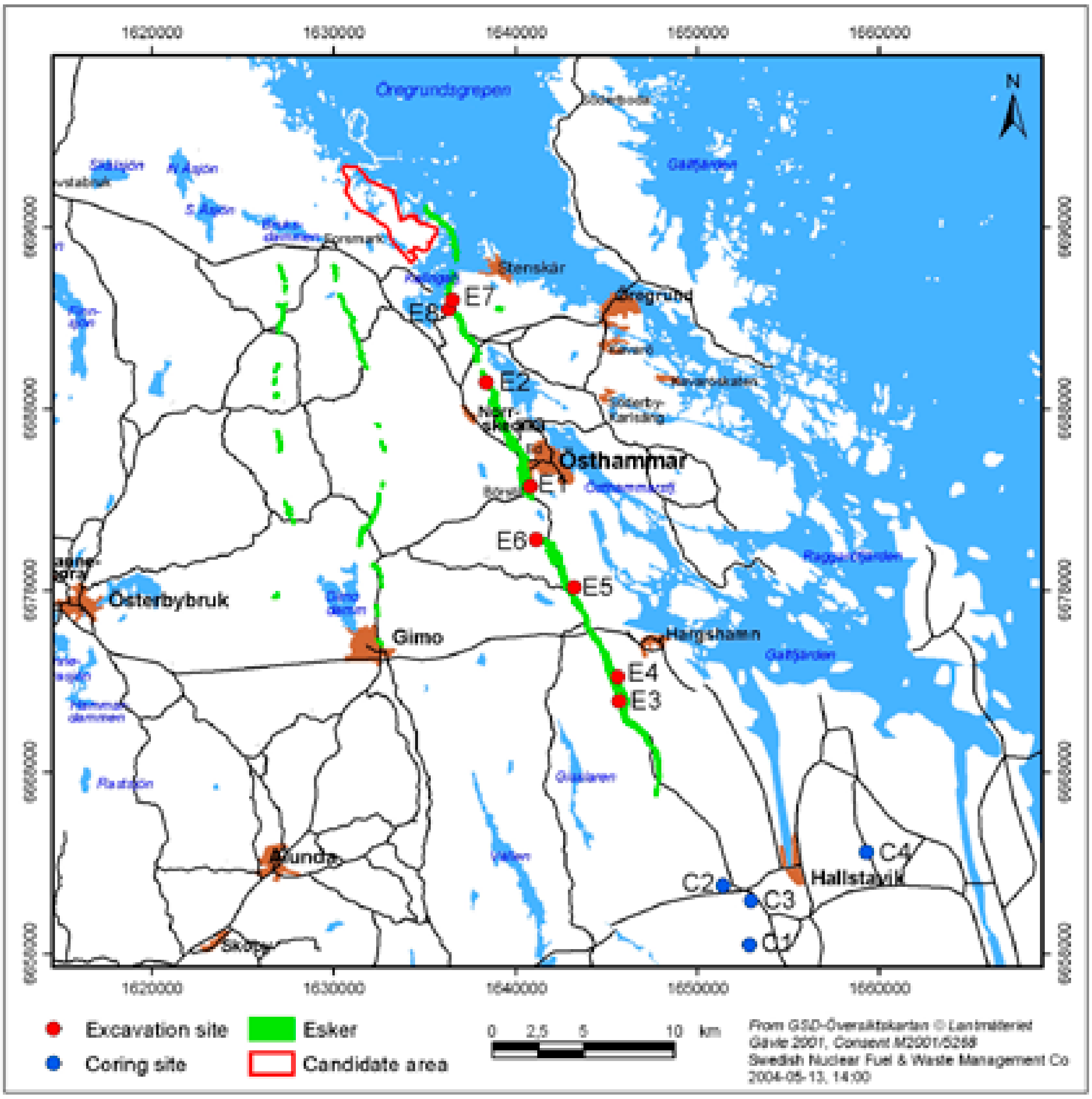


Figure 5-18. Map showing the sites included in the stratigraphic investigations by /Lagerbäck et al. 2004, 2005/. Location and name of excavation (E) and coring (C) sites. E1 Börstil, E2 Lindersvik, E3 Hultet, E4 Kråkmötet, E5 Lädra, E6 Marka, E7 Örnäs, E8 Östansjö, C1 Hammarby, C2 Kristinelund, C3 Söderängen and C4 Kusby.

Figure 5-19. *A raised shingle beach at the crest of the glaciofluvial Börstilåsen.*

Fine-grained glacial sediment

The distal glaciofluvial sediments represented by glacial clay and silt were deposited in stagnant water some distance from the retreating inland ice front. The areas covered by glacial clay in the terrestrial area are generally small and are concentrated in local depressions, such as the bottom of lakes and small ponds. These small patches in the terrestrial area only constitute c 4% of the surface (Table 5-1). These deposits are often only a few decimetres thick and are probably remnants of erosion that occurred when the site was located at the bottom of the Bothnian Sea. Glacial clay is also found in association with lakes or wetland, e.g. south-east of Lake Fiskarfjärden and south of Lillfjärden. The uppermost surface of these localities often has a thin cover of organic sediment such as gyttja, gyttja clay or clay gyttja or postglacial sand or gravel.

In off shore areas, glacial clay occurs more frequently, covering c 40% of the surface in the marine area. The largest areas are found in the areas with a water depth of > 6 m (Table 5-1 and Figure 5-10). Both in the terrestrial area and off shore, a layer of postglacial sand and/or gravel often covers the glacial clay, interpreted as the result of erosion and transportation of sand/gravel on the bottom.

Stratigraphical investigations of fine-grained glacial sediments were conducted on the flanks of the Börstilsåsen Esker south-east of the Forsmark candidate area /Lagerbäck et al. 2004, 2005/. Altogether, 48 trenches with an overall length of c 900 m were excavated at 18 sites located in conjunction with glaciofluvial eskers within north-eastern Uppland (Figure 5-18). The primary objective of the excavations was to search for traces of late- or postglacial faulting. The process of any eventual dislocation of the bedrock may have been associated with high magnitude earthquakes that could have produced characteristic distortions in waterlogged sandy or silty sediments. Thus, fault movements may be indicated either directly by distinct dislocations manifested in the bedrock surface or the covering regolith or indirectly by seismically-derived deformations of certain types of QD.

In almost all the trenches, sequences of varved glacial clay and silt showed distortions, interpreted as the result of sliding or folding along the gentle slope of the eskers. Slabs of clayey and silty deposits have detached along planar failures parallel to the bedding and then slid down the slope to cover older sediments. These deposits vary from plates of more or less undisturbed sediments (Figure 5-20) to strongly folded sequences (Figure 5-21) or a chaotic mixture of all kinds of sediments without any primary structures preserved (Figure 5-22). It was not possible to date the individual sliding events, but from the occurrence of a marker horizon, the so-called spot zone, and the deglaciation history /Strömberg 1989/, it appears that the most intense sliding occurred at least several hundred years after local deglaciation, i.e. they are of postglacial age. The reason for the sliding was probably settling and dewatering of the waterlogged, underlying glaciofluvial deposits covered by fine-grained sediments. There is no evidence of simultaneous sliding at the investigated sites, something that would indicate influence of external forces, e.g. earthquakes, but this alternative cannot be totally excluded /Lagerbäck et al. 2005/. The erosion and re-deposition of sediments have probably contributed to the levelling of the upper surface close to the esker in the southern parts.

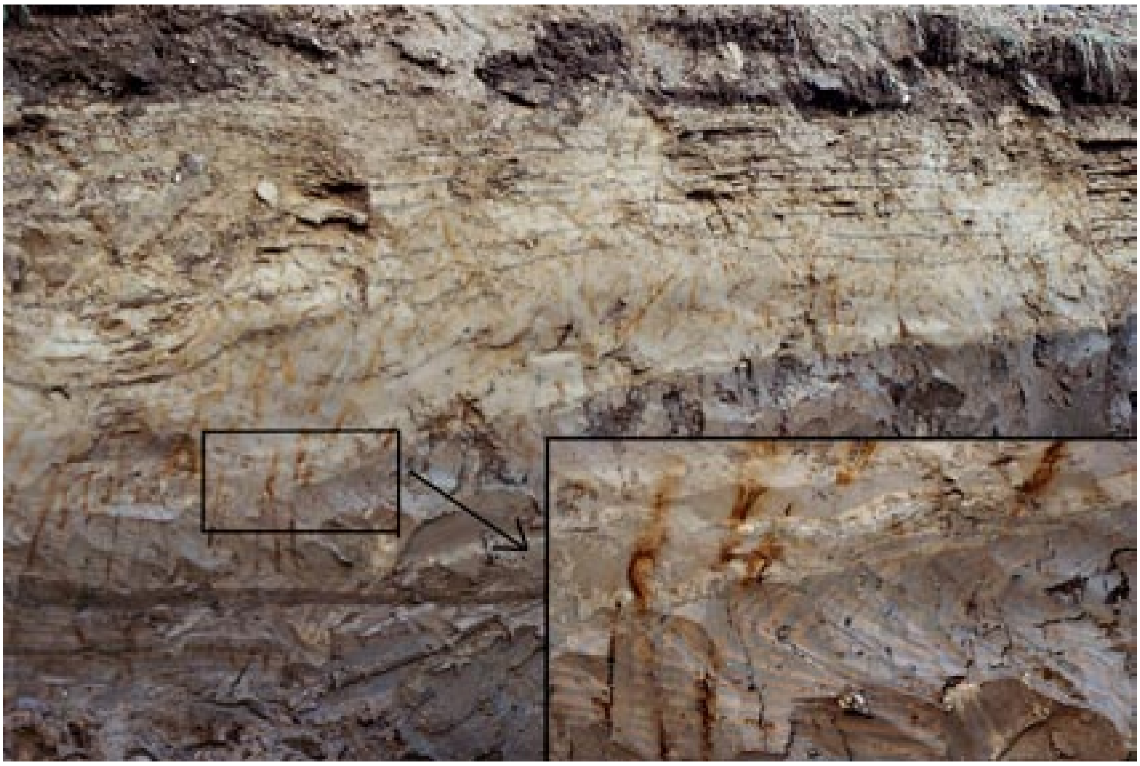


Figure 5-20. *One of the excavations at the Börstilåsen Esker shows illusory stratigraphy due to graceful sliding at Örnäs (E7 in Figure 5-18). An almost undeformed slab of thick-varved, sandy silt (light coloured with thin, dark layers of clay) has come to rest on varved glacial clay. The uppermost bed consists of ploughed top-soil rich in pebbles and cobbles. The close-up photo in the lower right-hand corner shows the slip surface with drag folds in the upper parts of the clay. The dislocation is interpreted as a result of sliding when the site was located on the bottom of the Baltic and the sediments were waterlogged.*

***Figure 5-21.** Gently folded silt and fine sand at Östansjö, E8 in Figure 5-18.*

***Figure 5-22.** Chaotically-mixed slide deposits of fine sand, silt and glacial clay at Hultet, E3 in Figure 5-18.*

Postglacial deposits

The postglacial deposits at Forsmark are of these main types: sand and gravel, clay gyttja and gyttja and peat. After the deglaciation, the Forsmark area was situated below the Baltic Sea up until the last few thousand years and the central part of the candidate area was below sea level up until less than one thousand years ago. Thus, the formation, erosion and relocation of postglacial deposits have been mainly taking place on the floor and in the water column of the Baltic Sea. These processes are still active in the areas located under sea level, as reflected in the accumulation of postglacial clay in the protected and/or deeper areas. In the terrestrial areas, postglacial sediments and peat are formed in the many wetlands, ponds and lakes.

Postglacial sand and gravel has been recognised during the geological mapping in the terrestrial and marine area, as well as in corings in lakes and mires /Sohlenius et al. 2004, Elhammer and Sandkvist 2005, Hedenström 2004a/. The postglacial gravel and sand often superimpose glacial clay and are interpreted to mainly represent deposition after erosion and transport by currents on the sea floor. A large number of small areas are covered by postglacial sand and gravel, however, the spatial coverage is only 4% of the mapped area (Table 5-1). The largest area of postglacial sand in the terrestrial area is recorded north-east of Lake Fiskarfjärden where the sediment has accumulated in a sheltered position.

Organic deposits occur frequently in the surface of the wetlands. Both peat and clay gyttja, alternatively gyttja clay, were identified in the wetlands during the field inventory. Peat formation starts after the basin is uplifted from the Baltic and filled in with sediment, hence the peat thickness is generally a function of elevation. Based on the surface distribution of organic deposits, the terrestrial area has been divided into two general domains based on whether the site is located above or below the 5-m isoline (Figure 5-23). The first domain includes the organic deposits in the south-western part, Organic Domain A, while the organic deposits in the north-eastern part are included in Organic Domain B. The difference in composition of the organic deposits in these two areas is basically a result of how much time has passed since their emergence from the sea. The QD at 0.5-m depth is displayed on the geological map. Actual peat accumulations thicker than 0.5 m are predominantly found in subarea A. This is the highest area that has been situated above sea level long enough for peat to form. Altitudes from the 5-m isoline and upwards are the approximate heights where the wetlands have a peat thickness greater than 0.5 m. These areas have been isolated from the Baltic for more than approximately 800 years. The peatlands identified at Forsmark are both fens and bogs. The bogs are few in number and still young, while rich fens are the dominating peatland /Löfgren 2008/.

The wetlands situated in subarea B may have peat cover thinner than 0.5 m and have therefore generally not been marked as peat on the QD map. Stratigraphical observations of 82 sites show that the average depth of the peat layer is 0.4 m in Area B. The wetlands located at low levels have not been above sea level long enough for actual peat to form.

In the youngest part of the regional model area, postglacial clay, including gyttja clay, clay gyttja and gyttja, occurs frequently as the superficial QD and covers many small (less than 50×50 m) areas. With a similar distribution pattern as the postglacial sand and gravel, these small deposits are high in number, but cover only 4% of the terrestrial area (Table 5-1). Extensive areas of postglacial clay are e.g. along the shore of Lake Fiskarfjärden and Lake Gällsboträsket (Figure 5-24). The Forsmark area has less clay, gyttja clay and postglacial sand and gravel (10%) compared to the national averages (26%), (cf. Table 5-2). This is probably the result of effective erosion and reworking of the fine-grained sediments in deeper areas.

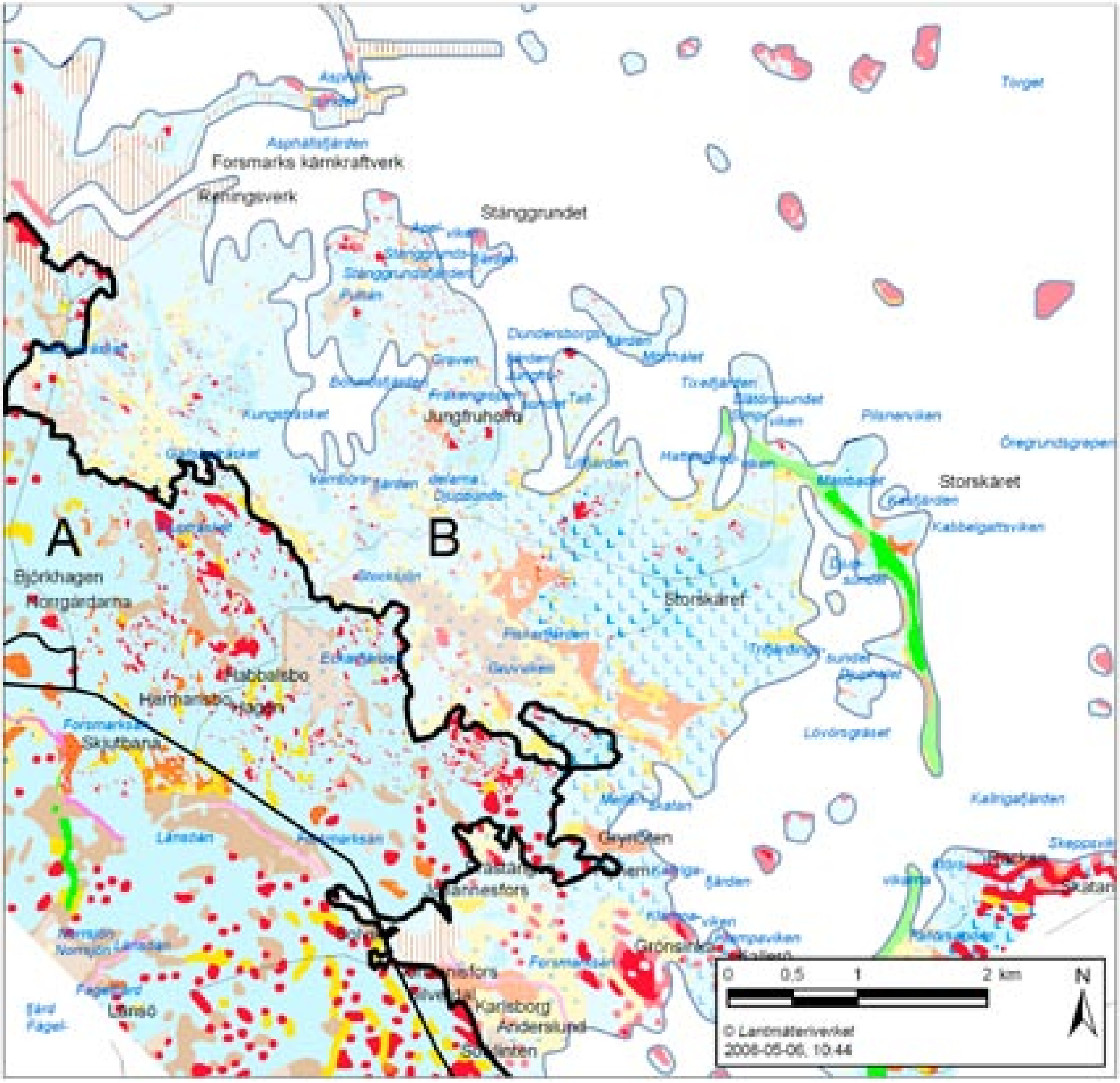


Figure 5-23. Distribution of the two generalised domains for organic deposits at Forsmark. The domains are based on altitude. Domain A represents areas above 5 m above sea level, whereas Domain B represents organic deposits in the areas from 0 to 5 m above sea level.

Figure 5-24. *At the fen surrounding Lake Gällsboträsket, the surface layer is covered by clay gyttja. The basin is to a large extent overgrown with reed (Phragmites) /from Sohlenius et al. 2004/.*

Artificial filling

There are two areas with artificial filling within the Forsmark regional model area (Figure 5-10). The largest one is the area around the nuclear power plant where the filling material consists mainly of blast bedrock and regolith excavated from the sea bottom /Carlsson 1979/. For example, large volumes of rock and unconsolidated deposits were produced during construction of the channel for cooling water to the power plants. At an excavation south of the reactor at Forsmark 3, 2 m of artificial filling material was exposed on top of the bedrock (Figure 5-25). The sediment had an appearance very similar to the till from Till Area I. A grain size distribution analysis of a sample collected from a 1.2-m depth from a pit in the filling material was analysed and classified as sandy till.

The second area with artificial filling material is located at Johannisfors in the south-eastern part of the regional model area. The deposit at Johannisfors consists of calcareous waste material (Swedish *mesa*) from an old pulp mill. The mill was closed after a fire in 1932 and no industrial activity has been performed at this site since. Prior to the pulp mill, industrial activities such as iron manufacturing and timber preparation took place at the site. These types of deposits are known to contain pollutants, mainly heavy metals, originating from the pulp production. The Johannisfors site has been the object of an assessment on the risk of pollutants in the filling material, performed by The County Administrative Board of Uppsala (Sw: *Länsstyrelsen Uppland)* /Jansson 2005/.

Figure 5-25. *An excavation close to the reactor Forsmark 3 shows the artificial filling material consisting of blast bedrock material and re-deposited till (PFM004760).*

Quaternary deposits in the off shore area

The distribution of QD in the off shore area has been investigated in several projects, using different methods and equipment. The resulting maps were constructed according to interpretations of geophysical data (Areas 4 and 5 in Figure 2-1) and/or corings or probings (Area 6 in Figure 2-1). The stratigraphical distribution of the different geological units is well documented along the measuring lines for the survey vessels /Elhammer and Sandkvist 2005/. For a comprehensive description of the marine eco system at Forsmark, see /Wijnbladh et al. 2008/.

Compared to the QD map for the terrestrial area, the sea floor is mainly covered by clay rather than till (Table 5-1). The QD in the marine area are dominated by glacial and postglacial clay, together covering c 58% of the sea floor, compared to less than 10% of the terrestrial area. In the shallow coastal area, gyttja and gyttja clay covers 15% and postglacial sand and gravel 29% of the area. The clay deposits are predominantly overlain by a thin layer of silt, sand or gravel, i.e. similar to the distribution in the terrestrial area. The area covered by glacial till in the terrestrial area is c 75%, but only c 30% on the sea floor. The difference is partly the result of the erosion of fine-grained material, e.g. postglacial clay, and sedimentation in the deeper areas on the bottom of the sea. The discrepancy between the compositions of the QD presented on the different maps may also to some extent be exaggerated by the different methods used in the mapping.

Based on the results of the study by /Elhammer and Sandkvist 2005/ the boulder frequency on the sea floor in Area 4 (Figure 2-1) between approximately 3 m and 6 m water depth was interpreted. The major part of the boulder-rich area is located within the till areas, but small areas are also located at sites described as bedrock on the marine geological map (Figure 5-27). During interpretation of sediment echo-sounding, it is likely that there were difficulties distinguishing between bedrock/fractured bedrock and boulder-rich till. The distribution of the boulder-rich areas indicates that the boulder-rich area or fractured bedrock observed close to the Börstilåsen Esker continues in the off shore area.

The thickness of the regolith in the marine area varies between 0 m and 42 m. The clay in the marine area mainly occurs in areas with water deeper than 6 m. The postglacial clay especially is concentrated to the deeper areas (Figure 5-26). Two belts with thick regolith are located from the bay Kallrigafjärden towards the north-east and along the coast line towards the north-west, approximately at the position of the Singö regional fracture zones. These belts closely follow the coastline (see further the section describing the Regolith Depth Model, section 5.2.1).

In coastal areas exposed to currents and erosion from wave-washing, glacial deposits such as till and glacial clay are exposed at the surface. This clay, however, is often covered with a layer of postglacial sand and/or gravel. The typical stratigraphy consists of glacial clay with an erosive contact to postglacial gravel, followed successively by finer fractions upwards. The stratigraphy indicates that erosion and sediment transport has been active on the bottom. A similar stratigraphy is often identified in the terrestrial areas of the lakes and in the marine areas.

In the areas too shallow for the regular marine geological investigations, including the inner part of the Kallrigafjärden Bay, mapping of the distribution of QD was carried out in two separate activities. During a field course arranged by Stockholm University, stratigraphical investigations were performed from a small boat along two perpendicular profiles in the Kallrigafjärden /Bergkvist et al. 2003/. Additional investigations were performed along the shallow coast where the bottom substrate was investigated along profiles through corings and probings in order to present a geological map for the areas between the detailed terrestrial map and the marine geological map /Ising 2006/. In the terrestrial area, the stratigraphical investigations of the wetlands have shown that accumulation of clay gyttja and gyttja probably started prior to emergence from the Baltic in basins located in a sheltered topographical position. This has also been recognized at several sites in the shallow coastal area. For example, in the bays of Kallrigafjärden and Tixelfjärden, algal gyttja and clay gyttja are presently accumulating in sub-basins unaffected by erosion (Table 5-3). Accumulation bottoms are also located e.g. in the shallow basins close to the Börstilåsen Esker. In the exposed areas, glacial deposits dominate the bottom substrate, indicating recent erosion and/or transport of sediment. The variation between accumulation and erosion bottoms is seen clearly in a stratigraphical profile from the inner part of the

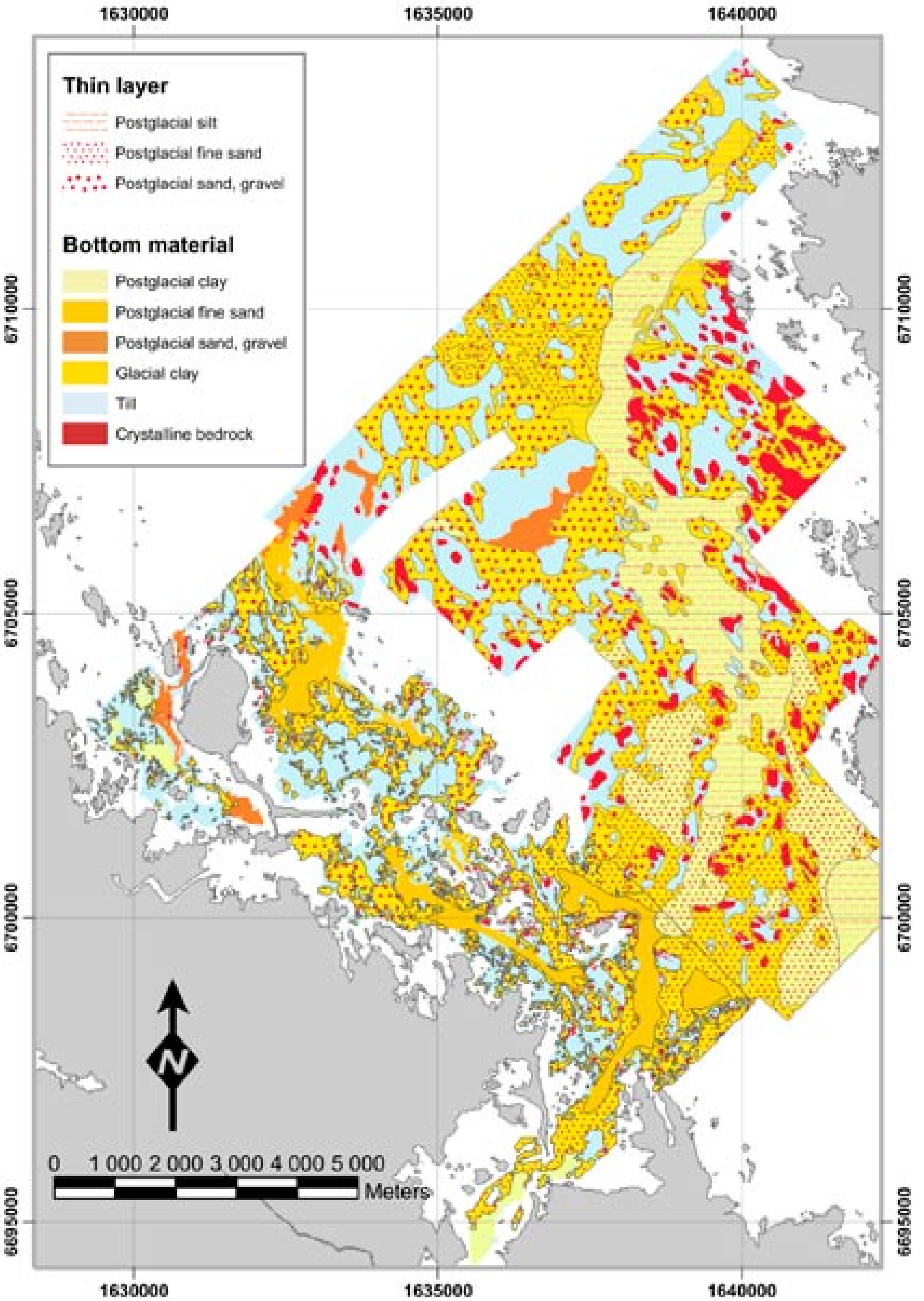


Figure 5-26. *The distribution of QD and bedrock exposures in the marine area. Compared to the terrestrial area, clay is more wide spread on the bottom of the sea.*

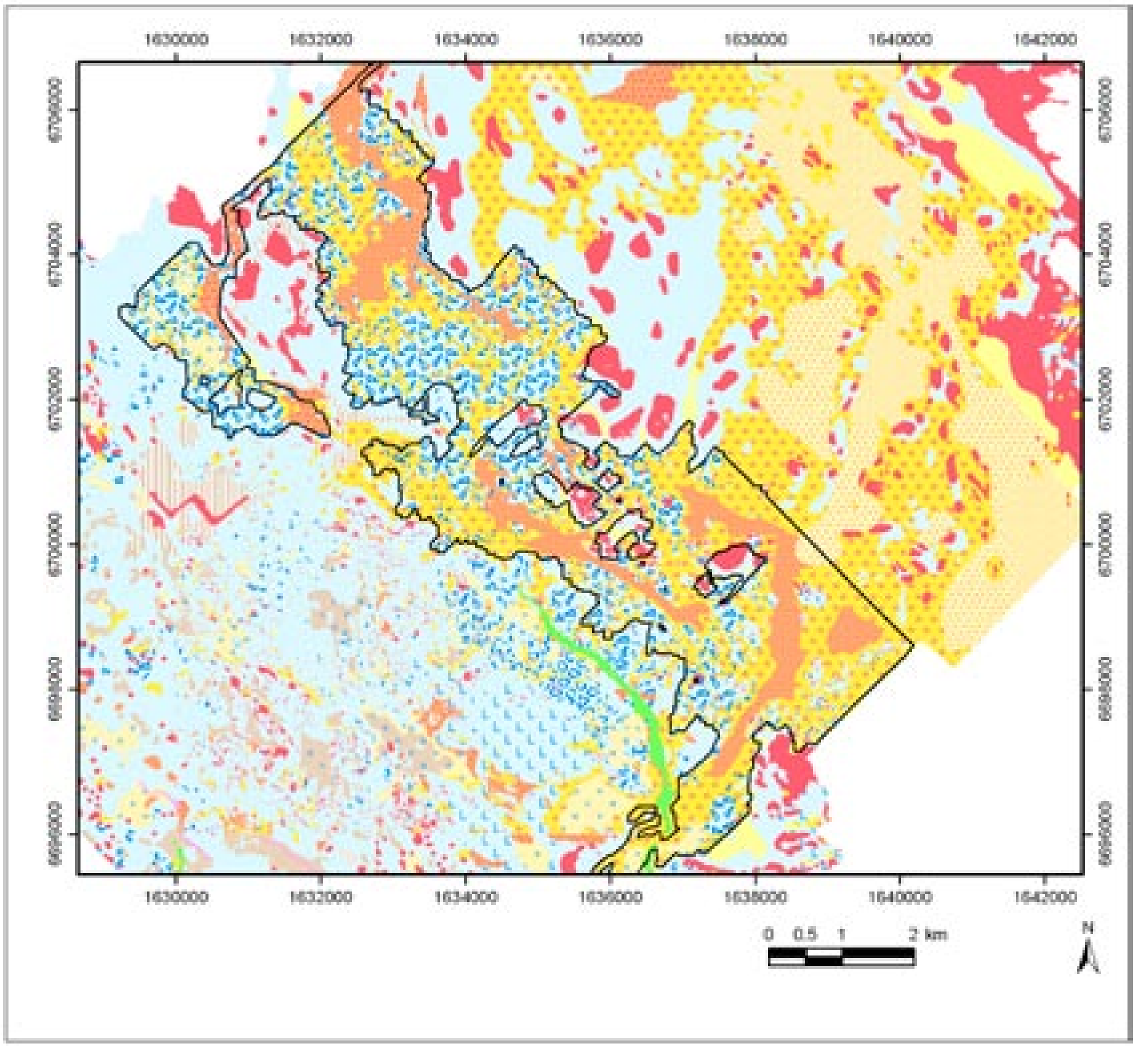


Figure 5-27. Areas with a high frequency of boulders in the terrestrial area and on the sea floor.

Kallrigafjärden Bay. In the central part of the profile, till is the QD at the surface layer, hence no accumulation takes place in this area, whereas a c 2-m deep layer of gyttja clay and clay gyttja covers the bottom in the eastern and western parts of the basin /Bergkvist et al. 2003/. No postglacial sediment has accumulated close to the mouth of the outlet from the River Olandsån whereas the discharge from the River Forsmarksån is contributing with organic sediments to the Kallrigafjärden bay (Figure 5-28).

Table 5-3. Summary of some of the more complete sediment stratigraphy from different coastal areas /Ising 2006/. All depths are presented as metres below the water surface.

	Kallrigafjärden		Tixelfjärden		Jungfrufjärden	Asphällsfjärden
	PFM006074	PFM006076	PFM006054	PFM006062	PFM006046	PFM006111
Algal gyttja	1.75 – 1.97	3.77 – 4.36	2.12 – 3.24	1.15 – 2.05	1.80 – 2.30	Absent
Clay gyttja	Absent	Absent	Absent	2.05 – 2.24	Absent	Absent
Postglacial sand-gravel	1.97 – 2.20	4.36 – 4.70	3.24 – 3.43	2.24 – 2.31	2.30 – 2.40	1.30–1.60
Glacial homo-geneous clay	2.20 – 5.57	4.70 – 5.90	3.43 – 3.80	2.31 – 2.70	2.40 – 4.00	1.60–2.50
Glacial varved clay – silt	5.57 – 6.31	5.90 – >6.60	3.80 – 4.95	2.70 – >5.09	4.00 – 4.20	

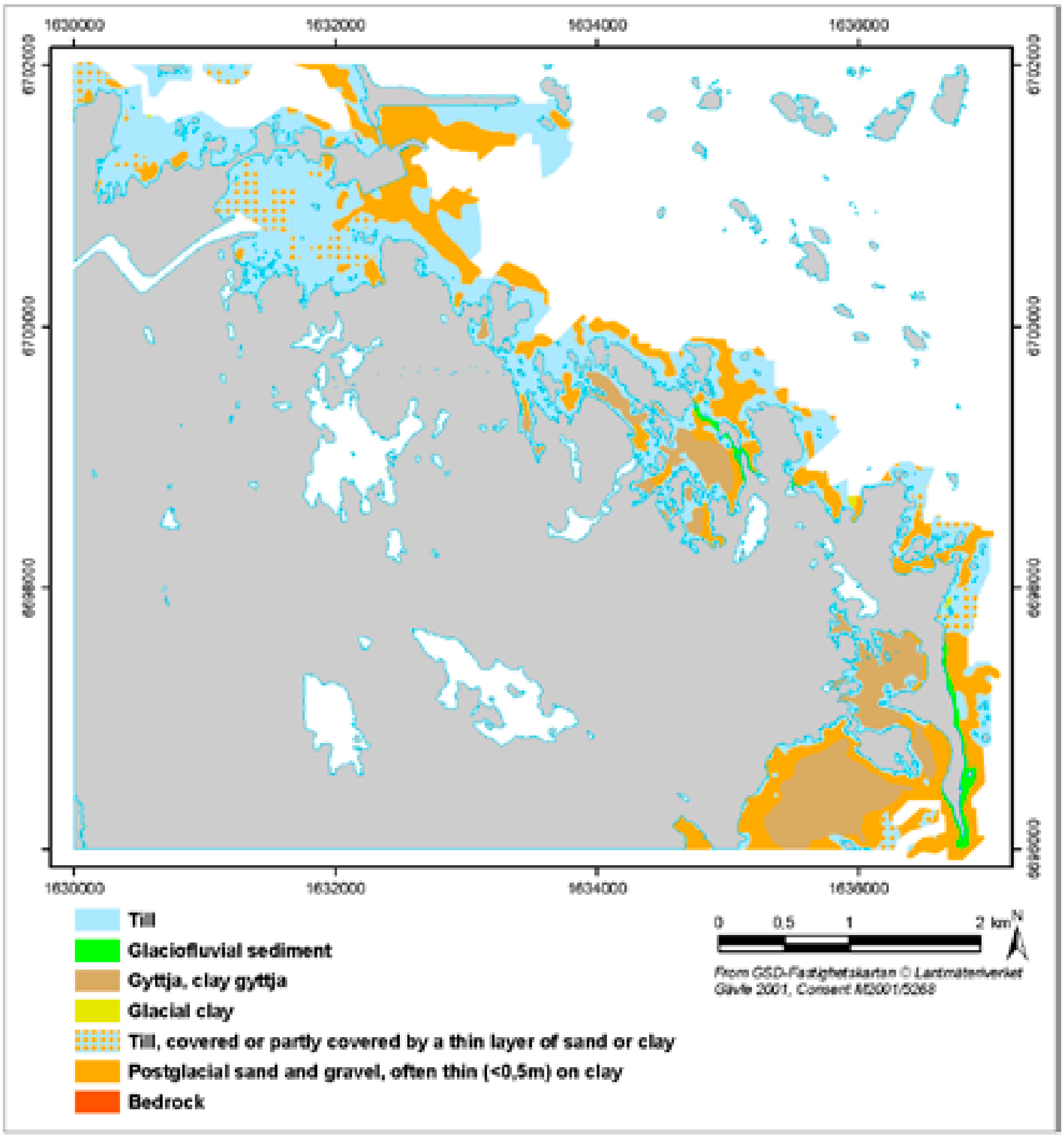


Figure 5-28. *The distribution of QD in the shallow coastal areas, based on interpretations of probings and corings /Ising 2006/.*

The QD map covering the shallow coastal area (Figure 5-28) is based on interpretation of corings and probings in the upper sediments /Ising 2006/. In Figure 5-29, the stratigraphical columns and bottom substrate of each investigation point are presented. It is obvious from the distribution pattern of gyttja and clay gyttja that the protected areas are accumulation bottoms, whereas the areas more exposed to waves and currents are characterized by erosion or transport.

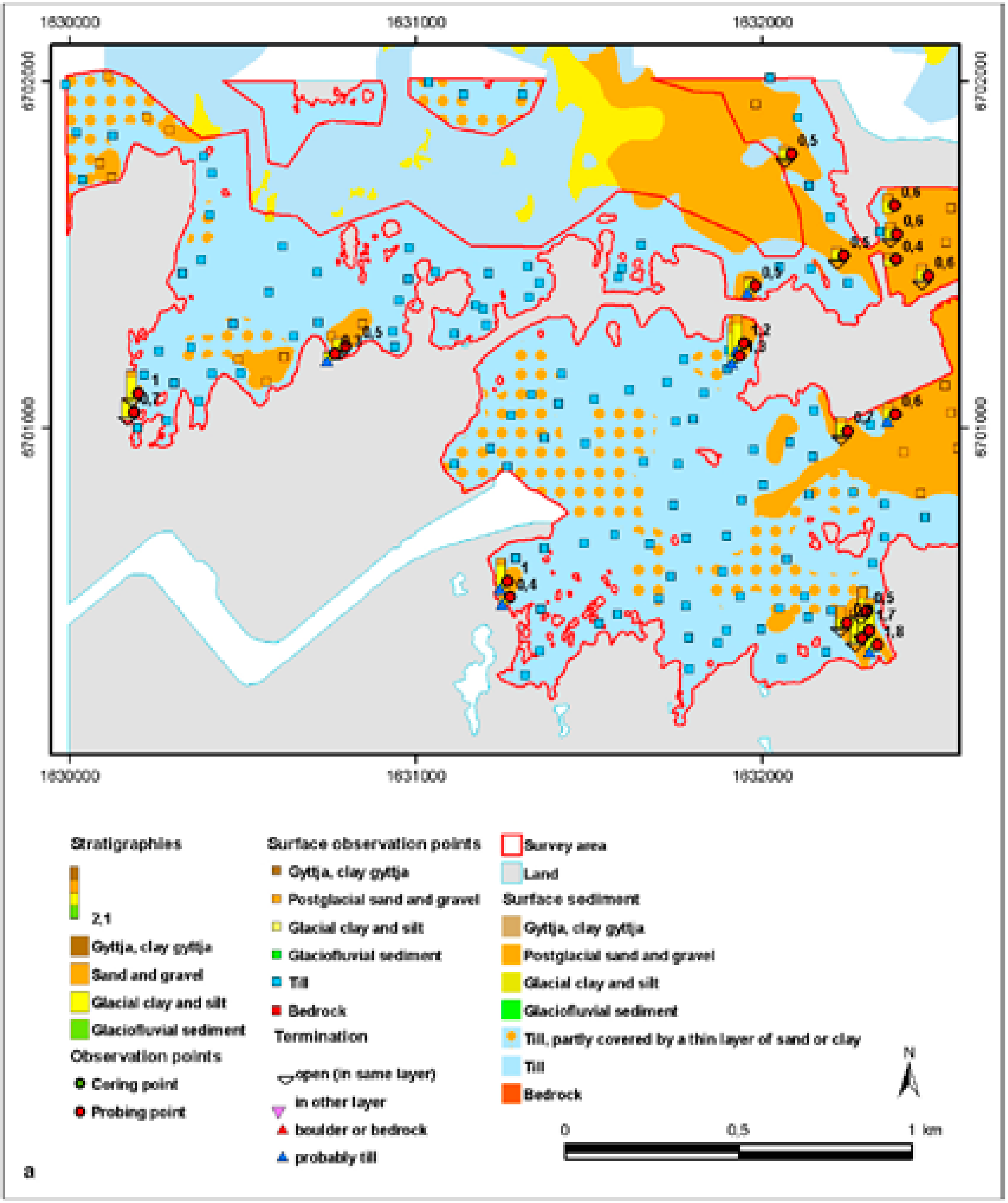
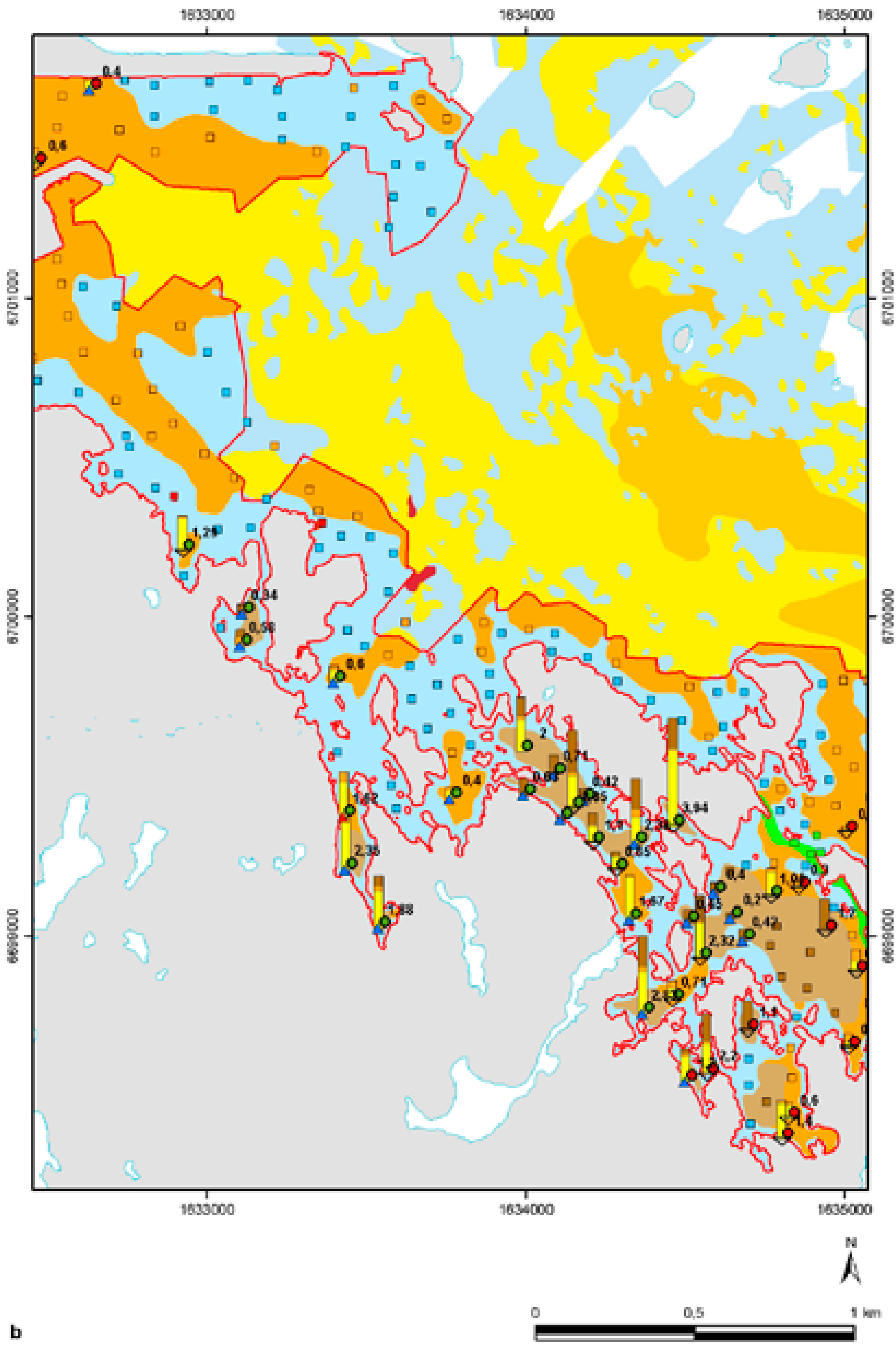


Figure 5-29. *A–C. Observation points and stratigraphic columns used for the construction of the map shown in Figure 5-28. The label at the stratigraphic column displays the penetrated sediment depth.* ***A)*** *The western part of the area, dominated by till.* ***B)*** *The central part of the area characterised by sand in the outer parts and gyttja in the Jungfrufjärden Bay and Tixelfjärden Bay.* ***C)*** *The south-eastern part of the area with sand and gravel around the Börstilåsen Esker and large quantities of clay and gyttja in the Tixelfjärden Bay and Kallrigafjärden Bay.*



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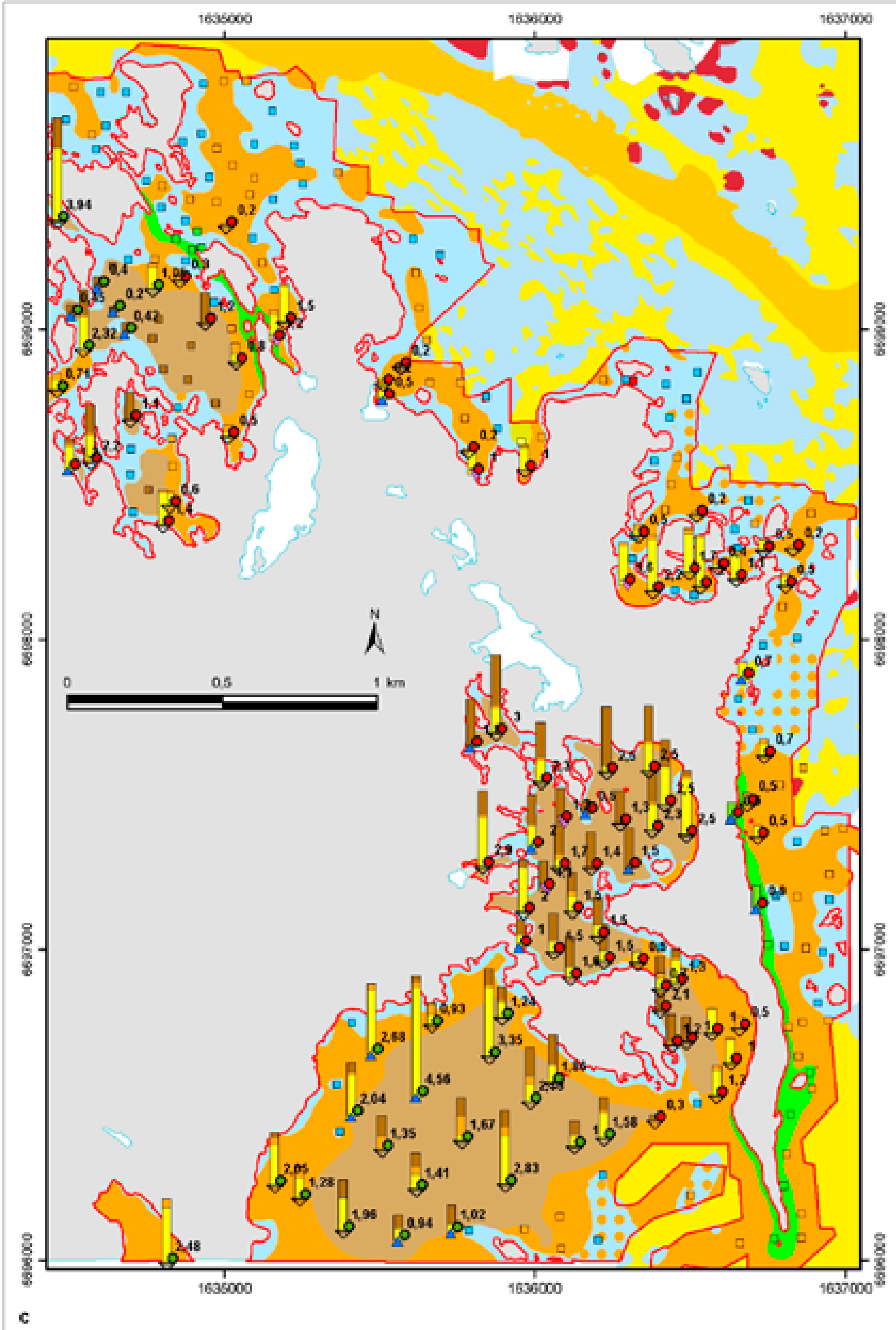
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5.1.3 Distributin of soils

A map showing the spatial distribution of different soil classes was produced within the site investigations /Lundin et al. 2004/. The map presented in Figure 5-30 is an updated version of the soil type map where a GIS analysis was based partly on the detailed map of QD /Sohlenius et al. 2004/. The distribution of the soil types as presented in the updated map is presented in Table 5-4. Eight classes were defined to characterise the main soil conditions in the Forsmark area. The class names are in accordance with the soil classification /WRB 1998/, although in many cases, the classes have been slightly modified or extended to cover the characteristics of the Forsmark area.

The physical properties of the soils at Forsmark area are similar to other land types found in large parts of Sweden /Lundin et al. 2004/. The considerable influence of calcareous soil material favours nutrient-rich conditions that, in these fairly summer-warm conditions, provide a rich and diversified flora. However, the phosphorus (P) in calcareous soils is usually not easily assessable, hence this compound will only provide a minor nutrient input. The soils in the Forsmark area are typically immature, poorly-developed soil types on till or sedimentary parent material, which is influenced by calcareous material /Lundin et al. 2004/. The dominating soil type is Regosol but six other soil classes also occur. Soils influenced by water, e.g. Gleysols and Histosols, are also frequently found (Figure 5-30). Typical soils for Sweden are Podsols, but this soil type has not yet developed in the Forsmark area. The poor soil development is the result of Forsmarks young age, since most of the candidate area emerged from the sea during the last 1,500 years. A description of the classes and the criteria for the map classification are summarised below.

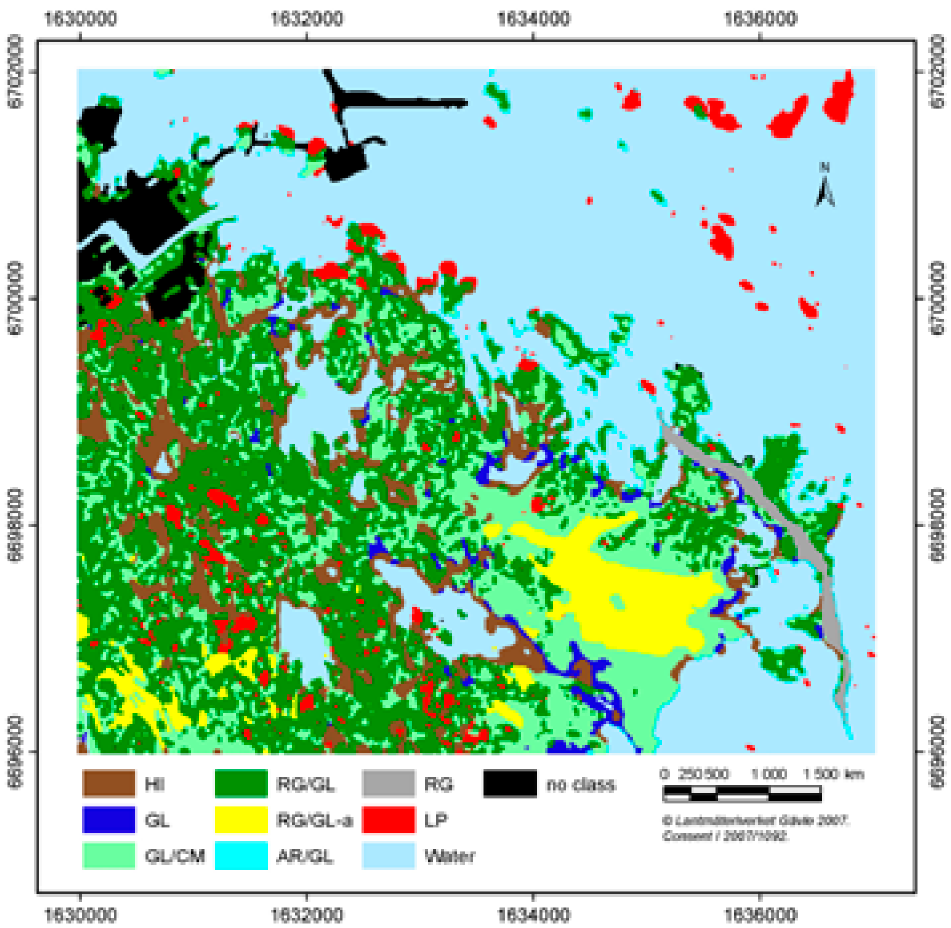


Figure 5-30. The spatial distribution of the soil types in the Forsmark regional model area /updated after Lundin et al. 2004/.

Table 5-4. Distribution of the dominating soil classes for the central part of the Forsmark area.

Code	Soil class	Forsmark area (%)
	Unclassified	5.1
HI	Histosol	11.2
GL	Gleysol	2.3
GL/CM	Gleysol/Cambisol	24.4
RG/GL	Regosol/Gleysol	42.2
RG/GL-a	Regosol/Gleysol on arable land	6.8
AR/GL	Arenosol/Gleysol	1.8
RG	Regosol	1.5
LP	Leptosol	4.7

Histosol – HI

This class covers the peatland soils and includes open mires and forest-covered peatland. Histosol comprises organic soils of at least 0.4 m depth. In the Forsmark area, the Histosol soils are typically covered by a sparse tree layer of birch, pine and alder. The definition of Histosols has also been extended to include reed areas surrounding many of the lakes, although these reed belts often grow directly on till. This class was assigned to areas with a ground layer of the "Peatland" type or the "Not peatland (Wetland)" type in case the field layer was sedge-reed. Furthermore, the areas classified as peat according to the map of QD were also included.

Gleysol – GL

This class include moist soils that are not peatland, e.g. swamp forests. Gleysol represent soils that are periodically saturated with water. This leads to reduced conditions and gives rise to the typical gley properties, which should be found within a depth of 0.5 m. The soil wetness is moist and the parent material is coarse-textured mineral soil. The humus type is peaty mor. Forests include spruce and deciduous trees and herbs dominate the field layer. This class was assigned to areas with a ground layer of the "Not peatland (Wetland)" type. Peat areas according to the QD map were excluded, as well as the areas where the field layer was sedge-reed. The reed belts surrounding the lakes were not included in this soil class although they normally would be, thus the histosols may be over represented at the cost of gleysol.

Gleysol/Cambisol – GL/CM

This class covers fertile forest soils on fine-textured parent material often located low in the landscape. Cambisol is a young soil that develops on fine textured material and has no visible horizons in the topsoil. Below the topsoil, the mineral soil has developed into a distinct B horizon. The humus form is of the mull type. This class was assigned to areas where the tree layer consisted of deciduous trees and where the field layer was of the herb or herb-heath type. Areas with a forest type dominated by spruce, mixed forest, young birch, or without a tree layer (possible clear-cuttings) were included in this class if they had a high topographical wetness index (TWI 8). Further, all areas of the previously mentioned forest types were included if they were located on clayey till. All areas in this class had a ground layer of the moss type (i.e. no wetlands).

Regosol/Gleysol – RG/GL

This class is forest soils found in upslope locations with a fresh soil moisture class. The Regosol soil is formed on unconsolidated, coarse-textured parent material and is characterised by a minimal soil profile development as a consequence of its young age. A soil type also present is Gleysol. Humus forms are moor or moder. The mixed coniferous forests are dominated by spruce with herbs and heath in the field layer. This class was assigned to areas with pine forest and a field layer of the herb or herb-heath type. Furthermore, forest types dominated by spruce, mixed forest, young birch, or without a tree layer (possible clear-cuttings) were included in this class if they had a low topographical wetness index (< 8). Areas located on clayey till were excluded. All areas in this class had a ground layer of the type moss (i.e. no wetlands).

Regosol/Gleysol, arable land – RG/GL-a

This class covers arable land, pasture and abandoned arable land. This class also includes fertile arable land located on clayey till with soils of the Cambisol type, although these areas were not represented among the sampling sites due to ongoing agricultural activities. The soil moisture class is fresh or fresh-moist and the humus form is mainly of the mull type. Broad-leafed grass and cereal crops dominates the field layer. This class was assigned to areas with a ground layer of the arable land type, pasture or meadow.

Arenosol/Gleysol – AR/GL

This class is found along the shoreline and is influenced by its closeness to water. The Arenosol soils are formed on sandy material of sedimentary origin, which has been deposited in different stages of shoreline displacement. In places that are periodically inundated, the soil type becomes a Gleysol. The humus forms are peaty moor. This class was assigned to shoreline areas along the coast and formed a 10-m wide (one pixel) zone. Shoreline areas located on bedrock (LP) or on organic soil (HI) were excluded from this class.

Regosol – RG

This class is found on the Börstilåsen Esker in the eastern part of the area. The soil moisture class is mainly fresh or partly dry. The texture is rich in coarse material, such as gravel and stones. The humus forms are mull or mull-like moder. The tree layer is sparse and the field layer is dominated by grass. This class was assigned to areas located within the glaciofluvial sediments according to the map of QD.

Leptosol – LP

This class covers shallow soils typically found in upslope locations. Leptosols have a soil depth of less than 0.25 m overlying the bedrock or very coarse soil material. This soil class has been expanded to also include bedrock outcrops. The tree layer is dominated by pine and some spruce, and the field layer is mainly of the heath type. This class was assigned to areas classified as bedrock according to the map of QD, thus the actual soil depth should be close to zero. Areas with the field layer "Dry heath" were also included.

5.2 Stratigraphy and total depth

The stratigraphical distribution of the regolith in the Forsmark area agrees with the general stratigraphy in areas below the highest shoreline in eastern Sweden. Based on the results from the site investigations, a general stratigraphy can be presented for the Forsmark area (Table 5-5). The thickest regolith is found in the marine areas, whereas the areas with high proportions of exposed bedrock are found in the highest areas in the south-western part of the model area and along the present shoreline.

Table 5-5. Generalised stratigraphical distribution of QD in lakes and mires.

Environment/facies	Lithology	Relative age
Bog	Bog peat	Youngest
Fen	Fen peat	
Freshwater lake	Microphytobenthos/Gyttja/ Calcareous gyttja	↑
Freshwater lake and shallow coastal basin	Algal gyttja	
Postglacial Baltic basin	Clay gyttja-gyttja clay	↑
Coast and off-shore	Post-glacial sand and gravel	
Postglacial Baltic basin	Postglacial clay	↑
Late glacial Baltic basin	Glacial clay	
Late glacial	Glaciofluvial sediment	
Glacial	Till	Oldest

5.2.1 Regolith depth model

A geometric model for the regolith depth was constructed based on the surface distribution and stratigraphy of the QD previously presented in this chapter /Hedenström et al. 2008/. The geometry of the regolith was modelled according to the seven layers presented in (Figure 4-2). The geometry of the lake sediments found in eight of the lakes studied was modelled as separate sub-models, i.e. lake sediment lenses.

Vertical profiles generated using the GeoModel tool are presented as illustrative examples in the following description and in /Hedenström et al. 2008/. The elevation of observation points and depth of geological units may differ from the modelled layers displayed in the profiles in some of the illustrated profiles. The discrepancies are the result of the 20×20 m resolution of the model, hence each coring site may not represent the exact elevation of the grid cell. Furthermore, the vertical profiles include bore holes located some distance (e.g. 50 m) from the profile rather than only those located exactly on the profile.

The total modelled regolith depth in the whole model area is presented in (Figure 5-31) and a detail of the central part of the model area is presented in (Figure 5-32). The modelled regolith depth varies between 0.1 m and 42 m. The average and median regolith depth of the input data from different sources are presented in (Table 5-6) and the depth of the interpolated and adjusted model is shown in (Table 5-7). Areas with thin regolith and frequent bedrock outcrops are e.g. the present coastal zone and islands, including the shoreline close to Gräsö Island. Generally, the regolith is deeper in the marine area where the average regolith depth is c 8 m, whereas the average total depth in the terrestrial area is approximately 4 m (Figure 5-31).

Within the terrestrial area, Till Area II (clayey till) generally has a thicker regolith than the rest of the terrestrial area. A zone with a relatively deep regolith and few bedrock outcrops in the terrestrial area is recorded from the inlet of Lake Fiskarfjärden, including the lake basin and further to the north-west. In the marine area, both the total regolith thickness and the thickness of each individual QD layer is greater than in the terrestrial part of the model area. The maximum regolith depth in the model is about 42 m, recorded in a south-west to north-east striking lineament outside the outlet of Kallrigafjärden Bay. The majority of the observations with a regolith deeper than 20 m are located within the coastal area. The maximum regolith depth observed in direct measurements (i.e. not geophysical) is 16 m, located at SFM0026 south-east of Lake Fiskarfjärden.

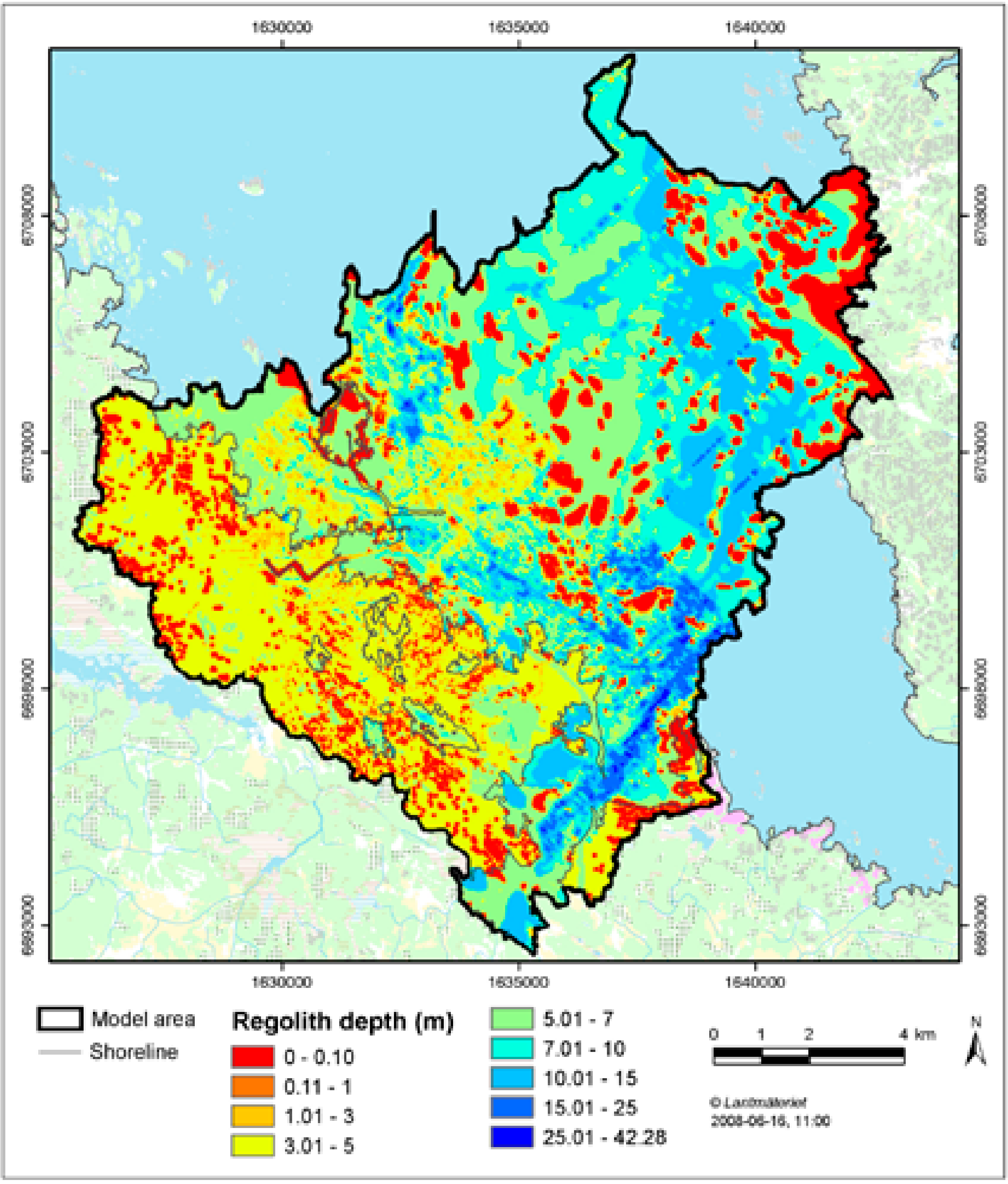


Figure 5-31. *Total modelled regolith depth /from Hedenström et al. 2008/.*

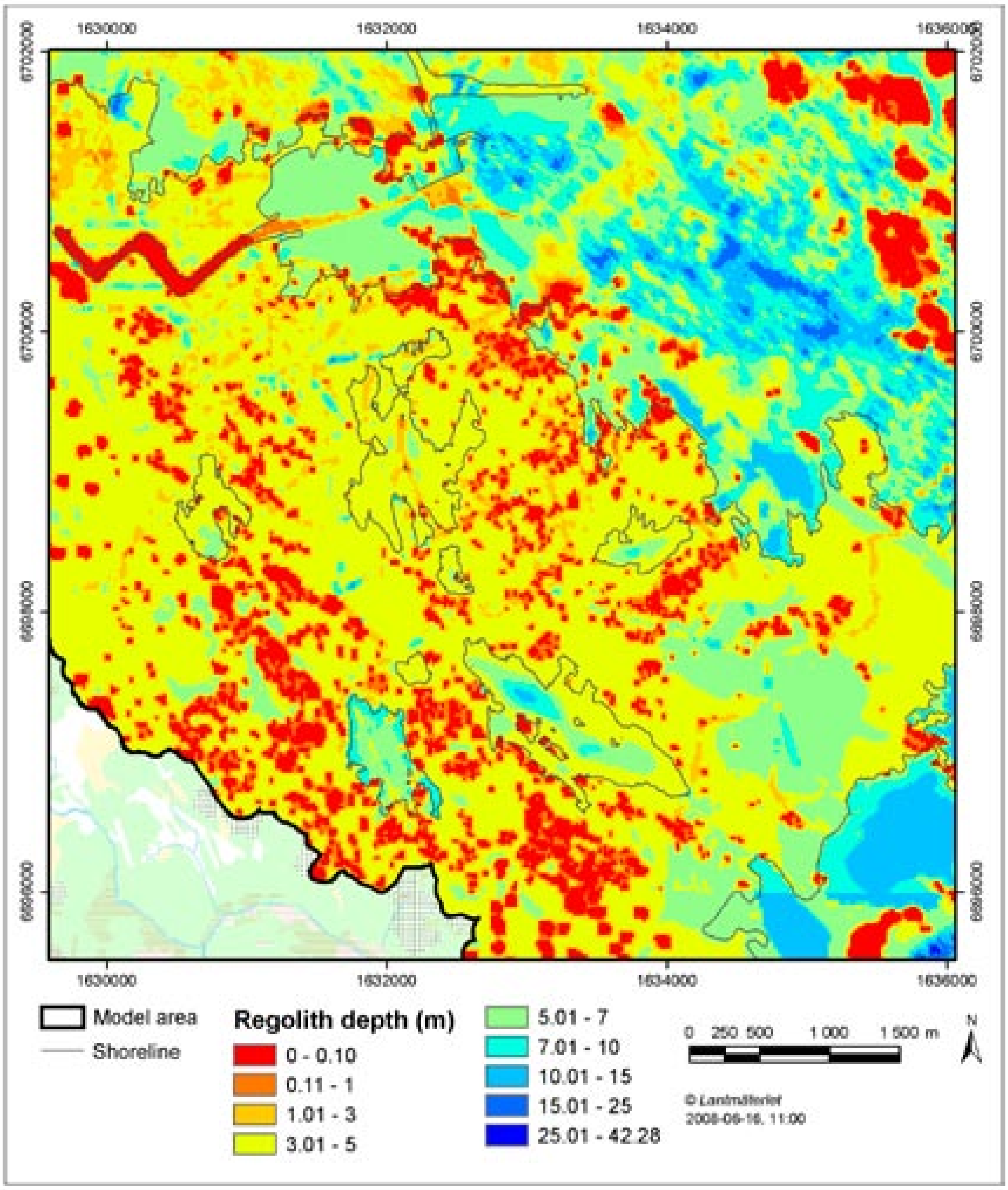


Figure 5-32. *Total modelled regolith depth in the central area /from Hedenström et al. 2008/.*

In (Figure 5-33), a vertical profile representing the marine area is presented. The thickness of the till is up to c 20 m in the profile and the glacial clay is more than five m thick at some places.

In (Table 5-6) the average, median and maximum regolith depths are presented based on input data from the different data sources. The average depth from the model, excluding bedrock outcrops, approximately agrees with the average values from the input data (cf.Table 5-7).

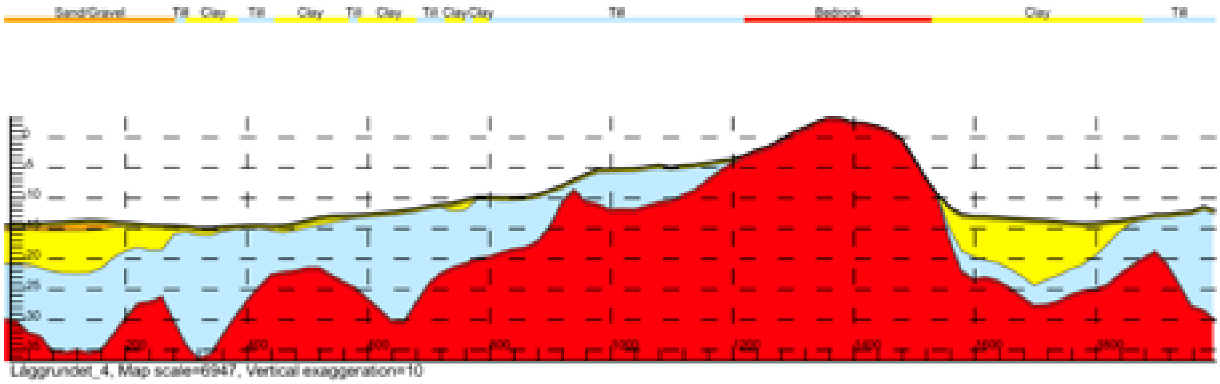


Figure 5-33. *Stratigraphical profile from the marine area /from Hedenström et al. 2008/.*

Table 5-6. Average, median and maximum regolith depth calculated from different sources of input data.

Type of data	Number of observations	Average QD depth (m)	Median QD depth (m)	Maximum QD depth (m)
Corings and excavations				
Ocean sediment core sampling	1	5.5	5.5	5.5
QD mapping and stratigraphic observations, Neotectonic stratigraphic observation	23	3.9	3.5	11.6
SGU's archive of wells	5	2.5	1.5	6
Cored, percussion and probing boreholes, monitoring well in soil	116	4.8	4.2	16.0
Geophysical data				
Refraction seismic measurement data	6,853	4.0	3.6	29.9
Ground penetration radar measurement data	439	3.38	3.12	8.79
Continuous Vertical Electrical Soundings (CVES)	264	6.25	5.84	18.60
Seismic and sediment echo sounding data	147,151	8.65	6.93	43.78
Reflection seismic	421	3.46	2.75	11.11
	155,273	8.41	6.65	43.78

Table 5-7. Average and median total modelled regolith depth.

Type of data	Average QD depth (m)	Standard deviation of average QD depth (m)	Median QD depth (m)
Whole model (including bedrock outcrops)	5.63	4.07	5.68
Whole model except bedrock outcrops	6.51	3.67	6.09

Based on the surface and stratigraphical distribution of the QD, the model area for regolith depth was divided into nine sub-domains (Figure 5-34). Since the total depth to bedrock, as well as the depth of each type of QD, is larger in the marine area than in the terrestrial area, an initial subdivision of the model area was conducted along the present shoreline. A description of some of the characteristics for each sub-domain is found in (Table 5-8). The regolith depth model is presented in a separate report /Hedenström et al. 2008/.

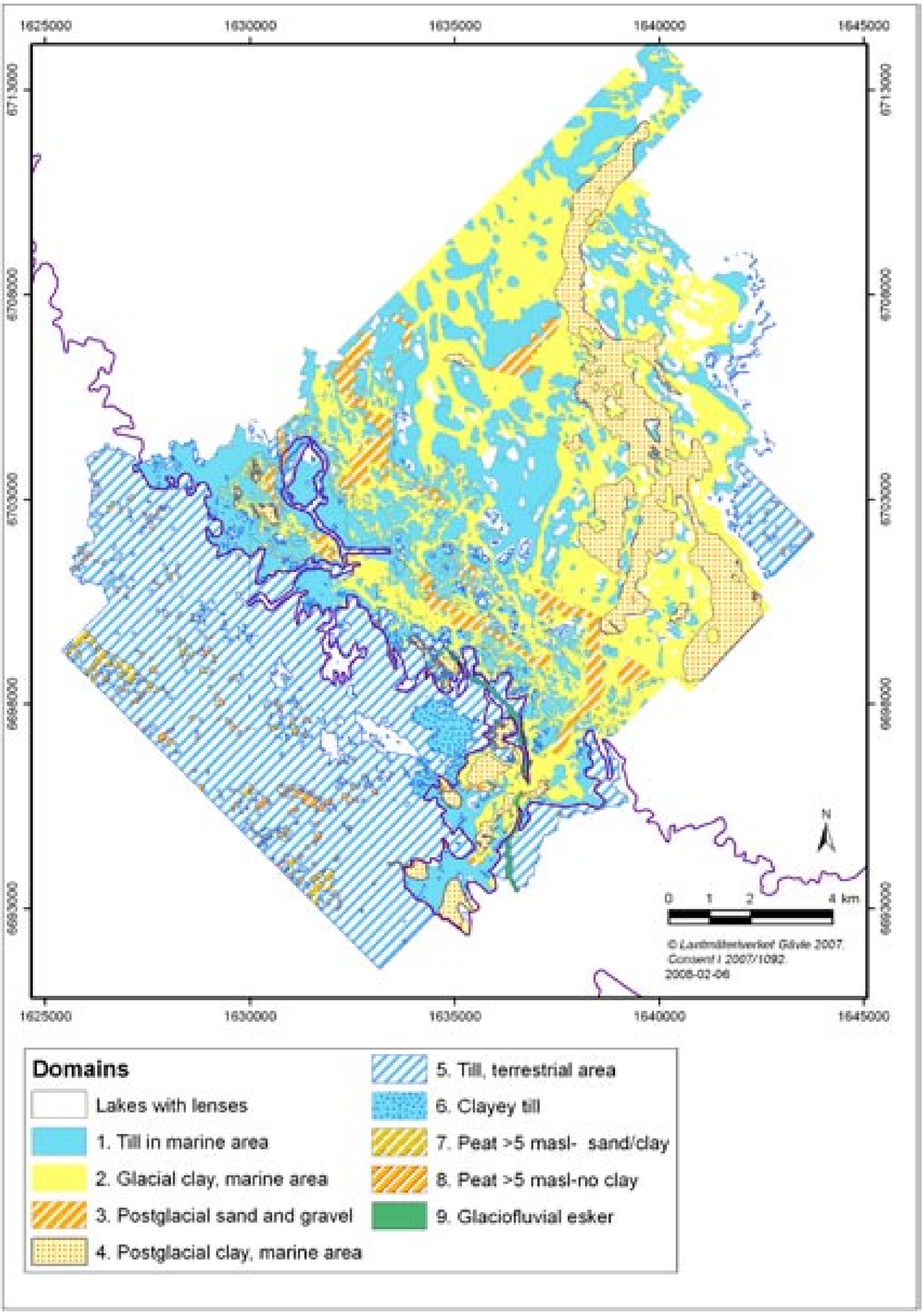


Figure 5-34. *The sub-domains used for modelling regolith depths /from Hedenström et al. 2008/.*

Table 5-8. The different sub-domains used for ascribing average QD depth values in areas without primary observation points /from Hedenström et al. 2008/.

Sub-domain		Quaternary deposit	Layers included in the domain	Depth of layers included	Total depth (m)
1	Marine area	1) Till	Z5	6.2	6.2
		2) Clayey till or boulder clay			
		3) Till with a thin surface layer of sand or clay			
2	Marine area	1) Clay	Z5+Z4b	6.2+3.2	9.4
		2) Glacial clay with a thin surface layer of postglacial sand			
3	Marine area	1) Postglacial fine sand	Z5+Z4b+Z3	6.2+3.2+0.9	10.3
		2) Postglacial sand			
		3) Postglacial sand-gravel			
4	Marine area	1) Clay gyttja with a thin surface layer of postglacial fine sand	Z5+Z4b+Z4a	6.2+3.2+0.9	10.3
		2) Clay gyttja with a thin surface layer of postglacial silt			
		3) Clay gyttja			
		4) Gyttja			
5	Terrestrial	All QD in the terrestrial area, except those included in Domains 6–9 or areas where lenses are modelled.	Z5	3.56	3.6
6	Terrestrial	Clayey till with a low boulder frequency	Z5	5.76	5.8
7	Terrestrial	Peat > 5 m.a.s.l. intersecting to sand, gravel or glacial clay in the QD map	Z5+Z4b+Z3+Z2	3.56+0.5+0.2+1.4	5.7
8	Terrestrial	Peat > 5 m.a.s.l. not intersecting sand, gravel or glacial clay in the QD map	Z5+Z3+Z2	3.56+0.2+1.4	5.2
9	Marine/Terrestrial	Glaciofluvial sediment	Z3	5.76	5.8

5.2.2 Till stratigraphy

The stratigraphic distribution of the different QD has been investigated through corings and excavations. Since till is the most common deposit, a wide range of analyses have been performed in order to construct a glacio-geological model for the Forsmark site. The stratigraphical relations between the till units and the length and direction of glacial transport have been investigated in a number of projects within the site investigations. Till fabric analysis and glacial striae were used to determine the direction of the glacial transport /Sundh et al. 2004, Albrecht 2005/. Geochemical analysis of basal till was compared to the geochemistry of the bedrock in order to evaluate ore potential /Nilsson 2003/. Reworked microfossils were also analysed in till samples /Robertsson 2004/. Additionally, the petrography of boulders and gravel was analysed in the three till areas and compared to the local bedrock in order to determine the length of glacial transport /Bergman and Hedenström 2006/. It was concluded that the petrography of the boulders is comparable to that of the local bedrock in the Forsmark area /Bergman and Hedenström 2006/. Based on a comparison between the lithology of the boulders and the bedrock of the region, two major directions of glacial transportation were indicated, i.e. from the west to north-west and north-west with an approximated transport distance of between 0.5 km and 8 km (Figure 5-35). The suggested direction of transport coincides with the most common till fabric directions observed in the Forsmark area /Sundh et al. 2004/. A north-west to south-east trend

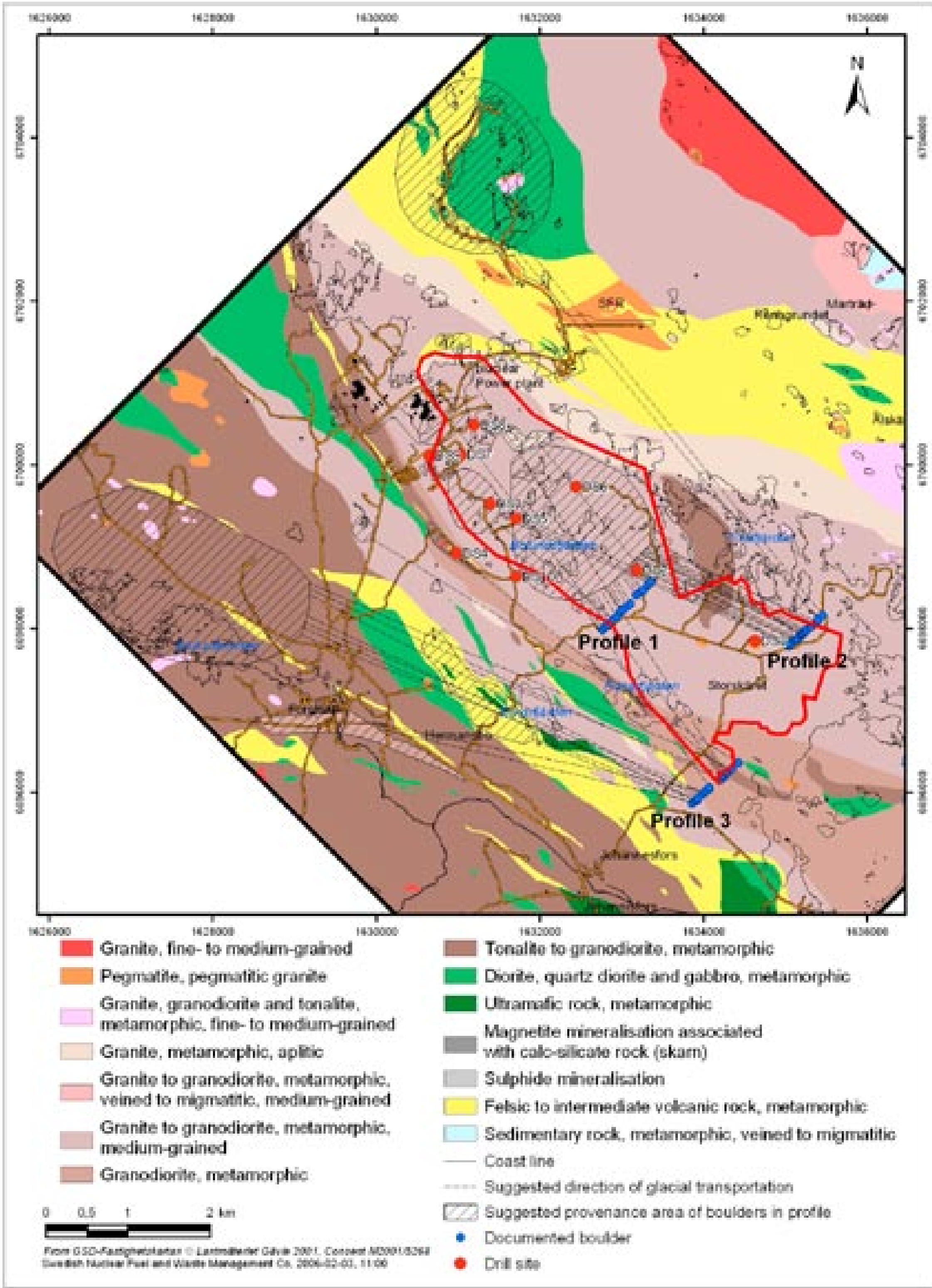


Figure 5-35. *Bedrock geological map of the Forsmark area (Bergman et al.2004). Blue dots show the location of documented boulders and the striped areas are suggested provenance areas for the boulders /from Bergman and Hedenström 2006/.*

was also detected in the geochemical anomalies of the element distribution in till at Forsmark /Nilsson 2003/. However, deviating directions of transport were recorded in the majority of the glacial striae, which were formed from the north /Sohlenius et al. 2004/. The northerly direction of transport is also valid for the Palaeozoic limestones that were transported at least 10 km from the bottom of the Bothnian Sea (cf. Figure 5-2).

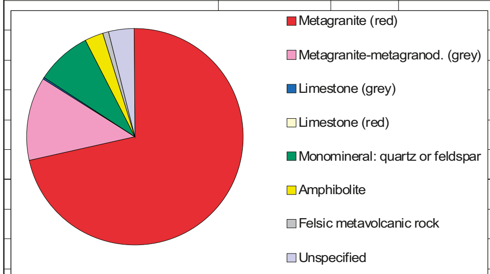
The occurrence of limestone is generally between 20% and 40% in the gravel fraction, indicating a longer transport distance than that of the boulders. However, no boulders of limestone were observed in any of the profiles. In samples of gravel from Till Area II, the content of limestones is higher (43%) than that in Till Area I (20%). A comparison between the two till units at PFM002581 showed that the upper sandy till contained much less limestone than the lower clayey till unit (Figure 5-36). In one sample (PFM002589, 2.4 m), 48% of the identified gravel particles were red and grey limestone /Bergman and Hedenström 2006/. The stones in Till Area II showed a higher degree of roundness than those found in Till Area I /Sundh et al. 2004/, which further supports the concept of a longer transport distance for the till in Till Area II.

The stratigraphical relations between the different till beds at Forsmark were studied in a targeted campaign where 22 machine-cut trenches were evenly distributed within Till Areas I and II (Figure 2-6). Additionally, till stratigraphical investigations were performed in trenches at Drill Site 5 and along the road towards Drill Site 6 (LFM000810 and LFM000811). The results from the stratigraphical investigations are summarised in Table 5-9.

In summary, the stratigraphic investigations confirmed the results from the survey on the surface. Till Area I is dominated by sandy and silty till, whereas clayey till and boulder clay dominate Till Area II (Table 5-9). There are some sites within Till Area I where clayey till was observed below the surface layer, e.g. PFM002581, PFM002582 and PFM002578 (Table 5-9). Within Till Area II, the clayey till/boulder clay observed on the surface was verified in all of the open pits. Because the area with a high frequency of large boulders, Till Area III in Figure 5-13, is situated within the Kallrigafjärden Nature Reserve, no excavations were performed.

Petrographic analysis: gravel fraction, Forsmark

Lab id: 28039	SKB id: PFM002581		Depth: 1,0 m
Rocktype	Number of grains	%	Roundness
Metagranite (red)	318	71,30	2
Metagranite-metagranod. (grey)	56	12,56	2
Limestone (grey)	1	0,22	4
Limestone (red)			
Monomineral: quartz or feldspar	37	8,30	2
Amphibolite	13	2,91	4
Felsic metavolcanic rock	4	0,90	3
Unspecified	17	3,81	2
Sum	446	100,00	



Petrographic analysis: gravel fraction, Forsmark

Lab id: 28041	SKB id: PFM002581		Depth: 3,6 m
Rocktype	Number of grains	%	Roundness
Metagranite (red)	220	25,64	2
Metagranite-metagranod. (grey)	166	19,35	2
Limestone (grey)	83	9,67	3
Limestone (red)	190	22,14	3
Sandstone	17	1,98	4
Monomineral: quartz or feldspar	90	10,49	2
Amphibolite	11	1,28	2
Felsic metavolcanic rock	28	3,26	3
Hard clayey till	21	2,45	5
Unspecified	32	3,73	2
Sum	858	100,00	

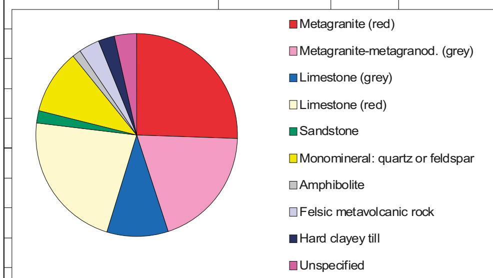


Figure 5-36. *Petrographical analysis of till from two till units at PFM002581. The left-hand diagram is from sandy till at a depth of 1 m and the right-hand diagram represents the hard clayey till at a depth of 3.6 m /from Bergman and Hedenström 2006/.*

Table 5-9. Summary of the results from the till stratigraphical investigations /Sundh et al. 2004, Albrecht 2005, Petersson et al. 2007, Forssberg et al. 2007/. ID numbers in bold are located within Till Area I and ID numbers in italic are located within Till Area II.

ID-number	Description of till-unit (local unit within brackets)	Depth (m)	Fabric (°)	Striae (°)/bedrock
PFM004761	Sandy till	0–1.6	353	/not reached
PFM002576	Sandy-silty till, boulder-rich surface	0.4–5.2		/not reached
PFM002577	Sandy-silty till, wave-washed surface, resting on bedrock	0.3–0.9		Younger 350 older 310
PFM002578	(1) Sandy-silty till, stone-enriched surface	0–0.5		
	(2) Clayey sandy-silty till, the layer ceases in a vertical contact towards sandy-silty till	0.5–1.9		
	(3) Sandy-silty till, resting on bedrock	1.9–4.2	313	300
PFM002579	(1) Sandy-silty till, gravel on clay in surface	0.4–0.7		
	(2) Sandy till, resting on bedrock	0.7–1.4		Younger 350 older 320
PFM002580	Sandy till, gravel on clay in surface	0.6–5.0		/not reached
PFM002581	(1) Sandy till with erosive contact against Unit 2, gravel on clay in surface	0.4–1.9		
	(2) Clayey sandy-silty till – boulder clay, hard	1.9–5.0	2	/not reached
PFM002582	(1) Sandy till -slided material, gravel in surface, glacial clay beneath.	0.4–0.7		
	(2) Clayey till – stone rich, sandy layer beneath	1.0–1.3		
	(3) Sandy till, resting on bedrock	1.6–2.6		no striae/
PFM002583	Sandy till, stone rich with stone-enriched surface	0.2–2.1	Random	345
PFM002584	Sandy till, resting on bedrock	0.2–0.9		355
PFM002585	Sandy till, resting on bedrock	0.4–1.2		355
PFM002586	Sandy till, stone rich with stone-enriched surface	0.2–1.8	329	320
PFM002587	(1) Sandy till, local or ablation till	0.2–2.8		
	(2) Sandy till, resting on bedrock	2.8–3.3		no striae/
PFM002588	(1) Sandy-silty till, stone rich	0.4–1.2		
	(2) Clayey sandy-silty till	1.2–1.9		
	(3) Boulder clay	1.9–2.9	337	
	(4) Sandy-silty till, resting on bedrock	2.9–3.1		younger 350 older 320
PFM002589	(1) Clayey sandy-silty till	0–2.0	331	
	(2) Boulder clay	2.0–4.3	339	
	(3) Sandy till	4.3–5.0		/not reached
PFM002590	(1) Sandy-silty till	0.2–1.2		
	(2) Clayey sandy-silty till, resting on fragmented rock	1.2–4.6	322	no striae/
PFM002591	(1) Clayey gravelly till, no consistent layer	0–1.3		
	(2) Clayey sandy silty till	1.3–3.5		/not reached
PFM002592	(1) Clayey sandy silty till	0.2–1.6	318	
	(2) Boulder clay	1.6–4.1	327	/not reached
PFM002593	(1) Clayey sandy silty till	0.4–1.4		
	(2) Boulder clay	1.4–3.6		/not reached
PFM002594	(1) Clayey sandy-silty till	0–1.2	3	
	(2) Clayey and sandy-silty till layers build-up the till	1.2–4.0	332	/not reached
PFM002595	Clayey sandy-silty till, resting on an uneven bedrock-surface	0–1.2		younger 360–20 older 285
PFM004514	(1) Clayey sandy-silty till	0–1.2		
	(2) Sandy till, steep contact against Unit 1, underlain by glacial clay	1.2–1.4		
	(3) Boulder clay	1.4–2.4		
	(4) Clayey sandy-silty till	2.4–3.0		/not reached
LFM000810				
PFM004455	(D) Gravelly till sand	0–0.2		
	(C) Sandy till	0.2–2	Random	
	(B) Clayey sandy-silty till	2–3		340–350/

ID-number	Description of till-unit (local unit within brackets)	Depth (m)	Fabric (°)	Striae (°)/bedrock
LFM000811				
PFM004459	(D) Sand	0–0.25		
	(C) Sandy till	0.25–1		
	(B) Sandy silty till	1–2.5	Random	
	(A) Boulder clay	2.5–4	76	
AFM001265	(5) Sandy till	0–0.8		
PFM006614	(6) Sandy till, hard	0.8–2.5	9	Dominating 360, younger 295
AFM001264	(1) Artificial fill	0–0.8		
PFM006609	(2) Sandy till (old soil horizon)	0.8–1.0		
	(3) Sandy silty till	1.0–2.2	10	
	(4) Silty till	2.2–3.3		
	(5) Silt – fine sand	3.3–3.4		
	(6) Sandy till, hard	3.4–3.5		0–20

The depth of the 16 trenches cut in Till Area I vary between 0.9 m and > 5 m. The bedrock was reached at nine of the sites, but at four sites the depth of the QD exceeded 5 m, thus the excavator could not continue further down. The average depth of the nine trenches that reached bedrock in Till Area I was c 2.8 m. In Till Area II, the bedrock was reached at three of the nine trenches, thus the remaining six trenches had a depth exceeding 5 m. This difference in depth is consistent with the results from corings where the deepest QD were recorded in the eastern part of the investigated area /cf. Johansson 2003/. Analysed samples from the stratigraphical investigations show that the calcium carbonate ($CaCO_3$) content is generally high in the fine fraction (< 0.06 mm) of both till types, varying between 16–28% in till with a sandy to sandy-silty matrix and between 9–32% in till with a clayey matrix. The stone and boulder fractions of the sandy till are dominated by crystalline basement rock types. The high clay content in the boulder clay is most likely derived from re-deposited sedimentary (water-laid) clay /Appendix 1 in Sundh et al. 2004/. At some sites, small lumps of clay were detected in the till matrix. At PFM004514, glacial clay, with preserved primary varves, was incorporated in the upper till unit (Figure 5-37). Analysis of grain size distribution of a till sample from PFM002592 showed a clay-content of 32%, probably resulting from incorporation of glacial clay. The original age of the glacial clay is not known, although one alternative is that the clay was deposited during the latest deglaciation and successively incorporated into the till during a short advance of the inland ice. Another alternative would be that the glacial clay was initially deposited during a previous deglaciation. A high content of well-rounded stones, a high percentage of limestones, and the massive, homogeneous texture of the boulder clay gives an impression of the dominance of a fairly long-transported material. This theory is supported by the high proportions of pre-Quaternary microfossils, most probably originating from Palaeozoic limestones /Robertsson 2004/. Considering these circumstances, the most likely source area for the ice to pick ingredients to form the clayey till is situated on the floor of the Bothnian Sea, north or north-east of the investigated area, although crystalline bedrock material of a possibly local origin is also found in the clayey till /Bergman and Hedenström 2006/.

The results from the clast fabric analysis provides evidence of a transport direction from the north-west in both the sandy and clayey till /Sundh et al. 2004/. However, analyses performed close to the ground surface indicate the most recent transport from the north. The till fabric, together with analysis of glacial striae and re-deposited microfossils, indicates at least three generations of preserved ice flow directions: the probable oldest ice flow direction came from the north, the median age (dominating) direction from the north-west, and finally, the youngest ice flow transport once again from the north. Based on the stratigraphical investigations /Sundh et al. 2004, Albrecht 2005/ it is assumed that at least the two youngest ice flow directions originate from the latest glaciation and deglaciation.

Figure 5-37. *A layer of varved clay that is up to 0.5-m in thickness, eroded and folded in its upper part and incorporated in the till (PFM004514). For location, see Figure 2-6 /from Sundh et al. 2004/.*

Stratigraphical and analytical data based on some corings and excavations within Till Areas I and II are described by /Hedenström et al. 2004/. For location of these sites, see Figure 5-39. A transect with simplified stratigraphical profiles represents three corings and one excavation from Till Area I (Figure 5-41). Additional information is derived from the large number of corings performed during the initial site investigations, e.g. during the installation of groundwater monitoring wells /Johansson 2003/. The thickness of the QD observed in corings varies between 0 m and 16 m within the investigated terrestrial area. In the north-western part of the investigated area in Till Area I, the depth to bedrock is generally between 4 m and 8 m /Johansson 2003/. Close to Drill Site 1, the thickness of the regolith varies between c 4 m and 12 m in eight corings located within c 200 m from the drill site. On the other hand, the upper surface of the regolith is flat and the height varies between c 2 m and 4 m above sea level. This supports the model of the small scale undulating bedrock surface with a till cover that fills up the depressions and leaves a flat surface.

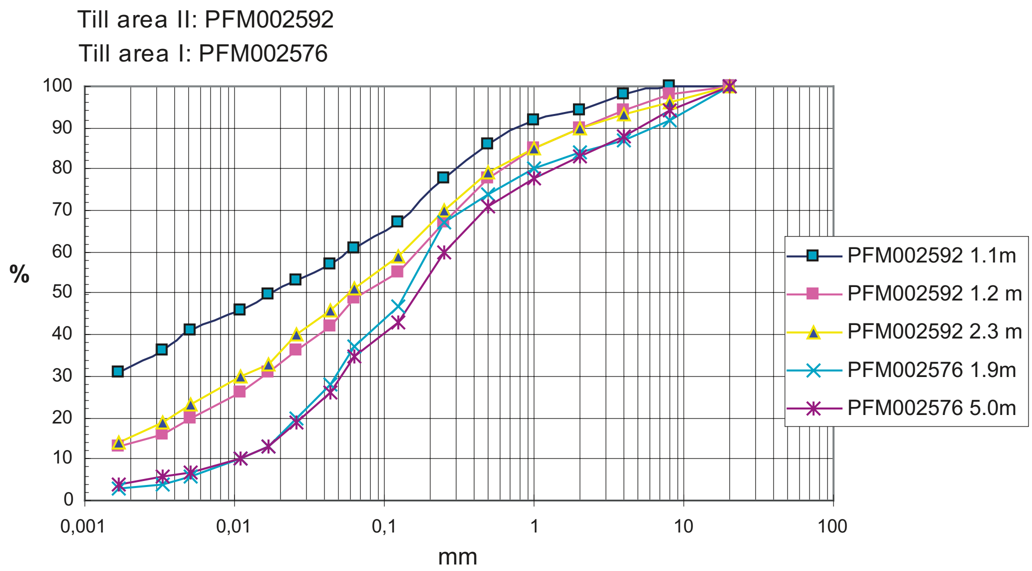


***Figure 5-38.** Grain size distribution from two samples from Till Area I (PFM002576) and three samples from Till Area II, collected at PFM002592. For location, see Figure 2-6.*

***Figure 5-39.** Situation map of investigated sites where stratigraphic investigations have been performed, mentioned in this section.*

This means that the depth from the ground surface to the bedrock varies by several metres over short distances, although the impression from the surface is that it is flat and homogenous. Thus, the geometrical modelling of the regolith depth at Forsmark is associated with significant uncertainties surrounding the details and should be considered as a model on a landscape level /Hedenström et al. 2008/. In the central part of the candidate area, close to Lake Bolundsfjärden, the thickness of the glacial till as recorded in drillings is less than 4 m. One typical sequence from Till Area I is from SFM0030, showing c 3.5 m sandy silty till on the bedrock (Figure 5-41).

The till stratigraphy has been recorded to be more complex within Till Area I, south and east of Lake Eckarfjärden. A clayey till was found beneath the sandy till at e.g. SFM0016 (Figure 5-40), where 5.7 m sandy till cover a dense and hard clayey till. A similar stratigraphy was observed by /Sundh et al. 2004/ in a machine-cut trench north of Lake Gällsboträsket (PFM002581), where sandy till covered a very hard, dark clayey till, see further below in this section.

Figure 5-40. *The auger drill collects a 1.5-m long sample of till at SFM0016. An over-consolidated boulder clay, coloured red by Palaeozoic limestone, was retrieved at a depth of 5.7 m.*

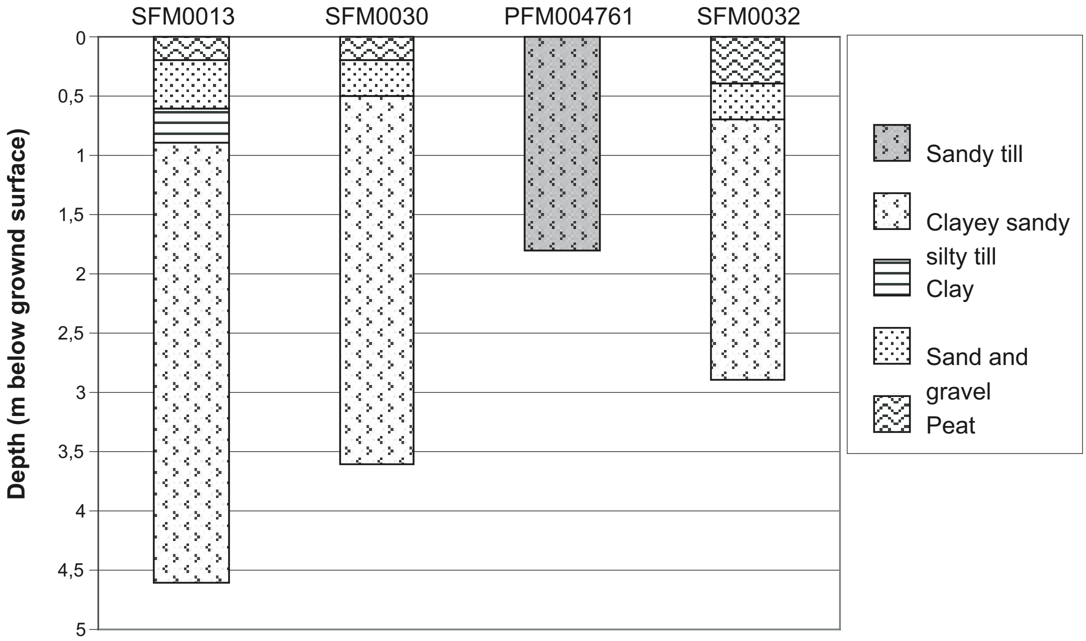


Figure 5-41. *Simplified stratigraphical profiles from the area south-west of Lake Bolundsfjärden in Till Area I. The information from PFM004761 is based on a machine-cut trench. The bedrock was not reached at this site, which is why the 1.8-m depth is a minimum depth value /from Hedenström et al. 2004/. The depth to bedrock at the coring sites is c 3–4 m and no stratification was observed within the till bed. The till is clayey sandy-silty, and at PFM004761, sandy at a depth of 0.5 m. At SFM0013, SFM0030 and SFM0032, a surface layer of sand and gravel was observed in the upper part of the profile. The upper unit represents wave-washing on top of the profile due to beach processes in connection with sub-recent shore displacement. A thin layer of clay is present between the sand and the till in section SFM0013. Similar occurrences of small, thin pockets of clay have frequently been observed in the superficial QD /Sohlenius et al. 2004/.*

In Till Area II, the depth to bedrock is generally greater than that in Till Area I and the clay content is higher. It is within this domain that the thickest cover of regolith, as identified by corings during the site investigations, was recorded /Johansson 2003/. However, an observation of a relatively steep and small scale undulating bedrock topography was indicated in this area.

Five simplified stratigraphical profiles observed in corings in Till Area II at Storskäret are displayed in Figure 5-42. In four of the corings, boulder clay (> 15% clay content) was obtained in the surface above a coarser, clayey sandy till. A typical sequence example observed in Till Area II is PFM002464, where a c 9 m glacial till covered the bedrock. Clayey till and boulder clay covered a coarser (clayey silty) till. At PFM002463, the grain size distribution of four samples was analysed and plotted in the same diagram (Figure 5-43). The clay content in the upper two samples was 15% and 14% respectively, whereas the sample from 7.2 m contained 6% clay, and the lowermost sample, collected at 10.1 m depth and classified as sandy till, contained only 3% clay. There are too few observations to make a generalization of this stratigraphy within Till Area II.

At PFM002574, boulder clay is absent and the depth to bedrock is only 1.8 m. This site is located closer to the bedrock outcrops south of Drill Site 3.

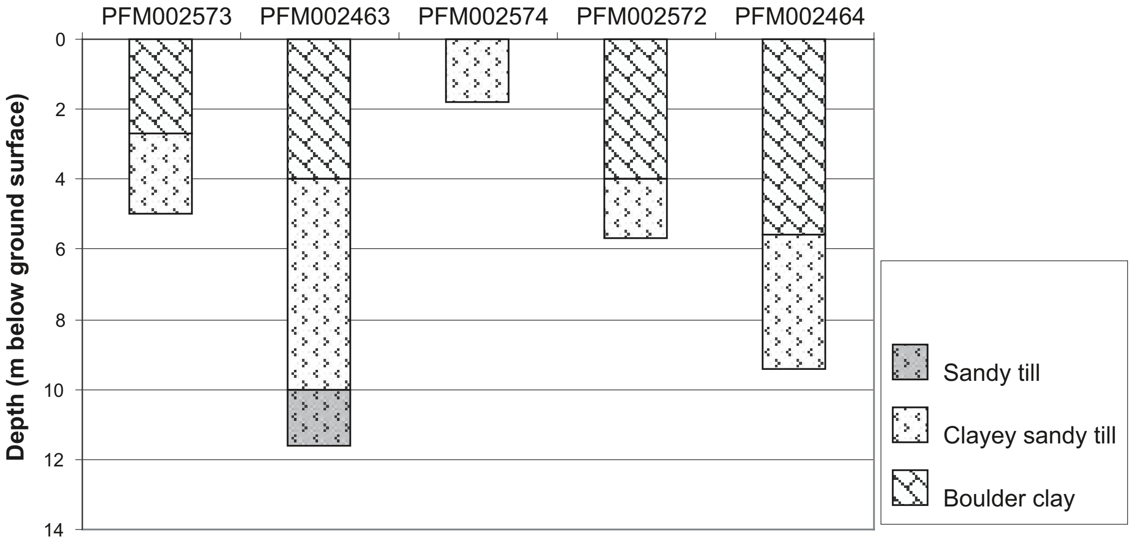


Figure 5-42. *Simplified stratigraphical profiles from the eastern part of Till Area II. A consistent feature is that of a coarser, sandy silty till, located beneath the boulder clay /from Hedenström et al. 2004/. All profiles reach the bedrock. The grain size distribution curves on four samples collected at PFM002463 are presented in Figure 5-43.*

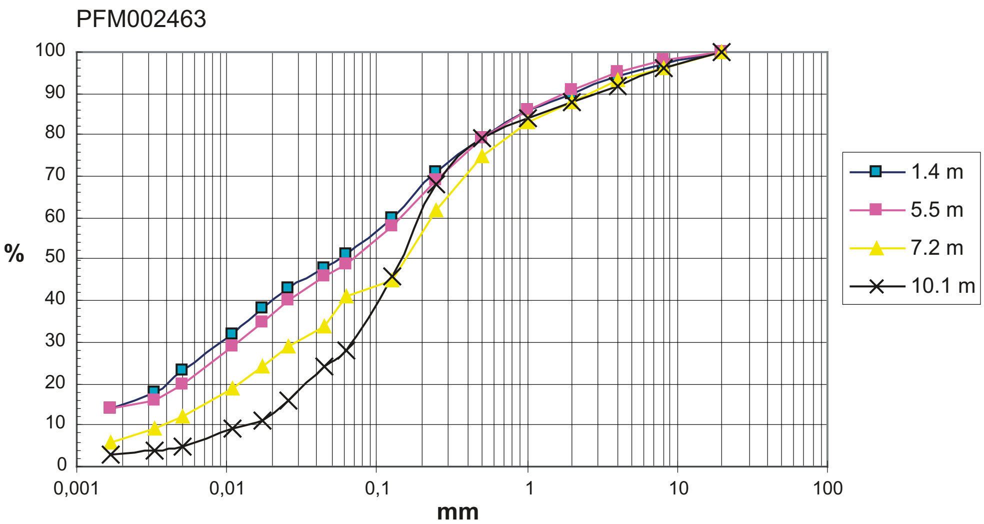


Figure 5-43. *Diagram showing the grain size distribution curves for samples collected at four different depths from the profile at PFM002463, located c 200 m south-west of Drill Site 3 within Till Area II. The clay content is higher (c. 15%) in the upper two samples (clayey till and boulder clay), whereas the lower sample is coarser and consists of sandy till.*

Hard clayey till

Complex stratigraphical sequences containing several till units were revealed in some places. Stratigraphical investigations in machine-cut trenches showed that lumps of clayey till were incorporated as lenses in the sandy till, thus showing that the clayey till was deposited prior to the sandy till /Sundh et al. 2004/. Clayey till was also encountered within Till Area I (e.g. PFM002581, SFM0016, SFM0017), where it was found under the sandy-silty till deeper in the stratigraphy. At investigation site PFM002578, a clayey till layer (clay content 13.5%) was found incorporated in a sandy-silty till /Appendix A in Sundh et al. 2004/. A similar stratigraphic sequence has also been reported from a percussion borehole adjacent to PFM002578, close to Drill Site 2 /Sohlenius and Rudmark 2003/, which implies that these two sites are situated on a transition zone between the sandy and the clayey till.

Another example of a complex till stratigraphy is site PFM002581, located within Till Area I north of Lake Gällsboträsket (Figure 5-44). A c 2-m thick unit consisting of sandy-silty till was underlain by a dark, clayey till. Grain size analysis of a sample from the upper part of the clayey till showed a clay content of 11%, at a greater depth it changed into boulder clay with a clay content of 19%. The calcium carbonate ($CaCO_3$) content in the upper part was 24% and decreased to 18% further down. The most striking physical property of the clayey till at PFM002581 was the extreme degree of consolidation such that it even resisted ordinary machine-digging methods. An excavator-ripper had to be used to cut into the hard till. The contact between the two till-beds is sharp and erosive with sharp-edged lumps of hard clayey till incorporated into the base of the overlaying sandy-silty till in some places. The high degree of consolidation in the clayey till apparently already existed before the deposition of the superimposed sandy-silty till (Figure 5-45).

Till fabric analysis of the hard clayey till shows an ice movement direction from the north /Sundh et al. 2004/ and from the east north-east /Albrecht 2005/ as compared to the dominating transport direction from the north-west. The north-easterly direction was also observed in glacial striae on the islands north-east of Forsmark /Persson 1986/.

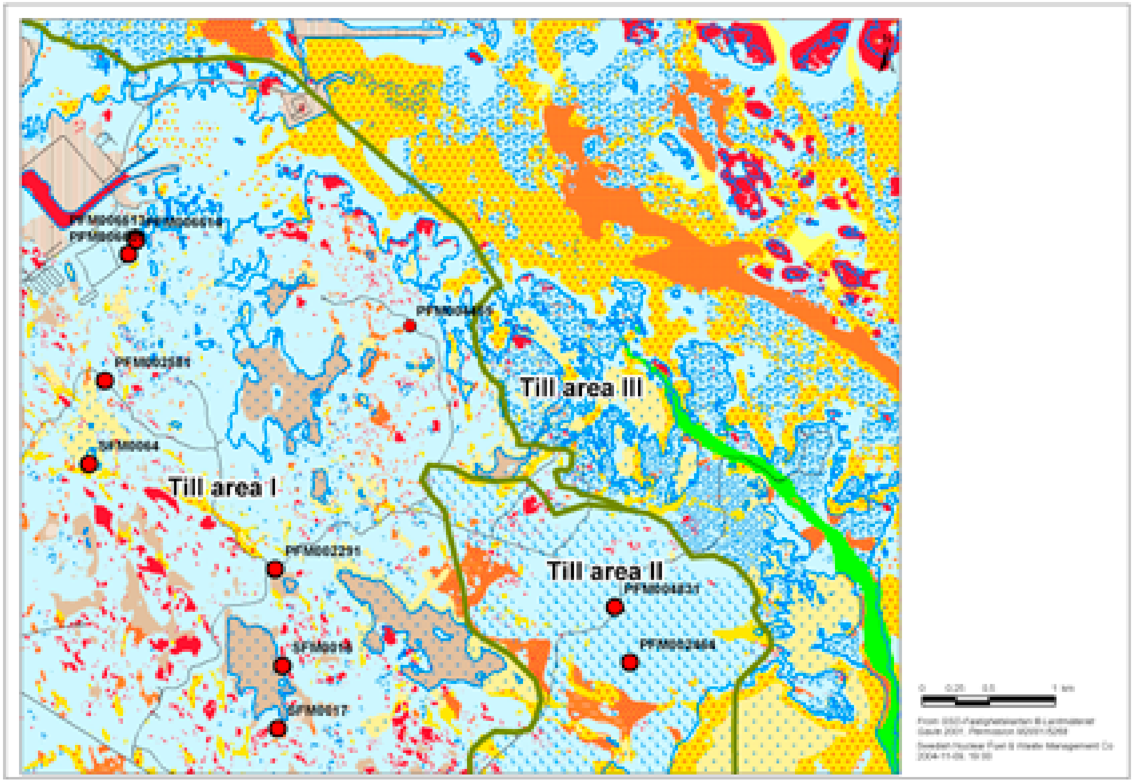


***Figure 5-44.** Location of the sites where hard clayey till has been observed and the depth below the surface of the till unit. SFM00016 (5.7–7.2m), SFM00017 (3.7–4.0m), SFM00064 (3.0–4.0m), PFM002581 (1.9–3.4m), PFM002291 (0.6–1m), PFM002464 (7.7–9.4m), PFM004459 (3–4m), PFM004831 (0.5–1.8m), PFM006609 (3.4–3.5m), PFM006613 (2.7–3.5 m), PFM006614 (0.8–2.5 m), Forsmark power plants.*

Figure 5-45. Erosive contact between the two till-beds: sharp-edged lumps of clayey till intercalate into the base of the super-imposed, sandy-silty till (PFM002581).

In trench LFM00810 /Albrecht 2005/, the lowermost unit, here named Unit A, is a till unit that occurred only in the deepest part of the trench. It is dark grey in colour and 1.5 m thick at most (Table 5-9). Characteristic properties are hardness, high clay content (15.7%) and a high frequency of Palaeozoic limestones in the gravel fraction. The formation of this sediment was interpreted as sub-glacial, over-consolidated till (Boulder clay).

Further observations of complex till stratigraphy were made during the installation of ground-water monitoring wells, Close to Lake Eckarfjärden (SFM0016, SFM0017) and at Lake Gällsbo-träsket (SFM0064), a unit consisting of hard clayey till/boulder clay was observed under the sandy till. These observations are tentatively correlated to the lithological unit described above. Furthermore, during the construction of the Forsmark nuclear power plant, an over-consolidated till unit was discovered /Carlsson 1979/. Based on these observations, it can be assumed that this till unit may be preserved at sheltered locations, e.g. cavities in the bedrock, at least in the western part of the candidate area.

In central and northern Sweden, a very hard clayey till, probably the same age as the unit observed at PFM002581, was observed at several locations beneath a coarser till /Björnbom 1979/. Litho- and biostratigraphical analysis was performed on samples of dark clayey till obtained from sites located in central and northern Sweden, including samples from the Forsmark site investigations /Robertsson et al. 2005/. Pollen analysis was performed in order to provide information on the age of the lithological unit. The pollen flora was interpreted to be re-worked interglacial, since it contained relatively high frequencies of *Alnus* (alder) and *Corylus* (hazel) and low frequencies of arboreal pollen known from deposits originating from the latest interglacial, the Eemian or MIS 5e, c 120,000 years ago. This composition gave an assumed maximum age of the deposition of the unit to be post Eemian, i.e. some time during the Weichselian glaciation. /Robertsson et al. 2005/ suggest that the dark clayey till was deposited in MIS 4 after the Odderade Interstadial c 70,000 years ago. High content of both calcite and clay, together with a high content of re-worked pre-Quaternary microfossils /Robertsson 2004/, indicates that the parent material originates from the areas north or north-east of Forsmark with Palaeozoic limestones present at the sea floor /Axberg 1980, Persson 1992/. Petrographical analyses of gravel from the two lithological units at PFM002581 were performed. It is interesting to note that the hard clayey till contains 32% limestone (3.6 m depth), whereas the sandy till at 1.0 m only contained one limestone out of the 446 particles analysed (Figure 5-36).

Stratigraphy under lakes and mires

Lakes cover a substantial part of the region in the Forsmark area. The biotic part of the limnic ecosystems of the lake basins in the Forsmark area are described by /Nordén et al. 2008/ whereas the description in this report focuses on the distribution and properties of the a-biotic components, i.e. the regolith. The stratigraphical distribution of organic sediments and clay have been analysed in detail /Hedenström 2003, 2004a/, but information regarding the underlying till has been sparse in previous model versions. This final description contains stratigraphical information regarding the whole sequence of QD close to some basins and is derived from SFM-corings in, or very close to the lakes. Analytical information of e.g. grain size distribution is available from Lake Fiskarfjärden, Lake Bolundsfjärden, and Lake Gällsboträsket and from the shores of Lake Eckarfjärden, Norra bassängen and Puttan (Appendix C). Based on the information gained at the corings, it is suggested that the till below the lakes and mires has properties similar, e.g. texture and thickness, to those in the terrestrial areas, with the exception of the absence of soil-forming processes and wave-washing. The occurrence of clayey till under the lake sediments in Lake Gällsboträsket and close to Lake Eckarfjärden is consistent with the information on till stratigraphy gained from the trenches that showed small patches of till with a higher content of fine fraction within Till Area I /cf. Sundh et al. 2004/.

In general, the minerogenic sediments under the wetlands consist of clay, sand and gravel and till /Lokrantz and Hedenström 2006/. All units are present at some sites, while the organic sediment rests directly upon the till at others. Puttan is partly covered by clay under the organic sediments and examples of mires without a clay layer under the organic deposits are a part of the fen Stenrösmossen.

5.2.3 Glaciofluvial sediment

The glaciofluvial sediments at Forsmark are concentrated to the small Börstilåsen Esker, which passes through the south-eastern part of the model area. Since the Börstilåsen Esker is completely located within the Kallrigafjärden Nature Reserve, the stratigraphical information from the site is restricted. Drillings at the crest of Börstilåsen (SFM0060) showed c 7 m of glaciofluvial sediments (gravel) resting directly on the bedrock. Open sections, i.e. abandoned gravel pits, display a coarse material dominated by gravel and stones. Wave washing has affected the surface of the esker, resulting in a raised shingle shoreline with medium to well rounded stones. The esker has not been detected during investigations at the sea floor /Ising 2006, Elhammer and Sandkvist 2005/. Further south, however, the archive of wells /SGU 2007/ has documented records of depth to bedrock that varies between 2 m and 16 m (average 8 m) within the areas displayed as glaciofluvial sediment on the QD map. In (Figure 5-46) a cross section from the RDM shows the modelled depth of the esker.

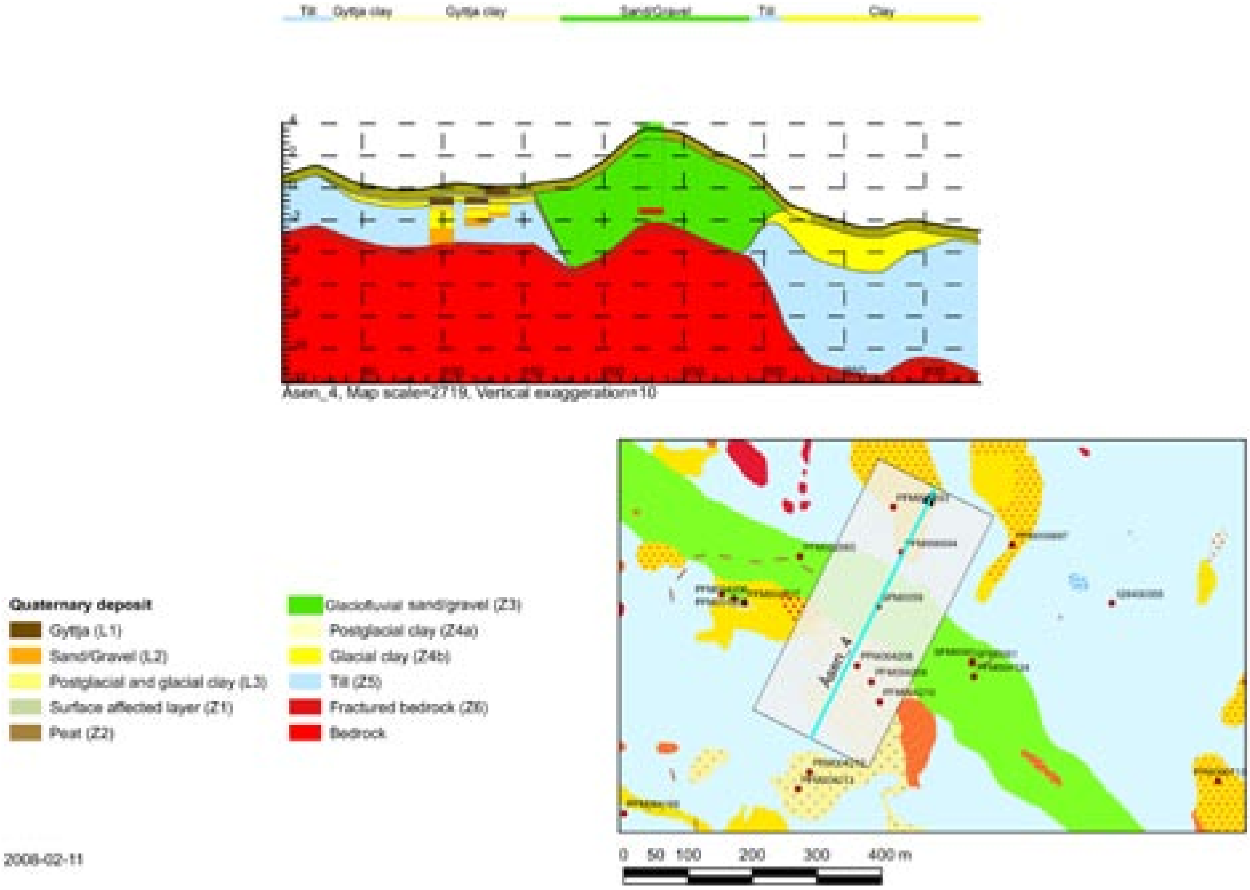


Figure 5-46. Cross section of the Börstilåsen Esker as presented in the RDM. The glaciofluvial sediment is dominated by gravel /from Hedenström et al. 2008/. Maximum depth to bedrock (7 m) was recorded at SFM0060 whereas the northernmost coring site (PFM002565) reached bedrock at c 2 m depth.

5.2.4 Postglacial sediments and peat

This section describes the distribution of the water-laid sediments and peat covering the till or the bedrock in the lakes and ponds of Forsmark. Generally, the lake sediments are deposited in sedimentary basins located at topographically sheltered low points that favour sediment accumulation. The ongoing isostatic uplift results in the emergence of new land areas from the sea, which transfer the basins to sheltered positions that favour the accumulation of clay gyttja and gyttja. Many of the ponds and lakes in the Forsmark area are very shallow, often less than a 1-m water depth at the deepest and will exist only a short time as a lake/pond before the basin is filled in and developed into a wetland /cf. Brydsten 2004/. Some of the shallow basins are in fact hard to classify as lakes or wetland, i.e. Lake Kungsträsket and Lake Stocksjön. Based on the sedimentary strata, the basins are instead divided into two main groups based on the presence or absence of clay in the bottom of the sedimentary basin. An inventory of small and shallow basins, including fens located in the central part of the candidate area, showed that approximately half of the investigated sites have a layer of glacial clay under the organic sediment (Figure 5-47). Of the three larger lakes at Forsmark, Lake Eckarfjärden and Lake Fiskarfjärden have a more or less continuous layer of glacial clay on top of the till, whereas Lake Bolundsfjärden has postglacial sediments that are partially located directly on the till /Hedenström 2004a/.

Figure 5-47. *Map showing the bottom substrate at sites underneath wetlands in the central part of the Forsmark regional model area /from Lokrantz and Hedenström 2006/. About half of the inventoried sites had a layer of clay between the organic sediments and the till.*

Contradictory to the complex composition and distribution of the glacial till described above, the distribution of sediments in the lakes and ponds in the Forsmark region follow a uniform pattern. In a majority of the lakes investigated, the total thickness of the sediments (not including glacial till) was less than 2 m /Hedenström 2004a/. Only in Lake Eckarfjärden, Lake Fiskarfjärden and the small pond close to the Börstilåsen Esker, were 4 m of sediments retrieved when coring /Hedenström 2004a/. The maximum depth of the lake sediments in the Forsmark area was 8.3 m, recorded in the north-western part of Lake Fiskarfjärden (PFM004195). A generalised outline of stratigraphical units in the investigated sediments at Forsmark is presented in Table 5-5. It should be noted, however, that not all strata were present in every basin. Typical sections from the larger basins are described below.

Lake Eckarfjärden

Lake Eckarfjärden basin follows a north-west to south-east strike and is located in a depression in the bedrock. Bedrock outcrops occur predominantly in the area north-east and south-west of the basin (Figure 5-48). The sedimentary sequence in Lake Eckarfjärden follows a consistent pattern starting from the bottom with till, glacial clay, postglacial sand, clay gyttja and gyttja and microphytobenthos (cf. Table 5-10). One of the profiles from the RDM is presented in (Figure 5-49). The depth of the till is based on interpretations of ground penetrating radar /Marek 2004b/, while the depth of the sedimentary strata is based on hand-driven corings /Hedenström 2004a/. The depth to bedrock, including the till and lake sediments, is approximately 10 m throughout the central part of the lake basin.

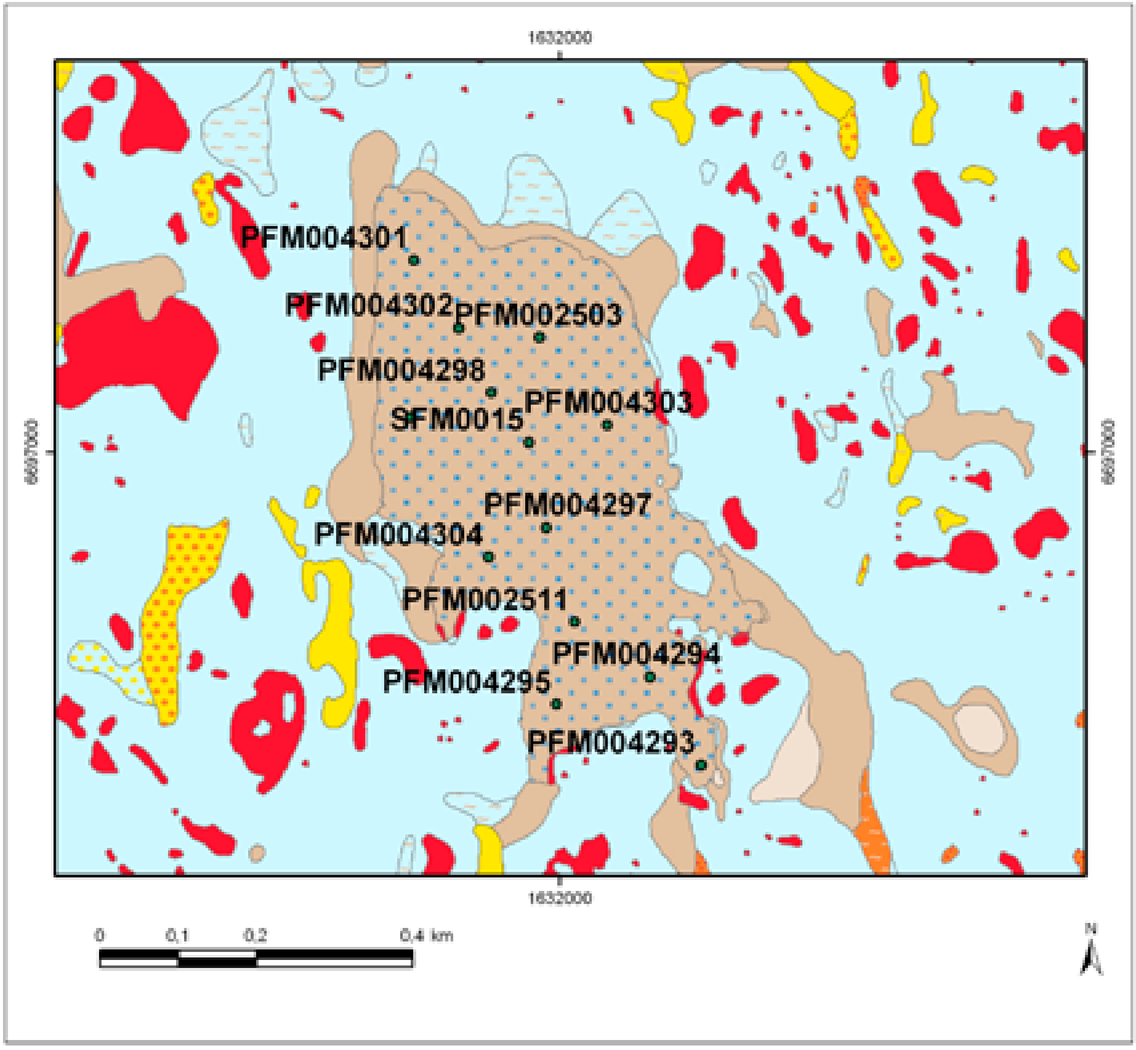


Figure 5-48. QD map for the Lake Eckarfjärden Basin; for the legend, see Figure 2-2.

Table 5-10. Generalised stratigraphic description of the sediment profiles from a representative coring site at Lake Eckarfjärden (PFM004303). See Figure 5-47 for location of the coring site. The depths are measured from the surface of the ice.

Depth (m)	QD
0.00–2.14	Water
2.14–2.95	Algal gyttja
2.95–2.99	Calcareous gyttja
2.99–3.48	Algal gyttja
3.48–3.56	Clay gyttja
3.56–3.86	Postglacial sand
3.86–4.29	Glacial clay
4.29	Probably till

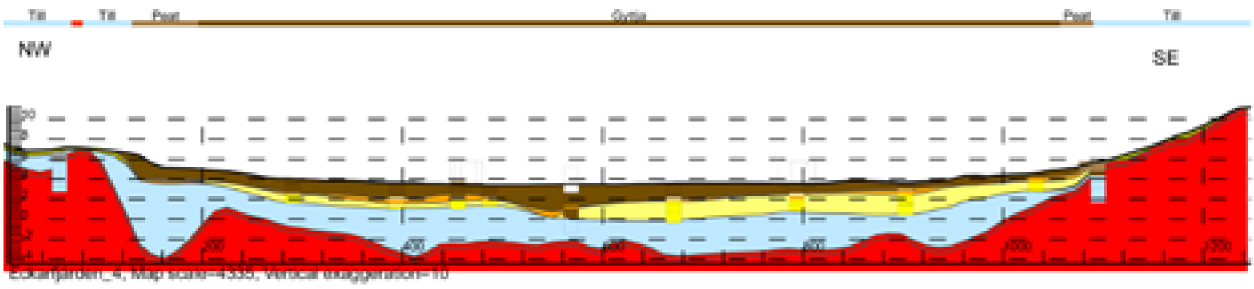


Figure 5-49. Profile showing a north-south transect through the sediments in Lake Eckarfjärden. The profile is from the RDM /Hedenström et al. 2008/. The three lake sediment lenses are, from the bottom: glacial clay, postglacial sand and gyttja. Postglacial clay contributes only minor patches, thus is not represented in the stratigraphical profile. The unit consisting of postglacial sand and gravel forms a layer that has been continuously identified under the gyttja sediments in this basin.

Lake Fiskarfjärden

Lake Fiskarfjärden basin follows a north-west to south-east strike and is located in a bedrock trough in a belt with relatively few bedrock outcrops and deep till cover. Additionally, the thickest lake sediments observed during the site investigations were found in this lake at PFM004195 /Hedenström 2004a/. A comparison between the average stratum thicknesses showed that the sediment column in Fiskarfjärden is more than twice the thickness of the corresponding sediment in Lake Eckarfjärden (Table 5-10 and Table 5-11). Since the basin is located at approximately the same level as the present sea level, a majority of the gyttja and gyttja clay have been deposited in brackish water when the lake was located in a narrow bay of the Kallrigafjärden.

Table 5-11. Generalised stratigraphic description of the sediment profile from a representative coring site at Lake Fiskarfjärden (PFM004204). The depths are measured from the surface of the ice.

Depth (m)	QD
0.00–0.59	Water
0.59–1.65	Algal gyttja
1.65–2.14	Clay gyttja/gyttja clay
2.14–2.19	Postglacial sand
2.19–3.62	Postglacial clay
3.62–4.9	Glacial clay
4.90–4.94	Sand
4.94	Probably till

Lake Bolundsfjärden

Another example of sedimentary sequence is represented in Lake Bolundsfjärden. In this basin, the sediment sequence is generally much thinner than in both the Lake Eckarfjärden and Lake Fiskarfjärden basins /Hedenström 2004a/. At several of the coring sites, coarse minerogenic material, interpreted as till, was recorded directly on the bottom of the lake. This is displayed on the QD map covering the lake basin where glacial till is present in the surface of the south-western and north-western parts, as well as the small island in the middle of the basin. Additionally, the continuous clay layer observed at the bottom of Lake Eckarfjärden and Lake Fiskarfjärden is replaced by thin patches of clay in Lake Bolundsfjärden. The sediment is generally less than 2 m thick with a majority located in the central part of the lake. At PFM004231, the c 0.6-m deep sedimentary sequence starts with a thin layer of sand covered by gyttja clay and gyttja. Erosion has probably been more effective in this basin compared to e.g. Eckarfjärden since there is almost no shelter from wave activity from the north. Lake Bolundsfjärden is still occasionally in contact with the Baltic. There are no analytical data of sediments from Lake Bolundsfjärden.

Many of the present wetlands situated in organic subarea B (Figure 5-23) have a surface layer of gyttja clay and clay gyttja, often covered by growing *Phragmites* (reed) and a thin (up to a few dm) layer of *Phragmites* peat. Some of the small wetlands are still partly ponds with an open body of water surrounded by organic sediment and peat, e.g. Puttan, Stocksjön, Gällsboträsket and Kungsträsket. The Puttan basin and Norra bassängen are two of the small basins that have been mapped for lake sediments and later investigated for groundwater circulation in the till layer underlying the water-laid sediments /Hedenström 2003, 2004a, Werner et al. 2006, Lokrantz and Hedenström 2006/.

Table 5-12. Generalised stratigraphic description of the sediment profile from a representative coring site at Lake Bolundsfjärden (PFM004231). The depths are measured from the surface of the ice.

Depth (m)	QD
0.00–0.87	Water
0.87–1.38	Algal gyttja
1.38–1.44	Clay gyttja/gyttja clay
1.44–1.50	Postglacial sand
1.5	Probably till

Puttan

The Puttan basin (Wetland 1 in /Lokrantz and Hedenström 2006/) is partly filled with sediment and *Phragmites* today, while other parts of the basin still have open water. The water table at SFM0084 was levelled at 0.7 m above sea level at the time of the installation of the groundwater monitoring well, hence a rough estimate using the present relative land uplift of 6 mm/year indicates that the Puttan basin has risen above sea level for approximately 100 years, even if temporal inflow of water from the Baltic probably still occurs at high sea level. This indicates that the majority of the sediments in the Puttan basin were deposited when the basin was connected to the Baltic. A map showing the QD in the surface is presented in (Figure 5-50) and generalised stratigraphical descriptions based on the field investigations are presented in Table 5-13. The basin is shallow: water depth is c 1 m and maximum depth to the till is 2.5 m.

The major part of the sediment column is classified as algal gyttja (1.47 m) at the ocular inspection in the field. Samples were collected and later analysed for carbon (C), nitrogen (N) and sulphur (S). The sediment had a consistence typical for algal gyttja. Analytical results, however, show organic content in the range of 11–28% (clay gyttja and gyttja). This indicates that the ocular field inspection sometimes over-estimates the organic content in the sediment. Based on the analysis of C content (recalculated into organic matter according to van Bemmelen), only the upper 30 cm sediment was actually classified as gyttja (organic matter > 20%) whereas the remaining sediment column down to the sand layer was clay gyttja (organic matter 6–20%).

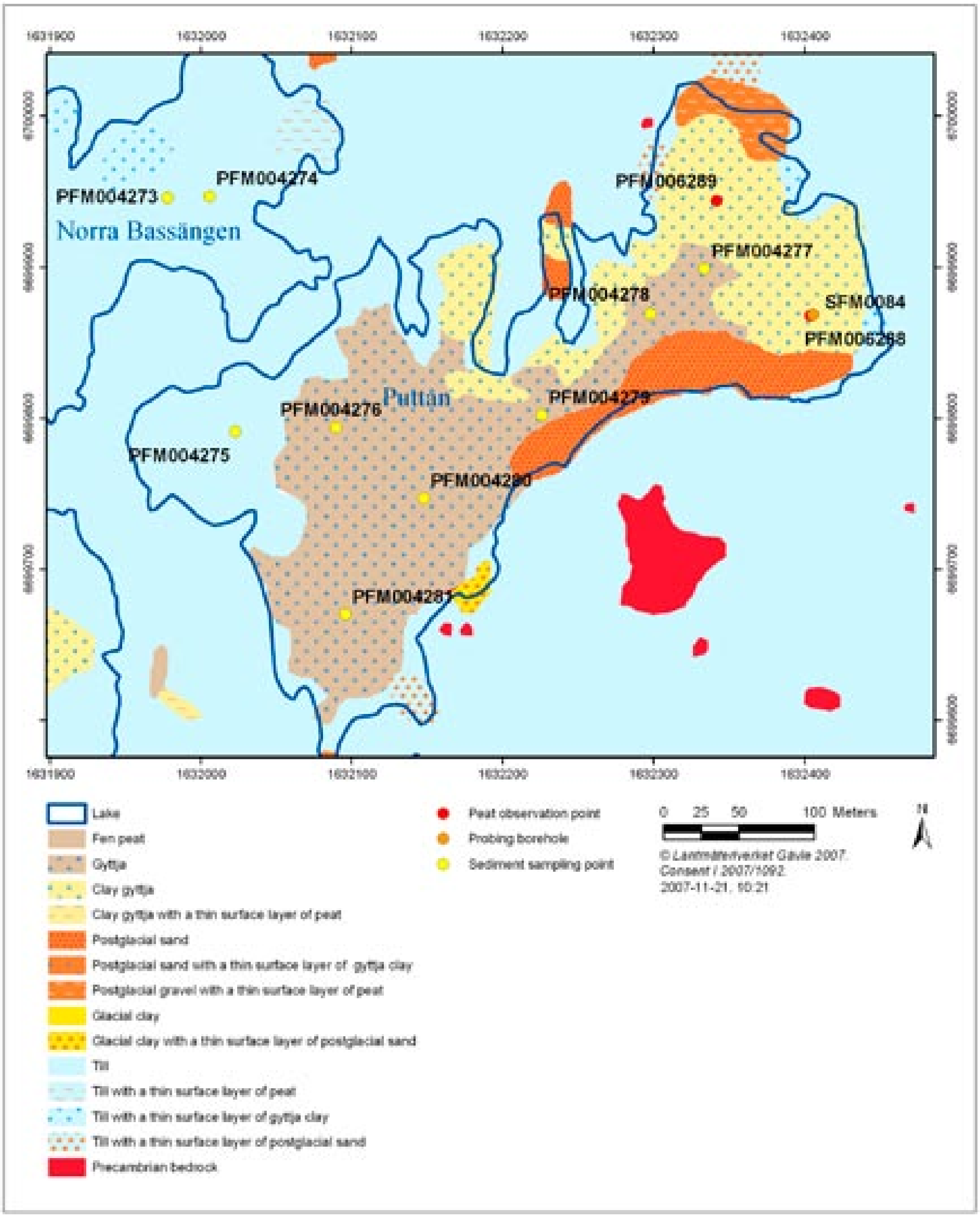


Figure 5-50. Map showing the QD and coring sites at Puttan and the eastern part of the Norra Bassängen. Note that the basin is partly filled with water, which is not displayed on the map. Generalised stratigraphical description for the sites is presented in Table 5-13.

Table 5-13. Generalised stratigraphical descriptions from the Puttan Basin /Hedenström 2003, 2004a, Werner et al. 2006/. The depth values are from the ground or water surface and represent minimum values usually not including the till. Analyses of carbon (C), nitrogen (N), sulphur (S) and calcium carbonate ($CaCO_3$) content from site PFM004280 are presented in (Figure 5-56). For location of the sites, see Figure 5-50.

IDCODE	Depth (m)	QD
SFM0084	0.00 – 0.35	Water
	0.35 – 0.80	Gyttja
	0.80 – 1.29	Clay gyttja
	1.29 – 1.74	Sand
	1.74 – 2.46	Clay
	2.46 – >3.55	Till
PFM006288	0.00 – 0.30	Water
	0.30 – 0.70	Gyttja
	0.70 – 1.20	Clay gyttja
	1.20 – 1.65	Sand
	1.65 – 2.40	Clay
	2.40	Till
PFM006289	0.00 – 1.20	Gyttja
	1.20 – 1.50	Sand
	1.50 – 1.80	Clay
	1.80	Till
PFM004276	0.00 – 0.72	Water
	0.72 – 1.50	Gyttja
	1.65 – 1.70	Clay gyttja
PFM004277	0.00 – 0.40	Water
	0.40 – 1.56	Gyttja
	1.56 – 1.59	Clay gyttja
	1.59 – 1.80	Sand
PFM004278	0.00 – 0.56	Water
	0.56 – 1.50	Gyttja
PFM004279	0.00 – 0.64	Water
	0.64 – 1.62	Gyttja
	1.62 – 1.70	Sand
PFM004280	0.00 – 0.86	Water
	0.86 – 2.33	Gyttja
	2.33 – 2.41	Clay gyttja
	2.41 – 2.75	Sand
PFM004281	0.00 – 1.16	Water
	1.16 – 1.95	Gyttja
	1.95 – 2.10	Sand

Under the gyttja and clay gyttja layers, postglacial sand and gravel occurs anywhere from a few cm-up to a dm-thick layer that continues up to the surface layer on land (Figure 5-50). Stratigraphical information from > 350 PFM-sites within the regional model area showed that the average depth of postglacial sand and gravel is 0.22 m in the terrestrial and lacustrine areas, whereas the average depth in the marine area is 0.9 m. In the investigations conducted using a hand-driven corer /Hedenström 2003/, the layer under the sand was not reached. Approximately 0.7 m clay was identified under the sand at SFM00084, which was cored with a geotechnical auger drill /Werner et al. 2006/.

Norra bassängen

In the Norra bassängen basin /Wetland 2 in Lokrantz and Hedenström 2006/, the investigation of water-laid sediment showed that only thin layers of gyttja and sand rest on the till /Hedenström 2003/. In the QD map, till represents the surface layer in the major part of this basin (Figure 5-50), indicating that the basin has been subject to erosion or non-deposition. The water table of this basin was levelled at 0.6 metres above sea level at the time of the installation of the groundwater monitoring well. Several observations of brackish water intrusions indicate that the isolation process of the basin is not fully completed /Juston and Johansson 2005/.

Peatlands

The wetlands at Forsmark are dominated by nutrient-rich fens and only a few sites can be characterised as bogs. The peatlands are concentrated to Area A in the generalised domains for organic deposits (Figure 5-23). Three small peatlands within subarea A (Figure 2-9) were investigated in separate campaigns /Fredriksson 2004, Lokrantz and Hedenström 2006/. The elevation of the investigated peatlands are > 8 m above sea level, thus they represent some of the older mires for the Forsmark area (Table 5-14). Stratigraphical observations from two peatlands (Stenrösmossen and the mire at Rönningarna) showed that the average depth of the peat layer within subarea A was 1.4 m.

The investigation by /Fredriksson 2004/ comprised investigations of two small peatlands, Stenrösmossen, and a peatland 500 m west of Lersättermyran. That mire was investigated since the site can be used for comparison with a (slightly) older mire, although it is located west of the model area. The two mires were systematically cored along baselines systems. The peat and the peatlands were classified in the field and samples were collected. The stratigraphical profiles for each coring site are presented in Appendix F. Both mires are very shallow, young fens originating from overgrown lakes, which was indicated by bottom layers of gyttja and light yellow, low-humified *Phragmites* peat, followed by medium- to well-humified wood-*Carex* peat and *Carex* peat (sedge) (Appendix F). There are small areas that could be characterised as pine bogs in both fens, where the peat layers are dominated by low-humified *Sphagnum* peat mixed with *Amblystegium* peat (brown mosses), especially in the deeper layers.

Table 5-14. Elevation, mire age, maximum depth of peat and long-term accumulation rate in three mires. See Figure 2-9 for location.

Site	Elevation (m.a.s.l.)	Age (years since emergence from the Baltic Sea)	Max depth of peat (m)	Acc rate/year long term estimated (mm/year)
Stenrösmossen mire	8	1,280 (based on shore displacement)	1.2	0.9
Rönningarna	11	1,720 (^{14}C dated clay/peat 380 AD)	1.9	1.1
Lersättermyran	16	2,400 (based on shore displacement)	2.7	1.1

Stenrösmossen

Stenrösmossen /AFM001245, TM 1 in Fredriksson 2004/ is to a large extent a shallow minerotrophic horizontal fen originally developed in a stagnant body of water. Today the north-western and southern parts of the fen are covered by forest vegetation, dominated by pine and spruce in the north-west and predominantly birch, alder and aspen in the south. The open, central parts of the fen are mostly covered by different *Carex* species mixed in a bottom layer of brown mosses and a scattered distribution of more nutrient-demanding *Sphagnum* species, together with *Ledum palustre* (labrador-tea), *Myrica gale* (bog myrtle), *Calluna vulgaris* (heather) and *Empetrum nigrum* (crowberry). This part of the mire currently has relatively nutrient-poor vegetation and the surface can be classified as a nutrient-poor fen. Values of pH in the surface water in this part of the fen are between 5 and 6. In the south-west, the vegetation is richer and more nutrient-demanding with different grasses, herbs, lingon-berry and fern. The pH-value in the surface water in this part of the fen is between 6 and 7, indicating contact with ground water. The main part of the Stenrösmossen mire is influenced by minerotrophic, nutrient-rich groundwater from the surrounding mineral soils. The horizontal surface of the mire today reflects the groundwater surface. However, the west-central part of the mire contains an area that can best be described as a well-drained pine bog that is, and has been, influenced by less nutrient-rich water. A generalised picture over the peat stratigraphy in the Stenrösmossen mire is shown in Figure 5-51**.** The stratigraphy is characterised by a thin layer of gyttja or clay-gyttja deposited directly on the till representing a short lake stage of the basin. The next unit consists of a thin layer of pure, low-humified, light yellow *Phragmites* (reed) peat, normally mixed with *Equisetum* (horsetail) remnants, which represents the first stage of the overgrowth of the basin. Above these layers, the peat normally consists of medium- to well-humified wood-*Carex* peat, *Carex* peat, *Carex*-*Bryales* peat and *Carex*-*Spagnum* peat. These layers also represent the present vegetation of the fen, with the exception of the northern part, where the densely forested mire shows a higher humification of the remaining peat layers due to ditching and oxidation. A 0.5 m to 1 m thick pure low-humified *Carex* peat also occurs in some of the open parts of the fen.

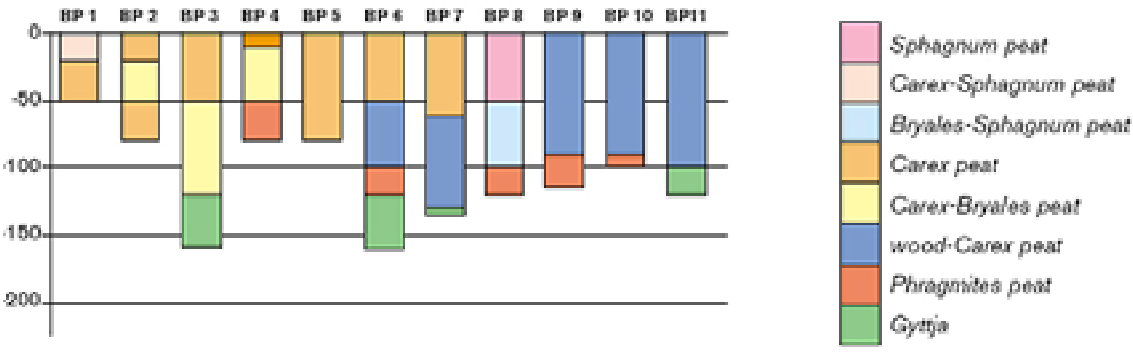


***Figure 5-51.** Generalised stratigraphy of the organic sediments and peat in Stenrösmossen, AFM001245 /from Fredriksson 2004/.*

Lersättermyran

The peatland west of Lersättermyran /AFM001246, TM 2 in Fredriksson 2004/ is predominantly a shallow forest fen typical for this region. Today, these types of peatlands are often used for forestry and sometimes even for agriculture. In the northern part of the mire, there is an area that can best be classified as a pine bog, in spite of an abundance of blueberries (*Vaccinium myrtillus*), lingonberries (*Vaccinium vitis idaea*) and mosses that normally do not occur in bog vegetations. There is also an occurrence of *Ledum palustre*, *Myrica gale* and *Sphagnum* spp. This pine bog area shows many similarities to the pine bog area in the west-central part of Stenrösmossen mire. The pH-values in the pore water in the uppermost layers in this part of the mire are between 4 and 5, i.e. several units lower than the c 1,200 years younger Stenrösmossen mire. The southern part of the mire has been used for forestry. The bottom layers of the mire are characterised by gyttja deposited directly on till, representing the lake stage of the basin, except for the southern part, where the gyttja or clay gyttja is deposited on sand. The peat layers consist of medium- to well-humified wood-*Carex* peat or *Carex-Bryales* peat, representing formation in a fen. In the northern, pine bog part of the fen, a 1- to 2-m thick layer of low-humified Sphagnum peat occurs, representing formation in more nutrient-poor conditions. This mostly ombrotrophic *Sphagnum* peat layer is covered by a thin layer of oxidised wood-*Sphagnum* peat. The *Sphagnum* peat is underlain by *Carex*-*Bryales* peat, *Carex* peat and finally, gyttja.

The chemical analysis performed on samples from Stenrösmossen and Lersättermyran are presented in the section on Properties (Chapter 5.3).

Since wetlands in general are considered as discharge areas, they are of special interest for hydrogeological modelling and safety assessments. A project designed to study the hydrogeology at the interface between the upper geosphere and the biosphere included supplementary drilling, soil sampling, and installation of groundwater monitoring wells in QD, pumping wells in soil-rock and BAT filter tips in QD in three types of wetlands /Werner et al. 2006, Lokrantz and Hedenström 2006/. The objective of the project was to obtain supplementary information concerning depth and composition of the regolith, groundwater levels and pore pressures in the area. The wetlands were selected to represent different sedimentary environments and ages: 1) A young wetland with a bottom layer of clay (Puttan), 2) one young wetland where the organic deposit is deposited directly on the till (Norra bassängen) and 3) one “old” mire with peat in the surface layer and clay in the bottom (Rönningarna).

Rönningarna

The mire at Rönningarna /Wetland 3 in Lokrantz and Hedenström 2006/ consists of a central part characterised as a pine bog covered by e.g. *Ledum palustre*, *Myrica gale* and *Sphagnum* spp (Figure 5-52). The distal areas of the mire are characterised as a fen dominated by richer and more nutrient-demanding vegetation, such as different grasses and *Carex*. Samples were collected in the central part of the bog at SFM0095 through 3 m of peat and sediments using a Russian peat corer, and through the till down to bedrock at a depth of 5 m by auger drilling using a drilling rig. A generalised stratigraphy for the mire at Rönningarna is presented in Table 5-15.

Table 5-15. Generalised stratigraphical description of the sediment profile from the central part of the mire at Rönningarna (SFM0095). For location of the coring site, see Figure 2-9.

Depth (m)	QD
0.0–1.65	Peat
1.65–1.85	Algal gyttja
1.85–2.12	Clayey gyttja
2.12–2.96	Clay
2.96–5.0	Till
5.0	Bedrock

Figure 5-52. *The central part of the mire at Rönningarna is characterised as a pine bog.*

The mire at Rönningarna is located at 11 metres above sea level. Radiocarbon dating of the transition between clay and peat shows that the peat formations started at c 380 AD. The central part of the mire is characterised as a pine bog, whereas the distal part is a minerotrophic fen.

The bedrock surface is covered by more than 5 m of QD. Coring down to the till surface at a 3-m depth revealed an almost 1-m thick unit of varved clay at the bottom, red in the lower part and grey at the top. Several corings, separated by less than 0.5 m, revealed a patchy sand cover on top of the grey clay. The clay and/or sand were overlain by a grey clayey gyttja that is greenish at the top and then gradually transforms into gyttja (Figure 5-53). The gyttja is a red algal gyttja of the same appearance as gyttja layers in e.g. Lake Eckarfjärden and the small pond Lake Stocksjön /Hedenström 2003/. Upwards, the sediment becomes rich in coarse detritus, such as sedge. The gyttja is capped by a thin layer of *Phragmites* peat, gradually merging into a more than 1.5-m thick layer of *Sphagnum* peat. Probings along an east-west trending transect generated a depth profile showing that the bog is situated within a sedimentary basin with an observed maximum depth of approximately 4 m sediment and peat covering the till /Lokrantz and Hedenström 2006/.

The assumption above of wetlands being discharge areas is not valid for the many small shallow wetlands located on a thin layer/lens of clay. This type of wetlands has a higher local ground-water table, isolated from the regional one, especially during the spring when a high water table is recorded at these sites (Figure 5-54). These wetlands are often only 10 to 50 m in diameter and contribute to the small scale mosaic of QD at Forsmark.

Figure 5-53a. *The geotechnical drilling rig with a sample showing a part of core SFM0095 (c. 1–2.5 m depth). The lithostratigraphy is from the top: peat, reed peat, algal gyttja, clayey gyttja, sand, varved glacial clay.* ***b.*** *A sediment core collected using a Russian peat corer covering 1.5–2.5 m at SFM0095 /from Lokrantz and Hedenström 2006/.*

Figure 5-54. *Example of a wetland located on a small patch of clay. A local water table is developed in the Spring. (PFM004175).*

5.3 Properties

5.3.1 Physical properties

The physical properties of the regolith include grain size distribution, hydraulic conductivity, bulk density and porosity. Measurements were taken for these properties, thus the major part of the presentation in this chapter is based on site-specific data. Some of the hydraulic conductivity values, however, are based on calculations. The following description is divided according to QD. The section regarding properties of the soil horizons is mainly applicable to till since this was the QD in the majority of the trenches and test pits dug for investigation of the soil properties. For a thorough description and analysis of the hydraulic properties based on measurements from the site, see /Johansson 2008/.

Till

It is assumed in the following description that sandy and silty till belongs to Till Area I, whereas the clayey till and boulder clay are typical for Till Area II. Other till types were also observed, e.g. gravelly till, however, this was not strictly connected to either of the till areas. In Table 5-16, a summary of the grain size distributions on till samples from the terrestrial area is presented. The results are grouped according to the till-types defined earlier, however, no analyses were performed on samples from Till Area III. The results from each individual grain size distribution analysis performed within the site investigations are presented in Appendix C.

The most commonly occurring till type representing Till Area I was dominated by sand (51%) and silt (23%), while the average clay content was c 4%. The concentration of calcium carbonate ($CaCO_3$) was 19% of the fine fraction. The uniformity coefficient (46) is indicative of a poor degree of graduation, typical for till. Examples of grain size distribution curves from Till Area I are found in (Figure 5-38).

The samples representing Till Area II were also dominated by sand (41%) and silt (32%). The average clay content was as high as 11% and the calcium carbonate ($CaCO_3$) was slightly higher (23%) than in the samples representing Till Area I. The uniformity coefficient for samples with > 5% clay content is usually not applicable. Examples of grain size distribution curves from Till Area II are found in (Figure 5-43).

Additional till samples were classified as gravelly till, containing not only 45% gravel, but also high proportions of sand (41%). The content of silt (13%) and clay (2%) was lower than in the other till types. The calcium carbonate ($CaCO_3$) however, was also high in this till type (18%). Gravelly till was found in both Till Area I and Till Area II, thus was not restricted to a specific area or domain. The uniformity coefficient was high (132), indicating very poor graduation.

In general, the texture of the QD is better known in the terrestrial area since almost all analyses have been performed on samples collected there. The properties of each QD are generally assumed to be similar regardless of whether the site is located in the terrestrial area or the marine area. Some analytical results of the deposits in the shallow coastal area are presented in (Table 5-17)

Based on secondary analysis of the grain size distribution curves, hydraulic conductivity and porosity for each till type were calculated (Table 5-18). It should be pointed out that these values are based on secondary analyses and are generally of a poorer quality than values based on actual measurements. /Johansson 2008/ has evaluated the hydraulic properties of the different QD units at Forsmark, based on both measurements and calculations. According to Fair Hatch /Freeze and Cherry 1979/, the most common till type at Forsmark, sandy till, had a hydraulic conductivity (K-value) of 1.3×10^{-6} m/s, whereas the boulder clay had a K-value of 2.2×10^{-7} m/s. The porosities calculated according to /Andersson et al. 1984/ were between 8% and 9% in the sandy and silty till, which is less than half of the measured porosity values (Table 5-19).

The physical parameters measured are compiled in Table 5-19. Measured K-values for sandy till were c 3×10^{-6} m/s and clayey sandy till c 9×10^{-8} m/s. Boulder clay and gravelly sand from the upper part of the profiles had K-values of c 4×10^{-7} m/s and 4×10^{-5} m/s respectively. The measured K-values are generally in agreement with the calculated ones. Unfortunately, no K-value was presented for the hard clayey till at PFM004459. However, the physical appearances make it probable that the hydraulic conductivity of this unit is very low. For an evaluation and analysis of the hydraulic properties of the regolith at Forsmark, the reader is referred to /Johansson 2008/.

A comparison between the hydraulic conductivity values obtained from slug test and those calculated has been presented by /Johansson 2008/. It was showed that the K-values obtained from slug tests generally are higher compared to the corresponding calculated value, especially for the till/bedrock interface.

Measurements of the dry bulk density of the upper 0.6 m of the regolith were performed at different profiles in the soil type inventory /Lundin et al. 2004/. In the upper part of the horizon, very low bulk density values were recorded: 0.4–1.5 g/cm^3. The density increased downwards to 1.4–2.3 g/cm^3. Additional measurements were performed in two trenches located within Till Area I /Lundin et al. 2005/. The dry bulk density of till samples as recorded in these measurements ranged from 1.5–2.0 g/cm^3 in the upper horizon of the soil profile to densities between 1.9 g/cm^3 and 2.3 g/cm^3 in the deeper layers. Porosity is highest at the surface, c 30–40% and decreased to c 10–20% at a c 2-m depth, i.e. the measured porosity was generally higher than the calculated. The soil physical parameters presented in (Table 5-19) clearly show that these properties vary with depth. The dry bulk density and hydraulic conductivity is higher in the upper layer due to soil-forming processes . In the hydrological description, a differentiation of the hydraulic properties has been made between the upper 0.6 m of the profile and the deeper parts of the profiles for some of the QD /Johansson 2008/. The change of the physical properties of the regolith is gradual towards depth. However, in the 3D geometrical RDM, a distinct layer representing the upper 0.6 m of the regolith was modelled /Hedenström et al. 2008/.

Chemical composition and some physical properties were analysed for type samples, representing the different object types at Forsmark, i.e. terrestrial, lakes, mires /Hannu and Karlsson 2006/ (Chemistry 3 in Figure 2-9). Dry substance and loss on ignition from the sediment and till collected in terrestrial, limnic and marine environment are presented in (Appendix K). Till samples are represented by sandy till from Till Area I (PFM004460, PFM002578) and boulder clay from Till Area II (PFM004459). As would be expected, the proportion of dry substance was high in the till samples, varying between 99.8% and 94.0%.

Glaciofluvial sediments

Since the glaciofluvial Börstilåsen Esker is completely located within the Kallrigafjärden Nature Reserve, no samples were collected and hence no laboratory analyses have been performed from the site. However pumping tests were performed at SFM0060, resulting in K-values between 1.2×10^{-4} m/s and 2.5×10^{-4} m/s, i.e. typical for a coarse-grained sorted sediment /Werner et al. 2004/.

Clay

The grain size distribution curves for clay are largely based on samples of glacial clay since this is the most frequently occurring clay type at Forsmark. The samples originate from the bottom of the lakes or mires /e.g. Hedenström 2004a, Lokrantz and Hedenström 2006/, from the shallow coastal area /Ising 2006/ and from the deep sea off shore of Forsmark /Risberg 2005/. A few samples were collected from small clay patches in the terrestrial area /Sohlenius and Rudmark 2003/. The physical properties of the clay, however, were similar at the sampled sites.

The dominating grain size was clay (57%) but high proportions of silt (42%) also constituted much of the clay. Samples of glacial clay collected from the bottom of Lake Eckarfjärden, the mire at Rönningarna and the shallow coastal area at Tixelfjärden contained between 65% and 46% dry substance /Sternbeck et al. 2006, Nordén 2007/.

Analytical results of grain size distribution, calcium carbonate ($CaCO_3$) and organic carbon content from the marine area are found in Table 5-20.

Postglacial sand and gravel

The surface layers of two sites at the trenches within Till Area I contained postglacial, gravelly sand. The results from measurements of the soil physical parameters showed that the dry bulk density was between 1.6 g/cm^3 and 2.0 g/cm^3 and the relative pore volume was c 30%. The hydraulic conductivity was c 5×10^{-5} m/s, i.e. less than the conductivity measured at the glacio-fluvial esker at SFM0060.

Texture analyses of postglacial sand show that sand dominates (68%), while gravel makes up 17% and silt another 13% (Table 5-24). The uniformity coefficient was 10, indicating a rather uniform composition. A layer of sand in Puttan contained 85% dry substance. Calculated hydraulic conductivity for sandy gravel was 7×10^{-4}m/s, i.e. higher than the measured K-value from the measurements of the surface layer containing gravelly sand. Five samples of a coarser postglacial sediment were dominated by gravel (53%) and sand (44%).

Gyttja and clay gyttja

The water-laid sediments with organic content of > 6% are gyttja and clay gyttja. These sediments were predominantly collected from the bottom of the lakes and ponds, under mires and in the coastal area. Organic sediments have not been subject to texture analysis, thus the physical properties of these sediments are water content, dry matter, bulk density and porosity.

Analytical results of organic carbon content and calcium carbonate ($CaCO_3$) content from the samples collected at wetlands are presented in (Table 5-21). The proportion of dry substance in the fresh samples is presented according to QD type in the general stratigraphy presented in Table 5-22.

Dry substance content in the gyttja and clay gyttja samples was between 2% and 22%. The lowest content of dry substance was recorded in a gyttja layer collected in the upper part of the sediment column. The porosity in the gyttja layers was c 92–96% (Table 5-22). Gyttja collected below the peat layer at Rönningarna mire had a dry substance of (5.7%).

Peat

The physical properties of peat are described by dry substance, porosity and bulk density. The water content in the peat from Stenrösmossen and Lersättermyran was c 90% and the ash content was c 9%. The wet bulk density was 1.004 g/cm^3 and the porosity c 92% (cf. Table 5-23).

Table 5-16. Statistics for the grain size distribution and calcium carbonate ($CaCO_3$) content of the fine fraction (< 0.063 mm) for the different till types at Forsmark. Results for each individual sample are presented in Appendix C. D60/D10 is a uniformity coefficient. Values > 15 are indicative of a poor degree of graduation typical for till.

Deposit	Gravel %	Sand %	Silt %	Clay %	D60/D10	$CaCO_3$ %
Sandy and sandy silty till (Till Area I) n=66	22.1 (±7.8)	50.8 (±10.1)	23.5 (±8.9)	3.6 (±1.1)	46.4 (±29.5)	19.1 (±5.7)
Clayey till and boulder clay (Till Area II) n=103	15.8 (±8.1)	41.2 (±6.8)	32.3 (±7.2)	10.8 (±4.4)	104.0 (±155.4)	23.4 (±6.6)
Gravelly till n=15	44.8 (±8.8)	40.7 (±10.7)	12.7 (±5.4)	2.4 (±1.1)	132.6 (±105.7)	17.5 (±5.3)

Table 5-17. Physical properties of samples from the shallow coastal area. Results are from grain size and calcium carbonate ($CaCO_3$) analyses with theoretically-calculated hydraulic conductivity /Freeze and Cherry 1979/. The samples were collected from coastal areas /Ising 2006/.

Id code	Depth (m)	Quaternary deposit	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	$CaCO_3$ (%)	Hydraulic cond (m/s)
PFM006073	4.13–4.18	Clay	0	10.9	42.7	46.4	20	
PFM006073	4.18–4.31	Clayey sandy till	17.7	42.5	26.3	13.5	8	2.7×10^{-8}
PFM006094	1.55–1.87	Sand	13.6	80.7	3.1	2.6	0.4	3.0×10^{-5}
PFM006095	0.29–0.59	Sand	0	94.9	2.0	3.1	0.3	4.2×10^{-5}
PFM006095	2.20–2.50	Clay	0	1.5	32.7	65.8	29	
PFM006095	2.76–3.00	Boulder clay	9.2	37.6	37.5	15.7	25	1.7×10^{-8}
PFM006097	3.55–3.67	Clayey sandy till	17.7	42.4	26.7	13.2	10	2.6×10^{-8}

Table 5-18. Theoretically-calculated hydraulic conductivity and porosity values for the different till types and sediment at Forsmark. It should be noted that the values are based on secondary analyses based on the grain size distribution curve. K-values are calculated according to /Freeze and Cherry 1979/, while porosity values are according to /Andersson et al. 1984/.

	K (m/s)	Porosity (%)
Sandy till (Till Area I) n=23	1.28×10^{-6} ($\pm 1.87 \times 10^{-6}$)	9.47 (±1.65)
Clayey sandy till (Till Areas I and II) n=14	4.75×10^{-7} ($\pm 4.42 \times 10^{-7}$)	8.75
Clayey sandy silty till (Till Areas I and II) n=12	1.17×10^{-6} ($\pm 3.04 \times 10^{-6}$)	8.00
Boulder clay (Till Area II) n=2	2.22×10^{-7}	
Gravelly till n=5	2.09×10^{-6} ($\pm 2.63 \times 10^{-6}$)	
Sandy gravel n=3	7.01×10^{-4}	12.2

Table 5-19. Soil physical parameters as measured at different horizons in two trenches within Till Area I. Depth from/to refers to ground level /data from Lundin et al. 2005/.

Id	Depth (m)	QD	Dry bulk dens (g/cm³)	Matrix vol (%)	Pore vol (%)	Water content (%)	Hydraulic cond. K (m/s)
PFM004455	0.10–0.15	Gravelly sand	1.60	62.1	37.9	3.6	5.84×10^{-5}
	0.20–0.25	Sandy till	1.60	58.0	42.0	8.3	3.70×10^{-5}
	0.50–0.55	Sandy till	1.90	69.0	31.0	7.4	1.91×10^{-7}
	0.80–0.85	Sandy till	2.00	75.7	24.3	10.4	1.16×10^{-7}
	1.20–1.25	Sandy till	2.00	72.9	27.1	11.7	2.31×10^{-8}
	1.70–1.75	Sandy till	1.90	70.2	29.8	17.1	1.16×10^{-7}
	2.50–2.55	Clayey sandy till	2.10	77.0	23.0	14.4	9.26×10^{-8}
PFM004458	0.05–0.10	Sandy till	2.00	74.0	26.0	15.7	1.27×10^{-6}
	0.20–0.25	Sandy till	1.90	72.7	27.3	13.4	4.63×10^{-7}
	0.50–0.55	Sandy till	2.10	77.4	22.6	15.6	6.94×10^{-7}
	0.80–0.85	Gravelly till	2.10	77.8	22.2	15.3	9.26×10^{-7}
	1.20–1.25	Gravelly till	2.20	81.7	18.3	14.9	2.31×10^{-7}
	1.70–1.75	Sandy till	2.20	83.7	16.3	15.1	2.31×10^{-8}
	2.50–2.55	Sandy till	2.20	83.0	17.0	13.3	1.04×10^{-7}
PFM004459	3.50–3.55	Clayey sandy silty till	2.20	80.2	19.8	18.9	–
PFM004460	0.05–0.10	Gravelly sand	2.00	73.6	26.4	13.4	3.01×10^{-5}
PFM004460	0.20–0.25	Boulder clay	1.60	59.8	40.2	37.1	4.63×10^{-7}
	0.50–0.55	Sandy till	2.10	78.1	21.9	14.9	3.47×10^{-8}
	0.80–0.85	Sandy till	2.10	79.3	20.7	16.0	2.31×10^{-8}
	1.20–1.25	Sandy till	2.20	83.4	17*	16.8	1.16×10^{-8}
	1.70–1.75	Sandy till	2.30	86.0	16*	15.9	8.10×10^{-9}

*The values are corrected based on recommendations by Lundin, September 2008.

Table 5-20. Analytical results of grain size distribution, calcium carbonate ($CaCO_3$) and organic carbon content, together with the lithological classification of nine samples from the marine sediment core PFM004396. The site is representative for the deep part of the marine area. Clay and silt content was not calculated for the samples 48–55 cm and 450–460 cm because of flocculation during sedimentation /from Risberg 2005/. The depths are below the sea floor.

Depth (cm)	QD	Clay (%)	Silt (%)	Sand (%)	$CaCO_3$ (%)	Org. C (%)	Baltic Sea stage
40–48	Clayey silty sand	6	32	62	0	0.2	Littorina Sea
48–55	Silty sand	–	–	62	0	0.1	Littorina Sea
60–70	Gyttja clayey silt	15	53	32	1	2.0	Littorina Sea
220–230	Gyttja clay	24	70	6	0	2.4	Littorina Sea
343–350	Clay	30	51	19	0	1.5	Littorina Sea
400–410	Clayey silt	14	82	4	1	1.4	Littorina Sea
450–460	Clay	–	–	4	0	0.3	Yoldia Sea
500–510	Clay	80	20	0	5	1.0	Yoldia Sea
550–560	Clay	73	27	0	11	1.5	Yoldia Sea

Table 5-21. Analytical results of organic content, calcium carbonate ($CaCO_3$) content and theoretically calculated K-values from three wetlands at Forsmark. K-values are calculated from grain size analyses according to /Freeze and Cherry 1979/, from /Lokrantz and Hedenström 2006/. The colour codes are according to /Munsell 1975/.

Coring ID	Depth (m)	Lithology	K-value (m/s) (Fair Hatch)	Loss on ignition (weight %)	Colour Munsell	$CaCO_3$ (%)
SFM0084	0.35–0.50	Gyttja		36.7	5Y3/1	1.5
Organic	0.50–0.60	Gyttja		25.3	5Y3/2	0.9
Domain B	0.70–0.75	Gyttja		24.1	5Y3/2	2.5
	0.85–0.90	Clayey gyttja		20.7	5Y3/2	1.0
	0.95–1.00	Clayey gyttja		19.5	5Y3/2	1.1
	1.15–1.20	Clayey gyttja		21.9	2.5Y3/2	0.4
	1.20–1.25	Clayey gyttja		7.8	10YR5/1	35
	1.25–1.28	Clayey gyttja		9.8	5Y3/2	2.2
	1.40–1.50	Sand	$3.38x10^{-04}$		5Y3/1	0.7
	1.55–1.70	Sandy gravel	$9.67x10^{-06}$		5Y3/1	1.2
	1.85–1.90	Clay			5Y4/1	7
SFM0091	0.55–0.64	Gyttja		30.1	5Y3/2	4.5
Organic	0.68–0.75	Gyttja		20.5	5Y3/2	1.0
domain B	0.85–0.90	Clayey gyttja		19.4	5Y3/2	0.4
	0.94–1.00	Clayey gyttja		17.5	5Y3/2	0.5
	1.18–1.24	Sandy gravel	$1.23x10^{-03}$		5Y3/2	9
	1.26–1.31	Clay			5Y4/1	35
SFM0094	0.9–1.30	Clayey sandy till	$5.06x10^{-07}$		5Y5/2	26
Organic domain A	1.60–1.90	Clayey sandy till	$1.16x10^{-07}$		5Y5/2	20
	2.20–2.70	Clayey sandy till	$9.09x10^{-08}$		2.5Y5/2	21

Table 5-22. Properties of water-laid sediments in the lakes at Forsmark. */Hedenström 2004a/, site specific **Eckarfjärden /Hedenström and Risberg 2003/. * /Nordén 2007/ and values from Frisksjön, Oskarshamn.**

Stratum/lake	Stratum thickness (m)*	C** (% of dw)	Water content*** (% of wet sample)	Dry material (% of wet sample)	Wet bulk density g/cm^3	Porosity %
Eckarfjärden	(Σ 1.75 m)					
Gyttja	0.96	27	93	7	1.024	95.2
Clay gyttja	0.11	8	86	14	1.081	93.5
Clay	0.68	1	53	47	1.405	74.6
Fiskarfjärden	(Σ 3.52 m)					
Gyttja	1	17	93	7	1.032	96.5
Clay gyttja	0.61	05	86	14	1.087	93.8
Clay	1.91	1	53	47	1.404	74.6
Stocksjön	(Σ 0.49 m)					
Gyttja	0.4	27	86	14	1.049	91.8
Clay gyttja	0.03	8	86	14	1.081	93.5
Clay	0.06	1	53	47	1.405	74.6
Gällsboträsket	(Σ 1.41 m)					
Gyttja	0.34	27	86	14	1.049	91.8
Clay gyttja	0.37	8	86	14	1.081	93.5
Clay	0.7	1	53	47	1.405	74.6
Bolundsfjärden	(Σ 0.6 m)					
Gyttja	0.48	27	90	10	1.035	94.3
Clay gyttja	0.07	8	86	14	1.081	93.5
Clay	0.05	1	53	47	1.405	74.6
Puttan	(Σ 0.82 m)					
Gyttja	0.8	20	89	11	1.047	94.2
Clay gyttja	0.02	9	86	14	1.080	93.4
Clay	0	1	53	47	1.404	74.6
N:a Bassängen	(Σ 0.16 m)					
Gyttja	0.15	27	86	14	1.049	91.8
Clay gyttja	0.01	8	86	14	1.081	93.5
Clay	0	1	53	47	1.413	74.9

Table 5-23. General stratigraphical distribution and average content of carbon (C), nitrogen (N), sulphus (S) and phosphorous (P) as recorded in marine and lacustrine sediments and peat at Forsmark.

Environment	Lithology	Relative age	C %	N %	S %	P %	Water content %	Porosity %	Bulk density g/cm^3
Bog/Fen	Peat	Youngest	55	0.68	0.7	0.02	90	91.9	1.004
Freshwater lake	Gyttja	↑	18	1.4	1.9		93	95.2	1.031
Shallow Baltic basin	Clay gyttja	↑	6.2	0.6	1.6	0.09	86	93.4	1.085
Coast	Postglacial sand and gravel						8.5	32	1.600–2.000
Postglacial Baltic basin	Postglacial clay	↑	1.8						
Late glacial Baltic basin	Glacial clay	Oldest	1.00	0.11	0.76		53	74.6	1.400

Table 5-24. Statistics for the texture of the different types of postglacial sediments and clay at Forsmark. Results for each individual sample are presented in Appendix C. D60/D10 is a uniformity coefficient. Values > 15 are indicative of a poor degree of graduation, while lower values are indicative of a higher degree of graduation.

Deposit	Gravel %	Sand %	Silt %	Clay %	D60/D10	$CaCO_3$ %
Gravel n=5	53.1 (±6.7)	44.2 (±6.1)	1.5 (±1.2)	1.2 (±1.1)	16.8 (±4.1)	
Sand n=15	16.9 (±16.2)	68.0 (±14.1)	13.0 (±15.4)	2.7 (±2.2)	10.6 (±8.1)	
Silt n=4	0.2 (±0.5)	15.9 (±13.7)	68.9 (12.6)	15.0 (±6.8)	9.9	
Clay n=30	0.6 (±1.8)	3.0 (±7.2)	41.6 (±16.1)	54.8 (±13.8)		18.0 (±13.3)

5.3.2 Chemical properties

The chemical properties of the regolith have been analysed in several activities and the most commonly occurring QD and soil types are included. A statistical evaluation of chemical data from regolith samples, available at the SICADA database in May 2005, has been presented by /Tröjbom and Söderbäck 2006/. In the summary below, additional analyses performed after May 2005 are included.

Chemical characterisation of the elemental composition of the different QD such as till, clay, gyttja and peat, was performed on representative samples from the Forsmark area /Hannu and Karlsson 2006/.

Calcium carbonate ($CaCO_3$), clay mineralogy and geochemical composition of extractable elements from till samples were analysed in order to characterise the properties of the till units in the area /Sohlenius and Rudmark 2003/. Elemental analyses of the fine fraction from samples of basal till collected at corings and machine-cut trenches was performed with the primary focus being to analyse any potential for ore exploration at Forsmark /Nilsson 2003/.

One sediment core from Lake Stocksjön was subject to elemental analysis of 12 samples at various depths /Strömgren and Brunberg 2006/. The total content of carbon (C), nitrogen (N) and sulphur (S) was analysed in sediment from the bottom of the lakes /Hedenström 2004a/. The sediments in the shallow coastal areas were analysed for content of C, N and phosphorus (P) /Sternbeck et al. 2006/.

Peat chemistry includes ash content and element analyses /Fredriksson 2004, Hannu and Karlsson 2006/.

In the investigation of soil types, soil pH values, carbon (C) and nitrogen (N) contents were analysed at each horizon of the soil classes /Lundin et al. 2004, 2005/.

Chemistry of till

The geochemical distribution pattern of trace elements in the till has been presented in two reports /Sohlenius and Rudmark 2003, Nilsson 2003/. The study by /Nilsson 2003/ focused on basal till from the Forsmark area. The investigation by /Sohlenius and Rudmark 2003/ was made for geochemical characterisation of the QD. Additionally, four till samples were included in the characterisation of the different QD /Hannu and Karlsson 2006/. The samples for arsenic (As), cadmium (Cd), copper (Cu), cobalt (Co), hydrogen (Hg), nickel (Ni), lead (Pb), selenium (Se) and sulphur (S) were digested in nitric acid (HNO_3) and thereafter analysed with ICP-MS. The remaining elements were presented as total content (Appendix H).

Elemental analyses of four till samples from Forsmark /Hannu and Karlsson 2006/ were compared with till samples from Simpevarp area /Sohlenius et al. 2006/ and the national geochemical survey /SGU 2006/. The calcium oxide (CaO) had a much higher concentration in the Forsmark samples when compared to both the national and Simpevarp concentrations (Table 5-25). All other elements occurred in lower concentrations than in the reference till samples. The total content of oxides was significantly lower in the four samples from Forsmark (c. 90%) compared with both the Simpevarp and national values, which were c 99% of the dry weight. The reason for the low concentration of oxide in the till from Forsmark may possibly be explained by the high concentration of clay, which is reflected in a surprisingly high loss on ignition in the till samples.

A summary of geochemical analyses of the fine fraction from till representing the terrestrial part of the Forsmark model area as compared to national averages is presented in (Table 5-26). The complete analytical results of till samples are found in (Appendix H).

Analyses of trace and major elements in till has been performed by SGU that cover a large part of southern Sweden /SGU 2005/, however, the Forsmark region is not included. That survey was carried out within the regular geochemical mapping programme of SGU. The fine fraction of the till (< 0.063 mm) was digested in Aqua Regia and analysed using the ICP-AES-method. When the median concentrations of elements in till from the Forsmark area were compared to the Swedish reference data, the majority of the elements were within a factor ±2 compared to the median values of the Swedish references /Tröjbom and Söderbäck 2006/.

As described earlier, the till at Forsmark is characterised by a high content of calcium (Ca). The statistical comparison with national references confirms that Ca and strontium (Sr) are the two exceptions. The content of these elements in the till from the Forsmark area was clearly higher than the Swedish reference data (Table 5-26).

/Nilsson 2003/ compared the concentration of extractable elements obtained from the fine fraction of till from Forsmark with the distribution of element values obtained from a regional, near-surface till survey carried out by the Swedish Geological Company (SGAB) /GVR 1993/ in central Sweden during the years 1987–1991. The concentrations of the base metals and gold are moderate to low compared to regional concentrations (Table 5-27).

The arsenic (As) content was high in the basal till, probably due to the precipitation of Ca-arsenates, which is favoured by the occurrence of calcite /cf. Nilsson 2003/.

The study by /Nilsson 2003/ suggests that there is no potential for ore explorations of copper (Cu), lead (Pb), zinc (Zn) or gold (Au) in the Forsmark area. In accordance with /Sohlenius and Rudmark 2003/, this study showed high strontium (Sr) levels, about seven times higher than the Swedish reference (Table 5-26). A similar enrichment is recorded in the surface waters in the Forsmark area and are compared to a sample of Swedish lakes /Tröjbom et al. 2007/. The high Sr concentrations in the surface waters are probably caused by the high content of Sr in the till, originating from the sedimentary limestones of Gävlebukten.

Table 5-25. Elemental analyses, expressed as oxides, of till samples from Forsmark, Simpevarp and Swedish national geochemical survey.

Element	Unit	Forsmark (n=4) Mean	Simpevarp (n=6) Mean	Swedish national (n=26,343) Mean
Al_2O_3	%	9.8	14.1	13.59
CaO	%	11.21	2.02	2.26
Fe_2O_3	%	2.33	3.98	3.86
K_2O	%	2.90	4.19	2.88
MgO	%	0.75	1.41	1.38
MnO	%	0.057	0.061	0.063
Na_2O	%	2.25	3.55	2.68
P_2O_5	%	0.102	0.181	0.233
SiO_2	%	60.7	69.2	72.1
TiO_2	%	0.275	0.485	0.739
Summa	**%**	**90,374**	**99,177**	**99,785**

Table 5-26. Compilation of ICP-MS analyses of extractable fractions of selected elements from till samples (fraction < 63 µm) obtained from the terrestrial part of the Forsmark area. Note that two different solvents were used for extraction prior to analysis, Aqua Regia (AR) or 7M nitric acid (HNO_3). Data from a national geochemical survey are used as reference and samples were extracted from the fine fraction using Aqua Regia (AR) /SGU 2005/. The reference data were analysed by either ICP-AES or ICP-MS techniques. /from Tröjbom and Söderbäck 2006/. Calcium (Ca) and strontium (Sr) are in bold since they are the two elements with concentrations deviating from the Swedish reference values.

	Element	Solv	Unit	Till – Forsmark (ICP-MS)						Till – Swedish reference						
				No	Min	25-p	50-p	75-p	Max	Method	No	Min	25-p	50-p	75-p	Max
Al	Aluminium	AR	%	43	0.36	0.52	0.61	1.03	4.92	ICP-AES	15822	< 0.0003	0.74	1	1.3	6.7
Ca	Calcium	AR	%	43	2.78	6.315	7.29	8.6	10.5	ICP-AES	15844	< 0.001	0.22	0.29	0.36	38
Fe	Iron	AR	%	43	0.81	1.02	1.25	1.785	8.23	ICP-AES	15844	< 0.001	1.2	1.6	2.1	9.3
K	Potassium	AR	%	43	0.07	0.12	0.14	0.225	0.47	ICP-AES	15844	< 0.001	0.067	0.11	0.18	1.3
Mg	Magnesium	AR	%	43	0.22	0.33	0.39	0.465	4.85	ICP-AES	15844	0.001	0.21	0.31	0.44	4.1
Mn	Manganese	AR	%	43	0.025	0.032	0.038	0.042	0.19	ICP-AES	15844	< 0.001	0.016	0.023	0.034	0.81
Na	Sodium	AR	%	43	0.012	0.018	0.022	0.032	0.089							
Na	Sodium	HN	%	8	0.013		0.018		0.023	ICP-MS				< 0.02		
P	Phosphorus	AR	%	43	0.044	0.054	0.058	0.061	0.168	ICP-AES	7341	< 0.001	0.069	0.09	0.11	0.7
S	Sulphur	AR	%	43	0.005	0.01	0.05	0.09	0.16							
Ti	Titanium	AR	%	43	0.04	0.052	0.060	0.082	0.233	ICP-MS				0.069		
Ag	Silver	AR	ppm	43	0.013	0.022	0.026	0.032	0.048							
Ag	Silver	HN	ppm	8	0.06		0.08		0.31	ICP-MS				0.043		
As	Arsenic	AR	ppm	43	0.9	1.8	2.1	2.9	4.5							
As	Arsenic	HN	ppm	8	1.7		2.6		3.3	ICP-MS				3.1		
Au	Gold	AR	ppm	43	< 0.2	< 0.2	0.3	0.85	2.6	AAS				< 1		
Cu	Copper	AR	ppm	43	5.6	8.26	11	14	16	ICP-AES	7341	< 1	8	12	18	229
La	Lanthanum	AR	ppm	43	16	21	23	26	42	ICP-AES	15844	< 2	21	26	33	338
Ni	Nickel	AR	ppm	43	3	6	7.8	14	32	ICP-AES	15843	< 2	6	10	15	179
Pb	Lead	AR	ppm	43	< 5	6.5	8.3	11	27	ICP-AES	15843	< 7	5	9	13	423
Sr	Strontium	AR	ppm	43	27	59	72	81	175	ICP-AES	15844	< 2	8	11	16	462
Th	Thorium	AR	ppm	43	4.1	7.5	8.6	9.5	13							
Th	Thorium	HN	ppm	8	5		6.5		8.4	ICP-MS				7		
U	Uranium	AR	ppm	43	1.1	1.6	1.8	2.8	9	ICP-MS				1.5		
Zn	Zinc	AR	ppm	43	19	26	37	45	141	ICP-AES	15843	< 1	25	35	47	2.197

Table 5-27 Comparisons of concentration of selected elements from the fine fraction of till from Forsmark and a regional survey carried out by the Swedish Geological Company (SGAB), modified from /Nilsson 2003/. All concentrations are ppm except calcium (Ca), which is presented as a percentage.

Element	Cu Forsmark	Cu SGAB	Pb Forsmark	Pb SGAB	Zn Forsmark	Zn SGAB	Au Forsmark	Au SGAB	Ca (%) Forsmark	Ca (%) SGAB
Median	10.5	8.5	7.8	7.6	32.3	26.3	0.2	0.1	8.5	0.18
Max	15.9	1,190.0	25.0	345.0	140.8	283.0	2.6	95.7	10.5	11.0
N	28	1,986	28	1,986	28	1,986	28	1,986	28	1,986

Some elements show a large spread between the minimum and maximum values, e.g. sulphur (S), iron (Fe) and vanadium (V), with a max/min ratio of about 10, while other elements, such as arsenic (As), copper (Cu) and bismuth (Bi) are more evenly distributed with a maximum/minimum ratio of about 3 (Table 5-26). The analyses of heavy metals from the fine fraction of basal till shows that the contents of copper (Cu), lead (Pb) and zinc (Zn) in the till coincide with that of the local bedrock /Nilsson 2003/. The area west of Lake Bolundsfjärden had a relatively low content of Cu (Figure 5-55), Pb and Zn. This area coincides with the area of granitic bedrock that occupies the central part of the Forsmark candidate area. The highest contents of Cu, Pb and Zn coincide with areas with felsic to intermediate meta-volcanic rocks and amphibolites, situated in the north-eastern and south-western parts of the investigated area. Most bedrock types in the Forsmark area had a north-west to south-east strike, which corresponds to the dominating direction of the ice movements (Figure 5-4). This may have strengthened the pattern of element anomalies. The contents of Cu, Zn, and Pb are close to the median values for till in central Sweden (Table 5-26 and Table 5-27). The calcium (Ca) of 7.3% content is much higher than the 0.29% median in central Sweden as an effect of the high content of calcite in the till.

A comparison between the different till types shows that till with a clay content higher than 5% (Till Area II) has a slightly higher content of calcite (average content 23%, n=106) in the fine fraction (grain sizes < 63µm) compared to the sandy till (average content 19% n=66).

The geochemical analyses presented by /Sohlenius and Rudmark 2003/ show a positive correlation between the clay content and the contents of most elements in the eight samples analysed. This is probably explained by a more effective leaching with nitric acid (HNO_3) from fine-grained material compared to coarser material. The results from this investigation indicate to what degree different elements can be leached and taken up by biota in the natural soil environment.

In the statistical analysis, /Tröjbom and Söderbäck 2006/ showed that the extractable elements from the fine fraction of three sampling sites deviated in the chemical composition of the till (Appendix H, Table G2): SFM0016 and SFM0017 in the vicinity of Lake Eckarfjärden and to some extent, SFM0057, show higher contents of aluminium (Al), iron (Fe), magnesium (Mg) and manganese (Mn) and somewhat lower contents of calcium (Ca) and sulphur (S). Till from these sites also showed deviating contents of some of the trace elements. The silver (Ag) and cadmium (Cd) contents are especially low, whereas the contents of bismuth (Bi), boron (B), gallium (Ga), scandium (Sc), strontium (Sr), uranium (U), vanadium (V), and zinc (Zn) are more or less elevated at these sample sites. It is of interest to note that these three sites have stratigraphy with a (hard) silty/clayey under a sandy till (cf. section 5.2). In a study of hard clayey till from central Sweden, /Björnbom 1979/ showed that the hard clayey till had higher concentrations of Zn and chromium (Cr) in the fine fraction than the average sandy till.

Loss on ignition (combusted at 550°C) was analysed on the type samples, including till. The results of 7–10% were surprisingly high in the till samples (Appendix K). The values were not corrected for any clay content, which probably caused the surprisingly high LOI values.

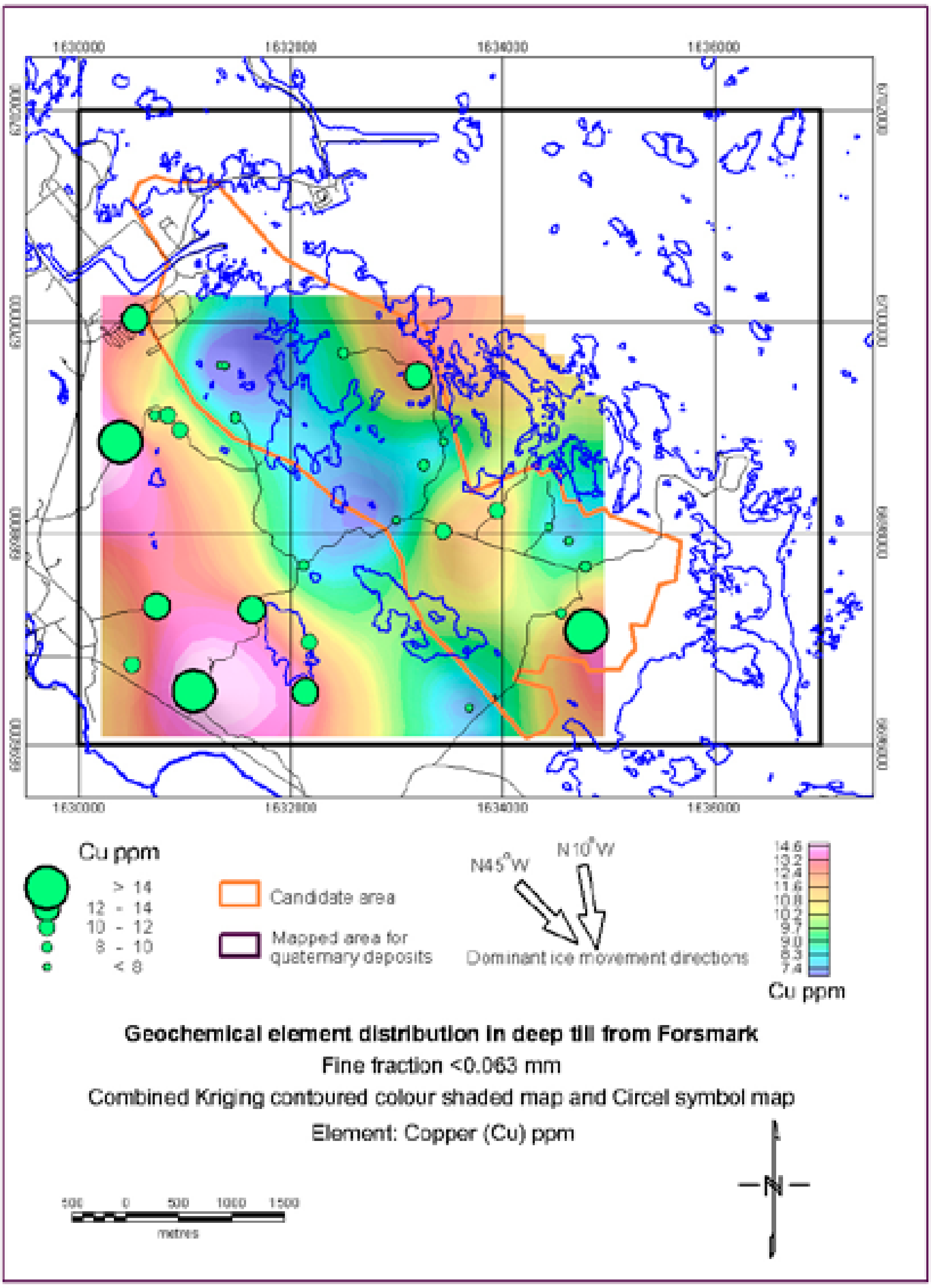


Figure 5-55. *The content of extractable copper (Cu) from the fine fraction of basal till /from Nilsson 2003/. The highest values are recorded in the area north-east and south-west of the candidate area, while the lowest concentration was recorded in the till samples collected west of Lake Bolundsfjärden.*

Qualitative mineralogical analysis was performed using XRD of bulk soil material. The mineralogical composition showed small variations in the contents of most silicate minerals in the till /Sohlenius and Rudmark 2003/. The samples contain almost 40% quartz, which is similar to most of the bedrock in the investigated area. There is a relatively high content of hornblende in the two samples from HFM02, situated west of Lake Bolundsfjärden. The hornblende may emanate from an occurrence of gabbro, c 1 km west of that site.

The qualitative XRD analyses of clay mineralogy show that illite is the most common clay mineral in all four samples analysed. The result shows that the illite/chlorite ratio is higher in the clayey till compared to the silty-sandy till. It has been shown in an earlier study that the illite/chlorite ratio is higher in eastern Uppland compared to Södermanland, probably due to different bedrock mineralogy /Snäll 1986/.

Petrography/mineralogy of boulders and gravels were analysed to test if the composition was similar to the bedrock /Bergman and Hedenström 2006/. The analyses showed that the chemical and mineralogical compositions of the till mainly reflect that of the local bedrock. The high calcium carbonate ($CaCO_3$) content of the till showed, however, that clasts of the till had been transported several tens of kilometres.

Chemistry of lake sediments

A general stratigraphy has earlier been established for the marine and lacustrine lake sediments (cf. Table 5-23). Not all these sediment types were present in all the investigated lakes. The general stratigraphy represents the development from late glacial sea bottom to a shallow lagoon stage, and finally the isolation from the Bothnian Sea into a fresh-water body of the lake stage. One sediment core from Lake Fiskarfjärden, Puttan and the small pond close to the Börstilåsen Esker were collected and analysed with respect to content of carbon (C), nitrogen (N) and sulphur (S) /Hedenström 2004a/.

In the three lakes investigated, the concentration of carbon (C), nitrogen (N) and sulphur (S) shows an increasing trend from the oldest to the youngest sediments (Figure 5-56). The total contents of C, N, and S are relatively low in the glacial clay. The average content of C, N and S in glacial and postglacial clay (n=6) and algal gyttja (algal gyttja n=27, gyttja clay n=14) has been calculated and is presented in the general stratigraphy (Table 5-23).

The carbon (C) and nitrogen (N) contents increase stepwise at the transitions to gyttja clay and algal gyttja (Figure 5-56). The sulphur (S) contents are close to or higher than 1% in all sediments overlying the glacial clay. The highest values, up to 3%, were recorded in the organic rich gyttja sediments.

Nitrogen (N) and carbon (C) contents are well correlated in sediments from the three lakes (Figure 5-56) and the C/N ratio is between 8 and 12. Some samples, however, have a higher C/N ratio, indicating the presence of calcium carbonate ($CaCO_3$). Higher productivity in lagoons and lakes compared to the open sea probably caused the relatively high content of organic carbon and nitrogen preserved in the sediments deposited in these environments.

Sulphur (S) in the sediments may be partly associated with organic material, but most -S in postglacial organic-rich sediments is bound in iron sulphides /cf. Sternbeck and Sohlenius 1997/. The sulphides are formed as a consequence of reduction of ferric iron and sulphate during the anaerobic breakdown of organic matter. It is therefore likely that the postglacial gyttja sediments and clays in the Forsmark area contain significant amounts of iron sulphides.

The mapping of QD showed that many of the wetlands are made up of clay gyttja at the surface /Sohlenius et al. 2004/. It is likely that the clay gyttja shown on the map of QD has contents of carbon (C), nitrogen (N) and sulphur (S) similar to that recorded in the clay gyttja from the lakes. As mentioned above, the high content of S in the clay gyttja reflects the occurrence of iron

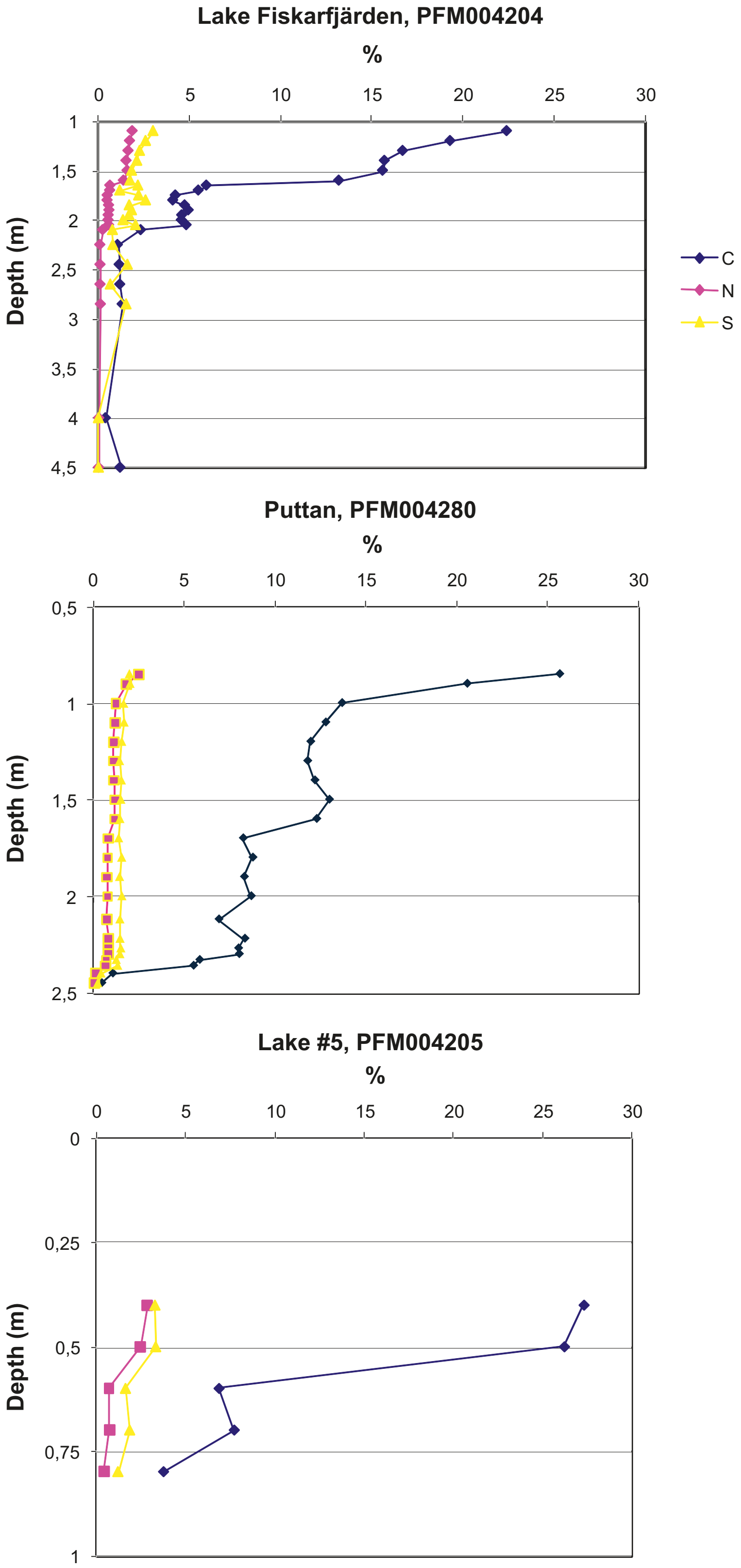


Figure 5-56. *The distribution of carbon (C), nitrogen (N) and sulphur (S) in the stratigraphical profile from Lake Fiskarfjärden (PFM004204), Puttan (PFM004280) and the small pond at the Börstilåsen Esker (PFM004205). The depths are from the ice surface /from Hedenström 2004a/.*

sulphides. Iron sulphides can easily oxidise if the groundwater table is lowered, due to e.g. ditching or isostatic land upheaval. Oxidation of iron sulphides may cause acidic soil conditions and increased leaching of trace elements /e.g. Åström and Björklund 1995/, however the high content of calcium carbonate ($CaCO_3$) in the regolith at Forsmark will probably delay the acidification.

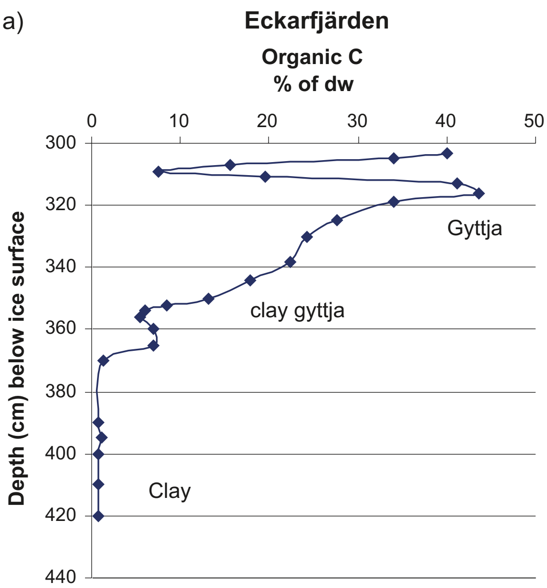
The sediment core from Lake Eckarfjärden analysed for diatoms and carbon 14 (^{14}C) dating was also analysed for organic carbon (C) and calcium carbonate ($CaCO_3$) /Hedenström and Risberg 2003/, whereas another sediment core was analysed for biogenic silica (SiO_2) /Baxter et al. 2007/. Additionally, one sediment core was used for chemical characterization /Hannu and Karlsson 2006/. The description of the accumulation environment and rates based on the analysis of sediments from Lake Eckarfjärden are presented in section 5.3.3.

As would be expected, the algal gyttja had a high concentration of both organic carbon (C) and biogenic silica (SiO_2), whereas the calcareous gyttja shows lower values of these components (Table 5-28 and Figure 5-57).

Table 5-28. Biogenic silica (SiO_2) analysed on a sediment core from the northern part of Lake Eckarfjärden (PFM004298) /from Baxter et al. 2007/. The depths are from the surface of the ice.

Depth (m) From	QD	Average conc. (%) Biogenic silica
2.75–2.82	Algal gyttja	4.37
2.83–2.85	Calcareous gyttja	1.98
2.85–2.92	Algal gyttja	1.75
2.93–3.03	Algal gyttja	2.94
3.03–3.10	Algal gyttja	3.61
3.20–3.27	Algal gyttja	11.9
3.40–3.50	Algal gyttja	3.98
3.62–3.65	Clay gyttja	4.3
4.15–4.20	Clay gyttja	–no value

a)



b)

__Figure 5-57.__ a) Organic carbon (C) content in the sediment from Lake Eckarfjärden. The low organic C content at c 3.10 m corresponds to a layer of calcareous gyttja where the organic C content decreases, whereas the $CaCO_3$ increases /modified from Hedenström and Risberg 2003/. b) The upper 70 cm of the analysed sediment core from Lake Eckarfjärden. The light brown layer in the upper part represents calcareous gyttja with $CaCO_3$ content of c. 30–60%, corresponding to the drop in organic carbon content displayed in figure a) at c. 310 cm depth.

The results from analyses of calcium carbonate ($CaCO_3$) show that the content of this compound is low in a majority of the gyttja sediments (Figure 5-57). Glacial clay underlying the gyttja sediments in many lakes has an average $CaCO_3$ content of 26%. In some lakes, the $CaCO_3$ content is high in the youngest sediments formed during the present lake stage. The highest $CaCO_3$ content of over 60% was recorded in the calcareous gyttja from Lake Stocksjön and Lake Eckarfjärden /Hedenström 2004a/. The $CaCO_3$ in these lake sediments has been precipitated due to the high concentration of dissolved Ca^{2+} and HCO_3^- ions in the lake water according to the formula (1). The carbonate in the water has been leached from the regolith in the surroundings due to chemical weathering of calcite. During the growing season, the carbon dioxide (CO_2) concentration in the water decreases and causes precipitation of calcite that later accumulates in the sediments.

$$Ca^{2+} + 2\left(HCO_3^-\right) \Leftrightarrow CaCO_{3(S)} + CO_2 \qquad (1)$$

The chemical characterisation of regolith and biota included samples of marine and lacustrine sediments and peat /Hannu and Karlsson 2006/. The detailed analytical results are presented in Appendix H, where each analysis is presented. Additional chemical analysis was performed on a 0.55-m long sediment core from Lake Stocksjön /Strömgren and Brunberg 2006/. The elements analysed on the Stocksjön sediments are listed in (Table 5-29). The Stocksjön sediment core was sliced into 5-cm thick sections analysed for 55 different elements at each level (Table 5-29) by Analytica AB using the technique of ICP-MS. For the detailed description of each sample and evaluation of the chemical stratigraphy of the sediment core, see /Strömgren and Brunberg 2006/. Below is a compilation of the major elements separated into the different types of water-laid sediments (Table 5-30) based on data from Lake Stocksjön /Strömgren and Brunberg 2006/ and the type deposits analysed by /Hannu and Karlsson 2006/.

Table 5-29. Analyses performed on the sediment core from Lake Stocksjön. For results of analyses of heavy metals and trace elements, see /Strömgren and Brunberg 2006/.

Main elements	Heavy metals	Trace elements
Ca, Si, Al, Fe, K, Mg, Na, Ti, Mn, P, S % ash	Cu, Zn, Pb, Ni, Cr, As, Cd, Hg, Co, V, Sn	Ba, Zr, Y, Li, Cs, U, La, Dy, Ho, Ce, B, Sr, Lu, Sb, Rb, Sm, Sc, Be, Nb, Mo, Nd, Th, Pr, Er, Ta, Eu, Tb, W, Yb, Hf, Tm, Gd

Table 5-30. Results of analyses of major elements in the different types of water-laid sediments expressed as oxides. All values shown are in percent of dry weight. The clay samples were collected in both the marine and lacustrine area.

	Algal mat (n=4)	Algal gyttja (n=8)	Calcareous gyttja (n=7)	Clay gyttja (n=4)	Clay (n=8)	Marine surface sed (n=2)	Sand (n=1)
Al_2O_3	0.79	3.26	0.57	8.78	14.63	10.07	11.20
CaO	7.69	5.21	22.26	5.00	4.13	1.21	6.17
Fe_2O_3	0.63	2.08	0.64	4.37	7.36	3.79	3.85
K_2O	0.22	0.83	0.16	2.44	3.75	2.83	2.86
MgO	0.26	0.66	0.22	1.66	2.70	1.38	0.78
MnO	0.03	0.03	0.03	0.05	0.08	0.04	0.06
Na_2O	0.17	0.51	0.12	1.11	1.71	2.47	3.01
P_2O_5	0.20	0.10	0.08	0.14	0.18	0.12	0.08
SiO_2	11.60	20.61	12.94	51.43	52.80	57.90	66.00
TiO_2	0.04	0.16	0.03	0.44	0.71	0.36	0.26
Sum oxides	18.40	33.31	36.97	75.43	88.13	80.20	94.30
Loss on ignition	79.00	69.65	63.10	21.45	8.50	13.10	5.20

The analysed sediment from Lake Stocksjön consists of very loose, green microbial mat in the upper c 0.2 m, followed by calcareous gyttja and algal gyttja down to the bottom sample representing clay.

The analysis of the main elements includes ten elements that are common components in silicate bedrock. Sulphur (S) is also included in this group due to its high concentration in the sediment, as well as the proportion of ash, i.e. the minerogenic component of the sediment.

In general terms, three different patterns of stratigraphy were derived from all of the analysed elements. The dominating element in the sediment is calcium (Ca), especially in the upper 0.3 m of the core, with a peak of Ca at the level with calcareous gyttja (Table 5-31).

Silicon (Si), aluminium (Al), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), and titanium (Ti) showed the reverse distribution pattern (Table 5-31). The lowest concentrations of these elements were found in the algal mat from the upper 0.3 m of the sediment. Below this level, there was a gradual rise in concentration downwards with the highest concentrations in the clay samples at the bottom of the sediment core.

Table 5-31. Total concentration of main elements in the upper 0.55 m of a sediment core collected at Lake Stocksjön /Strömgren and Brunberg 2006/. The depths are from the top of the sediment core.

Depth (m)	Si (ppm)	Al (ppm)	Ca (ppm)	Fe (ppm)	K (ppm)	S (ppm)
0.00–0.05	61,665.6	1,900.0	118,638.7	2,315.1	1,369.7	8,620
0.05–0.10	63,067.1	2,101.1	113,635.9	2,350.1	1,178.8	8,600
0.10–0.15	71,008.9	3,170.2	133,647.2	3,581.1	1,245.2	11,300
0.15–0.20	85,023.8	3,980.0	129,359.1	4,882.0	1,303.3	14,900
0.20–0.25	85,023.8	2,582.7	147,226.3	4,112.6	1,012.8	14,200
0.25–0.30	66,804.5	2,805.0	211,548.5	4,714.1	1,535.8	11,000
0.30–0.35	137,813.4	24,398.5	57,961.4	18,534.8	9,961.8	23,700
0.35–0.40	107,447.7	17,200.7	63,750.4	15,247.5	6,865.3	25,300
0.40–0.45	72,877.6	14,819.0	22,584.2	15,457.3	5,960.5	34,500
0.45–0.50	129,404.4	29,585.1	21,583.7	22,451.6	11,539.1	28,600
0.50–0.54	147,156.7	32,548.9	21,726.6	24,200.1	12,618.2	478
0.54–0.55	217,231.3	44,615.9	20,940.4	26,088.6	19,010.4	474

Table 5-31 continued.

Depth (m)	Mg (ppm)	Mn (ppm)	Na (ppm)	P (ppm)	Ti (ppm)	Ash
0.00–0.05	1,153.5	408.1	986.7	545.5	140.2	45.3
0.05–0.10	1,111.0	429.0	710.0	352.6	207.4	46.0
0.10–0.15	1,262.8	398.8	905.1	412.4	192.4	53.3
0.15–0.20	1,159.6	213.0	1,112.8	368.3	197.2	55.5
0.20–0.25	1,050.3	175.0	845.7	294.6	121.7	57.5
0.25–0.30	1,499.5	266.4	957.0	204.2	140.8	69.5
0.30–0.35	4,990.4	276.5	4,851.7	373.1	1,324.5	56.5
0.35–0.40	3,727.6	226.9	3,917.0	352.2	947.0	48.8
0.40–0.45	3,460.5	211.4	3,642.5	365.7	833.1	33.5
0.45–0.50	6,131.7	310.5	6,439.3	409.4	1,672.2	48.8
0.50–0.54	6,617.4	316.0	6,758.3	412.0	1,810.0	53.3
0.54–0.55	7,770.9	343.8	8,753.9	436.4	2,205.6	72.9

The manganese (Mn) concentration of c 400 ppm in the sediments taken from Lake Stocksjön was highest in the upper 0.15 m of the sediment core, which consisted of a microbial mat. Further down, the concentration decreased to 45 cm, following by an upwards trend in the bottom three samples down to 55 cm.

The amount of phosphorus (P) was highest in the uppermost sample: 546 ppm (Table 5-31) followed by a gradual decrease down to 0.30 m, where the minimum quantities of P in the sediment were recorded, c 200 ppm. Below 0.3 m, the concentrations were again higher and increased slightly downwards to a level of 436 ppm.

The concentrations of sulphur (S) were relatively low in the upper part of the sediment core, with the lowest concentration in the surface sediments, c 8,000 ppm. The concentrations increased substantially below the 0.3 m depth, with a maximum level of 34,500 ppm at 40–45 cm. The bottom layer of the core at the 50–55 cm level seems to be almost completely depleted of S. The concentrations and distribution pattern of S in the sediments in Lake Stocksjön were comparable to the results from the three other lakes, presented in Figure 5-56.

The ash content was between c 40% and 70 % in the sediments. The highest ash content was found at a depth of 0.3 m and at the bottommost samples representing clay. The high ash content at 0.3 m is recorded at the level with high calcium (Ca), probably caused by a high concentration of calcium carbonates ($CaCO_3$), whereas the high ash content in the bottom samples is due to clay particles. In the bottom half of the sediment core, the ash content and the concentration of silicon (Si), aluminium (Al), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), titanium (Ti), and manganese (Mn) followed the same distribution pattern, i.e. decreasing from 30 cm down to 45 cm, and then higher concentrations and an increasing trend in the last three samples down to 55 cm, where again the ash content was c 70% of the dry weight. Concentrations of phosphorus (P) did not seem to be related to the ash content, while the concentrations of sulphur (S) showed an inverse pattern to ash content at levels below 30 cm depth.

In a comparison between the surface sediments and bottom samples from Lake Stocksjön and Swedish reference data /Tröjbom and Söderbäck 2006/, many trace metals occurred in markedly lower levels in superficial sediments from Forsmark compared with lake sediments from the southern and northern parts of Sweden. This was especially evident for cobalt (Co), chromium (Cr), mercury (Hg), lead (Pb), thorium (Th) and vanadium (V), whereas tungsten (W) occurred at elevated levels.

In the deeper sediments from Lake Stocksjön, the content of rubidium (Rb) and zirconium (Zr) seems to be higher compared with the available references (Table 5-32).

The clay mineralogy was investigated by qualitative XRD analysis of three samples of clay collected at Lake Fiskarfjärden and a small pond close to the Börstilåsen Esker /Hedenström 2004a/. One sample from Lake Fiskarfjärden consisted of postglacial clay (FPM004204, collected at 2.22 m depth). Two samples of glacial clay were collected at the small pond close to the Börstilåsen Esker (PFM004205, collected at 1.1 m and 1.37 m depth). The uppermost sample was collected from disturbed distal varves, while the bottom sample represents the proximal varves.

The qualitative XRD analyses showed an almost identical clay mineral content in the three samples analysed /Hedenström 2004a/. Just like in the till samples, illite is the most common clay mineral in the clay samples. One apparent discrepancy between the clay samples was that the postglacial clay did not contain any calcite, which was present in the two glacial clay samples. Furthermore, detailed comparisons of the graphs showed that a sample consisting of glacial clay with disturbed distal varves contained more quartz and plagioclase, i.e. primary rock-forming minerals compared with a sample of un-disturbed varved clay. The results from the XRD analyses of clay were very similar to the results of the XRD analyses performed on the till samples described above /Sohlenius and Rudmark 2003/. The results from the XRD analyses showed similar distribution of clay minerals in glacial and postglacial clay, which is in accordance with other clay-mineralogical studies in Uppland /Persson 1985, Snäll 2004/. Illite is the dominating clay mineral, followed by chlorite and small amounts of kaolinite. The results imply that the clay has only been affected to a small degree by chemical weathering /cf. Snäll 2004/.

Table 5-32. Contents of trace elements in two different layers of a sediment core sample from Lake Stocksjön in the Forsmark area (ppm dw). Reference data from lake sediments and deeper samples of glacial and postglacial clay /from Tröjbom and Söderbäck 2006/.

Element		Stocksjön		Lake sediments of south Sweden[a)]		Lake sediments of north Sweden[a)]		Glacial and post glacial clay in Sweden[b)]
		0–5cm	54–55cm	0–1cm	c 20cm	0–1cm	c 20cm	c 1 m
As	Arsenic	1.0	4.5	21	11	86	21	3.4
B	Boron	36	37					
Ba	Barium	100	380	170	160	380	180	80
Be	Beryllium	< 0.3	1.6	3.1	2.1	1.1	1.4	0.99
Cd	Cadmium	0.24	0.76	3.6	1.7	1.0	0.6	0.08
Ce	Cerium	13	83	190	190	66	83	
Co	Cobalt	0.45	7.2	15	13	16	11	9.6
Cr	Chromium	1.7	34	20	17	23	24	22
Cs	Cesium	0.10	3.4	1.2	0.9	1.5	1.6	
Cu	Copper	19	44	32	23	14	16	16
Dy	Dysprosium	1.2	6.1	12	12	5	7	
Er	Erbium	< 0.1	2.1	8	8	3	4	
Eu	Europium	< 0.05	0.86	2.9	2.9	1.0	1.3	
Ga	Gallium	< 1	< 1	6.9	5.9	5.0	4.6	
Gd	Gadolinium	< 0.3	1.8	18	17	8	10	
Hf	Hafnium	< 0.1	4.4	0.55	0.49	0.73	0.37	
Hg	Mercury	0.069	0.058	0.23	0.15	0.18	0.12	
Ho	Holmium	0.83	1.2	2.5	2.4	1.1	1.3	
La	Lanthanum	8.0	43	103	105	33	46	40
Li	Lithium	0.65	20	6	5.7	9.7	12	19
Lu	Lutetium	0.15	0.55	1.2	1	0.4	0.5	
Mn	Manganese	390	260	2,500	1,100	9,500	1,200	440
Mo	Molybdenum	< 2	20	2.1	1.8	9.8	7.1	0.36
Nb	Niobium	< 0.2	11	0.9	0.89	1.1	1.5	
Nd	Neodymium	7.0	39	101	101	37	51	
Ni	Nickel	< 5	19	14	10.8	19	20	16
Pb	Lead	12	13	214	110	33	19	12
Pr	Praseodymium	< 1	15	26	27	9	13	
Rb	Rubidium	< 2	132	11	10	16	16	12
S	Sulphur	8,600	470					
Sb	Antimony	0.089	< 0.02	0.84	0.34	0.14	0.07	
Sc	Scandium	< 0.5	8.1					
Sm	Samarium	< 0.3	5.6	18	17	7	10	
Sn	Tin	< 1	2.9	3.2	0.83	0.8	0.2	0.27
Sr	Strontium	51	87	57	53	32	34	23
Ta	Tantalum	< 0.06	0.87	0.04	0.034	0.02	0.02	
Tb	Terbium	0.36	0.58	2.6	2.5	0.12	0.06	
Th	Thorium	1.2	12	11	11	6	6	12
Tm	Thulium	0.32	0.68	1.1	1	0.4	0.5	
U	Uranium	2.9	24	4.8	4.9	6.4	9	2.5
V	Vanadium	1.6	35	52	37	31	30	41
W	Tungsten	0.64	2.6	0.18	0.08	0.7	0.4	0.05
Y	Yttrium	4.3	24	68	63	27	36	23
Yb	Ytterbium	< 0.2	3.4	7.5	6.7	2.9	3.6	
Zn	Zinc	53	85	310	180	180	180	63
Zr	Zirconium	6.6	120	10	8.4	15	8.9	

a) Content of acid soluble (7M HNO_3) metals and half-metals /from Litner et al. 2003/. ICP-MS analysis technique.
b) Post glacial and glacial clays at a depth of approximately 1 m. Median values from the geochemical database of /SGU 2005b/. Solvent 7M HNO_3 and ICP-MS analysis technique.

Chemistry of marine sediments

Total chemical composition of marine sediments are presented by /Hannu and Karlsson 2006/ and in (Appendix I). The elemental composition of clay and clay gyttja from the marine area is included in (Table 5-30). The two samples of surface sediments represent recent accumulation.

A comparison between the composition of the surface sediments from marine and limnic samples showed a much higher content of aluminium (Al) and silica (SiO_2) in the marine samples. This indicates that the marine surface samples contained high proportions of mineral grains, i.e. sand, while the microbial mat from the lake consisted of high proportion of organic carbon (C) and calcium carbonate ($CaCO_3$).

A long sediment core collected off-shore of Forsmark was analysed for organic carbon (C), calcium carbonate ($CaCO_3$), diatom stratigraphy, grain size distribution and radiocarbon datings /Risberg 2005/. The organic C content in the sediment varied between c 1% and 4% with a weak trend of increasing values from a depth of approximately 440 cm (Figure 5-58). Based on the radiocarbon datings and diatom stratigraphy, the highest concentration of organic C was correlated to increased salinity during the Littorina Sea stage /Risberg 2005/.

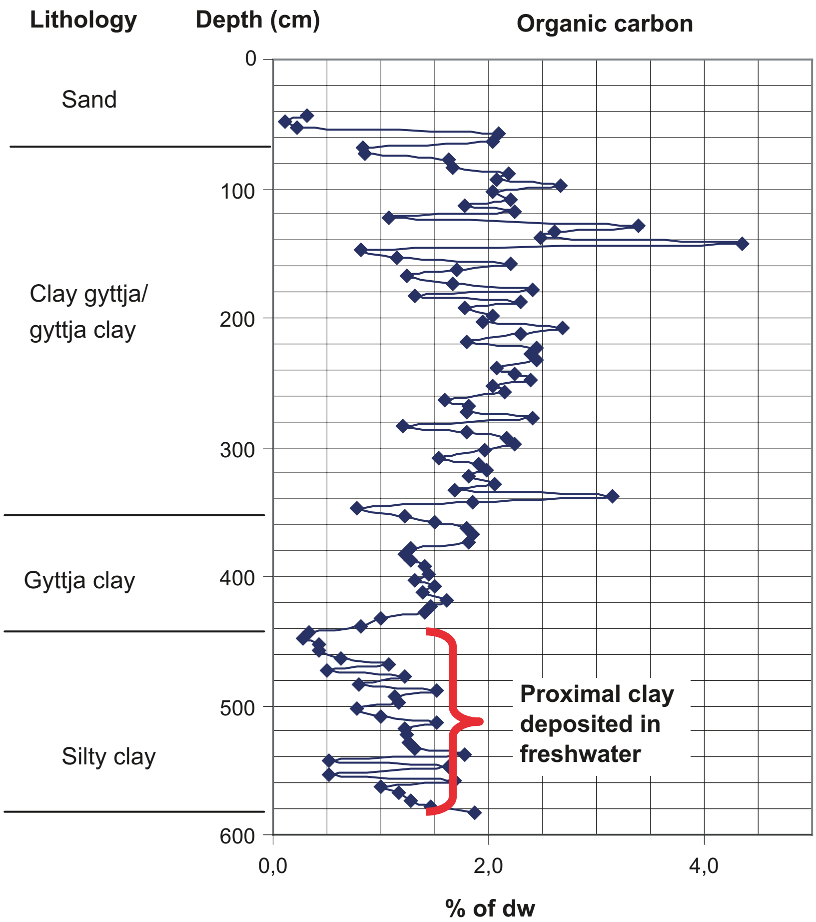


Figure 5-58. The stratigraphical distribution of organic carbon (C) in a 6-m long sediment core collected at PFM004396 off shore Forsmark /from Risberg 2005/.

Chemistry of peat

Stratigraphical and chemical characterisation of peat were carried out in three peatlands, Stenrösmossen (AFM001245), Lersättermyran, which is located 4 km south-west of Forsmark (AFM001246) /Fredriksson 2004/ and the Rönningarna mire /Lokrantz and Hedenström 2006, Hannu and Karlsson 2006/. For locations, see Figure 2-9.

The results from the investigation are used to understand the historical and future development of wetlands in the area. The chemical composition of the peat may be used to better understand the groundwater chemistry of the area and to help predict future land use. The analytical results from /Fredriksson 2004/ were summarised and compared with the mean and median values for Swedish peatlands (Table 5-33). The peat in Stenrösmossen is influenced by an occurrence of calcium carbonate ($CaCO_3$) in surrounding QD, which is reflected by a high content of calcium (Ca). This is expressed as 47% CaO in the ash produced by ignition at 550°C. The ash from the peatland at Lersättermyran (AFM001246) has a CaO content closer to the average for Swedish peat (Table 5-33).

Table 5-33. Concentration of major and trace element in samples of peat ash from Stenrösmossen (S) and Lersättermyran (L) in the Forsmark area /Fredriksson 2004/. Mean and median values for Swedish peat soils are presented for comparison in the right-hand columns /Fredriksson 1984/. The samples from Forsmark are analysed using the ICP technique, whereas the Swedish reference samples are analysed using the XRF technique.

		S 0–1 m	L 0–1 m	L1–2 m	Mean Sweden	Median Sweden	Std dev Sweden
CaO	% (in ash)	47.1	20.8	8.2	24.7	21.6	2.9
Al_2O_3	“	2.19	7.9	10.2	10.5	9.7	5.6
Fe_2O_3	“	2.69	6.7	7.0	17.8	16.6	10.0
K_2O	“	0.56	1.85	2.64	0.48	0.35	0.41
MgO	“	1.6	1.7	1.7	2.8	2.0	2.8
Na_2O	“	0.40	1.15	1.33	0.38	0.26	0.46
MnO	“	0.07	0.06	0.08	0.27	0.22	0.16
P_2O_5	“	1.00	1.03	0.54	1.82	1.8	0.97
SiO_2	“	7.6	41.3	60.5	22.0	17.7	16.6
TiO_2	“	0.05	0.34	0.51	0.29	0.26	0.17
Co	ppm (in ash)	5.7	10.6	11.4	33.8	33.0	21.1
Cr	“	25	63	86	120	100	83
Cu	“	104	90	79	228	200	128
Mo	“	19.8	15.3	11.6	55.1	36.0	49.6
Ni	“	35.3	47.5	56.1	101.5	85.0	73.9
Pb	“	116.5	1,600	79.5	64	35	93
Sr	“	513.4	370.7	172.6	567.5	515.0	224.3
Th	“	–	–	–	40	35	26
U	“	77.8	< 20	< 20	70	34	110
V	“	24	64	76	134	98	124
Zn	“	620	951	1,526	227	170	311
As	ppm DS	1.4	1.4	1.0	4.3	1.0	12.0
Cd	“	0.20	0.17	0.14	0.23	0.10	0.23
Hg	“	0.086	0.094	0.030	0.055	0.010	0.114
Ra-226	Bq/kg (wf)	–	–	–	9	–	–
Ash	% DS	9.7	7.7	9.5	5.1	4.3	3.4
S	”	0.72	0.30	0.37	0.27	0.24	0.14

The concentrations of trace elements in the samples from the two peatlands are normal except for lead (Pb) and zinc (Zn). The uppermost general sample from Lersättermyran has a high content of Pb, 1,600 ppm, compared to the Swedish mean value of 64 ppm. The Zn content is high in both of the investigated peatlands, with values between 620 ppm and 1,526 ppm in the Forsmark samples, as compared to the Swedish mean value of 227 ppm. The reason for these anomalies is not known and both peatlands are situated far from any present industrial activity. The content of these two elements in the till are in line with national mean values (Table 5-26). The mires however, are situated in an area that was earlier used for mining and the Forsmark mill is located only a few kilometres from the mires.

There is a relatively high content of sulphur (S) in peat sampled from Stenrösmossen (Table 5-33). High S content is common in peatlands along the Baltic Sea coast and may emanate from brackish water that remained after the site was covered by the sea. This high S content makes it unlikely that peat from Stenrösmossen will be used as fuel.

A sediment core from the mire at Rönningarna was included in the characterisation of type deposits /Hannu and Karlsson 2006/. The site was represented by a stratigraphical profile containing till, clay, clay gyttja, gyttja and peat (cf. section 5.2). The different layers were analysed for dry substance, LOI, total and organic carbon (C) and nitrogen (N), other elements and the oxides of each QD /Hannu and Karlsson 2006/. The results from all the marine and lacustrine sediments and peat samples are presented in (Appendix I).

5.3.3 Properties of the soil horizons

The spatial distribution, physical and chemical properties of the soils at Forsmark are presented in detail by /Lundin et al. 2004/. They present surface and stratigraphic distribution of e.g. pH values, carbon (C) and nitrogen (N) content, as well as the density and porosity of the regolith. Complementary analyses of physical and chemical properties of the regolith at two large trenches (LFM00810 and LFM00811) located within Till Area I are presented by /Lundin et al. 2005/. Below follows a summary of their results.

The most characteristic compound for the soils at Forsmark is calcium carbonate ($CaCO_3$). Analyses of $CaCO_3$ in the fine fraction (material < 0.06mm) of the till have been performed on > 200 samples during the site investigations. Almost all the samples contained $CaCO_3$, even in the upper layers, (see Appendix G, and /e.g. Hedenström 2004b/). However, the soil profiles from the regional model area /Lundin et al. 2004/ showed that leaching of $CaCO_3$ occurs in the upper 0.55 m. In the central part of the candidate area, only the upper 0.15 m showed traces of leaching /Lundin et al. 2005/.

A regional study of leaching of calcium carbonate ($CaCO_3$) in the till from northern Uppland /Ingmar and Moreborg 1976/ showed that the depth of the carbonate-free, leached zone increased from a few decimetres at sites close to the sea level up to > 6 m depth at inland sites. An explanation for the deep carbonate-free zone can possibly be that different till beds superimpose each other, possibly originating from deviating directions of ice movement. Nevertheless, the occurrence of ($CaCO_3$) high up in the soil horizons at Forsmark shows that the soil profiles are still unweathered. This is especially true for the areas located at low altitudes in the central part of the candidate area. The sites located at low altitudes are still too young for severe leaching to have taken place.

The calcareous soil material contributes to nutrient-rich conditions, which can be observed in the rich and diverse flora of the area /Löfgren 2008/. This can also be seen in the predominantly mull humus forms and the intermediate moder types, which indicate a rich soil fauna. However, the phosphorus (P) is strongly bound in calcium (Ca)-rich regolith, thus all available P will not be accessible for plants. Because of the young age of the soils, the Forsmark area exhibits less Podsol type soil than other similar areas in Sweden. Instead, the typical soil types are the lesser-developed Regosol soils, together with Gleysols and Histosols, which are formed under moist conditions.

The chemical properties of the regolith were analysed at various depths in five profiles during the soil inventory /Lundin et al. 2005/. The profiles were located in trenches in Till Area I (Appendix J). The calcium carbonate ($CaCO_3$) content was high in all samples, which is reflected in relatively high pH values that often exceeded 6 (Table 5-34).

Exchangeable contents of calcium (Ca), magnesium (Mg) and potassium (K) were determined at the trenches within Till Area I (Table 5-34). The Cation Exchange Capacity (CEC) gives information on the sorption capacity of the different QD. The stratigraphical distribution patterns were similar, with high concentrations in the organic horizon, low concentrations in the very top mineral soil, higher again in the top soil layer below the mineral soil, and there was almost no stratification further down in the soil /Lundin et al. 2005/.

Calcium (Ca) content levels were comparably high when compared with ordinary Swedish forest soils. In the organic layer, the concentration range was 20–80 $mmol_c$/100 g, whereas the content in ordinary Swedish forest soils with a Podsol profile could be 5–10 $mmol_c$/100 g and c 20 $mmol_c$/100 g in a Cambisol profile. The values were 1–3 $mmol_c$/100 g in the top mineral soil layers where Ca actually had been leached, but higher values up to 12 $mmol_c$/100g occurred immediately below with some Ca accumulation. In ordinary Swedish forest podsolic 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 in other Swedish sites, values between 0.01–0.4 $mmol_c$/100 g are common, while values of c 10 $mmol_c$/100 g were recorded in the deep layers at the trenches at Forsmark /Lundin et al. 2005/.

Exchangeable magnesium (Mg) in the profiles shows a similar distribution as calcium (Ca). The Mg content in the O-horizon was between 2.6 $mmol_c$/100 g and 4.3 $mmol_c$/100 g, which is comparable to podsolic forest soils in Sweden, but lower than compared to some Cambisols. Low concentrations were found in the upper part of the mineral soil, where only c 0.1 $mmol_c$/100 g to 0.3 $mmol_c$/100 g was recorded. These values are comparable with Swedish forest soil values of 0.2 $mmol_c$/100 g in both top mineral horizons. In the deeper layers, values for the profiles were 0.1–0.2 $mmol_c$/100 g, with the profile PFM004459 deviating at c 0.7 $mmol_c$/100 g, which is very high for podsolic soils and is usually only reached in Mg-rich soils.

Exchangeable potassium (K) shows similar stratigraphical patterns as calcium (Ca) and magnesium (Mg), but with a more pronounced increase in the B-horizon. Organic soil concentrations were generally between 1.0 and 1.3 $mmol_c$/100 g. In the upper part of the mineral soil, the contents were 0.02–0.05 $mmol_c$/100 g, increasing downwards to 0.03–0.08 $mmol_c$/100 g. The exchangeable K concentrations are comparable with Swedish forest soils. The complete analytical results from the soil chemical investigations by /Lundin et al. 2005/ are presented in (Appendix J).

The average pH and contents of carbon and nitrogen in soils from the Forsmark regional model area /Lundin et al. 2004/ were compared with the average values for forested areas in Sweden (Table 5-35 and Table 5-36). The results show that the pH values in all horizons are significantly higher at the Forsmark sites as compared to the national averages. The pH value in the O horizon in the Forsmark area is in general high with values around 6, whereas Sweden on average shows values between 4 and 5. The humus layer is influenced by the underlying mineral soil and the pH value is 6.5 on average, which can be compared to values around 5 for most of Sweden. The average pH in the uppermost mineral layer in the Forsmark area has pH value of 6.5 compared to pH of 4.9 for the average for Sweden. The pH map (Figure 5-59) was produced by extrapolating data from soil studies at 16 sites representing eight land types /Lundin et al. 2004/. The soil pH value is generally above or close to 7 in mineral soil sampled 0.55–0.65 m below the ground surface. The relatively high pH value is the result of calcium carbonate ($CaCO_3$) present in most of the QD. The lowest pH values were recorded on the glaciofluvial esker, which may indicate the absence of fine-grained calcite in these deposits since the esker is dominated by coarse material. Stones and limestone gravel are, however, present in the esker.

The average carbon stocks for the soil classes shown on the soil type map (Figure 5-30) are presented in Table 5-37. As can be expected the largest carbon stocks are associated with areas classified as Histosol (peat). The carbon content at different levels are presented in (Table 5-35)

Table 5-34. Soil chemical parameters including concentration of exchangeable contents of calcium (Ca), magnesium (Mg) and potassium (K) as recorded in the trenches within Till Area I /Lundin et al. 2005/. The horizons are H for humus and M for mineral soil; the depths of the mineral soils are below the humus layer. In podsols, the layer 0–5 cm of the B-horizon was added.

Horizon ID	pH water	C tot of ts (%)	N tot of dw (%)	Ca ($mmol_c$/100g ts)	Mg ($mmol_c$/100g ts)	K ($mmol_c$/100g ts)	CEC tot ($mmol_c$/100g ts)
PFM004455							
H30	3.58	55.6	1.9	21.40	2.95	1.00	140.7
MP5	5.69	1.1	0.08	4.60	0.39	0.04	7.0
M010	5.07	0.8	0.06	1.98	0.22	0.04	4.5
M020	6.31	1.3	0.06	12.30	0.20	0.04	12.6
M065	7.13	1.8	0.02	11.10	0.15	0.04	11.4
M100	7.73	1.7	0.01	10.40	0.12	0.03	10.6
M150	7.87	1.5	0.02	10.40	0.11	0.03	10.6
M200	8.08	2.0	0.02	10.60	0.11	0.04	10.8
M230	7.98	2.1	0.02	10.70	0.12	0.05	10.9
PFM004457							
H30	3.69	56.0	1.98	25.80	4.31	1.29	146.1
MP5	7.22	1.3	0.07	13.20	0.31	0.04	13.6
M010	5.06	0.4	0.04	0.90	0.14	0.02	1.9
M020	5.74	0.8	0.06	5.60	0.32	0.03	6.4
M065	6.76	1.9	0.02	10.70	0.13	0.04	10.9
M100	7.23	1.5	0.02	10.00	0.11	0.03	10.1
M130	7.30	1.9	0.02	10.60	0.11	0.04	10.8
PFM004458							
H30	5.73	39.4	1.22	68.80	4.01	1.15	108.6
M010	6.10	1.2	0.02	10.40	0.16	0.03	10.7
M020	6.68	1.5	0.01	10.30	0.14	0.03	10.5
M065	6.33	1.5	0.01	10.40	0.14	0.04	10.6
M100	6.54	1.7	0.01	10.50	0.14	0.04	10.7
M150	7.37	1.9	0.01	10.40	0.14	0.04	10.7
M200	8.01	2.0	0.02	10.90	0.17	0.08	11.3
M250	8.41	1.7	0.01	10.50	0.13	0.05	10.7
M300	8.19	1.5	0.01	10.40	0.14	0.05	10.6
PFM004459							
H30	5.64	38.4	1.42	70.10	4.29	1.36	109.9
M010	6.35	1.9	0.04	12.00	0.23	0.05	12.3
M020	7.49	2.3	0.02	11.40	0.18	0.05	11.7
M065	8.15	2.4	0.01	11.50	0.20	0.06	11.8
M100	8.50	1.8	0.02	10.70	0.15	0.05	10.9
M150	6.96	2.0	0.01	10.90	0.16	0.08	11.2
M200	7.42	2.1	0.02	11.40	0.67	0.23	12.4
M350	8.14	2.4	0.02	11.60	0.75	0.26	12.7
PFM004460							
H30	7.25	15.0	0.86	78.10	2.60	0.33	81.2
M010	7.29	0.3	0.03	2.82	0.08	0.02	3.0
M020	6.97	0.2	0.02	2.90	0.09	0.03	3.0
M065	7.19	2.2	0.01	11.00	0.20	0.04	11.3
M100	7.87	2.0	0.01	11.50	0.24	0.07	11.8
M150	8.20	2.2	0.01	10.90	0.15	0.06	11.2
M200	8.29	2.0	0.01	10.40	0.13	0.05	10.7

Table 5-35. Summary of the results from the soil survey in the Forsmark regional model area /from Lundin et al. 2004/. The B horizon is represented by the samples from the M 0-10 cm and M 10-20 cm levels. The C horizon is represented by the sample from the M 55-65 cm level. The O horizon refers to the organic material overlaying the minerogenic soils.

Parameter		Valid N	Average	Min	Max
pH (H_2O)	O horizon	68	6.2	3.8	7.8
	0-10 cm	110	6.5	4.2	8.3
	10-20 cm	111	6.7	4.5	8.7
	55-65 cm	56	7.2	5.2	8.7
Carbon (%)	O horizon	69	27.6	1.7	49.1
	0-10 cm	110	5.2	0.1	24
	10-20 cm	111	2.3	0.1	9.2
	55-65 cm	56	1.7	0.1	3.1
Nitrogen (%)	O horizon	69	1.3	0.2	2.4
	0-10 cm	110	0.3	0	1.2
	10-20 cm	111	0.2	0	0.6
	55-65 cm	56	0.04	0.01	0.1

Table 5-36. Reference data from the Survey of forest Soils and Vegetation /SML 2005/, reproduced from /Tröjbom and Söderbäck 2006/. The O horizon refers to the organic material overlaying the minerogenic soils.

Parameter		Valid N	Average	Min	Max
pH (H_2O)	O horizon	6429	4.2	3.0	7.8
	B horizon	1842	4.9	3.8	8.6
	C horizon	484	5.3	3.5	9.2
Carbon (%)	O horizon	5449	33.7	0.0	56.4
	B horizon	1509	2.3	0.0	42.8
	C horizon	1213	0.7	0.0	46.5
Nitrogen (%)	O horizon	5449	1.1	0.0	13.3
	B horizon	1509	0.1	0.0	1.5
	C horizon	1213	0.04	0.0	2.0

Table.5-37. Carbon stock for the soil type map classes in Forsmark regional model area. All values are presented as kg/m². H represents the humus layer, whereas 65 represent the C-horizon at 0.55-0.65 m below the humus layer.

Soiltype	$C_{(H)}$	$C^{(65)}$	$C_{(tot)}$
AR/GL	0.86	1.70	2.6
GL	2.59	3.37	5.96
GL/CM	0.00	13.55	13.55
HI	43.28	–	43.28
LP	0.83	0.73	1.56
RG	0.00	6.81	6.81
RG/GL	2.92	4.59	7.51
RG/GL-a	0.00	13.88	13.88

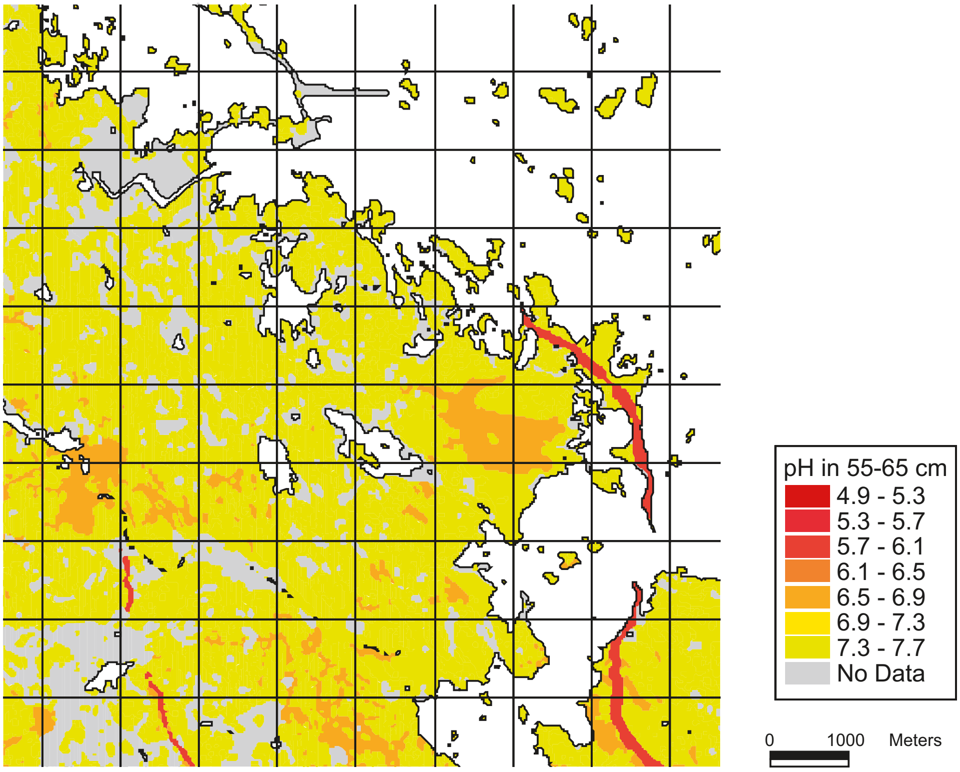


Figure 5-59. *Mineral soil pH value 0.55–0.65 m below the ground surface /from Lundin et al. 2004/.*

and comparable reference values are presented in (Table 5-36). The average carbon content in the humus layer at Forsmark is c. 28%. The C content decreases further down in the soil profiles. In the mineral soil, the influence of calcium carbonate ($CaCO_3$) makes the concentration of C higher at Forsmark compared to the general values for Sweden, reflected in values between 2.3% and 5.7% in Forsmark compared to c. 2% in the B-horizon for Sweden. Also, the C-horizon shows higher carbon concentrations at Forsmark, 1.7% compared to 0.7% in Sweden. This distribution pattern is similar in the majority of the soil types except for Histosol that has high carbon content through the profile.

The carbon stocks at different site types, representing the soil classes found in Forsmark are presented in Table 5-38. The soil classes shown are the same as presented on the soil type map (Figure 5-30). In /Lundin et al. 2004/ these properties have been transformed into maps showing the geographical distribution of carbon, pH and N in the different soil horizons. Since the class LP consists of a mosaic of thin soil and bedrock, the carbon stock was calculated by assuming that 50% of the area has no soil, 40% only has a humus layer and 10% has a soil layer down to 65 cm. The carbon stocks were calculated based on soil pits located where there was at least 65 cm mineral soil.

Nitrogen (N) concentration in the humus layer coincides fairly well with most parts of Sweden. However, the values are somewhat lower (1.3%) compared to what usually has been observed in Uppsala County (3.6%) /Lundin et al. 2004/. The stratification of N content with depth is from 1.3% in the topsoil to only 0.04% in the C-horizon, values similar to the common values for Sweden. One deviation was in the upper B-horizon, where the Forsmark area often showed high values reflecting partly fertile soils. The peatland sites, however, have high concentrations of N throughout the soil profile.

Extractable phosphorus (P) is important as a plant nutrient. Both nitrogen (N) and P may be strongly bound to mineral soils, especially calcium (Ca)-rich soils. Easily accessible P, mainly reflecting organically-bound P, was extracted using ammonium lactate (AL). The concentrations in the organic soil horizon are 2–10 $P_{(AL)}$ mg/100 g. Stronger-bound, but potentially available P was determined in hydrogen chloride (HCl) extraction and these values were considerably

Table 5-38 Carbon stock for the individual sites at each map class in the Forsmark regional model area. All values are presented as kg/m². H represents the humus layer, whereas 0–65 represent the average C content at 0–0.65 m below the humus layer, C tot represents the average carbon stock of each soil class.

Map class	Soil class	ID	Land type	$C_{(H)}$	$C_{(0–65)}$	$C_{(tot)}$
AR/GL	Arenosol/Gleysol	AFM001074	Shoreline	0.71	1.36	2.56
AR/GL	Arenosol/Gleysol	AFM001075	Shoreline	1.01	2.04	
GL	Gleysol	AFM001076	Moist soils periodically inudated i.e. swamp forest	2.44	1.72	5.96
GL	Gleysol	AFM001077	Moist soils periodically inudated i.e. swamp forest	2.75	5.01	
GL/CM	Gleysol/Cambisol	AFM001070	Fertile forest soil fine textured	0.00	15.02	13.55
GL/CM	Gleysol/Cambisol	AFM001071	Fertile forest soil fine textured	0.00	12.09	
HI	Histosol	AFM001078	Peatland/mires	43.73	–	43.28
HI	Histosol	AFM001079	Peatland/mires	42.84	–	
LP	Leptosol	AFM001066	Thin soil and bedrock	3.32	5.30	1.56
LP	Leptosol	AFM001067	Thin soil and bedrock	0.00	9.33	
RG	Regosol	AFM001072	Esker, rich in stones and boulders, dry	0.00	4.34	6.81
RG	Regosol	AFM001073	Esker, rich in stones and boulders, dry	0.00	9.28	
RG/GL	Regosol/Gleysol	AFM001068	Forest soil in upslope locations TWI < 8	1.62	5.33	7.51
RG/GL	Regosol/Gleysol	AFM001069	Forest soil in upslope locations TWI < 8	4.22	3.84	
RG/GL-a	Regosol/Gleysol-arable	AFM001080	Arable land	0.00	14.56	13.88
RG/GL-a	Regosol/Gleysol-arable	AFM001081	Arable land	0.00	13.20	

higher, i.e. 29–35 $P_{(HCl)}$ 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 phosphorus $(P)_{(AL)}$ are in the range of 1–2 mg/100 g and of $P_{(HCl)}$ in the range of 30–40 mg/100 g. Comparable values for forest soils are 4–5 mg $P_{(AL)}$/100 g and 50–100 mg $P_{(HCl)}$/100 g, also implying rather low concentrations of easily accessible P in the deeper layers of the Forsmark soils.

The thicknesses of the organic soil layer were on average 7.2 cm and 10.7 cm in the two trenches located within Till Area I /Lundin et al. 2005/. The root depth was measured at LFM00810. Most of the roots reach between 0.1 m and 0.4 m (average 0.25 m). Fine roots were found as deep as 0.57 m below the ground surface and coarse roots were observed down to a depth of 0.25 cm /Lundin et al. 2005/. The investigation of physical and hydraulic properties in the trenches included measurements of e.g. stoniness and porosity.

Concentration of stones and boulders in the soil has a significant influence on soil hydrology and soil chemistry. Two methods were used to describe the concentrations of stones and boulders in the trench investigations. One was based on the rod penetration method /Viro 1958/ and the other was actual measurements on the soil profile wall. One problem with the rod method is the fairly poor validation to actual content, which resulted in somewhat uncertain values of stones and boulders occupying c 37% and 49% of the volume in the two trenches investigated.

The physical properties of the soil horizons are described also in the section regarding physical properties of till, hence they are only summarized below.

The dry bulk density from the Forsmark area is typical for Swedish forest soils with low values in the upper layers of 0.4/cm^3 to 1.5 g/cm, increasing with depth and reaches up to 2.3 g/cm^3 at a depth of 0.6 m /Lundin et al. 2004/.

Porosities measured at the trenches were 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. These values coincide fairly well with ordinary porosities in till soils without wave-washing /Lundin 1982/.

The hydraulic conductivity of the profiles in the trenches mainly showed the ordinary pattern for till soils with relatively high conductivities in the upper soil layers (2–4×10^{-5} m/s) and a considerable decrease downwards to values below 10^{-7} m/s already at a depth of 0.5 m.

5.3.4 Erosion and accumulation

The Forsmark regional model area is situated up to 190 m below the highest shoreline. It should be noted however, that there was no shoreline at all in the Forsmark region during the deglaciation; the closest land at that time was c 100 km to the west (Figure 3-4). After the deglaciation, the water of the former Baltic stages Yoldia Sea and Ancylus Lake was lacustrine, (cf. Figure 3-2). The highest limit for the brackish water of the Littorina Sea was c 70 m above sea level /Hedenström and Risberg 2003/. The highest altitudes (c. 25 m above sea level) for the area investigated are found in the south-western corner of the Forsmark area (Figure 5-3). Around 500 BC, the first small islands in the Forsmark area appeared above sea level, whereas the majority of the land area emerged from the sea after 1000 AD. See the section on shoreline displacement in /Söderbäck (ed.) 2008/. A small-scale topography is reflected in a large number of small and shallow lakes, small ponds and wetlands in the present landscape at Forsmark. The flat upper surface, in combination with the relatively fast land upheaval, results in rapid growth of new land areas as well as a continuous formation of new lakes and ponds. At present, the land upheaval is 6 mm/year /Ekman 1996/. The effect of wave-washing of the surface layers can be seen at some locations exposed to the waves. The uppermost layer of till may be depleted of fine fraction at some sites while it may be covered by wave-washed sand at protected sites. Raised beaches and shingle shorelines have developed at sites exposed to wave action, e.g. at the Börstilåsen Esker and at some small islands (Figure 5-60).

In the deeper and more protected areas, the mass balance is positive, e.g. at accumulation bottoms in the marine and limnic areas and in the mires. During both sub-recent times, i.e. the 20th century, and long ago, i.e. postglacial, rates of accumulation of sediment and peat have been investigated using radiometric dating methods. The ages from various depths in the sediment column have been used for interpolation of accumulation rate, expressed in a semi-qualitative manner as mm sediment/year /Bergström 2001, Hedenström and Risberg 2003, Risberg 2005/. /Sternbeck et al. 2006/ have quantified the mass accumulation rate expressed as g m^{-2} yr^{-1} (Table 5-40), as well as the accumulation rates of carbon (C), nitrogen (N) and phosphorus (P) (Table 5-41). Additional estimations of long-term accumulation were performed in the sediment collected from the inner part of Kallrigafjärden /Bergkvist et al. 2003/, where diatom and pollen analyses were used for relative dating of the sediment core.

Based on the general stratigraphy of the water-laid sediments and peat (Table 5-5), the sediments are correlated to the different facies. The accumulation rates have been determined in the sediments deposited in marine, shallow coast, lake and mire facies.

Figure 5-60. *Example of a shingle shoreline at one of the small islands off-shore of Forsmark (PFM004796).*

Marine accumulation

For the marine environment, a c 6-m long sediment core collected in a deep area offshore of Forsmark (PFM004396) was analysed for diatom stratigraphy, organic carbon (C) content, calcium carbonate ($CaCO_3$), content, grain size distribution and radiocarbon dating. The ages were between 4910 BC and 95 AD (Table 5-39), which indicates continuous sedimentation during the Littorina Sea stage, but erosive conditions during sub-recent times. Estimates of accumulation rates for the marine facies of the Littorina Sea stage is c 1 mm sediment/year and c 20 (15–35) g C m^{-2} yr^{-1}. The values are considered uncertain since the water content and volume of the sediment were not analysed. A comparison to the accumulation rates as recorded offshore Laxemar /Kaislahti Tillman and Risberg 2006/ and the shallow coastal area /Sternbeck et al. 2006/ shows that the estimated values at PFM004396 are probably too low. However, the sampling sites offshore Laxemar are located in shallow, protected bays, whereas the Forsmark sediment was collected in deep, open water. Despite these uncertainties, a general trend of increasing accumulation rates was recorded from the initial Littorina Sea stage onwards /Risberg 2005/. The sediment core was representative of the deep basin, with more or less continuous accumulation. Compared to the organic accumulation recorded off-shore of Laxemar, the values from Forsmark were c 10 times lower, which to some extent can be explained by the differences in the sedimentary basins. The results from the radiocarbon datings are presented in Table 5-39.

The results from the analysis of diatoms, organic carbon (C) content, radiocarbon dates and sediment composition was the input for a qualitative model for the marine environment presented by /Risberg 2005/.

Table 5-39. Results from radiocarbon dates of a marine sediment core (PFM004396), presented as ^{14}C ages before AD 1950 and calendar years BC/AD /from Risberg 2005/.

Depth from sediment surface (cm)	^{14}C age	Presumed reservoir age	Corr. ^{14}C age	BC/AD ±1σ	Comment
44.5–45.5	2,390±30	Littorina Sea/–400	1,990±30	40 BC–95 AD	
99.5–100.5	4,150±40	Littorina- Sea/–400	3,750±40	2270–2040 BC	
159.5–160.5	4,270±35	Littorina Sea/–400	3,870±35	2460–2280 BC	
219.5–220.5	4,505±35	Littorina Sea/–400	4,105±35	2860–2300 BC	
279.5–280.5	5,400±40	Littorina Sea/–400	5,000±40	3910–3700 BC	
339.5–340.5	5,040±40	Littorina Sea/–400	4,640±40	3510–3360 BC	
409.5–410.5	6,350±40	Littorina Sea/–400	5,950±40	4910–4730 BC	
469.5–470.5	18,370±140	Yoldia Sea/reworked			Too small sample
519.5–520.5	26,380±350	Yoldia Sea/reworked			Too small sample
579.5 – 580.5	22,000±400	Yoldia Sea/reworked			Too small sample

Coastal area

The sub-recent and long-term rates of sedimentation and peat accumulation in the Forsmark area have been dated by radiometric methods [lead 210 (^{210}Pb) and carbon 14 (^{14}C)] by /Sternbeck et al. 2006/. The results were used to calculate the accumulation rates of carbon (C), nitrogen (N) and phosphorus (P) in sediments and peat. The average long-term accumulation covers a period of several thousand years and it should be noted that the accumulation rates have probably varied considerably throughout that period.

In order to quantify the sedimentation rate in the coastal area, cores were collected from the Kallrigafjärden and Tixelfjärden basins and the sediments were used for radiometric datings and analysis of organic carbon (C), nitrogen (N) and phosphorus (P) /Sternbeck et al. 2006/. According to the QD map for the shallow coastal area, both areas are covered with postglacial sediments, thus they may represent accumulation bottoms (Figure 5-28). The sub-recent accumulation rate for coastal sediments was dated using lead 210 (^{210}Pb) dating. Two cores were used: PFM005785 from Tixelfjärden and PFM005784 from Kallrigafjärden. A short (c. 0.40 m) core was collected from each site and used for dating and analysis. The sediments were oxidised in the upper c 3–10 cm and reduced below that level. The results from the radiometric dating of the two sediment cores are presented in Figure 5-61 (sub-recent). The mass accumulation rates in the two basins are almost identical: 1,070 and 1,080 g m^{-2} yr^{-1} during the 20th century (Table 5-40). The sub-recent accumulation rates are in agreement with previous measurements on the Swedish coast (400–1,900 g C m^{-2} yr^{-1}) /El -Daoushy 1986/. It should be kept in mind that the values from Forsmark are based on very few measurements and that the sampling sites are located in the shallow coastal area, thus currents and waves may relocate the sediments.

For the long term accumulation rate at Kallrigafjärden, one 2-m long sediment core (PFM005793) was used for carbon 14 (^{14}C) dating. The stratigraphy of the long core from the surface was: gyttja 0–0.70 m, sandy gyttja 0.70–0.73 m, sandy gravel with gyttja 0.73–0.76 m, laminated clay with light grey and dark grey sections between 0.76 m and 1.05 m and glacial clay between 1.05 m and 2.00 m. The results from the lead 210 (^{210}Pb) and ^{14}C dating are combined in the time/depth diagram and used to calculate accumulation rates (Figure 5-62).

The long term accumulation rate based on carbon 14 (^{14}C) dating for sediment from Kallrigafjärden is presented in Figure 5-65. The long term accumulation rate for Kallrigafjärden of 250 g C m^{-2} yr^{-1} is lower than the sub-recent rate but still a factor 10 higher than the longterm accumulation in the deep marine area .

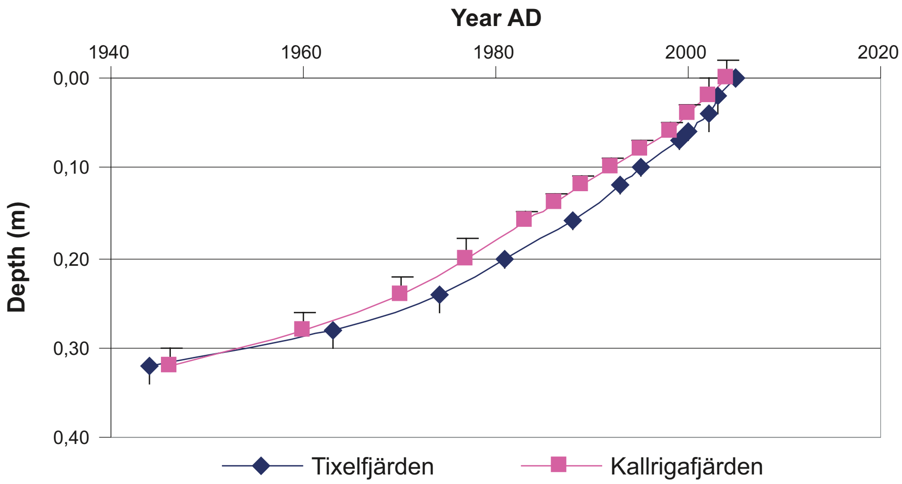


Figure 5-61. *Time/depth diagram for the sub-recent sediments from two coastal sites at Forsmark. The two sites (PFM005785 from Tixelfjärden and PFM005784 from Kallrigafjärden) show similar accumulation rates during the 20th century.*

Table 5-40. Average mass accumulation rates of sediments and peat (g m^{-2} yr^{-1}) at two coastal sites and one wetland at Forsmark. The ^{210}Pb record covers the 20th century, whereas the ^{14}C ages have been used to calculate the long-term accumulation /from Sternbeck et al. 2006/. (S=sediment, P=peat).

Site	^{210}Pb, average	^{210}Pb, range	Average long term (^{14}C)	Long term cal yrs ago
Kallrigafjärden (S)	1,070	500–1,500	250 ±125	0–500
Tixelfjärden (S)	1,080	200–1,900		
Rönningarna (P)			69 ±18	0–1,600

Table 5-41. Average accumulation rates of carbon (C), phosphorus (P) and nitrogen (N) at two coastal sites and one wetland at Forsmark /from Sternbeck et al. 2006/. The long term average is shown in bold (S=sediment, P=peat).

Depth, cm	Organic carbon accumulation rate (g C m^{-2} yr^{-1})		Nitrogen accumulation rate (g N m^{-2} yr^{-1})		Phosphorus accumulation rate (g P m^{-2} yr^{-1})	
Kallrigafjärden (S)	**Average**	**SD (1σ)**	**Average**	**SD (1σ)**	**Average**	**SD (1σ)**
2–4	101	13	13.0	1.3	1.69	0.31
16–18	71	14	9	1.7	0.85	0.20
32–34	38	7	3.8	0.6	0.30	0.06
0–70	14	7	1.6	0.8	0.20	0.10
Tixelfjärden (S)						
2–4	118	15	15.3	1.4	3.00	0.53
10–12	92	12	12.6	1.2	1.55	0.28
16–18	67	9	8.3	0.8	0.95	0.17
32–34	13	2	1.6	0.2	0.17	0.04
Rönningarna (P)						
0–190	38	11	1.1	0.3	0.02	0.01

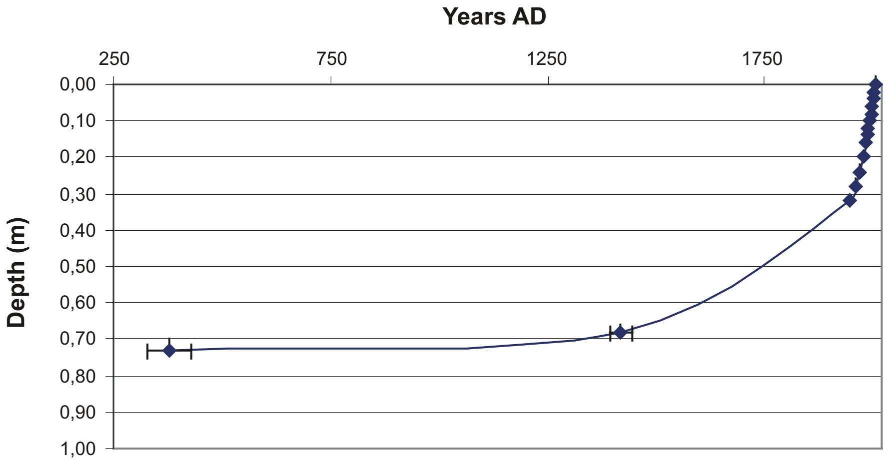


Figure 5-62. *Long-term time/depth diagram for Kallrigafjärden. The input data to the graph is based on ^{210}Pb datings for the upper sediment and ^{14}C for the two lower samples.*

Both the accumulation rates of dry mass and organic carbon (C) content increased during the 20th century and are generally higher than the long-term rates. The increased accumulation rate may reflect the transition of the bay from deep to shallow water, the changes in the fluvial regime and a greater influence of nutrients from the drainage area. The Kallrigafjärden Basin is the recipient of two major rivers in northern Uppland; the Forsmarksån River and the Olandsån River, together draining c 1,250 km^2 of the province of Uppland /Brunberg and Blomqvist 1998/. The River Olandsån has 27% of its origin in agricultural areas, thus sediment and nutrients upstream will eventually be partially deposited in the accumulation areas of the Kallrigafjärden Bay (Table 5-42). Only 9% of the drainage area of the River Forsmarksån constitutes agricultural land, whereas the wetlands comprise 17% including the large mire complex Florarna /Ingmar 1963/.

Table 5-42. The land use for the catchment area draining into the Kallrigafjärden bay /Brunberg and Blomqvist 1998/.

Catchment	Area (km^2)	Forest (%)	Wetlands (%)	Agricultural (%)	Lakes (%)
River Forsmarksån	375	69	17	9	5
River Olandsån	886	67	4	27	2

Lake sedimentation

The accumulation rate of the sediments collected at Lake Eckarfjärden was estimated in a semi-quantitative way (mm/year) using carbon 14 (^{14}C) dating of macrofossils from the sediment column. The sediment core was also subjected to detailed stratigraphical investigations in order to reconstruct the shore displacement in northern Uppland /Hedenström and Risberg 2003/.

The lithology at the sampling spot at Eckarfjärden consists of clay, sand, clay gyttja, gyttja, algal gyttja and thin lenses of calcareous gyttja incorporated into the algal gyttja layer. Diatoms were analysed in order to reconstruct the palaeo ecology of the basin. The ages of the dated samples were between c 8000 BC as recorded in the glacial clay and 1100 AD as recorded in the gyttja more than 1 m below the sediment/water interface (Table 5-43). It was concluded that the bottom layer of clay was deposited shortly after the de-glaciation during the Yoldia Sea stage of the Baltic. A layer of gravel and sand represents a hiatus of c 9,000 years in the sediments (Figure 5-63). The clay gyttja following the postglacial sand was deposited in brackish water, whereas gyttja started to form during the lagoonal stage of the Eckarfjärden basin. The increase in organic content reflected an increase in bio-productivity as a result of the more sheltered environment during isolation of the basin (cf. Figure 5-64). The high concentrations

Figure 5-63. *Part of the lithological sequence from the sampling site at Lake Eckarfjärden. Down is to the right where clay was obtained. Note the erosive contact between the clay and the sand, representing a hiatus of approximately 9,000 years. The upper part of the core consists of gyttja and is not presented in this picture.*

of biogenetic silica (Si) recorded in the clay gyttja and algal gyttja (Table 5-28) is most probably the result of a high production of diatoms during the isolation of the basin. The isolation of Lake Eckarfjärden from the Baltic has been dated to c 1100 AD (850 cal years BP), recorded in the sediment column at approximately the transition between clay gyttja and gyttja layer. After the isolation, algal gyttja and calcareous gyttja was deposited in the freshwater lake.

Based on an interpolation between the radiocarbon dates of macrofossils extracted from the sedimentary column and the present sediment surface, the average rate of sediment accumulation during the last 850 years has been c 1 mm/year. This is consistent with the modelled accumulation rate for Lake Eckarfjärden, which is 1.36 mm/year /Brydsten 2004/. Other lakes from north-eastern Uppland, included in the study by /Hedenström and Risberg 2003/ as well as the results from the Vissomossen mire, located c 20 km west of Forsmark /Bergström 2001/ showed that accumulation rates during the lacustrine phases vary between c 0.3 mm/year and up to 4 mm/year as the most.

The recent and sub-recent conditions of the Lake Eckarfjärden ecosystem are described by /Nordén et al. 2008/.

Table 5-43. Results from radiocarbon dating of plant macrofossils and sediments from Lake Eckarfjärden /from Hedenström and Risberg 2003/.

Depth below lake ice (m)	Material dated	^{14}C yrs BP ± 1σ	BC/AD (± 1σ)
3.10	Betula, Pinus, Alnus	850±65	AD 1150 (1120–1270)
3.40	Pinus	1245±95	AD 775 (680–890)
3.44	Betula	1060±85	AD 975 (880–1050)
3.87	Bulk sediment	8805±105	BC 7950 (8200–7650)

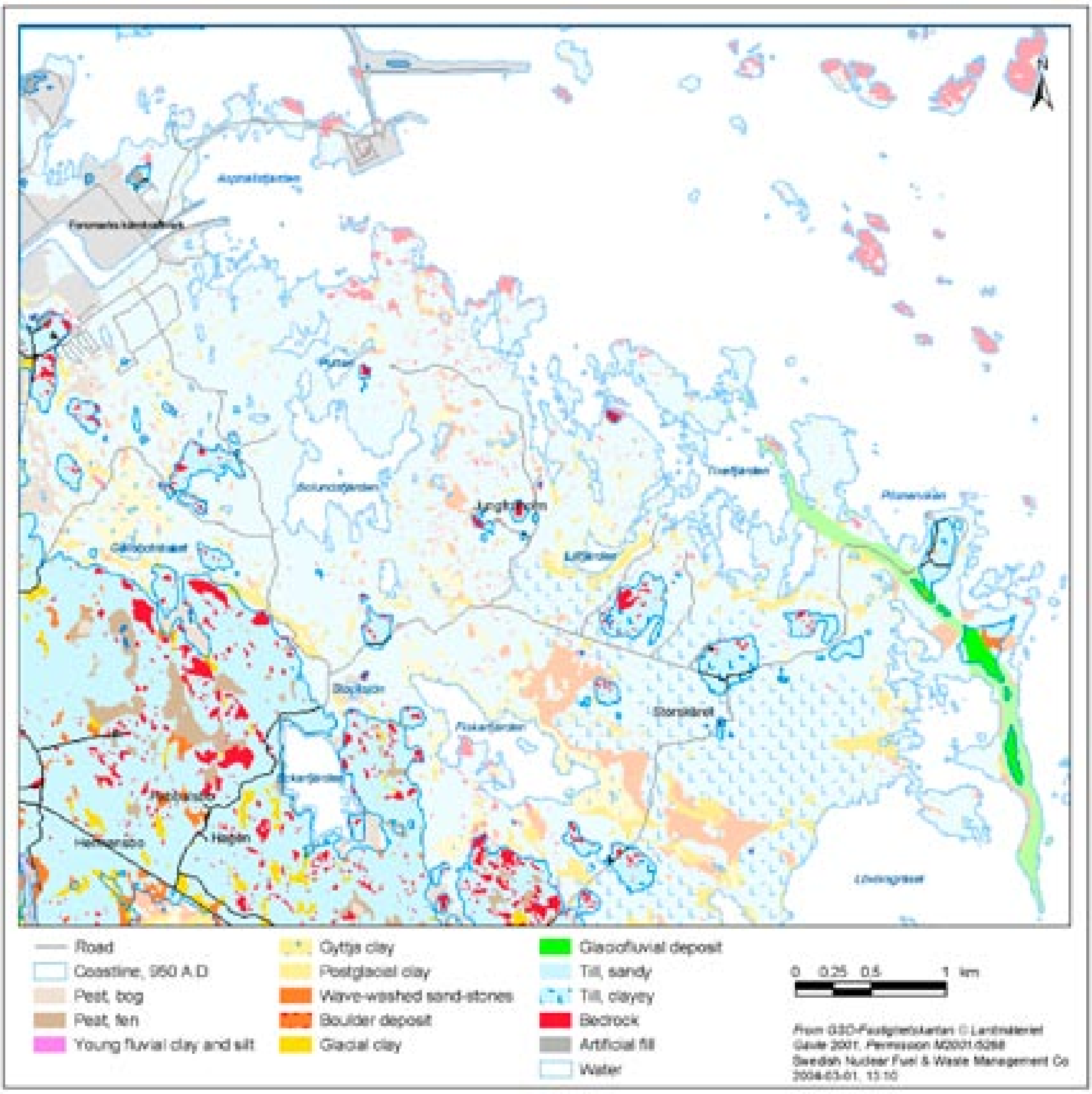


__Figure 5-64.__ Palaeogeographical map showing the areas situated above and below sea level at 950 AD. Lake Eckarfjärden is located in a sheltered bay, favouring a high production of diatoms in the lagoonal stage during the isolation of the basin.

Peatland accumulation

The long-term accumulation rate for a peatland was determined at the mire at Rönningarna /Sternbeck et al. 2006/. A 2.5 m-sediment core at PFM006025 was analysed. The stratigraphy of the dated sequence was: peat 0.1–1.89 m and clay 1.89–1.97 m /Lokrantz and Hedenström 2006/. The average long-term accumulation rate of carbon (C) and nitrogen (N) at the Rönningarna mire was 38 g C m^{-2} yr^{-1} and 1.1 g N m^{-2} yr^{-1} (Table 5-41). As a comparison, the sub-recent accumulation rates of C and N in peat were analysed at two ombrotrophic peatlands in Uppland /Borgmark 2006/. The mean accumulation rate of C and N during the last 157 years at Ältabergsmossen was 73 g C m^{-2} yr^{-1} and 1 g N m^{-2} yr^{-1} respectively. Borgmark concluded that these levels are similar to those found in other investigations, as well as to more theoretically-deduced numbers. The long-term accumulation rate of C at Rönningarna is lower than the sub-recent accumulation rate at Ältabergsmossen, whereas the accumulation rates of N are the same in the two mires.

6 Uncertainties

The uncertainties in the description of the regolith at Forsmark can be divided between uncertainties in the spatial distribution of the regolith on one hand and uncertainties in the analyses and properties on the other hand. The uncertainties in the data and models presented in this report are discussed in this section. The uncertainties in the regolith depth and stratigraphy model and the data used for that model are further discussed in /Hedenström et al. 2008/.

The map of Quaternary deposits (QD) has been produced using several mapping methods and the reliability of the resulting map therefore varies considerably within the model area. In the central parts of the regional model area, the map was produced after extensive field inventories, thus both the spatial resolution and the quality of the map in these parts is high. A comparison between the most detailed map /Sohlenius et al. 2004/ and the initial QD maps /Persson 1985, 1986/ showed that the occurrence of peatlands was exaggerated and that the number and size of the bedrock outcrops were described in a generalized manner on the initial maps. Furthermore, many small bedrock outcrops were not displayed at all on the initial maps. In the terrestrial areas outside the detailed map, these uncertainties are still present. The exact boundary between the sandy and the clayey till is another example of uncertain classification. However, the general distribution of the upper layers of the QD is judged to be reliable. In the marine areas mapped using regular marine geological methods, the quality of the map is high, especially in the near-shore area and along the measuring lines for the survey vessels. Both in the terrestrial and marine areas, the separation of fractured bedrock from boulder-rich till are judged as uncertain. Areas with the highest uncertainties are those based on interpretations from the point observations, i.e. in the very shallow areas close to some islands.

The geometrical model of total depth and stratigraphy of the regolith is produced by combining data from several different investigation methods, both direct observations (corings and excavations) and indirect interpretation of geophysical measurements. The model is constructed in accordance with the conceptual model of the Quaternary geology of the Forsmark area, which means that the general spatial distribution of different QD is important input to the model. The quality of the model varies with the density of direct observations reaching the bedrock surface, and is, accordingly, highest in the central parts of the candidate area. However, the quality of the model is also high in the shallow coastal parts of the marine area, even though the model in this area is based almost exclusively on geophysical data /Hedenström et al. 2008/. In large parts of the model area, especially in the distal parts and Till Area II, the regolith depths are almost completely represented by average depth values, originally based on interpretation of geophysical data. Comparisons between direct observations and geophysical data indicates that the latter may produce too shallow regolith depths /Hedenström et al. 2008/. The spatial resolution of the model is 20×20 m. Detailed studies of the bedrock surface at Forsmark have revealed that a pronounced small-scale topography characterises the bedrock surface, although the regolith surface is remarkably flat. The spatial resolution of the model and the use of average regolith depths in large parts of the model area mean that the RDM contains many uncertainties in the local scale (tens of metres). The RDM should mainly be regarded as a general geometric model of the area on a landscape level.

The quality of the soil-type map partly depends on the quality of the QD map since the soil-type map is based on relatively few field inventories extrapolated by GIS analyse of the geological map. It should also be noted that the properties of the agriculture land as presented in the soil type inventory was not based on clayey till, which in fact, is the QD used for almost all cultivation at Forsmark. It should be noted that the soil type was not investigated at all of the different QD during the field work. The Histosol class, which by definition covers peatland soils, in this presentation includes reed areas surrounding many of the lakes. Reeds (*Phragmites*) have, however, been observed to grow directly on till or gyttja clay at many at of the places observed.

The spatial distribution of the water-laid sediments in lakes and small ponds is well known from the central part of the regional model area and the uncertainties are considered very low at the sites investigated. Although an extensive coring programme was conducted, stratigraphical distribution of the bottom substrate of some of the wetlands was not investigated. The spatial distribution and chemical properties of peat are based on investigations of only three peatlands. However, it is assumed that they are representative for the entire area and thus resulting in relatively good knowledge. The chemical and physical properties of the till have been determined using a number of different methods. The majority of the samples analysed were from the central part of the regional model area. Grain size distribution and calcium carbonate ($CaCO_3$) content were the most reliable parameters since they were analysed at all of the occurring minerogenic deposits. The measurements of physical properties in the open trenches are based on only a few measurements. The chemical and physical properties of the marine sediments are also only based on a few samples, but the information is acceptable since the lithological units probably have similar properties to those of the terrestrial sediments.

The accumulation rate in marine, coastal, limnic and terrestrial areas has been quantified, but the quantification is based on only 1–2 sites per type area. Thus, the uncertainties are judged as moderate to relatively high. The samples representing coastal environment were collected in rather shallow areas, thus it cannot be ruled out that some re-deposition of the sediments takes place.

7 Resulting description

The Forsmark area is unique in many ways and does not represent a typical Swedish coastal site at the shoreline of the Baltic Sea. The most characteristic properties for regolith at Forsmark is the flat upper surface, young and unweathered soils, a high content of calcium carbonate ($CaCO_3$) and the occurrence of till with a high clay content. The shoreline of northern Uppland is characterised by the high frequency of boulders from the till. The soil profiles are typically poorly developed and dominated by Regosols, Gleysols and Histosols. The high concentration of ($CaCO_3$) has resulted in high pH values in the near-surface groundwater and a rich flora. Furthermore, the lakes and mires are young and the postglacial sediments are generally thin. Typical for the young wetlands is that many of them have a surface layer of clay gyttja, i.e. they are not peatlands. The Forsmark area is characterized by small-scale topography with limited variations in altitude and is almost entirely located below 25 m above sea level and has been completely below water for most of the Holocene, the highest areas emerged from the Bothnian Sea as late as 1000 BC. The flat topography of the land surface, together with a relative fast land upheaval results in a rapid growth of the terrestrial areas and a very young terrestrial system.

The distribution of Quaternary deposits (QD) is shown in Figure 5-10. The surface distribution of the QD is in accordance with the regional pattern for eastern Sweden (Figure 5-1 and Figure 5-2). The general stratigraphy for Forsmark is summarised in Table 5-5. The state of knowledge of the distribution of the QD at the site is reflected in the construction of the conceptual model used for the Regolith Depth Model (RDM) (Figure 4-2). The conceptual model presented for the Forsmark site is in accordance with the general distribution of QD in areas situated below the highest coastline (Figure 4-1).

The bedrock outcrops in the model area are characterised by glacial abrasion with a dominating ice movement direction from the north and a sub-dominant (older) direction from the north-west. The surficial bedrock at excavated sites has displayed horizontal to sub-horizontal fractures. Boulders and uplifted blocks of bedrock have been observed after removing covering till layers in the western part of the investigated area /Leijon (ed.) 2005/. The uplifted blocks were partly resting upon silty laminated sediments. Furthermore, a relatively high hydraulic conductivity has been recorded at the transition between bedrock and regolith /Johansson 2008/ indicating that the surficial bedrock covered by regolith probably has more fractures than the bedrock outcrops.

Till is the overall dominating QD that fills small-scale crevasses in a bedrock dominated by granites. The Forsmark model area is separated into three till areas, Till Areas I, II and III (Figure 5-13). Till Area I, representing the major part of the terrestrial area, is dominated by sandy and silty till. Till Area II, located around Storskäret, is dominated by clayey till and boulder clay, whereas Till Area III consists of the area close to the Börstilåsen Esker with high concentrations of large boulders in the surface. Characteristic for almost all till material at Forsmark is the occurrence of calcium carbonate ($CaCO_3$) in the fine fraction. Furthermore, the high clay content in Till Area II has resulted in that the agriculture land at Forsmark is almost entirely located on till. The stratigraphical distribution of the till units appears to be complex, although the till type from the surface usually dominates down to bedrock. At several sites within Till Area I, a very hard clayey till was observed under the upper, younger, till unit, whereas in Till Area II, a sandy till was observed below the clayey till. There is no conclusive evidence of deposits older than the latest glaciation in the Forsmark area. The oldest regolith observed is a lithological unit consisting of hard clayey till that has been observed under a younger till unit at several sites within the Forsmark regional model area. The exact age of this till unit is not known, but it has been suggested that it was deposited during a stage of the Weichselian glaciation (c. 75,000–60,000 years ago) /Robertsson et al. 2005/.

The composition of the till generally indicates a short transport distance with a petrographical composition that mainly reflects that of the local bedrock, except for the relatively high amount of Palaeozoic limestones present in the gravel and fine fractions of till and clay. The limestones originate from the marine area north and north-east of Forsmark. It has been shown that the major part of the till in the area has been deposited by ice moving from the north-west, however, at some localities, the uppermost and youngest till units have been deposited from the north /Sundh et al. 2004/. Consequently, it can be concluded that most of the till emanates from bedrock situated north to north-west of the site. It must, however, be kept in mind that the till material may have been re-deposited during several glaciations and that some of the bedrock material in the till may therefore originate from other directions. The north and north-western directions of transport are verified also by high concentrations of re-worked Palaeozoic microfossils in the till samples from the Forsmark area /cf. Robertsson 2004/.

Most of the glaciofluvial sediments at Forsmark are concentrated to the Börstilåsen Esker. The major part of the esker is found south of the regional model area. The part of the esker that passes through the south-eastern part of the model area is built up by sand, gravel and stones resting directly on the bedrock.

The distribution of fine-grained, water-laid sediments mainly follows the large-scale bedrock morphology, thus the greatest amount of clay is found in depressions in the marine area and under the present lakes. Glacial clay is the oldest fine-grained sediment, deposited in relatively deep water during the latest deglaciation, c 8800 BC. Since the most elevated areas in the Forsmark area are only c 25 m above sea level, the Forsmark area has been situated below the Baltic Sea until the last few thousand years. Thus, the formation, erosion and reworking of postglacial deposits have mainly been taking place prior to their emergence from the Baltic Sea. However, since the appearance of the first islands, the flat topography in combination with the fast land upheaval, has resulted in a remarkably fast growth of new land in the Forsmark area. A summary of salinity variations and the rate of land growth at Forsmark after the latest deglaciation are presented in (Figure 7-1). The rapid changes in the distribution of land and sea can also be visualised in a series of palaeogeographical maps (Figure 7-2).

Typical for the postglacial sediments in the Forsmark area is that they are generally thin and mainly located in the deeper marine areas, sheltered shallow basins or in the lakes. A layer of postglacial sand and gravel is frequently recorded on top of glacial clay, representing deposition after erosion and transport by currents on the sea floor. Postglacial clay, including clay gyttja,

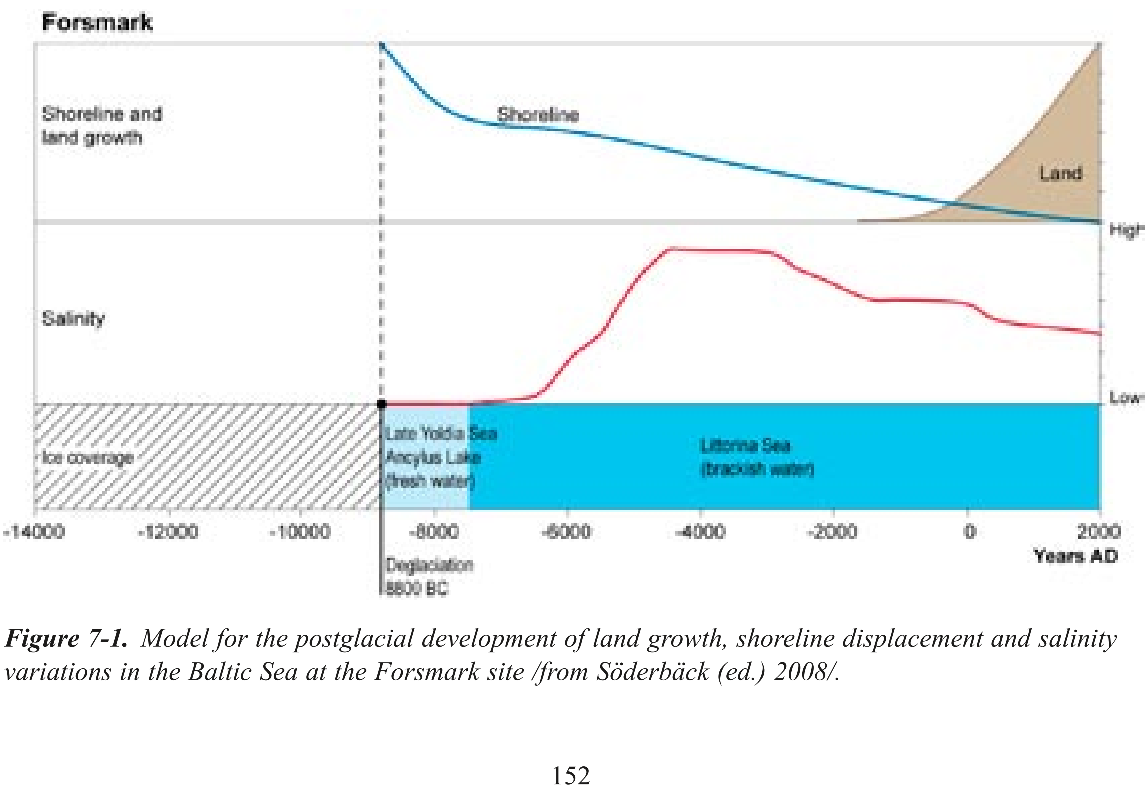


Figure 7-1. Model for the postglacial development of land growth, shoreline displacement and salinity variations in the Baltic Sea at the Forsmark site /from Söderbäck (ed.) 2008/.

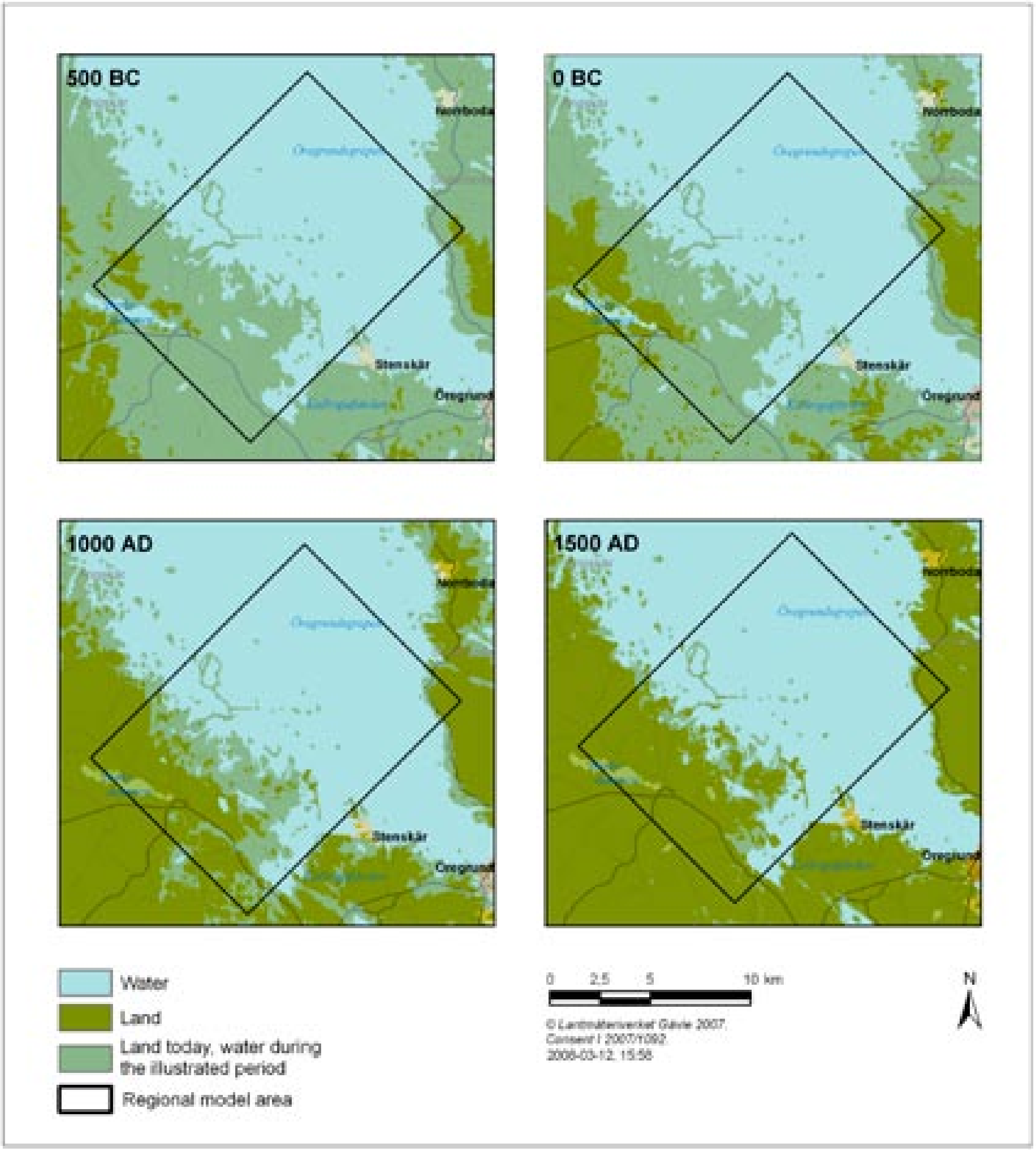


Figure 7-2. Palaeogeographical maps showing the distribution of land and sea at the Forsmark site at four different occasions since the emergence of the first land areas /from Söderbäck (ed.) 2008/.

is predominantly found in the deeper parts of the sea floor. The ongoing isostatic uplift transfers sedimentary basins to sheltered positions, favouring the accumulation of organic sediments. The distribution of organic deposits in the terrestrial area has been divided into two general domains, one representing areas above 5 m altitude and one representing organic deposits located in areas below 5 m altitude. Actual peatlands are only found in areas at elevations higher than 5 m altitude in the south-western part of the model area. These areas have been above sea level long enough for the basins to fill in and for peat to form. Bogs do occur, but are few in number and are still young, while rich fens are the dominating peatland type.Clay gyttja is common at the surface of the wetlands located at low altitudes, e.g. along the shores of Lake Fiskarfjärden and Lake Gällsboträsket. Gyttja is presently formed in lakes and consists mainly of remnants from algae that have grown in the lake. In areas with calcareous soils such as those found in the Forsmark area, calcareous gyttja forms when calcium carbonate precipitates in the water. There is a gradual transition upward from the gyttja to a layer of microphytobenthos and then lake water in the lakes. They are generally quite shallow with thin sedimentary layers. The accumulation of gyttja will fill the lakes and ponds and eventually transform them into wetlands.

There are two areas with artificial filling within the Forsmark regional model area. The largest one is the area around the Forsmark nuclear power plants, where the filling material consists mainly of blasted rocks and QD excavated from the sea bottom. Thus, the deposits have physical and chemical properties similar to the natural cover of till and clay in the area. The second area of artificial filling material is located in the distal part of the regional model area at the former pulp mill at Johannisfors. This deposit consists of calcareous waste material (Swedish *mesa*) from an old pulp mill. These types of deposits are known to contain pollutants, mainly heavy metals, originating from the pulp production.

The soil types in the Forsmark area are typically immature, poorly-developed soils on till or sedimentary parent material, which are highly influenced by the calcareous material. The dominating soil types are Regosols, but six other soil classes also occur. Typical soils for Sweden are Podsols, but this soil type has not yet developed at Forsmark. The poor soil development is a result of its young age.

7.1 Stratigraphy and depth

This section is a summary of the properties of the different domains used in the RDM and gives reference to the data. Table 7-1 should be used as a guide to determine the physical and chemical properties of the different layers and lenses defined in the RDM. The spatial distribution of the sub-domains is found in (Figure 5-34).

Terrestrial area

Glacial till

The terrestrial area is in general dominated by till (65% of the surface). The majority of the terrestrial area is represented by Sub-Domain 5 in the RDM. This sub-domain is defined to include Till Areas I and III (Figure 5-34), which are dominated by sandy till. The general stratigraphy in this domain consists of sandy till/(hard clayey till)/bedrock and the average total depth to bedrock is 3.6 m. The Forsmark candidate area is almost completely located within this sub-domain. The land use is dominated by forestry and the dominating soil types are Regosol and Gleysol. Areas with lakes and mires are treated as separate sub-domains.

Till Area II was distinguished as Sub-domain 6 in the RDM (Figure 5-34). The QD are till with a high clay content and low boulder frequency, thus Till Area II includes the majority of the agricultural area in the Forsmark area. The general stratigraphy in this domain consists of clayey till or boulder clay/(sandy till)/bedrock. The average total depth to bedrock is 5.8 m. The soil types are Regosol/Gleysol on arable land.

Glaciofluvial esker

All areas covered with glaciofluvial sediments are included in Sub-Domain 9 (Figure 5-34). The rather sparse stratigraphical information from the site shows that the sediment is dominated by gravel and sand located directly on the bedrock. The general stratigraphy in this domain consists of glaciofluvial sediments/bedrock. The average total depth to bedrock is 5.8 m. The land is presently used as forest and pastures within the Kallrigafjärden Nature Reserve. The soil type is Regosol.

Organic Domain A

All areas located higher than 5 m above sea level and are represented by peat on the geological map, are included in Sub-Domains 7 and 8 (Figure 5-34). This area corresponds to Sub-Domain A for organic deposits (Figure 5-23). The reason for separating the organic deposits above this altitude is based on the stratigraphical investigations. The general stratigraphy in this domain starting from the ground surface is peat/gyttja/clay gyttja/sand/(clay)/till/bedrock. The average depth of the peat is 1.4 m, whereas the average total depth to bedrock is 5.7 m when clay is present or 5.2 m when clay is absent. The peat layer in the wetlands located below the 5 m

Table 7-1. Reference guide for physical and chemical properties of the most common QD. C, N and S refers to carbon, nitrogen and sulphur in organic deposits.

Layer in RDM	QD	Physical properties	Chemical properties	C,N,S
L1	Gyttja	Table 5-22 Table 5-23 Appendix K	Table 5-23 Table 5-28 Table 5-30 Table 5-31 Table 5-32	Table 5-23 Appendix G Appendix I
L2	Postglacial sand and gravel	Table 5-22 Table 5-23 Appendix K	Table 5-23	
L3	Clay	Table 5-22 Table 5-23 Appendix K	Table 5-23 Table 5-28 Table 5-30 Table 5-31 Table 5-32 Appendix I	Table 5-23 Appendix G Appendix I
Z1	Top layer of all QD except Z2	Table 5-16, Table 5-18 Table 5-19 Appendix C Appendix D Appendix E Appendix K	Table 5-25 Table 5-26 Table 5-27 Table 5-34 Appendix H Appendix J	Appendix G
Z2	Peat	Table 5-23 Appendix F Appendix K	Table 5-33 Appendix I	Table 5-23
Z3	Postglacial and glacial sand and gravel, artificial filling	Table 5-16 Table 5-23 Table 5-24 Appendix C	Table 5-30 Appendix I	Table 5-23
Z4a	Postglacial clay, clay gyttja, gyttja clay	Table 5-17 Table 5-20 Table 5-21	Table 5-30 Appendix I	Table 5-20 Table 5-23 Figure 5-58 Appendix G
Z4b	Glacial clay	Table 5-17 Table 5-20 Table 5-21 Appendix C	Table 5-23 Appendix I	Table 5-20 Figure 5-58
Z5	Till	Table 5-16 Table 5-19 Table 5-21 Appendix C, Appendix D Appendix E Appendix K	Table 5-25 Table 5-26 Table 5-27 Appendix H	
Z6	Surficial bedrock			

altitude is not thick enough to be included as the surface layer on the geological map. The soil type is Histosol and the land is presently dominated by forests. Typical areas for this domain are the mire at Rönningarna and Stenrösmossen mire.

Organic Domain B

Areas with organic deposits at altitudes below 5 m above sea level were not modelled as separate sub-domains in the RDM, but are separated as an organic deposit domain in the description. The reason for this is that the sediments are thin, thus they are included in the upper layer (Z1). The general stratigraphy within this domain consists of a thin organic layer, possibly containing peat, gyttja or clay gyttja, but together not constituting a depth of more than 0.6 m. The average total depth to bedrock is 3.6 m and the soil type is Histosol.

Lake sediments

Areas located inside the boundary of eight selected lakes were treated as separate sub-domains in the RDM. The detailed information regarding the stratigraphy was generalised the RDM into three lake sediment lenses: gyttja (L1), sand and gravel (L2) and clay (L3). In the modelled lake sediment lenses, the actual depth of each layer is used, hence they are not based on average values. It is suggested that the till below the lakes and mires has properties, e.g. texture and thickness, similar to those in the terrestrial areas, with the exception of the absence of soil-forming processes and wave-washing.

Marine area

A vertical profile from the marine area is presented in (Figure 5-33). The profile includes Sub-Domains 1, 2 and 3. The major difference between the terrestrial and marine area is that the total regolith depth is larger in the marine area and that the clay is more frequent in the marine area.

Glacial till

Sub-Domain 1 represents the areas with till as the surface layer that make-up 30% of the marine area. The till is not classified regarding the grain size distribution of the matrix. Based on a comparison with the regional terrestrial distribution, it is plausible that the distribution in the marine area displays a similar pattern as that in the terrestrial area. Therefore, it is assumed that both clayey and sandy-silty till occurs in the marine area. In the shallow coastal area, a few analyses of till samples showed that clayey till and boulder clay occur. The calcite content is similar to the composition of the till in the terrestrial area. However, leaching in the surface layer was not initiated in the sub-aquatic environment. Boulder frequency at the bottom was analysed for the near-shore areas, showing that the boulder-rich area represented by Till Area III in the description can be followed in the off-shore area. Since there is no stratigraphical information from the boulder-rich area, it has not been separated into a sub-domain in the RDM. The average depth of the till in the off shore areas is c 6 m.

Glacial clay

The areas with glacial clay and glacial clay with a thin cover of postglacial sand are the upper layers in the marine area. These areas represent 41% of the marine area and are classified as Sub-Domain 2. The stratigraphical investigations from the marine geological survey show that the glacial clay is usually underlain by till. Thus the general stratigraphy in this sub-domain comprises glacial clay and till on bedrock. The properties of the glacial clay are similar to the clay in the terrestrial area.

Postglacial sand

The areas with postglacial sand or gravel as the QD, covering 6% of the the marine geological map, arerepresented by Sub-Domain 3. The average depth of postglacial sand and gravel is 0.9 m. The general stratigraphy comprises postglacial sand, glacial clay and till on bedrock. The properties of the sediment are similar to the postglacial sediments in the terrestrial area.

Postglacial clay

The areas with clay gyttja or gyttja as the cover layer are found at 17% of the marine areas, represented by Sub-Domain 4. The average depth of postglacial clay in the marine area is 0.9 m. Areas with thin surface layers of postglacial sand or silt are also included in this sub-domain. The properties of the postglacial clay are similar to the postglacial sediments in the terrestrial area.

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Map of the Forsmark area

Appendix B

Stratigraphical description of all of the sites, in Swedish

Attached on CD.

Appendix C

Grain size distribution for minerogenic QD

Table C-1. Sandy and silty till.

ID code	Sampling depth (m)	QD	QD Swedish	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	D60/D10 (no unit)
HFM01	1.25	sandy till	Sandig morän	32.9	50.1	14.9	2.1	34.5
HFM01	6.00	sandy till	Sandig morän	22.4	57.7	17.4	2.6	27.9
HFM01	9.00	sandy silty till	Sandig-siltig morän	3.0	56.7	37.3	3.0	10.5
HFM02	11.00	sandy silty till	Sandig-siltig morän	15.8	36.2	45.5	2.5	21.5
HFM03	6.00	sandy till	Sandig morän	10.1	50.9	36.2	2.8	12.4
HFM03	9.00	sandy silty till	Sandig-siltig morän	6.6	52.8	38.4	2.2	13.5
HFM09	2.00	sandy till	Sandig morän	23.3	46.2	26.3	4.1	36.4
PFM002462	2.30	sandy till	Sandig morän	19.7	55.3	20.9	4.1	45.5
PFM002463	10.45	sandy till	Sandig morän	11.8	61.6	23.9	2.7	13.2
PFM002576	1.90	sandy till	Sandig morän	16.4	52.3	27.9	3.4	17.8
PFM002576	5.00	sandy till	Sandig morän	16.9	54.9	23.7	4.5	21.3
PFM002581	1.00	sandy silty till	Sandig-siltig morän	10.1	48.4	37.8	3.7	13.7
PFM002582	0.60	sandy till	Sandig morän	23.9	55.0	16.9	4.1	63.2
PFM002582	1.70	sandy till	Sandig morän	25.4	50.4	19.5	4.7	113.9
PFM002586	1.40	sandy silty till	Sandig-siltig morän	19.1	43.5	33.0	4.4	54.1
PFM002587	3.00	sandy till	Sandig morän	30.0	37.6	27.5	3.9	76.8
PFM002589	4.70	sandy till	Sandig morän	11.1	51.3	32.9	4.7	27.9
PFM002687	1.00	sandy till	Sandig morän	16.2	46.0	33.4	4.4	31.7
PFM002801	0.40	sandy till	Sandig morän	25.8	51.0	19.3	3.9	47.3
PFM002802	1.30	sandy till	Sandig morän	27.4	47.6	20.6	4.4	44.7
PFM003742	0.50	sandy silty till	Sandig-siltig morän	5.5	59.4	30.3	4.8	23.4
PFM004455	0.23	sandy till	Sandig morän	34.4	50.1	12.0	3.4	90.1
PFM004455	0.53	sandy till	Sandig morän	25.3	51.0	18.9	4.9	83.6
PFM004455	0.83	sandy till	Sandig morän	26.9	49.7	18.8	4.6	86.7
PFM004455	1.23	sandy till	Sandig morän	22.9	52.3	20.8	4.0	61.6
PFM004455	1.73	sandy till	Sandig morän	12.0	59.5	24.8	3.7	19.7
PFM004458	0.08	sandy till	Sandig morän	29.7	54.5	13.6	2.2	32.3
PFM004458	0.23	sandy till	Sandig morän	29.1	55.1	13.6	2.2	35.1
PFM004458	0.53	sandy till	Sandig morän	25.3	57.5	15.0	2.3	28.8
PFM004458	1.73	sandy till	Sandig morän	28.5	44.8	22.2	4.5	95.7
PFM004458	2.53	sandy till	Sandig morän	27.7	48.0	19.7	4.6	89.9
PFM004460	0.53	sandy till	Sandig morän	25.0	47.9	23.2	3.9	64.8
PFM004460	0.83	sandy till	Sandig morän	22.3	49.0	24.5	4.3	67.6
PFM004460	1.23	sandy till	Sandig morän	21.8	49.4	24.7	4.1	60.3
PFM004460	1.73	sandy till	Sandig morän	24.9	46.6	23.6	4.9	89.8
PFM004514	1.50	sandy till	Sandig morän	27.5	50.7	18.7	3.2	41.3
PFM004752		sandy till	Sandig morän	26.3	48.6	23.5	1.7	37.9
PFM004760	1.25	sandy till	Sandig morän	28.7	35.9	31.4	4.0	54.5
PFM004761	0.55	sandy till	Sandig morän	30.7	45.1	20.0	4.2	54.3
SFM0002	1.50	sandy till	Sandig morän	31.9	45.4	19.6	3.1	75.4
SFM0002	3.50	sandy till	Sandig morän	33.0	42.0	21.4	3.6	50.4
SFM0002	5.00	sandy till	Sandig morän	19.6	50.4	27.3	2.6	20.5
SFM0003	1.25	sandy till	Sandig morän	27.2	56.5	13.9	2.4	58.2
SFM0003	4.00	sandy till	Sandig morän	18.2	49.4	28.2	4.2	17.7
SFM0005	1.25	sandy till	Sandig morän	30.1	37.0	28.3	4.6	110.5
SFM0008	4.50	sandy till	Sandig morän	29.0	48.6	17.9	4.5	105.2
SFM0011	1.75	sandy till	Sandig morän	28.4	35.7	31.5	4.5	64.1
SFM0011	3.25	sandy till	Sandig morän	29.4	37.9	29.6	3.1	41.9
SFM0016	0.58	sandy till	Sandig morän	16.4	65.7	14.4	3.5	14.3
SFM0016	1.90	sandy till	Sandig morän	20.3	51.1	24.5	4.2	28.5
SFM0016	4.85	sandy till	Sandig morän	20.8	46.3	27.8	4.2	32.2

ID code	Sampling depth (m)	QD	QD Swedish	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	D60/D10 (no unit)
SFM0019	1.25	sandy till	Sandig morän	25.3	52.9	18.0	3.8	38.5
SFM0019	4.25	sandy till	Sandig morän	26.0	54.2	16.1	3.8	37.2
SFM0022	4.30	sandy till	Sandig morän	16.7	77.9	2.4	3.1	5.1
SFM0030	0.83	sandy till	Sandig morän	25.4	49.5	20.3	4.8	68.5
SFM0030	1.55	sandy till	Sandig morän	26.6	44.6	24.1	4.8	70.1
SFM0034	1.45	sandy till	Sandig morän	21.5	42.7	30.9	4.9	44.5
SFM0036	0.80	sandy till	Sandig morän	20.2	32.6	42.3	4.9	29.7
SFM0062	2.95	sandy till	Sandig morän	2.2	86.3	8.4	3.0	4.5
SFM0063	2.50	sandy till	Sandig morän	17.7	77.6	3.8	0.9	6.3
SFM0081	3.25	sandy till	Sandig morän	14.4	80.4	4.3	0.9	6.0
SFM0104	6.00	sandy till	Sandig morän	14.1	47.2	37.5	1.2	16.2
SFM0105	0.75	sandy till	Sandig morän	22.6	40.1	32.6	4.6	73.0
SFM0107	3.70	sandy till	Sandig morän	10.9	52.5	31.8	4.8	30.6
SFM0107	4.15	sandy till	Sandig morän	32.5	39.9	23.1	4.5	120.8
SFM0108	0.70	sandy till	Sandig morän	32.9	45.2	19.6	2.3	50.3

Table C-2. Clayey till and boulder clay.

ID code	Sampl. depth (m)	QD	QD Swedish	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	D60/D10 (no unit)
HFM05	2.25	Clayey sandy silty till	Lerig sandig-siltig morän	12.8	38.4	34.3	14.6	
HFM05	3.25	Clayey sandy till	Lerig sandig morän	16.2	53.3	25.4	5.1	40.5
HFM06	1.25	Clayey sandy till	Lerig sandig morän	27.3	34.8	27.9	10.0	262.1
HFM07	1.25	Boulder clay	Moränlera	7.9	40.6	35.2	16.4	
HFM08	2.00	Clayey sandy silty till	Lerig sandig-siltig morän	10.1	39.2	36.5	14.1	
HFM08	4.50	Clayey till	Lerig morän	0.9	34.8	49.5	14.8	
KFM01A	5.25	Clayey sandy silty till	Lerig sandig-siltig morän	12.1	46.9	35.2		40.8
PFM002461	1.12	Clayey sandy till	Lerig sandig morän	24.5	42.6	27.9	5.0	77.8
PFM002461	2.20	Clayey sandy till	Lerig sandig morän	34.1	33.3	19.1	13.5	
PFM002462	0.40	Clayey sandy silty till	Lerig sandig-siltig morän	13.0	40.7	33.3	13.0	
PFM002463	1.50	Boulder clay	Moränlera	9.8	39.3	35.8	15.1	
PFM002463	5.30	Clayey sandy silty till	Lerig sandig-siltig morän	8.9	43.2	33.8	14.1	
PFM002463	7.50	Clayey sandy till	Lerig sandig morän	11.6	58.4	23.4	6.6	58.2
PFM002464	3.70	Boulder clay	Moränlera	8.1	40.3	36.2	15.4	
PFM002464	5.15	Boulder clay	Moränlera	10.1	42.4	32.3	15.2	
PFM002464	5.75	Clayey sandy silty till	Lerig sandig-siltig morän	12.7	39.5	38.5	9.4	68.5
PFM002464	7.40	Clayey sandy silty till	Lerig sandig-siltig morän	6.9	50.5	34.9	7.7	32.7
PFM002464	8.00	Clayey sandy silty till	Lerig sandig-siltig morän	12.5	40.9	31.8	14.8	
PFM002464	9.20	Clayey sandy silty till	Lerig sandig-siltig morän	2.5	20.5	62.2	14.9	
PFM002572	1.55	Boulder clay	Moränlera	11.0	38.0	36.0	15.0	
PFM002572	4.20	Blayey sandy till	Lerig sandig morän	15.6	48.3	29.0	7.1	50.3
PFM002572	5.40	Blayey sandy till	Lerig sandig morän	19.5	41.7	30.6	8.3	58.6
PFM002573	1.55	Boulder clay	Moränlera	11.2	39.0	34.9	15.0	
PFM002573	3.55	Clayey sandy till	Lerig sandig morän	16.0	41.1	36.6	6.3	51.3
PFM002574	1.60	Clayey sandy silty till	Lerig sandig-siltig morän	12.0	40.0	34.3	13.7	2.7
PFM002577	0.60	Clayey sandy till	Lerig sandig morän	22.6	51.9	19.0	6.5	74.0
PFM002578	1.30	Clayey sandy silty till	Lerig sandig-siltig morän	13.9	37.2	35.4	13.5	
PFM002578	3.80	Clayey sandy silty till	Lerig sandig-siltig morän	7.4	38.8	48.0	5.8	14.0
PFM002581	2.40	Clayey sandy till	Lerig sandig morän	13.7	44.2	31.2	11.0	
PFM002581	3.70	Boulder clay	Moränlera	12.6	37.6	30.7	19.0	
PFM002586	0.60	Clayey sandy till	Lerig sandig morän	20.6	41.9	32.3	5.3	56.2
PFM002588	2.10	Clayey sandy silty till	Lerig sandig-siltig morän	13.6	38.6	34.7	13.0	
PFM002589	1.30	Clayey sandy till	Lerig sandig morän	12.1	39.1	36.4	12.4	
PFM002589	2.40	Boulder clay	Moränlera	11.7	38.1	35.2	15.1	
PFM002590	2.30	Clayey sandy silty till	Lerig sandig-siltig morän	12.1	40.6	35.3	12.0	
PFM002591	0.90	Clayey Gravelly till	Lerig grusig morän	49.2	21.9	21.4	7.5	1026.3
PFM002591	2.00	Clayey sandy silty till	Lerig sandig-siltig morän	13.8	37.6	34.7	13.9	
PFM002591	3.20	Clayey sandy silty till	Lerig sandig-siltig morän	13.5	39.2	36.2	11.2	
PFM002592	1.20	Clayey sandy silty till	Lerig sandig-siltig morän	9.9	44.5	32.2	13.4	
PFM002592	2.80	Boulder clay	Moränlera	10.5	39.6	34.6	15.3	
PFM002594	0.60	Clayey sandy silty till	Lerig sandig-siltig morän	10.3	38.8	36.4	14.4	
PFM002594	1.40	Clayey sandy till	Lerig sandig morän	14.1	39.9	35.8	10.3	92.1
PFM002687	0.50	Clayey sandy till	Lerig sandig morän	13.5	45.5	27.8	13.2	34.1
PFM002760	1.00	Clayey sandy till	Lerig sandig morän	14.9	38.3	33.3	13.5	
PFM002761	0.50	Clayey sandy till	Lerig sandig morän	11.3	47.2	31.0	10.5	119.0
PFM002762	0.50	Clayey sandy till	Lerig sandig morän	15.1	41.7	31.8	11.5	
PFM002767	0.80	Clayey sandy silty till	Lerig sandig-siltig morän	9.8	41.8	35.1	13.4	
PFM002768	1.00	Clayey sandy till	Lerig sandig morän	25.9	42.3	24.8	7.0	117.7
PFM004454	1.43	Clayey sandy till	Lerig sandig morän	18.7	54.6	21.5	5.2	47.5
PFM004455	2.08	Clayey sandy silty till	Lerig sandig-siltig morän	12.2	42.1	40.2	5.5	30.5
PFM004455	2.53	Clayey sandy till	Lerig sandig morän	17.8	45.1	28.9	8.2	113.7
PFM004456	1.93	Clayey sandy silty till	Lerig sandig-siltig morän	9.6	40.5	44.0	5.9	26.1
PFM004459	2.58	Boulder clay	Moränlera	12.2	39.6	32.5	15.7	
PFM004459	3.50	Clayey sandy silty till	Lerig sandig-siltig morän	10.6	36.3	41.6	11.5	
PFM004460	0.23	Boulder clay	Moränlera	21.7	23.5	28.9	25.9	
PFM004460	1.33	Clayey sandy till	Lerig sandig morän	22.3	44.5	27.7	5.6	70.4
PFM004460	1.58	Clayey sandy till	Lerig sandig morän	24.1	46.4	23.8	5.8	94.5

ID code	Sampl. depth (m)	QD	QD Swedish	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	D60/D10 (no unit)
PFM004460	1.93	Clayey sandy silty till	Lerig sandig-siltig morän	3.9	35.8	52.8	7.5	19.4
PFM004514	0.90	Clayey sandy silty till	Lerig sandig-siltig morän	18.6	39.6	31.3	10.5	123.9
PFM004514	2.30	Boulder clay	Moränlera	10.4	36.3	35.1	18.3	
PFM004514	2.80	Clayey sandy till	Lerig sandig morän	21.7	45.5	26.3	6.5	75.4
PFM004762	0.45	Clayey sandy till	Lerig sandig morän	22.3	41.4	29.5	6.8	82.4
PFM006073	4.25	Clayey sandy till	Lerig sandig morän	17.7	42.5	26.3	13.5	
PFM006095	2.88	Boulder clay	Moränlera	9.2	37.6	37.5	15.7	
PFM006097	3.61	Clayey sandy till	Lerig sandig morän	17.7	42.4	26.7	13.2	
SFM0001	3.75	Clayey sandy silty till	Lerig sandig-siltig morän	16.2	49.8	26.0	8.0	91.9
SFM0004	2.75	Clayey sandy till	Lerig sandig morän	25.4	48.5	20.6	5.5	78.0
SFM0006	1.50	Clayey sandy silty till	Lerig sandig-siltig morän	11.4	41.8	33.8	13.0	
SFM0007	2.00	Clayey sandy silty till	Lerig sandig-siltig morän	15.7	35.5	35.5	13.3	
SFM0007	4.50	Clayey sandy till	Lerig sandig morän	18.9	40.2	32.2	8.7	104.6
SFM0008	1.50	Boulder clay	Moränlera	10.4	32.8	32.9	23.9	
SFM0008	5.00	Clayey sandy till	Lerig sandig morän	30.4	31.9	31.7	6.1	125.8
SFM0010	1.05	Clayey sandy silty till	Lerig sandig-siltig morän	12.1	33.4	46.7	7.8	36.2
SFM0011	0.90	Clayey sandy till	Lerig sandig morän	38.0	22.6	31.5	8.0	507.0
SFM0016	5.90	Clayey sandy silty till	Lerig sandig-siltig morän	13.2	42.9	29.2	14.8	
SFM0016	6.90	Clayey sandy till	Lerig sandig morän	15.7	43.7	28.0	12.6	
SFM0017	3.35	Clayey sandy silty till	Lerig sandig-siltig morän	14.7	37.2	37.4	10.8	
SFM0018	3.20	Clayey sandy till	Lerig sandig morän	13.6	38.3	41.7	6.4	22.4
SFM0018	4.30	Clayey Gravelly till	Lerig grusig morän	44.7	30.6	19.4	5.3	375.4
SFM0020	2.55	Clayey sandy till	Lerig sandig morän	18.0	43.1	33.0	6.0	49.7
SFM0021	0.65	Clayey sandy till	Lerig sandig morän	25.2	38.1	30.9	5.8	94.0
SFM0021	1.45	Clayey sandy till	Lerig sandig morän	19.5	45.2	28.6	6.7	55.0
SFM0026	3.60	Clayey sandy till	Lerig sandig morän	14.3	43.7	27.7	14.3	
SFM0026	6.50	Clayey sandy silty till	Lerig sandig-siltig morän	6.2	42.7	37.2	13.9	
SFM0027	3.50	Clayey sandy silty till	Lerig sandig-siltig morän	11.2	42.2	34.3	12.3	
SFM0028	3.35	Clayey sandy till	Lerig sandig morän	15.0	42.9	31.3	10.8	
SFM0028	5.75	Clayey sandy silty till	Lerig sandig-siltig morän	7.0	59.0	27.2	6.8	36.7
SFM0028	6.50	Clayey sandy till	Lerig sandig morän	19.3	39.0	32.3	9.4	106.2
SFM0030	3.10	Clayey sandy till	Lerig sandig morän	16.5	50.3	28.1	5.2	55.5
SFM0032	1.05	Clayey sandy till	Lerig sandig morän	21.5	50.7	22.8	5.0	42.1
SFM0034	0.33	Clayey sandy till	Lerig sandig morän	30.1	38.3	26.5	5.1	101.2
SFM0057	3.00	Clayey sandy till	Lerig sandig morän	27.3	46.7	20.6	5.3	107.7
SFM0064	3.20	Boulder clay	Moränlera	19.6	42.4	18.1	20.0	
SFM0065	3.85	Clayey sandy till	Lerig sandig morän	10.2	66.5	17.9	5.4	42.9
SFM0070	1.53	Clayey sandy silty till	Lerig sandig-siltig morän	8.4	39.8	38.9	12.9	
SFM0071	3.38	Boulder clay	Moränlera	8.3	39.0	36.4	16.3	
SFM0072	8.45	Clayey sandy silty till	Lerig sandig-siltig morän	5.2	44.9	39.7	10.2	61.2
SFM0094	1.10	Clayey sandy till	Lerig sandig morän	34.9	39.2	21.0	5.0	157.1
SFM0094	1.75	Clayey sandy till	Lerig sandig morän	12.7	49.0	32.8	5.6	32.9
SFM0094	2.45	Clayey sandy till	Lerig sandig morän	13.2	47.2	26.9	12.8	
SFM0105	1.85	Clayey sandy till	Lerig sandig morän	19.6	40.5	34.4	5.5	64.9
SFM0106	0.75	Clayey sandy silty till	Lerig sandig-siltig morän	12.6	38.7	36.2	12.5	
SFM0106	3.30	Clayey sandy till	Lerig sandig morän	17.2	38.2	34.5	10.1	100.0

Table C-3. Gravelly till.

ID code	Sampl. depth (m)	QD	QD Swedish	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	D60/D10 (no unit)
HFM02	2.00	Gravelly till	Grusig morän	30.0	64.1	5.1	0.8	11.0
HFM02	4.00	Gravelly till	Grusig morän	45.5	41.7	12.2	0.6	67.5
HFM03	1.50	Gravelly till	Grusig morän	43.5	52.1	3.8	0.6	20.4
HFM04	0.70	Gravelly till	Grusig morän	53.9	32.3	11.3	2.5	199.2
HFM10	1.50	Gravelly till	Grusig morän	37.8	40.7	17.5	4.0	112.6
PFM002587	1.00	Gravelly till	Grusig morän	46.7	30.2	19.7	3.4	385.2
PFM004458	0.83	Gravelly till	Grusig morän	35.0	51.9	10.4	2.7	42.7
PFM004458	1.23	Gravelly till	Grusig morän	28.9	56.7	11.4	3.0	30.4
SFM0001	1.15	Gravelly till	Grusig morän	53.0	35.0	10.5	1.5	123.3
SFM0001	3.00	Gravelly till	Grusig morän	51.0	31.1	14.8	3.1	212.4
SFM0017	1.50	Gravelly till	Grusig morän	48.6	32.9	14.7	3.9	246.4
SFM0017	1.90	Gravelly till	Grusig morän	44.9	39.8	13.0	2.3	141.2
SFM0049	2.00	Gravelly till	Grusig morän	49.6	33.2	13.9	3.3	242.1
SFM0057	2.00	Gravelly till	Grusig morän	43.8	39.1	14.8	2.3	84.8
SFM0103	4.00	Gravelly till	Grusig morän	60.0	30.3	7.7	2.0	69.4

Table C-4. Water-laid sediments.

ID code	Sampling depth (m)	QD	QD Swedish	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	D60/D10 (no unit)
PFM004396	2.25	Gyttja clay	Gyttjelera	0.0	6.0	70.1	23.9	
PFM004396	0.65	Clayey gyttja silt	Gyttjig lerig silt	0.0	32.9	52.2	14.9	
PFM004396	4.05	Clayey silt	Lerig silt	0.0	3.5	82.7	13.8	
HFM09	3.50	Sandy silt	Sandig silt	0.9	21.0	70.7	7.4	9.9
PFM002783	0.30	Sandy gravel	Sandigt grus	51.5	45.6	1.8	1.0	17.2
PFM004531		Sandy gravel	Sandigt grus	46.8	51.4	0.7	1.1	14.9
SFM0069	0.50	Sandy gravel	Sandigt grus	50.3	47.3	1.5	1.0	16.1
SFM0084	1.63	Sandy gravel	Sandigt grus	52.4	41.3	3.3	3.0	12.4
SFM0091	1.21	Sandy gravel	Sandigt grus	64.5	35.5	0.0	0.0	23.5
PFM002462	0.20	Gravelly sand	Grusig sand	26.3	67.5	3.3	2.9	6.9
PFM004294		Gravelly sand	Grusig sand	22.0	75.0	3.0		5.1
PFM004455	0.13	Gravelly sand	Grusig sand	44.4	53.9	0.0	1.7	11.4
PFM004460	1.08	Gravelly sand	Grusig sand	45.4	53.2	0.6	0.8	8.8
PFM004460	0.08	Gravelly sand	Grusig sand	40.2	58.4	0.7	0.6	7.7
PFM004396	0.44	Clayey silty sand	Lerig siltig sand	0.0	61.7	32.5	5.8	9.0
PFM002687	1.50	Clayey sand	Lerig sandig silt	5.9	40.7	46.2	7.2	26.1
PFM004222	1.90	Sand	Sand	11.0	85.0	4.0		3.3
PFM006094	1.71	Sand	Sand	13.6	80.7	3.1	2.6	2.7
PFM006095	0.44	Sand	Sand	0.0	94.9	2.0	3.1	2.4
SFM0003	8.75	Sand	Sand	3.9	82.1	9.9	4.1	26.5
SFM0084	1.45	Sand	Sand	19.7	72.0	8.3		10.2
KFM01A	2.50	Silty sand	Siltig sand	1.3	67.7	27.8	3.2	17.3
PFM004193	2.25	Silty sand	Siltig sand	19.5	65.0	15.5	0.0	
PFM004396	0.52	Silty sand	Siltig sand	0.0	62.5	37.5	0.0	
PFM002783	0.60	Clay	Styv lera	0.0	0.0	36.6	63.4	
PFM004204	2.38	Clay	Styv lera	0.0	0.2	50.7	49.1	
PFM004204	2.57	Clay	Styv lera	0.0	0.0	52.0	48.0	
PFM004204	2.77	Clay	Styv lera	0.0	0.0	57.0	43.0	
PFM004204	3.53	Clay	Styv lera	0.0	0.0	47.0	53.0	
PFM004204	4.28	Clay	Styv lera	0.0	0.0	35.0	65.0	
PFM004204	4.87	Clay	Styv lera	0.0	1.0	38.0	61.0	
PFM004205	1.32	Clay	Styv lera	0.0	0.0	34.0	66.0	
PFM004205	1.58	Clay	Styv lera	0.0	0.0	34.0	66.0	
PFM004205	1.73	Clay	Styv lera	0.0	0.0	26.0	74.0	
PFM004205	1.76	Clay	Styv lera	0.0	0.0	44.0	56.0	
PFM004205	1.88	Clay	Styv lera	0.0	0.0	45.0	55.0	
PFM004205	1.88	Clay	Styv lera	0.0	0.0	26.0	74.0	
PFM004205	1.97	Clay	Styv lera	0.0	0.0	47.0	53.0	
PFM004205	2.07	Clay	Styv lera	0.0	0.0	46.0	54.0	
PFM004205	2.21	Clay	Styv lera	0.0	0.5	56.5	43.0	
PFM004205	2.21	Clay	Styv lera	0.0	0.0	42.0	58.0	
PFM004216	3.71	Clay	Styv lera	0.0	0.5	47.5	52.0	
PFM004216	4.05	Clay	Styv lera	0.0	0.0	67.0	33.0	
PFM004396	4.55	Clay	Styv lera	0.0	4.0	96.0	0.0	
PFM004396	5.05	Clay	Styv lera	0.0	0.0	19.5	80.5	
PFM004396	5.55	Clay	Styv lera	0.0	0.0	26.7	73.3	
PFM004514	1.60	Clay	Styv lera	0.3	3.9	29.3	66.5	
PFM006073	4.16	Clay	Styv lera	0.0	10.9	42.7	46.4	
PFM006095	2.35	Clay	Styv lera	0.0	1.5	32.7	65.8	
SFM0084	1.88	Clay	Styv lera	1.8	4.7	11.4	82.1	
SFM0091	1.29	Clay	Styv lera		3.3	31.4	65.3	
SFM0095	2.85	Clay	Styv lera	7.9	10.6	30.6	50.9	
PFM002592	1.10	Clay	Mellanlera	6.1	33.4	28.3	32.2	
PFM004396	3.47	Clay	Mellanlera	0.0	19.1	50.9	30.0	
SFM0095	2.26	Clay	Mellanlera			60.2	39.8	

Appendix D

Theoretically calculated hydraulic conductivity values for the till at the SFM sites

ID code	Sampling depth (m)	$K_{(HAZEN)}$ (m/s)	$K_{(FAIR\ HATCH)}$ (m/s)	$K_{(GUSTAFSON)}$ (m/s)	Porosity $_{(GUSTAFSSON)}$ (%)	Quaternary deposit
SFM0001	1.50–2.00	2.34×10^{-5}	6.43×10^{-6}	4.35×10^{-6}		gravelly till
SFM0001	2.50–3.50	3.96×10^{-6}	2.76×10^{-6}	5.37×10^{-7}		gravelly till
SFM0001	3.50–4.00	1.20×10^{-7}	8.31×10^{-7}	2.67×10^{-8}		clayey sandy silty till
SFM0002	1.00–2.00	1.79×10^{-6}	1.40×10^{-6}	4.48×10^{-7}		sandy till
SFM0002	3.00–4.00	1.89×10^{-6}	1.57×10^{-6}	6.03×10^{-7}		sandy till
SFM0002	4.50–5.5	2.72×10^{-6}	1.40×10^{-6}	1.53×10^{-6}		sandy till
SFM0003	1.00–1.50	3.56×10^{-6}	2.97×10^{-6}	1.04×10^{-6}		sandy till
SFM0003	3.50–4.50	1.95×10^{-6}	1.68×10^{-6}	1.20×10^{-6}		sandy till
SFM0003	8.50–9.00	4.57×10^{-6}	2.34×10^{-5}	2.18×10^{-6}		sand
SFM0004	2.50–3.00	6.71×10^{-7}	1.55×10^{-6}	1.64×10^{-7}		clayey sandy till
SFM0005	1.00–1.50	4.90×10^{-7}	3.83×10^{-7}	9.72×10^{-8}		sandy till
SFM0006	1.50		3.45×10^{-7}			clayey sandy silty till
SFM0007	2.00		3.49×10^{-7}			clayey sandy silty till
SFM0007	4.50	6.97×10^{-8}	3.83×10^{-7}	1.43×10^{-8}		clayey sandy till
SFM0008	1.50		3.01×10^{-7}			boulder clay
SFM0008	4.50	9.23×10^{-7}	2.84×10^{-7}	1.89×10^{-7}		sandy till
SFM0008	5.00	2.11×10^{-7}	9.32×10^{-7}	3.88×10^{-8}		clayey sandy till
SFM0010	0.80–1.30	7.98×10^{-8}	1.95×10^{-7}	3.13×10^{-8}		clayey sandy silty till
SFM0011	0.50–1.30	9.53×10^{-8}	2.25×10^{-7}	7.94×10^{-9}		
SFM0011	1.50–1.90	6.08×10^{-7}	4.17×10^{-7}	1.68×10^{-7}		sandy till
SFM0011	3.00–3.50	1.58×10^{-6}	5.32×10^{-7}	5.64×10^{-7}		sandy till
SFM0013	5.00–5.20	1.36×10^{-2}	1.40×10^{-3}	1.77×10^{-2}		gravel (kax)
SFM0013	5.30–5.60	4.48×10^{-2}	3.70×10^{-3}	6.92×10^{-2}		gravel (kax)
SFM0016	0.40–0.80	6.30×10^{-6}	1.64×10^{-6}	4.43×10^{-6}		
SFM0016	1.80–2.10	1.71×10^{-6}	7.65×10^{-7}	7.81×10^{-7}		
SFM0016	5.70–6.10		1.99×10^{-7}			
SFM0016	6.60–7.20		2.77×10^{-7}			
SFM0017	1.20–1.80	1.95×10^{-6}	9.87×10^{-7}	2.43×10^{-7}		
SFM0017	1.30–2.50	3.90×10^{-6}	1.21×10^{-6}	6.70×10^{-7}		
SFM0017	3.00–3.70		2.08×10^{-7}			
SFM0018	2.90–3.50	3.46×10^{-7}	2.59×10^{-7}	1.83×10^{-7}		
SFM0018	4.00–4.60	5.33×10^{-7}	6.15×10^{-7}	5.24×10^{-8}		
SFM0019	1.00–1.50	2.12×10^{-6}	1.06×10^{-6}	8.00×10^{-7}		sandy till
SFM0019	4.00–4.50	3.08×10^{-6}	1.20×10^{-6}	1.19×10^{-6}		sandy till
SFM0019	5.20–5.50	1.63×10^{-6}	8.97×10^{-7}	5.74×10^{-7}		silty sand (kax)
SFM0020	2.30–2.80	3.23×10^{-7}	3.25×10^{-7}	1.04×10^{-7}		clayey sandy till
SFM0021	0.40–0.90	2.12×10^{-7}	2.34×10^{-7}	4.64×10^{-8}		clayey sandy till
SFM0021	1.20–1.70	2.61×10^{-7}	3.58×10^{-7}	7.88×10^{-8}		clayey sandy silty till
SFM0022	4.00–4.60	8.03×10^{-5}	1.08×10^{-5}	1.00×10^{-4}		clayey sandy silty till
SFM0026	3.40–3.80		2.96×10^{-7}			sandy till
SFM0026	6.20–6.80		1.41×10^{-7}			clayey sandy till
SFM0027	3.30–3.70		1.67×10^{-7}			clayey sandy silty till
SFM0028	3.10–3.60		1.71×10^{-7}			clayey sandy till
SFM0028	5.50–6.00	2.14×10^{-7}	3.76×10^{-7}	8.32×10^{-8}		gravelly till
SFM0028	6.00–7.00	5.03×10^{-8}	1.97×10^{-7}	1.02×10^{-8}		sandy till
SFM0030	0.60–1.05	9.23×10^{-7}	6.80×10^{-7}	2.44×10^{-7}		sandy till
SFM0030	1.40–1.70	5.92×10^{-7}	4.52×10^{-7}	1.54×10^{-7}		clayey sandy silty till
SFM0031	2.80–3.40	3.90×10^{-7}	3.68×10^{-7}	1.17×10^{-7}		clayey sandy till
SFM0032	0.90–1.20	9.34×10^{-7}	6.22×10^{-7}	3.33×10^{-7}		sandy till
SFM0034	0.20–0.50	4.88×10^{-7}	4.75×10^{-7}	1.02×10^{-7}		gravelly till

ID code	Sampling depth (m)	K (HAZEN) (m/s)	K (FAIR HATCH) (m/s)	K (GUSTAFSON) (m/s)	Porosity (GUSTAFSSON) (%)	Quaternary deposit
SFM0034	1.30–1.60	4.62×10^{-7}	3.87×10^{-7}	1.59×10^{-7}		gravelly till
SFM0036	0.40–1.20	3.41×10^{-7}	2.52×10^{-7}	1.52×10^{-7}		clayey sandy silty till
SFM0049	1.50–2.50	2.09×10^{-6}	9.65×10^{-7}	2.63×10^{-7}		clayey sandy till
SFM0062	2.75–3.15	3.24×10^{-5}	5.19×10^{-6}	4.27×10^{-5}		sandy till
SFM0063	2.10–2.90	1.15×10^{-4}	8.02×10^{-6}	1.30×10^{-4}		sandy till
SFM0065	3.70–4.00	7.39×10^{-7}	8.52×10^{-7}	2.61×10^{-7}		clayey sandy till
SFM0069	0.30–0.70	3.35×10^{-4}	2.37×10^{-5}	2.19×10^{-4}		sandy gravel
SFM0070	1.40–1.65		1.24×10^{-7}			clayey sandy silty till
SFM0071	3.25–3.50		1.42×10^{-7}			boulder clay
SFM0072	8.20–8.70	3.79×10^{-8}	1.46×10^{-7}	1.07×10^{-8}		clayey sandy silty till
SFM0081	2.10–4.40	9.26×10^{-5}	1.39×10^{-5}	1.10×10^{-4}	16.7	
SFM0084	1.55–1.70	5.51×10^{-4}	9.67×10^{-6}	4.35×10^{-4}	13.3	sandy gravel
SFM0084	1.85–1.90					stiff clay
SFM0091	1.18–1.24	1.10×10^{-3}	1.23×10^{-3}	5.85×10^{-4}	11.1	sandy gravel
SFM0091	1.26–1.31					stiff clay
SFM0094	0.90–1.30	5.59×10^{-7}	5.06×10^{-7}	9.30×10^{-8}	7.3	clayey sandy till
SFM0094	1.60–1.90	3.42×10^{-7}	1.16×10^{-7}	1.47×10^{-7}	10.2	clayey sandy till
SFM0094	2.20–2.70		9.09×10^{-8}			clayey sandy till
SFM0095	2.21–2.31					medium clay
SFM0095	2.80–2.90					stiff clay
SFM0103	3.00–5.00	4.29×10^{-5}	4.42×10^{-7}	1.16×10^{-5}	8.6	
SFM0104	5.50–6.50	1.38×10^{-6}	1.22×10^{-7}	9.26×10^{-7}	12.3	sandy till
SFM0105	0.50–1.00	2.96×10^{-7}	8.64×10^{-8}	7.74×10^{-8}	8.5	sandy till
SFM0105	1.60–2.10	2.11×10^{-7}	7.26×10^{-8}	5.93×10^{-8}	8.7	sandy till
SFM0106	0.60–0.90		1.26×10^{-8}			clayey sandy till
SFM0106	3.00–3.60	4.08×10^{-8}	1.48×10^{-8}	8.84×10^{-9}	8.0	clayey sandy silty till
SFM0107	3.40–4.00	4.22×10^{-7}	1.23×10^{-7}	1.89×10^{-7}	10.4	sandy till
SFM0107	4.00–4.30	6.33×10^{-7}	1.76×10^{-7}	1.23×10^{-7}	7.7	sandy till
SFM0108	0.50–0.90	3.63×10^{-6}	8.76×10^{-7}	1.19×10^{-6}	9.2	sandy till

Appendix E

Physical parameters from the soil profiles at the trenches

ID code	Sampling depth (m)	QD	QD Swedish	Rel matrix VOL (%)	Rel pore vol (%)	Pf 0 (%)	Pf 10 (%)	Pf 50 (%)	Pf 100 (%)	Pf 500 (%)	Water content (%)	Density (g/cm**3)	Dry bulk density (g/cm**3)	K (m/s)
PFM004455	0.10–0.15	Gravelly sand	Grusig sand	62.1	37.9	29.0	24.0	7.2	5.4	4.5	3.6	2.60	1.60	5.84×10^{-5}
PFM004455	0.20–0.25	Sandy till	Sandig morän	58.0	42.0	39.9	30.7	19.8	15.7	10.3	8.3	2.70	1.60	3.70×10^{-5}
PFM004455	0.50–0.55	Sandy till	Sandig morän	69.0	31.0	26.7	20.9	17.8	14.6	9.9	7.4	2.70	1.90	1.91×10^{-7}
PFM004455	0.80–.085	Sandy till	Sandig morän	75.7	24.3	23.3	19.2	17.3	14.9	10.8	10.4	2.70	2.00	1.16×10^{-7}
PFM004455	1.20–1.25	Sandy till	Sandig morän	72.9	27.1	22.8	18.0	16.7	14.2	10.3	11.7	2.70	2.00	2.31×10^{-8}
PFM004455	1.70–1.75	Sandy till	Sandig morän	70.2	29.8	25.7	21.8	20.2	16.8	9.0	17.1	2.70	1.90	1.16×10^{-7}
PFM004455	2.50–2.55	Clayey sandy till	Lerig sandig morän	77.0	23.0	22.4	16.8	15.9	15.1	13.9	14.4	2.70	2.10	9.26×10^{-8}
PFM004458	0.05–0.10	Sandy till	Sandig morän	74.0	26.0	26.5	23.8	18.6	15.1	9.2	15.7	2.70	2.00	1.27×10^{-6}
PFM004458	0.20–0.25	Sandy till	Sandig morän	72.7	27.3	25.6	21.1	16.6	13.2	7.6	13.4	2.70	1.90	4.63×10^{-7}
PFM004458	0.50–0.55	Sandy till	Sandig morän	77.4	22.6	23.9	20.1	17.3	14.3	8.0	15.6	2.70	2.10	6.94×10^{-7}
PFM004458	0.80–0.85	Gravelly till	Grusig morän	77.8	22.2	22.5	19.3	14.9	12.6	7.1	15.3	2.70	2.10	9.26×10^{-7}
PFM004458	1.20–1.25	Gravelly till	Grusig morän	81.7	18.3	19.1	16.6	15.0	12.9	6.6	14.9	2.70	2.20	2.31×10^{-7}
PFM004458	1.70–1.75	Sandy till	Sandig morän	83.7	16.3	18.7	16.3	15.5	14.9	11.0	15.1	2.70	2.20	2.31×10^{-8}
PFM004458	2.50–2.55	Sandy till	Sandig morän	83.0	17.0	19.4	16.2	15.2	14.5	10.0	13.3	2.70	2.20	1.04×10^{-7}
PFM004459	3.50–3.55	Clayey sandy silty till	Lerig sandig-siltig morän	80.2	19.8	25.5	20.6	19.3	19.1	17.8	18.9	2.70	2.20	
PFM004460	0.05–0.10	Gravelly sand	Grusig sand	73.6	26.4	28.7	23.9	13.5	13.0	11.0	13.4	2.70	2.00	3.01×10^{-5}
PFM004460	0.20–0.25	Boulder clay	Moränlera	59.8	40.2	46.1	41.5	38.0	37.6	33.6	37.1	2.70	1.60	4.63×10^{-7}
PFM004460	0.50–0.55	Sandy till	Sandig morän	78.1	21.9	23.3	19.1	17.2	16.3	12.6	14.9	2.70	2.10	3.47×10^{-8}
PFM004460	0.80–0.85	Sandy till	Sandig morän	79.3	20.7	22.1	17.0	16.2	15.7	13.1	16.0	2.70	2.10	2.31×10^{-8}
PFM004460	1.20–1.25	Sandy till	Sandig morän	83.4	17.0	19.9	16.5	16.3	15.7	14.5	16.8	2.70	2.20	1.16×10^{-8}
PFM004460	1.70–1.75	Sandy till	Sandig morän	86.0	16.0	18.0	15.8	15.2	14.6	13.7	15.9	2.70	2.30	8.10×10^{-9}

Appendix F

Stratigraphical descriptions of the peatlands

ID code	Depth (m)	Qd	Colour	Humification	Wetness	Fibres	Rots	Wood	Observation
Stenrösmossen									
PFM004414	0.00–0.20	Carex-Spagnum peat	Brown-black	H7	B2	F0	R1	V0	Oxidised surface layer
	0.20–0.50	Carex peat	Brown	H5	B3	F0	R2	V0	EQ
	0.50	Stop on stone							
PFM004415	0.00–0.20	Carex peat	Dark brown	H4	B3	F0	R2	V0	Oxidised surface layer
	0.20–0.50	Carex-Bryales peat	Light brown	H3	B4	F0	R3	V0	
	0.50–0.80	Carex peat	Light brown	H6	B4	F0	R2	V0	EQ, PR, Gyttja H_2S
	0.80	Stop on stone or till							
PFM004416	0.00–0.15	Carex peat	Dark brown	H3	B3	F0	R2–3	V0	Oxidised surface layer
	0.15–0.50	Carex peat	Light brown	H3	B3	F0	R3	V0	S
	0.50–1.00	Carex-Bryales peat	Light brown	H4	B3	F0	R2	V0	S, EQ, PR
	1.00–1.20	Carex-Bryales peat	Light brown	H5	B3	F0	R2	V0	EQ Gyttja mixed
	1.20–1.60	Gyttja clay	Brown-green						
	1.60	Stop on till							
PFM004417	0.00–0.10	Carex peat	Dark brown	H5	B2	F0	R1	V0	Oxidised surface layer
	0.10–0.50	Carex-Bryales peat	Dark brown	H4	B3	F0	R2	V0	Oxidised
	0.50–0.80	Phragmites peat	Light yellow	H4	B3	F0	R2	V0	B
	0.80	Stop on stone till							
PFM004418	0.00–0.20	Carex peat	Dark brown	H5	B2	F0	R2	V1	Oxidised surface layet
	0.20–0.60	Carex peat	Dark brown	H3–4	B3	F0	R2–3	V0	B
	0.60–0.80	Carex peat	Light brown	H5	B4	F0	R2	V0	PR, EQ, H_2S
	0.80	Stop on stone or till							
PFM004419	0.00–0.10	Carex peat	Dark brown	H5	B2	F0	R1	V0	Oxidised surface layert
	0.10–0.40	Carex peat	Dark brown	H4	B3	F0	R2	V1	
	0.40–0.90	Wood-Carex peat	Brown	H4	B3	F0	R1	V1	

ID code	Depth (m)	Qd	Colour	Humification	Wetness	Fibres	Rots	Wood	Observation
	0.90–1.00	Oxidised surface layer	Light brown	H5	B4	F0	R1	V1	EQ
	1.00–1.20	Carex-Phragmites peat	Brown	H7	B3	F0	R1	V1	EQ, PR
	1.20–1.60.	Clay gyttja							
	1.60	Stop on stone							
PFM004420	0.00–0.40	Carex peat	Dark brown	H6	B2	F0	R0–1	V0	Oxidised surface layer
	0.40–0.50	Carex peat	Dark brown	H7	B3	F0	R0–1	V0	
	0.50–0.60	Carex peat	Brown	H5	B3	F0	R2	V0	
	0.60–1.30	Wood-Carex peat	Brown	H6	B3	F0	R1	V1	
	1.30–1.35	Gyttja							
	1.35	Stop on stone							
PFM004421	0.00–0.50	Sphagnum peat	Brown	H5	B3	F0	R0	V0	Mixed with Brown mosses
	0.50–1.00	Sphagnum peat	Light brown	H4	B3–4	F0	R0–1	V0	B, EQ, C, PR, Brons coulor
	1.00–1.20	Phragmites peat	Light brown	H6	B4	F0	R2	V0	EW
	1.20	Stop on stone							
PFM004422	0.00–0.50	Wood-Carex peat	Dark brown	H6	B3	F0	R1	V1	
	0.50–0.90	Wood-Carex peat	Dark brown	H7	B3–4	F0	R2	V0–1	
	0.90–1.15	Phragmites peat	Light brown	H6	B4	F0	R1	V0	Mixed with Gyttja
	1.15	Stop on stone							
PFM004423	0.00–0.50	Wood-Carex peat	Black	H8	B2	F0	F0	V0–1	
	0.50–0.90	Wood-Carex peat	Black	H8	B3	F0	R0	V1	
	0.90–1.00	Phragmites peat	Brown-yellow	H5	B3	F0	R1	V0	
	1.00	Stop on till							
PFM004424	0.00–0.80	Wood-Carex peat	Black	H8	B1–2	F0	R0	V1	
	0.80–1.00	Wood-Carex peat	Black	H7	F3	F0	R1	V1	
	1.00–1.20	Claygyttja							
	1.20–1.2	Stop in sand							
Lersättermyran									
PFM004425	0.00–0.10	Carex-Bryales peat	Dark brown	H5	B2	F0	R0–1	V0	
	0.10–0.50	Carex-Bryales peat	Brown	H5	B3	F0	R0–1	V0	

ID code	Depth (m)	Qd	Colour	Humification	Wetness	Fibres	Rots	Wood	Observation
	0.50–1.00	Bryales-Carex peat	Brown	H6	B3	F0	R1–2	V0	EQ
	1.00–1.40	Bryales-Carex peat	Brown	H7	B3	F1	R2	V1	EQ, PR
	1.40–1.70	Clay gyttja							
	1.70	Stop on stone							
PFM004426	0.00–0.20	Wood-Sphagnum peat	Dark brown	H5	B2	F0	R1	V1	Oxidised surface layer
	0.20–0.50	Sphagnum peat	Light brown	H4	B2	F0	R0–1	V0	
	0.50–0.90	Sphagnum peat	Light brown	H4	B3	F0	R0	V0	
	0.90–1.40	Sphagnum peat	Light brown	H3	B3	F1	R0	V0	
	1.40–2.00	Sphagnum peat	Light brown	H4	B3	F0	R0	V0	B
	2.00–2.50	Carex-Byales peat	Light brown	H4–5	B3	F0	R1	V0	PR
	2.50–2.70	Carex peat	Light brown	H4	B3	F0	R2	V0	B, PR, EQ
	2.70–2.85	Course detritus gyttja	Brown-green						
	2.85–3.00	Gyttja	Grey-green						
	3.00–3.20	Clay gyttja							
	3.20	Stop?							
PFM004427	0.00–0.10	Forest fen peat	Dark brown	H5	B2	F0	R0	V0	
	0.10–0.55	Forest fen peat	Brown	H5	B3	F0	R1	V0–1	
	0.55	Stop on stone							
PFM004428	0.00–0.50	Forest fen peat	Brown-black	H7	B2	F0	R1–2	V0–1	
	0.50–0.80	Forest fen peat	Brown-black	H7	B3	F0	R2	V1	Carex rots
	0.80–0.90	Gyttja							
	0.90	Stop on till or sand							
PFM004429	0.00–0.20	Forest fen peat	Brown-black	H7	B2	F0	R0–1	V0	
	0.20–0.70	Forest fen peat	Brown-black	H7	B2–3	F0	R0–1	V1	
	0.70–0.80	Carex-Phragmites peat	Brown	H7	B3	F0	R1	V0	
	0.80–0.90	Clay gyttja							
	0.90	Stop in sand							

Appendix G

Summary of organic carbon and $CaCO_3$ analyses

ID code	Sampling depth (m)	$C_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
HFM01	1.00–1.50					15.5	
HFM01	5.50–6.50					17.0	
HFM01	8.50–9.50					9.0	
HFM02	1.50–2.50					14.0	
HFM02	3.50–4.50					14.0	
HFM02	10.50–11.50					20.5	
HFM03	1.00–2.00					8.0	
HFM03	5.50–6.50					15.0	
HFM03	8.50–9.50					16.0	
HFM04	0.50–0.90					18.0	
HFM05	2.00–2.50					23.0	
HFM05	3.00–3.50					22.0	
HFM06	1.00–1.50					27.0	
HFM07	1.00–1.50					27.0	
HFM08	2					27.0	
HFM08	4.5					33.0	
KFM01A	2.00–3.00					3.5	
KFM01A	5.00–5.50					7.0	
PFM002461	1.10–1.40					29.0	
PFM002461	2.00–2.40					28.0	
PFM002462	0.10–0.30					9.0	
PFM002462	0.30–0.50					19.0	
PFM002462	2.20–2.40					26.0	
PFM002463	1.40–1.60					32.0	
PFM002463	5.10–5.50					28.0	
PFM002463	7.20–7.80					32.0	
PFM002463	10.10–10.80					21.0	
PFM002464	3.50–3.90					24.0	
PFM002464	5.00–5.30					21.0	
PFM002464	5.60–5.90					31.0	
PFM002464	7.20–7.60					28.0	
PFM002464	7.80–8.20					29.0	
PFM002464	9.00–9.40					33.0	
PFM002572	1.40–1.70					23.0	
PFM002572	4.00–4.40					32.0	
PFM002572	5.10–5.70					27.0	
PFM002573	1.40–1.70					21.0	
PFM002573	3.40–3.70					30.0	
PFM002574	1.40–1.80					26.0	
PFM002576	1.9					17.0	sandy till
PFM002576	5					16.0	sandy till
PFM002577	0.6					23.0	clayey sandy till
PFM002578	1.3					25.0	clayey sandy silty till
PFM002578	3.8					24.0	clayey sandy silty till
PFM002581	1					16.0	sandy silty till
PFM002581	2.4					24.0	cleyey sandy till
PFM002581	3.6					18.0	boulder clay
PFM002582	0.6					22.0	sandy till
PFM002582	1.7					21.0	sandy till
PFM002586	0.6					21.0	clayey sandy till
PFM002586	1.4					16.0	sandy silty till
PFM002587	1					25.0	gravelly till
PFM002587	3					21.0	sandy till

ID code	Sampling depth (m)	C $_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
PFM002588	2.1					23.0	clayey sandy silty till
PFM002589	1.3					28.0	clayey sandy till
PFM002589	2.4					29.0	boulder clay
PFM002589	4.7					28.0	sandy till
PFM002590	2.3					32.0	cleyey sandy silty till
PFM002591	0.9					19.0	clayey gravley till
PFM002591	2					27.0	clayey sandy silty till
PFM002591	3.2					30.0	clayey sandy silty till
PFM002592	1.1					14.0	boulder clay
PFM002592	1.2					9.0	clayey sandy silty till
PFM002592	2.8					22.0	boulder clay
PFM002594	0.6					23.0	clayey sandy silty till
PFM002594	1.4					30.0	clayey sandy till
PFM002687	0.5					24.0	
PFM002687	1					34.0	
PFM002687	1.5					29.0	
PFM002760	1					17.0	
PFM002761	0.5					18.0	
PFM002762	0.5					20.0	
PFM002767	0.8					15.0	
PFM002768	1					10.0	
PFM002783	0.3					0.4	
PFM002783	0.6					0.4	
PFM002801	0.4					17.0	
PFM002802	1.3					21.0	
PFM003742						19.0	sandy silty till
PFM004204	1.10–1.13	22.40		3.00	1.86		algal gyttja
PFM004204	1.13–1.16					0.0	
PFM004204	1.20–1.22	19.30	32.81	2.59	1.72		algal gyttja
PFM004204	1.30–1.32	16.70	28.39	2.26	1.64		algal gyttja
PFM004204	1.32–1.36					0.7	
PFM004204	1.40–1.42	15.70	26.69	2.11	1.53		algal gyttja
PFM004204	1.50–1.52	15.60	26.52	1.82	1.59		algal gyttja
PFM004204	1.56–1.60					0.4	
PFM004204	1.60–1.62	13.20	22.44	1.73	1.39		algal gyttja
PFM004204	1.65–1.67	5.94	10.10	2.17	0.66		clay gyttja
PFM004204	1.67–1.70					0.5	
PFM004204	1.70–1.72	5.50	9.35	1.17	0.65		clay gyttja
PFM004204	1.75–1.77	4.24	7.21	2.21	0.52		clay gyttja
PFM004204	1.80–1.82	4.10	6.97	2.59	0.51		clay gyttja
PFM004204	1.85–1.87	4.75	8.08	1.69	0.59		clay gyttja
PFM004204	1.87–1.90					0.6	
PFM004204	1.90–1.92	4.95	8.42	1.82	0.61		clay gyttja
PFM004204	1.95–1.97	4.59	7.80	1.68	0.57		clay gyttja
PFM004204	2.00–2.04	4.57	7.77	1.35	0.56		clay gyttja
PFM004204	2.05–2.07	4.84	8.23	2.04	0.59		clay gyttja
PFM004204	2.10–2.12	2.34	3.98	0.77	0.27		clay gyttja
PFM004204	2.25–2.28	1.07	1.82	0.79	0.12		postglacial clay
PFM004204	2.30–2.45					0.9	clay
PFM004204	2.45–2.48	1.16	1.97	1.59	0.13		postglacial clay
PFM004204	2.48–2.65					0.6	clay
PFM004204	2.65–2.68	1.20	2.04	0.65	0.13		postglacial clay
PFM004204	2.68–2.85					0.0	clay
PFM004204	2.85–2.88	1.33	2.26	1.52	0.15		postglacial clay
PFM004204	3.45–3.60					0.8	clay
PFM004204	4.00–4.04	0.41	0.70	0.00	0.06		glacial clay
PFM004204	4.20–4.35					26.0	clay
PFM004204	4.50–4.54	1.21	2.06	0.00	0.05		glacial clay

ID code	Sampling depth (m)	C $_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
PFM004204	4.80–4.94					16.0	clay
PFM004205	0.40–0.45	27.30	46.41	3.27	2.88		algal gyttja
PFM004205	0.50–0.55	26.20	44.54	3.31	2.47		algal gyttja
PFM004205	0.60–0.65	6.85	11.65	1.64	0.69		algal gyttja
PFM004205	0.70–0.75	7.70	13.09	1.87	0.73		algal gyttja
PFM004205	0.80–0.85	3.74	6.36	1.22	0.39		clay gyttja
PFM004205	1.27–1.37					20.0	clay . distal varves
PFM004205	1.50–1.65					26.0	clay. proximal varves
PFM004205	1.65–1.81					14.0	clay. winter layers
PFM004205	1.70–1.81					29.0	clay. summer layers
PFM004205	1.81–1.94					14.0	clay. summer layers
PFM004205	1.81–1.94					33.0	clay. winter layers
PFM004205	1.94–2.00					26.0	clay
PFM004205	2.14–2.27					38.0	clay. winter layers
PFM004205	2.14–2.27					22.0	clay. summer layers
PFM004216	3.62–3.79					33.0	clay
PFM004216	4.00–4.10					35.0	clay
PFM004280	0.85–0.90	25.70	43.69	2.01	2.55		algal gyttja
PFM004280	0.90–0.95	20.60	35.02	2.05	1.86		algal gyttja
PFM004280	1.00–1.03	13.70	23.29	1.70	1.27		algal gyttja
PFM004280	1.03–1.10					0.9	algal gyttja
PFM004280	1.10–1.13	12.80	21.76	1.72	1.21		algal gyttja
PFM004280	1.20–1.23	11.97	20.35	1.59	1.13		algal gyttja
PFM004280	1.30–1.33	11.80	20.06	1.47	1.14		algal gyttja
PFM004280	1.33–1.40					0.8	algal gyttja
PFM004280	1.40–1.45	12.20	20.74	1.57	1.16		algal gyttja
PFM004280	1.50–1.55	13.00	22.10	1.54	1.21		algal gyttja
PFM004280	1.55–1.60		0.00			0.6	
PFM004280	1.60–1.65	12.30	20.91	1.49	1.18		algal gyttja
PFM004280	1.70–1.75	8.25	14.03	1.42	0.83		algal gyttja
PFM004280	1.75–1.80					0.1	
PFM004280	1.80–1.85	8.78	14.93	1.59	0.80		algal gyttja
PFM004280	1.90–1.95	8.31	14.13	1.47	0.78		algal gyttja
PFM004280	2.00–2.05	8.69	14.77	1.60	0.80		algal gyttja
PFM004280	2.05–2.12					0.3	algal gyttja
PFM004280	2.12–2.15	6.91	11.75	1.49	0.75		algal gyttja
PFM004280	2.22–2.27	8.34	14.18	1.50	0.85		algal gyttja
PFM004280	2.27–2.30	7.99	13.58	1.54	0.82		algal gyttja
PFM004280	2.30–2.33	8.03	13.65	1.49	0.83		algal gyttja
PFM004280	2.33–2.36	5.85	9.95	1.29	0.72		clay gyttja
PFM004280	2.36–2.39	5.51	9.37	1.37	0.69		clay gyttja
PFM004280	2.40–2.45	1.06	1.80	0.45	0.12		sand
PFM004280	2.45–2.50	0.45	0.77	0.27	0.05		sand
PFM004284	0.87–0.92					63.0	calcareous gyttja
PFM004284	0.92–0.97					57.0	calcareous gyttja
PFM004396	0.40–0.48					0.0	clayey silty sand
PFM004396	0.43	0.32	0.54				sand
PFM004396	0.48	0.11	0.19				sand
PFM004396	0.48–0.55		0.00			0.0	silty sand
PFM004396	0.53	0.23	0.39				sand
PFM004396	0.58	2.10	3.57				sandy gyttja clay
PFM004396	0.60–0.70					1.0	clayey silt
PFM004396	0.63	2.04	3.47				sandy gyttja clay
PFM004396	0.68	0.83	1.41				sandy gyttja clay
PFM004396	0.73	0.84	1.43				sandy gyttja clay
PFM004396	0.78	1.62	2.75				clay gyttja-gyttja clay
PFM004396	0.83	1.66	2.82				clay gyttja-gyttja clay
PFM004396	0.88	2.18	3.71				clay gyttja-gyttja clay

ID code	Sampling depth (m)	$C_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
PFM004396	0.93	2.08	3.54				clay gyttja-gyttja clay
PFM004396	0.98	2.67	4.54				clay gyttja-gyttja clay
PFM004396	1.03	2.04	3.47				clay gyttja-gyttja clay
PFM004396	1.08	2.21	3.76				clay gyttja-gyttja clay
PFM004396	1.13	1.78	3.03				clay gyttja-gyttja clay
PFM004396	1.18	2.23	3.79				clay gyttja-gyttja clay
PFM004396	1.23	1.08	1.84				clay gyttja-gyttja clay
PFM004396	1.28	3.39	5.76				clay gyttja-gyttja clay
PFM004396	1.33	2.61	4.44				clay gyttja-gyttja clay
PFM004396	1.38	2.48	4.22				clay gyttja-gyttja clay
PFM004396	1.43	4.35	7.40				clay gyttja-gyttja clay
PFM004396	1.48	0.82	1.39				clay gyttja-gyttja clay
PFM004396	1.53	1.15	1.96				clay gyttja-gyttja clay
PFM004396	1.58	2.20	3.74				clay gyttja-gyttja clay
PFM004396	1.63	1.70	2.89				clay gyttja-gyttja clay
PFM004396	1.68	1.24	2.11				clay gyttja-gyttja clay
PFM004396	1.73	1.67	2.84				clay gyttja-gyttja clay
PFM004396	1.78	2.41	4.10				clay gyttja-gyttja clay
PFM004396	1.83	1.31	2.23				clay gyttja-gyttja clay
PFM004396	1.88	2.30	3.91				clay gyttja-gyttja clay
PFM004396	1.93	1.78	3.03				clay gyttja-gyttja clay
PFM004396	1.98	2.05	3.49				clay gyttja-gyttja clay
PFM004396	2.03	1.94	3.30				clay gyttja-gyttja clay
PFM004396	2.08	2.68	4.56				clay gyttja-gyttja clay
PFM004396	2.13	2.29	3.89				clay gyttja-gyttja clay
PFM004396	2.18	1.80	3.06				clay gyttja-gyttja clay
PFM004396	2.20–2.30					0.0	gyttja clay
PFM004396	2.23	2.44	4.15				clay gyttja-gyttja clay
PFM004396	2.28	2.39	4.06				clay gyttja-gyttja clay
PFM004396	2.33	2.45	4.17				clay gyttja-gyttja clay
PFM004396	2.38	2.08	3.54				clay gyttja-gyttja clay
PFM004396	2.43	2.24	3.81				clay gyttja-gyttja clay
PFM004396	2.48	2.40	4.08				clay gyttja-gyttja clay
PFM004396	2.53	2.04	3.47				clay gyttja-gyttja clay
PFM004396	2.58	2.15	3.66				clay gyttja-gyttja clay
PFM004396	2.63	1.59	2.70				clay gyttja-gyttja clay
PFM004396	2.68	1.81	3.08				clay gyttja-gyttja clay
PFM004396	2.73	1.80	3.06				clay gyttja-gyttja clay
PFM004396	2.78	2.41	4.10				clay gyttja-gyttja clay
PFM004396	2.83	1.20	2.04				clay gyttja-gyttja clay
PFM004396	2.88	1.80	3.06				clay gyttja-gyttja clay
PFM004396	2.93	2.18	3.71				clay gyttja-gyttja clay
PFM004396	2.98	2.24	3.81				clay gyttja-gyttja clay
PFM004396	3.03	1.96	3.33				clay gyttja-gyttja clay
PFM004396	3.08	1.53	2.60				clay gyttja-gyttja clay
PFM004396	3.13	1.91	3.25				clay gyttja-gyttja clay
PFM004396	3.18	1.99	3.38				clay gyttja-gyttja clay
PFM004396	3.23	1.81	3.08				clay gyttja-gyttja clay
PFM004396	3.28	2.06	3.50				clay gyttja-gyttja clay
PFM004396	3.33	1.69	2.87				clay gyttja-gyttja clay
PFM004396	3.38	3.14	5.34				clay gyttja-gyttja clay
PFM004396	3.43–3.50					0.0	clay
PFM004396	3.43	1.85	3.15				clay gyttja-gyttja clay
PFM004396	3.48	0.78	1.33				clay gyttja-gyttja clay
PFM004396	3.53	1.22	2.07				clay gyttja-gyttja clay
PFM004396	3.58	1.50	2.55				gyttja clay
PFM004396	3.63	1.80	3.06				gyttja clay
PFM004396	3.68	1.85	3.15				gyttja clay

ID code	Sampling depth (m)	$C_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
PFM004396	3.73	1.82	3.09				gyttja clay
PFM004396	3.78	1.28	2.18				gyttja clay
PFM004396	3.83	1.21	2.06				gyttja clay
PFM004396	3.88	1.28	2.18				gyttja clay
PFM004396	3.93	1.41	2.40				gyttja clay
PFM004396	3.98	1.45	2.47				gyttja clay
PFM004396	4.00–4.10					1.0	clayey silt
PFM004396	4.03	1.32	2.24				gyttja clay
PFM004396	4.08	1.50	2.55				gyttja clay
PFM004396	4.13	1.38	2.35				gyttja clay
PFM004396	4.18	1.61	2.74				gyttja clay
PFM004396	4.23	1.47	2.50				gyttja clay
PFM004396	4.28	1.42	2.41				gyttja clay
PFM004396	4.33	1.00	1.70				clay
PFM004396	4.38	0.82	1.39				clay
PFM004396	4.43	0.34	0.58				clay
PFM004396	4.48	0.28	0.48				clay
PFM004396	4.50–4.60					0.0	clay
PFM004396	4.53	0.43	0.73				clay
PFM004396	4.58	0.43	0.73				clay
PFM004396	4.63	0.62	1.05				clay
PFM004396	4.68	1.07	1.82				clay
PFM004396	4.73	0.49	0.83				clay
PFM004396	4.78	1.23	2.09				clay
PFM004396	4.83	0.79	1.34				clay
PFM004396	4.88	1.52	2.58				clay
PFM004396	4.93	1.14	1.94				clay
PFM004396	4.98	1.16	1.97				clay
PFM004396	5.00–5.10					5.0	clay
PFM004396	5.03	0.79	1.34				clay
PFM004396	5.08	1.00	1.70				clay
PFM004396	5.13	1.51	2.57				clay
PFM004396	5.18	1.23	2.09				clay
PFM004396	5.23	1.24	2.11				clay
PFM004396	5.28	1.26	2.14				clay
PFM004396	5.33	1.32	2.24				clay
PFM004396	5.38	1.77	3.01				clay
PFM004396	5.43	0.52	0.88				clay
PFM004396	5.48	1.62	2.75				clay
PFM004396	5.50–5.60					11.0	clay
PFM004396	5.53	0.52	0.88				Clay
PFM004396	5.58	1.68	2.86				clay
PFM004396	5.63	1.00	1.70				clay
PFM004396	5.68	1.17	1.99				clay
PFM004396	5.73	1.27	2.16				clay
PFM004396	5.78	1.46	2.48				clay
PFM004396	5.83	1.87	3.18				clay
PFM004454	1.2–1.65					25.0	clayey sandy till
PFM004455	0.10–0.15					0.0	gravelly sand
PFM004455	0.20–0.25					9.0	sandy till
PFM004455	0.50–0.55					25.0	sandy till
PFM004455	0.80–0.85					25.0	sandy till
PFM004455	1.20–1.25					25.0	sandy till
PFM004455	1.65–2.5					27.0	clayey sandy silty till
PFM004455	1.70–1.75					21.0	sandy till
PFM004455	2.50–2.55					27.0	clayey sandy till
PFM004456	1.65–2.20					24.0	clayey sandy silty till
PFM004458	0.05–0.10					19.0	sandy till

ID code	Sampling depth (m)	$C_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
PFM004458	0.20–0.25					20.0	sandy till
PFM004458	0.50–0.55					21.0	sandy till
PFM004458	0.80–0.85					20.0	gravelly till
PFM004458	1.20–1.25					24.0	gravelly till
PFM004458	1.70–1.75					26.0	sandy till
PFM004458	2.50–2.55					28.0	sandy till
PFM004459	1.65–3.50					23.0	boulder clay
PFM004459	3.5					26.0	clayey sandy silty till
PFM004460	0.05–0.10					0.0	gravelly sand
PFM004460	0.20–0.25					17.0	boulder clay
PFM004460	0.50					0.1	gravelly sand
PFM004460	0.50–0.55					24.0	sandy till
PFM004460	0.80–0.85					25.0	sandy till
PFM004460	1.00–1.65					23.0	clayey sandy till
PFM004460	1.20–1.25					24.0	sandy till
PFM004460	1.50–1.65					30.0	clayey sandy till
PFM004460	1.65–2.20					25.0	clayey sandy silty till
PFM004460	1.70–1.75					25.0	sandy till
PFM004514	0.9					22.0	clayey sandy silty till
PFM004514	1.5					21.0	sandy till
PFM004514	1.6					12.0	clay
PFM004514	2.3					22.0	boulder clay
PFM004514	2.8					22.0	clayey sandy till
PFM006073	4.13–4.18					20.0	clay
PFM006073	4.18–4.31					8.0	clayey sandy till
PFM006094	1.55–1.87					0.4	sand
PFM006095	0.29–0.59					0.3	sand
PFM006095	2.20–2.50					29.0	clay
PFM006095	2.76–3.00					25.0	boulder clay
PFM006097	3.55–3.67					10.0	clayey sandy till
SFM0001	1.50–2.00					19.0	
SFM0001	2.50–3.50					19.5	
SFM0001	3.50–4.00					12.5	
SFM0002	1.00–2.00					17.0	
SFM0002	3.00–4.00					14.0	
SFM0002	4.50–5.50					12.5	
SFM0003	1.00–1.50					12.5	
SFM0003	3.50–4.50					13.5	
SFM0003	8.50–9.00					18.0	
SFM0004	2.50–3.00					30.0	
SFM0005	1.00–1.50					25.0	
SFM0006	1.5					31.0	
SFM0007	2					23.0	
SFM0007	4.5					30.0	
SFM0008	1.5					19.0	
SFM0008	4.5					30.0	
SFM0008	5					31.0	
SFM0010	0.80–1.30					27.0	
SFM0011	0.50–1.30					23.0	clayey sandy till
SFM0011	1.60–1.90					24.0	
SFM0011	3.00–3.50					17.0	
SFM0016	0.35–0.80					11.0	
SFM0016	1.75–2.05					22.0	
SFM0016	4.50–5.20					12.0	
SFM0016	5.70–6.10					15.0	
SFM0016	6.60–7.20					10.0	
SFM0017	1.20–1.80					11.0	
SFM0017	1.30–2.50					19.0	

ID code	Sampling depth (m)	$C_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
SFM0017	3.00–3.70					17.0	
SFM0018	2.90–3.50					20.0	
SFM0018	4.00–4.60					18.0	
SFM0019	1.00–1.50					15.0	
SFM0019	4.00–4.50					18.0	
SFM0019	5.20–5.50					8.0	
SFM0020	2.30–2.80					25.0	
SFM0021	0.40–0.90					30.0	clayey sandy till
SFM0021	1.20–1.70					26.0	
SFM0022	4.00–4.60					12.0	sandy till
SFM0026	3.40–3.80					6.0	
SFM0026	6.20–6.80					28.0	
SFM0027	3.30–3.70					32.0	
SFM0028	3.10–3.60					30.0	
SFM0028	5.50–6.00					24.0	
SFM0028	6.00–7.00					29.0	
SFM0030	0.60–1.05					21.0	sandy till
SFM0030	1.40–1.70					18.0	sandy till
SFM0030	2.80–3.40					17.0	
SFM0032	0.90–1.20					21.0	
SFM0034	0.15–0.50					22.0	
SFM0034	1.30–1.60					22.0	
SFM0036	0.40–1.20					25.0	
SFM0049	1.50–2.50					12.0	
SFM0062	2.75–3.15					11.0	sandy till
SFM0063	2.10–2.90					11.0	sandy till
SFM0064	2.00–4.40					24.0	boulder clay
SFM0065	3.70–4.00					30.0	clayey sandy till
SFM0069	0.30–0.70					5.0	sandy gravel
SFM0070	1.40–1.65					22.0	clayey sandy silty till
SFM0071	3.25–3.50					24.0	boulder clay
SFM0072	8.20–8.70					26.0	clayey sandy silty till
SFM0081	2.10–4.40					10.0	sandy till
SFM0084	0.35–0.50		36.70			1.5	gyttja
SFM0084	0.50–0.60		25.30			0.9	gyttja
SFM0084	0.70–0.75		24.10			2.5	gyttja
SFM0084	0.85–0.90		20.70			1.0	clay gyttja
SFM0084	0.95–1.00		19.50			1.1	clay gyttja
SFM0084	1.15–1.20		21.90			0.4	clay gyttja
SFM0084	1.20–1.25					35.0	clay gyttja
SFM0084	1.25–1.28		9.80			2.2	clay gyttja
SFM0084	1.40–1.50					0.7	sand
SFM0084	1.55–1.77					1.2	sandy gravel
SFM0084	1.85–1.90					7.0	clay
SFM0091	0.55–0.64		30.10			4.5	gyttja
SFM0091	0.68–0.75		20.50			1.0	gyttja
SFM0091	0.85–0.90		19.40			0.4	clay gyttja
SFM0091	0.94–1.00		17.50			0.5	clay gyttja
SFM0091	1.18–1.24					9.0	sandy gravel
SFM0091	1.26–1.31					35.0	clay
SFM0094	0.90–1.30					26.0	clayey sandy till
SFM0094	1.60–1.90					20.0	clayey sandy till
SFM0094	2.20–2.70					21.0	clayey sandy till
SFM0095	0.15–0.25		95.20			1.6	bog peat
SFM0095	0.45–0.55		95.20			0.4	bog peat
SFM0095	0.90–1.00		95.60			0.8	bog peat
SFM0095	1.10–1.20		90.60			0.4	bog peat
SFM0095	1.35–1.45		94.80			0.9	bog peat

ID code	Sampling depth (m)	$C_{(org)}$ %	Org. matter %	S %	N %	$CaCO_3$ %	Qd
SFM0095	1.50–1.60		94.20			0.5	peat
SFM0095	1.68–1.73		89.90				algal gyttja
SFM0095	1.76–1.81		87.30				algal gyttja
SFM0095	1.86–1.90		19.10			1.1	clay gyttja
SFM0095	1.93–1.98		16.50			0.4	clay gyttja
SFM0095	2.04–2.09		15.70			0.5	clay gyttja
SFM0095	2.21–2.31					32.0	clay
SFM0095	2.80–2.90					36.0	clay
SFM0103	3.00–5.00					24.0	gravelly till
SFM0104	5.50–6.50					18.0	sandy till
SFM0105	0.50–1.00					26.0	sandy till
SFM0105	1.60–2.10					29.0	clayey sandy till
SFM0106	0.60–0.90					23.0	clayey sandy silty till
SFM0106	3.00–3.60					32.0	clayey sandy till
SFM0107	3.40–4.00					19.0	sandy till
SFM0107	4.00–4.30					14.0	sandy till
SFM0108	0.50–0.90					10.0	sandy till

Chemical composition of till

Table H-1. Compilation of ICP-MS analyses of till samples (fraction < 63 µm) from the terrestrial part of Forsmark area. Two different solvents were used for extraction prior analysis Aqua Regia (AR) or 7M HNO_3 (HN). Data from a national geochemical survey are used as reference /SGU 2005/. The reference data are analysed by either ICP-AES or ICP-MS techniques. /Compilation from Tröjbom and Söderbäck 2006/. Ca and Sr are in bold since they are the two elements with concentrations deviating from the Swedish reference values.

	Element	Solv	Unit	Till – Forsmark (ICP-MS)						Till – Swedish reference						
				No	Min	25-p	50-p	75-p	Max	Method	No	Min	25-p	50-p	75-p	Max
Al	Aluminium	AR	%	43	0.36	0.52	0.61	1.03	4.92	ICP-AES	15822	< 0.0003	0.74	1	1.3	6.7
Ca	**Calcium**	**AR**	**%**	**43**	**2.78**	**6.315**	**7.29**	**8.6**	**10.5**	**ICP-AES**	**15844**	**< 0.001**	**0.22**	**0.29**	**0.36**	**38**
Fe	Iron	AR	%	43	0.81	1.02	1.25	1.785	8.23	ICP-AES	15844	< 0.001	1.2	1.6	2.1	9.3
K	Potassium	AR	%	43	0.07	0.12	0.14	0.225	0.47	ICP-AES	15844	< 0.001	0.067	0.11	0.18	1.3
Mg	Magnesium	AR	%	43	0.22	0.33	0.39	0.465	4.85	ICP-AES	15844	0.001	0.21	0.31	0.44	4.1
Mn	Manganese	AR	%	43	0.025	0.032	0.038	0.042	0.19	ICP-AES	15844	< 0.001	0.016	0.023	0.034	0.81
Na	Sodium	AR	%	43	0.012	0.018	0.022	0.032	0.089							
Na	Sodium	HN	%	8	0.013		0.018		0.023	ICP-MS				< 0.02		
P	Phosphorus	AR	%	43	0.044	0.054	0.058	0.061	0.168	ICP-AES	7341	< 0.001	0.069	0.09	0.11	0.7
S	Sulphur	AR	%	43	0.005	0.01	0.05	0.09	0.16							
Ti	Titanium	AR	%	43	0.04	0.052	0.060	0.082	0.233	ICP-MS				0.069		
Ag	Silver	AR	ppm	43	0.013	0.022	0.026	0.032	0.048							
Ag	Silver	HN	ppm	8	0.06		0.08		0.31	ICP-MS				0.043		
As	Arsenic	AR	ppm	43	0.9	1.8	2.1	2.9	4.5							
As	Arsenic	HN	ppm	8	1.7		2.6		3.3	ICP-MS				3.1		
Au	Gold	AR	ppm	43	< 0.2	< 0.2	0.3	0.85	2.6	AAS				< 1		
B	Boron	AR	ppm	43	1	2	3	5	8							
Ba	Barium	AR	ppm	43	19	31	36	44	84.2	ICP-AES	15844	< 10	30	40	50	140
Be	Beryllium	HN	ppm	8	< 0.2		0.26		0.51	ICP-MS				0.39		
Bi	Bismuth	AR	ppm	43	0.1	0.12	0.14	0.18	0.35							
Bi	Bismuth	HN	ppm	8	0.07		0.11		0.17	ICP-MS				0.09		
Cd	Cadmium	AR	ppm	43	0.04	0.07	0.1	0.12	0.21							
Cd	Cadmium	HN	ppm	8	0.06		0.09		0.12	ICP-MS				0.073		
Cr	Chromium	AR	ppm	43	7.6	12	15	22	77	ICP-AES	7341	< 1	9	13	20	230
Cu	Copper	AR	ppm	43	5.6	8.26	11	14	16	ICP-AES	7341	< 1	8	12	18	229
Ga	Gallium	AR	ppm	43	1.5	2.1	2.7	3.9	15.2							
Hg	Mercury	AR	ppm	43	< 0.005	< 0.005	0.006	0.010	0.018							
La	Lanthanum	AR	ppm	43	16	21	23	26	42	ICP-AES	15844	< 2	21	26	33	338
Li	Lithium	HN	ppm	8	< 5		7.5		17	ICP-MS				9.1		
Mo	Molybdenum	AR	ppm	43	0.3	0.44	0.56	0.66	1.36							
Mo	Molybdenum	HN	ppm	8	0.18		0.4		1.19	ICP-MS				0.33		
Ni	Nickel	AR	ppm	43	3	6	7.8	14	32	ICP-AES	15843	< 2	6	10	15	179
Pb	Lead	AR	ppm	43	< 5	6.5	8.3	11	27	ICP-AES	15843	< 7	5	9	13	423
Rb	Rubidium	HN	ppm	8	6.4		15		32	ICP-MS				12.4		
Sb	Antimony	AR	ppm	43	0.02	0.03	0.05	0.08	0.41							
Sc	Scandium	AR	ppm	43	1.8	2.4	2.7	3.7	23							
Se	Selenium	AR	ppm	43	< 0.1	0.2	0.2	0.3	0.5							
Se	Selenium	HN	ppm	8	0.15		0.24		0.35	ICP-MS				0.2		
Sn	Tin	HN	ppm	8	0.25		0.48		3	ICP-MS				0.3		
Sr	**Strontium**	**AR**	**ppm**	**43**	**27**	**59**	**72**	**81**	**175**	**ICP-AES**	**15844**	**< 2**	**8**	**11**	**16**	**462**
Te	Tellur	AR	ppm	43	< 0.02	< 0.02	< 0.02	< 0.02	0.03							
Th	Thorium	AR	ppm	43	4.1	7.5	8.6	9.5	13							
Th	Thorium	HN	ppm	8	5		6.5		8.4	ICP-MS				7		
Tl	Thallium	AR	ppm	43	0.05	0.13	0.16	0.21	0.32							
Tl	Thallium	HN	ppm	8	0.1		0.18		0.25	ICP-MS				0.13		
U	Uranium	AR	ppm	43	1.1	1.6	1.8	2.8	9	ICP-MS				1.5		
V	Vanadium	AR	ppm	43	11	15	18	27	106	ICP-AES	7341	< 2	19	25	32	183
W	Tungsten	AR	ppm	43	< 0.1	0.3	0.4	0.95	5.1							
W	Tungsten	HN	ppm	8	< 0.1		0.11		32	ICP-MS				0.09		
Y	Ytterbium	HN	ppm	8	14.6		15.6		21.2	ICP-MS				11		
Zn	Zinc	AR	ppm	43	19	26	37	45	141	ICP-AES	15843	< 1	25	35	47	2.197
Zr	Zirconium	HN	ppm	8	7.4		8.2		17							

Table H-2 . Major constituents in the fine fraction of till (< 63µm) from the Forsmark area (mean values of 1–3 sub-samples per object). Samples were extracted by Aqua Regia, and anlysed by ICP-MS /Sohlenius and Rudmark 2003/. The content of major constituents is expressed as percent of dry weight. The three highest values per element are marked in bold. The number of sub samples per observation are listed in the column headed "Subs". /from Tröjbom and Söderbäck 2006/.

ID code	Depth (m)		Subs	Element (%)									
	From	To	N	Al	Ca	Fe	K	Mg	Mn	Na	P	S	Ti
HFM11	2.5	2.5	1	0.71	5.3	1.4	0.13	0.42	0.034	0.025	0.058	0.02	0.068
HFM13	3	3	1	0.55	5.7	1.2	0.16	0.3	0.031	0.026	0.044	0.05	0.061
PFM002461	2	2.4	1	0.81	9.1	1.5	0.21	0.44	0.041	0.023	0.059	**0.10**	0.069
PFM002572	5.1	5.7	1	0.73	8.1	1.3	0.19	0.39	0.036	0.022	0.061	0.08	0.070
PFM002573	4.5	5	1	0.52	9.0	1.0	0.13	0.33	0.035	0.016	0.054	0.06	0.052
PFM002576	5	5	1	0.36	6.3	0.81	0.08	0.22	0.025	0.015	0.061	**0.10**	0.040
PFM002577	0.6	0.6	1	0.52	**9.2**	1.2	0.13	0.32	0.038	0.015	0.059	0.02	0.049
PFM002581	2.4	2.4	1	0.91	7.5	1.6	0.25	0.41	0.047	0.043	**0.062**	**0.13**	0.079
PFM002582	1.7	1.7	1	0.6	8.2	1.2	0.14	0.33	0.037	0.021	**0.062**	0.01	0.051
PFM002586	1.4	1.4	1	0.76	6.4	1.3	0.16	0.46	0.038	0.019	0.054	0.01	0.069
PFM002587	3	3	1	0.55	6.9	1.0	0.11	0.38	0.031	0.020	0.061	0.09	0.050
PFM002588	2.1	2.1	1	1.0	7.6	1.7	**0.27**	0.51	0.038	0.024	0.060	0.08	**0.089**
PFM002592	2.8	2.8	1	1.0	7.3	1.7	**0.27**	0.58	0.040	**0.047**	0.059	**0.10**	0.087
PFM004514	2.8	2.8	1	0.52	9.0	1.0	0.12	0.33	0.035	0.018	0.057	0.09	0.056
SFM0002	1	5.5	3	0.40	6.4	0.94	0.10	0.26	0.028	0.042	0.053	0.08	0.048
SFM0004	1	5	3	0.53	9.3	1.1	0.14	0.34	0.038	0.019	0.057	0.06	0.056
SFM0005	1	2	3	0.91	7.4	1.6	0.21	0.40	0.040	0.023	0.057	0.01	0.078
SFM0007	1	5.5	3	0.89	8.6	1.6	0.21	0.44	0.042	0.025	0.063	0.01	0.079
SFM0008	1	5.5	3	0.92	8.4	1.6	0.23	0.46	0.041	0.022	0.060	0.04	0.075
SFM0010	0.8	1.3	2	0.65	7.5	1.2	0.15	0.44	0.040	0.018	0.054	0.01	0.063
SFM0011	3	3.5	2	0.45	6.5	0.98	0.10	0.32	0.030	**0.048**	0.060	0.09	0.050
SFM0016	6.6	7.2	2	**4.5**	3.7	**5.3**	0.08	**4.7**	**0.118**	0.012	0.050	0.02	0.056
SFM0017	3.7	4	1	**4.9**	4.8	**8.2**	0.12	**3.8**	**0.192**	0.045	**0.168**	0.02	**0.219**
SFM0019	4.5	4.8	1	0.5	6.4	1	0.12	0.27	0.030	0.021	0.056	0.07	0.057
SFM0020	2.3	2.8	1	0.49	8.4	0.93	0.12	0.31	0.032	0.018	0.058	0.08	0.051
SFM0021	1.2	1.7	1	0.5	**9.2**	1.0	0.13	0.34	0.037	0.018	0.060	0.09	0.052
SFM0049	1.5	2.5	2	0.70	4.8	1.4	0.16	0.44	0.028	0.034	0.046	**0.16**	0.069
SFM0057	1	1	2	**1.3**	2.9	**2.6**	**0.47**	**0.90**	**0.053**	**0.087**	**0.098**	0.01	**0.228**

Table H-3. Minor constituents and trace elements. expressed as parts per million. in the fine fraction of till (< 63 um) from the Forsmark area/Sohlenius and Rudmark 2003/ (means of 1–3 sub-samples per object). Samples were extracted by Aqua regia, and analysed by ICP-MS. The three highest values per element are marked in bold. The number of sub-samples per observation plot, as well as the sampling depth interval, is listed in Table A2. /From Tröjbom and Söderbäck 2006/.

ID code	Element (ppm)												
	Ag	As	Au	B	Ba	Bi	Cd	Cr	Cu	Ga	Hg	Mo	Ni
HFM11	0.034	1.5	1.0	2	32	0.12	**0.15**	15	13	3.0	0.005	**1.03**	6.6
HFM13	0.022	1.3	**2.5**	2	37	**0.24**	0.07	11	8	2.6	< 0.005	0.91	5.7
PFM002461	0.032	2.8	0.4	**5**	43	0.15	0.10	19	11	3.1	**0.018**	0.44	10
PFM002572	0.028	2.5	< 0.2	3	37	0.12	0.09	16	9.9	2.8	< 0.005	0.40	8.5
PFM002573	0.024	2.0	0.5	3	32	0.12	0.06	13	8.0	2.1	0.005	0.41	6.7
PFM002576	0.020	1.9	< 0.2	2	19	0.10	0.07	7.6	5.6	1.5	< 0.005	0.39	3.0
PFM002577	0.029	**4.2**	1.0	1	37	0.15	0.14	12	13	2.3	0.005	0.33	7.8
PFM002581	**0.037**	**3.8**	**2.1**	4	45	0.14	0.11	16	12	3.5	< 0.005	0.65	10
PFM002582	0.032	**4.0**	< 0.2	2	34	**0.24**	0.13	11	**15**	2.4	< 0.005	0.67	5.1
PFM002586	0.025	1.7	< 0.2	1	39	0.14	0.14	15	**16**	2.8	0.010	0.31	7.2
PFM002587	0.023	1.3	0.2	3	25	0.10	0.07	17	12	2.1	< 0.005	0.53	6.2
PFM002588	0.036	3.0	0.6	**5**	44	0.16	0.12	21	12	3.7	< 0.005	0.55	12
PFM002592	**0.038**	3.3	**1.3**	**5**	33	0.18	0.10	21	**14**	3.9	0.010	0.62	**16**
PFM004514	0.026	2.1	< 0.2	3	33	0.12	0.09	11	7.2	2.1	0.007	0.31	5.3
SFM0002	0.020	1.9	0.4	2	28	0.11	0.07	8.7	6.1	1.8	0.004	0.54	5.0
SFM0004	0.030	2.5	0.5	3	35	0.14	0.11	13	8.8	2.2	0.006	0.45	8.5
SFM0005	0.030	3.2	0.4	**5**	44	0.17	0.13	19	13	3.4	0.008	0.53	13
SFM0007	0.030	3.3	1.0	**5**	49	0.16	0.12	**23**	13	3.5	**0.011**	0.72	**15**
SFM0008	**0.040**	3.7	**1.3**	3	**52**	0.17	0.10	20	13	3.6	0.010	0.47	14
SFM0010	0.028	1.9	0.8	2	38	0.14	**0.20**	15	**14**	2.7	0.008	0.61	6.8
SFM0011	0.020	1.8	0.2	2	30	0.12	0.07	15	8.7	2.0	< 0.005	0.63	5.4
SFM0016	0.019	0.9	0.6	**8**	24	**0.30**	0.04	**76**	12	**14**	< 0.005	0.84	**32**
SFM0017	0.013	1.3	< 0.2	**8**	**52**	**0.35**	0.06	12	**14**	**15**	< 0.005	0.60	8.5
SFM0019	0.024	2.3	< 0.2	2	30	0.12	0.07	12	8.2	2.2	0.006	0.53	4.8
SFM0020	0.020	1.9	< 0.2	2	32	0.11	0.08	10	7.1	2.0	0.009	0.30	5.2
SFM0021	0.023	2.1	0.6	2	47	0.13	0.08	12	9.1	2.3	0.007	0.43	6.4
SFM0049	0.031	1.9	< 0.2	3	33	0.17	**0.15**	18	13	3.2	**0.012**	**1.23**	14
SFM0057	0.030	1.6	0.4	**5**	**84**	0.20	0.08	**33**	11	**5.3**	0.008	**1.35**	13

ID code	Pb	Sb	Sc	Se	Sr	Te	Th	Tl	U	V	W	Zn	La
HFM11	8.3	0.04	2.7	0.2	49	< 0.02	**9.8**	0.13	2.1	21	1.6	37	24
HFM13	7.7	**0.41**	2.5	0.2	52	< 0.02	**12**	0.14	3.5	14	3.5	26	30
PFM002461	7.9	0.07	3.2	0.2	**85**	< 0.02	7.5	0.18	1.8	21	0.2	34	22
PFM002572	7.4	**0.20**	2.8	0.1	76	< 0.02	7.3	0.17	1.6	21	0.2	36	20
PFM002573	6.7	0.04	2.2	0.2	81	< 0.02	6.9	0.17	1.6	17	0.2	27	19
PFM002576	5.2	0.03	1.8	0.2	54	< 0.02	8.4	0.11	2.2	11	0.3	19	22
PFM002577	**17**	0.07	2.5	**0.5**	80	**0.03**	9.1	**0.28**	1.7	16	0.3	42	23
PFM002581	10	**0.09**	3.2	0.2	62	< 0.02	7.5	0.21	1.8	23	0.1	41	20
PFM002582	12	0.07	2.9	0.2	72	< 0.02	8.2	0.16	1.6	16	0.3	32	23
PFM002586	11	0.02	3.0	0.1	60	< 0.02	9.3	0.20	1.3	20	0.3	41	22
PFM002587	6.2	0.03	2.2	0.2	64	< 0.02	8.0	0.12	**5.9**	18	0.3	24	18
PFM002588	8.6	0.07	3.7	0.2	76	< 0.02	8.1	0.23	2.3	27	0.1	40	23
PFM002592	8.1	**0.09**	3.4	**0.4**	83	< 0.02	8.6	0.23	2.3	26	0.2	45	24
PFM004514	6.4	0.03	2.5	0.1	82	< 0.02	7.1	0.16	1.5	15	0.3	25	20
SFM0002	6.4	0.06	2.1	0.2	59	< 0.02	9.2	0.12	2.9	13	1.0	21	24
SFM0004	9.4	0.04	2.4	0.2	83	**0.02**	7.4	0.18	1.7	16	0.5	31	20
SFM0005	10.6	0.07	3.2	0.2	74	< 0.02	8.6	**0.25**	1.2	24	0.7	41	24
SFM0007	10.1	0.07	3.4	**0.3**	82	**0.02**	8.8	**0.26**	1.6	24	1.7	43	25
SFM0008	10.4	0.07	3.4	**0.3**	79	**0.02**	8.6	0.24	1.4	24	0.6	**47**	25
SFM0010	9.6	0.04	2.6	0.2	68	**0.02**	9.0	0.18	1.8	18	0.6	**47**	23
SFM0011	5.1	0.04	2.2	0.2	59	< 0.02	9.1	0.11	2.2	14	0.5	22	22
SFM0016	**26**	0.02	**22**	< 0.1	**102**	< 0.02	4.2	0.05	**7.6**	**78**	< 0.1	**103**	16
SFM0017	**14**	0.03	**8.2**	0.2	**175**	< 0.02	7.7	0.06	**9.0**	**106**	0.3	**141**	**42**
SFM0019	7.3	0.05	2.5	0.2	56	< 0.02	9.5	0.14	2.9	15	0.3	23	26
SFM0020	6.3	0.02	2.2	0.2	76	< 0.02	6.9	0.16	1.5	15	0.2	24	20
SFM0021	6.3	0.05	2.5	0.2	82	**0.02**	8.1	0.15	2.6	15	0.2	28	24
SFM0049	13	0.08	3.5	0.3	48	< 0.02	**13**	0.12	3.7	18	3.1	37	**39**
SFM0057	5.9	0.06	**7.2**	0.2	27	< 0.02	9.6	0.22	5.2	**61**	4.8	42	27

Table H-4. Heavy metals in basal till. From /Nilsson 2003/.

ID code	Cons Id	Rand Id	Depth (m)	Composition	Colour	Cu ppm	Pb ppm	Zn ppm	Au ppb
HFM11	1	MIR007	2.5	silt-sand	Grey	12.92	8.26	37.0	1.0
HFM13	2	MIR030	3.0	sand-silt	Grey	8.10	7.68	25.5	2.5
PFM002461	3	MIR009	2.0-2.4	sand-silt	Grey	11.48	7.86	33.7	0.4
PFM002572	4	MIR008	5.1-5.7	silt	Grey	9.90	7.36	33.5	< .2
PFM002573	5	MIR032	4.5-5.0	silt	Grey	7.96	6.71	26.7	0.5
PFM002576	6	MIR005	5.0	sand-silt	Grey	5.56	5.20	18.7	< .2
PFM002577	7	MIR040	0.6	sand-silt	Beige-grey	13.27	16.68	41.5	1.0
PFM002581	8	MIR015	2.4	silt	Dark grey (old)	11.75	10.13	40.9	2.1
PFM002582	9	MIR004	1.7	silt-sand	Brown-grey	15.49	11.48	32.3	< .2
PFM002586	10	MIR016	1.4	sand-silt	(Brown)Grey	15.88	10.56	40.6	< .2
PFM002587	11	MIR021	3.0	sand-silt	Grey	11.79	6.21	24.1	0.2
PFM002588	12	MIR017	2.1	silt-clay	Dark grey	11.96	8.61	39.6	0.6
PFM002592	13	MIR035	2.8	silt-clay	Dark grey	14.09	8.08	44.8	1.3
PFM004514	14	MIR020	2.8	sand-silt	Grey	7.19	6.45	25.2	< .2
SFM0002D*	15	MIR034	1.0-1.5	sand-silt	Grey	6.65	6.55	23.3	0.9
SFM0002	16	MIR031	5.0-5.5	silt-sand	Grey	5.84	6.51	20.6	< .2
SFM0002DD*	17	MIR002	1.0-1.5	sand-silt	Grey	5.81	6.12	19.4	< .2
SFM0004D	18	MIR039	1.0-1.5	sand-silt	Grey	10.35	10.91	36.9	0.8
SFM0004	19	MIR022	4.5-5.0	sand-silt	Grey	7.72	7.28	27.2	0.2
SFM0004DD	20	MIR001	1.0-1.5	sand-silt	Grey	8.40	9.87	28.8	0.4
SFM0005D	21	MIR029	1.0	sand-silt	Dark grey	15.97	11.09	46.3	0.3
SFM0005	22	MIR013	1.5-2.0	silt-sand	Brown-grey	8.43	10.20	30.7	< .2
SFM0005DD	23	MIR019	1.0	sand-silt	Dark grey	15.19	10.65	46.5	0.7
SFM0007D	24	MIR033	1.0	sand-silt	Grey	14.76	11.29	47.5	0.4
SFM0007	25	MIR038	5.5	silt-sand	Brown-grey	9.61	7.79	32.3	2.6
SFM0007DD	26	MIR028	1.0	sand-silt	Grey	15.17	11.16	48.0	< .2
SFM0008D	27	MIR041	1.0	sand-silt	Grey	16.02	11.85	57.9	1.8
SFM0008	28	MIR026	5.5	sand-silt	Grey	7.34	7.86	27.0	< .2
SFM0008DD	29	MIR042	1.0	sand-silt	Grey	16.21	11.42	55.1	1.9
SFM0010	30	MIR023	0.8-1.3	sand-silt	Grey	13.21	9.86	44.5	< .2
SFM0010DD	31	MIR037	0.8-1.3	sand-silt	Grey	13.82	9.28	49.5	1.4
SFM0011	32	MIR036	3.0-3.5	silt-sand	Grey	9.22	5.27	23.4	0.4
SFM0011DD	33	MIR012	3.0-3.5	silt-sand	Grey	8.27	4.93	21.0	< .2
SFM0016	34	MIR025	6.6-7.2	sand-silt	Dark grey	11.45	25.04	107.6	0.3
SFM0016DD	35	MIR003	6.6-7.2	sand-silt	Dark grey	11.97	27.42	98.0	0.9
SFM0017	36	MIR018	3.7-4.0	sand-silt	Dark grey	13.79	14.34	140.8	< .2
SFM0019	37	MIR011	4.5-4.8	sand-silt	Grey	8.17	7.27	23.4	< .2
SFM0020	38	MIR027	2.3-2.8	sand-silt	Grey	7.09	6.28	23.6	< .2
SFM0021	39	MIR043	1.2-1.7	sand-silt	Grey	9.08	6.31	27.5	0.6
SFM0049	40	MIR024	1.5-2.5	silt-sand	Grey	13.32	13.23	36.6	< .2
SFM0049DD	41	MIR014	1.5-2.5	silt-sand	Grey	12.74	12.34	36.5	< .2
SFM0057	42	MIR006	1.0	sand-silt	Grey	11.10	5.71	42.1	0.5
SFM0057DD	43	MIR010	1.0	sand-silt	Grey	11.85	6.17	42.9	0.2

* D and DD in the end of Sample_Id means duplicate samples.

Table H-5. Total chemistry in till /from Hannu and Karlsson 2006/.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Dry subst %	Ash subst %	Total C mg/kg dw	Total organic C mg/kg dw	Total N mg/kg dw	Total organic N mg/kg dw	PO_4 mg/kg dw	Al mg/kg dw	Al_2O_3 %	Ca mg/kg dw	CaO %	Fe mg/kg dw	Fe_2O_3 %	K mg/kg dw	K_2O %	Mg mg/kg dw	MgO %	Mn mg/kg dw	MnO %	Na mg/kg dw	Na_2O %	P mg/kg dw	P_2O_5 %
PFM004459	3.5	3.5	1	1	boulder clay	99.3								9.4		13.4		2.88		2.86		0.91		0.0761		1.76		0.122
PFM004460	1	1	1	1	till	99.8								10.2		10.1		2.23		3.04		0.72		0.0507		2.48		0.093
PFM004460	1.5	1.5	2	1	till	99.8								9.9		11.4		2.14		2.86		0.74		0.0512		2.47		0.092
PFM002578	0.7	0.7	1	1	Clayey till	94								9.7		9.94		2.08		2.87		0.66		0.0514		2.29		0.103

Table H-5. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Si mg/kg dw	SiO_2 %	Ti mg/kg dw	TiO_2 %	Sum oxides %	Loss on ignition %	Ag mg/kg dw	As mg/kg dw	B mg/kg dw	Ba mg/kg dw	Be mg/kg dw	Br mg/kg dw	Cd mg/kg dw	Ce mg/kg dw	Cl mg/kg dw	Co mg/kg dw	Cr mg/kg dw	Cs mg/kg dw	Cu mg/kg dw	Dy mg/kg dw	Er mg/kg dw
PFM004459	3.5	3.5	1	1	boulder clay		56.3		0.36	88.1	10.5	5.46	25.4	<0.3	452	1.56	0.603	0.093	42.3	26	6	40.6	2.63	12	3.91	1.92
PFM004460	1	1	1	1	till		62.6		0.25	91.8	7.4	5.14	8.59	<0.3	524	1.87	<0.3	0.061	38.7	26	3.71	33.7	1.75	7.25	3.59	2.21
PFM004460	1.5	1.5	2	1	till		60.5		0.24	90.4	8.3	5.13	6.01	<0.3	483	1.6	<0.3	0.059	39.4	33	3.76	24.6	1.46	7.37	3.06	2.16
PFM002578	0.7	0.7	1	1	Clayey till		63.7		0.25	91.6	7.5	4.82	14.7	<0.3	454	1.76	<0.3	0.077	32.8	139	3.54	29	1.44	7.45	2.98	2.17

Table H-5. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Eu mg/kg dw	Ga mg/kg dw	Gd mg/kg dw	Hf mg/kg dw	Hg mg/kg dw	Ho mg/kg dw	I mg/kg dw	La mg/kg dw	Li mg/kg dw	Lu mg/kg dw	M_o mg/kg dw	Nb mg/kg dw	Nd mg/kg dw	Ni mg/kg dw	Pb mg/kg dw	Pr mg/kg dw	Rb mg/kg dw	S mg/kg dw	S_b mg/kg dw	Sc mg/kg dw	Se mg/kg dw	Sm mg/kg dw	Sn mg/kg dw	Sr mg/kg dw
PFM004459	3.5	3.5	1	1	0.793	12.1	3.4	5.09	<0.01	0.822	<0.01	25.4	148	0.287	<0.5	6.52	19.6	9.39	20.8	4.74	84.3	1,470	0.771	6.43	<0.1	3.6	2.33	171
PFM004460	1	1	1	1	0.625	7.98	3.19	5.85	<0.01	0.778	<0.01	21.7	94.9	0.298	<0.5	5.98	17.3	4.61	16.3	4.36	82	247	0.727	5.04	<0.1	3.46	7.26	182
PFM004460	1.5	1.5	2	1	0.579	9.21	3.06	4.63	<0.01	0.783	<0.01	23.6	94.6	0.305	<0.5	6.36	16.9	4.7	19.8	4.68	78.9	854	0.647	5.38	<0.1	3.22	3.16	179
PFM002578	0.7	0.7	1	1	0.618	4.78	3.16	6.17	<0.01	0.649	<0.01	20	82.4	0.291	<0.5	5.33	16.7	4.39	17.3	4.08	76.5	205	0.444	4.75	<0.1	2.88	1.36	176

Table H-5. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Ta mg/kg dw	Tb mg/kg dw	Th mg/kg dw	Tl mg/kg dw	Tm mg/kg dw	U mg/kg dw	V mg/kg dw	W mg/kg dw	Y mg/kg dw	Yb mg/kg dw	Zn mg/kg dw	Zr mg/kg dw
PFM004459	3.5	3.5	1	1	0.621	0.654	7.55	0.691	0.323	4.26	38	1.16	22.2	1.96	385	182
PFM004460	1	1	1	1	0.761	0.536	7.17	0.604	0.401	2.77	25.1	0.65	21.3	1.96	308	206
PFM004460	1.5	1.5	2	1	0.68	0.538	6.91	0.624	0.341	2.9	24.1	0.913	21.5	1.96	289	157
PFM002578	0.7	0.7	1	1	0.672	0.489	5.57	0.58	0.31	2.03	24.6	0.754	20.3	2.04	292	233

Appendix I

Chemical composition of marine and lake sediments and peat

Table I-1. Total chemistry of lake sediments and peat, from terrestrial area /Hannu and Karlsson 2006/.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Dry subst %	Ash subst %	Total C mg/kg dw	Total organic C mg/kg dw	Total N mg/kg dw	Total organic N mg/kg dw	PO_4 mg/kg dw	Al mg/kg dw	Al_2O_3 %	Ca mg/kg dw	CaO %	Fe mg/kg dw	Fe_2O_3 %	K mg/kg dw	K_2O %	Mg mg/kg dw	MgO %	Mn mg/kg dw	MnO %	Na mg/kg dw
PFM006023[1)]	0.66	0.69	1	1	wetland clay, gyttja	14.8			110,000					6.9		1.28		3.02		1.88		1.37		0.0273	
PFM006023[2)]	1.03	1.06	2	1	wetland clay, gyttja	14.3		99,000	100,000	2,180	1,580	39		6.5		1.16		3.37		1.77		1.29		0.0285	
PFM006023	1.58	1.61	3	1	wetland, sand	84.6		2,400	2,102	1,640	1,560	18		12.3		1.59		4.56		3.84		0.54		0.0579	
PFM006023	1.93	1.96	4	1	wetland, glacial clay	48.8		8,400	3,821	1,680	1,510	54		16.8		3.9		8.25		4.3		3.16		0.0819	
PFM006024[3)]	0.33	0.36	1	1	peat	8.8		440,000	460,000	3,900	3,700		426		1,390		580		–200		535		4		371
PFM006024[3)]	1.13	1.16	2	1	peat	6.2		440,000	440,000	3,150	3,200		148		8,830		250		–200		1,160		11		218
PFM006024[3)]	1.53	1.56	3	1	Phragmites peat	7.7		480,000	460,000	21,030	19,000		533		22,600		500		210		1,880		44		212
PFM006024[4)]	1.73	1.76	4	1	wetland algae, gyttja	5.7			400,000	4,890	1,720			0.3		2.35		0.17		0.12		0.27		0.0108	
PFM006024	1.93	1.96	5	1	wetland, clay	28.2		81,000	78,950	2,390	1,710	38		9		1.67		3.95		2.41		1.57		0.0439	
PFM006024	2.63	2.66	6	1	wetland, glacial clay gyttja	61.9		35,000	6,123	1,620	1,410	39		12.4		15.8		5.84		3.67		2.47		0.087	
PFM002501	0	0.16[7)]	1	1	lake sediment			350,000	180,000	33,400	31,900	450		0.9		3.3		0.72		0.23		0.28		0.0192	
PFM002501	0.2	0.3[7)]	2	1	lake sediment			400,000	370,000	34,400	32,900	160		1.3		3		0.91		0.29		0.35		0.0165	
PFM002502[5)]	0	0.03[7)]	1	1	algal mat, lake		23.5	380,000	410,000	37,300	35,500			0.6		7.44		0.56		0.2		0.22		0.0239	
PFM004298[6)]	2.53	2.64[7)]	1	1	Lake sediment, algae gyttja	6.4		440,000	400,000					1.2		10.3		1.04		0.32		0.31		0.0197	
PFM004298[3)]	2.64	2.71[7)]	2	1	Lake sediment, calcareous gyttja	7.1		240,000	210,000	18,500	16,900			0.6		25.9		0.83		0.17		0.27		0.0253	
PFM004298[6)]	3.1	3.2[7)]	3	1	Lake sediment, algae gyttja	8.6		350,000	270,000					2.2		2.8		1.66		0.58		0.61		0.0388	
PFM004298	3.56	3.62[7)]	4	1	Lake sediment, clay gyttja	30.7		88,000	80,000	5,980	4,120	84		9.3		1.77		5.26		2.43		1.52		0.0464	
PFM004298	3.87	3.92[7)]	5	1	Lake sediment, clay	65								18.8		1.67		9.76		4.52		3.53		0.0942	
PFM004298	4.02	4.07[7)]	6	1	Lake sediment, clay	65.1								15.5		5.89		9.51		4		2.89		0.0973	
PFM004298	4.2	4.25[7)]	7	1	Lake sediment, clay	64.6								16.1		7.01		7.77		4.2		2.99		0.0896	

Table I-1. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Na_2O %	P mg/kg dw	P_2O_5 %	Si mg/kg dw	SiO_2 %	Ti mg/kg dw	TiO_2 %	Sum oxides %	Loss on ignition %	Ag mg/kg dw	As mg/kg dw	B mg/kg dw	Ba mg/kg dw	Be mg/kg dw	Br mg/kg dw	Cd mg/kg dw	Ce mg/kg dw	Cl mg/kg dw	Co mg/kg dw
PFM006023[1)]	0.66	0.69	1	1	wetland clay, gyttja	1.13		0.091		55.5		0.34	71.6	26.6	<0.2	2.39	<0.3	249	1.42	11.8	1.17	15.5	3,810	6.03
PFM006023[2)]	1.03	1.06	2	1	wetland clay, gyttja	0.984		0.111		56.2		0.32	71.7	26.4	<0.2	3.46	<0.3	239	1.3	6.39	0.968	49.9	1,380	6.49
PFM006023	1.58	1.61	3	1	wetland, sand	2.94		0.085		72.4		0.17	98.5	1.1	<0.2	0.787	<0.3	599	1.67	<0.3	0.065	27.9	78	2.05
PFM006023	1.93	1.96	4	1	wetland, glacial clay	1.76		0.172		51.8		0.78	91	5.7	0.37	5.69	<0.3	642	2.66	<0.3	0.209	100	129	19.3
PFM006024[3)]	0.33	0.36	1	1	peat		123		322		8.63				<0.1	0.409	0.318	2.7	0.01	9.65	0.178	0.2	680	0.122
PFM006024[3)]	1.13	1.16	2	1	peat		116		250		3.6				<0.1	0.225	0.953	6	<0.005	5.75	0.133	0.1	500	0.057
PFM006024[3)]	1.53	1.56	3	1	Phragmites peat		311		460		9.65				<0.1	0.402	16.6	26.3	0.02	84	0.055	1.3	700	0.312
PFM006024[4)]	1.73	1.76	4	1	wetland algae, gyttja	0.076		0.066		1.5		0.02	5		<0.1	0.514	<0.3	37.6	<0.005	1.08	0.12	2.9	168	1.16
PFM006024	1.93	1.96	5	1	wetland, clay	1.07		0.193		56.5		0.46	76.9	19.4	0.26	3.5	<0.3	370	1.78	7.1	0.376	63	77	7.98
PFM006024	2.63	2.66	6	1	wetland, glacial clay gyttja	1.08		0.141		39.6		0.66	81.8	12.1	3.01	3.35	<0.3	437	2.04	<0.3	0.159	71.8	<10	13.5
PFM002501	0	0.16[7)]	1	1	lake sediment	0.183		0.277		12.4		0.04	18.4	79.8	5.9	4.53	4.23	55.9	0.27	23.5	1.23	13.9	1,010	2.91
PFM002501	0.2	0.3[7)]	2	1	lake sediment	0.235		0.151		12.8		0.06	19.1	78.2	4.89	6.37	3.58	70.6	0.37	16.4	1.13	17.2	1,020	3.19
PFM002502[5)]	0	0.03[7)]	1	1	algal mat, lake	0.125		0.263		8.2		0.03	17.7		14.5	1.66	7.13	66.4	0.13	12.6	0.305	31.1	518	1.5
PFM004298[6)]	2.53	2.64[7)]	1	1	Lake sediment, algae gyttja	0.194		0.159		9.9		0.06	23.5	75.4	21.5	3.02	86	82.6	0.17	14.4	0.711	13.4	591	2.74
PFM004298[3)]	2.64	2.71[7)]	2	1	Lake sediment, calcareous gyttja	0.115		0.108		5.8		0.03	33.9	63.1	45.2	2.67	36.9	81.9	0.13	16	0.262	6.8	452	1.9
PFM004298[6)]	3.1	3.2[7)]	3	1	Lake sediment, algae gyttja	0.353		0.118		24.5		0.11	33	63.9	16.6	2.71	69.9	132	0.45	68	0.463	19.7	832	3.48
PFM004298	3.56	3.62[7)]	4	1	Lake sediment, clay gyttja	1.23		0.198		54.4		0.45	76.6	20.7	23.5	6.14	<0.3	468	3.91	93.8	0.259	60.9	334	23.5
PFM004298	3.87	3.92[7)]	5	1	Lake sediment, clay	2.21		0.225		56.2		0.94	98	5	8.78	11.7	21	945	3.84	2.69	0.111	120	76	17.6
PFM004298	4.02	4.07[7)]	6	1	Lake sediment, clay	1.84		0.217		53.8		0.81	94.6	6.7	8.26	6.81	22.7	720	3.15	1.32	0.056	99.3	70	19.8
PFM004298	4.2	4.25[7)]	7	1	Lake sediment, clay	1.72		0.184		52.8		0.79	93.6	8.2	7.5	5.19	22.8	674	3.14	1.01	0.164	92.5	84	15.7

Table I-1. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Cr mg/kg dw	Cs mg/kg dw	Cu mg/kg dw	Dy mg/kg dw	Er mg/kg dw	Eu mg/kg dw	Ga mg/kg dw	Gd mg/kg dw	Hf mg/kg dw	Hg mg/kg dw	Ho mg/kg dw	I mg/kg dw	La mg/kg dw	Li mg/kg dw	Lu mg/kg dw	Mo mg/kg dw	Nb mg/kg dw	Nd mg/kg dw	Ni mg/kg dw	Pb mg/kg dw	Pr mg/kg dw
PFM006023[1)]	0.66	0.69	1	1	52.3	3.8	53.8	1.19	0.585	0.18	<0.001	1.05	0.615	0.042	0.244	1.62	9.38	22.3	0.1	5.1	2.32	9.74	27.5	74.9	2.32
PFM006023[2)]	1.03	1.06	2	1	53.4	3.59	33.9	2.72	1.27	0.649	3.7	2.41	1.33	<0.01	0.579	1.75	23	21.1	0.219	14.2	6.74	22.7	28.3	130	5.3
PFM006023	1.58	1.61	3	1	99.2	1.79	5.26	1.5	1.53	0.582	6.84	2.24	1.45	<0.01	0.374	<0.01	15.4	12.9	0.195	<0.5	3.91	12.7	5.16	137	3.33
PFM006023	1.93	1.96	4	1	116	10.1	41.2	4.76	3.22	1.09	19.9	4.37	4.6	<0.01	1.02	<0.01	49.5	62.6	0.43	<0.5	16.8	42.5	46.4	107	12
PFM006024[3)]	0.33	0.36	1	1	0.327	0.0092	0.58	0.0072	0.0046	0.0015	0.0779	0.0063	0.0082	0.024	0.0014	0.61	0.105	0.11	–0.0007	0.07	0.0353	0.0843	0.413	9.6	0.0239
PFM006024[3)]	1.13	1.16	2	1	0.244	0.0075	0.53	0.005	0.0027	0.0011	0.0209	0.0047	0.0033	<0.01	0.001	0.48	0.0654	0.1	–0.0007	0.06	0.0126	0.0496	0.496	1.27	0.0145
PFM006024[3)]	1.53	1.56	3	1	0.723	0.0272	2.05	0.129	0.088	0.0219	0.0521	0.11	0.0343	<0.01	0.0286	1.3	0.819	0.18	0.0128	0.57	0.0663	0.845	2.09	1.01	0.211
PFM006024[4)]	1.73	1.76	4	1	<0.01	0.181	9.46	0.491	0.448	0.067	<0.001	0.407	<0.001	<0.01	0.0969	0.502	3.33	2.01	–0.04	<0.5	0.269	3.41	8.6	356	<0.01
PFM006024	1.93	1.96	5	1	67.8	4.86	33.6	4.44	2.21	0.902	7.91	5.21	3.5	<0.01	0.879	1.12	34.7	27.4	0.418	3.05	9.88	33.8	28.1	17.2	8.54
PFM006024	2.63	2.66	6	1	87.3	9.58	25.1	3.86	1.71	0.931	15.8	3.28	2.5	<0.01	0.74	<0.01	37.5	49.9	0.272	<0.5	15.8	31	28.5	162	8.78
PFM002501	0	0.16	1	1	22.3	0.458	53.9	1.88	1.28	0.267	<0.001	1.97	0.905	0.21	0.481	8.88	8.17	2.77	0.174	3.49	0.905	9.78	19.9	68.1	2.4
PFM002501	0.2	0.3	2	1	16	0.601	71.6	2.8	1.68	0.326	<0.001	2.63	0.56	0.111	0.554	7.57	11.7	3.86	0.269	6.48	0.74	14.2	19.1	57.6	3.01
PFM002502[5)]	0	0.03	1	1	10.3	0.213	17.3	5.16	2.92	0.646	<1	4.69	2.11	0.068	1.08	6.04	20.4	–2	0.441	17.9	3.06	24.1	8.25	20.6	5.8
PFM004298[6)]	2.53	2.64	1	1	20.1	0.698	64.6	2.05	1.72	0.386	<1	2.04	0.991	0.077	0.604	7.41	13.1	27.8	0.216	3.06	1.3	12.5	18.8	39.2	2.76
PFM004298[3)]	2.64	2.71	2	1	13.4	0.329	39.9	1.36	0.716	0.225	<1	0.401	0.256	0.042	0.378	8.31	5.82	20.6	0.145	2.71	0.842	7.49	12.6	24.6	1.79
PFM004298[6)]	3.1	3.2	3	1	29.6	1.17	57.7	1.94	0.97	0.335	1.99	1.85	1.3	<0.01	0.456	11.9	14.8	63.7	0.209	7.98	3.26	13.4	29.8	12.8	3.2
PFM004298	3.56	3.62	4	1	67.2	9.68	39.4	4.53	2.74	0.826	17.2	3.86	3.88	<0.01	0.966	7.88	41.2	269	0.362	6.95	7.85	31.1	29.1	42.6	9.03
PFM004298	3.87	3.92	5	1	131	8.45	48.9	7.21	4.12	1.5	27.4	8.21	5.3	<0.01	1.42	<0.01	76.5	642	0.587	<0.5	21.1	49.9	51.5	37	13.7
PFM004298	4.02	4.07	6	1	122	9.31	39.7	7.11	3.85	1.53	21.3	7.94	5.15	<0.01	1.38	<0.01	59.1	528	0.498	<0.5	18.6	46.7	41.2	25.9	11.6
PFM004298	4.2	4.25	7	1	104	9.6	37.4	6.46	3.04	1.37	23.1	6.88	5.71	<0.01	1.25	<0.01	55.3	563	0.549	<0.5	17.2	44.7	38.1	26.3	11

Table I-1. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Rb mg/kg dw	S mg/kg dw	Sb mg/kg dw	Sc mg/kg dw	Se mg/kg dw	Sm mg/kg dw	Sn mg/kg dw	Sr mg/kg dw	Ta mg/kg dw	Tb mg/kg dw	Th mg/kg dw	Tl mg/kg dw	Tm mg/kg dw	U mg/kg dw	V mg/kg dw	W mg/kg dw	Y mg/kg dw	Yb mg/kg dw	Zn mg/kg dw	Zr mg/kg dw
PFM006023[1)]	0.66	0.69	1	1	27.6	10,600	–0.04	7.37	<0.1	1.87	<0.05	84.3	0.286	0.135	2.07	0.777	<0.01	6.33	46.4	0.634	19.8	0.71	125	82.7
PFM006023[2)]	1.03	1.06	2	1	72.5	17,200	–0.04	7.13	<0.1	4.98	1.71	78.9	0.715	0.414	5.87	0.612	0.2	11.1	47.4	1.17	18.7	1.68	111	74.7
PFM006023	1.58	1.61	3	1	123	1,570	0.244	2.58	<0.1	2.83	<0.05	154	0.432	0.236	5.43	0.912	0.171	2.05	34	0.706	13	1.34	41.8	123
PFM006023	1.93	1.96	4	1	195	539	0.358	17.1	<0.1	6.68	3.18	145	1.33	0.851	16.2	1.48	0.528	8.01	123	1.77	32.7	3.51	145	170
PFM006024[3)]	0.33	0.36	1	1	0.2	1,210	0.189	0.0426	0.223	0.0112	0.1	5.5	0.014	0.0011	<0.01	–0.03	<0.01	0.0188	0.403	0.0371	0.071	0.0046	10.3	0.289
PFM006024[3)]	1.13	1.16	2	1	0.2	460	0.059	0.0247	0.198	0.0079	0.04	22.2	0.013	0.001	<0.01	<0.01	<0.01	0.0099	0.166	<0.01	0.035	0.0023	2.4	0.114
PFM006024[3)]	1.53	1.56	3	1	0.5	8,110	0.135	0.152	0.401	0.148	0.04	39.8	0.024	0.0204	0.0477	<0.01	0.0127	3.02	0.845	0.0135	1.06	0.084	2	1.12
PFM006024[4)]	1.73	1.76	4	1	3.8	13,600	0.19	<0.01	<0.1	0.667	<0.05	57.6	<0.01	<0.01	1.02	0.051	<0.01	8.32	3.58	<0.01	<0.01	0.491	73.5	2.6
PFM006024	1.93	1.96	5	1	102	15,100	<0.01	10.4	<0.1	5.52	<0.05	90	0.735	0.717	10	0.707	0.412	10.6	62.5	1.47	31.8	2.39	75.5	140
PFM006024	2.63	2.66	6	1	151	195	2.4	12.7	<0.1	5.81	3.35	182	1.25	0.661	12	1.1	0.319	4.58	90.4	1.2	25.5	2.15	115	115
PFM002501	0	0.16	1	1	7.4	17,900	1.44	2.13	1.17	1.86	<0.05	31	0.181	0.353	0.372	0.3	0.215	26	12.8	2.57	12.5	0.996	138	14
PFM002501	0.2	0.3	2	1	9	22,700	1.73	3.23	1.65	2.9	<0.05	37.2	0.131	0.506	0.672	0.363	0.269	49.4	14.7	1.77	18.3	1.47	119	19.8
PFM002502[5)]	0	0.03	1	1	19.9	11,700	0.522	1.39	<0.1	4.42	4.82	37.7	0.305	0.751	3.87	0.104	0.602	70.3	8.28	4.77	8.37	2.72	36	14.3
PFM004298[6)]	2.53	2.64	1	1	8.6	18,800	1.27	2.55	<0.1	2.53	<0.05	56.9	0.245	0.192	1.89	0.869	0.291	34.6	13.8	1.96	15.4	1.47	754	15.2
PFM004298[3)]	2.64	2.71	2	1	4.8	13,300	1.41	1.4	<0.1	1.87	<0.05	100	0.274	<0.01	0.81	0.266	<0.01	23.7	11.4	1.05	9.2	1.25	426	6.3
PFM004298[6)]	3.1	3.2	3	1	22.4	21,300	0.694	3.09	<0.1	1.92	<0.05	60.4	0.431	0.384	1.6	0.335	0.167	41.1	25.8	1.46	13.9	1.23	447	25.2
PFM004298	3.56	3.62	4	1	98.1	16,500	1.26	10.6	<0.1	5.09	<0.05	99.2	0.884	0.991	9.45	1.68	0.416	10.2	60.9	2.04	29.6	2.44	682	140
PFM004298	3.87	3.92	5	1	151	5,100	0.843	20	<0.1	9	3.9	163	1.77	1.36	19.9	1.42	0.729	3.98	149	2.29	43.2	4.34	1,570	179
PFM004298	4.02	4.07	6	1	127	538	0.752	16.5	<0.1	8.8	4.14	163	1.66	1.27	17	0.883	0.681	3.15	120	2.63	37.4	3.89	1,150	192
PFM004298	4.2	4.25	7	1	138	438	0.782	16.7	<0.1	7.78	2.8	164	1.5	0.936	16	1.02	0.6	4.22	118	2.48	35.1	3.56	1,140	180

[1)] Too small sample volumes. TOC, total N, organic N and PO_4^{3-} could not be analysed.
[2)] For analyses of Ag, B, Be, Co, Cs, Pb, Sb, Se, Tl, Li, Zn, Br, Cl, I, dry substance, TOC, organic N and total N an extra sample from 1.00–1.03 cm was used.
[3)] Too small sample volumes. PO_4^{3-} could not be analysed.
[4)] For analyses of Ag, B, Be, Co, Cs, Pb, Sb, Se, Tl, Li, Zn, Br, Cl, I, dry substance, TOC, organic N and total N an extra sample from 1.70–1.73 cm was used. Too small sample volumes. TOC and PO_4^{3-} could not be analysed.
[5)] For analyses of Ag, B, Be, Co, Cs, Pb, Sb, Se, Tl, Li, Zn, Br, Cl, I, dry substance a mixture of samples from 0–5 cm was used, for other analyses only samples from 0–2.5 cm were used. Too small sample volumes. PO_4^{3-} could not be analysed.
[6)] Too small sample volumes. Total N, organic N and PO_4^{3-} could not be analysed.
[7)] Different sampling techniques and reference systems have been used for PFM002501 and PFM002502 than for PFM004298. For the first samples the sediment surface was used as 0-level, for PFM002501 there was no algal mat, thus 0 = top of sediment, while for PFM002502 0 = top of algal mat. These samples were collected with a Kajak sampler. For PFM004298 0-level is the top of the ice, water depth has been determined with a sounding lead and the sampling of the sediments were done with a Russian core sampler. The measured water depth is probably over estimated (2.30 m) and probably contain algal mat. There is some overlap for PFM002501 and PFM004298.

Table I-2. Total chemistry of marine sediments /Hannu and Karlsson 2006/.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Dry subst %	Ash subst %	Total C mg/kg dw	Total organic C mg/kg dw	Total N mg/kg dw	Total organic N mg/kg dw	PO_4 mg/kg dw	Al mg/kg dw	Al_2O_3 %	Ca mg/kg dw	CaO %	Fe mg/kg dw	Fe_2O_3 %	K mg/kg dw	K_2O %	Mg mg/kg dw	MgO %	Mn mg/kg dw	MnO %	Na mg/kg dw	Na_2O %	P mg/kg dw
PFM002560	0.14	0.16	1	1	Marine sediment			100.000	100.000	6.200	5.850	38		7.5		0.89		3.69		2.03		1.71		0.0336		2.61	
PFM002560	0.28	0.3	2	1	Marine sediment			9.900	9.800	1.330	1.190	42		11.9		1.45		3.28		3.59		0.67		0.0348		2.93	
PFM006062	2.09	2.21	1	1	Marine sediment	37.9		34.000	36.000	5.000	4.600	50		10.8		1.29		4.4		2.86		1.77		0.0547		1.88	
PFM006062	2.24	2.3	2	1	Marine sediment; sand/gravel	72.8								11.2		6.17		3.85		2.86		0.78		0.0606		3.01	
PFM006062	2.34	2.41	3	1	Marine sediment. clay	56								18.4		1.62		9.54		4.53		3.64		0.0862		2.02	
PFM006062	2.6	2.67	4	1	Marine sediment. clay	63.3								14		8.34		6.39		3.7		2.49		0.0807		1.86	
PFM006062	2.8	2.87	5	1	Marine sediment. clay	63.6								14.2		10.5		6.82		3.81		2.68		0.089		1.67	

Table I-2. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	P_2O_5 %	Si mg/kg dw	SiO_2 %	Ti mg/kg dw	TiO_2 %	Sum oxides %	Loss on ignition %	Ag mg/kg dw	As mg/kg dw	B mg/kg dw	Ba mg/kg dw	Be mg/kg dw	Br mg/kg dw	Cd mg/kg dw	Ce mg/kg dw	Cl mg/kg dw	Co mg/kg dw
PFM002560	0.14	0.16	1	1	Marine sediment	0.115		38.4		0.33	57.3	24.5	7.27	5.45	<0.3	282	1.62	91.7	1.54	52	16.800	7.91
PFM002560	0.28	0.3	2	1	Marine sediment	0.092		73.2		0.21	97.4	2.5	4.98	2.42	<0.3	580	1.9	9.83	0.142	34.8	1.550	4.9
PFM006062	2.09	2.21	1	1	Marine sediment	0.166		62.1		0.53	85.9	12.3	0.16	6.52	<0.3	441	1.32	19.3	0.254	57.2	3.850	10.7
PFM006062	2.24	2.3	2	1	Marine sediment; sand/gravel	0.084		66		0.26	94.3	5.2	0.05	5.46	<0.3	496	0.65	4.39	0.131	36.5	757	5.66
PFM006062	2.34	2.41	3	1	Marine sediment. clay	0.186		53		0.87	93.9	5.5	0.16	14.1	<0.3	682	2.81	6.66	0.198	96.5	1.820	24.6
PFM006062	2.6	2.67	4	1	Marine sediment. clay	0.157		52.3		0.66	90	9	0.1	6.18	<0.3	547	1.78	4.62	0.167	68.9	1.260	15.8
PFM006062	2.8	2.87	5	1	Marine sediment. clay	0.155		47.8		0.69	88.4	11.3	0.1	6.68	<0.3	552	1.86	5.04	0.165	69.8	1.380	17.2

Table I-2. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Cr mg/kg dw	Cs mg/kg dw	Cu mg/kg dw	Dy mg/kg dw	Er mg/kg dw	Eu mg/kg dw	Ga mg/kg dw	Gd mg/kg dw	Hf mg/kg dw	Hg mg/kg dw	Ho mg/kg dw	I mg/kg dw	La mg/kg dw	Li mg/kg dw	Lu mg/kg dw	Mo mg/kg dw	Nb mg/kg dw	Nd mg/kg dw	Ni mg/kg dw	Pb mg/kg dw	Pr mg/kg dw	Rb mg/kg dw	S mg/kg dw	Sb mg/kg dw
PFM002560	0.14	0.16	1	1	57.5	4.35	47.7	3.48	2.31	0.617	15.7	3.31	1.88	<0.01	0.675	10.3	27.1	23.9	0.245	17.7	2.38	26.6	30.2	22.1	6.7	79.6	15.300	0.587
PFM002560	0.28	0.3	2	1	43.7	2.48	13.8	2.34	1.27	0.493	17	2.17	3.09	<0.01	0.506	1.04	22.7	14.5	0.219	<0.5	6.14	15.4	13.4	19.4	4.84	116	3.630	0.308
PFM006062	2.09	2.21	1	1	82.7	4.84	53.4	4.61	2.46	0.781	17.3	3.92	4.78	<0.01	0.853	1.36	36	26.6	0.333	2.64	11	28.8	33.8	27.2	7.87	94.7	14.000	0.041
PFM006062	2.24	2.3	2	1	45.8	1.32	15.7	2.99	2.26	0.535	9.35	3.26	3.69	<0.01	0.686	<0.1	19	10.5	0.299	1.69	5.45	19.2	12.2	8.04	4.84	84.2	4.090	–0.04
PFM006062	2.34	2.41	3	1	124	9.52	52.9	4.96	2.57	1.02	19.4	4.73	4.2	<0.01	1.05	<0.1	62.5	66.4	0.376	0.69	16.6	43.1	67.2	29.7	11.6	172	4.970	–0.04
PFM006062	2.6	2.67	4	1	98.9	7.15	32.3	4.26	2.42	0.846	14.5	4.19	4.02	<0.01	0.852	<0.1	36.8	47.5	0.301	<0.5	13.5	33.1	42.6	20.1	8.37	132	510	–0.04
PFM006062	2.8	2.87	5	1	94.1	7.86	34.4	3.78	2.62	0.888	15	4.17	3.48	–0.04	0.826	–0.5	42	51	0.296	0.45	14.5	33.3	44.9	19.8	8.83	140	545	–0.04

Table I-2. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sc mg/kg dw	Se mg/kg dw	Sm mg/kg dw	Sn mg/kg dw	Sr mg/kg dw	Ta mg/kg dw	Tb mg/kg dw	Th mg/kg dw	Tl mg/kg dw	Tm mg/kg dw	U mg/kg dw	V mg/kg dw	W mg/kg dw	Y mg/kg dw	Yb mg/kg dw	Zn mg/kg dw	Zr mg/kg dw
PFM002560	0.14	0.16	1	1	8.05	<0.1	3.33	<0.05	97.9	0.542	0.639	5.18	0.608	0.284	11.3	53.7	1.47	22.9	1.75	290	63.1
PFM002560	0.28	0.3	2	1	4.6	<0.1	2.69	1.69	155	0.361	0.454	5.21	0.763	0.227	1.99	27.8	1.38	15.6	1.29	44.1	125
PFM006062	2.09	2.21	1	1	11.2	<0.1	5.69	<0.05	109	0.941	0.827	8.04	0.489	0.347	4.97	74.1	2.49	31.9	2.69	131	201
PFM006062	2.24	2.3	2	1	5.72	<0.1	2.93	1.14	131	0.49	0.528	6.2	0.204	0.331	2.56	41.4	1.75	24.2	2.05	46.2	168
PFM006062	2.34	2.41	3	1	19	<0.1	7.54	1.42	140	1.52	1.03	13.9	0.998	0.559	5.35	142	2.89	35.9	2.65	159	178
PFM006062	2.6	2.67	4	1	13.2	<0.1	5.94	1.18	163	1.17	0.854	9.89	0.793	0.391	4.55	118	1.91	30.8	2.47	112	188
PFM006062	2.8	2.87	5	1	14.1	<0.1	5.19	1.24	167	1.17	0.818	9.74	0.769	0.403	3.34	102	1.83	29	2	111	142

Table I-3. C, N, S, P and $CaCO_3$ composition of sediments and peat.

ID code	Depth from (m)	Depth to (m)	Quaternary deposit	$C_{(org)}$ %	N %	S %	P %	$CaCO_3$ %	Org matter % (C_{org} x 1.7)	Estimated facies
Lake Fiskarfjärden										
PFM004204_27	1.13	1.16	algal gyttja					0.0		lake
PFM004204_2	1.2	1.22	algal gyttja	19.3	1.7	2.6		-		lake
PFM004204_3	1.3	1.32	algal gyttja	16.7	1.6	2.3		-		lake
PFM004204_28	1.32	1.36	algal gyttja					0.7		lake
PFM004204_4	1.4	1.42	algal gyttja	15.7	1.5	2.1		-		lake
PFM004204_5	1.5	1.52	algal gyttja	15.6	1.6	1.8		-		lake
PFM004204_1	1.1	1.13	algal gyttja	22.4	1.9	3.0		-	38.3	lake
PFM004204_27	1.13	1.16	algal gyttja					0.0		lake
PFM004204_2	1.2	1.22	algal gyttja	19.3	1.7	2.6		-	33.0	lake
PFM004204_3	1.3	1.32	algal gyttja	16.7	1.6	2.3		-	28.6	lake
PFM004204_28	1.32	1.36	algal gyttja					0.7		lake
PFM004204_4	1.4	1.42	algal gyttja	15.7	1.5	2.1		-	26.8	lake
PFM004204_5	1.5	1.52	algal gyttja	15.6	1.6	1.8		-	26.7	lake
PFM004204_29	1.56	1.6	algal gyttja					0.4		lake
PFM004204_6	1.6	1.62	algal gyttja	13.2	1.4	1.7		-	22.6	lake
PFM004204_7	1.65	1.67	clay gyttja	5.9	0.7	2.2		-	10.2	shallow coast
PFM004204_30	1.67	1.7	clay gyttja					0.5		shallow coast
PFM004204_8	1.7	1.72	clay gyttja	5.5	0.7	1.2		-	9.4	shallow coast
PFM004204_9	1.75	1.77	clay gyttja	4.2	0.5	2.2		-	7.3	shallow coast
PFM004204_10	1.8	1.82	clay gyttja	4.1	0.5	2.6		-	7.0	shallow coast
PFM004204_11	1.85	1.87	clay gyttja	4.8	0.6	1.7		-	8.1	shallow coast
PFM004204_31	1.87	1.9	clay gyttja					0.6		coast
PFM004204_12	1.9	1.92	clay gyttja	5.0	0.6	1.8		-	8.5	coast
PFM004204_13	1.95	1.97	clay gyttja	4.6	0.6	1.7		-	7.8	coast
PFM004204_14	2	2.04	clay gyttja	4.6	0.6	1.4		-	7.8	coast
PFM004204_15	2.05	2.07	clay gyttja	4.8	0.6	2.0		-	8.3	coast
PFM004204_16	2.1	2.12	clay gyttja	2.3	0.3	0.8		-	4.0	coast
PFM004204_17	2.25	2.28	postglacial clay	1.1	0.1	0.8		-	1.8	off shore
PFM004204_18	2.3	2.45	postglacial clay					0.9		off shore
PFM004204_19	2.45	2.48	postglacial clay	1.2	0.1	1.6		-	2.0	off shore
PFM004204_20	2.48	2.65	postglacial clay					0.6		off shore
PFM004204_21	2.65	2.68	postglacial clay	1.2	0.1	0.7		-	2.1	off shore
PFM004204_22	2.68	2.85	postglacial clay					0.0		off shore
PFM004204_23	2.85	2.88	postglacial clay	1.3	0.2	1.5		-	2.3	off shore
PFM004204_24	3.45	3.6	postglacial clay					0.8		off shore
PFM004204_33	4	4.03	glacial clay	0.4	0.1	0.0		-	0.7	glacio lacustrine
PFM004204_25	4.2	4.35	glacial clay					26.0		glacio lacustrine
PFM004204_34	4.5	4.54	glacial clay	1.2	0.1	0.0		-	2.1	glacio lacustrine
PFM004204_26	4.8	4.94	glacial clay					16.0		glacio lacustrine
Small pond #5										
PFM004205_1	0.4	0.45	algal gyttjaa	27.3	2.9	3.3		-	46.7	small lake/pond
PFM004205_2	0.5	0.55	algal gyttjaa	26.2	2.5	3.3		-	44.8	small lake/pond
PFM004205_3	0.6	0.65	algal gyttjaa	6.9	0.7	1.6		-	11.7	small lake/pond
PFM004205_4	0.7	0.75	algal gyttjaa	7.7	0.7	1.9		-	13.2	shallow coast
PFM004205_5	0.8	0.85	clay gyttjaa	3.7	0.4	1.2		-	6.4	shallow coast
PFM004205_6	1.27	1.37	glacial clay. distal varves					20.0		glacio lacustrine
PFM004205_8	1.5	1.65	glacial clay. 8 prox varv					26.0		glacio lacustrine
PFM004205_9	1.65	1.81	glacial clay. winter layers					14.0		glacio lacustrine
PFM004205_10	1.7	1.81	glacial clay. summer layers					29.0		glacio lacustrine
PFM004205_11	1.81	1.94	glacial clay. summer layers					33.0		glacio lacustrine
PFM004205_12	1.81	1.94	glacial clay. winter layers					14.0		glacio lacustrine
PFM004205_13	1.94	2	glacial clay. 4 varves					26.0		glacio lacustrine
PFM004205_14	2	2.14	glacial clay. 7 varves					28.0		glacio lacustrine
PFM004205_15	2.14	2.27	glacial clay. 6 summer layers					22.0		glacio lacustrine
PFM004205_16	2.14	2.27	glacial clay. 6 winter layers					38.0		glacio lacustrine

ID code	Depth from (m)	Depth to (m)	Quaternary deposit	$C_{(org)}$ %	N %	S %	P %	$CaCO_3$ %	Org matter % (C_{org} x 1.7)	Estimated facies
Bredviken										
PFM004216_1	3.62	3.79	glacial clay					33.0		glacio lacustrine
PFM004216_2	4	4.1	glacial clay. bottom slayer					35.0		glacio lacustrine
Puttan										
PFM004280_1	0.85	0.9	algal gyttja	25.7	2.6	2.0		-	43.9	small lake/pond
PFM004280_2	0.9	0.95	algal gyttja	20.6	1.9	2.1		-	35.2	small lake/pond
PFM004280_3	1	1.03	algal gyttja	13.7	1.3	1.7		-	23.4	small lake/pond
PFM004280_22	1.03	1.1	algal gyttja					0.9		small lake/pond
PFM004280_4	1.1	1.13	algal gyttja	12.8	1.2	1.7		-	21.9	small lake/pond
PFM004280_5	1.2	1.23	algal gyttja	12.0	1.1	1.6		-	20.5	shallow coast
PFM004280_6	1.3	1.33	algal gyttja	11.8	1.1	1.5		-	20.2	shallow coast
PFM004280_23	1.33	1.4	algal gyttja					0.8		shallow coast
PFM004280_7	1.4	1.45	algal gyttja	12.2	1.2	1.6		-	20.9	shallow coast
PFM004280_8	1.5	1.55	algal gyttja	13.0	1.2	1.5		-	22.2	shallow coast
PFM004280_24	1.55	1.6	algal gyttja					0.6		shallow coast
PFM004280_9	1.6	1.65	algal gyttja	12.3	1.2	1.5		-	21.0	shallow coast
PFM004280_10	1.7	1.75	algal gyttja	8.3	0.8	1.4		-	14.1	shallow coast
PFM004280_25	1.75	1.8	algal gyttja					0.1		shallow coast
PFM004280_11	1.8	1.85	algal gyttja	8.8	0.8	1.6		-	15.0	shallow coast
PFM004280_12	1.9	1.95	algal gyttja	8.3	0.8	1.5		-	14.2	shallow coast
PFM004280_13	2	2.05	algal gyttja	8.7	0.8	1.6		-	14.9	shallow coast
PFM004280_26	2.05	2.12	algal gyttja					0.3		shallow coast
PFM004280_14	2.12	2.15	algal gyttja	6.9	0.8	1.5		-	11.8	shallow coast
PFM004280_15	2.22	2.27	algal gyttja	8.3	0.9	1.5		-	14.3	shallow coast
PFM004280_16	2.27	2.3	algal gyttja	8.0	0.8	1.5		-	13.7	shallow coast
PFM004280_17	2.3	2.33	algal gyttja	8.0	0.8	1.5		-	13.7	shallow coast
PFM004280_18	2.33	2.36	clay gyttja	5.9	0.7	1.3		-	10.0	shallow coast
PFM004280_19	2.36	2.39	clay gyttja	5.5	0.7	1.4		-	9.4	shallow coast
PFM004280_20	2.4	2.45	sand	1.1	0.1	0.5		-		off shore
PFM004280_21	2.45	0.92	sand	0.5	0.1	0.3		-		off shore
Stocksjön										
PFM004284_1	0.87	0.92	calcareous gyttja					63.0		small lake/pond
PFM004284_2	0.92	0.94	calcareous gyttja					57.0		small lake/pond
Kallrigafrjärden										
PFM005791	0.02	0.04			0.9		0.1		6.9	shallow coast
PFM005791	0.18	0.2			0.8		0.1		6.4	shallow coast
PFM005791	0.34	0.36			0.8		0.1		7.8	shallow coast
PFM005791	0.65	0.68			0.6		0.1		5.7	shallow coast
Kallrigafjärden										
Not in sicada. (R-03-26)	0		clay gyttja						6.3	shallow coast
	0.05		clay gyttja						6.3	shallow coast
	0.1		clay gyttja						6.0	shallow coast
	0.15		gyttja clay						5.7	shallow coast
	0.2		gyttja clay						5.8	shallow coast
	0.25		gyttja clay						5.7	shallow coast
	0.3		gyttja clay						4.9	shallow coast
	0.35		gyttja clay						5.0	shallow coast
	0.4		gyttja clay						4.0	shallow coast
	0.45		gyttja clay						4.0	shallow coast
	0.5		gyttja clay						3.2	shallow coast
	0.55		gyttja clay						4.0	shallow coast
	0.6		gyttja clay						4.0	shallow coast
	0.65		gyttja clay						3.2	shallow coast
	0.7		gyttja clay						4.3	shallow coast
	0.75		gyttja clay						5.8	shallow coast
	0.8		clay gyttja						11.0	shallow coast
	0.85		clay gyttja						10.0	shallow coast
	0.9		clay gyttja						10.0	shallow coast
	0.95		clay gyttja						10.0	shallow coast

ID code	Depth from (m)	Depth to (m)	Quaternary deposit	C $_{(org)}$ %	N %	S %	P %	$CaCO_3$ %	Org matter % (C_{org} x 1.7)	Estimated facies
	1		clay gyttja						8.2	shallow coast
	1.05		clay gyttja						9.0	shallow coast
	1.1		clay gyttja						9.0	shallow coast
	1.15		clay gyttja						8.5	shallow coast
	1.2		clay gyttja						8.3	shallow coast
	1.25		clay						1.0	offshore
	1.3		clay						1.0	offshore
	1.35		clay						1.0	offshore
Tixelfjärden										
PFM005792	0.02	0.04		6.4	0.8		0.2		6.4	shallow coast
PFM005792	0.1	0.12		6.1	0.8		0.1		6.1	shallow coast
PFM005792	0.18	0.2		6.0	0.7		0.1		6.0	shallow coast
PFM005792	0.34	0.36		5.5	0.7		0.1		5.5	shallow coast
Rönningarna										
PFM006025	0.26	0.28		56.0	1.0		0.0		56.0	bog
PFM006025	0.6	0.65		57.0	0.4		0.0		57.0	bog
PFM006025	1.46	1.5		55.0	1.3		0.0		55.0	fen
PFM006025	1.85	1.87		50.0	3.9		0.0		50.0	fen
Eckarfjärden										
Not in SICADA. (TR-03-17)	303		gyttja	40.0						lake
	305		gyttja	34.0						lake
	307		gyttja	15.6						lake
	309		gyttja	7.5						lake
	311		gyttja	19.6						lake
	313		gyttja	41.1						lake
	316		gyttja	43.6						lake
	319		gyttja	34.0						lake
	325		gyttja	27.7						lake
	330		gyttja	24.3						lagoon
	338		gyttja	22.3						lagoon
	344		gyttja	18.0						lagoon
	350		clay gyttja	13.1						lagoon
	352		clay gyttja	8.4						lagoon
	354		clay gyttja	6.1						lagoon
	356		clay gyttja	5.5						coast
	360		clay gyttja	7.0						coast
	365		clay gyttja	7.0						coast
	370		clay	1.4						glacio lacustrine
	390		clay	0.7						glacio lacustrine
	395		clay	1.2						glacio lacustrine
	400		clay	0.8						glacio lacustrine
	410		clay	0.8						glacio lacustrine
	420		clay	0.7						glacio lacustrine

Chemistry of the soil profiles.

Table J-1. Total chemical analyses in soil profiles /Hannu and Karlsson 2006/.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Dry subst %	Ash subst %	Total C mg/kg dw	Total organic C mg/kg dw	Total N mg/kg dw	Total organic N mg/kg dw	PO_4 mg/kg dw	Al mg/kg dw	Al_2O_3 %	Ca mg/kg dw	CaO %	Fe mg/kg dw	Fe_2O_3 %	K mg/kg dw	K_2O %	Mg mg/kg dw	MgO %	Mn mg/kg dw	MnO %
AFM001068	0	0.03	1	1	Soil. humus	54		200.000	190.000	8.460	7.940	330		8		3.48		2.59		2.24		0.78		0.0467
AFM001068	0.03	0.03	2	1	Soil. humus	66.5		240.000	190.000	6.760	6.180	160		6.8		2.49		2.16		1.99		0.48		0.0343
AFM001068	0	0.1	3	1	Soil. mineral soil	79.1		110.000	97.000	6.480	6.070	130		10.5		3.02		3.66		2.8		1.05		0.0553
AFM001068	0.1	0.2	4	1	Soil. mineral soil	80.6		110.000	100.000	4.970	4.360	115		11.4		3.28		3.83		3.04		1.13		0.0584
AFM001068	0	0.1	5	1	Rhizosphere soil. mineral soil	80.4		120.000	120.000	4.570	4.040	115		10.1		3.08		3.53		2.73		1.01		0.0533
AFM001068	0.1	0.2	6	1	Rhizosphere soil. mineral soil	83.1		100.000	96.000	4.920	4.420	60		11		3.01		3.66		3		1.09		0.0532
AFM001076	0	0.03	1	1	Soil. humus	37		200.000	200.000	12.400	11.300	215		4.9		1.82		1.27		1.55		0.31		0.0252
AFM001076	0.03	0.03	2	1	Soil. humus	59.4		170.000	150.000	5.680	4.900	71		8.2		2.57		2.24		2.37		0.49		0.0355
AFM001076	0	0.1	3	1	Soil. mineral soil	74.2		120.000	98.000	5.400	4.790	64		9.4		2.96		2.03		2.72		0.56		0.0443
AFM001076	0.1	0.2	4	1	Soil. mineral soil	84.8		49.000	48.000	4.630	4.340	60		10.8		2.21		1.88		3.15		0.5		0.0374
AFM001076	0	0.1	5	1	Rhizosphere soil. mineral soil	77.7		130.000	110.000	5.650	5.020	63		9		2.86		2.28		2.61		0.54		0.0414
AFM001076	0.1	0.2	6	1	Rhizosphere soil. mineral soil	77.2		110.000	89.000	4.670	4.210	63		9.8		2.81		2.45		2.85		0.55		0.0423
AFM001247	0	0.03	1	1	Soil. humus	34.4	18.5	480.000	330.000	18.400	17.100	460		1.9		1.68		0.39		0.59		0.15		0.0522
AFM001247	0.03	0.03	2	1	Soil. humus	36.3	17.7	470.000	200.000	18.500	17.500	310		1.8		1.12		0.40		0.55		0.11		0.0152
AFM001247	0	0.1	3	1	Soil. mineral soil	79.4	69.6	130.000	89.000	13.000	12.800	56		8.3		1.68		1.72		2.19		0.41		0.0219
AFM001247	0.1	0.2	4	1	Soil. mineral soil	82.3	85.5	63.000	53.000	10.500	10.300	30		9.6		2.11		1.90		2.86		0.52		0.0350
AFM001247	0	0.1	5	1	Rhizosphere soil. mineral soil	58.7	55	290.000	150.000	19.100	18.700	114		6.4		1.22		0.82		1.94		0.21		0.0145
AFM001247	0.1	0.2	6	1	Rhizosphere soil. mineral soil	74.8		150.000	150.000	12.300	11.700	120		9.1		3.36		2.79		2.45		0.47		0.0719

Table J-1. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Sample name	Na mg/kg dw	Na_2O %	P mg/kg dw	P_2O_5 %	Si mg/kg dw	SiO_2 %	Ti mg/kg dw	TiO_2 %	Sum oxides %	Loss on ignition %	Ag mg/kg dw	As mg/kg dw	B mg/kg dw	Ba mg/kg dw	Be mg/kg dw	Br mg/kg dw	Cd mg/kg dw	Ce mg/kg dw	Cl mg/kg dw	Co mg/kg dw
AFM001068	0	0.03	1	1	Soil. humus		1.59		0.143		42.6		0.27	61.7	36	5.89	1.53	<0.3	395	1.21	2.51	0.303	35.1	71	5.09
AFM001068	0.03	0.03	2	1	Soil. humus		1.46		0.12		39.7		0.2	55.4	42.5	6.02	2.41	<0.3	345	1.04	3.58	0.229	24.8	103	3.14
AFM001068	0	0.1	3	1	Soil. mineral soil		1.98		0.124		53.6		0.37	77.2	20	5.7	2.11	<0.3	488	1.61	3.01	0.177	47	38	8.52
AFM001068	0.1	0.2	4	1	Soil. mineral soil		2.15		0.134		59.3		0.41	84.7	19	5.66	1.89	<0.3	545	1.64	3.23	0.214	45.7	26	7.53
AFM001068	0	0.1	5	1	Rhizosphere soil. mineral soil		1.9		0.13		52.3		0.36	75.2	22.6	5.85	2.28	<0.3	475	1.69	2.9	0.181	51.5	30	6.83
AFM001068	0.1	0.2	6	1	Rhizosphere soil. mineral soil		2.04		0.119		57.3		0.38	81.7	17.6	5.73	2.24	<0.3	519	1.81	3.35	0.223	55.2	38	7.86
AFM001076	0	0.03	1	1	Soil. humus		1.15		0.111		31.4		0.1	42.7	56.6	4.36	1.86	<0.3	247	0.7	5.17	0.17	15.1	229	1.92
AFM001076	0.03	0.03	2	1	Soil. humus		1.87		0.082		46.2		0.17	64.2	30	5.15	2.7	<0.3	387	1.22	7.12	0.138	27.8	167	4.2
AFM001076	0	0.1	3	1	Soil. mineral soil		2.15		0.073		57.4		0.2	77.5	19.1	4.87	2.18	<0.3	445	1.43	4.93	0.114	25.6	53	3.84
AFM001076	0.1	0.2	4	1	Soil. mineral soil		2.54		0.063		71.5		0.22	92.9	8.2	4.63	1.46	<0.3	518	1.65	2.62	0.063	32.7	<10	3.33
AFM001076	0	0.1	5	1	Rhizosphere soil. mineral soil		2.1		0.077		52.9		0.2	72.6	22	4.57	1.41	<0.3	428	1.3	6.84	0.123	27.1	77	3.91
AFM001076	0.1	0.2	6	1	Rhizosphere soil. mineral soil		2.24		0.074		58.8		0.21	79.8	15.9	4.74	2.11	<0.3	466	1.5	5.81	0.121	32.2	43	4.21
AFM001247	0	0.03	1	1	Soil. humus		0.43		0.190		12.2		0.06	17.7		6.66	0.218	<0.3	154	0.21	2.31	0.06	7	281	0.872
AFM001247	0.03	0.03	2	1	Soil. humus		0.41		0.134		12.2		0.05	16.8		5.13	0.414	<0.3	165	0.19	1.63	0.097	7.2	173	0.768
AFM001247	0	0.1	3	1	Soil. mineral soil		1.86		0.105		52.0		0.24	68.5		5.55	1.57	<0.3	376	1.16	1.41	0.293	36.2	57	3.24
AFM001247	0.1	0.2	4	1	Soil. mineral soil		2.09		0.118		58.1		0.24	77.6		5.38	2.21	<0.3	472	1.58	1.09	0.357	49.8	<10	4.51
AFM001247	0	0.1	5	1	Rhizosphere soil. mineral soil		1.56		0.069		41.4		0.12	53.8		5.02	1.23	<0.3	323	0.88	1.75	0.327	11.8	67	1.71
AFM001247	0.1	0.2	6	1	Rhizosphere soil. mineral soil		2.02		0.172		51.7		0.19	72.3	25.9	7.61	3.44	<0.3	427	1.52	3.73	0.86	48	72	6.98

Table J-1. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	Cr mg/kg dw	Cs mg/kg dw	Cu mg/kg dw	Dy mg/kg dw	Er mg/kg dw	Eu mg/kg dw	Ga mg/kg dw	Gd mg/kg dw	Hf mg/kg dw	Hg mg/kg dw	Ho mg/kg dw	I mg/kg dw	La mg/kg dw	Li mg/kg dw	Lu mg/kg dw	Mo mg/kg dw	Nb mg/kg dw	Nd mg/kg dw	Ni mg/kg dw	Pb mg/kg dw	Pr mg/kg dw	Rb mg/kg dw
AFM001068	0	0.03	1	1	33.9	2.19	49.7	2.68	2.06	0.545	6.66	3.18	2.78	<0.01	0.605	1.03	23.7	13.2	0.25	<0.5	3.83	17.5	35.6	21.1	4.85	79.4
AFM001068	0.03	0.03	2	1	36.2	1.48	16.3	2.3	1.12	0.557	9.15	1.63	2.92	0.15	0.471	1.96	16.7	7.28	0.187	<0.5	2.48	11.4	9.25	28	3.51	70.4
AFM001068	0	0.1	3	1	49.8	2.94	19.4	3.62	2.02	0.767	11.1	3.94	4	<0.04	0.821	1.14	31.3	19	0.289	<0.5	5.76	20.2	13.1	24.4	6.51	101
AFM001068	0.1	0.2	4	1	57	3.48	81.2	4.22	2.15	0.755	11.5	4.39	3.09	<0.01	0.851	1.04	34.6	19.4	0.306	2.72	5.87	23	14.6	25.5	6.02	110
AFM001068	0	0.1	5	1	53.6	3.28	20	3.64	2.13	0.674	11.2	4.52	3.78	<0.01	0.853	1.01	31.6	18.5	0.269	<0.5	6.62	24.3	13.1	26.1	6.63	91.4
AFM001068	0.1	0.2	6	1	64.2	3.32	24.8	2.95	2.36	0.745	17.9	2.92	3.72	0.064	0.681	1.12	33.2	19.9	0.254	2.63	6.1	26.9	16.9	24.7	6.85	103
AFM001076	0	0.03	1	1	18.7	0.864	9.45	1.25	1.16	0.311	9.16	0.934	1.53	0.116	0.388	1.5	6.81	3.74	0.124	<0.5	2.71	7.02	4.75	20.2	2.63	50.6
AFM001076	0.03	0.03	2	1	27.8	1.53	14.9	2.09	1.04	0.479	13.2	2.91	1.86	0.074	0.432	1.59	9.07	7.17	0.186	4.86	1.67	14	9.18	20.2	3.53	71.4
AFM001076	0	0.1	3	1	37	1.73	7.74	2.5	1.83	0.59	10.8	2.35	2.25	<0.01	0.604	1.21	12	7.89	0.198	<0.5	2.73	13.5	6.33	16.5	3.87	89.8
AFM001076	0.1	0.2	4	1	36.8	1.78	5.53	1.99	1.51	0.564	13.7	2.06	2.79	<0.01	0.478	0.578	22.1	8.76	0.217	<0.5	4.59	16.4	5.04	16.5	4.72	101
AFM001076	0	0.1	5	1	39.9	1.68	13.6	2.79	1.53	0.444	6.73	2.17	2.4	<0.01	0.593	1.58	13.5	7.76	0.205	<0.5	1.9	12.4	7.48	18	3.71	76.2
AFM001076	0.1	0.2	6	1	52.2	1.85	14.9	2.4	1.6	0.455	13.6	2.01	2.56	0.042	0.64	1.31	16.4	8.49	0.206	<0.5	2.67	14.6	10.3	18.6	4.26	91.4
AFM001247	0	0.03	1	1	9.96	0.489	1.31	2.76	0.105	0.372	1.8	0.505	1.05	0.052	0.107	1.4	3.29	1.39	0.0461	0.58	1.16	3.24	0.416	32.1	0.783	16.5
AFM001247	0.03	0.03	2	1	7.48	0.322	1.37	0.464	0.0929	0.315	2.6	0.404	1.03	0.05	0.117	1.02	3.36	0.92	0.0358	0.6	1.08	2.81	0.32	36.8	0.819	14.3
AFM001247	0	0.1	3	1	21.3	1.11	6.52	2.64	0.452	1.29	<0.001	2.53	4.63	0.088	0.489	1.03	15.2	7.49	0.2	<0.5	5.15	15.3	2.36	31.7	4.22	66.7
AFM001247	0.1	0.2	4	1	25.7	2.04	9.83	3.68	0.545	2.1	<0.001	3.29	3.94	0.061	0.649	1.06	21.5	14	0.203	<0.5	5.08	20.9	4.98	24.9	5.45	81.6
AFM001247	0	0.1	5	1	13.6	0.911	7.2	1.12	0.289	0.819	1.15	3	2.03	0.085	0.202	1.11	6.21	4.16	0.115	<0.5	1.95	4.83	1.45	33.3	1.35	51.8
AFM001247	0.1	0.2	6	1	37.5	1.81	39.3	3.69	1.32	0.646	9.12	3.98	1.9	0.122	0.691	3.47	37.9	9.36	0.228	<0.5	4.03	22	13.3	41.5	6.02	85.3

Table J-1. Continued.

ID code	Secup m	Seclow m	Sub-sample no	DNO	S mg/kg dw	Sb mg/kg dw	Sc mg/kg dw	Se mg/kg dw	Sm mg/kg dw	Sn mg/kg dw	Sr mg/kg dw	Ta mg/kg dw	Tb mg/kg dw	Th mg/kg dw	Tl mg/kg dw	Tm mg/kg dw	U mg/kg dw	V mg/kg dw	W mg/kg dw	Y mg/kg dw	Yb mg/kg dw	Zn mg/kg dw	Zr mg/kg dw
AFM001068	0	0.03	1	1	984	0.409	5.48	<0.1	2.35	<0.05	118	0.567	0.537	1.55	0.591	0.264	5.75	32.7	2.87	18.3	1.96	62.1	84.8
AFM001068	0.03	0.03	2	1	1.250	0.734	4.28	<0.1	1.65	1.65	110	0.496	0.299	2.5	0.475	0.183	2.14	22.4	0.898	14	1.22	34.7	88.1
AFM001068	0	0.1	3	1	753	0.524	7.73	<0.1	3.24	1.98	133	0.586	0.733	3.48	0.73	0.424	6.72	46.8	3.3	22.9	2.34	53.4	142
AFM001068	0.1	0.2	4	1	817	0.489	8.1	<0.1	3.74	1.88	144	0.736	0.712	3.16	0.738	0.351	8.58	50.2	7.93	24.7	1.74	52	123
AFM001068	0	0.1	5	1	836	0.504	7.49	<0.1	4.53	2.25	129	0.852	0.691	3.19	0.747	0.258	7.42	44.6	2.19	21.6	1.79	52.6	101
AFM001068	0.1	0.2	6	1	776	0.485	8.02	<0.1	4.05	2.06	140	0.946	0.771	6.98	0.762	0.328	6.57	47.8	1.47	24.4	1.96	56.8	158
AFM001076	0	0.03	1	1	1.440	0.488	2.78	<0.1	1.38	<0.05	89.5	0.404	0.288	1.41	0.311	0.145	1.27	11.2	0.847	8.98	0.931	36.6	34.2
AFM001076	0.03	0.03	2	1	1.300	0.468	4.14	<0.1	2.26	1.74	126	0.336	0.4	2.15	0.485	0.255	2.55	17.7	0.907	14.8	1.57	21.3	57.8
AFM001076	0	0.1	3	1	897	0.322	5.37	<0.1	2.14	7.17	144	0.402	0.342	2.15	0.549	0.251	3.61	20.6	0.769	16.9	1.43	17.9	73.2
AFM001076	0.1	0.2	4	1	567	0.229	5.23	<0.1	2.34	2.58	154	0.413	0.395	5.39	0.619	0.214	2.61	19.7	1.01	16.1	1.48	17.5	114
AFM001076	0	0.1	5	1	962	0.387	4.87	–1	2.01	<0.05	138	0.287	0.443	1	0.568	0.233	4.1	22.5	2.45	15.4	1.44	18.4	71
AFM001076	0.1	0.2	6	1	927	0.457	5.47	<0.1	2.72	<0.05	147	0.41	0.449	3.12	0.594	0.219	3.46	24	0.829	17.2	1.95	20.7	96.5
AFM001247	0	0.03	1	1	1.820	0.702	1.08	<0.1	0.511	0.79	47.4	0.182	0.0746	0.494	0.251	0.0537	0.814	8.26	1.03	3.26	0.309	85.5	28.2
AFM001247	0.03	0.03	2	1	1.820	0.809	1.07	<0.1	0.566	1.22	46.3	0.166	0.0667	0.542	0.158	0.0572	1.16	6.91	0.756	3.1	0.285	83.6	28.3
AFM001247	0	0.1	3	1	906	0.326	4.21	<0.1	2.9	1.92	120	0.692	0.385	4.86	0.478	0.252	3.6	21.9	1.22	14.8	1.36	56.9	141
AFM001247	0.1	0.2	4	1	656	0.214	5.29	<0.1	4.33	1.44	131	0.695	0.56	5.04	0.59	0.286	5.52	23.8	1.77	20.4	1.53	35.6	128
AFM001247	0	0.1	5	1	1.230	0.365	2.62	<0.1	1.06	1.17	93.6	0.369	0.17	0.973	0.433	0.111	1.79	11.2	1.43	7.29	0.742	42.5	71.5
AFM001247	0.1	0.2	6	1	890	0.702	5.13	<0.1	3.83	1.45	131	0.486	0.688	2.38	0.655	0.272	9.89	27.7	0.865	23.6	1.8	41.3	66.8

Table J-2. CEC of soil horizons. From /Lundin et al 2005/. Samples described by /Albrecht 2005/.

ID code	Horizon ID	TS (%)	pH water (pH unit)	pH CaCl2 (pH unit)	C TOT OF TS (per_cent)	C_OORG_OF_TS (per_cent)	N TOT OF TS (per_cent)	MN (mmolc/ 100g ts)	MG (mmolc/ 100g ts)	CA (mmolc/ 100g ts)	NA (mmolc/ 100g ts)	K (mmolc/ 100g ts)	TOT ACIDITY (mmolc/ 100g ts)	CEC TOT (mmolc/ 100g ts)	K_AL (mmolc/ 100g ts)	K_HCL (mmolc/ 100g ts)	P_AL (mg/ 100g ts)	P_HCL (mg/ 100g ts)	CU_HCL (mg/ kg_ts)
PFM004455	H30	91.32	3.58	2.91	55.600		1.930	0.03	2.95	21.40	0.70	1.00	114.50	140.70	0.82	0.98	5.27	32.70	5.500
	M010	99.63	5.07	4.29	0.838		0.059	0.00	0.22	1.98	0.03	0.04	2.20	4.50	0.05	0.90	0.40	6.40	0.800
	M020	99.56	6.31	5.88	1.320	0.610	0.060	0.01	0.20	12.30	0.03	0.04	0.00	12.60	0.03	1.63	1.06	28.10	1.600
	M065	99.78	7.13	6.30	1.850	1.760	0.017	0.02	0.15	11.10	0.02	0.04	0.00	11.40	0.02	1.71	1.60	32.70	4.700
	M100	99.87	7.73	6.37	1.670	1.760	0.011	0.02	0.12	10.40	0.01	0.03	0.00	10.60	-0.01	1.30	1.54	30.50	2.400
	M150	99.88	7.87	6.40	1.510	1.600	0.022	0.02	0.11	10.40	0.01	0.03	0.00	10.60	-0.01	1.10	1.47	32.50	4.200
	M200	99.87	8.08	6.42	1.980	1.870	0.022	0.02	0.11	10.60	0.01	0.04	0.00	10.80	-0.01	1.19	1.71	38.50	4.800
	M230	99.88	7.98	6.44	2.060	1.960	0.016	0.03	0.12	10.70	0.01	0.05	0.00	10.90	0.03	1.63	2.02	38.00	3.500
	MP5	99.37	5.69	5.14	1.140		0.076	0.01	0.39	4.60	0.03	0.04	1.90	7.00	0.07	1.45	0.82	14.20	1.000
PFM004457	H30	90.95	3.69	3.08	56.000		1.980	0.15	4.31	25.80	0.71	1.29	113.90	146.10	0.98	1.05	9.82	35.20	5.200
	M010	99.83	5.06	4.20	0.359		0.035	0.00	0.14	0.90	0.01	0.02	0.90	1.90	0.05	0.78	0.29	9.00	0.700
	M020	99.46	5.74	5.17	0.828		0.055	0.00	0.32	5.60	0.02	0.03	0.40	6.40	0.05	1.19	1.17	28.30	0.700
	M065	99.83	6.76	6.16	1.890		0.017	0.01	0.13	10.70	0.02	0.04	0.00	10.90	0.02	1.57	1.44	42.00	3.200
	M100	99.87	7.23	6.31	1.540		0.018	0.01	0.11	10.00	0.01	0.03	0.00	10.10	0.07	1.18	1.53	32.30	2.200
	M130	99.84	7.30	6.41	1.910		0.018	0.02	0.11	10.60	0.01	0.04	0.00	10.80	0.10	1.52	1.49	35.10	3.600
	MP5	99.33	7.22	6.65	1.290		0.070	0.01	0.31	13.20	0.03	0.04	0.00	13.60	0.04	1.24	1.26	32.30	1.500
PFM004458	H30	92.54	5.73	5.18	39.400		1.220	0.09	4.01	68.80	1.09	1.15	33.50	108.60	1.06	1.42	3.37	28.70	9.400
	M010	99.82	6.10	5.65	1.250		0.023	0.01	0.16	10.40	0.02	0.03	0.00	10.70	-0.01	1.09	1.21	27.20	3.000
	M020	99.87	6.68	6.09	1.540		0.015	0.01	0.14	10.30	0.02	0.03	0.00	10.50	-0.01	1.08	1.38	36.40	3.800
	M065	99.88	6.33	5.82	1.540		0.013	0.01	0.14	10.40	0.03	0.04	0.00	10.60	-0.01	0.91	1.46	28.10	4.100
	M100	99.90	6.54	5.83	1.710		0.013	0.02	0.14	10.50	0.03	0.04	0.00	10.70	0.03	0.98	1.65	31.60	2.900
	M150	99.92	7.37	6.24	1.940		0.013	0.03	0.14	10.40	0.03	0.04	0.00	10.70	0.07	0.92	1.90	28.00	2.800
	M200	99.91	8.01	6.37	2.050		0.015	0.03	0.17	10.90	0.03	0.08	0.00	11.30	0.11	1.82	2.27	32.40	3.700
	M250	99.93	8.41	6.49	1.720		0.011	0.03	0.13	10.50	0.03	0.05	0.00	10.70	0.05	1.32	1.79	30.90	3.000
	M300	99.92	8.19	6.56	1.540		0.014	0.02	0.14	10.40	0.03	0.05	0.00	10.60	0.08	1.09	1.79	31.90	3.300
PFM004459	H30	92.38	5.64	5.13	38.400		1.420	0.08	4.29	70.10	0.31	1.36	33.80	109.90	1.11	1.42	4.05	34.80	9.200
	M010	99.68	6.35	5.92	1.900		0.037	0.01	0.23	12.00	0.02	0.05	0.00	12.30	0.03	1.72	1.44	33.50	4.100
	M020	99.83	7.49	6.44	2.300		0.022	0.02	0.18	11.40	0.02	0.05	0.00	11.70	0.08	2.00	1.76	32.80	4.900
	M065	99.86	8.15	6.52	2.440		0.013	0.02	0.20	11.50	0.01	0.06	0.00	11.80	0.08	1.90	1.84	34.90	4.800
	M100	99.91	8.50	6.56	1.810		0.015	0.03	0.15	10.70	0.01	0.05	0.00	10.90	0.03	1.30	1.85	31.90	3.500
	M150	99.90	6.96	6.08	2.010		0.013	0.03	0.16	10.90	0.02	0.08	0.00	11.20	0.05	1.39	2.00	34.80	3.600
	M200	99.84	7.42	6.16	2.110		0.020	0.03	0.67	11.40	0.11	0.23	0.00	12.40	0.14	2.08	2.24	37.00	4.300
	M350	99.83	8.14	6.48	2.350		0.016	0.03	0.75	11.60	0.10	0.26	0.00	12.70	0.16	2.41	2.30	40.40	5.000
PFM004460	H30	95.21	7.25	6.57	15.000		0.861	0.07	2.60	78.10	0.11	0.33	0.00	81.20	0.32	0.98	2.14	35.20	10.000
	M010	99.79	7.29	6.59	0.304		0.034	0.00	0.08	2.82	0.01	0.02	0.10	3.00	0.02	0.69	0.37	16.00	0.800
	M020	99.80	6.97	6.44	0.242		0.021	0.00	0.09	2.90	0.01	0.03	0.00	3.00	0.02	1.26	0.60	18.30	1.900
	M065	99.89	7.19	6.50	2.200		0.012	0.01	0.20	11.00	0.01	0.04	0.00	11.30	0.04	1.33	1.58	32.30	5.000
	M100	99.83	7.87	6.54	2.020		0.014	0.02	0.24	11.50	0.01	0.07	0.00	11.80	0.06	2.14	1.54	34.70	5.900
	M150	99.90	8.20	6.57	2.220		0.012	0.03	0.15	10.90	0.01	0.06	0.00	11.20	0.03	1.74	1.92	36.20	4.700
	M200	99.93	8.29	6.56	1.990		0.012	0.03	0.13	10.40	0.01	0.05	0.00	10.70	0.07	1.42	1.95	36.50	4.700

Table J-3. Chemistry of soil horizons. from /Lundin et al. 2004/

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001066	**Borr 2:1**	0–30	H	6.14	5.73	18.1	0.8
AFM001066	Borr 2:1	0–10	M+	6.77	6.35	0.9	0.1
AFM001066	Borr 2:1	10–20	M	7.21	6.52	1.2	0.0
AFM001066	Borr 2:1	55–65	M	7.21	6.65	1.9	0.0
AFM001066	**Borr 2:11**	0–30	H	7.19	6.44	28.1	1.3
AFM001066	Borr 2:11	0–10	M	6.24	5.76	1.6	0.1
AFM001066	Borr 2:11	10–20	M	6.70	6.44	1.4	0.1
AFM001066	**Borr 2:13**	0–30	H	3.95	3.18	34.6	1.2
AFM001066	Borr 2:13	0–10	M	5.72	5.05	2.5	0.1
AFM001066	Borr 2:13	10–20	M	6.72	6.26	2.1	0.1
AFM001066	Borr 2:13	55–65	M	7.62	6.79	2.3	0.0
AFM001066	**Borr 2:16**	0–30	H	4.20	3.42	34.6	1.3
AFM001066	Borr 2:16	0–10	M	6.24	6.02	3.3	0.2
AFM001066	Borr 2:16	10–20	M	6.93	6.46	1.7	0.1
AFM001066	**Borr 2:4**	0–30	H	4.51	3.74	34.1	1.0
AFM001066	Borr 2:4	0–10	M	4.33	3.57	3.5	0.2
AFM001066	Borr 2:4	10–20	M	5.68	5.05	1.6	0.1
AFM001066	**Borr 2:5**	0–30	H	4.18	3.42	33.7	1.0
AFM001066	Borr 2:5	0–10	M	6.15	6.01	1.0	0.1
AFM001066	Borr 2:5	10–20	M	6.95	6.37	2.1	0.1
AFM001066	Borr 2:5	55–65	M	7.89	6.52	2.5	0.0
AFM001066	**Borr 2:7**	0–30	H	6.87	5.99	25.2	1.1
AFM001066	Borr 2:7	0–10	M	6.86	6.38	0.3	0.0
AFM001066	Borr 2:7	10–20	M	6.67	6.44	1.2	0.0
AFM001066	**Borr 2:9**	0–30	H	4.33	3.56	33.2	1.1
AFM001066	Borr 2:9	0–10	M	6.04	5.76	3.1	0.2
AFM001066	Borr 2:9	10–20	M	6.82	6.56	2.1	0.1
AFM001066	Borr 2:9	55–65	M	7.24	6.41	1.7	0.0
AFM001067	**Borr 3:1**	0–10	M+	6.81	5.84	6.5	0.4
AFM001067	Borr 3:1	10–20	M	6.83	6.21	3.8	0.2
AFM001067	Borr 3:1	55–65	M	7.54	6.70	2.3	0.0
AFM001067	**Borr 3:2**	0–10	M+	7.04	6.72	11.0	0.7
AFM001067	Borr 3:2	10–20	M	7.35	7.09	8.1	0.5
AFM001067	Borr 3:2	55–65	M	7.63	7.31	3.1	0.0
AFM001067	**Borr 3:3**	0–10	M+	7.36	6.66	5.6	0.3
AFM001067	Borr 3:3	10–20	M	6.95	7.06	3.2	0.2
AFM001067	Borr 3:3	55–65	M	7.61	6.70	2.1	0.0
AFM001067	**Borr 3:4**	0–10	M+	7.31	6.64	14.2	1.0
AFM001067	Borr 3:4	10–20	M	7.08	6.77	0.7	0.1
AFM001067	**Borr 3:5**	0–10	M+	6.90	6.40	7.8	0.5
AFM001067	Borr 3:5	10–20	M	5.99	5.51	3.0	0.2
AFM001067	**Borr 3:6**	0–10	M+	6.73	6.38	12.0	0.7
AFM001067	Borr 3:6	10–20	M	7.10	6.70	9.2	0.6
AFM001067	**Borr 3:7**	0–10	M+	6.94	6.75	9.6	0.5
AFM001067	Borr 3:7	10–20	M	7.36	7.06	3.5	0.2
AFM001067	Borr 3:7	55–65	M	7.64	6.69	2.4	0.0
AFM001067	**Borr 3:8**	0–10	M+	7.24	6.22	6.3	0.4
AFM001067	Borr 3:8	10–20	M	6.65	6.11	6.4	0.3

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001068	**FG 1:1**	0–30	H	6.63	5.92	6.4	0.4
AFM001068	FG 1:1	0–10	M	7.00	6.61	2.9	0.2
AFM001068	FG 1:1	10–20	M	7.33	6.91	1.8	0.1
AFM001068	FG 1:1	55–65	M	8.46	6.92	2.3	0.0
AFM001068	**FG 1:10**	0–30	H	6.12	5.70	7.1	0.3
AFM001068	FG 1:10	0–10	M	6.84	6.52	2.8	0.1
AFM001068	FG 1:10	10–20	M	7.20	6.67	2.4	0.0
AFM001068	FG 1:10	55–65	M	7.86	6.71	2.2	0.0
AFM001068	**FG 1:11**	0–30	H	7.46	6.66	8.6	0.4
AFM001068	FG 1:11	0–10	M	7.41	7.06	5.0	0.2
AFM001068	FG 1:11	10–20	M	7.08	6.85	2.5	0.1
AFM001068	**FG 1:13**	0–30	H	7.19	6.77	10.4	0.5
AFM001068	FG 1:13	0–10	M	7.81	7.15	4.8	0.2
AFM001068	FG 1:13	10–20	M	7.52	7.10	2.6	0.0
AFM001068	FG 1:13	55–65	M	8.07	7.26	2.3	0.0
AFM001068	**FG 1:15**	0–30	H	7.33	6.60	6.5	0.3
AFM001068	FG 1:15	0–10	M	7.21	6.95	2.4	0.1
AFM001068	FG 1:15	10–20	M	7.72	6.83	2.3	0.1
AFM001068	**FG 1:4**	0–30	H	4.57	3.80	31.4	1.1
AFM001068	FG 1:4	0–10	M	6.64	6.31	1.8	0.1
AFM001068	FG 1:4	10–20	M	7.55	6.75	2.7	0.1
AFM001068	**FG 1:5**	0–30	H	7.15	6.79	6.8	0.3
AFM001068	FG 1:5	0–10	M	7.49	7.00	4.9	0.2
AFM001068	FG 1:5	55–65	M	7.33	6.91	2.4	0.0
AFM001068	**FG 1:8**	0–30	H	7.40	6.70	10.2	0.5
AFM001068	FG 1:8	0–10	M	6.81	6.81	0.5	0.1
AFM001068	FG 1:8	10–20	M	7.27	6.91	1.6	0.1
AFM001069	**FG 2:1**	0–30	H	5.63	4.57	26.6	1.1
AFM001069	FG 2:1	0–10	M	5.43	4.59	8.0	0.4
AFM001069	FG 2:1	10–20	M	6.79	6.42	1.9	0.1
AFM001069	FG 2:1	55–65	M	7.26	6.85	1.9	0.0
AFM001069	**FG 2:11**	0–30	H	3.96	3.20	49.1	1.7
AFM001069	FG 2:11	0–10	M	4.99	4.25	1.9	0.1
AFM001069	FG 2:11	10–20	M	6.66	6.34	1.8	0.1
AFM001069	**FG 2:14**	0–30	H	3.82	3.00	39.9	1.6
AFM001069	FG 2:14	10–20	M	5.12	4.46	1.1	0.1
AFM001069	FG 2:14	55–65	M	6.42	6.23	2.2	0.0
AFM001069	**FG 2:2**	0–30	H	4.10	3.30	40.6	1.6
AFM001069	FG 2:2	0–10	M	4.97	4.07	2.6	0.2
AFM001069	FG 2:2	10–20	M	6.56	6.38	2.2	0.1
AFM001069	FG 2:2	55–65	M	6.20	5.71	2.1	0.0
AFM001069	**FG 2:3**	0–30	H	4.19	3.37	34.3	1.3
AFM001069	FG 2:3	0–10	M	4.34	3.55	1.9	0.1
AFM001069	FG 2:3	10–20	M	5.17	4.32	0.9	0.1
AFM001069	**FG 2:6**	0–30	H	4.05	3.39	45.0	1.7
AFM001069	FG 2:6	0–10	M	4.71	3.86	1.8	0.1
AFM001069	FG 2:6	10–20	M	6.28	5.64	1.4	0.1
AFM001069	FG 2:6	55–65		7.49	6.44	1.7	0.0
AFM001069	**FG 2:7**	0–30	H	4.27	3.46	39.5	1.8

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001069	FG 2:7	0–10	M	4.70	3.85	1.4	0.1
AFM001069	FG 2:7	10–20	M	6.51	6.05	1.1	0.1
AFM001069	**FG 2:9**	0–30	H	5.19	4.38	21.6	1.0
AFM001069	FG 2:9	0–10	M	5.22	4.34	2.5	0.2
AFM001069	FG 2:9	10–20	M	6.73	6.40	1.9	0.1
AFM001070	**FL 1:1**	0–10	M+	6.08	5.83	14.8	1.0
AFM001070	FL 1:1	10–20	M	6.54	6.16	3.4	0.3
AFM001070	**FL 1:11**	0–10	M+	7.36	6.85	4.9	0.4
AFM001070	FL 1:11	10–20	M	7.56	6.90	3.1	0.2
AFM001070	**FL 1:13**	0–10	M+	7.08	6.65	7.7	0.6
AFM001070	FL 1:13	10–20	M	7.21	6.85	5.6	0.5
AFM001070	FL 1:13	55–65	M	7.60	6.81	2.2	0.0
AFM001070	**FL 1:15**	0–10	M+	7.20	6.79	9.9	0.7
AFM001070	FL 1:15	10–20	M	7.13	6.84	4.4	0.3
AFM001070	FL 1:15	55–65	M	6.54	6.04	2.4	0.0
AFM001070	**FL 1:3**	0–10	M+	6.48	6.08	10.9	0.9
AFM001070	FL 1:3	10–20	M	7.04	6.54	1.6	0.1
AFM001070	**FL 1:6**	0–10	M+	6.83	6.58	7.8	0.6
AFM001070	FL 1:6	10–20	M	7.28	6.81	4.9	0.4
AFM001070	FL 1:6	55–65	M	7.89	6.88	2.2	0.0
AFM001070	**FL 1:7**	0–10	M+	7.31	6.74	9.6	0.7
AFM001070	FL 1:7	10–20	M	7.39	6.90	4.4	0.3
AFM001070	**FL 1:9**	0–10	M+	7.05	6.70	7.4	0.6
AFM001070	FL 1:9	10–20	M	7.24	6.75	5.4	0.5
AFM001070	FL 1:9	55–65	M	7.92	6.87	2.2	0.0
AFM001071	**FL 2:1**	0–10	M+	7.03	6.50	4.8	0.4
AFM001071	FL 2:1	10–20	M	6.95	6.82	2.9	0.2
AFM001071	FL 2:1	55–65	M	7.14	6.86	1.7	0.0
AFM001071	**FL 2:11**	0–10	M+	7.28	6.71	5.3	0.4
AFM001071	FL 2:11	10–20	M	7.36	6.92	3.3	0.3
AFM001071	**FL 2:13**	0–10	M+	7.26	6.86	6.3	0.5
AFM001071	FL 2:13	10–20	M	7.23	6.87	1.9	0.1
AFM001071	FL 2:13	55–65	M	7.56	6.98	1.7	0.0
AFM001071	**FL 2:15**	0–10	M+	7.39	6.77	8.0	0.6
AFM001071	FL 2:15	10–20	M	7.39	7.00	2.5	0.2
AFM001071	**FL 2:3**	0–10	M+	7.30	6.77	7.7	0.7
AFM001071	FL 2:3	10–20	M	7.05	6.95	4.5	0.3
AFM001071	**FL 2:5**	0–10	M	7.02	6.80	8.9	0.6
AFM001071	FL 2:5	10–20	M	7.22	6.97	4.8	0.4
AFM001071	FL 2:5	55–65	M	7.64	7.02	2.6	0.0
AFM001071	**FL 2:7**	0–10	M+	7.03	6.56	6.9	0.5
AFM001071	FL 2:7	10–20	M	6.63	6.36	3.2	0.3
AFM001071	**FL 2:9**	0–10	M+	7.06	6.66	6.7	0.5
AFM001071	FL 2:9	10–20	M	7.23	6.83	4.8	0.4
AFM001071	FL 2:9	55–65	M	7.27	6.97	1.7	0.0
AFM001072	**R 1:1**	0–10	M+	5.12	4.45	3.6	0.2
AFM001072	R 1:1	10–20	M	5.44	4.61	1.4	0.1
AFM001072	R 1:1	55–65	M	6.62	6.24	0.7	0.0
AFM001072	**R 1:11**	0–10	M+	5.36	4.76	15.2	0.8

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001072	R 1:11	10–20	M	5.48	4.46	2.4	0.1
AFM001072	**R 1:14**	0–10	M+	4.21	3.42	12.4	0.7
AFM001072	R 1:14	10–20	M	4.69	3.81	2.5	0.2
AFM001072	R 1:14	55–65	M	5.96	5.38	0.9	0.1
AFM001072	**R 1:15**	0–10	M+	4.95	4.13	8.3	0.4
AFM001072	R 1:15	10–20	M	5.23	4.29	1.3	0.1
AFM001072	**R 1:4**	0–10	M+	4.59	3.76	7.2	0.4
AFM001072	R 1:4	10–20	M	4.53	4.03	0.9	0.1
AFM001072	**R 1:5**	0–10	M+	4.44	3.74	9.2	0.5
AFM001072	R 1:5	10–20	M	5.13	4.22	1.4	0.1
AFM001072	R 1:5	55–65	M	6.43	6.10	2.3	0.0
AFM001072	**R 1:8**	0–10	M+	4.64	3.74	9.0	0.5
AFM001072	R 1:8	10–20	M	5.05	4.06	1.4	0.1
AFM001072	**R 1:9**	0–10	M+	5.35	4.72	9.8	0.5
AFM001072	R 1:9	10–20	M	5.61	4.83	3.4	0.2
AFM001072	R 1:9	55–65	M	6.54	6.36	1.7	0.0
AFM001073	**R 2:1**	0–10	M+	4.60	3.95	11.2	0.6
AFM001073	R 2:1	10–20	M	4.91	4.14	0.6	0.1
AFM001073	R 2:1	55–65	M	5.65	4.80	0.5	0.1
AFM001073	**R 2:11**	0–10	M+	5.83	5.22	6.2	0.4
AFM001073	R 2:11	10–20	M	5.46	4.59	3.2	0.2
AFM001073	**R 2:13**	0–10	M+	4.30	3.68	13.3	0.6
AFM001073	R 2:13	10–20	M	5.10	4.00	2.1	0.1
AFM001073	R 2:13	55–65	M	5.35	4.72	0.5	0.0
AFM001073	**R 2:15**	0–10	M+	5.35	4.84	24.0	1.2
AFM001073	R 2:15	10–20	M	6.08	5.59	2.2	0.1
AFM001073	**R 2:3**	0–10	M+	5.28	4.72	16.6	1.0
AFM001073	R 2:3	10–20	M	5.83	5.06	4.0	0.3
AFM001073	**R 2:6**	0–10	M	5.31	4.69	14.3	0.8
AFM001073	R 2:6	10–20	M	5.45	4.53	2.6	0.2
AFM001073	R 2:6	55–65	M	5.87	5.22	0.3	0.0
AFM001073	**R 2:7**	0–10	M+	5.17	4.54	12.6	0.7
AFM001073	R 2:7	10–20	M+	5.41	4.63	1.6	0.1
AFM001073	**R 2:9**	0–10	M+	4.09	3.37	15.2	0.7
AFM001073	R 2:9	10–20	M	4.87	3.96	2.0	0.1
AFM001073	R 2:9	55–65	M	5.62	4.90	0.4	0.0
AFM001074	**S 1:1**	0–30	H	5.86	5.23	19.8	1.3
AFM001074	S 1:1	0–10	M	6.63	5.62	0.2	0.0
AFM001074	S 1:1	10–20	M	6.52	5.90	0.1	0.0
AFM001074	S 1:1	55–65	M	5.03	4.50	0.1	0.0
AFM001074	**S 1:2**	0–30	H	6.13	5.55	14.4	0.9
AFM001074	S 1:2	0–10	M	6.58	6.40	0.2	0.0
AFM001074	S 1:2	10–20	M	6.99	6.39	0.1	0.0
AFM001074	**S 1:3**	0–30	H				
AFM001074	S 1:3	0–10	M	6.69	6.39	0.1	0.0
AFM001074	S 1:3	10–20	M	7.04	6.36	0.1	0.0
AFM001074	S 1:3	55–65	M	7.57	6.66	1.7	0.0
AFM001074	**S 1:4**	0–30	H	6.27	4.98	12.6	0.9
AFM001074	S 1:4	0–10	M	6.81	6.14	0.2	0.0

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001074	S 1:4	10–20	M	6.83	6.35	0.1	0.0
AFM001074	**S 1:5**	0–30	H	5.72	5.37	15.5	1.1
AFM001074	S 1:5	0–10	M	6.36	6.09	0.2	0.0
AFM001074	S 1:5	10–20	M	5.25	5.04	0.2	0.0
AFM001074	S 1:5	55–65	M	5.15	4.72	0.1	0.0
AFM001074	**S 1:6**	5	H	5.99	5.72	27.1	1.9
AFM001074	S 1:6	0–10	M+	6.25	5.98	0.2	0.0
AFM001074	S 1:6	10–20	M	6.98	6.40	0.1	0.0
AFM001074	**S 1:7**	0–30	H	6.69	6.25	21.2	1.3
AFM001074	S 1:7	0–10	M	7.36	7.11	0.2	0.0
AFM001074	S 1:7	10–20	M	7.13	7.06	0.7	0.0
AFM001074	S 1:7	55–65	M	8.50	7.08	2.0	0.0
AFM001074	**S 1:8**	0–30	H				
AFM001074	S 1:8	0–10	M	8.29	7.04	0.2	0.0
AFM001074	S 1:8	10–20	M	5.53	4.48	0.1	0.0
AFM001075	**S 2:1**	0–30	H	6.39	6.08	18.1	1.4
AFM001075	S 2:1	0–10	M	7.59	7.19	0.3	0.1
AFM001075	S 2:1	10–20	M	8.32	7.07	2.2	0.0
AFM001075	S 2:1	55–65	M	8.35	6.90	1.1	0.0
AFM001075	**S 2:2**	0–30	H	7.16	6.38	23.1	1.7
AFM001075	S 2:2	0–10	M	7.70	7.04	0.8	0.1
AFM001075	S 2:2	10–20	M	7.34	7.09	2.0	0.0
AFM001075	**S 2:3**	0–30	H	6.96	6.33	28.4	1.9
AFM001075	S 2:3	0–10	M	7.30	7.27	0.7	0.1
AFM001075	S 2:3	10–20	M	7.77	7.05	1.4	0.0
AFM001075	S 2:3	55–65	M	6.72	5.58	1.9	0.0
AFM001075	**S 2:4**	0–30	H	6.67	5.84	14.2	1.0
AFM001075	S 2:4	0–10	M	7.40	6.84	0.4	0.1
AFM001075	S 2:4	10–20	M	7.80	6.79	1.7	0.0
AFM001075	**S 2:5**	0–30	H			18.6	1.4
AFM001075	S 2:5	0–10	M	6.26	5.61	0.4	0.1
AFM001075	S 2:5	10–20	M	7.11	6.45	1.0	0.0
AFM001075	**S 2:6**	0–30	H	7.19	6.71	20.8	1.5
AFM001075	S 2:6	0–10	M	6.65	6.25		
AFM001075	S 2:6	10–20	M	7.24	7.13	1.1	0.1
AFM001075	**S 2:7**	0–30		7.39	7.12	24.0	1.8
AFM001075	S 2:7	0–10	M	7.01	6.36	1.7	0.1
AFM001075	S 2:7	10–20	M	7.20	6.79	0.8	0.1
AFM001075	S 2:7	55–65	M	7.60	6.93	2.0	0.0
AFM001075	**S 2:8**	0–30	H	7.69	7.28	1.7	0.0
AFM001075	S 2:8	0–10	M	7.98	6.98	1.6	0.1
AFM001075	S 2:8	10–20	M	7.89	7.23	2.1	0.1
AFM001075	S 2:8	55–65	M	8.04	7.44	1.6	0.0
AFM001076	**SS 1:1**	0–30	H	6.22	5.64	16.9	1.1
AFM001076	SS 1:1	0–10	M	6.66	6.09	0.3	0.1
AFM001076	SS 1:1	10–20	M	6.80	6.35	0.2	0.0
AFM001076	SS 1:1	55–65	M	7.57	6.59	1.9	0.0
AFM001076	**SS 1:11**	0–30	H	6.73	6.28	15.9	1.1
AFM001076	SS 1:11	0–10	M	6.96	6.56	0.2	0.0

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001076	SS 1:11	10–20	M	7.75	6.69	2.0	0.0
AFM001076	SS 1:11	55–65	M	7.50	7.04	2.3	0.0
AFM001076	**SS 1:13**	0–30	H	6.07	5.30	9.2	0.5
AFM001076	SS 1:13	0–10	M	6.81	6.34	0.2	0.0
AFM001076	SS 1:13	10–20	M	6.85	6.68	0.3	0.0
AFM001076	SS 1:13	55–65	M	7.60	6.71	1.5	0.0
AFM001076	**SS 1:15**	0–30	H	7.30	6.63	16.0	1.0
AFM001076	SS 1:15	0–10	M	7.39	6.94	1.2	0.0
AFM001076	SS 1:15	10–20	M	7.92	7.11	2.0	0.0
AFM001076	SS 1:15	55–65	M	8.21	6.96	1.8	0.0
AFM001076	**SS 1:3**	0–30	H				
AFM001076	SS 1:3	0–10	M	8.05	7.00	1.6	0.0
AFM001076	SS 1:3	10–20	M	8.32	7.01	2.4	0.0
AFM001076	**SS 1:5**	0–30	H	7.11	6.24	19.7	1.3
AFM001076	SS 1:5	0–10	M	7.20	6.62	0.3	0.1
AFM001076	SS 1:5	10–20	M	7.59	6.85	1.8	0.0
AFM001076	**SS 1:7**	0–30	H	6.84	6.47	26.1	1.5
AFM001076	SS 1:7	0–10	M	7.22	6.85	0.2	0.0
AFM001076	SS 1:7	10–20	M	7.23	6.88	1.5	0.0
AFM001076	**SS 1:9**	0–30	H	6.65	6.23	35.6	2.4
AFM001076	SS 1:9	0–10	M	6.86	6.31	1.5	0.1
AFM001076	SS 1:9	10–20	M	6.71	6.51	0.3	0.1
AFM001077	**SS 2:1**	0–30	H	7.32	6.67	18.6	1.3
AFM001077	SS 2:1	0–10	M	7.27	6.61	0.4	0.1
AFM001077	SS 2:1	10–20	M	7.32	6.69	0.2	0.0
AFM001077	**SS 2:10**	0–30	H	6.93	6.58	15.8	0.9
AFM001077	SS 2:10	0–10	M	5.93	5.47	0.3	0.1
AFM001077	SS 2:10	10–20	M	7.22	6.48	1.3	0.1
AFM001077	SS 2:10	55–65	M	7.72	6.86	0.9	0.0
AFM001077	**SS 2:15**	0–30	H	7.32	6.41	19.3	0.9
AFM001077	SS 2:15	0–10	M	7.22	6.74	0.2	0.0
AFM001077	SS 2:15	10–20	M	7.33	6.83	0.3	0.0
AFM001077	SS 2:15	55–65	M	7.55	6.89	2.1	0.1
AFM001077	**SS 2:18**	0–30	H	7.39	6.95	10.1	0.6
AFM001077	SS 2:18	0–10	M	7.47	6.82	0.7	0.1
AFM001077	SS 2:18	10–20	M	7.65	7.01	2.4	0.1
AFM001077	SS 2:18	55–65	M	7.91	7.26	1.0	0.0
AFM001077	**SS 2:23**	0–30	H	7.84	6.76	20.1	1.2
AFM001077	SS 2:23	0–10	M	7.32	6.76	4.7	0.4
AFM001077	SS 2:23	10–20	M	7.45	6.90	4.2	0.3
AFM001077	SS 2:23	55–65	M	7.70	7.17	1.6	0.1
AFM001077	**SS 2:3**	0–30	H	6.84	6.55	9.7	0.7
AFM001077	SS 2:3	0–10	M	6.90	6.74	0.6	0.1
AFM001077	SS 2:3	10–20	M	6.98	6.84	1.1	0.1
AFM001077	**SS 2:6**	0–30	H	6.97	6.70	23.2	1.6
AFM001077	SS 2:6	0–10	M	6.92	6.63	5.8	0.5
AFM001077	SS 2:6	10–20	M	7.12	6.71	2.0	0.2
AFM001077	**SS 2:7**	0–30	H	6.85	6.58	21.7	1.2
AFM001077	SS 2:7	0–10	M	7.02	6.89	0.2	0.0

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001077	SS 2:7	10–20	M	6.98	6.85	0.1	0.0
AFM001078	**T 1:1**	0–30	H	5.84	5.18	46.0	1.8
AFM001078	T 1:1	40–60	H	5.83	5.37	46.2	2.2
AFM001078	**T 1:11**	0–30	H	5.94	5.61	46.8	1.7
AFM001078	T 1:11	40–60	H				
AFM001078	**T 1:13**	0–30	H	6.13	5.86	45.3	1.9
AFM001078	T 1:13	40–60	H	6.44	6.07	46.4	1.8
AFM001078	**T 1:2**	0–30	H	5.40	4.87	46.6	1.9
AFM001078	T 1:2	40–60	H	5.83	5.33	45.9	2.0
AFM001078	**T 1:4**	0–30	H	5.96	5.55	46.0	1.6
AFM001078	T 1:4	40–60	H	6.25	5.75	45.8	1.6
AFM001078	**T 1:5**	0–30	H	5.52	5.17	46.9	1.9
AFM001078	T 1:5	40–60	H	6.19	5.76	45.5	1.9
AFM001078	**T 1:7**	0–30	H	5.78	5.27	46.7	1.6
AFM001078	T 1:7	40–60	H	6.02	5.63	46.2	2.2
AFM001078	**T 1:9**	0–30	H	5.46	4.93	46.8	1.9
AFM001078	T 1:9	40–60	H				
AFM001079	**T 2:1**	0–30	H	6.30	5.71	46.0	2.2
AFM001079	T 2:1	40–60	H	6.15	5.59	46.0	1.9
AFM001079	**T 2:11**	0–30	H	6.02	5.61	45.4	2.0
AFM001079	T 2:11	40–60	H	6.11	5.66	47.3	2.0
AFM001079	**T 2:13**	0–30	H	6.09	5.65	45.8	1.8
AFM001079	T 2:13	40–60	H	5.85	5.46	46.1	1.8
AFM001079	**T 2:15**	0–30	H	6.00	5.64	46.4	2.1
AFM001079	T 2:15	40–60	H	6.18	5.79	46.9	2.6
AFM001079	**T 2:3**	0–30	H	6.07	5.65	46.1	2.1
AFM001079	T 2:3	40–60	H	6.01	5.52	45.5	1.6
AFM001079	**T 2:5**	0–30	H	5.81	5.49	47.2	1.9
AFM001079	T 2:5	40–60	H	6.12	5.70	49.4	2.5
AFM001079	**T 2:7**	0–30	H	6.03	5.73	45.8	2.0
AFM001079	T 2:7	40–60	H	6.04	5.56	45.0	1.6
AFM001079	**T 2:9**	0–30	H	6.22	5.73	45.9	2.0
AFM001079	T 2:9	40–60	H	6.41	6.05	47.2	3.0
AFM001080	**Å 1:1**	0–10	M+	7.87	6.92	3.9	0.4
AFM001080	Å 1:1	10–20	M	7.01	6.83	3.5	0.4
AFM001080	Å 1:1	55–65	M	7.98	7.13	1.2	0.0
AFM001080	**Å 1:11**	0–10	M+	7.34	6.57	2.4	0.2
AFM001080	Å 1:11	10–20	M	7.09	6.94	2.0	0.2
AFM001080	**Å 1:14**	0–10	M+	7.13	5.97	2.3	0.2
AFM001080	Å 1:14	10–20	M	6.58	5.91	1.8	0.2
AFM001080	Å 1:14	55–65	M	6.87	6.56	2.5	0.1
AFM001080	**Å 1:3**	0–10	M+	6.90	6.05	3.2	0.3
AFM001080	Å 1:3	10–20	M	5.36	5.26	2.5	0.3
AFM001080	**Å 1:5**	0–10	M+	6.30	5.53	2.6	0.3
AFM001080	Å 1:5	10–20	M	6.35	5.54	2.1	0.2
AFM001080	Å 1:5	55–65	M	6.83	6.55	1.4	0.1
AFM001080	**Å 1:7**	0–10	M+	6.79	5.95	3.5	0.4
AFM001080	Å 1:7	10–20	M	6.14	5.61	2.9	0.3
AFM001080	**Å 1:9**	0–10	M+	6.91	6.24	4.0	0.4

ID code	Pit ID	Depth (cm)	Horizon	pH water	pH $CaCl_2$	C (% of dw)	N (% of dw)
AFM001080	Å 1:9	10–20	M	7.15	6.83	2.9	0.3
AFM001080	Å 1:9	55–65	M	7.89	7.14	2.3	0.1
AFM001081	**Å 2:1**	0–10	M+	5.83	5.21	8.6	0.7
AFM001081	Å 2:1	10–20	M	5.80	5.04	4.5	0.4
AFM001081	Å 2:1	55–65	M	6.04	5.36	0.4	0.0
AFM001081	**Å 2:13**	0–10	M+	5.79	5.09	11.3	0.9
AFM001081	Å 2:13	10–20	M	6.16	5.05	2.2	0.2
AFM001081	**Å 2:15**	0–10	M+	5.89	5.19	5.7	0.5
AFM001081	Å 2:15	55–65	M	6.74	6.55	1.4	0.1
AFM001081	**Å 2:3**	0–10	M+	5.79	5.12	6.8	0.6
AFM001081	Å 2:3	10–20	M	5.82	4.99	2.5	0.2
AFM001081	**Å 2:5**	0–10	M+	5.95	5.33	6.3	0.5
AFM001081	Å 2:5	10–20	M	6.00	5.19	4.0	0.3
AFM001081	**Å 2:6**	0–10	M+	6.38	5.84	7.3	0.6
AFM001081	Å 2:6	10–20	M	6.28	5.39	3.4	0.3
AFM001081	Å 2:6	55–65	M	6.17	5.38	0.6	0.1
AFM001081	**Å 2:7**	0–10	M+	5.82	5.13	8.3	0.7
AFM001081	Å 2:7	10–20	M	6.03	5.08	3.8	0.3
AFM001081	**Å 2:9**	0–10	M+	5.95	5.22	10.6	0.9
AFM001081	Å 2:9	10–20	M	5.91	5.37	4.8	0.4
AFM001081	Å 2:9	55–65	M	6.34	5.57	0.8	0.1

Appendix K

Physical properties of the type deposits

Type of site	ID code	Depth from (m)	Depth to (m)	Sample name	Dry substance %	LOI/DS (%)
Lake sediment						
Eckarfjärden	PFM002501	0.00	0.16	lake sediment		79.8
Eckarfjärden	PFM002501	0.20	0.30	lake sediment		78.2
Eckarfjärden	PFM002502	0.00	0.03	algal mat		
Eckarfjärden	PFM004298	2.53	2.64	algal gyttja	6.4	75.4
Eckarfjärden	PFM004298	2.64	2.71	calcareous gyttja	7.1	63.1
Eckarfjärden	PFM004298	3.10	3.20	algal gyttja	8.6	63.9
Eckarfjärden	PFM004298	3.56	3.62	clay gyttja	30.7	20.7
Eckarfjärden	PFM004298	3.87	3.92	clay	65.0	5.0
Eckarfjärden	PFM004298	4.02	4.07	clay	65.1	6.7
Eckarfjärden	PFM004298	4.20	4.25	clay	64.6	8.2
Mire						
Puttan	PFM006023	0.66	0.69	gyttja	14.8	26.6
Puttan	PFM006023	1.03	1.06	clayey gyttja	14.3	26.4
Puttan	PFM006023	1.58	1.61	sand	84.6	1.1
Puttan	PFM006023	1.93	1.96	glacial clay	48.8	5.7
Rönningarna	PFM006024	0.33	0.36	peat	8.8	
Rönningarna	PFM006024	1.13	1.16	peat	6.2	
Rönningarna	PFM006024	1.53	1.56	phragmetes peat	7.7	
Rönningarna	PFM006024	1.73	1.76	algal gyttja	5.7	
Rönningarna	PFM006024	1.93	1.96	clayey gyttja	28.2	19.4
Rönningarna	PFM006024	2.63	2.66	glacial clay	61.9	12.1
Rönningarna	PFM006025	0.26	0.28	peat	10.4	
Rönningarna	PFM006025	0.60	0.65	peat	7.8	
Rönningarna	PFM006025	1.46	1.50	peat	10.0	
Rönningarna	PFM006025	1.85	1.87	peat	7.0	
Marine sediment						
Kallrigafjärden	PFM005792	0.02	0.04	marine sediment	13.9	
Kallrigafjärden	PFM005792	0.18	0.20	marine sediment	16.3	
Kallrigafjärden	PFM005792	0.34	0.36	marine sediment	15.0	
Kallrigafjärden	PFM005792	0.65	0.68	marine sediment	19.1	
Off shore	PFM004512	0.00	0.01	marine sediment		12.1
Tixelfjärden	PFM002560	0.14	0.16	marine sediment		24.5
Tixelfjärden	PFM002560	0.28	0.30	marine sediment		2.5
Tixelfjärden	PFM005791	0.02	0.04	marine sediment	12.4	
Tixelfjärden	PFM005791	0.10	0.12	marine sediment	14.4	
Tixelfjärden	PFM005791	0.18	0.20	marine sediment	14.7	
Tixelfjärden	PFM005791	0.34	0.36	marine sediment	19.7	
Tixelfjärden	PFM006062	2.09	2.21	marine sediment	37.9	12.3
Tixelfjärden	PFM006062	2.24	2.30	sand/gravel	72.8	5.2
Tixelfjärden	PFM006062	2.34	2.41	clay	56.0	5.5
Tixelfjärden	PFM006062	2.60	2.67	clay	63.3	9.0
Tixelfjärden	PFM006062	2.80	2.87	clay	63.6	11.3
Terrestrial area						
FORSMARK	PFM004459	3.50	3.50	boulder clay	99.3	10.5
FORSMARK	PFM002578	0.70	0.70	till	94.0	7.5
FORSMARK	PFM004460	1.00	1.00	till	99.8	7.4
FORSMARK	PFM004460	1.50	1.50	till	99.8	8.3