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Oskarshamn site investigation

Investigation of Quaternary deposits 2003–2004

Lars Rudmark, Kärstin Malmberg-Persson, Henrik Mikko
Geological Survey of Sweden (SGU)

September 2005

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

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Keywords: Quaternary deposit, Exposed bedrock, Till, Glaciofluvial deposit, Clay, Peat, Glacial striae, Extension, Thickness, Wave washing, Stratigraphy.

Summary

Swedish Nuclear Fuel and Waste Management Co (SKB) performs site investigations for localisation of a deep repository for high level radioactive waste. The investigations are performed at two sites, Forsmark and Oskarshamn. This report presents a map of the Quaternary deposits in the Oskarshamn area. The knowledge and the composition of Quaternary deposits are of crucial importance for the understanding of the hydrological, chemical and biological processes taking place in the uppermost part of the geosphere.

The aim of this report is to describe the aerial distribution of the uppermost unconsolidated deposits and, where possible, the stratigraphical distribution and thickness of Quaternary deposits covering the bedrock. The map includes all identified bedrock exposures and Quaternary deposits, which exceed about 1,500 m². The map was produced for presentation in the scale 1: 50,000. The investigated area is about 75 km². In the eastern part of this area, the investigation is done more exact with a presentation scale of 1:10,000. All bedrock exposures and Quaternary deposits with areas exceeding 100 m² are marked in this part.

The information is based upon observations of the ground and upon results from excavations and borings. The stratigraphical distribution and the thickness to a depth of 2–3 m's of peat layers, glacial clay and other fine-grained sediments were regularly determined by boring with a so-called Edelmann hand-driven probe at about 300 localities. Besides, deep stratigraphical investigations were made in 13 excavated trenches. Samples were taken and analysed in respect of grain size, lime content and organic matter.

The thickness of the Quaternary deposits is in general thin. As a consequence, there are many outcrops all over the investigation area. Altogether 35 per cent of the area constitutes exposed bedrock or areas with a very thin cover (< 0.5 m) of Quaternary deposits. However, the frequency of exposed bedrock varies. Certain areas, e.g. the southern part of the so-called local model area, have a relative low frequency of exposed bedrock. On the other hand, areas in the north and in the archipelago have a high frequency of exposed bedrock with very little of Quaternary deposits.

The Quaternary glaciers polished the bedrock surface to a large extent. Rock fragments in the ice abraded exposed bedrock surfaces on which glacial striae were formed. At the field work, glacial striae were observed at almost 130 localities. The main part of the striae was observed in the archipelago on outcrops at the present shoreline. Most of the glacial striae indicate an ice movement from the northwest. Because of this frequent occurrence, these striae reflect most probably the movement in the ice front zone during the deglaciation. At a few localities, two older systems of striae with different directions occur.

The predominating Quaternary unit in the area is a sandy or gravelly till, which was most likely deposited during the late Weichselian. Till covers about 43 per cent of the investigated area (Table 5-1). The till bed lies directly on the Precambrian bedrock and is generally thin, less than 3 m. The morphology of the till areas normally reflects the morphology of the bedrock surface. In general, the boulder (and stone) frequency of the till surface is intermediate but areas with a high boulder frequency occur. The main till unit is a brown, sandy or gravelly, massive till with a normal degree of consolidation. It is often rich in cobbles and small boulders, which are generally angular or very angular and consist of the local bedrock type.

There are two glaciofluvial deposits within the investigated area, which are arranged in systems of more or less continuous eskers. They are built up of sand and gravel with varying thickness. There are many gravel pits in the large esker Tunaåsen in the neighbourhood of the village Fårbo. At present, the exploitation of sand and gravel has ended and there is no activity in the gravel pits. The Tunaåsen is in general 5–15 m in height and between 300 and 500 m broad. A small esker is running near and north of the nuclear power plant.

Glacial clay and other fine-grained sediments have a restricted distribution (Table 5-1) in the investigated area. However, younger postglacial sediments often overlie them. Glacial clay occurs all over the area and is most common in valleys with thickness up to about 3 m.

The investigated area is situated below the highest shoreline. Therefore, the upper parts of till and glaciofluvial deposits have more or less been re-worked by wave washing in exposed parts of the area. The littoral deposits cover c 4 per cent of the land area. Small but well developed shingle fields are found on the island of Ävrö to the north of the nuclear power plant.

As a result of wave washing and redeposition of till and especially of glacial clay, fine-grained sediments were deposited as a cover over the glacial clay in the lower parts of the area. Of these sediments clay gyttja is the most common. Many observations and drillings indicate that the thickness of the clay gyttja is up to 6 m.

The mires are divided into two types: bogs and fens. Often the peat deposits have been developed in basins of former lakes. The stratigraphy is therefore characterized by peat covering different kinds of gyttja and clay gyttja. The thickness of the peat is in general 1–2 m. Fens are more common than bogs. The mires cover c 8 per cent of the investigated area.

Sammanfattning

Svensk Kärnbränslehantering AB genomför undersökningar på två platser, Forsmark och Oskarshamn. Denna rapport behandlar de jordartsgeologiska förhållandena i Oskarshamn som framkommit vid undersökningar under åren 2003 och 2004. Den använda metodiken vid jordartskartering framgår i detalj i SKBs metodbeskrivning.

Jordartskarteringen i Oskarshamn har bedrivits med två olika ambitionsnivåer. Inom det lokala modellområdet (se figur 2-1) har en detaljerad undersökning genomförts där minsta markerade yta är ca 100 m² och lämplig presentationsskala 1:10 000. En något mera översiktlig undersökning har ägt rum inom delar av det regionala modellområdet. Lämplig presentationsskala är där 1:50 000 och den minsta markerade yta i detta område är ca 1 500 m². Den använda metodiken och jordartsindelningen är desamma i de båda områdena.

Resultaten bygger på direkta iakttagelser i markytan och i skärningar samt på borrningar och grävningar. Drygt 300 lagerföljder har undersökts till djup på 2 á 3 m med hjälp av enkla handborrar. Mäktigare jordlagerföljder har studerats och dokumenterats genom maskingrävningar på ett 15-tal platser. I gropar och schakt har prover tagits vilka analyserats med avseende på bl a kornstorlek och kalkhalt.

Jordartskarteringen visar att jordtäcket i området mestadels är tunt och därför förekommer talrikt med bergblottningar. På ett stort antal hällytor finns tydliga och distinkta isräfflor. Dessa förekommer främst i skärgården och där ofta på välformade rundhällar. Räfflorna visar att den senaste landisen rörde sig från nordväst mot sydost ut till östersjösänkan under isens avsmältningsskede. På några enstaka hällar redovisar räfflor dessutom en något äldre och mera nordlig isström. I undersökningsområdet finns även en lokal med räfflor från en landis som rört sig från nordost.

Sandig morän är den dominerande jordarten och täcker ca 43 % av det undersökta området. Eftersom yngre jordarter på många ställen överlagrar morän är den verkliga täckningsgraden något större. I allmänhet återspeglar moränytan i stora drag den underliggande berggrundsytans morfologi. Mindre områden med låga moränkullar, ett s k moränbacklandskap, förekommer dock på ett par platser. Genomgående är moränen grovkornig med höga andelar gruspartiklar. I markytan är moränen ofta både sten- och blockrik. Många skärningar visar att moränen är korttransporterad bl a på grund av att de enskilda större partiklarna är extremt kantiga. Moränens mäktighet är i allmänhet begränsad till högst ca 3 m. Större moränmäktigheter kan dock i undantagsfall förekomma i landskapets dalgångar eller i vissa begränsade områden.

Det finns ett större och ett mindre stråk med isälvsavlagringar i området, s k åsar eller rullstensåsar. Tidigare har stora sand- och grusvolymer brutits i den s k. Tunaåsen kring samhället Fårbo men denna verksamhet har numera nästan helt upphört. Åsen är där och i hela sin sträckning genom det regionala modellområdet några hundratals meter bred med relativa höjder på mellan 5 och 15 m. Isälvssedimentens mäktighet på över 20 m i Tunaåsen är det största kända jorddjupet i undersökningsområdet. En andra och betydligt mindre ås finns vid och söder om Gässhult.

På några ställen förekommer glacial lera med mäktigheter på upp till ca 3 m. Det är framför allt i markanta dalgångar som denna finkorniga jordart avsattes under landisens avsmältningsskede. Ofta överlagras den glaciala leran av yngre finkorniga sediment eller torv.

Undersökningsområdet är ganska flackt och småkuperat. I smala dalgångar finns som regel leriga gyttjiga sediment vilka nyttjas som jordbruksmark. Sedimenten avsattes i havsvikar eller grunda sjöar då landskapet sakta steg upp ur havet. Sedimenten i de högre belägna områdena är således äldre än de som ligger på lägre nivåer och närmare den nuvarande kusten. I dagens grunda havsvikar med ymnig vassvegetation kan man studera den pågående gyttjeavsättningen.

Förutom gyttjiga sediment finns även svallsediment, framför allt sand men även grus och i mindre omfattning klapper. Totalt täcker svallsediment drygt 4 % av det undersökta området.

Dessa sediment vittnar om landhöjningen och dess förlopp under tiden efter den senaste istiden. Väl utbildade klapperfält finns exempelvis på Ävrö alldeles norr om Simpevarps kärnkraftsverk.

På många platser finns torvmarker vilka har indelats i mossar och kärr. Dessa är vanligen ganska små med torvmäktigheter på i allmänhet endast ett par meter. Torvmarker täcker ca 8 % av det undersökta området.

Contents

1 Introduction

This document reports the results gained by the geological investigation of Quaternary deposits, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-03-022. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method description are SKB's internal controlling document.

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

Activity plan	Number	Version
Jordartskartering	AP PS 400-03-022	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för jordartskartering	SKB MD 131.001	1.0

The investigation of the deposits from the Earth's youngest period, the Quaternary, started in the beginning of 2003 and was finished after two years. The information of thickness, extension and composition of these deposits is an important basis for many other activities.

Some examples are

- Knowledge of the distribution of exposed bedrock and areas with a thin cover of Quaternary deposits on the bedrock surface is essential when the bedrock is investigated.
- Information on the thickness of Quaternary deposits is important for geophysical investigations.
- The distribution and thickness of different Quaternary deposits gives information of the ground-water flow directions. It is also important when soil types are investigated.
- The composition of the Quaternary deposits and the extension of exposed bedrock are the ecological foundations for vegetation.
- The composition of the Quaternary deposits is a geological archive, which can be used to reconstruct the Late Quaternary development in the area.

The data, which reference to this activity, are shown in Table 1-2. About 300 field notes originate from borings and about 125 from glacial striae observations.

Table 1-2. Data references.

Subactivity	Database	Identity number
	SICADA	PSM002580–PSM002726
		(except PSM002641; PSM002697)
		PSM002880–PSM002928
		PSM004763–PSM004799
		PSM005094–PSM005126
		PSM005300–PSM005424
		(except PSM005313,PSM005314,
		PSM005369,PSM005379,PSM005388)
		PSM005450–PSM005507
		PSM005600–PSM005635

2 Objective and scope

In this report a map of the Quaternary deposits is presented. The aim is to describe the distribution of the uppermost deposits and, where possible, the stratigraphical distribution and thickness of the Quaternary deposits overlying the bedrock. The investigation area is shown in Figure 2-1. It covers in broad outlines the catchment area of the surface water within the regional model area. The information is produced for presentation in the scale 1:50,000. Therefore, the smallest marked area is in general about 40×40 m. However, small observed bedrock outcrops have been marked as dots. The local model area has been investigated more in detail with an applicable scale of 1:10,000. This means that the map of the local model area shows all identified bedrock exposures and Quaternary deposits that exceed 100 m^2. The principle of classification is the same in the two areas.

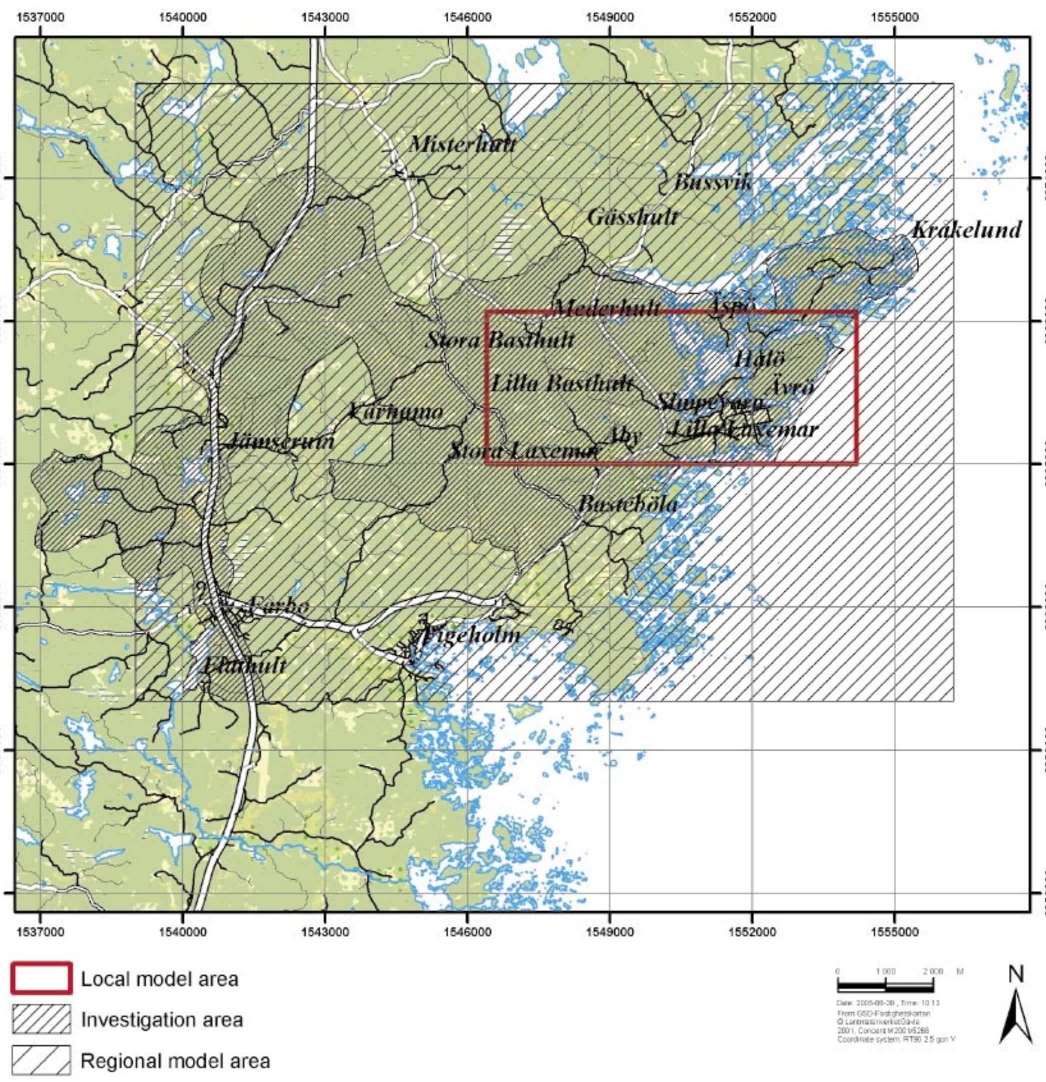

Figure 2-1. *Quaternary deposits and bedrock outcrops have been investigated in the marked area. The information is produced for presentation in the scale 1:50,000. The investigation within the local model area is made in greater detail with an applicable scale of 1:10,000.*

The information in the peripheral parts of the regional model area is only founded upon aerial photo interpretation together with fieldwork along the roads. Consequently, the work is not carried out in accordance with activity plan AP PS 400-03-022 concerning classification and precision. The positions of the different deposits of this parts are summary presented in Figure 5-1 together with information from the investigation area.

The Quaternary deposits of the area have earlier been investigated by the Geological Survey of Sweden /19/. This information is relatively old and has only been presented in a survey map in scale 1:100,000. This map was published 1903 and shows the distribution of the Quaternary deposits and exposed bedrock approximately but has a low accuracy of geographical positioning.

A new geological map of the Quaternary deposits was presented in 1998 /1/. This map is only based on interpretation of aerial photos and areas with exposed bedrock are over-represented.

North of the regional model area are some well-known boulder accumulations with caves /21/. The caves and the surroundings were documented in 2000 in order to investigate possible associations to late- or postglacial movements in the bedrock /2/. No such association was observed in this summary documentation.

Data from the Simpevarp peninsula and the adjacent islands of Ävrö and Hålö were collected in the field during 2003. These map data were delivered at the end of 2003 but are included in the deliveries listed in Chapter 4.3. A map with a description of the Quaternary deposits and exposed bedrock in this coastal region has already been presented /15/.

3 Equipment

The uppermost deposits were investigated using a spade and two different hand-driven probes (Figure 3-1 and 3-2). Some localities with relatively thick layers of till were examined in machine-dug trenches (Figure 3-3). Trenches were also excavated in areas with stratigraphical problems. GPS and aerial photos (geographically corrected IR photos taken from a height of 2,300 m, scale 1:5,000) were used for orientation. A mirror compass was used to measure the directions of the glacial striae. The photos were taken with digital cameras.

All field data have been digitally stored in a database in accordance with the SKB method description.

Figure 3-1. *A spade and a hand-driven probe used in the field.*

Figure 3-2. *The Edelmann hand-driven probe was valuable in the field-work.*

Figure 3-3. *The tractor excavator at a trench in the local model area near Laxemar (PSM005410).*

4 Execution

4.1 General

The methods used are described in detail in SKB MD 131.001. The classification of Quaternary deposits follows this document and is the same as recent SGU investigations in the area /18/. The nomenclature used in SGU's investigation in the municipality of Oskarshamn is slightly different /14/.

Before the fieldwork started, aerial infrared photos taken from a height of 2,300 m were interpreted in order to separate different Quaternary deposits and bedrock outcrop. This interpretation of bedrock outcrops was used to determine soil types in the area. The infrared aerial photos were taken at the end of June with luxuriant vegetation. This fact made the interpretation difficult as the vegetation prevented good insight. There are many phenomena in the infrared photos, which are used at the interpretation work. The colour-scale, the landscape morphology, the vegetation and the land-use are the most important. The old geological map of the area /19/, was used as a support. Eight different Quaternary deposits and areas with exposed bedrock were distinguished from each other. The result of the interpretation was transferred to ArcView format with the help of the digital orthorectified aerial photographic data. Different areas with Quaternary deposits were separated with lines. Each area was marked with a specific labelpoint for the different Quaternary deposit or exposed bedrock.

At the fieldwork, all information from the aerial photo interpretation was checked. New and correct boundaries showing exposed bedrock and the distribution of different Quaternary deposits at a depth of 50 cm were drawn on the aerial photos or in a PDA. Peat areas with a thickness less than 50 cm were also marked in field (e.g. peat overlaying other deposits). All Quaternary deposits, which have an area larger than about 1,500 m^2, were marked as surfaces. In the local model area, all areas larger than about 100 m^2 were marked. The stratigraphical distribution and the thickness to a depth of 2–3 m's of peat layers, glacial clay and other fine-grained sediments were regularly determined by boring with a so-called Edelmann hand-driven probe at about 300 localities.

Stratigraphical investigations were made in 13 excavated trenches. The localities were chosen to provide information from different types of till in different topographic positions. A few localities were also chosen in order to solve stratigraphical problems. Most of the trenches are located in the Laxemar subarea. Two sites are located further to the west, where the till is assumed to be thicker. The sections were cleaned manually with shovels and scrapers (Figure 4-1) and documented according to SKB MD 131.001. Studies were made of the stratigraphies, including description of bed geometry, sedimentary and deformational structures, lithology, sorting, particle roundness, colour etc. All sections were photographed and in some cases sketches of the sections were drawn. Till fabric analyses were made at two localities. They were made according to a standard method /11/. Orientation of a-axes of 25 elongated particles with a/b axial ratio ≥ 1.5 was measured in a horizontal shelf prepared in the till.

The stratigraphies in all excavations are summarized in Appendix 1.

Figure 4-1. *Cleaning a section in a trench near Laxemar (PSM005410).*

Information concerning bedrock exposures from the detailed bedrock investigations was taken into consideration. Glaciers have polished the bedrock surface to a large extent. During the fieldwork, glacial striae directions were observed and measured at about 130 localities.

There were certain difficulties in mapping the Quaternary geology during the fieldwork.

- The superficial boulder (and stone) frequency of the till varies throughout the area. It is sometimes difficult to define surfaces with a certain boulder frequency. The boundaries between different classes of till boulder frequency are diffuse. This is especially obvious between areas with a intermediate boulder frequency and a high boulder frequency. The map shows the dominating boulder frequency within each till area.
- In areas with an extremely high boulder frequency, it is difficult to separate a weathered and cracked bedrock surface from a till surface with very high boulder frequency.
- Sandy till is the dominating till type throughout the whole investigation area. Gravelly till occurs here and there within small areas. It is difficult or impossible to separate these two till types from each other in the field without extensive investigations. Therefore, sandy till has been marked all over the area.
- In some areas it was difficult to distinguish primary till boulders and stones from material re-deposited by waves or sea ice. At some localities glacial clay or sand was found below stones and small boulders, which shows that the coastal processes can redeposit coarse material. Some of these stones covered clay or sand deposits may have been overlooked since they are difficult to distinguish from till.

The field map was redrawn on a plastic film, which was scanned, and digitized. All surfaces were given label codes representing the different Quaternary deposits.

Grain size analyses were made by sieving and sedimentation analysis by Sweco geotechnical laboratory, Stockholm, following standards methods according to SS-ISO-112 77. Measurements of particles in the fabric analyses were stored in Jorddagboken database. Eigenvectors and normalized eigenvectors were calculated with the program Stereo Net. This program was also used to draw the fabric diagrams.

4.2 Preparations

The GPS was controlled at points with known positions. The two most used points have positions 6367749 N, 1551366 E and 6368318 N, 1540813 E. This control defined a position better than ± 10 m.

4.3 Data handling

The coordinates of observation points for stratigraphical data, direction of glacial striae, photos etc were recorded with GPS. All observation points were given id-numbers (PSM-numbers), together with the observation date. The geological information connected to the id-numbers was stored in SGU's database (Jorddagboken version 5.4.3). All points and dates were later stored in SICADA. Data from the SGU database were exported to Excel files, which were delivered on a CD to SKB.

The drawings of exposed bedrock and Quaternary deposits on the field maps (aerial photos) were scanned and transformed into a database. This information was delivered to SKB in Arc View shape on a CD-ROM.

The deliverables to SKB for the mapping of unconsolidated Quaternary deposits includes:

- Map of Quaternary deposits and bedrock exposures (Arc View).
- Stratigraphy of Quaternary deposits (SICADA).
- Point observations from surface mapping (SICADA).
- Direction of glacial striae (SICADA).
- Digital photos (File archive).
- Analyses of grain size composition, lime content and organic matter.

4.4 Nonconformities

The investigation of the local model area was carried out in compliance with the Activity Plan AP PS 400-03-022. The methods used are described in SKB MD 131.001. All identified Quaternary deposits with an area larger than 10×10 m are shown on the map in accordance with the activity plan.

The Activity Plan says that a regional investigation should be done within the whole regional model area. However, outside the local model area and catchment area, aerial photo interpretation and fieldwork along roads are the only basis of Quaternary information. The used methods in the catchment area described in SKB MD 131.001. All identified Quaternary deposits with an area larger than about 40×40 m are shown on the map in accordance with the activity plan. The map shows, however, all identified bedrock exposures, which include outcrops smaller than 40×40 m. These small outcrops are marked with a dot.

New and modern information from the uninvestigated parts of the regional model area has been delivered to SKB from an internal SGU projekt.

5 Results and discussions

5.1 Introduction

In this report the information of Quaternary deposits is presented in four different maps (Figure 5-1; Figure 5-2; Figure 5-3; Figure 5-3) in order to exhibit as much information as possible. The maps give an overview of the surface distribution of the Quaternary deposits in the Oskarshamn area. They confirm to a large extent the information of an earlier map from the area /19/. However, this present investigation gives a more complete and detailed information in many respects. Numerous, earlier unknown, localities with water-laid sediments, peat, or bedrock outcrops have been found.

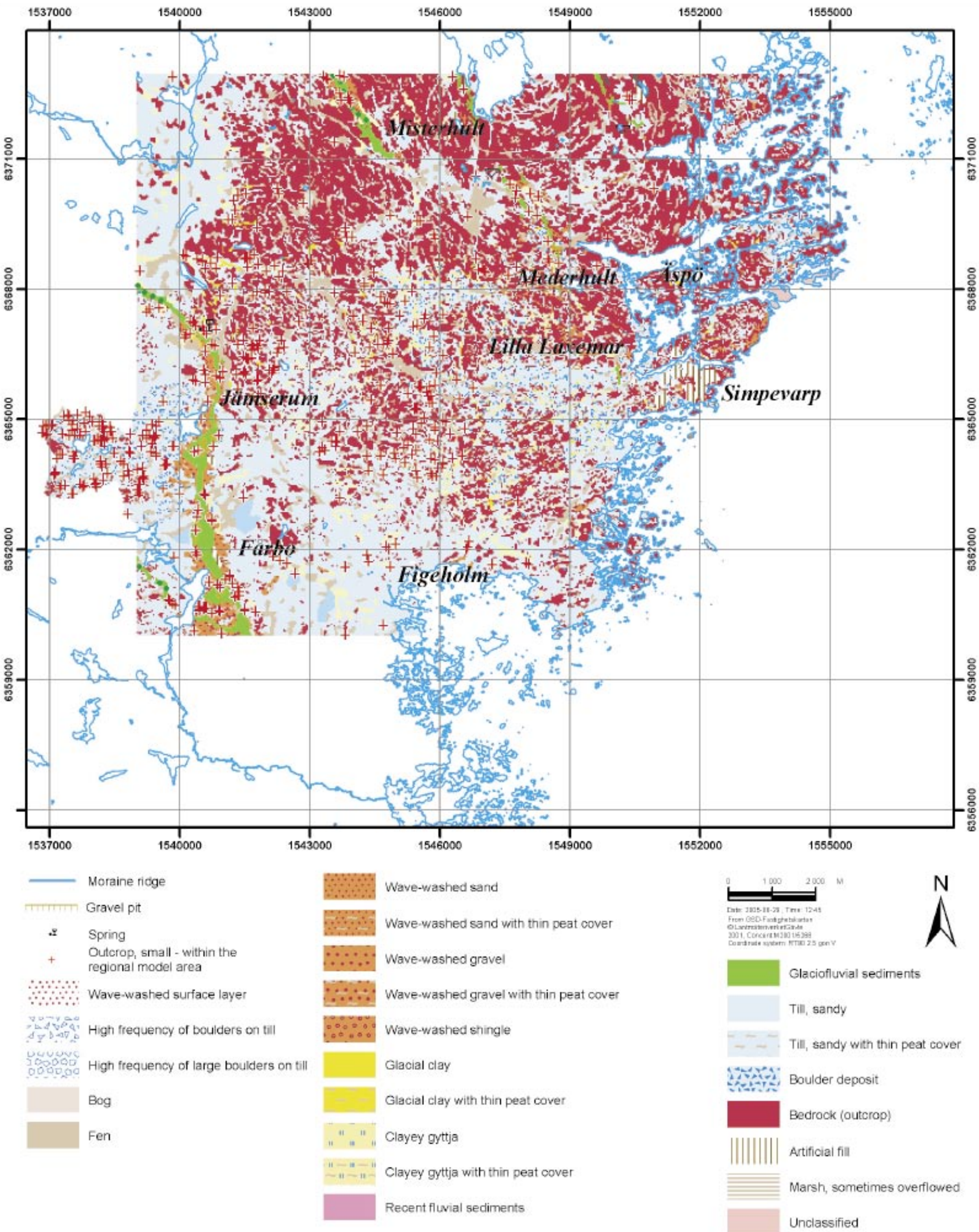

Figure 5-1. *A survey map of the Quaternary deposits and exposed bedrock within the regional model area.*

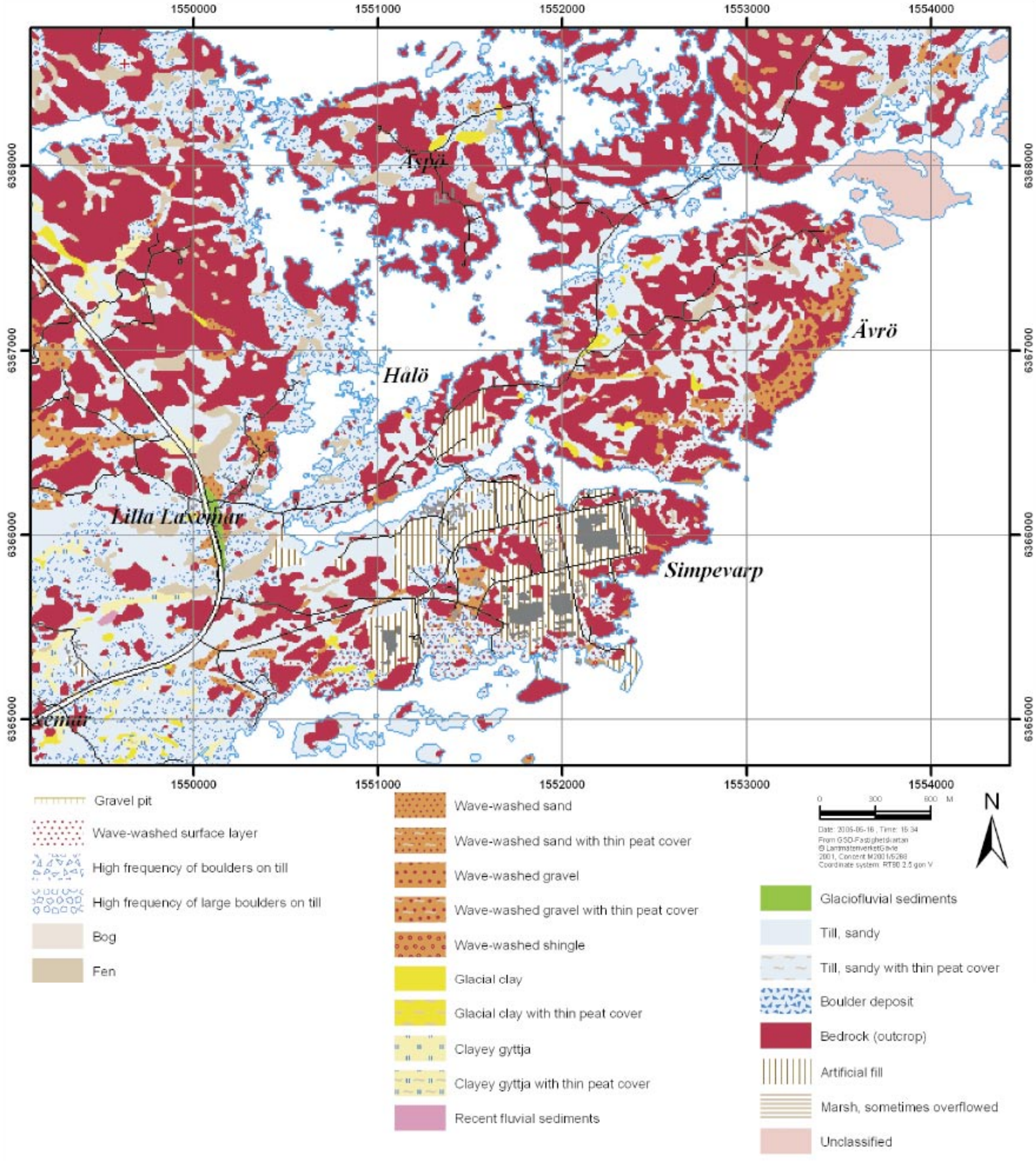

Figure 5-2. *A map of the Quaternary deposits and exposed bedrock within the eastern part of the local model area.*

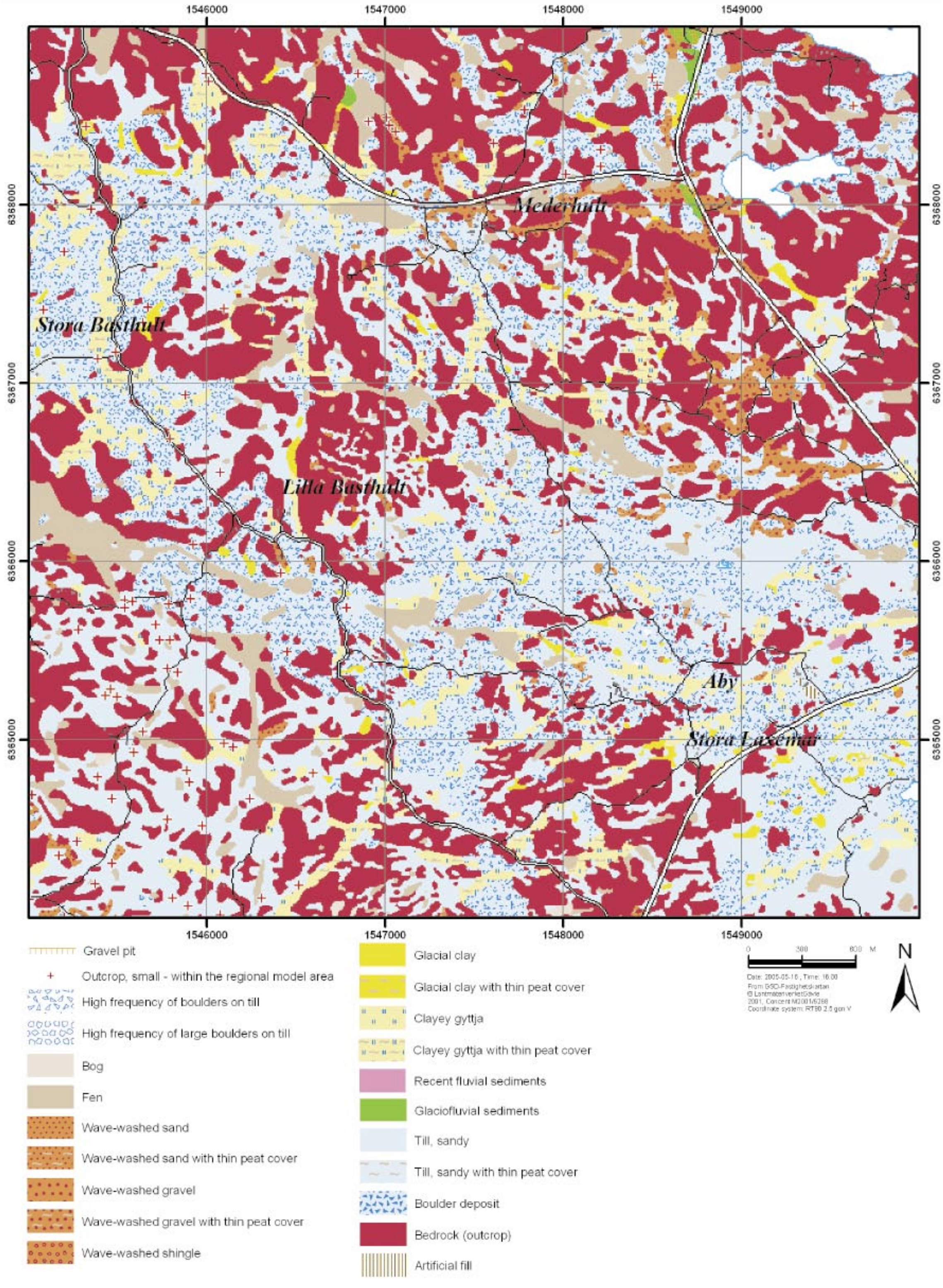

Figure 5-3. *A map of the Quaternary deposits and exposed bedrock within the western part of the local model area and adjacent areas.*

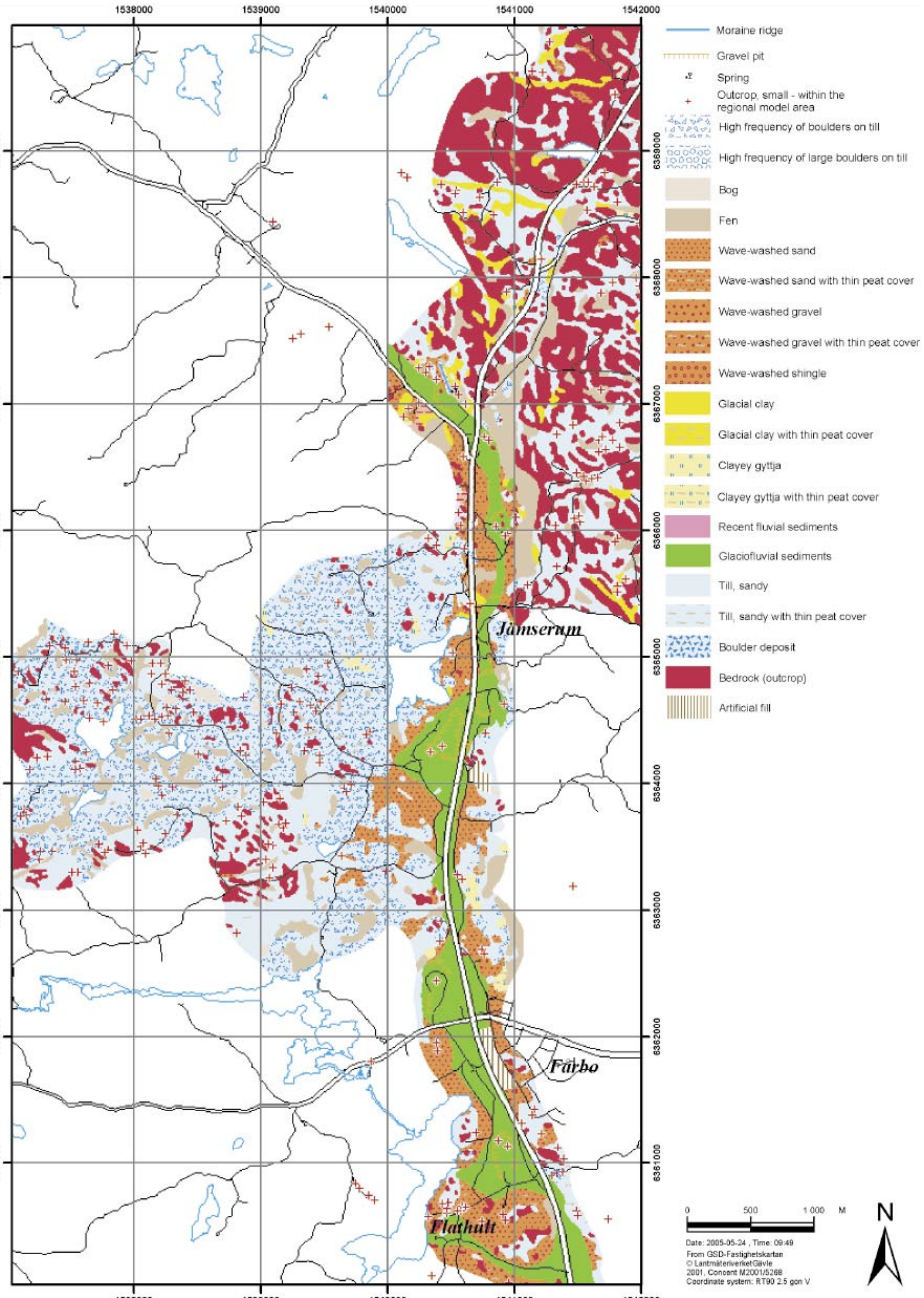

Figure 5-4. *A map of the Quaternary deposits and exposed bedrock within the western part of the investigated area. The esker Tunaåsen and the littoral sediment around the esker are the dominating elements in this region.*

The investigated area (Figure 2-1) is relatively flat and glacial till is the most common Quaternary deposit. The proportional distribution of different Quaternary deposits on land is summarised in Table 5-1. The investigated area is situated below the highest shoreline. The highest altitudes reach about 60 m a s l, which is more than 40 or 50 m below the late-glacial highest shoreline. As a consequence the surfaces of till areas and eskers were re-worked by wave washing during the land-uplift. In exposed positions this has resulted in depositions of a thin cover of sand and gravel above the till. A shore-displacement curve for the Oskarshamn area /20/ and information of the development of the Baltic Sea /5/ show that the first small islands reached above water level 10,000 BC (before Christ) in the Baltic Ice Lake. Some centuries later, the water level regressed very abruptly to the level of about 30 m a s l in the region. After that fall, the water level slowly regressed during 2,000 years to the level of about 20 m a s l This slowly regression has continued to present times. At some stages, the water level has risen during short transgression phases, the Ancylus transgression, which took place approximately 8,300 BC, and the complex Littorina transgressions. Because of the slow regression, most of the investigated area has been land during thousands of years. At present, the land upheaval is 1 mm/year.

More detailed information from the Oskarshamn region about the relation between land and water in the Baltic Sea basin is given in a geological map description /14/.

In the western part of the area there is a large esker (the Tunaåsen esker) with a north-south direction, which in the north changes to northwest/southeast. The whole area is relatively rich in peatland. Glacial clay, clay gyttja, sand, gravel and peat occur frequently as superficial Quaternary deposits on many small surfaces. These small deposits are frequent, but cover only a small part of the total investigation area. The till and glacial clay have no or very little $CaCO_3$-content.

The area around the nuclear power plant is dominated by artificial filling material consisting mainly of blast bedrock but also containing reworked Quaternary deposits.

Table 5-1. The proportional distribution of Quaternary deposits extracted from the map presented in this report.

Quaternary deposit	Coverage %
Peat	8.0
Gyttja, clayey	3.4
Wave washed sand, gravel and shingle	4.3
Glacial clay and silt	1.3
Glaciofluvial sediment	3.0
Till, sandy with a medium boulder frequency	22.9
Till, sandy with a high boulder frequency	18.6
Till, sandy with a high frequency of large boulder	1.7
Total area covered by till	43.2
Artificial fill	1.3
Bedrock exposures and areas with a thin cover (< 0.5 m) of Quaternary deposits	35.5

5.2 Glacial striae and exposed bedrock

The Quaternary glaciers moved over the landscape and rock fragments in the ice abraded exposed bedrock surfaces on which glacial striae were formed. These striae reflect the direction of the glacial movements. Glaciers also polished the bedrock surface to a large extent. Many rock outcrops are "Roches moutonnées" with a smooth abraded northwest side and a rough, steep, plucking side leaning towards southeast.

At the fieldwork, glacial striae were observed at almost 130 localities. The main part of the striae was observed in the archipelago on outcrops at the present shoreline. For instance, about 50 striae localities were found in this position on the islands of Ävrö and Hålö. On the other hand, only a few striae were observed in the western part of the investigated area. Consequently, the distribution of observation is not uniform. This fact depends mainly upon a weathered bedrock surface.

At some places, the striae are well shaped and well preserved. About 200 m southeast of the harbour of Kråkelund there are very distinct striae, which are about 2 cm deep (PSM002676). Besides, these striae are wide with sharp edges. Near the meteorological station on Äspö there is an outcrop which is about 100 m in length. This outcrop is nearly covered by striae (PSM002702).

Most of the glacial striae indicate an ice movement from the northwest (Figure 5-5). Striae in this direction (310°–320°) occur at all localities with only one exception. Because of this frequent occurrence, these striae reflect most probably the movement in the ice front zone during the deglaciation. Striae observations outside the investigated area have confirmed this northwesterly ice direction during the deglaciation phase /13, 14, 18, 19/.

***Figure 5-5.** A bare laid rock at the shore on the island of Jungfrun west of Äspö with a young system of striae in 310°.*

At six localities, two distinct systems of striae with slightly different directions occur. Besides the above-mentioned direction, a somewhat more northerly striae direction has been observed (325°–345°). One outcrop with this striae direction is the northernmost cape of Hålö (PSM002590). Probably, these striae indicate a somewhat older ice movement during the deglaciation. An alternative interpretation is that the more northerly striae only indicate local deviations caused by the bedrock morphology.

Glacial striae which indicate an ice movement from the northeast have been observed in the bottom of a trench (PSM005407) south of the village Mederhult. Beneath a till bed of 1.2 m a very small bedrock surface was covered by finely shaped but distinct striae indicating an ice movement from the northeast (45°). It is not possible to make any conclusions regarding this observation. However, some striae investigations from the surrounding archipelago have supposed an old ice movement from the northeast /see e.g. 6, 13, 14/.

Altogether 35 per cent of the investigation area constitutes exposed bedrock and areas with a very thin cover (< 0.5 m) of Quaternary deposits (Table 5-1). This means that there are a large number of outcrops all over the area. However, the frequency of exposed bedrock varies. Certain areas, e.g. the southern part of the local model area and the area to the west of the esker Tunaåsen, have a relative low frequency of exposed bedrock. On the other hand, areas in the north and in the archipelago have a high frequency of exposed bedrock with very little of Quaternary deposits.

5.3 Till

The predominating Quaternary unit in the area is a sandy or gravelly till, which was most likely deposited during the late Weichselian. Till covers about 43% of the investigated area (Table 5-1). The till bed lies directly on the Precambrian bedrock and is generally thin, less than 3 m. The predominating striae direction in the area indicates a last regional ice flow from 310–320°. This most probably corresponds to the ice movement direction at the time of till deposition, i.e. indicates the relative strain direction.

The morphology of the till areas normally reflects the morphology of the bedrock surface. Only one small but distinct moraine ridge has been observed at the mapping work. The ridge is situated in connection to the esker Tunaåsen in northwest. The ridge is about 30 m in broad with a relative height of 3 or 4 m. Small areas of low-relief hummocky moraine exist in some places.

In general, the boulder (and stone) frequency of the till surface is intermediate (Figure 5-6) but areas with a high boulder frequency occur (Figure 5-7), especially in the local model area and to the west of the esker Tunaåsen. There are also a few small areas with a high frequency of large boulders. The internal frequency of boulders in till is in general intermediate. The relation between different kinds of boulder frequency in till surface is clear from Table 5-1.

According to the composition of the matrix most of the till is sandy. Also coarse till, i.e. gravelly, is found in some sections and trenches. This till type has been observed in trenches south of Skölkkärret on Ävrö (6366808 N, 1552525 E) and east of the bridge at Lindströmmen (6367413 N, 1552297 E). It was impossible to separate these two till types during field-mapping. Therefore, all till areas have been named sandy in this investigation.

Figure 5-6. *Till surface with intermediate frequency of boulders south of Mederhult village.*

Figure 5-7. *Till surface with high boulder frequency near Stora Laxemar in the local model area.*

The main (upper) till unit is a brown, sandy or gravelly, massive till with a normal degree of consolidation. It is often rich in cobbles and small boulders, which are generally angular or very angular and consist of the local bedrock type. The maximum thickness of till is 3 m, with very few exceptions.

Laminae and lenses of sorted gravel, sand and silt occur in the till, and are unevenly distributed. In some cases the lower part of the till is silty. This may be remnants of a lower till bed (see below), which was eroded, deformed and incorporated into the upper till bed.

The till lacks enough distinguishing characteristics to make a detailed genetic interpretation possible, but its position directly on the bedrock and general appearance make it likely that it is a basal till. A thin draping silt lamina (up to 2 mm thick) is often present in the till/bedrock interface. This was probably subglacially deposited by a meltwater/sediment slurry below the warm-based ice. The fact that the bedrock surface generally has a rough, unabraded appearance (Figure 5-8) implies that the ice was not very erosive, but the main subglacial process was till deposition by lodgement/accretion.

Figure 5-8. *0.5 m sandy till on unabraded bedrock in a section within the local model area (6366330 N, 1548788 E; PSM005411).*

In one section south of the village Mederhult (6367397 N, 1547630 E; PSM005406) an older till unit was found below the main sandy till. This till differs significantly from the upper normal regional till unit and is most probably the eroded remnants of an older till bed. The lower till has a light brown colour and is only 20 cm thick. It has a silty sandy and slightly clayey matrix and is very strongly consolidated and contains intraclasts of sedimentary clay. Glacial striations on the bedrock surface below this unit are from the northeast (PSM005407). Although this unit was only found in one place, it could have a regional extent and may possibly underlie the sandy till in other places. This is indicated by the abundance of silt beds and intraclasts in the lower part of the main (upper) till in other sites, which may be due to erosion of a silty till bed. It could have any age, but a likely interpretation is that it was deposited during the main Weichselian, during an earlier phase than the main till, when glacial flow from the Baltic entered the area from the northeast.

A much thicker till bed was found in a till quarry in the westernmost part of the regional model area (6364964 N, 1538918 E; PSM005413). The quarry is located in a low-relief hill in the southwestern part of an irregular till accumulation, about one kilometre long and with a southwest-northeast extension. The average thickness in this till accumulation is somewhat greater than in the local model area. A section was cleaned and excavated to a depth of 5 m below ground surface. The bedrock was not reached.

A sketch of this section is shown in Figure 5-9. The upper 0.9 m consist of a loose, sandy till with a diffuse, uneven contact to the lower till, which is at least 4 m thick (Figure 5-10). The lower till also has a sandy composition and differs from the upper one mainly by being more consolidated. It displays angular cobbles arranged in horizontal concentrations. These do not form proper boulder pavements, and the upper surfaces are not abraded or striated. The till has, in places, a weak horizontal fissility. Slightly deformed lenses and laminae of sand and silt occur. All these characteristics suggest that the lower till is a basal till, most likely mainly deposited by lodgement.

A fabric analysis at a depth of 1.4 m did not show a pattern typical for a lodgement till, however. The fabric (Figure 5-11) displays a girdle pattern centred around the south, with no measurements at all in the expected north-westerly direction. The main vector is the SW (232°). An ice flow direction from the south or southwest is not conceivable in this area. The fabric has a rather low strength (S1= 0.62) which is also not typical /cf 4, 7/. One single fabric analysis is however probably not enough to get a reliable result.

The upper till bed in this site is interpreted as a (subaqueous) flow till based on its low degree of consolidation and position uppermost in a positive landform below the highest coastline. It is deposited at the deglaciation of the same glacial event as the main till and is not a regional stratigraphical unit.

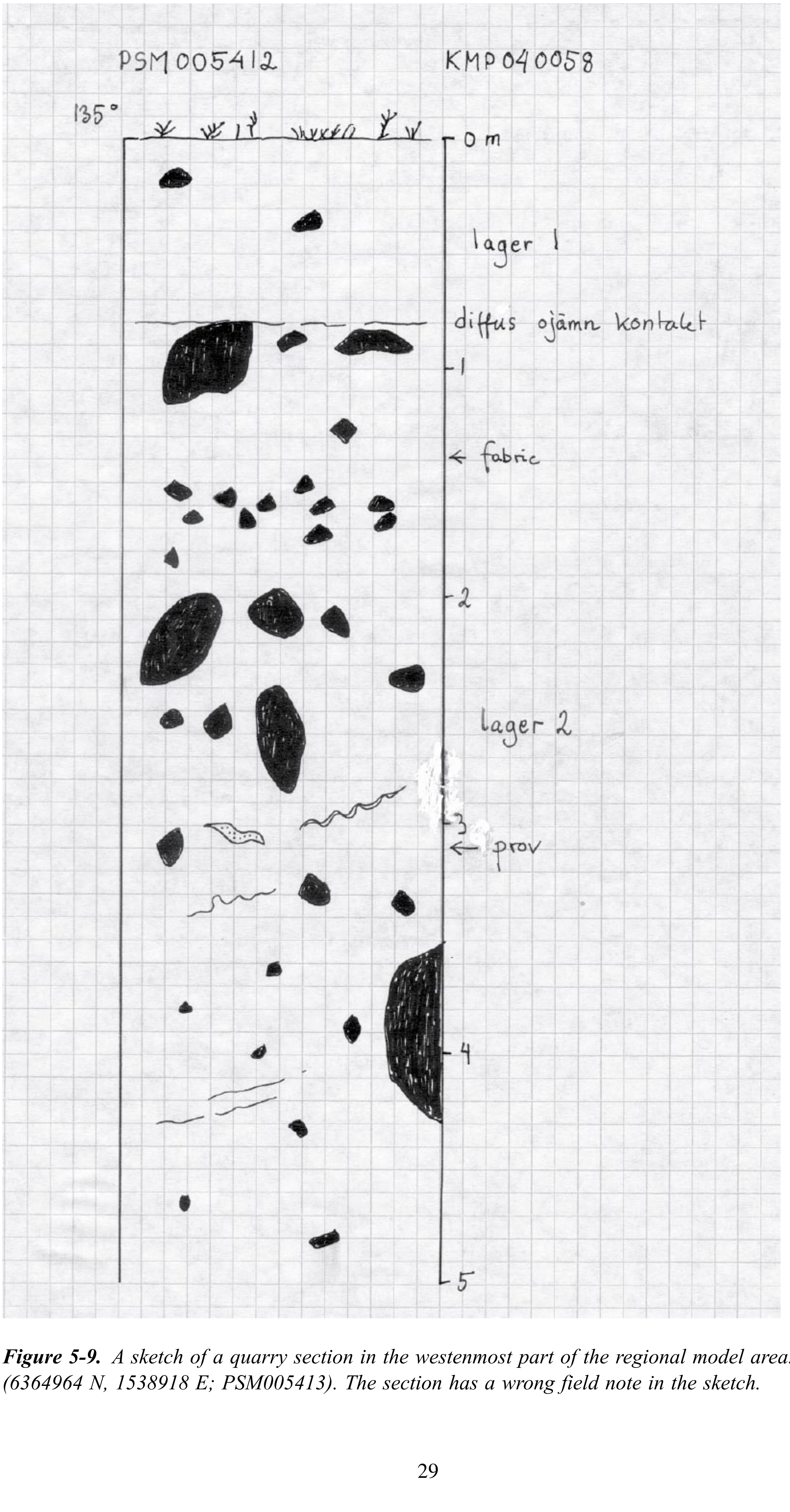

Figure 5-9. A sketch of a quarry section in the westenmost part of the regional model area. (6364964 N, 1538918 E; PSM005413). The section has a wrong field note in the sketch.

Figure 5-10. *The upper part of a quarry section (PSM005413) displays 0.5 m of poorly consolidated flow till, underlain by at least 4 m of hard sandy basal till.*

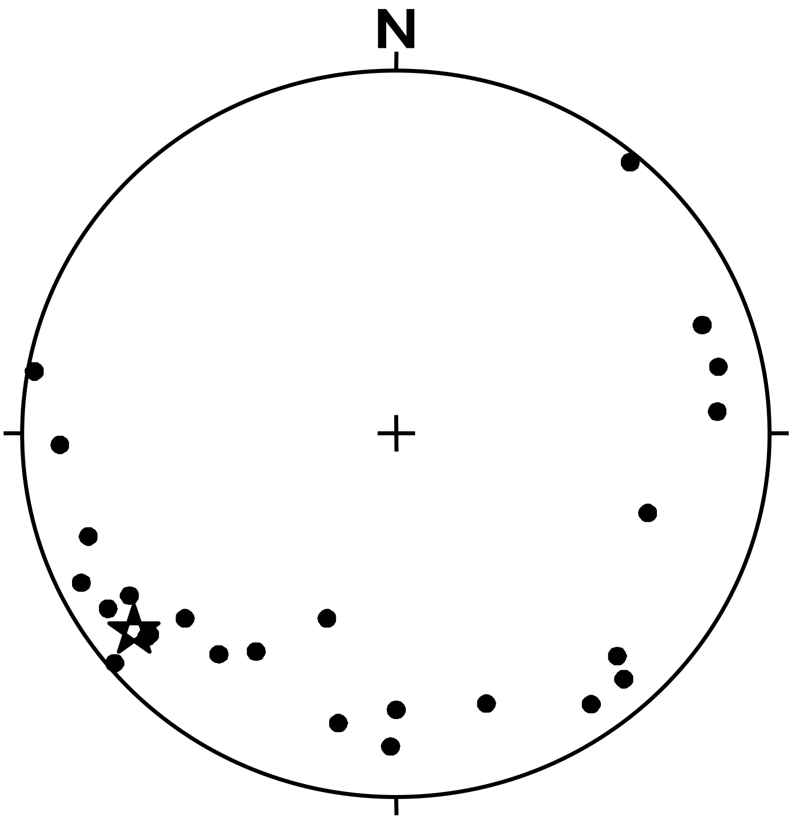

Figure 5-11. *Fabric in bed 2. 1.4 m below ground surface. PSM005413.*

5.4 Glaciofluvial deposits

During the deglaciation, the melt water from the ice deposited large amounts of sand, gravel and stones, which often formed eskers. These deposits are referred to as glaciofluvial deposits and are better sorted with respect to grain size compared to the glacial till.
The eskers were formed in tunnels in the ice sheet, often close to the receding ice front. Generally, the eskers in the southern and middle parts of the county of Kalmar have a northwest-southeast direction and were formed successively as the ice retreated towards the northwest. They show a clear draining pattern of meltwater during the deglaciation phase.

The highest shore line in the Oskarshamn region has been established to a level of about 100 á 110 m above the present sea level /9, 20/. The whole investigated area was situated beneath the shoreline during the deglaciation and therefore the eskers are subaquatically deposited and affected by wave action to a large extent. Owing to this wave action, the esker surface is in many places covered by boulder remnants (Figure 5-12). The gravel and sand fractions have been eroded. The melt water from the receding ice contained suspended silt and clay, which was deposited in the deepest depressions. These deposits are often referred to as glacial clay and are further discussed in Chapter 5.6.

There are two eskers within the investigated area, the large esker Tunaåsen in the west and the small esker Gässhultsåsen in the east. With respect to both water and ballast supply, large eskers are valuable. Therefore, the glaciofluvial sediments have earlier been investigated concerning ground water, ballast and some other aspects as archaeology and nature conservation. The first classification /8/ was detailed and was based upon geological, morphological and biological facts. Other investigations show the ground water content /12/ or the quantity and grain size composition of the material /16/.

Figure 5-12. *An esker surface in Fårbo village with a high boulder frequency.*

The esker Tunaåsen is a large and well-developed esker, which is running roughly north-south within the investigated area. The esker can be followed throughout the area from south to north, a distance of about 8 km. In general, the esker is 100–300 m broad and 5–10 m high. At two sites, south of Lake Jämsen and south of Fårbo village, there are large accumulations with heights of up to 20 m. In general it is affected by wave action to a large extent with well-developed ridges of littoral sand and gravel on its sides. Besides, there are wide areas of littoral sediments alongside the esker.

There are many gravel pits in the esker Tunaåsen (Figure 5-13). There is no gravel exploitation at present and the sections are generally covered with scree. Therefore, it is difficult or impossible to study the internal structure without machine excavations. Gravel and sand are predominating but there are parts with a very coarse composition of boulders and stones.

The groundwater resources in the esker Tunaåsen have been estimated as good /12/. This means that the resources are in the order of 5–25 l/s with very good or excellent exploitation potential. In the Fårbo village close to the Lake Fårbosjön, there is a municipal well with

protection areas. In connection with this SKB investigation, a spring was observed at the foot of the esker with a yield of about 1 l/s. The position of the spring is 6367087 N, 1540422 E.

Along the main road to the west of the nuclear power plant, there are some hills with probably constist of glaciofluvial sediments. They are the southernmost part of a small esker, the Gässhultsåsen. The hills are some metres in height and have no boulders in the surfaces. Therefore they are easy to separate from the surrounding till. There are two or three very small gravel pits in the area but the material was exploited a long time ago.

To the west of the farm L. Laxemar, there are some valleys that are partly filled up with sand and gravel. Probably this sediment has a glaciofluvial origin but only excavations and drillings can prove this assumption.

Glaciofluvial sediment makes up a sand field at the road to the west of Lake Frisksjön. A machine-dug trench (6367978 N, 1548719 E) showed sediments mainly consisting of gravelly and silty sand with few primary sedimentary structures. Instead, the sediments are generally massive and display deformations such as high-angle faults, loaded contacts and steeply dipping bedding planes (Figure 5-14). Gravitational mass movements probably caused the deformations.

North of Lake Frisksjön the esker Gässhultsåsen is ridge-shaped with abandoned gravel pits with sections of about 3 m. A gravel pit quite close to the road is almost totally filled up with wastes of unknown origin.

There are no or very limited groundwater resources in the esker Gässhultsåsen according to an estimation /12/. This means that the resources are in the order of < 1 l/s (< approximately 80 m^3/d).

Figure 5-13. *A 7 m high section in glaciofluvial sediments dominated by gravel and sand just south of lake Jämsen (PSM005621). Some internal structures as loadcast and ripples can be observed in the section.*

Figure 5-14. *Deformed beds of glaciofluvial sand and silty sand in a section near Frisksjön (6367978 N, 1548719 E; PSM005401).*

5.5 Effects of wave washing

The land started to rise when the pressure from the ice sheet was reduced and the water depth decreased subsequently. As the water depth decreased, waves and streams eroded and reworked some of the previously deposited Quaternary deposits.

Streams and waves also reworked the glaciofluvial deposits and till as the water depth successively decreased. In exposed positions, the finest grains have therefore often been washed out from the uppermost parts of the till.

The material eroded from the till, e.g. sand and gravel, was later deposited at more sheltered positions. Such deposits of sand and gravel often cover the glacial clay and are further discussed in Chapter 5.6.

At places, which were exposed to wave erosion, clay and silt fractions have been washed out from the uppermost decimetres of the till. Areas where the till was eroded by wave-washing were delimited during the fieldwork. It was rather difficult to do this separation. Therefore, some till areas with a wave-washed surface layer have probably not been marked in a satisfactory way.

At some sites, which have been exposed to extreme wave washing, the uppermost till consist of a stony layer, so called shingle (Figure 5-15). Such enrichment of stones can also be seen at several places along the present shore, especially on the island of Ävrö (Figure 5-16). In most cases the shingle layers are thinner than 2 m. Their positions on Ävrö are shown in the map in Figure 5-2.

Figure 5-15. *A small shingle field at a till crest (6365482 N, 1549516 E; PSM005376) about 2 km west of the nuclear power plant.*

Figure 5-16. Thin shingle field and small bedrock outcrops on the eastern side of the island of Ävrö (6366944 N; 1553357 E; PSM005123).

5.6 Fine grained water laid sediments

After the deglaciation, glacial clay and, later, postglacial clay was deposited in depressions in the landscape. As the water depth decreased, also sand and gravel, eroded from the till and glaciofluvial deposits, was deposited in these sheltered positions.

Postglacial clay, which was and still is deposited at the deepest parts of sheltered bays, contains organic material, which emanates from algae and other vegetation in the neighbourhood. The organic material is refered to as gyttja, and the sediments containing gyttja are called gyttja clay, clay gyttja or gyttja depending on their content of organic material (gyttja clay < clay gyttja < gyttja). At the field work, areas with gyttja clay and clay gyttja were not separated and have received an uniform name; clayey gyttja.

The areas with glacial clay and postglacial clayey gyttja only cover about 5% of the investigated area. The covering of glacial clay (about 1.3%) is very low compared to other areas in the region, the Västervik area northwards or the Baltic area eastwards. A possible explanation is that the investigated area is rather flat with few major valleys, which were sheltered from the erosion forces of the sea waves.

A general stratigraphy can be established for the water laid sediments in the Oskarshamn area. The oldest sediment is glacial clay, which normally is brownish. Near the ground surface, the glacial clay has a greyish colour shade. Often this fine-grained deposit occurs as a cover in many valleys and younger postglacial sediment often overlie it. The thickness of the glacial clay is in most cases less than 2 m. It is possible or likely that the thickness can be more in large valleys. Investigations have stated that the glacial clay is varved in the region /see e.g. 10, 18, 19/ but these phenomena have not been observed in this work.

A few analyses of samples with superficial glacial clay have shown no or very low lime content. Perhaps this fact depends upon modern-date processes. Hundred years old analyses from the region have stated lime content in the glacial clay /19/. It is possible that the lime content of superficial glacial clay has been dissolved by acid rain.

A thin layer of sand and/or gravel often overlay the glacial clay. The sand and gravel originates from older deposits (e.g. till or glaciofluvial deposits) that have been eroded by waves or sea floor currents.

Clayey gyttja and gyttja are the youngest and uppermost sediments deposited in lakes, bays and inlets along the coast. The deposition of organic material occurs today in many small inlets (Figure 5-17). Most of the cultivation in the local model area takes place upon clay gyttja. Investigation of sediments in the coastal area between Karlskrona and Oskarshamn has shown that gyttja deposition has occured in many Baltic inlets /3/. The thickness of the gyttja and clay gyttja is large in some places. A drilling at Södra Uvö between the village of Figeholm and the peninsula of Simpevarp shows more than 6 m of gyttja /3/.

Fluvial sediments (clay and silt) were found in one area close to a small river near the village Ström. These deposits were formed during periods, when the water table in the river was high, covering the surrounding flat areas.

Figure 5-17. *An inlet with gyttja deposition in progress in the north-eastern part of the island of Äspö. A boring with the Edelmann hand-driven probe in the innermost part of the inlet shows a thin peat cover above 1 m of gyttja upon sand and gravel (PSM002698).*

5.7 Peat

Peat consists of dead vegetation remnants, which are preserved in areas (often mires) where wet conditions prohibit breakdown of organic material. The peat mires are divided into two types: bogs and fens. A coherent cover of Sphagnum-species characterises the bogs. The fens are characterised by sedges of different species, reed, moisture-seeking herbs etc. Fens are more common than bogs.

Mires are in most cases small in the investigated area owing to the morphology of the landscape. Nevertheless, they cover about 8% of the investigated area (Table 5-1). This means that mires are more common than wave washed sediments, glaciofluvial sediments, glacial clay or clay gyttja.

Often the peat deposits have been developed in basins or valleys of former lakes (Figure 5-18). The stratigraphy is therefore characterised by peat covering different kinds of gyttja, clay, sand and till. The total thickness of the peat is in general 1–3 m (Figure 5-19). In the neighbourhood of the Baltic, the normal peat thickness is about 1 m. The thickness of the bog peat (Sphagnum peat) is in most cases limited to about 0.5–1 m in the whole investigated area.

Nowadays, some fens have been more or less affected by man-made drainage. Often these fens area are covered with spruces. Other fens are intact and some of these are considered to be especially valuable for nature conservation. A survey of wetlands in the county of Kalmar registered two mires with great nature values /17/ within the investigation area.

Figure 5-18. *A valley with steep sides which partly is filled up with gyttja and peat (6365710 N, 1549660 E; PSM005378).*

Figure 5-19. *A mire near the farm St. Fjälltorpet (6364891 N, 1545411 E; PSM005110). The peat thickness is somewhat more than 1 m.*

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Appendix 1

Summary of stratigraphy in the sections

Id-number	Stratigraphy (facies code)	Depth (m)	Bedrock
PSM 005401	1.Littoral gravelly sand	0–0.5	
	2. Glaciofluvial gravelly sand (Sm)	0.5–1.4	
	3. Glaciofluvial silty sand (Spp)	1.4–2.0	Not reached.
PSM 005402	1. Littoral gravelly sand	0–0.8	
	2. Glaciofluvial gravelly sand (Sm)	0.8–2.0	
	3. Glaciofluvial silty sand (Spp)	2.0–3. 0	Granite w. unabraded surface.
PSM 005403	1. Gravelly till (Dms)	0–1.3	Unabraded surface.
PSM 005404	1. Sandy till (Dmm)	0–1.6	Unabraded surface.
PSM 005405	1. Sandy till (Dmm) deformed silt laminae in lower part	0–1.4	Unabraded surface.
PSM 005406	1. Sandy till (Dmm)	0–1.0	
	2. Clayey silty till (Dmm)	1.0, 1.2	Abraded surface w. striae from 45.
PSM 005408	1. Sandy gravelly till (Dmm)	0–1.98	
	2. Subglacially deposited silt	1.98–2.0	Slightly abraded quartz dioritoid surface.
PSM 005409	1. Littoral gravelly sand	0–0.6	
	2. Glaciolacustrine silty clay (Cm)	0.6–1.1	
	3. Sandy gravelly till	1.1–1.6	Not reached.
PSM 005410	1. Littoral sandy gravel (Gcm)	0–0.9	
	2. Littoral gravelly sand	0.9–1.6	
	3. Glaciolacustrine sandy silt (Sil)	1.6–2.2	Unabraded surface.
PSM 005411	1. Sandy till (Dmm)	0–0.5	Unabraded surface.
PSM 005412	1. Gyttja clay	0–0.75	
	2. Glaciolacustrine clay (Cl)	0.75–1.0	
	3. Sandy till (Dmm)	1.0–1.4	Not reached.
PSM 005413	1. Sandy till (Dmm), probably flow till	0–0.8	
	2. Sandy till (Dmm), probably basal till	0.8–5.0	Not reached.
PSM 005414	1. Littoral medium sand	0–0.5	
	2. Littoral sand (Stc)	0.5–1.4	
	3. Subglacially deposited or glaciolacustrine silt (Sim)	1.40–1.45	Unabraded surface.