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Forsmark site investigation

Searching for evidence of late- or post-glacial faulting in the Forsmark region

Results from 2003

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Geological Survey of Sweden (SGU)

June 2004

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Keywords: AP PF 400-03-20, Late- or postglacial faulting, Earthquake, Quaternary deposits, Seismically induced liquefaction, Sliding, Field note: Forsmark 229.

Summary

Stratigraphical investigations in machine-cut trenches were carried out at eight localities along the Börstil esker, situated to the southeast of Forsmark. A total of some 450 m of trenches were dug and investigated. The most remarkable result of the study was the discovery of extensive and repeated sliding along the very gentle slopes of the esker. Evidence of sliding was encountered in almost all of the trenches, without any regional divergence as regards the extent or character along the esker. There is no evidence of simultaneous sliding at the different sites, something that would indicate the influence of external forces, but neither can this alternative be excluded. Hypothetically, the sliding may have been triggered by moderately strong earthquakes in the vicinity or by more distant earthquakes of higher magnitude. However, if triggered by moderately strong earthquakes in the Forsmark area, more intense effects would be expected along the northern than along the southern parts of the Börstil esker. No such zonation was indicated. The general stratigraphy along the flanks of the esker, loosely packed deposits of sand and coarse silt covered by a cap of less permeable, fine-grained silty and clayey sediments, has provided good opportunities throughout postglacial times for development of liquefaction features if subjected to strong earthquakes. The fact that no such features related to seismic shaking were found appear to exclude major (> M 7) postglacial earthquakes in the close vicinity, the Forsmark area included.

Sammanfattning

Stratigrafiska undersökningar i maskingrävda schakt har utförts på åtta platser utmed Börstilåsen sydost om Forsmark. Den sammanlagda längden på de undersökta schakten är ca 450 m. Den allmänt förekommande jordlagerföljden utmed åsens flackt sluttande sidor, luckert lagrad isälvssand och finmo som täcks av mjäla och varvig lera, kan i vattenmättat tillstånd utveckla s k liquefaction om den utsätts för starka markskakningar. Jordlagren förlorar då sin hållfasthet och försätts i ett flytande tillstånd, ofta med omfattande deformationer av de primära lagringsstrukturerna som följd. Eftersom grävplatserna varit täckta av hav till i geologiskt sett sen tid och att grundvattenståndet ännu i dag är högt, har lagerföljderna under hela den postglaciala tiden haft goda förutsättningar att registrera större jordskalv inom regionen.

Den mest anmärkningsvärda iakttagelsen vid undersökningen av lagerföljderna är spåren efter en synnerligen omfattande skredaktivitet. Sjok av finkorniga sediment har vid upprepade tillfällen glidit utför de mycket svaga sluttningarna med starkt störda lagerföljder som följd. Eftersom det inte varit möjligt att tidsbestämma skredrörelserna på de enskilda platserna finns för närvarande inget som antyder att de inträffat samtidigt från plats till plats, något som skulle kunna peka mot en gemensam utlösande faktor. Ett samband mellan skredrörelser och vattenavgångar från underliggande sandiga sediment antyds dock och det kan inte uteslutas att jordbävningar orsakat sättningar i jordlagren, med viss kompaktion och avvattning som följd.

Lagerföljderna uppvisar spår efter upprepad erosion av den forna havsbottnen, sannolikt av starka bottenströmmar. Inte minst tycks betydande mängder sediment ha mobiliserats kort tid innan området höjdes ovanför havets nivå. Det betonas starkt att den information som ernåtts i de undersökta schakten inte på något vis är tillräcklig för en mer komplett rekonstruktion av vad som inträffat sedan isavsmältningen, men det faktum att inga jordbävningsrelaterade liquefactionfenomen påträffats antyder ändå att några verkligt stora (> M 7) postglaciala jordskalv knappast inträffat inom den närmaste regionen, kandidatområdet i Forsmark inräknat. Det bedöms inte heller som särskilt sannolikt att skredrörelserna utlösts av måttligt stora (> M 6) skalv inom Forsmarksområdet eftersom sådana i så fall borde ha lett till betydligt mer omfattande effekter utmed de norra delarna av Börstilåsen än utmed de södra. Så tycks inte vara fallet men fortsatta undersökningar kommer förhoppningsvis att kunna utvisa om någon regional zonering av jordskred eller andra presumtivt jordskalvsrelaterade fenomen föreligger inom undersökningsområdet.

Contents

1 Introduction

This document reports the results gained by the *Searching for evidence of late- or post-glacial faulting in the Forsmark region*, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF400-03-20 and Method description MD 133.001 (Both SKB internal controlling documents).

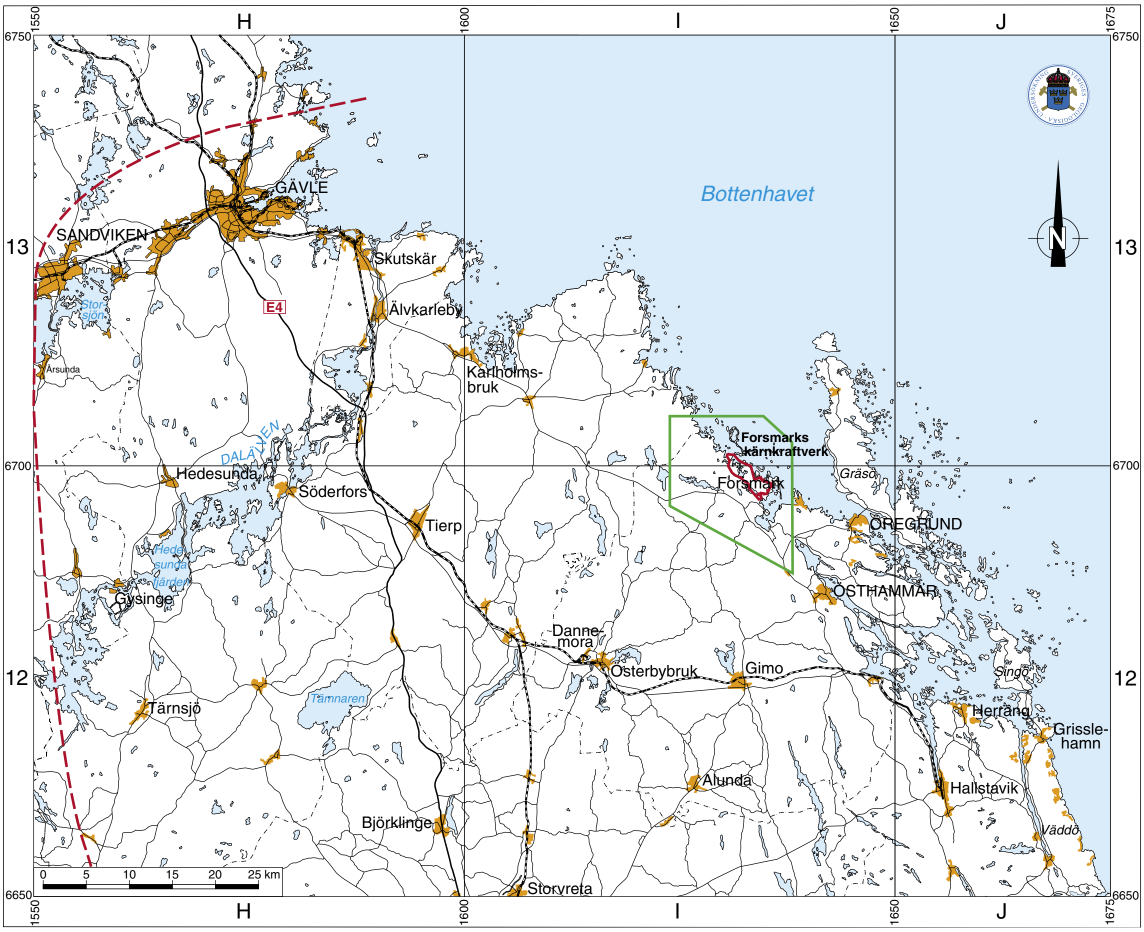

Figure 1-1. Map of the investigation area in north-eastern Uppland (mainland areas to the east of the stippled red line). A continuous red line marks the candidate area for detailed site investigations and the green line marks the area covered by low-altitude aerial photographs.

2 Objective and scope

The study aims to elucidate whether any major late- or post-glacial faulting has occurred in the proposed repository area in Forsmark or in its vicinity. ”Major faulting” in this context means dislocations in the order of several metres along faults of several kilometres length. Faults of these dimensions may, if conditions are favourable, be detected by means of air-photo interpretation. The process of dislocation may have been associated with high magnitude earthquakes that may produce characteristic distortions in water-saturated sandy or silty sediments. Thus, fault movements may be indicated either directly by distinct dislocations manifested in bedrock surface or covering regolith, or indirectly, by seismically derived deformations of certain types of Quaternary sediments. If late- or postglacial fault movement is indicated and assigned to a specific fault or fault zone, the event should, as far as possible, be dated and fault displacement be quantified. This report includes results from fieldwork performed 2003. The study was initiated 2002 /Lagerbäck & Sundh 2003/ and is planned to be finalised after the field season 2004.

3 Equipment

3.1 Description of equipment

Air-photo interpretation was performed in a Wild Aviopret stereoscope using IR-images at the scale of 1:30 000 (1:15 000 within the site-investigation area).

Excavators (preferably of crawler type for moist or cultivated ground) capable of cutting trenches to a depth of some 5 m were used for stratigraphical work (Figure 3-1). Buckets with a flat cutting edge facilitated subsequent manual cleaning of trench walls by shovels, bricklaying trowels and joint fillers (curved and sharpened). Trench wall sections were documented in sketches and photographs.

A hand-held drilling machine (Cobra) combined with a through-flow sampler (giving cores 500 x 33 mm in size) was used for coring of sediments.

Hand-held GPS was used for positioning.

Figure 3-1. *During 2003 the activities within the project were focussed on stratigraphical investigations in machine-cut trenches. Crawler excavators capable of cutting trenches to a depth of some 5 metres were used. Trenching at Hultet, E3 in Figure 4-1.*

4 Execution

The study includes several steps according to SKB MD 133.001.

1. A brief review of geological literature and other relevant information from the area. Any information that may indicate recent faulting or earthquakes is recorded for later following-up in the field.
2. Air-photo interpretation. Any indications of recent faulting or earthquakes (landslides etc.) are recorded for later following-up in the field. Gravel- and sand-pits are marked out on maps for later examination in the field.
3. Field reconnaissance. Any indications on recent faulting or earthquakes recorded during the literature study or air-photo interpretation are checked. Stratigraphies in gravel- and sand-pits in operation, temporary road cuttings, etc. are examined for any seismically induced distortions. Bedrock exposures in parts of the coastal areas are inspected for any fault-related displacements in the glacially polished rock surface.
4. Stratigraphical investigations in machine-cut trenches, mainly dug in sediments of favourable composition for developing earthquake-induced liquefaction phenomena.

Activities according to 1-3 were realized in 2002 /Lagerbäck and Sundh, 2003/. In 2003 the study was focusing on stratigraphical work, mainly in machine-cut trenches but supplemented by a few bore holes.

4.1 Stratigraphical investigations in machine-cut trenches

In all seventeen trenches and a few minor pits were excavated at seven different sites in 2003. Included in the study is also an 80 m long trench and two minor pits excavated in 2002 /Lagerbäck and Sundh, 2003/. All excavation sites are situated along the Börstil esker to the southeast of Forsmark (Figure 4-1). The trenches were cut on the flanks of and perpendicular to the esker with the ambition to reach sandy glaciofluvial deposits or coarse glacial silt, ideally covered by a moderately thick bed of more fine-grained sediments. All of the trenches were cut in level or only gently sloping ground (Figure 4-2) and reached to depths between some 1.5 to 5.0 m. The total length of all trenches measured some 450 m. Trench walls were cleaned manually and afterwards documented in sketches and photographs. The documentation had to be brief. The time available for excavation, documentation and restoring of the cultivated ground was, on average, two days at each site.

4.2 Sediment coring

Coring of clay beds intercalated by sandy layers was carried out at four sites (C1-C4) in the vicinity of Hallstavik (Figure 4-1). The deepest bore hole reached c. 9 m while the others were finished at a few metres depth after penetrating the sandy layer sought for and the upper part of underlying clay.

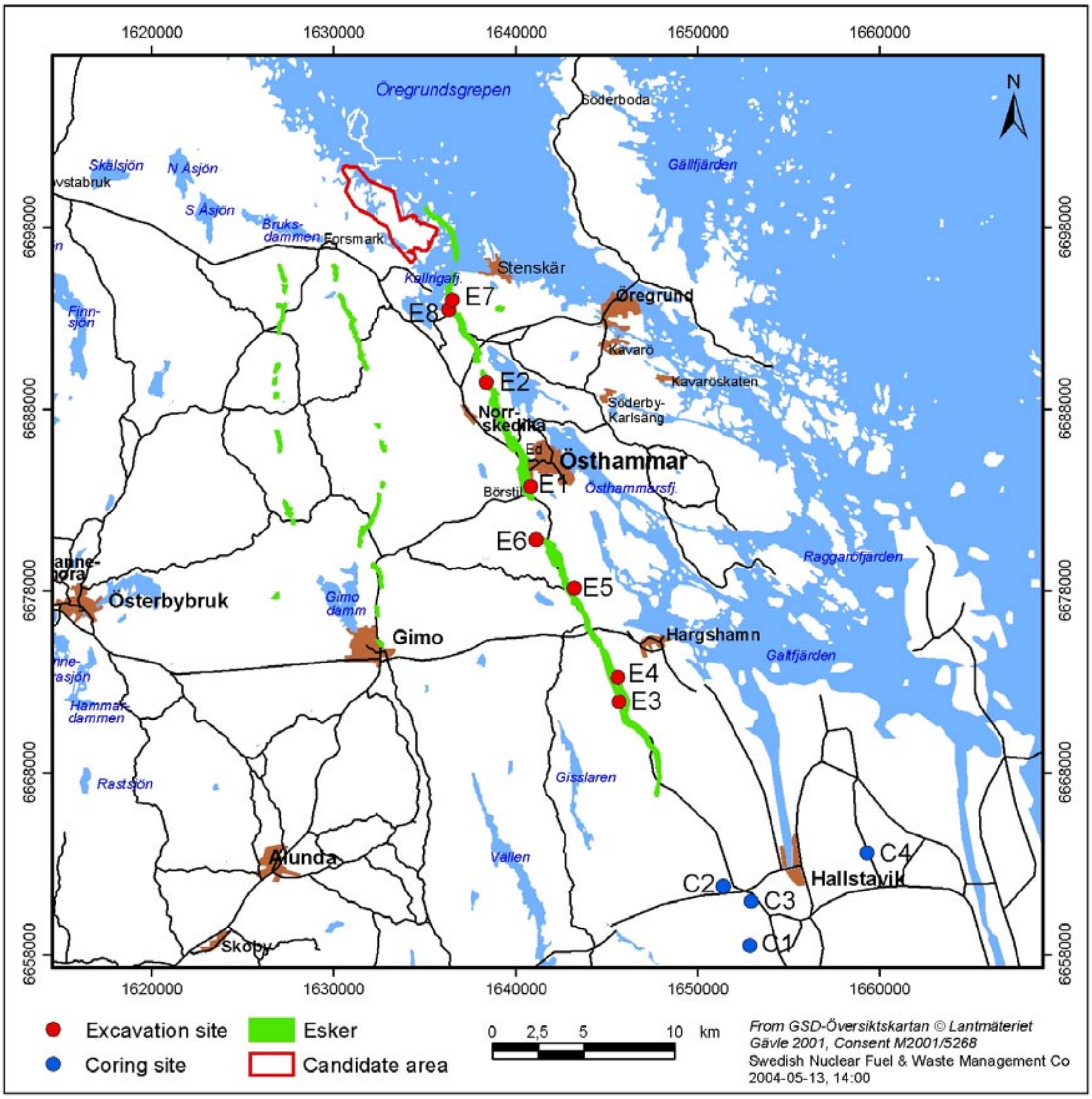

Figure 4-1. *Location and names of excavation (E) and coring (C) sites. E1 Börstil. E2 Lindersvik. E3 Hultet. E4 Kråkmötet. E5 Lädra. E6 Marka. E7 Örnäs. E8 Östansjö. C1 Hammarby. C2 Kristinelund. C3 Söderängen. C4 Kusby.*

Figure 4-2. *Typical excavation site in very gently sloping ground along the Börstil esker. Kråkmötet (E4) after opening of a first test pit.*

4.3 Data handling

The positions of stratigraphical observations were determined by GPS. The dates of the observations were notified and they were all given PFM numbers. All points and dates were later stored in SICADA under Field note: Forsmark 229. The geological information connected with the PFM numbers was stored in SGUs database (Jorddagboken version 5.4.3). Data from the SGU database were exported to Excel, TIF and JPG files.

The deliverance to SKB from the investigations carried-out during 2003 consists of:

1. Data files with stratigraphical information.
   SKB_PFM_NEO040401.xls

2. Data files with photos and sketches.
   Foton_PFM_NEO_040401(jpg) (69 photos)
   Skisser PFM_NEO_040401 (tif) (37 sketches)

4.4 Analyses and interpretation

The ultimate interpretation of the stratigraphical information gained in the machine-cut trenches, i.e. - were there any major postglacial earthquakes in the vicinity of Forsmark? - is based mainly on the concept of earthquake-induced liquefaction. If loosely packed, water-logged, frictional sediments are subjected to strong ground shaking they may lose their strength and behave like liquids. As a consequence of liquefaction the primary sedimentary structures will be destroyed and replaced by a variety of deformational features. Earthquake-induced liquefaction is controlled by a number of variables such as packing and grain size of sediment, location of water table, duration of earthquake, amplitude and frequency of shaking and, not at least, distance from earthquake epicenter.

It is commonly considered that liquefaction phenomena may develop in highly susceptible sediments at magnitudes as low as M_w 5 but become more common at M_w 6 or higher. A shallow-focus, M_w 6 earthquake may cause liquefaction features at a distance of some 20 km from epicenter, a M_w 7 earthquake within some 100 km, while a major M_w 8 earthquake may induce liquefaction as far away as 300 km /e.g. Obermeier 1996/. Furthermore, the Lansjärv and Burträsk areas in northern Sweden, in similar geologic settings as northern Uppland, may serve as reference areas when evaluating the results from the present investigation. In both of these areas postglacial faulting induced a great variety of regionally distributed liquefaction phenomena /Lagerbäck, 1990; Lagerbäck and Sundh, unpubl./.

5 Results

5.1 Stratigraphical investigations in machine-cut trenches

Deposits of loosely packed sand or coarse silt covered by clayey beds were encountered in almost all of the trenches. If shaken by strong earthquakes in a water saturated state, such deposits are highly susceptible for development of liquefaction. The fact that the excavation sites are situated no more than 5 – 20 m above present sea level means that the deposits were entirely waterlogged from the moment of deglaciation until they fairly recently were raised above the sea. Furthermore, a present-day high ground-water table in most of the sections means that the deposits largely have remained susceptible for liquefaction throughout the Holocene (Figure 5-1).

Figure 5-1. *Deposits of fine-grained sand and clay-laminated silt on top of loosely packed glaciofluvial sand at Marka (E6). The uppermost dark horizon consists of cultivated top-soil. The rust-coloured horizon in the glaciofluvial sand indicates a stable groundwater table.*

Although favourable conditions, no significant features related to liquefaction were noticed in any of the trenches (Figure 5-2). Minor deformations indicating limited liquefaction occurred localized to some boulders embedded in silty glacial sediments. These deformations are interpreted to have developed when the boulders penetrated into the sediments after being dropped from ice-bergs. Without exception the glaciofluvial sand proved to be quite loose with the primary sedimentary structures perfectly preserved except for minor faults and water-escape features (Figure 5-3). Minor faults and water-escape structures were also found in the more fine-grained sediments covering the glaciofluvial deposits.

The water escape structures, mainly in the shape of sand filled pipes or more diffuse seepage features, were generally of small magnitude. Most of them originated in the glaciofluvial sandy deposits but reached to and finished at varying depths of the covering sediments, sometimes in the shape of a thin sand layer. It appears that dewatering has occurred repeatedly during the deposition of sediments.

Figure 5-2. *Typical for the stratigraphy along the Börstil esker, this trench section at Östansjö (E8) shows a bed of fine sand and coarse silt covered by a bed of clay-laminated silt. The uppermost 0.4 m consists of cultivated top-soil. Extended excavation revealed loosely packed and saturated glaciofluvial sand to a depth of at least 5 m. Although the stratigraphy is considered to be highly susceptible to liquefaction, no deformations related to seismically induced liquefaction were found here or elsewhere along the Börstil esker.*

Figure 5-3. *Minor faults and water escape structures occur rather frequently in the thick, sandy glaciofluvial deposits at Östansjö (E8). Scale in cm and dm.*

The most remarkable discovery made during the excavations however, was the extensiveness of translational sliding along the very gentle slopes of the esker. Evidence of sliding or folding was met within almost all of the trenches. Slabs of clayey and silty deposits have detached along planar failures parallell to the bedding and then slided down“slopes” to cover previously deposited sediments. The slided deposits vary from plates of more or less undisturbed sediments (Figure 5-4) to strongly folded sequences (Figure 5-5) or a chaotic mixture of all kinds of sediments without any primary sedimentary structures preserved (Figure 5-6). In some of the sections there is evidence of at least three episodes of sliding separated by erosional events or by periods of undisturbed sedimentation. No regional, north-southerly divergence concerning the character or extent of sliding was indicated along the esker.

Not surprisingly, sliding and folding proved to be more intense in apparently inclined ground, to decrease and finally cease towards level terrain. However, the extent of sliding is probably not only a matter of gradient but also depends on the character of underlying sediment. It appears that the slided deposits were easily mobilized when they originally rested on sandy glaciofluvial deposits. The occurrence of dewatering features follows the same pattern and most likely there is a causal relationship between sliding and dewatering of underlying sediments. Where resting on glacial till, the fine-grained sediments remained undeformed despite sloping ground. Due to a low porosity and tight packing, glacial till cannot produce an excess of water to initiate and facilitate sliding by lubricatation. Furthermore, till boulders protruding into the overlying water-lain sediments constitute obstructions that prevent slide movements.

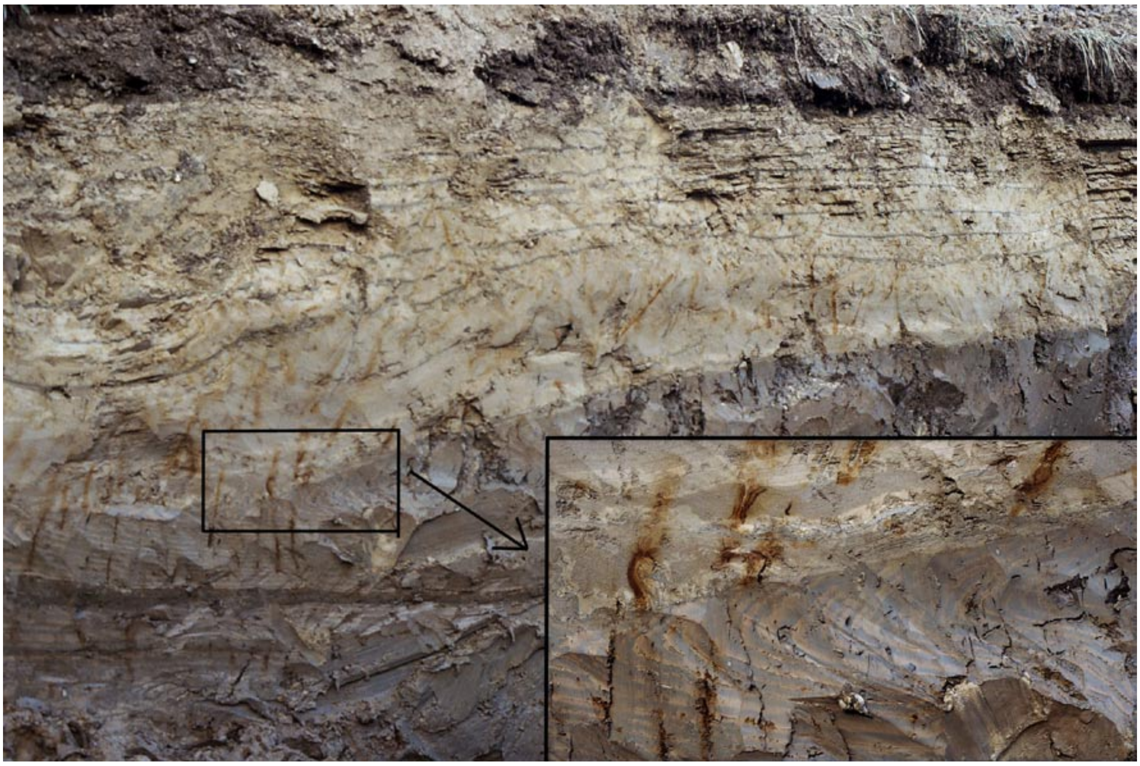

Figure 5-4. *Illusory stratigraphy due to graceful sliding at Örnäs (E7). An almost undeformed slab of thick-varved, sandy silt (light coloured with thin, dark layers of clay) has come to rest on varved glacial clay. The uppermost bed consists of cultivated top-soil rich in pebbles and cobbles. The close-up photo in the lower right-hand corner shows the slip surface with drag folds in the upper parts of the clay.*

It has not been possible to accurately date the sliding in any of the trenches and, accordingly, it is not possible to establish any synchronism of events between the different sites. The only chronostratigraphical marker horizon in the sections is the so-called spot zone, a sequence of clay characterized by a high content of Ordovician limestone fragments. The most characteristic part of the spot zone comprises some 90-110 thin varves of clay, deposited while the receeding ice sheet rapidly melted away from the southern part of the Bothnian Sea /Strömberg, 1989/. The spot zone clay is included in the slided deposits in several of the investigated trenches, but in one of the trenches it also occurred in an apparently undeformed bed intercalating slided masses of clay and silt.

Figure 5-5. *Gently folded silt and fine sand at Östansjö (E8).*

Figure 5-6. *Chaotically mixed slide deposits of fine sand, silt and glacial clay at Hultet (E3).*

Most of the clay involved in the sliding is clearly varved and probably of glacial origin. Micro-varved clay or clay without any visible varves occurred in a few sections but unmistakable postglacial clay was found neither in slided deposits nor undeformed on top of these. It appears that sliding had occurred on several occasions during the late- or early postglacial period, whereas there is no evidence of this in any later episodes. However, it should be strongly emphasized that the information gathered in the restricted number of trenches is fragmentary and by no means sufficient for an adequate reconstruction of the geological evolution at the bottom of the ancient sea. The stratigraphies recorded varied from place to place and were sometimes quite different on each side of one and the same trench. The variation of sediment stratigraphy from one trench to another demonstrates that it is a matter of chance what a single trench will display. Furthermore, as the terrain was effectively smoothened by erosion before it was raised above the sea, the exterior of ground surface gives almost no guidance for what will appear at depth when chosing excavation sites (Figure 5-7).

Figure 5-7. *How to find adequate stratigraphies for investigation? Due to intense post-sedimentary erosion the exterior of ground surface gives almost no guidance for what will appear at depth. Although only three metres apart these two pits close to the completely flattened Börstil "esker" (situated at the trees just beyond the car, cf. Figure 5-9) at Lindersvik (E2) display completely different stratigraphies; > 4.5 m of dense, clayey glacial till (foreground) and > 4.5 m of saturated glaciofluvial sand respectively.*

Substantial deposits and, as a result, information is missing due to erosion. Erosional unconformities, most likely indicating bottom currents in the ancient sea, occur between some of the stratigraphic units in several of the sections. Furthermore, in most of the sections the uppermost stratigraphic unit consists of a thin sandy or gravelly layer, with an erosional unconformity to underlying deposits. Also in sections where this layer of coarse-grained sediments is missing, there is good evidence for very intense surficial erosion since bedding as well as deformational structures are discordantly cut at ground surface (Figure 5-8). Where the glaciofluvial deposits contain boulders, especially frequently close to the central parts of the esker, there is often no more left than a pavement of enriched residual boulders in ground surface (Figure 5-9). This very intense erosion probably dates back to a rather late stage of the land upheaval.

Figure 5-8. *Abruptly cut folds in glacial silt at Marka (E6) indicate substantional erosion of a formerly thicker sequence.*

Figure 5-9. *The trivial remnant of a formerly more pronounced ridge-shaped Börstil "esker" at Lindersvik (E2) after being intensely abraded by the sea is just a pavement of residual boulders.*

5.2 Sediment coring

Coarse-grained sediments separating typical postglacial gyttja clay from glacial clay were met with at all four coring sites around Hallstavik (Figure 5-10). The thicknesses of these chiefly sandy layers varied between 0.1 and c.1 m. At one of the sites there was coarse sand throughout, at two of them the sediments displayed graded bedding, fining upwards from gravelly sand to coarse silt, while at the fourth site the sequence was more complex, containing not only sand and gravel but also richly shell-bearing sand and a thin layer of clay. The high content of shells in this sequence indicates that the deposition of sediments, and most probably also the erosion of underlying clay, occurred in rather shallow water during a late stage of the Holocene.

Figure 5-10. *Sediment core from Söderängen (C3) consisting of an upper gyttja clay (right) and a lower bluish clay intercalated by a sandy layer. Graded bedding of sand and an unconformity between sand and underlying clay indicates erosion and deposition by a current of decreasing velocity.*

5.3 Summary and discussions

Although susceptible deposits are present in most of the investigated sections along the Börstil esker, no significant liquefaction features indicating strong seismic shaking were noticed. A comparison with areas in similar geological settings elsewhere, where the relation between major fault movements and secondary, seismically induced deformations have been studied, may be of some interest. Major early postglacial faulting in the Lansjärv area in northern Sweden, generating an earthquake with a magnitude estimated to ~ Mw 7.8 /Muir Wood, 1993/, resulted in a great variety of deformations of the Quaternary overburden /Lagerbäck, 1990/. In the Burträsk area, likewise in northern Sweden, a fault of somewhat less dimensions was associated by extensive deformation of late-glacial sediments /Lagerbäck and Sundh, unpubl./. Laterally persistent and regionally distributed liquefaction features occur very frequently in both of these areas. The fact that no such features whatsoever were found in the trenches along the Börstil esker appear to exclude major postglacial earthquakes in the vicinity.

On the other hand, evidence of surprisingly extensive and repeated sliding occurs even in very gently sloping terrain along the Börstil esker. It has not been possible to accurately date the single sliding events but, based on the occurrence of the so-called spot zone clay and deglaciation chronology /Strömberg, 1989/, it appears that the most intense sliding occurred at least several hundreds of years after local deglaciation. Settling and dewatering of underlying glaciofluvial deposits provide a reasonable explanation of the extent of the sliding. Excess of pressurised pore water in glaciofluvial sand and coarse silt, trapped by the fine grained and less permeable covering beds, may have initiated and facilitated sliding by lubrication. It is not evident if settling, dewatering and sliding have occurred spontaneously due to loading solely or if the phenomena were triggered by the influence of any external factor. There is no evidence for simultaneous sliding at the investigated sites, something that would indicate influence of external forces (e.g. earthquakes), but neither can this alternative be excluded.

Hypothetically the sliding may have been triggered by moderately strong earthquakes in the vicinity or by more distant earthquakes of higher magnitude. However, if triggered by moderately strong earthquakes in the Forsmark area, more intense effects would be expected along the northern than along the southern parts of the Börstil esker. The northernmost trenches are situated only a few kilometres away from the candidate area, whereas the distance to the southernmost measures some 30 km. No such zonation is indicated in the trenches investigated

The upper parts of the sediment sequences appear to be stongly eroded before the sites were raised above the sea. Typical postglacial clay was not met with at any of the sites whereas evenly spread sand or gravel, with a clear erosional unconformity to underlying deposits, occurred in the ground surface at most of them. It is reasonable to assume that this sand and gravel correspond to the sandy or gravelly layer separating the postglacial clay from the glacial clay at the coring sites. A distinct, sandy layer between glacial clay and overlying postglacial clay is known to be a characteristic element of the sediment stratigraphy in the region /e.g. Hedenström and Risberg, 2003/.

An erosional unconformity accompanied by a laterally persistant layer of coarse-grained sediments, occurring not only in positions that were exposed to the waves of the ancient sea but also in sheltered positions in the terrain, indicates that potent currents rather than wave-washing were responsible for erosion and deposition. Strongly shell-bearing sand at one of the coring sites indicates that deposition and preceding erosion took place in rather shallow water during a late stage of the Holocene. A similar conclusion is drawn by Hedenström and Risberg /2003/ who suggest that the flat topography of northern Uppland, in combination with strong currents, has resulted in erosion and transport of fine grained particles towards the deeper parts of the Baltic basin. Together with sliding, this erosion has resulted in an extensive redistribution of sediments and in a substantial levelling of the terrain.

Finally, it is strongly stressed that the geological development at the bottom of the ancient sea obviously was complicated and by no means is fully understood. The excavations have probably provided no more than a few pieces of the relevant information needed for a more comprehensive understanding of what has taken place during the postglacial period. Important pieces of information about the geological course of events are forever lost, or at least very difficult to achieve, due to the extensive erosion of the sediment sequences.

References

Hedenström A, Risberg J, 2003. Shore displacement in northern Uppland during the last 6500 calender years. SKB TR-03-17, Svensk Kärnbränslehantering AB.

Lagerbäck R, 1990. Late Quaternary faulting and paleoseismicity in northern Fennoscandia, with particular reference to the Lansjärv area, northern Sweden. Geologiska Föreningens i Stockholm Förhandlingar 112, 333-354.

Lagerbäck R, Sundh M, 2003. Searching for evidence of late- or post-glacial faulting in the Forsmark region. Results from 2002. SKB P-03-76, Svensk Kärnbränslehantering AB.

Muir Wood R, 1993. A review of the seismotectonics of Sweden. SKB TR-93-13, Svensk Kärnbränslehantering AB.

Obermeier S F, 1996. Use of liquefaction-induced features for paleoseismic analysis – An overview of how seismic liquefaction features can be distinguished from other features and how their regional distribution and properties of source sediment can be used to infer the location and strength of Holocene paleo-earthquakes. Engineering Geology 44,1-76.

Strömberg B, 1989. Late Weichselian deglaciation and clay varve chronology in East-Central Sweden. Sveriges geologiska undersökning, Ser. Ca 73.