P-05-232

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Searching for evidence of late- or postglacial faulting in the Oskarshamn region

Results from 2004

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Geological Survey of Sweden (SGU)

November 2005

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Summary

In connection with previous aerial photo interpretation, a number of prominent escarpments, hypothetically indicative of late- or postglacial faulting, were noted in the mainland part of the investigation area. Most of these scarps were field-checked in 2004 and found to be more or less intensely glacially abraded, i.e. formed prior to the last deglaciation. On the island of Öland a very distinct, straight lineament was likewise noticed in connection with aerial photo interpretation. In the field the lineament was identified as a step in the ground surface or as a very distinct vegetational boundary, the latter due to a difference in thickness of the soil cover on either side of the lineament. The step in the ground surface clearly derives from a bedrock scarp but it was not possible to determine its nature or age in the absence of stratigraphical information.

No systematic search for unstable boulders, tentatively refuting the occurrence of major earthquakes in the vicinity, was carried out, but a few specimens were encountered during minor excursions in different parts of the investigation area. However, without estimating how much earthquake-induced ground motion these boulders could withstand before they would topple over, it is difficult to judge their significance as palaeo-earthquake indicators.

Stratigraphical investigations in machine-dug trenches were carried out at three localities along the Fårbo esker, all situated west of the candidate area at Simpevarp. A total of some 170 m of trenches were excavated and investigated. Deposits of loosely packed sand and coarse silt were encountered in almost all the trenches and in some of them a clayey bed covered the sandy-silty deposits. When shaken by strong earthquakes in a water-saturated state, such deposits are highly likely to liquefy but no significant features related to liquefaction were noted in any of the trenches. However, as the excavation sites are situated some 30–100 m above the present sea level, they must have been raised above the ancient sea fairly soon after the deposition of sediments. Consequently, the deposits were completely waterlogged and susceptible to liquefaction only during a limited period of time.

The most remarkable observation made during the stratigraphical investigations was the occurrence of slide deposits at Fårbosjön, near Simpevarp. It was not possible to date the sliding in any of the trenches but, as the slide deposits were covered with beach sand, sliding must have occurred some time between deglaciation and the upheaval above the sea, some 11,000 years ago. It is an open question whether the sliding occurred spontaneously due solely to loading, or whether the phenomenon was triggered by an external event. Hypothetically this may have been moderately strong earthquakes in the vicinity or more distant earthquakes of greater magnitude.

The frequent occurrence of periglacial features in those parts of the investigation area located above the sea during the Younger Dryas period some 12,000 years ago suggests that frost processes must be seriously considered as an alternative to seismically induced liquefaction when deformed sediments are encountered.

Sammanfattning

I samband med tidigare genomförd flygbildstolkning noterades ett antal iögonfallande och relativt uthålliga berggrundshak inom fastlandsdelen av undersökningsområdet, dvs strukturer som skulle kunna tyda på unga förkastningsrörelser. Flertalet av dessa fältkontrollerades 2004 och det visade sig att de var mer eller mindre starkt slipade av inlandsis och därmed äldre än den senaste isavsmältningen. I samband med flygbildstolkningen noterades också ett mycket tydligt lineament på Öland. På marken visade sig lineamentet som ett steg i terrängen, där den västra sidan ligger lägre eller har en helt annan vegetation till följd av ett mäktigare jordtäcke. Steget i markytan motsvaras entydigt av ett språng i berggrundsytan men utan stratigrafisk information var det inte möjligt att bedöma orsaken till detta eller dess ålder.

Någon mer systematisk rekognosering efter instabilt liggande block fanns det inte utrymme för men ett fåtal sådana hittades i samband med kortare utflykter till olika delar av undersökningsområdet. Utan beräkningar av hur starka markskakningar som skulle behövas för att välta omkull blocken är det emellertid svårt att bedöma deras tillförlitlighet som garanter för att några större jordbävningar inte ägt rum i närområdet.

Stratigrafiska undersökningar i maskingrävda schakt med en sammanlagd längd på ca 170 m genomfördes på tre platser utmed Fårboåsen väster om Simpevarp. Avlagringar bestående av löst lagrad sand och grovsilt påträffades i nästan alla av schakten och i några av dem överlagrades sanden och silten av lera. I vattenmättat tillstånd är denna typ av jordlagerföljder känsliga för markskakningar och försätts lätt i ett flytande tillstånd, s k liquefaction, med deformationer av de primära sedimentstrukturerna som följd. Inga sådana deformationer påträffades, men det faktum att undersökningsplatserna är belägna mellan 30–100 m över havet betyder att de höjdes ovanför havsytan relativt kort tid efter sedimentens avsättning och att dessa därför var helt vattenmättade och mottagliga för störningar endast under en begränsad tidsperiod.

Den mest anmärkningsvärda iakttagelsen i samband med de stratigrafiska undersökningarna var förekomsten av omfattande skredavlagringar vid Fårbosjön nära Simpevarp. Det gick inte att avgöra åldern på skreden, men eftersom skredavlagringarna täcktes av svallsand måste skreden ha gått någon gång under tiden från isavsmältningen till att platsen höjdes ovanför havsytan för 11 000 år sedan. Det är f.n. en helt öppen fråga om skreden gått spontant eller om de utlösts av någon yttre påverkan, t ex jordbävningar.

Periglaciala fenomen uppträder allmänt i de delar av undersökningsområdet som låg ovanför havsytan under Yngre Dryas, ett skede med bistert klimat för ca 12 000 år sedan. Förutom jordskalv måste därför frostprocesser övervägas som orsak till störningar i sedimentlagerföljder inom dessa högre belägna områden.

Contents

1 Introduction

This document reports the results obtained from *Searching for evidence of late- or postglacial faulting in the Oskarshamn region*, 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 400-03-011 and Method description MD 133.001 (both SKB internal controlling documents). The area under investigation is shown in Figure 1-1. Data are stored in the SICADA database.

- Topografiskt underlag: Översiktskartan. © Lantmäteriet, Gävle. Dnr L 2002/174.

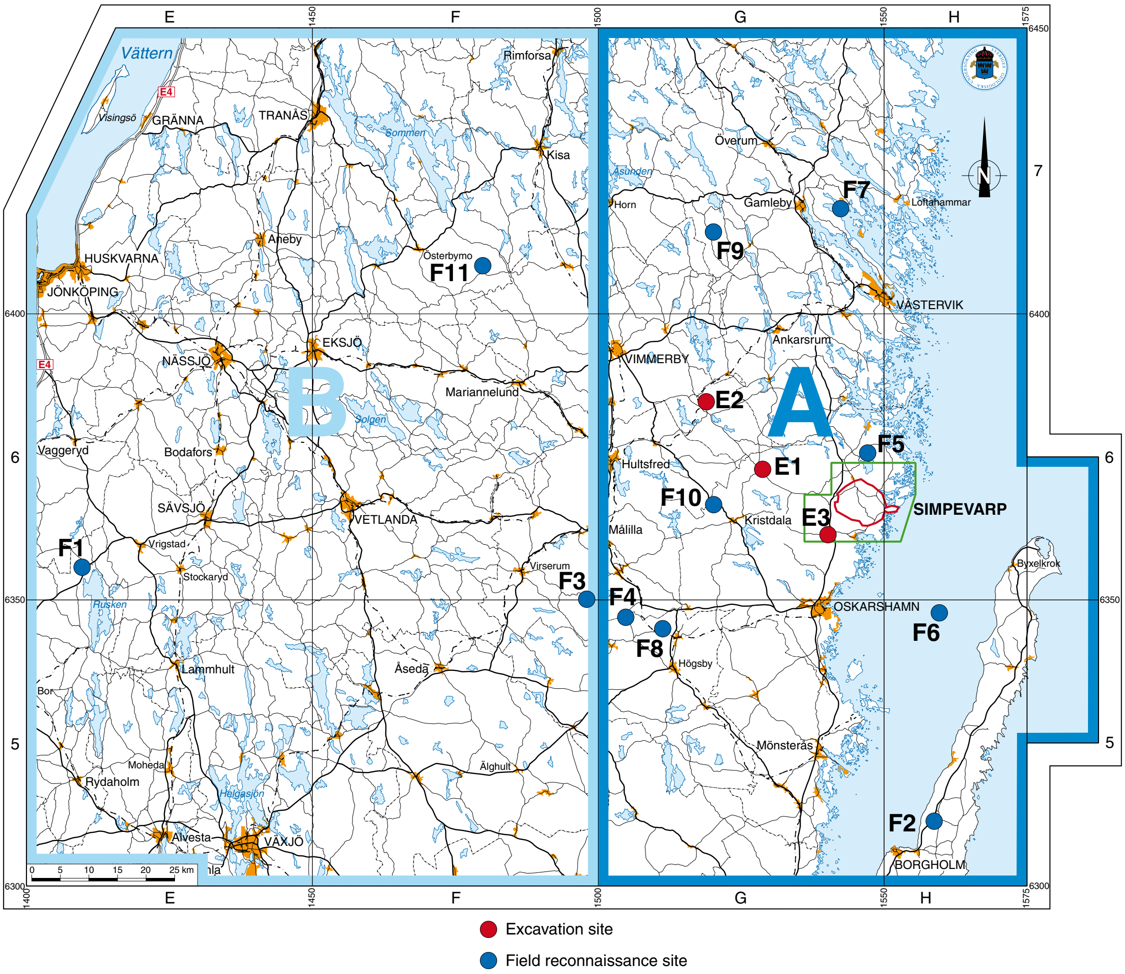

Figure 1-1. Map of the investigation area in eastern Småland and southern Östergötland. The area, covering some 24,000 km², is divided into two subareas. In the eastern subarea (A), situated mainly below the highest coastline, more comprehensive investigations are planned than in western subarea (B) which is situated mainly above the highest coastline. A continuous red line outlines the candidate area for detailed site investigations and the green line marks the area covered by low-altitude aerial photographs. Excavation sites: E1 Ishult. E2 Malmgrava. E3 Fårbosjön. Field reconnaissance sites: F1 Klevaberget. F2 Lineament NE of Borgholm. F3 Moredalen. F4 Trånshult. F5 Göljhult and Vällehorva. F6 Blå Jungfrun. F7 Pukens grotta. F8 Lillsjödal. F9 Hängesten. F10 Vederhult. F11 Dunkullen.

2 Objective and scope

The study aims to establish whether any major late- or postglacial faulting had occurred in the proposed repository area at Simpevarp or in its vicinity. “Major faulting” in this context means dislocations in the order of several metres along faults extending several kilometres. Faults of such dimensions may, if conditions are favourable, be detected by means of aerial photo interpretation. The process of dislocation may have been associated with high magnitude earthquakes that could produce 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 covering regolith, or indirectly by seismically derived deformation 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.

3 Equipment

3.1 Description of equipment

Excavators capable of digging trenches to a depth of some 5 m were used for the stratigraphical work. Trench wall sections were cleaned manually with shovels, bricklaying trowels etc, and then documented with sketches and photographs.

GPS (hand-held) was used for positioning.

4 Execution

The study comprises four main steps according to SKB MD 133.001.

1. A brief review of the geological literature and other relevant information about the area. Any information that may indicate recent faulting or earthquakes is recorded for subsequent follow-up in the field.
2. Aerial photo interpretation. Any indications of recent faulting or earthquakes (landslides, etc) are recorded for subsequent follow-up in the field. Gravel- and sand pits are marked out on maps for later examination in the field.
3. Field reconnaissance. Any indications of recent faulting or earthquakes recorded during the literature study or aerial 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 glacially polished rock surface. Reconnaissance for unstable boulders, contradicting strong seismic shaking, was originally not planned, but was subsequently included in the study.
4. Stratigraphic investigations in machine-dug trenches, mainly in sediments with favourable composition for developing earthquake-induced liquefaction phenomena.

Activities according to 1–3 were carried out mainly in 2003 /Lagerbäck et al. 2004/. In 2004 the intention was to focus on stratigraphical work in machine-dug trenches but due to limited permission for excavation this work had to be considerably curtailed.

4.1 Field reconnaissance

No systematic field reconnaissance was carried out in 2004 but a number of features that hypothetically might indicate, or refute, late- or postglacial faulting were inspected or sought. Examples of such features are prominent escarpments or lineaments noted in connection with aerial photo interpretation /see Figure 5-2 in Lagerbäck et al. 2004/, cave formations and unstable boulders. A few of the numerous sites visited are commented on in Section 5.1 and marked out in Figure 1-1.

4.2 Stratigraphical investigations in machine-dug trenches

Altogether, twelve trenches with a total length of some 170 m were dug and investigated at three different sites along the Fårbo esker, located west of the candidate area at Simpevarp (Figure 1-1). The trenches were dug on the flanks of and perpendicular to the esker in the hope of reaching sandy glaciofluvial deposits or coarse glacial silt, ideally covered by a moderately thick bed of more fine-grained sediments. All trenches were dug in level or only gently sloping ground and reached to depths between about 1.5 and 4 m. Trench walls were trimmed manually and afterwards documented in sketches and photographs.

4.3 Data handling

The positions of stratigraphical and geological observations, photos, etc, were determined by GPS or topographical maps. The dates of the observations were noted and all were given PSM numbers. All points and dates were later stored in SICADA. The geological information connected with the PSM numbers was stored in the SGU database (*Jorddagboken,* version 5.4.3). Data from the SGU database were transferred to Excel files.

Delivery to SKB from the investigations carried out during 2004 consists of:

1. Data files with stratigraphical and other geological information.

   GE141_PSM_NEO_050405.xls

   GE509_PSM_NEO_050405.xls

   SKB_PSM_NEO_050405.xls

2. Data files with photos and sketches.

   Foton_PSM_NEO_050405 (jpeg) (82 photos)

   Skisser_ PSM_NEO_050405 (jpeg) (13 sketches)

4.4 Basic principles for analyses and interpretation

The ultimate interpretation of the stratigraphical information obtained from the machine-dug trenches, i.e. were there any major postglacial earthquakes in the vicinity of Simpevarp?, is based mainly on the concept of earthquake-induced liquefaction. When loosely packed, waterlogged, 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 least, distance from the earthquake epicentre. It is commonly considered that liquefaction phenomena may develop in highly susceptible sediments at magnitudes as low as M5 but become more common at M6 or higher. A shallow-focus, M6 earthquake may cause liquefaction features at a distance of some 20 km from epicentre, a M7 earthquake within some 100 km, while a great M8 earthquake may induce liquefaction as far away as 300 km /e.g. Obermeier 1996/.

Whereas the presence of liquefaction features may be indicative of strong paleoearthquakes, absence of such features, provided that susceptible sediments are widespread, strongly indicates that no major earthquakes have occurred in the vicinity since deposition of the sediments. The Lansjärv and Burträsk areas in northern Sweden, in geological settings similar to those in eastern Småland, may serve as reference areas when the results of the present investigation are evaluated. In both these areas, postglacial faulting induced a great variety of regionally distributed liquefaction phenomena /Lagerbäck 1990, Lagerbäck and Sundh unpublished /.

Presence of numerous rockfalls, or landslides developed in frictional deposits, may indicate strong earthquakes, while an absence of falls or slides hardly excludes earthquakes, etc. Unstable boulders may serve as non-recurrent seismoscopes and provide evidence that no major earthquakes have occurred in the vicinity since they came to rest in their current unstable positions. In glaciated areas such as Småland, some of the erratic boulders are analogous to the "precariously balanced rocks" in arid areas described by Brune /e.g. Brune et al. 1996/.

Thus, any phenomenon that might indicate recent faulting or earthquakes, but likewise also circumstances that refute such events, is of interest for the study. When, ultimately, the results of the study are to be interpreted and evaluated, the outcome of all these and any other relevant aspects should hopefully become mutually consistent and fit into a clear-cut pattern.

5 Results

5.1 Field reconnaissance

In connection with the aerial photo interpretation a number of prominent escarpments, hypothetically indicative of late- or postglacial faulting, were noted in the mainland part of the investigation area /see Figure 5-2 in Lagerbäck et al. 2004/. Most of these scarps, when field-checked, were found to be more or less intensely glacially abraded, i.e. were probably neither late- nor postglacial in age. However, a few of the bedrock scarps have a remarkably fresh appearance and as it was not possible to confirm any glacial impact on the lowermost parts of the cliffs, one or two of these features are to be revisited in 2005 (Figure 5-1).

Figure 5-1. *South of Lake Vättern a set of sustained, north-south directed escarpments were identified during aerial photo interpretation. The photograph shows part of a 700 m long cliff at Klevaberget (F1 in Figure 1-1) some 25 km south-west of Sävsjö. The uppermost parts of the cliff are obviously abraded by inland ice but it has not yet been possible to establish any glacial impact on the lower, virtually vertical parts.*

To the northeast of Borgholm on the island of Öland a very distinct and straight lineament was noted during aerial photo interpretation /F2 in Figure 1-1, see also Figure 5-3 in Lagerbäck et al. 2004/. Except for its northern- and southernmost parts, where the over-burden appears to be thick, the lineament was easily identified in the field as a step in the ground surface (Figure 5-2) or as a very distinct vegetational boundary (Figure 5-3). The step in the ground surface clearly derives from a bedrock scarp but this is partly obscured by a significantly thicker overburden on the western, foot-wall side, giving the feature a smooth configuration. The overburden also prevents a closer investigation of the scarp, but there are indications that it might be connected with an open fracture in the bedrock (Figure 5-4).

Figure 5-2. *The step in ground surface at the lineament northeast of Borgholm is visualized by the configuration of the stone wall crossing the lineament. Photograph taken 800 m west of Knäppinge.*

Figure 5-3. *The distinct vegetational boundary along parts of the lineament on Öland is due to differences in overburden thickness on either side of the bedrock scarp. In the foreground, i.e. east of the scarp, the Ordovician limestone is exposed or covered by only a few centimetres of humic soil and sparse vegetation, while on the western side a significant cover of overburden is present. Photograph taken 600 m west of L. Haglunda.*

Figure 5-4. *Damage to road surface caused by loss of underlying filling where the road crosses the lineament some 600 m west of St. Dalby. According to residents in the neighbourhood this problem has occurred on more than one occasion.*

/Tirén et al. 2001/ reported tentative neotectonic fault movement along Moredalen (F3 in Figure 1-1), a glaciofluvially incised canyon some 50 km west of Oskarshamn. An argument for a late- or postglacial fault movement along the canyon is that the surface of a glaciofluvial delta formation (F4 in Figure 1-1) located east of the canyon appears to be vertically offset by some 3.5 m. However, a brief visit to the area did not confirm fault movement after the glaciofluvial drainage along the canyon and the associated formation of the delta. The delta stratigraphy, as seen in a major sand- and gravel pit 1 km south of Trånshult, i.e. very close to the proposed dislocation zone, displayed a 2 m thick and laterally extended bed of fine sand and coarse silt without any sign of deformation (Figure 5-5). If co-seismic faulting had occurred soon after the delta formation, i.e. while the deposits were still waterlogged, extensive liquefaction features would be expected in the sandy-silty deposits. The complete absence of deformational features in the sediments, not only liquefaction features but even minor faults indicating settling, contradicts faulting in the vicinity after formation of the delta. Likewise, the presence of several fragile and apparently unstable rock pillars in the very canyon is contradictory to co-seismic faulting in the immediate vicinity (Figure 5-6). Erosion and lowering of the southern part of the delta due to prolonged discharge of glaciofluvial water through the canyon during land-upheaval is a more likely cause of the apparent offset of the delta surface (H Agrell 2004 pers comm).

Two disrupted bedrock outcrops at Göljhult and Vällehorva (F5 in Figure 1-1), located close to each other some 10 km northwest of Simpevarp, were visited and very briefly inspected. The mass of angular blocks with interstitial cavities form so-called "boulder caves", which among speleologists are believed to have formed in connection with earthquakes after withdrawal of the inland ice sheet. The features were described by /Sjöberg 1994/ and /Bergman et al. 2000/, of whom the former suggested a seismo-tectonic origin of disruption. Rounded erratics, i.e. boulders transported and deposited by the inland ice, were found

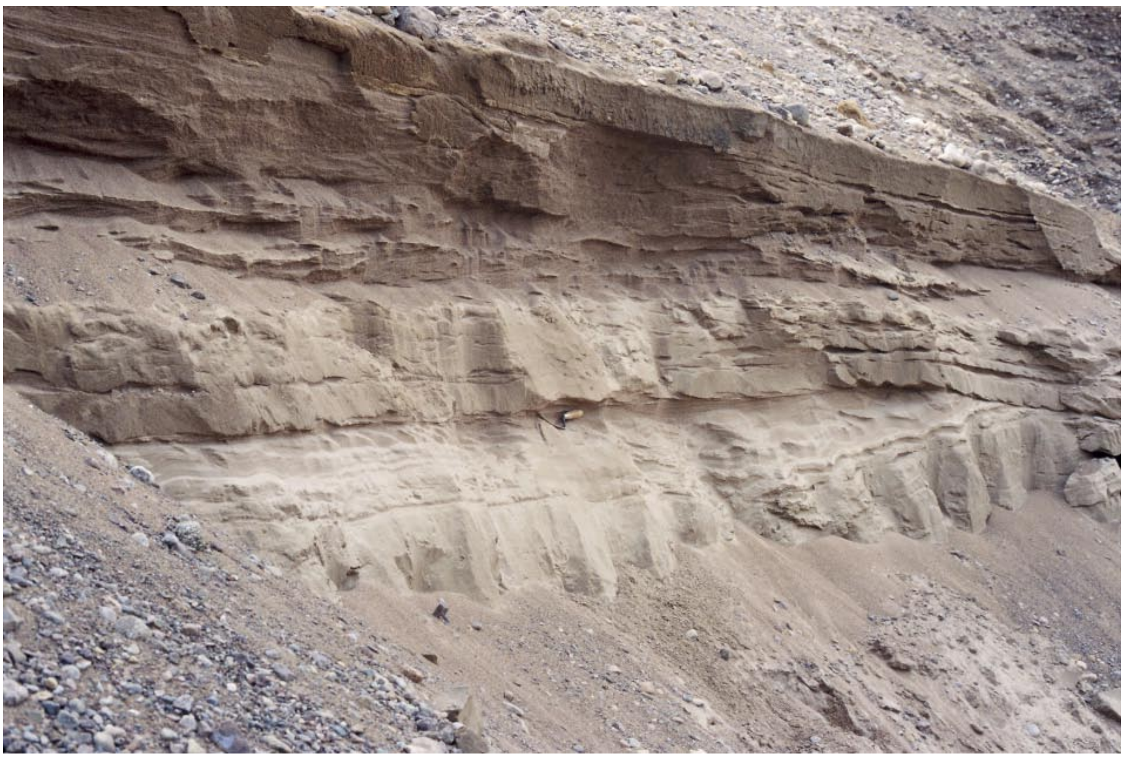

Figure 5-5. *The stratigraphy of the glaciofluvial delta formation at Trånshult contains a 2 m thick bed of undeformed fine sand and coarse silt.*

Figure 5-6. Rock pillars close to More kastell, a major pinnacle-shaped erosional remnant in the Moredalen canyon.

beneath the mass of angular blocks at both sites, indicating that the rocky masses were slightly dislodged from their original positions. Furthermore, several of these blocks in the main rock mass at Göljhult were stacked in an "imbricated" manner (inclined but not necessarily overlapping), likewise indicating the impact of an overriding ice sheet. Thus, field evidence indicates that the features developed before the inland ice receded from the area but the origin of the intense fracturing is still rather enigmatic. Similar features in northeastern Uppland are associated with a high boulder frequency in the surroundings, strongly indicating a phase of intensified fracturing and quarrying of bedrock below marginal parts of the receding inland ice sheet /Lagerbäck et al. 2005/.

According to hearsay, the island of *Blå Jungfrun* (the "Blue Maiden", F6 in Figure 1-1) may have experienced disruption in postglacial times. A visit to the island revealed some spectacular fractures, forming cavities like *Kyrkan* and *Jungfrukammaren* (Figure 5-7) in the dome-shaped granitic formation, but it was neither possible to confirm nor to refute recent movements.

Pukens grotta is a minor bedrock cave formation some 5 km east of Gamleby (F7 in Figure 1-1). The cave is located in an old thrust zone but an apparently more recent fracturing of the brecciated quartzite in the deformation zone suggests younger dislocation. However, the fact that the scarps associated with the thrusting are affected by glacial abrasion contradicts postglacial fault movements (Figure 5-8).

The frost-heaved bedrock blocks at Lillsjödal (Figure 5-9, site F8 in Figure 1-1) described by /Holst 1893/ belong to the more spectacular varieties of periglacial phenomena encountered in the investigation area. The frequent occurrence of periglacial features in superficial parts of the overburden suggests that frost processes must be seriously considered as an alternative to seismically induced liquefaction when deformed sediments are encountered in those parts of the investigation area located above the sea during the Younger Dryas period.

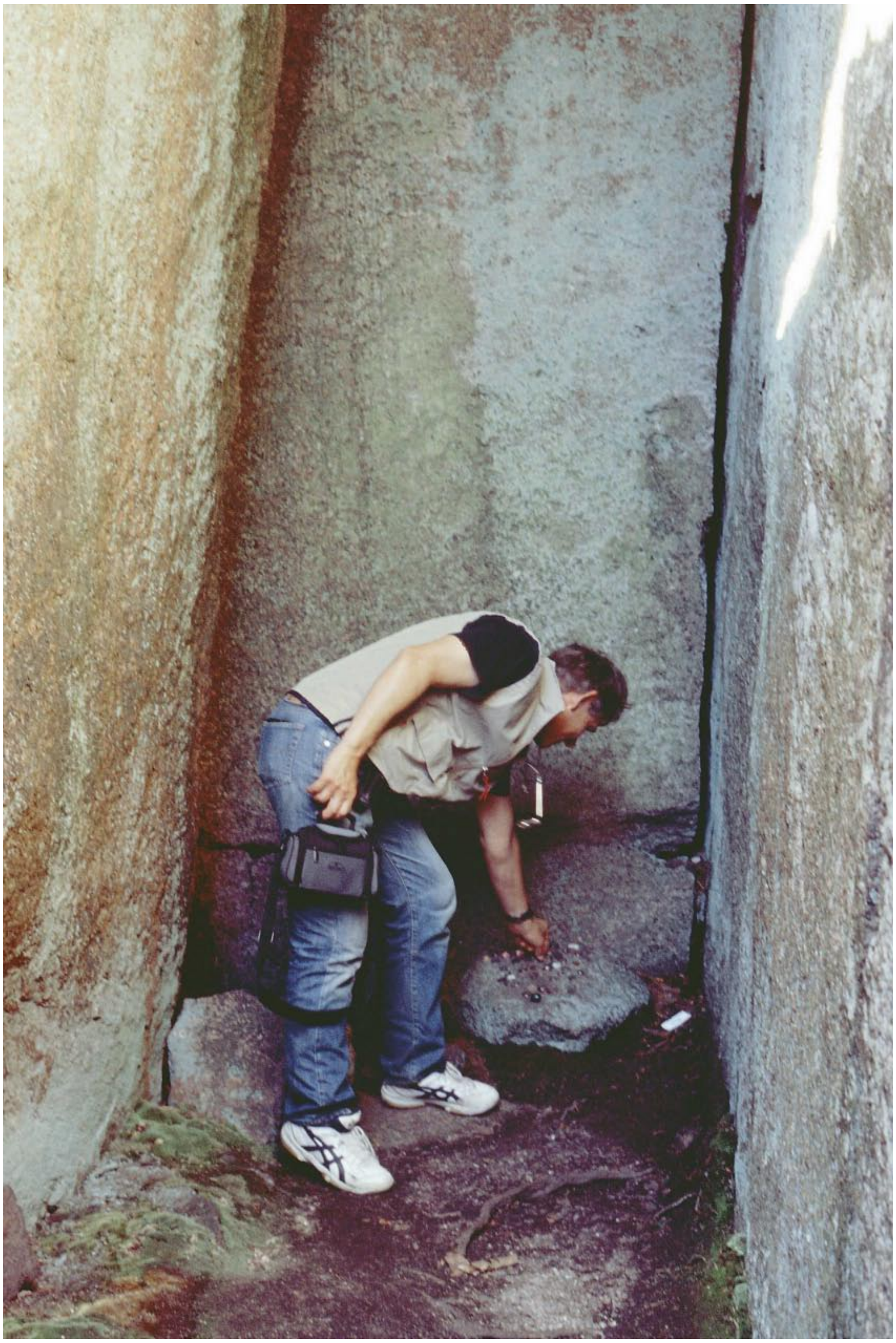

Figure 5-7. *Just inside the narrow entrance, the cavity Jungfrukammaren (the "Maidens' chamber") widens. Despite close examination into the very bottom of the formation it was not possible to establish anything indicative of Recent opening of the fracture.*

Figure 5-8. *Minor escarpment along an old deformation zone at Pukens grotta. Although strongly weathered, the scarp exhibits evidence of glacial abrasion and, accordingly, is not postglacially developed.*

Figure 5-9. *The spectacular frost heaving of bedrock blocks at Lillsjödal, with contemporaneous lifting of erratics, has occasionally resulted in unstable boulders.*

No systematic search for unstable boulders was carried out in 2004 but a few specimens were encountered during minor excursions in different parts of the investigation area (Figures 5-10 to 5-12). However, without estimates of how much earthquake-induced ground motion these boulders could withstand before they were toppled, it is difficult to judge their significance as palaeoearthquake indicators.

Figure 5-10. *"Hängesten" (the "hanging boulder") in the northeastern part of the investigation area (F9 in Figure 1-1) is well known for its apparently unstable position on a cliff ledge. However, the impressive piece of rock (some 200 m³) is supported by another major boulder and is not regarded as one of the most "precariously balanced boulders" within the investigation area.*

Figure 5-11. *Although top-heavy and narrow at the base, this fellow at Vederhult (F10 in Figure 1-1), some 30 km northwest of Oskarshamn, was not toppled over by human endeavour. However, a similar boulder, previously located quite close by, was toppled when the man of action was a young boy! Very likely, many precariously balanced boulders have suffered the same fate, as the native people in this part of Sweden cannot resist their instinct to rearrange nature.*

Figure 5-12. *This boulder, resting with three contiguous tips on a slightly inclined bedrock exposure at Dunkullen (F11 in Figure 1-1), in the northern part of the investigation area, is probably rather susceptible to strong seismic acceleration in any direction.*

5.2 Stratigraphical investigations in machine-dug trenches

Deposits of loosely packed sand or coarse silt were encountered in almost all trenches excavated along the Fårbo esker and, in some of the trenches, a clayey bed covered the sandy-silty deposits. When shaken by strong earthquakes in a water-saturated state, such deposits are highly susceptible to develop liquefaction. The excavation sites are situated some 30–100 m above present sea level, which means that most of them were raised above the ancient sea shortly after deposition of the glacial sediments. Whereas deglaciation occurred about 13,500 years BP /Lundqvist 2002), the lowermost site, Fårbosjön (E3 in Figure 1-1) at 30 m asl, was raised above the sea as early as about 11,000 years BP /Påsse and Andersson 2000/ and, accordingly, the deposits were entirely waterlogged during only a short period of time. However, a fairly high ground-water table at some of the sites means that those deposits have to some degree remained susceptible to liquefaction throughout the Holocene (Figure 5-13).

Figure 5-13. *Trench dug at Malmgrava (E2 in Figure 1-1) along the Fårbo esker some 30 km northwest of Simpevarp. Although raised above the sea very shortly after deposition and, thus, entirely water-logged during only a few years or decades, the sandy-silty deposits have to some degree, due to a fairly high groundwater table, remained susceptible to seismically induced deformation.*

No significant features related to liquefaction were noted in any of the trenches dug along the Fårbo esker. The most remarkable observation made during the investigations was the occurrence of slide deposits along the gentle slopes of the esker at Fårbosjön (E3 in Figure 1-1). Evidence of sliding or folding was encountered in almost all trenches here. Slabs of silty and fine-sandy deposits have detached along planar failures parallel to the bedding and then slid down slopes to cover previously deposited sediments. The slide deposits varied from plates of more or less undisturbed sediments, to strongly folded sequences (Figures 5-14 and 5-15).

Figure 5-14. *Strongly folded deposits of fine-grained sand and laminated silt on the western flank of the esker at Fårbosjön. Bleaching and precipitation of iron hydroxides consistent with stratification help to visualize the fold structures.*

Not surprisingly, sliding and folding proved to be more intense in obviously inclined ground, decreasing and finally ceasing towards level terrain. Most of the silty and fine sandy sediments involved in the sliding were clearly varved and, accordingly, of glacial origin. Neither glacial nor postglacial clay was found within, or on top of, the slide deposits but clay of uncertain age was found in level ground slightly west of the excavation area.

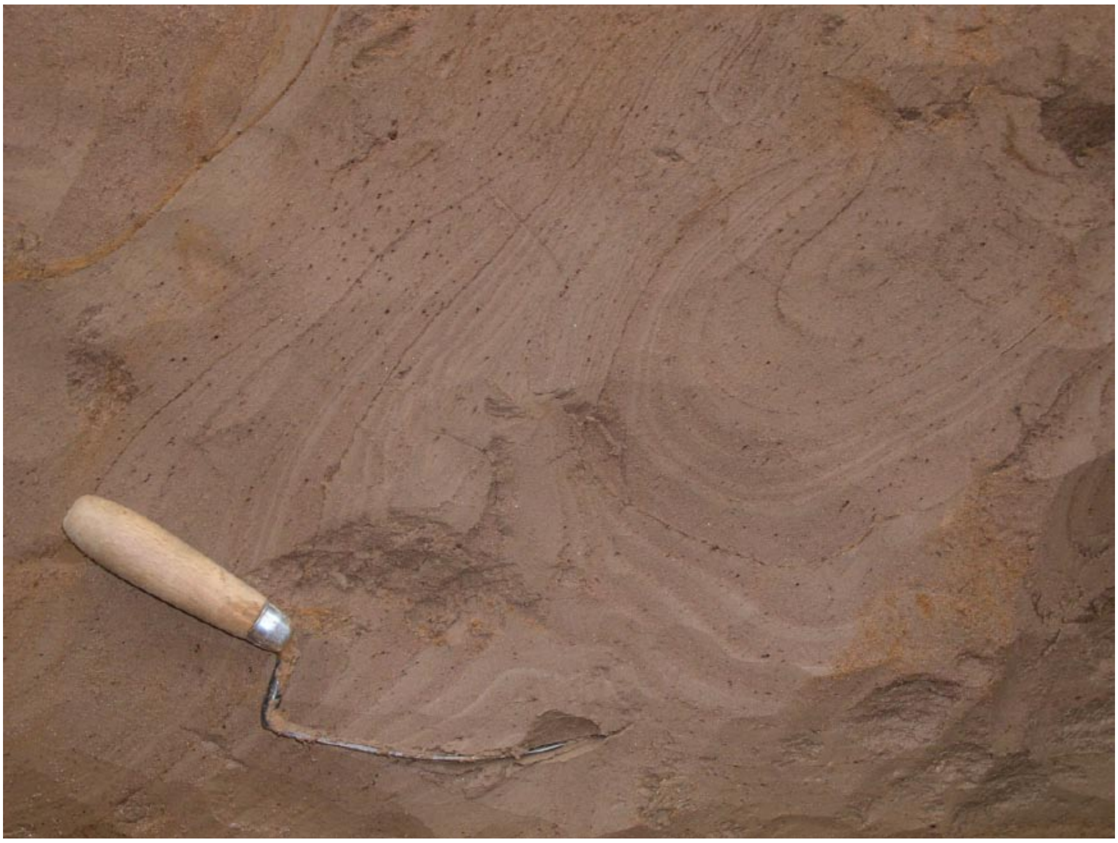

Figure 5-15. *Close-up of fold structures developed in fine-grained sand and silt at Fårbosjön. Despite deformation, the primary sedimentary structures are still very well preserved.*

Deformed and contorted sediments of a different origin were encountered at Malmgrava (E2 in Figure 1-1). The excavation site is situated about 100 m above the present sea level, close to the highest coastline. An intricate pattern of cryoturbation structures, reaching to a depth of about 1 m, occurred in otherwise stratified silty and fine sandy sediments covering glaciofluvial sand. Besides involutions, an ice-wedge cast and part of a polygonal pattern occurred in one of the trenches (Figure 5-16). These periglacial features formed as a result of seasonal freezing and thawing of the superficial part of the otherwise permanently frozen ground during the Yngre Dryas period, some 12,000 years ago.

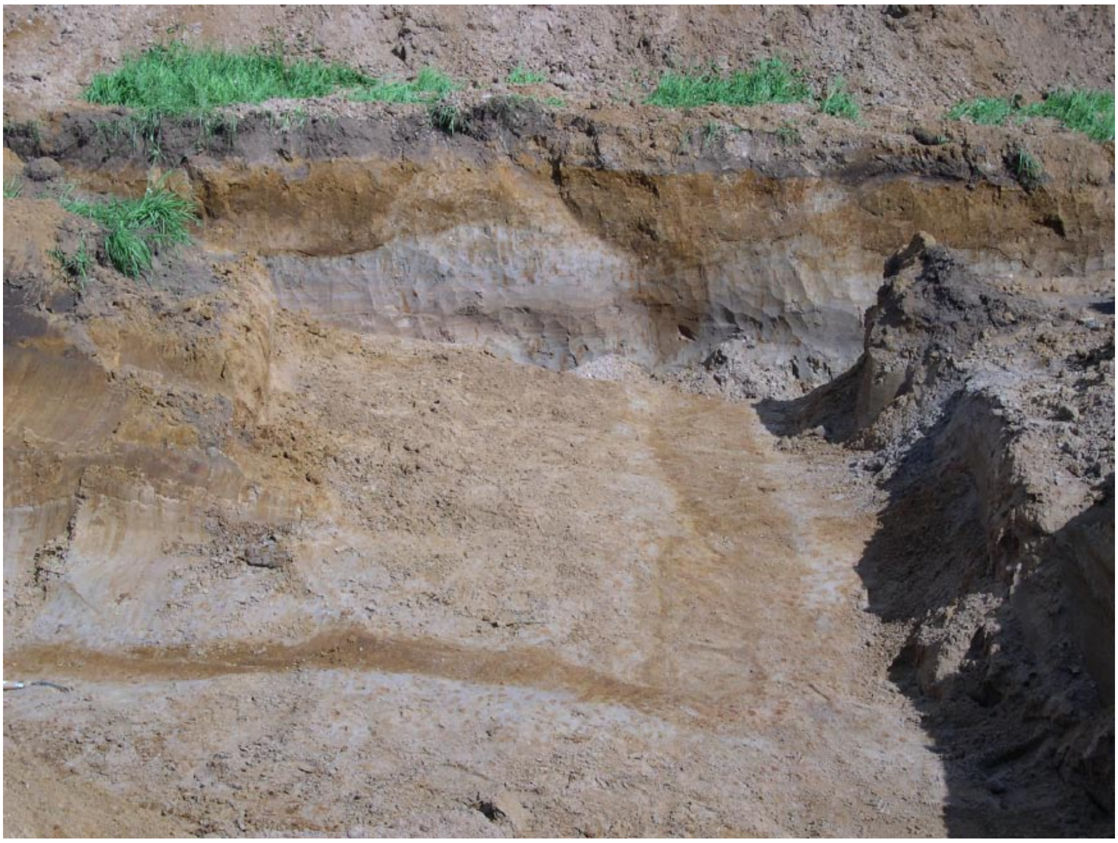

Figure 5-16. *Rust-coloured, V-shaped ice-wedge cast (seen in trench wall in background) and corresponding part of a tundra polygon (foreground) at Malmgrava.*

5.3 Summary and discussion

Most of the fairly prominent escarpments identified in the mainland part of the investigation area were field-checked and found to be more or less intensely glacially abraded, i.e. probably not late- or postglacial. As it was not possible to establish glacial impact on the lowermost parts of some of the most prominent scarps one or two of these are to be revisited for a more thorough examination in 2005.

The very distinct, straight lineament on Öland obviously corresponds to a scarp cutting the flat surface of the Ordovician limestone. The origin of the scarp could not be determined in the absence of stratigraphical information, but two conceivable processes suggest themselves: glacial plucking along a fracture zone, and faulting. However, selective glacial plucking along a several km long straight line is perhaps not particularly likely. Nor was it possible without stratigraphical information to form any firm opinion about the age of the scarp. The thicker overburden on the foot-wall side may imply that the scarp was formed prior to deglaciation, but could just as easily be the result of wave washing and deposition of littoral sediments during land upheaval. Trenching across the scarp for an examination of the bedrock and Quaternary stratigraphy is the obvious next step towards a better understanding of the phenomenon.

It should be emphasized that escarpments of this magnitude can easily evade detection in the mainland areas where the topography is much more broken and the overburden generally thicker and more densely vegetated. The extremely flat surface of the Ordovician limestone, lacking or with only a thin overburden, constitutes a perfect reference surface for tracing minor bedrock displacement. Aerial photo interpretation and targeted reconnaissance of the Great Alvar on southern Öland, from where bedrock scarps have been reported previously /e.g. Königsson 1968/, may help elucidate the nature and extent of these features.

Field inspection of the disrupted bedrock outcrops at Göljhult and Vällehorva indicates that the fracturing occurred prior to deglaciation and that the features were slightly dislocated by inland ice, but the nature and origin of the fracturing is still rather enigmatic. Trenching and removal of the overburden near to a minor occurrence of the same sort (there are several in the region) would elucidate the extent and nature of the fracturing as well as its relation to the Quaternary deposits.

Although susceptible deposits were present in most of the investigated sections along the Fårbo esker, no significant liquefaction features indicating strong seismic shaking were noted. On the other hand, there was evidence of surprisingly extensive sliding in very gently sloping terrain along the esker at Fårbosjön. It was not possible to date the sliding in any of the trenches but, as the slide deposits were covered by beach sand, sliding must have occurred some time between deglaciation and the upheaval above the sea, some 11,000 years ago. It is an open question whether the sliding occurred spontaneously due solely to loading or whether the phenomenon was triggered by the influence of some external factor. Comparison with the extensive sliding encountered along the Börstil esker close to Forsmark in northeastern Uppland may be of some interest in this context /Lagerbäck et al. 2004/. A tentative explanation for the sliding along the Börstil esker was provided by settling and dewatering of underlying glaciofluvial deposits, though the possibility of influence by external factors, e.g. earthquakes, was held open. However, such settling appears not to be an appropriate explanation for the sliding at Fårbosjön, as bedrock was encountered more or less directly beneath the slide deposits.

The fact that no sliding whatsoever was observed at Ishult (E1 in Figure 1-1) may indicate the influence of an external triggering factor for the sliding at Fårbosjön. As the excavated ground at Ishult is located significantly higher (65 m vs 30 m asl) but only some 15 km away, it must have been raised above the sea and stabilized long before the excavation site at Fårbosjön. Hypothetically an earthquake may have triggered the sliding at Fårbosjön some time after Ishult was raised above the sea, but while Fårbosjön still was covered. However, this is mere speculation and it should be strongly emphasized that the stratigraphical information gained so far is too meagre for any conclusions whatsoever concerning the presence or absence of earthquakes in the distant past. Furthermore, as the investigated trenches are situated some 30–100 m above present sea level, most of them were raised above the ancient sea shortly after the deposition of sediments and, accordingly, the deposits were entirely waterlogged and susceptible to liquefaction during only a short period. Consequently, the continuing stratigraphical investigations should as far as possible be concentrated to low-level sites.

The apparently unstable boulders that have been encountered sporadically in the areas located above the highest coastline may provide complementary information about the tentative occurrence of palaeoearthquakes in the region. Furthermore, in contrast to excavation sites, which, depending on their elevation above sea level, were active only during a restricted period of time, unstable boulders may serve as seismoscopes for the entire postglacial period. However, without estimates of how much earthquake-induced ground motion these boulders could withstand before they were toppled, it is difficult to judge their significance as palaeoearthquake indicators.

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