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1. Introduction

This report is a brief summary of findings and results from the SGU-funded (Geological Survey of Sweden) project "Submoräna sediment på Småländska urbergsslätten – åldersställning och implikationer för sydsvensk glacial stratigrafi och dynamik" (sub-till sediments on the Småland peneplain – their age, and implications for south-Swedish glacial stratigraphy and glacial dynamics). The project got a 3-year funding for the period 2007-2009. Reconnaissance was mainly carried out during 2007, while the major stratigraphic work in machine-dug trenches was carried out in 2008, with some additional field work in 2009. The main chronological work is by OSL dating, of which the results came in February, 2010. Still pending is a number of cosmogenic nuclide surface exposure datings and radiocarbon datings, related to sub-projects that have sprung out from the main project. Thus the compilation of all geologic and chronologic data is not finalized, and this report is only a preliminary 'state of the art' over-view. Results are planned to be published at least as three individual papers in international scientific journals.

2. Background

A paradigm in Swedish glacial geology has been that most glacial sediments and landforms – at least for southern Sweden – were formed during the last, i.e. the late Weichselian, glaciation/deglaciation. The general concept has been that sediment from the core area of Scandinavian Ice Sheets (SIS) was mostly eroded away or, alternatively, remoulded into new sediments and landforms. This preconception is not that strange; contrary to areas in Germany, Denmark or southernmost Sweden, being more closely located to the maximum positions of the SIS, there are not that many localities in Sweden showing complex series of tills, clastic sorted sediments and interbedded organic strata. The few localized sites with sorted sediment and possibly also interbedded organic strata have thus always drawn large attention in quaternary research. This early paradigm was seriously flawed during the 1980ies and forward when it was clearly demonstrated by the pioneering work of Lagerbäck (Lagerbäck 1988a, 1988b; Lagerbäck and Robertsson, 1988) that large parts of interior northern Sweden consist of sediments and landforms deposited during Early Weichselian (115-75 kyr BP) glaciations and deglaciations from

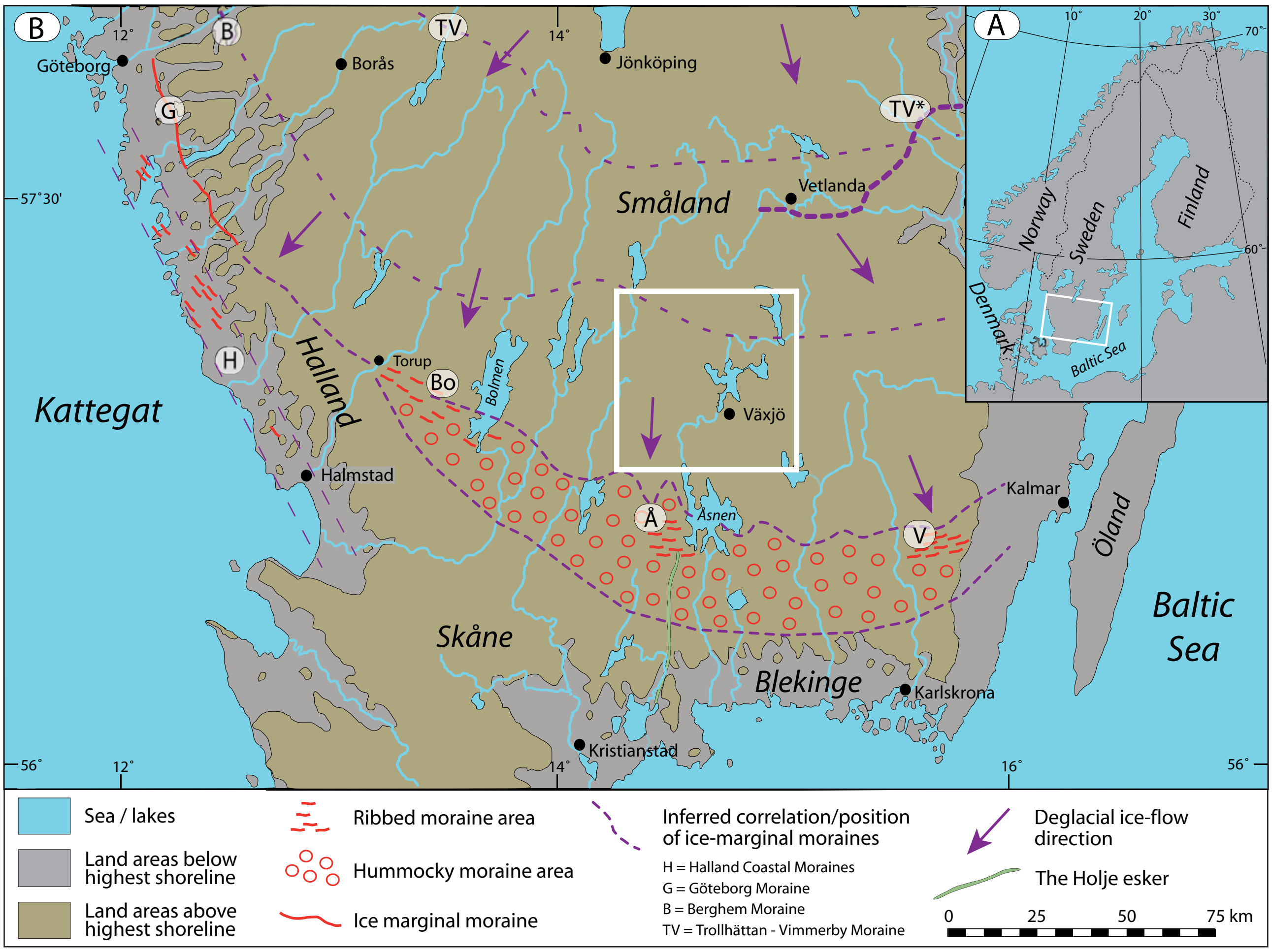

Fig. 1. Map of southern Sweden (for location, insert (A)), showing areas above and below the highest shoreline (marine limit in the west) at deglaciation, and inferred ice-marginal positions according to Lundqvist (2009). An alternative position for the eastern part of the Trollhättan-Vimmerby Line (TV) is indicated, this position according to Malmberg Persson et al. (2008). The continuation of the Göteborg moraine (G) into a regional coverage of hummocky moraine and ribbed moraine is indicated. Larger ribbed moraine areas are: Bo = the Bolmen area (Johnsson, 1956), Å = the Åsnen area (Möller, 1987), V = the Vissefjärda – Karlslunda area (Bergdahl, 1953). Ribbed moraine areas occur at a number of other sites within the demarcated zone, but on smaller scales, intercalated with hummocky moraine. North of here the terrain is dominated by streamlined terrain, with most drumlins of the rock-cored type. White frame centred around Växjö marks area in which till-capped sediment sequences (often as large drumlins with sediment cores) occur. (Redrawn from Möller, 2010).*

more west-centred and smaller ice sheets than later during the Weichselian. This has later repeatedly been confirmed by the research group around J. Kleman (e.g., Kleman, 1994; Kleman et al., 1997; Kleman and Stroeven, 1997; Kleman and Hättestrand, 1999; Kleman and Glasser, 2007). The preservation of these older sediments and landforms is thought to be due to cold-based ice conditions during most of the mid- to late Weichselian glaciations over these areas. This has been an eye-opener for most quaternary geologists and has given fundamental new insight into glacier dynamics and an understanding that older sediment – and landforms – can be preserved though repeated cycles of waxing and waning SIS´s.

There are early observations from the south Swedish Småland peneplain (Fig. 1) that sorted sediments at places are overlain by till (Fredholm, 1875; Hummel, 1877). In a more systematic manner such sequences were investigated in a core area around the town of Växjö (Fig. 1) by an amateur geologist named Strandmark. His results were never officially published except for some posthumously published talks (Strandmark 1956, 1957). More detailed work came from Rydström (1965, 1971) who described these deposits to occur both in open-terrain position as cores in low-relief drumlins and as valley-side sediments along low-relief valleys stretching north to south. Strandmark (1956) was of the opinion that these sediments represent deltaic sequences, deposited in glacial meltwater-fed lakes during the last deglaciation (glacial Lake Värend, the later an old-time name of the district around the town of Växjö), later over-run by the glacier during an ice-front oscillation. As the distance between the northernmost observed site (Kråkerum at Lake Asasjön) and the southernmost site (the Grimslöv-Ströby height at the northern tip of Lake Åsnen) with till on top of sorted sediment is ~50 km, it was suggested that the ice-front oscillation was of equal magnitude, after which the general ice retreat continued. Rydström (1965, 1971) found additional till-capped localities and documented more complex sediment successions and relations, among other things glacio-tectonized varved clay sequences. As at least 300 annual varves were measured, Rydström (1965, 1971) concluded that there had been a too short time frame for deposition of the glaciolacustrine sediments, an ice advance of at least 50 km and then retreat, given what at that time was known on deglaciation chronology for Småland. He instead proposed that the sediments were old, possibly representing deglacial sediments from the Early Weichselian (Brørup interstadial), later eroded and deformed during the last glaciation/deglaciation. Such a scenario with primary deposition of the sub-till sediments in this region in the Early Weichselian is contradicted from what we know today about SIS distribution over the last glacial cycle (e.g. Svendsen et al., 2004).

The area in question has been mapped by the Swedish Geological Survey (SGU) with start in the 80ies at a scale of 1:50,000 for two map sheets, each covering 25*25 km (Växjö SV and SO; Daniel, 1989, 1994), and then very recently in four map sheets north and south of these (Växjö NV (Daniel, 2009a); Växjö NO (Magnusson, 2009a); Tingsryd NV (Daniel, 2009b); Tingsryd NO (Magnusson, 2009b)). In addition to the till-capped sites with sorted sediments, described by Strandmark and Rydström (most often sand quarries now inaccessible and/or levelled), these mapping efforts have revealed new such sites, both from open sections or as documented from well logs or personal communication with land owners. Based on observation during mapping of map sheet Växjö SO, Daniel (1989) more or less give support for the views of Strandmark (1956), i.e. the till-caped sediments were deposited during the last deglaciation and then over-run by the glacier during a regional ice-margin oscillation of substantial size. However, any chronological proof for this was not given.

3. Aim of this study and project setup

In the application to SGU for this research project, two scenarios were put up:

- Scenario I; Till-caped glaciofluvial and glaciolacustrine sediments of unknown age, but older than the last glaciation, were eroded and/or deformed during the last glaciation, i.e. the Late Weichselian glacial stage, at which the capping till was deposited.
- Scenario II; Till-caped glaciofluvial and glaciolacustrine sediments were deposited at the latest ice recession over the area, and after that eroded and/or deformed during a regional ice front oscillation at which the capping till was deposited.

The crucial point in these scenarios is of course age determination of the sub-till sediments. During the investigations referred to above, no such means were at hand as no organics are incorporated for which radiocarbon dating would have been possible. However, during the last decades the Optically Stimulated Luminiscence (OSL) dating method have been used with varying successes for dating clastic sediment, and this also for sediment beyond the range of radiocarbon dating. Examples of success is from the large co-operation project QUEEN ("Quaternary Environments of the Eurasian North", e.g., Svendsen et al., 2004) and another example is that the glacial stratigraphy for parts of Denmark have been revised and given absolute dates by means of OSL dating (Houmark-Nielsen, 2004). However, large problems with what is thought to be 'erroneous' OSL ages have also come up from recent projects, actually in quite nearby areas to Växjö (e.g. Alexanderson and Murray, 2007; Alexanderson and Murray, in press), yielding to old ages than expected or ages suggesting ice-free conditions for periods when our current knowledge suggest that the area in question was covered by ice. The obvious and well-known flaw with this method is sediments to be bleached enough for resetting the 'geologic clock' before sediment burial. For a number of depositional environments this certainly is not the case, i.e. the sediments are incompletely bleached (e.g., Gemmel, 1988, 1999; Rickards, 2000; Lukas et al., 2006; Fuchs and Owen, 2008; Alexanderson and Murray, 2007, in press), resulting in age overestimates.

The project set-up was to localize as many of the previously known sites with till-capped sediments as possible in the area around Växjö (white frame, Fig. 1). Based on accessibility (land-owner permission, levelling degree/infill of old sand pits, forest denseness, etc) and assessment of sediment sequence suitability for OSL dating, it was planned to dig trenches at possible sites with excavator for sediment logging and sampling for OSL dating. To our excitement two sites with till-capped organic deposits were encountered during the field campaign. This then called for sampling for radiocarbon dating and pollen and macrofossil analyses. Based on a preliminary bachelor thesis, this has evolved into a specific subproject, described below. During the research process it became clear that the OSL dating technique had run into problems in the parallel work carried out in the geographical area north of Växjö (Alexanderson and Murray, 2007). To tackle this, another sub-project was launched with aim to compare OSL deglacial ages from three type sites (topset/foreset sediments from deglacial ice-contact kame deltas) with radiocarbon dating and cosmogenic nuclide surface exposure dating around the same sites as a comparative study of different dating techniques (see below).

3. Methods

Stratigraphic analyses, till-capped sorted sediments. – Out of 24 excavated sites, 15 sites revealed clastic sorted sediment below till, whereas two sites exposed highly compressed peat and gyttja. Thus, at seven sites no sub-till sediments were encounterd even though earlier studies had indicated that such should be present. At a few places it turned out that the original sand quarry sites were refilled to an extent that the till-capped sediments were unreachable. At a few other sites the trenching was obviously not carried out at the exactly right place; basis for localization in these cases were photographs of sand quarries taken in the 1930ies (archives from Strandmark at our disposition) at which the landscape has changed dramatically over the years. Trenches on flat ground were dug out as deep as possible (technical depth at maximum 6 m), usually resulting in 4-5 m deep pits. Old section walls were reopened in a stair-case manner, if possible down to ground-water level, the highest section being ~9 m. Sediments were logged mostly at 1:10 scale using standardized lithofacies codes, adapted after Eyles et al. (1983) (Table 1). Fabric analyses in diamict beds were carried out at some sites. Measured clasts, all lying freely in matrix for avoiding clast direction interference, were taken from horizontal benches dug into the diamict and sampled over a vertical distance of less than 20 cm. Each analysis comprised 25 prolate-shaped clasts with longest axis 3-10 cm and a/b-axis ratios >1.5. Glaciotectonic structures as fold axes, fold limbs or overthrusts were measured to their three-dimensional orientation. All orientation data were statistically evaluated according to the eigenvalues method (Mark, 1973) and graphically manipulated in StereoNet for Windows.

Stratigraphic analyses, deglacial kame deltas. – Three sites were chosen for a comparative study between different methods for dating the last deglaciation. Two of these sites were active sand quarries, while one was a levelled such that was re-opened by excavator. The sites were dug out in a stare-case manner and the sediment successions, being between 4.5 and 8 m high, were logged as described above.

Lake sediments. – Three lakes situated close to the deglacial kame delta sites were cored with a 10 cm 'Russian corer'. Only the lowermost 1 metre of each lake sediment successions was retrieved and brought to the laboratory. There it was logged for sediment description, after which the sediments were cut in 3 to 5 cm pieces for wet sieving. Macrofossils – leafs, seeds, small twigs with well preserved bark, water moss – were extracted under a binocular light microscope for radiocarbon dating purpose.

Table 1. Lithofacies codes (1st, 2nd and 3d order code system) as used in this work, notably in Figs. 6 and 8. Basic system according to Eyles et al. (1983).

Lithofacies code:	Lithofacies type description: Grain size, grain support system, internal structures
D(G/S/Si/C)	Diamict, gravelly, sandy, silty or clayey. One or more grain-size code letters within brackets
D( )mm	Diamict, matrix-supported, massive
D( )ms	Diamict, matrix-supported, stratified
D( )mm/ms(s)	Diamict, …., sheared
D( )ms(a)	Diamict, …., attenuated
Co--	Cobbles, as below
D( )mm(ng)	Diamict, matrix-supported, massive, normally graded
D( )mm(ig)	Diamict, matrix-supported, massive, inversely graded
D( )mm (ing)	Diamict, matrix-supported, massive, inverse to normally graded
Gmm	Gravel, matrix-supported, massive
Gcm	Gravel, clast-supported, massive
Gcm(ng); --(cng), --(mng)	Gravel, clast-supported,massive, normally graded; clast normal grading, matrix normal grading
Gcm(ig)	Gravel, clast-supported, massive, inversely graded
Bo/Glg	Boulder/Gravel lag
Sm	Sand, massive
Sm(ng)	Sand, massive, normally graded
Sm(ig)	Sand, massive, inversely graded
Spp	Sand, planar parallel-laminated
Spc	Sand, planar cross-laminated
Stc	Sand, trough cross-laminated
Sr	Sand, ripple-laminated
Sl(def)	Sand, laminated, deformed
S--sf	Sand --, shallow scour fill
Sim	Silt, massive
Sm(ic)	Sand, massive, intraclast
Sil	Silt, laminated
S--(s)	Sand --, sheared
Cl	Clay, laminated
Cm	Clay, massive
Cm(dr)	Clay, massive (dropstones)

Chronology. - A total of 45 OSL ages from the till-capped sorted sediment successions were determined at the Nordic Laboratory for Luminescence Dating at Aarhus University, Denmark (Table 2). In addition to this there are 14 pending OSL ages from the sediment successions in last deglacial kame deposits. The samples were taken from cleaned and logged section wall in opaque plastic tubes, 20 cm long and 6 cm in diameter, and sealed until opened under darkroom conditions. The single aliquot regenerative dose protocol applied to quartz grains was used to estimate the equivalent dose (Murray and Wintle, 2000), with blue (470±30 nm) light stimulation, a 260 °C preheat for 10 s, and a cut heat of 220 °C. Photon detection was through a U-340 glass filter.

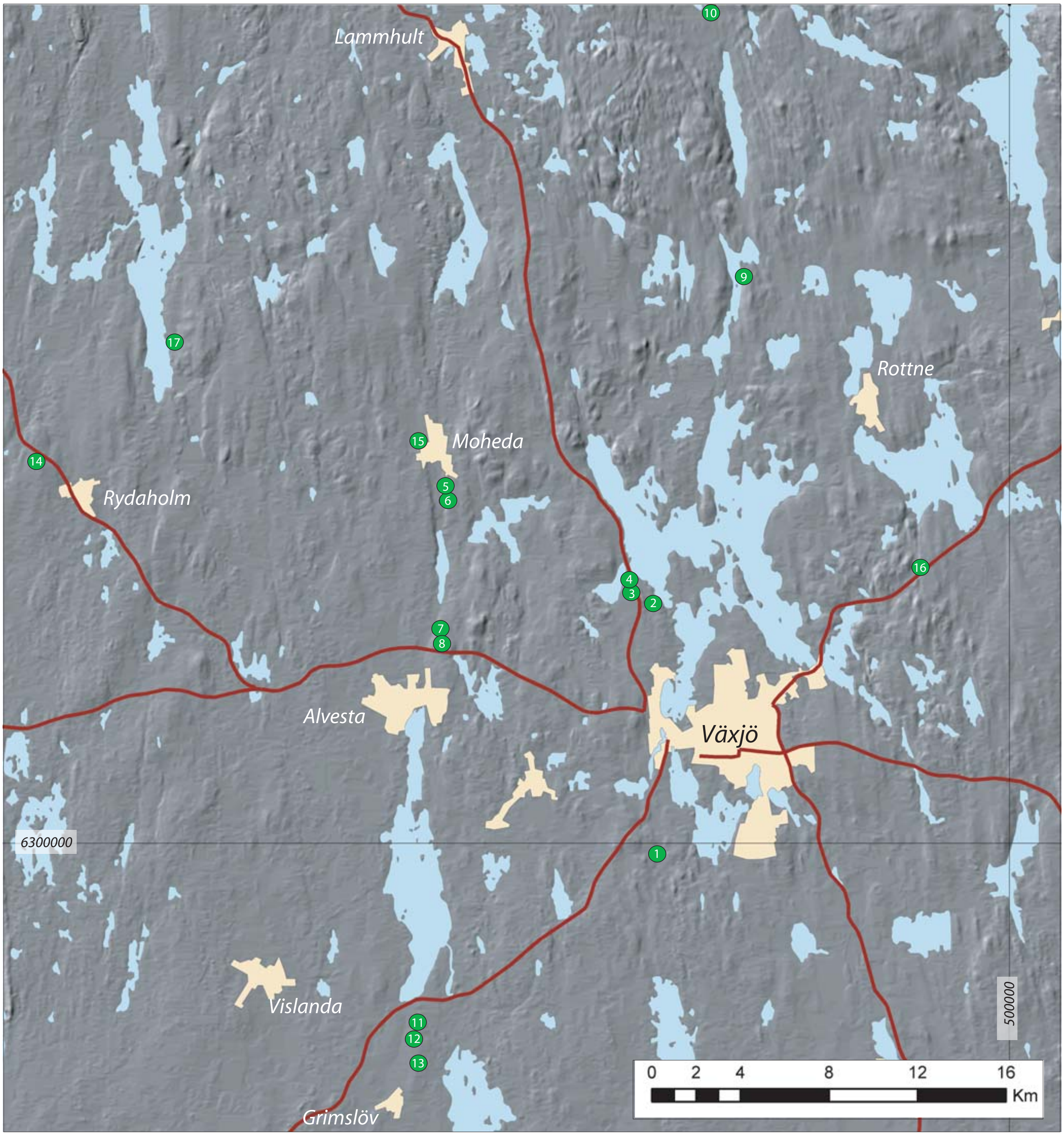

Fig. 2. Hill shaded relief map of the investigation area. Excavated sites are indicated by green dots, and numbers refer to sites names as in Tables 2 and 3. map. Coordinate system in map is according to SWEREF99 TM.

The samples were analyzed for natural series radionuclide concentrations in the laboratory, using high-resolution gamma spectrometry (Murray et al., 1987). These concentrations were converted into dose rates using conventional factors listed by Olley et al. (1996).

A total of 8 cosmogenic nuclide surface exposure samples were extracted from large boulders (>2*2*2 m) on till slopes or from bedrock surfaces close to the deglacial kame delta sites. Dating is in progress (pending December, 2010). Samples will be prepared at the Cosmogenic Nuclide Laboratory at the University of Glasgow following procedures modified from Kohl and Nishiizumi (1992) and Child et al. (2000). AMS measurements will be carried out at the Scottish Universities Environmental Research Centre (SUERC) AMS facility. ^{10}Be concentrations will be converted to surface exposure ages using the online CRONUS-Earth ^{10}Be-^{26}Al exposure age calculator Version 2.2 (http://hess.ess.washington.edu/math/) (Balco et al., 2008). Pending ages will be reported using the time-dependent spallation scaling scheme of Lal (1991) and Stone (2000), assuming no atmospheric pressure anomalies, no significant surface erosion during exposure, no prior exposure, and no snow shielding.

A total of 15 AMS ^{14}C ages are pending (May, 2010) from the AMS Radiocarbon Dating Laboratory, Department of Geology, Lund University, Sweden (LuS samples) of which all but one are on macrofossils (leafs, e.g. *Dryas*, seeds, small twigs, water moss) extracted from the lowermost lake sediment succession close to the deglacial kame delta sites. All age determinations in ^{14}C years BP will be calibrated into calendar years (cal yr BP), using OxCal v4.1 (Bronk Ramsey, 1995, 2001). In addition to this, twigs extracted from peat and gyttja below till have been dated both at the AMS Radiocarbon Dating Laboratory, Department of Geology, Lund University, Sweden (two LuS samples) and at the Radiocarbon Dating Laboratory at Heidelberg University, Germany (conventional ^{14}C dating of old and large samples) (two Hd samples, Table 3).

4. Results – so far

4.1. Till-capped sorted sediments

Till-caped sorted sediments around Växjö (white frame, Fig. 1; Fig. 2) seem to be confined to three geographical areas with somewhat different geomorphological expressions, from west to east:

- An area centred around the Rydaholm village. This is a quite flat to streamlined till plain with low relief drumlins. Well logs from this area indicate extraordinary thick deposits of Quaternary sediments in the order of ~50 m.
- The Stråken valley between Alvesta and Moheda. In this area there are numerous reports on sand quarries, varying from fine sand to very coarse gravel to cobble deposits, quarries that since long are closed down and levelled. Most quarries were opened up along the valley sides, especially the eastern one. The valley is ~25 m deep, surrounded by a quite flat, partly streamlined till plain. Well logs indicate that the till-capped sediments exposed at the valley sides also continue in lateral directions, as reported from a number of well diggings.
- The flat lake plain between Lake Åsnen and Lake Helgasjön, and continuing northwards into the more high relief terrain north of Lake Helgasjön. The till-capped sorted sediments form cores in more or less pronounced drumlins/streamlined terrain (Fig. 3). Most drumlins in this area are, however, built around bedrock cores.

Out of 15 excavated sites where sorted sediments were found below a capping till, only one had a sediment composition unsuitable for OSL dating (to coarse sediment for sampling). In this report only three sites are described as examples of occurring sediments.

4.1.1. Katrinedal

The Katrinedal site is located in the western flank of a low-relief drumlin (Fig. 3B). A small sand quarry for local consumption, in which sand also have been extracted at least 2 m below ground-water level, was re-excavated into a ~8 m wide and 3 m high section (Fig. 4), logged in its central part (Fig. 5). The sediment sequence continues downwards, but is here below the ground-water level and was thus not excavated. The lower part consists of large-scale trough cross-laminated medium sand to gravelly sand and sandy gravel, individual troughs being 2-4 m wide. Palaeocurrent measurements indicate a flow towards a sector between SSW-SE, i.e. perpendicular to slightly oblique into the section (Fig. 4). Sedimentary facies suggests subaerial deposition from migrating three-dimensional bars in an intermediate-type sandur (braidplain) setting.

The sandur sediments have a slightly gradual contact to overlying diamicton, with the matrix being deformed sandur sediments but with addition of boulders up to 0.4 m in diameter. With decreasing frequency upwards, the massive, sandy-gravelly diamicton carries sand to gravelly sand intraclasts (10-20 cm in diameter) that are slightly stretched in their configuration. At places there are thin, more continuous sand intrabeds. One clast fabric measurement shows a clustered unimodal fabric shape with strong preferred orientation (S_1 = 0.865; V_1 = 10°/3°), suggesting a stress transfer – and thus ice-movement direction – from the north that parallels the flanking drumlin. The diamict is interpreted as a glacial till, in its lower part mainly being a deformable bed deposit and higher up being an ordinary traction till with inclusions of sediment derived from its basal contact but deposited as boudins within the till or as sheared-out sorted sediment lenses.

Four OSL dates yield a quite large spread in ages between 62 ± 5 and 43 ± 4 ka with a mean age of 52 ka. However, it can be argued that the youngest age is the most accurate one, and that the older ages are due to insufficient bleaching due to within-channel sand-grain traction transport and deposition in turbid water, giving age overestimates. The mean age of the OSL datings falls in the early part of Marine Isotope Stage (MIS) 3, and sediments are definitely older than the last deglaciation.

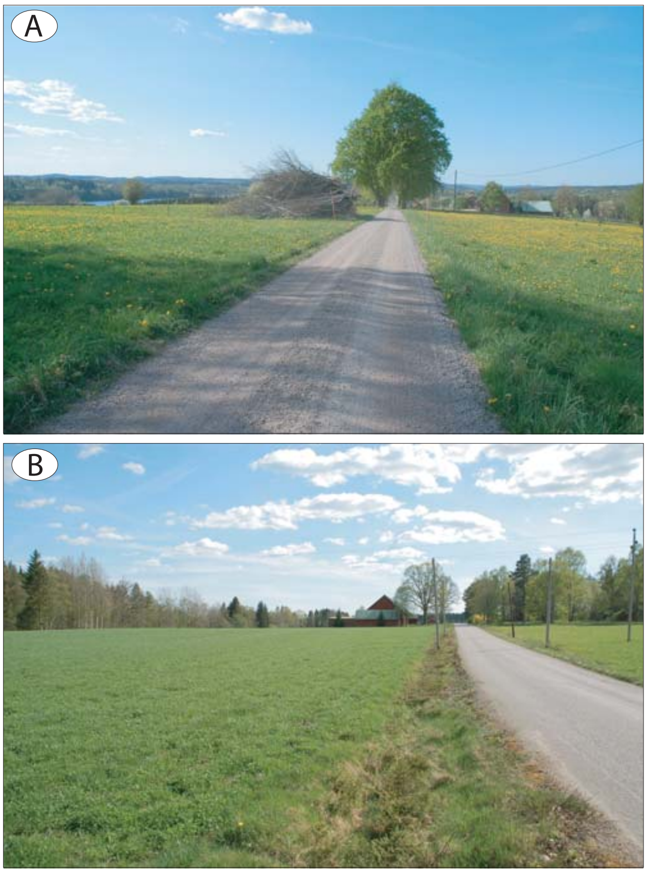

Fig. 3. Drumlins with sorted sediment cores. (A) The Nykulla drumlin north of Lake Helgasjön; view direction is north. (B) The Katrinedal drumlin south of Helgasjön; view direction is south. The excavated sediment sequence (Fig. 4) is just at the tree line to the left.

Fig. 4. Sediment section at the Katrinedal site: large-scale trough cross-bedded sand and gravelly sand, overlain by till. The section is facing north.

4.1.2. The Grimslöv- Ströby drumlin

The Grimslöv-Ströby drumlin, situated west of the northwestern tip of Lake Åsnen (Fig. 2) is the southernmost site with till-capped sorted sediment. It forms a 1.5 km wide and 4 km long streamlined height stretching N-S and rising ~10 m above surrounding glacial lake sediments, the latter deposited at the last deglaciation of the area. Most farms have their own groundwater well, the dug ones documented in the old archives of Strandmark and new ones documented in the SGU wells archive. This information clearly indicates that the whole height has a core of sediment, varying from interbedded silt and clay to sands and gravels, resting on a lower till and draped by a surficial till being 0.5 to 3 m thick. Documented thickness of the sorted sediment core varies between 20-50 m. Three trenches were made in the Grimslöv-Ströby drumlin along its centreline, from north to south (i) at the Lövkvist farm in Ströby, (ii) at Ströby Jakobsgård and, (iii) at Grimslöv School, of which the two first sites are briefly described here.

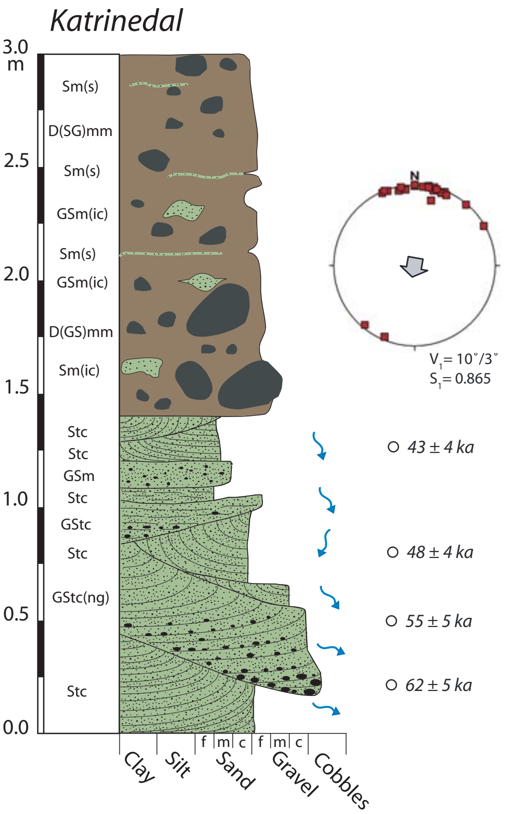

Fig. 5. Logged sediment succession at the Katrinedal site (N56° 50.325'; E14° 44.345').

Lövkvist farm, Ströby. – This site in an old sand pit in the western slope of the proximal part of the drumlin. Field notes and photographs dated 1924 from the Strandmark archives gave hints of spectacular glaciotectonics, which was fully confirmed at re-excavation of a 4 m high and 6 m wide section (Fig. 6A). The section trends 30°-210° (~NE-SW) and is thus oblique to the drumlin axis trend. All beds are standing at a very high angle with bedding surfaces striking WSW-ENE and dipping 82-88° towards SSE (Fig. 7). The sediment sequence, when logged way-up from left to right comprise at the base planar parallel-laminated gravelly sand, overlain by repeated sets of interbedded planar parallel-laminated medium sand and bedsets of ripple-laminated fine sand, the latter often as multiple 10-20 cm thick sets of type A ripple lamination transforming into type B ripple lamination, draped by silt. Such a sedimentary sequence clearly suggests deposition in a glaciolacustrine setting as lower delta-slope/delta-toe sediments, predominantly from density underflows.

The present position and shape of the sediment suggest glacial deformation with a stress direction from NNW, i.e. slightly oblique to the drumlin-axis trend, at which the primary sediments were isoclinaly folded – and shortened – into a close to vertically standing fold of which the sediments shown in the section represent the right-hand limb of that fold. At a later stage the sediments experienced brittle deformation manifested by low-angle overthrusts from NNW (Fig. 6A and B). The fold neck is eroded with a sharp contact to overlying shear-laminated sand, the source of which is the sediment below the indicated décollement. Below the same surface are shallow drag folds, indicating stress transfer down into underlying sediments. The shear-laminated sand is in turn overlain by a ~0.7 m thick massive, silty-sandy diamict, carrying boulders up to 1.5 m in diameter.

Fig. 6. Trenched sediments in the Grimslöv-Ströby drumlin. (A) The Ströby site (Lövkvists farm). A close to vertically standing succession of laminated gravelly sand and sand, interbedded with ripple-laminated fine sand and rhythmically laminated silt and clay (way up is to the right) (log, Fig. 7). The sediment succession forms the right-hand limb of an isoclinal fold with the top anticline eroded and overlain by a till. Glaciotectonic stress direction is diagonally into the right-hand corner of the section (from 340°). (B) Blow-up of the white rectangle area in (A), showing some details in the sediment succession. A low-angle thrust from NNW, postdating the fold formation, is indicated by red arrows. (C) The Ströby Jakobsgård site with a trench reaching down into rhythmically laminated silt and clay below the covering till. (D) Trench bottom, showing the intricately folded silt and clay beds, primarily being a succession of proximal varved clay, i.e. thick summer beds between winter clay beds.

Four OSL dates yield quite a narrow time span between 32 and 37 ka (mean age 35 ± 3 ka), i.e. an age frame falling into MIS 3.

Ströby Jakobsgård. – This is a 4 m deep trench, situated ~750 m south of Lövkvist farm at Ströby, dug on a flat till surface at the centreline of the Grimslöv-Ströby drumlin (Figs. 6C, 8). The lowermost 1.9 m is a heavily deformed sequence of rhythmically interbedded silt and clay with clay beds 2-5 mm thick, while interbedded silt to very fine sand is 2-30 cm thick (Figs. 6D, 9). The sediments are interpreted as glaciolacustrine varved clay deposited in a proximal setting to the ice margin, with summer deposition of silt and fine sand from sediment density underflows, whereas the clay beds represent winter deposition from suspension. The intense folding is three-dimensional in nature, i.e. fold axes are not linear but curved (sheath folds, e.g. van der Wateren et al., 2000), resulting in fold noses forming eye structures in cuts being oblique to transverse to the deformation direction (Fig. 9). Measured folds suggest a glaciotectonic stress from NNW (339°).

The deformed glaciolacustrine succession is overlain by a silty diamict with deformed and drawn-out sandy-silty intra-clast, interpreted as derived from the underlying sediments and during the deforming bed process transformed into glaciotectonic boudins. The diamict is vaguely stratified and some of this lamination come out from or fall into the deformed intraclasts. This stratification is concordantly interpreted as sheared-out sediment intraclasts. At the basal contact, boulders from the diamict can be observed to be pressed down into underlying silt, buckling sediments in lee-side positions. Upwards is a gradual transformation into a massive sandy diamicton with observed largest boulder size of ~1.5 m.

Two OSL dates yield a larger age spread than at Lövkvist farm, but in the same magnitude: 32 ± 2 and 28 ± 2 ka, i.e. also these ages fall into MIS 3.

4.2. The complete OSL chronology data set

As stated above, only three investigated sites of the in total 14 sites with OSL ages are presented in this report to their sedimentological properties. The complete presentation will occur in a near-future paper. However, the presented sites are

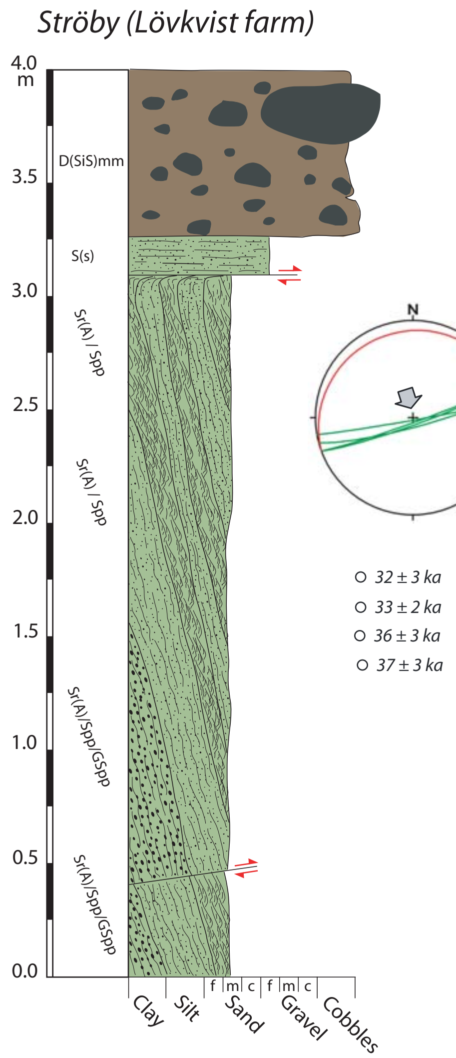

Fig. 7. Logged sediment succession in the Grimslöv-Ströby drumlin; site Lövkvist farm in Ströby (N56° 46.191'; E14° 33.723'). Green planes in the stereo net indicates strike and dip direction of high-angle bedding surfaces, while the red plane represents strike and dip of the overthrust plane in the lower part of the section.

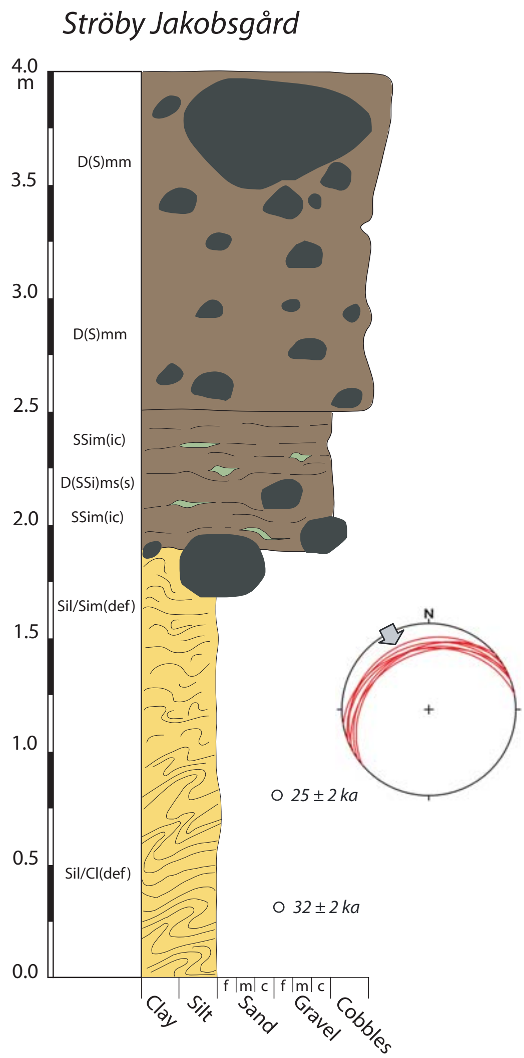

Fig. 8. Logged sediment succession in the Grimslöv-Ströby drumlin; site Ströby Jakobsgård (N56° 45.771'; E14° 33.558'). Red planes in stereonet are measured fold limbs, suggesting a glaciotectonic stress from NNW.

Fig. 9. (A) Sheath-folded varved clay in the Ströby Jakobsgård trench. (B) Cartoon showing the three-dimensional structures of a sheath fold. The folds appear as low-angle attenuated isoclinal folds parallel to deformation direction, while they form eye or concentric ring shapes in a section perpendicular to the shear direction (van der Wateren, 1995; van der Wateren et al., 2000).

typical for occurring sediment succession and the depositional settings they represent, varying from proglacial glaciofluvial sediment succession representing sandur deposits to glaciolacustrine sediment successions deposited both in settings proximal to meltwater influx points and in more distal settings. All sites thus represent sediment succession deposited in a proglacial environment and, if sufficiently bleached, capable of giving an OSL age estimate of their deposition. However, what do they date with respects to glacial phases? If the proglacially deposited sediment succession is not covered by a till, then there usually is no question about it; it postdates the last glaciation and we get a close age estimate of the deglaciation. If retrieved OSL ages are too old compared to other deglacial age determinations, e.g. from radiocarbon dating of organic remains, then we usually explain this with insufficient bleaching, giving age overestimates of the deglaciation. However, this must not always be the case. What might be interpreted as an age overestimate of, e.g., 10-15 kyr can equally well represent a true depositional age if the sediments are NOT of deglacial origin, but instead are proglacial advance phase sediments, left more or less undisturbed by the later overflowing glacier and no till is ever deposited. Such a scenario might not be that common, but must be considered when higher than expected ages show up. When proglacial sediment sequences turn up in stratigraphic succession between tills, this question starts to be delicate; is it tied to the lower till and dating the deglaciation of that glacial advance, or is it tied to the overlying till, giving an age of (pre-date) that glacial advance? The answer is not at all straight forward if not interstadial deposits also are bracketed between tills and proglacial sediment units!

All dated sites with their retrieved 45 OSL ages are shown in Table 2. Except for one site with a singe OSL date, all other sites have two to six dates. When all ages are plotted individually it is possible to distinguish one older age group and one younger age group, though with some age overlap. This pattern becomes much more evident if ages are plotted as means for each investigated site (Fig. 10). In this case the older age group falls approximately between 48-56 kyr for seven sites, while the younger age group is c. between 28-36 kyr for 5 sites. The site with a single OSL age falls older than the oldest group and one site falls between the two groups at c. 42 kyr. Also the two youngest OSL ages at the Växjö airport site fall outside these age groups. Which approach should then be taken for assessment of 'true' depositional age? OSL ages from sites with two or more datings spread in best cases 2-5 kyr, in worst cases up to 20 kyr in age difference between the individual datings and the determined age error for individual datings is in the order of ±2-6 kyr at 1 σ. Taking the depositional environment into consideration for each sediment succession, total deposition time over their heights should not be many hundreds of years; thus the spread in ages at an individual site – even for those with the most clustered age determination – is unrealistic. Differences in age at an individual site are most probably due to (i) the difficulty to model water content in the sediment over time, or (ii) poor exposure to sunlight at sediment transport and deposition, giving age overestimates. The first problem has fundamental importance for age calculation and can give both age overestimates and age underestimates (see discussion in, e.g., Alexanderson et al., 2010). If differences over time in water content are considered the most probable cause of such age difference within a section that ought to give more or less the same age, then the most accurate approach would be to take the mean age as the best possible estimate of depositional age. However, if poor bleaching is suspected to be the most important factor for spread in retrieved ages, causing age overestimates for some samples, then the appropriate approach might be to consider the younger ages as most 'true' depositional ages.

The sorted sediment sequences from investigated sites in the Växjö area are unfortunately not constrained in any stratigraphic context, more than being overlain by a till that we suppose is a till from the LGM SIS advance and retreat over the area. The sorted sediment sequences thus only

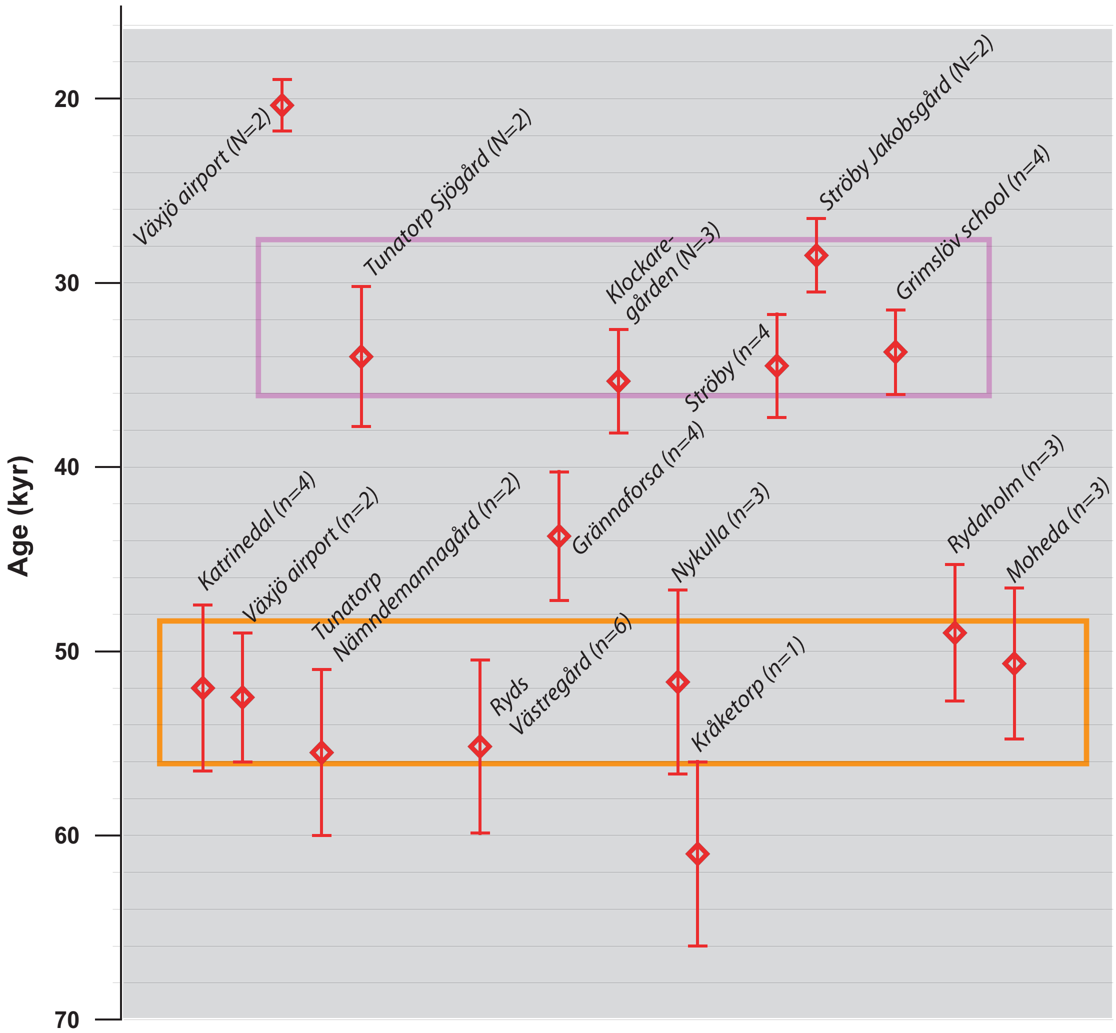

Fig. 10. Fourteen sites with OSL dated till-capped sorted sediments, plotted as mean OSL age from each sites, except for site Växjö airport, where the stratigraphy clearly indicate two individual stratigraphic units, and obviously with different ages.

form 'hanging time windows' representing phases of passing proglacial environments during glacial retreats, or possibly glacial advances, older than the last glaciation. If the two time boxes indicated in Fig. 10 has a true temporal meaning, then these passing glacial environments occurred during MIS 3 (c. 60-30 kyr ago), i.e. during relatively warm, interstadial conditions which *per se* might be seen problematic, especially as a number of recent reviews of the glaciation history of Fennoscandia suggest very limited ice coverage during MIS 3 (Helmens and Engels, 2010; Lambeck et al., 2010; Wohlfarth, 2010). Opposed to this view come the results of the latest revision of Danish glacial stratigraphy, suggesting the first Weichselian ice advances into the SW perimeter of the SIS distribution area are from MIS 3, namely the Ristinge and Klintholm ice advances (Houmark-Nielsen, 2010) (Fig. 11). Bracketed between the Ristinge and Klintholm tills, and all below the tills and associated sediments from the LGM ice advances and retreats over Denmark, are numerous OSL and AMS ^{14}C dated lacustrine, fluvial and aeolian sediment successions. From theses dates, Houmark-Nielsen conclude that the Ristinge advance occurred around 50 ± 4 kyr and that the Klintholm advance occurred at around 32 ± 4 kyr, with the Sejerø interstadial in between. The two OSL age frame boxes, as depicted in Fig. 10, thus more or less completely conform to the proposed MIS 3 Ristinge and Klintholm ice advances into Denmark, advances that also must have crossed central Småland (Fig. 11). Thus the OSL mean ages do not postdate these advances, which should be the case if representing deglacial sediment sequences for those glacial phases. However, if we consider the mean ages of proglacial sediments around Växjö (Fig. 10) to be a bit on the old side due to incomplete bleaching, typical for such environments (e.g. Fuchs and Owen, 2008), then such an event correlation seems to be quite probable. Correlations and the problematic relations to sugested ice-free or restricted ice cover in northern and central Scandinavia at the same time period (e.g., Wohlfarth, 2010; Wohlfart and Näslund, 2010) will be a central topic in a forthcoming paper.

4.3. Organic sediments below till

In the 1970ies it was reported to the Department of Geology in Lund that "peat" below till had been collected by well diggers at Nybygget, located c. 13 km NE of Växjö. Except for a conventional radiocarbon dating (Lu-1296, >40 600 yr BP), nothing more was done to the few samples sent to us. At reconnaissance work for this project in 2007 it was learnt from an excavator operator that when burying foundation stones from a torn-down old barn at Gäddevik, c. 30 km NW of Växjö, he found 'twigs and leaves a few metres down in the till'. Both these localities were localized and trenched in the summers of 2007 and 2008, respectively (localities 16 and 17, Fig. 2).

Table 2. Optically Stimulated Luminescence (OSL) ages from investigated sites. For locations, see Fig. 2.

Site no.	Site	Coordinates Lat	Coordinates Long	Sample No.	Lab No.	sample depth (cm)	n	w.c. %	Dose (Gy)	Dose Rate (Gy/ka)	OSL age (ka)
1	Katrinedal	N56° 50,325'	E14° 44,345'	20088001A	081007	275	20	8	160 ± 12	3.71 ± 0.20	43 ± 4
	Katrinedal			20088001B	081008	275	23	6	168 ± 11	3.46 ± 0.19	48 ± 4
	Katrinedal			20088002A	081009	275	21	6	210 ± 13	3.79 ± 0.21	55 ± 5
	Katrinedal			20088001B	081010	275	23	8	219 ± 14	3.53 ± 0.19	62 ± 5
2	Växjö airport	N56° 56,467'	E14° 44,145'	200803	081011	1080	29	24	131 ± 3	2.86 ± 0.14	46 ± 3
	Växjö airport			200804	081012	980	28	20	172 ± 6	2.91 ± 0.15	59 ± 4
	Växjö airport			200805	081013	800	23	14	66 ± 2	3.10 ± 0.16	21.4 ± 1.4
	Växjö airport			200806	081014	500	23	16	57 ± 2	2.97 ± 0.15	19.3 ± 1.3
3	Tunatorp Nämndemannagård	N56° 56,768'	E14° 43,185'	200807	081015	250	24	12	171 ± 9	3.05 ± 0.15	56 ± 4
	Tunatorp Nämndemannagård			200808	081016	150	20	18	174 ± 12	3.15 ± 0.16	55 ± 5
4	Tunatorp Sjögård	N56° 56,984'	E14° 43,063'	200809	081017	320	36	18	84 ± 3	3.00 ± 0.15	28.0 ± 1.8
	Tunatorp Sjögård			200810	081018	380	24	22	114 ± 3	2.84 ± 0.14	40 ± 2
5	Ryds Västregård	N56° 59,288'	E14° 34,693'	200811	081019	1540	25	21	162 ± 11	2.91 ± 0.15	56 ± 5
	Ryds Västregård			200812	081020	1500	19	14	198 ± 13	3.15 ± 0.17	63 ± 6
	Ryds Västregård			200813	081021	1340	27	10	156 ± 10	3.32 ± 0.18	47 ± 4
	Ryds Västregård			200814	081022	920	27	9	165 ± 10	3.26 ± 0.06	54 ± 4
	Ryds Västregård			200815	081023	840	22	12	209 ± 11	3.25 ± 0.18	64 ± 5
	Ryds Västregård			200816	081024	500	22	6	174 ± 12	3.74 ± 0.21	47 ± 4
6	Grännaforsa	N56° 58,935'	E14° 34,750'	200817	081025	800	28	18	124 ± 5	2.86 ± 0.14	44 ± 3
	Grännaforsa			200818	081026	770	24	7	138 ± 7	2.83 ± 0.16	49 ± 4
	Grännaforsa			200819	081027	730	27	10	132 ± 7	2.96 ± 0.16	45 ± 4
	Grännaforsa			200820	081028	450	24	10	118 ± 6	3.17 ± 0.17	37 ± 3
7	Klockaregården	N56° 55,794'	E14° 34,475'	200821	081029	420	24	11	96 ± 5	2.99 ± 0.16	45 ± 4
	Klockaregården			200822	081030	230	18	10	108 ± 5	3.35 ± 0.18	29 ± 2
	Klockaregården			200823	081031	120	29	8	177 ± 8	3.42 ± 0.18	32 ± 2
8	Bockaboda	N56° 55,372'	E14° 34,630'	no sample							
9	Nykulla	N57° 04,430'	E14° 48,130'	200824	081032	700	18	13	177 ± 8	3.53 ± 0.19	50 ± 4
	Nykulla			200825	081033	470	16	8	256 ± 22	4.68 ± 0.26	55 ± 6
	Nykulla			200826	081034	470	20	8	219 ± 19	4.40 ± 0.24	50 ± 5
10	Kråketorp	N57° 10,993'	E14° 46,614'	200827	081035	280	22	18	204 ± 13	3.32 ± 0.17	61 ± 5
11	Ströby, Lövkvist farm	N56° 46,191'	E14° 33,723'	200828	081036	300	24	10	123 ± 8	3.82 ± 0.21	32 ± 3
	Ströby, Lövkvist farm			200829	081037	300	25	13	110 ± 5	3.34 ± 0.17	33 ± 2
	Ströby, Lövkvist farm			200830	081038	300	26	8	121 ± 6	3.39 ± 0.19	36 ± 3
	Ströby, Lövkvist farm			200831	081039	300	22	9	116 ± 6	3.17 ± 0.17	37 ± 3
12	Ströby Jakobsgård	N56° 45,771'	E14° 33,558'	200832	081040	360	25	23	111 ± 5	3.43 ± 0.16	32 ± 2
	Ströby Jakobsgård			200833	081041	310	18	24	88 ± 5	3.54 ± 0.17	25 ± 2
13	Grimslöv School	N56° 45,188'	E14° 33,767'	200834	081042	400	26	15	112 ± 4	2.99 ± 0.15	37 ± 2
	Grimslöv School			200835	081043	290	26	13	125 ± 6	3.17 ± 0.16	39 ± 3
	Grimslöv School			200836	081044	280	24	10	110 ± 5	3.30 ± 0.17	33 ± 2
	Grimslöv School			200837	081045	260	37	10	102 ± 6	3.28 ± 0.18	26 ± 2
14	Rydaholm	N56° 59,832'	E14° 16,566'	200838	081046	700	22	10	171 ± 10	3.28 ± 0.18	52 ± 4
	Rydaholm			200839	081047	520	37	12	132 ± 7	3.20 ± 0.17	41 ± 3
	Rydaholm			200840	081048	380	20	9	173 ± 7	3.18 ± 0.17	54 ± 4
15	Moheda	N57° 0,370'	E14° 33,634'	200841	081049	200	26	8	152 ± 9	3.82 ± 0.21	40 ± 3
	Moheda			200842	081050	200	25	6	210 ± 10	3.50 ± 0.19	60 ± 5
	Moheda			200842	081051	200	20	7	200 ± 11	3.81 ± 0.21	52 ± 4

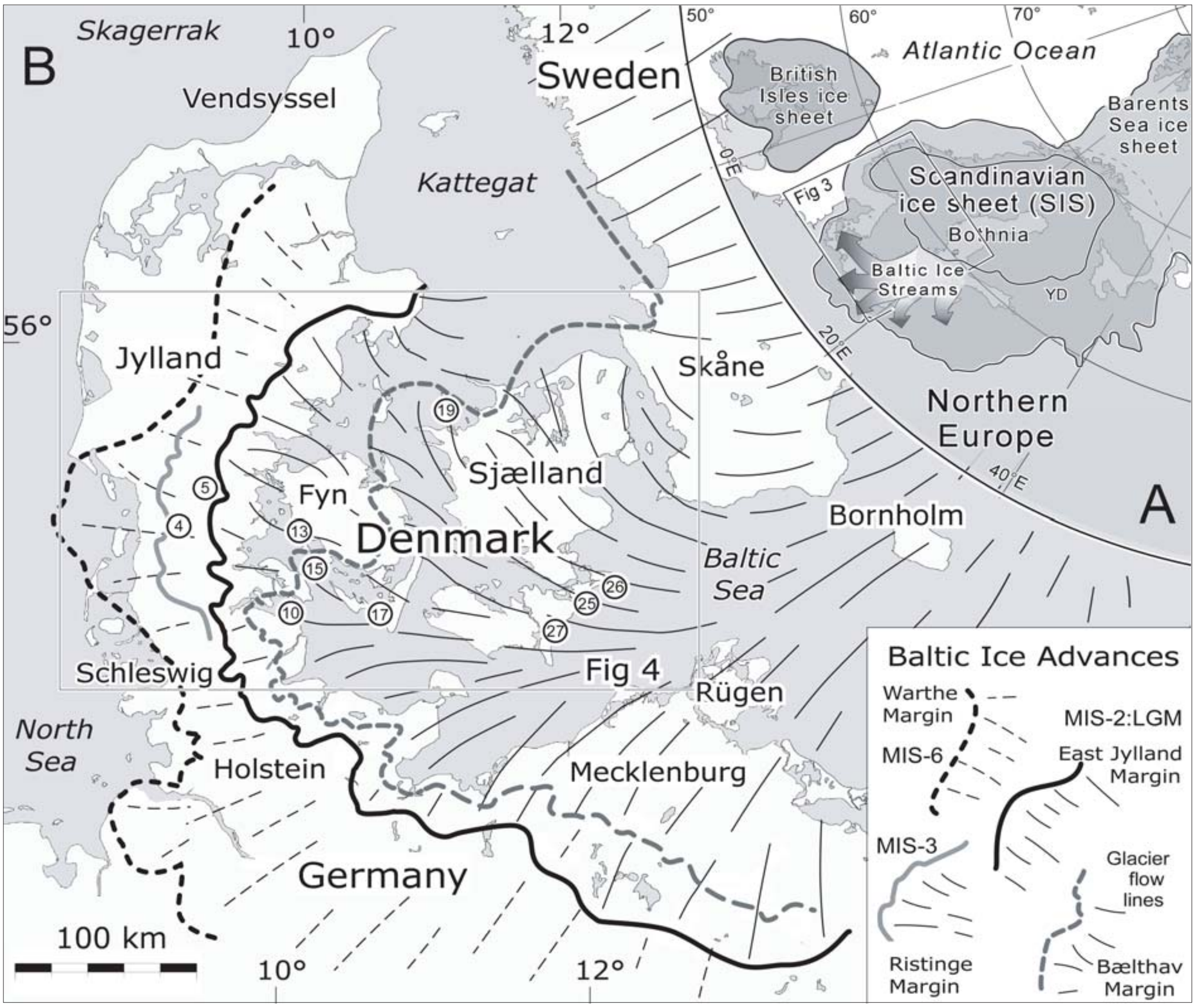

Fig. 11. Weichselian ice sheet advances into the southwestern maximum spreading sector of the SIS according to Houmark-Nielsen (2010). (A) Weichselian ice sheets in northern Europe at LGM. (B) MIS 6, 3 and 2 ice marginal positions and flow trajectories of Baltic ice advances. Reprinted from Houmark-Nielsen (2010).

At Nybygget, below 3.7 m of till, is a 1.4 m thick lake sediment and peat succession on top of a lower till. The uppermost till is a silty-sandy diamict with maximum boulder sizes between 1-1.5 m and the lowermost part of it contains peat and gyttja intraclasts, 10-15 cm in diameter. Two clast fabric measurements from the upper till reveal clustered unimodal fabric shapes with strong preferred orientations (S_1 = 0.89-0.85; V_1 = 20°/6° and 360°/1°, respectively) and suggest a stress transfer – and thus ice-movement direction – from the north. Unfortunately, the organic succession is not *in situ*; below the upper contact is an intermix with pebble to cobbles, and such occur through the whole succession, though with lower frequencies downwards. Also the organic deposits are internally disturbed as suggested from peat clasts dispersed in a gyttja matrix. The peat clasts are dominated by sphagnum, numerous macro-remains as seeds and leaf fragments (Fig. 12C), and twigs with a diameter up to 4 cm. Wood anatomic analyses have revealed occurrence of *Alnus, Salix, Corylus* and *Pinus*, the first two with counted tree rings suggesting an age of ~70 years at burial (personal communication, Hans Linderson, Laboratory for Wood Anatomy and Dendrochronology, Lund University). Two AMS radiocarbon datings on wood and macrofossils suggest an infinite age of >45 kyr BP (LuS-7399 and LuS-74400), and one radiocarbon date extends the age even further back to >57 kyr BP (Hd-26815) (Table 3).

The pollen spectra at Nybygget (according to a preliminary survey in the bachelor thesis by Arvidsson (2008)) have been compared to other south-Scandinavian sites with interglacial sediments, e.g. the Eemian in Hollerup, Den-

Table 3. Radiocarbon ages.

Site no.	Sites	Sample No.	Coordinates Lat	Coordinates Long	Dated material	Sample depth (cm)	Lab No.	^{14}C yr BP 1 σ error	δ ^{13}C
16	Nybygget	Nb 1a	N56° 57,404'	E14° 55,981'	Wood	490.0	LuS-7399	> 45 000	
	Nybygget	Nb 1b			*Potamogeton* seeds	490.0	LuS-7400	> 45 000	
	Nybygget	Nb 1c			Wood	490.0	Hd-26815	>57 000	-28.3
17	Stora Gäddevik	2008046	N57° 02,776'	E14° 22,628'	Wood (*Betula*)	320.0	Hd-28056	>57 000	-27.9

LuS: AMS Radiocarbon Dating Laboratory, Department of Geology, Lund University, Sweden

Hd: Radiocarbon Dating Laboratory at Heidelberg University, Germany

Fig. 12. (A) Sampling organic material from the Gäddevik site. Approximately 1.5 m of highly compressed gyttja below sand and till. (B) Highly compressed stem of Betula from the Gäddevik site, giving infinite radiocarbon age >57 kyr. (C) Peat from the Nybygget site, rich in macroscopic vegetation remains. Brown macrofossils are Potamogeton seeds. A scarlet beetle wing is seen in the lower right.

mark (Andersen, 1965; Björck et al., 2000) and Stenberget in southern Skåne (Berglund and Lagerlund, 1981), and also interstadial sites of Weichselian age, e.g. Brørup (Andersen, 1961), Odderade (Averdieck, 1998) and Gärdslöv (Miller, 1977). There are similarities and differences to all these, but a best fit of the pollen spectra at Nybygget is the Eemian. The species composition suggests deposition at the end of a warm period in transfer towards a cooler climate.

At the Gäddevik site there was ~1.5 m of organic sediment below 2.7 m of sand and till (Fig. 12A). The organic succession is a very hard, over-consolidated gyttja, obviously not at an *in situ* position as indicated from the occurrence of gravel to small pebble clast within the sequence and the gyttja is at places fragmented into clasts in a sand matrix. There is a large occurrence of macrofossils and wood fragments with diameters up to 6 cm. Three wood fragments were all determined to be *Betula*, the thickest representing a stem, 27 years of age at burial (Fig. 12B). One radiocarbon date suggest an infinite age >57 kyr BP (Hd-28056).

A not yet completed pollen analysis and quantitative vegetation reconstruction from the less disturbed sediments at Gäddevik show a vegetation composition for southern Scandinavia during parts of the Eemian. The sediments suggest well developed aquatic and terrestrial ecosystems with a species composition dominated by *Pinus, Picea, Betula, Alnus, Quercus* and *Corylus*, and indicating deposition during the Eemian climatic optimum. Charcoal and burnt vegetation fragments indicate reoccurring forest fires, which has not previously been documented from southern Scandinavia. Even though the Gäddevik site only covers a fragmental part of the Eemian, it is a unique finding as it shows a vegetation composition not previously described from southern Sweden, different from the also not complete sediment sequence from the Stenberget site in Skåne (Berglund and Lagerlund,1981). The Nybygget and Gäddevik sites will be comprehensively described by Broström et al. (in prep) when analyses are finalized, and there are plans for a reconnaissance of more complete and undisturbed sediment successions in connection to these sites.

4.3. Comparative dating of the last deglaciation

Frequently, retrieved OSL ages yield higher ages than expected, or when compared to ages determined by other dating methods. As already touched upon before, there is the general problem of reconstructing water content in sampled sediment trough time, a reconstruction that becomes even more complex when sediment sequences have experienced a number of changes over repeated glacial cycles. To this comes the problem of estimating a correct burial depth of the sampled level over time; sediments are added and/or removed over time when we deal with sediments from numbers of glaciations back. Thirdly, the sediments used in this study are ice-proximal proglacial sediments which are not the ideal sediments when it comes to OSL dating because of the risk of insufficient bleaching and thus age overestimates of the burial age – but that is what we have! As mentioned before, there have been problems both in OSL age consistency and unexpected high ages for supposed deglacial sediments in a geographical area north of Växjö (Alexanderson and Murray, 2007). We therefore launched a sub-project, as a test of reliability of the older OSL ages, with aim to compare LGM deglaciation ages at three sites along a north-south, close to 100 km long transect over the Växjö area from independent dating methods, namely (i) OSL age of ice-contact kame deltas (Fig. 13A), (ii) AMS radiocarbon dating of first organic remains (macrofossils) in lake sediments in close-by lake basins (Fig. 13B) and, (iii) cosmogenic nuclide surface exposure dating of large boulder on nearby till surfaces or on nearby, since deglaciation, exposed bedrock surface (Fig. 13C). This work is still in progress.

5. Final remarks

As stated in the introduction, this is only a report on carried out investigations and some preliminary results. The main part of this investigation dealing with till-capped sorted sediment is in the phase of being summed up, but some time will still be need for treatment of the data before a manuscript can be submitted. The analyses on Eemian deposits are close to finished and a first draft is gradually evolving. For the comparative study of deglaciation age, the exposure datings will appear at the end of 2010. Hence, this paper lies a little bit more in the future.

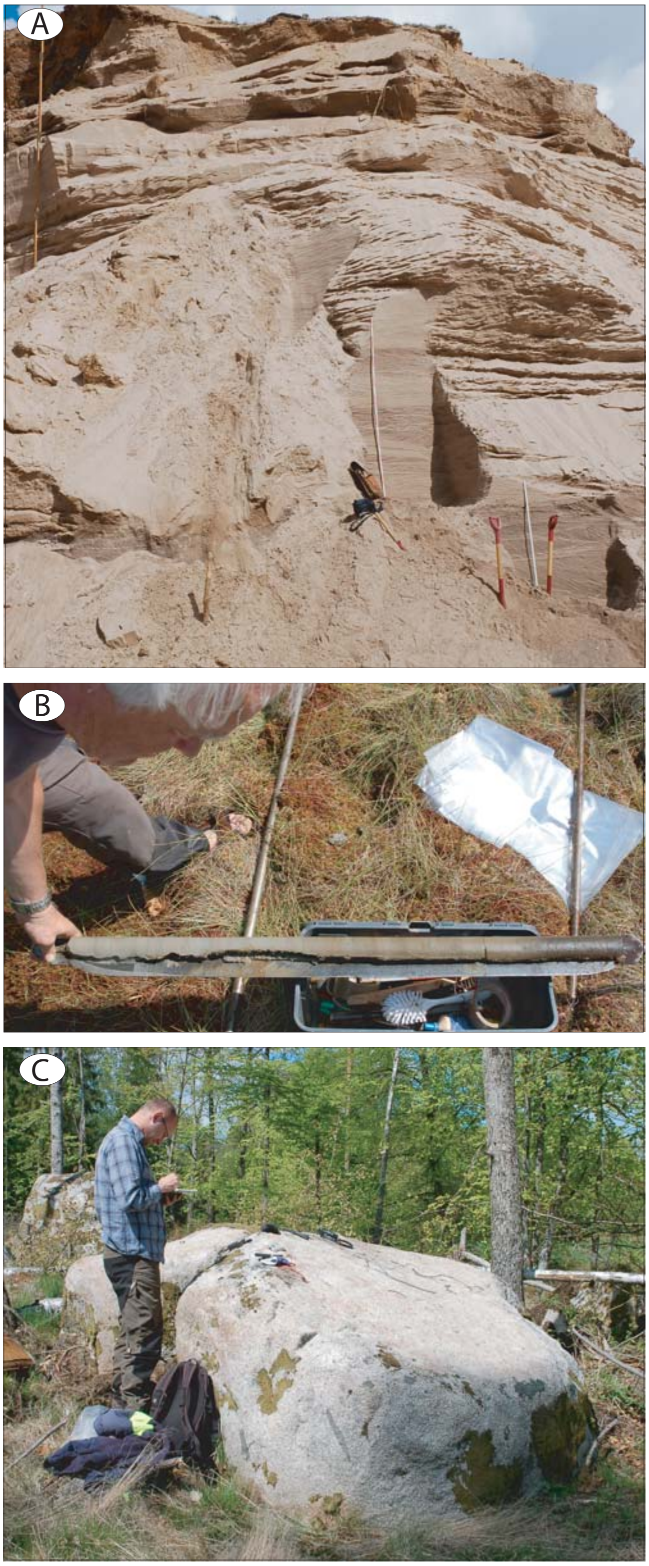

Fig. 13. (A) Kame delta at Råhult (N57° 14.049'; E14° 12.661'), sampled for OSL dating of last deglaciation. (B) Late glacial lake sediments retrieved from a small pond ~400 m SW of the kame delta at Råhult. The boundary between Holocene and Younger Dryas sediment is clearly marked by colour change from brown to brownish grey. The late glacial is ~80 cm of silty gyttja, changing to grey silty sand. Six AMS ^{14}C dates on macrofossils from the lowermost 30 cm are pending. (C) Large boulder on an adjacent till surface to the Ålshult kame delta (N56° 30.852'; E14° 40.463'), sampled for cosmogenic nuclide surface exposure dating.

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