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Composition and origin of the Middle Weichselian interstadial deposit in Veskoniemi, northern Finland

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Abstract. The stratigraphy and sedimentology of a diamicton-stratified sand deposit have been studied in the Veskoniemi area, near Lake Inarijärvi in central Finnish Lapland. Test pit excavations were used for stratigraphical investigations. Till-covered laminar and cross-bedded sands were dated using optically stimulated luminescence (OSL). Ages range between 21.0 ± 1.5 and 22.4 ± 1.6 ka for laminated sands at upper levels and 39 ± 3 and 46 ± 3 ka for sands at deeper levels. These dating results strengthen the evidence for a Middle Weichselian interstadial in northern Finland during oxygen isotope stage 3, and can be compared with other results in eastern and southern Lapland. This is the first time that sediments from the Middle and Late Weichselian contact have been identified in Finland. These new dating results indicate that an ice-free period could have lasted from halfway through the Middle Weichselian to the beginning of the Late Weichselian about 22–25 ka ago in northern Finland.

Key words: stratigraphy, stratified sand, till, optically stimulated luminescence, interstadial, Middle Weichselian, Veskoniemi, Lapland, Finland.

INTRODUCTION

Over the last ten years the age of stratified inter-till layers has been the subject of intense investigations both in Finland and in other areas influenced by the Scandinavian Ice Sheet (SIS). The purpose of the research is to find further evidence for the debate on the extent and timing of these intestadial/interglacial stratified deposits. For example, there is disagreement concerning phases of the Middle Weichselian (oxygen isotope stage 3) and also concerning phases during the transition from the Eemian stadial to the Early Weichselian interstadial/-glacial cycles. Both these issues require further investigation.

Since 2008, the Geological Survey of Finland (GTK) has been executing a project that aims to update the Quaternary chronostratigraphy of northern Finland (Sarala 2008). Most of the sites under investigation are sections that were first studied several decades ago, but only using radiocarbon and/or micro- and macrofossil age determination (cf. Hirvas 1991). Most of the new data are obtained by studying the stratigraphy and sedimentology of the sections in open pits and test pits and by using optically stimulated luminescence (OSL) dating for the till-covered and/or inter-till stratified layers. Optically stimulated luminescence provides a method for re-analysing deposits to estimate ages older than 40–50 ka and to obtain ages for deposits that do not contain organic material. New OSL sampling will supplement earlier studies in southwestern (Mäkinen 2005; Sarala et al. 2005; Sarala & Rossi 2006; Auri et al. 2008) and eastern (Helmens et al. 2001, 2007) Lapland. Also, new sampling targets are actively sought in the areas from which earlier studies did not yield dating results, in order to tighten the stratigraphical observation grid in northern Finland.

Several sections with known inter-till deposits occur in central Lapland in the area of the last ice-divide zone (Sarala 2008). One of these is Veskoniemi (Fig. 1), on the southern side of Lake Inarijärvi, near Ivalo village. The site is situated about 125–150 m above present sea level (a.s.l.) and consists of glaciogenic hummocky terrain that shifts into larger bedrock-core moraine hummocks eastwards. The Geological Survey of Finland has undertaken some earlier stratigraphical studies in the area (Hirvas et al. 1977; Hirvas 1991), but no instrumental age estimations are available. Through stratigraphical correlation and till fabric analyses, the age of deposits has been estimated to be older than the Late Weichselian.

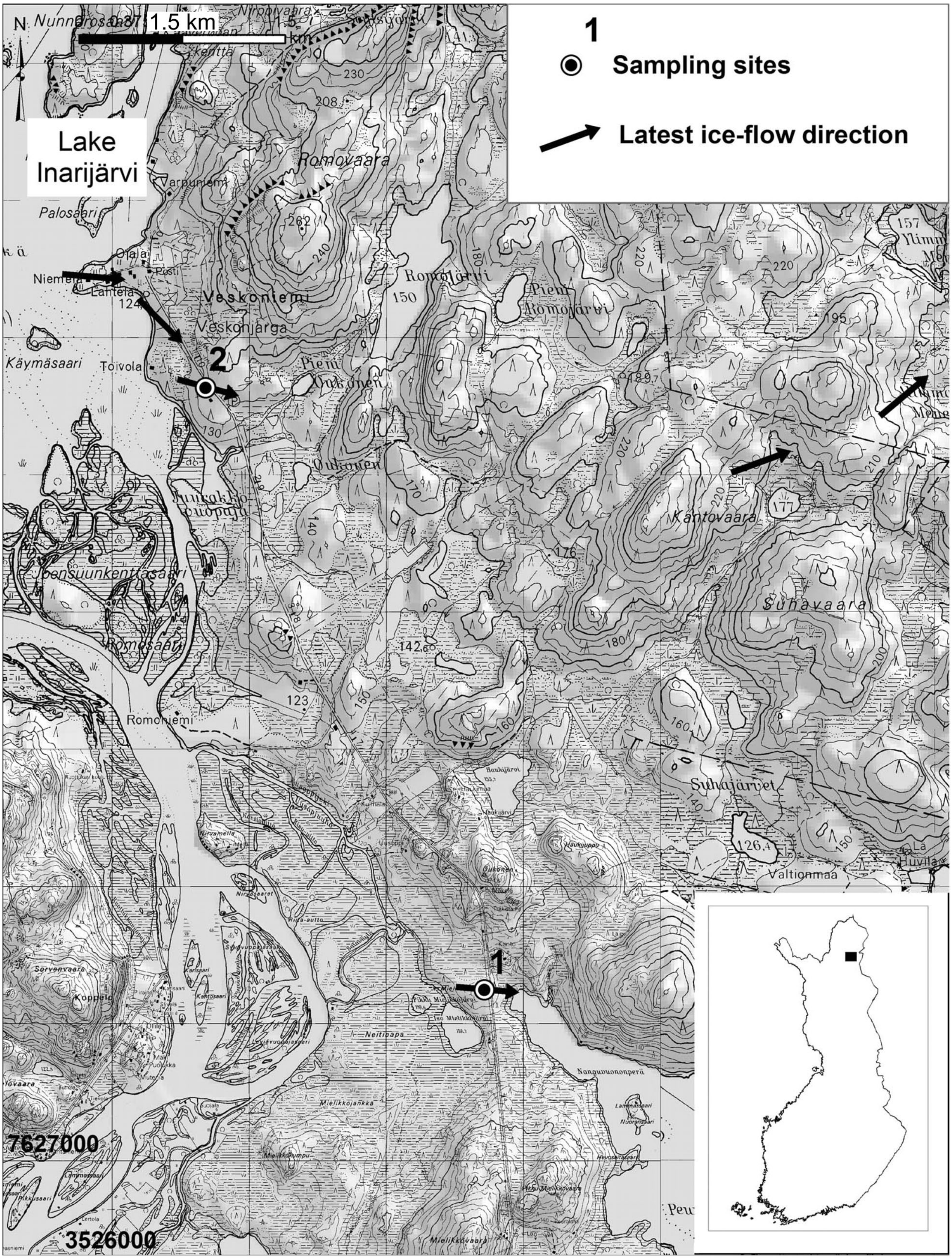

Fig. 1. Map of the sampling sites and the latest ice-flow directions after Hirvas (1991). Base map © National Land Survey of Finland, permission No. 13/MYY/09.

One of the previously investigated test pits in Veskoniemi (Hirvas 1991) was adopted to this study (site 1 in Fig. 1). The test pit (VESKO 1) was located in a small moraine hummock, near the main road, at the same place as test pit 78-HH-75 from 1975 (GTK's database). The surface of the hummock is about 129 m a.s.l. Based on earlier stratigraphical observations, stratified sands occur at the bottom of a 3 m deep section, under a 2 m thick diamicton deposit. Pebbles in the diamicton are oriented towards the SSE, that is from the direction of 280° (Fig. 1).

METHODS

Different methods have been used for morphological and stratigraphical study of glacial landforms in the area. Glaciogenic landform identification was undertaken using digital elevation model interpretation (ArcMap 9.2 software) and subsequent field work. Stratigraphical studies were carried out in test pits. Sections were cleaned and sedimentary structures and composition described. Grain size distribution was used to clarify the till stratigraphy. Lithofacies codes are according to Eyles et al. (1983; Table 1). Till fabric analyses from the earlier test pit surveys in the area have been used to complement our stratigraphical observations. The OSL sampling was done manually from the stratified sand deposit above the water table. The water content of the samples was measured by heating them at 110 °C for 12 h. The OSL measurements were performed at the Nordic Laboratory for Luminescence Dating (Århus University) based at Risø DTU, Denmark. Quartz equivalent doses were estimated using a single aliquot regenerated (SAR) dose protocol (Murray & Wintle 2000, 2003) with a preheat of 10 s at 260 °C, cut heat of 220 °C, blue LED (470±30 nm; 50 mW cm^{-2}) stimulation with the sample held at 125 °C and irradiation using a $^{90}Sr/^{90}Y$ calibrated beta source. Dose rates were derived from high-resolution gamma spectrometry (Murray et al. 1987), assuming that samples were fully saturated with water throughout their burial time. Cosmic ray dose rates were calculated following Prescott & Hutton (1994).

Table 1. Facies codes used in Fig. 2, after Eyles et al. (1983)

Code	Description
Dmm	Diamicton, matrix-supported, massive
Gms	Gravel, matrix-supported, stratified
Fl	Silt and clay, fine lamination
Sd	Sand, deformed bedding
Sl	Sand, horizontal lamination

RESULTS

Lithofacies characteristics and architecture of the VESKO 1 section

The lower part of the VESKO 1 section consists of a 2.8 m thick unit of deformed laminated silt and sand (Unit 1; Figs 2 and 3). The lowermost part of this unit is composed of 1.6 m thick folded sand, where original 0.5–2 cm thick lamination still exists among the overturned folds. The contact between this folded sand and an irregularly shaped 0.5–3 cm thick grey silt layer is erosional. Deformed laminated and in places cross-bedded sands, 1.2 m thick, overlie the silt layer (Fig. 4). The thickness of bent and sheared sand laminas varies between 0.5 and 1 cm (Fig. 5).

The deformed sand is overlain by a 1.8 m thick grey sandy diamicton unit (Unit 2). In the lowermost part (2.8–3.3 m) of this diamicton the stone content is low and the stones are rounded (4–5 in 5-class classification). In addition, the unit contains sand lenses and flame-type

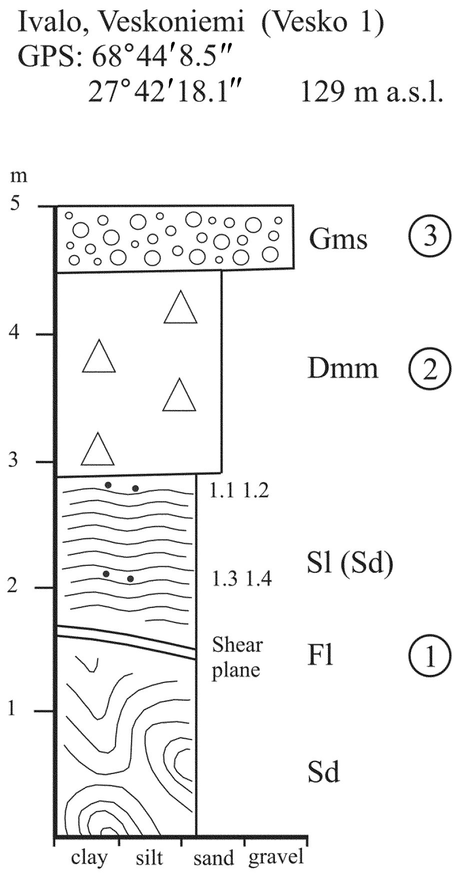

Fig. 2. Stratigraphic log of the VESKO 1 section in Veskoniemi. See the text for the description of stratigraphical units 1–3. For facies codes see Table 1.

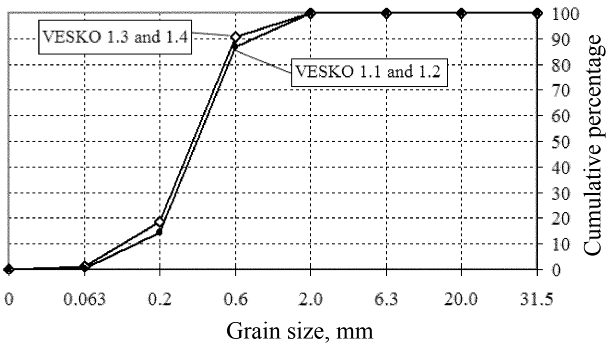

Fig. 3. Grain size distribution curves of OSL samples from the VESKO 1 section. For sampling sites see Fig. 4.

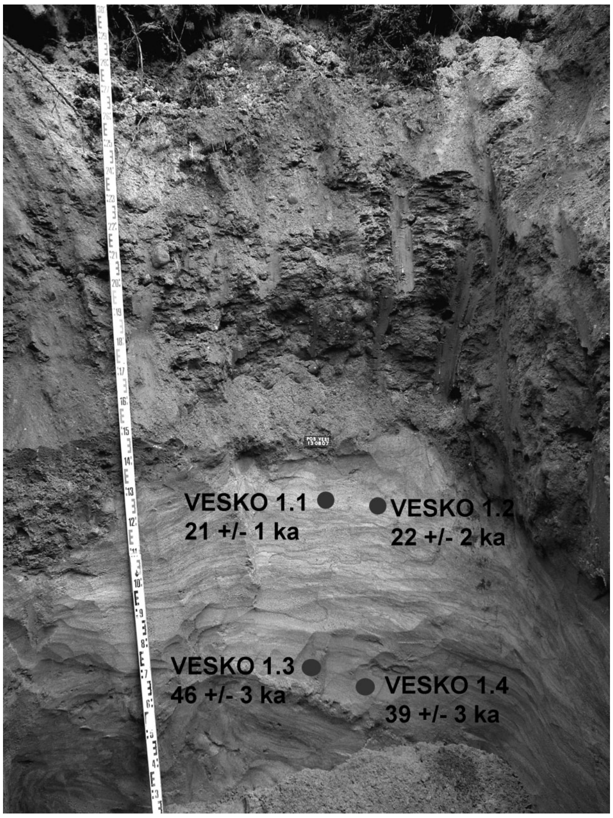

Fig. 4. Sampling site VESKO 1 with OSL dating results. Under the massive or partly laminated diamicton there is a sand deposit where horizontally laminated and cross-bedded sands grade into deformed sands at the bottom of the section. Photo by P. Sarala, 2007.

structures (Fig. 6). The contact between the sand and the diamicton is erosional. Catchment and shear structures along with load cast and injection structures occur above this contact. The lower diamicton grades to a massive, often fissility laminated, grey sandy diamicton (3.3–4.6 m). Sand lenses exist in the upper part of this

Fig. 5. Horizontally and cross-bedded sands showing a normal fault in the lower part of the VESKO 1 section. Photo by P. Sarala, 2007.

unit. The stone content of the unit is low. Stones are rounded (3–4), <10 cm in diameter and composed of granulite and granite which are the main rock types of the bedrock in the area. In the upper diamicton, according to fabric analysis, the a-axis of the stones is pointing in the down-ice direction (i.e. to the east).

The uppermost unit of the VESKO 1 section (Unit 3, 4.6–5.0 m) consists of matrix-supported and clast-supported gravel, with sand layers and lenses. The lithology of well-rounded clasts complies with the local bedrock composition. Some deformation structures occur only in the lower part of the unit.

Interpretation

The facies that were observed in the both test pits make up the general (local) stratigraphy. The subtill sands found in the VESKO 1 section represent an interstadial phase, older than the Late Weichselian glaciation. The sands in the upper part of the unit represent plane beds and have been deposited by shallow, streaming water sediments that are lightly deformed with faults and small convolution structures in the upper part of the

Fig. 6. Flame structures, shearing and deformation in the lower part of the diamicton unit. Both injection and load cast structures occur at the contact between the diamicton and sands. The ice flow direction has been from left to right. Photo by P. Sarala, 2007.

deposit. Primary beddings are still common. The lower part of the sand deposit is strongly deformed with chaotic, non-oriented convolution structures and foliation.

Both parts of the sand unit have the same origin but due to redeposition/deformation by the glacial overriding, the architecture is totally different. The sand deposit presumably represents Middle Weichselian sediments deposited in shallow or occasionally flowing water. During the Late Weichselian ice drifted over the sands and caused strong deformation of the water-saturated sediments. In places ice captured sediments as frozen plates adhering to the ice bottom. After a short transport distance the plates were deposited, preserving any original structures. Minor deformation, such as faults, folds and shear structures, came during the melting phase of the glacier, at the end of deglaciation. Thin silt/fines layer between the upper and lower sands represent a decollement surface as a mark of shear during the plate transport.

The first diamicton unit above the sands represents an initial glaciation phase that followed the sand deposition, after an ice-free interstadial period. Based on the structures and composition, this unit is identified as Till 1. During deposition the climate was cold and underlying sediments were frozen with a ductile or semiductile structure; this is indicated by deformation structures such as flames and shearing. Later, when the frozen body of sediment melted, load cast and injection structures were formed at the contact between the till and the sands.

The upper part of the diamicton is basal till typical of the area and includes some lamination, indicating subglacial formation. In the uppermost part it turns into a sandy matrix, representing the melting phase of the last glaciation (Late Weichselian). The till is comparable with the Till bed II in the stratigraphy described by Hirvas (1991).

Age of the deposits

Four OSL samples were taken from the upper part of the sand deposit of the VESKO 1 section. Two parallel samples (Fig. 4) were taken from a depth of 2.8 m (VESKO1.1 and VESKO1.2) and 2.2 m (VESKO1.3 and VESKO1.4). Water contents were 6.7% by weight for the upper samples and 4.1% by weight for the lower samples, at the time of sampling. The ability of our protocol to measure a known dose was tested by bleaching fresh aliquots of quartz at room temperature with blue light in the reader. It gives a known dose approximately

Table 2. OSL ages of the sand deposit in the VESKO 1 section

Sample ID	Risø ID	Depth, cm	Age, ka	Dose, Gy	*n*	Dose rate, Gy/ka	Water content, %
VESKO1.1	073406	280	21.0 ± 1.5	38 ± 2	17	1.81 ± 0.07	22
VESKO1.2	073407	280	22.4 ± 1.6	37 ± 2	19	1.67 ± 0.07	21
VESKO1.3	073408	220	46 ± 3	79 ± 4	24	1.73 ± 0.07	22
VESKO1.4	073409	220	39 ± 3	69 ± 4	29	1.78 ± 0.07	22

equal to the burial dose. Then the dose was measured in the usual manner. This test gave a measured/given dose ratio of 0.88 ± 0.07 ($n = 12$). This result is considered acceptable; the unusually large standard deviation on the mean (standard error) reflects the low sensitivity of these samples.

The luminescence ages of the samples are presented in Table 2. On the basis of these ages the upper part of the sand unit was deposited in the mid/late Middle Weichselian stage. The ages of the lower two samples (46 and 39 ka) represent a period when the sampling site 1 was at least periodically covered by shallow water, allowing the deposition of sand to begin. The ages in the upper part are clearly younger (21 and 22 ka). It is possible that the deposition continued until the beginning of the Late Weichselian and that the Veskoniemi area was ice-free from ca 45 to 22–25 ka. This suggestion of continuous sedimentation is supported by the observation of stratified, continuing sandy layers in the section.

This interstadial period was followed by the Late Weichselian stadial, when the two till units were deposited. Since the area was in the central part of the SIS and in the region of the most recent ice-divide zone, the Late Weichselian tills are usually thin in this area. As a result, the deformation and erosion of underlying sediments were minor. However, the surficial part of the till is commonly reworked and washed by local proglacial lakes that existed at the end of deglaciation. At the highest, these lakes had an elevation of 140–150 m a.s.l., but the water level dropped quickly to the level of the present-day Lake Inarijärvi (ca 130 m a.s.l.) as spillways were opened by the retreat of the ice margin.

DISCUSSION

Till-covered, stratified sand deposits are commonly found in the central parts of the SIS (Hirvas 1991; Kujansuu 2005). Many of these are related to Early Weichselian interstadials and to the Eemian interglacial, but some have also deposited in the glacier marginal zone during the Late Weichselian deglaciation. The Veskoniemi area is the northernmost location in Finland where till-covered sands are found and, because of the lack of organic material, it has not been possible to determine the deposition ages earlier.

Topographically, the VESKO 1 site is located in a lowland area, which has contributed to preservation of old stratified deposits during the later glaciation phase. However, the northwestern till fabric in Veskoniemi is unusual for the area. The latest ice-flow direction recorded by the cobble fabric in the till was mainly from SW to NE (Hirvas 1991). Anomalous ice-flow directions are probably due to separation of the ice margin into smaller ice-lobes with variable flow directions at the end of the last deglaciation.

The OSL ages indicate that the till-covered sand was originally deposited during the Middle Weichselian. On the basis of stratigraphic evidence it is argued that the sand unit in fact represents a period of more or less continuous deposition during the later part of the Middle Weichselian. The difference in OSL ages show that this ice-free period lasted at least 20 ka. This is the first time that the stratified sediments from the end of the Middle Weichselian have been identified and dated in the central part of the SIS.

The OSL ages can be in error because of the effect of water content. In this work we have assumed a water saturation of sediments throughout the burial period. Especially for the upper (youngest) samples some drainage could have occurred at various times. In that case the dose rate would have been higher on average, and so the ages would have been overestimated. For instance, had the average water contents of the upper samples been the same as today's values (6.7%), the ages would decrease to 18.2 ± 1.3 ka (VESKO1.1) and 19.7 ± 1.4 ka (VESKO1.2) (cf. Aitken 1985; Kolstrup 2007; Kolstrup et al. 2007). These ages seem unlikely, as discussed below. Another possible source of error in the OSL ages is incomplete bleaching. In this scenario the sediment was not sufficiently exposed to light immediately before deposition, leaving a finite OSL signal at the time of deposition, rather than the zero value assumed. In the worst case, this could lead to a significant age overestimate. However, this seems to be unlikely in our case, because the till overlying the two younger samples must be representing the Late Weichselian Maximum (LGM). This puts a firm younger limit of about 20 ka on the two ages, which are only somewhat older (see Table 2) than this limit. It is concluded that there is no obvious reason to doubt the reliability of the OSL ages of this sand unit.

In northern Finland and the surrounding areas interstadial deposits ranging in age from 45 to 25 ka are rare. Some samples have been dated from southwestern Finnish Lapland, where stratified inter-till deposits have given OSL ages ranging from 65 to 35 ka (Mäkinen 1999, 2005; Sarala 2005, Sarala et al. 2005; Sarala & Rossi 2006). Dates on mammoth remains from central and southern Finland in the age range 32–22.5 ka (Ukkonen et al. 1999) are the closest to the ages from Veskoniemi. However, there are some other observations of a Middle Weichselian interstadial deposit with an OSL date of 48 ± 16 ka from eastern Lapland (Helmens et al. 2001, 2007) and from Ostrobothnia, central Finland (Salonen et al. 2008). Other ages indicating an ice-free period of 45–25 ka are available from southern Sweden (Kjær et al. 2006; Alexanderson & Murray 2007), far from central Lapland. Age estimations of 44–26 ka for mammoth's remains in Sweden were recently presented by Ukkonen et al. (2007). Finally, the Middle Weichselian interstadial was reported in northwestern Russia as a result of the QUEEN project (Svendsen et al. 2004).

CONCLUSIONS

In this paper the sedimentology and structures of the test pit section in the Veskoniemi area, near Lake Inarijärvi in central Finnish Lapland, were described. Together with OSL dating of stratified, till-covered sands, the stratigraphy of the area was presented. The OSL ages range between 21.0 ± 1.5 and 22.4 ± 1.6 ka for laminated sands at a depth of 2.8 m, and between 39 ± 3 and 46 ± 3 ka for sands at a depth of 2.2 m. Based on the age difference between the two levels, the sand deposit is considered to represent an ice-free period at the end of the Middle Weichselian interstadial. New dating results indicate that this ice-free period may have lasted up to the beginning of the Late Weichselian, about 22–25 ka ago, in northern Finland. The sands are covered with Late Weichselian tills, which enhances the reliability of the OSL ages. The uppermost part of till cover was influenced by the wave wash and shoreline processes of proglacial lakes during the last deglaciation.

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Kesk-Weichseli interstadiaalsed setted Veskoniemi läbilõikes Põhja-Soomes

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Moreenialused paralleel- ja põimjaskihilised liivad Inari järve lähedal paiknevas Veskoniemi läbilõikes dateeriti optiliselt stimuleeritud luminestsentsmeetodil (OSL). Liivakompleksi ülemise osa vanuseks saadi $21 \pm 1{,}5$ ja $22{,}4 \pm 1{,}6$ tuhat OSL-aastat ning liiva alumiste kihtide vanuseks 39 ± 3 ja 46 ± 3 tuhat OSL-aastat. Saadud vanused kinnitavad Kesk-Weichseli interstadiaali toimumist Soome põhjaosas ja on võrreldavad varasemate tulemustega Soome Lapimaa ida- ning lõunaosast. Ühtlasi on dateeritud liivakompleks esimene Soomes teadaolev koht, kus on jälgitav kontakt Kesk- ja Hilis-Weichselis moodustunud setete vahel ning mis kinnitab jäävaba Kesk-Weichseli olemasolu kuni Hilis-Weichseli jäätumise alguseni umbes 22 000–25 000 aastat tagasi.