From past to present – Late Pleistocene, last deglaciation and modern glaciers in the centre of northern Fennoscandia

INQUA Peribaltic Working Group Meeting and Excursion 2017, 20 – 25 August 2017

Excursion guide and Abstracts

Edited by Pertti Sarala and Peter Johansson

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Geological Survey of Finland
Rovaniemi 2017

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Geological Survey of Finland, GTK
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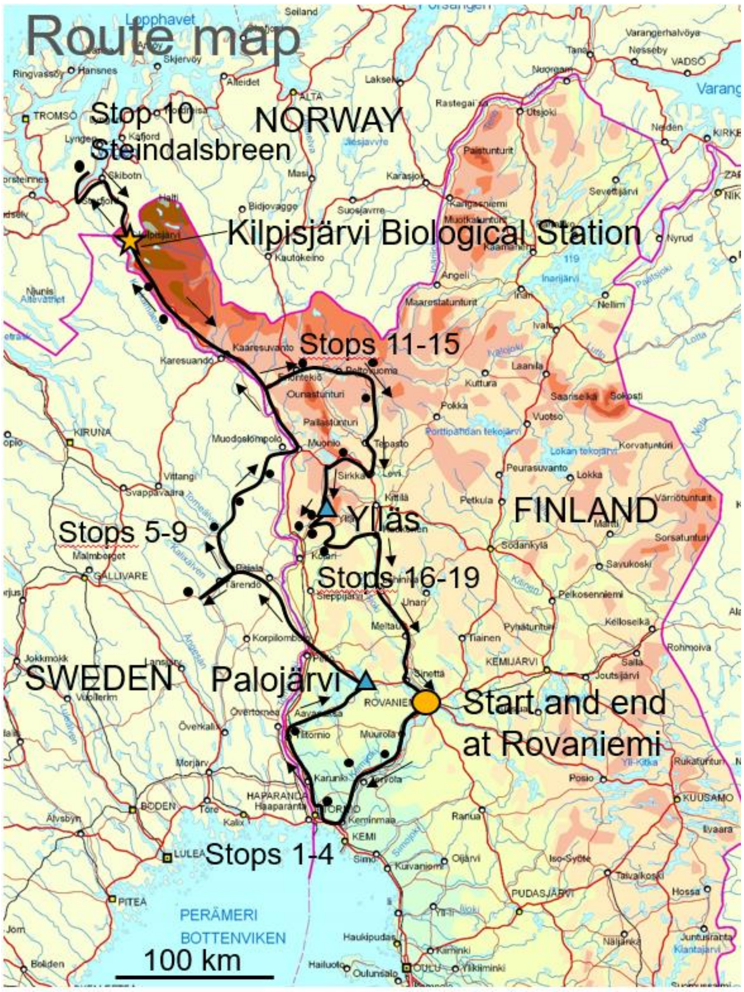

Stops

Sunday, August 20

(Start at 12 from GTK, Rovaniemi)

Stop 1.	Peuranpalo - Paleoproterozoic stromatolites	V. Perttunen
Stop 2.	Sihtuuna moraine (minor ribbed moraines)	P. Sarala (PS)
Stop 3.	Liakka (Mid-Weichselian glaciofluvial system)	PS
Stop 4.	Aavasaksa ancient shore line (Deglaciation)	P. Johansson (PJ)

Sonka (Palojärven Lomakeskus), accommodation, dinner and Get to together party

Monday, August 21

Stop 5.	Glacially lineated terrain in northern Sweden – drumlins in Kompelusvaara (Middle-Late Weichselian)	N. Putkinen (NP)
Stop 6.	Veiki moraines and Lainio Arc, Junosuando, Sweden (Middle-Late Weichselian)	NP, PJ, PS
Stop 7.	Riipiharju esker and Tärendö interstadial, Sweden (Early-Middle Weichselian)	PJ, PS

Field lunch

Stop 8.	Parkajoki – a Neogene landscape with only minor modification by successive Fennoscandian ice sheets	A. Hall, K. Ebert, C. Hättestrand

Kilpisjärvi (Biological Station and Kilpisjärven retkeilykeskus), accommodation, dinner and sauna

Tuesday, August 22
Stop 9. Steindalsbreen Glacier, Lyngen, Norway (*trekking whole day*) NP, PJ
Field Lunch
Kilpisjärvi (Biological Station and Kilpisjärven retkeilykeskus), accommodation, dinner and sauna

Wednesday, August 23
Seminar and poster session in the Biological Station; lunch and afternoon coffee
Business Meeting and Conference dinner
Kilpisjärvi (Biological Station and Kilpisjärven retkeilykeskus), accommodation

Thursday, August 24
Stop 10. Palsa mires in Iitto, Käsivarsi (*short trekking*) PJ
Stop 11. Deltaic deposit of the Könkämäeno Ice Lake PJ
Stop 12. Fell Lapland Visitor Centre in Hetta
Stop 13. Hietatievat deflation plane in Enontekiö PJ
Field Lunch
Stop 14. Pulju moraines (Ice divide zone and deglaciation) PJ, NP
Stop 15. Kulkujoki Outwash Channel (Ice Lakes and Deglaciation) PJ
Äkäslompolo, Ylläs (Hotel Kuerkievari), accommodation, dinner and sauna

Friday, August 25
Stop 16. Hannukainen open pit (Middle Weichselian) Juha Pekka Lunkka (JPL), PS
Stop 17. Rautuvaara open pit (Early an Middle Weichselian) JPL, PS
Stop 18. Pakasaivo Lake (Deglaciation and melt-water activity) PJ
Field Lunch
Stop 19. Teuravuoma (Aapa mire, *trekking*) PJ

Drive to Rovaniemi -> at 16:00-17:00 via Airport and Railway station

Accommodation

Accommodation will be arranged in 2-4 persons' rooms or apartments in Palojärvi Lomakeskus (www.palojarvenlomakeskus.fi) near Rovaniemi (first night), Kilpisjärvi Biological Station and Kilpisjärven Retkeilykeskus Camping (www.helsinki.fi/kilpis/english/index.htm, www.kilpisjarvi.info/EN/main.html) in Enontekiö, north-western Finnish Lapland (three nights) and Kuerhotel (www.kuerkievari.fi) in Ylläs (last night). The symposium residence will be at Kilpisjärvi Biological Station.

Preface

The Peribaltic Working Group is an INQUA (International Union for Quaternary Research) research group. It brings together Quaternary and ice age researchers from countries around the Baltic Sea once a year for over twenty years now. The Peribaltic WG is one of the most active working groups and its activities are subordinated to the INQUA Commission on Terrestrial Processes, Deposits and History (TERPRO). The aim of the working group is to enhance the research co-operation between the countries around the Baltic Sea and to create contacts between researchers in different countries.

The excursion in 2017 will start on Sunday 20th and end on Friday 25th August in Rovaniemi, Finland. The meeting includes a five-day-excursion to northern Finland, Sweden and Norway, with the theme of 'From past to present – Late Pleistocene, last deglaciation and modern glaciers in the centre of northern Fennoscandia'. Besides the key stratigraphical points in western Finnish Lapland, the participants will visit different kind of geological localities in northern Fennoscandia, where the glacial dynamics and the circumstances of the glacigenic deposits in the last deglaciation stage are well visible. The field trip will include both the classical localities and new, recently investigated areas as well as one day visit to the modern glacier in Steindalsbreen, Norway. Furthermore, there is one day symposium with paper and poster presentations in the Kilpisjärvi Biological Station at north-western Finnish Lapland. Researchers from eight different countries are gathered together to give lectures, discuss and share the latest research results.

At the meeting, 28 lectures are given, 17 of which are oral presentations and 11 flash speeches. In addition, 32 poster presentations are given. This publication contains the revised abstracts of the oral and poster presentations. Prof. Pertti Sarala and Dr. Peter Johansson served as the reviewers and the editors of this publication. This volume is available in the GTK's web pages as an electronic version at https://gtk.verkkokirjasto.fi/web/arena.

The symposium and excursion were organised by the Geological Survey of Finland (GTK) and INQUA Finnish National Commission with the help of the Oulu Mining School at the University of Oulu and University of Stockholm. Special thanks go to Emilia Kosonen, Adrian Hall, Juha Pekka Lunkka and Niko Putkinen. Financial support was given by the Council of Finnish Academies. The editors express our gratitude to all supporting people and organizations.

Pertti Sarala and Peter Johansson

Rovaniemi 7.8.2017

INTRODUCTION

Geological background and environments

Pertti Sarala and Peter Johansson

Finland and northern Fennoscandia are located in the area of the central part of the last Scandinavian Ice Sheet (SIS) of the Weichselian Ice Age (Fig. 1). SIS centre situated in the Scandinavian mountain range and covered Finland and the north-western Russian Plain during several times cold stages of the Quaternary period (e.g. Svendsen et al., 2004; Johansson et al., 2011). It is not known precisely how many times Finland and the northern areas were covered by ice during the Quaternary. This is because the area is situated close to the glaciation centre and the ice advances eroded and deformed most of previously deposited interglacial and glacial sediments during the cold stages (Johansson et al., 2011).

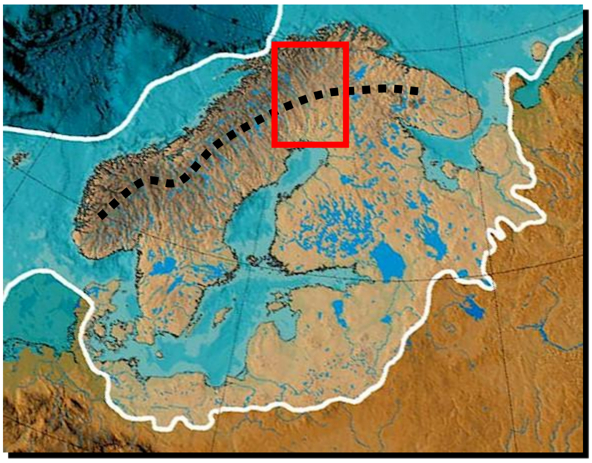

Fig. 1. Location of the INQUA Peribaltic Group Meeting and Excursion in 2017 in the centre of SIS (red box). Dashed line shows the zone of last ice divide. Modified after Svendsen et al. (2004).

The glaciogenic morphology of Finland varies from subglacial to ice-marginal depositional environments and from active, warm-based ice-lobe network in the south to cold-based, more passive ice in the ice-divide zone in the north (Johansson et al., 2011). Glacial deposits are related to several glacial phases with separate till sheets each associated with glacial striations and till fabrics with varying orientations (Hirvas, 1991; Sarala, 2005). Due to the glaciogenic nature of surficial sediments and their extensive cover (97 % of Finland's land area) (Johansson & Kujansuu, 2005), surficial geology and morphology form a foundation to nature and all human activities in northern environments.

In Finland, and particularly in northern Finland, pre-glacial, weathered bedrock has been largely preserved beneath glacial deposits (Hirvas, 1991; Nenonen, 1995; Hall et al., 2016). The ice divide zone of Central Lapland is the area where the remnants of weathered regolith from some tens of centimetres up to tens of meters thick are frequently found. The thickest weathering profiles are found in topographic depressions under till cover. Typically only the saprock has been preserved, but in places also the lower saprolite (Sarala & Ojala, 2008; Hall et al., 2016), and parts of the upper saprolite are still present displayed as kaolinite deposits. The saprock horizons are strongly fractured and therefore are zones of preferential groundwater movement with enrichment of secondary iron minerals like goethite and some clay minerals (Sarala, 2015). Weathered bedrock has also been served as a ground for glacial erosion and a source for till material which is seen in the composition of the till.

Glacigenic sediments are dominant in most of the northern areas (Johansson & Kujansuu, 2005). The Quaternary cover is thickest in depressions and river valleys, thinning out on hill slopes. Till is the most widely spread deposit type and is formed different landform associations in the areas of active ice sheets. Morphologies includes well-formed drumlin and ripped moraine fields but also flat or gently undulating basal till areas and hummocky moraine fields. Sorted sediments relating mainly to the glaciofluvial and glaciolacustric activity and sediment deposition are clearly in minor position, but can form very distinct formation areas in esker and delta valleys. Typical feature in the depression of northern areas is the occurrence of large aapa mire areas which cover underlying sediments and large/long river valleys and lake bodies. In the northernmost fell and mountain areas rocky surface and bedrock outcrops as well as boulder fields are dominant landscape creators.

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Long term geomorphology and weathering in northern Fennoscandia

Adrian Hall, Karin Ebert, Clas Hättestrand and Pertti Sarala

Four fundamental topographic elements can be recognised in northern Fennoscandia (Fig. 2): the mountain shoulder of the North Atlantic passive margin, the major escarpment that forms the major drainage divide of northern Fennoscandia, with its backslope in northern Finland and Sweden and its foreland on the Kola Peninsula.

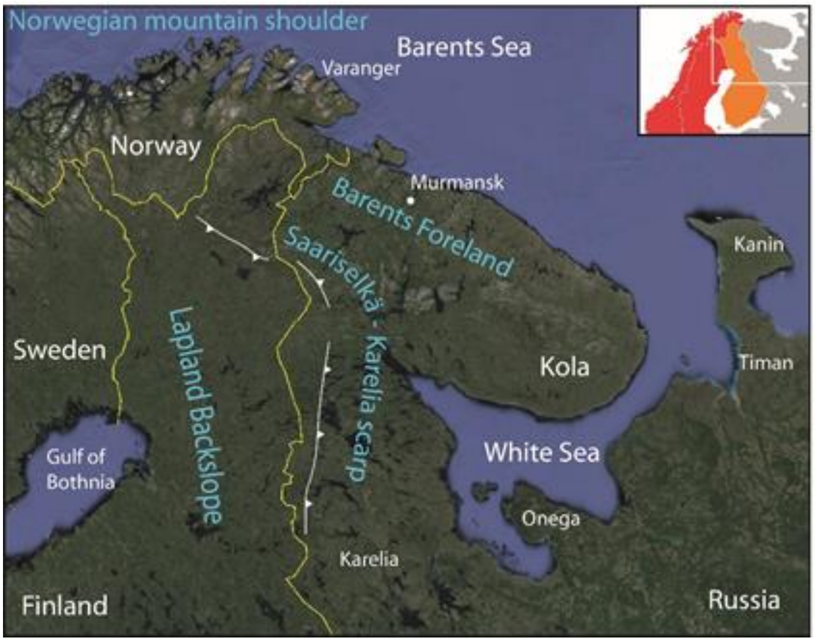

Fig. 2. Location of northern Fennoscandia.

The *Norwegian mountain shoulder* rises to elevations of >2 km in northern Norway and is developed mainly in the Caledonide nappes. Elevations fall south-eastwards towards the shield plains in northern Sweden. The mountains are deeply dissected but retain fragments of stepped planation surfaces (Lidmar-Bergström et al., 2007).

The *Saariselkä-Karelia scarp* (SKS) reaches 800 m a.s.l. The mainly northward- and eastward-facing SKS is located ~200 km inland of the Barents and White Sea coastlines. The SKS is developed in Precambrian basement and connects in the west via the Saariselkä and other granulite massifs to the northern edge of the Norwegian passive margin in Varanger. In Karelia, the scarp crest drops in elevation southwards and the cuesta form become less distinct and is replaced by the elongate dome of the Maanselkä.

The *Lapland backslope* extends for 300 km from Saariselkä to the Gulf of Bothnia but shortens to <200 km where the scarp turns to the south. The backslope is developed in basement and subsumes several large topographic basins that lie between prominent ridges and hill masses developed on granitic, quarzitic and basaltic gneisses and granulites (Hall et al., 2015).

The *Barents foreland* includes hill masses in Kola that rise in places to elevations equal to or greater than the scarp crest and includes a prominent ridge line that extends from the Saariselkä granulite massif to include the Monchegorsk ultrabasic hills and the Devonian Khibiny and Lovozero alkaline massifs. The foreland also includes major topographic basins, such as the Inari basin, separated by lower hill masses. The eastern Kola Peninsula is formed in Archaean gneisses and shows mainly low relief dominated by an extensive planation surface at 150-200 m a.s.l.

These topographic elements are products of episodic Cenozoic uplift and erosion as indicated by analysis of the tectonics of the continental margin (Redfield and Osmundsen, 2013), cooling histories derived from Apatite Fission Track Analysis (Hendriks and Andriessen, 2002; Veselovskiy et al.; Japsen et al., 2016), the sedimentary record of the Norwegian and Barents Sea shelves (Faleide et al., 1993; Musatov and Pogrebitskij, 2000; Petrov et al., 2008; Eidvin et al., 2014) and uplifted planation surfaces (Fjellanger and Sørbel, 2007; Lidmar-Bergström et al., 2007; Lidmar-Bergström and Olvmo, 2015). Eocene and younger marine diatoms found in tills in northern Finland have been interpreted previously as derived from former Palaeogene to Neogene marine sediments in northern Finland (Hirvas and Tynni, 1976; Hirvas, 1991). No *in situ* sedimentary material has yet been found however and an alternative origin has been proposed with wind transport from eroding sediments of this age exposed on the floor of the Barents Sea during the Early Pleistocene (Hall and Ebert, 2013).

Superimposed on these major topographic elements is a series of relief generations, each an extensive assemblage of landforms that developed before and during the Cenozoic in response to prevailing tectonic and climatic regimes and erosional processes (Büdel, 1982). The relief generations exist today in the present landscape of northern Fennoscandia due largely to low Phanerozoic erosion rates (Hall, 2015), including the generally low impact of Pleistocene ice sheet erosion (Ebert et al., 2012) The oldest relief generation is represented by Early Palaeozoic peneplains exhumed from beneath Ediacaran and Cambrian sedimentary cover rocks (Lidmar-Bergström, 1996; Grazhdankin, 2003). Deep erosion occurred during the Late Devonian in Kola but was focussed on the uplifted terrain around the main magmatic centres of Khibiny and Lovozero and decreased into northern Finland (Hall, 2015). By the end of the Triassic relief was low and remained so until the latest Mesozoic (Lidmar-Bergström et al., 2007) but long term cratonic erosion rates of 1-10 m/Myr make it unlikely that any Mesozoic relief elements remain today unless such elements have been exhumed from beneath cover rocks. Younger relief generations developed during regional planation phases in the Palaeogene and Neogene (Ebert et al., 2011; Lidmar-Bergström and Olvmo, 2015). The youngest relief generation is represented by the bedforms of the Fennoscandian ice sheets.

Uplift of the Norwegian passive margin commenced in the Late Cretaceous and continued at intervals through the Cenozoic, with an important late uplift phase at ~4 Ma in the Barents Sea (Knies et al., 2014). Humid sub-tropical climates prevailed through the Cretaceous and Palaeogene in northern Fennoscandia. At the Palaeogene–Neogene transition (~23 Ma), cool to warm temperate conditions were established across Fennoscandia and around the Arctic. Cooling at ~10Ma led to the first appearance of sea ice and the establishment of boreal to sub-arctic biomes around the Arctic Ocean (Lavrushin and Alekseev, 2005). By the Early Pliocene (4–5Ma), MATs had fallen to −1°C in the high Arctic (Csank et al., 2011). The onset of glaciation on the Fennoscandian Shield occurred in the Late Pliocene (~2.8Ma) (Flesche Kleiven et al., 2002). Modern MATs are ~1°C in N Finland.

Relief generations on the Norwegian mountain shoulder are represented mainly by uplifted and tilted residual hill masses and planation surfaces and former drainage patterns (Fjellanger and Sørbel, 2007; Ebert et al., 2011; Lidmar-Bergström and Olvmo, 2015). On the Lapland backslope in Finland, planation surfaces are represented mainly on the floors of extensive topographic basins separated by large hill masses. In northern Sweden (Fig. 3) extensive inselberg plains are developed on a stepped sequence of planation surfaces. On both the backslope and foreland and within parts of the Saariselkä-Karelia Scarp zone deep weathering mantles are preserved (Kiselev, 1979; Pekkala and Yevzerov, 1990; Islam et al., 2002). Two main types of weathering are recognised: clay-rich kaolinitic saprolite of probably Miocene age (Gilg et al., 2013) or older and sand-rich (grus) saprolite, with vermiculite-dominated clay mineral assemblages of likely Pliocene to Early Pleistocene age (Hall et al., 2015). Weathering mantles extend to depths of many tens of metres in boreholes. In northern Finland the extensive preservation of deep weathering allows the main elements of the Neogene landscape to be reconstructed (Fig. 4), along with the original form of granite inselbergs (Fig. 5).

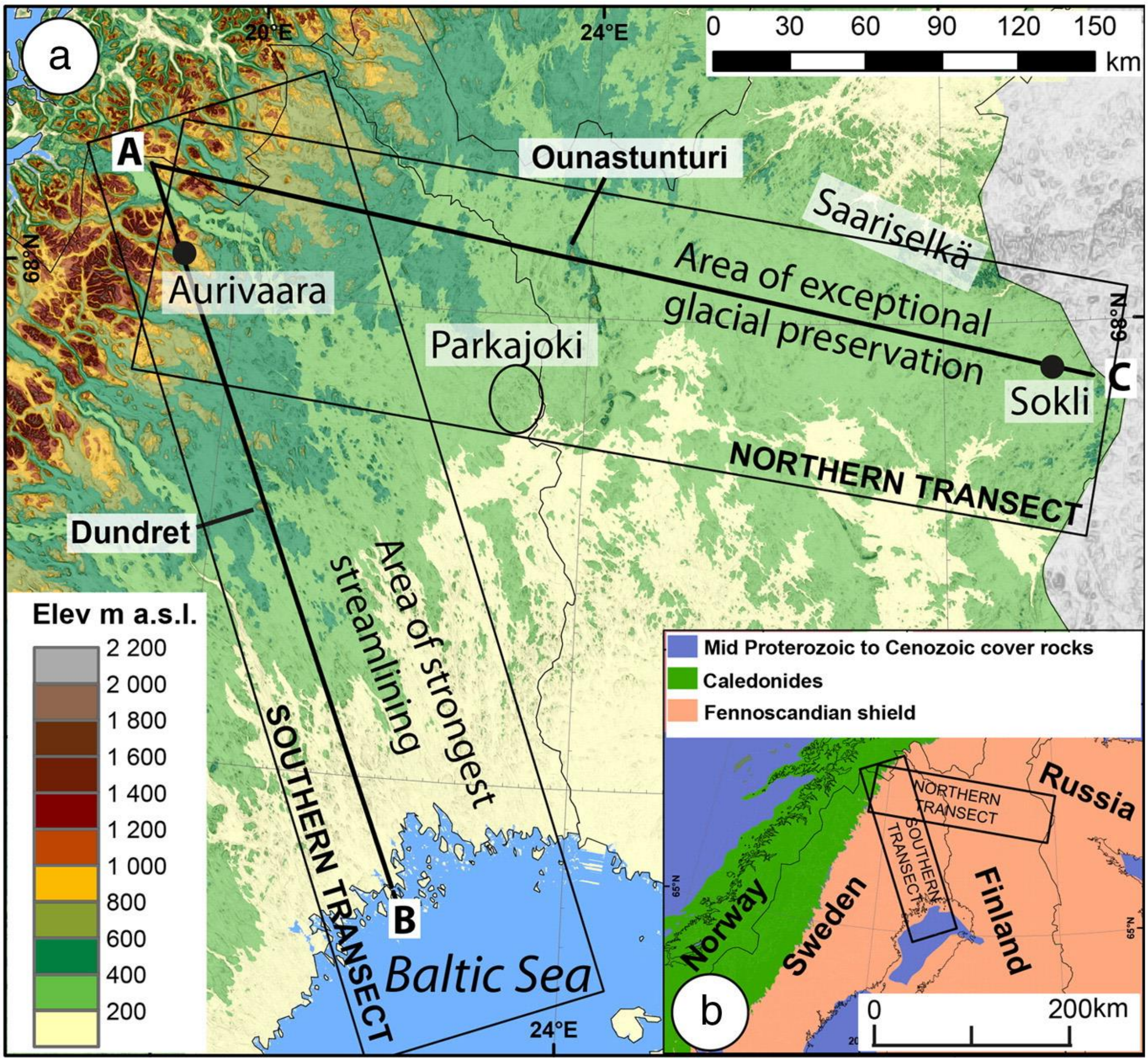

Fig. 3. Elevations (a) and geological context (b) of glacial erosion transect areas in northern Sweden (Ebert et al., 2015).

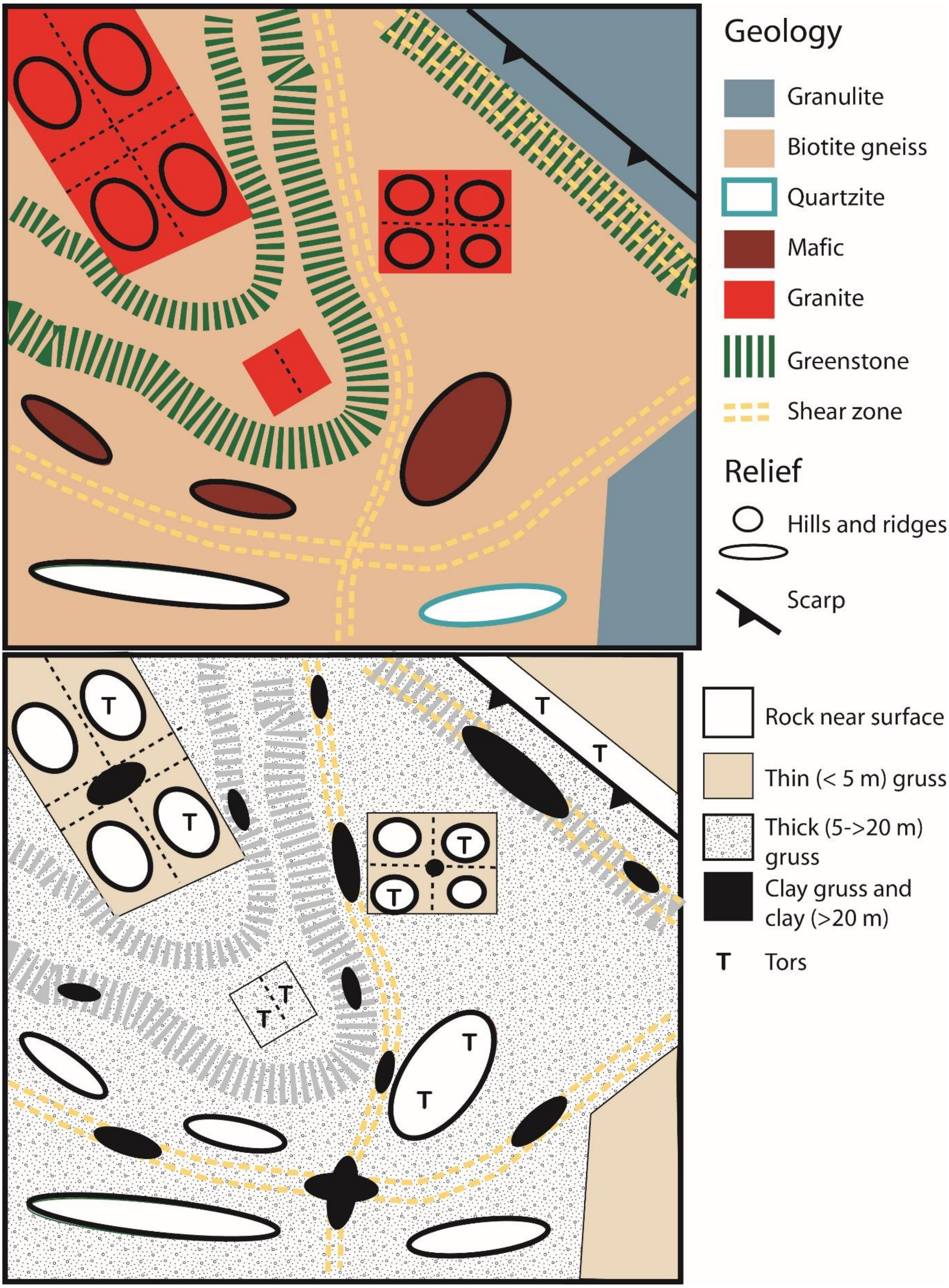

Fig. 4. (A). Schematic model of the weathered Late Neogene landscape in northern Finland; (B). Schematic model of Late Neogene weathering profiles in northern Finland.

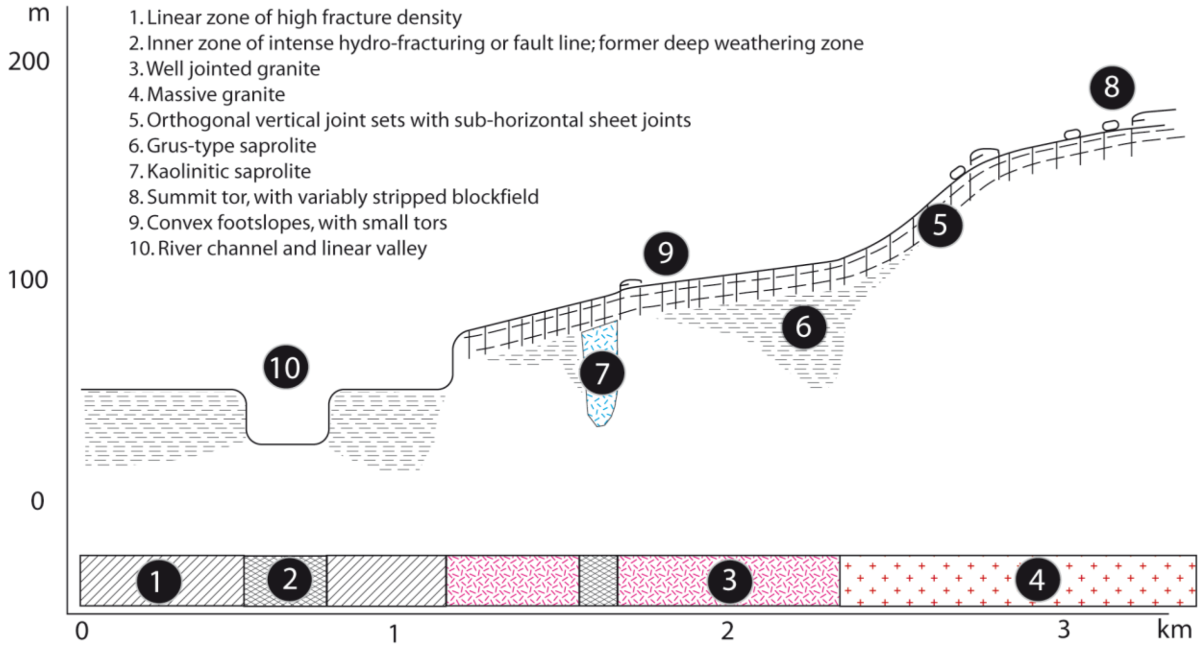

Fig. 5. Model of the key features of granite inselbergs in northern Sweden.

The impact of glacial erosion on the Lapland backslope has been variable. In the ice divide zone that stretches from Kiruna eastwards to the Russian border (Fig. 6a), there is extensive preservation of preglacial landforms and weathering (Fig. 7). In contrast in the corridor that extends from Kiruna south towards the Gulf of Bothnia (Fig. 6a) bedrock hills are streamlined, drainage patterns disrupted, valleys have been excavated and deepened along fracture zones and virtually all saprolite has been removed (Fig. 7). These contrasts indicate that the Fennoscandian ice sheet behaved differently in these areas. In the ice divide zone, ice was dominantly non-erosive because successive ice sheets remained cold-based for long periods and ice flow was divergent (Fig. 6b). In the Kiruna corridor, warm-based ice, weakly convergent in its flow (Fig. 6b) operated repeatedly during the Pleistocene, allowing stripping of regolith and erosion of hard gneissic bedrock. Semi-quantitative estimates of glacial erosion on inselbergs, on surrounding palaeosurfaces and in valleys provide

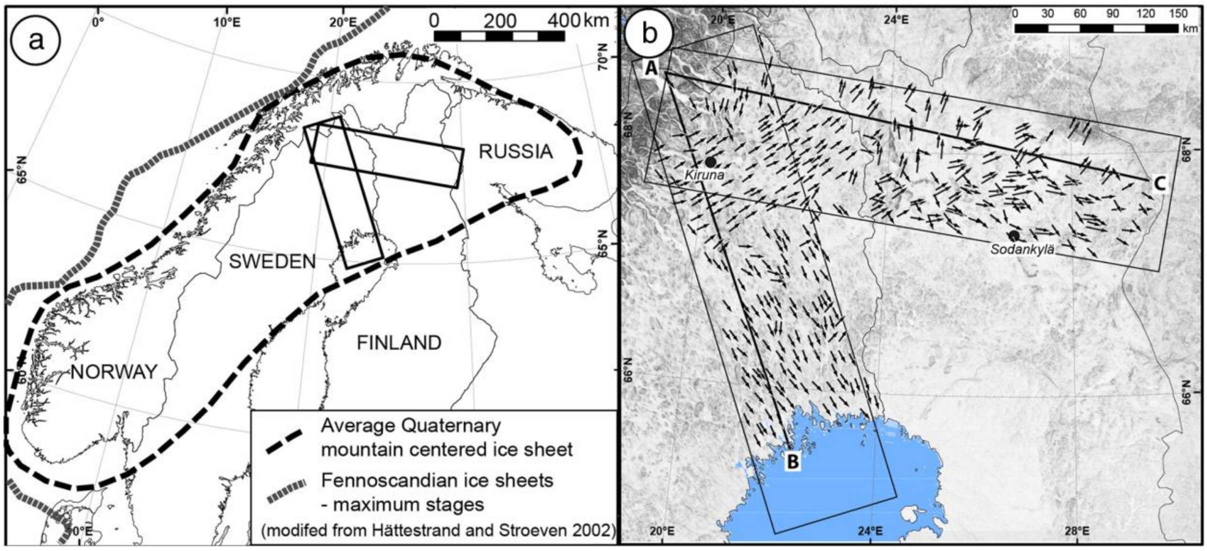

Fig. 6. (a) Ice sheet types and ice flow patterns in northern Fennoscandia (Ebert et al., 2015). Both transects were covered both by the average Quaternary mountain centred ice sheets and by Fennoscandian ice sheets. (b) Main ice flow directions of the Weichselian (Hirvas, 1991; Hättestrand et al., 2004).

mean totals for glacial erosion of 8 ± 8 m in the ice divide zone and 27 ± 11 m in the Kiruna corridor. These estimates support previous views that glacial erosion depths and rates on cratons can be low and that pre-glacial landforms can survive long periods of glaciation, including episodes of wet-based flow (Hall et al., 2013).

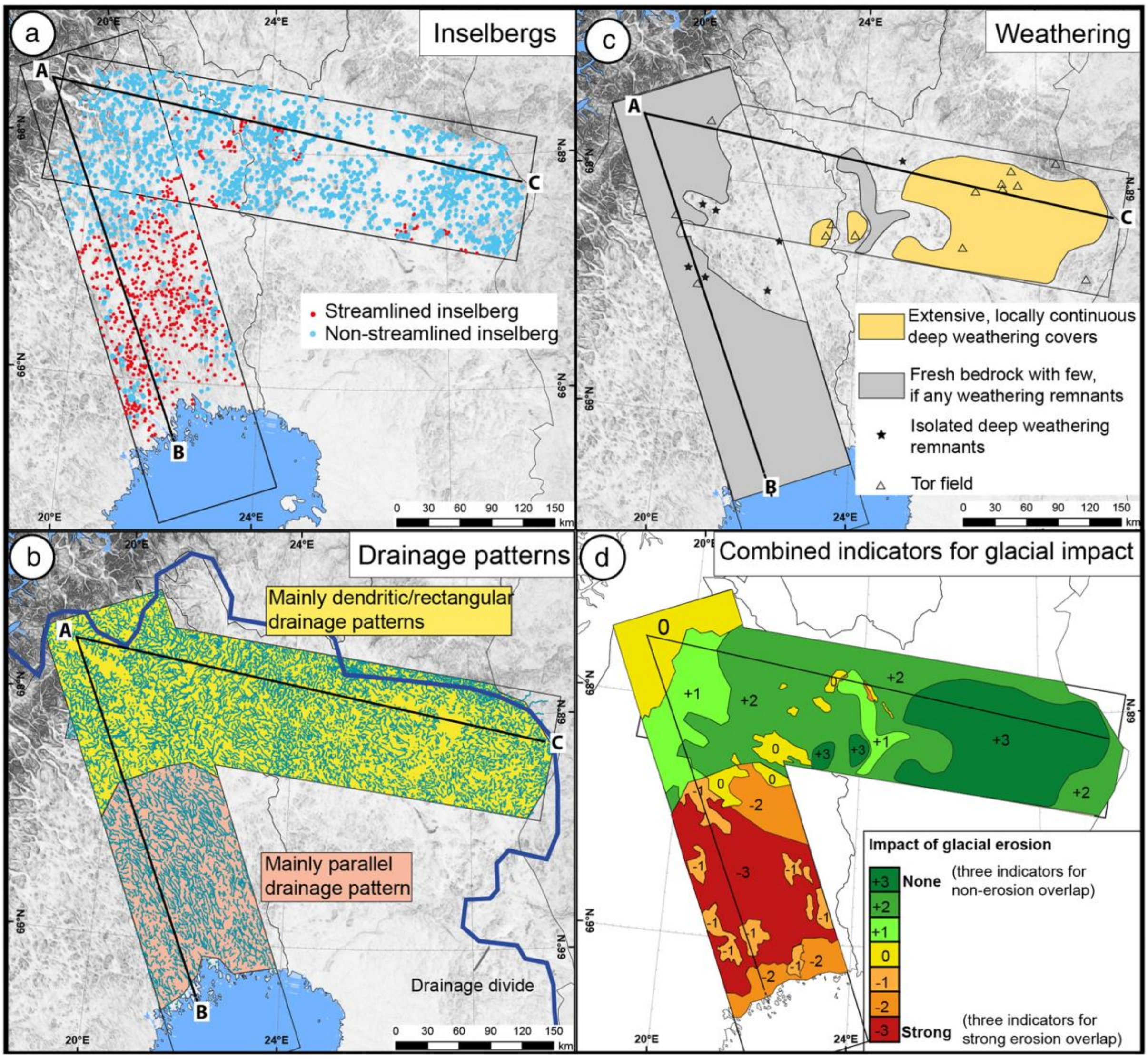

Fig. 7. Indicators for ice sheet erosional impact. (a) Streamlined (strong impact) and non-streamlined (low impact) inselbergs. (b) Parallel (strong impact) and dendritic/rectangular (low impact) drainage patterns. (c) Absence (strong impact) and presence (low impact) of weathering remnants. (d) Combination of all indicators - the higher the value, the lower the ice sheet erosional impact.

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Late Pleistocene glacial history and stratigraphy

Pertti Sarala, Peter Johansson and Juha Pekka Lunkka

Most of the Quartenary sediments are glacigenic in origin and were deposited during the last cold stage (Weichselian) directly on the fresh or pre-glacially weathered Pre-Cambrian bedrock. Except for some scattered remnants of the Saalian esker ridges (Kujansuu & Eriksson, 1995) in the ice-divide zone of northern Finland (Finnish Lapland) and in the major river valleys in the Pohjanmaa area, in western Finland, there are no distinct geomorphological landforms related to pre-Weichselian glaciations. However, there are a number of sites where Middle and Late Pleistocene organic and glacial sediments have been preserved, particularly in northern Finland and in Ostrobothnia, western Finland (cf. Hirvas, 1991; Nenonen, 1995). These sites provide the basis for the general Quaternary stratigraphy of Finland and at the same time of northern Fennoscandia.

According to the Finnish till stratigraphy, there are six, stratigraphically-significant till beds in Finnish Lapland. The key site for the till stratigraphy is the Rautuvaara area in western Finnish Lapland (Hirvas et al., 1977; Hirvas, 1991). The three uppermost till beds are thought to represent Weichselian-age tills (Till Beds I – III), two of these (Till Bed I and II) are thought to have been deposited during the Late Weichselian. The so-called Till Bed IV was laid down during the Saalian glaciation. The two lowermost till beds (Till Beds V-VI) that occur beneath the Holsteinian peat horizon may represent Elsterian or pre-Elsterian tills (cf. Hirvas and Nenonen, 1987; Hirvas, 1991). However, recent revision of some keysite targets in northern Finland has led to the revision of the chronology and ages of key sections (Helmens et al., 2007; Helmens & Engels, 2010; Salonen et al. 2014; Howett et al., 2015; Lunkka et al., 2015). Based on new OSL datings of inter-till stratified sediment layers from different keysites, it is most evident that the till beds even in the thickest sequences have been formed during Weichselian ice age and only in places, the deepest i.e. oldest can be from Saalian glaciation (Lunkka et al., 2015).

Southern Finnish Lapland

Based on stratigraphical and morphological evidence, two glaciation phases of the Weichselian age have been observed in southern Finnish Lapland (Sarala, 2005). The bluish grey Kemijoki Till is representing the Middle Weichselian glacial advance phase and the greyish or brownish grey Tervola Till with three till units represents the Late Weichselian glaciation phase. The glacial morphology is dominantly composed of the assemblage of drumlins, flutings and ribbed moraines. These forms exist as fields in the area and indicate active ice-lobe formation during the late stage of deglaciation. Active-ice landforms dominate in the area of Kuusamo and Oulu ice-lobes. The Ranua interlobate area in between those ice-lobes and with the north-northwest to south-southeast oriented drumlin field is a relic of the older glacial phase, which is correlative with the Middle Weichselian glaciation. Older drumlin field has preserved under cold-based subglacial conditions under central part of the Late Weichselian glaciation. Recent (OSL) dating results prove that the Middle Weichselian glaciation was the first one to cover the southern Finnish Lapland after the Eemian interglacial.

The development of active-ice landforms from east to west in the area of Kuusamo ice-lobe indicates fast-flowing ice streams during deglaciation. The subglacial conditions at the outer margin of glacier were warm and wet during the formation of large Kuusamo drumlin field in the east. In the central and western parts, closer the glacier centre, the ribbed moraines with the fields of Ranua, Tervola and Kemijärvi are common. The ribbed moraine formation is relating with the retreating boundary of cold- and warm-based glacier, in an internal part of the glacier margin during deglaciation. An existence of those landforms indicates cold-based subglacial conditions still prevailed in an internal part of the ice-lobe, while the marginal parts were warm-based. The most probable starting point for the ice-lobe separation and the development of fast-flowing ice streams during deglaciation was rapid climate warming at the end of the cold, Younger Dryas period, about 11,600-11,800 years ago.

Middle-Weichselian interstadials in Lapland

Re-evaluatio of the several keysites in northern Finland have increased knowledge of previous climate conditions. Based on sedimentological, paleontological and geochronological methods new information about dynamics of stadial-interstadial conditions and the environments have been produced. In addition to the Early Weichselian interstadials (115-70 ka, MIS 5b and 5d), there has been noticed several, relatively short, warm stages during the Middle Weichselian (MIS3) (Johansson et al., 2011; Salonen et al., 2014; Lunkka et al., 2015). Recently, several observation of the Middle Weichselian interstadial deposits have been made in Finland having the particular interest on the stratified inter-till layers (Nenonen, 1995; Mäkinen, 2005; Sarala, 2005; Sarala et al., 2005; Helmens et al., 2000, 2007a, 2007b; Auri et al., 2008; Salonen et al., 2008; Helmens and Engels, 2010; Sarala et al., 2010, 2016; Sarala and Eskola, 2011; Salonen et al., 2014; Lunkka et al., 2015).

For example, the recent study in the Kaarreoja river in northern Finland revealed inter-till gyttja − silt deposit with organic material, wood peaces and intervening, well-preserved peat layer (Sarala et al., 2016). The peat deposit is composed of Betula-Salix dominant pollens and macrofossils, and includes pieces of well-preserved birch and willow wood particles. Age of the peat is c. 36,000 years BP (14C, cal) for the bulk sample and >45,000 BP (AMS) for the wood pieces. OSL age of the sand under the organic sediment deposit is 52 ± 12 ka. The interstadial deposit in the Kaarreoja sequence is interpreted to represent almost whole deposition and vegetation history of MIS3. Furthermore, it proves present-day like, stabile ice-free period to be existed a long time during the MIS3, before the Late Weichselian cold stage. This interpretation strengthen the observations made from the large areas in northern Finland as well as northern Sweden.

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Deglaciation and proglacial lake systems in northern Finland

Peter Johansson

The deglaciation phase and the final disappearance of the Late-Weichselian ice sheet were examined in Finnish Lapland by studying different glacial processes and their resulting landforms. These are subglacial meltwater action, glaciofluvial hydrography and ice flow directions, proglacial, marginal and lateral meltwater action and the development and types of the ice lakes. Tanner (1915) was the first to study deglaciation in northern Finland. The first model of the retreating glacial margin was created by him and is still valid in a broad scale. Mikkola (1932), Penttilä (1963), Kujansuu (1967), Aario & Forsström (1978), Johansson (1995), Lunkka et al. (2004), Johansson et al. (2011) and many others have by their research added more details to the picture of the deglaciation. Compared with southern and central Finland, the advantage of studying deglaciation in northern Finland lies in the fact that most of the retreating ice sheet melted in a supra-aquatic (terrestrial) environment, resulting in various kinds of erosional and depositional landforms. Subaquatic conditions existed only in the southwestern part of Lapland because that area was covered by the waters of the Ancylus Lake phase. Some small subaquatic areas exist in the northern part, where the Arctic Ocean for a short time penetrated into the river valleys of Teno and Lutto (Saarnisto, 1973) and into the Inari Lake basin (Kujansuu et al., 1998).

The youngest ice flow direction has been used to delineate the retreat of the ice sheet, because in many areas this retreat was in the opposite direction to that of the last ice flow. The network of late Weichselian subglacial glaciofluvial systems (esker chains) shows the direction of the retreating ice sheet even more accurately. These systems contain depositional landforms, i.e. steep-sided and sharp-crested esker ridges with zones of glaciofluvial erosion between them. Esker chains are often associated with sandy deltaic formations, formed at the ice margin, indicating the level of the sea or a local ice lake. The radial pattern of the Late Weichselian subglacial drainage systems reflects the direction of ice-marginal retreat towards the ice divide zone in Central Lapland. In the northernmost part of Lapland, the ice margin retreated towards the south – south-west and in the southern part of Lapland to the north-west.

Younger Dryas ice-marginal landforms

The Younger Dryas ice-marginal landforms are situated in North Norway only 20 kilometres from the northernmost part of Finnish Lapland (Sollid et al., 1973; Andersen et al., 1995). At that time the ice-divide zone i.e. the centre of the ice dome located in Central Lapland, and the active ice flow was in North Lapland towards the north or north-east and in South Lapland towards the south-east or east. Extensive drumlin fields in Inari and in Kuusamo, were formed. In Inari the drumlin field extends as far as the Younger Dryas ice-marginal landforms in Norway and Pechenga area, NW Russia (Marthinussen, 1962; Yevzerov and Kolka, 1993; Semenova, 2005). In the Kuusamo drumlin field about 4,000 separate drumlins have been counted, with their shapes ranging from streamlined and elongated forms to drop-like and even round-ridged forms. It extends to the Younger Dryas ice-marginal landforms of Russian Karelia (Putkinen and Lunkka, 2008). Hummocky moraines also occur as fields, including one in the Kemijärvi - Vikajärvi area, which comprises moraine hillocks and short ridges of various shapes. The most typical landform of the area is ribbed moraine with short ridges at right angles to the last direction of glacier flow (Sarala, 2005).

The ice margin started to retreat from the Younger Dryas End Moraines about 11,600 years ago (Saarnisto, 2000; Saarnisto and Saarinen, 2001). At the same time the highest felltops in northwestern and northern Lapland appeared from the ice as nunataks. In the northern part of Lapland, the ice margin retreated towards south-southwest and in the southern part of Lapland to northwest. The surroundings of the Lake Inari were deglaciated approximately 10 800 years ago (Kujansuu et al., 1998). The ice margin reached the Lemmenjoki – Saariselkä fell range about 10,600 years ago. In the mountainous area the deglaciation was first thinning of the ice. During the nunatak phase many of the overflow channels in the Saariselkä area were also formed as a result of meltwater erosion. As the ice sheet became thinner and its surface sank, the nunataks expanded into larger ice-free areas. The ice flow stagnated behind the nunataks, and fractures and crevasses were consequently formed at the margin of the ice sheet. The meltwaters penetrated under the ice margin, eroded subglacial chutes and deposited engorged eskers (Johansson, 1994).

Ice lakes and successive meltwater channel systems

The meltwater action at the boundary of the ice sheet and an exposed fell slope next to it produced series of shallow meltwater channels, i.e. lateral drainage channels. The channels generally occur in groups, running side by side gently sloping down the fell side. These channels are of great importance in the study of deglaciation in minor scale, since they help to construct the position of the ice margin in a great detail, which gives a picture of the inclination of the surface of the ice sheet. Additionally they indicate that the ice margin was unbroken. In favourable places on the fell slopes channel systems comprising several tens of channels were formed in which the distance between the individual channels remains nearly constant (Fig. 1). In these places the channels may have formed as a consequence of the annual thinning of the ice sheet and they can be used to document the rate of melting (Penttilä, 1963; Kujansuu, 1967; Johansson, 1988, 1995). Their distribution indicates that the gradient of the ice surface was between 1.5 and 3:100 m and the ice margin thinned approximately 1.6 m per year. In Saariselkä area the rate of recession of the ice margin varied 130 – 170 m per year, approximately 140 m per year (Johansson, 1995). In western Lapland the deglaciation rate was faster. Lateral drainage channels on the fellslopes in the Ylläs area show that the annual thinning was about 2.5 – 3 m and the ice retreat about 170 m per year (Abrahamsson, 1974; Kujansuu, 1967). The melting accelerated due to the decreasing mass of the continental ice sheet as the deglaciation proceeded and to warming of the climate, which also contributed to the acceleration. As the retreat of the ice margin continued, the southern edge of the Lemmenjoki - Saariselkä fell range became exposed. The ice margin was pressing against the fell range. It became undulated with tens of kilometres long ice lobes penetrating into the valleys of Lemmenjoki and Suomujoki. At the end of the ice-lobe stage, the lobes turned passive and melted down after they had lost contact with the active ice sheet.

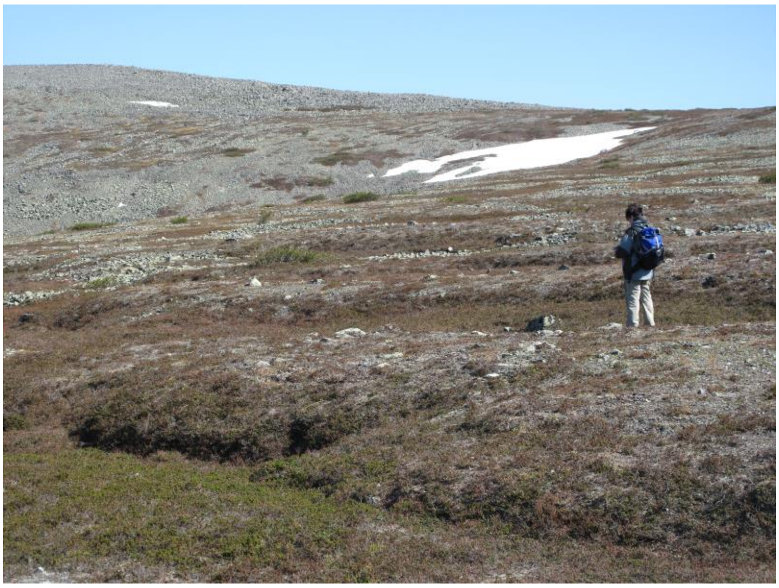

Fig. 1. At high elevations the lateral channels are often short and shallow, less than 0.5 m. Some have a gouge like form, whereas others may simply have a cross-section that resembles a step or a terrace cut into the slope. Photo by P. Johansson.

While the ice sheet was still leaning against the southern slope of the Lemmenjoki-Saariselkä fell range, several ice lakes started to form in depressions between the fell tops (Tanner, 1915; Penttilä, 1963; Johansson, 1995). They were short-lived and small, but since they occupied valleys between fells they became deep, and contained a considerable volume of water. On even terrains large and shallow ice lakes were formed. The largest of these ice lakes were located in Salla, eastern Lapland, in the Muoniojoki and Ounasjoki river valleys, western Lapland, and in the Inari Lake basin, northern Lapland. They covered thousands of square kilometres. A requirement for the formation of an ice lake was that the ice margin retreated downslope along the main river valleys. The glacier had to be active and solid at its edges to be able to dam any meltwater. The different lake phases are indicated by the presence of raised shorelines and outlet channels, coarse outwash sediments and fine-grained glaciolacustrine sediments. The ice lakes drained from one river valley to another across the water divides creating erosional landforms, i.e. narrow and deep overflow channels and broad and shallow marginal and extramarginal channels. Successive marginal and extramarginal meltwater systems formed along the retreating ice front and some of them can be followed hundreds of kilometres from the higher terrain in northwestern Lapland to the lower levels in eastern Lapland (Kujansuu, 1967; Johansson, 1995). Initially the meltwater flowed northwards, across the main water divide towards the Arctic Ocean. As the ice sheet became smaller and retreated southwestwards the meltwater flow switched eastwards towards the White Sea and finally southeastwards along the retreating ice margin towards the Baltic Basin. The extensive marginal and extramarginal channel systems indicate that the ice sheet remained dynamically active.

In eastern Lapland the deglaciation was accompanied by the damming of the largest ice lake of northern Finland, the Salla Ice Lake, in the area between the present water divide and the ice margin (Johansson, 1995). The water from the Salla Ice Lake flowed east through the Kutsajoki river to the White Sea. When the second outlet channel, which led to Korouoma, had opened under the margin of the retreating glacier about 10,500 years ago, the surface of the Salla Ice Lake sank by more than 50 m in a short time. Extensive areas near the ice margin turned into dry land. This may have had a significant effect on the stagnation of the ice margins, the ice retreat and on the formation of the areas of hummocky moraines and ribbed moraines in the vicinity of Rovaniemi and Kemijärvi (Kurimo, 1978; Kujansuu, 1992; Sarala et al., 2009). In southern Lapland, the division of the ice sheet into two ice lobes influenced the deglaciation. It was in between these two ice lobes that the interlobate system of Pudasjärvi – Taivalkoski – Hossa was deposited (Aario and Forsström, 1978; Sutinen, 1992).

Disappearance of the glacier in the ice-divide area

When the margin of the retreating glacier had reached the ice-divide area in northern central Lapland about 10,300 years ago, it stagnated in several places at Posoaapa and Koitelainen areas and melted in situ, partially as separate patches of dead ice. Landforms typical of subglacial and marginal meltwater processes such as eskers and various channels are almost entirely missing. This shows that the marginal parts of the glaciers were broken and not capable of controlling the meltwater systems. The shallow ice lakes were obviously largely filled with ice blocks. In western part of the ice-divide area the ice margin was sufficiently intact to dam ice lakes. It retreated mainly to the west and at the final stage to the southwest. Some erosional remnant fells, such as Kumputunturi (Johansson et al., 1996), Aakenustunturi and the Pallas–Ounastunturi controlled the ice flow locally and divided the ice margin into separate lobes. West of Pallas- Ounastunturi the margin retreated to the south-southwest and on the east side to the south or south-southeast (Kujansuu, 1967).

Collecting all the palaeohydrographic information, for example by mapping the ice dammed lakes and the extra-marginal channels between them, it is possible to reconstruct a reliable picture of successive stages of the ice retreat in the supra-aquatic areas (Fig. 2) (Johansson, 2007). Glacial processes and morphology give a reliable picture of the ice recession but offer no basis for dating.

The deglaciation of northern Finland lasted about 1,600 years and its beginning (11,600 years ago) can with certainty be connected with the end of the Younger Dryas chron. The last remains of the glacier disappeared from Kolari, western Finnish Lapland as the ice margin retreated to northern Sweden, which according to estimation occurred about 10,000 years ago (Saarnisto, 2000; Lundqvist, 2004). Radiocarbon dating of the bottom layers of peat deposits has been used to get an approximate age of the earliest vegetation, but these ages are inaccurate, mainly too old, to represent the final stage of deglaciation (Ignatius et al., 1980). After the retreat of the glacier the southern Lapland was to a great extent covered by the Ancylus Lake. Due to subsequent land uplift, the highest shore features formed during this phase now lie at altitudes of 220 metres above present sea level (Saarnisto, 1981).

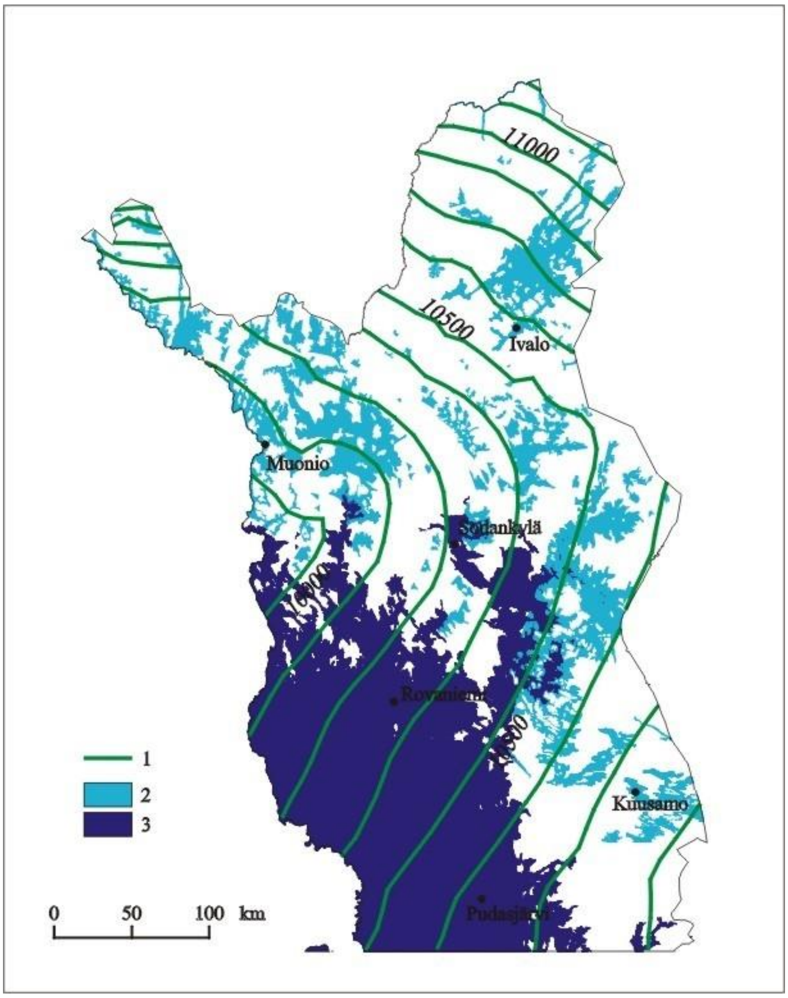

Fig. 2. Recession of the margin of the glacier in northern Finland towards the end of the last deglaciation.1 = position of the ice margin, 2 = areas covered by ice-dammed lakes and 3 = Ancylus Lake. After Johansson (2007).

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EXCURSION STOPS

STOP 1: Peuranpalo - Paleoproterozoic stromatolites

Vesa Perttunen

The bedrock of the Peräpohja Schist Belt consists of alternating metasedimentary and mostly mafic metavolcanic formations of Paleoproterozoic age (Fig. 1). Quartzite is the most common sedimentary rock but dolomite formations are common, too. The volcanites include lavas as well as tuffitic rocks. The metamorphic grade of the rocks is low and the primary features are often exceptionally well preserved. The lavas are mostly amygdaloidal tholeiitic basalts. The tuffites are graded bedded. The quartzites contain ripple mark and mud crack layers. The dolomite outcrops in the Peräpohja area exhibit stromatolite structures (Fig. 2).

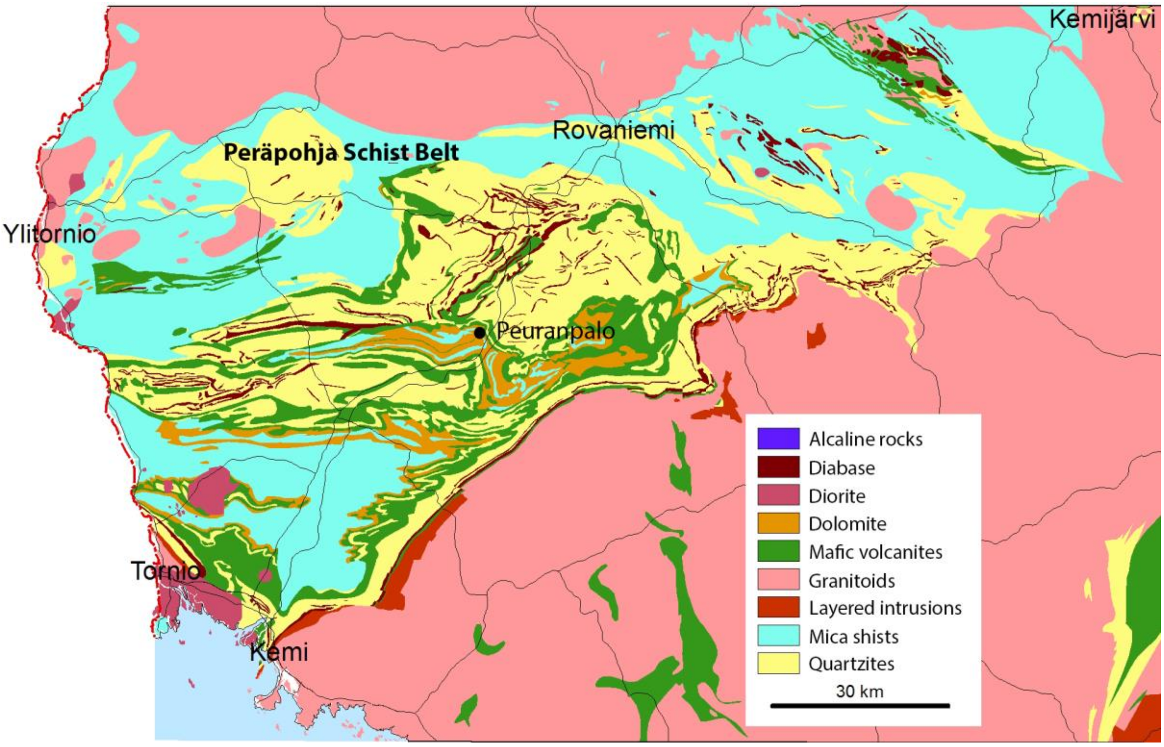

Fig. 1. Lithology of the Peräpohja Schist Belt. Bedrock map © GTK.

Stromatolites are organosedimentary structures formed in shallow water by the trapping, binding and cementation of sedimentary grains by microorganisms, especially cyanobacteria. Stromatolites are the earliest fossil evidence of life on Earth. Cyanobacteria are the predominant form of life on Earth for more than 2 billion years, and were likely responsible for the creation of Earth's atmospheric oxygen. Stromatolites began to decline in abundance and diversity about 700 million years ago. Modern stromatolites are few, mostly found in hypersaline lakes and marine lagoons.

The stromatolite-bearing dolomites of the Peräpohja area exhibit a pronounced positive δ^{13} C anomaly, interpreted as being related to global increase of atmospheric oxygen c. 2.2 Ga ago.

Fig. 2. Stromatolites in the bedrock at Peuranpalo. Photos by V. Perttunen.

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STOP 2: Sihtuuna moraines at Sihtuuna, Tervola

Pertti Sarala

The Sihtuuna moraine was found about 25 km northwest from the village of Tervola, southern Finnish Lapland (Fig. 1). The area of this moraine type covers about 10 km^2. Sihtuuna moraines are formed of ridges perpendicular to the latest ice-flow direction from the west to the east. The ridges have the dimensions of 100-500 metres in length, 10-50 metres in width and 3-5 metres in height (Aario et al., 1997; Sarala, 2003). They are formed of two till beds with stratified sands and gravels in between. The surface of ridges is covered with large and angular boulders transported only a very short distance.

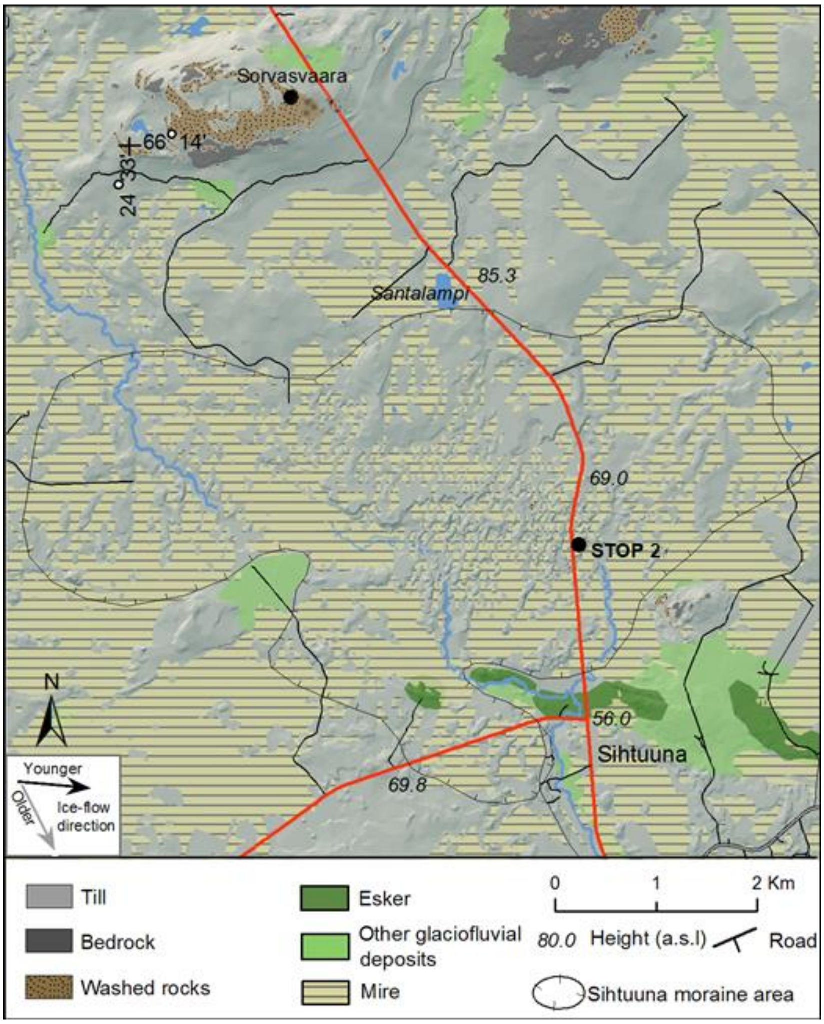

Fig. 1. Glacial morphology and bedrock relief of the Sihtuuna area, Tervola. Digital elevation model, topographic features and roads © National Land Survey of Finland.

The ridges are composed of several stratigraphical units (Fig. 2). On the bottom is a bluish grey till unit with a consolidated, sandy or fine-grained matrix. It is massive in structure and the pebble orientation shows ice-flow direction from the northwest. Rounded pebbles with a large variation of petrographic composition indicate a distant source for debris.

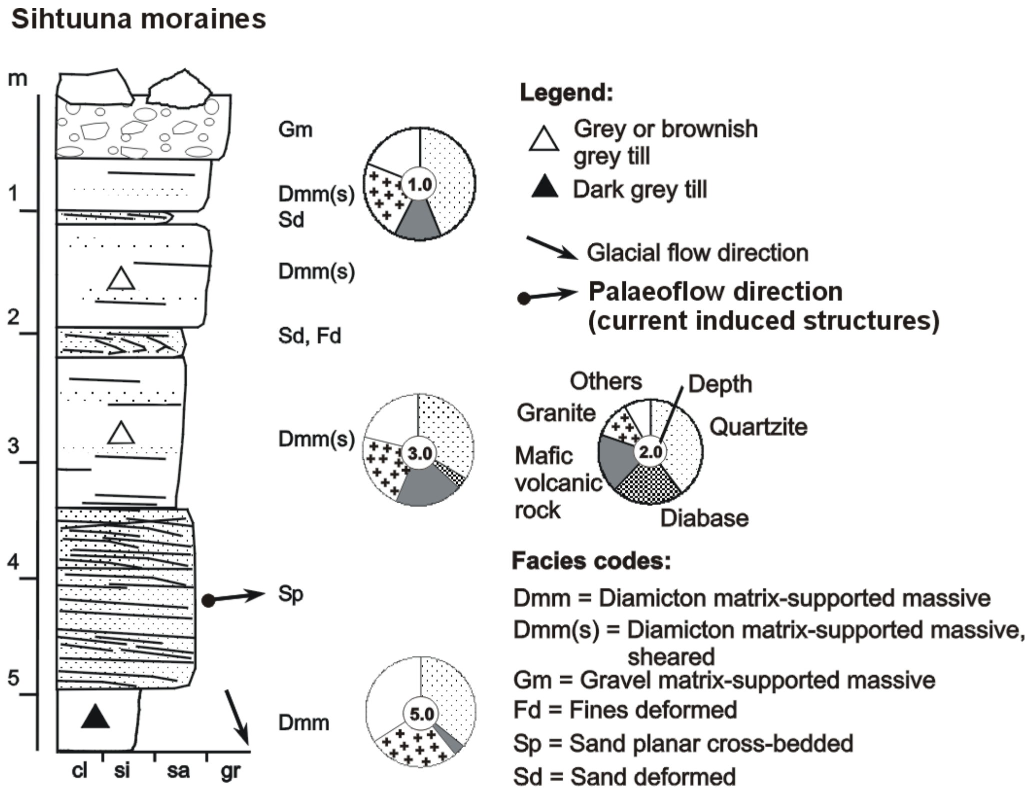

Fig. 2. Composition stratigraphy of minor ribbed moraines in Sihtuuna with lithofacies and pebble countings.

The composition of the uppermost part of the ridges, from the depth 1–1.5 m to top, is gravelly and heterogeneous in its structure. Material is debris-supported and has features like fine-grained laminae, shear planes and faults as a marker of glaciotectonic deformation it can be classified as till. Commonly, the most surficial part of the till has been washed to form massive and mainly clast-supported gravelly unit, representing the shore deposit of the Ancylus Lake stage. The great amount of local boulders both in the uppermost till unit and at the surface is a reminder of strong quarrying related to ribbed moraine formation process (cf. Aario et al., 1997).

Cross-sections through the ridges prove that the Sihtuuna moraines are depositional formations, not push or squeeze forms. Structures and beddings in the sedimentary units and upper tills evenly follow the outer ridge form (Fig. 2). Due to the sandy or even gravelly matrix of the upper tills and the existence of sandy lenses and intermediate layers, one of the sources must have been stratified sediment. Since the formation process of ribbed moraines favours quarrying (cf. Aario and Peuraniemi, 1992; Sarala and Rossi, 1998, 2000, 2006), the sandy material in the upper tills is mostly a result of redeposition of sediments between the ridges. Part of the sandy lenses and layers may also have been deposited because of the melt-waters and mass-flow of sediments existing during formation (cf. Aario et al., 1997). Due to the lack of relation with drumlins or drumlinized elements and the narrower and lower shape, Sihtuuna moraine ridges cannot be directly compared with Rogen moraines, but the description is suitable for minor ribbed moraines (cf. Hätterstrand, 1997).

Aario et al. (1997) presented that the origin of the Sihtuuna moraine was a two-step process. Initially plenty of streaming water together with subglacial mass-flowage existed. Sarala (2005, 2006) presented that at least part of the sands are re-deposited from the pre-existing delta formation to present position. The second stage was related to bouldery surface of the ridges and represents strong quarrying activity of the glacier during the formation process.

Fig. 3. Sandy and gravelly till with sandy inter-till layer of the Sihtuuna moraine ridge. The surface of ridges is covered with big, angular boulders. Photo P. Sarala.

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Stop 3: Liakka – Till covered Mid-Weichselian glaciofluvial system

Pertti Sarala

While studying Quaternary geomorphology, sedimentology and stratigraphy in southern Finnish Lapland many till-covered, stratified sand deposits were observed. Many of them are northwest southeast oriented esker formations, obviously from the Early or Middle Weichselian. Some deposits are interpreted to include glaciolacustric delta or shore deposits, which should be suitable for dating purposes due to excellent bleaching of minerogenic material under sunlight. For estimating the age of those sediments, samples were collected and analysed in the Dating Laboratory of the University of Helsinki using OSL method. Study areas lie in southwestern Lapland including several targets: Liakka, Sihtuuna and Sompujärvi (Fig. 1).

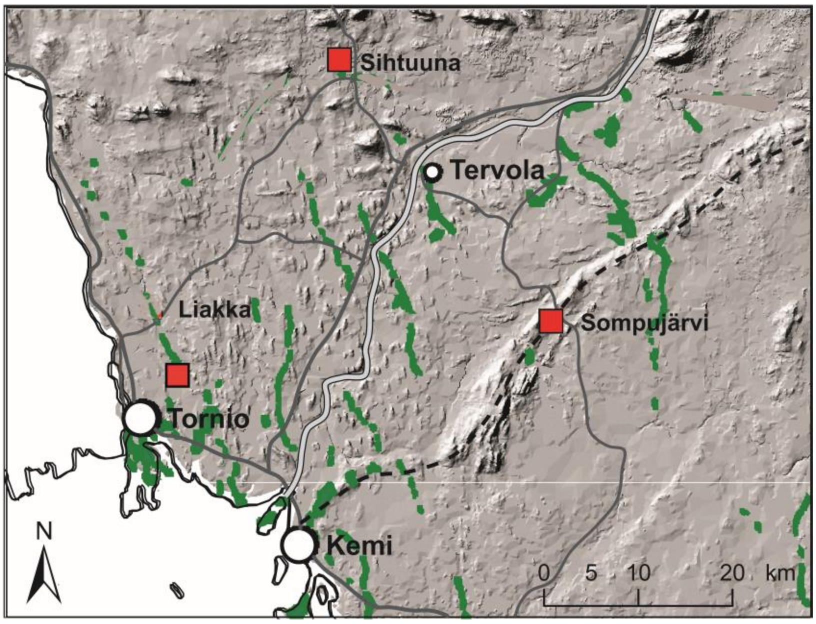

Fig. 1. Location of Liakka, Sihtuuna and Sompujärvi study sites on the DEM map. Map shows also almost N-S oriented Middle Weichselian drumlin field and till covered esker chains (green).

The Liakka study area includes two old sand/gravel pits (Pyöreäkumpu and Rantamaa, Fig. 2) that have been sedimentological studied and dated. The glacial morphology of the Liakka area is mainly composed of a northwest southeast oriented drumlin field, which is a relict of the earlier glacial phase of the Weichselian glaciation. The Late Weichselian ice sheet has covered the area but the glacial erosion has been weak and only slightly smoothed the ground. Because the cold-based centre of the glacier situated over the area during the Late Weichselian maximum and deglaciation, the glacial erosion was only modest preserving older morphology. During the latest phase of deglaciation, thin till sheet, about 1-2 metres thick, was deposited over the pre-existing tills and stratified sediments when glacier melted away.

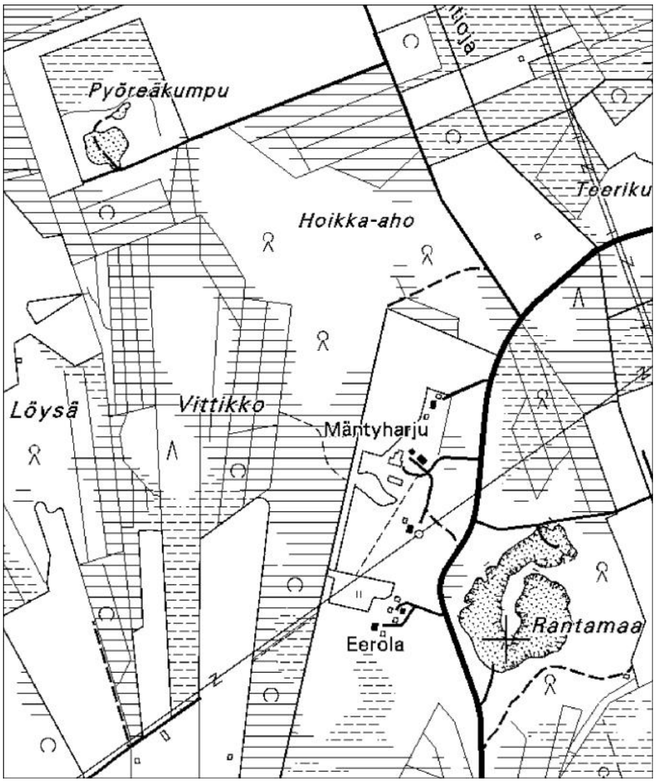

Fig. 2. Location of two studied sand pits in Liakka.

In the Liakka area, there occur NNW oriented gravelly and sandy formation where the thickness of stratified sediments is over five metres. In Pyöreäkumpu, glacially deformed planar or cross bedded sands were found under two metres basal till cover (Fig. 3). OSL samples were collected in 2005 on the upper part of the sand deposits. In Rantamaa, core parts of the sedimentary sequence is composed of coarse gravels indicating large cross/planar bedding with some indication of lowering of the grain size to upward (Fig. 4A, 3D). Cross and planar bedding, ripple marks (Fig. 4B) and graded bedding, different interlayers (fine sediments and gravels) indicate glaciofluvial deposition environment typical for esker system. Deformation of the stratified sediments is moderate including some shear structures and small faults and catchment/injection structures (e.g. Fig. 4A). OSL samples were collected from the layer including the ripple marks and on the upper part of the planar bedded sands.

Fig. 3. Glacially deformed sands under two metres thick basal till cover in Pyöreäkumpu, Liakka. Photo by P. Sarala.

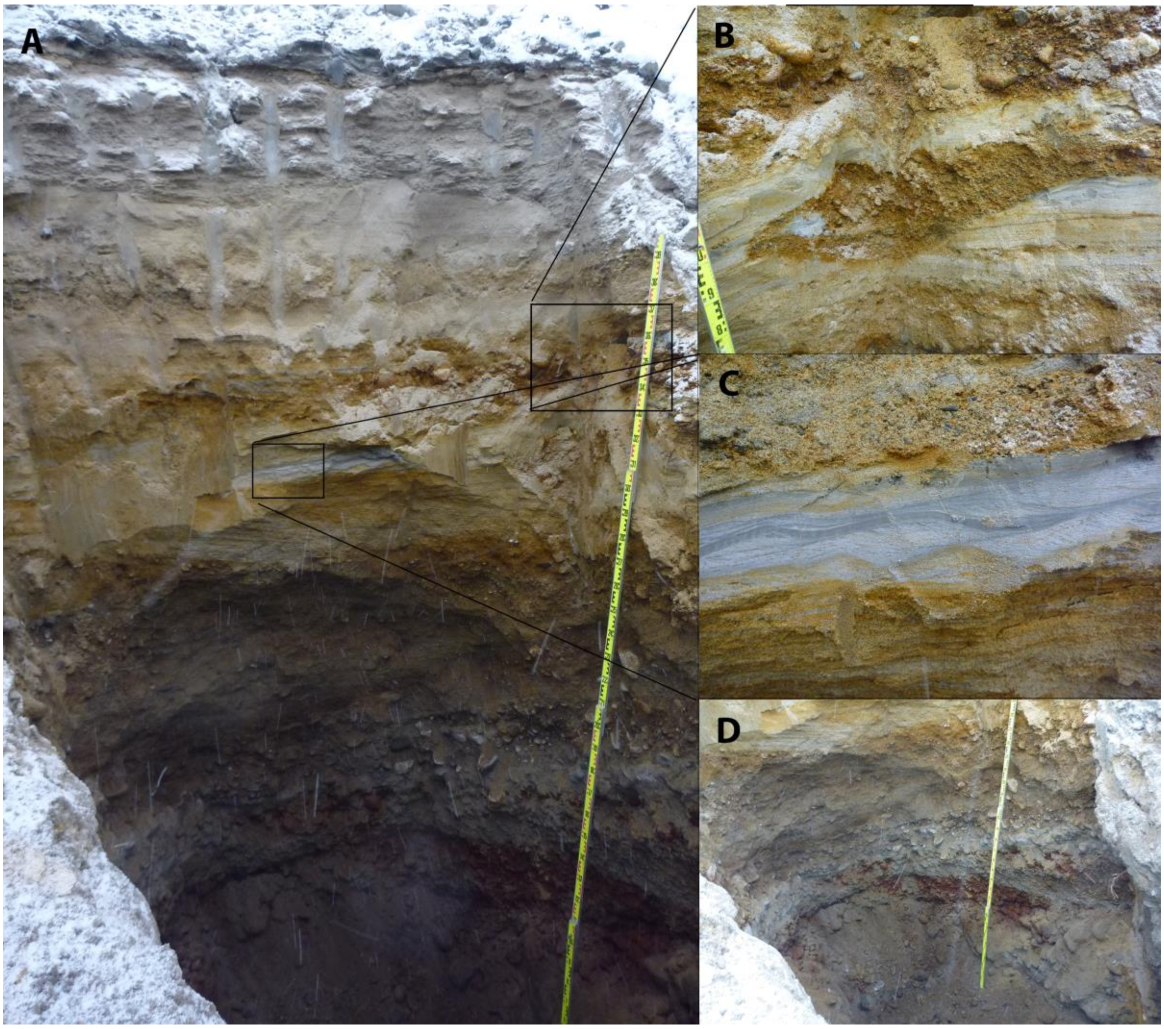

Fig. 4. Stratified sediment sequence under three metres thick till cover in Rantamaa sand pit, Liakka. Coarse core part composed of gravels is seen on the bottom (A, D). Upper parts includes cross and planar bedded sands with gravelly or silty interlayers. Some catchment/injection structures (B) and ripple marks (C). Photos by P. Sarala.

Ground penetrating radar (GPR) profile (Fig. 5) over the Rantamaa test pit shows a continuum of the sands and gravels under the upper tills. Furthermore, GPR data reveals that sands display planar lamination dipping towards south (i.e. meltwater flow direction). Those structures resembles foreset layers of the deltaic formation. Upper part (2-3 m) is composed of two till beds from which the lower is deformed and disturb underlying sands.

OSL datings were done in the Dating laboratory of the Helsinki University. Age determination gave the ages of about 29 +/- 2.8 ka and 29 +/- 6.1 ka years for the sands in Pyöreämaa. Data analysis for the Rantamaa OSL samples is not ready at the time of writing this description. However, it is assumable that the ages are in line with Pyöreämaa, because there are many age estimations younger than 40,000 years from the several places in the area of southern Finnish Lapland. This means that southern Finnish Lapland has been ice-free during the later stage of Middle Weichselian, in MIS 3. This interpretation is also supported by the TL ages clustering around 37,000 +/- 500 – 55,000 BP and OSL ages clustering around 41,000 +/- 2,000 – 66,000 +/- 5,000 BP, which were done of the samples taken earlier from Kauvonkangas in Tervola and the area surrounding the towns of Kemi and Tornio (Hütt et al., 1984; Mäkinen, 1999 and 2005). Furthermore, the new age estimations presented here correlate well with the age determination of mammoth and reindeer bones (22,500-

34,000 BP) done, for example, from the basins of Iijoki River and Tornionjoki River in southwest Lapland (Ukkonen et al., 1999; Lunkka et al., 2001).

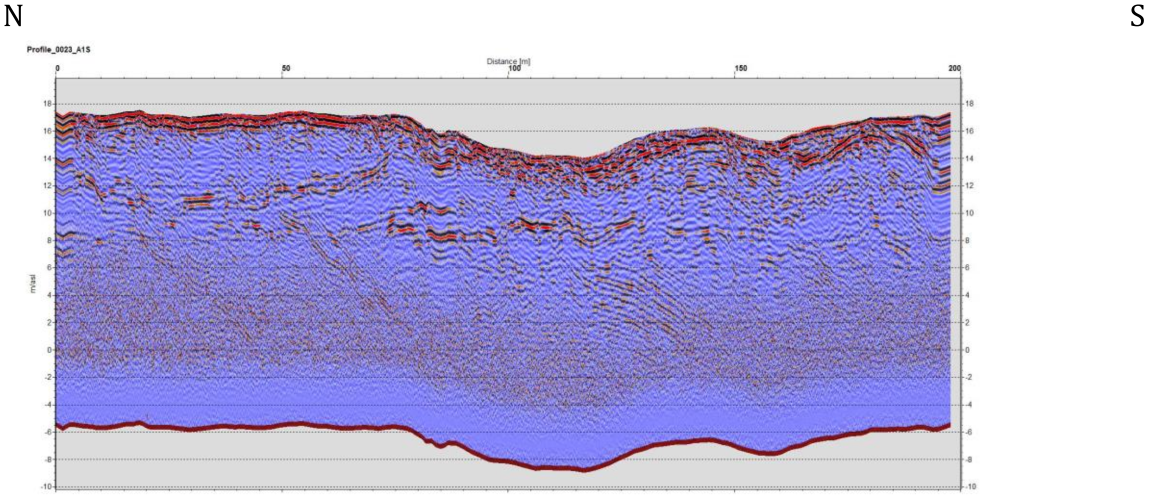

Fig. 4. About N-S oriented GPR profile following the margin of the eastern edge of the Rantamaa sand pit. Data collection and processing by Juho Kupila.

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Stop 4: Aavasaksa ancient shore line

Peter Johansson

The general deglaciation direction in Central Lapland was towards the west or the north-west, as interpreted from the esker chains general directions. The last recession in the SIS in Finland took place in the Pello – Kolari area of the Tornio River valley. The land was first covered by Baltic Sea (Ancylus Lake) waters and during the thousands of years that followed, the region was uplifted and the area was exposed to the strong currents and wave activity in the shallow water. During the postglacial time waters extended along the river valleys as far as Kolari in the Tornio-Muonio River valley, to Kittilä in the Ounas River valley and to Sodankylä in the Kemi River valley. At the beginning of their postglacial history the rivers were almost 200 km shorter than they are today.

This region belongs to the Fennoscandia Centre of the Isostatic Uplift and it is noted that the present day 6 mm/year uplift rate was ten times faster being more than 60mm/year. During those days Ancylus Lake was lying between the levels 200 and 219 meters (Saarnisto 1981). The highest shoreline is seen on the slope of a rock hill as a washout limit, that is, the limit extensive wave activity washed out the soil covering the bedrock. This region is pointed by littoral boulder belts and boulder fields that are widely identified from those regions. The hill-tops above the highest shoreline were not affected by the action of waves. They are often covered by unwashed till, which nowadays supports dense spruce and pine forest, and forms caps, which serve as distinctive features of the landscape. In northern Finland the region of the most representative till-capped hills stretches from Ainiovaara – Reväsvaara area in Tornio River valley to Vammavaara – Pisavaara area in the Kemi River valley (Fig. 1).

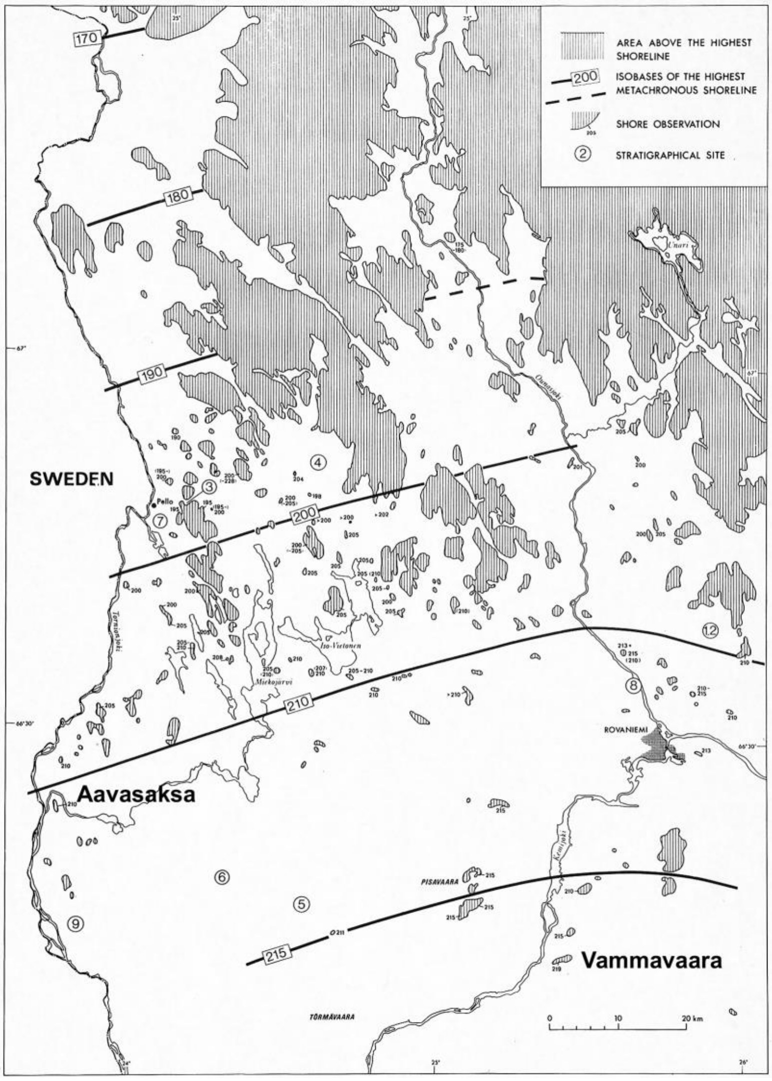

Fig. 1. Distribution of land and water during the formation of the metachronous highest shoreline in southern Lapland. The highest shoreline was formed around 10,000 B.P. during the Ancylus Lake stage of the Baltic Basin. (Saarnisto, 1981).

Aavasaksa hill is the most famous till-capped supra-aquatic location in Finland. This 242 m high granitic hill was deglaciated ca. 10,000 years ago. After ice retreat from the region, Aavasaksa was left as an isolated island in the sea. Strong marine currents and wave energy strongly reshaped the rocky slopes and steep cliffs leaving coarser material to the higher elevations whereas the finer materials were transported to the lower slopes. As a result of strong littoral processes a twenty meters high wave washed boulder belt was formed below the level of the highest shoreline (208 m). Above the wave-washed zone the supra-aquatic till cover was preserved formed a till cap or a calotte. Especially, the eastern cliff is almost vertical and an impressive sight (Fig. 2).

Fig. 2. Aavasaksa, view from the Tengeliöjoki River valley. The top is covered by a spruce-forested till cap above the wave-washed zone with a steep cliff marking the highest shoreline. Further down there are boulders and stones that have fallen from the slope and accumulated by littoral action. Photo by P. Johansson.

Aavasaksa is a well-known scenic attraction and vantage point. Visitors can admire one of Finland's official national landscapes from the summit. Between pine trees whose bushy branches take on dramatic shapes, a visitor can take in sweeping views across large swaths of northern Finland and Sweden. In the panorama, the River Tornio curls like a blue ribbon through the valley, punctured by a border bridge; the Swedish village of Övertorneå is also visible. Curving around the northern and eastern sides of Aavasaksa is the River Tengeliö, which flows into the Tornio River.

Aavasaksa is Lapland's oldest travel destination. It is known as "the sun hill" because visitors come there to admire the midnight sun every year. Located approximately 18 kilometres to the south from the Arctic Circle, Aavasaksa is the southernmost place in Finland where the sun does not set at the Summer Solstice (June 21). The Midsummer Festival in Aavasaksa is very old tradition and still very popular event in Torniojoki River valley. In the scientific literature the name of Aavasaksa became famous because of the geographic work of The French Academy of Sciences in 1736-37. The expedition was led by Pierre Louis Maupertuis, who tried to find evidence for his theory that the earth was not perfectly round, but rather slightly flattened near the poles. In the summer of 1799, Italian explorer Giuseppe Acerbi made the same pilgrimage, and his writings further increased interest in the mountain. Among others who came to the Tornio River Valley to enjoy the midnight sun was Sweden's King Karl XI, who visited there in 1694. The Russian Tsar Alexander II was expected to visit in 1882, and the Imperial Lodge was built for him. The Tsar didn't make it due to the unstable political situation at the time, but the hunting lodge still stands on Aavasaksa. Aavasaksa is surrounded by a network of hiking trails, their lengths ranging from less than half a kilometre to four kilometres. Along the paths, there are shelters and lookout points complete with benches. Wooden duckboard walkways carry explorers across the most challenging parts of the trails, while trailside signs offer factoids of local history and nature.

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Stop 5: Glacially lineated terrain in northern Sweden – drumlins in Kompelusvaara

Niko Putkinen

Finland, Sweden and Norway are located in the core region of the Scandinavian Ice Sheet (SIS) during the last glaciations. SIS' Late Weichelian major ice streams migrated hundreds of kilometres toward the south and east, but none of their roots extended to the northern regions that belongs to an ice divide zone. This zone and its surrounding areas are a classical cold-based glacier region of gently undulating ground and/or hummocky moraines consisting of diamicts as well as sorted glaciofluvial or glaciolacustrine sediment that have been deposited on stagnant ice. These sediments are ultimately redeposited during ice melting, forming a hummocky or 'kettled' surface.

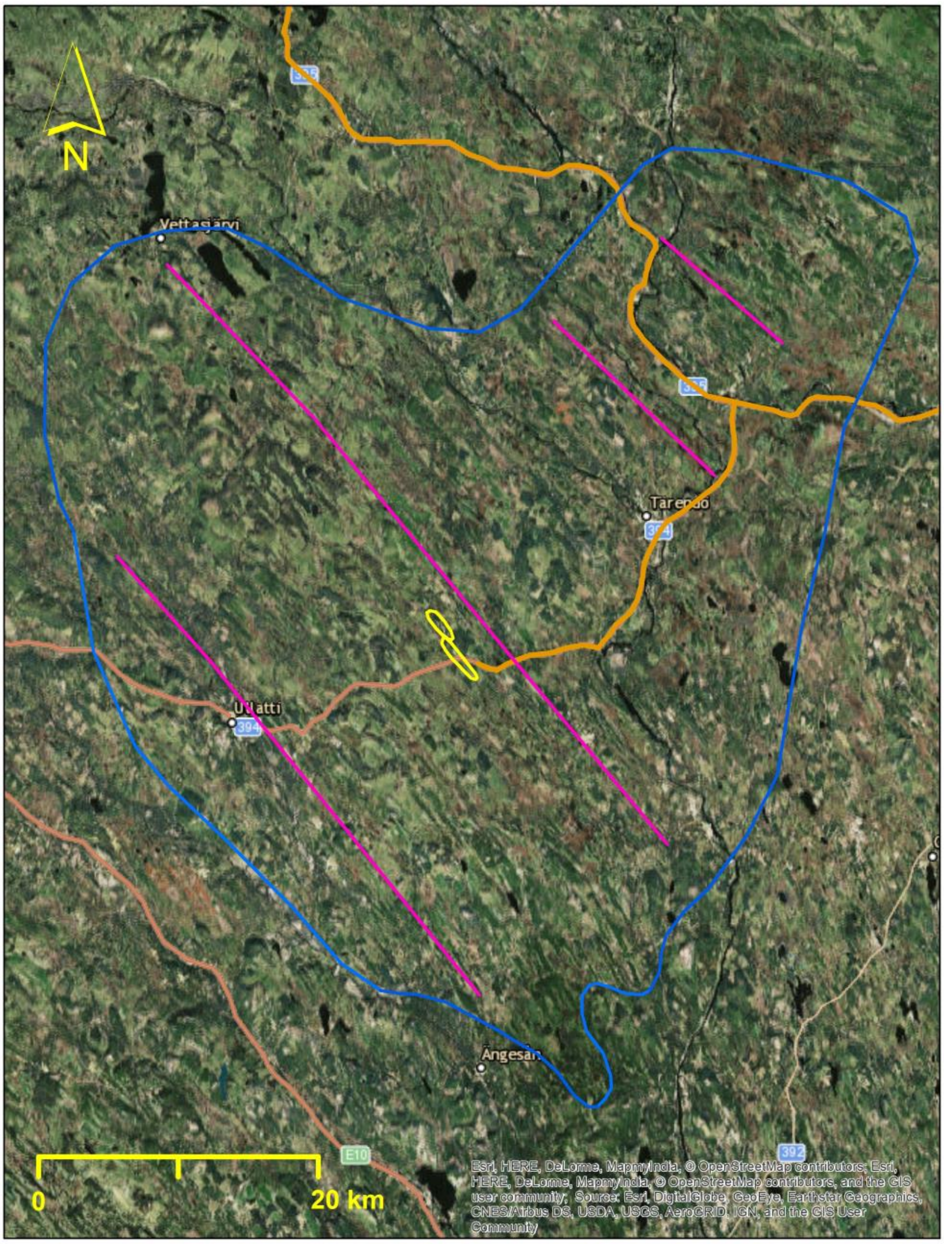

Fig. 1. Main glacier flow lines (pink) inside the Kompelusvaara flow set region (blue). Excursion stops are indicated by drumlins (yellow).

According to satellite imagery interpretation, a relatively small glacially lineated terrain is facing southward from Vettasjärvi – Kääntöjärvi – Ruokojärvi – Lauttakoski – Junosuvanto line indicating the southern boundary of the ice divide zone. In the region a wide variety of elongated bedforms like megaflutings, drumlins and much smaller flute ridges were deposited sublacially parallel to south-southeastern ice flow. These sediment or rock-cored forms build up a 40 km^2 Kompelusvaara flow set between Gällivare and Pajala (see blue polygon in Fig. 1). In the northwestern part of this region, large scale rock forms were sculpted along the bedrock structures and sometimes forming large cone-shaped crag and tail drumlins and more elongated megaflutings. Locally ‘hard bedded’ glaciers left behind bare bedrock exposures or thin sediment cover without significant ‘glacial footprint’ suggesting bedrock topography that is strongly controlled by the glacier flow velocities. In the central and eastern sector, highly lubricated, fast flowing ‘soft bedded’ glaciers found their way to the lower elevations until flow ceased in the east from Ängesån (see the blue polygon southern margin in the Fig. 1). In this region good examples of megaflutings and drumlins are present next to the main road (Fig. 2).

This region is also expressed a superposed crossing striations and glacially streamlined bedforms overlain by drumlins and flutings that represent ‘ice flow switching’ during the deglaciations. According to a Northern Sweden paleo-glaciological studies, Kompelusvaara flow set belongs to southern ice flow of the Early Weichselian glaciation (Hättestrand et al., 1999). It seems they have counterparts to the pre-Late Weichselian morphology in Kemi - Ranua region in the Finland (see Stop 3), although Sarala (2005) and Johansson et al. (2011) were presented them to belong Middle Weichselian glaciation (MIS4). Late Weichselian deglaciation ice flow is oriented to the north-east (Hättestrand et al., 1999).

Fig. 2. Typical drumlin landscape in Kompelusvaara. Photo was taken from the distal head of the drumlin towards the northwest. Photo by P. Sarala.

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Stop 6: Lainio arc and Veiki moraines in Junosuando

Pertti Sarala and Niko Putkinen

Veiki moraine is a landform area consisting of rim-ridged subcircular hummocks with lower plateaus in the centre. Hummocks are sharply elevating from the depressions in between. The Veiki moraines are mostly located within a N-S extending zone of a hummocky landscape in northern Sweden (Fig. 1). The name is derived from the village Veiki, close to Gällivare in Norrbotten, northernmost Sweden (Hoppe, 1952). In the stop we are going to visit in relative large Veiki moraine ridge on the eastern side of Junosuando village (Fig. 2). There we can see deep slopes of the margins of the rim-ridge and flat plateau inside the Veiki hummock. In the centre, there is even a little pond with surrounding peatland area (Fig. 3).

Due to their good preservation, the Veiki moraine provides a valuable information on the glaciation and prevailing environmental conditions in northern Sweden during the earlier stages of Weichselian glaciations, as well as the ice dynamics of the late Weichselian ice sheet.

The Veiki moraine type is believed to be a multiphase formation process having the pre-late Weichselian origin but finishing during the last deglaciation. The Veiki moraine zone shows a distinctly lobate configuration of the former ice streams that was survived overriding by ice during the subsequent glaciations. The northernmost and the most prominent lobe is called the Lainio arc (Fig. 1). The eastern limit is commonly marked with terminal moraines (Hättestrand 1998).

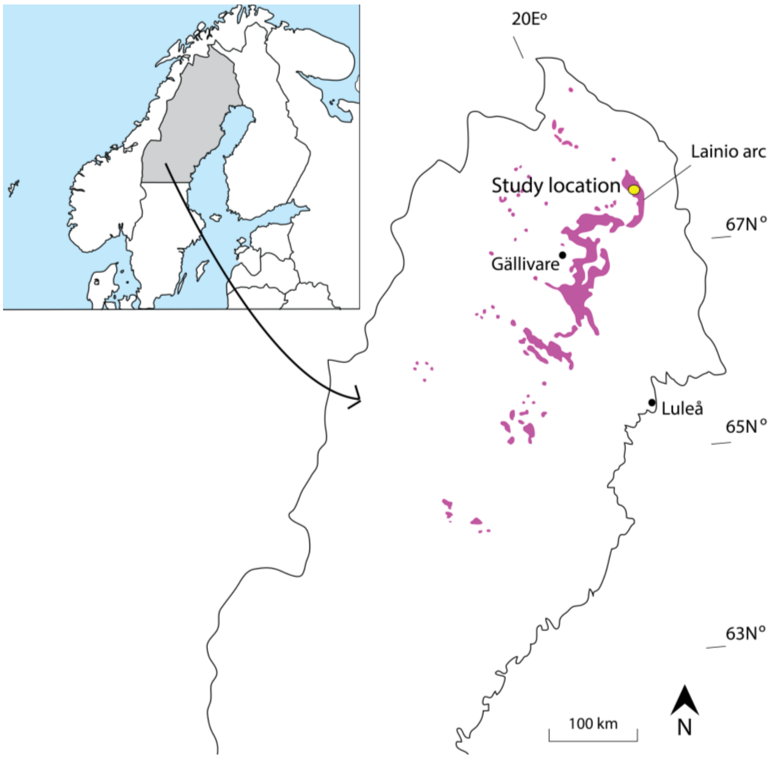

Fig. 1. The distribution of the Veiki moraine hummocks and plateaus in northern Sweden. Lainio arc is located in the northernmost part of the Veiki moraine field. After Hättestrand (1998).

Several studies from northern Sweden shows that the centre of the ridges is composed of massive diamicton (Hoppe, 1952; Lundqvist, 1981; Lagerbäck, 1988; Sigfúsdóttir, 2013). According to Sigfúsdóttir (2013) the rim ridges are built up by stratified debris flow units, partly underlain by organic-rich lake sediment (Fig. 4). The elevated position of these sediments indicates that the moraines were surrounded by ice at the time of deposition. They are interpreted to have formed by debris and meltwater inflow into depressions on a debris-covered stagnant ice mass. After the surrounding ice was melted they were left standing as high points in the landscape. The moraine plateaus and the surroundings are covered by a thin till bed deposited by subsequent glaciations.

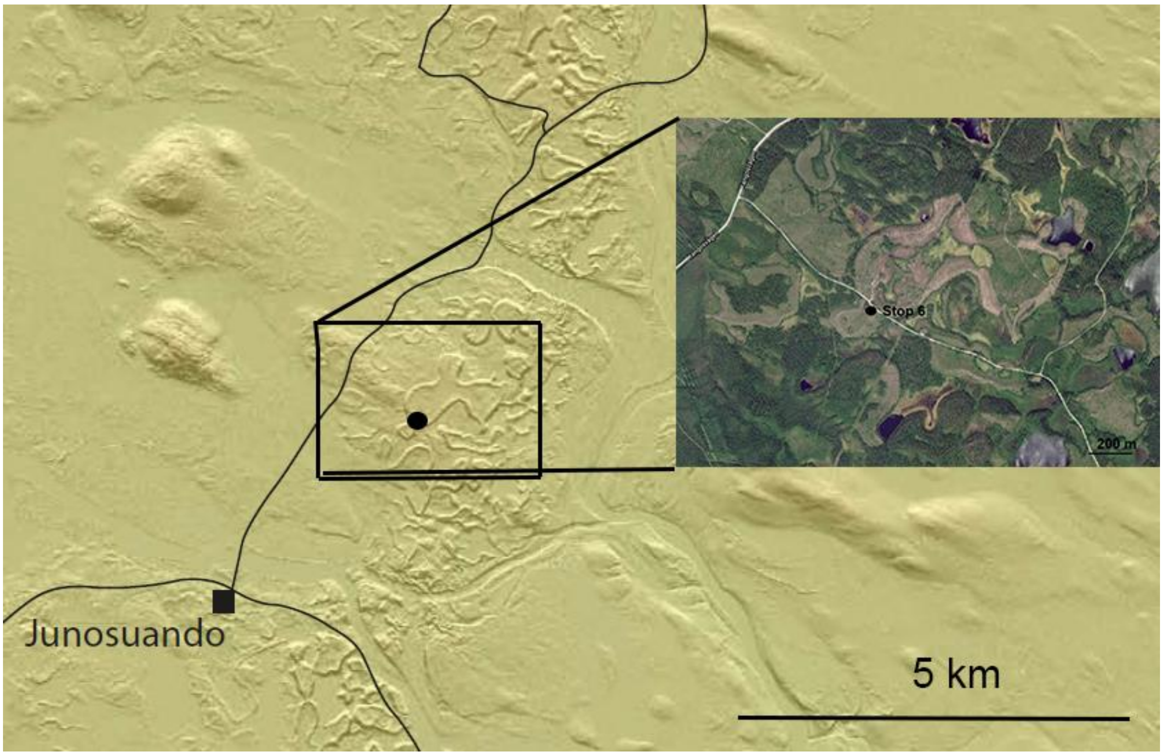

Fig. 2. Lainio arc seen as a belt of the Veiki moraine ridges near Junosuando.

Fig. 3. A panorama view over the Veiki moraine ridge in Junosuando. The steep slope of the rim-ridge is seen on left part of the photo collage. The plateau is typically found inside the hummocky and in places, even a small pond or mire can be found in the centre (right part in this photo). Photos by P. Sarala.

The most widely accepted depositional model today was proposed by Lagerbäck (1988), mostly supraglacial deposition during downwasting of debris covered dead-ice. Accumulation of flowtill and water reworked sediments into ice walled lakes built the main parts of the landform, either with contact to the ground or in depressions in the ice. The disposition of the Veiki moraines reflects the last glacier movements before an ice sheet retreats, and their final form is given by the melting of dead-ice and the development and sedimentation of glacial lagoons between dead-ice cored rims during interstadial periods. In the case of the Veiki moraines of Sweden, the interstadial during which the lagoons sedimented is believed to have occurred in the early Weichsel glaciation. Thus, the Veiki moraines of Sweden are a relict landform that has largely survived later glacier action.

Dating of lake sediment using both radiocarbon and OSL methods suggest deposition around 50,000 years BP (Sigfúsdóttir, 2013). This indicates deposition during MIS3 which is also supported high macrofossils content of the lagoons sediment unit. That indicates deposition during a relatively warm interstadial period. These ages fit well with the Tärandö II interstadial

(Hättestrand & Robertsson, 2010), placed into MIS 3, which followed the glaciation in MIS 4 during the Weichselian glaciation cycle.

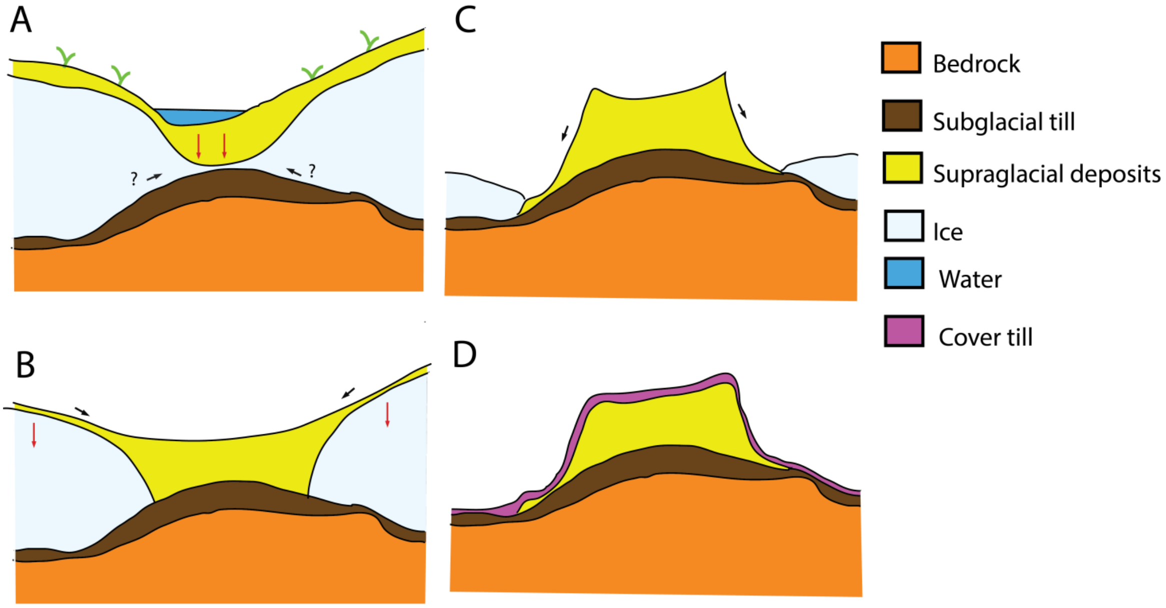

Fig. 4. Depositional model. A: Lake sediments are deposited into ice depressions during a warm period, the lake slowly melts through the ice over the pre-existing diamicton layer. Possibly the weight of the surrounding glacier squeezes some material into the area of lower pressure, under the depression. B: Mass movements from the surrounding ice cover the lake sediments. C: The ice back-wastes from the moraine plateau so it is left standing as a high point in the landscape. Slope failures might have occurred after loss of the supporting ice. D: The moraine is overriden by a sluggish ice which remolds it and leaves behind a thin till layer on top of the moraine. After Sigfúsdóttir (2013).

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Stop 7: Riipiharju esker and Tärendö interstadial

Pertti Sarala and Peter Johansson

Riipiharju esker is located about 20 km north–northeast of Junosuando in northernmost Sweden and approximately 275 m above sea level (m a.s.l.) (Fig. 1). The 8 km long Riipiharju esker is an integral part of the old northwest–southeast oriented glacial landscape of northeastern Sweden. The topography in the surrounding area is characterized by a low undulating relief with scattered hills 150–450 m a.s.l.; the predominant Quaternary deposit is till. The Riipiharju esker is generally sharp-crested and well preserved. In some areas, the esker is cut by glaciofluvial erosion and the lower parts have a 0.5–1m thick till cover, in places consisting of two different till beds (Hättestrand & Robertson, 2010).

The studies reported by Lagerbäck & Robertsson (1988) include three sites (Riipiharju I-III). The type site of the Tärendö II Interstadial, Riipiharju I, consists of a sediment sequence from a kettlehole at the northwest/southeast oriented Riipiharju esker (Lagerbäck & Robertsson, 1988) (Fig. 1). The stratigraphy at Riipiharju I includes two organic-bearing layers separated by a till unit. The lower/older of the organic layers was suggested to represent the end of the Tärendö I Interstadial and the overlying/younger organic sequence the Tärendö II Interstadial (Hättestrand & Robertson, 2010). The Riipiharju II core is the most complete sequence from Weichselian interstadials in northern Sweden. It includes sediments from two interstadials (Tärendö I and II). In many cases the radiocarbon dates are reversed and give finite ages between c. 30,000 and 45,000 years BP, mixed with infinite ages for the same sequences (Lagerbäck & Robertsson, 1988).

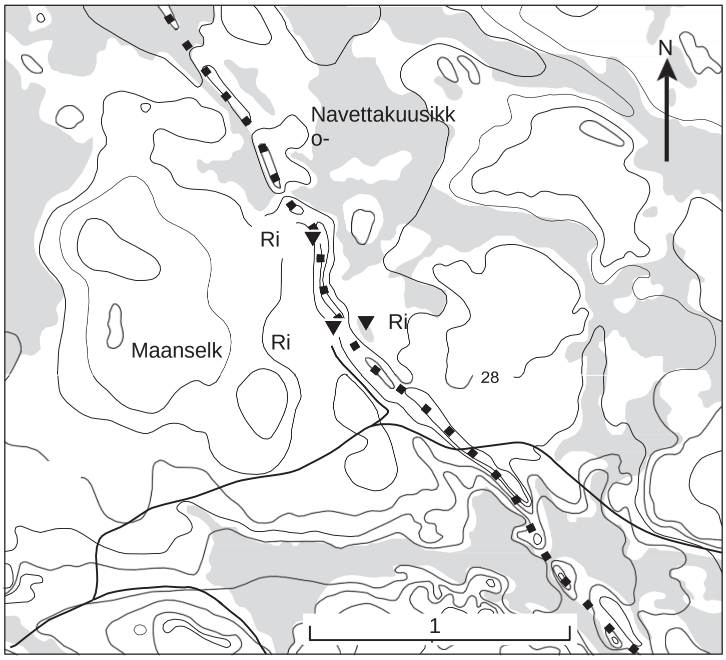


Fig. 1. Detailed map of the Riipiharju esker (dotted line in the centre) and the location of the cores Riipiharju I, II and II. Mires are indicated with grey shading. After Hättestrand & Robertson (2010).

Based on recent pollen analysis of the Riipiharju bore holes, new interpretation was done of the Weichselian interstadial vegetation deveploment (Hättestrand & Robertson (2010). The vegetation during the warmer interstadial phases probably consisted of subarctic shrub tundra or subarctic birch forests. The dominant pollen taxa during these phases are Betula sect. Albae and Betula sect. Nanae. The vegetation during the cold parts of the Weichselian interstadials was probably scarce and steppe-like. The pollen assemblages are dominated by Artemisia, Gramineae and Cyperaceae with an admixture of Chenopodiaceae (Fig. 2).

Earlier the interstadials Tärendö I and Tärendö II have been placed in the Early Weichselian and correlated to the North European interstadials Brørup (103-95 ka) and Odderade (85-74 ka) (Lagerbäck & Robertsson 1988),). However, new results by Hättestrand & Robertsson (2010) based on new palynological investigations of the stratigraphy from Riipiharju suggest an alternative chronology (Fig. 3), where the two interstadials instead represent Odderade (85-74 ka) and a Mid-Weichselian interstadial (59-24 ka). Those interpretations fit well to results from the northeastern Finland, the Sokli site (Helmens et al., 2000, 2007).

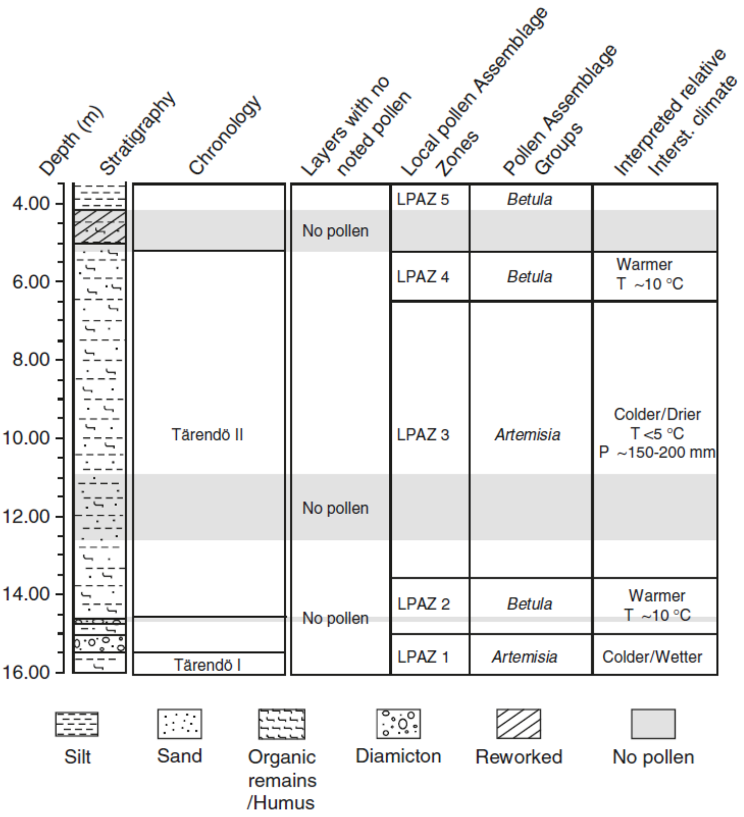
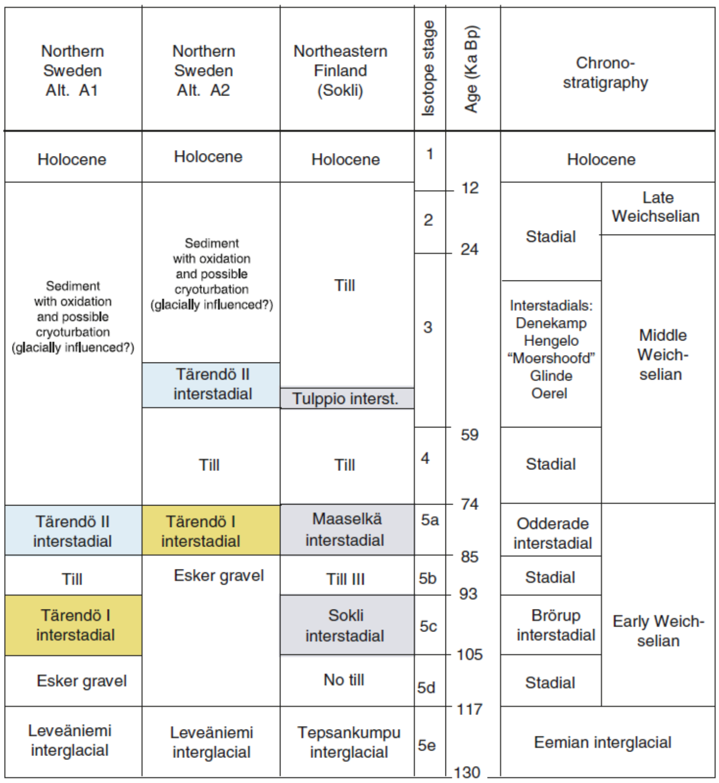


Fig. 2. Interpretation of the Weichselian stratigraphy of the Riipiharju II core. T=mean July temperature; P=precipitation. After Hättestrand and Robertson (2010).



Northern Sweden Alt. A1	Northern Sweden Alt. A2	Northeastern Finland (Sokli)	Isotope stage	Age (Ka Bp)	Chrono-stratigraphy	
Holocene	Holocene	Holocene	1		Holocene	
Sediment with oxidation and possible cryoturbation (glacially influenced?)	Sediment with oxidation and possible cryoturbation (glacially influenced?)	Till	2	12 24	Stadial	Late Weichselian
	Tärendö II interstadial	Tulppio interst.	3		Interstadials: Denekamp Hengelo “Moershoofd” Glinde Oerel	Middle Weich-selian
	Till	Till	4	59	Stadial	
Tärendö II interstadial	Tärendö I interstadial	Maaselkä interstadial	5a	74	Odderade interstadial	Early Weich-selian
Till	Esker gravel	Till III	5b	85	Stadial	
Tärendö I interstadial		Sokli interstadial	5c	93	Brörup interstadial	
Esker gravel		No till	5d	105	Stadial	
Leveäniemi interglacial	Leveäniemi interglacial	Tepsankumpu interglacial	5e	117 130	Eemian interglacial	

Fig. 3. Two option for correlating the Tärendö I and Tärendö II Weichselian interstadials in the Riipiharju sequence to northeastern Finland. After Hättestrand and Robertson (2010).

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Stop 8: Parkajoki – a Neogene landscape with only minor modification by successive Fennoscandian ice sheets

Adrian Hall, Karin Ebert and Clas Hättestrand

The Parkajoki area of NE Sweden lies in a zone of low Pleistocene glacial erosion that extends westwards from the ice-divide zone of N Finland (Ebert et al., 2015). The area displays non-glacial features of likely Neogene to Early Pleistocene age. These include large landforms, such as granite domes, rectinlinear valley sections and topographic basins, small landforms such as tors and boulder fields and saprolites (Fig. 1).

The large landforms are typical of granite landscapes where differential weathering and erosion has acted under non-glacial conditions for long periods. The granite domes are developed in areas with widely-spaced fractures whereas the valleys follow the main fracture zones. The domes are representatives of suites of non-oriented and oriented inselbergs mapped across northern Sweden that lack signs of glacial streamlining (Ebert and Hättestrand, 2010). The domes in in the Parkajoki area are mainly low, with a relative relief of 50–150 m, and flanking slope angles of less than 11°. The inselbergs rise from structurally controlled rectangular plinths and have convexo-concave slopes that conform to sheet structures in the granite (Ebert et al., 2012a). The edges of the thickest sheets form small cliffs fringed by collapsed granite blocks but these rock steps lack a consistent orientation in relation to ice flow. Sheet joints flatten in the footslope zone, maintaining conformity with surface slopes. The bases of the hills are mantled by till, at least 7 m thick in places, but till tails are not present. Mechanical excavations have revealed at least four separate till units, including Middle Pleistocene or older weathered till units where biotite gneiss boulders have thoroughly disintegrated to grus. Tills in excavations rest on truncated grus-type weathering profiles at least 3 m deep (Ebert et al., 2012b).

Tors up to 5 m high and extensive boulder fields are widespread on dome summits and flanks. Comparison with models of the glacial modification of tors (André, 2004; Hall and Phillips, 2006) indicates that the Parkajoki tors may have lost some superstructure to glacial erosion but remain substantially intact, an interpretation consistent with glacial disturbance evident in summit blockfields. The hill Naakakarhakka carries a summit tor (Fig. 2). Adjacent summit surfaces have been partly stripped of regolith, but excavations here show that thin saprolites may survive beneath till close to the tor base. The summit tors have a history that may span the Quaternary (Hättestrand and Stroeven, 2002). Prolonged exposure of tor summit surfaces is confirmed by cosmogenic nuclide dates that indicate exposure ages of up to 301 ka and a minimum total exposure history of 605 ka for individual tors (Stroeven et al., 2002; Li et al., 2008).

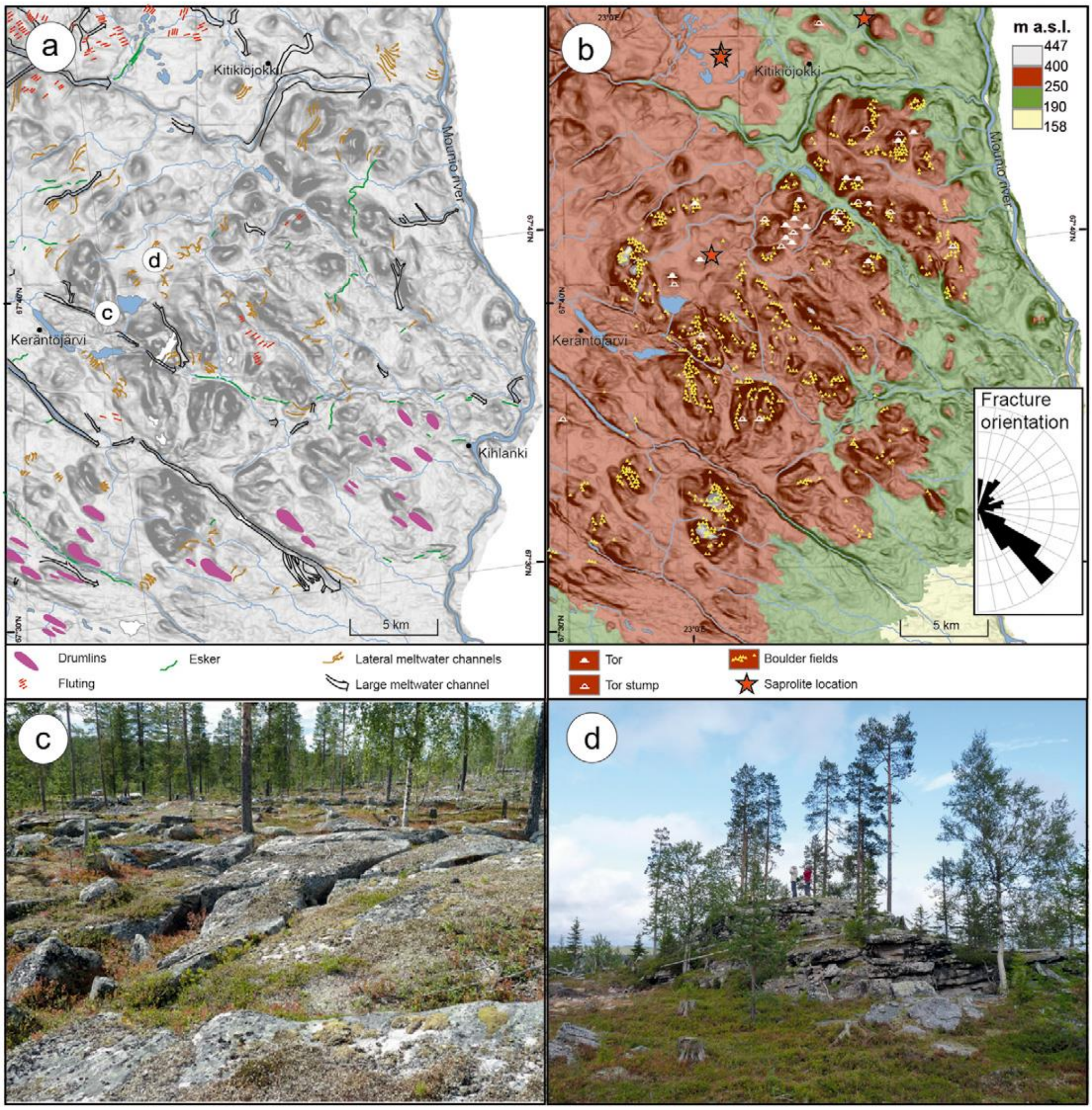

Fig. 1. Geomorphology of the Parkajoki area (Hall et al., 2013). (a) Glacial landforms, modified from Hättestrand and Stroeven (2002). (b) Non-glacial and pre-glacial landforms, modified from (Hättestrand and Stroeven, 2002). (c) Glacially-stripped and pulled apart granite surfaces, near Keräntöjärvi. This area is unusual for Parkajoki as it displays a range of glacial erosion indicators, including stripped surfaces, rock-cut meltwater channels and small, lake-filled rock basins. (d) Tor on the summit of the small granite inselberg, Naakakarhakka. The tor and its surroundings may have lost some superstructure and regolith but glacial erosion otherwise has been very limited. The tor summit has yielded cosmogenic exposures for ^{10}Be and ^{26}Al that indicate an exposure history of >485 kyr (Stroeven et al., 2002).

A shallow topographic basin is developed in biotite gneiss at Anokangas. Grus-type saprolites developed in diorite and biotite gneiss occur widely on this basin floor and beneath parts of the Pakko and Lule planation surfaces (Ebert et al., 2011) and are associated with smooth surface textures on DEMs. First attempts to date these saprolites using meteoric cosmogenic nuclide inventories indicate an age of over 1 Myr (Ebert et al., 2012b). These saprolites are more than 3 m thick in excavations but the maximum depth of weathering is uncertain. Ice-roughened bedrock terrain in the zone of small lakes in the south-west of the Parkajoki area, probably close to the basal surface of weathering from which saprolite has been stripped, indicates a former maximum saprolite thickness of 10–20 m. Similar and greater depths of weathering are recorded in boreholes in the ice-divide zone in Finland (Hall et al., 2015).

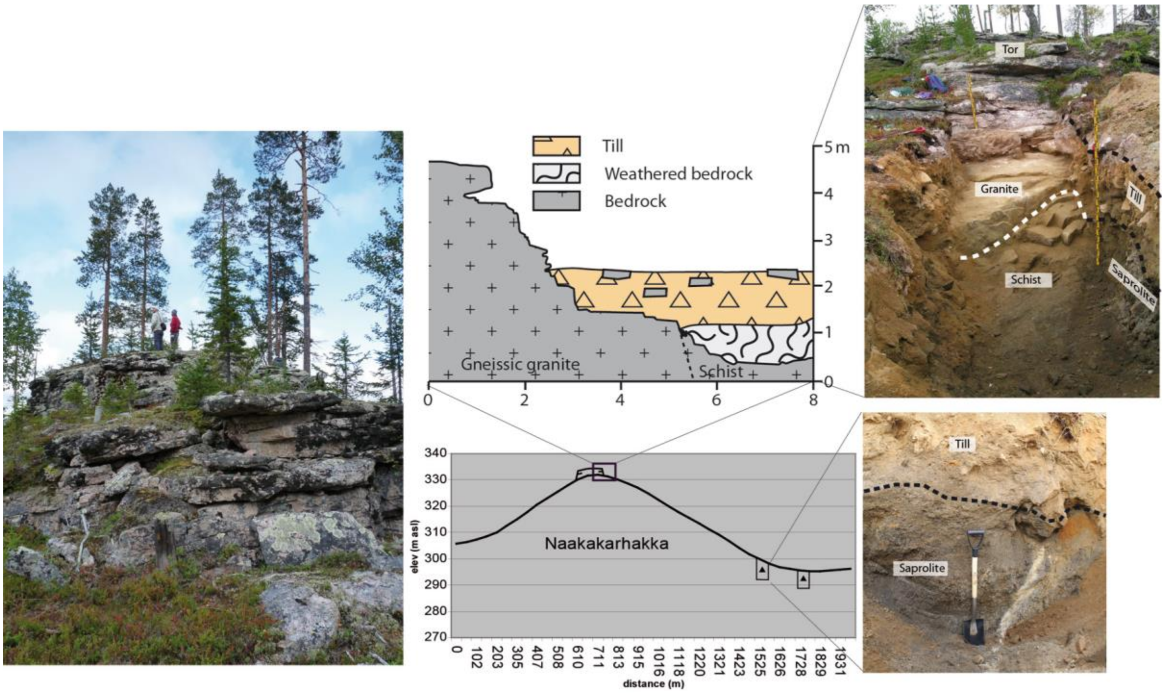

Fig. 2. The dome Naakakarhakka with its summit tor. Excavations showed saprolite and till thickening beneath surrounding hill slopes.

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Kilpisjärvi

Kilpisjärvi Biological Station

Kilpisjärvi Biological Station is situated in the northwesternmost part of Finland, in the municipality of Enontekiö. Here the landscape is dominated by fells extending into the Scandinavian mountain range, such as the Saana Fell (1029m) and the Pikku-Malla Fell (738m). Kilpisjärvi lies 473 metres above sea level.

The Kilpisjärvi Station, established in 1964, is a scientific research station belonging to the University of Helsinki. The principal aim of the station is to promote biological and geographical research in the north as well as to provide students of biology and geography with information about natural phenomena.

The unique nature of the Kilpisjärvi area was one of the reasons why the Biological Station was founded there. Kilpisjärvi is the only part of Finland extending into the Scandinavian mountain ridge. Rocks containing limestone are abundant in the area. The area belongs to the subalpine birch forest zone, mountain birch being the dominant plant species. The majority of the area is a mosaic of treeless alpine heath and ponds. The climate is arctic and the annual mean temperature is only -2.3°C which is one of the lowest in Continental Europe.

The silhouette of the fell Saana

Peter Johansson

Finland’s northwestern part “Käsivarsi” (in English “Arm”) has the country’s most mountainous scenery. Finland’s highest point is located at Halti, on the border between Finland and Norway. The highest point is on the fell’s slope, 1324 m above the sea-level. It is located 55 km from the village Kilpisjärvi and the Nordic hiking route, “Nordkalottleden Trail” leads there.

A much shorter walk takes you to the top of the Fell Saana. This strange looking mountain is 1029 m high and it has a very interesting geological history: The Scandinavian Caledonide mountain range is floored by Archaean basement granodiorites. On that structural basement lie latest Proterozoic/Early Cambrian sedimentary rocks, still in an autochthonous position, which are overtrusted from WNW by thick sequences of allochthonous schistose and strongly lineated nappes of Cambro-Ordovician emplacement (Lehtovaara 1995).

The Archaean basement granodiorite was cratonized 2,700 – 2,800 Ma ago, followed by some 2,000 Ma of erosion. The general appearance of the rock is migmatitic. Amphibolitic rocks are common in a zone southwards from Saana and they can be divided into basic, intermediate and acidic volcanic rocks.

Caledonian sedimentary layers were laid down upon that old surface. The predecessor of the Atlantic, the Iapetus Ocean was formed by continental rift and plate-tectonic divergence. The lowermost tectonostratigraphic unit, Dividal Group starts with a basal conglomerate and fines upwards to shales. The sandstone layers are of pure quartz and also structurally mature. The beds are still in autochthonous positions.

On top of this unit are situated sedimentary rocks of the Jerta Group. They are only weakly recrystallized, not much more affected than the sedimentary rocks of the Dividal Group. The most common rock types are a fissile slate and a recrystallized blue-grey quartzite. A micritic white dolomite is typical of this unit. All these rocks were pushed slightly to the ESE in Caledonian overthrusts (Fig. 1).

The uppermost part consist of the Caledonian overthrust, which was emplaced from the WNW above the sedimentary rocks, which took place during the later Cambrian and early Ordovician time. It monotonously consists of arkose quartzites that is thinly striped with layers rich biotite and chlorite. This hard rock forms the precipices on the “Caledonian Front” and shelters the softer rocks underneath it. It characterizes the present margin of the Fell of Saana and creates its silhouette (Fig. 2).

Fig. 1. The Fell Saana is the hallmark of the Finnish Caledonian margin area. It rest on a Precambrian basement and, behind the talus blocks, it consists of slates and dolomites, which are capped by an overthrust sheet of arkose quartzites. Photo by P. Johansson.

Fig. 2. The silhouette of the Fell Saana behind the Lake Kilpisjärvi. Photo by P. Johansson.

Finland's northwestern part is favourable as a growth spot for demanding species because of calciferous dolomite bedrock. There are various mountain plants, which do not grow in any other part of Finland. Most of these rarities are protected by law. Examples of these plants are Glacier Crowfoot (*Ranunculus glacialis*), the Hairy Lousewort (*Pedicularis hirsute*), the Arctic bellflower (*Campanula uniflora*), the Alpine Fleabane (*Erigeron borealis*) and *Rhododendron lapponicum*. The *Ranunculus sulph*ureus grows in the area's snow beds and Mountain Tobacco (*Arnica augustifolia ssp. alpine*) and the Snow Cinguefoil (*Potentilla nivea*) are found on calciferous cliff-faces.

You can climb to the top of Saana along a trail, which starts at the Kilpisjärvi tourist centre. The trail is 8 km long. There is also a 12 km long hiking trail which circles Saana.

On the other side of the highway there is Malla Strict Nature Reserve. It is Finland's oldest strict nature reserve, established in 1916. Because the area has calciferous bedrock and till cover, there is a diverse array of fell vegetation there. Three nations' Border Point (Finland, Norway and Sweden) is located 11 km to the west from the village of Kilpisjärvi.

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Stop 9: Steindalsbreen glacier, northern Norway

Pertti Sarala and Niko Putkinen

A one-day-trip to northern Norway include a bus drive 1) from Kilpisjärvi to Skibotten village through the border zone of Finland and Norway over the Norwegian mountains, 2) driving following the Storfjord of Atlantic Ocean from Skibotten to Storeng village, and 3) visit to the Steindalsbreen glacier.

Steindalen is located on the eastern side of the Lyngen Peninsula. The glacier front is situated just 460 m a.s.l. and the walk up to it takes about a couple of hours. Several localities with different glacigenic morphologies and phenomenon along the way reveal the glacial and landscape evolution history of the area and how the glacier has retreated after the ice age. For example, the glacigenic sediments and the ice front deposition environment with end moraine ridges, deformation till and meltwater sediment deposition and sandur fields can be seen during this trip (Fig. 2).

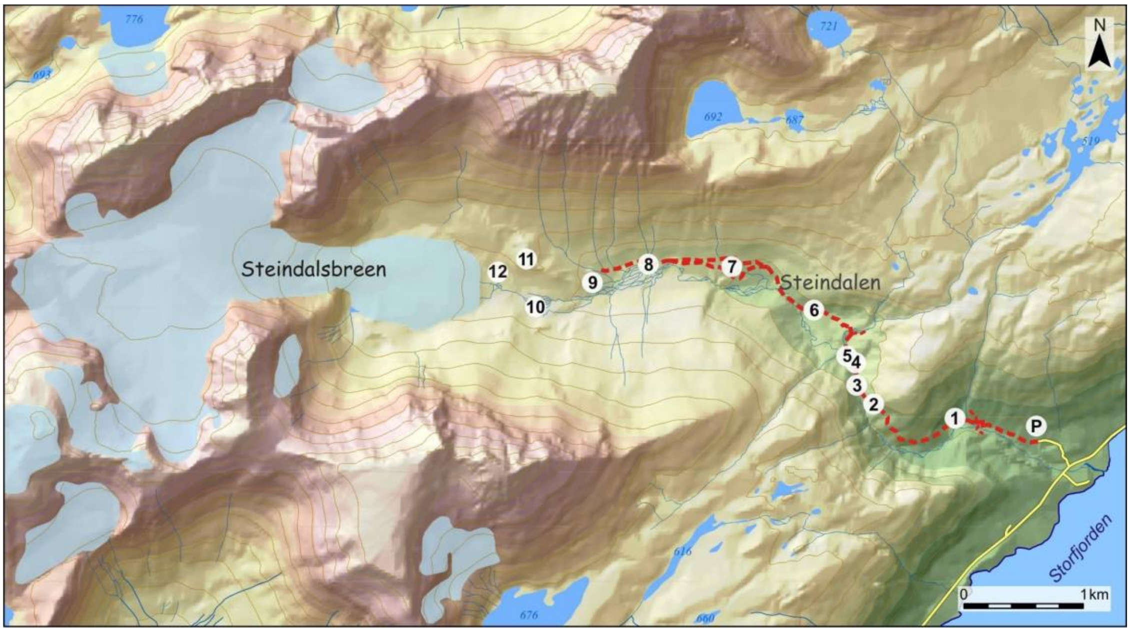

Fig. 1. Map showing the root from the fjord to the Steindalsbreen glacier. Twelve localities are also marked after Corner (2008): 1) River terraces, 2) rock treshold, 3) rapids, 4) rockslide moraine, 5) rock flour, 6) end moraines, 7) valley side fans, 8) outwash plain, 9) moraine ridges, 10) kettle hole, 11) view to the glacier and 12) glacier.

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Fig. 2. Photos from the Stendalsbreen glacier. Upper left overview to the glacier, upper right outwash plain, down left rapids in the river valley and down right till material releasing from the glacier. Photos by P. Sarala.

Stop 10: Iitto palsa mire

Peter Johansson

Palsa means a giant peat hummock, which rise above the mire surface in the zone of discontinuous permafrost. They contain perennially frozen peat with segregated ice and small ice crystals. The frozen core is surrounded by unfrozen peat and mineral soil underneath. In Finland the diameters of palsas range from a few meters to several tens of meters and their height from less than 0,5 m up to 7 m in Finland. At Iitto the largest ones are almost five meters high (Fig. 1). The surface peat on a palsa mound is produced mainly by Bryales mosses, lichens and Ericales schrubs. It can be also old moss peat eroded by wind. Below the dry surface, peat is the original mire peat formed of Sphagnum, Carex and Eriophorum remains (Seppälä, 2006). When the palsa grows in height, its peat surface cracks. Pieces slide down the slopes. As a consequence the palsa loses its insulation layer, the frozen core starts to melt, and finally the palsa collapses. When the cores of palsas have thawed completely, thermokarst hollows may form closed ponds that indicate the former distribution of palsas (Luoto and Seppälä, 2003). The recent trend has been for palsas to thaw, rather than for new palsas to be formed (Seppälä, 2005a).

Fig. 1. The palsa mounds at Iitto. Photo by P. Johansson.

Palsa mounds require dry and cold winters to develop, as well as a snow cover which is kept partly thin by wind. Frost can penetrate deeply into the peat already in early winter. This causes initial upheaval of the surface, and during subsequent winters the hump has a greater tendency to become snow-free and the thickness of the frozen layer increases. An insulating peat layer is important for preserving the frozen core during the summer. The peat should be dry during the summer, thus having a very low thermal conductivity, and wet in autumn, when the freezing starts, giving a much higher thermal conductivity. This allows the cold to penetrate so deep into the peat layers that they do not thaw during the summer (Seppälä, 2006).

Palsas mainly occur in northernmost Finland between 180 and 390 metres a.s.l. (Seppälä, 2005a). Palsas are found in valleys where the insulating peat layers are thick enough (50 – 70 cm) to preserve the frozen core from thawing but the snow cover is thin enough to let cold penetrate deep into the peat layers. The southern limit of the palsa region in Finnish Lapland, 68° 30’, coincides with the -1°C mean annual air temperature isotherm and has an annual precipitation below 400 mm (Fig. 2). Less than half of precipitation is snow, received during 8 winter months when the air temperature is below zero.

According to radiocarbon datings most palsas are less than 1000 years old (Seppälä, 2005b). By means of plant macrofossil analyses, physico-chemical analyses and AMS-radiocarbon dating of peat deposits Oksanen (2006) concluded that the first permafrost aggradation on a palsa mire in North Finland took place c. 2460 years B.P.

The Iitto palsa mire is an official mire protected area. The different stages of palsa can be found there: embryos, growing mounds, melting mounds and mounds that have already collapsed. The area is also used for research and education. A wooden boardwalk trail leads the visitor to the palsa mounds. The information boards by the trail tell about the structure of palsas and their life span.

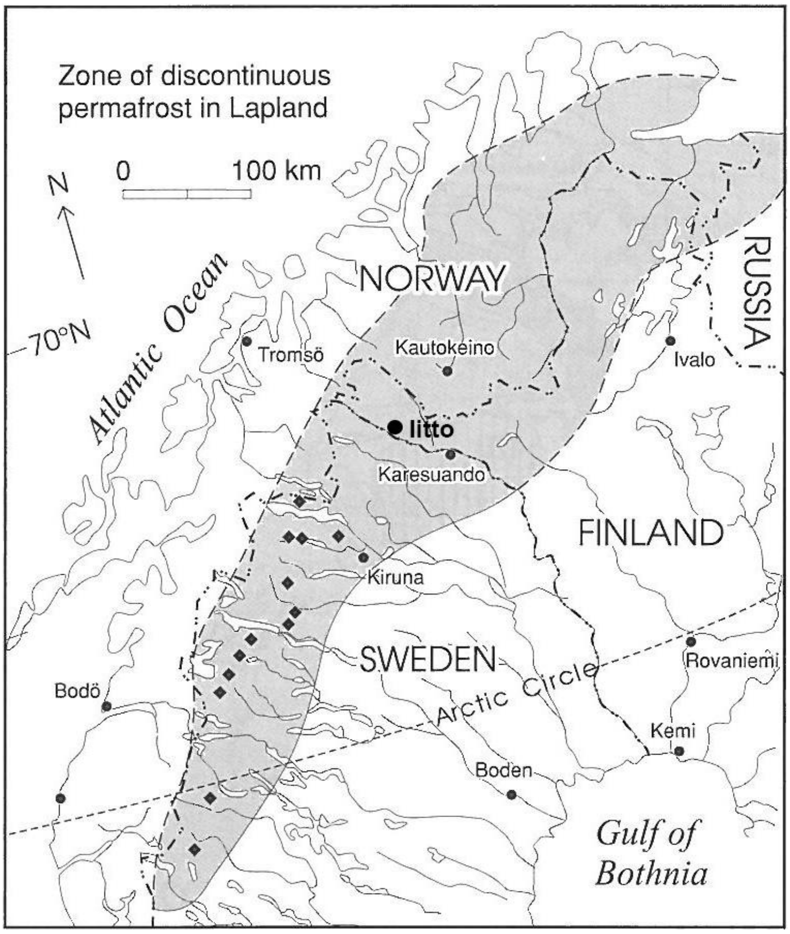

Fig. 2. Distribution of discontinuous permafrost on northern Fennoscandia. Shaded area represents the zone of palsa mires at low levels according to Seppälä (1979).

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Stop 11: Könkämäeno Ice Lake and Siikavuopio extramarginal deltas

Peter Johansson

In the final part of the Weichselian glaciations, around 10,500 – 10,200 years ago, extensive areas in Muonio River valley and in Könkämäeno River valley were covered by an ice lake. The ice lake was formed, when the glacier margin retreated towards the south and dammed the melt waters flow to the south along the Muonio and Tornio river valleys. The oldest spillway lied in Kilpisjärvi at Galgunjarga, 525 meters level from the present sea level, from where the waters flowed northwards over the water divide to Skibotn and Barents Sea. The spillway may still be seen as a steep-walled, 10 m deep overflow channel gorge at the Finnish/Norwegian border (Fig. 1). It was generated even before the ice lake phase, as it was originally the conduit for the glaciofluvial melt waters. The next spillway was at Kolttajärvi, at 493 meters level, near the Three Nation's Border Point, where the borders of Finland, Norway and Sweden meet. From there the waters flowed to the Stordalselva River valley and Barents Sea.

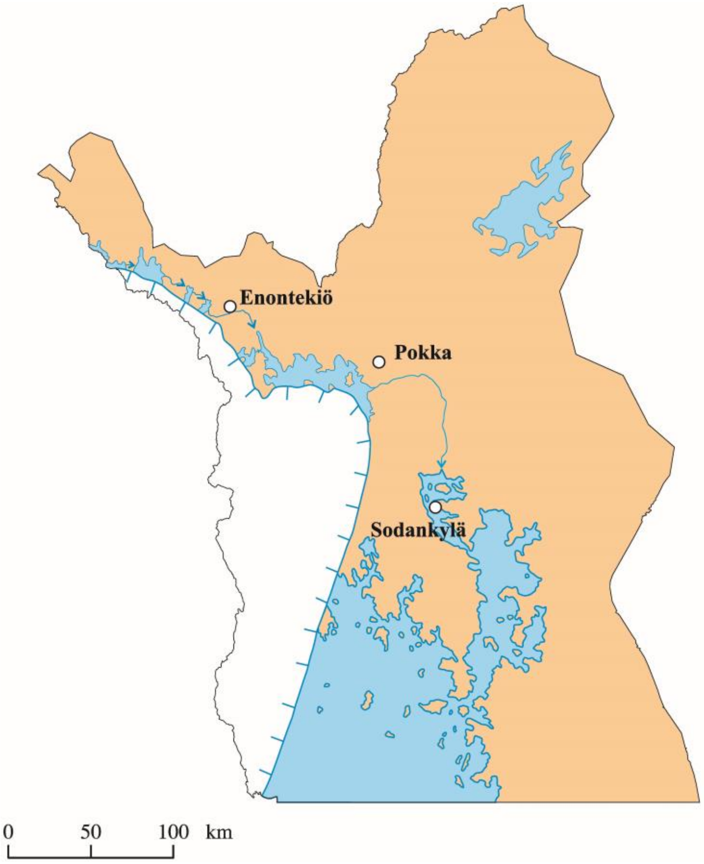

Fig. 1. Position of the glacier margin and ice dammed lakes about 10,200 years ago.

Subsequent spillways of the Könkämäeno ice lake formed marginally between the ice margin and the Kalkkoaivi – Ruossakero fells. The ice lake drained stepwise towards the east to Lätäseno and Tarvantojoki river valleys and left several spillways that may be observed at 515, 500, 415 and 367 meter levels from the present sea level (Fig. 1) (Johansson and Kujansuu, 2005). When the spillway was opened at Autsasenkuru Gorge, the ice lake stayed at 415 meters level for several decades forming littoral boulder belts and rocky wave-washed zones. At Siikavuopio extramarginal deltas were formed in the ice-dammed lake by subglacial melt waters. These extramarginal deltas (Fig. 2) are seen on the western side of the Könkämäeno River valley in Swedish side of the border (Tanner, 1915; Kujansuu, 1967).

Fig. 2. Extramarginal deltas at Siikavuopio, Sweden. Photo by P. Sarala

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Stop 12: Fell Lapland Visitor Centre in Hetta

Fell Lapland Visitor Centre is one of the Finnish Nature Centres managed by Metsähallitus, the Finnish Forest authority. Focus in this centre is in fell nature, nomadic Sámi culture, history of northern Finland and Enontekiö region. The exchibition gives colourful overview to the polar nights of winter and the sunlit summer nights, Hetta's open pine and birch forests give a powerful taste of the real Lapland. There is also Vuovjjuš – Wanderers exhibition which tells about the nomadic Sámi culture and northern nature. More info at http://www.nationalparks.fi/en/felllaplandvisitorcentre

Photos: Maarit Kyöstilä.

Stop 13: Hietatievat and the aeolian erosion in Finnish Lapland

Peter Johansson

Discontinuous permafrost area occurs throughout the Arctic. In Finnish Lapland it covers some 15,000 km^2. There are many aeolian landforms to be found in this area. They are inland dunes, which have been created in periglacial conditions as a result of the action of northwesterly winds soon after the deglaciation, around 10,500 – 9,000 years BP. At that time the plant cover was sparse and the climate still relatively dry and cool. The actual dune formation came to an end by the time pine spread to the region at the beginning of the postglacial climatic optimum, about 7,000 years BP. Later the dune formations have undergone only surface deformation (Seppälä, 1974; Tikkanen and Heikkinen, 1995).

Hietatievat is situated in eastern Enontekiö, in Finnish Lapland (68° 28’ N and 24° 42’ E). It is a part of a larger system of eskers which begins at Kätkäsuvanto, in Muonionjoki River valley, crosses the Pallas-Ounastunturi Fell ridge and continues to the NE to the Norwegian border. Hietatievat itself is a broad rolling esker ridge, about four kilometers long and one and half kilometers wide. The relative altitude of the esker ridge is 35 meters and its highest parts are 385 m a.s.l. The forests of Hietatievat consist of fell birch (Betula pubenscens) and single pines (Pinus silvestris). The region is not very far from the northern limit of the pine.

On the esker itself and on its edges have been deposited sand dunes, which are at present partly anchored by vegetation and are partly open blow-outs (Fig. 1). The largest dunes lie to the eastern side of the esker, running parallel with the esker ridge and rising from 4 to 10 meters above the surface of the mires at the edge of the dunes. The grain size distribution of the sediments in many eskers makes them suitable for aeolian transport. Having already been sorted by melt waters from the ice margin, it has been easy for the wind to sort and accumulate the sediments into dunes. At Hietatievat dunes are asymmetric and of varying morphology. The development of dunes began with the accumulation of aeolian sand transverse to the direction of wind which was from the NW. As the dune migrated it usually developed into a parabolic form with the arc opening upwind. When the horns of the dune increased in length the dune broke into two adjacent dunes that the wind then straightened into parallel longitudinal dune ridges. The dunes at Hietatievat compose of sand with an average grain size of 0.2 mm. The aeolian processes are effective only in summer time and they are almost absent in winter, when the dunes are under the snow. The average rate of sand transportation is about 0.150 g/cm/h. Mean annual accumulation rate at the edges of blow-outs is 2.1 cm. If the sand accumulation rate is constant, then a two meters high dune will form in 100 years (Seppälä, 1974).

Fig. 1. Hietatievat dune area seen from the air and ground. Deflation basins with flat-topped juniper bushes growing along the edges are typical. Photos by P. Johansson.

At Hietatievat the largest active vegetationless deflation basins is about 5 hectares in area, and more than 3 meters deep, in some cases 10 meters. Deflation basins are in connection with the dunes and the sandy esker ridges. At Hietatievat there were found old organic horizons with charcoal buried in the dune sand (Seppälä, 1995). The charcoal is as a consequence of forest fires in the dense pine forest. By radiocarbon datings many of them have been accumulated thousands of years ago (3230 ± 120, Hel-516, 3690 ± 150, Hel-590), when the region was covered by pine forests (Seppälä, 1995). Many of the fires must have been started by lightning. Obviously the deflation activity often began as the forest fire destroyed the vegetation cover responsible for binding the aeolian deposits (Kotilainen 1991). The last large forest fire was recorded about 1825 A.D. according to dendrochronological measurements of a living pine. Burnt wood gave a date 140 ± 90 (Hel-517) and the age of a charcoal layer from a redeposition layer was 170 ± 120 (Hel-592). Both dates correspond well with the dendrochronological results (Seppälä, 1995).

The last distinct phase of destruction of aeolian deposits occured in more resent centuries. It has been attributed sometimes to the climatic deterioration of the Little Ice Age and also to human interference in form of careless use of fire. The Samí people and the Finnish settlers used fire for the trapping of wild reindeer with pits. Probably these fires spread into extensive forest fires from time to time, often destroying the entire vegetation cover. And so erosion started again, along with sand transport and deposition.

During the present century the human interference in the form of the grazing of reindeer is nowadays the main reason for deflation activity and soil erosion. The reindeer husbandry is an important line of business in Lapland and it is closely connected with the culture of the Samí people. The most extensive damage is found near reindeer fences and roundup corrals, where the reindeer as well as the terrain vehicles used in reindeer management have broken up the plant cover. Erosion of the aeolian deposits has started, as shown by the occurrence of barren deflation areas, blow-outs and embryonic dunes, which have formed on the surface of the sand.

The sandy glaciofluvial and aeolian landforms at Hietatievat area offer good examples of various stages of soil erosion caused by a combination of wind, frost, overgrazing by reindeer, trampling by man and /or reindeer, construction of roads, excavations for cables and use of motor vehicles (Johansson et al., 1995). If the annual rate of erosion is more than 2 cm, it is sufficient to ensure that no plants can take root on a sandy patch. Once the deflation basin has formed, recovery of the vegetation is a very slow process under the subarctic conditions. In northern Finland tourism connected to natural attractions is a rapidly growing industry, too. The impact of expanding holiday resorts may soon have an even more detrimental influence upon the vegetation. As a result of a national esker protection program, some areas of aeolian deposits covering eskers are now protected. In tourist areas, it is possible to keep visitors on the marked hiking trails and vehicle routes by arranging guided tours and trails with information signs, so that the surroundings are kept fairly untouched.

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Stop 14: The ring ridges of Pulju moraine type

Peter Johansson

In northern Finland morphologically annular or curved moraine hummocks are called Pulju moraines. In aerial photographs they appear worm-like and winding, forming areas of hummocky moraine on valley bottoms and hollows. They are typical especially north of the late Weichselian ice-divide zone, in Inari, in Enontekiö and in the northern part of Kittilä (Aartolahti, 1974). The largest and most well-known area of occurrence is around the village of Pulju, hence the name of this moraine type (Kujansuu, 1967).

The structure and till stratigraphy of the moraine hummocks and their relation to the ice-flow directions were investigated using air-photo interpretation, hydraulic drilling, and by digging test pits with an excavator (Fig. 1) (Johansson & Nenonen, 1991). Drilling and test pit sites were chosen from different parts of the moraine ridges; on crests of the ring ridges, on proximal and distal slopes, in hollows inside the ring ridges, and between the ridges. Stratigraphical interpretations, sampling and till fabric analyses were carried out in the investigated area.

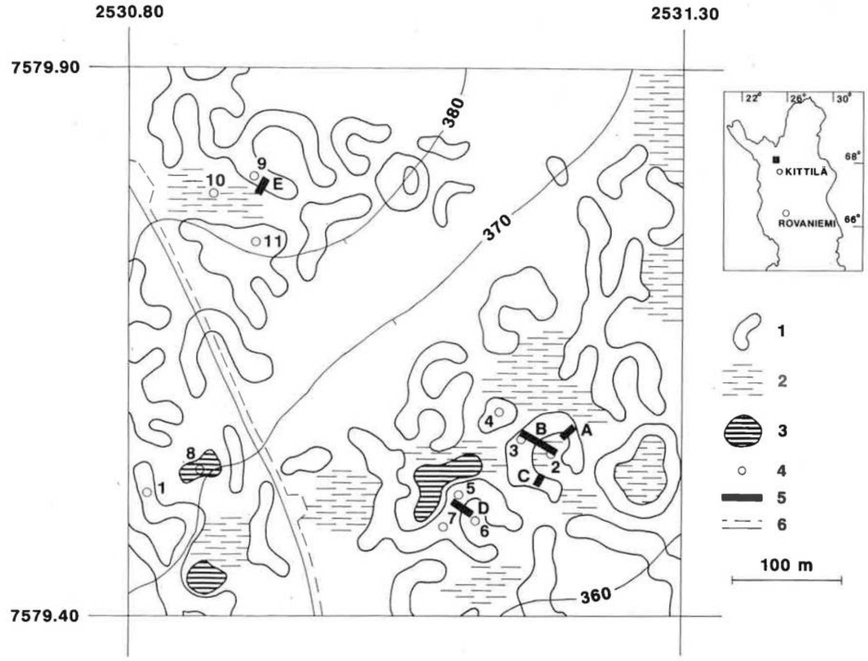

Fig. 1. Investigation area at Pulju. 1 = Pulju moraine ridge, 2 = mire, 3 = pool, 4 = drilling site, 5 = test pit, 6 = road.

The Pulju moraine ridges are seldom full circles. Instead, they are mostly open on one side and interconnected. Their diameter varies from 20 to 150 m. The height of the ridges varies between one and four meters. The hollow of a ring ridge lies two to five meters below the crest. As a result of paludification the thickness of the peat varies between one and two meters. There are considerable height differences in the water level of the mire pools between adjacent hollows indicating poor water permeability in the ridge till material.

Three distinct till units were distinguished (Fig. 2). The lower till unit is dark-grey and dense in structure. The material is stony sandy till. The thickness is more than three meters. The total thickness is unknown, because the solid bedrock was not surely reached. Its upper contact is even and has not been influenced by the overlying till units or their thickness. The middle unit is looser than the lower one, and grey brown in colour. Streaks caused by precipitation can be observed between stones. The thickness varies between two and five meters, being thickest in the ridges and thinnest in the central hollows. The upper unit is light brown in colour, loose, and sandy till with thin sandy lenses and layers. In the lower parts of the ridges and in the central hollows the upper till unit consist almost solely of sand with structures caused by flowage. On the crests of the ridges, the upper unit is from 0.8 to 1.2 m in thickness, and in the hollows about 0.5 m.

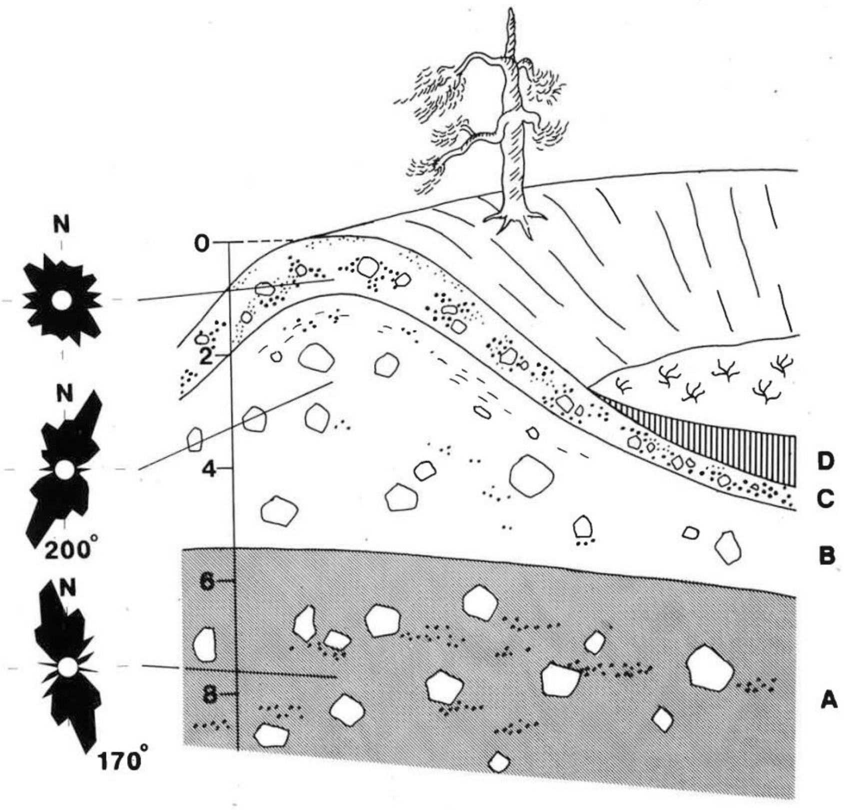

Fig. 2. The stratigraphy of the Pulju moraine ridge (according to Johansson & Nenonen, 1991). A = lodgement till, B = basal melt-out till, C = supraglacial till, D = Postglacial peat.

The till fabric of the lowest till unit varies from 170° to 190°. It is equal to the younger southerly direction of ice flow and it is consistent throughout the test pits. In the middle unit, clear orientation is distinguished which, however, parallel with the crest orientation. The upper unit shows no orientation or ambiguous orientation, and does not correspond to the direction of the ice movement.

The lowest stratigraphic unit consists of lodgement till, which has been interpreted while having been formed during the Late Weichselian stage in the ice sheet base as the glacier was flowing northwards from the Central Lapland ice divide zone (Hirvas, 1991) (Fig. 3). This is implied by both the physical properties of the till material and the results of the fabric analyses. Its upper contact forms a gently undulating even surface, upon which the younger till units were deposited.

The middle unit is basal till interpreted as having been formed as basal melt out till near the margin of the glacier, in its basal part. It forms the core of the Pulju moraine ridge which was formed during the deglaciation stage when the ice margin had broken up into blocks and the weight of the ice blocks forced the water-saturated till upwards into the crevasses and fractures of the ice sheet base (Fig. 3). The stones of the till were oriented transversely with respect to the direction of the squeezing and movement of the till. The till fabric correspond to the results obtained by Aartolahti (1974) from the so called lower till unit. In the Kaaresuvanto area the till fabric of the ring ridge moraines is parallel to the direction of the active ice movement (Aario, 1990).

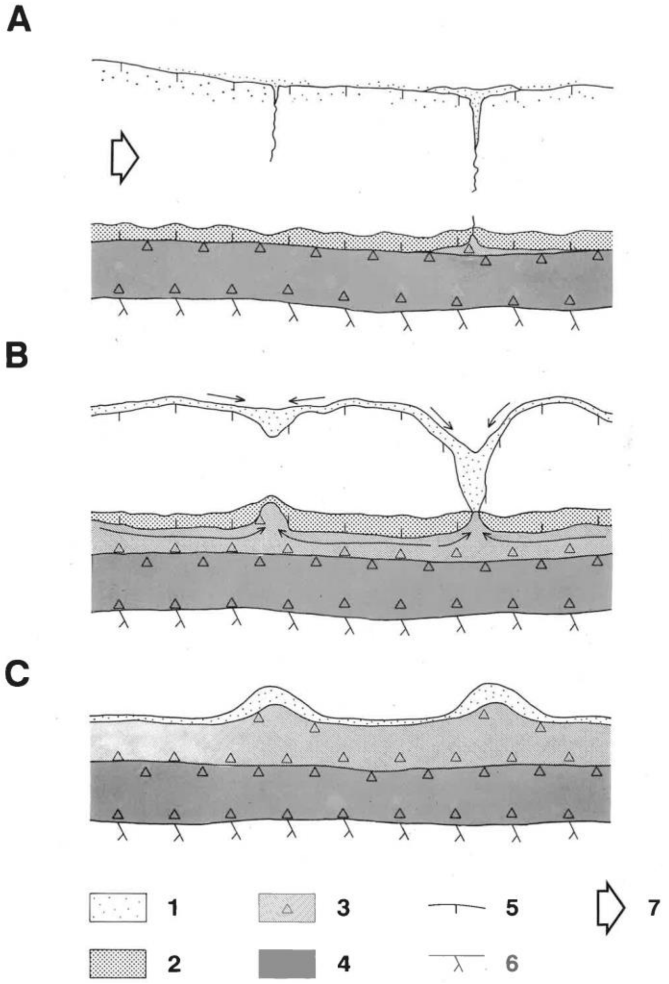

Fig. 3. Graphic presentation of the genesis of Pulju moraine ridges. 1 = supraglacial debris and till, 2 = subglacial debris, 3 = basal melt-out till, 4 = lodgement till, 5 = glacier, 6 = presumed bedrock surface, 7 = ice flow direction. (according to Johansson & Nenonen, 1991).

The upper unit is formed from supraglacial material accumulated on the ridges in the weak areas of glacier and in the ice fractures. The varying topography of the area, especially the mountainous area to the south formed obstacles and contributed to the breaking up of the ice margin. The basal parts of the ice margin which retreated to the south stagnated, and an area of melting dead ice was left. The ice margin broke down into blocks, which were deposited on the ridges and the supraglacial material fell in between these blocks (Fig. 3). As the ice blocks left in the hollows melted, they released meltwater which as it streamed down, made openings in the ridges. This is the reason why Pulju moraine rings are open downslope.

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Stop 15: Kulkujoki glaciofluvial delta and meltwater channel

Peter Johansson

In the final part of the Weichselian glaciations, around 10,500 – 10,200 years ago, extensive areas in Lapland were covered by ice lakes for centuries. The Muonio Ice Lake was formed in the Muonio River valley, when the glacier margin retreated towards the south to dam the glacier melt waters. The ice lakes in northern Finland were usually of short duration, only for a few years, but the Muonio Ice Lake most probable is estimated to have stayed at the same water level for tens of years. During this period of time ancient shorelines were deposited on the hills in Muonio area with typical landforms representing such as littoral boulder belts, boulder fields and rocky wave-washed zones (Johansson et al., 2005).

The oldest spill-way of the ice lake lied near the village Palojoensuu, at the 294 meters level, from where the waters flowed over the water divide to the Lake of Ounasjärvi and to the river basin of Ounasjoki. When the glacier margin had retreated south and reached the line Muonio – Keimiötunturi Fell, the ice lake was at its greatest extent. It covered an area about 800 km2. Because of the isostatic uplift was stronger in the southern part of the ice lake than in the northern part, the ancient shorelines are nowadays inclined towards north and lie about 15 meter higher (at 310 m level) than in the northern part.

When the retreating ice margin passed by Keimiötunturi Fell, a new outlet channel was opened marginally along the Kulkujoki valley at 293 m level (Kujansuu, 1967). The level of the ice lake dropped about 17 meters in a short time, which was a dramatic event during the time. The waters flowed eastwards to the Ounasjoki river valley where an ice lake was lying at about 218 m level. The discharge of the waters eroded the surficial deposits away and washed bedrock surfaces on the walls and floor of the valley (Fig. 2). This remarkable outlet channel is 7 km long, 600 m in width and 20-30 m in depth (Fig. 3). The material washed from the slopes and bottom of the valley were deposited to the northeast as a delta with several deposition levels in front of the channel. The melt-water flow ended when the retreating ice margin had passed by the Kolvakero Fell and a new channel at Pahtavuoma valley was opened at 278 m level.

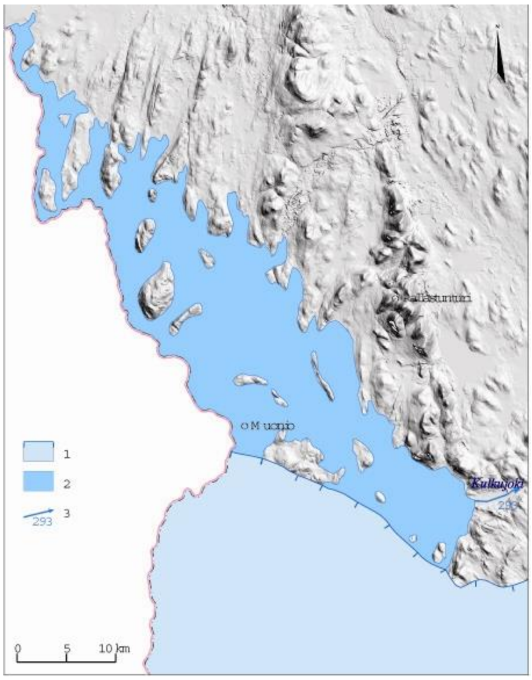

Fig. 1. At its greatest extent the Muonio Ice Lake covered an area of about 800 km^2. 1 = glacier, 2 = ice dammed lake and 3 = spillway with attitude.

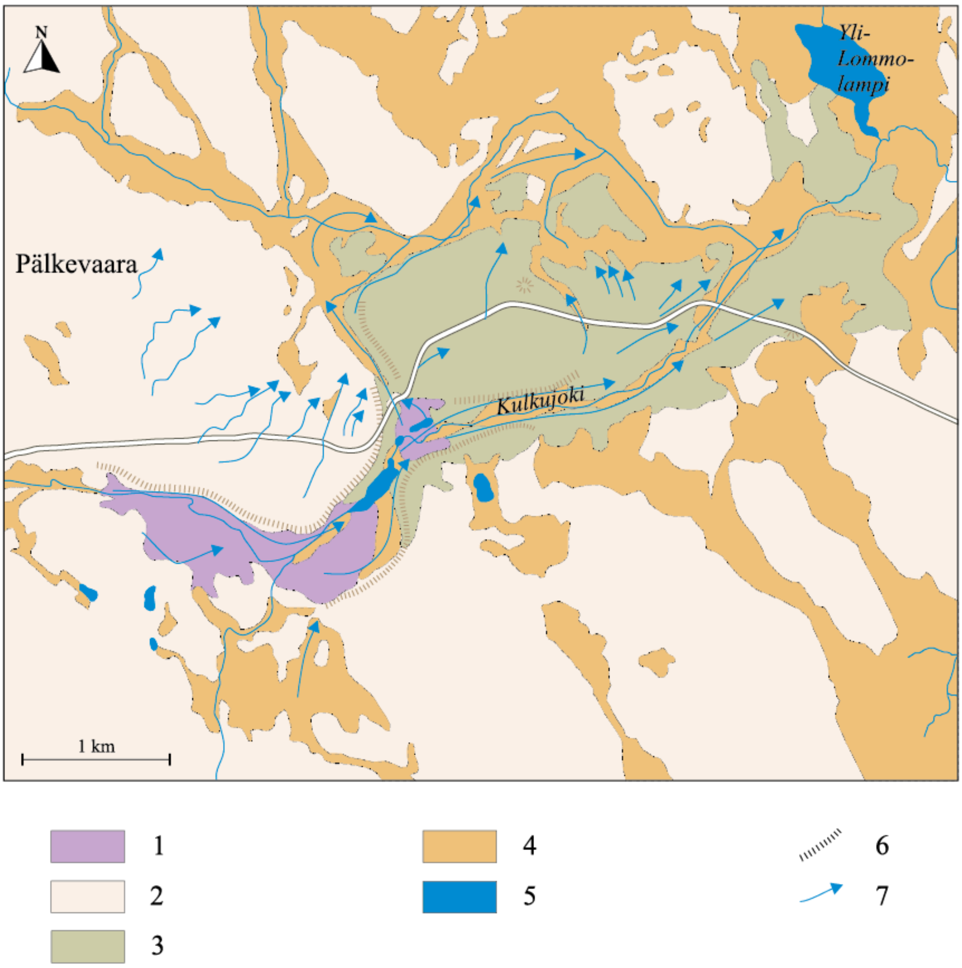

Fig. 2. A map of the outlet channel of Kulkujoki, Kittilä. 1 = delta gravel and sand, 2 = washed bedrock surfaces in the channel, 3 = till, 4 = peatland, 5 = delta, 6 = erosion cliff and 7 = direction of meltwater flow.

Fig. 3. Rock exposures worn by outflows from the Muonio Ice lake at Kulkujoki. Photo P. Johansson.

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Ylläs

Ylläs is the one of the most attractive nature tourism and winter sport centres in Finland. It has many different kind of activities to offer, variety of services, events and new experiences for you on your holiday. Travel and tourism lives strongly in the area and the local people are genuine. There is two different Lappish villages in the area; Äkäslompolo village and Ylläsjärvi village. There are total of 850 persons living in the area. There are 63 prepared ski slopes in Ylläs. Finland's largest vertical drop and the longest ski slope are both in the Ylläs Ski Resort.

Pallas–Yllästunturi National Park

The landscape of Pallas–Yllästunturi National Park is dominated by fells (Fig. 1) and the unscathed forests and wetlands surrounding them. The well-marked trails, clean and beautiful nature and varied terrain of the area provide excellent opportunities for trips and wandering in nature. The fell range in the national park is almost one hundred kilometres long in total. The picturesque, beautiful Pallas fells have been chosen as one of Finland's national landscapes. Visitors to the national park are served by a large network of resting places and wilderness huts and the unique chain of three nature centres of the Forest and Park Service (Äkäslompolo, Pallas and Hetta).

Fig. 1. A scenery over the Ylläs fell. Photo by Krsitina Lehtinen.

The lateral drainage channels at Ylläs

Peter Johansson

The fell area of Ylläs, in western Lapland, including the fell tops of Ylläs, Lainiotunturi and Pyhätunturi was favourable for the meltwater activity (Kujansuu, 1967; Abrahamsson, 1974). At the final stage of the deglaciation the warm based ice lobes covered the valley floors while the summits and the upper slopes remained nunataks. The supraglacial snow and glacier melt streams ended up to the contact between the ice margin and the sloping fell side to erode lateral melt water channels during the summer. This phenomena has a strong seasonal control and during the melt seasons new cracks are formed to the glacier margin allowing the melt waters evolving new subglacial routes to the new glacier margin position. This mechanism explains how a large set of sequential ice marginal channels were formed on the Lainiotunturi Fell side to reflect the position of the ice margin during the various stages of deglaciation (Fig. 1). Spacing and rates of channel formation were controlled by the slope topography, erodibility of the till surface and melt stream discharge capacity.

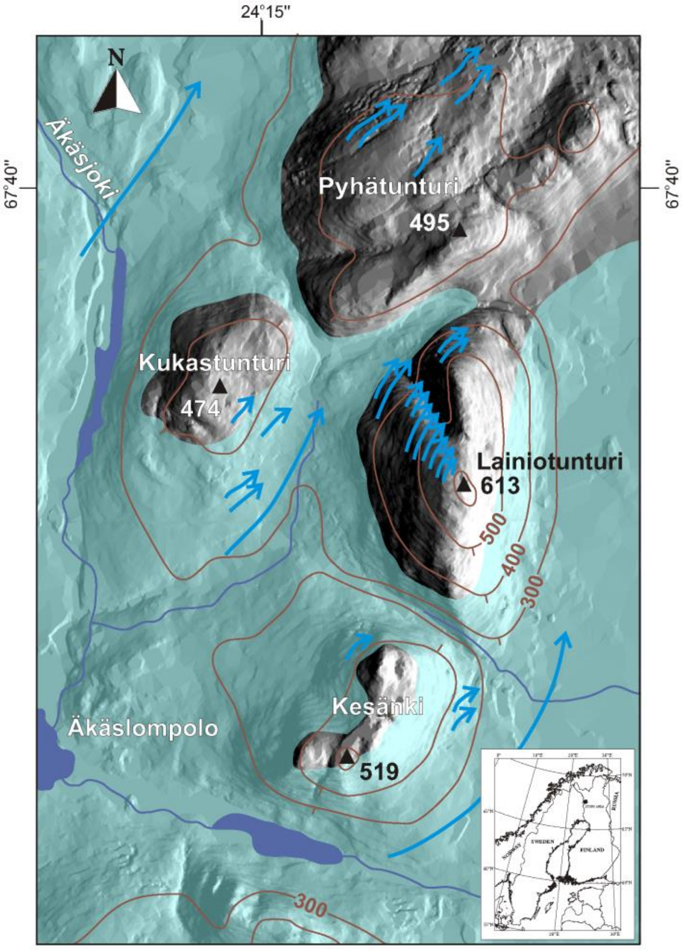

Fig. 1. The location of Lainiotunturi Fell and the succession of the retreat of the ice margin.

At Lainiotunturi Fell the lateral meltwater channels begin inconspicuously about 30 m below the fell top. On the upper slope, between the levels of 590 and 510 m there are about 46 channels, one below the other. The channels have been eroded into a sandy till where the land surface slopes between 6° and 7°. The landforms are clearly visible in the terrain, almost straight depressions, about 100 – 250 m long, 1 – 1.5 m wide and less than 0.5 m deep. Their profile is asymmetric with a 30 – 60 cm high upper side and a 10 - 20 cm high lower side. Some of the smaller channels, which have only an upper side, form a step or terrace. The channels on the upper slope are gently inclined toward northeast, about 2 – 2.5 m per 100 m. Their vertical distance is 1.1 – 2.5 m and horizontally they are 5 - 10 m apart (Fig. 2).

Fig. 2. At high elevations the channels are often short and shallow, less than 0.5 m (upper photo). Some have a gougelike form, whereas others may simply have a cross-section that resembles a step or a terrace cut into the till. On the lower fellside the lateral and sublateral drainage channels are distinct and 2 – 4 m deep (lower photo). Photos by P. Johansson

Between the elevations of about 510 and 460 m the slope gets steeper, up to 9° - 10°. Here the number of channels is about 25. They increase in length to 200 – 400 m. They are 1 – 1.5 m wide, 0.5 m deep, and asymmetrical but clearly gouge-like in profile, winding on the slope. The channels slope to the northeast by about 2.5 - 5 m per 100 m. The vertical distance between them is 1.3 – 1.5 m and the horizontal on average 10 m. Between the elevations of about 460 m and 415 m the slope gets still steeper to 12° - 14°. The channels number about 20, but they are weakly developed, diffusely formed elongated depressions or some tens of meters long and 0.5 – 0.7 m deep.

At low elevations, between the levels 380 – 415 m, the land surface slopes between 3° and 7°. The channels are distinct. Their length ranges from 100 to 400 m, they are 1 – 6 m deep, and the vertical distance is 3 – 10 m and the horizontal 15 – 25 m (Fig. 2). This is due to the fact that the rate of melting and the volume of the meltwater were greater as the ice lobe diminished. The lateral channels are commonly open at both ends, beginning and ending inconspicuously. They may also terminate in downslope chutes as meltwater was diverted into the glacier via a crevasse (cf. Michelson, 1971). There are also examples of how meltwater concentrated only along one margin of the ice lobe, due to the fact that this area was in a position to receive solar radiation while the opposite margin was in the shade most of the time. At Lainiotunturi Fell the majority of the lateral meltwater channels are situated between altitudes of approximately 380 m and 580 m. The deepest channels were formed at the sides of the ice lobes since the water flow and erosion here was strongest. On the proximal slopes of the nunataks, the gradients were gentle and the channels that formed were shallow.

The lateral meltwater channels are essential for the study of the melting of the glacier, including the thinning and retreat of its margin. According to Kujansuu (1967) the lateral meltwater channels resemble the varved clays of the supra-aquatic area. They cannot be directly connected to the annual retreat distance of the ice sheet, but they make it possible to define the positions of the ice margin with great accuracy. Regular series of channels enable us to get a picture of the gradient and direction of the ice sheet inclination and of the thinning of the ice. The same view has been arrived at by Mannerfelt (1945, 1949), Sissons (1961), Penttilä (1963) and Johansson (1988, 1995). Lateral meltwater channels in the process of being formed or recently formed, have also been found at the margins of present-day glaciers, and it has been possible to follow this process for years (Schytt, 1956; Dyke, 1993; O'Cofaigh et al., 1999; Hättestrand & Stroeven, 2002). Especially series of shallow lateral meltwater channels on gentle slopes have shown such regularity that it has been possible on the basis of them to trace the margin of the ice sheet in great detail and to calculate its thinning. In some places the annual withdrawal of the ice has been followed, too.

At Ylläs area the gradient of the retreating ice masses ranged from 2.5 m near the top of the fell to 5 m each 100 metres in the lower areas, indicating steepening of the ice margin at its snout. The ice margin thinned approximately 1.2 to 3.5 m per year. The channels have been used to delineate the retreat of the ice margin, as well. In some favourable places, the individual channels are regular and the distance between them remains almost constant. There they may have formed due to the annual rate of recession of the ice margin. The rate varied in different parts of northern Finland. In the most northern and eastern parts of Lapland, which deglaciated around 10,800 – 11,300 years ago, the recession of the ice margin varied 70-130 m per year. In the final phase of the deglaciation in western Lapland, ca. 10,000 years ago, the rate of retreat increased to 120-220 m. This illustrates the climate warming and the contraction of the continental ice sheet, which in turn accelerated melting and the retreat of the glacial margin. The results from the lateral channels are compatible with the general development trend of deglaciation in north-western Finland (Kujansuu, 1967).

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Stop 16: Hannukainen

Pertti Sarala & Juha Pekka Lunkka

Finnish Lapland is an area where a number of sediment exposures show stratigraphical sequences laid down during Pleistocene glacial and interglacial periods. There are numerous sites particularly in central and western Lapland where more than three till beds occur representing (e.g. Hirvas, 1991; Johansson et al., 2011). Sediment sequences are not only composed of separate till units but they are also interbedded with stratified sediments including organic remains that are useful for dating purposes (e.g. Hirvas et al., 1977; Hirvas, 1991; Saarnisto et al., 1999; Helmens et al., 2000, 2007; Mäkinen, 2005; Helmens & Engels, 2010; Sarala et al., 2010; Sarala & Eskola, 2011).

One of the recent sedimentological research campaigns was done in an open pit of the former Hannukainen Iron Mine in Kolari (Fig. 1), near the Ylläs ski resort (Salonen et al., 2014). Although there were large continuous sedimentary sections available for stratigraphical studies in 1980’s, the exposures remained unstudied until Salonen et al. (2014) carried out their investigations at the Hannukainen site. According to Salonen et al. (2014), ten different sedimentary units were identified in sections displaying a variety of depositional environments (glacial, glaciolacustrine, fluvial and aeolian). They are all – except for the lowermost, deeply weathered till – interpreted to be of Mid- or Late Weichselian/Holocene age. Five OSL samples from fluvial sediments give ages ranging from 55 to 35 ka, indicating two MIS 3 ice-free intervals of unknown duration. According to Salonen et al. (2014), results indicate that the Mid-Weichselian interstadial deposit was overridden by glacier and the re-advance event, which occurred later than 35 ka.

Several excavations, dating and structural measurements provide a fresh sedimentological data set, which gives an insight into this critical area for Finnish palaeoglaciology during the Mid-Weichselian. Salonen et al. (2014) examined four sections (LAU-1, LAU-2, LAU-3 and LAU-4; Fig. 2) to obtain the composite sediment record on the northern edge of the Laurinoja open pit (Fig. 3).

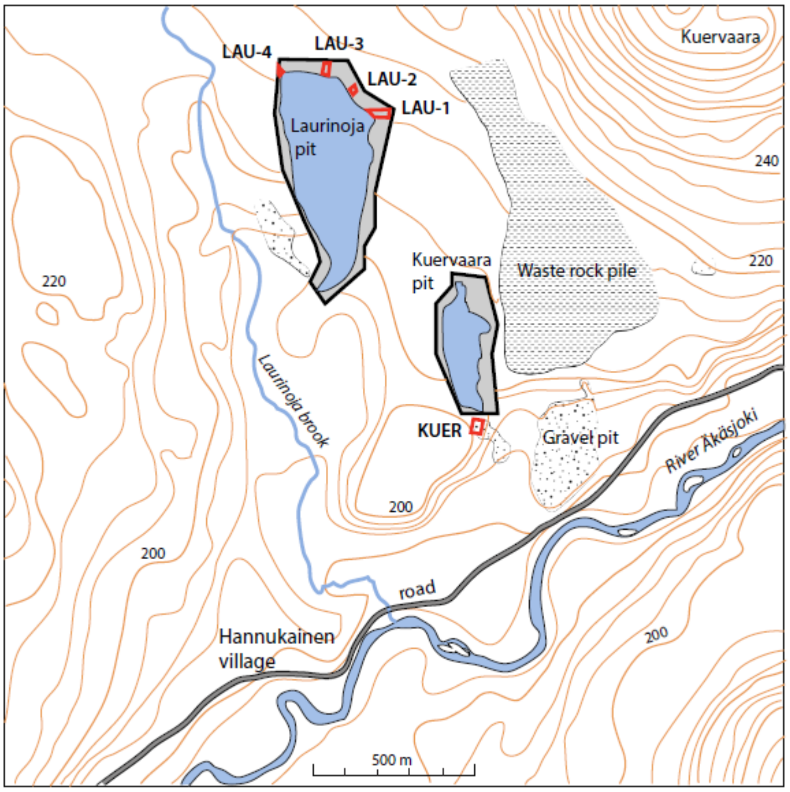

Fig. 1. Hannukainen open pits with the studied sections marked as red boxes. Contour lines are in m a.s.l. After Salonen et al. (2014).

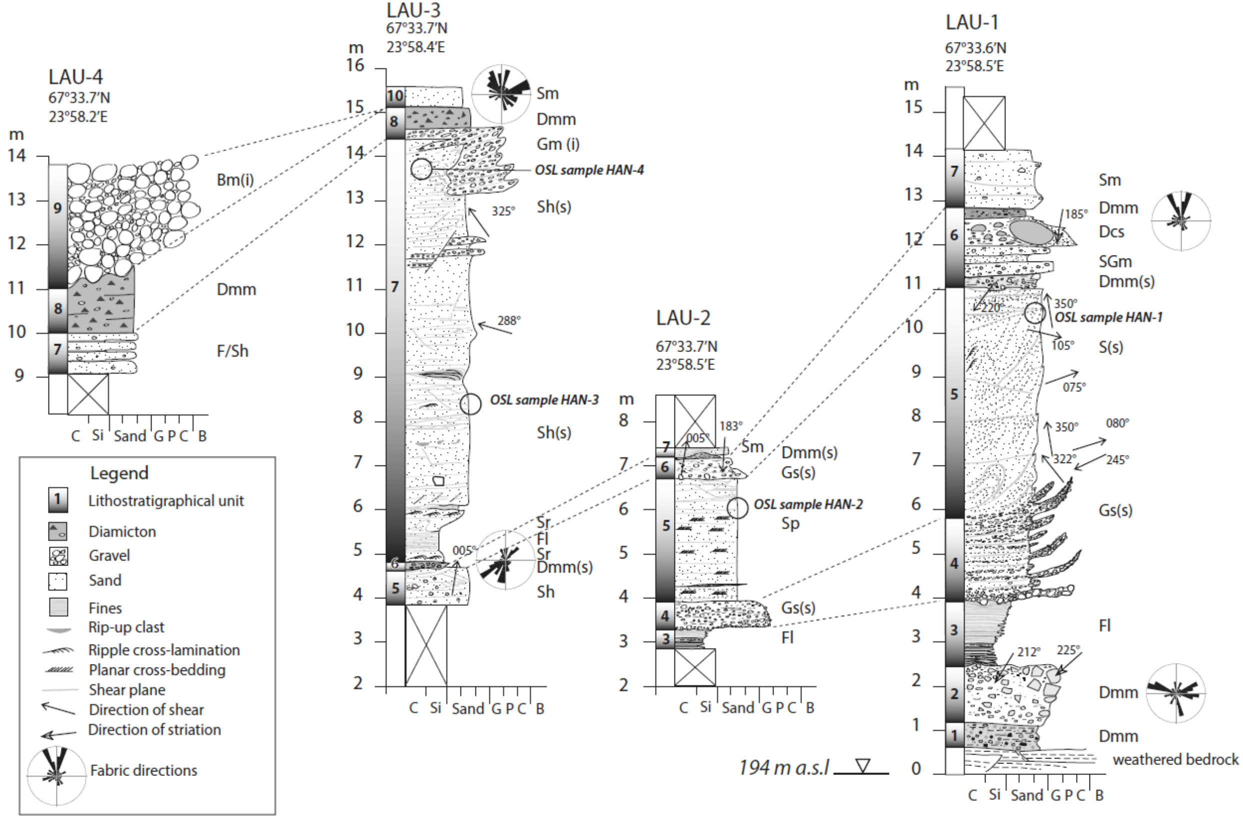

Fig. 2. Sediment logs at Laurinoja pit. See the location in Fig 1. After Salonen et al. (2014).

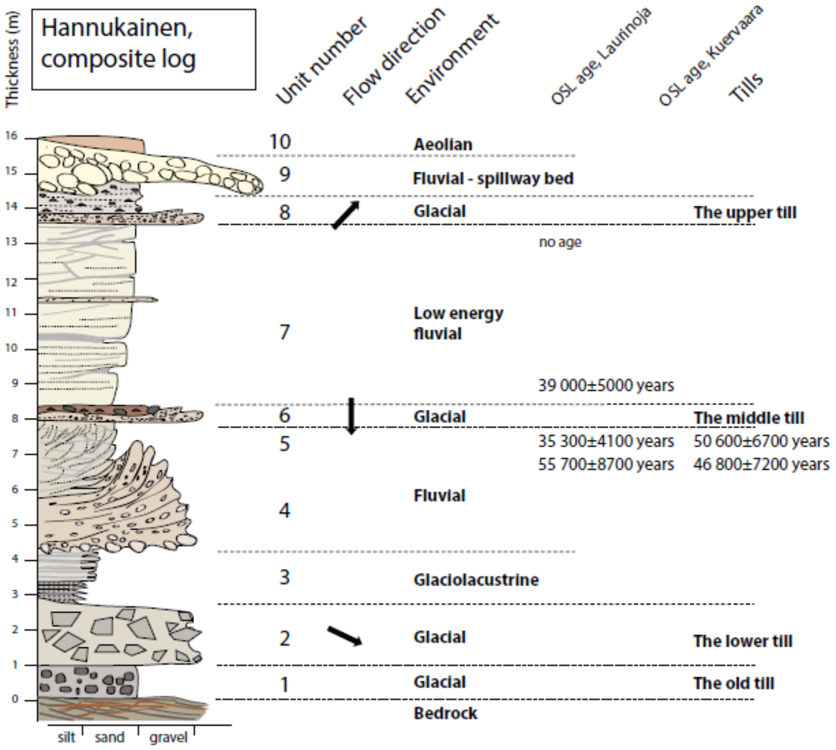

Fig. 3. Composite sediment sequence from the Laurinoja pit section with interpreted sedimentary environments and OSL dates. After Salonen et al. (2014).

According to Salonen et al. (2014) the sedimentary succession starts with two till units (massive, matrix-supported diamicton) that lay above the bedrock. The lower till unit (0.8-1.3 m thick) includes a lot of strongly weathered rock material and magnetite ore fragments from the underlying ore deposit. The upper till unit (1.3-3.0 m thick) displays crude stratification and includes more clasts which consists of unweathered silicate rocks of different lithologies. Till clast fabric is not well developed and only indications of an ice flow direction are a couple of abraded blocks with 225–045° and 212–032° striation directions on their top surfaces. Overlying units 3-5 are composed of different stratified sediments starting from laminated silt deposit (0.9 m thick) which is coarsening upwards. It is followed by a poorly sorted, coarse gravel unit (1.6 m thick) with rounded to subrounded 1–4 cm clasts mixed with medium sand. The upper part is crudely bedded and strongly deformed. Unit 5 above is composed of intensely deformed and folded sands (6.0 m thick) which were originally horizontally bedded and contain planar cross-bedded laminations and in places weakly deformed/sheared light grey medium sands.

Above the stratified sediments is a diamicton unit (unit 6), which consists of an association of crudely stratified and poorly sorted gravels, horizontally bedded sands, passing into a gravel-rich diamicton. The thickness of the unit varies between 0.1 m to 1.6 m and it is interpreted as till. It is displaying an ice induced shear stress in a north-to-south direction (003°, 185°).

Units 7 and 8 consist of stratified sediments, mainly of horizontally bedded sands having a total thickness of 8.6 m (Unit 7). These sands have some lamina, ripple laminations and flaser-wavy bedding on the upper part of the unit. Different deformation structures, shear planes also occur and they are more frequent towards the top of the unit. Unit 8 (c. 2.0 m thick) is separated into two associated parts, gravels at the base and diamicton at the top. The gravels are deformed and a few shear planes are found across the sediments. The erosional contact separates lower sediments from the thin, grey, sandy, massive and matrix supported diamicton

Unit 9 (3.0 m thick) consists of massive or weakly stratified boulder-rich unit with an erosional contact to the underlying diamicton. This well-bedded gravel with southwards dipping strata forms the western wall of the Laurinoja pit and it continues at least 400 m to southwards. Unit 10 (0.8 m thick) is a massive medium-grained sand layer with well-developed podsolic soil horizons that rests at the top of the sequence.

Two OSL dates (Fig. 4) from the lower and three from the upper interstadial sands suggest ice-free intervals for MIS 3 age (56–35 ka). However, the precision of the dates is too poor to determine the exact age and duration of the interstadials or the precise timing of the glacial advance. Data from Hannukainen fit well with recent studies from Lapland and adjacent regions that indicate distinct phases of Mid-Weichselian ice-free intervals.

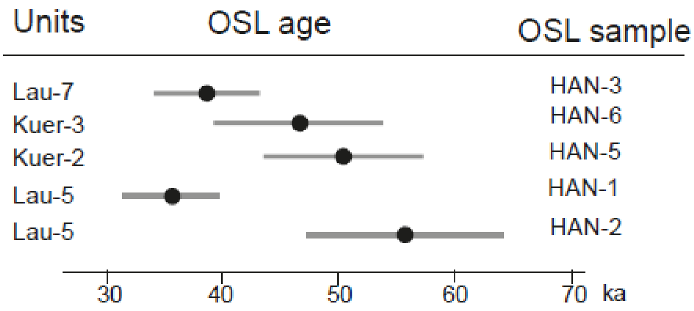

Fig. 4. OSL ages with error bars displayed in their relative stratigraphical order. After Salonen et al. (2014).

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Stop 17: Rautuvaara

Pertti Sarala & Juha Pekka Lunkka

The Rautuvaara section in northern Finnish Lapland has been widely considered as the stratotype for the northern Fennoscandian late Middle and Late Pleistocene (e.g. Hirvas, 1991; Johansson et al., 2011). It exposes several till units interbedded with sorted sediments resting on Precambrian bedrock. The sedimentary sequence is exposed as an open pit at the Rautuvaara Iron Mine (active 1974-1988), in Kolari, western Finnish Lapland (Fig. 1). It is only about 7-8 kilometres from Hannukainen mine site to the south-west (stop 16).

A part of the ore body was mined as an open pit. Due to thick Quaternary glacigenic deposits great amounts of land mass movement were needed. The open pit was studied for the first time during the 1970’s when the deepest section was almost 25 m thick. Several till units and stratified inter-till layers were interpreted to represent five separate glaciation phases with glaciolacustrine and -fluvial interlayers (Hirvas, 1991). The exposure extends ~400 m laterally and occurs at ~205–215 m a.s.l. At present, only the upper ~12 m of the section is exposed, the lower 12 m of the exposure being submerged.

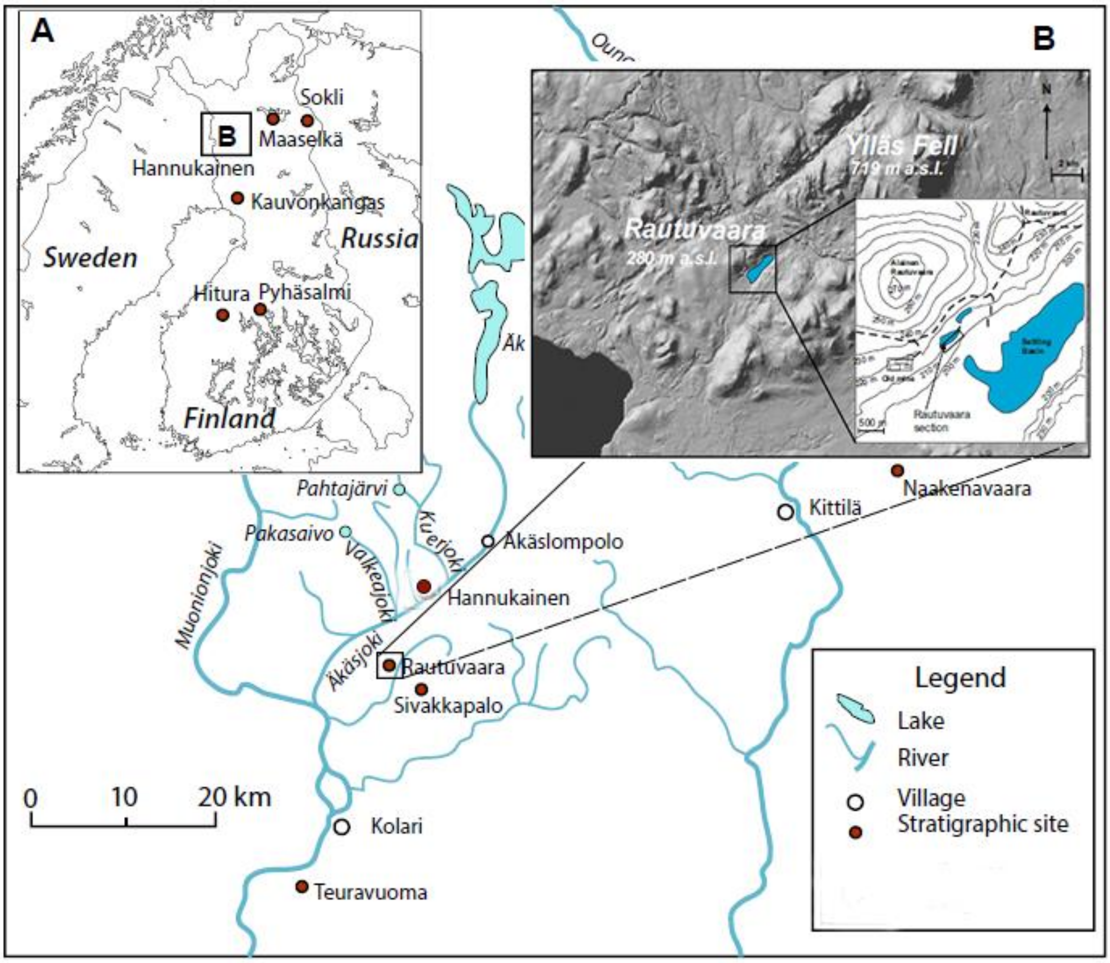

Fig. 1. Location of the Rautuvaara site in Kolari. Modified after Salonen et al. (2014) and Lunkka et al. (2015).

Based on till stratigraphy of whole northern Finland, Hirvas (1991) concluded that six stratigraphically significant till beds, interbedded with silt, sand and peat/gyttja, occur in Finnish

Lapland. The uppermost three of these (Till Beds I–III) were thought to have been deposited by the Scandinavian Ice Sheet (SIS) during the Weichselian Stage and underlying Till Beds IV-VI would have represented Saalian glaciation or older. Therefore, a widely accepted view of the glacial history and the Quaternary stratigraphy of Finnish Lapland is that the glacial and nonglacial sediments in Lapland were deposited during the time-span between the Holocene and the Cromerian stages (Fig. 2).

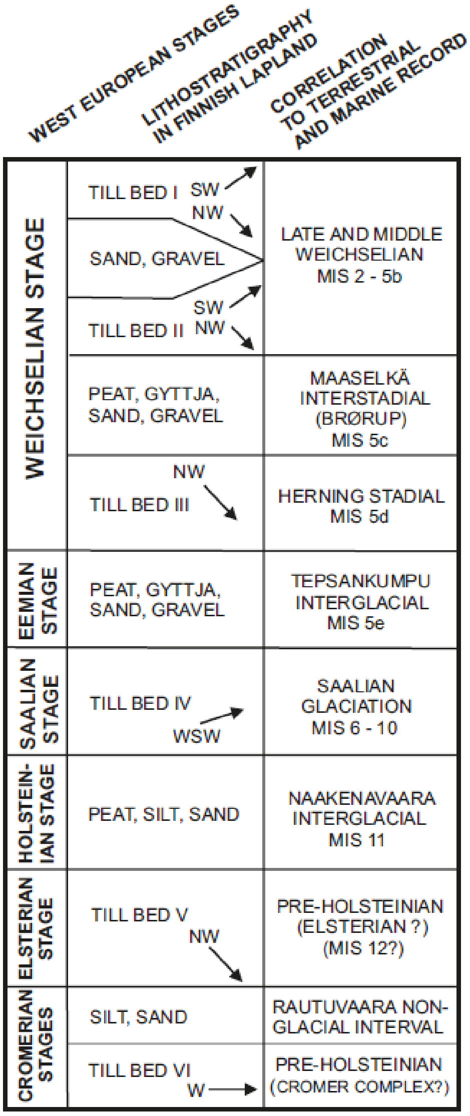

Fig. 2. The stratigraphy of Finnish Lapland and its suggested correlation to the NW European Pleistocene stages after Hirvas (1991). The correlation of the NW European Pleistocene stages to the Marine Isotope Stages (MIS) is also indicated. After Lunkka et al. (2015).

As part of the larger re-evaluation campaign of the Finnish stratigraphical key sites, a new chronostratigraphical studies were carried out at the Rautuvaara site (Auri et al., 2008; Lunkka et al., 2015). The succession was studied using sedimentological methods and different sand-rich units between till units were dated using the Optical Stimulated Luminescence (OSL) method. Nowadays, only the upper part of the section (12-14 m) is seen over the ground water level and that was studied visually after cleaning the sections (Fig. 3). Deeper section under water table was sampled using percussion drilling equipment.

A new sedimentological investigation (Lunkka et al., 2015) confirmed the earlier (Hirvas et al. 1977; Hirvas, 1991) observations of the five till beds. Stratified inter-till layers were also observed as reported earlier but re-investigation of the sediment succession led to a new interpretation of the upper part of the sequence. A sand and silt unit (Units 7 and 8 in Fig. 4), earlier interpreted as representing a part of the Eemian sediments, was re-interpreted as glaciolustrine in origin deposited during the Wichselian. On top, only one diamicton unit is observed indicating the latest deglaciation.

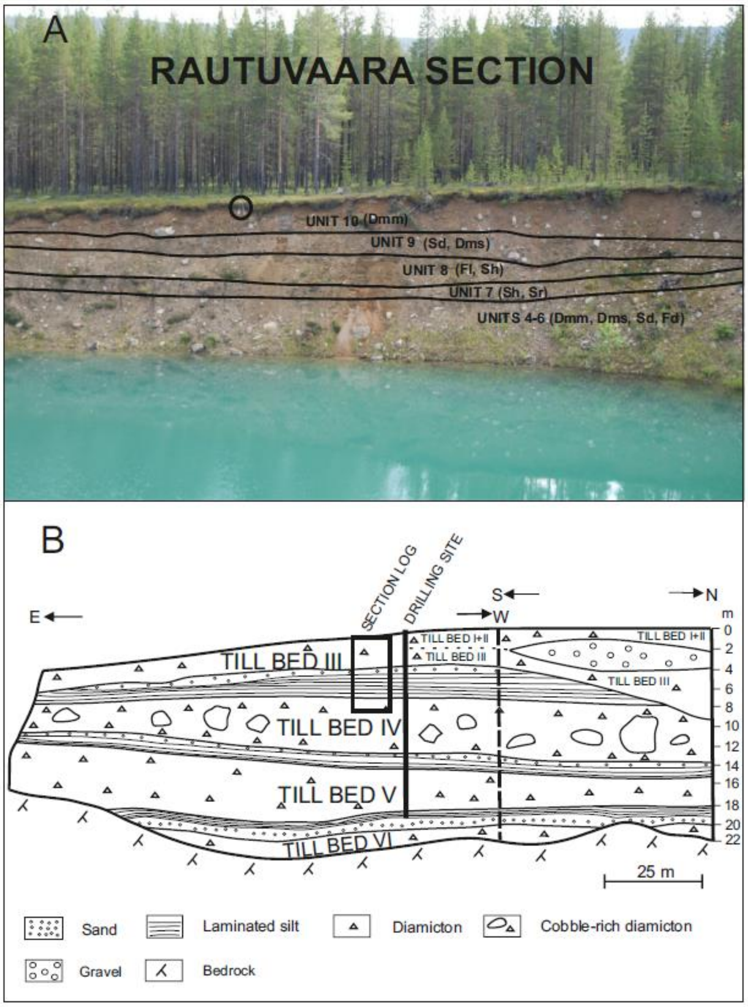

Fig. 3. A. A photograph of the section studied in the Rautuvaara pit with the main lithostratigraphical units in the exposed part of the section above the water level indicated. For scale, the two spades (circled) are 1.4 m long. B. A section drawing of the Rautuvaara succession based on observations made by Hirvas et al. (1977).After Lunkka et al., (2015)

OSL ages of the samples that were collected from each of the stratified inter-till layers were not indicating particular suggestion, because the ages were quite same from bottom to up. Actually, the oldest age (171 ka) was measured from the top of the sandy/silty sediments. The youngest age (60 +/- 8 ka) was recognised under till bed IV (based on Hirvas, 1991) indicating the deposition at the end of the Middle Weichselian glaciation (MIS4). However, all the stratified sediment layers show strong influence of the Early Weichselian ages, which is a sign of incomplete bleaching (Lunkka et al., 2015).

In addition, Howett et al. (2015) reported parallel sedimentological results from the surrounding areas of the Rautuvaara Mine site, at the Niesajoki valley. Based on sedimentary observations and OSL ages eight separate stratigraphical units were identified. These eight units, their occurrence and their stratigraphical relationship, can be visualised on the composite map (Fig. 6). Main units were same than observed by Lunkka et al. (2015). A remarkable difference is related to OSL ages. The OSL-ages which gave significantly younger ages (mostly Mid Weichselian; Fig. 6) than found in open pit. However, age ranges are well in balance with the stratigraphy and with the interpretation made by Lunkka et al. (2015) and strengthen the new interpretation of the younger ages of the Rautuvaara sediments.

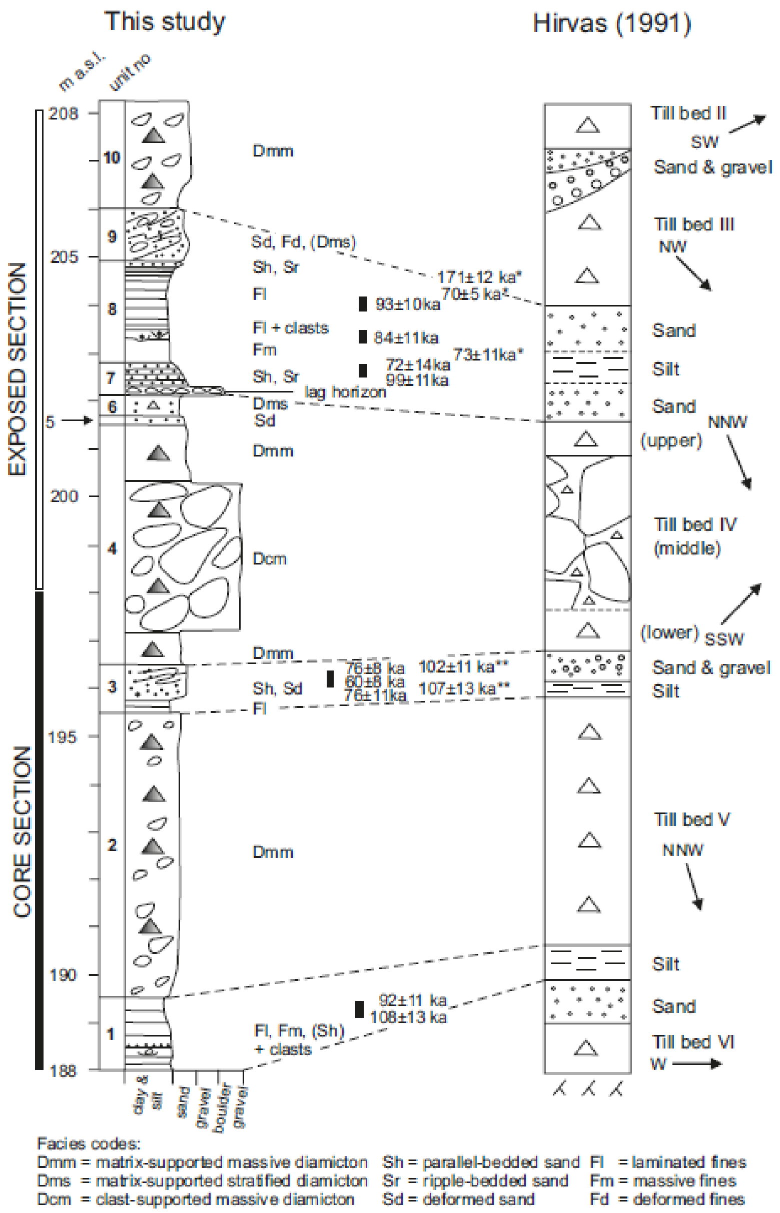

Fig. 4. A sediment log of the Rautavaara section and the correlation of the lithostratigraphical units defined in this study with those units observed in the same section by Hirvas (1991). The OSLdating results from different levels of the section are indicated. After Lunkka et al., (2015)

The sedimentary succession at Rautuvaara is complex, containing a variety of Late Pleistocene anf Holocene deposits that represent glacial and ice-free events. The results obtained indicate that the whole sediment succession at Rautuvaara was deposited during the Weichselian Stage and there is no indication of older deposits as was presented by Hirvas (1991). The SIS advanced across Finnish Lapland to adjacent areas to the east at least once during the Early Weichselian, twice during the Middle Weichselian (~MIS 4 and MIS 3) and once during the Late Weichselian substages. Glaciolacustrine sediments interbedded between the till units indicate that a glacial lake repeatedly existed after each deglacial phase. The results also suggest that there were two ice-free intervals in northern Fennoscandia during the Middle Weichselian close to the SIS glaciation centre.

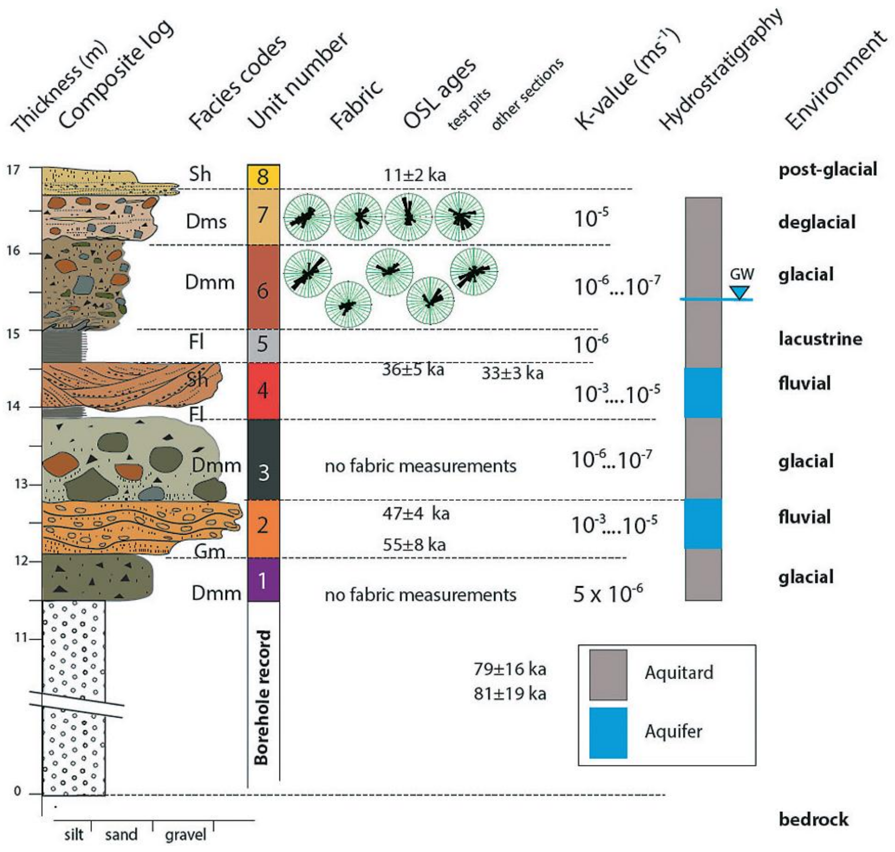

Fig. Composite log showing the stratigraphical sequence of the eight identified units within the study area based on OSL dates, lithofacies characteristics and fabrics. After Howett et al. (2015).

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Stop 18: Pakasaivo Canyon Lake

Peter Johansson

In western Finnish Lapland there are hollow-like canyon lakes known as "saivos”. Saivos are round lakes or ponds with clear water, typically of a considerable depth and generally occurring in connection with glaciofluvial systems. According to Sámi legends (Paulaharju, 1922), only lakes with no distinct surface flow or discharge streams can be considered saivos proper. They receive their water from underwater springs and water also flows out of them into bedrock fractures. The saivos are impressive erosional features, often bordered by block-laden steep shores or almost vertical rock walls. Geologically, the saivos are not a uniform type of feature, but at one or more stages their formation has been influenced by the meltwater action of the continental ice sheet.

Pakasaivo is the most famous saivo in northern Finland (Fig. 1). It is situating in the vicinity of the Ylläs fell range (67°37'00" N and 23°47'45" E) in an almost uninhabited wilderness region between the western Lapland mountain region and Muonionjoki, the river on the border between Finland and Sweden. Multiple glacial advances and retreats have been described in the region (Hirvas, 1991; Salonen et al., 2014; Lunkka et al., 2015). The last flow direction of the Weichselian ice sheet was towards the north-northeast. The region was deglaciated approximately 10,000 years ago (Johansson & Kujansuu, 2005). In the vicinity there are glaciofluvial features typical of the supra-aquatic area, such as sharp-crested, steep-sided and winding esker ridges, alternating with gorges and channels, eroded deep into the glacial deposits, in places even into the bedrock. These features are evidence of the action of abundant meltwater flows. Pakasaivo, which is about one kilometre long and in places only tens of metres wide, is a canyon lake located in a bedrock fracture zone (surface 218 m a.s.l.). At the southern end, its shores are fairly gentle and stony. In the middle, the shores get steeper and the lake narrows between 20 – 25 metres high rock walls. At the northern end, the lake widens into a circular hollow 120 – 140 metres in diameter, surrounded by steep rock walls.

Fig. 1. At the northern end of Pakasaivo, the steep rock walls rise up to 40 metres above the surface of the lake. Photo by P. Johansson.

In the summer of 2000, the Geological Survey of Finland carried out basic mapping of Quaternary deposits and related studies in the Yllästunturi region. The depth of Pakasaivo and its bottom topography were studied by echo sounding from a boat (equipment Furuno FE-881 MK II) (Johansson, 2003). The sounding profiles show the water depth at the southern end and narrow middle of Pakasaivo to range, on average, between two and five metres and in the basin-like depressions between eight and ten metres. At the circular northern end of the lake, the bottom dives to a depth of tens of metres only a few metres from the shore, and in its middle the soundings show the depth to be 60 metres (Fig. 2). From all directions, the submerged rock walls slope steeper than 50 degrees towards the centre of the lake. The bottom is bedrock and a gyttja layer over seven metres thick and blocks that have tumbled down from the steep canyon walls. Observations indicated that the gyttja is composed of fragments of ligneous and herbaceous plants, such as leaves and pine needles (Fig. 3) (Johansson et al., 2006). The total depth of the canyon, including the 30-40 metres high rock walls on land, is over 100 metres, making it the second deepest lake in northern Finland (Karlsson, 1986). Pakasaivo is classified as a meromictic lake (Wetzel 1983), as it undergoes incomplete mixing of its water column during spring and autumn overturn periods. The thermocline, or the layer between the epilimnion and hypolimnion, is at a depth of five to ten metres. Here an abrupt change in the oxygen content occurs, and the hypolimnion is oxygen-free and sulphurous. A study by the Lapland Regional Environment Centre in 1993 showed the oxygen content of the water to be 9 mg O2/litre at a depth of five metres and only 0.8 mg at a depth of ten metres. Deeper down, the water was oxygen-free (P. Räinä, Lapland Regional Environment Centre, personal communication 2005). Meromictic lakes are important study sites due to their permanent chemical stratification of a water column. Anoxic conditions prevailing in the lower water body enhance the preservation of macrofossils, such as leaves and needles, in sediment deposits. In addition, a strong stratification prevents bioturbation, the major cause of sediment disturbance in deep basins.

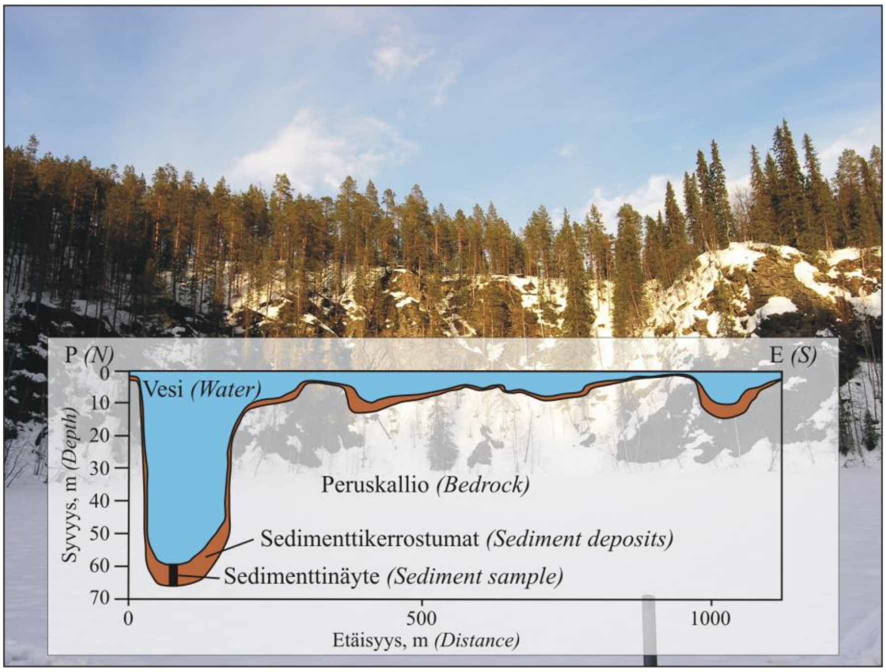

Fig. 2. At the northern end of Pakasaivo, a basin over 60 meters deep, with exceptionally steep edges, collects the majority of allochthonous and autochthonous matter that is and has been accumulating into the lake over thousands of years.

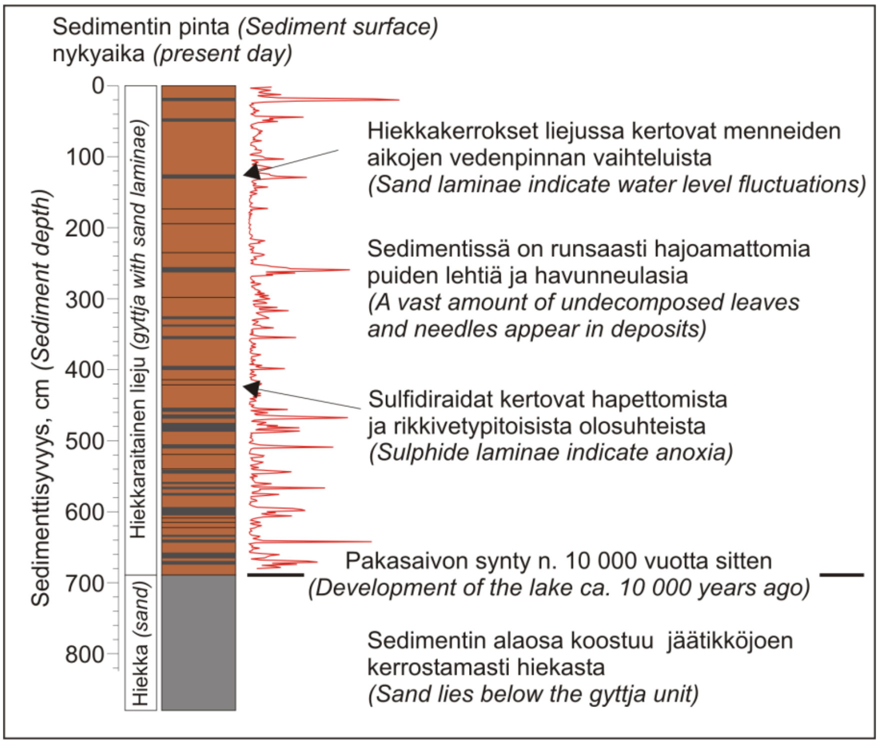

Fig. 3. The sediment sequence from Pakasaivo provides an undisturbed record of past environment.

The formation of Pakasaivo was a result of several geological processes. Fracture zones, formed between intact parts of the bedrock millions of years before the Ice Age, controlled the location and form of Pakasaivo. As a result of glacial erosion over several glaciations, the bedrock around the fracture zones was eroded into depressions. During the last deglaciation, the meltwater formed a subglacial meltwater system, where the water flowed with great force in the direction of the pressure gradient towards the ice margin in the north and north-east. Pakasaivo is related to the glaciofluvial system that crossed the top of the nearby Karhulaki hill (370 m a.s.l.), creating glaciofluvial erosion and deposition features on the hillslopes (Johansson, 2005).

In the initial phase of the deglaciation, the glaciofluvial action was mainly erosion. The canyon of Keinokursu, which is incised into Karhulaki hill in the direction of the meltwater tunnel, was formed (Fig. 4). Keinokursu is over four kilometres long, 50 - 150 m wide and 30 m deep. The tunnel continued in the direction of the fracture zone across Pakasaivo. At the northern end of Pakasaivo, a powerful subglacial meltwater whirl, evidently of long duration, was formed in the meltwater stream. The whirl ground a deep, pothole-like hollow into the broken rock (Fig. 5). Although the walls show no distinct surfaces ground by the water whirl (cf. Shaw, 1996), the form and exceptional depth of the saivo are clear evidence of the subglacial meltwater activity. In northern Sweden, there are canyon-like valleys known as kursu valleys, major erosional features eroded into broken bedrock by enormous masses of meltwater. Rudberg (1949) and Olvmo (1989) suggested that these canyons were formed subaerially. In the cases of Pakasaivo and Keinokursu, the subaerial alternative is not possible since the subglacial esker ridges related to these canyons could only be formed at the base of the ice in a completely water-filled conduit, where the meltwater stream, subjected to high hydrostatic pressure, was in balance with the pressure caused by the surrounding ice sheet (Clark & Walder, 1994; Brennand, 2000). Evidence of subglacial origin is also evident in the fact that the meltwater stream did rise uphill on Karhulaki hill (cf. Shreve, 1972).

Fig. 4. Aerial photograph of the meltwater channels at Karhulaki.

As the deglaciation proceeded, the location of the subglacial meltwater tunnel shifted to the north of Pakasaivo. This happened before the decrease in the meltwater pressure due to the thinning of the ice sheet (Johansson, 2005). The Pakasaivo canyon must have been covered by the ice even earlier, since this is the only way the sediments transported by the glacial river could have been kept from accumulating there. As a result of the subglacial accumulation process, the almost 40 metres high Pakajärvi esker was deposited on the shore of the Pakajärvi lake about 500 metres from Pakasaivo. The Pakajärvi esker is a typical Late Weichselian subglacial esker ridge with steep slopes and sharp crest. It is part of a meltwater system from the last deglaciation that starts at the ice divide of central Lapland and continues northwards from Pakasaivo.

During the last stage of deglaciation, meltwater was dammed in front of the retreating ice sheet and the Muonio Ice Lake was formed. At its largest the ice lake covered an area of about 800 km^2 on the Finnish side of the Muonio river valley. From the lake, spillways of various ages and at various altitudes led eastwards to the Ounasjoki river valley (Kujansuu, 1967). Due to the retreat of the ice margin, the ice lake spillway shifted southwards to the neck of land between Pakasaivo and Pakajärvi. Water discharged from the ice-dammed lake first broke off the Pakajärvi esker, and then plunged into the hollow of Pakasaivo. The rock wall bounding it in the north served as a threshold, controlling the water level of the ice lake behind it at a level of 238 metres (Fig. 5). As the water was discharged across the threshold, a 20 metre high cataract was formed. In fact, the form of the steep northern shore of Pakasaivo resembles a cataract lip and the deep hollow of the lake itself may be a plunge pool lake formed at the base of the cataract. The water rushing into the hollow possibly yielded vertical vortices that caused a turbulent plucking action. Similar deep hollows created by the discharge of ice-dammed lakes are also found for example in the Channeled Scabland in the state of Washington, USA (Baker, 1978 and 1987).

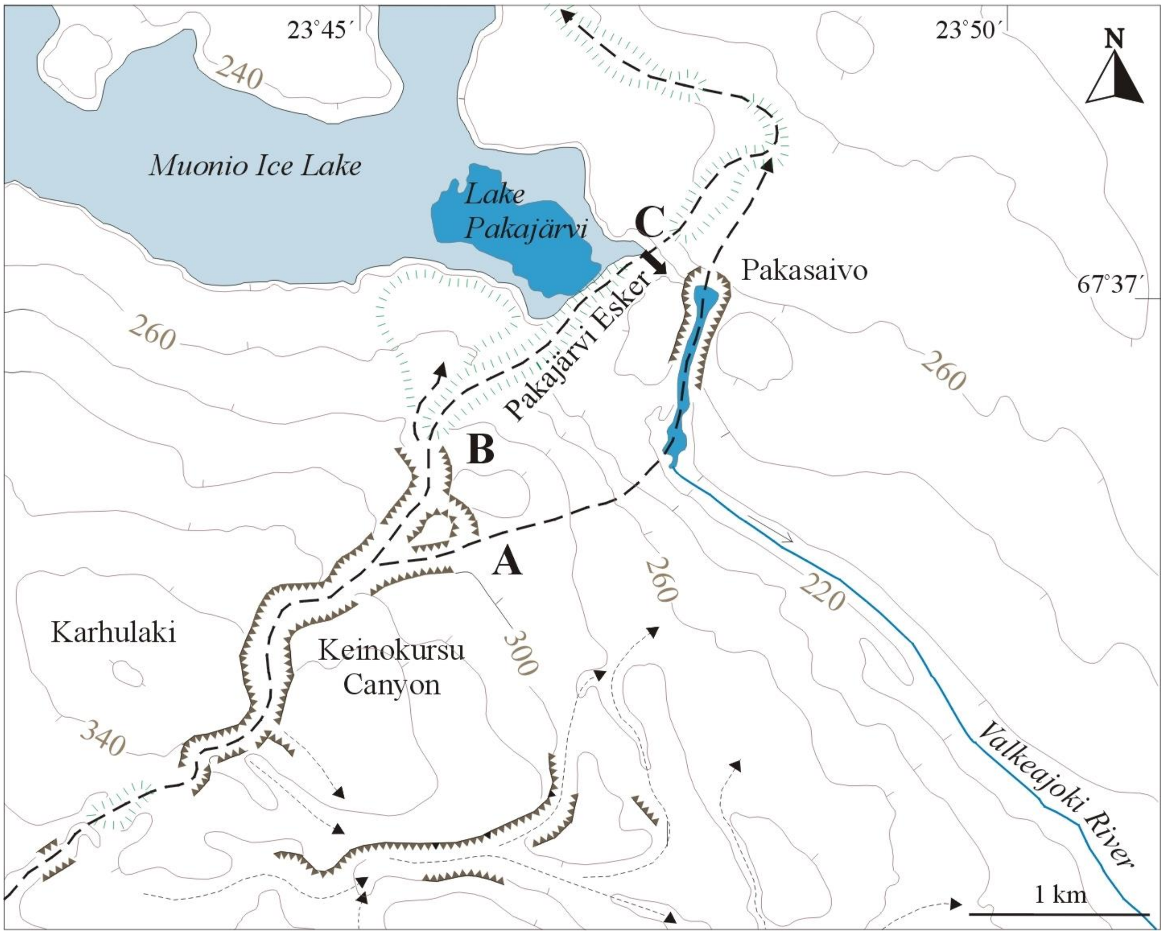

Fig. 5. Glaciohydrographic history of the Pakasaivo area. A = Route of the subglacial meltwater stream during its early stage, B = Route of the subglacial meltwater stream during its late stage, C = Spillway during the ice lake stage.

Pakasaivo is also a cultural historical locality. For centuries saivos have fascinated the minds of local Sámi people and many beliefs and myths relate to them. Sacrificial gifts have been brought to these lakes in order to assure good fishing and hunting luck, and veneration has been shown by naming sacrificial stones (seitas) on their shores (Kotivuori & Torvinen, 1993). Pakasaivo continues fascinate people up to present time, and it has become a popular attraction for geotourism, too.

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Stop 19: Teuravuoma mire

Peter Johansson

Teuravuoma is the largest mire in Finland in terms of surface area (7,080 hectares). It is part of the Natura 2000 network and the international important Ramsar wetland convention. Teuravuoma is a good example of aapa mires of northern Finland (Lappalainen, 2001). Aapa mires are supplied in nutrients by the run-off waters flowing in from the surrounding mineral soil areas. Central areas of them are generally open treeless fens and dotted with open watered flarks. The flark pools are separated by low strings of peat covered by Sphagnum mosses and shrubs. The marginal parts of mires are bogs with stunted pines or swamps with spruce and birch. The dominant mire types are the eutrophic fen, eutrophic flark fen and various treeless fens. There are also patches of eutrophic birch fen. In northern Finland mires are often in a natural state, and they provide for wanderers fine sceneries as well as an opportunity to pick tasty mire berries like cranberries (*Vaccinium oxycoccos*) and cloudberries (*Rubus chamaemorus*).

The formation of mires began very soon after the ice had melted. Favourable sites for peat deposition included depressions, the wet areas in the valleys between fells and near rivers and creeks. After forests had spread to the area about 9,000 years ago, the most common type of mire formation was forest paludification (the replacement of forested areas by mires). This was caused by an increase in the height of the groundwater table, which turned low-lying areas into permanently wet areas. Some mires, such as Lompolojänkkä in Kittilä, have developed as overgrowing of lakes and ponds and, which may happen either along the bottom or over the surface. Filling in along the bottom takes place primarily in eutrophic lakes with lush vegetation. Organic sediments deposit gradually, filling in the basin until palustrine vegetation becomes predominant. A formerly open lake gradually turns into an open mire. Surficial overgrowth happens in oligotrophic, acidic ponds. Sphagnum moss, which thrives in water, forms moss floats round the edges of the pond. These gradually expand until they eventually cover the once open water as continuous Sphagnum peat. Paludification of alluvial soil takes place mainly along river banks in the valley of the Ounasjoki. Water from the overflowing river remains in flood plain hollows and keeps them wet throughout most of the summer and provides good conditions for the growth of palustrine vegetation.

The Carex-dominant peat is the main peat type. Peats dominated by Sphagnum mosses also occur in the margin areas, which are poorer in nutrients. Basal peat layers usually contain the remains of common reed (*Phragmites australis*), lake cub-rush (*Schoenoplectus lacustris*) and horsetail (*Equisetum fluviatile*). The upper parts mainly consist of the remains of sphagnum, brown mosses and carex. In northern Finland the mean thickness of the peat layer is nearly two metres. The thickness of the peat layer is constantly increasing, but very slowly by fractions of a millimetre a year (Lappalainen, 1970).

There are a lot of small rich fens in western Lapland, because limy and nutrient-rich bedrock has affected the formation of these mires. Rich fens are the most nutrient-rich mire types in Finnish Lapland. Typical plants found in these include eutrofic brown mosses, herbs like tormentil (*Potentilla erecta*), goldenrod (*Solidago virgaurea*), yellow marsh saxifrage (*Saxifraga hirculus*), Scottish asphodel (*Tofieldia pusilla*), and different orchids. Juniper is also an easily identifiable plant in rich fens.

Teuravuoma is an excellent destination for hikers interested in mires and bird watching. Mires are especially important to the bird populations, and Teuravuoma forms one of Lapland's best avifauna sites. The hiking trail called "Telatie" is equipped with duckboards and passes from one area to another. The path opens up a rich world of nature, history and culture (Fig. 1). Along the hiking trail there are two observation towers and several campfire sites. On the northern side of the mire, a bird-watching tower opens up a panorama of mire landscape towards the Ylläs Fell.

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Fig. 1. The hiking trail “Telatie” at Teuravuoma Mire. Photo by P. Johansson.

INQUA Peribaltic Working Group Meeting 2017 - Symposium in Kilpisjärvi 23rd Aug 2017

8.30-9.00		Presentation uploading and posters' hanging
Session 1	*Chairmen: Sokołowski, R. & Johansson, P.*	
9.00-9.10	Sokołowski, R.	Opening
9.10-9.25	Hall, A. et al.	Pre-Quaternary geomorphology of northern Fennoscandia: framework for Quaternary studies
9.25-9.40	Grube, A.	Prehistoric earthquakes and neotectonics in Hamburg and Schleswig-Holstein (NW´ Germany)
9.40-9.55	Pisarska-Jamroży, M. et al.	Silty clasts in a Saalian glaciolacustrine gravity-flow deposit, western Poland
9.55-10.10	Forysiak, J. et al.	Organic deposits (Eemian-Vistulian) in selected kettle-hole basins in Central Poland
10.10-10.25	Sokołowski, R. et al.	Mechanisms of evolution of Pleistocene fluvial systems in northern Poland
Break		
Session 2	*Chairmen: Sokołowski, R. & Johansson, P.*	
10.45-11.00	Czubla, P. et al.	The Baltic Ice Stream System – did it really exist? Consideration based on petrographic analyses results
11.00-11.15	Narloch, W.	Link between subglacial drainage system and strain magnitude recorded in the Late Weichselian till in Poland
11.15-11.30	Piotrowski, J. et al.	Insights into subglacial till deformation from laboratory experiments
11.30-11.45	Bitinas, A. et al.	Some aspects of drumlin field formation
11.45-12.00	Räsänen, M.	Weichselian glacial cycle in southern Finland
Lunch		
Flash speeches	*Chairman: Nenonen, K.*	
13.15-13.20	Börner, A. et al.	Exploration of the potential for sustainable REE extraction from offshore heavy mineral bearing sands from the southwestern Baltic Sea floor - the SEEsand project
13.20-13.25	Woronko, B. et al.	3D-microtomography - A nondestructive method to reconstruct cold region rock weathering
13.25-13.30	Krotova-Putintseva, A.	Genesis of buried valleys in the north-west of the East-European Platform
13.30-13.35	Vaikutienė, G. et al.	Palaeoenvironment of SE Baltic region in Late Pleistocene and Holocene: results of paleolimnological study of Kamyshovoe Lake, Kaliningrad Region
13.35-13.40	Woźniak, P. et al.	Lithic clasts and soft-sediment clasts as indicators of debris-flow direction in subaquatic environment
13.40-13.45	Makeev, A. et al.	Russian Plain: Late Holocene landscape dynamic based on the study of buried soils of archaeological sites
13.45-13.50	Hughes, A. et al.	Evolution of the Eurasian ice sheets: what did we learn from DATED, and what now?
13.50-13.55	Rudnickaite, E.	Lithological variability in tills of the Švenčionys Upland (Lithuania) and their correlation
13.55-14.00	Gedminienė, L. et al.	Lateglacial and Early Holocene (a)biotic environment in response to climatic shifts: an example from Lieporiai Lake, northern Lithuania
14.00-14.05	Rusakov, A.	Soils of Medieval burial mound as paleoenvironmental archive (Leningrad region, North-West Russia)
Break		

Session 3	*Chairmen: Piotrowski, J. & Börner, A.*	
14.20-14.35	Zaretskaya, N. et al.	The SIS southeastern limits and related proglacial events: state-of-art
14.35-14.50	Tylmann, K. et al.	^{10}Be age of the Local Last Glacial Maximum in the southern fringe of the Scandinavian Ice Sheet
14.50-15.05	Woronko, B. et al.	Dry valley development during MIS 6 - MIS 1 in a glacial landscape - an example from Poland
15.05-15.20	Subetto, D. et al.	GIS-modelling of the Onego ice lake

Coffee break

Session 4	*Chairmen: Piotrowski, J. & Börner, A.*	
15.45-16.00	Möller, P. et al.	Man and deglaciation – the Mesolithic site at Aareavaara, northernmost Sweden
16.00-16.15	Petera-Zganiacz, J. et al.	Morphogenetic processes as determinants of vegetation patterns under impact of the Younger Dryas global climatic changes – main objectives of the research project
16.15-16.30	Börner, A. et al.	The GREBAL project - general overview about active tectonics and glacio-isostatic rebound in NE Germany
16.30-16.45	All	Discussion and closing

Posters and refreshments
16.50-17.30 (Posters' removal before 17.30)

Business meeting
17.45-18.30

Conference dinner at 19.00

Posters

Belzyt, S. et al.	Glacitectonically-deformed moraine sediments with ruptured pebbles, Koczery study site, E Poland
Błaszkiewicz, M. et al.	New high-resolution and integrated analyses of environmental response to climate change over the last 15 000 years from Lake Gościąż – Poland
Börner, A. et al.	Exploration of the potential for sustainable REE extraction from offshore heavy mineral bearing sands from the southwestern Baltic Sea floor - the SEEsand project
Dzieduszynska, D, et al.	Small-scale geologic and morphogenetic evidence of the Lateglacial coolings
Forysiak, J.	Diversity of geomorphological features of peatland basins in Central Poland
Gedminienė, L. et al.	Lateglacial and Early Holocene (a)biotic environment in response to climatic shifts: an example from Lieporiai Lake, Northern Lithuania
Grigienė, A. et al.	Kames in the Storiai Landscape Reserve
Hermanowski, P. et al.	Morphometry of the Stargard drumlin field (NW Poland) in the terminal zone of a major Weichselian palaeo-ice stream
Hughes, A. et al.	Evolution of the Eurasian ice sheets: what did we learn from DATED, and what now?
Johansson, P.	The assessment of threatened geological habitat types in NW Finnish Lapland
Jusienė, A.	Inland dunes in the western part of Lithuania

Karpukhina, N. et al.	Features of varved clays formation in the Obdekh River paleovalley (Pskov region, Russia)
Konstantinov, E. et al.	The lake sedimentation in the central part of Pskov lowland during the Late glacial time and the Holocene
Koskinen, H. et al.	Advanced indicator mineral identification techniques in critical mineral exploration
Krotova-Putintseva, A.	Genesis of buried valleys in the north-west of the East-European Platform
Kupila, J.	The coordination of groundwater protection and aggregates industry in Finnish Lapland, phase II
Minina, M. et al.	PALEOLADOGA DataBase as a tool for the reconstruction of Lake Ladoga shore line displacement in the past
Mleczak, M. et al.	Saalian seismites in the Ujście Basin, western Poland
Nenonen, K. et al.	The fells in Finnish Lapland: LiDAR technology helping to study the landforms
Petera-Zganiacz, J. et al.	Morphogenetic processes as determinants of vegetation patterns under impact of the Younger Dryas global climatic changes – main objectives of the research project
Poleshchuk, A. et al.	On the origin of deformation structures of plastic squeezing in late-glacial sediments of the southern margin of the Fennoscandian shield in potential connection with the earthquakes
Putkinen, N. et al.	A new glacial geomorphological landforms map database of Finland
Rudnickaite, E.	Lithological variability in tills of the Švenčionys Upland (Lithuania) and their correlation
Rychel, J. et al.	Dynamics of the Saalian ice sheet in the Polish-Belarusian border area
Shvarev, S. et al.	Identification of active tectonic structures and parameters of paleo-earthquakes based on deformations in rocks and in late- and in post-glacial sediments in the Karelian Isthmus
Subetto, D. et al.	Catastrophic changes of the Karelian Isthmus hydrographic network in the Late Glacial – Holocene: palaeoseismological origin
Taivalkoski, A. et al.	Geochemical baseline mapping in northern Finland
Tylmann, K. et al.	Exploring morphometry of drumlins within isolated upland of varied topography
Vaikutienė, G. et al.	Palaeoenvironment of SE Baltic region in Late Pleistocene and Holocene: results of paleolimnological study of Kamyshovoe Lake, Kaliningrad Region
Woronko, B. et al.	3D-microtomography - A nondestructive method to reconstruct cold region rock weathering
Woźniak, P. et al.	Lithic clasts and soft-sediment clasts as indicators of debris-flow direction in subaquatic environment
Wysota, W. et al.	Lithic clasts and soft-sediment clasts as indicators of debris-flow direction in subaquatic environment

Glacitectonically-deformed moraine sediments with ruptured pebbles, Koczery study site, E Poland

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The Koczery site is located about 2 km NE of Drohiczyn (E Poland). The study site is exposed in an active gravel pit, in one of the end moraines deposited during Saalian glaciation (MIS 6; Nitychoruk *et al*., 2006). Flat morainic plateau occur N and NW of the end moraines in their hinterlands. The morainic plateau is built by strongly calcareous, clay rich glacial till and is inclined to E and S according to the relatively steep slope.

The sedimentary succession in the Koczery site contains glaciofluvial deposits and glacial till above. The glaciofluvial deposits form the glacimarginal fan. The thickness of glaciofluvial deposits reaches up to 25 m, the lateral extent is 1 km long and 0.5 km wide. Strongly calcareous glacial till cover the glaciofluvial deposit in the N part of the gravel pit. Thickness of the glacial till is various, and ranges from 1.5 to 7 m. Glaciofluvial sediments are dominated by horizontally-stratified gravels, gravelly sands and sands (lithofacies Gh, SGh, Sh); massive gravels (lithofacies Gm) are the secondary, occasional lithofacies. Two rhythms were recognized in the glaciofluvial succession: Gh→SGh and Gh→Sh. Stratified and massive gravels, gravelly sands and sands were deposited southwards from high-energetic sheet flows. In the upper part of the glaciofluvial sediments there are folds, normal and reverse faults, both interpreted to be developed during the glaciotectonic processes. The fabric orientation in the glacial till suggest the ice-sheet transgression from NNE and NW, and corresponds to the fold vergence in glaciofluvial deposits. Moreover, in the *en block* deformed glaciofluvial sediments occur ruptured pebbles. Originally horizontally-stratified sediments were reoriented and stratification is inclined in the first section between 38-40° SE, and in the second section between 70-76° SE. Most fractures in pebbles are parallel or subparallel to the stratification here, so in the first section pebble fractures are inclined 28-58°, and in the second 40-88°. Standard deviation of stratification inclination reach 1-2, but in the case of clast fractures: 8-16.

The pebble fractures analysis may be helpful in indicating palaeostress. They were also used as a tool for recognizing tectonic activity and earthquake hazard (Eidelman & Reches, 1992; Harker, 1993; Tokarski *et al*., 2007). One of the possible factors causing stress increase is an intrapebble amplification of the tectonic forces (Eidelman & Reches, 1992). A common feature of layers with ruptured pebbles in Holocene and Pleistocene deposits (mainly on fluvial terraces) is their occurrence close to the map-scale faults (Tokarski & Zuchiewicz, 1998). On the base of fracture architecture, pebbles geometry (size, shape) and petrography, the deformation trigger process could be proposed. Ruptured pebbles are commonly described in 'tectonic' settings, but in the Pleistocene glaciofluvial sediments have not been described earlier.

The main goals of the study are to determine the processes of pebbles fracture forming and to examine if there are any petrographical or geometrical (size, shape) preferences of the process. In order to determine the pebbles vulnerability to fracturing under stress, petrographic analyses of fraction between 0.5-10 cm were provided. Additionally, the stratification inclination and direction of main fracture axes of the pebbles were measured.

The collected pebbles were divided into two groups: (1) the first group contains ruptured pebbles surrounded by a sandy and silty-sandy matrix; and (2) the second group consists of pebbles which surrounded/blocked ruptured pebbles. The first group consists of 49 % of palaeozoic limestones, 25 % of sandstones and mudstones, 23 % of plutonic rocks (granitoids) and 3 % of volcanic rocks (basalts and porphyries). The second group contains 67 % paleozoic carbonates (mainly limestones), 17% of plutonic rocks (granitoids), 8% of volcanic rocks (basalts and porphyries), 6 % of metamorphic rocks (orthogneisses), and 2 % of sandstones. Both groups have big heterogeneity in the size and roundness. Most of them are sub-angular to rounded. Their shape is usually from sub-spherical to flatten.

The obtained results suggest that the uncommon fractures observed in numerous pebbles within glaciofluvial deposits in the Koczery site were formed due to stress increase caused by glaciotectonic processes. The pores in such poorly-sorted glaciofluvial sediments were infilled by water, and afterwards by ice, so the stress caused by the glaciotectonic processes affected frozen sediments. Glaciotectonic processes deforming *en block* sediments caused only brittle deformation. The processes caused fracture of pebbles more or less parallel to the stratification in gravelly lithofacies. The architecture of the fractures is independent clasts size, shape and petrography. Most fractures are parallel or subparallel to the stratification in gravelly sediments, but diversity of fracture inclination is bigger.

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Some aspects of drumlin field formation

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Drumlins are one of the most attractive subjects of Quaternary geology: over the last several decades, especially in the second half of the past century, a big number of special research studies and purposive international symposiums were dedicated to the issues of drumlin's structure and genesis (Menzies & Rose, 1987). The detailed analysis of internal structure of drumlins and their formation taking into account different factors (thermal regime beneath the ice sheet, pore-water pressure in the subglacial substratum, meltwater flow through the substratum, etc.) are widely discussed in a number of papers (Boulton, 1987; Shoemaker, 1995; Piotrowski *et al*., 2004, etc.). However, despite the abundance of information collected on this issue, there is no common opinion about the origin of drumlins and other subglacial landforms. Thus, certain issues about the origin of drumlins still attract the attention of researchers. One of still unclear and discussible issues of the drumlins origin is why they occur only beneath the certain parts of an ice sheet.

The drumlins are widespread only in groups and form the drumlin fields located exceptionally in the inner part of the Last Glacial ice sheet. The morphology and location of separate drumlin fields in the areas former covered by both the Laurentide and Scandinavian Ice Sheets demonstrate a mosaic character of their disposition. The shape and spatial distribution of separate drumlin fields suggest that they were formed by the fast ice streams that were of convergent nature. It is likely that this assumption may explain the stress direction from the inter-drumlin depressions that were determined by till fabric and AMS measurements in the drumlin fields (Baltrūnas *et al*., 2014). It is possible to maintain that separate sectors of the cold-based or slow-moving ice, as well as the died-ice massifs left by the former glacial advances served as the "banks" of the mentioned fast ice streams. Such explanation is possible only taking into account the paradigm that the areal deglaciation prevailed during the Last Glacial degradation (Bitinas, 2012).

The presented suggestions on palaeogeographic conditions during recessional glacial advances of the Last Glacial and the existence of the mentioned "banks" formed from the same ice (already melted) are only of theoretical character. Thus, the ice lobe that occupied the Beagle Channel (South America) during the Last Glacial was analyzed as a sample of fast moving convergent ice stream with real "banks" formed by metamorphic rocks. The investigations were carried out in the Harberton drumlin field (in the Isla Gable) located in the central part of the Beagle Channel and covered granulometric analysis of sediments, measurements of till fabric, and IR-OSL dating.

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New high-resolution and integrated analyses of environmental response to climate change over the last 15 000 years from Lake Gościąż – Poland

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Lake Gościąż is located within the Płock Basin, in the bottom of one of subglacial channels dissecting the surface of a spillway terrace. The lake started to form during the Allerød due to melting of buried dead ice. In 1985 AD the laminated sediments of Lake Gościąż were discovered by Kazimierz Więckowski. It was shown that the composite profile from this lake, except of the topmost part, has a continuous sequence of annual laminations. The comprehensive research by an interdisciplinary team became a milestone in the understanding paleoclimatic and environmental change related in particular to the Younger Dryas and the onset of the Holocene in Central Europe (Goslar *et al.*, 1995, Goslar *et al.*, 2000, Ralska-Jasiewiczowa *et al.* 1998).

The main objective of the new project is twofold: (1) to apply latest cutting-edge methodological approaches for ultra-high resolution analyses, including, amongst others, a combination of microlithofacial analyses on large-scale thin sections and µXRF element scanning, deuterium isotopes on biomarkers from leaf waxes for sophisticated reconstruction of past hydrological changes, 15N isotope analyses of organic matter to develop a new environmental proxy, and, (2) integrating the sediment core analyses focusing on past climate and environmental changes with observations and monitoring of the modern lake system and its catchment. On the one hand, this will provide information how lake systems respond to present-day climate and environmental changes, and on the other hand these data will allow to better calibration of the sediment core data for improved proxy interpretation of past variability. Finally, the new data from the Lake Gościąż record will become an eastern extension of an West-East transect of annually laminated lake sediments, that are presently under investigation, including Lake Meerfelder Maar (Brauer *et al.*, 1999; 2008) in W Germany, Lake Hämelsee in Central Germany, Rehwiese palaeolake (Neugebauer *et al.*, 2012) and Lake Tiefer in NE Germany (Dräger *et al.*, 2016) and lakes Czechowskie and Głęboczek in northern Poland (Słowiński *et al.*, 2017, Wulf *et al.*, 2016). The aim of this transect is to decipher differences in past climate changes from maritime to continental regions. The key varved lake records, Lake Gościąż and Lake Meerfelder Maar, will form the eastern and western end points of this first palaeoclimate transect at annual resolution. A precise synchronisation of these profiles will be achieved by tephrochronological techniques and systematic search for cryptotephra in all investigated lake records.

Recently, we obtained a set of new sediment cores from Lake Gościąż and established a 21 m long sediment profile. Except of the topmost part of the core, it is continuously laminated down to glacifluvial sands. Here, we will present preliminary results including magnetic susceptibility, µXRF core scanning and microfacies images.

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The GREBAL project - general overview about active tectonics and glacio-isostatic rebound in NE Germany

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The fluctuations in the extent of the Weichselian ice sheet induced - and still induce - earthquakes, and thus also represent potential natural hazards. Understanding the character of glacio-isostatic rebound during the Quaternary can deepen the insight into the behaviour of ice sheets, and help to mitigate potentially negative consequences of present and future deglaciation. The overall objective of the GREBAL project is to refine the palaeoenvironmental understanding of the neotectonic history of southern Peribaltic countries on the basis of reconstructions of glacio-isostatic rebound resulting from retreat of the Scandinavian Ice Sheet (SIS). Isostatic rebound led to earthquakes that, if the conditions were suitable, left traces in the form of laterally extensive seismites characterised by a concentration of sometimes chaotic soft-sediment deformation structures.

Recent neotectonics in eastern Germany are expressed through predominantly NW-SE trending active vertical faults which divide eastern Germany into individual blocks (Ihde *et al.*, 1987). The velocities of the fault movements between the blocks are very low, measuring less than 0.1 mm/year on average (Ellenberg, 1991). Thus north-central Europe is generally regarded as a low-seismicity area; nevertheless numerous noteworthy earthquakes (e.g. up to MW 3.4 near Rostock in 2001) have been historically documented over the last millennium. Within the GREBAL project, sedimentological analyses of relatively young Pleistocene sediments are used as an important tool for an extensive reconstruction of the paleoseismic activity in formerly glaciated areas.

Intermediate to distal alluvial-fan deposits in the Oerlinghausen sand pit at Osning Thrust (NW Germany) show a variety of soft-sediment deformation structures, including closely spaced small-offset normal faults, ball-and-pillow structures, sills and irregular sedimentary intrusions, dikes and sand volcanoes; these deformations must have been triggered by earthquake-induced shocks (Brandes *et al.*, 2015). The seismic events of Osning Thrust took place between 15.9±1.6 ka and 13.1±1.5 ka, so during the Weichselian deglaciation of northern Germany; a magnitude of at least 5.5 has been calculated by Brandes and Winsemann (2013).

Seismically-induced deformation structures in NE Germany, including liquefaction, slumping, and faulting, have first been documented by Hoffmann and Reicherter (2012). These deformations occur in a Weichselian glaciolacustrine succession exposed in a cliff section on the Gnitz peninsula (Usedom island, western Pomerania). The disturbed layers were interpreted to have been caused by earthquake-induced ground shaking, triggered by neotectonic activity due to postglacial isostatic crustal rebound. Two layers with similar soft-sediment deformation structures in postglacial Late Saalian/Early Eemian lacustrine sediments at Siekierki (W Poland) were interpreted as seismites by Van Loon & Pisarska-Jamroży (2014). The two ‘event horizons’ show intense folding, collapse, sag and load structures, indicative of liquidization and fluidization. According to the authors, these structures must have been caused by sudden shocks, most probably resulting from earthquakes that were induced by glacio-isostatic rebound, probably connected with isostatic rebound after the Saalian deglaciation.

Another causal mechanism of neotectonics in N Germany are halokinetic movements related to the upward movement of Zechstein salt domes. Detailed seismic measurements and lithostratigraphical investigations in SW Mecklenburg suggest the existence of graben-like structures at the top of the salt pillows at Schlieven and Marnitz (Müller & Obst, 2008). A genetic relationship between the increasing thickness of Quaternary successions on top of these salt structures and young halokinetic movements (post-Elsterian glaciation/Holsteinian), probably induced by glacio-isostatic processes, is likely.

In the extended compilation of the Paleoseismic Database PalSeisDBv1.0, paleoseismic features (soft-sediment deformations, mass movements, etc.) are recorded from Germany and adjacent regions (Hürtgen *et al.,* 2015). This database is intended to serve as an important basis for future seismic-hazard assessments. Our investigations will concentrate on the recognition of seismites and on the analysis of their soft-sediment deformation structures, as well as on tracing faults in the bedrock which may have been reactivated during glaciation and deglaciation phases. Many of these faults must be considered as ‘active faults’ because the great majority of seismites worldwide occur in tectonically active areas. However, the areas south of the Baltic Sea Basin are presently not affected by significant tectonic activity, so the faults in the vicinity of the Quaternary seismites in this area were most probably reactivated by the changing pressures exerted by the advancing and retreating ice fronts. It is likely that also differences in the thickness of the Quaternary sediments nearby these faults contributed to their reactivation.

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Exploration of the potential for sustainable REE extraction from offshore heavy mineral bearing sands from the southwestern Baltic Sea floor - the SEEsand project

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"SEEsand" aims at assessing the technical feasibility and viability of the extraction of rare-earth elements (REE) from zircon minerals actually being mined as a by-product from off-shore aggregates. The research challenge is to separate the REE bearing zircon-fraction and to extract REE by means of chemical and microbiological leaching processes. "SEEsand" is formed by an interdisciplinary team from geological state agencies ([1,7]), industry ([2,4,5]), academia ([3]), and a network association of upstream and downstream industry ([6]). The REE comprise a group of critical chemical elements with special electronic, magnetic, optical and catalytic properties that are crucial for a range of EU high-tech industries. The light-REE (LREE), e.g. Neodymium, Praseodymium) which represent the majority of the SEEsand resource target, are regarded as key elements in the automotive, wind-energy, electronics, and metallurgy sectors. Current estimates predict that by the year 2035 the global demand for light-REE will rise to 64,000 t and that of heavy-REE (HREE, e.g. Dysprosium, Terbium) to about 7,400 t, representing a 2-3 fold increase compared to current production levels (Marscheider-Weidemann *et al*., 2016).

The most important primary minerals in which REE occur are found in alkaline magmatic and metamorphic complexes and carbonatite rocks. Eroded rocks of that types were transported through the modern Baltic Sea basin by the advancing Scandinavian Ice Sheet (SIS) and associated glacial melt waters during the Quaternary period. The project addresses the outlined supply issues and environmental challenges by contributing to the supply security in terms of by-product valorisation of aggregate mining; an ongoing mining of a high mass balance. The project focuses on the extraction of REE from zircon in heavy-mineral enriched marine sands of the south-western Baltic Sea, following earlier studies from the study region, which have demonstrated that zircon minerals from Baltic heavy mineral bearing marine sand contain approximately 0.7 % of extractable REE (Becker et al., 1986). These sands are being heavily mined for coastal protection and construction purposes and offer a steady resource stream of heavy mineral concentrate.

During the first phase of the SEEsand project the distribution and concentration of detrital heavy minerals in offshore areas of the southwestern Baltic Sea have been determined, using archival information from the exploration of near-surface clastic soft-sediments on the Baltic Sea shelf conducted from 1975 to 1989 by the Central Geological Institute of GDR (ZGI Berlin). Granulometric and mineralogical analyses of these sediments show that zircon minerals are enriched in the 0.063 - 0.1 mm sand fraction. The zircon maximum in this fraction is likely to reflect the general small zircon crystal size within the Scandinavian source rocks, rather than being caused by a transport related grain size reduction. A spatial examination of 21,629 measurements from 3,508 sampling localities across 15 offshore exploration areas show an aerially averaged (mineralogically undifferentiated) heavy mineral content between 0.2 and ≥1.0 % mass (derived from averaging the heavy mineral content from the <1.0 mm fraction of all available sediment cores). Detailed mineralogical investigations in areas with elevated heavy mineral contents show a zircon concentration in the 0.063 - 0.1 mm size fraction of up to 13.8 % mass.

The technical processing concept of the heavy mineral fraction in connection with the extraction of the aggregates aims at developing an integrated processing step on board. Further mineral processing on land will extract zircon and other heavy minerals from the pre-concentrate using a standard combination of magnetic, electrostatic and density separation methods. The following final extraction of heavy REE (with focus on Yttrium, Dysprosium, Terbium, and Ytterbium) from zircon will use beyond conventional and mechano-chemical leaching methods an innovative approach of microbial leaching by acidophilic bacteria such as *Acidithiobacillus ferrooxidans* (Glombitza et al., 1988) and the biosorption of heavy REE from the leachate into cellular structures (cf. Schippers, 2007, Andrès and Gérente, 2011). Another objective of SEEsand R&I approach using microbiological separation is the transfer of the determined zircon based technology to its application on Eudialyte from Nordic European deposits by achieving synergies on REE research. SEEsand will also contribute to the utilization of heavy mineral bearing by-products from aggregate mining through further investigation of selected on shore deposits of aggregates which were subject to paleogeographic placers in order to encourage operators to better commercialise mineral resources.

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The Baltic Ice Stream System – did it really exist? Consideration based on petrographic analyses results

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The dynamics of Pleistocene ice sheets is one of the most interesting issues of modern glacial geology. Undoubtedly, the presence and periodic activity of ice streams in the modern Antarctic ice sheet prompts the interpretation and structure of the Pleistocene ice sheets in an analogous way. It is currently assumed that the last Fennoscandian Ice Sheet contained an ice stream system (Punkari, 1997; Kleman *et al.*, 1997; Boulton *et al.*, 2001), which exceeded the solid rock base and in the southern edges of the ice sheet entered the area of unconsolidated rocks. In the light of the model referred to, during the Late Weichselian the northern part of Poland was under the influence of the Baltic Ice Stream (abbr. BIS; ice stream B in Punkari, 1997). The Baltic Ice Stream supposedly had numerous branches, of which at least three, i.e. B2, B3 and B4 could have had a significant impact on glacial sedimentation in Poland.

The Weichselian system of ice streams described by Marks (2005) suggests that the maximum extent of the ice sheet was comparable, and perhaps even greater, in the Wielkopolska inter-lobe area than in the Odra and Vistula lobes, which were described as distal ice stream sections. There are therefore doubts as to why the fast ice-stream flowing, leaving clear geological evidence (e.g. Wysota *et al.*, 2009; Narloch *et al.*, 2013), in this case did not lead to the formation of distinct lobes extending far beyond the ice-sheet front. The logical explanation for this situation is the assumption that the life-span of ice streams south of the Baltic Sea was very short, and this prevented the significant protruding of the ice streams to the south. During these episodes of ice-stream activity, the ice-sheet margin was only slightly altering its position.

The petrographic analyses of glacial sediments carried out by the authors in the western vicinity of the Gulf of Gdańsk and the Lower Vistula Valley (e.g. Czubla, 2015, Woźniak & Czubla, 2015, 2016) seem to indicate the ice inflow directly from the north and north-west and not along the Baltic depression, which would be expected in the course of the ice-stream movement according to the Punkari model. Similar conclusions are drawn from the analysis of the research results in the Odra lobe and its surroundings (Górska-Zabielska, 2008). Her research has shown a very high proportion of Småland, and Skåne rocks and only occasional occurrence of east Baltic erratics, which proves the dominance of the ice inflow from the north, i.e. transversely to the hypothetical BIS.

A serious interpretation problem is the almost complete cut-off of the eastern part of the Central European Lowlands from the Scandinavian Peninsula during the BIS activity. A stable (or reactivated in the same place) ice stream would constitute a barrier to the inflow of rocks from central and southern Sweden into the area of Poland and Baltic states, while the cited research demonstrates the common presence of indicator rocks from these regions in Weichselian sediments. It seems unlikely the ice masses would "interlace" within the ice stream, so that the rocks transported in the north-western fringe of the ice stream could be diverted to its south-eastern periphery and thus feed the branches that go south. The common occurrence of Swedish rocks in the glacial sediments of the Odra and Vistula lobes can be explained in this context either by the incorporation of older deposits, or by the dominance of the radial spread of ice and the adoption of the ice-stream nature only in the late phase of its development. In the latter case, ice streams could have led to the formation of linear landforms, but would have left sediments documenting the composition of debris mainly from the earlier stage of its transport from the source areas (the stage of radial spread of ice).

The ice streams of the Odra and Vistula could have formed at the end of the Poznań/Frankfurt Phase (see Wysota *et al.*, 2009). They were not, however, branches of the BIS, as it probably did not exist at that time. At the maximum of the Pomeranian Phase, the Odra and Vistula ice streams could have reactivated, which seems to be indicated by the lobe-shaped ice margin during this phase (Marks, 2005). The proper BIS developed later, perhaps at the end of the Pomeranian Phase, and, with the rapid flow of the ice to the west (Kjaer *et al.*, 2003), prevented the influx of ice towards areas south of the Baltic Sea. In this way, it could have stopped the functioning of the Odra (B2) and Vistula (B3) ice streams, and − perhaps − contributed to more intensive deglaciation of northern Poland.

The model of the BIS (Punkari, 1997) suggested a different pattern of ice flow than that observed in the modern-day Antarctic Ice Sheet (e.g. Rignot *et al.*, 2011) or adopted in the Laurentian ice sheet reconstruction (incl. Stokes & Clark, 2001; Kleman & Glasser, 2007; Stokes *et al.*, 2016). Active ice streams erode the substrate and supplied by smaller ice streams (forming systems similar to the main river with tributaries) discharge the majority of the ice and sediment associated with the Antarctic Ice Sheet. There are no indications that the main stream split into several large ice streams. Some researchers are starting to see this contradiction, because they have abandoned following the Punkari concept in favour of a much simpler scheme (Forsström *et al.*, 2003; Kleman & Glasser, 2007 − Fig. 13b). The results of our petrographic studies of glacial sediments support the need to correct the current ice-stream model in the southern part of the Fennoscandian Ice Sheet (in both spatial and temporal context), in particular replacement of the southern branches of the BIS proposed by Punkari with separated and shortened ice streams and their sporadic switching on and off.

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Small-scale geologic and morphogenetic evidence of the Lateglacial coolings

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The Lateglacial coolings, in spite of their relatively short time, promote significant change in sedimentary environments. These changes were recorded in river pattern, intensification of slope processes and formation of inland dunes. Major geomorphological responses to climate changes were accompanied by numerous small-scale processes which complement the picture of changes in environment. The small-scale processes are understand as phenomena which slightly influence the geological or geomorphological pattern, but are outstanding in reconstructing instability of the environment of the Pleistocene decline. These processes are connected with periglacial domain and combination of wind action and slope processes and are pronounced as small periglacial involutions, small ice fissures, transformation of soil structure, sharp-edged lumps in alluvia and snow-cover sediments.

The small-scale evidence were studied in the Łódź Region located in Central Poland. The Łódź Region is an area where palaeogeography of the Lateglacial is well recognized, which allows recognition of these small-scale proofs related to the period we are interested in. They were recorded in different sedimentary environments as: river valleys, dry valleys and dunes.

Small involutions were documented in the Warta River valley in north-west part of the Łódź Region, and they were very thoroughly studied and dated at the Younger Dryas and their relationship with the periglacial environment has been proven (Petera-Zganiacz & Dzieduszyńska, 2015; Petera-Zganiacz, 2016). In deposits of the dune located in Witów, Lateglacial involutions were find as well (Chmielewski, 1970).

There are some localities in the Łódź Region were ice-wedge or frost fissures of the Lateglacial age were recognized, but the most interesting and significant as a point in the discussion about permafrost reactivation in the last stadial of Pleistocene are structures developed in the Younger Dryas. Periglacial phenomena have been described in the Bełchatów brown-coal open pit. At the base of the aeolian dune sands Kasse *et al.* (1998) reported ice-wedge casts, ~ 3 m deep and ~ 0,2 m wide, and small narrow sand wedges in a similar position. Frost fissures existing at least few seasons were present in the Warta River valley and were studied in the Adamów brown-coal open pit (Petera-Zganiacz & Dzieduszyńska, 2015).

Evidence of the permafrost presence is registered as sharp-edged lumps of medium-grained sand with preserved internal structure found in the Younger Dryas channel deposits of the middle Warta River valley (Petera, 2002; Turkowska et al., 2004). The Younger Dryas floodplain freezing was registered also in other valleys in Central Poland, e.g. the Ner River valley as the occurrence of fossilized lumps of overbank deposits buried in channel filling (Turkowska & Dzieduszyńska, 2011).

The next small-scale evidence of climate cooling during the Lateglacial are transformations of a soil cover – usually soil of the Alleröd age – expressed by its marbling structure or/and presence of fragipans. The changes of the soil structures were best recognized in the soils developed in sandy-silty Plenivistulian series or in sandy deposits of dunes. Both are connected with periglacial environment as promoting, but not necessary factor (Manikowska, 1966, 1985).

On the slopes of dry valleys the oversnow deposition took place (Klatkowa, 1997; Dzieduszyńska, 2011). The deposit consists of vari-grained material of disturbed lamination with small faults and folds. Its origin was connected with deposition on the frozen snow cover by wash, mudflow or wind. The thawing of the snow resulted in the development of collapse structures.

These deposits are evidence of the prominent role of snow in Central Poland and intensification of morphogenetic (slope) processes in response to the Younger Dryas cooling (Dzieduszyńska, 2011). Information about significance of a snow cover are provided also by denivation slide structures developed on the steep slopes of dunes as a result of movement of the sand conglomerated by plant roots and soil during thawing of snow (Manikowska, 1995).

From the described groups of small-scale geologic and morphogenetic evidences of climate changes during the Lateglacial, involutions and frost fissures are the easiest to recognize. Effects of transformation of the soils are often studied as well. The oversnow deposits and denivation slide structures seem~~s~~ to be more problematic to study but crucial in collection of information about the specificity of the Lateglacial. The discussed structures survived – in some cases – thanks to decrease of intensity of morphogenetic processes during the Holocene. On the other hand, the near-surface position and accompanied soil weathering processes could seriously obliterate their diagnostic features.

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Diversity of geomorphological features of peatland basins in Central Poland

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Geological and geomorphological studies focused on over 30 sites in the Łódź region (Central Poland), this area was last glaciated during the Cold Warta Stage (MIS 6). The peatland basins are located mainly in valleys and on morainic uplands. The diversity of the basins in these areas was affected by geomorphological processes: glacial, fluvioglacial, slope, aeolian, thermokarst and fluvial. Peatland formation in this region occurred in different groups of basins: basins located in the upland area (glacial origin with subsequent transformations), basins of aeolian origin, basins located in valleys (separately in the active river valleys and in inactive valleys), also in marginal valleys. The vast majority of the mires are located in the valleys, while those existing on morainic uplands are extremely rare. Paleoecological analyses of biogenic deposits show the development of peatlands occurring since the Late Vistulian to the Subatlantic Period. The creation and development of the peatlands provided evidence of a strong influence of geological and geomorphological factors.

The diversification of the genesis of the peatland basins allowed to divide peatlands based on their location (in valleys or upland mires) and the processes forming their basins (e.g.: glacigenic, eolian, fluvial or thermokarst processes). The peats prevail in the structure of the sediments that exist in the analysed basins of peatlands; among them the most predominant ones are fens, while the percentage of raised peatbogs is low; in parts of the analysed objects there are lake sediments, which usually form the bottom layers of the profiles of the biogenic sediments, usually accumulated in the Late Vistulian. Some of the analysed profiles contain lake sediments of the Holocene age, which is a proof of lake functioning in that period also outside the floors of river valleys. The development of upland basins, as well as valley basins of aeolian origin, is of endogenous character; it begins at a lake stage and it subsequently changes into fens, a transitional peatland and raised peatbogs. Biogenic accumulation basins located in the river valleys do not provide constant sediment growth as they are dependent on variable dynamics of fluvial processes, which means that the registered growth of biogenic sediments is not synchronous in all valley peatlands of the region. Objects that are fed by groundwater and which are located in inactive valleys, can also show varied intensity of the growth of biogenic sediments.

Organic deposits (Eemian-Vistulian) in selected kettle-hole basins in Central Poland

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In Central Poland there are several dozen known kettle-hole basins containing biogenic sediments which have been dated at the Eemian Interglacial and Early Vistulian with the palynological method (e.g.: Klatkowa, 1990 and Roman, 2016). The reservoirs are located in different geological and geomorphological locations. Since 2015, a project is being carried out to study the kettle-hole basins located in watershed areas of the moraine section of the Łódź Hills. The studied basins contain mineral and biogenic sediments. The examination of the sediments is aimed at establishing a timeline of the process of infilling as well as the episodes of the basins functioning as a lake or mire. The works are carried out in a number of test sites. The Józefów site contains sediments that have already undergone palynological studies in the 1960's (Sobolewska, 1966), and are deposited within a form that is described as a fossil pingo (Dylik, 1967). A new profile that has been extracted displays a continuous series of biogenic sediments, i.e.: organic silts, gyttja and peat with a combined thickness of 5.3 m. At the second study side - Rogów - a basin containing lake deposits and peats has been documented as well. The biogenic sediments rest on top of Wartanian till and are covered with mineral formations deposited under periglacial conditions. Such a sequence of deposits has allowed to formulate a thesis on the Eemian-Vistulian origin of the biogenic sediments (Majecka *et al.* work in progress) and the conducted palynological studies will allow to verify it. At the next study site of Pieńki, a series of biogenic sediments has also been identified in one of the kettle-hole basins and it was preliminarily ascribed to series connected in terms of age with the Eemian and Early Vistulian (Majecka *et al.* work in progress). This series rests on top of sandy and fluvioglacial sediments. The site of Żabieniec, where a few basins with biogenic sediments have been documented, serves as a reference site. For two of the basins the profiles have been processed in accordance with the palynological method. In the site of South Żabieniec, biogenic sediments were deposited on tills since the end of the cool Wartanian period to the Early Vistulian. The central part of the area, on the other hand, allowed for a palynological study of a top series of sediments belonging to the Late Vistulian and Holocene. The sediments deposited below have not been studied with paleobotanical methods.

Biogenic sediments constitute a primary core of the infillings of many kettle-holes in moraine areas. Regardless of their geological and geomorphological location, their functioning is mainly limited to the period of the Eemian Interglacial and Early Vistulian. The climatic shifts in the Plenivistulian were the main cause of their rapid and synchronic degradation.

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Lateglacial and Early Holocene (a)biotic environment in response to climatic shifts: an example from Lieporiai Lake, Northern Lithuania

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In this study we present the results of the detailed multi-proxy analyses (LOI, magnetic susceptibility, grain-size and geochemical survey) that help to reconstruct the Lateglacial and Early Holocene environment pattern in the northern part of Lithuania, emphasizing history of abiotic environment. Chronology of the sediment core was based on the interpolation of biostratigraphical and isotope (^{14}C, $\delta^{18}O$, $\delta^{13}C$) data previously collected from the sedimentary basin. Collected data suggests the onset of the sediments formation during the GI-1e event. Further development of the investigated sequence indicates instability in sedimentation regime and ecohydrogeological conditions suggesting cooler and warmer intervals as well as water table changes between 14,000 and 8,200 cal BP in Lieporiai Lake.

The accumulation of coarse well-washed sand and gravel, enriched by Si and Na, started immediately after the retreat of the ice cover. Sedimentation of dark calcareous and silty gyttja containing very low amount of organic started in about 13,900 cal BP. Sedimentation was comparably fast and silty sediments enriched by heavy minerals and consisting of various geochemical elements such as Si, Ti, K, Ba, Rb, Al, Zn, Mg etc. deposited at the beginning. This type of bottom sediments suggests very scarse terrestrial vegetation supporting active inwash. The fruits of *Betula nana* L. were recorded during the initial stages of the sediment formation suggesting local presence of this tree and tundra type communities with *Artemisia,* Cyperaceae, Poaceae, *Salix*, *Hyppohae* predominating at that time. A very few northern-Alpine pioneer epiphytic species of less sensitive forms i.e. *Fragilaria* spp. existed in the lake. At the same time the complex of water plants including *Chara*, *Potamogeton filiformis* and *P. vaginatus* suggests high water turbidity with the intensive mineral inwash to newly formed deep cold oligotrophic water body.

The further investigations confirm the drop of the water table which initiated *Carex* sp. growth on the newly formed shallow lake shore where temporal wetlands started to form and total NAP concentration increased subsequently. This period correlates with warmer G1-1a event. Mentioned changes determinated lower inflow of the terigenic matter clearly seen in geochemical record where curves of mostly weathering elements lowered. The diatom species with low nutrient requirements i.e. *Cyclotella meneghiniana* and *C. radiosa* culminated simultaneously. A number of small visible shells and increasing participation of Ca and Sr seen in record suggest higher productivity of the basin with increasing value of carbonates. This relatively calm sedimentation period lasted until about 13,000 cal BP.

A high input of terigenic matter including fine-grained sand and very fine-grained sand was recorded after 13,000 cal BP proving intensive erosion processes. Simultaneously value of Ti, Al, Si, Na, Fe increased remarkably. Higher water saturation with carbonates is proved by increasing number of *Chara* sp.

During the initial stages of the Early Holocene some sedimentation hiatus occurred as it seen from the data collected. Further development of the environmental record varies around the 9,000 cal BP when soil became stabilized and introduction of the thermophilous species (*Alnus, Corylus, Tilia, Querqus*) started forming closed woodland in the lake catchment. At around 8,000 cal BP light yellowish gyttja enriched by small mollusk shells deposited. This might have been initiated by drop of the water table as deposition of the peat in the basin started after 8,200 cal BP.

The analysed area is currently populated, but no pollution has been observed at the top layer. Higher amounts of Cu, Br, Mn exceeding background values is determined, but it can be connected with organic matter absorption processes.

Kames in the Storiai Landscape Reserve

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The study area is situated in the Anykščiai district, northeastern Lithuania. The relief of this area was formed by melting ice of the Last Glacial (Late Weichselian) and is assigned to the Aukštaičiai Upland. The Storiai kames are located in the interlobate hilly massif formed in the contact zone between two ice-tongues. The entire hilly massive is represented by morainic and glaciofluvial hills and ridges of various size and height, as well as depressions among them. The altitude of this hilly massive reaches 150-160 m a.s.l.. Through environment point of view, the mentioned kames are published as the Storiai Landscape Reserve.

The Storiai kames differs from the surrounding relief of their height and shape (Fig. 1.). They are regular in shape, with steep slopes. The relative height varies from 18 to 27 meters. The absolute heights of the tops of kames varies from 188 to 194 m a.s.l. The diameter of kames at their foot varies from 200 to 350 meters. There is a very limited amount of information about geological structure of kames – only a few boreholes by hand auger were drilled. Most likely the expressive and well-preserved forms of kames depends of their internal structure. Thus, it can be assumed that the foundation of kames is composed by till. Meanwhile the upper part of kames is composed by sandy-clayey sediments (Fig. 1.): kame A is covered by laminated thickness of fine-grained sand, very fine-grained sand and clayey sand; kame B (the highest) – by laminated fine-grained, various and fine-grained sand with gravel, D – by clay. Only kame C is covered by till. The mentioned kames were formed in ice cavities, very likely, later have not been extremely eroded by melt-water. The kames are mutually separated by the marshy depressions.

The Storiai kames are surrounded by an abundance of low (relative height up to 3-6 meters) morainic hills, generally an asymmetrical shape with two or more tops. Several kettle-holes of glaciokarst origin are developed in this relief.

The issue of the Storiai kames's genesis is still under discussion and requires an additional geological information.

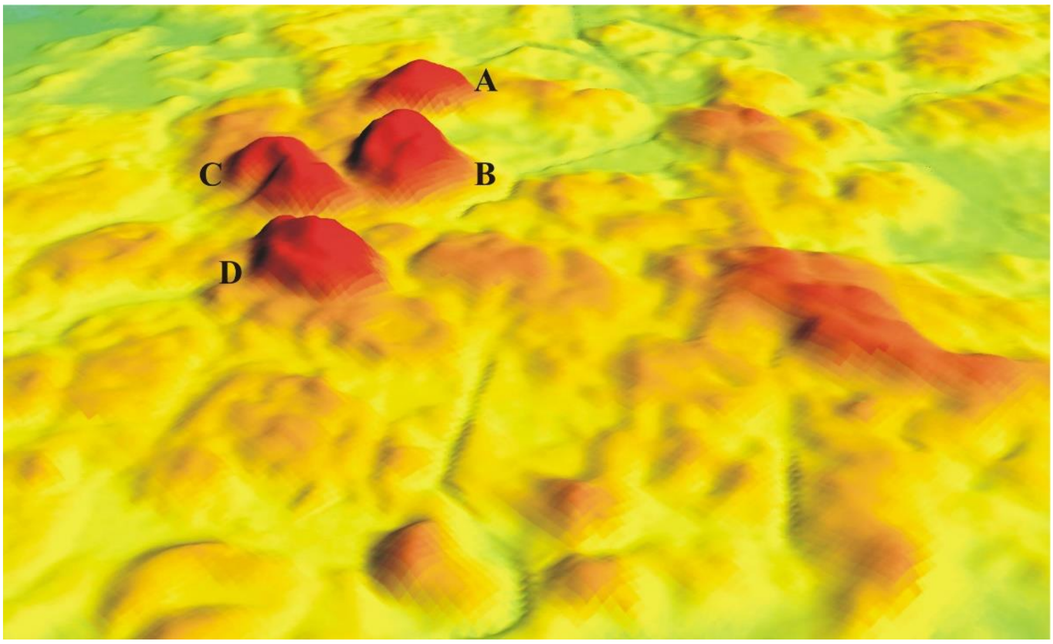

Fig. 1. 3D model of Storiai kames (compiled by V. Mikulėnas).

Prehistoric earthquakes and neotectonics in Hamburg and Schleswig-Holstein (NW´ Germany)

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North Germany is considered a low seismic area (Leydecker 2011). According to Reicherter et al. (2008) no seismogenic faults have been active during the Holocene. Possible seismites as evidence for earthquake-induced dislocations as a result of postglacial rebounds were recently described by Hoffmann & Reicherter (2012) from the island of Usedom (NE Germany). Brandes, Polom & Winsemann (2011) found corresponding indications for a reactivation of disturbances during the late Pleistocene on the southern flank of the Wesergebirge (NW-Germany). In general, caution is required in the interpretation of suspected tectonic structures, as different non-tectonic geological processes such as subglacial processes (streamlining), glacitectonics, dead ice processes and periglacial processes can lead to very similar structural forms. In Hamburg-East, earthquake structures have been mapped. Blowout clastic dykes, injection dykes, seismoslumps and seismites occur as seismically induced structures. Syngenetic infill structures and their organic fillings could be used for an absolute dating of the events. Indications of Prehistoric-holocene seismic events were found. The structures could be linked to a NW-SE spreading fault. A site at Peissen in West-Holstein shows a complicated fault system, which until now has been linked to karst processes. The area, now classified as tectonically influenced, was active during the Saalian, the Weichselian-Lateglacial, and probably the Holocene. The dominant type are normal faults and graben structures. Faults are primarily oriented in a NW-SE- and a W-E-direction. Offsets are usually a few decimeters, in individual cases they reach meter scale. Seismite-like sediment structures and extensive dewatering structures are also present.

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Pre-Quaternary geomorphology of northern Fennoscandia: framework for Quaternary studies

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Northern Fennoscandia is dominated by shield rocks of mainly Archaean age and bounded by the Caledonide mountains in the west and the Riphean intra-cratonic basins of the Bothnian Sea in the south and the White Sea in the east. Proterozoic and Phanerozoic sedimentary rocks offlap the basement on the Barents Sea shelf and on the Russian Platform. Uplift of the northern Norwegian margin occurred from the Late Cretaceous and continued at intervals into the Pliocene (Knies *et al*., 2014). We have analysed topographic profiles generated from new Digital Elevation Models (DEMs) that indicate uplift and warping of the sub-Vendian and sub-Cambrian peneplains and the emergence and progressive denudation of the Saariselkä-Maanselkä scarp. A series of relief generations that developed through the Cenozoic is recognised on the foreland and backslope of the scarp. Long term rates of basement erosion were low (<10 /Myr) (Hall, 2015). Kaolinitic deep weathering developed during the Miocene and possibly also in earlier periods (Gilg *et al*., 2013). Cooling from the Late Miocene onwards led to its replacement by gruss-type weathering (Pekkala and Yevzerov, 1990).

At the onset of ice sheet glaciation at 2.8 Ma (Flesche Kleiven *et al.*, 2002), the landscape of northern Fennoscandia was a mosaic topography of extensive planation surfaces, valleys and topographic basins with deeply weathered floors and ridges and hill masses formed on rocks resistant to chemical weathering (Hall *et al.*, 2015). Across large areas, the impact of glacial erosion on this landscape has been minor (<20 m) (Ebert *et al*., 2012; Ebert *et al*., 2015). In the ice-divide zone in northern Finland, the heavy mineralogy of tills indicates that glacial transport distances were also low (Sarala and Ojala, 2008; Sarala and Peuraniemi, 2007; Sarala *et al*., 2009). Understanding the dynamics of ice movement across this old landsurface is fundamental to many questions in Quaternary research and to the interpretation of results from mineral prospecting surveys.

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Morphometry of the Stargard drumlin field (NW Poland) in the terminal zone of a major Weichselian palaeo-ice stream

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A large body of literature concerns the morphology and spatial patterns of drumlins, mega-scale glacial lineations and other related subglacial bedforms. Geomorphological analyses of these streamlined bedforms facilitate identification of palaeo-ice streams and yield data to constrain their dynamics in time and space. In this study we investigated the morphometric characteristics and spatial patterns of over 1300 streamlined bedforms in the Stargard drumlin field (NW Poland) marking a terminal area of a major last-glacial palaeo-ice stream based on a high-resolution digital terrain model (LiDAR).

Most of the streamlined bedforms are 600 to 800 m long, while the modal class of their widths is from 200 to 250 m. Almost 50% of the bedforms are between 3-6 m high and only slightly below 4 % are higher than 10 m. The elongation ratios of ca. 60 % of the population range from 1.5 to 3.0 and the modal class is 2.00-2.25. The overall pattern of the field (Fig. 1) reveals a distinct curvature corresponding to a radial flow pattern in a big ice lobe, but local deviations grouped in several discrete zones occur.

The relationships between drumlin orientations, local geology and relief of the ice/bed interface (Hermanowski 2015) suggest that the ice flow pattern was controlled by the topography and the nature of subglacial deposits. Ice acceleration is evident in the northeastern part of the field where a transition occurs from densely packed to sparser but longer drumlins in parallel with the increasing down-ice dip of the bed. In some parts of the field the elongation ratios are very high (>10:1), which is consistent with low ice-bed elevation and the occurrence of fine-grained, low-conductivity deposits in the bed. The later would increase the basal meltwater pressure and decrease the basal coupling thus accelerating the ice flow. Assuming that the length and elongation ratios of drumlins are modulated by ice sheet velocity (e.g. Briner 2007, King *et al*. 2009, Stokes *et al*. 2013) the ice velocity in the main trunk area of the palaeo-ice stream was several hundred metres per year and at least twice as fast as in the eastern neighbouring area. In sum, the morphometric characteristics of Stargard drumlins reflect a spatial mosaic of ice flow dynamics influenced by the ice/bed relief and geology.

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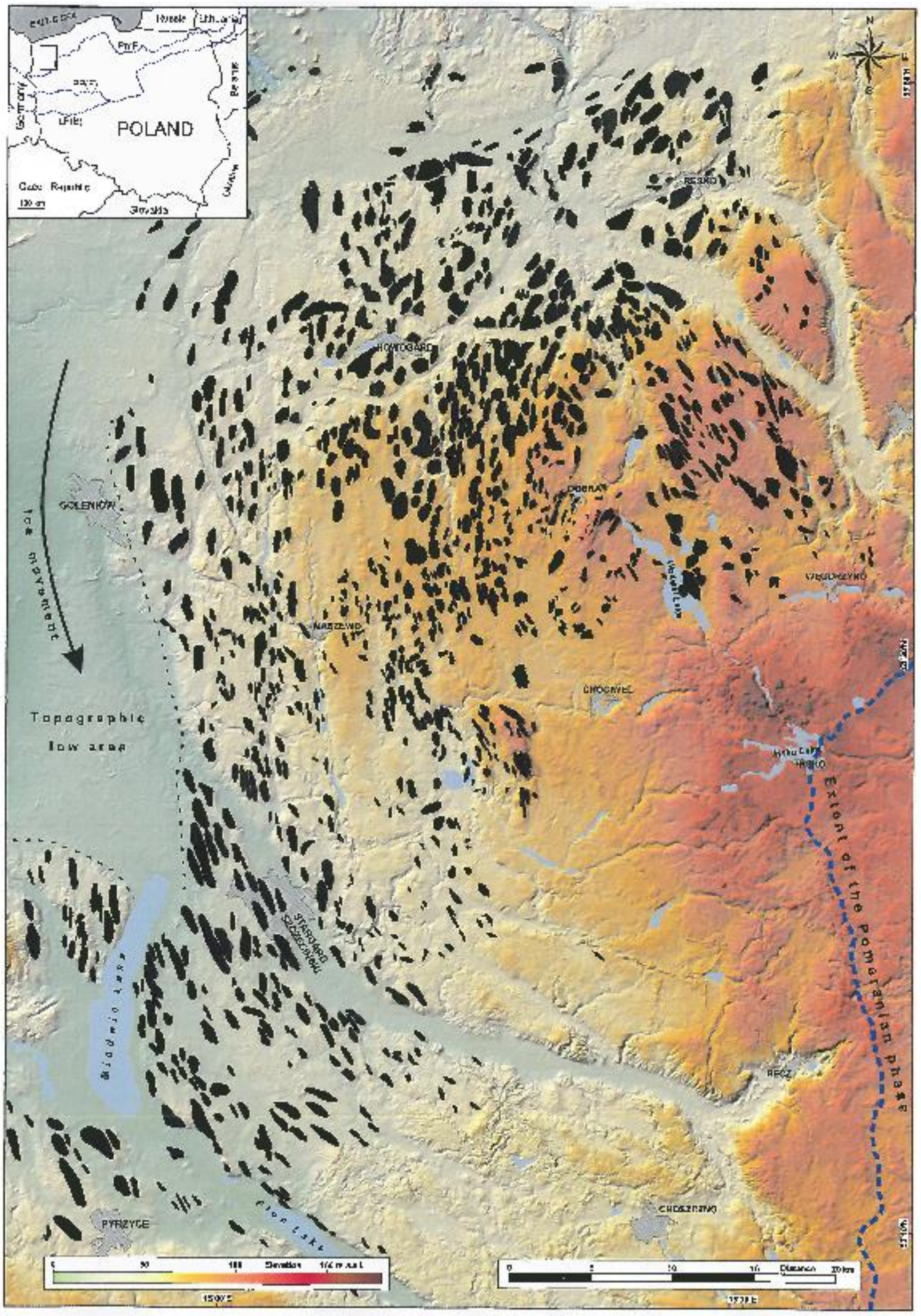

Fig. 1. General view of the Stargard drumlin field, NW Poland.

Evolution of the Eurasian ice sheets: what did we learn from DATED, and what now?

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In 2016 we released the first version of a 10-year project (DATED) to compile all available chronological evidence for the advance and retreat of the last Eurasian ice sheets, in order to generate a more nuanced picture of the evolution of the ice sheet extent through the last 40,000 years. Just under 5500 dates were assessed in terms of reliability and used to derive a series of maps detailing the extent of the ice sheets at four time-periods between 40-27 ka and every 1000-years between 25-10 ka. We pioneered the use of maximum and minimum bounding lines to reflect uncertainties in timing and margin position (both quantitative and qualitative, e.g. precision and accuracy of numerical dates, correlation of moraines, stratigraphic interpretations). Large uncertainties (>100 km) exist; predominantly across marine sectors and other locations where there are spatial gaps in the dating record (e.g. the timing of coalescence and separation of the Scandinavian and Svalbard-Barents-Kara ice sheets) but also in well-studied areas due to conflicting yet apparently equally robust data.

Since the DATED-1 census (1 January 2013), the volume of new information (from both dates and mapped glacial geomorphology) has grown significantly although there are only limited changes in the overall spatial distribution (>1000 new dates, Fig. 1). Here, we present the updated version of the dataset and discuss the implications for the revised time-slice maps (DATED-2).

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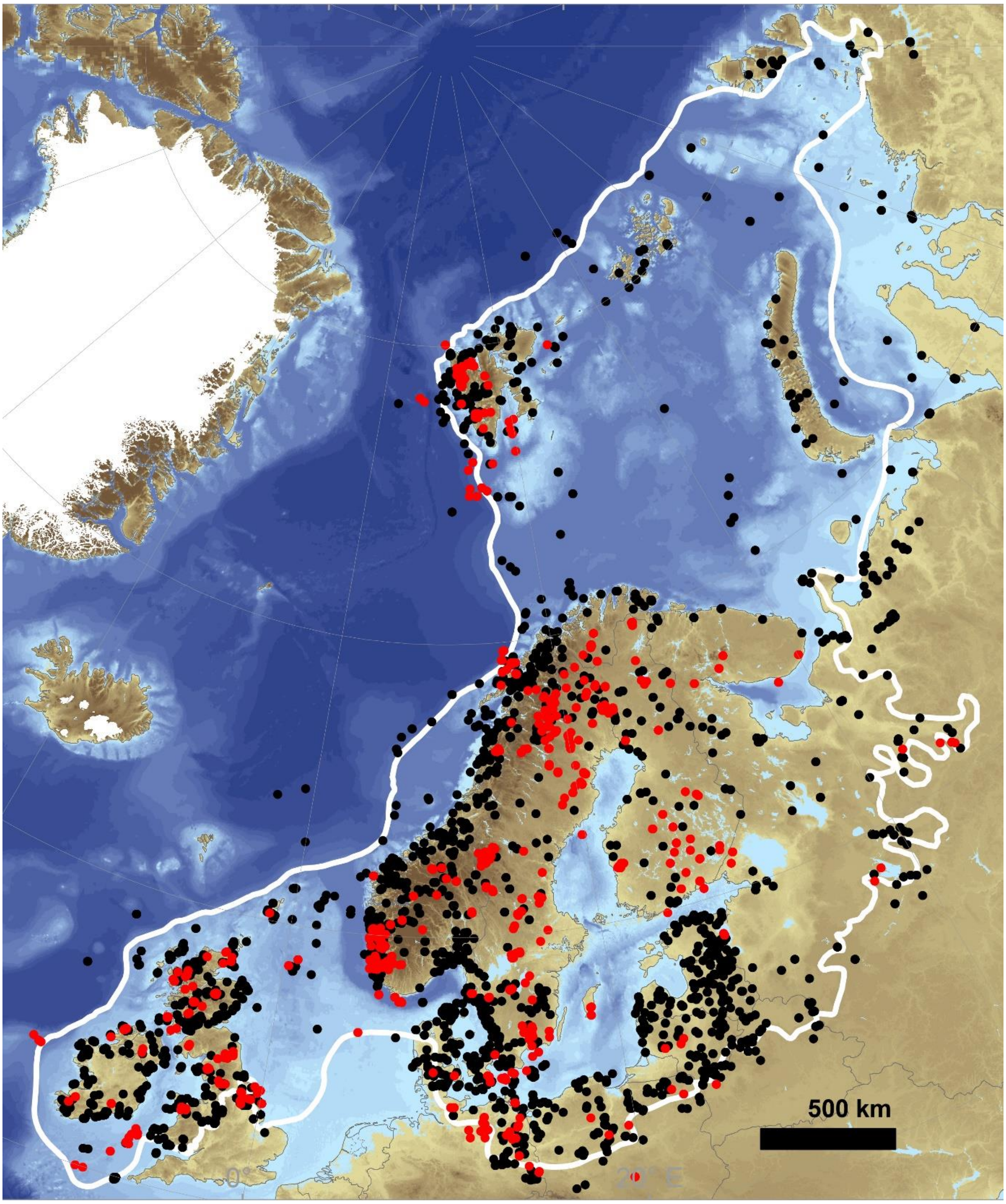

Fig. 1. Distribution of sites within the DATED-1 (black) and DATED-2 (red) databases. Maximum achieved extent of ice during MIS2 glaciation shown by white line (after Svendsen *et al*., 2004).

The assessment of threatened geological habitat types in NW Finnish Lapland

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The assessment of threatened habitat types was conducted for the first time ten years ago and the preliminary results were published as two reports (Kontula & Raunio, 2005 and Norokorpi *et al.*, 2008). The second assessment process started two years ago. The objective is to provide a complete description of the current state of the habitat types, their development during the recent decades and the threats they are likely to face in the future. The assessment is conducted by broad-based expert groups that consisted of specialists in geology, ecology, biology, geography, forest science and other fields of expertise, from various research institutes, universities and administrative bodies. The project was coordinated by the Finnish Environment Institute and Geological Survey of Finland was as a partner.

The assessment of geological types in the fell areas in northwestern Finnish Lapland is a part of the joint project. The geological habitat type refers to spatially definable land areas with characteristic environmental conditions which are similar between these areas but differ from areas of other habitat types. The assessment covered overall 46 biological and geological habitat types in the fell areas. The geological habitat types were divided into 11 groups:

- Patterned grounds (on flat areas and on slopes)
- Bedrock outcrops and boulder fields (oligotrophic and mesotrophic)
- Steeps (oligotrophic and mesotrophic)
- Calcareous bedrock outcrops and boulder fields
- Serpentine bedrock outcrops
- Talus formations (oligotrophic and mesotrophic)
- Calcareous talus formations
- Canyons
- Gorges
- Aeolian formations and deflation basins.
- Frost influenced heaths

The report provides the assessment results, photos and characterizations for each habitat type. The characterization includes also topography, vegetation and moisture conditions. The main threats in the past and in the future are listed and the reasoning for the threat category assignment is given.

In the preliminary stage of the project the method of assessment was developed for the threatened habitat types based on the methods developed in Germany (Blab *et al.*, 1995). It has two main criteria, criterion A relates to the change in the total area or the number of occurrences of a given habitat type and criterion B to their qualitative development. Habitat types are RE (regionally extinct), CR (critically endangered), EN (endangered), VU (vulnerable), NT (near threatened) and LC (least concern).

The results of the assessment showed the geological habitat types in the fell areas are not threatened on average. Most of the geological habitat types are LC. Most significant reasons for the habitat types being threatened are construction (roads and building of houses) in the bedrock outcrops, overgrazing of reindeers in aeolian formations, overgrowing of open bedrock areas and extraction activities in calcareous and serpentine rock outcrops. In terms of future threats, the relative importance of various factors is very similar to that of the reasons for being threatened. The significance of climate change is estimated to increase overgrowing in patterned grounds and in calcareous bedrock outcrops and boulder fields.

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Inland dunes in the western part of Lithuania

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The study area is located in the western part of Lithuania. The spatial geological mapping of the Kvėdarna area (813.9 km^2) was carried out at a scale 1:50 000 in the period 2012 – 2015. Geological and geomorphological maps of the Quaternary deposits were created at a scale 1:50 000 on the basis of the material collected in the course of mapping. The creation of maps was based on the airborne aerial photo interpretation, field observations and analysis of high resolution LiDAR digital elevation model (DEM). Separate inland dunes were mapped in the western part of investigated area. The dunes were identified and mapped from hillshade images of the DEM. The dunes have been developed on the surface of the distal side of the Late Weichselian glaciofluvial delta, Lateglacial and Holocene alluvial terraces. Aeolian sand is fine-grained and very fine-grained (45-77% of the sediment volume consisting of 0.1- 0.05 mm particles), very well sorted, light-yellow color. Feldspar and quartz dominate in the sand. Some dunes were formed on the three different surfaces (Fig. 1.). It indicates that the aeolian processes started not earlier than in the Late Subboreal. Formation of flood plain terraces started at this time (Dvareckas, 1998).

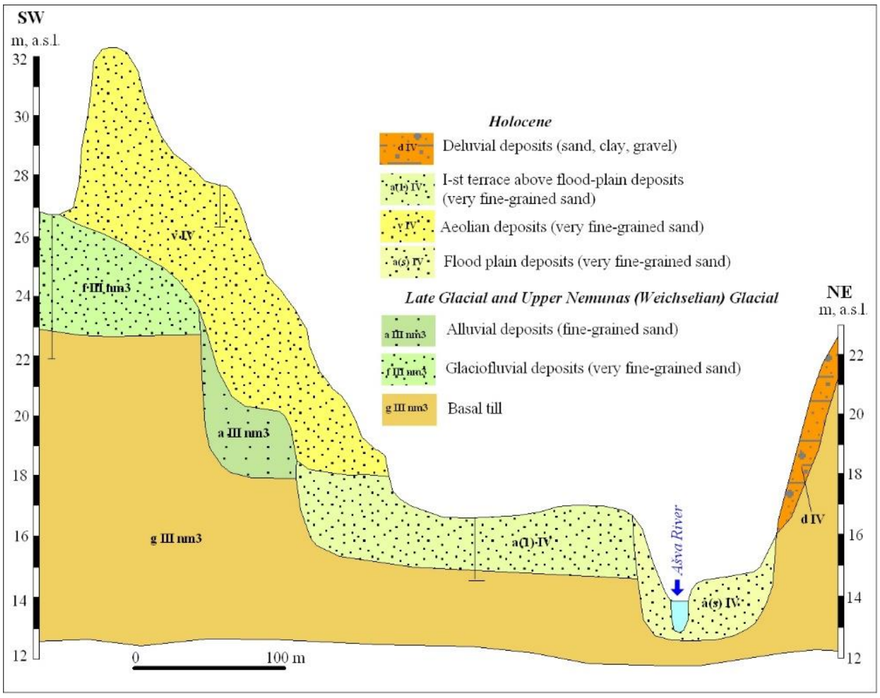

Fig.1. The geological cross-section.

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Features of varved clays formation in the Obdekh River paleovalley (Pskov region, Russia)

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The preglacial river network in the north-west of the East European Plain retained its general outlines despite the repeated transformations caused by ice-sheets. The Obdekh River valley located at the boundary between the Haanja Upland and the Pskov Lowland (Fig. 1) gives a typical example of the valley development during the last glacial sedimentation cycle. The width of the valley is 400-1000 m; its cross-section profile has the shape of a trapezium. The depth of the modern river valley is 40-50 m, while that of the buried paleovalley is about 100 m. The thickness of the glacial deposits of the Late Pleistocene filling in the paleovalley reaches 50 m (Sammet *et al.*, 1967). On the valley bottom, the glacial relief was developed.

Drilling along the longitudinal and transverse profiles in the upper part of the paleovalley revealed a layer of varved clays at the depth of 6.5 to 9 m under peat and lake sediments (clayey loam, sandy loam and lime). The thickness of varves is at least 5 m. At the present, we have not found varved sediments further to the north from the Lake Mal'skoe (Fig. 1), near the hills and ridges of the glacial origin because of the thick cover of sand and gravel material. Probably, the sandy and gravelly material belongs to a fluvial delta. Thus, it is assumed that the proglacial lake existed only in the upper part of the paleovalley at the beginning of the deglaciation of the area, and later it was drained off. Traces of the spillway are visible in the relief in the form of a channel, and the structure of sediments reflects a rapid decline in the water level of the proglacial lake.

AMS 14C dates obtained so far have not allowed to judge reliably about the age of varves. Apparently, the formation of these varved clays took place in a deep proglacial lake during the Late Glacial time, as the end moraine of the Luga (Haanja) stage, aged app. 15 ka BP, is situated only 4 km to the north-west from the studied paleovalley (Tatarnikov, 2007). There are two hypotheses about the origin and age of varved clays in the area. According to the first hypothesis, the proglacial lake formed during the deglaciation of the Pskov Lowland at the beginning of Bølling. The second hypothesis relates the formation of a lake, where varved clays accumulated, with the melting of dead ice masses that filled the bottom of the paleovalley during the Allerød interstadial.

The chemical composition of varved clays is characterized by high proportion of the mineral phase, high content of Si and other elements typical of the mineral class of silicates – Al, Na, K, Mg, Ti, and Fe. Similar chemical composition of the entire varved clay thickness indicates a single stable sediment source, such as masses of dead ice rich in till, which filled the paleovalley and blocked the runoff at its narrow part. At some places in the valley, glacial-accumulative relief forms (kames, kame terraces and hummocky moraines) indicate the former position of till-containing dead ice.

As a whole, in the main core 265 varves were counted. The thickness of varved clays consists of two parts separated by the layer of sand and silt. The individual varves in the lower part of clays are from 10 to 77 mm thick; those in the upper part are from three to 52 mm thick. The varve thickness depends mainly on that of the summer layer. The thickness of an individual varve in the upper varved clay layer increases from the bottom to the top of the layer. The color of the lower layer of varved clay is gray-brown, that of the upper one is reddish-brown. Seasonal layers within individual varves contain additional microlayers and disturbance traces visible on the photographs of thin sections under large magnification. The lower layer of varved clay has more of such microlayers and disturbances. The reason of it could be the impact of bottom currents carrying material from a near melting dead ice. The upper layer of varved clay has mainly undisturbed seasonal laminations. The granulometric composition of the two layers of varved clay is also different. The size of particles in summer layers in the lower clay is finer than that the upper one, while the size of particles in winter layers is similar in both layers of varved clay. The thickest varves containe the largest particles, which could reflect a paleoclimatic signal in the character of sedimentation. The chemical composition of seasonal layers of varved clay is different. In particular, the ratio of Al/Si in the summer and winter layers is opposite. This feature can help in the separation and counting of particularly thin varves.

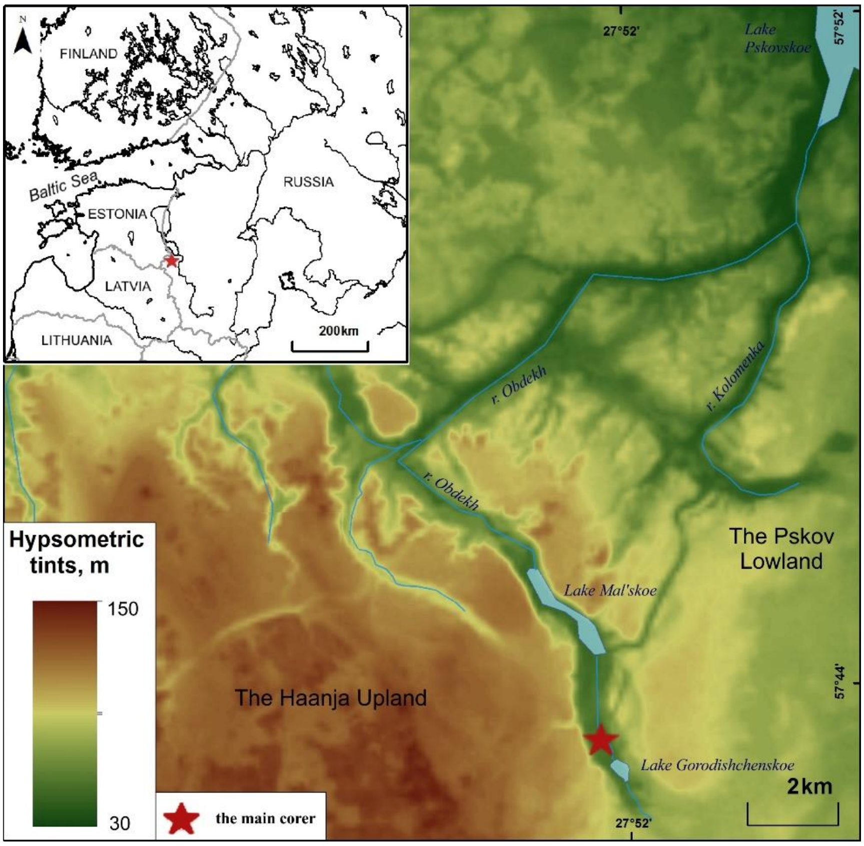

Fig. 1. Geoposition of the investigation region.

The obtained results indicate that in the reference core both proximal and distal varved clays can be distinguished. The formation of proximal varves (those in the lower varved clay layer) took place in conditions of close location of melting dead ice, abundant supply of fine-grained clastic material and with the participation of turbid flows. Accumulation of distal varves (those in the upper varved clay layer) took remote part in the part of the basin in calm conditions with predominance of gravitational sedimentation processes. The works of a number of researchers (Kolka, 1996; Bakhmutov *et al.*, 2006, and others) established that for the purposes of varvochronology only distal varved clays are suitable. In our main core, 217 distal varves are counted within the upper varved clay layer. In other cores, located to the south of the main one, similar distal-type varved clays were found.

The study was supported by the Russian Science Foundation Project 17-17-01289.

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The lake sedimentation in the central part of Pskov lowland during the Late glacial time and Holocene

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The paleohydrology of small lakes in the central part of the Pskov Lowland in the Late Pleistocene and Holocene has not been developed sufficiently. To clarify the history of lakes, investigations of bottom sediments of Lake Belaya Struga (Palkinsky District, Pskov Region, Russia) were carried out. The lake is located on the surface of the limnoglacial plain in front of the marginal formations of the Luga stage of the Late Valdai (Weichselian) glaciation (Isachenkov, 1972, Tatarnikov, 2007). The age of the Luga stage is estimated at 15.7–14.7 ka (Kalm, 2012). From the drill hole BS-1 (N57.47195 ° E28.11337 °), located in the center of the lake, a column of bottom sediments was obtained. The water depth of the lake at the drilling point is 3.5 m. The total length of the core is 9.25 m. The structure of the lake sediments is following: 0.0-7.4 m - gyttja; 7.4-8.35 m - loam; 8.35-8.45 m - peaty loam; 8.45-8.62 m - sandy loam / fine sand; 8.62 - 9.25 m - clay. For samples from the core, the following analyses were performed: LOI (550 and 1000 °C), elemental XRF, granulometric, diatom. Received five ^{14}C dates.

The results of analyses made it possible to reconstruct the history of the lake. Lake conditions formed after the retreat of the glacier in 14.4 to 13.8 ka. The composition of the sedimentary material indicates that the lake in the Late Glacial was oligotrophic, and its level was highly variable. During Holocene the lake was mesotrophic and eutrophic. During the Bölling and the Middle Dryas, against a background of dry and cold climate, the lake level was low. During Alleröd, in the conditions of climate humidification and warming, the water level of lake rises. During Younger Dryas, the lake level could decrease slightly. With the beginning of Holocene, the water level was risen again. During Holocene, the water level fluctuated insignificantly, and its depth gradually decreased due to accumulation (7.4 m of sediment per Holocene).

The research was supported by the Russian Science Foundation, project 17-17-01289.

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Advanced indicator mineral identification techniques in critical mineral exploration

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Increasing self-sufficiency in terms of critical minerals is one of the focus points of the mineral strategy of the EU and Finland. The aim is to decrease dependency on imports from outside the EU and, therefore, ensure the availability of raw materials for high-technology industries. Metals defined to be critical by the EU include rare earth elements (REE), antimony, cobalt, magnesium, niobium and platinum group metals (PGM) that are used in the electronics industry, smart products, catalytic converters and batteries.

GTK's Indika project (Automated identification of indicator minerals in the exploration of critical minerals, 2016–2018) investigates the suitability of new automated field methodologies for the exploration of indicator minerals. Indicator minerals are interesting in terms of research in that they accompany specific ore types and, therefore, indicate the existence of an ore deposit. Usually, there are more indicator minerals and in a larger area than actual ore minerals, which makes mineral exploration easier. Particularly, in the glaciated terrains glacigenic sediments like till and fine grained materials including clays give good ground for indicator mineral exploration.

The Indika project has produced a new pre-processing and research procedure for indicator mineral samples which has been tested in practice and documented. Modern field analysers, such as portable XRD and XRF devices, samples can already be analysed mineralogically and geochemically in the field. With a support of advanced electron optical methods, minerals can be identified fully or semi automatically. Those methods speeds up the work process and improves the cost-efficiency of exploration. Another aim is to improve digital data collection and management.

As a result of the Indika project, mining operators will work and interact more closely together, which is expected to benefit, for example mineral exploration companies. Research partners in the Indika project are GTK, Oulu University and Lapland University of Applied Sciences. In addition, the project parties work together with a number of companies operating in the industry.

Indika project is funded by the European Regional Development Fund (ERDF).

Genesis of buried valleys in the north-west of the East-European Platform

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On the territory of the northwestern East European Platform, which was covered by the Scandinavian Ice Sheet at least 6 times during Pleistocene, a lot of buried valleys exist. Valleys are mainly filled with glacial and fluvioglacial sediments, alluvial deposits were not detected in valleys' bottoms. They are deeply cut in the pre-Quaternary rocks (thalweg marks – 282 m b.s.l. and lower, depth of incision is up to several hundred meters). Most of the valleys have V-shaped cross-sections and undulating longitudinal profiles.

Buried valleys by Russian geologists are usually considered as fragments of the pre-glacial river network, which was formed during global sea-level drop in the Neogene (e.g. Malakhovsky & Markov, 1969; Kirikov & Yanovskiy, 1989). On the territory of Belorus, Poland and especially of Northern Europe (Denmark, Nertherlands, Northern Germany), which was also affected by the Scandinavian glaciations, buried valleys are referred to as tunnel valleys formed by subglacial meltwater erosion (Van der Vegt et al., 2012). In Northern Europe buried valleys are associated to the Elsterian or pre-Elsterian, Saalian and Weichselian glaciation.

Substrate properties, defining subglacial drainage, as well as ice sheet parameters and climate, are the main factors controlling tunnel valleys formation (Kehew et al., 2012). To test hypothesis that buried valleys of Pskov, Novgorod and Leningrad Regions were formed as a result of subglacial meltwater erosion, correlation between valleys distribution and substrate properties was analyzed. (Geology of the study area is given by Verbitskiy et al., 2012.)

Within the Baltic-Ladoga Lowland (area of the Luga Bay, the Koporye Bay and Saint-Petersburg) substrate is mainly composed of the Upper Vendian- Lower Cambrian impermeable clays and siltstones, less often - of sands and sandstones. Valleys have V-shaped cross-sections, widths of 800-3000 m and depths of the bottoms at 90-110 m b.s.l. They are down-cut in the pre-Quaternary bedrock into 50-80 m. Quaternary deposits thickness in the valleys is up to 115 m. Deep valleys, which were detected on land by boreholes, were also traced by seismoacoustic profiling in the Gulf of Finland. Valleys have undulating longitudinal profiles.

Southward, within the Izhora and Volkhov Plateau substrate is composed of the Ordovician fractured limestones and dolomites. On the Izhora Plateau, where limestone is highly affected by karst processes, maximum transmissibility value of 1000-5000 m^2/day is observed. On the Volkhov Plateau, where karst processes are not intensive, transmissibility is 50-100, 100-500 m^2/day. Buried valleys are not detected within the plateaus.

Adjoining plateaus on the south is plain of the Main Devonian Field, which is composed of sandy-argillaceous and carbonate sediments. Its altitudes vary from 25 to 100 m a.s.l., reaching up to 170 m within rises. Buried valleys network of NW-SE course was detected in the northern part of this plain, where substrate consists of the Middle Devonian sands and poorly consolidated sandstones. Valleys bottoms' marks reach 73 m b.s.l., depth of incision is more than 100 m. Dominant transmissibility of the substrate is 100-200 m^2/day.

The lowest part of the plain is occupied by Lake Ilmen depression, where branched network of buried valleys with radial pattern was detected (Verbitskiy et al., 2007). Minimum marks of valleys bottom are lower than 55 m b.s.l. Depth of incision is up to 60 m. Estimated valleys width - a few hundred meters. Here substrate is composed of limestones, dolomites and marls. Dominant transmissibility of the substrate is 10-50 m^2/day, seldom - more than 100 m^2/day.

Eastern part of the Main Devonian Field consists of the Upper Devonian interstratifying limestones, marls, sands, sandstones and clays. Transmissibility of substrate is insignificant - 10-50 m^2/day, seldom – 100-500 m^2/day. Palaeovalley with tributaries that stretches from SW to NE along the "Carboniferous" plateau's scarp was traced by boreholes from town of Demyansk to town of Tikhvin. Its total length is about 250 km (Malakhovsky & Markov, 1969). Valleys bottoms' marks reach 130 m b.s.l., depths of incision – more than 200 m. Valleys width is ranging from 800 m to 2-3 km, sometimes to 5-6 km. Valleys have V-shaped cross-sections. Some valleys have V-shaped upper part and canyon-like lower part. Longitudinal profile of the main valley thalweg is undulating.

The "Carboniferous" plateau forms the highest relief level. Plateau is mostly composed of the Carboniferous limestones and dolomites interstratifying with sandy-argillaceous sediments and marls, and also of impermeable clays with sand and sandstone layers (which reach the pre-Quaternary surface in the form of narrow strips). Plateau's surface inclines from 150-277 m on the western margin south-eastward to 75-100 m. Due to different level of fracturing and karst processes in limestone transmissibility parameters vary from 10-30 to more than 5000 m^2/day. Buried valleys were detected only within the northern part of plateau and on its slope. Valleys depths are from 60 to 150 m, their width is 1-2 km. Some of the valleys are partly buried and have U-shaped cross-sections. Minimum bottom depth is 23 m b.s.l. To the north of the study area, on the "Carboniferous" Plateau's slope paleovalley of the Urya River was detected. Its depth of incision in bedrock reaches 230 m, depth is 50 m b.s.l. It has canyon-like cross-section.

Above-stated data do not contradict that buried valleys were formed by subglacial meltwater erosion. This is also confirmed by undulating longitudinal profiles of valleys, which is one of the main characteristics of tunnel valleys. Undulating thalweg profiles are the result of substrate erosion by basal meltwater under high hydraulic pressures (Kehew et al., 2012; Van der Vegt et al., 2012). Such uneven, stepped longitudinal profiles have palaeovalleys of Northern Estonia, which is neighboring to study area and has similar geological structure (Tavast & Raukas, 1982).

Irregular distribution of valleys bottoms depths without general trend toward basis of erosion cannot be referred to river-erosion hypothesis. Lack of alluvial sediments in valleys bottoms evidences not river-erosion genesis of the valleys. In addition to that, base of the Neogene alluvial and limnoalluvial sediments in neighboring territories is at 70-150 m that is much higher than buried valleys thalwegs. Although problem of the buried valleys origin can not be considered as completely solved, most of the modern data more likely evidence glaciofluvial genesis of the buried valleys.

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Environmental variability and the anthropogenic influence in the sediments of Chistoe Lake (Vishtynetsk Highland, Kaliningrad region)

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The Kaliningrad Region is ideal for paleogeographical reconstructions of the southeastern Baltic region because it straddles the boundary between the landscapes of northern Poland and western Lithuania. The oldest deposits are found in the Vishtyneck Highland where ice sheet retreat occurred earlier compared to other parts of the Kaliningrad region. Although previous studies focused on this region the Holocene pollen record is missing. This study presents the reconstruction of environmental variability based on sediment cores from Chistoe Lake, a lake located at of the highest elevation in the Vishtyneck Highland.

Sediment cores from the lake were described, analyzed for organic content using loss on ignition (LOI), and pollen dominance. A radiocarbon chronology was applied, as well. Environmental changes were identified (Fig. 1) and classified into nine distinct units.

The record covers a period > 12.5 ka to present. The organic content in the record varied between 2-75 % LOI. The core record indicates the environmental conditions transitioned from a colder period where shrublands, communities of steppe herbs and *Pinus* sp. were the dominant vegetation, to warmer conditions with increasing dominance of deciduous (e.g. *Corylus*, *Ulmus*, *Tilia*, *Alnus*) followed by cooling as indicated by a sharp decrease of deciduous pollen accompanied by *Picea* pollen increase. Pollens of cultivated cereals (*Secale*) also provide evidence for agriculture.

Our study is an important addition to the understanding of climatic variability in the eastern Baltic region. This study however, differs significantly from comparable studies in the Vishtyneck Highland, particularly concerning age of buried peat at bottom part of column. According radiocarbon dating it is relate to Younger Dryas period, but same layer from Kamishovoe Lake older more than 1,000 yrs. and relate to Allerod period (Druzhinina *et al.*, 2015). Therefore the question about chronology is still open.

The first evidence of agriculture was identified by pollen of *Secale* and rise of post-pyrogenic type of flora. Due intensive erosion processes this lithological unit has a specific feature: grey-olive color and extremely rapid LOI decrease. Same lithological unit from Kamishovoe Lake has age 2,748-2,490 cal. BP. (Kublitskiy *et al.*, 2014, 2016). Preliminary, this age could be considered as beginning of agriculture in region.

Although our results provide insight into past climatic conditions and anthropogenic influence, additional geochemistry and radiocarbon analyses will provide a more detailed record.

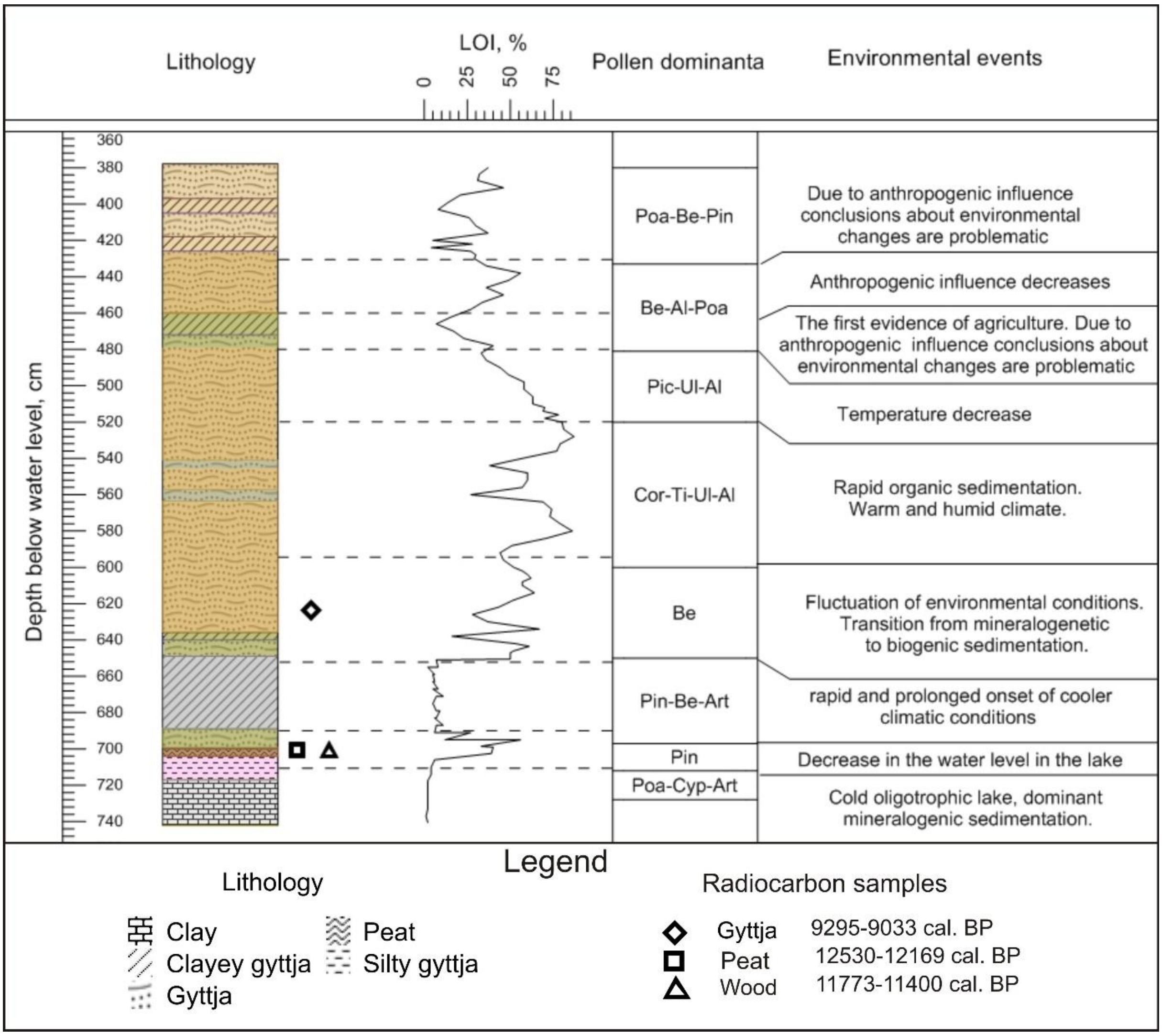

Fig. 1. Environmental variability by sediments records of Chistoe lake (Vishtineckaya highland).

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The coordination of groundwater protection and aggregates industry in Finnish Lapland, phase II

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Since the 1990s, a huge amount of data related to the groundwater and soil has been collected in several regional projects in Finland. EU funded project “The coordination of groundwater protection and aggregates industry in Finnish Lapland, phase II” started in July 2016 and it covers the last unstudied areas in these projects in Finland. Project is carried out by the Geological Survey of Finland (GTK), the University of Oulu and the Finnish Environment Institute and the main topic is to consolidate the groundwater protection and extractable use of soil resource in Lapland, northern Finland. As earlier, several kinds of studies are also carried out throughout this three-year research and development project. These include e.g. drilling with setting up of ground water observation wells, GPR-survey and many kinds of point-type observations, like sampling and general mapping on the field.

The key objective of the project is to improve the practices used in local aggregates industry and ground water protection towards a more sustainable and efficient direction. The long term objective for the aggregates industry is to point out the actions to the areas where they don’t weaken the values of the nature or landscape and not to areas that are essential ground water sources for communities. The objective for ground water protection is to concentrate protection to the areas where the distinct needs of the protection are fulfilled. At the project area, the water supply and aggregates industry are in many cases situated in the same locations, so the long term aim is to regionally separate these actions.

GTK has the main role in this project with support from national and local authorities and stakeholders. The project is funded by the European Regional Development Fund with support from local communes, branch enterprises and executive quarters of the project. Implementation period is 2016-2019.

European Union
European Regional Development Fund
Leverage from the EU 2014–2020
Centre for Economic Development, Transport and the Environment
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Russian Plain: Late Holocene landscape dynamic based on the study of buried soils of archaeological sites

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Russian Plain in the second half of the Holocene is an area of rhythmic climatic variations. Temporal and spatial variability of climatic changes still remains uncertain. Climatic rhythms entailed the transformation of the whole complex of landscape parameters, including soils. Early Iron Age in the center of the Russian Plain is the time broad penetration of sedentary tribes that introduced the culture of fortified settlements starting from the VII century BC. All studied soils are buried under the fortification earth walls of ancient settlements. Nozha-Var settlement was studied in the deciduous forest area (Chuvash Republic). Three settlements were studied in the central part of the forest-steppe zone (Lipetsk region). The bank of Ksizovo settlement is dated by the 5th century BC, while Mukhino and Degtevoye settlements show two banks each due to multiple uses by successive tribes. In Mukhino there are banks of the 5th century BC and the 5th century AD, in Degtevoye – banks of the 5th and 3rd centuries BC. Altogether soils buried under these banks in similar landscape positions on loess sediments constitute a chronosequence. Borisovka settlement is situated in the southern part of the forest-steppe zone (Belgorod region). Burial time of soils differs from each other for one or two hundred years within the Early Iron Age allowing studying variation of soil properties based on short chronosequences within these ranges, and thus reconstruct climatic trends.

The complex landscape dynamics in the second half of the Holocene is revealed based on these studies. Thus, clear unidirectional trend of soil evolution associated with the onset of the forest to the steppe in Sub-Atlantic is recorded in Borisovka settlement. Indicators of such changes are the formation of cutan complex in the subsoil horizons and the appearance of uncoated sand and silt grains in the lower part of the Mollic horizon. Soil evolution results in the formation of modern polygenetic Luvic Phaeozems with features both of forest and steppe pedogenesis.

The study of soil chronosequence in the central part of forest steppe area revealed multidirectional landscape dynamic. The soil buried under the fortification walls of Early Iron Age (5th centuries BC) are similar to modern surface soils – Greyzemic Luvic Phaeozems Loamic. Clay cutans are recorded in the subsoil horizons, and abundance of uncoated sand and silt grains are present in the lower part of the Mollic horizons. The soils buried under the fortification walls of early Middle Ages (5th century AD) are presented by polygenetic Luvic Chernozems. There are no uncoated grains in the Mollic horizon, carbonates are abundant in various forms: impregnation of plasma, soft and hard nodules and carbonate films over clay cutans. Clay cutans proved to be preserved from the previous (forest) stage. Thus, chronosequences of Zadonsk site indicate that the central forest steppe area in the second half of the Holocene experienced landscape dynamics: a change in the conditions of forest to steppe and back to forest steppe. The indicators of such trends are:

1. A complex of clay cutans are already present in the soil buried under the fortification walls of V century BC, indicating that during or before the Early Iron Age soil experienced forest-type pedogenesis. Clay cutans are then inherited by the subsequent stages of evolution till present day;
2. Bleached (uncovered) sand and silt grains in the lower part of the humus horizon. This feature proves to be rather dynamic and can appear, disappear and reappear again;
3. Calcareous profile is dynamic enough feature, subject to reversible changes within the studied space-and-time range.

Due to a combination of stable and unstable features the soils of the chronosequence are polygenetic indicating both forest and steppe pedogenesis.

In line with morphological and analytical soil features microbiomorphic analyses provide further evidence of environmental dynamic since the Early Iron Age. According to pollen spectrum broad-leaved forests with Tilia dominated in the studied area in 5th century BC. A large number of herbaceous detritus and amorphous organic matter, but a small amount of phytoliths, registered in the spectrum. The content of dicotyledonous grasses reaches 84%, forest cereals - 12%, meadow grass - 4%.The composition of the phytoliths complex indicates meadow-forest grass vegetation. The buried soil of the 5th century AD is characterized by the absence of forest cereals and somewhat different ratio of grass species: the content of dicot grains is 91%, meadow grass -9%. As a result, the phytoliths complex can be identified as meadow-grass with participation of deciduous trees. The surface soils develop under the canopy of meadow-forest associations with a high proportion of grasses.

The study of Nozha-Var settlement shows that buried and surface soils (Retisols) are quite similar in grain size distribution. Both soils have well developed clay cutans. Carbonates are present deep in the subsoil horizons. Microbiomorphic analyses (pollen, phytolith, microbial genes) also confirm landscape stability since the Early Iron Age.

The study of buried soils in the steppe, forest steppe and deciduous forests displayed critical stages of the landscape evolution for the Early Iron Age when short climatic cycles could cause a noticeable change in the environmental parameters, reflected in the properties of buried and surface soils. By ranking soil features in their degree of resistance to the landscape dynamics of the second half of the Holocene a group soil indicators of critical points of evolution was revealed. For instance, humus profile, bleached sand and silt grains, carbonate neoformations can serve as indicators of multi-directional trends of landscape evolution. They can appear and disappear in the studied time-and-space range. Clay cutans are indicators of one-way evolution. In the soils of the central and northern forest-steppe and southern taiga, they could be formed throughout the whole Holocene. However, once appeared, they retain stability even under significant climatic changes and so they are indicators of landscape stability. Thus, in the buried soils of the fifth century AD they are preserved in carbonate horizons, and even covered by carbonaceous films. However, buried soils in the southern forest-steppe area display no clay cutans because they have not been formed here before Sub-Atlantic time. In these landscapes, clay cutans are indicators of the onset of the forest to the steppe. Analyses of soil features as indicators of the landscape dynamics are very promising for soil genetic studies. For example, the surface Greyzemic Phaeozems of the forest-steppe areas are polygenetic and reflect dynamic changes in the border between forest and steppe landscapes. The study of soil chronosequence in the southern part of the forest-steppe area indicates that clay cutans could form rather quickly.

In conclusion, the Russian plain in the second half of the Holocene seems to be an arena of complex interactions of different civilizations. Ethnic shifts were largely determined by the climatic rhythms recorded in the buried soils of archaeological sites. In this regard, paleolandscape reconstructions are important for understanding the causes of ethnic shifts and migration waves. Fortification walls of the Early Iron Age and burial mounds of the Bronze Age are not only indicators of landscape dynamics, but also the unique cultural heritage of the East European Plain. Further studies will link the critical stages of evolution with the migration waves of the ancient tribes.

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PALEOLADOGA DataBase as a tool for the reconstruction of Lake Ladoga shore line displacement in the past

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The main goal of paleogeography is the reconstructions of physical and geographical conditions of the past. Paleogeographic researches in the Baltic region are organized during more than 150 years. During this time in detail studied the dynamics of the natural conditions of the Holocene. However, despite of the long period of studying the history of the Baltic region development we have a lot of controversial issues about geo-ecology, geology and paleogeography (Zemljakov, 1940; Saarnisto, 1970; Saarnisto & Saarinen, 2001; Subetto *et al.*, 2002; Subetto *et al*., 2003; Biskje *et al*., 2007; Subetto, 2007; Saarnisto, 2008; Aleksandrovskij, 2009; Gerasimov & Subetto, 2009a; Gerasimov & Subetto, 2009b; Saarnisto & Siiriainen, 2013).

The purpose of this work is to mark the stages of development of Ladoga Lake paleobasin in post-glacial time by using the geographic information system (GIS).

The mains tasks of this work are:

-Generalization of information about the Holocene history of the region using dates from deposits and archaeological dates;

-Identify stages and characteristics of the Ladoga Lake basin in the late Pleistocene and Holocene.

For the achievement of the goal we used modern information techniques, in particular GIS techniques to systemize, analyse and visualize information about the history of the Ladoga Lake in the last we have created the palaeogeographical database - «PALEOLADOGA», which provides information about the structure of the bottom sediments of the Ladoga Lake and the surrounding lakes and formed by using all the material which was collected about this study region. The paleogeographic information was compiled from the published literature (journal articles, books, theses, geological survey reports and maps), also materials from currents fieldworks, archaeological dates (Fig. 1).

According to available data, the most important information that characterizes the stages and peculiarities of occurrence of Quaternary deposits can be sampled using queries. The sample can be organized by height above sea level, coordinates and other parameters embedded in the database. As information is received, the database is supplemented with new information about the objects already included in it, as well as information about other lakes not previously described.

Based on previous studies, Ladoga Lake can be considered as a residual (relict) reservoir, because at the end of the glacial epoch, at a higher altitude level, Yoldia, Ancylus Lake and Litorina Sea were reached in its place. In accordance with the foregoing, the first part of this document has been given a more detailed presentation.

The stages of development and characteristics of the lake in the late Pleistocene and Holocene literary sources were analysed, was compiled summarizing scheme of the history of Ladoga Lake. Unfortunately, the north-west territory is very poor in dating the bottom sediments, especially in the eastern part of the lake, therefore it’s difficult to trace the ancient history of Ladoga Lake development, however, analysis of available dating shows the stages of isolation of small lakes from Ladoga Lake from west to north which are quite clearly identified. Comparison with the results of other studies, helped us to solve named problem and was a prerequisite for future modelling of the Ladoga Lake basin.

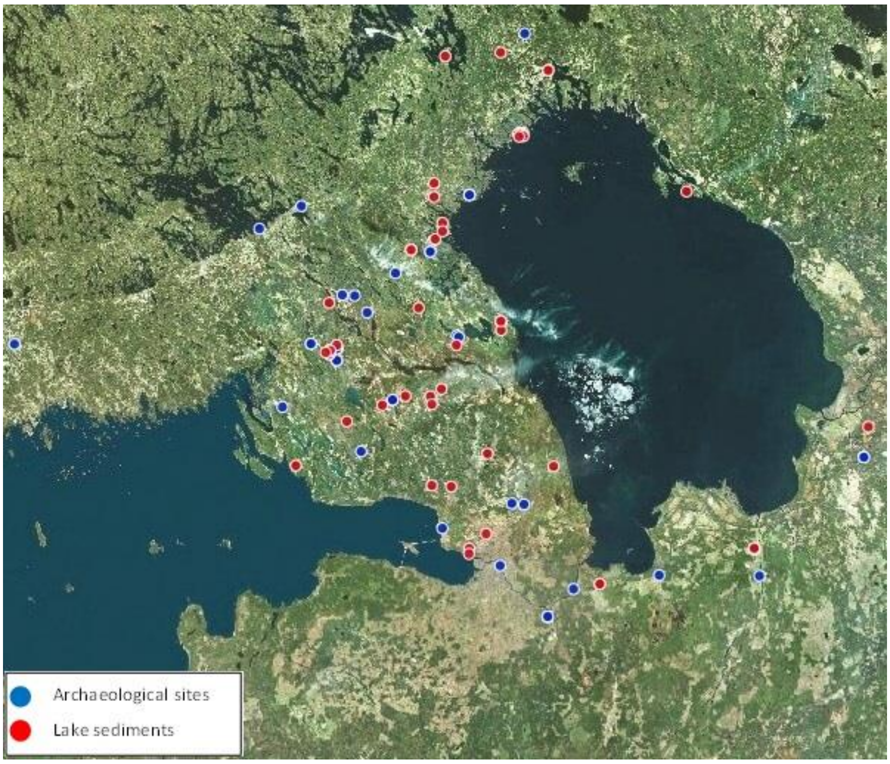

Fig. 1. Location of database objects.

For the achievement of the goal is necessary to use modern information techniques, in particular GIS techniques to summarize, organize and visualize all the material which was collected about this study region. With a view to simulating the development of the Lake Ladoga basin which based on available cartographic material, it is possible to create a digital elevation model of the development of the basin's relief. Using GIS methods, it will be possible to perform high-precision calculations of lake levels in different historical periods and determine its basic morphometric characteristics in the past, and also to identify the stages of deglaciation.

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Saalian seismites in the Ujście Basin, western Poland

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A sand layer (lithofacies Sd) of 0.5 m thick in the middle part of a sandy Saalian glaciolacustrine succession near Ujście (W Poland) contains two horizons with abundant soft-sediment deformation structures (SSDS). One of them (horizon SSDS-S1) is situated in its lower part, and the other one (SSDS-S2) in its upper part. The grain size of the deformed horizons is the same as that of the undeformed sands: coarse silt (31-63 μm) and very fine-grained sand (63–125 μm) with admixtures of clay (<3.9 μm), commonly in the form of alternating laminae. The lateral extent of the horizons with SSDS is significant: at least 350 m (the whole extent of the outcrop). The two horizons of soft-sediment deformation structures are interbedded between similar sediments that do not show any significant SSDS.

The lower deformed horizon (SSDS-S1) is about 20 cm thick and is deformed over its total exposed length. Most of the SSDS are complex, sometimes even chaotic; most of them are load casts and genetically related flame structures. Most load casts are 5-20 cm in cross-section, and they occur at several heights, commonly deforming each other, thus showing that this horizon has been deformed during several phases. The flame structures are up to 7 cm high and 0.5-2 cm wide; they are frequently bent at their tops, sometimes to a more or less horizontal position. The upper deformed horizon (SSDS-S2), of which the thickness varies from 10 to 20 cm, consists exclusively of pseudonodules. The kidney- and oval-shaped pseudonodules are composed mainly of silt and fine-grained sand; they are 0.5-7 cm wide, and 0.5-3.5 cm high in cross-section.

The occurrence of two deformed horizons indicates that some deformation process was repeated. This indicates that the liquefaction required for the origination of these SSDS was the most probably induced by a trigger that was several times repeated so quickly after each other that no distinguishable sediment could accumulate in the meantime. The overlying younger deposits are undeformed. Loading can take place only if liquefaction takes place in the layer under the parent layer of the load casts or pseudonodules (Moretti & Ronchi, 2011). Liquefaction requires that the sediment involved is fully water-saturated (Campbell, 2003), but it needs a trigger (Allen, 1982; Owen, 1995; Jones & Omoto, 2000). The two ‘event horizons’, which show intense folding, collapse, and load structures indicative of liquefaction and fluidization, must therefore have been liquefied by a triggering process that acted repeatedly. The trigger must have induced shocks. It is most probable that the shocks resulted from earthquakes that were induced by glacio-isostatic rebound during deglaciation. The two deformed levels must consequently be considered to be seismites.

In the vicinity of the Ujście quarry some Jurassic faults occur, the most nearby one at a distance of about 12 km. These faults may have become re-activated by the late Saalian crustal rebound. Comparable seismites of late Saalian age have been described earlier from NW Poland (Van Loon & Pisarska-Jamroży, 2014).

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Sedimentological trace of the historical, extreme storm surges on the selected SE Baltic coasts

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During past centuries, South-Eastern Baltic Coast was affected by several extreme storm surges, which influenced local communities, infrastructure and natural environment. Condition of the knowledge and recognition of the sedimentological trace of these events are still insufficient. In central and west part of the Polish coasts, sediments left by 1497 surges were recognized and described (Piotrowski *et al.,* 2015). Geomorphological impact of present-day storm surges was also reported (Łabuz, 2009; Wróblewski and Moskalewicz, 2014). Hence, the new studies aimed to identification of historical marine floods in SE part of the Baltic Coasts were initiated.

During the field work several locations along SE Baltic coasts, with well-preserved sandy layers of potentially storm related origin were examined and cored to the depth of 0.5m. Additional surface samples from neighbour sedimentary environments were taken for provenance studies. Laboratory work included grain size, quartz morphology, heavy minerals, loss on ignition, and diatom analyses. For the purpose of determining the time scale of sedimentation processes, ^{137}Cs and ^{210}Pb dating on gamma spectroscopy was performed.

We present three key sites, where storm surge sediments were recognized. The first one, Messynian Barrier, located in western part of the Vistula Barrier is an example of young, sandy barrier with wide beach, dunes with height up to 3 m, and washovers on the backside of the dune ridge.

Active washover fan was built with two sandy layers which showed horizontal and low-angle stratification in lower part and through-cross stratification in upper part. Textural features of sands showed similarity to the dune and the beach sediments. Analysis of satellite images helped in establishing the time of the washover formation at early 80'. Sediments of inactive washover fan were built with low-angle stratified sands and 10 cm thick peats at the top. ^{137}Cs and ^{210}Pb dating revealed that last marine inflow occurred at the beginning of XX century.

The second key site is located near Mechelinki village within the lowlands close to the Puck Bay. The coast at this site is generally built with narrow, steep beach with poorly developed dune ridge (up to 0.5m high) and wide, flat peatland. Within the peats, 15cm sandy layer was found. It revealed presence of rip-up clasts, gravel clasts and high content of heavy minerals. Textural features of sandy layer were similar to the lower beach but different from the dune ridges. ^{137}Cs and ^{210}Pb dating of peats revealed that the sandy layer was formed at the beginning of XX century.

The third key site is located near town Wladyslawowo within wide peatlands. History archives provided information about common marine floods in the past. The core contained two peat layers separated by 2cm thick sands. Textural analyses revealed modest changes in sand composition within the whole core. The source material was probably aeolian (long distance transport of fine fractions) and marine origin (coarser particles delivered from the Puck Bay). Meaningful results were revealed by diatom analysis, which allowed to separate horizons of crushed brackish and fresh water assemblages. ^{137}Cs and ^{210}Pb dating of peats revealed at least two significant marine floods from the beginning of XX century and early 80'.

Provided results indicate relationship between coast configuration and sedimentation style of storm surge. In the case of well-developed dune ridge, wide beach and positive sediment supply, breaching is the most common storm deposition process in SE Baltic region. Breaching cause the formation of the washover fans with textural features of its sediments similar to the dune deposits. If dune ridge was not well developed and beach was narrow, sediments indicated rapid deposition, which may be related to inundation process. In distal parts of the coast, within the peatlands, sedimentological trace of storm surges is limited mostly to biological evidences, like presence of crushed, brackish diatoms.

Dating results revealed that only extreme storm surges left distinguishable sedimentological trace. Up to date, in presented three key sites in the eastern part of polish coasts, only series of catastrophic storms from the beginning of XX century and the storm surge from 1983 were recognized. However, more research is needed for the purpose of linking geological effects of marine floods with meteorological measurements, prediction and coastal hazard assessment of extreme storm surges.

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Man and deglaciation – the Mesolithic site at Aareavaara, northernmost Sweden

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During an archaeological survey in Pajala parish, northernmost Sweden, clusters of quartz waste from knapping and burnt bone were discovered on a glaciofluvial gravel plateau close to Aareavaara village in the Muonio River valley. Sampled materials from a larger area and small-scale excavations (in total 6 m^2) are interpreted as resulting from short-stay hunter-gatherer camps. Radiocarbon dating on burnt bones suggest an age of occupancy at ~10 700 cal. yr BP, which is more or less contemporary to the 'Komsa Phase' sites on the north coast of Norway (~300-360 km northwards). The Aareavaara site should thus be the so far oldest known archaeological site in northern Sweden (Möller *et al.*, 2013).

A palaeoenvironmental reconstruction, based on pollen analysis of sediment cores from two nearby lakes and radiocarbon dating of macrofossils for construction of time/depth sedimentation curves, suggests a deglaciation age of the area corresponding to early man occupation (~10,700 cal. yr BP). Vegetation quickly developed after deglaciation. During the first 100 years after deglaciation (10,700 to 10,350 cal. yr BP) the area was characterized by open vegetation, including occasional birch trees and an abundance of willow and dwarf birch. The Aareavaara archaeological site coincides with this period, and the vegetation reconstruction gives at hand that there was a clear wood source for fireplaces in which the burnt bones were found. The same type of vegetation continued into the subsequent period (10,350 – 9,600 cal. yr BP), though with a more dense vegetation. However, at 9,600 cal. yr BP there was a distinct change in vegetation when pine and alder expanded.

Aareavaara was at deglaciation situated in a transitional zone between areas in the northeast that were characterized by a subaqueous deglaciation, i.e. the ice margin was retreating with water at its front – in this case the Ancylus Lake – and, in the southwest, a continuation with subaerial deglaciation, i.e. dry land in front of the receding ice margin. Thus the regional highest shoreline developed here behind an archipelago towards a NE sector, approximately at an altitude of 170 m a.s.l. This consisted of both high and low-lying islands, the latter quickly growing in size at the same time as new islands rose above the water level at progressive relative land uplift. This uplift was rapid in its early phase (Lindén *et al.*, 2006), followed by a decreasing uplift rate. The hunter-gatherer camp sites at Aareavaara were thus, both in time and space, located in close proximity to the retreating ice sheet margin, but also in a waterfront location, in fact on an island in the Ancylus Lake.

From where did the first people around Aareavaara come? Having boats, it would have been simple to travel along the Ancylus Lake shoreline from the east, though few contemporary Mesolithic sites are known in that direction (the oldest Mesolithic sites on the Finnish side of the Ancylus Lake are several hundreds of years younger). However, according to Dulokhanov & Khotinskiy (1984) and Matiskainen (1996) there are Early Mesolithic sites on the White Sea coast and on the Kola Peninsula, a possible source area with early deglaciation in the far north. From here it would have been feasible to travel westwards, reaching the Ancylus Lake coast, and then further towards northwest, a total distance from the White Sea coast at around 400-600 km, and without any glacial ice blocking the route at that time.

However, with no so far documented contemporary Finnish Ancylus Lake shoreline sites, it might be more plausible that the travel route to Aareavaara was through the oldest Mesolithic sites in northern Norway, all somewhat older than Aareavaara. It would have been fully possible to follow the receding ice-sheet margin southwards towards Aareavaara along the river valleys, a distance from the closest fjords at about 300-350 km. There are still uncertainties considering the origin of the first humans coming to this part of northern Norway, whether they came from the southwest following the Norwegian ice-free coast or from the Kola/White Sea area in the east e.g. Blankholm (2008), Rankama & Rankaanpää (2008), questions left to be answered.

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Link between subglacial drainage system and strain magnitude recorded in the Late Weichselian till in Poland

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Subglacial water plays a dominant role in many glacial processes influencing till formation processes and mechanisms of ice sheet movement over the substrate (Clarke, 2005). Widespread deformation of soft, water-saturated basal sediments beneath the Pleistocene ice sheets was a consequence of glacier stress exerted on the bed. However, fluctuations of subglacial water pressure around hydraulic ice lifting level along the ice/bed interface caused cyclic ice sheet decoupling from the bed and enhance basal sliding. Water between ice and bed was a barrier for shear stress transmition into the underlying sediments stopping their deformation (Evans *et al*., 2006).

A combination of sedimentary characteristics, grain-size distribution, till fabric and till micromorphology analyses was applied to investigate in detail the properties of the Late Weichselian till at Kozlowo in northern Poland. The till was up to 6 m thick and consisted of number of structurally diversified facies which recorded variable subglacial drainage conditions, till formation processes and ice sheet movement over the bed by a combination of basal sliding and bed deformation.

Estimated microfabric and macrofabric S1 eigenvalues together with IL indexes (Thomason & Iverson, 2006) indicate low shear strains in the order of $10\text{-}10^2$. Relatively highest strains were recorded in the facies of the highest water pressure where decoupling of the ice sheet from the bed was frequent process along with the basal sliding.

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The fells in Finnish Lapland:
LiDAR technology helping to study the landforms

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A new method is introduced to study the geomorphology of the fells or residual hill landscape in Finnish Lapland. Conventionally, topographical maps and elevation information derived from stereographic aerial photographs have been used. Now, laser scanning LiDAR data produced and delivered by the National Land Survey of Finland has opened a new way to examine the geomorphology and terrain in considerable detail. The method is based on laser altitude measurements from a flight altitude of 2000 m, so that the laser beam emitted from the aircraft has a footprint of 60 cm on the ground. The average density of laser measurements is 0.5 per square metre of ground, and the elevation accuracy is at best 15 cm. The bulk of the laser measurements form a digital point cloud that can be processed and handled geometrically. With modern data handling methods and powerful computers, large quantities of geometric material can be rapidly modelled and processed online (National Land Survey of Finland).

We applied the new method to the same area studied by Kaitanen (1985) in the River Kemijoki drainage basin. With accurate elevation data and images, we were able to detail the morphology of the inselbergs and explain the processes that currently alter the terrain. The LiDAR data opened a view into the preglacial history and processes, enabling some preliminary evaluations of the rate and amount of preglacial erosion, or denutation, to be made (Figure).

It appears that the erosion rate may have been in order of 10–50 m per million years in Lapland. However, the dating and the stratigraphic evidence are sparse and incomplete. The weathering and erosion history of Lapland is long, as the kaolinite clays in the weathered bedrock could be of Mesozoic or even Mesoproterozoic age. The fells both in the Swedish and Finnish Lapland seems mostly to have developed as a result of long lasting erosion and weathering and thus fits well to the concept of inselberg or monadnock hill (Ebert *et al.*, 2012).

An inselberg can be an isolated bedrock hill, knob, rocky ridge, or a small mountain that rises abruptly from a gently sloping or virtually level surrounding plain. An inselberg, according to the original German concept is an isolated hill that stands above well-developed plains and appears not unlike an island rising from the sea. However the fells in Lapland are modest examples of inselbergs, when compared to the famous inselbergs like and the inselberg archetype, Sugarloaf Mountain in Rio de Janeiro, Brazil or Uluru/Ayers Rock in Northern Territory of Australia.

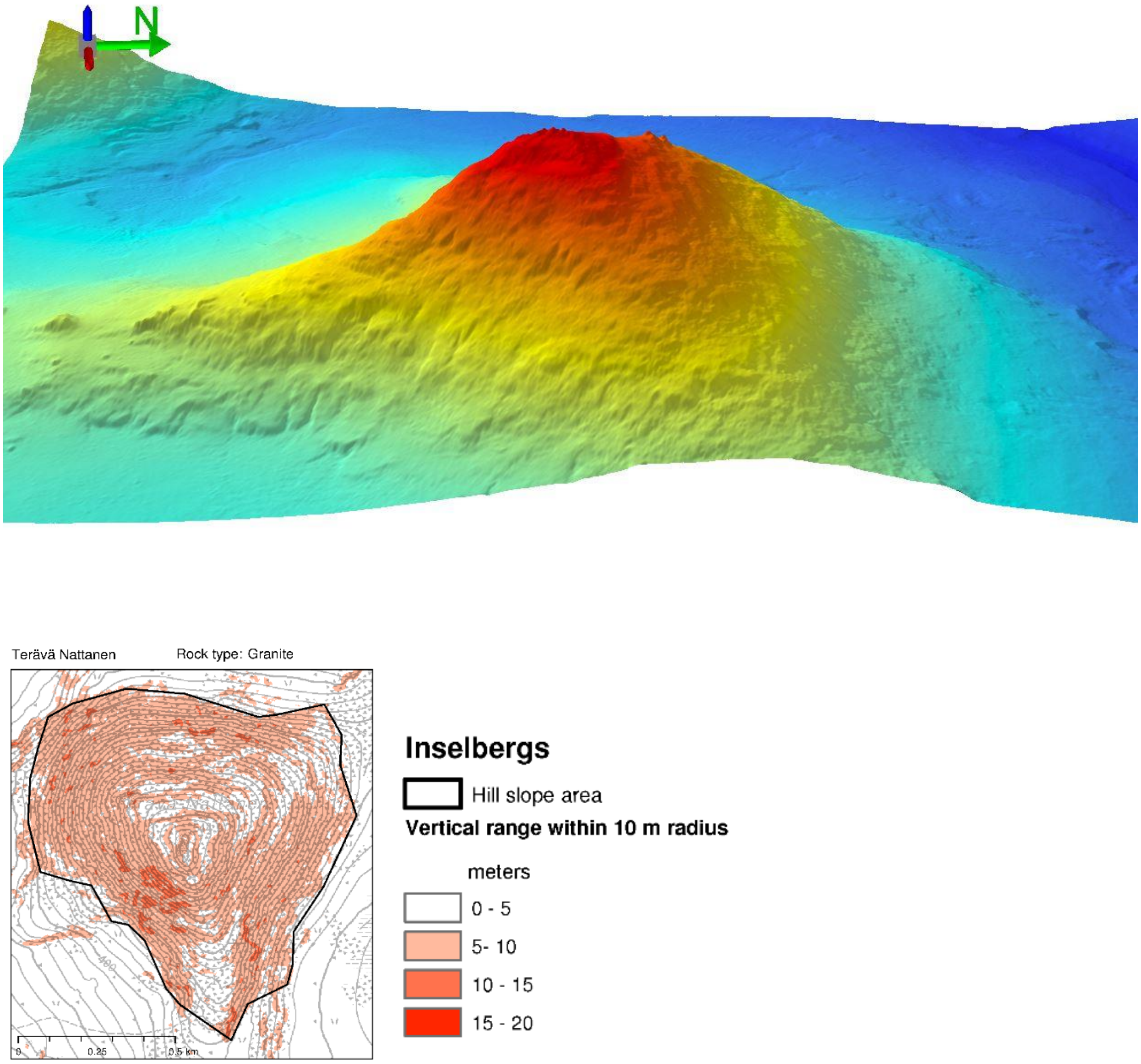

Fig. 1. Terävä-Nattanen granitic inselberg. View from the east. Image produced with ArcScene software from LiDAR DEM by J.-P. Palmu (GTK). The National Land Survey of Finland (Maanmittauslaitos) point cloud data processed into a DEM by M. Larronmaa (GTK). Vertical exaggeration 2. Map area 1668 m (W–E) x 2652 m (N–S). Elevation between 287.4–546.1 metres. Lower image is example of a pure inselbergs Terävä Nattanen described by V. Kaitanen (1985). Processed from LiDAR data by O. Sallasmaa (GTK).

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Morphogenetic processes as determinants of vegetation patterns under impact of the Younger Dryas global climatic changes – main objectives of the research project

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Younger Dryas is a period intensively investigated in the Łódź Region (Central Poland), located in extraglacial area of the Weichselian ice-sheet. The studies conducted there have been mainly focused on the effects of intensified morphogenetic processes as well as on the palynological record. Reconstructions of vegetation cover are in the study area based on pollen diagram of several sites.

The Younger Dryas palynological record varies in the pollen diagrams from sites located close to each other. The reasons for this variability at regional level have not been studied so far. We assume that spatial differences did not occur either because of climatic factors in a relatively small area or due to differences in hipsometry, but can be ascribed to local abiotic components of the environment. In the previous studies it was indicated that processes transforming the surface were activated in all sedimentary environments (e.g. Dzieduszyńska, 2011). Among these processes, of a special importance for the landscape were: significant remodelling/destruction of inland dunes (e.g. Manikowska, 1985), intensified accumulation in river valleys and transformation of river channel patterns (Turkowska *et al.*, 2004; Petera-Zganiacz *et al.*, 2015), activation of slope processes (Klatkowa, 1984; Dzieduszyńska, 2011). An important factor influencing the environment during the Younger Dryas was the possibility of the local permafrost reactivation (e.g. Dzieduszyńska *et al.*, 2014; Dzieduszyńska & Petera-Zganiacz, 2016). Therefore for each locality there is a need to identify the Younger Dryas environment and detect the significance of the impact of particular factors on the succession of vegetation.

Among the analyzed diagrams, particular attention was paid to the Koźmin Las profile, located on the low terrace of the Warta River valley. The organic-mineral series was there accompanied by remains of riparian forest from the Younger Dryas beginning. Based on pollen results, other biological proxies (cladocera, chironomid, diatoms, dendrology) and chronological methods (radiocarbon dating, dendrochronology, OSL measurements), a sequence of environmental events as response to climate cooling was reconstructed, including the time of the forest existence and its destruction, thus the pace of the Younger Dryas events (Dzieduszyńska *et al.*, 2104). In case of the second very well evidenced palynological record of the Younger Dryas in the study area, the Witów profile (Wasylikowa, 1964), located in the contact zone between the dune slope and the palaeolake basin, interesting is to what extent the dune morphology and lithological conditions controlled changes in vegetation.

The results of preliminary analyzes of the relationship between the biotic and abiotic zones of Koźmin and Witów have led to discussion on the dynamics of vegetation transformation in the age of global climate cooling during the Younger Dryas and the diverse responses of plant communities resulting from specific geological and geomorphological conditions. For this purpose a research project was formulated, which received the positive opinion of experts and reviewers of National Science Centre (Poland) and was directed to implementation in 2017-2020 (No. 2016/21/B/ST10/02451).

In the project we put the following research hypotheses:

1. Climate cooling of the Younger Dryas, resulted in a considerable change in vegetation formed during the preceding warming phase of Alleröd, favoured initiation of intense morphogenetic processes leading to changes in surface geology, in relief topography and soil transformations or their degradation. We assume that even a slight change in the local abiotic landscape could have the significant influence on vegetation composition.
2. The diversity of vegetation and direction of its change had to be dependent on local abiotic conditions, because the area of the Łódź Region is relatively small and during the Younger Dryas was characterized by uniform climate conditions, the same degree of soil development and similar distances from the plant refugia.

Apart from the sites of Koźmin and Witów, most pollen diagrams elaborated so far from the Łódź Region we consider prepared with too low resolution in the section covering the Younger Dryas. This means that they are not satisfactory enough from the point of view of the proposed project**.** Thus, it will be necessary to increase the resolution in the selected profiles where the previously performed expertises or low resolution studies indicate a well-preserved pollen record dated at the Younger Dryas period.

The detailed geological and geomorphological studies are necessary in order to reconstruct conditions of the abiotic environment of the Younger Dryas in surroundings of the sites with palynological record of this age. Activation of morphogenetic processes as response to rapid climate deterioration caused instability of abiotic components. Vegetation reacted to the climatic changes as well as to dynamic geological, geomorphological and hydrological events. Archives of the Younger Dryas changes of vegetation patterns are basins in which organic material accumulated, both small basins without outflow and extensive pools in the floodplains.

Results achieved as an effect of the research project will contribute to the paleogeographical reconstruction, pointing to the importance of studying phenomena at the local level, with a detailed recognition of all components of the natural environment. Models of the interrelationships between biotic and abiotic spheres under influence of global climatic changes will be presented in spatial terms. Based on statistical approach, it will be possible to point the regularities having universal features. The results of the study will allow for participation in the discussion about the sensitive components of the environment in an age of global climate change.

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Insights into subglacial till deformation from laboratory experiments

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Deformation of soft sediment along the ice/bed interface is important for glacier stability, continental-scale sediment redistribution and the formation of glacial tills and certain landforms. However, the nature of this deformation (plastic or viscous; brittle or ductile) and the recognition of its signature in the geological record remain contentious. In a detailed study of mega-scale glacial lineations (MSGLs) left by a Weichselian palaeo-ice stream in Poland, Spagnolo *et al.* (2016) analysed multiple parameters of the land-forming till and concluded that it originated at the base of a fast moving glacier by a combination of lodgement and thin-skinned deformation whose cumulative effect was the formation of the MSGL field. A remarkable consistency of the till-forming processes in space and time was suggested.

To further advance our understanding of till formation and deformation postulated by Spagnolo *et al.* (2016) we conducted a series of experiments on this till in a large ring-shear apparatus intended to mimic subglacial shearing (Fig. 1; Bering Holdensen 2017). The shearing was conducted under fully drained conditions at a constant velocity of 2 mm/min and effective normal stress of 85 kPa to the total displacement of 1152 cm. Recorded on-line was the shear stress and till compaction. Undisturbed, oriented samples for micromorphological analyses were taken at displacement intervals of 0, 9, 18, 36, 72, 144, 288, 576 and 1152 cm. Tracers revealed that the till sheared mainly in a 1.8-2.4 cm thick zone yielding a total cumulative stain of up to 640.

Till microstructures mapped on vertical thin sections across the zone of shearing gave intriguing and hitherto unmatched insights into the development and evolution of till properties during shearing under controlled boundary conditions. The overall signatures determined in the course of the shearing are: (1) increase in the number of turbate structures, (2) increase in the number of grain lineations, (3) no trend in the number of grain stacks, (4) increase in the total number of microstructures, (5) no trend in the I_L-index, (6) increase in the I_S-index, and (7) positive correlations between the number of grain stacks and grain lineations, and between the number of turbate structures and grain lineations. We stress that the above signatures often varied non-systematically between the sampled intervals. Three-dimensional microtomographic scanning of the samples showed intervals of relatively stable till fabrics intervening with phases of fabric re-orientation towards new equilibria. Shear stresses during the deformation showed a distinct cyclicity indicating formation and collapse of grain bridges. Collectively, we interpret the ring-shear data as an indication of permanent and sometimes unsystematic evolution of till structure with a general trend towards more ductile and less brittle deformation with increasing strain. These results bear on the reconstruction of past subglacial processes and we advocate extreme caution with interpreting the history of natural tills based on micromorphological signatures alone.

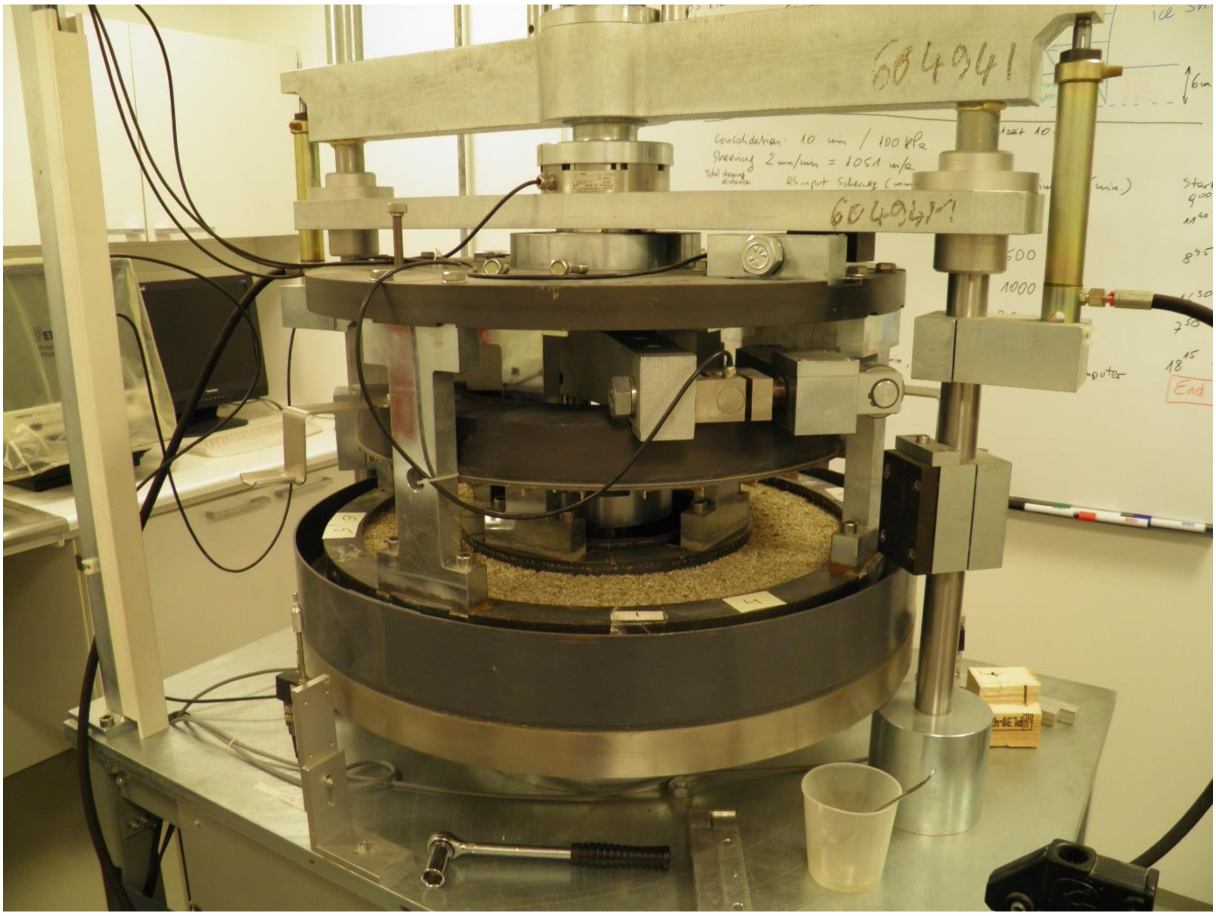

Fig. 1. Ring-shear apparatus at the Department of Geoscience, Aarhus University used for till deformation experiments.

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Silty clasts in a Saalian glaciolacustrine gravity-flow deposit, W Poland

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A sandy Saalian glaciolacustrine succession near Ujście (W Poland) contains a breccia layer that is exceptional because of two aspects: it consists of fine-grained material (mainly silt), and it contains numerous clasts with irregular shapes, consisting of unconsolidated, laminated silt. The breccia does not fit in the general picture of a lacustrine setting as it has not only an overall entirely different lithology, but also because of its extremely bimodal grain-size distribution: cm-sized soft-sediment clasts (SSC) of unconsolidated silt float in a silty matrix that does not show any traces of internal lamination. This layer is 35 cm thick and has sharp upper and lower boundaries. The sediments below and above this layer have mutually identical characteristics, suggesting that the depositional conditions did not change significantly, apart from the event when the breccia layer was deposited. The laminae in the SSC commonly show a distinct bending, indicating more or less complex deformation before or during transport. The SSC are distributed throughout the silt in an apparently haphazard way. Some SSC are rounded, whereas other SSC are sub-angular. Even SSC with a relatively high length/width ratio show no clear preferred orientation with their longest axis parallel to the bedding plane. Wherever elongated SSC are positioned more or less parallel to the bedding plane, the direction of the internal lamination of the silt SSC can be different. Moreover, some pseudonodules are present in the breccia matrix. They show no other granulometry than the surrounding sediments. Water-escape structures up to 35 cm high and up to 0.5 cm wide are also present in the breccia layer.

The fine-grained, predominantly silty matrix with the embedded centimetre-sized silty SSC exclude deposition by a stream: silt would not have been deposited while cm-sized clasts could still be transported. Settling from suspension cannot explain the characteristics either: if this would have happened, it might be expected that some grading and/or some lamination in such thick sediments would have originated, but such features are absent. The SSC might, in principle, have been released from melting ice rafts, but if the SSC would be dropstones, the more or less elongated SSC would have taken a more or less bedding-parallel position, or they would, after moving downwards through the water in a vertical position, have penetrated the water-saturated silty bottom sediment, and they would have either retained this vertical position or they would have tumbled over to obtain a (sub)horizontal position. The breccia shows neither of these features, however.

The only feasible explanation for a breccia in this succession of glaciolacustrine sediments is deposition by a gravity flow. The flow responsible for deposition of the breccia under study must initially have contained almost exclusively fine-grained (silty) material, and on its way downslope it must initially have had sufficient erosive capability to pick up parts of the (frozen) laminated silty sediments on the basin's marginal slope. The turbulence within the flow was high enough to keep the silty SSC distributed all over the flow, and explains why the SSC show haphazard orientations. During the turbulent flow, the individual silty SSC must have bumped against each other and thus became bent, which was made possible because their outer rims gradually became unfrozen thanks to the temperature of the water in the flow. Why a gravity flow, resulting in a deposit with significant thickness and extent, could develop within the overall quiet environment, cannot be established with certainty. There are features, however, that suggest that the trigger may have been an earthquake-related shock: two laterally extensive levels in the succession contain abundant soft-sediment deformation structures that point at repeated phases of disturbation. Considering the context, it is most likely that the sediments were affected by seismic shocks that resulted from postglacial glacio-isostatic rebound of the earth crust. The two levels might consequently be considered as seismites. Comparable seismites of late-Saalian age have been described earlier from NW Poland (Van Loon & Pisarska-Jamroży, 2014). The strong indication for seismic shocks makes it probable that also the breccia layer represents a gravity-flow deposit that was triggered by a seismic shock.

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On the origin of deformation structures of plastic squeezing in late-glacial sediments of the southern margin of the Fennoscandian shield in potential connection with the earthquakes

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A catastrophic deep discharge voltage causes the formation on the earth's surface specific structures of the seismic dislocations, the study of which is the subject of numerous studies. One of the promising areas of their study is the area bounding the southeast of the Fennoscandian shield. In this area, we have identified specific protrusive dislocation squeezing watered clay-sandy rocks among the erratic boulders (Fig. 1) in the late post-glacial eskers deposits of the south-east of Kamennogorsk (on Vuoksa River).

Here, to the west of Lake Borovskoe (N: 60.93090267°; E: 29.31466242°) in the south-eastern side of a large sand pit clearing opened section of esker, folded clay-sand sediments, with a capacity of about 10 m of sedimentary strata form a small depression in width about 10 m and a depth of 5 m in the central part of which there are two smoothed boulders of metamorphic rocks in the thick clay and sand (with an admixture of debris) deposits. Detailed observations show that under the boulders are fragments of the original layering of deposits – layered sands under the right boulder and a small pocket of sandy rocks under the left boulder. These sediments are cut by contact with a layer of clay and sand, the direction of the implementation of which took place from the bottom up (in the direction of the arrow, Fig. 1, III), with the introduction of captured debris and small boulders of metamorphic rocks, up to 10-15 cm. The clay and sand strata characterized by a strong and complicated dislocation orientation of the clay layers (shown by curved black lines). The upper contact of boulders and clay with sand deposits is cutting by erosion surface, which lie under a sandy sediments with coarse-grained material and layering in some areas enveloping large boulders (Fig.1)

The reconstructed formation of these structures took place in several stages:
1 – stage of deposition of the underlying sand and clay rocks; 2 – stage of deposition of the big boulders; 3 – stage of protrusive squeezing watery clay and sand mixture into the space between boulders; 4 – stage of a burial of large boulders under the sand and pebble deposits with the formation of enveloping lamination of sediments. An extrude flooded sediments could occur due to several reasons: A – under the weight of large boulders detached from the floating ice and plunged vertically downwards; B – by boulders rolling down the slope of depression; C – under the pressure of a glacial bed on large boulders; D – as a result of shaking the column with large boulders at earthquakes.

The first possible reason (A) is not the most likely, since its implementation would have to assume simultaneous separation of different size boulders and their simultaneous immersion in depression with wet sand and clay sediments. Rolling boulders down the slope of depression (B) would not lead to the preservation of the original layering pieces at the foot of the boulders, and would entail the formation of structures in the seaming wet sediments around the boulders, which is not confirmed by observations. The pressure of the glacier bed (C) would entail a reorientation of the long axes of the boulders to the horizontal direction.

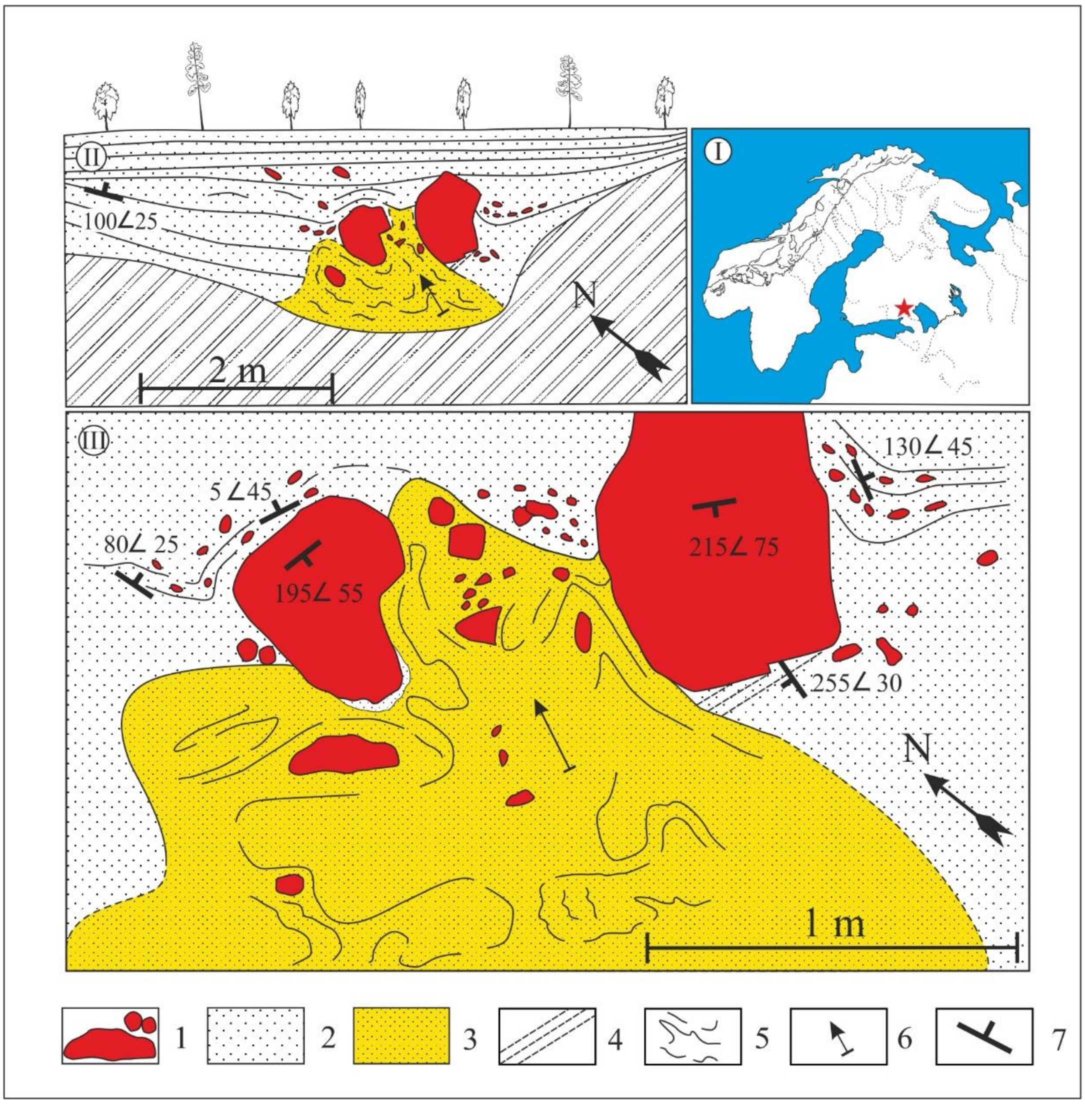

Fig. 1 . Protrusive dislocation squeezing watered clay-sandy rocks at the foot of erratic boulders, formed presumably due to seismic event.

I – a general view, II – a fragment of the section of the quarry, III – a detail view of excavation.

1 – Large and small boulders and pebbles of metamorphic rocks; 2 – sandy and loamy postglacial sediments; 3 – clay and sand sediments, protrusive squeezed into the space between the large boulders; 4 – pieces of lamination sandy and sandy sediments under the right boulder; 5 – pieces of lamination sandy and sandy loam, clay and sand strata; 6 – reconstructed protrusive direction of intrusion; 7 – dip angles of the layers.

The most probable is the last option (D) formation of protrusive structures due to the shaking of boulders and sediment liquefaction followed by mobilization and sediment squeezing into the space between the boulders by the earthquakes. This option does not require significant spatial displacement and reorientation of boulders after their deposition on due to the short duration of seismic phenomena in comparison with other reconstructed version of events, as well as successfully explains the co-presence of fragments of the original stratification of sediments under the bottom of boulders and sediment structures squeezing into the space between the boulders.

If our reasoning is correct, then the age of the dislocated sediments squeezed into the space between boulders can be used to correlate with known seismic events recorded on the Fennoscandian shield.

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A new glacial geomorphological landforms map database of Finland

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Renewing of the glacial geomorphological landforms map database is going-on in the Geological Survey of Finland (GTK). It includes both a new definition of the landform categories and mapping work based on the 2-metre resolution LiDAR (Light Detection And Ranging) data interpretation with ArcGIS software. The definition combines present geomorphological knowledge, various Quaternary geological map databases between 1:20 000 and 1: 200 000 and other geological data. Preliminary sources for map polygons and lines are: 1. LiDAR-DEM data provided by National Land Survey of Finland. 2. GTK's Quaternary geological data, 3. aggregate, engineering geological and groundwater aquifer investigations.

The multi-year project aims to produce 'the best mapping data for each location in Finland' with a cost-effective processing approach. The various themes combine both the main geological unit information with the new, landsystems-based glacial geomorphological themes. The mapping process emphasizes the interpretation of the above mentioned data sets to an integrated, holistic thematic combination with minimal fieldwork.

Previously, the sediment type mapping information in the 200k scale was the most accurate nationwide map set available. Recent studies have shown that previously detected large mega-scale landforms, such as mega lineations, drumlins and end moraine complexes, show up in LiDAR-based digital elevation models (DEM) in greater detail than ever before, and landforms that are smaller than resolved from topographic maps and 10 m grid DEMs can now be detected and examined using LiDAR DEMs. New map themes will additionally include the classification of glacigenic deposit types and differentiate between glacifluvial deposits and littoral deposits typically forms the same polygon in 200k maps. The glaciodynamic themes included in the database are: Glacifluvial deposits, glacially lineated terrains and various types of other moraines referred to much slower ice flow velocities or different glacier margin landforms (ribbed moraines, hummocky moraines, De Geer moraines and end moraines).

The new map database will significantly improve mineral exploration, groundwater studies and land use planning and management. It will also increase the understanding of glaciodynamics and glacigenic morphological evolution in Finland. In the future, the database will be linked to the nationwide stratigraphical units and be extended to the national subsurface 3D databases.

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The terrestrial Eemian to late Weichselian sediment record at Beckentin (NE-Germany): first results from lithostratigraphic, palynological and geochronological analyses

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Over recent decades a growing number of well-documented records from terrestrial Last Interglacial sites across central Europe have substantially improved our understanding of Eemian climate and landscape dynamics. Despite this progress, there are also large areas from which only few Last Interglacial records have become available, thus representing significant paleo-geographic gaps in the record. Among the regions with still inadequate paleo-environmental information are the maritime influenced areas of NE-Germany at the southern margin of the Eemian (Baltic) Sea. Here we present first results from a geological investigation of a new Last Interglacial site, recently discovered during archaeological excavations near Beckentin (SW-Mecklenburg). The study area is located approximately 25 km to the south of the maximum MIS-2 ice limit of the Scandinavian Ice Sheet (local LGM) in NE-Germany, and thus lies outside the Weichselian belt of glaciation. Based on lithostratigraphic and sedimentological logging, complemented by geochemical (XRF) and palynological investigations, we divide the local succession into three sections: (1) a basal facies comprising Saalian till and associated glaciofluvial sand, followed by a middle section (2) consisting of a fen peat which grades into laminated organic to minerogenic mud. The organic deposits of section (2) preserves a near complete Eemian pollen inventory, encompassing pollen zones (PZ) I to VI (Menke and Tynni 1984). Above this rest (3) poorly sorted periglacial sands with ventifacts and evidence for cryogenic deformation (ice-wedge casts). Geochronological results from ^{230}Th/U dating of the buried organic-rich deposits, show that these units accumulated in a former dead ice depression during the Eemian Interglacial at c. 118 – 114 ka ago. High-resolution optically stimulated luminescence (OSL) profiling undertaken with a portable luminescence reader reveals a significant hiatus between the lacustrine fines and the overlying periglacial cover sand. Five OSL ages obtained from these cover sediments and the sand-filling of ice-wedge casts show that these strata formed under periglacial conditions during the late Weichselian period (18 – 14 ka).

Fig. 1. (a) The studied excavation pit at Beckentin, exposing a local stratigraphy of dark-colored organic-rich deposits overlain by light-colored periglacial cover sands. Note the sand-filled cryogenic deformation feature, interpreted as an ice-wedge cast, which cuts stratigraphically across the organic sequence. Also visible is an oak-lined Bronze-age well structure, which was the subject of a separate archaeological investigation. The image to the right (b) shows the pit wall with inserted Kubiëna-type metal boxes, which were recovered for further laboratory analyses.

Lithological variability in tills of the Švenčionys Upland (Lithuania) and their correlation

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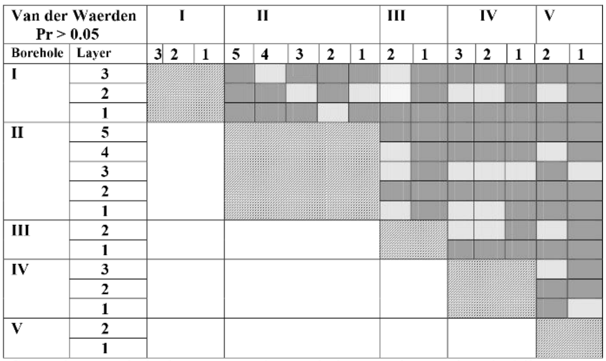
This investigation was conducted in Eastern part of Lithuania in zone of marginal moraines – Švenčionys Highland. Cores of shallow boreholes drilled in five orographically and geomorphologically different surface areas (Rudnickaitė *et al.*, 2015) were investigated. Analysis of sediments was done according to method described by E.Rudnickaitė in Sanko *et al.* (2008), Kabailienė *et al.* (2009). Not only mineral calcite but also dolomite could be determined using this method. The carbonates content of sediments was determined for bulk sample. The till samples were analysed for carbonate content, percentages of dolomite and calcite, and ratio dolomite *vs* calcite (d:c) in all 293 samples taken from the cores of the five boreholes (Fig. 1). For the further comparison of beds Van der Waerden criterion was used.

Fig. 1. **A** - A map showing the location of the studied area and **B** – Planar distribution of shallow cartographic boreholes in the Švenčionys Highland on the Lithuania Quaternary geological map (Guobytė, 2002) cutout background.

According to d:c ratio, using Van der Waerden criterion, three different homogeneous till layers were distinguished in the vertical section of Kusliškės (Gr-1, I) borehole; five different homogeneous till layers were distinguished in the vertical section of Strūnaitis (Gr-2, II) borehole; two different homogeneous till layers were distinguished in the vertical section of Vidutinė (Gr-3, III) borehole; three different homogeneous till layers were distinguished in the vertical section of Minelіškės (Gr-4, IV) borehole; three different homogeneous till layers were distinguished in the vertical section of Papinigiai (Gr-5, V) borehole (Fig. 2).



Van der Waerden Pr > 0.05		I			II					III		IV			V	
Borehole	Layer	3	2	1	5	4	3	2	1	2	1	3	2	1	2	1
I	3	▨	▨	▨	▓	░	▓	▓	▓	░	▓	▓	▓	▓	▓	▓
	2	▨	▨	▨	▓	▓	░	▓	░	░	▓	░	░	▓	░	▓
	1	▨	▨	▨	▓	▓	▓	░	▓	▓	▓	▓	▓	▓	▓	▓
II	5				▨	▨	▨	▨	▨	▓	▓	▓	▓	▓	▓	▓
	4				▨	▨	▨	▨	▨	░	▓	▓	▓	▓	░	▓
	3				▨	▨	▨	▨	▨	░	▓	░	░	░	▓	░
	2				▨	▨	▨	▨	▨	▓	▓	▓	▓	▓	▓	▓
	1				▨	▨	▨	▨	▨	░	▓	░	░	▓	▓	▓
III	2									▨	▨	░	░	▓	░	▓
	1									▨	▨	▓	▓	▓	▓	▓
IV	3											▨	▨	▨	░	▓
	2											▨	▨	▨	▓	▓
	1											▨	▨	▨	▓	░
V	2														▨	▨
	1														▨	▨

** Grey colour stands for homogeneous layers, dark grey – for significantly different layers.*

Fig. 2. Homogeneity of the layers of glacial deposits in the investigated boreholes distinguished according to dolomite *vs* calcite ratio.

Development of stratigraphic correlation scheme of tills for further individual geological sections may chance “criss-cross” correlation of layers what is impossible in natural environment. This situation, especially in the zone of glacial marginal formations, is explainable by correlation of the same layers, which in one borehole are bedding in situ whereas in the other borehole it is bedding as a till erratic (not in situ) incorporated in the layer of younger till. For example, correlation layers I_1 – II_2 and I_2 – II_1 layers (Fig. 3) in the same scheme is impossible: one correlation link should be eliminated and interpreted as result of glaciotectonic dislocation.

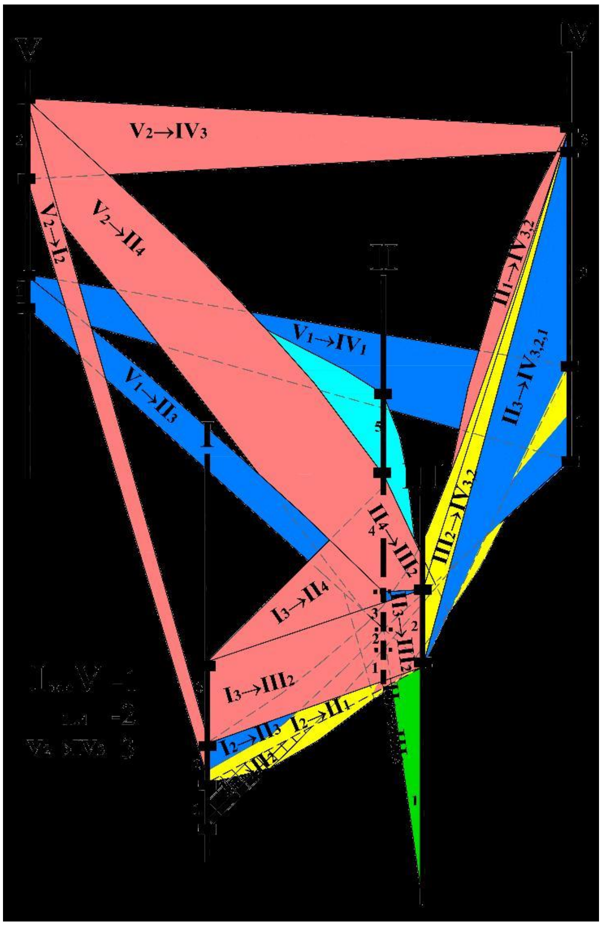


Fig. 3. Block diagram of correlation links of homogenous layers: 1 – borehole numbers; 2 – numbers of distinguished homogeneous layers; 3 – relationships of the distinguished layers.

It is a common case when during stratigraphic correlation till layers in one borehole are distinguished as inhomogeneous but in the final version they are ascribed to the layer of the same glacial advance (stage, substage). The stratigraphic subdivision of spatially correlated till layers is determined according to the established index d:c for these layers. This index also may be helpful in determining the stratigraphic subdivision of erratics incorporated in younger tills (*ex situ*).

The aim of further investigation was to compare all till layers distinguished according to d:c ratio and to subdivide them into stratigraphic units. For this purpose, every newly distinguished layer could be collated with all investigated layers using SAS and by Van der Waerden criterion homogeneous layers could be determined vertically and horizontally. The next step would include search for homogeneous layers and determination of presumptive stratigraphic position of investigated layer.

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Soils of Medieval burial mound as paleoenvironmental archive (Leningrad region, North-West Russia)

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Old settlements are among important geoarcheological objects that allow using paleopedological methods for paleolandscape reconstructions. Soils deeply buried under ancient constructions, especially ramparts and mounds, keep features developed under climatic conditions preceding burial and could be considered as valuable paleoenvironmental archive.

On the territory of the Leningrad region, North-West Russia, there are many archaeological sites, represented mainly by burial mounds of the 12th-13th centuries. However, these archaeological sites of particular interest are being intensively studied only in the last decade. Mound burial grounds located in the forest zone of the North-West of Russia, are still looking like "white spot" from both geographical and historical points of view. The study of buried soils of burial cemeteries, which for the first time undertaken by soil scientists, can help in solving both the problems facing archaeologists and in the questions of paleoecological reconstruction of the natural environment of the sub-Atlantic period of the Holocene.

The objects of our study were soils buried by the bulk layer as a result of the burial site at the end of the 12th-early 13th centuries. As the recent soil was chosen soil, located at a small distance from the barrow, at approximately one hypsometric level. The buried soils within the archaeological excavation are sporadic; scalped soil-forming rocks are revealed under the embankment - water-glacial (kame) sands and sandy loams, in some cases underlain by moraine loams. All this makes difficult to reconstruct the component composition of the soil cover when reconstructing the original landscape conditions.

This study of the composition of buried soils formed on the surface of a kame hill, to which the Kurgan Izhora burial mound is restricted (medieval age of 800 years), showed that the initial soil cover was represented by variations of automorphic Al-Fe-humus soils (Rustic Podzols and Entic Podzols), components which are also characteristic of modern biogeocenosis. This indicates a similar trend of pedogenesis in the medium-term (hundreds of years) gap. It is established that the construction of the burial mound was accompanied by the reduction of the forest, its burning out, settlement of atypical for the present habitats representatives of the Cyprian family.

Analysis of the structure of the profiles of the studied buried soils, as well as the bulk of the barrow and recent soil, revealed the change in the morphological structure of soils. In particular, the scalping of the upper humus-accumulative horizons of soils at different thicknesses (from several centimetres to tens of centimetres), up to the soil-forming rock. Apparently, this can be explained by the leveling of the buried day surface during the construction of the cemetery.

The degree and character of diagenetic changes in buried Al-Fe-humus soils have been revealed: the carbon content in the preserved humus-accumulative horizons has decreased tens of times as compared to recent (surface) soil. Along with this, despite the long burial, soil parameters were established, the values of which remained practically unchanged: hygroscopic moisture, bulk density of, actual acidity. It is established that during the burial period, a newly formed weakly developed initial soil began to form on the allochthonous material with signs of podzolization in the lower part of the low-thickness (7 cm) humus-accumulative horizon.

The kame hills, composed of light and water-permeable soil-forming rocks, in view of their relative (up to 5–8 m) elevation above the terrain, excluding ground swamping, were a convenient place for the construction of Kurgan medieval cemeteries.

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Dynamics of the Saalian ice sheet in the Polish-Belarusian border area

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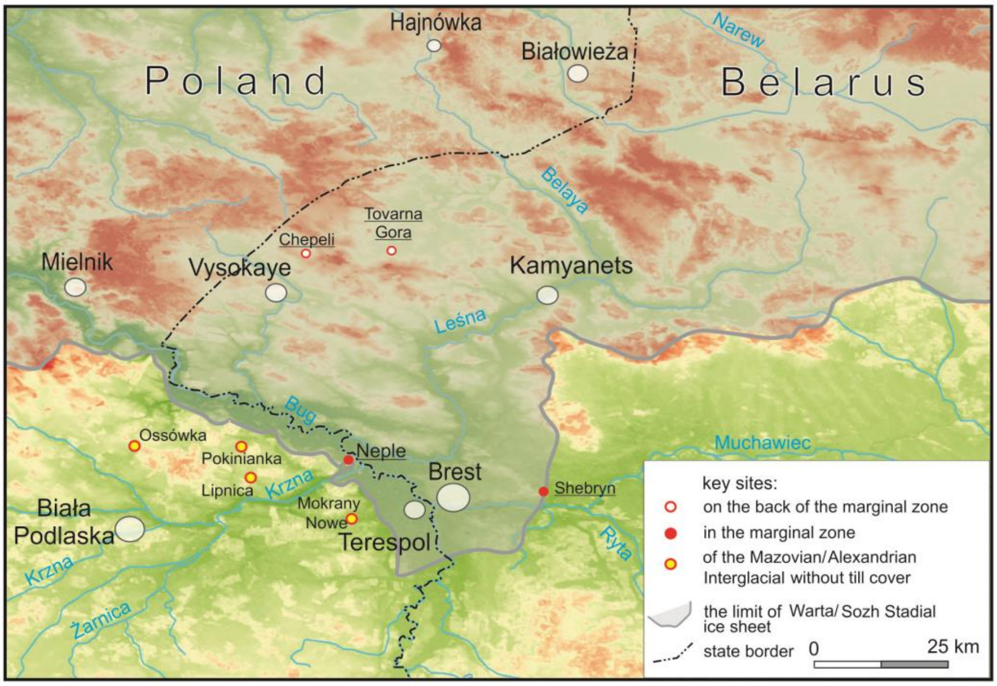

Fig. 1. Location of key sites in study area.

The determination of the limit of the Saalian Glaciation in the southern part of the Polish-Belarusian cross-border area was one of the main objectives of the international cooperation (Marks *et al*., 2016). It was connected with geological and geomorphological investigations. The correlation of the regional stratotype horizons was based mostly on vegetation and paleoclimate changes recorded in glacial and interglacial lake deposits in new key sites and sections of regional significance for Central Europe. A lot of different analyses were made in the investigated outcrops e.g. lithological, petrographical, palinological and OSL dating (Woronko *et al*., 2016). Many sites are connected with the marginal zone of ice sheet during the Odranian Glaciation Warta/Sozh Stadial (Saale MIS-6), e.g. Tovarna Gora and Chepeli are located in the back of the marginal zone, Shebryn and Neple in this zone and Ossówka, Lipnica, Mokrany Nowe and Pokinianka in the front of this zone (Woronko *et al*., 2016). The greatest dynamics of the ice sheet were observed in outcrops of marginal zone, e.g. the deformations of glacial deposits in Neple. On the back of marginal zone galcifluvial deposits were covered by glacial till of Warta/Sozha stadial, e.g. Tovarna Gora. Mazovian/Alexandrian sediments (MIS 5) which were observed in the sites that are located on the front of marginal zone, were covered only of slope deposites. This investigations gave the possibility to revise the existing limit of Saalian ice sheet in studied area (Fig. 1.). High influence on dynamics of Saalian ice sheet was diversified of quaternary bedrock morphology (Rychel & Nowacki, 2016) and tectonic uplifting in the studies area.

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Weichselian glacial cycle in southern Finland

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Reconstructions of the last Weichselian glacial cycle 117,000-11,700 years (kyr) ago propose that S Finland, adjacent Russia and the Baltic countries in the S-SE sector of the Eurasian Ice Sheet (EIS), were glaciated during the Middle Weichselian time [marine isotope stage (MIS) 4, 71-57 kyr ago] and that this glaciation was preceded in S Finland by an Early Weichselian interstadial (MIS 5c, 105-93 kyr ago) with pine forest (Fig. 1).

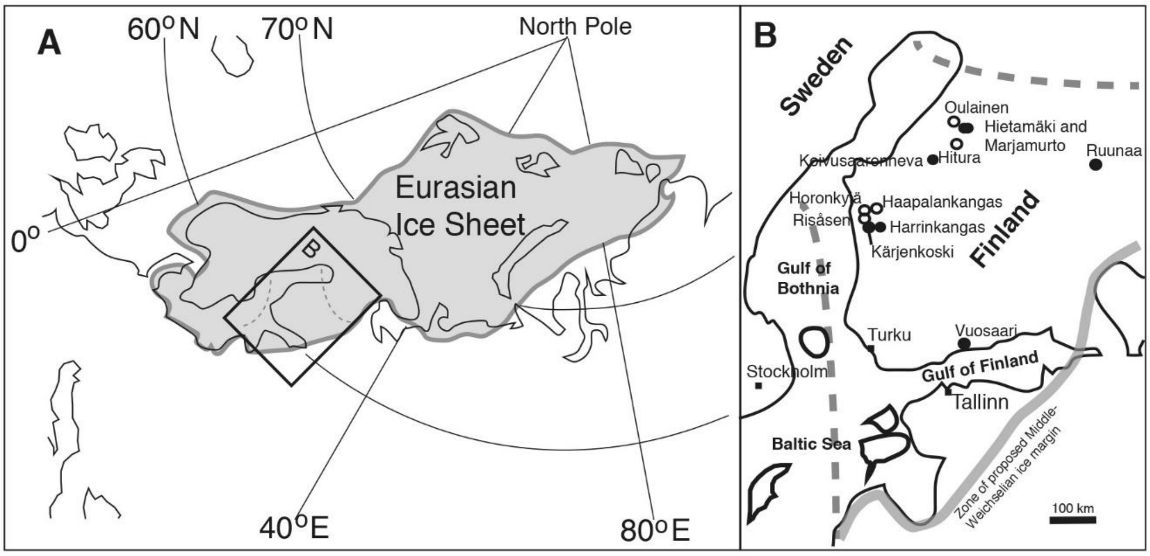

Fig. 1. Suggested EIS marginal positions during the Middle Weichselian (Svendsen *et al*., 2004). (A) The S-SE sector discussed is marked with dashed lines. B-Ksc = Barents-Kara spreading center, Ssc = Scandinavian spreading center. (B) Open circles are locations where proposed Middle and Late Weichselian tills have been reported in the same section and which are discussed in detail. Black circles indicate other important sites.

In this study glacial sequence stratigraphy (Powell & Cooper, 2002) is applied to isolated Late Pleistocene onshore outcrop sections in S Finland. The reviewed and analysed sedimentary records have traditionally been investigated, interpreted and published separately by different authors without an attempt to a methodologically more systematic survey. By putting new field data and old observations into a regional sequence stratigraphic framework it is shown how previously unnoticed important depositional trends can be found in the lithofacies and fossil successions.

The results indicate that, according to the studied dataset, the proposed Middle Weichselian glaciation or the pine dominated interstadial did not take place at all (Räsänen *et al*., 2015). The one Late Weichselian glaciation (MIS 2, 29-11 kyr ago) at the S-SE sector of EIS was preceded in S Finland by a nearly 90 kyr long still poorly known non-glacial period, featuring tundra with permafrost and probably birch forest. The new Middle Weichselian paleoenvironmental scenario revises the configuration and hydrology of the S part of EIS and gives new setting for the evolution of Scandinavian biota.

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Identification of active tectonic structures and parameters of paleo-earthquakes based on deformations in rocks and in late- and in post-glacial sediments in the Karelian Isthmus

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The unusual fragmentation of rocky outcrops near the former village Sokkola, now the village Krasny Sokol in the North of the Karelian Isthmus (Leningrad (Saint-Petersburg) district), located near the town of Kamennogorsk (Antrea) (Fig.1.1) are under consideration. This specific object had been noticed in the XIX century by the famous Russian geologist A. A. Inostrantsev. In 2010-2016 this area was studied by the authors, it is named below as "Inostrantsev Caves" (Nikonov *et al.,* 2014). The site is located in the tectonic zone of large ancient faults (Vuoksinsky fault zone) in the crystalline basement (State…, 1999), which is manifested in the relief in the form of rectilinear valleys of the Vuoksa River, and in the surface of rock under the loose sediments in the form of deep hollow, revealed the drilling data. Post-glacial activity of the Vuoksinsky fault zone manifested itself in forms of fragmentation of rocks, in rock falls and displacements of blocks along the river banks. Our research of rocky outcrops at river banks allowed us to establish the neotectonic shear displacements in the fault zone. Within the survey area we studied different forms of seismogenic deformations which includes seismo-gravitational and seismo-vibrational deformations in rocks, and plicative and disjunctive dislocations in loose sediments. We have established that all types of deformations are closely connected and their parameters are similar in the massif, in contact zone with it, and in the peripheral area (at distances of a few kilometers). The site (key point) includes three zones of deformations: 1) the Central Fractured Massif (CFM); 2) seismo-colluvial fan; 3) zone of deformation in loose sediments (Fig.1.2). CFM is the main zone of crushing. It is located at the SE edge of the rock ridge, which consists of granitoids and is elongated in a NW (310º–320º) direction. CFM is broken into large blocks (to 7-9 m) by a set of mutually perpendicular and quasi vertical or weakly inclined cracks. Vertical cracks has width of 10–30 (to 50) cm and belongs to main directions 310º–320º and 50º–60º (Fig.3, a). Seismo-colluvial fan extends to a distance of 33–35 m to NE from the CFM. Many blocks have dimensions of up to 3-4 m in diameter, rarely to 5–7 m. Complex of deformations in loose depositions includes several types. First type is parallel waviness of varved clays with amplitude in the first tens of cm and in increments to 0.4-0.6 m. Second type is small folds complicated by micro thrust faults characteristic of the upper half of varved clays layer. Third type is wedge-shaped branched cracks which are interconnected with fold deformations. Fourth type is thin cracks intersecting the entire thickness of the varved clays layer with vertical (including by an upthrust character) and with horizontal shear displacements with an amplitude to the first cm. Orientation of cracks includes two main directions: NW (310-320°) and NE (35-55°) (Fig.3, b). Kinematical types of disjunctives includes ruptures with vertical offsets-faults, reverse faults, and thrusts, as well as shear faults along cracks of the North-Western direction. We believe that totality of the mentioned features cannot be explained in terms of the alternative model of glacial or cryogenic dislocations. Detailed examinations of geometrical position of the displaced blocks, the magnitude and direction of displacements, their spatial and temporal relationships allow us to distinguish presumably three generations of deformations: 1) Late-Glacial; 2) Early Holocene; 3) Middle-Late Holocene. We determined intensity of earthquakes as I = IX, IX and VII-VIII respectively, using "The INQUA scale" (Michetti *et al*., 2004) and new method, based on measurements of the seismogenic displacements of the blocks (Rodkin *et al*., 2012).

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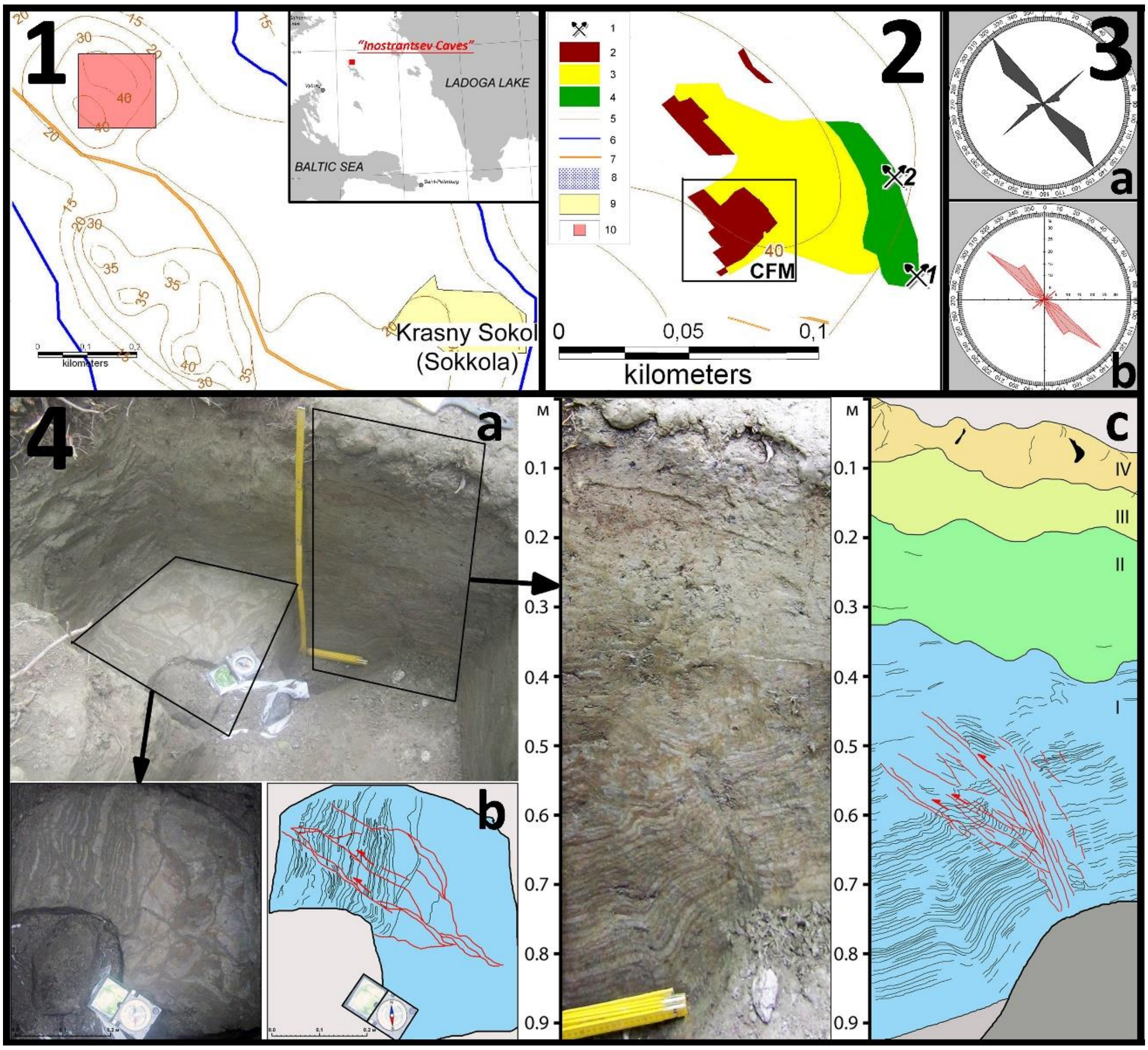

Fig. 1. Part 1. Location of the key plot “Inostrantsev Caves”. Part 2. Zones of deformations. Legend: 1 – pits in loose depositions; deformation zones: 2 – fragmentation of the massif; 3 – colluvial fan; 4 – folds and faults in loose sediments; other designations: 5 – isohypses; 6 - rivers; 7 – road; 8 – lakes; 9 – settlements; 10 – key area. Part 3. Orientation of cracks and faults: a) in rocks; b) in loose sediments. Part 4. Deformations in loose sediments: a) main view; b) shear faults; c) reverse faults.

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Mechanisms of evolution of Pleistocene fluvial systems in northern Poland

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The Fluvial systems are an essential element of most continental interior and continental margin successions of sedimentary environments. Their evolution is an interaction between autogenic processes and allogeneic ones, as tectonic activity, base-level and climate changes. Changes of fluvial style (meandering vs. braided) and relation of aggradation to erosion were during the middle and late Pleistocene under strong influence of glacial-interglacial cycles. Especially in regions which were covered by ice-sheets, fluvial systems have been repeatedly rebuilt. One of such areas is Gdańsk Pomerania region, northern Poland. It was during the entire Pleistocene under direct influence of Scandinavian Ice Sheet (SIS). In this region several Pleistocene fluvial series of different types and age were detected (Moskalewicz *et al.*, 2016; Sokołowski, 2016).

Conducted studies of Pleistocene fluvial series in the Gdańsk Pomerania region suggest that palaeovalley system were transformed during the following SIS advances. Some of palaeovalleys were finally covered by glacial series and never again used as a part of fluvial system. The directions of palaeoflow have been changed. In some cases palaeoflow direction was towards south, but most of them transported material to west-north west, or even to south-west.

Some fluvial systems have evolved typically for transition from ice-marginal system of braided style to meandering system without glacial influence. This type of evolution have been recognized in the lower part of Chłapowo cliff section (Moskalewicz *et al.* 2016). Another type have been detected in the Mrzezino site (Sokołowski, 2016), where fluvial system evolved from sand-bed, braided river into low-energy meandering system. This system functioned under more or less stable, boreal climate. The third type have been documented in the Reda site. In this case, a shallow, sand-bed braided system (warm climatic conditions) changed into a meandering system, which have been developed under severe, periglacial conditions. These examples show that evolution of fluvial systems may depend on both internal and external controls.

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Catastrophic changes of the Karelian Isthmus hydrographic network in the Late Glacial – Holocene: palaeoseismological origin

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According to modern concepts, the formation of the Vuoksa River is associated with the catastrophic water breakthrough of Lake Saimaa across the boundary ridge Salpausselkä-1 of about 5,700 years ago (Saarnisto, 1970). Abrupt alteration of the flow of the lake basin and the earlier changes in flow direction which occurred here were usually associated with the postglacial isostatic uplift. Detailed reconstruction of this process is shown in (Pajunen, 2004). It is known that on the background of intensive general uplift of the territory during the entire post-glacial period, including the Holocene, there were strong earthquakes on the territory of Fennoscandia (Mörner, 2003) and, in particular in Finland, adjacent to the Karelian isthmus (Kuivamäki *et al.*, 1998), which could have an impact on the settling of ancient people in the study area. A place with seismic deformations earlier discovered in the basin of Vuoksa River (Nikonov *et al.*, 2014). It was established that three seismic events happened here during the Holocene. This place of deformations is associated with activation of the ancient fault zone "Vuoksinsky", extending over several tens of kilometers from the Finnish border in south-eastern direction in the form of several subparallel branches. It was suggested that earthquake was the reason of breakthrough of Saimaa Lake to the Vuoksa valley because the riverbed of Vuoksa River inherits this activated fault zone. Strong seismic event was trigger that led to the violations of the integrity of the substrate (forming the gap) and/or to the overflow of the waters through the Salpausselkä -1 barrier.

Looking for possible seismic deformations in the rock framed valleys of Vuoksa River, and in loose sediments on its borders we have screened a part of the valley from the town of Imatra (the outflow of Vuoksa River) till the town of Kamennogorsk on the length of about 50 km. Seismogenic deformations are widespread in the rocks in the upper reaches of the valley, on the site of the former thresholds on Vuoksa River in the borders of city Imatra. They embrace: vertical longitudinal tear with displacement of the lateral wings to several tens cm; transverse cracks with the offset of adjacent blocks and with the fragmentation of bedrock. This set of deformations determines the shear ensemble caused by the postglacial seismic activity of an ancient fault zone. Downstream, near the city Kamennogorsk (Antrea) we studied the complex of terraces, including levels with relative height of 15 m; 6-6.5 m, 3-3.5 m. In a loose strata at all levels we have detected deformations with obvious signs of seismic effects of different ages or related catastrophic processes. The youngest deformations are confined to the sediments of the terrace with relative height of 3-3.5 meters. In three places, far from each other to some kilometers, we discovered that cross-sections are radically different from each other (Fig. 1). In the first area the terrace is composed of unsorted boulder and gravel-pebble sediments with sandy loam to sandy filler and varved clay fragments, covered with a several sub-horizontal layers of sand and loam. In the second case we can see sandy stratum inclined to the North with different inclinations of layers: the lower part has a more steep inclination (30°) than the upper (about 10°). The slope of the bottom part, obviously, is secondary, because there are some fine layers in the stratum formed under conditions of weak stream, and a bias occurred in subaqueous conditions. We can approve it because of discovered traces of leakage of several layers, which deform the initially parallel stratificated stratum. In the third case, the sediment stratum is consisted of parallel stratified sandy layers, with interbedded gravel and silt inclined to the North. The sublatitudinal fault dissects the stratum with an amplitude of displacement of 0.3 m. It can be reasonably assumed that the vertical displacements and distortions of sediments in a body of 3-3.5 m high terraces are connected with dips and cracks of the rocks under loose sediments, and in turn caused by strong seismic motions, while chaos of blocks and boulders is the result of the simultaneous debris flow. Thus, there are definite signs of catastrophic water breakthrough of Lake Saimaa and the formation of the modern valley of Vuoksa River as a result of strong seismic effects of 5,700 years ago. This event led to the transfer of the waters of Lake Saimaa to Lake Ladoga and caused the restructuring of the water regime of the Karelian Isthmus and significant landscape changes.

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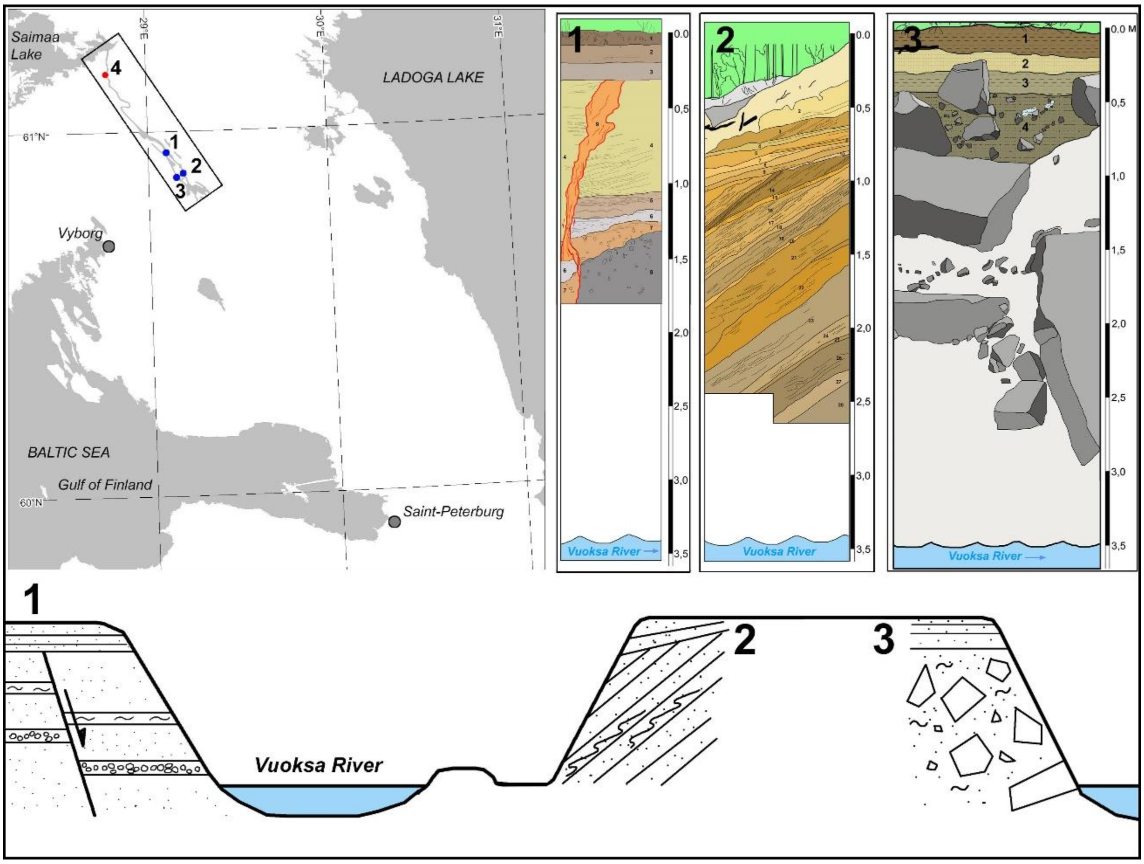

Fig. 1. Location of the cross-sections in the segments of 3.0-3.5 m terraces in the valley of the Vuoksariver, their documentation and the scheme of relationship: 1) cross-section with the normal fault; 2) cross-section with the steep inclined layers; 3) cross-section with the debris flow layer.

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GIS-modelling of the Onego ice lake

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Lake Onego is the second largest lake in Europe with a surface area approximately ten thousand square kilometers. The Lake is located on the border between crystalline rocks of the Fennoscandian Shield and sedimentary rocks of the East European Platform. The lake depression was covered with glacial streams or proglacial lakes during the Pleistocene Scandinavian glaciations (Lake Onego, 2010).

The contemporary model of lake depression deglaciation proposed by I. Demidov (2006) was implemented for GIS modeling of the six main stages of lake depression development in late Pleistocene (14 500-12 300 yrs BP).

The DEM (Digital Elevation Model) of the terrain developed by J. Ferranti (2016) was used as a source of watershed elevation data. This is the first freeware global elevation model with spatial resolution tree arc seconds with coverage of the studied region.

The DEM of lake depression was developed by using *GIS Surfer* software and was based on depth measurements, obtained from the navigation charts of Lake Onego and Svir River (1988). The lake depression DEM was led to the Sea level (SL) and combined with terrain elevation DEM. Thus, the present-day DEM of lake watershed and its depression was obtained. The depressions of 125 medium and large lakes situated within the boundaries of maximum Onego lake development were also embed into DEM to calculate the paleolake volume. To remove flat surfaces that were occur during marshlands formation the DEM was converted into isoline relief and then interpolated to a raster form.

The Earth's crust was flexed in the studied region because of considerable pressure going out from overlaid glacial shields. Later, when glacial shields were melting the area begun to suffer the compensational glacioisostatic uplift, which leads to migration of the lake shoreline position. The data of I. Demidov (2006) and new field observations were implemented to take into account Earth's crust uplift by interpolation of elevation marks and evolving of present-day DEM using *ArcGIS 10.2.2* software with *Spatial Analysis* package.

The paleoreconstructions are available online (Subetto et al., 2016). Paleogeographic maps were verified by hand-drawn images of I. Demidov. Compared with hand drawings of I. Demidov, our maps were detailed considerably and had strict geographic reference. The smallest and the largest stages of the Onego ice lake development presented on Fig. 1.

The developed paleogeographic DEMs were used to calculate the morphometric characteristics of Lake Onego in the Past (Table 1).

The quantitative data obtained in this study is valuable for estimation of rates of water discharge in the past.

The study is supported by the Russian Fund for Basic Research, projects 16-05-00727.

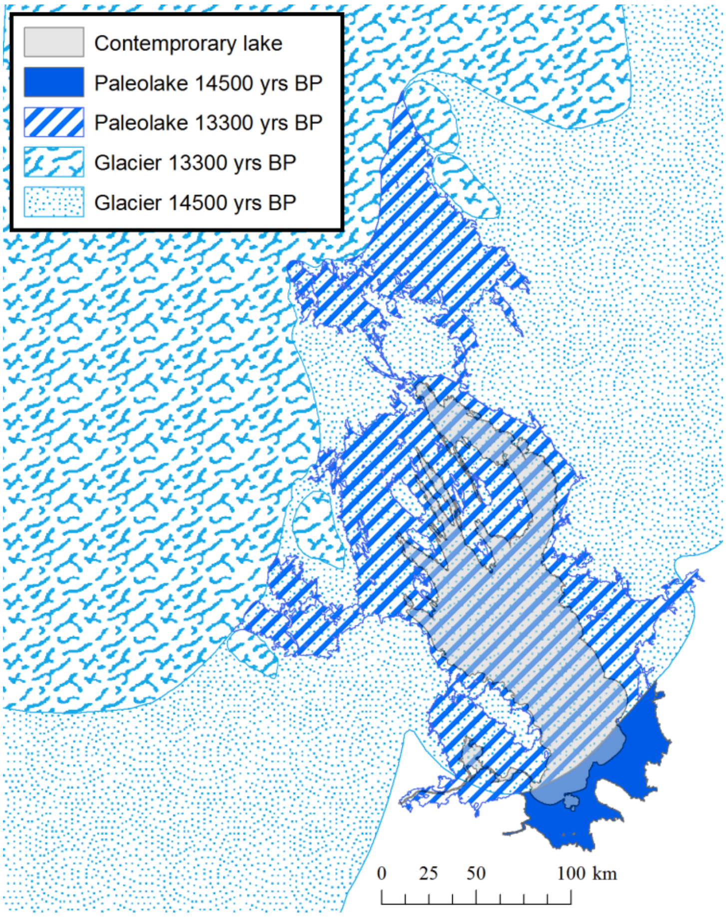

Fig. 1. The smallest and the largest stages of OnegoLake development.

Table 1. Morphometric characteristics of Lake Onego. Confidential interval given with α=0.05.

Period, yrs BP	Volume, km^3	Surface area, km^2	Mean depth, m	Max depth, m
14 500	180±5	2711±64	66.5±0.5	114±2
14 000	796±73	14 785±684	53.5±2.5	168±5
13 300	1640±167	32 328±1484	50.5±2.5	184±5
13 200	1201±117	24 879±1078	48.5±2.5	174±5
12 400	1080±112	22 591±1169	47.5±2.5	169±5
12 300	967±105	21 484±1149	44.5±2.5	164±5

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Geochemical baseline mapping in northern Finland

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Both natural geological background concentrations and the diffuse anthropogenic input of substances are included in soil geochemical baselines. Concentrations of the chemical substances in topsoil in natural and especially in urban soils are important to know for planning the land-use and detecting contaminated areas. The geochemical baseline studies are basic tools for example in the preparation of legislation, in the reviews of the environmental baseline, and in the assessment of contamination and remediation needs.

In Finland, the geochemical baseline mapping is based on the Government Decree on the Assessment of Soil Contamination and Remediation Needs 214/2007 (Ministry of the Environment, 2007). It is obligates to take into account geochemical baselines in the assessment of soil contamination and remediation needs. According to the Decree, the amount of contamination and a remediation plan have to be estimated if one or more harmful elements show higher values than the threshold values given in the Decree (Ministry of the Environment, 2007). However, if the local baseline concentration of a contaminant is higher than the threshold value given in the regulation, the baseline is used as a trigger value.

The Geological Survey of Finland (GTK) has carried out several geochemical baseline studies in Finland since 2003. The EuroGeoSurveys urban geochemistry sampling protocol was followed and soil samples were collected from upper soil, approximately 0-10 cm in depth. The samples were dried, sieved into < 2 mm fractions and then analysed using the multi-elemental analysis package (ICP-OES/-MS) after aqua regia of nitrogen acid digestions. In the urban areas, the samples were also analysed for the PAH- and PCB- concentrations.

In northern Finland, top soil samples (consisting mostly glacial till) were collected in three forested areas, the Kittilä (31 samples) and Savukoski (31 samples) areas in 2012 and Kemi area in 2016 to assess natural geochemical background concentrations of the areas. The Kittilä area is located in one of the four arsenic provinces in Finland (Fig. 1). Savukoski is situated in the Lapland metal province and Kemi area is situated in the Kemi metal province, which are two of the seven metal provinces (Fig. 2). An urban geochemical baseline studies were done in 2013 and 2014 in the Rovaniemi city area (Fig. 2), where 100 sampling points were located in areas of different urban land use, such as parks, schoolyards and the sides of paved paths.

According to the results, the concentrations of elements included in the Decree were usually below the recommended values in the study areas in northern Finland. Only some exceptions occurred. For example, in the Kittilä area some element concentrations were higher than those given in the Decree. A main result was that a baseline value of 14 mg/kg of arsenic should be used in the Kittilä arsenic province for the assessment of soil contamination instead of the Decree threshold value 5 mg/kg. Upper limits for baseline variations were higher than the threshold value also for chromium (140 mg/kg vs. threshold 100 mg/kg) and nickel (56 mg/kg vs. threshold 50). In the Savukoski area, the element concentrations were low and the threshold values are under the Decree. In the whole dataset, there were only a couple of elevated chromium concentrations (156 and 103 mg/kg) reflecting natural background of the ultramafic rocks in the bedrock. In the Kemi area, most of the element concentrations were below the threshold values but single outliers shows elevated arsenic (up to 7 mg/kg), cobalt (up to 23 mg/kg) and vanadium (up to 166 mg/kg) concentrations.

In the Rovaniemi city area, all the concentrations were well below recommended values. Only a few exceptions were observed such as arsenic in three data points (max. 8.7 ppm, threshold value 5 ppm) and cobalt (max. 26.4 ppm, threshold value 20 ppm), copper (max. 186.0 ppm, threshold value 100 ppm) and vanadium (max. 104.0 ppm, threshold value 100 ppm) at a single data point in the southern part of town. Concentrations of lead, cadmium and antimony were slightly greater near the centre of the city and close to major roads, mostly caused by the normal long-term strain of traffic and construction. PAH- and PCB- concentrations were below detection limits in all ten samples, indicating no signs of pollution caused by the long-range transport of airborne pollutants.

Information on soil geochemical baselines is available from the national geochemical baseline database, Tapir (www.geo.fi/tapir). It is a free database having the public user interface, which includes statistical summary information from several pre-defined geochemical provinces within Finland. The database is hosted by GTK and is described by Jarva et al. (2010).

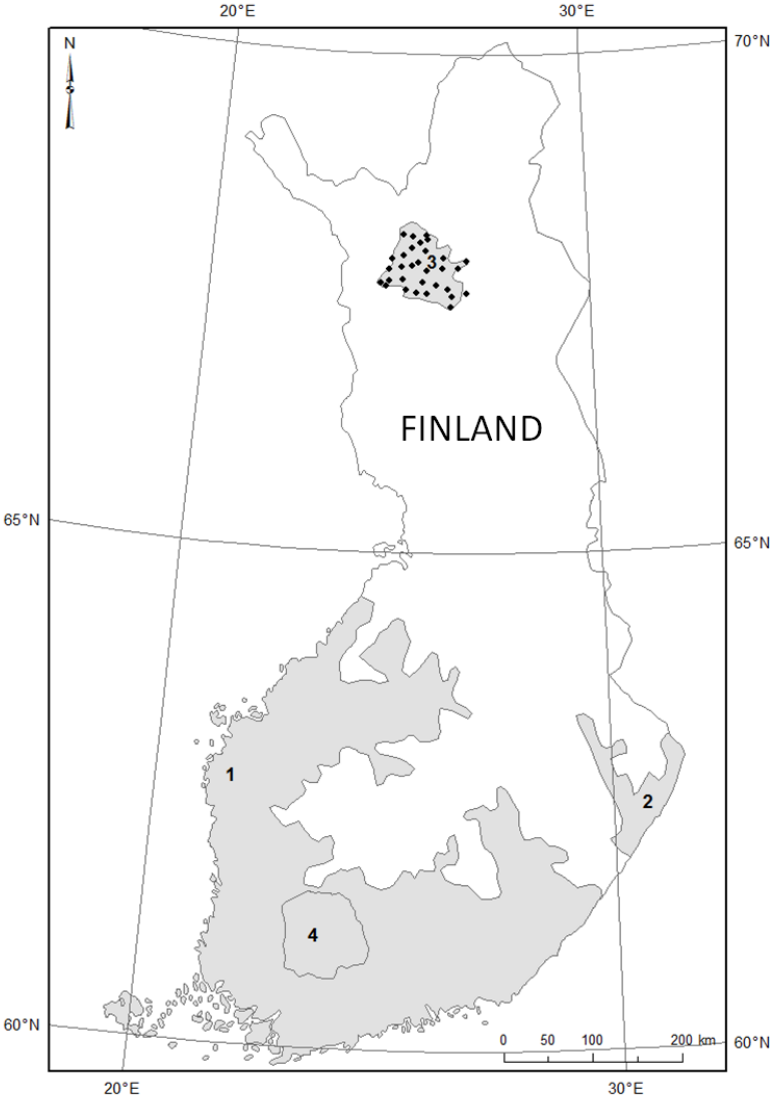

Fig. 1. Geochemical baseline provinces for arsenic (Jarva et al. 2010): 1 = southern Finland arsenic province; 2 = Ilomantsi arsenic province; 3 = Kittilä arsenic province; 4 = Southern Pirkanmaa arsenic province. The sampling sites in the Kittilä arsenic province are marked as black dots.

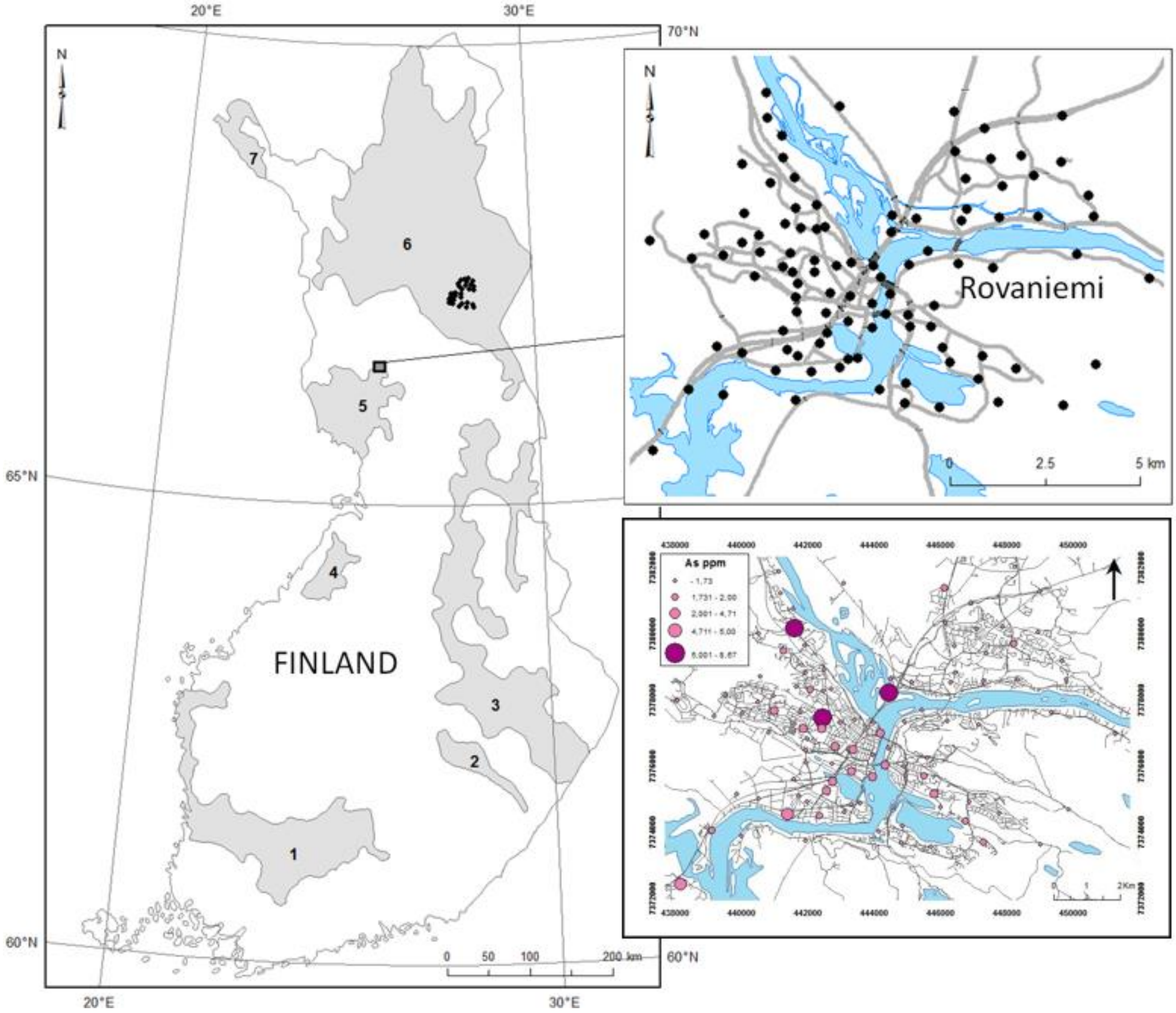

Fig. 2. Geochemical baselines provinces for metals (Jarva et al. 2010): 1 = Southern Finland metal province; 2 = Varkaus metal province; 3 = Northeastern metal province; 4 = Oulainen metal province; 5 = Kemi metal province; 6 = Lapland metal province; 7 = Enontekiö metal province. The sampling sites in the Savukoski area are marked as black dots. The inset maps show the sampling sites (black dots) and arsenic contents in Rovaniemi. The main roads are marked as grey lines and the water systems with blue colour. Basemaps: © National Land Survey of Finland.

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^{10}Be age of the Local Last Glacial Maximum in the southern fringe of the Scandinavian Ice Sheet

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The Last Glacial Maximum (LGM) is defined as the most recent period with the maximum global integrated volume of ice-sheets and the corresponding minimum global sea level. It is usually dated at 24-18 cal. ka BP and centred at 21 cal. ka BP. However, most of the ice sheets reached their maximum expansion in a 7,500 year time interval between 26.5 ka and 19.0 ka, and the maximum extents of specific ice sheets were found to be asynchronous and not always in agreements with the global LGM. Therefore, the term Local Last Glacial Maximum (LLGM) is used to define the timing of the regional maximum expansion of a particular ice sheet.

Here we present a set of ^{10}Be exposure ages of erratic boulders located in the vicinity of the last Scandinavian Ice Sheet (SIS) maximum limit in Poland. The largest erratic boulders located in-situ on glacial landforms were our target for sampling. Samples were taken with a manual jackhammer from the upper surface of stable, massive boulders of quartz-rich lithologies and were subjected to the standard laboratory procedure of quartz purification and ^{10}Be measurements used in terrestrial cosmogenic nuclide exposure dating.

Our results consist of exposure ages for seven boulders located in front of the last SIS maximum extent and for 13 erratics located within the extent of the last SIS, close to its maximum limit. Moreover, we recalculated already existing ^{10}Be ages for seven boulders according to the most recent production rate. The exposure ages of pre-LLGM erratics show significant scatter, ranging from 7.1 ± 1.0 to 122.2 ± 14.2 ka. For LLGM erratics, ^{10}Be ages range between 6.1 ± 1.0 and 72.2 ± 7.8 ka. The distribution of the LLGM population reveals three significantly different subsets: the youngest including two ages of 6.1 ± 1.0 ka and 7.4 ± 1.0 ka, an intermediate consisting of ages ranging between 13.8 ± 1.8 and 26.0 ± 2.8 ka, and the oldest including ages ranging between 36.1 ± 4.0 and 72.2 ± 7.8 ka. To support our interpretation of the exposure ages of LLGM erratics, we used published ^{14}C ages of organic deposits as a background indicator of the possible time window for the LLGM. This external constraint suggests that the exposure ages of the intermediate subset overlap with the possible time window of the LLGM in Poland.

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Exploring morphometry of drumlins within isolated upland of varied topography

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The Elbląg Upland in north Poland is one of an isolated Pleistocene elevations (iPe) located between ice streams of the last Scandinavian Ice Sheet, south of the Baltic Sea. It is a conspicuous ice-shoved hill of diversified topography, rising above the surrounding lowlands up to 200 m. Its inner structure reveals glacitectonically disturbed strata (thrust structures) covered discordantly by basal till. On the top of the upland streamlined, elongated landforms occur. The general picture of their distribution and orientation shows two main arc-shaped sets: one oriented north-west – south-west (in the western part of the upland) and another one oriented north-east – south-east (in the eastern part of the upland). Besides the traditional “drumlin-like” concept of their genesis, lateral moraines of two glacial lobes or streamlined hillocks mimicking the sub-till surface of glacitectonic thrusts were also proposed to explain their origin. It was argued that they were probably formed in an interlobate zone of the last Scandinavian Ice Sheet, under the influence of ice streams flowing from the north-west and north-east. This study aims to identify the morphometric features of Elbląg Upland drumlins and verify their possible connection with glacitectonic thrust structures occurring within the upland core.

This poster presents the results of detailed mapping and morphometric analysis of studied landforms based on LIDAR elevation data. Digital Terrain Model (DTM) with a horizontal resolution of 1 m, as well as geological maps of the region were used to identify the individual landforms in GIS. Elongated, drumlin-like hills were mapped manually by outlining their basal break of slope using variously illuminated hillshade models with a vertical exaggeration of 5 and topographic contours. The morphometric parameters such as: length, width, elongation ratio, height and index of topographic profile asymmetry were calculated and analysed statistically. Additionally the 2D Fourier transform of the DTM has delivered information on autocorrelation length of mentioned area as a specific measure of its heterogeneity and roughness.

Palaeoenvironment of the SE Baltic region in Late Pleistocene and Holocene: results of the paleolimnological study of Kamyshovoe Lake, Kaliningrad Region

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Numerous lakes were formed after the retreating of the last, Weichselian, Glacier in the territory of Baltic Uplands (South-Eastern Baltic). As the lacustrine sedimentation started shortly after the retreat of the glacial cover in the mostly basins paleolimnological investigation of the sediment strata enables reconstruction of environmental conditions throughout the entire postglacial. The sediment section taken from the Kamyshovoe Lake (Kaliningrad District, Russia) was analyzed by the means of pollen, diatoms, total organic carbon (TOC) and ^{14}C analyses. Alongside with this the nonmetric multidimensional scaling (NMDS) and the matrix log transformed pollen and diatom data matrixes were used describing the coherence between the general vegetation pattern and basin ecology. The analysis was done using R-project software and Vegan package. The Bray-Curtis distance measure was used and Monte Carlo permutaton applied to check the statistical significance of the particular diatom taxa. Obtained data revealed lacustrine sedimentation with characteristic natural environmental changes, which started at the very end of the Late Pleistocene and continued throughout the Holocene in the Kamyshovoe Lake.

Variable composition of sediments and radiocarbon data indicate the lacustrine sedimentation started during the Lateglacial Interstadial i.e. ca.13400 cal BP. *Betula-Pine* predominating vegetation flourished in area at that time. In the bottom part of the section (1199-1020 cm) diatoms are absent and content of the TOC is less than 6% that is characteristic for the low bio-productivity of the lake when input of mineral matter during cold climatic conditions prevailed (Kublitsky *et al*., 2013). Upwards, at the 1020-880 cm interval diatoms are numerous, represented by such species like *Amphora ovalis*, *A. ovalis* var. *pediculus*, *Fragilaria construens*, *F. brevistriata*, *Platessa holsatica*, *Achnanthidium exiguum*, *Planothidium lanceolum*, *Martyana martyi*, *Navicula scutelloides*. The content of TOC gradually increases 13% upward. Initially sedimentation in shallow, alkaline basin took place. Ongoing deposition of the lacustrine layers was recorded at the very beginning of Holocene, between 11800-9000 cal BP, when shift from cold to warmer environmental regime was indicated according to data collected. Changes from open cold-tolerant vegetation to birch-predominating open forest later replaced by *Pinus-Ulmus* woods with remarkable participation of *Corylus* seen in pollen record.

At the depth of 880-690 cm the diversity and number of identified diatoms is higher, although small benthic alkaliphilous *Fragilaria construens*, *F. brevistriata*, *Martyana martyi*, *Navicula scutelloides* species still prevail. However, increased content of planktonic species (*Cyclotella ocellata*, *C. radiosa*, *Stephanodiscus parvus*) point to raised water table in the lake. *Stephanodiscus parvus* usually indicate initial enrichment of the lake. Meanwhile, acidophilous, reophilic *Tabellaria fenestrata* is associated with the increasing organic input and higher acidity of the basin. Content of TOC reaches 40% and is related to increasing bio-productivity, predominance of autochthonous sedimentation during the warm, humid Middle Holocene (9000-6400 cal BP) when basin became deeper and enriched in nutrients and well developed broad-leaved predominating forest flourished in surroundings.

The sediment interval at the depth of 690-530 cm was formed between 6400-4000 cal BP approximately. Still numerous benthic *Fragilaria construens* indicate that the lake depth remained almost the same. Increased number of planktonic *Cyslostephanos dubius*, *Aulacoseira granulata*, *A. ambigua* species characteristic of eutrophic water indicate ongoing enrichment of the lake. Content of TOC vary between 38 % and 46 %. Decreased percentage of reophilic diatoms confirm relatively stable, nutrient rich lacustrine environment at the beginning of the Late Holocene. Describing the terrestrial vegetation pattern decreasing participation of broad-leaved taxa alongside with the rising importance of spruce should be noted.

At the depth of 530-360 cm sediments were deposited approximately in 4000-2500 cal BP. Decreased content of benthic and prevalence of planktonic *Cyclostephanos dubius Aulacoseira granulata*, *A. ambigua*, *A. alpigena* species characterizes the environment of eutrophic, deep lake. Slightly rised percentage of acidophilous diatoms indicates inflow of organic matter. However, TOC content vary in a range of 37-50 %. Increased amount of planktonic-benthic diatoms show more active hydrodynamic environment in the lake during the Late Holocene. At that time spruce predominated in the local vegetation.

At the depth of 360-230 cm, the topmost sediments were formed approximately in 2500-600 cal BP. Decreased content of previous dominated planktonic diatoms and increased benthic species (*Fragilaria construens*, *F. brevistriata*, M*artyana martyi*, *Navicula scutelloides*) point to lowered water level in the lake. Content of TOC vary in a great range, from 17 % till 56 %. Significant drop of TOC (till 17 %) at the depth of 370-350 cm possibly is related to changed local environmental, as diatom species composition do not show any significant environmental changes. The alkaline lake became shallow, organic rich at the end of the Late Holocene. Simultaneously formation of open vegetation with increasing participation of human activity indicators was noted in pollen record.

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3D-microtomography - A nondestructive method to reconstruct cold region rock weathering

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Rock weathering is a major destructive process operating on the Earth surface. In cold regions, it is well known that mechanical processes associated with freeze-thaw weathering predominate, whereas the biogeochemical processes of the cryosphere have been underestimated for decades (Hall & Thorn, 2011). Both mechanical and biological weathering are capable of changing the surface relief of clasts on both a micro- and macroscale, and to alter the internal structures of rocks as well (Etienne, 2002; Salvatore *et al.*, 2013). One of the effects associated with this overlooked process is the development of a weathering rind. A weathering rind can be used to determine the age of clasts, to reconstruct paleoclimate conditions, or, on a practical note, to restore damaged monuments. We propose the use of the 3D-microtomography to analyse the weathering rind without doing structural harm-avoiding the need to crush a clast or to disturb its surface in any way. To check the feasibility of this methodology, three test stones were selected - two of quartzite sandstone and one of gneiss. All three stones were collected from rock fields located in the Äkäslompolo region of Finnish Lapland -one on the summit (740 m a.s.l.) -one on the eastern slope (437 m a.s.l.) of Kukastunturi Hill - one at the base of the western slope of Lainiotunturi Hill at an altitude of 305 m a.s.l. According to Köppen's climate classification, this region of Finland belongs to the continental, the subarctic, climate zone. The clasts to be analysed varied in their surface freshness, their exterior ranging from completely fresh to entirely lichen covered.

X-ray high-resolution computed microtomography is a non-destructive and non-invasive method based on X-ray-absorption coefficient differences within the studied material. It provides three-dimensional information about the structure of the analysed object, discerning attributes like the spatial distribution of pores. During the first stage of this method, a set of 1024 X-ray grey-scale images of a sample -'radiographs'–are registered. The acquisition of 1024 x 1024 pixel images took 2 h 51 minutes. Sample images were then reconstructed into a representative 3-D volume of the sampled rock. The samples were scanned by XradiaMicroXCT-ray with a Hamamatsu L8121-03 source, which generates X-rays in the range of 40 to 150 kV.A CCD video system was used to convert the obtained images into digital data.

Based on the obtained results, quantitative parameters describing the degree of weathering of the clast surface and the thickness of the weathering rind were determined: 1) V_V – the ratio of pore volume to the total volume (porosity) (%); 2) R_q– the mean square deviation of the profile, which reflects the average surface roughness (μm), and 3) R_t – the distance between the highest point and therecess of the profile (μm). $R_t$is the largest difference in the height on the sample surface and WR_T – thickness of the weathering rind (μm), which is a measure of density according to its X-ray absorption coefficient. The last of the indices allows for the presence of macropores and micropores as well as individual features of minerals (*e.g.* inclusions). In addition, the qualitative picture of spatial variation within the clast's internal structure was obtained, enabling a better understanding of the processes related to changes in the internal matrix and the surface of the studied clasts.

The obtained results enabled a determination of the intensity of biochemical and mechanical weathering within one clast, allowing a calculation of the clast's weathering rind thickness, thus providing an understanding of how rock coatings (*e.g.* by lichens) might influence weathering rind characteristics. The 3D-microtomography method also enabled the reconstruction of clast-destruction stages related to the environmental record of individual stones, prior exposure to processes such as frost shattering or chemical alterations due to oxidation, reduction, or chelation (Salvatore *et al.*, 2013),also the mobilisation of various elements like aluminium or compounds like ferric iron (Walton, 1985).

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Dry valley development during MIS 6 - MIS 1 in a glacial landscape - an example from Poland

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The terrain of Sokólskie Hills in NE Poland was formed of the Warta Stadial till of the Odranian Glaciation (Saalian; MIS 6). Today that landscape is characterised by the presence of dry valleys - artefacts of cold climate conditions. Most of these periglacial "dells" are notable for being of considerable length, having irregular longitudinal profiles, and for having developed high- (fourth-) order tributaries (Rychel *et al.* 2014; Woronko *et al.* 2013; 2017). In reconstructing the evolution of these valleys during the period from MIS 6 to MIS 1, we add insight into the broader functional dynamics of other areas that once resided with in periglacial zones. Three areas were analysed in detail - Starowlany, Jałówka, and Sadowo. In Starowlany, the lower section of the valley was analysed; in Jałówka, the middle section; and in Sadowo, the upper one. Our research entailed detailed geomorphological and geological mapping, including the drilling of a number of boreholes. We were conducting electrical resistivity tomography surveys at two sites. Material obtained from the borings was OSL-dated, the grain size distribution analysed, the morphoscopy of quartz-sand grains investigated, and the pollen examined. Additionally, OM, pH, and the content of major and trace elements were all determined.

The obtained results show that, regardless of the location and the size of the landform, the bottom of each surveyed dry valley - both in first- and fourth-order tributaries - contained numerous small, isolated, and relatively deep depressions. Some of the depressions were up to 20 m across and 3–4 m deep, thus evincing that the studied dry valleys did not always function as conventional river valleys. These depressions could have developed either as a result of the subglacial water runoff during the recession of the Odranian glaciation (Warta Stadial), and/or were associated with formation of thermokarst ponds in periglacial conditions. Depending on both their size and depth, it is believed that these depressions served as open water bodies or functioned as peat bogs during the Eemian Interglacial (MIS 5e). The water level in each of them widely fluctuated depending on several factors, the most important of which was the condition of the local climate. A large inclination to the basins' slopes led to gravity movements (mass wasting) and the supplementation of mineral material into open water bodies. The transition from MIS 5e to MIS 5d was marked by increased basin water-fill, marking the beginning of an accumulation of brown clay - being rich in mineral matter. The MIS 5c - 5a period was characterised by water-level fluctuations in these basins. And so began a return to the accumulation of mineral material. During MIS 4, when permafrost developed in the substrate, some of valleys were incorporated for the first time into the drainage-system runoff. Most likely that erosion resulted from the initiation of a new nival (snowmelt) discharge regime. This increased runoff on the slopes was caused - *inter alia* - by climate cooling and lower evapotranspiration. Furthermore, MIS 4–MIS 3 was characterised by the development of aeolian and large-scale slope processes, particularly visible in lower sections of dry valley bottoms. On the other hand, it appears that in the upper sections of the analysed valleys, shallow water reservoirs remained. At MIS 3's end, these lakes ceased to function, and the bottom of dry valleys became smoother in contour, and their axis modified.

During the LGM, permafrost aggradation returned to the study area. Under cooling conditions, two generations of epigenetic sand wedges developed and aeolian processes initiated. However, the intensity of full-glacial aeolian processes was minor and most likely short-lived, basically not being reflected in the relief or textural characteristics of the studied dry valley deposits. The Holocene did not affect the morphology of these dry valleys.

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Lithic clasts and soft-sediment clasts as indicators of debris-flow direction in subaquatic environment

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Glaciolimnic sedimentation of silty, clayey and sandy deposits were widely described (e.g. Ashley, 1975; Smith & Ashley, 1985; Brodzikowski & Van Loon, 1991; Brodzikowski, 1993) but glaciolimnic debrites (sediments deposited by debris flows) are unique in glaciolimnic successions (e.g. Eyles, 1987).

We recognized subaqueous debrites indicating multiple cohesive debris flows on subaqueous fan at Rzucewo, northern Poland. The study site is situated on the Baltic Sea coast in the cliff of Puck Bay. Studied glaciolimnic sediments were deposited during the Middle Weichselian at the margin of the ice sheet during its decay stage. The sedimentation spread on the palaeoslope of subaqueous fan, so the lamination in the sands and silty sands occurred in the Rzucewo succession is related to the palaeoslope inclination. Altogether, the lithofacies inclination, the asymmetrical ripple marks topography occurred in succession, the folds and flexures vergence in succession, the faults inclination, and the folds slip faces inclination indicate northern palaeotransport direction on the subaqueous fan.

Debrites in Rzucewo succession are reach not only in lithic clasts but in soft-sediment clasts (abbr. SSC) as well. What is more, SSC diverse by dimensions, shape, built material and rate of preservation of its original structure. The type of debris flow (cohesive or cohesionless), the type of the transported material, and the transport conditions controlled the erosional activity of the flows over the fan, and consequently the various shapes and sizes of the soft-sediment clasts that they carried along.

Analysis of debrites fabric enabled us to trace debris-flow directions along the fan. At least 30 clasts, usually 50 clasts (in each set) of considerable elongation (length ratio of pebble axes a/b – at least 1.5/1) with the a-axis length between 2 and 10 cm, were selected. Mostly lithic clast were analysed, but some SSC (rolled and elongated) were included (as a individual set). The measurements were analysed with the Stereonet program and are presented on rose graphs and contour diagrams. Eigenvalues and eigenvectors were calculated according Mark (1973).

Obtained results confirmed general northern palaeotransport direction, but distinct variability of palaeoflow directions are observed in debrites (between NW and E sector). Concentration of the a-axis azimuth of clasts is variable as well: usually moderate to strong, but in some sets scattered distribution was noted. What is more, clasts reveal variable direction of inclination (up- or down-palaeoslope or heterogeneous).

In proximal part of the subaqueous fan, debrites show variable directions of clasts inclination and mostly scattered distribution of their a-axis azimuth. In middle and distal parts of the fan clasts are better ordered and usually reveal down-palaeoslope inclination. Moreover, debrites reveal more variable directions of flow in the distal part than in the middle part. Observed variability is attributed to (1) local stress field (tension or compression), (2) radial spreading of flow material, and (3) splitting of the flow head into minor lobes. Tension is most probably responsible for downslope clasts ordering. During decelerating and halting of a flow compression induced clasts rotation and change of their inclination (cf. Major, 1998). What is more, in area of flattened topography (in distal part of the subaqueous fan) minor lobes in which the flow head was splitted may spread more freely into different directions.

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Geomorphological evidences of Late Pleistocene glacial megafloods in north-east Poland

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Geomorphological evidences of catastrophic glacial floods have been discovered in many formerly glaciated terrains on Earth (Carling et al., 2009). The prominent examples of such megaflood events are known from the ice-dammed Lake Missoula in the eastern Washington State (USA) where a wide range of characteristic erosional and depositional forms created by multiple outbursts were discovered (Bretz, 1923; Baker, 2009). Similar suits of landforms produced by cataclysmic floods were also recognized in other areas of North America (Teller, 2004; Wiedmer *et al.*, 2010) and in the mountains of Siberia and Central Asia (Carling, 1996; Rudoy, 2002; Herget, 2005, 2012; Komatsu *et al.*, 2016).

Within the area of the last Scandinavian Ice Sheet extension to the European Lowland a wide range of landforms related to glacial meltwater flows, such as tunnel valley systems, eskers, sandur fans and plains, and spillways were documented (Woldstedt, 1955; Galon, 1964). However, no unequivocal geomorphological signatures of cataclysmic glacial outburst floods have been discovered up to now.

The main aim of our research was to recognise geomorphological traces of glacial megafloods in the area of northern Poland that had been covered by the Late Weichselian Ice Sheet. The detailed geomorphic analyses of outwash plains in the area of north-eastern Poland revealed suits of landforms which proves their origin may be related to catastrophic glacial floods.

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The SIS southeastern limits and related proglacial events: state-of-art

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The history of the White Sea sector of the Scandinavian Ice Sheet (SIS) during the LGM and its retreat has two “open questions” which are still unresolved despite the decades of years of investigations and many efforts of different research groups.

The basic question is the LGM boundary of the SIS in the north-west of the Russian Plain, especially in the North Dvina Basin, which is still “migrating” depending on different concepts and collected data of many research groups over time. Krasnov (1948) who located the maximum Late Pleistocene glacial boundary in the upper reaches of the river Vychegda. In 1970s after the extensive field works and geological mapping (Atlasov *et al*., 1978; Ostanin *et al*., 1979), the LGM boundary was put off to the middle reaches of the North Dvina river and reconstructed as lobate-type extending further up the river valleys. The LGM map of QUEEN project in its southeastern flank mostly repeated these reconstructions (Svendsen et al., 2004). At the beginning of 2010s, a cardinal revision of the glacial boundary in the Northern Dvina basin was published (Lyså *et al.*, 2011; Larsen *et al*., 2014), based on a data of glaciomorphological analysis of space images (Fredin *et al.,* 2012), suggesting a much more distant advance of ice sheet lobes into the valleys of Vaga and Vychegda than was previously thought. The above review illustrates that the position of maximum ice limit in the north-west of the Russian Plain remains debatable and is probably the least reliable compared to the other parts of the south-eastern sector of SIS.

The second question emerges from the first one: the last SIS advance in it southeastern sector was accompanied by damming of rivers and the formation of proglacial lakes in the valleys of Severnaya Dvina and Vaga and their tributaries. Meanwhile, many questions concerning the paleogeography of glacier-dammed lakes are far from being resolved. Areas of flooding, elevation of lake levels in relation to the thresholds of runoff, location and chronology of overflow events, restructuring of valley systems - these issues have still been addressed mainly on the morphological basis by the examination of maps and airborne and space images (Larsen *et al.,* 2014; Fredin *et al.,* 2012; Hughes *et al.,* 2015; etc.). Virtually no geologically confirmed facts has still been published to reliably prove the occurrence of LGM till and lacustrine deposits that would indicate the presence of water overflow from the dammed lakes to the basins of Kama river in the LGM and Late Glacial.

The idea of widespread existence of ice-dammed lakes’ runoff in the rivers of the northern direction was proposed by A.S. Lavrov (1968, 1975). Hereafter D.D. Kvasov (1975) developed these ideas and assumed that, until the Valdai epoch, the Keltma trough served not just a passive overflow of ice dammed lakes, but embraced the upper valley of the Kama, which flowed into Vychegda. During the LGM, the reverse of runoff was reconstructed - the water discharge of so-called Kotlas proglacial lake through the Keltma pass to the south, into the Kama basin (Kvasov, 1975).

Later, A.S. Lavrov and L.M. Potapenko (2005) reconstructed the two stages (LGM and Late) of ice-dammed lake in the Northern Dvina basin during the last glaciation, the first of which reached altitudes of 135 m and overflowed through Keltma spillway. Further development of the concept of Late Pleistocene glacial lakes and overflowing through the main water-divide have received through the work of international projects PECHORA and QUEEN. For the LGM, in several recent publications (Larsen *et al,,* 2014; Lyså *et al.,* 2011; 2014) the formation of the ice-dammed lake in the Vychegda valley is assumed, which reached a threshold of 130 m a.s.l. and spilled over the

Keltma pass into the Kama basin. According to these authors, the proglacial lake was blocked by a glacier lobe which penetrated far into the valley of Vychegda. Some contemporary Russian authors (Nazarov *et al.,* 2015) share this point of view. On the other hand, there are the arguments in favor of the limited distribution of this lake only in the most downstream of Vychegda valley (Sydorchuk *et al*., 1999, 2000; Sidorchuk *et al*, 2001) and in the middle reaches of the Northern Dvina (Zaretskaya *et al.,* 2011; 2013).

In conclusion, it should be noted that the most recent serious geological studies, including drilling, at the key points of the drainage system restructuring, were conducted in 1930-40's (Krasnov, 1948; Yakovlev, 1956). Most of the subsequent reconstructions in relation to overflows of dammed waters and restructuring of river valleys (Kvasov, 1975; Lavrov & Potapenko, 2005; Lyså, 2011, 2014; Larsen *et al.,* 2014, etc.) used the results of old surveys and relied mainly on the analysis of the morphology (from the maps and aerial and satellite images) of knee-shaped bends of the river valleys, on the ratio of the heights of the terraces, which the researchers believed to be of lake origin, and on the heights of the flow thresholds. In no case a geological study of spillways themselves has been conducted, no data on the sediments filling in these landforms or their chronology were gathered; the geological data on abandoned valleys and breakthrough valleys also do not exist. As a result, the majority of the above-mentioned reconstructions have to be considered hypothetical.

A new project of Russian Science Foundation was launched this year to resolve the history of glacial dammed lakes in the Vychegda valley.

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