EXCURSION GUIDE

LATE PLEISTOCENE GLACIGENIC DEPOSITS
IN THE CENTRAL PART OF THE
SCANDINAVIAN ICE SHEET

THE INQUA PERIBALTIC GROUP FIELD SYMPOSIUM IN FINLAND, SEPTEMBER 11.-15. 2006

EDITED BY
PERTTI SARALA, PETER JOHANSSON AND JUHA-PEKKA LUNKKA

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SYMPOSIUM PROGRAMME

Day 1 (Monday, 11.9.)  Stops 1-4, Ostrobothnia
Day 2 (Tuesday, 10.9.)  Stops 5-8, Ostrobothnia - Koillismaa
Day 3 (Wednesday, 13.9.)  Paper and Poster Sessions, Oulunka Research Station, Stop 9
Day 4 (Thursday, 14.9.)  Stops 10-14, Koillismaa - Southern Lapland
Day 5 (Friday, 15.9.)  Stops 15-19, Southern Lapland

ORGANIZING COMMITTEE

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EXCURSION ROUTE AND STOPS

A map of the excursion area in the Central Finland with the route and the location of the excursion stops 1-19.
OSTROBOTHNIA REGION

INTERLOBATE FORMATION BETWEEN THE NORTH KARELIAN LOBE AND THE MIDDLE BOTHNIAN TRIANGLE

Juha-Pekka Lunkka

The excursion route on the first and the second day introduces an ice contact glaciofluvial formation in Isonniemenkangas area (STOP 1) and passes one of the interlobate formations that were formed between ice lobes during the course of the last deglaciation in western Finland (Fig. 1). In this area a relatively continuous glaciofluvial formation is running from the Gulf of Bothnia north of Rahe southeastwards to Siilinjärvi, Central Finland and beyond to the Salpausselkä zone at Jaamankangas close to Joensu (cf. Niemelä et al. 1993). In the interlobate zone that extends more than 250 km from Rahe to Siilinjärvi, we will stop at Vihanti and Piippola (Fig. 1).

Fig. 1. Location map showing the areas of Pyhäntä-Piippola and Vihanti that are situated in the interlobate formation between the North Karelian Ice Lobe (NKIL) and the Middle Bothnian Triangle (MBT). Ss I and Ss II refer to the First and Second Salpausselkä ridges. Map is modified from Niemelä et al. (1993) where the main glacigenic features are indicated. Red areas = bedrock, green lines = eskers, dark brown areas = moraine complexes, light brown = till, yellow = fluvial sediments, blue = silt and clay, grey = peat. Geological map © GTK.

According to Punkari (1980) the glaciofluvial formation from Rahe to Siilinjärvi represents so-called interlobate esker that was laid down between the North Karelian Ice Lobe and a passive ice area of the Middle Bothnian triangle of the Scandinavian Ice Sheet (SIS) (see Fig. 1). Since the interlobate nature of the glaciofluvial formation is only defined morphologically but not sedimentologically the exact nature of sedimentary environments during deposition is not known and
this matter is under investigation. Nevertheless, the primary glaciofluvial sediments in Raahe – Pyhäntä sector of the interlobate formation were laid down during deglaciation in time transgressive manner before 9,000 years ago (cf. Eronen and Haila, 1981). As the ice front terminated into water of more than 200 m deep (cf. Eronen and Haila, 1981), it can be assumed that primary deposition of glaciofluvial sediments took place subglacially in melt water tunnels and/or as ice contact subaquatic fans between the passive and active ice masses to the south and north. Subsequently, isostatic uplift caused rapid regression in water level during the Ancylus and Litorina phases of the Baltic Basin and primary glaciofluvial deposits were reworked by littoral processes during the time they emerged from the Ancylus Lake and the Litorina Sea. The highest shoreline defined for the Litorina Sea of the Baltic Basin range between 90-100 m above sea level (a.s.l.) in the area between Pyhäntä and Vihanti (cf. Eronen 1974).

**EXCURSION SITES IN THE AREA**

**STOP 1. Glaciotectonized glaciofluvial deposit in Isonniemenkangas, Haukipudas**

Antti Pasanen

The exposures are located in two open pits in Isonniemenkangas, Haukipudas (x=7229.00, y=2558.00). The top of the pits is at ca. 27 m a.s.l. Runteli ridge is the most distinguished geomorphological feature in Isonniemenkangas area. Vehkaperä (1988) suggests it as a marginal formation. The ridge is oriented from the north to the south and is located approximately 550-600 m west of the sections and it is therefore more proximal than the sections.

Section 1 consists of three facies (Fig. 2):

1. Lowermost facies is deformed sand facies. It consists of folded sand layers. The primary structures survived the deformation in places and they consist of horizontally bedded and ripple bedded sands (Fig. 3A). The facies is laterally continuous throughout the pit. The sand was probably originally sedimented as fan-delta. The fold planes in deformed sand facies dip to the northwest and fold axis dips to the northeast (Fig. 3B). The shear stress has been interpreted to apply from the northwest when the fold was formed. The lower contact of the facies was not possible to observe.

2. Above deformed sand facies is undeformed spitbar facies in places. It consists of massive matrix supported gravel with erosional lower contact (Fig 3A). Lateral continuity of the facies is approximately 25 metres.

3. Above spitbar facies and above deformed sand facies in places is undeformed sand and gravel facies, which consist of horizontally bedded sand and planar-cross bedded sand and gravel (Fig. 3A). The lower contact to the spitbar facies is depositional whereas the lower contact to deformed sand and is erosional. The facies is laterally continuous throughout the pit. Littoral and aeolian forces have probably reworked the facies. Undeformed sand and gravel facies and spitbar facies is considered to represent fan-delta sediments.
Deformed sand facies was only facies observed in section 2 (Fig. 4). Upper parts of the sequence have been excavated. Structures observed in section consist of folded sand. Ripple bedded sand structures were identified as primary structures. The fold planes in single fold show statistically stronger orientation from the northwest to the southeast but the orientation to the northeast can be easily identified (Fig. 4). The fold axis dips to the southwest supporting the northwest-southeast orientation. The lower contact of the facies was not possible to observe.

Fig. 4. Sedimentary log from the section 2. Facies codes are shown next to the log. Facies codes in parenthesis show primary sedimentary structures which were formed prior to and survived the deformation. The arrows show the shear stress directions. Solid arrow shows statistically more significant direction and hollow arrows statistically less significant direction.
Section 3 is situated in the pit, which is approximately 50 m to the W, and thus more proximal than the pit which contains sections 1 and 2. It consists of three facies (Fig. 5):

1. The lowermost facies consists of deformed sand and gravel. The primary structures consist of ripple bedded sand and massive matrix supported gravel (Fig. 6A). The facies is laterally continuous throughout the pit. Within the deformed sand occur folds which are filled with diamicton. The diamicton is thought to have extruded to deformed sand and gravel during the deformation. The lower contact of the facies was not possible to observe.

2. Above the deformed sand and gravel lays massive matrix supported diamicton unit in places. The diamicton is interpreted as deformation till facies. The rose diagram of the clast fabric analysis from the deformation till shows clear orientation to the southwest and weak orientation to the southeast (Fig. 6B). It was interpreted that the shear stress has applied mostly from the southwest during the deformation and deposition of the till. The lateral extent of the facies is approximately 5 m. The lower contact of the facies is probably erosional and deformed.

3. Above the deformation till facies is undeformed sand facies that consists of ripple bedded sand (Fig. 6A). The facies is laterally continuous throughout the pit and its lower contact is erosional.

![Fig. 5. Section 3 and facies observed. Photo A. Pasanen.](image)

The sequences in Isonniemenkangas suggest that after the deposition of the lower fan-delta sediments there have been multiphased deformation. The structural measurements show that the shear stress direction has applied from the northwest and from the southwest during the deformation of deformed sand and gravel facies and during the deposition and deformation of deformed till facies. The striae measurements north of Isoniemi show ice flow directions from the west and from the northwest (Hirvas and Nenonen, 1987; Mid-Norden Project, 1996). The northwestern ice flow direction predates the western ice flow direction (Mid-Norden project, 1996). The multiphased deformation could have occurred during the single glacier advance-retreat phase where the northwestern shear stress direction was applied during the advance stage of the glacier and the southwest direction during the retreat stage (see Pasanen, 2006, in preparation). Two separate glaciations could also have caused the similar results.
STOP 2. Ground penetrating radar (GPR) profile of the Vihanti formation
Juha-Pekka Lunkka

Due to lack of natural exposures, the internal structure of the Vihanti formation is depicted using the ground penetrating radar (GPR). In GPR profiles both bedrock and groundwater table were clearly detectable in more than 3 kilometre long sounding line in the southern part of Vihanti formation. The sounding line VIHANTI 1 (100 MHz, see Fig. 7) is crossing close to borehole KP 14 at 12 m from the datum point 0 (Fig. 7). During the drilling operation the ground water was found to be at 2.5-2.9 m below the ground surface. Roughly at this level 100 MHz image is picking up a horizontal reflection that continues throughout the image cutting all other reflections (mainly diagonal reflections, see Fig. 7). In the borehole data the bedrock is 16.9 m below the ground surface. Bedrock / weathered bedrock reflection zone in GPR image is also clearly visible although slight offset occurring at ca. 14 m below the ground surface (Fig. 7).

Grain size variations are relatively well detectable from the VIHANTI 1 image (Fig 7). Borehole data and grain size analysis indicate that extremely well sorted fine sand (60% of grains fall between 0.125-0.2 mm) occupies the top 9 m of the core while below ca. 9 m level sediment is mainly medium sand. In the GPR image there is a slight offset of depth model due to the fact that the sounding line VIHANTI 1 is located ca. 20 m west of the borehole. Nevertheless, GPR reflections do change dramatically at around 8 m depth. This change is very clear and mainly shows the change of sedimentary element from large-scale planar delta-type cross-beds to more horizontal sand sets. Two coarser pebbly sand horizons that occur in borehole at 9.0-9.5 m level and above bedrock at 16.0-16.9 m level could possibly correlate with broken reflections as shown in Fig 7.
STOP 3. Vuojalankangas, Oulainen

Juha-Pekka Lunkka

Forsström (1982) discovered one of the most important key sections for the Late Pleistocene stratigraphy of Central Ostrobothnia (Central Pohjanmaa) located in a till covered esker of Vuojalankangas close to Oulainen town (N64°14’, E24°56’, altitude 80 m a.s.l.; Fig. 8). A composite stratigraphy constructed by Forsström (1982) from all the available exposures in the Vuojalankangas pit from the base to the top included:

1. glaciofluvial gravel and sand unit (esker deposits)
2. organic-rich unit composed of gyttja, diatomite, peat and lacustrine sand
3. till unit (so-called Vuojalankangas Till)
4. sand unit
5. till unit (so-called Pokelanmäki Till)
Fig. 8. Location of the Vuojalankangas pit. The altitude of gyttja, diatomite and comminuted organic horizon in sections A, B and C studied by Forsström (1982) are also indicated. After Forsström (1982).

Forsström (1982) described in detail the organic rich gyttja and associated peat and diatomite bed that rests up on the esker sediments. Pollen analyses from gyttja at the most complete site A (for the stratigraphy see Fig. 9) indicate three pollen assemblage zones (Birch zone, Pine zone and Pine-birch(-hazel) zone; Fig 10) and the diatom flora indicate freshwater conditions.

Fig. 9. Stratigraphy of Section A in the Vuojalankangas exposure. a = sand and gravel, b-c = gyttja bearing silt and sand layers, d = homogenous gyttja and peat (14C sample analysed from this bed), e = gyttja bearing sand, f = horizontally bedded sand, g = till. After Forsström (1982).
Based on the results on organic sequence and associated sediments above at Vuojalankangas, Forsström (1982) interpreted that the sequence represents a part of an interglacial and he named it as Oulainen Interglacial. Later on, the organic succession at Oulainen was thought to represent a cooler time interval than an interglacial and was correlated with Brörup Interstadial (Donner et al. 1986, Donner 1988, 1995, Forsström 1988). Forsström (1991) reinterpreted the Oulainen gyttja deposit as representing reworked material of a cool stage towards the end of the Eem Interglacial. The material has yielded a C-14 date of 63,200 +5,500/-3,200 years BP (GrN-7892), TL dates around 100,000 BP and 120,000 BP and one U-series date of 150,000 +/- 17,000 years (GrU-90432).

Later on Nenonen (1995) presented additional data only 600 m NW of the sections Forsström (1982) studied. The section dug by an excavator contains two till beds separated by gravel, sand and silt/clay units (Fig. 11).
Based on Nenonen’s (1995) observations from Vuojalankangas site, it seems that the Ruuna Till was deposited by ice during the Saalian stage from the NW (Nenonen, 1995). The Ruuna Till is overlain by lowermost gravel which Nenonen (1995) interpreted as belonging to the lateral facies of the esker sediments proper. Laminited and massive silt and clay and parallel-bedded sand and gravel probably represent littoral deposits. Organic bearing massive silt, 0.2 metres thick, between two gravel units at the top of the section (see Fig. 11) contained small amount of most likely redeposited pollen including Betula (70%), Alnus (20%), Pinus (7%), Salix (2%) and Juniperus (1%).

Based on the results of Forsström (1982) and Nenonen (1995) it can be assumed that the Ruuna Till and esker deposits were laid down during the Saalian Stage, organic deposits either during the Eem Interglacial or Brørup Interstadial, Vuojalankangas Till during the Early Weichselian and Pokelanmäki Till during the Late Weichselian.

STOP 4. Vesiperä, Haapavesi
Juha-Pekka Lunkka

The Vesiperä sequence in Haapavesi was initially discovered during the ore exploration project carried out by the Outokumpu Ltd in 1985 and the site was subsequently investigated in detail by the Geological Survey of Finland in co-operation with the Outokumpu Exploration Ltd. The main sedimentary units discovered in the excavated sections are briefly summarized herewith and mainly based on descriptions and interpretations of Nenonen (1986), Hirvas and Nenonen (1987), Nenonen et al. (1991), Nenonen (1992) and Nenonen (1995).

Vesiperä site is located in Haapavesi in a relatively flat area (Map sheet 2433 02, x=7111.84, y=2548.35, z=105 m a.s.l.) where several sections were made using an excavator. The excavated pits were approximately 5 metres deep. The lithostratigraphy of the site is shown in Fig. 12.
Fig. 12. Stratigraphy of the Vesiperä section in Haapavesi. After Nenonen (1995).

The lowermost unit in the section is compact, grey, sand-rich till with shear structures and seams composed of sand. This, so-called Vesiperä Till was deposited by ice that entered the Vesiperä area from the northwest (see Fig. 12).

The Vesiperä till is overlain by silt and clay that passes into sand (Fig. 12). The pollen assemblage of clay reflects Betula-dominated vegetation while diatoms comprise mainly of freshwater resting spores. Sand above clay contains abundant sub-fossil roots and a palaeosol with dark brown, unconsolidated, decomposed organic matter and scattered wood remains, twigs and roots. From this palaeosol (so-called Vesiperä Geosol) twigs of Picea and fragments of Alnus were identified. The results of the pollen analyses from clay and sand are shown in Fig. 13. Organic matter from silt/clay and sand were dated using conventional $^{14}$C method and yield ages of 45,800 + 1,500/-1,200 BP (Su-1512), 40,500 +/- 800 BP (Su-1525) and > 48,800 BP (Su-1583).

The palaeosol is in turn overlain by till, so-called Haapavesi Till (see Fig 12). Haapavesi Till is clay-rich, blue-grey, matrix supported and massive till. According to the fabric analyses, till was deposited by ice that overrode the area from WNW ($280^\circ$-$300^\circ$). Thin units of laminated silt and clay, horizontally bedded sand and peat considered to be Holocene in age are overlain the Haapavesi Till (see Fig. 12).

Nenonen (1995) concluded that the Vesiperä Till was laid down during the Saalian stage. Pollen evidence and macrofossils indicate that clay and silt above Vesiperä Till were deposited during the early part of the Eemian while palaeosol developed during the warm stages of the Eemian Interglacial (Nenonen, 1995). The Scandinavian Ice Sheet in turn laid down Haapavesi Till during the Weichselian Glaciation, most likely during the Late Weichselian.
STOP 5. Hitura open pit, Nivala

Veli-Pekka Salonen, Anu Kaakinen, Juha-Pekka Lunkka

Hitura open pit provides an extensive and well exposed record of Late Pleistocene and Early Holocene glacial and non-glacial sedimentary events. The site lies in the low-relief Kalajoki river valley. Surface elevation of the pit rim is 72 m a.s.l. and its extent is more than 0.3 km² in area and about 500 metres in diameter. The mine pit was opened in 1970 to exploit low-grade nickel ore but as the mining operations went underground the pit walls were landscaped in 1980’s. Clay and peat deposits of Holocene epoch mantle the area, and the thickness of the Quaternary sediments varies from 10 to 50 metres within the pit periphery.

The overburden is thickest on the northern side of the pit, but on the southern and eastern side tills display largest lithologic variation. The general outline for the stratigraphy indicates that the fractured and topographically uneven bedrock surface is covered by a thick sequence of glaciofluvial gravels and sands (Fig. 14). These, evidently Late Saalian and Eemian sands were overlain by a series of Weichselian tills which grade up to glaciolacustrine silts, varved clays and massive sulfide clay on the top.
Hitura glacial record comprises sediments from two entire Weichselian glacial cycles. The strata support the idea that the Scandinavian Ice sheet did not extend to Ostrobothnia during the Early Weichselian.

There are two bounding discontinuities in the studied sections. The lower discontinuity between the units 2 and 3 is formed due to basal erosion and shear caused by the ice advance at the beginning of the Middle Weichselian sub-stage from the north. The upper discontinuity separates units 5 and 6. It is also caused by glacial erosion and shear, related to the activity of the Late Weichselian sub-stage, initiating from the west (270°-280°), but shifting later to be from a more northwesterly direction (325°).

Section 1. Fine grained sands and laminated clayey silts; indications of glacial deformation
The lowest sands form an up to 25 m thick succession dominated by fine to very fine, pale yellow sands with subordinate beds of grey silts. The sands are very well sorted and exhibit a general upward fining trend. The sedimentary structures include horizontal lamination and ripple-cross lamination indicating paleoflow towards easterly direction.

There is an unconformity between the sands and the overlying fine-grained deposits. The contact is marked by a thin, but laterally extensive shear plane, which has been developed to the base of the fine-grained sediment body. The unit comprises of 1 to 5 cm thick alternating beds of greyish silt and reddish clay. Individual layers often show evidence of soft sediment deformation for example in the form of drag folds and reverse faults.

The thrust is visible in both units as small-scale shear planes and drag folds. Normal faults and riedel shears were also observed. The measured directions of thrust display a mixture of two stress generations. There are strong indications of compressive stress and up-thrusting from the north (Eigenvector trend 1; 010°). In addition, dip directions of normal faults and tension veins indicate an extension stress from more westerly direction (280°).
**Section 2. Redeposited sediment inclusions and the two till complexes**

The section displays a body of chaotic diamicton, which can be laterally traced for more than 120 metres. Its thickness varies considerably from more than five metres to a few centimetres. The diamicton has an erosional basal contact. The lower subunit is structureless but in places includes indications of shearing and crushing of particles. According to fabric and glacial deformation data, diamicton has been deposited by a glacier overriding from the north. The ice advance is associated with pushing and ploughing and deforming of previously deposited sediments.

Detached interclasts of sorted sediments include trough cross-bedded gravels and sands presumably of fluvial origin. In places, the sands show a distinct podsol Ae and B horizons. At the section 2 the diamicton includes a one metre thick, 5 m long clast of nearly white well sorted fine sand body that is cryoturbated and podsolised, and includes organic fragments as powdered stripes or clusters.

The overlying diamicton consist of two units. The lower unit is massive, matrix-supported diamict that has an erosional basal contact and contains subrounded or bullet-nosed granule-sized clasts within sandy matrix. Striated clasts and oversized blocks were also observed. The unit shows sandy shearing layers and a distinct fabric from 325°. It has been interpreted to represent a lodgement till. The upper diamict unit has gradational basal contacts. It is matrix supported and shows stratification that is characterised by 1 to 5 cm thick interlayers of sorted sediment. The clasts are rare, tend to be granules in size and sub-rounded in shape. Fabric is from 320°-340°, and the diamict has been interpreted to represent the melt-out facies of the Late Weichselian glaciation.

**Section 3. Glaciofluvial and glaciolacustrine sands between the till complexes**

Sands and gravels show a sharp contact to the underlying diamicton. The unit is at its thickest (4.5 m). The basal part is consisted of trough cross bedded medium sands, the main body of the unit shows an upward coarsening trend from horizontal and ripple cross laminated silt and fine sands to alternating layers of horizontally laminated medium and gravelly sands. Silt layers are associated with stripes of allochtonous organic material and a few dropstones. The gravel clasts in the alternating pebble gravel-sand beds show a weakly developed imbrication. The unit 5 can be interpreted to represent a regressive succession after deglaciation in a proglacial lake, receiving sediment supply by meltwater pulses.

These deposits show frequent evidence of shearing. Shear planes follow bedding planes, but in places they also cross the strata. Shear has been extensive resulting to normal faulting. The structures indicate a deforming stress from a westerly direction (280°-300°).

Sands and gravels are overlain by a massive, matrix-supported diamict comprising clayey matrix and low proportion of granule-sized clasts. The intensively sheared diamicton facies is 20 to 50 cm thick and is separated by an erosional contact from the underlying unit, and its fabric indicates a preferred orientation of 100°.

The shearing relates to the activity of overriding ice, which is interpreted to represent a till related to an initial ice advance of the Late Weichselian glaciation from the west. The ice advance is evidenced by shearing and redeposition of underlying fine grained sediments, giving till a high proportion of fines and olive grey colour.
**STOP 6. Paskokangas, Piippola**

Juha-Pekka Lunkka

Paskokangas has formed in the junction of the two coalescing glaciofluvial ridges (Figs. 15 and 16), one joining the Paskokangas area from the north and the other from the west. Paskokangas and related glaciofluvial ridges demonstrate well that the Raahe–Vihanti–Pyhäntä glaciofluvial formation has been formed in an interlobate zone. The glaciofluvial accumulation at Paskokangas is relatively extensive (more than 3 km²) lying at about 110 m a.s.l. while the highest points are at around 120 m a.s.l. Surrounding peat lands are at around 105-107 m a.s.l.

![Fig. 15. Location map of Paskokangas near Piippola (upper red squares) where internal elements of glaciofluvial accumulation were studied. Note that Paskokangas site is situated in the junction of two coalescing glaciofluvial ridges, the northern one is interpreted as a feeding esker and the western one is part of the interlobate formation. For colours of the deposits see caption to Fig. 1. Map scale 1: 330 000. Geological map © GTK.](image)

**Sedimentological observations**

There are several gravel pits in the area although most of them are covered by talus. The best exposures are located SE part of Paskokangas where three sediment logs were constructed (Fig. 17). The main section studied is showing two architectural elements that are briefly described below in their depositional order.

*Arch bedded element* (with deformation) can be seen in all logs. Arch bedded units are relatively well sorted and form cyclic layers throughout the exposure. Coarser beds are composed of massive looking cobble gravel (maximum clast size 50 cm) while finer beds are composed of trough and planar cross-bedded sand. Arched structure is imminent in the exposures and may indicate full pipe flow conditions in a subglacial tunnel that was running approximately from the west towards the east. However, there are some open, almost horizontal faults that penetrate the arched structures. In addition, in log 3 there are signs of penecontemporaneous deformation in the lower part of the section where sand material has been injected upwards into gravels.
Fig. 16. A topographic map of Paskokangas with the location of GPR sounding lines. Lines 1 & 2 are discussed in text. Three sediment logs were constructed along the main sequence where Lines 1-2 are located. Topographic map © National Land Survey of Finland, permission number 62/LA/06.

Fig. 17. Sediment logs in the main section of Paskokangas (lines 1 & 2 in Fig. 16). For log locations see Figs 16 and 18. Vertical axes indicate altitude in metres above the present sea level. Horizontal axes show mean grain size of sedimentary units where $F =$ clay and silt, $S =$ sand, $G =$ gravel to cobbles gravel and $BG =$ boulder gravel. Facies codes: $Fl =$ laminated fines, $Sh =$ sand horizontal, $Sp =$ sand planar cross-bedded, $St =$ sand trough cross-bedded, $Gms =$ massive gravel, $Gm =$ crudely stratified gravel.
Sand sheet and laminated silt element is present in log 1 and log 3. It is composed of gravel and current bedded sands. It is suggested that the sands are not related to beach environment since in log 3 sands are covered by laminated silt that suggests deposition in deep water. Therefore it is thought that current bedded sand and associated gravels were deposited extra marginally and subaquatically above the tunnel sediments in for example glacial crevasse while laminated silt represents glaciolacustrine deposition further distal to ice margin.

GPR observations

The observations were made from the same sections (line 1 = line 2; line 1b = line 2b) as sedimentological observations with both 100 MHz and 250 MHz antennas. The sounding images of 100 MHz antenna that penetrates nearly to 20 m (ca. 400 ns) in sounding line 1 is presented here.

Reflections in the image are strong and the ground water table is relatively clear and continuous reflection at 19 m below the ground surface (Fig. 18). From the zero point up to the turning point of the sounding line 1, the image shows three different reflection patterns. In the top part of the image reflections are strong and continuous and correspond clearly with sand sheet element in log 1 and observed sediment sequence. Beneath this element down to ca. 7.5 m (150 ns) reflections are also strong but partially broken and curved. Below ca. 7.5 m (150 ns) depth reflections are strong but more broken compared to the upper seismic layers. From the turning point to 45 m datum of sounding line 1, reflections are strong overall. The strongest reflection appears between 60-75 ns (ca. 3-4 m). Further below there are also sets of strong and nearly continuous reflections interbeded between more broken reflection sets.

The arch bedded element is not well shown in the image of sounding line 1 with 100 MHz antenna. However, sedimentological observations clearly demonstrate that arch bedded element is present below sand sheet element. From the GPR image it is also noted that cyclic coarse - fine couplets can be detected and coarse sediments may cause more broken reflections below 7.5 m.

In sounding line 1b four different reflection patterns can be seen (Fig. 19). The arch bedded element is relatively clear below ca. 10 m depth (200 ns). Above this there are more horizontal and partially highly continuous reflection lines that according to sedimentological observations are caused by alternating sand and pebble gravel units. From 5 m depth (ca. 100 ns) upwards broken reflections are generated from more coarse pebble to cobble gravel unit. All these three GPR horizons are part of arch bedded structure that is fining upwards from the base of the sequence. Laminated silt and ripple bedded sand element at the top of the sequence is clearly visible in the GPR image (see Fig. 19).
Fig. 18. A 100 MHz GPR image of sounding line 1 at Paskokangas. Logging sites (log 1 – 2) are also indicated. Horizontal axis shows the length of sounding line 1. Turning point shows the point where sounding line turns 110° towards right. Left side of the vertical axis is the signal travel time in nano-seconds and on the right side calculated penetration depth. White line shows the level of the ground water table. Black line in the left upper corner separates sand sheet element from the arc-bedded element. Nearly continuous reflections within the arc-bedded element are indicated. Two continuous black lines indicate through and planar cross-bedded sand unit in Log 2.

Fig. 19. 100 MHz GPR image of sounding line 1b at Paskokangas which is a continuation of sounding line 1 (90° turn to right at the end of sounding line 1). Logging site (log 3) is also indicated. Horizontal axis shows the length of sounding line. Left side of the vertical axis is the signal travel time in nano-seconds and on the right side calculated penetration depth at 400 ns is 20 m. Four main facies are discussed in text.
STOP 7. Glaciofluvial and eolian deposits in Rokua, Muhos

Peter Johansson and Pertti Sarala

Rokuanvaara Hill in northern Ostrobothnia is part of the 20 km long, and 5 km wide NW-SE oriented esker formation surrounded by a flat expanse of mires. The formation includes also large sand dune field formed of esker sand. Sorted sediments and its barren dry forests are covered in bright white lichen. There are many small lakes with clear water, ancient shoreline embankments from the earlier stages of the Baltic Sea, and deep kettle holes in the esker.

The unique and diverse landscape of Rokua was formed as a consequence of Rokuanvaara Hill rising as an island out of the sea after deglaciation. Formed mainly of sand, the island was then sculpted by water and wind causing the redeposition of sands as the sandy dune deposits. The top is totally covered by parabolic dunes; the highest of them are 10-12 metres. From the shape of the dunes one can deduce that the dominating wind was westernly to northwesternly (Aartolahti, 1973). Nowadays the dune surface is hidden under forests and other vegetation. Beach ridges, created by ice and waves, indicate the water level at various postglacial stages of the Baltic Sea. Steep-sided kettle holes in the esker are marks of large blocks of ice, which got buried in the sand on melting phase of ice-sheet. Syvyydenkaivo, “the Well of Depth”, is the deepest hole formed this way in Finland.

An indication of the fact, that erosion is still capable of moving the surface deposits in Rokua, is the deflation areas, where logging or feet of hikers have exposed the ground (Fig. 20). On the slopes erosion can even cause small landslides and that is why the hiking is recommended only in marked nature trails.

Fig. 20. Eroded dune surface at Rokua, Muhos. Photo P. Johansson.
Rokuva's fauna and flora are of the typical barren forest kind with low biodiversity. The specialities of the set of the species in the area can be found on the slopes of the kettle holes, and on the steep southern hillsides parched by the sun. Several rare esker species grow there, such as the Creeping Thyme (*Thymus serpyllum*), the Shaggy Mouse-ear Hawkweed (*Pilosella peleteriana*), the Fragrant Solomon's Seal (*Polygonatum odoratum*) and the Rare Spring-Sedge (*Carex ericetorum*). Many threatened butterflies and hymenopteran species, which feed on the Thyme, have been found in Rokuva. In many places at Rokuanvaara Hill the ground is covered in bright white Reindeer Lichen (*Cladina rangiferina, C. stellaris*) in its natural state, which gives the landscape its unique appearance.

Most of the esker and dune area in Rokuva has protected by establishing Rokua National Park in 1956. Being the smallest National Park in Finland, it covers only an area of 4 km\(^2\) and is included in Natura 2000 network. The National Park is located on the southern side of the hill, where old pine forests grow in their natural state. The area is one of the northernmost places where rare and threatened species typical for eskers can be found.

**STOP 8. Katosharju Interglacial/Interstadial deposit, Pudasjärvi (Optional)**

Pertti Sarala

The Katosharju esker, in Pudasjärvi, is one of the key targets of Eemian-Weichselian stratigraphy in northern Finland (cf. Sutinen, 1992). Katosharju is part of the NW-SE oriented esker chain, which has fed almost the W-E oriented Viinivaara glaciofluvial formation in the Viinivaara area, to the southeast from the Katosharju. The Viinivaara formation is a part of the Pudasjärvi end moraine complex composed mainly of glaciofluvial material and till. Sutinen (1982) described a section in the gravel/sand pit having a gyttja unit with organic layers in between the sands at the bottom and till above. Pollen content in organic material was characterized by Betula-dominated (98%) AP flora. Minor amounts of Pinus, Salix and Corylus also existed. Based on the pollen evidence Sutinen (1992) interpreted it to be deposited during quite cold, interstadial period of the Early Weichselian.

Two organic samples were dated using \(^{14}\)C method. Age estimates were 49,200 ±3,200/-2,300 B.P. (Su-1159A) and 44,900 ±2,600/-2,000 B.P. (Su-1159B) in radiocarbon years (Sutinen, 1984). These ages are unfortunately over the maximum determination limit of the radiocarbon dating method and cannot be accurate (cf. Kitagawa and van der Plicht, 1998).

For getting reliable estimation of the age, three OSL dating samples were collected at the summer 2005. One of the samples was from the upper fine-sand/clayey-silt (=gyttja?) layer, second from the sand under that, and third from the top of bottommost, coarse-sand unit (Fig. 21). On the top, above the stratified sediments exist ca. 3 m thick matrix supported but poorly sorted stony sediment unit. Glaciotentropic structures like faults, shearing and overturning in stratified sediments reflect glacial overriding and maybe redeposition. Furthermore, there seems to be unconformity between the contact of coarse- and fine-sands. Organic material was not found during this time but general stratigraphy is still correlative with earlier studies. OSL age estimates dated back to the end of the Early Weichselian (table 1).
Table 1. OSL dates of sand deposit in Katosharju, Pudasjärvi.

<table>
<thead>
<tr>
<th>Helsinki lab no.</th>
<th>Field no.</th>
<th>Depth (m)</th>
<th>Site</th>
<th>Sediment</th>
<th>Age (ka)</th>
<th>Paleodose (Gy)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hel-TL04057</td>
<td>POS 2005-000005</td>
<td>4.0</td>
<td>Katosharju</td>
<td>Fine-sand / Clayey-silt</td>
<td>75 ± 16</td>
<td>170 ± 35</td>
<td>4</td>
</tr>
<tr>
<td>Hel-TL04058</td>
<td>POS 2005-000006</td>
<td>4.2</td>
<td>Katosharju</td>
<td>Cross-stratified sand</td>
<td>82 ± 9.6</td>
<td>180 ± 19</td>
<td>4</td>
</tr>
<tr>
<td>Hel-TL04059</td>
<td>POS 2005-000007</td>
<td>4.4</td>
<td>Katosharju</td>
<td>Coarse-sand</td>
<td>72 ± 13</td>
<td>170 ± 29</td>
<td>5</td>
</tr>
</tbody>
</table>

Samples were analyzed using SAR (single aliquot regenerative-dose) protocol in Dating laboratory of University of Helsinki. The equipment that was used was Risø TL-DA-12 expanded with OSL- and SG-detectors.

Based on new data, it is still hard to say if the fine-sand/clayey-silt layer interglacial or interstadial of origin. The sediments with glaciotectonic structures are hardly in their original position. OSL ages give an age of influence on light during the end of the Early Weichselian but a great deviation of the ages could be a sign of older deposition of sediments as well. This means that upper sediments with (older ages and) organic peat might be the remnants from the beginning of the Early Weichselian, possibly ice-free climatic conditions and have redeposited during the later glacial advances to the present position.
Koillismaa region is characteristically composed of hilly topography where the ground is about 200-500 m a.s.l. It begins from the Suomussalmi area in the south and continues as far as the Salla area in the north covering the areas of Kuusamo and Taivalkoski in the middle (Fig. 22). Part of the highlands in the Pudasjärvi and Posio municipalities is also considered to belong to the Koillismaa region. The bedrock of the area is composed of Archaean and Proterozoic igneous and sedimentary rocks which have been resistant to glacial erosion. Although a relief is smoothed indicating several glacial advances the hilly area is distinguished from the surrounding lowland areas in the south and west. For example, the southest fells (= treeless mountains, *tunturit* in finnish) of Finland, Iso-Syöte and Ruka, are situated in the area.

Fig. 22. Glacial morphology and bedrock relief of Koillismaa region. Digital elevation model, topographic features and roads © National Land Survey of Finland, permission number 62/LA/06.

Glacial landforms are mostly formed of streamlined features indicating ice-flow directions from the west or northwest. Thousands of drumlins and flutings form Kuusamo drumlin field, which is covering over 10,000 km² and is one of the largest fields in Finland. A northwest-southeast direction of the streamlined features indicates a margin of ice-sheet to be divided into the ice-lobes of Kuusamo and Oulu during the last deglaciation (Aario, 1977a, 1990; Aario and Forsström, 1979). There exists also an older drumlin field under younger one having the west-east orientation. It is indicating early
flow phase (Tuoppajärvi) of the last glaciation (Aario and Forsström, 1979). There is also indication of glacial advance before the Late Weichselian glaciation defined by the north-northwest to the southeast oriented large hills and topographic depressions presently seen as lakes.

According to Aario and Forsström (1979) the first recognizable flow phase, Tuoppajärvi phase, was a single comprehensive flow unit in the Koillismaa area during the early deglaciation. A flow direction was from the west to the east and of that, the grey or bluish grey, lodgement type till unit named the Soivio Till is representing the flow phase in the till stratigraphy (Fig. 23) and drumlins with the same orientation in the glacial morphology.

As deglaciation continued and ice margin retreated, rearrangement occurred and new ice lobes were formed. The Oulu lobe in southern parts of the area continued flowing from the west to the east but in the north, the flow direction of the Kuusamo lobe was turned from the northwest towards the Oulu lobe. Of that phase, the upper Jaalanka Till in the south and Kuusamo Till in the north are seen in the till stratigraphy. The tills were deposited under drumlin forming processes and were composed of melt-out and lodgement tills but having also features of flow processes and subglacial meltwater activity during the deposition.

Large interlobate system, The Pudasjärvi-Hossa Complex, composed mainly of glaciofluvial sediments was formed between the lobes. While the deglaciation still continued, ice lobe development reached a quite stationary stage and the interlobate complex was also formed westward continuing through the centres of Taivalkoski, Pudasjärvi and Yli-Ii and ending to Kuivaniemi in the west.

Fig. 23. Diagrammatic sketch of till stratigraphy of drumlins at Soivio, southern Kuusamo. After Aario (1990).
EXCURSION SITES IN THE AREA

STOP 9. Pudasjärvi-Taivalkoski-Hossa Interlobate Complex
Peter Johansson and Pertti Sarala

A large meltwater drainage system stretches across southern Finnish Lapland in W-E direction. The meltwater channel was filled with glaciofluvial gravels and sands, the formation, which is often several kilometers in width and from a few tens of meters up to 100 m in height. The length of this formation is over 300 km. The remnants of ice that were buried into stratified sediments during the deposition are now seen as kettle holes or hummocky morphology in between the esker-like ridges. A main road from the Pudasjärvi center to Taivalkoski goes along the glaciofluvial formation and on the way the huge size of formation is seen. A short stop will be on the Taivalvaara hill near the center of Taivalkoski (Fig. 24).

The glaciofluvial formation follows the boundary between the large ice-lobes of Kuusamo and Oulu and later Ranua and Oulu forming the Pudasjärvi-Taivalkoski-Hossa Interlobate Complex (Aario and Forsström, 1979). An orientation of the route is controlled rather by the activity of the ice-lobes than by topography or bedrock relief. The phenomenon is clearly seen in places where the glaciofluvial system crosses the hilly topography not seeking it's way to lowland channels or topographic depressions. Only in places when pre-existing fractured zone in bedrock exist at the same direction with the meltwater route, the gorges like Julma Ölkky on southern Kuusamo and Pahkakuru on eastern Taivalkoski, can be found in relation with the Interlobate Complex.

Fig. 24. Overview from the Taivalvaara hill top towards the east. Photo P. Sarala.

The composition of sediments is varying from large boulders and gravels to fine sand and silt. Core parts of the ridges are usually composed of gravels and rather poorly sorted pebble- and boulder-rich material (Fig. 25) like in eskers. Gravels in core could have been remnants of the earlier stages when meltwater activity and hydrostatic pressure sorted sediments in subglacial tunnels. Huge quantities of finer sorted fractions (mostly sands) are more common at the surface and at the marginal parts of the
Complex. Composition and structures are however very heterogenous due to vicinity of active ice margins and the relation to meltwater channels flowing from the ice towards the Interlobate Complex. The seasonal variation in melting, successive periods of deposition and flush out of meltwater are also the factors causing complexity (cf. Aario and Forsström, 1979).

![Sorted, gravelly material at the core parts of the Pudasjärvi-Taivalkoski-Hossa Interlobate Complex ca. 5 km from the centre of Pudasjärvi to the east. Photo P. Sarala.](image.jpg)

**STOP 10. Kiutaköngäs and Oulanka River valley, Kuusamo**

Peter Johansson

The Kiutaköngäs Rapids is the most popular sight in the Oulanka river valley. It can be easily reached the year around along the path starting from Oulanka Visitor Centre and The Research Station. The best way to getting acquainted with the rapids is by walking to the eastern point of the island in the middle of the rapids. A fine view opens from there of the waterfall, the red rock cliffs and the quiet waters below the rapids (Fig. 26). The waterfall pours out in a narrow gorge between brownish-red dolomite rock faces, dropping some 14 m over a distance of 200 m. The rock surface shows plenty of small potholes, proof of the eroding force of water.

The bedrock of the Oulanka area belongs to the Fennoscandian Shield, which was formed in Archaean times, more than 2.5 billion years ago. About 1.8–2.5 billion years ago, there were several earthquakes and volcanic eruptions and they produced volcanic rocks, which partly overlie Archaean rocks. The largest fracture zones were formed as results of earthquakes: the river valleys the Oulanka and Kitka and the lake basin of Lake Paanajärvi in Russia. The region is still seismically active, but earthquakes are very modest in force.

During the Late Weichselian the ice moved across the Oulanka area from west by northwest to east by southeast. The landscape is distinctly striated as a result of the action of the glacier. It eroded part of the bedrock underneath it, and carried away, ground up and eventually deposited in till layers. Some of the till material was accumulated to form drumlins. They are especially evident to the south of Oulanka. The thickest glaciofluvial accumulations are eskers and deltas in the Oulankajoki river.
valley. Lake Paanajärvi Basin, which after the deglaciation was a fjord of the present day White Sea, received thick mass of stratified clay material from the glacial rivers. As a result of the gradual uplifting the contact between supra-aquatic and subaquatic deposits is nowadays to be found at the height of 165-170 m at Kiutaköngäs and 157-160 m in the Finland – Russia border region (Koutaniemi, 1979).

Thanks to the volcanic and dolomite rocks and maritime layers the soil is very nutritious in places. The richness of the area's flora is sure to surprise even the most well-versed visitor. The soil enables demanding fell plants and orchids to grow in the area. You can encounter Oulanka's emblem plant, the calypso (Calypso bulbosa) and the mountain avens (Dryas octopetala) growing on rock ledges. There are booklets of the flora available from the Oulanka Visitor Centre.

**STOP 11. Noivioharjut Esker complex, Kuusamo**

Peter Johansson and Pertti Sarala

Huge subglacial glaciofluvial rivers developed under the melting continental ice sheet and directed the meltwaters from under the ice up to the margin of the ice sheet. In these subglacial tunnels the water flowed under hydrostatic pressure, eroding its base, pre-existing formations and fractured bedrock so effectively, that all loose material was carried away. Rock surfaces exposed by running water and mighty gorges are results of such subglacial meltwater erosion.
The meltwaters did not only erode their base, they also transported debris that, as the flow slowed down, deposited on the bottom of the tunnel or at its mouth. In supra-aquatic areas, like at Noivioharjut in Kuusamo, the eskers often have steep slopes and sharp crest, which show that the material was deposited inside the tunnel between glacier walls (Fig. 27). These eskers consist of coarse fragments like stones and gravel, which were deposited on the bottom of the channel. When the tunnel expanded close to the margin of the glacier or widened into an open crevasse the flow rate dropped and sand deposited on the coarse layers (Fig. 28). The flanks of the Noivionharjut esker are mainly sandy material. In places, the marks of reactivation are seen as shear and folded overthrust structures (Fig. 29).

![Fig 27. The Noivioharjut esker with steep slopes and the small lakes on both side of the ridge body. The scenery towards the west. Photo P. Sarala.](image1)

![Fig. 28. Stratified, horizontally bedded sands at the central part of Noivioharjut esker complex in Kuusamo. Photo by P. Sarala.](image2)

The esker chains mark the course of meltwater streams that run perpendicular to the ice front. Once under way, a subglacial stream kept on flowing for hundreds of years as melting proceeded. The stream had also tributaries, as is seen by the esker pattern on the figure 30. Noivioharjut belongs as a part of a long esker chain, which begins to the south of the ice-divide area of Central Lapland and transect southern Lapland from northwest to southeast. To the east from the Noivionharjut esker the chain can be traced in the Oulanka river valley and beyond the eastern border of Finland in the lake of Paanajärvi until the Younger Dryas End Moraines in Russia.
Fig. 29. Folded sands at the central part of Noivioharjut esker complex in Kuusamo. The fold planes dip towards the east. Photo by P. Sarala.

Fig. 30. Late-Weichselian esker chains in northern Finland and the location of Noivioharjut esker complex near the Kuusamo city. Modified after Johansson and Kujansuu (2005).
Glacial morphology at Oivanki, NW from the centre of Kuusamo, is composed of large, well-developed drumlins deposited during the WNW oriented (ca. 290°) ice-flow. Drumlins in this area are usually long (1-2 km) and narrow (200-500 m), and both the proximal and distal ends are tapering from the ground. The distal tail is usually somewhat narrower than proximal end. Sometimes complex drumlins, which have grown together in the middle or at the proximal end, are also seen.

Drumlin in Korkea-aho (Figs. 31 and 32) is composed of two till units (Fig. 33). The upper one is distinguished as brownish-grey, sandy, matrix-supported till having quite compact and massive structure. Some fissility structures and thin sandy or silty stripes can be seen as a mark of subglacial deposition - mostly as lodgement till. The boulder and pebble content is moderate and the roundness is good. The rock composition of the pebbles is indicating long glacial transportation. Fabric countings were only made from this till unit showing the same orientation with drumlin body in the topmost part of the ridge (Fig. 31). Both in southern and northern sides, at marginal parts of the ridge, fabrics showed that the stones have turned gently away from the drumlin’s centre line. This maybe indicating primary deposition phenomenon or could also be reflecting secondary flow or mass-movement on the marginal parts of the ridge (Fig. 34).
Fig. 32. Overview from the drumlin top towards the up-ice direction (to WNW). Photo P. Sarala.

Fig. 33. Two till units in the test pit M53 on the proximal part of drumlin at Korkea-aho, Kuusamo. Upper till unit is composed of homogenous sandy till with fissility structures (small figure), typical for subglacial lodgement till. Lower till (under 34 dm at measuring stick) includes sorted sandy lenses and bands indicating deposition as subglacial melt-out till. Photos P. Sarala.
The lower till unit is composed of grey, silty or sandy till having mostly quite massive structure. In places slightly laminated parts are seen. Fabrics were not been done but as it is possible to see in GPR profile, the lower till unit (reddish brown in Fig. 35) is occurring on the southern part of the drumlin body. The older ice-flow direction has been from the NW and till has probably been deposited during that flow phase on the stoss side of the bedrock top in the middle of the ridge. Later, the same bedrock has preserved the older till unit during the younger ice-flow phase. In between the tills occurs a unit of sandy/fines layers.

Drumlins appear to be partly erosional features but also depositional forms. The stratigraphy presented by Aario and Forsström (1979) from the Soivio area, southern Kuusamo, proved that till(s) in deeper parts of the drumlin body was deposited during the earlier ice-flow phases or even under
older glacial advance having variable flow directions. The upper parts of drumlin bodies, instead, are clearly formed by growing beneath the ice flown to the same direction as the lineation of drumlins. The bedrock core in the case of Korkea-aho has been a shelter against the glacial erosion and that is why the older sediments have been preserved on the marginal parts.

STOP 13. Korouoma Valley Complex and a diverse protected area, Posio

Peter Johansson

The Korouoma canyon, which lies near the road from Kuusamo to Rovaniemi (Fig. 22), is distinguished by its near-vertical, 100-130 m high granite walls (Fig. 36). Accentuated by brooks falling down the cliffs they form a unique, rugged scenery. In summer it is a lush canyon valley with winding river and small cascades. In winter the water freezes and magnificent icefalls begin to shape on the rock wall. They stay frozen long into the summer. Korouoma is a well-known geological object. It is famous for ice climbing and for the other outdoor activities, too.

The bedrock is mainly coarse-grained red granite. In the southeastern end of the canyon there are sedimentary rock types, such as mica shist and quartzite. At the foot of the cliffs there are rock walls and pillars that are crumbling away as a result of frost weathering. Boulders with freshly cracked surfaces, strewn around the foot of the slopes, bear witness to this. Large rockslide deposits of jagged boulders and stones have been accumulated at the bottom of the canyon. In the crevices of crags, slide heaps have formed talus cones, such as the one at the foot of the Piippuvaara hill.

A large part of the valley consists of protected old forests, where numerous species typical of primeval forests have been found. Spruce-dominated forests appear predominantly at the bottom of the canyon, where climatic condition differs essentially from the surrounding region. The soil has
more nutrients and moisture than in the arid slopes. This shows in many places in the peculiar vegetation and in the occurrence of many rare and endangered plant species. They are typical to stream valleys and herb-rich foresta below rocky cliffs. In the middle of the valley there is the winding Korojoki River, which flows towards northwest. The old annually flooded meadows along the river with the constructions from log-floating times are objects worthy of preservation.

The geological formation of Korouoma is polygenetic. Firstly, the canyon is a part of a fault or fracture zone in the bedrock, formed hundreds of millions of years ago and running NW-SE. The fracture zone continues in the surrounding area in the form of long river valleys, such as that of the Kemijoki River and Auttijoki River. During the ice ages the glaciers eroded the weathered rock, quarrying the bottom and walls of the canyon. At the final stage of the last glaciation the Korouoma canyon was located in the western part of the Kuusamo Ice Lobe. The glacier was flowing very intensely in the direction of the fault zone from the west-northwest towards the east-southeast. This powerful flow was accompanied not only by glacial erosion but also by the accumulation of drumlins with a height of tens of metres. These are now a part of the Kuusamo drumlin field.

Towards the end of the last glaciation, about 10,500 years ago, a subglacial meltwater system flowed through Korouoma towards southeast (Fig. 37a). The walls and floor of the canyon were quarried and worn by glaciofluvial erosion. The debris transported by the meltwater stream was washed, rounded and finally accumulated southeast of Korouoma, between the lakes Iso Aimojärvi and Pahajärvi, as steep-sided esker ridges and on the heath at Lapiosalmi as tens of metres thick sandur deposits. On the surface of the sandur there are braided channels, incised by the water emerging from the mouth of the meltwater tunnel.

At the end of the deglaciation, an ice margin penetrated to the southeast into the Korouoma canyon. In front of it a narrow ice lake was dammed, which had its outlet channel, known as Lisakinuoma, in the southeast. Its threshold point, at about 235 m, also regulated the level of the ice-dammed lake. The water flow through the ice-dammed lake was powerful, as an abundance of subglacial meltwater emerged from the mouth of a subglacial meltwater tunnel. When the margin of the retreating glacier had reached the northwestern end of the canyon, it became a part of the outlet channel of the Salla Ice Lake. At that time, about 10,500-10,700 years ago, the Salla Ice Lake covered an area of approximately 3,500 km², which made it the largest ice-dammed lake basin in northern Finland (Johansson, 1995). A new outlet channel for the Salla and Korouoma ice lakes opened on a lower level via Paasonjärvi and Kilsikangas to the Ancylus Lake (Fig. 37b). When the waters of the Ancylus Lake penetrated into the canyon, the highest shoreline was formed at an altitude of 205 m a.s.l. (Fig. 37c). Later the water level dropped and the floor of the Korouoma canyon turned into dry land. At Lapiosalmi, in the southeastern part of the Korouoma area there are transversal dunes, which are 400-800 m long and 4-5 m high. They are formed by strong northwestern winds blowing off the ice sheet soon after the deglaciation.

The location of the Korouoma area high above sea level (approximately 140-300 m a.s.l.) made it possible for peatlands to develop soon after the deglaciation. At first, peat was formed in depressions and water-logged areas of the terrain and later at the edges of small lakes as a consequence of overgrowth. The peatlands are located in a zone where the sedge-covered aapa mires typical of Ostrobothnia county are gradually replaced by flark aapa mires, which are common in southern Lapland. In the Korouoma area the peat forms aapa mires, typical of northern Finland. They require more precipitation than evaporation and a terrain of glacial till, which favours peat formation due to its landforms and hydraulic conductivity. The aapa mires are minerotrophic, meaning that they get their nutrients transported by surface water and groundwater from the surrounding till areas. In the
middle the mires are mostly treeless and open with alternating winding ridges, also known as strings, and watery flarks. The ridges often lie in a direction transverse to the slope of the mire. In this way they can both store flood water in spring and prevent drying of the mire in summer. The margins of the mires have a thin peat cover and grow either spruce and herbs or pine and dwarf shrubs. Small lakes, forest groves and brooks are typical elements of a mire landscape in this region.

Fig. 37. Glaciohydrographic history of the Korouoma area and disappearance of the glacier (A-C). 1 = Ice-dammed lake, 2 = Ancylus Lake, 3 = Subglacial meltwater system, 4 = Ice margin, 5 = Esker and sandur, 6 = Outwash delta, 7 = Outlet channel, 8 = Village, 9 = Present lakes and rivers and 10 = The Korouoma Canyon.
Both parallel and transverse elements are present in the glacial morphology of southern Lapland area. Under the active glacial flow, the glacier eroded bedrock and also deposited morainic landforms. The erosion forms, like rock drumlins and large, streamlined hills, indicate dominant glacial flow from the west to the east. Active ice forms like transversal ribbed moraines are the most dominant landforms in the area (Fig. 38). Ribbed moraines exist as uniform fields on lowland areas and are mainly composed of Rogen moraine or hummocky ribbed moraine types (cf. Hästestrand, 1997; Sarala, 2003) (Fig. 39). Furthermore, a small area of minor ribbed moraines occurs in the Sihtuuna area (cf. Aario et al., 1997). Ribbed moraines form together with drumlins and flutings assemblages of active ice morphology (cf. Aario, 1977a, 1990; Lundqvist, 1969, 1989). Quartzite hills or hill areas occurring transversal to the general glacial flow break the uniformity of the ribbed moraine-drumlin field.

The ice-lobe system formed during the latest retreating phase is clearly seen in the glacial morphology. Drumlin-ribbed moraine association occur on the Kuusamo Ice-lobe area and on the southern part, the Oulu Ice-lobe has flown towards the east. Between the active lobes, the Ranua Interlobate area has been existed preserving the older northwest-southeast oriented drumlin morphology around Ranua, south to the Kivalot hill chain and Portimojärvi area. Meltwater streams were followed the lobate structure including some larger channel systems like in the area of Korouoma valley (Fig. 38).
The Quaternary lithostratigraphy of southern Finnish Lapland is composed of three till beds and two inter-till, stratified minerogenic sediment layers containing sometimes organic material, and is proposed to call as the *Peräpohja Group* (Sarala, 2005b, c). The descriptions, formal names and type sections of the units are also presented (Table 2).

Table 2. *Quaternary lithostratigraphy, unit descriptions and formal names in Rovaniemi-Tervola area. A whole stratigraphic sequence is proposed to name as the Peräpohja Group. After Sarala (2005c).*

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Depth</th>
<th>Description</th>
<th>Interpretation</th>
<th>Chrono-stratigraphy</th>
<th>Type section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suolijoki</td>
<td>Formation</td>
<td>0.5 - 2 m</td>
<td>Stratified sand</td>
<td>Shore deposit</td>
<td>Holocene</td>
<td>N7345.5 I2561.5 M118, Vammavaara</td>
</tr>
<tr>
<td></td>
<td>Korttelivaara Till</td>
<td>0.1 - 1.5 m</td>
<td>Brownish grey sandy diamict</td>
<td>Melt-out, flow or waterlain till</td>
<td>Late Weichselian</td>
<td>N7334.0 I3444.6 M90, Korttelivaara</td>
</tr>
<tr>
<td></td>
<td>Petäjävaara Till</td>
<td>1 - 3 m</td>
<td>Brownish grey or grey gravelly diamict</td>
<td>Lodgement or basal melt-out till</td>
<td>N7358.5 I2564.1 M1, Petäjävaara</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vammavaara Till</td>
<td>1 - 4 m</td>
<td>Grey sandy diamict</td>
<td>Lodgement till</td>
<td>N7346.2 I2561.2 M25, Vammavaara</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sihtuuna Sands</td>
<td>1 - 2.5 m</td>
<td>Horizontally or cross bedded sand</td>
<td>Subaquatic fan</td>
<td>?</td>
<td>N7344.6 I2529.6 M124, Sihtuuna</td>
</tr>
<tr>
<td></td>
<td>Kemijoki Till</td>
<td>1 - 2 m</td>
<td>Bluish grey, compact sandy/silty diamict</td>
<td>Lodgement till</td>
<td>Early or Middle Weichselian</td>
<td>N7345.9 I2562.2 M21, Vammavaara</td>
</tr>
<tr>
<td></td>
<td>Saarenkylä Gyttja</td>
<td>2 - 3 m</td>
<td>Organic gyttja, silt and sand</td>
<td>Lacustrine or marine deposit</td>
<td>Eem Interglacial or Early Weichselian</td>
<td>N7382.5 I3447.6 Saarenkylä (Sutinen 1992)</td>
</tr>
<tr>
<td></td>
<td>Saarenkylä Till</td>
<td>&gt; 1 m</td>
<td>Grey, compact sandy diamict</td>
<td>Lodgement till</td>
<td>Saalian</td>
<td>N7382.5 I3447.6 Saarenkylä (Sutinen 1992)</td>
</tr>
</tbody>
</table>
The bottommost till unit, Saarenkylä Till, is interpreted to be an age of Saalian glaciation and can be correlated with Till Bed IV after the nomenclature of Hirvas (1991). Above that exists the Saarenkylä Gyttja, which has been deposited during the Eemian Interglacial (Sutinen, 1992) or possibly during the Early Weichselian Interstadial. The second, Kemijoki Till unit is known as dark till in literature (e.g. Ber and Kujansuu, 1974; Kujansuu et al., 1982) and is correlative with Till Bed III. It has been deposited during the first Weichselian glaciation that covered the southern Finnish Lapland area. The Sihtuuna Sands follows it in stratigraphy and represents the ice-free interstadial stage of the Middle Weichselian. The Tervola Till Formation including members of Vammavaara Till, Petäjävaara Till and Korttelivaara Till represents the Late Weichselian glaciation including the till units from advancing phase to melting phase with the redeposited unit related to ribbed moraine formation in between. The Korttelivaara Till is rare and has seldom preserved, because the upper parts of morainic landforms were washed during the later Ancylus Lake and Litorina Sea stages and changed to shore deposits of the Suolijoki Formation.

Based on studies on southern Lapland the glacial morphology and till stratigraphy were developed during the two Weichselian glacial phases (Sarala, 2005c). There is evidence of three glacial advances during the Weichselian glaciation but the first glacial stage was quite modest in extent and covered only the area of northernmost Finland. The glacier reached southern Finnish Lapland (and maybe whole Finland at the same phase) for the first time during the Middle Weichselian. The marginal formations in the Pudasjärvi area and from there to northeast (MZI-MZIV) deposited during the melting phase. The serie of marginal deposits described by Sutinen (1992) is now completed with the fourth zone, which goes through the Kauvonkangas esker system (Fig. 38). An interstadial phase (Peräpohjola Interstadial described initially Korpela in 1969) was followed the first glacial phase in OIS 3, meaning that most of the radiocarbon ages clustering to 40-55 ka are correct and supported with the latest TL and OSL age determinations (Sarala, 2005b; Sarala et al., 2005; Mäkinen, 2005). Finally, the interstadial was followed by the relatively short but very intensive and large Late Weichselian glaciation.

**RIBBED MORAINE FORMATION**

Pertti Sarala

Ribbed moraines were initially described by Hughes (1964) in North America. After that a lot of papers have been published from Scandinavia and North America concerning the existence, morphology, composition and structure of those landforms. Many theories of the formation of ribbed moraines from for example end, push and squeeze to annual or dead-ice disintegration moraines have been presented during the course of years. Since the end of 1960's the formation was considered to be an active ice, subglacial process controlled by different pressure, tension and temperature conditions (e.g. Cowan, 1968; Lundqvist, 1969; Aario, 1977a). The latest theories presented by Hättestrand (1997), Lundqvist (1997), Sarala (2005b; 2006) and Möller (2006) start with an assumption of multiphase formation controlled by the variable subglacial processes.

The observations made from the southern Finnish Lapland have proved that the formation process of ribbed moraines was a result of several subglacial stages (Sarala, 2006). During the early stage of deglaciation, on the retreating zone of subglacial frozen- and thawed-bed, pre-existing sediments and the bottommost part of the ice sheet formed a stagnant, stacked mass. Due to pressure and tension caused by the moving ice sheet, subglacial crack system was formed and the stagnant mass was
fractured (Fig. 40). When the zero-degree boundary was crossed the surface of bedrock or other weakness zone (e.g. till unit boundary, stratified layer, boulder pavement), fractured blocks were moved along the ice sheet forming rib-like morphology. Because of the prevailing cold conditions, followed freeze-thaw process was caused the quarrying in between the newborn ribs and a bit later, after the pressure increased on the proximal contact, the deposition of material (released from the ice bottom) on the surface of the ribs.

Fig. 40. Ribbed moraine formation as a result of subglacial fracturing, mass movement and followed quarring. Variable pressure conditions under moving ice-sheet initiated the freeze-thaw process that caused the subglacial quarring and deposition of local bedrock material on the ridge tops. After Sarala (2006).
The formation process described above is a very general presentation but is relevant for all the ribbed moraine types observed in southern Finnish Lapland. For example, an inner structure and the short glacial transportation of till material and boulders on surficial parts of ridges, and the relation between shapes of parallel ridges prove ribbed moraines to be deposition features.

Sarala (2005b, 2006) represented that quick and strong decrease of the air temperature and the subsequent imbalance between the surface and the basis of the ice-sheet might be the most suitable moment for the beginning of ribbed moraine formation at the end of Younger Dryas, on the early stage of deglaciation. The climate change during that time was a global phenomenon and thus, explains the occurrence of ribbed moraines in the central areas of the former glaciated areas. It is worth noticing that ribbed moraine formation was not a sudden, explosive process but it continued several hundreds or maybe over a thousand of years after the Younger Dryas. Rapid climate change during the Younger Dryas was only the starting point for the formation process. Suitable glacial conditions for ribbed moraine deposition could have varied both in spatially and temporally in different parts of continental ice-sheet in Scandinavia and North America.

THE USE OF RIBBED MORAINES IN ORE PROSPECTING

Pertti Sarala

Ribbed moraines have many features that make prospecting for Au and other metals easy. The best feature is their good indication of local bedrock composition in the uppermost part of ridges. It comes out as high metal contents in every till size fractions (<0.06 mm, 0.06-0.5 mm and >2 mm), in heavy mineral concentrate and in the composition of surface boulders on the distal side of mineralized bedrock (e.g. Peuraniemi, 1982, Aario and Peuraniemi, 1992, Sarala et al., 1998, Sarala and Rossi, 2000 and Sarala, 2005a). Glacial dispersal for the elements is very sharp near the mineralization with small outcrop. It maybe the benefit because the source(s) is easily detectable but also the restriction due to need of dense grid during sampling. In the case of large mineralized occurrence in the bedrock, high metal contents can be traced in a wide area by taking samples from the uppermost till unit but also from the lower, commonly distantly derived till units.

In many case studies like in the Petäjävaara and Vammavaara areas Au-Cu mineralized boulders were found at the surface of the moraine ridges (Sarala et al., 1998, Sarala and Rossi, 2000, 2006). Among boulders, the geochemistry of different till size fractions (<0.06 mm, 0.06-0.5 mm and >2 mm) and heavy mineral concentrate reflects short glacial dispersal of elements in the upper part of ribbed moraine ridges. Particularly, the uppermost till unit is useful in tracing potential sources in the bedrock. For prospecting Au, the most useful indicator elements in till geochemistry were among Au itself Cu, Te and Co. As a result of the study, Cu-Au mineralization was found at the Petäjävaara site (Sarala and Rossi, 1998). High Au contents exist in every till size fraction (<0.06 mm, 0.06-0.5 mm and >2 mm), but the coarsest fractions have the clearest indication of close vicinity of the mineralized bedrock. This is also seen in fresh pyrite and chalcopyrite grains in heavy mineral concentrate. These minerals are typical for hydrothermally altered Au-Cu mineralizations in the Peräpohja Schist Belt.

Till geochemistry proves that till in the upper part of the Sihtuuna moraine ridges (Aario et al., 1997) is also consisted of high contents of Au, Cu, Ni and Co particularly in a fine till size fraction (<0.06 mm). Especially the distribution of Au is highly anomalous in the fine till size fraction but also in heavy mineral concentrates of till. Because the high Au contents occur in the uppermost till unit, the possibility for an occurrence of Au mineralization(s) in the bedrock is great. Clear indication of
local rock types in the surficial part of ridges is also the feature that makes ore prospecting quite easy in the Sihtuuna area.

According Sarala (2005a) the use of ribbed moraines for prospecting Au and its pathfinder elements is useful because:

1. Ribbed moraines are common morainic landform type on the large areas in Finnish Lapland. An identification of this moraine type is easy with aerial photo interpretation or elevation models with high resolution. Prospecting strategy and sampling methods can be the same even if the ribbed moraine subtypes change.

2. The features of the upper till unit and the surficial boulders indicate strongly the variation of local, underlying bedrock. Short glacial transport distance of the till is seen in a sharp and anomalous dispersal of Au and its pathfinder elements in both horizontal and vertical dimensions. Boulders on the surface and in the upper till represent the local, quarrying activity of the ice during the formation of ribbed moraines (Fig. 41).

3. Different till size fractions indicate short glacial dispersal. Quarrying activity during the formation of ridges lift fresh mineralized material from the bedrock surface to the surficial parts of the ridges. Thus, ore indicators – mineralized boulders, heavy or other ore minerals and metal-rich till size fractions (<0.06 mm, 0.06-0.5 mm and >2 mm) are useful indicators of the mineralized bedrock.

4. Till sampling in the ribbed moraine areas can be easy, fast and cost-effective, because the samples can be taken only from the upper till unit.

![Fig. 41. A comparison of geochemical properties between ribbed moraines and drumlins. After Sarala and Nenonen (2005).](image-url)
EXCURSION SITES IN THE AREA

STOP 14. Ribbed moraines in Portimojärvi, Ranua
Pertti Sarala and Jorma Valkama

Ranua ribbed moraine field is one of the third ribbed moraine areas in southern Finnish Lapland. It is composed of transversal moraine ridges, which are usually 5-15 m high, 100-150 m wide and up to one kilometer long (Fig. 42). The form of ridges is often crescentic where the edges are pointing into the down-ice direction. These forms represent Rogen moraine type described by Lundqvist (1969). Hummocky ribbed moraine type (cf. Hättestrand, 1997; Sarala, 2003, 2006) is also common, although having not so clear indication of the ice-flow direction. Characteristically mires and little lakes exist in between the ridges (Fig. 43) and the ridge surface is mostly covered with boulders.

Fig. 42. Part of the ribbed moraine field in the north of Portimojärvi village in Ranua. Sounding profile is presented in Fig. 44. Digital elevation model, topographic features and roads © National Land Survey of Finland, permission number 62/LA/06.

The ribbed moraines in this area has been studied since 1975 (Aario, 1977a, 1977b; Aario, 1990; Aario and Peuraniemi, 1992) for investigating Quaternary geomorphology and stratigraphy and also, for ore prospecting. A lot of tractor excavations have been done during the latest decades including five test pits dug during the summer 2006 for this excursion. The ridges are composed more or less regularly of two till facies, a more densely packed lodgement and melt-out till with fine-grained matrix at bottom and homogeneous melt-out and flow till at the surficial parts. Pebble content increases upward while the roundness decreases. The transport distance of stone material is also highest at the bottom. On the surface and in the uppermost till, boulders are indicating local variation of the underlying bedrock composition. It is clearly coming out as short (some tens of meters wide and 200-300 m long) mineralized boulder trains traced in the area (Aario et al., 1985; Aario, 1990; Aario and Peuraniemi, 1992). Sandy layers or stone pavements exist sometime in the boundary between the units but more often the contact is hard to distinguish.
In places, the third, bluish grey till unit is also found in topographic depressions, like in between the bedrock tops. The till is clay-rich, matrix supported, compact and homogenous in structure deposited most commonly as basal, lodgement till. Unfortunately the surface of this till is at the level of 6-8 m from the top, so it is hard to reach during the studies. Different till units are seen in Half-Schlumberger sounding profile (Fig. 44) (see also Aario, 1990).

STOP 15. Potholes in Sukkularakka, southern Rovaniemi

Peter Johansson

In Finland the number of documented potholes is about 2,000. Most of them have been found in southern Finland, especially in the southern coastal region, where the bedrock is better exposed than anywhere else in the country. In northern Finland only a few potholes are known. Sukulanrakka, one of the best-known pothole areas in Finland and all of northern Europe is located about 20 km southwest of Rovaniemi (Fig. 45). On this hill 14 clearly distinguishable potholes shaped like churns or pots can be found, among them three centrally situated, remarkable large and deep ones.
Fig. 45. Map of the Sukulanrakka potholes in Rovaniemi. After Johansson and Kujansuu (2005).

The largest pothole is known among the local people as the "Devil's Soup Bowl". With its depth of 15.4 metres it is the largest pothole found in Finland. At the railing its diameter varies between 8.0 m at its widest and 5.7 m. The southern wall is almost completely missing due to quarrying by the glacier. The bottom of the pothole is normally covered by water. In the spring of 2002 it was pumped dry and cleaned and then two smaller potholes with a diameter of about 1.5 m were found on the bottom. Close to the largest pothole, in the hillside, there is another one with a depth of 8.7 m. It is called "Big Demon's Hide" and is oval in shape with a diameter of 6.4-3.6 m. Spirals can be seen in its well-polished rock walls. The third of the large potholes, "Bishop Hemming's Churn" (Fig. 46), lies northeast of the other two. It is a 10.1 m deep hollow, this one, too, with rifle-like spirals on its walls. At the bottom its diameter is 2.4 m and at its narrowest it is at the mouth, only 1.5 m. By the pothole you can see some rounded grinding stones found on its bottom.
The potholes of Sukulanrakka were formed during the last deglaciation, about 10,500-11,000 years ago, as the subglacial meltwater stream flowing northwest from the Muurola area towards Jokkavaara crossed the bedrock ridge of Sukulanrakka (see Fig. 38). At this ridge the highly pressurized meltwater stream formed eddies, which whirled around stones and finer sediment transported by the stream. Especially boulders loosened from the nearby diabase rock formed grinding stones, rounded and resistant to wear. As they rotated in the whirlpools, they bored into the rock on the tunnel floor, making potholes in it. The bedrock here contains cordierite-antophyllite rock, which is favourable to the formation of potholes, as it has low resistance to grinding. Potholes were formed until the glacier became thinner and the pressurized meltwater stream with its whirling water ceased. After the deglaciation, the potholes were partly filled with sediments and plant remains.

The Sukulanrakkka potholes are located in a small area of only about 0.3 hectares. The location forms a crossing point between the cordierite-antophyllite rock and the route of the glacial meltwater stream. Although the local people have known the place for centuries, it was not studied in detail until in the early 1960's. In times past, it was unknown how the potholes had actually formed. They were believed to be the work of giants, hence the fanciful names of the large potholes.

STOP 16. Ribbed moraines and the Weichselian stratigraphy in Vammavaara, Tervola
Pertti Sarala

Vammavaara is one of the highest hills (ca. 228 m a.s.l.) in southern Lapland (Fig. 47). It is smoothed on its edges and oval in shape indicating repeatedly glacial advances from the west-northwest towards the east. The hill is composed of quartzite, which is very resistive to glacial erosion. Its slopes are mainly covered with till although the washed stone fields on higher attitude as well as on lower levels on southern side are common. They represent shoreline development during the Ancylus Lake stage after deglaciation (Saarnisto, 1981). Only the top has been in a supra-aquatic position, while the highest shoreline reached ca. 220 m a.s.l. Furthermore, steep rock falls are characteristic for southern edge of the hill (upper part of the cover page) while the hilly topography is continuing to the north.
Ribbed moraine morphology is dominant on the southern side of the hill at the attitude of about 60–120 m a.s.l. (Fig. 48). The ridge morphology is consisted mainly of hummocky ribbed moraines and Rogen moraine types composed of three till units (Fig. 49). The lowest unit is a dark bluish grey till with a very dense package. The overall feature is a massive structure with some fissility or fine-grained laminae occurring in the upper parts of the unit. The matrix is composed of fine-grained sand and its clay content is relatively high (7%). Pebbles are rounded and composed of a wide variety of rock types mostly indicating long glacial transport from a north-northwest direction. Till fabric indicates the similar ice-flow direction (300°-330°). The second, sandy till unit was deposited under ice-flow from the west-northwest including lenses of bluish grey till. It has mainly composed of far-travelled debris. A massive structure with some fine-grained laminae and sand lenses indicates subglacial deposition, mostly as lodgement till. The upper till has a variable composition and structure. Fabric analyses showed that ice flowed from the west to the east. Contact between the till units is sharp.

The third, upper till unit is composed of sandy or gravelly matrix with a great portion of large angular boulders and pebbles. The composition of rock fragments is indicating local rock types in the underlying bedrock. The overall feature is often massive structure although fines layers and sandy lamination or flow structures are common. Stone orientation is usually unique with the second till unit, e.g. from the west to the east.

In western parts, glacial erosion was effective because a crescentic proximal trough (in Fig. 48) was formed (cf. Aario, 1977b). As a result, the glacier removed surface of the bedrock. The transported material was deposited into the ribbed moraine ridges on southern side of the Vammavaara hill so that the amount of fine-grained material decreases towards the east. In the western part, an intermediate layer of till material existed consisting of weathered bedrock that was fully composed of mafic volcanic rocks deriving from the bedrock only a few hundreds of meters to the east. The proportion of local rock fragments in the uppermost till and at the surface of the ridges was still characteristic of the ribbed moraines.
Fig. 48. Glacial morphology and test pit location in Vammavaara, Tervola. Digital elevation model, topographic features and roads © National Land Survey of Finland, permission number 62/LA/06.

Fig. 49. Composition stratigraphy of ribbed moraines in Vammavaara with lithofacies and pebble countings.
At the end of deglaciation, the presence of the water body of Ancylus Lake caused the till material released from the melting ice to be deposited as waterlain till or as washed sediments above earlier deposits. Also, some stratified sands and fine-grained sediments were deposited during the later fluvial stages (Fig. 50).

**Fig. 50.** Generalized cross-section over the western part of the Vammavaara area. Section is composed of sediments reflecting a whole deposition history during the Weichselian glaciation and followed Ancylus Lake and Litorina Sea stages. After Sarala and Rossi (2006).

**STOP 17. Sihtuuna moraines at Sihtuuna, Tervola**

Pertti Sarala

The Sihtuuna moraine was found northwest of the village of Tervola, southern Finnish Lapland (Fig. 51). The area of this moraine type covers about 10 km². Sihtuuna moraines are formed of ridges perpendicular to the latest ice-flow direction from the west to the east. Ridges are quite small in scale; commonly several hundreds of meters long, some tens of metres wide and from three to five metres high. 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.

The ridges are composed of several stratigraphical units (Fig. 52). 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.

The sorted sand deposit with planar bedding or small-scale cross-lamination exists above the bottommost till unit. For example, in test pit M124 beddings gently dip to the east (80°; dip 5°–10°) or the northeast (50°; dip 15°). The sand deposit (1–2 m thick) has been observed in many test pits. Stones are rare although some drop stones exist in the upper parts of the sediment unit. The uppermost part of the sand deposit is glacially deformed and includes, for example, glaciitectonic shear planes and faults. Planar bedding and small-scale cross lamination gives an impression of a restful meltwater stream discharging into the deep water-body. This formation is interpreted as a glaciofluvial delta, which was deposited during the short standstill of the glacier margin in its retreat stage (Sarala (2005c)).
The second till unit follows sands in succession. The matrix of this till unit is sandy or even gravelly, although the composition and structure are heterogeneous; many sandy lenses and layers together with fine-grained laminae occur (Fig. 53). The lenses and layers typically include glaciotectonic deformation structures like shear planes and faults. In some thicker lenses the involution structures caused by cryoturbation were found (Sarala, 2005c). These features are typically formed under periglacial conditions (cf. Lagerbäck, 1988). They cannot have formed after the Late Weichselian, because the area was submerged thousands of years after deglaciation. Also, during the Holocene the climate did not favor the formation of those structures. In many test pits, the uppermost part of the second till unit is composed of a gravelly, stratified sediment layer or gravelly, pebble rich till material.
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. When the 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. If material is gravelly, massive in structure and mainly clast-supported, it can be the shore deposit of the Ancylus Lake stage. The great amount of local boulders both in the uppermost unit and at the surface is a reminder of relation to ribbed moraines.

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. 54). 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 favors quarrying (cf. Aario and Peuraniemi, 1992; Sarala and Rossi, 1998, 2000, 2006), the sandy material in 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 more narrow 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 (2005c) 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.
STOP 18. Ancient shore deposits of the Ancylus Lake in Sorvasvaara, Tervola

Peter Johansson

Raised littoral formations have been an important target of research in attempts to unravel the history of the Baltic Sea. By mapping the area in which raised beaches occur, it has been possible to establish the extent and elevation reached by the waters of the Baltic Sea basin at different times and in different areas. The elevations of the raised beaches have been used in attempts to determine the varying rates of uplift (Saarnisto, 1981).

The Tervola area deglaciated ca. 10,300 years ago. The boulder field on Sorvasvaara hill (Fig. 54) was formed during the Ancylus stage ca. 9,800-9,500 years ago. The Ancylus Lake stage started when the great body of fresh water was impounded in the Baltic Sea basin above the ocean level. This resulted in a rapid rise in water level marking the onset of the Ancylus transgression at about 9,600 B.P., inundated vast areas of land on the coast of the Gulf of Bothnia (Fig. 55). However, uplift was so rapid that the water level continued to fall there throughout the Ancylus Lake stage (Fig. 56).

The summit of Sorvasvaara hill, at 109 m, is below the highest shoreline of the Baltic Sea, which would be at 215 m in this area. That is the reason why there is no till untouched by waves but rock and rubble left behind when the fine materials were transported to the lower slopes. On the southwestern, southern and southeastern slopes the boulder fields are well formed and clear. They continue as coherent layers down to the 140 m level and as an uncoherent cobble or boulder belts to...
the 120 m level (Johansson et al., 2000). The boulder belts are washed by waves and formed through the action of breakers and the thrust of the ice cover in winter. On the lower slopes there are beach ridges, which are littoral formations of cobbles, gravel and sand heaped up into mounds by the action of waves. The more forceful the action of the waves the coarser is the material.

Fig. 54. Ancient shore deposits of the Ancylus Lake in Sorvasvaara, Tervola. Photo R. Aario.

Fig. 55. Recession of the margin of the glacier in northern Finland towards the end of last glaciation. 1 = position of the ice margin, 2 = areas covered by ice-dammed lakes and 3 = Ancylus Lake. After Johansson and Kujansuu (2005).
STOP 19. Interstadial peat deposit at Kauvonkangas, Tervola

Kalevi Mäkinen

The glaciofluvial ice-marginal formation at Kauvonkangas, in Tervola, is covered by a till layer up to 2.5 m thick (Mäkinen, 1979). Beneath the till layer there is a peat layer, which was exposed in the section for 25 to 30 meters, but the same horizon with the organic constituents mixed with the till could be traced north of the section for at least 100 metres.

The stratigraphy of the Kauvonkangas section is following (Mäkinen, 1979). Uppermost in the section is a littoral deposits 1.0 m thick (Fig. 57), beneath which is up to 2.5 m bed of streaky grey-brown sandy till containing well-rounded stones shown by stone counts to have been transported to
the site from a considerable distance. Below this till bed is a 0.2-0.5 m horizon of deformed grey sand, which increases in organic content from the top downwards, at the same time as darkening somewhat in colour. Beneath this is a peat deposit of thickness 0.1-0.3 m. Immediately below the peat, there is a grey silt horizon of 0.2-0.6 m, which is followed by up to 1.0 m of brown sand and gravel. Below the glaciofluvial deposits there is a 1.8 m bed of tightly compacted grey till with a high stone content, the stones having been transported over a relatively short distance. This till bed lies on some 3 m of glaciofluvial gravel, under which is a further bed of relatively well compacted grey till 2.5 m thick. Borings and seismic soundings indicate that the bedrock surface is reached at a depth of 12 m.

Till fabric analysis show that the uppermost till was formed when ice flowed from west (280°), which corresponds to the flow stage II in western Lapland (Hirvas, 1991). The middle till bed has an orientation of 340°, which corresponds to the flow stage III (Hirvas, 1991). No till fabric analyse have been made from the lowermost till, because it has been met only in borings.

Initially in the pollen flora of the deposits from Kauvonkangas (Mäkinen, 1979), birch accounts for 85-95% of tree pollen and some 55-75% of all pollen. In a later more detailed analysis of four samples from Kauvonkangas peat deposits, concentrations of Betula tree pollen and Betula nana pollen were assessed separately. The total proportions of Betula tree pollen were 0-35% of all pollen, while Betula nana accounted for 8-31% of all the pollen (Fig. 58). In the lowest parts of the peat, all of the birch pollen consisted of Betula nana. In the upper layers of the deposits, the proportion of birch tree pollen rose to 35%. The proportion of Betula nana pollen was highest in the middle of the peat deposits, and declined to 8% higher up. The pollen flora also contained notable amounts of Cyperaceae herbs (38-60%) and Salix willows (12-13%). Pollen flora analyses of the Kauvonkangas Interstadial, a type locality for Peräpohjola Interglacial, indicate the presence of willow stands and dwarf birch heaths, as well as watery, sedge-dominated mires and grasslands (Eriksson, 2005).

The first 14C dating result from the peat layer at Kauvonkangas gave an age of >49,000 years BP (Su-657) and later new samples from the same peat layer gave ages of 48,000 +4,100/-2,400 (Su-688) and 48,100 +3,500/-2,400 years BP (Su-689).

![Kauvonkangas, Tervola](image)

**Fig. 58.** Pollen analyses from Kauvonkangas Peat (anal. B. Eriksson).
The ages of the peat samples from Kauvonkangas obtained using the U/Th method are fairly random, since the samples came from an open geochemical system. The peat deposits at Kauvonkangas are covered by thin layers sandy littoral deposits and sandy till, through which water can seep into the peat. Although these peat deposits have been dated at 92 ka old (Geyh, pers. comm. 1990), with corrective coefficients allowing for an age range of 80-100 years (Heijnis, 1992), this author would prefer to disregard these results, since they are too unreliable.

The samples from Kauvonkangas deposits were submitted also to TL and OSL dating. The sand sample above the peat layer gave TL age 55 ka. The silt sample beneath the peat layer gave TL age 74 ka and the sand sample 120 ka (Punning and Raukas, 1983). Ages obtained through OSL dating indicate that the age of sand layer above the peat is 57 ka and the sand layer beneath the peat 66 ka (Mäkinen, 2005).

When based on a larger amount of dating results (Fig. 59) from interstadial localities in western and southern Lapland the Peräpohjola Interstadial and its type locality Kauvonkangas is correlated with MIS 3 (Mäkinen, 2005). Till bed II, which overlays the dated organic and sorted deposits, was deposited during the Late Weichselian (MIS 2). Till bed III, which lies beneath these deposits, is older than MIS 3, and was deposited during either the Middle (MIS 4) as proposed in model 2 by Sarala (2005d) or the Early Weichselian (MIS 5d) as proposed by Hirvas (1991). If till bed III was deposited during the Middle Weichselian, this would mean that the Eem Interglacial and the possible subsequent interstadials of the Early Weichselian form an uninterrupted continuum, during which SW Lapland remained free of ice until the beginning of MIS 4.

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**Fig. 59.** Ages obtained through $^{14}$C, TL and OSL dating from SW Lapland compared with the deep sea isotope curve (Martinson et al. 1987). Symbols 1 = finite $^{14}$C age, 2 = infinite $^{14}$C age, 3 = TL age and 4 = OSL age. Chronostratigraphy in Finnish and Swedish Lapland after Hirvas (1991) and Lagerbäck and Robertsson (1988).
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