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Pertti Sarala and Juha Pekka Lunkka

Glacial geology field course in the central part of the Fennoscandian Ice Sheet: Field course guide. The 3rd PalaeoArc Conference in Finland, August 21-22, 2022. University of Oulu

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Cover Figure:

Till-covered esker in Liakka, southwestern Lapland
Photographer: Pertti Sarala

FIELD COURSE GUIDE

GLACIAL GEOLOGICAL FIELD COURSE IN THE CENTRAL PART OF THE FENNOSCANDIAN ICE SHEET

3RD PALAEOARC CONFERENCE IN FINLAND, AUGUST 21.-22. 2022

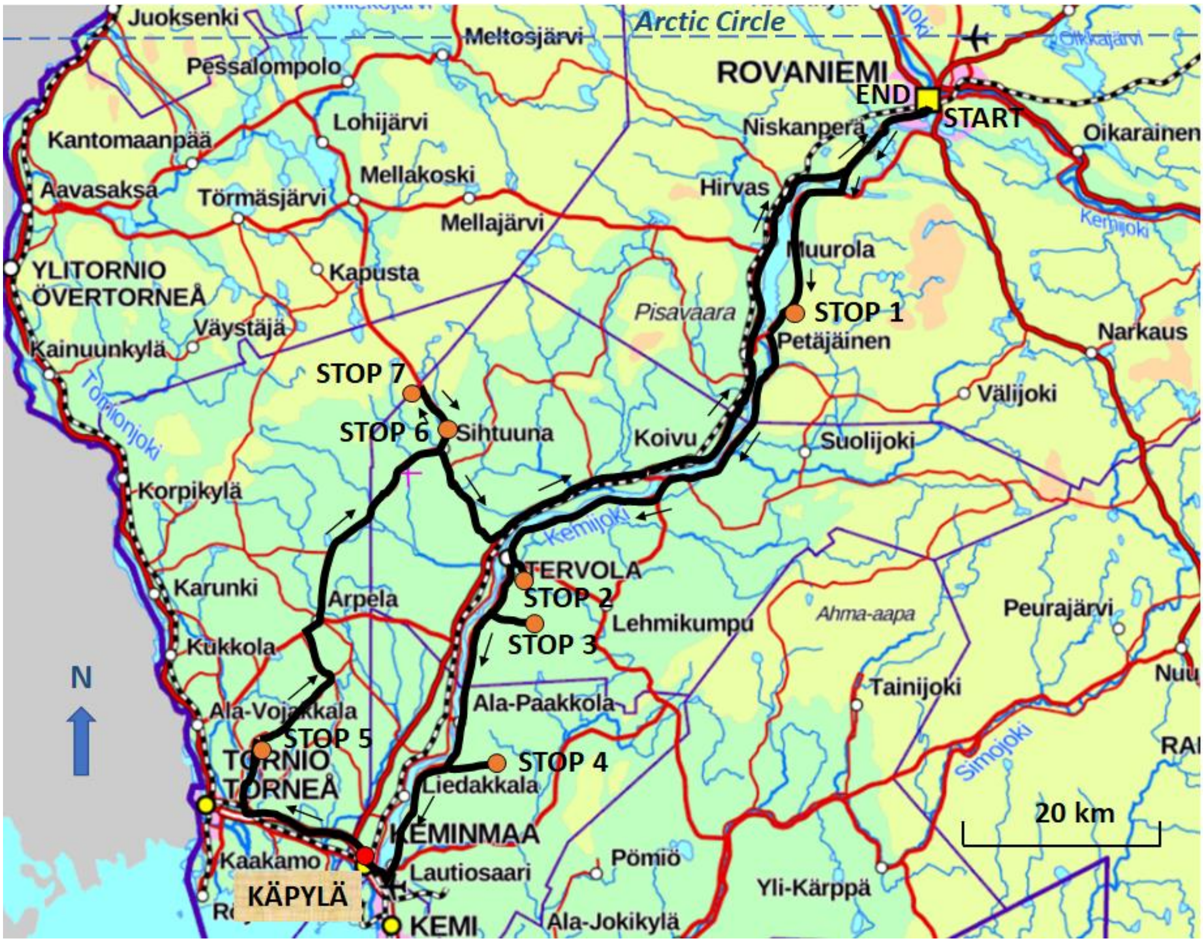
EDITED BY
PERTTI SARALA AND JUHA PEKKA LUNKKA

ORGANIZERS:

OULU MINING SCHOOL AND UNIOGS, UNIVERSITY OF OULU

FIELD COURSE ROUTE AND STOPS

A map of the field course route in the South-Western Finnish Lapland on August 21-22, 2022, with the locations of the stops 1-7, and the accommodation hotel Käpylä, Keminmaa.



CONTENT

SOUTH-WESTERN LAPLAND REGION

GLACIAL MORPHOLOGY AND STRATIGRAPHY IN SOUTHERN FINNISH LAPLAND

Pertti Sarala

Both elements, parallel and transverse to the past ice flow directions, exist in the glacial morphology of southern Lapland area. The active ice eroded bedrock and deposited subglacial landforms. The erosional subglacial forms, like rock drumlins and large, streamlined hills, indicate a dominant glacial flow from the west to the east. The active subglacial ice forms like transverse ribbed moraines are the most dominant landforms in the area (Fig. 1). Ribbed moraines exist as uniform fields in lowland areas and are mainly composed of Rogen moraine or hummocky ribbed moraine types (cf. Hättestrand, 1997; Sarala, 2003) (Fig. 2). In addition, a small-scale ribbed moraines occur in a small area at Sihtuuna (cf. Aario et al., 1997; Stop 6). Ribbed moraines together with drumlins and flutings form an active ice morphology assemblage indicating changes in compressive and extensional stresses in subglacial environment during ice flow over the area (e.g. Aario, 1977a, 1990; Lundqvist, 1969, 1989). Only the quartzite hills or hill areas occurring transverse to the general glacial flow break the uniformity of the ribbed moraine and drumlin field areas.

The ice-lobe system formed during the latest ice-retreat phase is clearly seen in the glacial morphology. Based on the interpretation of glacial landforms, there were two active ice lobes, i.e. Kuusamo and Oulu ice lobes in the area during the last deglaciation and one passive ice flow area, so-called Ranua Interlobate area. Drumlin – ribbed moraine associations indicating active ice-flow occur in the Kuusamo Ice-lobe area and in the southern part of the Kuusamo Ice-lobe (Fig. 1). Similar associations can also be seen in the Oulu Ice-lobe area where the last active ice-flow was towards the east. Between the active lobes, the Ranua Interlobate area the older northwest-southeast oriented drumlin morphology around Ranua, south to the Kivalot hill chain and Portimojärvi area have been preserved due to less active ice flow during the latest ice-retreat phase. Meltwater streams were followed the lobate structure including some larger channel systems like the one in the area of Korouoma valley (Fig. 1).

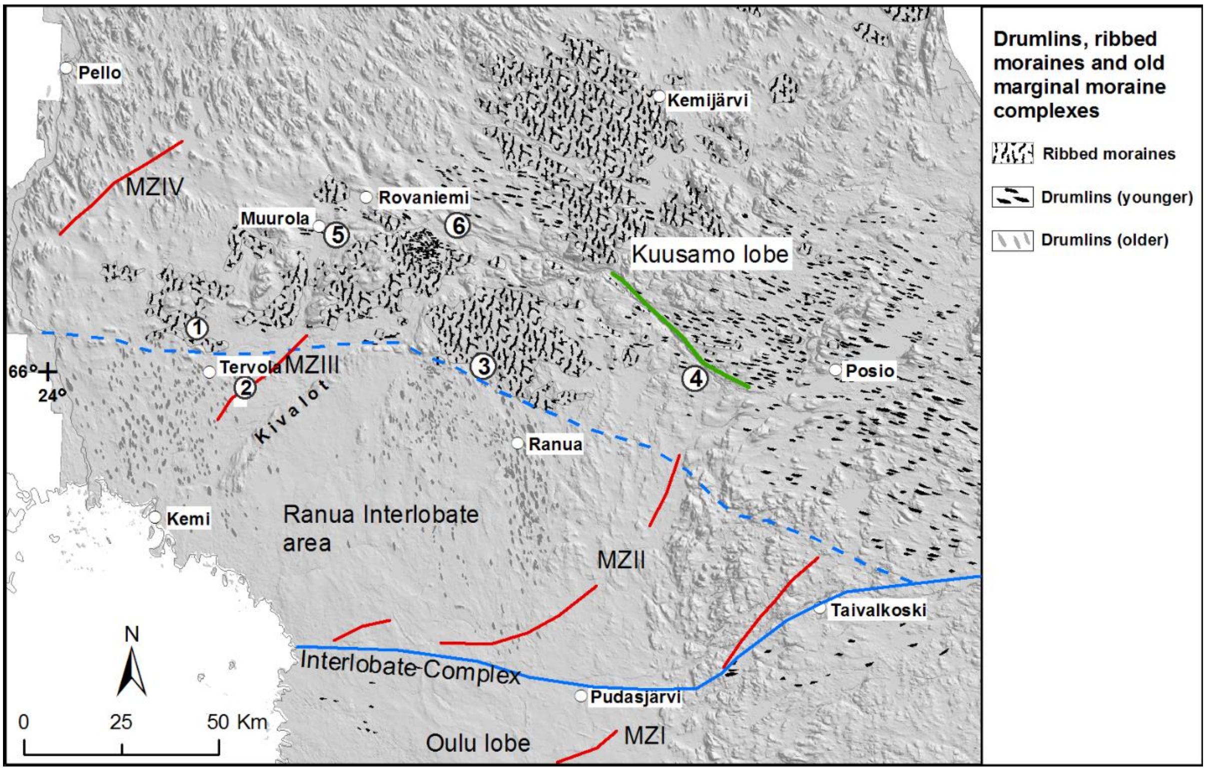


Fig 1. The occurrence of drumlins, ribbed moraines, old marginal zones MZI-MZIV (red) and Pudasjärvi-Taivalkoski-Hossa Interlobate Complex (blue) in southern Finnish Lapland. The places mentioned in text are: 1) Sihtuuna, 2) Kauvonkangas, 3) Portimojärvi, 4) Korouoma Valley Complex (green), 5) Sukulanrakka and 6) Jokkavaara. Digital elevation model © National Land Survey of Finland.

Fig. 2. Ribbed moraine ridges in Petäjäskoski, western Rovaniemi. Ice-flow has been from west to east (upper left corner to right down). Photo R. Aario.

The Quaternary lithostratigraphy of southern Finnish Lapland consists of three till beds and two inter-till, stratified minerogenic sediment layers containing organic material in places, and is proposed to be named as the *Peräpohja Group* (Sarala, 2005b, c; Table 1).

Table 1. Quaternary lithostratigraphy, unit descriptions and formal names in Rovaniemi-Tervola area. A whole stratigraphic sequence is proposed to be named as the Peräpohja Group. After Sarala (2005c).

Formation	Member	Depth	Description	Interpretation	Chrono-stratigraphy	Type section
Suolijoki Formation		0.5 - 2 m	Stratified sand and gravel	Shore deposit	Holocene	N7345.5 I2561.5 M118, Vammavaara
Tervola Till Formation	Korttelivaara Till Member	0.1 - 1.5 m	Brownish grey sandy diamict	Melt-out, flow or waterlain till	Late Weichselian	N7334.0 I3444.6 M90, Korttelivaara
	Petäjävaara Till Member	1 - 3 m	Brownish grey or grey gravelly diamict	Lodgement or basal melt-out till		N7358.5 I2564.1 M1, Petäjävaara
	Vammavaara Till Member	1 - 4 m	Grey sandy diamict	Lodgement till		N7346.2 I2561.2 M25, Vammavaara
Sihtuuna Sands		1 - 2.5 m	Horizontally or cross bedded sand	Subaquatic fan	?	N7344.6 I2529.6 M124, Sihtuuna
Kemijoki Till Formation		1 - 2 m	Bluish grey, compact sandy/silty diamict	Lodgement till	Early or Middle Weichselian	N7345.9 I2562.2 M21, Vammavaara
Saarenkylä Gytja		2 - 3 m	Organic gytja, silt and sand	Lacustrine or marine deposit	Eem Interglacial or Early Weichselian	N7382.5 I3447.6 Saarenkylä (Sutinen 1992)
Saarenkylä Till Formation		> 1 m	Grey, compact sandy diamict	Lodgement till	Saalian	N7382.5 I3447.6 Saarenkylä (Sutinen 1992)

The lowermost till unit, Saarenkylä Till, correlative with Till Bed IV after the nomenclature of Hirvas (1991) is interpreted as being deposited during the Saalian Stage. The Saarenkylä Gyttja is thought to have been deposited either during the Eemian Interglacial (Sutinen, 1992) or possibly during the Early Weichselian Interstadial. Kemijoki Till above is known as dark till in literature (e.g. Ber and Kujansuu, 1974; Kujansuu et al., 1982) and is correlative with Till Bed III of Hirvas (1991). It has been deposited during the first Weichselian glaciation that covered the southern Finnish Lapland area. The Sihtuuna Sands stratigraphically above the Kemijoki Till represents an ice-free interstadial phase of the Middle Weichselian substage. The Tervola Till Formation including members of Vammavaara Till, Petäjävaara Till and Korttelivaara Till represents the Late Weichselian glaciation including the till units from an ice-advance phase to a 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 in 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) for the first time during the Middle Weichselian. The marginal formations in the Pudasjärvi area and from there to northeast (MZI-MZIV in Fig. 1) deposited during the melting phase. Series of marginal deposits described by Sutinen (1992) is now completed with a fourth zone MZIV in Fig. 1), which runs through the Kauvonkangas ice-marginal formation (Fig. 1). An interstadial in the Middle Weichselian (MIS 3) age-bracketed to 40-55 ka with C-14, OSL and TL (the Peräpohjola Interstadial described by Korpela in 1969) confirms that the ice-free interval(s) existed in Lapland during the Middle Weichselian (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 descriped 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 over the 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 lowermost 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. 3). 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 new-born 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.

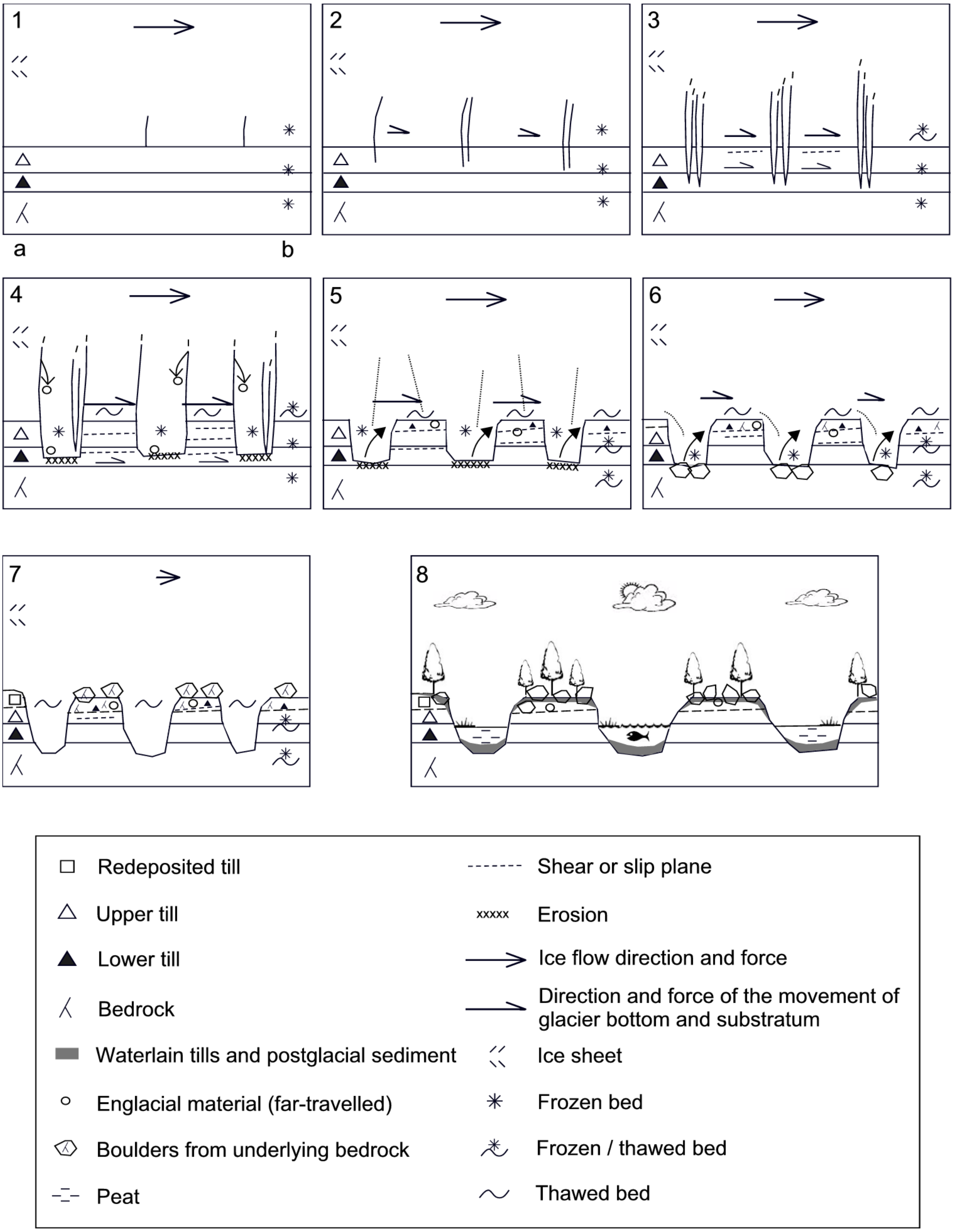


Fig. 3. Ribbed moraine formation because of subglacial fracturing, mass movement and followed quarrying. Variable pressure conditions under moving ice sheet initiated the freeze-thaw process that caused the subglacial quarrying and deposition of local bedrock material on the ridge tops. After Sarala (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 indicate that ribbed moraines are depositional features.

Sarala (2005b, 2006) represented that quick and strong decrease of the air temperature and the subsequent imbalance between the surface and the base of the ice sheet might be the most suitable moment for the beginning of ribbed moraine formation in the early stage of deglaciation at the end of Younger Dryas. 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 hundred 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 sheets 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 mineralization 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 to 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. 4).

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.

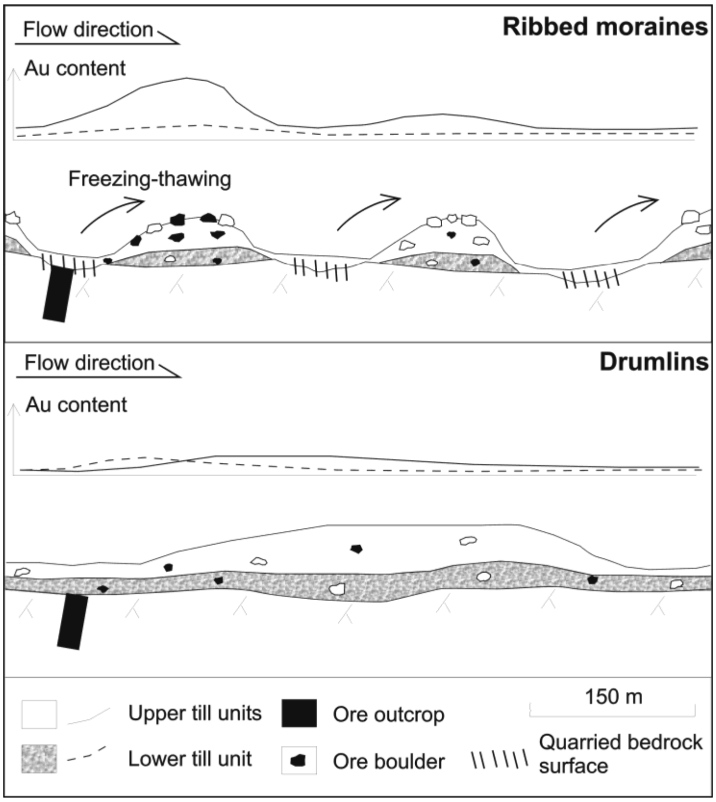


Fig. 4. A comparison of geochemical properties between ribbed moraines and drumlins. After Sarala and Nenonen (2005).

FIELD COURSE STOPS IN THE SOUTH-WESTERN FINNISH LAPLAND AREA

STOP 1. RIBBED MORAINES AND THE WEICHSELIAN STRATIGRAPHY IN PETÄJÄVAARA, ROVANIEMI

Pertti Sarala

Petäjävaara is one of the highest hills (ca. 220 m a.s.l.) in southern Lapland, almost as high as the Vammavaara Hill about 15 km to south (Fig. 5). It is smoothed on its edges and oval in shape indicating repeated 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 attitudes as well as on lower levels on southern side are common. They represent shoreline development during the Ancylus Lake stage of the Baltic Basin after the last deglaciation (Saarnisto, 1981). Only the small area on 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 and western slopes of the hill while the hilly topography is continuing to the east.

Fig 5. Oblique aerial photograph from the Vammavaara Hill with a view is towards the NW. The forested area on the top of hill is preserved over the highest shoreline of the Ancylus Lake after deglaciation. Photo R. Aario.

Ribbed moraine morphology is dominant on the western side of the hill at the attitude of about 60–110 m a.s.l. (Fig. 6). The ridge morphology is consisted mainly of hummocky ribbed moraines and Rogen moraine types composed of three till units (Fig. 7). 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 is mainly composed of long-distance 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 show that ice flowed from the west to the east. The lower contact between the till units is sharp.

The third, upper till unit has sandy or gravelly matrix with abundant large angular boulders and pebbles. The composition of rock fragments is indicating local rock types in the underlying bedrock. The overall appearance of the unit is often massive although silt and clay 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 the low elevation areas, close to river channel, glacial erosion was effective against the hill slope. As a result, the glacier eroded and removed the surficial part of the bedrock. The transported material was deposited into the ribbed moraine ridges on western side of the Petäjävaara Hill, so that the amount of fine-grained material decreases towards the east. The high proportion of local rock fragments in the uppermost till and at the surface of ridges was characteristic to the ribbed moraines.

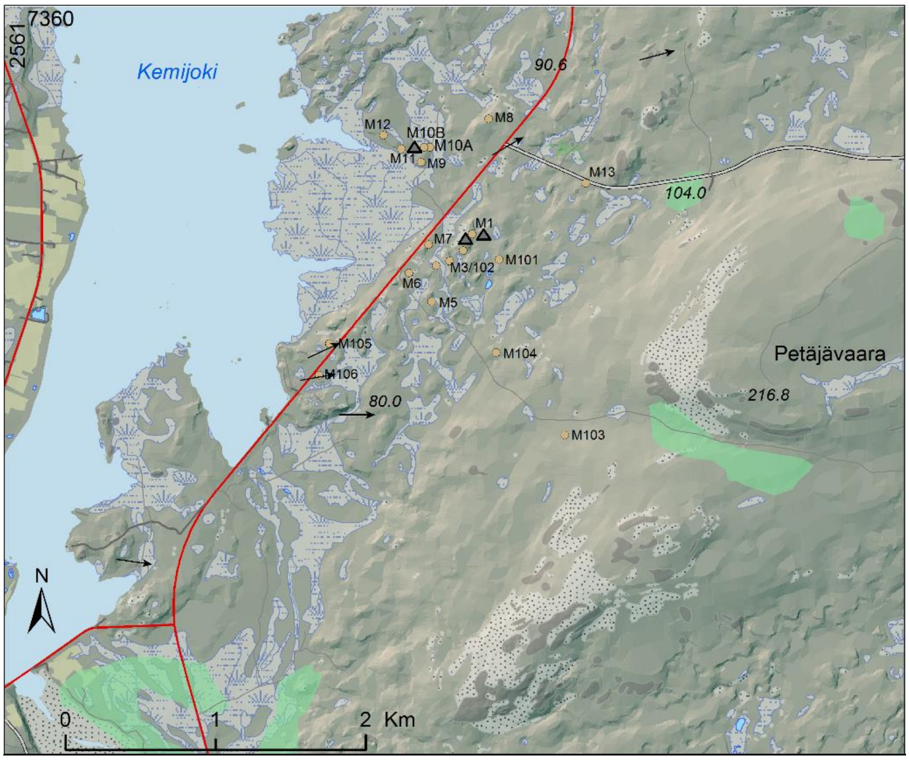


Fig. 6. Glacial morphology, striae observations and test pit location in Petäjävaara, Rovaniemi. Digital Elevation model, topographic features and roads © National Land Survey of Finland.

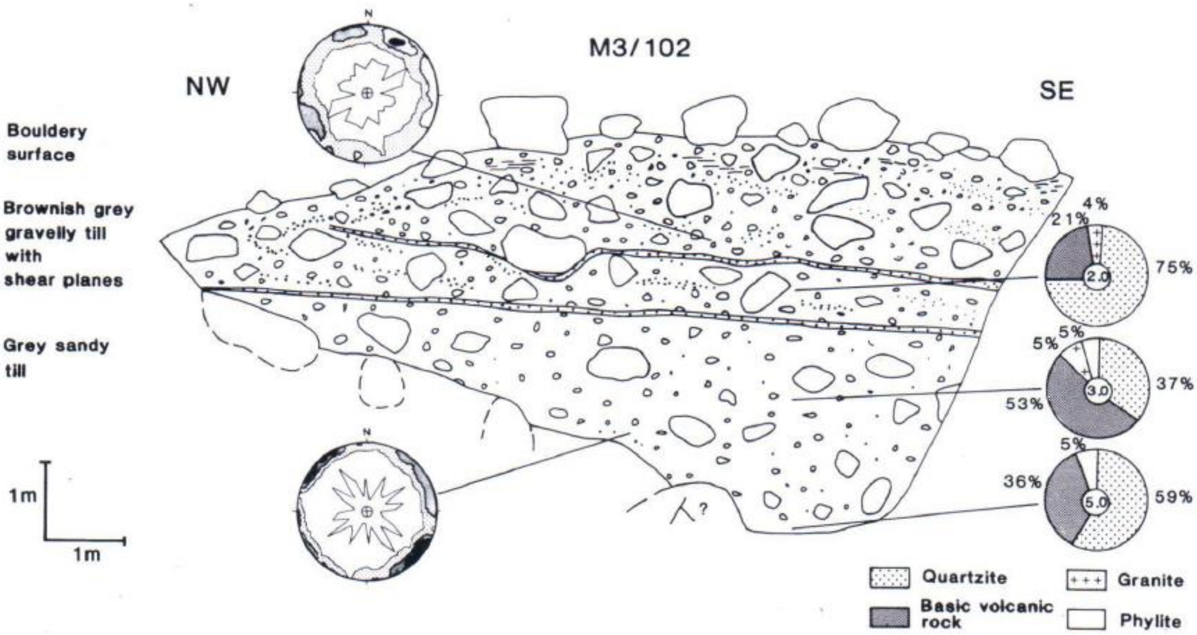


Fig. 7. Composition stratigraphy of ribbed moraines at Petäjävaara with lithological unit descriptions and pebble counts. After Sarala and Rossi (2000).

STOP 2. KAITAHARJU ESKER WITH A INTERNAL TILL UNIT AT TERVOLA

Juha Pekka Lunkka and Pertti Sarala

Subglacial, glaciofluvial esker ridge is located on the eastern side of the centre of Tervola municipality and is oriented almost N-S direction (Fig. 8). Although in places it has a typical ridge-type shape of an esker with steep slopes, in other places it almost disappears and has flat, smoothed surface covered by a diamicton layer.

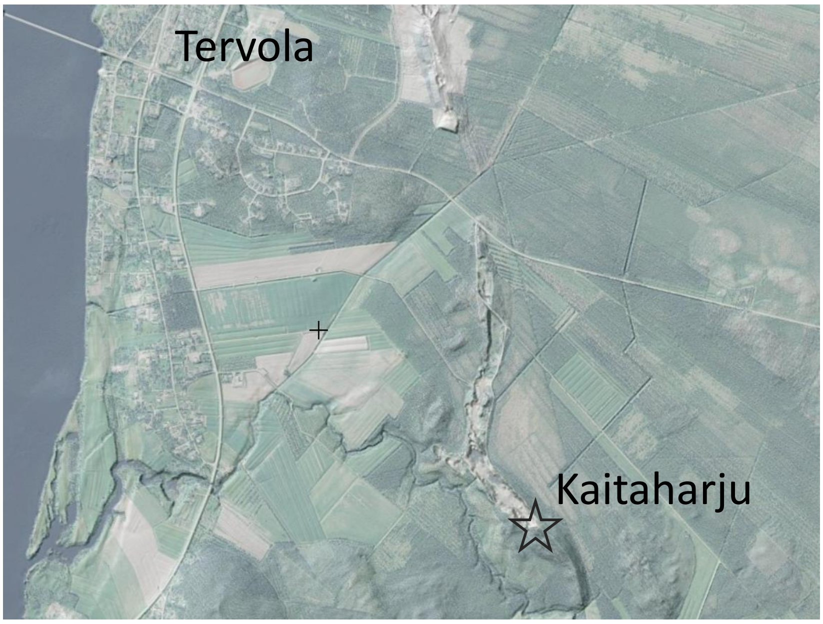


Fig. 8. Orientation of the esker ridge on the eastern side of the Tervola centre and the location of the target section. Background map and elevation model © National Land Survey of Finland.

The Kaitaharju esker has been under intense sand and gravel quarrying during decades, and most of the formation has been dug away. The esker is dominantly composed of stratified sediments including coarse to fine sand cross-bedded layers, gravelly and even bouldery inter-layers and silty diamicton inter-layers (see Fig. 9). Furthermore, shallow sandy or gravelly diamicton layer is also seen on the top of ridge.

Fig. 9. Cross-section of the Kaitaharju esker in eastern side of Tervola. Red line is indicating the location of bouldery till layer inside the esker ridge. Photo P. Sarala.

Orientation of the esker ridge (N-S) is transverse to the latest ice flow direction (W-E). The presence of diamicton layers both as inter-layers and as cover material indicates variable depositional conditions during the formation of esker formation. Stratified sands and gravels as well as boulder layers indicate glaciofluvial deposition in subglacial tunnel with high water stream velocity, and diamicton layers are deposited a) during subglacial conditions at the same time with the stratified sediments deposition, but b) also afterward due to glacier advance phase. Transverse orientation parallel to old drumlin field, erosional or reshaped features over the esker ridge and till cover are the evidence the esker was deposited prior to the last deglaciation.

STOP 3. INTERSTADIAL PEAT DEPOSIT AT KAUVONKANGAS, TERVOLA

Juha Pekka Lunkka and Pertti Sarala

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.

According to Mäkinen (1979), the stratigraphy of the Kauvonkangas section from the ground surface to the base of the 12 m sediment sequence is as follows (Fig. 10):
Unit 1: 1.0 m thick sand and gravel unit (interpreted as a littoral deposit). - Unit 2: Up to 2.5 m thick bed of streaky grey-brown sandy till containing well-rounded stones. Stone counts (lithology) indicate that stones in till have been transported to the site from a considerable distance. - Unit 3: 0.2-0.5 m thick horizon of deformed grey sand, which increases in organic content from the top downwards, at the same time as darkening somewhat in colour. - Unit 4: 0.1-0.3 m thick peat layer.

Unit 5: 0.2-0.6 m thick grey silt horizon. - Unit 6: Up to 1.0 m thick brown sand and gravel (interpreted as glaciofluvial sand and gravel). - Unit 7: 1.8 m thick bed of tightly compacted grey till with a high stone content, the stones having been transported over a relatively short distance. Unit 8: 3 m thick unit of glaciofluvial gravel. - Unit 9: 2.5 m thick bed of relatively well compacted grey till. Coring and seismic soundings indicate that the bedrock surface lies at the depth of 12 m.

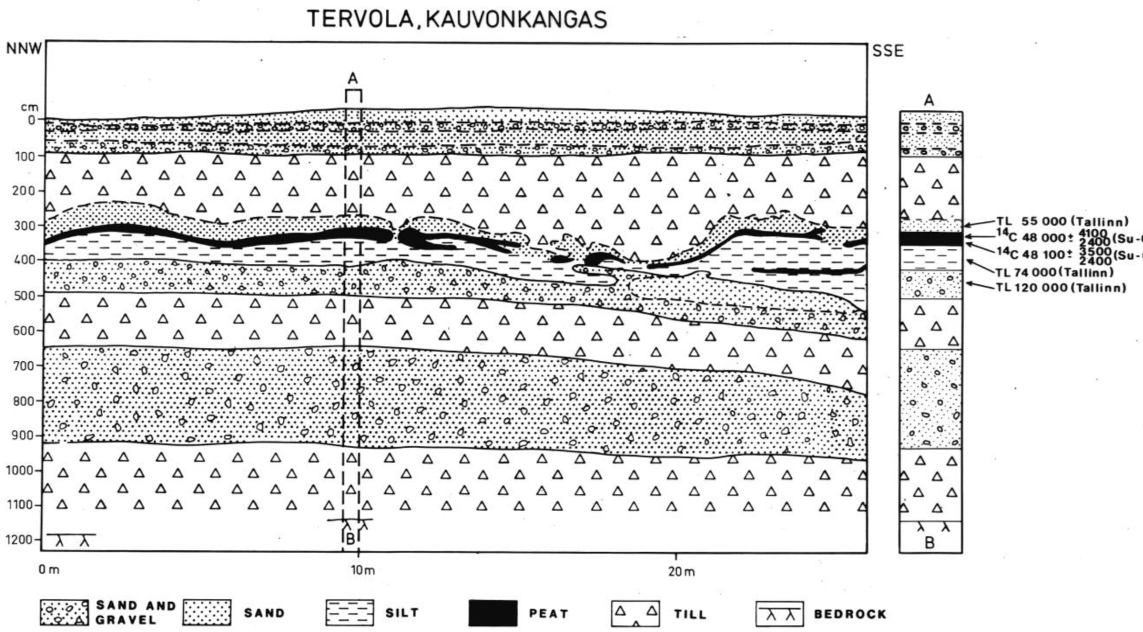


Fig. 10. The stratigraphy of the Kauvonkangas section (Mäkinen, 1979).

Till clast 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 clasts in the middle till bed has a preferred a-axis orientation of 340°, which corresponds to the flow stage III (Hirvas, 1991). No till clast fabric analyses have been made from the lowermost till because it has been met only in borings.

Initially the pollen content of the Kauvonkangas interstadial deposits (Mäkinen, 1979) show that birch accounts 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. 11). In the lowest parts of the peat unit, 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 Interstadial, indicate the presence of willow stands and dwarf birch heaths, as well as watery, sedge-dominated mires and grasslands (Eriksson, 2005).

The first ^{14}C 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).

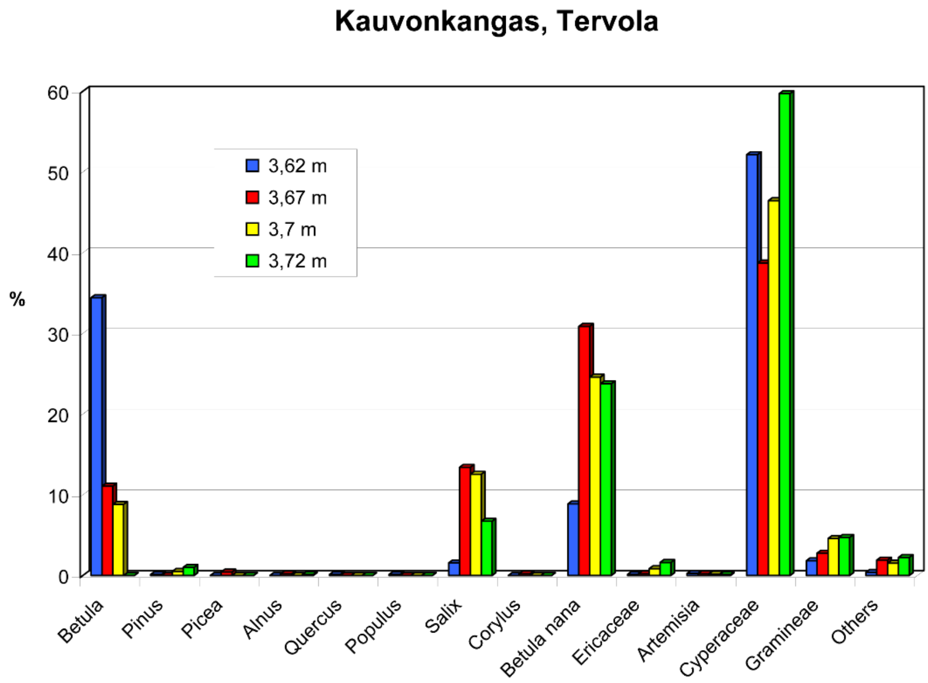


Fig. 11. Pollen analyses from Kauvonkangas Peat (anal. B. Eriksson).

The ages of the peat samples from Kauvonkangas obtained using the U/Th method are 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 a larger amount of dating results (Fig. 12) from interstadial localities in western and southern Lapland the Peräpohjola Interstadial and its type locality Kauvonkangas is considered and placed into the regional stratigraphic context the Kauvonkangas interstadial beds can be correlated with MIS 3 as earlier suggested by 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.

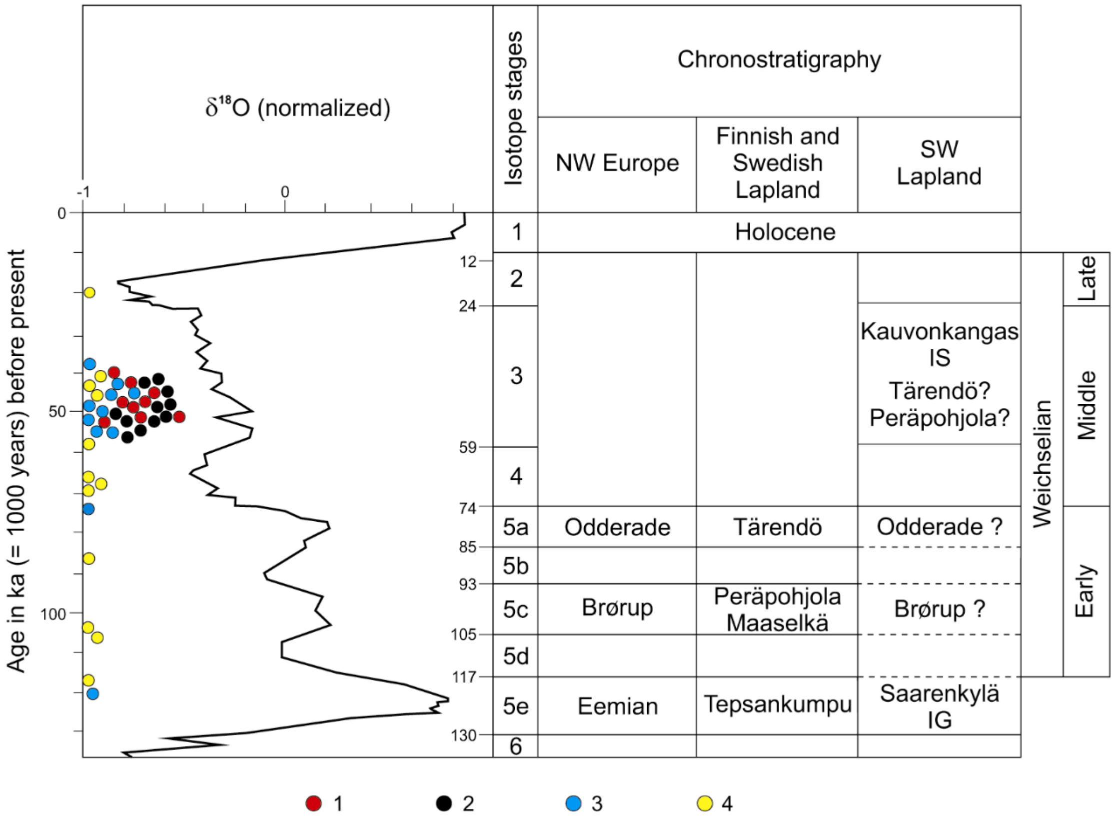


Fig. 12. Ages obtained using ^{14}C, TL and OSL dating methods from SW Lapland compared with the deep-sea isotope curve (Martinson et al. 1987). Symbols 1 = finite ^{14}C age, 2 = infinite ^{14}C age, 3 = TL age and 4 = OSL age. Chronostratigraphy in Finnish and Swedish Lapland after Hirvas (1991) and Lagerbäck and Robertsson (1988).

STOP 4. MIDDLE WEICHSELIAN DRUMLINS IN SAAVANPALO, KEMINMAA

Juha Pekka Lunkka and Pertti Sarala

Glacigenic landforms in the south-western Finnish Lapland are dominated by the N-S south oriented drumlins which form large field in the Kemijoki River valley and in the Ranua region (Fig. 1). In the eastern part of the Ala-Paakkola Village drumlins are well seen in the topography. Drumlin hills are relatively flat and at many places slightly smoothed and protruded towards east indicating later glacial movement from west to east over the pre-existing drumlin field. At the same time, the esker formations were also reshaped and covered by younger, Late Weichselian till unit (see Stop 5). Due to subaquatic position and later wave action during the lower water body phase of the Litorina Sea (the early phase of the present Baltic Sea), upper parts of the drumlins were partly reshaped and covered by shore deposits. Thise type of sediments and landforms can be seen in the Saavanpalo area (Fig. 13).

Fig. 13. Old, N-S oriented drumlin field in the Ala-Paakkola region.

STOP 5. LIAKKA – TILL COVERED MID-WEICHSELIAN GLACIOFLUVIAL SYSTEM

Pertti Sarala and Juha Pekka Lunkka

While studying Quaternary geomorphology, sedimentology and stratigraphy in southern Finnish Lapland many till-covered, stratified sand deposits were observed. Many of them are northwest southeast oriented esker formations, obviously from the Early or Middle Weichselian. Some deposits are interpreted to include glaciolacustric delta or shore deposits, which should be suitable for luminescence dating purposes due to excellent bleaching of minerogenic material under sunlight. For estimating the age of those sediments, samples were collected and analysed in the Dating Laboratory of the University of Helsinki using OSL method. Study areas lie in southwestern Lapland including several targets: Liakka, Sihtuuna and Sompujärvi (Fig. 14).

The Liakka study area includes two old sand/gravel pits (Pyöreäkumpu and Rantamaa, Fig. 15) that have been sedimentologically studied and dated. The glacial morphology of the Liakka area is mainly composed of a northwest southeast oriented drumlin field, which is a relic of the earlier glacial phase of the Weichselian glaciation. The Late Weichselian ice sheet has covered the area, but the glacial erosion has been weak and only slightly smoothed the ground. Because the cold-based centre of the glacier situated over the area during the Late Weichselian maximum and deglaciation, the glacial erosion was only modest preserving older morphology. During the latest phase of deglaciation, thin till sheet, about 1-2 metres thick, was deposited over the pre-existing tills and stratified sediments when glacier melted away.

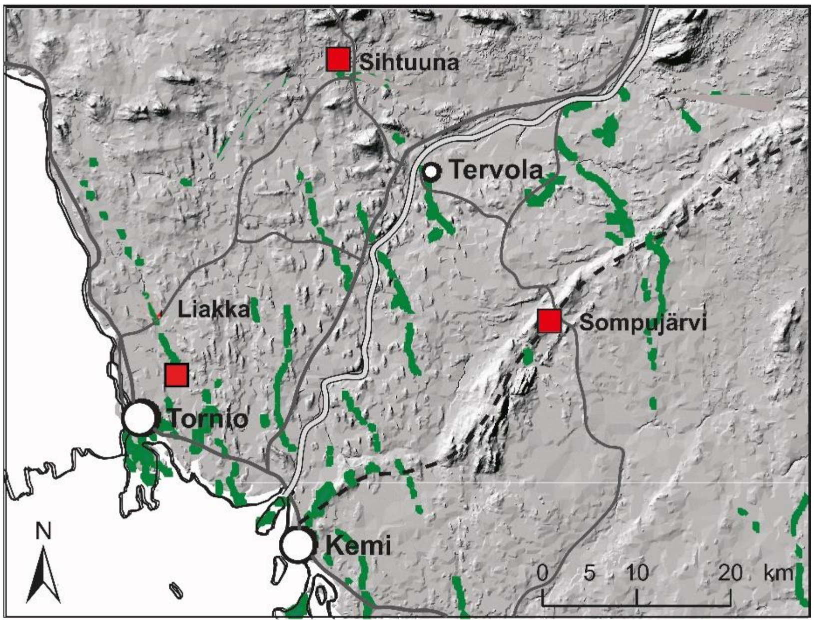


Fig. 14. Location of Liakka, Sihtuuna and Sompujärvi study sites on the DEM map. Map shows also almost N-S oriented Middle Weichselian drumlin field and till covered esker chains (green).

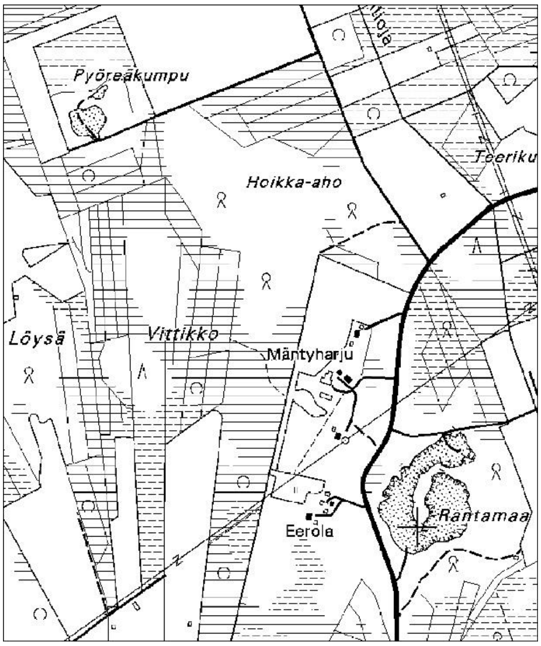


Fig. 15. Location of two studied sand pits, Pyöreäkumpu and Rantamaa in Liakka.

In the Liakka area, NNW oriented gravelly and sandy formation occur where the thickness of stratified sediments is over five metres. In Pyöreäkumpu, glacially deformed planar or cross bedded sands were found under two metres thick basal till cover (Fig. 16). OSL samples were collected in 2005 on the upper part of the sand deposits. In Rantamaa, core parts of the sedimentary sequence are composed of coarse gravels indicating large cross/planar bedding with some indication of sediments fining upwards (Fig. 17A, 17D). Cross and planar bedding, ripple marks (Fig. 17B) and graded bedding, different interlayers (fine sediments and gravels) indicate glaciofluvial deposition environment typical for esker system. Deformation of the stratified sediments is moderate including some shear structures and small faults and catchment/injection structures (e.g., Fig. 17A). OSL samples were collected from the layer including the ripple marks and on the upper part of the planar bedded sands.

Fig. 16. Glacially deformed sands under two metres thick basal till cover in Pyöreäkumpu, Liakka. Photo P. Sarala.

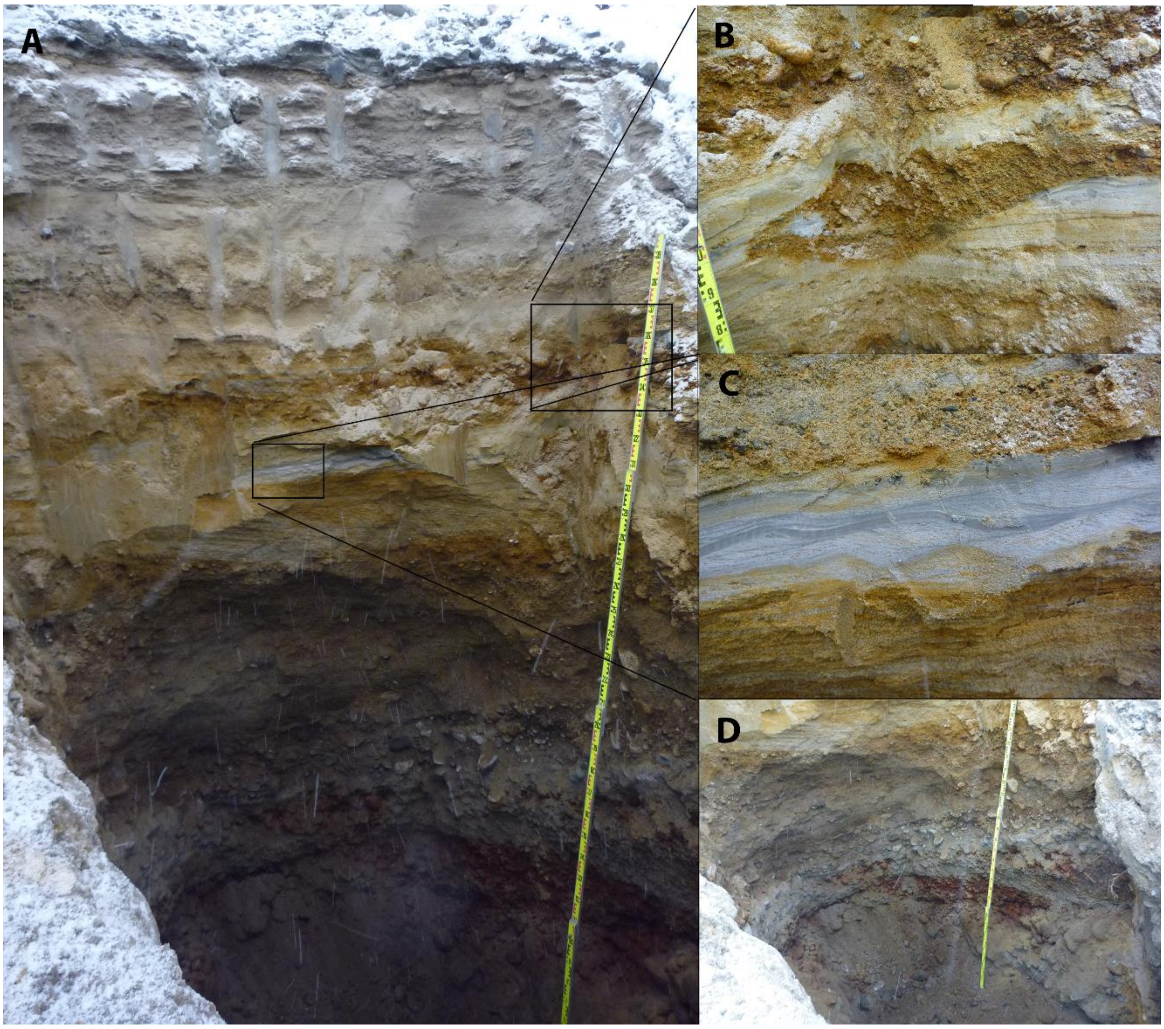


Fig. 17. Stratified sediment sequence under three metres thick till cover in Rantamaa sand pit, Liakka. Coarse core part composed of gravels is seen on the bottom (A, D). Upper parts include cross and planar bedded sands with gravelly or silty interlayers. Some catchment/injection structures (B) and ripple marks (C). Photos by P. Sarala.

Ground penetrating radar (GPR) profile (Fig. 18) over the Rantamaa test pit shows a continuum of the sands and gravels under the upper tills. Furthermore, GPR data reveals that sands display planar lamination dipping towards south (i.e., meltwater flow direction). Those structures resemble foreset layers of the deltaic formation. Upper part (2-3 m) is composed of two till beds from which the lower is deformed and disturb underlying sands.

OSL datings were done in the Dating laboratory of the Helsinki University. Age determination gave the ages of about 29 +/- 2.8 ka and 29 +/- 6.1 ka years for the sands in Pyöreämaa. Data analysis for the Rantamaa OSL sample from the sand at the depth 4.3 m gave the age c. 51 ka. Although, the age was clearly older than in Pyöreämaa, it still fits to the range of Middle Weichselian are found from the several places in southern Finnish Lapland. This means that southern Finnish Lapland has been ice-free during the later stage of Middle Weichselian, in MIS 3. This interpretation is supported by the TL ages clustering around 37,000 +/- 500 – 55,000 BP and OSL ages clustering around 41,000 +/- 2,000 – 66,000 +/- 5,000 BP, which were done of the samples taken earlier from Kauvonkangas and Sihtuuna in Tervola and the area surrounding the towns of Kemi and Tornio (Hütt et al., 1984; Mäkinen, 1999 and 2005; Sarala and Rossi, 2006). Furthermore, the new age results presented here correlate well with the age determinations of mammoth and reindeer bones (22,500-34,000 BP) done, for example, from the basins of Iijoki River and Tornionjoki River in southwest Lapland (Ukkonen et al., 1999; Lunkka et al., 2001).

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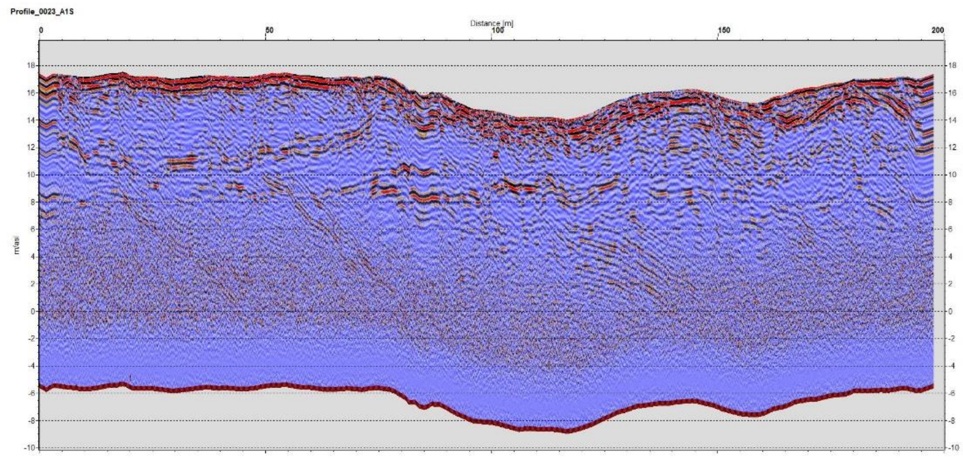

Fig. 18. About N-S oriented GPR profile following the margin of the eastern edge of the Rantamaa sand pit. Data collection and processing by Juho Kupila.

STOP 6. SIHTUUNA MORAINES AT SIHTUUNA, TERVOLA

Pertti Sarala

The Sihtuuna moraine was found northwest of the village of Tervola, southern Finnish Lapland (Fig. 19). The area of this moraine type covers about 10 km^2. Sihtuuna moraines are formed of ridges perpendicular to the latest ice-flow direction from the west to the east. 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. 20). 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, glaciotectonic shear planes and faults. Planar bedding and small-scale cross lamination give an impression of a restful meltwater stream discharging into the deep waterbody. 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).

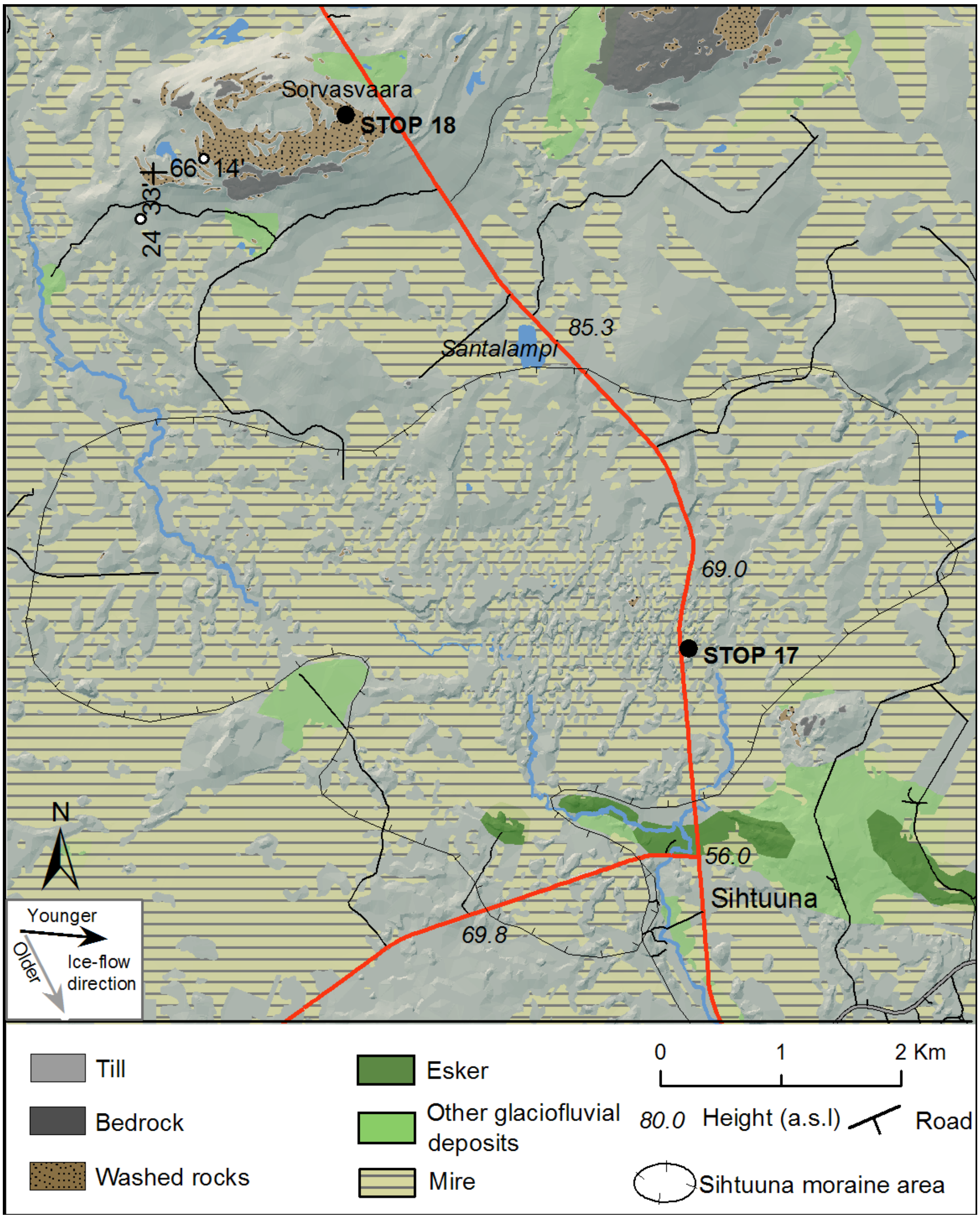

Fig. 19. Glacial morphology and bedrock relief of the Sihtuuna area, Tervola. Digital elevation model, topographic features and roads © National Land Survey of Finland.

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. 20). 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 favour 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 OSL datings from the sand layers gave ages 35+/-3.3 ka and 62+/-9.9 ka indicate deposition in the Middle Weichselian.

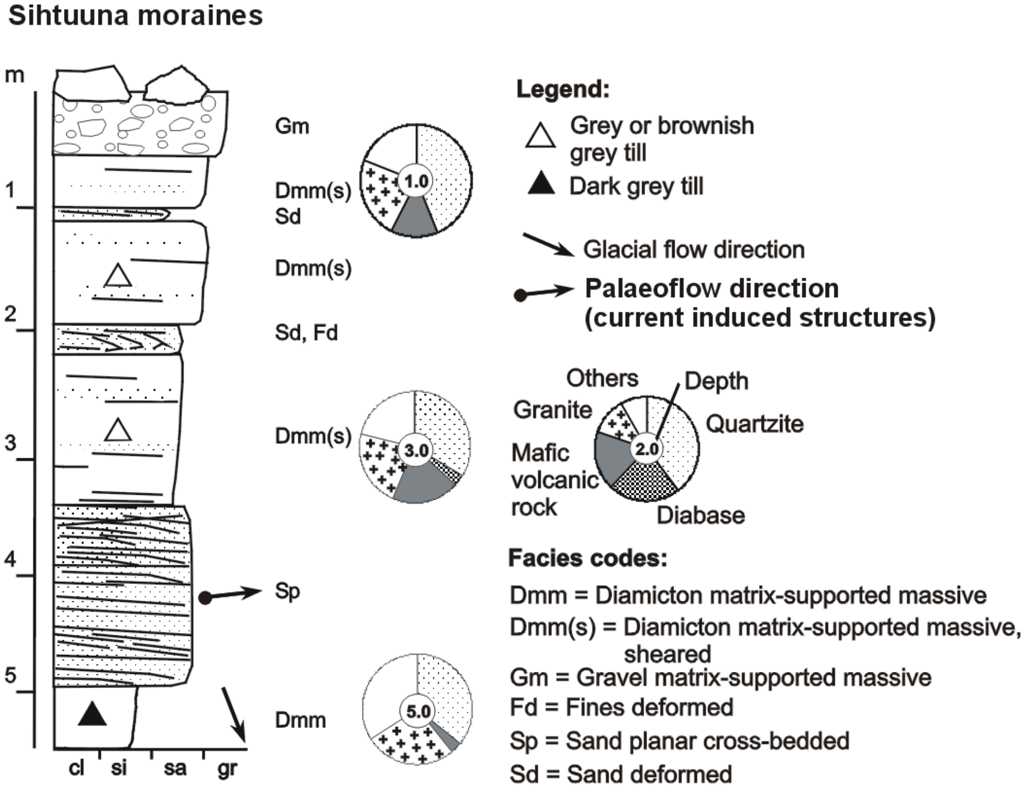

Fig. 20. Composition stratigraphy of minor ribbed moraines in Sihtuuna with lithofacies and pebble counts.

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 number 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. 21). 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 meltwaters 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 is re-deposited from the pre-existing delta formation to present position. The second stage was related to bouldery surface of the ridges and represents strong quarrying activity of the glacier during the formation process.

Fig. 21. Sandy and gravelly till with sandy inter-till layer of Sihtuuna moraine ridge. The surface of ridges is covered with big, angular boulders. Photo P. Sarala.

STOP 7. ANCIENT SHORE DEPOSITS OF THE ANCYLUS LAKE IN SORVASVAARA, TERVOLA

Pertti Sarala and Juha Pekka Lunkka

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. 22) 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. 23). However, uplift was so rapid that the water level continued to fall there throughout the Ancylus Lake stage (Fig. 24).

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

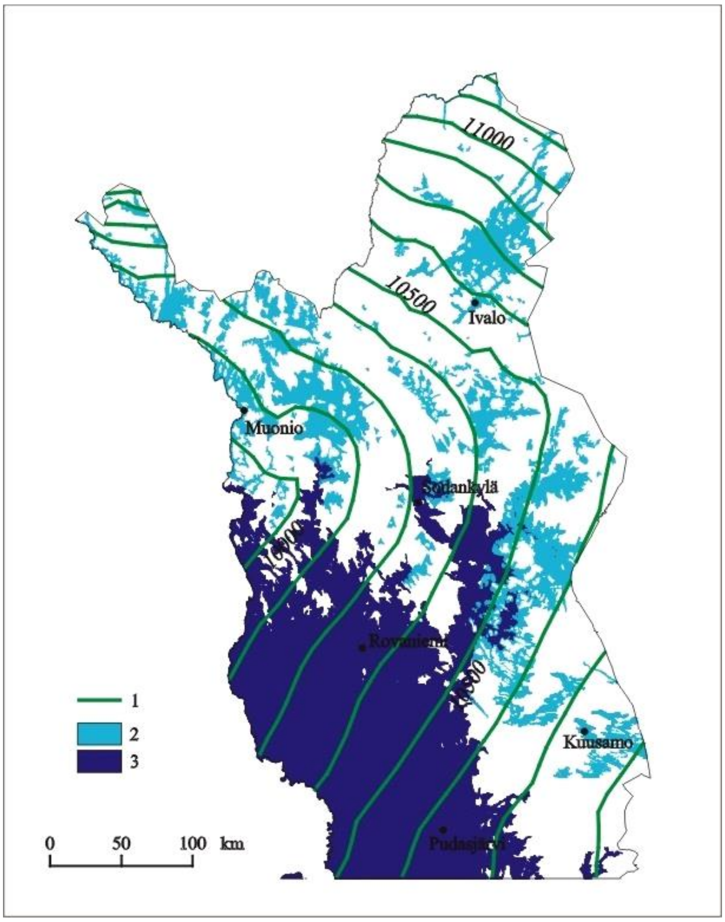

Fig. 23. Recession of the margin of the glacier in northern Finland towards the end of last glaciation. 1 = position of the ice margin, 2 = areas covered by ice-dammed lakes and 3 = Ancylus Lake. After Johansson and Kujansuu (2005).

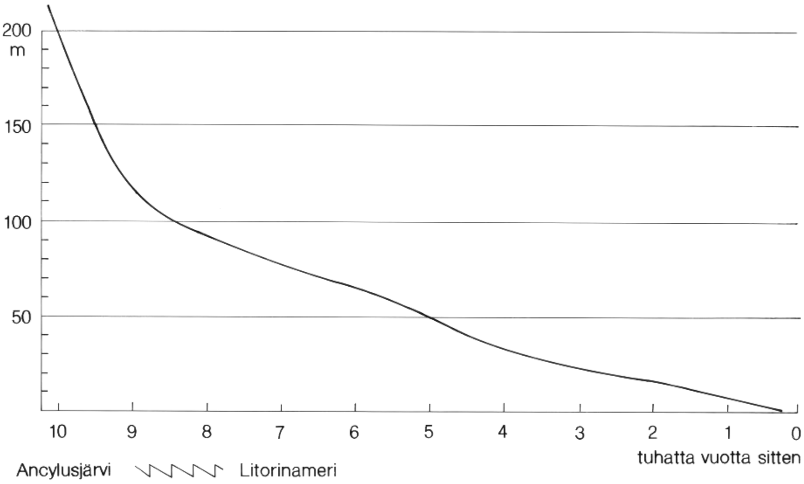

Fig. 24. Displacement curve showing the shoreline elevation of the ancient Baltic Sea above the current sea level in southern Finnish Lapland after deglaciation. The time scale shows calendar years. Ancylusjärvi = Ancylus Lake, Litorinameri = Litorina Sea and tuhatta vuotta sitten = thousands of years ago. After Saarnisto (2005).

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NOTES

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