LITHOSTRATOTYPES FOR WEICHSELIAN AND PRE-WEICHSELIAN SEDIMENTS IN SOUTHERN AND WESTERN FINLAND

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In this paper we define stratotypes for glacial and associated sediments in southern and western Finland. The Kauhajoki Formation in southern Ostrobothnia (*Pohjanmaa*) and the Kela Formation in western Uusimaa, comprise a complex sequence of sediments deposited during the Weichselian glaciation. Following the entrainment of debris by the first advancing ice, the deposition was initiated by lodgement of the Kauhajoki and Siuntio Tills. The ice was flowing towards the south. Later, during the deglaciation, deposition was largely by basal melt-out leaving the Espoo Till in western Uusimaa. The Pikkala Sands, sandwiched between the underlying till and overlying Espoo Till were deposited by subglacial meltwater. A comparable facies change, from lodgement to melt-out, is also recorded in the uppermost 1 metre of the Kauhajoki Till.

Other lithostratotypes are proposed for sediments underlying till (the so-called 'old' glaciofluvial and associated sediments) in southern Ostrobothnia. These include the Harrinkangas Formation.

The approach of using formal lithostratigraphical units is recommended because of the complexity and wide extent of the Pleistocene deposits of Finland. As a consequence of the present lack of bio- or chronostratigraphical data in southernmost Finland, the classification and subdivisions of stratigraphic units based on cold stage sediments requires detailed sedimentological analysis.

Key words: stratigraphy, till, genesis, deposition, stratotypes, Pleistocene, Weichselian, Finland, Siuntio, Kauhajoki.

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Introduction

Till in Finland is characterised by its areal continuity and the relatively limited compositional variation in its crystalline bedrock components. Various till sheets can be recognised, mainly on the basis of their stratigraphical position in a given section and on their clast fabric. The latter indicates the ice flow direction prevailing at the time of their deposition. For this reason, fabric measurements and mapping of interstratified organic and/or clastic sediments have been the main methods used to correlate till units and identify discrete glacial flow phases (Hirvas and Nenonen 1987). This method has been successful and has provided a detailed picture of ice movements and associated glacial deposition in Finland, especially in the north (Hirvas et al. 1977; Hirvas et al. 1988).

However, the recognition over the past 30 years that a more complex sequence of Pleistocene deposits is present in Finland than previously thought has led to the need for a more rigorous approach to the subdivision and classification of sediments. This need was arguably first recognised by Aario and Forsström (1979) following their work in Koillismaa and Kainuu. They proposed formal terms for five units in their study area. Similarly, stratotypes were defined for the Weichselian and Flandrian sediments in the Muhos area by Gibbard (1979). Donner, Korpela and Tynni (1986) established stratotypes for units representing ice-free events, interglacials or interstadials in Ostrobothnia, namely Oulainen (Early Weichselian interstadial) and Evijärvi (Eemian). Others have chosen not follow the approach of using consistent, formalised stratgraphic terms with the result that imprecise, sometimes confusing terms continue to be used.

The purpose of this paper is to provide a formal stratigraphical framework for the Weichselian glacial deposits of southern and western Finland. The paper is based on a number of new observations and re-interpretations of others, previously published. In the selected areas (Fig. 1), glacial deposits include evidence for at least two distinct glacial events, represented by two tills, informally known, from older to younger, as the *'dark till'* (Rainio and Lahermo 1976) or the *'old till'* (Hirvas and Nenonen 1987), overlain by the *'main till bed'*, the *'common sandy till'* or the *'pre-Salpausselkä phase till'*. In Ostrobothnia, the *'old'* or *'dark'* till is also known informally as *'mäkisavi* (hill clay) *till'*. Superimposed striae on bedrock outcrops in the same areas also indicate two successive glacial flow directions, trending southwards, and later generally southeastward.

In this paper we particularly describe the occurrence of the *'mäkisavi'* till and discuss its genesis as well as its use as a local or a regional

Fig. 1. Areas discussed in the present paper.

stratigraphic marker horizon in the Finnish till stratigraphy. We propose one new formation name for the Weichselian glacial sediments, and a second for pre-Weichselian glaciofluvial and associated sediments in Ostrobothnia. The formation rank is selected since it represents the basic unit in lithostratigraphy (Hedberg 1976) and because it can be subdivided into members, and these in turn into beds, as required. Formations can also be collected into groups, again as appropriate. However, it was not felt necessary to apply group-status units to the sequences described. As more information becomes available in future, this could be reassessed.

The new observations from western Uusimaa are from the Kela and Lommila sections. New data and interpretations are also presented for exposures in southern Ostrobothnia, centred on those at Harrinkangas. All the sections examined in detail and newly-reported here are located in the coastal zone of south and western Finland (Fig. 1). All the sites discussed are underlain by shield rocks in areas where final deglaciation occurred in water depths ranging from about 50 to 150 metres.

Till stratigraphy of western Uusimaa

Most of the stratigraphical information currently available for this area has been summarised by Hirvas and Nenonen (1987). This information is based on exposures around Helsinki, described by Rainio and Lahermo (1976; 1984), Kurkinen et al. (1989) and from sections in the Porvoo area, east of Helsinki (Hirvas and Nenonen 1987).

The most frequently observed uppermost till in the western Uusimaa region is sand-rich, has a well-developed clast fabric, a low organic content, and a predominance of shield-derived clast components. In the southern coastal area, this till forms a thin veneer of 'cover (ground) moraine', and in numerous localities shows evidence of reworking by glacial meltwater. The surface till is generally associated with the southeastward ice flow recorded by striae on outcrops in this region. An older glacial flow, trending south, is also frequently observed here (eg. Kaivopuisto, Helsinki, map sheet 2034 06: x= 6672.10, y= 553.85).

Rainio and Lahermo (1976) found numerous sites in southern Finland where an apparently discontinuous 'dark compact' grey silty till unit occurs below a regionally-extensive and frequently observed 'sandy till'. The former till unit was described as clay- and 'humus'-rich and it was found to extend from central to southern Finland. It is frequently recorded around Helsinki (Rainio and Lahermo 1984; Kurkinen et al. 1989). The till is compact and occurs mainly in sheltered positions, in relation to the last ice flow direction, where it occasionally rests on weathered bedrock. Rainio and Lahermo (1976) ranked the dark grey till as a bed in their stratigraphical terminology and assigned it tentatively to the initial phase of the last glacial stage. Radiocarbon dates on the humic matter included in this till suggest an age over 45 ka. The dark grey colour is caused by ferrous sulphide pigments (Rainio and Lahermo 1984).

Another 'lower till' is known to be present in the Porvoo sections; it is referred to as the 'old till'. It is a compact grey till, with a clay content of 10—15 %; it was deposited by southward flowing ice. Here and there occurrences of thin sand and gravel deposits, are sandwiched between that lower till and an upper 'common sandy till' (Hirvas and Nenonen 1987). According to these authors this lower till correlates with the 'dark compact silty' till reported by Rainio and Lahermo (1976; 1984). They suggested that this lower till was deposited either during the Saalian, the Early or the Late Weichselian glacial episode.

Description of the Kela Till Formation

At the Kela section, west of Helsinki, two till units are exposed and separated, in part, by sorted medium sands. The exposure is a road section in the Kela village of Siuntio Parish. The site is located on map sheet 2032 05, at co-ordinates x = 6667.05, y = 517.92, at 15 m a.s.l. The Kela Till Formation, a new term introduced here, refers to the entire complex of the two tills (Siuntio Till and Espoo Till members) with the intervening sands (Pikkala Sands Member); these sediments are proposed as the holostratotype for the glacial stratigraphy of the western Uusimaa coastal area (Fig. 2). The Lommila section (Fig. 3) (map sheet 2032 12, x = 6678.85, y = 536.37, z = 18 m. a.s.l.) is described here as an auxiliary reference section (hypostratotype).

The Siuntio Till

The lower diamicton unit (Fig. 2) here termed the Siuntio Till (Member), is clayey to silty in texture (clay content 12 %; K-1, Fig. 6), poorly sorted (index 3.7) and rests directly on bedrock. The latter locally shows a kaolin-rich weathering rind. The till is dark grey in colour and is 0—2 metres thick. The clast fabric, as well as the striations on the unweathered part of the underlying bedrock, indicate that the Siuntio Till was deposited by ice flowing southward (Fig. 2). In the lower part of the diamicton, clay stringers

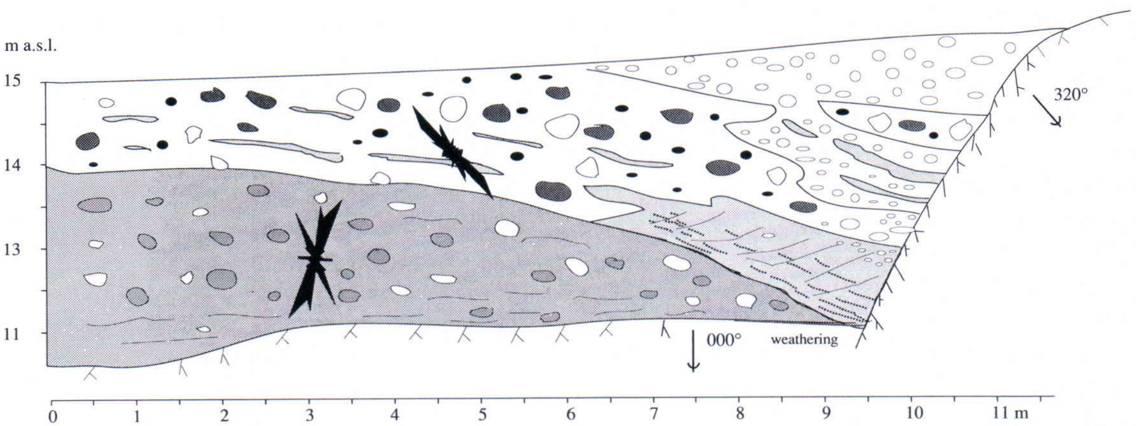

Fig. 2. Sketch of Kela section, western Uusimaa.

suggest development of shear planes near the base. The clast lithology indicates northern to northeastern provenance, with short transport distances (G.M. = 6.2 km; Table 1). The till lacks allochtonous fossil material. From the regional topography and the present location of the Kela section, it appears that the Siuntio Till was deposited as a lee-side accumulation on weathered bedrock, in a sheltered position.

In the Lommila section the lower diamicton unit is about 60 cm thick, patchy, and it occupies small fracture depressions of the bedrock surface. It is dark grey in colour, with a clay content of 16 % (L-1, Fig. 6) and sorting index 3.15. Fabric indicates that deposition occurred by southward flowing ice, there is one strong mode dipping to the direction of the ice flow (Fig. 3). Shear planes dip also to that direction indicating that the deposition was by lee-side lodgement. The composition reflects local provenance (the geometric mean of glacial transport distance is 5.0 km) and a significant proportion of clasts (8 %) have been derived from the Bodom granite in the north and northeast (Table 1). A clay clast, 10 × 40 cm in size was observed in the till. The clay has been folded by stress from the north.

Table 1. Petrographic composition (%) of Siuntio and Espoo Tills (fraction 2—10 cm) and distance (km) to provenance area in bedrock. Average transport distance of till units (G.M.) has been calculated after Salonen (1986).

Rock type	Kela-section				Lommila section			
	Siuntio Till		Espoo Till		Siuntio Till		Espoo Till	
	%	km	%	km	%	km	%	km
Microcline granite	37.3	0—16	55.7	0—13	28.0	0—24	50.0	0—20
Granodiorite	17.7	8—9	2.8	10—15	11.0	2—24	8.0	1—24
Basic volcanic rocks	7.8	2.5—4	2.8	4—5	20.0	38—50	10.0	40—50
Leptite	1.0	0—1	1.9	4—5	2.0	0—1	—	—
Diorite and gabbro	2.0	45—60	1.9	40—60	2.0	40—50	—	—
Mica schist	30.2	16—32	29.2	12—40	29.0	2—30	32.0	12—30
Amphibolite	2.0	8—10	3.8	9—13	—	—	—	—
Uralite porphyrite	1.0	80—120	—	—	—	—	—	—
Jotnian sandstone	1.0	140—200	—	—	—	—	—	—
Bodom granite	—	—	—	—	8.0	1.5—8	—	—
Average glacial transport (G.M.)	6.2 km		7.4 km		5.0 km		6.3 km	

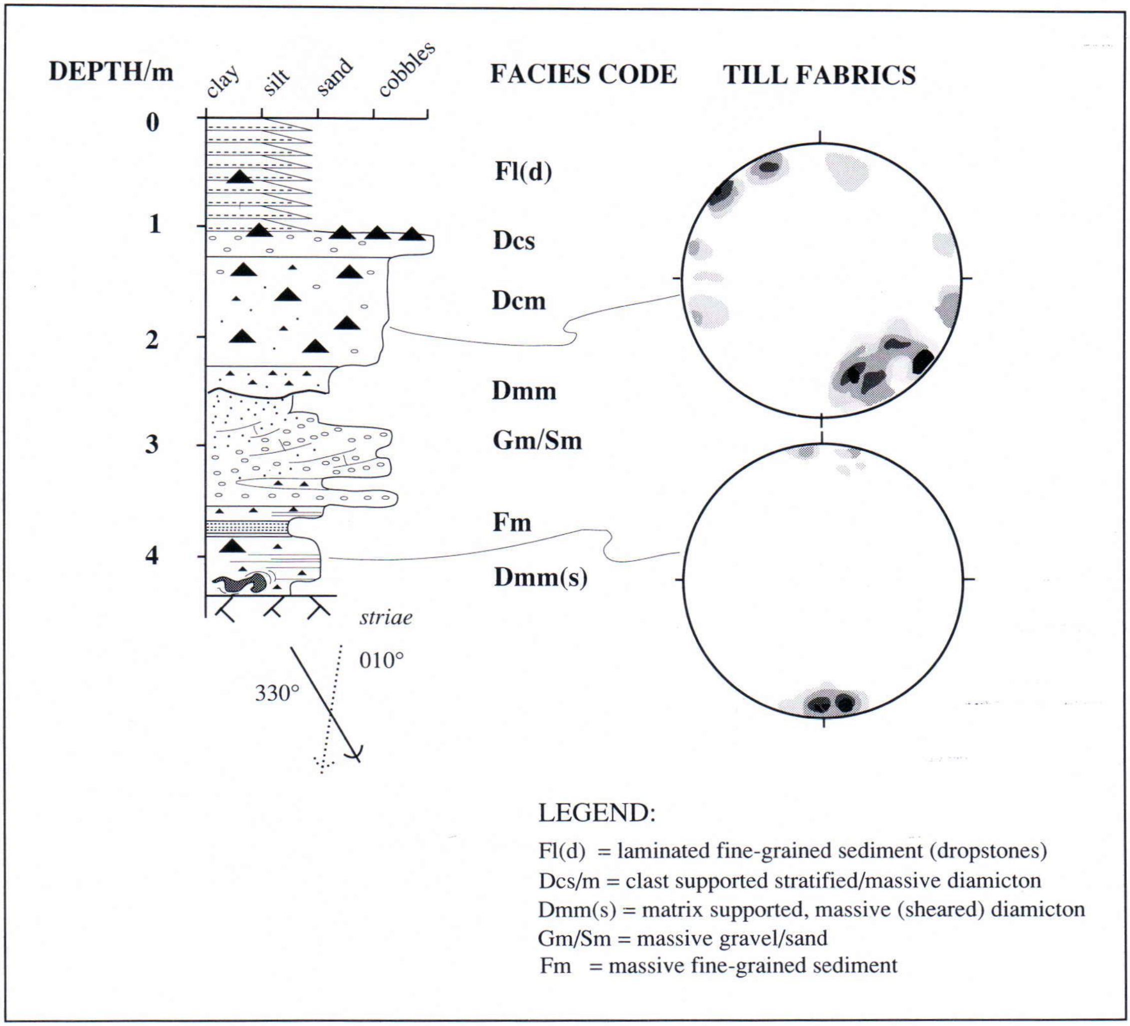

Fig. 3. Sketch of the Lommila section, Espoo. Lithofacies code after Miall (1983).

The Pikkala Sands

The Siuntio Till is overlain conformably by well sorted sands, here called the Pikkala Sands (Member). The unit is about 50 cm thick and is exposed laterally for over three metres. The sand is well laminated and shows some faulting, presumably formed by the overriding ice which deposited the upper diamicton unit (Fig. 2). The upper contact of the unit is sharply erosional and part of the overlying till is wedged into the sand. The Pikkala Sands do not contain organic matter and are unoxidised.

In the Lommila section (Fig 3) a similar unit 1.20 thick was exposed horizontally for about 10 metres. The grain size of the sands here varied from medium silt to gravel and the sediments were stratified. Lamination structures were undulating and their thickness was found to vary in the range 0.5—10 cm (Fig. 4). A till block, 5 × 30 cm in section, present in the massive gravel, was presumably torn-up from the under-

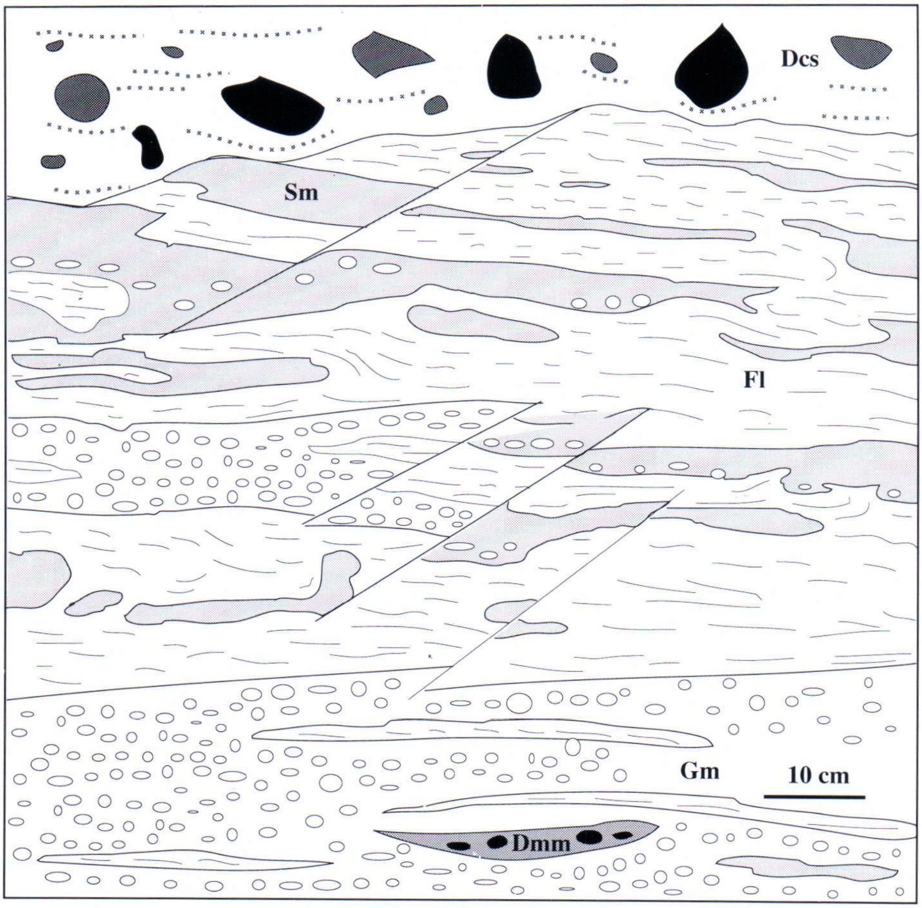

Fig. 4. Detail sketch of the exposure of the Pikkala Sands at Lommila section.

lying till unit carried upward and deposited by the flowing water that deposited the sands. No indication of soil formation or oxidation were observed in the sands, and only small normal faults indicating the loading pressure of the overlying till were found.

The sands include well-developed, but plastically-deformed laminations which probably indicate deposition by fast flowing water in a subglacial environment. The occurrence of the Pikkala Sands therefore does not imply deglaciation of the area in the interval between deposition of the underlying Siuntio Till and the overlying Espoo Till.

The Espoo Till

The upper diamicton unit (Fig. 2), here referred to as the Espoo Till (Member), is massive to stratified, sandy in texture (grain size distribution; K2-Fig. 6) and brown in colour. The clay content is 1.6 %. The till unit is about two metres thick and, according to its fabric, entrained by southeastward flowing ice (Fig. 2). The constituent clasts are angular and the till contains thin (0.2—2 cm) sandy laminae. There are no indications of shearing. In the Kela section there are no significant differences in the composition between this till and the lower, Siuntio Till (Table 1).

In the Lommila section (Fig. 3) the upper till is massive to stratified and clast-supported (L-2, Fig. 6). The contact with the sand below is gradational and, on the basis of the till fabric, was entrained by southeastward flowing ice. The petrographic composition (Table 1) indicates local provenance (G.M. = 6.3 km), but Bodom granites were not observed in the clast fraction.

Because of the presence of thin lenses of sand, and based on the lack of evidence of subglacial shear, it is suggested that the Espoo Till was deposited mostly by melt-out at the base of stagnant ice following the main phase of southeastward ice flow.

Interpretation

The main contrast between the two tills is the amount of fines, process of deposition and the fabric. Both tills have almost the same lithological composition. The deposition of the two till units clearly reflects a facies change during a single glacial event, the Siuntio Till representing an earlier depositional phase by basal lodgement or lee-side deposition, while the Espoo Till would represent the main depositional phase by basal melt-out (cf. Bouchard 1989). This interpretation is supported by Donner (1988) who stresses that the surface till in southern Finland, south of the Salpausselkä Moraines was deposited from more or less stagnant ice, by basal melt-out. The Pikkala Sands between the tills would represent the increasing influence of glacial meltwater and rising sea level on the mode of till deposition.

In the present paper we propose a Weichselian correlation for the entire Kela Formation (Table 2). The Kela section appears to record changing ice flow directions with changing subglacial conditions during a single glacial event.

Till stratigraphy in southern Ostrobothnia

In southern Ostrobothnia, the dark grey, clay-rich till (diamicton) is repeatedly found resting on linear glaciofluvial sedimentary accumulations interpreted as eskers. These features and the associated stratigraphy have been described by Niemelä and co-workers in a series of papers (Iisalo et al. 1974; Niemelä 1978; Niemelä and Tynni 1979; Niemelä and Raikamo 1983). In the region east of Kristiinankaupunki, the majority of these esker-like ridges trend broadly north-south (Gibbard et al. 1989). Niemelä (1978) has called these 'old' formations, to contrast with the so-called 'young' formations that lack a cover of till, such as Hämeenkangas.

Associated with these 'old' glaciofluvial formations at isolated localities are organic deposits, finds of which have been summarised by Niemelä and Tynni (1979). The organic deposits take various forms, but always underlie the dark grey till. The most impressive is that at Norinkylä, Teuva where almost 2 m of detritus mud, grey

Table 2. Events in the western Uusimaa area during the late Pleistocene.

Stage	Event	Formation/Members
Flandrian	5. Emergence	
	4. Glaciolacustrine sedimentation	
Weichselian	3. Deglaciation	
	2. Glaciation	Kela Formation
		c. waterlain (Espoo Till Member)
		b. sand deposition (Pikkala Sands Member)
		a. lodgement (Siuntio Till Member)
Pre-Weichselian	1. Weathered bedrock surfaces	

silt and sand have been glaciotectonically sheared and plastered against the western side of the esker-like gravel and sand ridge (Donner 1988). However, in some places *in situ* deposits have been found, such as at Oulainen (Forsström 1982; 1984), Vimpeli (Aalto et al. 1983; 1989), Haapavesi (Forsström et al. 1988), Harrinkangas, Kauhajoki (Gibbard et al. 1989) and Marjamurto (Peltoniemi et al. 1989).

At the Harrinkangas site (Fig. 5), Gibbard et al. (1989) demonstrated that the till represented a coherent depositional unit deposited predominantly as lodgement by ice advancing from the north-northwest. On the basis of this work, the till complex was formally termed the Kauhajoki Till Formation, the stratotype being sited at the Harrinkangas quarry (map sheet 1234 09, x= 6915.50, y= 560.45, z=140 m. a.s.l.). Here the till and associated sediments not only overlie a substantial thickness of glaciofluvial gravels and sands that comprise the esker-like ridge, but also the fossiliferous silt and sand kettlehole fill, mentioned above. These sediments are grouped together as the Harrinkangas Formation.

The Harrinkangas kettlehole sediments have been equated biostratigraphically with either the late Eemian or an Early Weichselian interstadial event (?Brørup), although the balance of the evidence favours that the sediments represent the former. If so, they span the Eemian — Weichselian Stage boundary. By contrast, the deposits at Haapavesi have been correlated with the first part of the Eemian Stage (Forsström et al., 1988). These correlations imply that the underlying glaciofluvial sands and gravels at Harrinkangas, and at many other localities throughout the area, were deposited during deglaciation in the period late Saalian-early Eemian. Further this indicates that the periglacial ground ice features, underlying the till at Harrinkangas, represent a prolonged period of subaerial exposure before arrival of the ice that deposited the Kauhajoki Till in the Late Weichselian Substage (Gibbard et al., 1989).

As a consequence of this work a regional investigation has shown that a consistent stratigraphy and sedimentary environment can be identified across the area. The results of this study are summarised below.

Description of the Kauhajoki Till Formation

Although variable in appearance, throughout the region the glacial diamicton (till) has a light grey, blue grey to dark grey, clay to silt-rich matrix. In places, where post-depositional oxidation has occurred the till matrix is mottled orange to light brown in colour. This is common where the till is thin. In general the till is massive, but frequently includes shear planes, particularly in the basal decimetre, usually represented by 2—3 mm thick sand laminae, either singularly or in groups. It possesses a strong clast fabric and contains clasts of local as well as more distant origin. Characteristically a considerable organic component occurs both in the matrix and as clasts (Rainio and Lahermo 1976; 1984).

The distribution of the till is quite variable. On the 'old' glaciofluvial accumulations it is truncated by the overlying littoral or beach deposits that form a carapace on such features over the whole area. This results in the till being often absent from or thin on the crests of the esker-like ridges, but being preserved on the flanks. The till therefore occurs as a continuous stratum or as a series of discontinuous pockets and consequently it varies in thickness from a few centimetres to a maximum of 4.5m. At Harrinkangas, the discordance of ice movement direction (NNW-SSE) and the pre-existing esker-ridge alignment (N-S) resulted in a lee-side effect, such that on the eastern side of the exposures, where the excavations were cut into the ridge flank, a complex series of conformable interbedded till and meltwater sediments were preserved at lower elevations (Gibbard et al. 1989, fig. 6). In contrast, where the till caps the crest of the ridge it is relatively thin and comprises a single stratum, as repeatedly seen elsewhere.

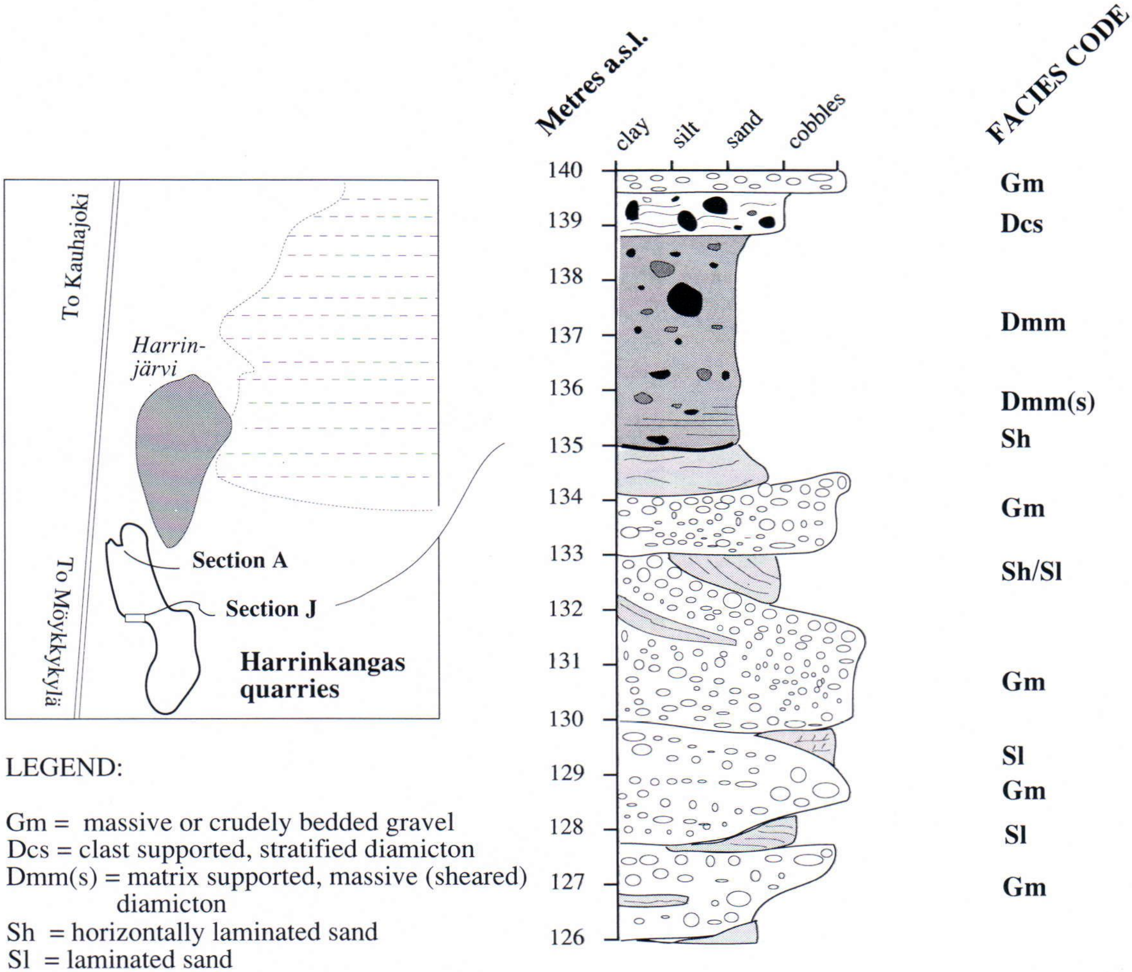

Fig. 5. Location map and the lithostratigraphy plot of section J (Gibbard et al. 1989).

At all localities the till rests on the underlying glaciofluvial gravel and sand deposits with a marked unconformity. At the type section, this unconformity truncates both the Harrinkangas Formation gravels and sands, as well as the kettle-hole fill sediments. Frequently, overturned beds have also been observed in the decimetre of sediment immediately below the till, such as at a quarry south of Jurva (Fig. 7). Whereas at Susivuori, Karijoki (Fig. 7), a small clastic wedge, c. 60cm deep terminating at the till base, was found. Incorporation of local sediment by low-angle shearing has also been repeatedly observed,

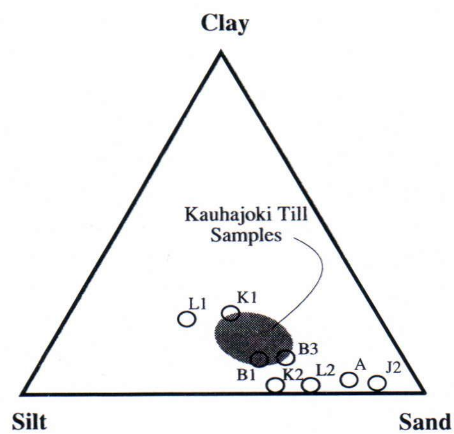

Fig. 6. Matrix grain size measurements.

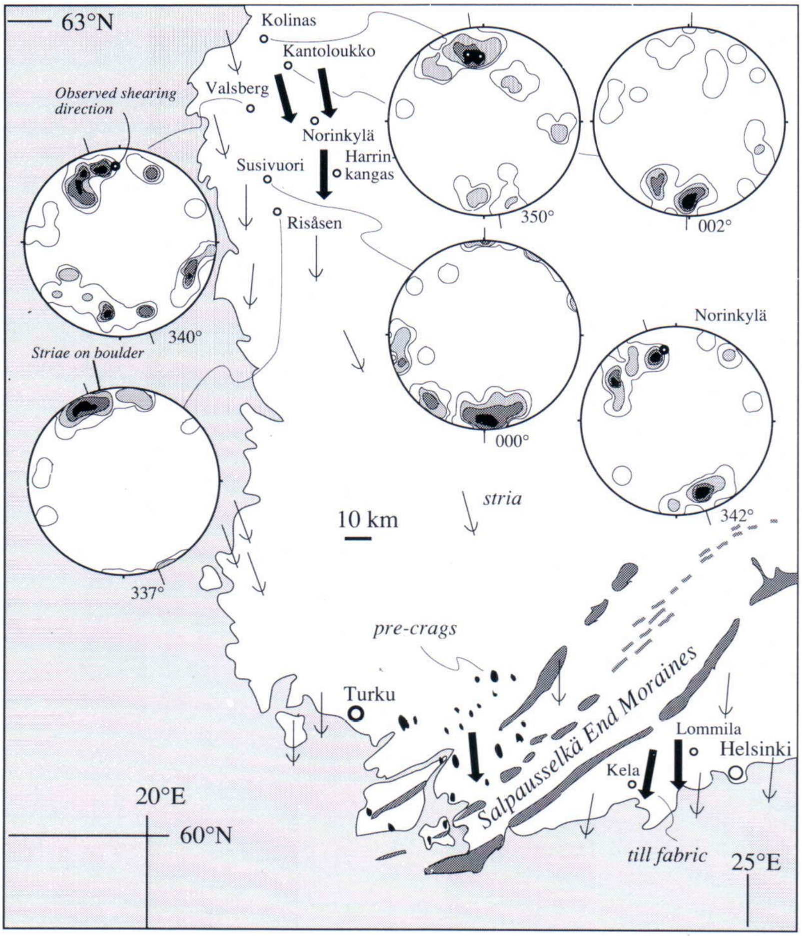

Fig. 7. The first depositional stage of the Weichselian glaciation is recorded in till fabrics, 'old striae system' (CSF, Department of Quaternary Geology 1986) and 'pre-crags' (Haavisto-Hyvärinen et al. 1989).

such as in an exposure south of Jurva. The direction of these shear structures and drag folds in all instances closely parallels that obtained from till fabric measurements (Fig. 7). For example, this is seen at Norinkylä where the strong shearing of fine, organic sediments penetrates at least 1m below the till (Donner 1988).

At Risåsen (Fig. 7) considerable large scale glaciotectonic disturbance of the underlying gravels and sands was observed. This disturbance, concentrated at the northern part of the quarry, included high angle thrusts and overturned recumbent folds the strike of which were all aligned ENE-WSW. The intensity of this disturbance progressively decreased in sections towards the south, such that by about 400 m from the northern end of the site the sediments were apparently undisturbed. The entire sequence of gravels and sands was truncated here by 1.5—2.5 m of blue grey till that in all respects resembles that at Harrinkangas. The fabric of the till indicates ice advance towards the SSE (Fig. 7), i.e. perpendicular to the strike of the glaciotectonic structures. It therefore appears that the ice greatly deformed the gravels and sands at Risåsen as it overrode them. It then deposited till above on a truncated surface of these deposits.

At Kantoluokko a substantial elongated boulder (1.4 m long) at the till base, had been bulldozed into the underlying gravels and sands, causing the latter to be forced upwards immediately in front. The direction of the boulder's movement parallels that of the till fabric from this site (Fig. 7).

At Harrinkangas, Gibbard et al. (1989) reported a facies change within the uppermost 1 m of the till at their point J. Here the till was grey green in colour, crudely stratified and contained a noticeably increased frequency of clasts, compared to that beneath. The laminations within the till consisted of fine to medium sand 1—3 cm thick; these features being emphasised by modern frost weathering close to the modern ground surface. The clasts varied considerably in size, but several were orientated with their long axes vertically. These clasts may be dropstones. A remarkably similar sequence, showing the sharp transition from a lower massive (1.5 m thick) to stratified upper facies (50 cm thick), was observed at Susivuori. Here the till is massive over most of the exposure, but the stratified diamicton is restricted to the northwestern corner. Fabric and grain size analyses were undertaken from the lower massive and upper stratified levels at Harrinkangas and Susivuori (see below). Subsequently a comparable internal facies change has been observed at Risåsen, but here the uppermost sediments (30 cm thick) have not been studied in detail. This structure appears to be restricted to the crests of the ridges.

At Myllykangas (Fig. 7) the gravels, sands and silts underlying the grey till are disturbed by ice collapse structures comparable to those at Harrinkangas. However, here the hollow only contains laminated silts interbedded with sands. The repeated occurrence of structures of this type reinforce the concept that all the esker-like accumulations were broadly contemporary and formed under similar ice retreat conditions.

Fabric

Three-dimensional clast fabrics have been undertaken at 6 sites (for the stratotype, see Gibbard *et al.* 1989). These indicate a well-defined fabric orientation at all sites broadly from the north to north-northwest (Fig. 7). Using the Dowdeswell and Sharp (1986) method for differentiating tills of different genesis, the eigenvectors for each fabric indicate that the till is lodgement. They closely compare with data obtained from the area by previous workers (Niemelä 1978; Donner 1988) and with measurements of shearing, overturned bedding and striae on isolated large boulders at the till base.

Regarding the fabrics for the upper stratified part of the Harrinkangas (locality J2) and Susivuori till units, the former showed a much weaker fabric that supports the concept that this sediment may be of waterlain basal meltout origin (Gibbard et al. 1989). This implies that the sediment formed beneath the ice where it lifted off the bed underwater, possibly during deglaciation. The latter could not be analysed because the sediment was exposed at approximately 1 m below the ground surface, a position where the clasts may have been disturbed by frost processes.

Grain size

Samples for grain size analysis were taken from 12 sites. These analyses were undertaken using both the hydrometer and sieve, and the sedigraph and sieve techniques. The results of both methods are combined in Fig. 6. As at previous sites the uniformity of grain size distribution is marked, with the exception of the stratified subunit at Harrinkangas (J2). The former comprise 14—17 % clay, 27—41 % silt and 59—72 % sand they are poorly sorted and positively skewed. These figures accord closely with those obtained by Rainio and Lahermo (1976, 1984). As already reported by Gibbard et al. (1989), the Harrinkangas sample J2 was better sorted, containing 10 % less clay and over 20 % less silt, being enriched with coarse sand. This was attributed to the inclusion of sorted sand laminae in the original sample. Interestingly, the similar sediment at Susivuori (samples B1, B3, Fig. 6) does not include this sand enrichment, the till matrix being indistinguishable from the lodgement by grain size.

Interpretation

On the basis of this synthesis and the previous descriptions, it appears that there is very consistent evidence for deposition of the Kauhajoki Till by a substantial ice advance from the north-northwest. During the advance the ice overrode pre-existing sediments, eroded, remodelled, pushed and tectonised them. It then predominantly deposited lodgement till, but in places in the lee of obstacles, meltwater activity seems to have occurred. This gave rise to local erosion of till subunits and deposition of sorted sands, gravels and fines (Gibbard et al. 1989). Subsequently during ice retreat, stratified till with dropstones was formed, probably beneath locally floating ice.

The till comprises both locally- and distantly derived material. The latter includes argillaceous marine sediment, presumably derived from the floor of the Gulf of Bothnia. That this sediment was formed, in part, during a preceding warm period is shown by the abundance of 'interglacial' type fossils, such as marine diatoms recovered from the till matrix (Rainio and Lahermo 1976; 1984; Niemelä and Tynni 1979; Gibbard et al. 1989). Indeed the occurrence of such assemblages within the Kauhajoki Till implies that there was no glacial advance of comparable magnitude across the Baltic basin in the area between deposition of the till, and of the primary marine sediment.

Predating the arrival of the glacial ice there appears to have been a period, during which cold climates predominated (Table 3). This conclusion is based on the occurrence of ground ice structures (thermal contraction crack and cryoturbation; the former implying the contemporary occurrence of permafrost) immediately beneath the till, but overlying the fossiliferous sediments at Harrinkangas (Gibbard et al. 1989). Similarly, the occurrence of niveo-aeolian sediment, in a comparable stratigraphic situation at Risåsen further reinforces this interpretation. This

Table 3. Events in the southern Ostrobothnia area during the late Pleistocene.

Stage	Event	Formation
Flandrian	8. Emergence 7. Beach and littoral deposits formed	
	6. Deglaciation	
Weichselian	5. Glaciation —	Kauhajoki Till Formation: b. waterlain a. lodgement and erosion
	4. Periglacial episode — niveo-aeolian sand deposition, cryoturbation and ground ice	
	3. Infill of kettle hole lake at Harrinkangas	
Eemian	2. Kettle hole formation, emergence and isolation from sea	
	1. Deposition of (esker sands and gravels) — followed by deglaciation	Harrinkangas Formation
Pre-Eemian	glaciation (?Saalian)	

evidence lends considerable support to Nenonen's (1986) concept of a single glaciation in the Late Weichselian, preceded by a lengthy non-glacial episode, potentially spanning much of the Early and Middle Weichselian Substages, and their constituent stadial and interstadial events.

Events in the southern Ostrobothnia region, based on the results presented in this paper and the previous interpretations of Niemelä and Tynni (1979) and Gibbard et al. (1989), are summarised in Table 3.

Discussion

Correlation

The Kauhajoki and Siuntio Tills most probably represent the 'dark (grey) till' of Rainio and Lahermo (1976), the lower till in southern Finland. Further north, Aario and Forsström (1979) have described a likely correlative unit, a dark grey plastic till unit, known as the Pudasjärvi Till. They interpreted this till as arising from deposition in a more central position beneath the ice sheet. An important observation made by Rainio and Lahermo (1984) was that the dark grey till has a common origin; it is formed from a single generation of debris, in which reworked older sediments, particularly Eemian marine sediments represent an essential component.

The general older direction of glacial flow in southern Finland has been towards the south-southeast (Hirvas and Nenonen, 1987). Till fabric and striae observations clearly indicate that deposition of both the Kauhajoki and Siuntio Tills can be related to this glacial flow event (Fig. 7). This might reflect the southward movement of the growing glacier by gliding over soft pre-existing sediments because indications of shearing are commonly observed in association with the till.

The Kauhajoki Till probably represents a deposit from the initial stage of the Weichselian glaciation. The 'old' esker system has not totally been eroded away in this area, but has been intensively compacted, deformed and moulded into drumlinoid forms. After having reached this form the sorted sediments themselves hampered the effects of glacial process by draining the basal part of the glacier leading to an increase in shearing and deposition of the dark grey diamicton. The intimate relationship of the Kauhajoki Till with the pre-existing glaciofluvial accumulations is therefore no accident.

The debris forming the first generation of glacial sediments, lithofacies 1 (Bouchard 1989), was deposited by lodgement in places of increased friction ('old eskers') or as lee-side deposition in sheltered positions. The upper surface of the pre-existing materials was eroded ('old eskers') or also moulded into drumlinoid features in southernmost Finland; the so-called 'pre-crags' (Haavisto-Hyvärinen et al. 1989).

This was then followed by a period of quiescence of unknown duration that began with subglacial meltwater activity. The ice sheet was reactivated and a lobate flow pattern developed during deglaciation (Punkari 1980). During this phase a new generation of glacial sediments were formed providing the ice sheet with a new, fresh load of debris in addition to the remaining load acquired during the initial stage of advance. Indeed, although Eemian sediments were seemingly incorporated by the Weichselian ice during its initial advance, some may have remained in the ice for a long period, and became deposited only once the ice became active just before deglaciation, when a second, new generation of debris was formed.

Under normal circumstances, the two debris generations would have been mixed totally and only traces of the earlier debris can be found in the till. However, in this situation they seem to have remained separated even during the final depositional phases. In western Uusimaa, deposition occurred in environments dominated by subaquatic sedimentation, or where the ice lost its power during deglaciation and decayed as dead ice. At the Kela and Lommila sections, the dark grey Siuntio Till was deposited as lee-side till in sheltered positions. The upper till unit, the Espoo Till, was deposited by basal melt-out, a depositional process that seems to preserve at least a part of the basal sediments. In southern Ostrobothnia, although the Kauhajoki Till is the only till unit of the area, it shows a facies change from subglacial lodgement to melt-out in at least three localities. The lower unit was better preserved in the southern Ostrobothnia area, and the upper facies better developed in the western Uusimaa area.

It is difficult to correlate tills only on the basis of their physical properties. In this example, the tills originate from a common debris source, but the sediments themselves were deposited at a different time in different depositional environments (basins). In geology, a basic criterion for correlation is that sediments originally formed a continuous sheet (i.e. they were in physical contact with each other) during deposition. In our case, debris might have been in physical contact, but because the deposition was time-transgressive and controlled by the basal temperature conditions of the ice sheet, it was deposited during different times at different places.

The Weichselian glacial episode is diachronous, and it is represented by unequal periods of deposition of stratigraphical unit assemblages. According to the views presented here, the deposition had possibly already begun after the Brørup Interstadial, and continued during the Late Weichselian Pandivere Stadial (Fig. 1), when ice flowed towards the south and dispersed Finnish crystalline indicator pebbles over Estonia (Raukas 1986). This advance was partially contemporary with the development of the so-called 'steady state' in the central areas of continental glaciation, whilst the remainder may have formed allochtonous lenses in deglaciation sediments (e.g. Kerkkolankangas; Rainio and Lahermo 1976).

The Kauhajoki and Kela Formations represent an important body of deposition during the Weichselian glaciation, but one should remember that the proposed stratotypes lack information for an essential piece of Quaternary history, i.e. deposition associated with the deglaciation of the Scandinavian ice. These deposits were controlled by shifting, lobate flow regimes of the waning ice sheet, and additional stratotypes will be required for the accurate classification of deposits associated with this, and later events.

Stratigraphical procedure

The International Stratigraphic Guide (IGS) (Hedberg 1976) states that all lithostratigraphical units (formations and members), in common with chronostratigraphical units (stages and substages) and biostratigraphical units (biozones), should be firmly-based and specifically-defined on actual stratotypes at type localities.

It is important to stress that stratotypes or type localities need not comprise or contain complete sequences, preserve the 'finest' development of a particular unit, contain all the units known to occur in the area under study or be permanently exposed (although ideally this would be preferable). The function of a stratotype is as a reference example of a particular unit or feature, and therefore it provides a locality at which the unit or feature is established. Such points are required prerequisites for firm, unambiguous inter-regional correlation (cf. Cowie et al. 1986; West 1989).

In this paper we have proposed formal terms for mappable scale units. Mappability at the surface or in the subsurface is an important criterion for the definition of formation-status units (cf. Hedberg 1976; Nystuen 1989). It is implicit, that if a formation in one area is initially correlated with that in another, there is no need to redefine units if this correlation is later shown to be false. Because this system has been adopted in many countries and applied in many differing geological settings, its utility is *'tried-and-tested'*. We therefore recommend that the approach of proposing regional terms for lithostratigraphical units, adopted in this paper, is followed in the Finnish Quaternary. This is because numerical or alphabetical systems fail when intervening units are discovered or missing, whilst local terms may vary in their meaning across the country. The problem is avoided by adopting the system we propose herein, which incorporates place names for unit terms, for the purpose of locating stratotypes. Such a system should ideally be applied throughout the country, since, as has been shown, it is equally applicable to both modern, and older investigations (Gibbard and Turner 1990).

Finally, the recently published recommendations of the Norwegian Commitee on Stratigraphy (Nystuen 1989) have proposed a new series of subdivisions; *diachronous units* (time transgressive event stratigraphy) that comprise episodes and events. These new units are intended to represent the time span of a geological event characterised by a specific geological process. For use in the Pleistocene such units may represent a glaciation, a marine transgression or a period of aeolian sand deposition, for example. They are clearly then very similar to the geologic-climate (climatostratigraphical) terms glacial and interglacial that have been in use in the Quaternary for a century. Although this is not the place to discuss the relative merits of these units in comparison to those already established, it is vitally important that an unambiguous distinction is made between any particular event (e.g. glacial advance or retreat) or episode (a glaciation) and the *time* (chronostratigraphical stage or geochoronological age) during which these events or episodes occurred. As an illustration, this means that the main Weichselian glaciation (Weichselian Glacial Episode), that in Southern Finland may have begun at c. 75 ka and ended by 8.9 ka, began in the Middle Weichselian Substage and ended in the early Flandrian Stage (Mangerud 1990). The Weichselian Stage (chronostratigraphy), the Weichselian Glaciation (climatostratigraphy) and the Weichselian Glacial Episode (event stratigraphy) are not therefore synonymous and cannot be used interchangeably. Clearly, the introduction and use of these diachronous units holds many potential problems, although they may be useful in some instances. For reasons of clarity we have avoided their use in the present paper.

Conclusions

In this paper formal stratigraphical terms have been proposed for the till and associated meltwater sediments deposited by the Scandinavian ice sheet in south and western Finland. The interpretation of the units suggested here is tentative, being based predominantly on the lithostratigraphical evidence. However, on the basis of the lateral and vertical relationships, it appears that the Espoo Till Member is the correlative of the 'upper' or the 'common' sandy till that appears to underlie the ground surface throughout much of southern Finland. This till was deposited by southeastward flowing ice, mainly by the basal-melt out process. In contrast to the underlying silty and clayey Siuntio Till Member, the Espoo Till is sand-rich and brown in colour. It is devoid of allochtonous microfossils and of organic matter. The till is therefore typical of the sand-rich facies of shield areas.

The Pikkala Sands Member represents an apparent change in subglacial conditions during the late stages of the ice cover during the Weichselian. The sands show no evidence of subaerial deposition, but they were deposited by fast flowing water in the subglacial environment.

The Siuntio Till Member was laid down by broadly southward flowing ice during an initial stage of the main Weichselian glaciation (Weichselian glacial episode). It was formed from the first generation of debris, and deposited predominantly by lodgement processes. The Siuntio Till is the lithological equivalent of the Kauhajoki Till Formation, which forms the superficial till in southern Ostrobothnia. On the basis of present knowledge, there is no evidence to demonstrate that the Siuntio and Kauhajoki Tills are actual time-equivalents. In reality, they probably originate from the same generation of debris, but their deposition was certainly time-transgressive. The depositional period possibly began during the first ice advance and ended during the deposition of the deglaciation sediments, and they therefore represent a single glaciation.

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References

Aalto, M.; Donner, J.; Niemelä, J. & Tynni, R., 1983. An eroded interglacial deposit at Vimpeli, South Bothnia, Finland. Geol. Surv. Finland, Bull. 324, 42 pp.

Aalto, M.; Donner, J.; Hirvas, H. & Niemelä, J., 1989. An interglacial beaver dam deposit at Vimpeli, Ostrobothnia, Finland. Geol. Surv. Finland, Bull. 348, 34 pp.

Aario, R. & Forsström, L., 1979. Glacial stratigraphy of Koillismaa and North Kainuu. Fennia 157:2, 49 pp.

Bouchard, M.A., 1989. Subglacial landforms and deposits in central and northern Québec, Canada, with emphasis on Rogen moraines. Sedim. Geol., 62, 293—308.

Cowie, J.W.; Zeigler, W.; Boucot, A.J.; Bassett, M. & Remane, J., 1986. Guideline and statutes of the International Commission on Stratigraphy (ICS). Cour. Forschnung-Inst. Senckenberg. 83, 1—4.

Donner, J.; Korpela, K. & Tynni, R., 1986. Veiksel-jääkauden alajaotus Suomessa. (The subdivision of the Weichselian Stage in Finland). Terra 98:3, 240—247.

Donner, J., 1988. The Eemian site of Norinkylä compared with other interglacial and interstadial sites in Ostrobothnia, western Finland. Ann. Acad. Sci. Fennicæ A, III. 149, 31 pp.

Dowdeswell, J.A. & Sharp, M.P., 1986. Characterisation of pebble fabrics in modern terrestrial glacigenic deposits. Sedimentol. 33, 699—710.

Forsström, L., 1982. The Oulainen interglacial in Ostrobothnia, western Finland. Acta Univ. Ouluensis A 136, Geologica 4, 116 pp.

Forsström, L., 1984. Eemian and Weichselian correlation problems in Finland. Boreas 13, 301—318.

Forsström, L.; Aalto, M.; Eronen, M. & Grönlund, T., 1988. Stratigraphic evidence for Eemian crustal movements and relative sea-level changes in eastern Fennoscandia. Palaeogeogr., Palaeoclimatol., Palaeoecol., 68, 317—335.

Gibbard, P.L., 1979. Late Pleistocene stratigraphy of the area around Muhos, North Finland. Ann. Acad. Sci. Fennicæ A, III. 129, 38 pp.

Gibbard, P.; Forman, S.; Salomaa, R.; Alhonen, P.; Jungner, H.; Peglar, S.; Suksi, J. & Vuorinen, A., 1989. Late Pleistocene stratigraphy at Harrinkangas, Kauhajoki, western Finland. Ann. Acad. Sci. Fennicæ A, III. 150, 36 pp.

Gibbard, P.L. & Turner, C. 1990. Cold stage type sections: some thoughts on a difficult problem. Quaternaire 1, 9—16.

Haavisto-Hyvärinen, M.; Kielosto, S. & Niemelä, J., 1989. Precrags and drumlin fields in Finland. Sedim. Geol. 62, 337—348.

Hedberg, H., D., 1976. International stratigraphic guide. J. Wiley & Sons, New York.

Hirvas, H.; Alftan, A.; Pulkkinen, E.; Puranen, R. & Tynni, R., 1977. Raportti malminetsintää palvelevista maaperätutkimuksista Pohjois-Suomessa vuosina 1972—1976 (A report on glacial drift investigations for ore prospecting purposes in Northern Finland 1972—1976). Geol. Surv. Finland, Rep. Invest. 19, 54 pp.

Hirvas , H. & Nenonen, K., 1987. The till stratigraphy of Finland. Geol. Surv. Finland, Spec. Paper 3, 49—63.

Hirvas, H.; Lagerbäck, R.; Mäkinen, K.; Nenonen, K.; Olsen, L.; Rodhe, L. & Thoresen, M., 1988. The Nordkalott Project: studies of Quaternary geology in northern Fennoscandia. Boreas 17, 431—437.

Iisalo, E.; Kurkinen, I. & Niemelä, J., 1974. Moreenipeitteisiä harjuja Pohjanmaalla. Geologi 26, 51—52.

Kurkinen, I.; Niemelä, J. & Tikkanen, J., 1989. Hienoainesmoreenia harjudeltan pohjalla. (Fine-grained till underneath an esker delta). Geologi 41, 47—50.

Mangerud, J., 1990. The Scandinavian ice sheet through the last interglacial/glacial cycle. Paläoklimatologie, Mainz. (In press).

Miall, A.D., 1983. Principles of sedimentary basin analysis. Springer Verlag, New York.

Nenonen, K. 1986. Orgaanisen aineksen merkitys moreenistratigrafiassa (The significance of organic material in till stratigraphy). Geologi 38, 41—44.

Niemelä, J., 1978. Etelä-Pohjanmaan sora- ja hiekkamuodostumien geologinen tausta. (The geological background of the sand and gravel deposits of Southern Ostrobothnia). Rakennusgeologinen yhdistys r.y:n julkaisu 12 91, 1—15.

Niemelä, J. & Tynni, R., 1979. Interglacial and interstadial sediments in the Pohjanmaa region, Finland. Bull. Geol. Surv. Finland, 302, 48 pp.

Niemelä, J. & Raikamo, E. 1983. Kallion ja maaperän omaleimaisia piirteitä. In: Kauhajoen Luonnonkirja. (Eds. J. Kleemola, T. Malmivaara, P.V. Rantaja and H. Taimi), 9—23. Lions Club: Kauhajoki.

Nystuen, J.P., (ed). 1989. Rules and recommondations for naming geological units in Norway. Norsk Geol. Tidsskrift, Vol. 69, (Suppl 1), 111 pp.

Peltoniemi, H.; Eriksson, B.; Grönlund, T. & Saarnisto, M. 1989. Marjamurto, an interstadial site in a till-covered esker area of central Ostrobothnia, western Finland. Bull. Geol. Soc. Finland 61:2. (In press).

Punkari, M., 1980. The ice lobes of the Scandinavian ice sheet during the deglaciation of Finland. Boreas 9, 307—310.

Rainio, H. & Lahermo, P., 1976. Observations on dark grey basal till in Finland. Bull. Geol. Soc. Finland 49, 137—152.

Rainio, H. & Lahermo, P., 1984. New aspects on the distribution and origin of the so-called dark till. Striae 20, 45—47.

Raukas, A., 1986. Deglaciation of the Gulf of Finland and adjoining areas. Bull. Geol. Soc. Finland 58:2, 21—33.

Salonen, V.-P., 1986. Glacial transport distance distributions of surface boulders in Finland. Bull. Geol.Surv. Finland, 338, 57 pp.

West, R.G., 1989. The use of type localities and type sections in the Quaternary, with special reference to East Anglia. In: Rose, J. & Schlüchter, Ch. (eds). Quaternary Type Sections: Imagination or Reality ? , 3—10. Balkema, Rotterdam.

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