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GLACIAL MORPHOLOGY AND ICE LOBATION IN SOUTHERN FINNISH LAPLAND

by
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The development of active-ice landforms from drumlins and flutings to ribbed moraines in the Kuusamo area ice-lobe indicates changing basal conditions of the glacier during the Late Weichselian deglaciation in southern Finnish Lapland. The large Kuusamo drumlin field in the eastern part of the Kuusamo ice-lobe reflects warm-based glacial conditions at the marginal part of the glacier while at the same time the central part of the lobe remained cold-based. Ribbed moraine morphology is common in the central and western parts of the Kuusamo ice-lobe.

The formation of ribbed moraines is closely related to the retreating boundary of cold- and warm-based glacier, in an internal part of the glacier margin during deglaciation.

The development of glacial landforms indicates fast flowing or even a surging type ice stream during deglaciation. A rapid climate warming at the end of the Younger Dryas has increased marginal and surface melting in the marginal parts of the ice-sheet. Simultaneously, the increase of snow accumulation in the central part of the ice lobe has caused an imbalance between the mass of the glacier's centre and the margin, which led to a fast movement of ice towards the margin.

Key words (GeoRef Thesaurus, AGI): glacial geology, glacial features, drumlins, ribbed moraines, deglaciation, glacial lobes, subglacial environment, Weichselian, Kuusamo, Ranua, Finland.

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INTRODUCTION

Glacial landforms have been successfully used to reconstruct glacier dynamics and lobe formation during the last decades. An interpretation of glacial morphology based on aerial photos and satellite images, of which the latter have been in use since the 1980's, from the entire glaciated terrain of the Northern Hemisphere. Active-ice landforms like drumlins and flutings are mainly associated with the warm-based subglacial conditions and indicate deposition in the marginal parts of actively moving ice-lobes (e.g. Aario 1990). The reconstruction of glacial processes and glacial dynamics has also been done in the central part of continental glaciers in Scandinavia and North America (e.g. Clark 1997, Punkari 1997, Kleman et al. 1997, Hättestrand 1997, Kleman & Hättestrand 1999, Sarala 2005a). The studies were mainly based on the use of subglacial transversal moraine formations like ribbed moraines and Veiki moraines with streamlined features (e.g. Hättestrand 1997).

Southern Finnish Lapland has been repeatedly situated in the central region of the last Scandinavian glaciation. Investigations for Quaternary geomorphology, sedimentology and stratigraphy have been done in many phases from the 1960's to present day in the area (e.g. Korpela 1969, Aario 1977, Kurimo 1977, Aario & Forsström 1979, Sutinen 1984, 1992, Aario 1990, Aario et al. 1997, Sarala et al. 1998, Sarala 2005a, b and c, Sarala 2006, Sarala et al. 2006). Studies were based on aerial photo interpretation, digital elevation models and test pit surveys together with analysis of spatial indicators of ice movement directions, including striae, till fabrics and the orientation of morainic landforms.

The glacial morphology in southern Finnish Lapland is dominantly composed of an assemblage of active-ice morainic landforms including streamlined features like drumlins and flutings and transverse ribbed moraines (Fig. 1) (Sarala 2005a). Large areas are also covered with relatively thick basal till deposits or thin, gently undulating till cover with a clear indication of bedrock topography (for example in the area from Ranua to the west). Based on the till stratigraphy, only two glaciation phases have existed during the Weichselian age (Sarala 2005b).

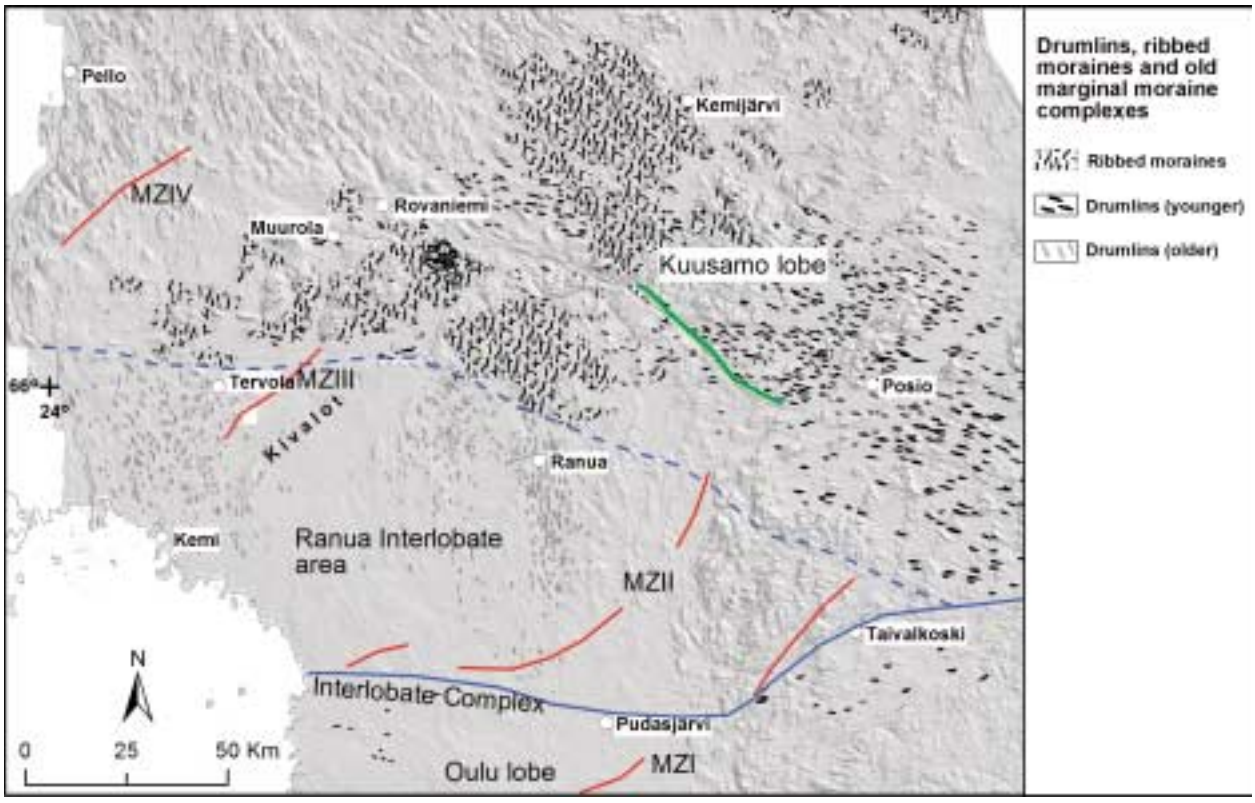

Fig. 1. The occurrence of streamlined drumlins and flutings with transverse ribbed moraines and old marginal zones MZI-MZIV (red) in southern Finnish Lapland. Digital elevation model © National Land Survey of Finland, permit No. 26/LA/07

DRUMLINS IN KUUSAMO AND RANUA

In Koillismaa area, around Kuusamo, thousands of drumlins and flutings occur forming the Kuusamo drumlin field (Glückert 1973). This drumlin field is one of the largest fields in Finland with an extent over 10,000 km^2. Ice flow has been from the northwest to the southeast during the formation of the main field. There also exists an older drumlin field below the younger one with a west-east orientation indicating an early ice flow phase (Tuoppajärvi) of the last deglaciation (Aario & Forsström, 1979).

The north-northwest to the southeast-oriented large hills and topographic depressions, presently seen as lakes and hills, are in places (for example on northern side of Taivalkoski), an indication of glacial advance before the Late Weichselian glaciation in the Kuusamo area. In the area of Ranua and towards the west, the same ice-flow phase is seen as a drumlin field. Drumlins are large with a clear indication of ice-flow from the north/northwest. There are only minor indications (western fabrics in the uppermost till and reshaped surface of some drumlins) of a later glacial advance, which overrode an older glacial morphology (Sarala 2005a, Sarala & Rossi 2006).

Glacial morphology at Oivanki (Fig. 2), northwest from the centre of Kuusamo, is composed of large, well-developed drumlins deposited during the WNW oriented (ca. 290°) ice-flow (Sarala et al. 2006). Drumlins in this area are usually long (1–2 km) and narrow (200–500 m), and both the proximal and distal ends are tapered from the ground. The distal tail is usually somewhat narrower than the proximal end. Sometimes complex drumlins, which have grown together in the middle or at the proximal end, are also seen.

A drumlin in Korkea-aho is composed of two till units (Fig. 3). The upper one is brownish-grey till with a sand matrix having a compact and mas-

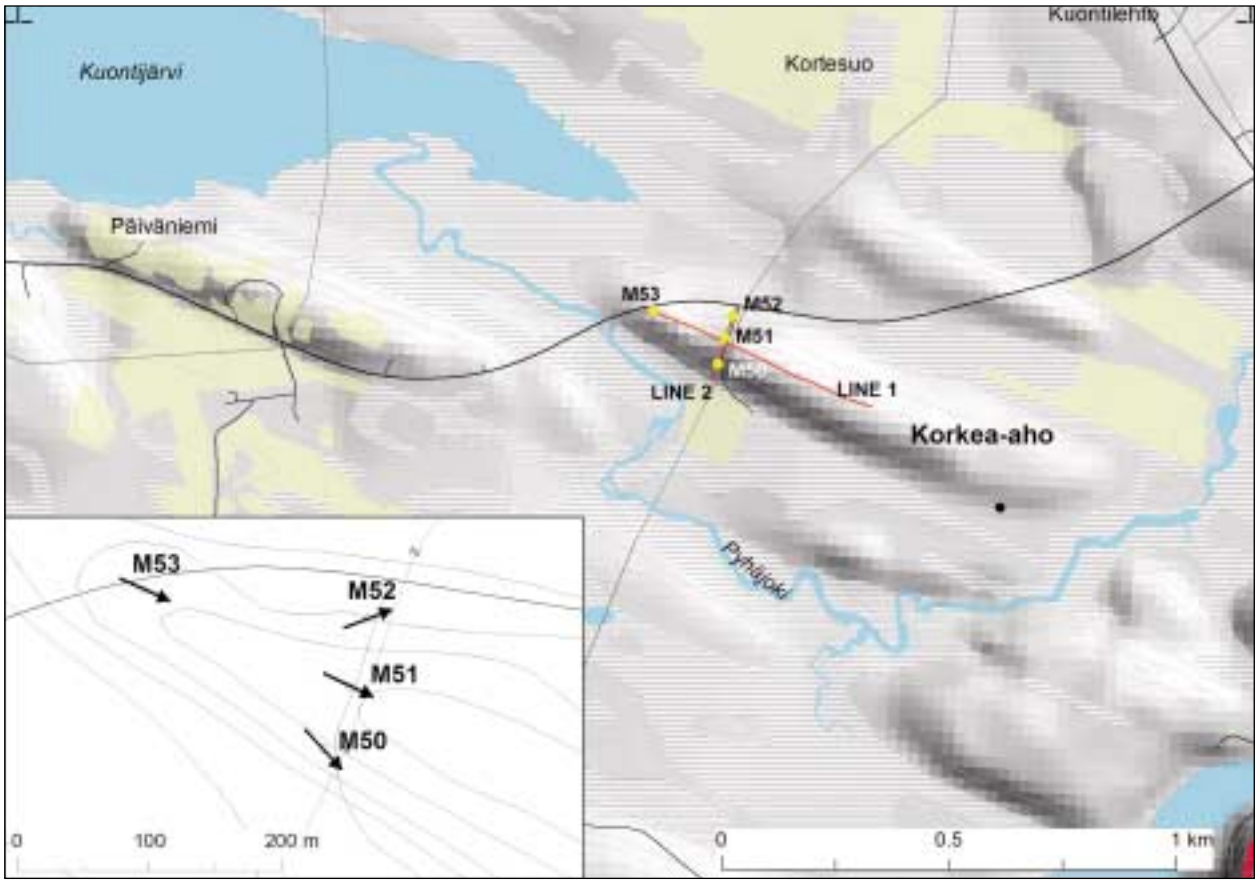

Fig. 2. Topographic map of the drumlins in Korkea-aho, Oivanki, Kuusamo. GPR (80 MHz) sounding lines 1 and 2 are marked as red lines. Till fabric of the upper till unit in different test pits (M50-M53) are presented in the lower left corner. Digital elevation model, topographic features and roads © National Land Survey of Finland, permission number 26/LA/07.

sive structure. Some fissility and thin sandy or silty stripes can be seen as a mark of subglacial deposition. The boulder and pebble content is moderate and the roundness is good. The petrographic composition of pebbles indicates long glacial transportation. Clast fabric measurements were only from this till unit in the topmost part of the ridge, showing the same orientation with a drumlin long axe (Fig. 2). Clast fabric measurements carried out in southern and northern marginal parts of the ridge showed that the stones have turned gently away from the drumlin's centre line. This is either the result of primary deposition or could also reflect secondary flow or mass-movement in the marginal parts of the ridge.

The lower till unit is composed of grey, silty or sandy till having a mostly massive structure and in places, slightly laminated parts are also seen. In a GPR (80 MHz) profile, it was possible to see that the lower till unit (Fig. 4) occurs on the southern part of the drumlin body. The older ice-flow direction has been from the northwest and till has probably been deposited during that flow phase on the stoss side of the bedrock top in the middle of the ridge. In between the tills, there is a unit of sandy/silty layers.

Fig. 3. Two till units in test pit M53 on the proximal part of the drumlin at Korkea-aho, Kuusamo. The upper till unit is composed of homogenous sandy till with fissility, typical of subglacial lodgement till. Lower till includes sorted sandy lenses and bands indicating deposition as subglacial melt-out till. Photo P. Sarala.

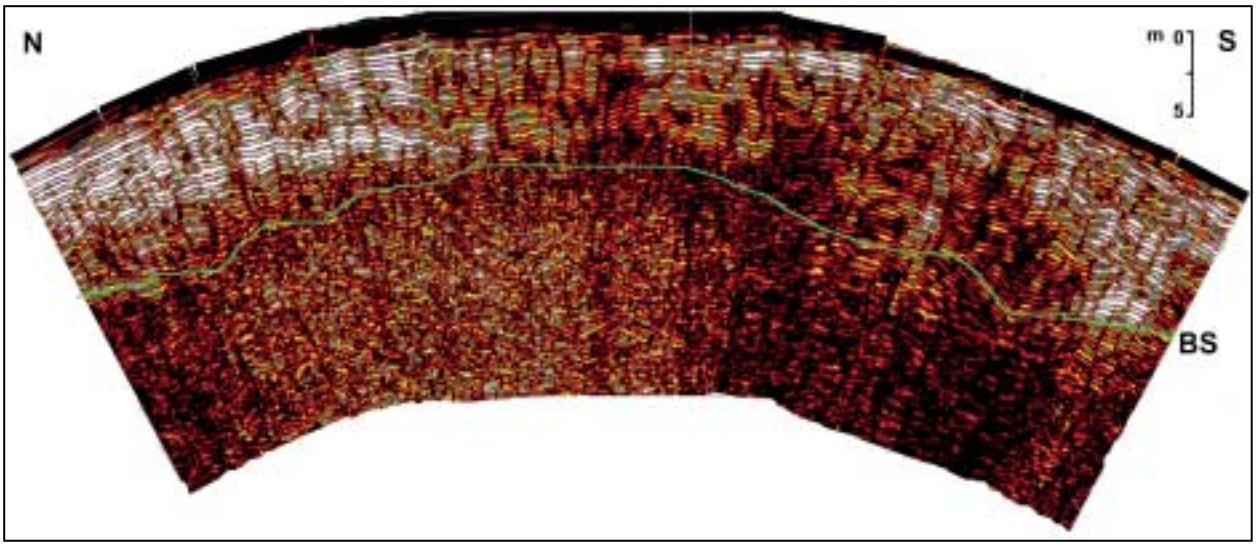

Fig. 4. GPR (80 MHz) sounding line 2 (see Fig. 2). Brownish red area above the bedrock surface (BS), on the southern side of the bedrock top is depicting lower till unit. The upper till is seen as a light grey color on the upper part of the ridge body. Between the tills occurs a unit of sandy and fines layers, sometimes also a boulder pavement.

RIBBED MORAINES IN SOUTHERN FINNISH LAPLAND

Ribbed moraines exist as uniform fields on lowland areas at the western parts of Kusamo ice-lobe and are mainly composed of Rogen moraine or hummocky ribbed moraine types (cf. Hättestrand 1997, Sarala 2003). Furthermore, a small area of minor ribbed moraines occurs in the Sihtuuna area (cf. Aario et al. 1997).

The Ranua ribbed moraine field is one of the three ribbed moraine areas in southern Finnish Lapland (cf. Sarala 2006). It was initially described by Aario (1977) and is based on his large field study data from the area. The field is composed of transverse moraine ridges, which are usually 5–15 m high, 100-150 m wide and up to one kilometre long (Fig. 5). The form of ridges is often crescentic where the edges are pointing the down-ice direction. These forms represent Rogen moraine types described by Lundqvist (1969). The hummocky ribbed moraine type (cf. Hättestrand 1997, Sarala 2003, 2006) is also common, although not with a clear indication of the ice-flow direction. Characteristically, mires and little lakes occupy depressions between the ridges (Fig. 5) and the ridge surface is mostly covered with boulders.

The ridges are composed more or less regularly of two till facies. A more densely packed lodgement and melt-out till with a fine-grained matrix occurs at the base (Fig. 6) while homogeneous melt-out and flow till occurs at the surficial parts. Pebble content increases while the roundness of pebbles decreases towards the top. The transport distance of stones is also longest at the bottom. On the surface and in the uppermost till, boulders indicate local variation of the underlying bedrock composition with very short, usually only some hundreds of meters long, transport distance. This feature has been used to trace mineralized boulders in the area (Aario et al. 1985, Aario 1990, Aario & Peuraniemi 1992). Sandy layers or stone pavements sometimes exist at the boundary between two units, although usually the contact is difficult to distinguish.

The third, bluish grey till unit (Fig. 6) is also found in places on topographic depressions, like in-between the bedrock tops. The till is clay-rich, matrix supported, compact and homogenous, indicating basal deposition, mainly by a lodgement process. Since the surface of this till is usually 6-8 m from the surface, it is hard to reach by tractor excavations but can be recognised from the ground penetrating sounding profiles (cf. Aario 1990).

Fig. 5. Part of the ribbed moraine field near the Portimojärvi village in Ranua. Test pits dug during 2005 are marked as M54-M58. Digital elevation model, topographic features and roads © National Land Survey of Finland, permission number 26/LA/07.

Fig. 6. The two lowest till units in test pit M55 at Portimojärvi, Ranua. A sharp contact between the bluish grey (bottommost) and grey tills are seen at the base of the section at a depth of about seven meters. Iron-stained, brown bands indicate the groundwater level variation. Photo P. Sarala.

GLACIAL DYNAMICS DURING THE FORMATION OF GLACIAL MORPHOLOGY

Drumlins appear to be partly erosional features but also depositional forms. The stratigraphy presented by Aario and Forsström (1979) from the Soivio area, southern Kuusamo, proved that till(s) in deeper parts of the drumlin body was deposited during the earlier Tuoppajärvi ice-flow phase, which was a single comprehensive flow unit in the Koillismaa area during the early deglaciation. The radar data from the Oivanki area (Fig. 4) shows indications of tills deposited most likely during the older glacial advance from the north-northwest. The upper parts of drumlin bodies, instead, are clearly formed by growth beneath the ice that flowed in the same direction as the lineation of drumlins. The deposition as basal lodgement and/or melt-out tills with stratified inter-till layers suggests that the subglacial conditions were mainly warm-based. The bedrock core in the case of Korkea-aho has been a shelter against the glacial erosion, thus explaining why the older deposits on the southern side of bedrock tops have been preserved.

Sarala (2006) indicated that ribbed moraine formation was a result of subglacial fracturing, mass movement and subsequent quarrying. The formation of ribbed formations initially occurred at the boundary between the frozen core and thawed or partially thawed, subglacial conditions (Fig. 7). This boundary existed about 100–150 km from the ice margin and the boundary retreated against the glacier core simultaneously with the marginal melting. Subsequently, after the fracturing and movement of subglacial ice-sediment blocks variable pressure conditions under the moving ice-sheet initiated the freeze-thaw process that caused the subglacial quarrying and deposition of local bedrock material on the ridge tops.

The glacial morphology in southern Finnish Lapland is indicative of ice-lobe development during the latest melting phase of the Scandinavian Ice-Sheet. As deglaciation continued and the ice margin reached the area of the modern border in eastern Finland, rearrangement occurred and the ice-lobes of Kuusamo and Oulu were formed. The Oulu lobe in the southern parts of the area contin-

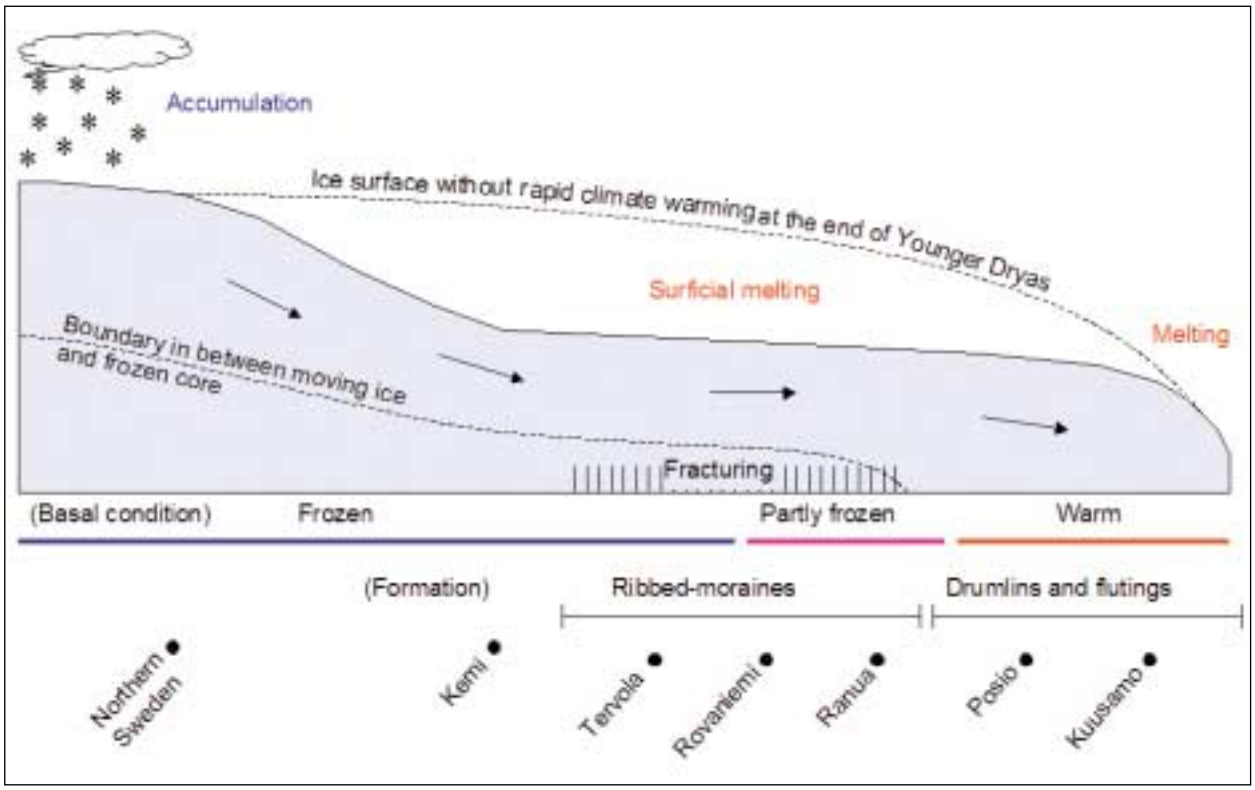

Fig. 7. A rapid marginal melting and precipitation with a subsequent increase of accumulation in the central parts of the glacier has sped up the flow rate of the Kuusamo ice-lobe. The ribbed moraine formation seems to be closely related to the retreating boundary of the cold- and warm-based glacier.

ued flowing from west to east but in the north, the flow direction of the Kuusamo lobe was turned from the northwest towards the Oulu lobe. A large Pudasjärvi-Taivalkoski-Hossa Interlobate Complex was initially formed into the contact between the Kuusamo and Oulu lobes (Aario 1977, 1990, Aario & Forsström 1979) but later on, at the second phase, at the contact between the Oulu lobe and the southern margin of Ranua Interlobate area (Sarala 2005a).

A large Kuusamo drumlin field in the east indicates warm-based glacial conditions at the outer margin of Kuusamo ice-lobe. In the central and western parts of the ice lobe area, the ribbed moraine fields of Ranua, Tervola and Kemijärvi were formed. The ribbed moraine formation was interpreted to be closely related to the retreating boundary of cold- and warm-based glacier, in an internal part of the glacier margin during deglaciation (Kleman & Hättestrand 1999, Sarala 2005a). A rapid marginal melting, increased precipitation and accumulation in the central parts of the glacier increased the flow rate of the Kuusamo ice-lobe (Fig. 7). Thus, the development of active-ice landforms from the eastern part of the Kuusamo ice-lobe to the west is indicative of fast flowing, even a surging-type ice stream during deglaciation (cf. Hart 1999).

AGE OF DEPOSITION

Based on the latest dating results, the build-up of glacial morphology in southern Finnish Lapland can, in most cases, be dated back to the Middle and Late Weichselian (Mäkinen 1999, 2005 and Sarala 2005a and b). The Middle Weichselian glacial advance was the first to cover the southern Finnish Lapland area after the Eemian interglacial. The Early Weichselian glacial advance(s) was probably so weak that it affected only the area of central and/or northernmost Finnish Lapland (cf. Svendsen et al. 1999, 2004, Siegert et al. 2001, Arnold & Sharp 2002).

The rapid warming of the climate at the end of the Younger Dryas (12.8-11.6 ka ago) (cf. Boulton et al. 2001, Bard 2002) increased mean temperature from 8–10°C during a few hundreds of years, causing a strong melting of the glacier margin and surface (Fig. 7). An imbalance between the warm surface and cold-based part of the moving ice sheet followed and might be the reason for the initiation of ribbed moraine formations in the core areas of the latest glaciers in the northern hemisphere (Sarala 2005a). Similar rapid climate change has not happened since, so it could be an explanation why the ribbed moraines are not present in modern glaciated areas.

The Ranua interlobate area in between the Kuusamo and Oulu lobes with the north-northwest to south-southeast oriented drumlin field is a relict from the older, probably the Middle Weichselian glacial phase (Sarala 2005a, Mäkinen 2006) and has been preserved under the cold-based, central area of the Late Weichselian glaciation.

DISCUSSION AND CONCLUSIONS

This study was based on the interpretation of glacial landforms with stratigraphical studies in the test areas in Kuusamo and Ranua, southern Finnish Lapland. As several earlier studies prove, the active ice landforms are useful in reconstructing glacial dynamics during deposition. Landforms like drumlins, flutings and ribbed moraines indicate the presence of active ice-lobes after the separation of the ice-sheet margin during deglaciation. In many cases, the interpretation of glacial morphology is difficult due to the existence of interlobate areas between the active lobes. As a relict of the cold-based glacier core and having only minor marks of basal movement, older glacial morphology has been preserved under passive interlobate areas (cf. Sarala 2005a). Thus, the glaciogenic landforms of different ages can be found in the same area or even overlapping each other.

The glacial morphology in southern Finnish Lapland is dominantly composed of assemblages of active-ice morainic landforms including streamlined drumlins, flutings and transverse ribbed moraines. These forms are the dominant landform types in the area of the Kuusamo ice-lobe and indicate the Late Weichselian glacial morphology. Instead, the Ranua

interlobate area with the north-northwest to south-southeast oriented drumlin field is a relict from the older, probably Middle Weichselian glacial phase and was preserved under the cold-based, central area of the Late Weichselian glaciation. According the latest dating results (Mäkinen 2005, Sarala 2005a and b), the Middle Weichselian glacial phase was the first one to cover the southern Finnish Lapland area after the Eemian interglacial.

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