The changing landforms of Finland

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This paper examines briefly the general outlines of the relief in Finland, bedrock and surficial landforms, their origins, and the factors that have affected their development. The basic framework for the relief in Finland is formed by the highly eroded Precambrian bedrock, between 3,000 and 1,500 million years of age. It is covered in most places by a 3–4-metre layer of much younger and clearly distinct surficial deposits. The ancient fold mountains that occupied the area of Finland have been worn down by weathering and erosion processes to form a fairly even peneplain with a mean height above sea level of 154 metres and a maximum height of 1,328 metres (Halti). About 80 percent of the country's surface area consists of low-lying land below 200 metres above sea level.

The fractured nature of the bedrock is reflected in the existence of elongated fissure valleys and fault cliffs, and rift valleys and erosion-smoothed horsts in places. Quartzite deposits, in particular, frequently stand out from their environment to form monadnocks. The remains of nine ancient meteorite craters have also been found in the bedrock. The most common type of surficial deposit is till, characteristically in the form of glaciogenic hummocky moraines, drumlins and end moraines, while glaciofluvial landforms, such as eskers, deltas, kame fields, and large ice-marginal complexes such as the Salpausselkä moraines, are also among the basic elements of the topography. The most notable among the landforms dating from after the deglaciation (12,000–9000 years ago) are clay plains, river valleys, beach and dune formations and mires. Particularly the glaciofluvial landforms have been badly spoiled by human activity in places, in the form of the large-scale extraction of sand and gravel.

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Introduction

The relief in Finland has been substantially evened out in general terms, although its more detailed topography is still highly variable. The topography as a whole is determined by the interaction of two elements, the solid bedrock and the loose surficial deposits. The boundary between the two is usually a very clearly defined one in Finland (Aartolahti 1990), on account of the fact that the older weathered layers were efficiently removed by glacial erosion. Such layers are to be found nowadays only in the ice divide zones of northern Finland, where glacial erosion was ineffective.

The mean height above sea level in Finland is 154 metres (Seppälä 1986) and the highest point, the fjeld of Halti on the border with Norway, 1,328 metres. Uplands above a level of 200 metres above sea level account for only 20 percent of the country's surface area, being located mostly in the east and north. Continuous areas of land of 300 metres in altitude are to be found only in north-western Lapland (Tikkanen 1994). The areas that lie below 100 metres above sea level form a strip some 30–100 kilometres wide along the coast and penetrate further inland along the banks of the main river systems flowing out of the Lake Region in Central Finland (CD-Fig. 1).

The present-day pattern of relief is the result of a long and varied history of geomorphological processes. The basis of the earth's crust in the area is formed by the ancient bedrock, which has assumed its present shape as a consequence of ancient folding, tectonic movements, and periods of erosion. The vast majority of the Finnish bedrock is aged between 3,000 and 1,500 million years, and there are only very restricted areas of rocks that are younger than this. Most of it is composed of granitic igneous rocks and crystalline schists. The area of Finland forms part of the Fennosarmatian bedrock craton, which borders on the considerably younger Caledonian mountain zone of Scandinavia in the west and north (Korsman & Koistinen 1998). Younger sedimentary rocks overlay the bedrock to the south and east from Finland.

The bedrock of Finland is either exposed at the surface or covered by younger sedimentary layers. The thickness of these loose deposits is in general no more than 3–4 metres, and it is only in certain places that accumulations of over 100 metres have been observed, in connection with specific glaciofluvial landforms (Aartolahti 1990; Taipale & Saarnisto 1991). The loose deposits mostly date back only to the Quaternary glaciation or afterwards, and the country's glacial topography may be said to have received more or less its present shape during the deglaciation stage, some 12,000–9000 BP (Aartolahti 1990; Tikkanen 1994; Saarnisto & Salonen 1995).

Although the earth's crust in the area of Finland had already been reduced to a peneplain by the end of the Precambrian, many changes in the relief have taken place since that time. The last major event in this process was the action of the ice during the last glaciation, which is estimated to have lowered the general relief by 7–25 metres and refashioned the surface topography with new depositional landforms (Taipale & Saarnisto 1991). The various post-glacial stages in the history of the Baltic Sea have subsequently given rise to thick clay deposits. The mires that have grown up in the lower-lying depressions have further evened out the irregularities in the post-glacial land surface. The most recent alterations in the surface topography may be ascribed to the action of flowing water, waves, winds, and human activity.

The following is a brief review of the stages in the development of the relief in Finland and a summary of the principal types of landforms.

Origins of the bedrock and its influence on relief

The oldest parts of the bedrock of Finland, located in the eastern and northern parts of the country, date back some 2,800–2,700 million years, having arisen in the course of the Late Archaean orogeny (Simonen 1980, 1990). This folding phase associated with tectonic movements also involved volcanic activity, during which vast masses of molten rock were discharged on the surface. This was followed by a long peaceful period in the course of which the high mountains were gradually reduced to a gently sloping peneplain, the weathering products being deposited as a sedimentary layer on top of the bedrock. The ancient volcanoes have similarly been worn away, so that only their bases are visible on the surface today (Fig. 1).

The majority of the bedrock nevertheless originates from the next period of folding, the Svecofennian orogeny, 1,900–1,800 million years ago (Korsman & Koistinen 1998). The metamorphic rocks that arose from it were mixed with granitic and granodioritic igneous rocks and the volcanoes again discharged their magma onto the land surface. This gave rise to extensive areas of igneous rocks in southern and central Finland and in Lapland. This orogeny created chains of mountains several kilometres in height across the country, but these were again eroded away during the Precambrian era. The thickness of the earth's crust in the area of Finland is 40–60 kilometres, although erosion has reduced the figure by an estimated 15 kilometres (Korsman & Koistinen 1998: 102).

The rocks that date from after this orogeny include the rapakivi granites of south-eastern and south-western Finland, of age around 1,600 million years. Their surfaces have been weathered down by as much as 1–2 metres in places. The sedimentary rocks are represented by the 1,400–1,300-million-year sandstones and claystones of the Gulf of Bothnia area and of the Muhos and Satakunta depressions, which were penetrated by large amounts of dark-coloured diabase some 1,270 million years ago. In addition one of the consequences of the Caledonian orogeny some 450–400 million years ago was that an overthrust plate extended into the area of Finland. Its remains are visible in the extreme north-west, in Enontekiö (Simonen 1980, 1990; Lehtovaara 1989; Korsman & Koistinen 1998). The fjeld schist that forms the top layer of this plate, being a highly resilient rock, has protected the underlying sedimentary rocks from weathering, as may be seen on the fjelds of Saana and Saivaara, for instance (Fig. 2).

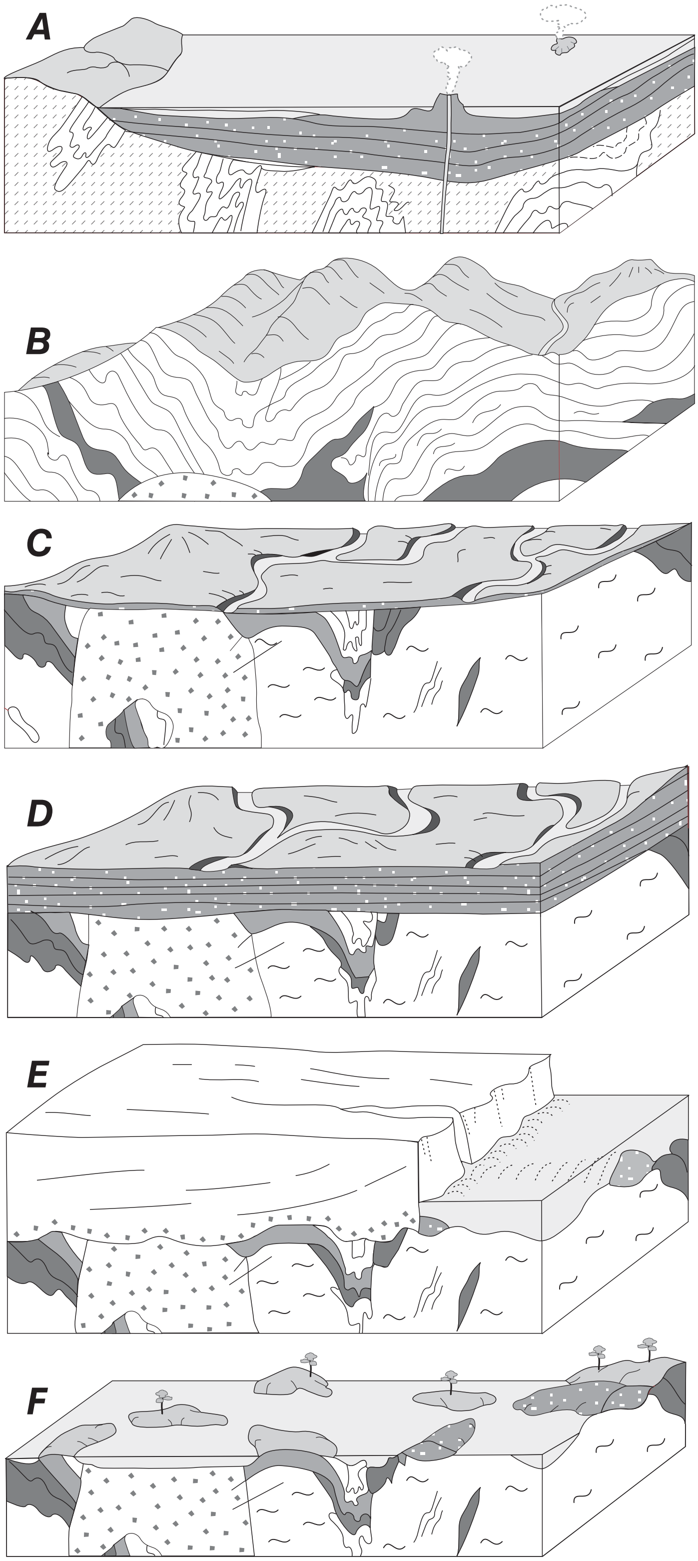

Fig. 1. Development of the archipelago in south-western Finland
(A) The sinking seabed gains deposits of weathering products from the nearby mainland, mainly sand and clay, and volcanoes discharge basaltic lava through these sediments.
(B) Orogenic processes form these deposits into crystalline schists, gneisses, and amphibolites at the same time as grey granite and dark, silica-poor rocks are introduced. As a consequence of erosion, the granite dome that had formed deep in the crust begins to rise towards the surface.
(C) As erosion continues, the mountains resulting from the orogenic processes, often several thousand metres in height, are reduced to a peneplain and the granite dome reaches the surface.
(D) The land is submerged beneath the sea from time to time, and sediments accumulate on the eroded bedrock surface, only to be eroded in turn as time goes by.
(E) The ice sheet advances over the area a number of times during the Quaternary, removing all the deposits of weathered material and replacing it with layers of till, gravel, and sand.
(F) The ice sheet has melted and the land surface has risen close to sea level. The bedrock outcrops and the crests of the eskers and till ridges protrude from the sea to form islands. The archipelago has emerged. Modified from Edelman (1974).

Fig. 2. Sedimentary rocks are overlain by the Caledonian crystalline schists and gneisses on the hill of Saivaara in Enontekiö, extreme northwest of Finnish Lapland. (Author's photo, 06/78)

Transport by plate-tectonic movements

Apart from giving rise to high mountain chains in the area of Finland, the tectonic movements also transported the whole of the Fennoscandian region on its continental plate from one part of the earth's surface to another in the course of time. This has been shown by means of latitudinal measurements of the location of the territory of Finland at different points in time, as determined from palaeomagnetic measurements performed on radiometrically dated rocks, although the method cannot be used for determining longitude (Pesonen & Mertanen 1990).

The measurements indicate that Finland and its continental plate spent long periods in the relatively warm climatic zones close to equator at one stage (Fig. 3), which must have accelerated weathering and the erosion of the land surface. At the time of folding of the oldest parts of the Finnish bedrock, Fennoscandia was nevertheless located just as far north as at present. It was only after that that the continental plate began to drift south, so that at the time of the Svecofennian orogeny Finland laid south of the Tropic of Cancer. From this point it continued further south, and by the emergence of the rapakivi granites and diabases it was located in the hot equatorial zone (Pesonen et al. 1989; Pesonen et al. 1991).

The plate movements then carried the Fennoscandian land mass still further south, until just under 1,000 million years ago it had reached the Antarctic Circle. From there its course was reversed, until it reached the Equator once more just under 400 million years ago. The Fennoscandian land mass has thus travelled to its present northerly location within the last 300 million years (Fig. 3). The mean rate of movement of the continental plate has been about two centimetres a year, although at its fastest it has reached almost ten centimetres a year (Pesonen & Mertanen 1990).

Reminders of the long migration of the Fennoscandian land mass exist in the form of the remains of weathering that took place under tropical climatic conditions and glacial deposits traceable to conditions of extreme cold. There are also signs that numerous meteorites fell in the area of Finland during these migrations. Nine craters of this origin have been discovered so far. The youngest is the basin of Lake Lappajärvi in Ostrobothnia, created some 77 million years ago and previously thought to be the crater of a former volcano (Lehtinen 1976). Considerably older than this is the circular area of flat agricultural land south of Vaasa that marks the Söderfjärden impact crater (Fig. 4), the edge of which rises some 20–40 metres above its surroundings (Lehtovaara 1992; Tikkanen 1994: 187). The other craters are the lakes Sääksjärvi in Satakunta, Iso-Naakkima

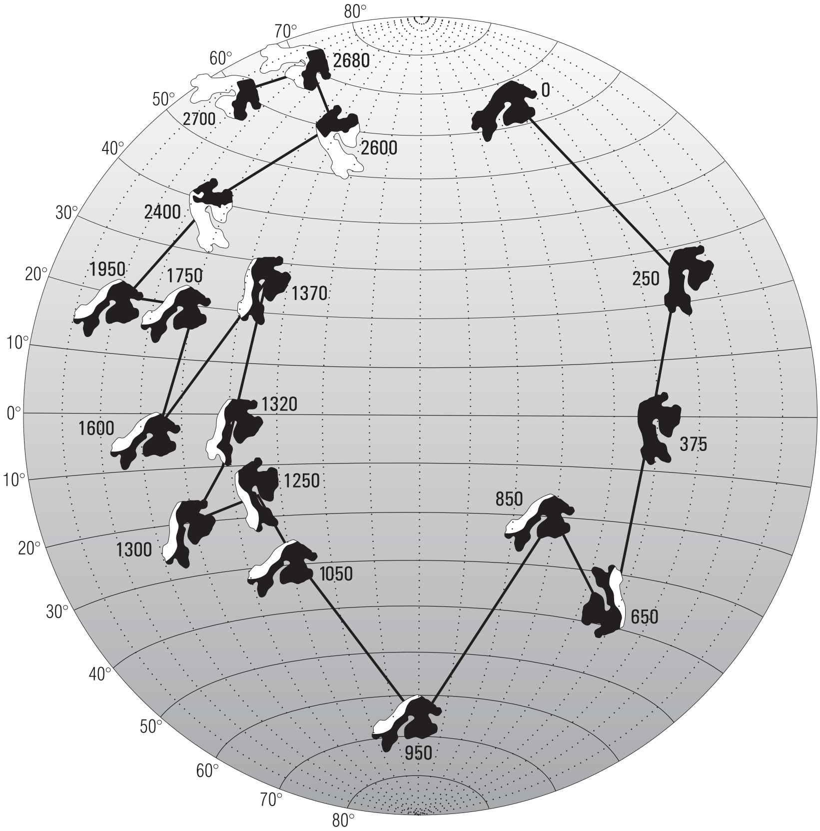

Fig. 3. Migration of the Fennoscandian continental land mass. The diagram depicts its movements over the earth's surface in a north–south direction from Late Archaean times up to the present. The time scale is in millions of years. The circular movement of the shield and the new bedrock areas added to Fennoscandia at different stages, indicated in black, are shown on the diagram.

Fig. 4. Deeply eroded remnant of the Söderfjärden meteorite impact crater, south of Vaasa. The diameter of the crater is five kilometres, and it is filled with sedimentary rocks and quaternary clay and silt sediments. (Author's photo, 07/94)

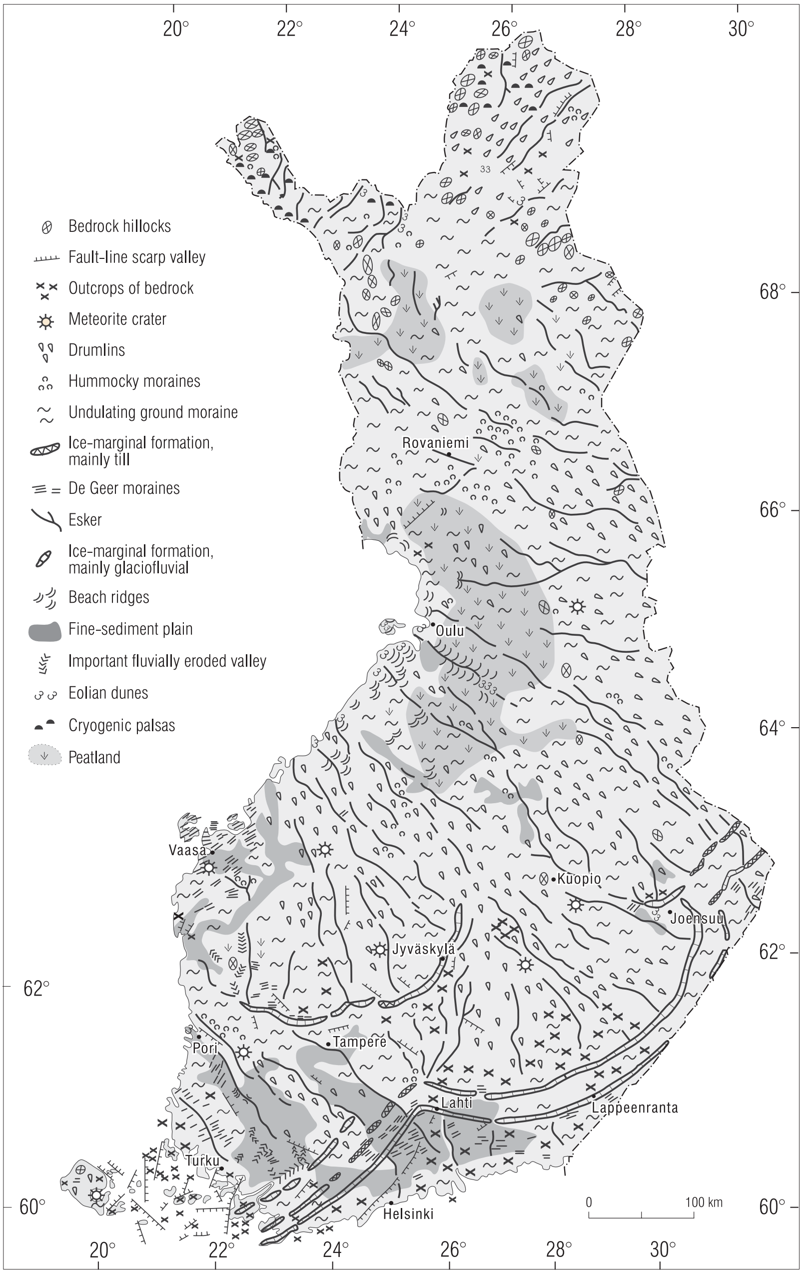

Fig. 5. Geomorphological map of Finland (modified mainly from Kujansuu & Niemelä 1984 and Fogelberg & Seppälä 1986).

near Pieksämäki, Suvasvesi in North Savo, Karikkoselkä in Petäjävesi, Saarijärvi in Taivalkoski, Paasselkä at Kerimäki, and the sea area of Lumparn on Åland. All of the craters are thus located in central and western Finland with the exception of Lake Saarijärvi in Taivalkoski (Fig. 5).

Bedrock topography

The effects of the ancient tectonic movements in the bedrock are still visible in many places. Lake Inari in northern Finland is located at least in part in a bedrock depression, or graben, and some of the groups of fjelds surrounding it are horsts rounded off by erosion. The tectonic movements in this area are thought to have taken place in the Tertiary, about 25–10 million years ago (Aartolahti 1990). Similarly the Satakunta and Muhos areas of sedimentary rocks on the west coast occupy graben formations, which are estimated to reach a depth of 600–1,000 metres (Elo et al. 1993). The Gullkrona graben in the Archipelago Sea in southwestern Finland still has its surface more than 40 metres below the level of the surrounding areas (Tikkanen & Westerholm 1992).

Also as a result of these movements the bedrock is broken up by numerous fault lines and fracture zones (Vuorela 1986). The impact of this may be seen in the landscape in the form of long, narrow, straightsided valleys edged by steep rock faces. In some places former sediments obscure these fault lines so that they are scarcely visible in the topography at all. The lakes and rivers nevertheless tend to favour fracture zones of this kind, and particularly Lake Päijänne and Lake Näsijärvi among Finland's largest lakes are located in zones of intersecting bedrock faults and fractures.

Apart from the depressions and protrusions brought about by tectonic forces, the relief also reflects the relative hardness of the various rock types, in that some remain stand out as others are eroded away, giving rise to monadnocks. The quartzite hills of eastern and northern Finland rise up several hundred metres above their surroundings, for instance, although the differences in relief attached to the other rock types are by no means so pronounced, e.g., the surfaces of the diabase dykes that cross the sandstones of Satakunta are around 50 metres above the surrounding terrain (Tikkanen 1981).

Topography of surficial deposits

The surficial deposits of Finland date largely from the last glaciation or from post-glacial times. The most common material covering the bedrock surface more or less throughout the country is a glacial till. On account of the active flow that took place in the glaciers, this till was deposited in places as streamlined ridges, or drumlins, that indicate the direction of movement of the ice. Individual drumlins can be as much as a hundred metres high and ten kilometres long (Tikkanen 1994) and they can occur in extensive fields or swarms in places in the Lake Region, eastern Finland or northern Lapland (see Glückert 1973). Most drumlins have a bedrock core, and some occur in conjunction with shallow flutings, which can differ in orientation from the drumlins themselves (Aario et al. 1974; Aario 1977; Heikkinen & Tikkanen 1989). The principal surficial landforms are detailed in Figure 5.

Rogen moraines, which are oriented perpendicular to the direction of ice movement, are usually regarded as glacial accumulation landforms (see Aario 1977). As they have sometimes been found to contain glaciofluvial material, their origins have also been linked to melting processes in a passive ice margin that have allowed gravel and sand sorted by the meltwater streams to be deposited in transverse cracks at the ice margin (Kurimo 1979). These landforms of height 5–15 metres are to be found in low-lying, flat areas in southern Lapland, Ostrobothnia and North Karelia, and would appear to be connected with the occurrence of drumlins and hummocky moraines.

Till material released from the ice during deglaciation can accumulate to form hummocky moraines of varying shapes. These are particularly common in southern Lapland, on the west coast and in eastern Finland. The most extensive area of hummocky moraines in northern Finland occupies some 1,600 square kilometres (Taipale & Saarnisto 1991). Individual hummocks are usually between 5 and 20 metres in height and do not normally have any distinct orientation, but elongated radial moraines are sometimes to found in association with them (Aartolahti 1995). There are ring-shaped mounds a few metres in height to be found in Lapland that have been termed Pulju moraines (Kujansuu 1967; Aartolahti 1974).

Till that has accumulated at an ice margin or in transverse cracks running parallel to the margin may be interpreted as forming end moraines, the largest of which in Finland are 20–30 metres high and located in conjunction with the Salpausselkä formations. Small end moraines, usually 1–3 metres high and 50–1,000 metres long and termed De Geer moraines, are to be found in swarms of several hundred at a time, especially in the subaquatic coast areas of southern and western Finland (Zilliacus 1987; Aartolahti 1995). Reference has been made to De Geer moraines when determining positions of the ice margin in western Finland (Aartolahti 1972).

The First and Second Salpausselkä Ice-marginal Formations constitute a zone some 20–50 kilometres wide and 600 kilometres long of broad glaciofluvial deltas and narrow chains of ridges running parallel to the ice margin stretching from South-western Finland well into the eastern part of the country. These formations are predominantly glaciofluvial, but they include some till forms. Other large formations of a similar kind are the Third Salpausselkä in western Finland and the Central Finland Ice-marginal Formation. These major marginal formations have arisen in front of the reactivated ice margin in the cause of a protracted stagnant phase. The Salpausselkä I and II Formations were laid down during the cold climatic period known as the Younger Dryas Stadial, being dated by reference to the varve chronology to 11,300–11,100 years ago and 10,800–10,600 years ago respectively. The whole deglaciation in Finland occupied the period 12,100–9,300 years ago (Saarnisto & Salonen 1995).

Apart from the major ice-marginal formations, large deposits of gravel and sand are to be found in the eskers that run across the country in chains that reach lengths of several hundred kilometres in some cases. The eskers are oriented approximately in the direction of glacial movement, and their examination in combination with the large marginal formations has enabled the flow pattern of a number of ice-lobes to be determined (Punkari 1993). The interlobate esker complexes lying between these are particularly prominent landforms (Taipale & Saarnisto 1991). Other smaller landforms that commonly occur in conjunction with the eskers and large glaciofluvial ice-marginal formations are kames, deltas, and sandurs in supra-aquatic areas.

The terrain in the southern and western coastal areas in particular is evened out somewhat by the presence of clay and silt deposits, which can be more than 70 metres thick (Haavisto et al. 1980). In many places rivers have gouged 20–30 metres deep valleys into these plains of fine-grained sediment in the course of post-glacial times, the slopes of these valleys being subsequently subject to landslip (Aartolahti 1975). Fluvial erosion has also been pronounced in the glaciofluvial fill material occupying some river valleys in northern Finland (Koutaniemi 2000). None of the rivers of Finland has succeeded in developing an extensive delta, as land uplift has been constantly shifting the river mouths further out to sea.

Since the majority of the area of Finland has been under water at some time or another, there are many places where beach ridges have been built up on slopes by wave action or shores have been eroded to leave cliffs or boulder fields. Beach ridges composed of sand are frequently to be found on the sides of eskers, and they are particularly common in the coastal zone bordering on the northern part of the Gulf of Bothnia (Helle 1965). The largest of these can be up to one hundred metres across and more than five metres high (Tikkanen 1981). Especially large, clearly defined shore landforms were laid down during the transgressive phases of the Ancylus Lake and Litorina Sea.

Active dunes can be found on the present-day sea shores mainly on the west coast (Alestalo 1979; Heikkinen & Tikkanen 1987; Hellemaa 1998), but most Finnish dunes are nowadays bound by a vegetation cover and exist in the interior of the country, most notably in eastern Finland and northern Lapland (Aartolahti 1980). The largest parabolic dunes in the upland area of Rokuanvaara, situated to the south-east of Oulu, for instance, are about 25 metres high (Aartolahti 1973). In the far north of Lapland, however, there are also some dune areas with vegetationless deflation surfaces, amounting to a total area of perhaps 300–400 hectares (Tikkanen & Heikkinen 1995; Käyhkö et al. 1996).

Mires cover almost a third of Finland's land area (see Seppä 2002). The peat in them can be over ten metres deep at its greatest. Since the mires are usually located in the lowest depressions, they also help to even out the topography, although raised bogs developing in flat clayey areas can rise as much as seven metres above their surroundings (Ikonen 1993). The formation of a mire can usually be traced back to either the paludification of forest land or the filling in of a lake basin with vegetation (Korhola 1990). The greatest proliferation of mires is in the aapa fen zones of North Ostrobothnia, Kainuu and central Lapland, while the aapa fens of northern Lapland commonly feature *palsas*, that is, mounds with a permafrost core that can reach heights of five metres or more (Seppälä 1979).

Man-made forms

The most rapid changes taking place in the forms of the land surface today are those brought about by human agency. The extraction of stone and loose materials for building and road construction purposes has quickly destroyed or eaten into many landscape elements such as eskers and bed-

Fig. 6. Original sharp-crested esker has been obliterated entirely by sand and gravel excavation at Raastaharju, Enontekiö. (Author's photo, 08/86)

rock outcrops (Fig. 6.), even ones of substantial size. At the same time, human activity has created new landforms such as embankments, cuttings, terraces, pits, and mounds composed of waste or landfill material (Tikkanen 1989). Human activity also has indirect effects on surficial landforms by enhancing or accelerating natural processes.

REFERENCES

Aario R (1977). Flutings, drumlins and Rogen-landforms. *Nordia* 2, 5–14.

Aario R, L Forström & P Lahermo (1974). Glacial landforms with special reference to drumlins and flutings in Koillismaa, Finland. *Geological Survey of Finland, Bulletin* 273, 1–30.

Aartolahti T (1972). On deglaciation in southern and western Finland. *Fennia* 114, 1–84.

Aartolahti T (1973). Morphology, vegetation and development of Rokuanvaara, an esker and dune complex in Finland. *Fennia* 127, 1–53.

Aartolahti T (1974). Ring ridge hummocky moraines in northern Finland. *Fennia* 134, 1–22.

Aartolahti T (1975). The morphology and development of the river valleys in southwestern Finland. *Annales Academiae Scientiarum Fennicae A III* 116, 1–72.

Aartolahti T (1980). Periglasiaalisen morfologian tutkimus Suomessa (Abstract: The research of periglacial morphology in Finland). *Terra* 92, 74–87.

Aartolahti T (1990). Suomen maankamaran vaiheet (Abstract: The development of the Earth's surface in Finland). *Terra* 102, 203–219.

Aartolahti T (1995). Glacial morphology in Finland. In Ehlers J, S Kozarski & P Gibbard (eds). *Glacial deposits in North-East Europe*, 37–50. AA Balkema, Rotterdam.

Alestalo J (1979). Land uplift and development of the littoral and Aeolian morphology on Hailuoto, Finland. *Acta Universitatis Ouluensis A* 82, *Geologica* 3, 109–120.

Edelman N (1974). Berggrund och ytformer. In Österholm H (ed). *Skärgård i omvandling*, 15–24. Nordenskiöld-samfundet i Finland, Helsingfors.

Elo S, T Kuivasaari, M Lehtinen, O Sarapää & A Uutela (1993). Iso-Naakkima, a circular structure filled with Neoproterozoic sediments, Pieksämäki, southeastern Finland. *Bulletin of The Geological Society of Finland* 65, 3–30.

Fogelberg P & M Seppälä (1986). Geomorfologinen yleiskartta 1:1 000 000. In Alalammi P (ed). *Atlas of Finland, Folio 122: Geomorphology*, 3–4. National Board of Survey & Geographical Society of Finland, Helsinki.

Glückert G (1973). Two large drumlin fields in central Finland. *Fennia* 120, 1–37.

Haavisto M, T Grönlund, P Lahermo & C-G Stén (1980). Someron kartta-alueen maaperä (Abstract: Quaternary deposits in the Somero map-sheet area). *Suomen geologinen kartta 1:100 000, Maaperäkarttojen selitykset, Lehti 2024*, 1–66. Geological Survey of Finland, Helsinki.

Heikkinen O & M Tikkanen (1987). The Kalajoki dune field on the west coast of Finland. *Fennia* 165, 241–267.

Heikkinen O & M Tikkanen (1989). Drumlins and flutings in Finland: their relationships to ice movement and to each other. *Sedimentary Geology* 62, 349–355.

Helle R (1965). Strandwallbildungen im Gebiet am Unterlauf des Flusses Siikajoki. *Fennia* 95, 1–35.

Hellemaa P (1998) The development of coastal dunes and their vegetation in Finland. *Fennia* 176, 111–221.

Ikonen L (1993). Holocene development and peat growth of the raised bog Pesäsuo in southwestern Finland. *Geological Survey of Finland, Bulletin* 379, 1–58.

Käyhkö J, K Pye & P Worsley (1996). Quantitave mapping of active Aeolian surfaces in northern Fennoscandia – Landsat TM hybrid classification. *Proceedings of the Fourth symposium on remote sensing of the polar environments, Lyngby, Denmark, 29 April–1 May 1996* (ESA SP-391, July 1996), 147–152.

Korhola A (1990). Suomen soiden synty ja kehitys (Abstract: The origin and development of the mires in Finland). *Terra* 102, 256–267.

Korsman K & T Koistinen (1998). Suomen kallioperän yleispiirteet. In Lehtinen M, P Nurmi & T Rämö (eds). *Suomen kallioperä – 3000 vuosimiljoonaa*, 95–103. Geological Society of Finland & Gummerus, Jyväskylä.

Koutaniemi L (2000). Meanderointi ja sen yhdentoista vuoden seuranta Oulankajoella Kuusamossa (Abstract: Meandering, and eleven years of its monitoring on the River Oulankajoki, Finland). *Terra* 112, 217–228.

Kujansuu R (1967). On the deglaciation of western Finnish Lapland. *Bulletin de la Commission géologique de Finlande* 232, 1–98.

Kujansuu R & J Niemelä (1990). Suomen maaperä 1:1 000 000. In Alalammi P (ed). *Atlas of Finland, Folio 123–126: Geology, Map appendix II*. National Board of Survey & Geographical Society of Finland, Helsinki.

Kurimo H (1979). Deglaciation and early postglacial hydrography in northern Kainuu ja Peräpohjola, North-East Finland. A glacial morphological study. *Publications of the University of Joensuu B II* 10, 1–65.

Lehtinen M (1976). Lake Lappajärvi, a meteorite impact site in western Finland. *Geological Survey of Finland, Bulletin* 285, 1–92.

Lehtovaara J (1989). Tectonostratigraphic position of the Finnish Caledonides at the Fennoskandian margin of the northern Scandes. *Bulletin of the Geological Society of Finland* 61, 189–195.

Lehtovaara J (1992). Söderfjärden: a Cambrian impact crater in western Finland. *Tectonophysics* 216, 157–161.

Pesonen LJ & S Mertanen (1990). Fennoskandian mannervaelluksesta. In Alalammi, P (ed). *Atlas of Finland, Folio 123–126: Geology*, 125. National Board of Survey & Geographical Society of Finland, Helsinki.

Pesonen LJ, S Mertanen & MAH Leino (1991). Fennoskandian pitkä matka. *Geologi* 43, 107–113.

Pesonen LJ, TH Torsvik, S-Ä Elming & G Bylund (1989). Crustal evolution of Fennoskandia – paleomagnetic constraints. *Tectonophysics* 162, 27–49.

Punkari M (1993). Modelling of the dynamics of the Scandinavian ice sheet using remote sensing and GIS methods. In Aber J (ed). *Glaciotectonics and mapping glacial deposits. Proceedings of the INQUA commission on formation and properties of glacial deposits*, 232–250. Canadian Plains Research Center, University of Regina.

Saarnisto M & V-P Salonen (1995). Glacial history of Finland. In Ehlers J, S Kozarski & P Gibbard (eds). *Glacial deposits in North-East Europe*, 3–10. AA Balkema, Rotterdam.

Seppä H (2002). Mires of Finland: Regional and local controls of vegetation, landforms, and long-term dynamics. *Fennia* 180, 43–60.

Seppälä M (1979). Recent palsa studies in Finland. *Acta Universitatis Ouluensis A* 82, *Geologica* 3, 81–87.

Seppälä M (1986). Korkeussuhteet. In Alalammi P (ed). *Atlas of Finland, Folio 121–122: Relief and landforms*, 1–5. National Board of Survey & Geographical Society of Finland, Helsinki.

Simonen A (1980). The Precambrian in Finland. *Geological Survey of Finland, Bulletin* 304, 1–58.

Simonen A (1990). Suomen kallioperä. In Alalammi P (ed). *Atlas of Finland, Folio 123–126: Geology*, 1–4. National Board of Survey & Geographical Society of Finland, Helsinki.

Taipale K & M Saarnisto (1991). *Tulivuorista jääkausiin*. WSOY, Porvoo.

Tikkanen M (1981). Georelief, its origin and development in the coastal area between Pori and Uusikaupunki, south-western Finland. *Fennia* 159, 253–333.

Tikkanen M (1989). Geomorphology of the Vantaanjoki drainage basin, southern Finland. *Fennia* 167, 19–72.

Tikkanen M (1994). Suomen pinnanmuodot (Abstract: The landforms of Finland). *Terra* 106, 181–192.

Tikkanen M & O Heikkinen (1995). Aeolian landforms and processes in the timberline region of northern Finnish Lapland. *Zeszyty Naukowe Uniwersytetu Jagiellonskiego. Pace Geograficzne – Zeszyt* 98, 67–90.

Tikkanen M & J Westerholm (1992). Kimitoön – en regional geografisk analys (A regional analysis of Kimito – an island in Southwestern Finland). *Bidrag till kännedom av Finlands natur och folk* 143, 1–95.

Vuorela P (1986). Kallioperän ruhjevyöhykkeet. In Alalammi P (ed). *Atlas of Finland, Folio 121–122: Relief and landforms*, 8. National Board of Survey & Geographical Society of Finland, Helsinki.

Zilliacus H (1987). De Geer moraines in Finland and annual moraine problem. *Fennia* 165, 145–239.