ICE-SHAPED LANDSCAPES IN ESTONIA AND SOUTHERN FINLAND

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Front cover: Lake-rich Vooremaa (Saadjärv Drumlin Field)

Back cover: Tarvanpää stronghold in Rakvere was built on top of an esker

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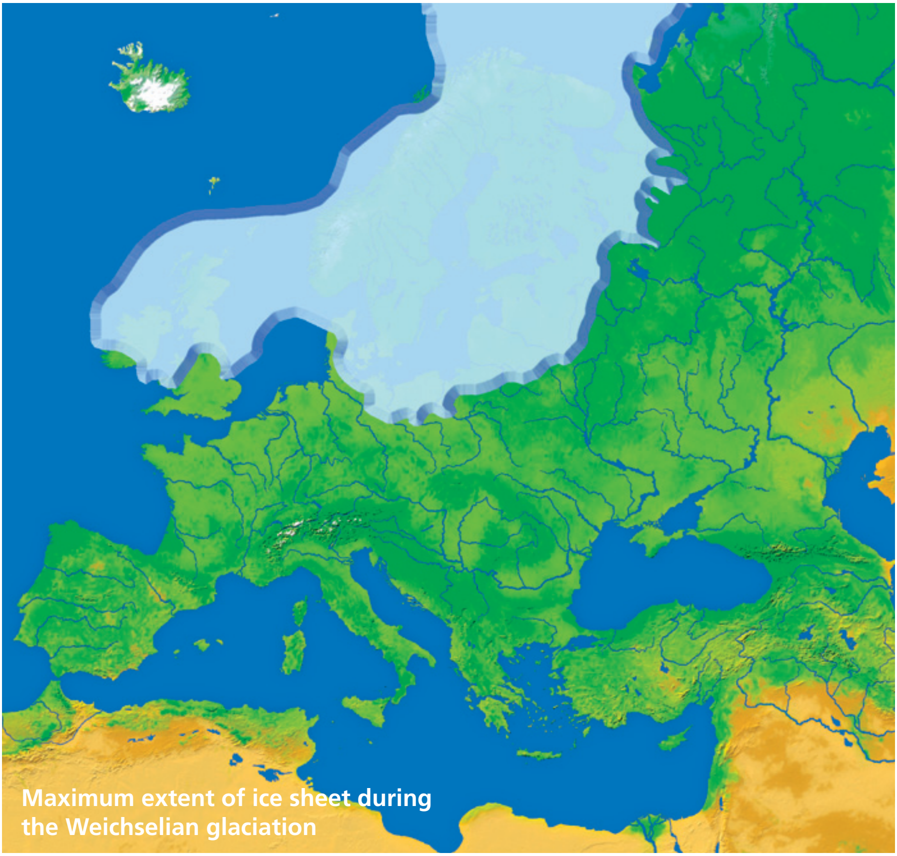
The landscapes of northern countries are unique and picturesque. The topography of Finland and Estonia has mostly been sculptured by ice in the recent past, when massive continental ice sheets covered large areas in the Earth. Today glaciers cover only 10% of the Earth's surface, but during the maximum ice age they took up an additional 23%. Periodical variations in the Earth's orbit cause variations in solar radiation. During rainy and cold seasons accumulation of snow is greatest in hollows and on slopes prone to snowdrifting. As a result of compaction under their own weight accompanied by repeated melting and freezing cycles, the snow sheet loses air trapped between ice crystals and due to recrystallization larger and larger ice crystals are produced. The resulting transformation product with a density of some 0.6 g/cm^3 is called firn. With an increasing density, the real ice layers (density 0.85–0.9 g/cm^3) form gradually, leading to the formation of massive glaciers. The glaciers start to flow downwards because of gravitation. Ice is quite different from snow: it is plastic and can be deformed under pressure. Plastic flow causes the movement of ice downslope, but when the ice sheet thickness has reached at least 60–65 m, it could move also laterally. The rate of glacier movement depends on several factors: the ice thickness and temperature, the slope inclination and outline. The greater the ice mass, the faster the flow. It should be noticed that ice being near the freezing point flows more rapidly than very cold ice, which is less plastic (more brittle).

Quite different climatic periods are distinguished in the geological history of the Earth. The present time is called the Quaternary period, which started after the Neogene some 2 million years ago. The Quaternary era has been rather unstable climatically when long-lasting ice ages have repeatedly alternated with warmer intervals, called interglacials. There is clear evidence available about the existence of the last three glaciations in the Estonian and Finnish areas: Elsterian (600000–380000 years ago), Saalian (240000–130000 years ago) and Weichselian glaciations (90000–10000 years ago), as well as about two interglacials: Eemian (125000–90000 years ago) and Holsteinian (380000–240000 years ago). The date of 10000 ^{14}C years marks the Pleistocene–Holocene geochronological boundary. However, ice ages which are palaeogeographical, not stratigraphical phenomena started and ended at different times in different areas. The territory of southern Estonia was freed from the ice 13000–12000 ^{14}C years ago, while southern Finland was still under thick ice cover. The present time we live



Maximum extent of ice sheet during the Weichselian glaciation

in is believed to be an interglacial period, which will be followed by the next glaciation.

Regularities in the glacial morphogenesis

Ice caps in Finland and Baltic States are responsible for three major types of geomorphic environments:

1) ice-scoured plains, largely coincident with ancient crystalline rocks

2) till plains, primarily in the central zone of former glaciation

3) outwash plains, forming the marginal area of glaciation

In reality such a rough division contains many depositional and erosional features, which are often rather chaotic and unsystematic. However, some clear regularities can still be observed. In the Late Weichselian, when most of the glacial features of southern Finland and northern

Distribution of ice-marginal formations in Finland: 1 – Salpausselkä I, 2 – Salpausselkä II, 3 – Salpausselkä III, 4 – ice-marginal formations in central Finland; , 5 – ice-marginal formations at Pielisjärvi

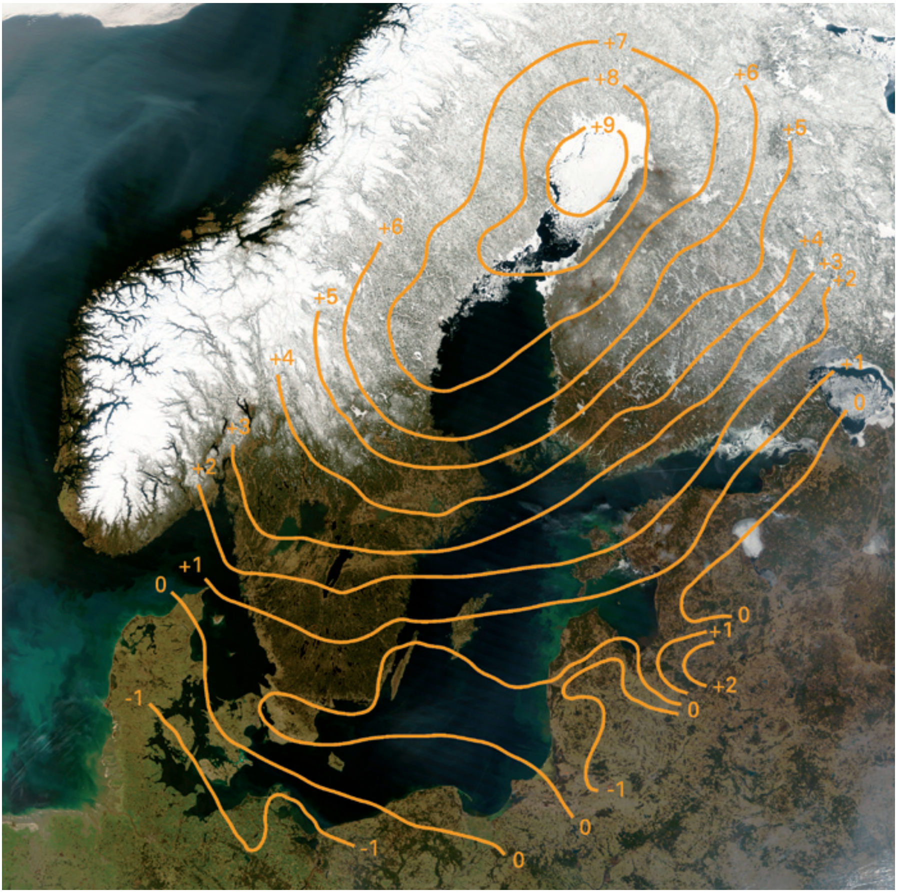
Estonia were formed, three different deglaciation stages are distinguished: Daniglacial (more than 13000 years ago), Gotiglacial (13000–10000 years ago) and Finiglacial (less than 10000 years ago). In contrast to the Daniglacial marginal type of morphogenesis, Gotiglacial time was characterized by high activity of glacial streams and lobes and the main processes were selective glacial erosion and accumulation. As a result, lobe depressions and interlobate uplands as topographic macroforms were formed. In Finiglacial time there existed distinct linear trends corresponding to flow streamlines, which are marked by eskers and giant grooves filled with lakes and bogs. Also large marginal forms, such as end moraines and outwash deltas, are present.

The Scandinavian continental glacier has a radial-sectoral structure and concentric belts reflecting palaeoglacial processes. It means that the regularities of the glacier structure were expressed in radial alternation of glacier flows and ice-shed areas and in the concentric distribution of landforms.

Land uplift

The main driving forces that determined the dynamics and structure of landscapes in the coastal areas of southern Finland and northern Estonia during Late and Post-Glacial time were related to the fluctuations of the Baltic Sea and crustal movements. Numerous concepts have been elaborated on the origin of crustal movements. Often linear movements are assumed to be of tectonic origin, whereas the exponential one is treated as being of glacioisostatic origin. It is frequently pointed out that the study area was subjected to glacioisostatic uplift during the Early and Middle Holocene, but afterwards the uplift was mainly tectonic. Yet, with no doubt the influence of the ice sheet has been considerable. The ice cap was thickest, even up to 3 km, in the area of the Gulf of Bothnia. The weight of the ice mass was enormous and the Earth's crust below it subsided by 800–1000 m. Ice masses started to melt when climate turned warmer and the Earth's crust, free from thick ice, began to recover its former state. Most of the uplift, up

Isolines of present land uplift (mm/year). Background photo: Image courtesy of MODIS Rapid Response Project at NASA/GSFC



to 500 m, took place below the final melting of ice sheet. After the melting of the ice, land uplift has been in a range of 200–300 m. Land uplift still continues, but is slowing down gradually. The land emerges from the sea, islands grow, the shoreline shifts towards the sea and bays turn into lakes. The rate of land uplift is greatest, 9 mm per year, in the area of the Gulf of Bothnia, where the ice sheet was thickest. In the Hanko and Hiiumaa area the present land uplift is 3 mm per year and in south-western Finland and north-eastern Estonia 1 mm per year. According to one point of view, the Earth's crust will rise by an additional 100–150 m in about 7000–12000 years. According to other viewpoints the glacioisostatic component decreased almost logarithmically from the end of the last glaciation and reached almost zero about 5000–3000 BP. It means that since that time the rate of uplift has evidently been equal to the present uplift rate and will stay constant in the future.

Stages of the Baltic Sea development and ancient littoral zones

The Baltic Sea basin has undergone different development stages during and after the last glaciation. Several factors including the continental glacier retreat, melting waters, land uplift and fluctuations of the ocean level have affected its volume and salinity of water. While the glacier was retreating from northern Estonia and southern Finland, large portions of the land were covered by water. Gradually the land emerged from the sea. Some 12000–10300 ^{14}C years ago a freshwater body called **Baltic Ice Lake** occupied the Baltic basin area. When the glacier retreated from the Billingen Mountain area in Central Sweden, a wide strait connecting the ice lake with an ocean formed and the water level of the Baltic Ice Lake dropped rapidly by 26–28 m to the ocean level, which initiated the stage of the brackish-water **Yoldia Sea**. Because of the land uplift, the connection to the ocean closed up about 9500 ^{14}C years ago and the freshwater **Ancylus Lake** stage began. Large continental ice masses melting all over the world discharged huge amounts of water to the ocean and its level rose gradually. About 8000 ^{14}C years ago Ancylus Lake turned into the brackish-water **Litorina Sea**. The last 4000-year period of the Baltic Sea is called the **Limnea Sea**.

Many ancient shoreline evidences of land uplift and different stages of the Baltic basin have been recorded: boulder accumulations, scarps, spits, bay-mouth bars and beach ridges. The most impressive coastal features were generated during the transgressions of the Baltic Ice Lake, Ancylus

The erratic boulders transported by the glacier to Pedassaare cape, Lahemaa

Lake and Litorina Sea when due to land uplift the water level stayed at the same level for a long time. In Finland large ancient littoral boulder fields are called *devil's fields*.

Landforms and deposits formed by glacier

The advancing ice stripped off and almost entirely removed older deposits that existed prior to glaciation. The existing roughlands were considerably smoothed as a result of scour and plucking. Bedrock hills were truncated or rounded off and rough surfaces were ground down and polished, sometimes into longitudinal ridges of bedrock that point in the direction of flow, with gentle slopes facing upstream and a rough, plucked surface, with a tail of till, facing downstream. The overall effect is an open, rolling topography with appreciable relief but a general predominance of smooth slopes, locally interrupted by rounded but steep-sided rock knobs.

As already mentioned, the side that was towards the ice flow, or the stoss side, is polished smooth and is gently sloping, while the lee side is often split vertically. The latter has been caused by lower pressure behind the rock, when the water that melted from the ice bottom penetrated under high pressure into cracks in bedrock, froze again and broke the rock. Frequently glacial outcrops bear many marks made by the moving rock material in the glacier's bottom, like striations and

Cliffs polished by glacier on Hanko coast

lunate fractures. The direction of striae gives information about the direction of glacier flow in the final phase of glaciation. The bedrock shaped by ice can be best detected in the places that are not affected by weathering and vegetation, for example bedrock near the seawater line, which has been above water level for quite a short time. In higher areas these marks have usually been worn away.

Potholes were formed in waterfalls and in high water turbulences beneath the glacier, where strong flows of meltwater started to rub loose rocks against the bedrock. Gradually stones drilled a round hole in the bedrock. Potholes are usually round, with polished smooth inner parts where rifle structures can be found. Sometimes grindstones can be found at the bottom of potholes. Most of the known potholes originate from the last glaciation, but they can still form in the bottom of present-day river rapids. The most famous potholes in Finland are a group of twenty potholes in Askola, the largest one being 4.2 m wide and 10.3 m deep.

Ice selectively grooves or gouges out hard rock basins along the existing valleys. Distinct linear trends, corresponding to flow streamlines, are apparent. Dimensions of such hollows are variable, but may exceed 100 m

Glacial striations on the surface of reef limestone in Vasalemma quarry

and giant grooves are many kilometres long. After deglaciation these rock basins, especially in Finland, formed basins of lakes, many of which are now filled with peat and have turned into bogs. Ice often left huge boulders on ridges and slopes, the largest ones in Estonia having a perimeter up to 58 m (Muuga Kabelikivi).

In vast areas the continental glacier created **till plains**. Occurring almost everywhere, till is the most common soil type in Finland and Estonia. Till was generated when glacier grabbed soil and bedrock along in transportation and finally deposited it. Usually till is a mixture of boulders, cobbles, pebbles, gravel, sand and finer material like silt and clay. The character of the glacier-transported material and its location within the continental glacier defined what kind of the till bed formed. **Basal till** formed from the material transported in the glacier base. It is usually tightly packed, unsorted and rocks in it are oriented along the direction of ice movement. Ablation till originated from the surface or inside of the glacier and was deposited by ice melting. Ablation till is usually less tightly packed and includes less clay material and more gravel than basal till.

Usually till occurs as a **cover till** and mostly follows the landscape topography. Clayey till plains are

Till covering Upper Ordovician limestones in Vasalemma quarry

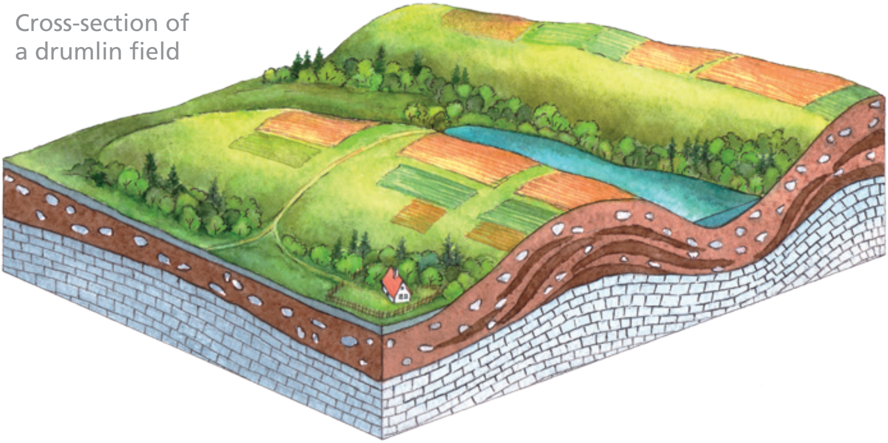
Glacier movement during the formation of the Otepää and Haanja heights (compiled by Reet Karukäpp) either monotonously flat or slightly undulating. Till surfaces are usually poorly drained and may contain widespread swamplands. Some of the lakes were dammed back behind end moraines because till disrupted or obstructed previous drainage, some were formed in older valleys, separated by till barriers.

Till is also common in end moraines, De Geer moraines, hummocky topography and drumlins. **End moraines** – great arcs of hummocky ridges – form impressive landforms. They are deposited in the glacier margin area as ridges parallel to the ice margin. The largest ones were formed when the glacier edge remained at the same position for a longer period. The sizes of end moraines vary, but for example in the area of Salpausselkä and in the central part of Saaremaa end moraines can be over 10 m high and dozens of kilometres long. End moraines normally consist of coarser material than basal till and show considerably more variation in topography. Erratic boulders, derived from outcrops of crystalline rocks by long-distance transport, are common at the surface. Kettles commonly occur as swarms of small depressions, and together with small hillocks favour an irregular knob-and-kettle topography. Some small end moraines, such as Naistevälja and Vatku in Estonia, were formed when ice pushed its way across beds. Interlobate morains develop along the contact between two glacier lobes. The end moraines that accumulated during the farthest advance of a particular glacial stage are called terminal moraines, as opposed to the recessional moraines of successive standstills, which may have constituted minor readvances during deglaciation.

De Geer moraines are ridges parallel to the ice margin. They were formed in the crevasses running parallel to the ice margin in sub-aquatic conditions. De Geer moraines are most commonly till ridges up to 5 m high, 10–50 m wide and a couple of hundreds metres long. Usually they occur in large groups. The best examples of clusters of De Geer moraines in Finland occur in the Raippaluoto (Replot) area in the vicinity of Vaasa. The areas with hummocky topography are characterized by a variety of regular and non-oriented hills, usually 5–20 m high, consisting of till or glaciofluvial material. Often they constitute so-called dead ice formations.

Drumlins are elongated, streamlined hills that occur in swarms on the surfaces of till plains. The upstream end of a drumlin is steep and fairly blunt, while the downstream end is smoother and the lee tail-like in shape. Oriented in the direction of ice movement, these features are commonly 30–50 m high and 1–5 km long.

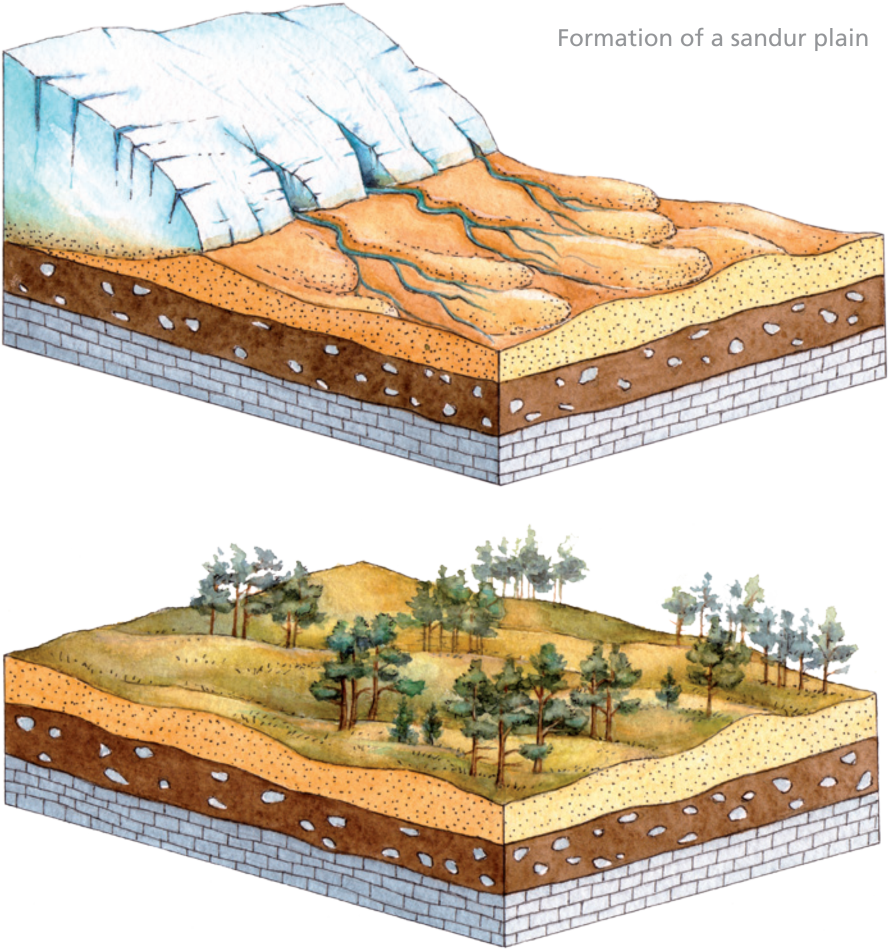
Cross-section of a drumlin field



The largest drumlins are found in the Saadjärv drumlin field in central Estonia. In Finland they are common in Savo and Kuhmo areas. Some drumlins consist entirely of till. These may be the result of the reshaping of basal till beneath the moving ice. Other drumlins have rock cores with a cap and tail of till. These drumlins probably formed in areas with reduced ice movement due to large bedrock obstacles. Drumlins occur usually in groups, forming drumlin fields.

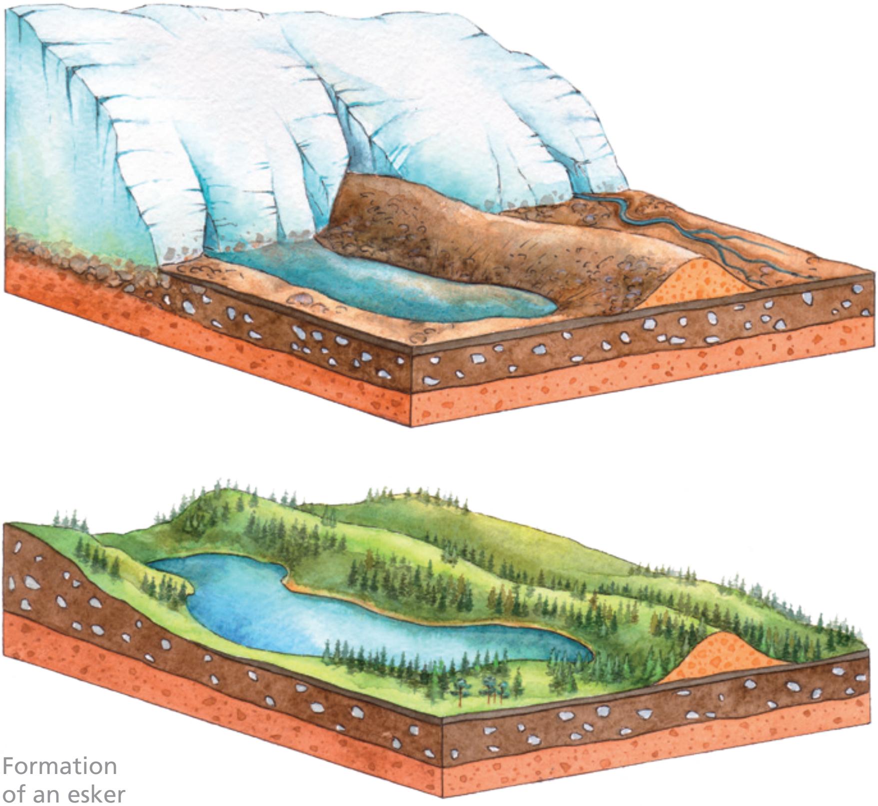
The formations generated by glacier meltwater are known as **glaciofluvial** and **glaciolacustrine formations**. During the melting of the ice sheet a huge amount of loose material was transported by meltwater, which flowed in the glacier crevasses and in tunnels below. Meltwater discharged in the ice-marginal area. When the waterflow was slowing down enough, gravel and sand transported by water were deposited in front of the glacier as **sandurs** or, if the material accumulated in ice lakes, as **glaciofluvial deltas**. Sandurs as typical outwash formations accumulated as a result of braided streams. Outwash deposits are well sorted and conspicuously stratified. The surfaces of such meltwater plains are flat, dipping gently away from the ice margin. Extensive glaciofluvial deltas are located in the Mustamäe and Männiku areas, Tallinn, as well as between Tallinn and Kunda in northern Estonia. Glacial rivers have deposited large sorted gravel and sand formations that nowadays are important ground water areas and valuable reserves of sand and gravel used in building industry.

Eskers are steep-sided, sinuous ridges of stratified sand and gravel, which can be followed even over



Formation of a sandur plain

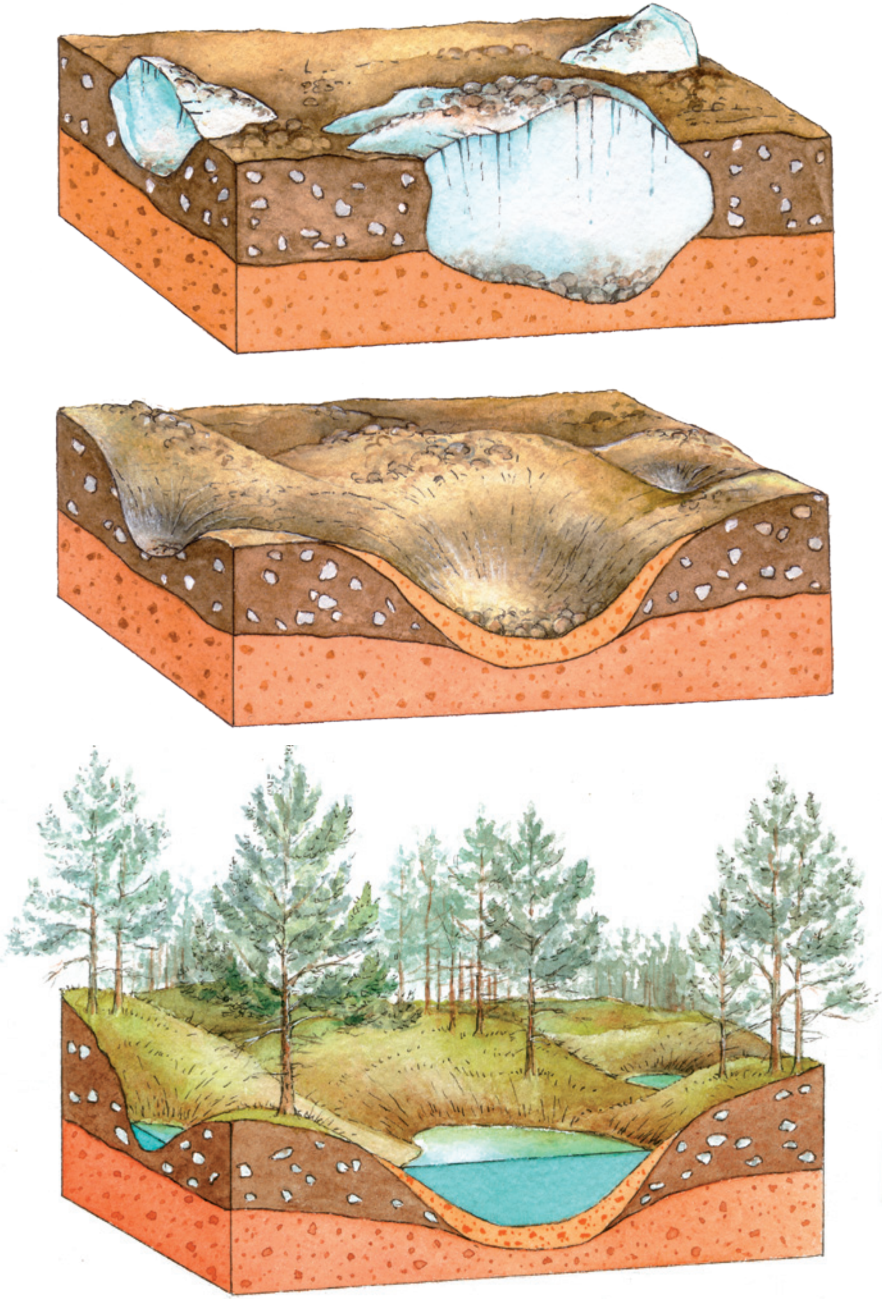
several tens of kilometres. They consist of streambeds, originally laid down within large crevasses of the glacier or deposited by meltwater moving through or beneath the ice. Meltwater usually runs downhill, but occasionally can run even uphill when flowing under great hydrostatic pressure, so the stream deposits may not be horizontal. Radial eskers mark the direction of continental ice sheet flow, while marginal eskers (narrow deltas) formed in front of the retreating ice sheet. Eskers consist mostly of sorted sand and gravel layers as well as rounded rocks. Their cores often contain coarser material than the upper sediment layers. In flat-lying areas eskers may be buried under silt and clay layers that have deposited



Formation of an esker

later. Picturesque eskers are found in Lääne-Viru County in Estonia.

A number of miscellaneous deposits of mixed stream origin and dissected hummocky topography are called **kames**. Kames are positive relief forms, hills or short ridges, resulting from the accumulation of aqueoglacial deposits in cracks and cavities of passive or dead ice or between isolated blocks of dead ice. According to the mode of formation kames are divided into direct and inversional ones; on the grounds of the location of the margin of an active glacier, distinction is made between radial, marginal and non-oriented kames; on the basis of the place of formation, subglacial, intraglacial, supraglacial, foreglacial and interblock kames are distinguished. Considering geological structure, one can speak about glaciofluvial (consisting of sand and gravel), limnoglacial (consisting of silty material) and complicated kames (with different material and sometimes with a thin till layer on the top). Morphologically kames are



Formation of a kame field

represented by hills, knolls, cupolas, crests, ridges, ramparts and plateaus. They form kame fields and kame groups. Many lakes are located in kame fields.

The **three Salpausselkä ridges**, called Salpausselkä "end moraines", are the most remarkable glacial formations in Finland. Salpausselkä end moraines were generated during the Younger Dryas phase when climate turned colder and glacier retreat stopped. The ridges Salpausselkä I and II are parallel, extending from the coast of South-West Finland to North Karelia. The Salpausselkä zone is 600 km long and 20–50 km wide.

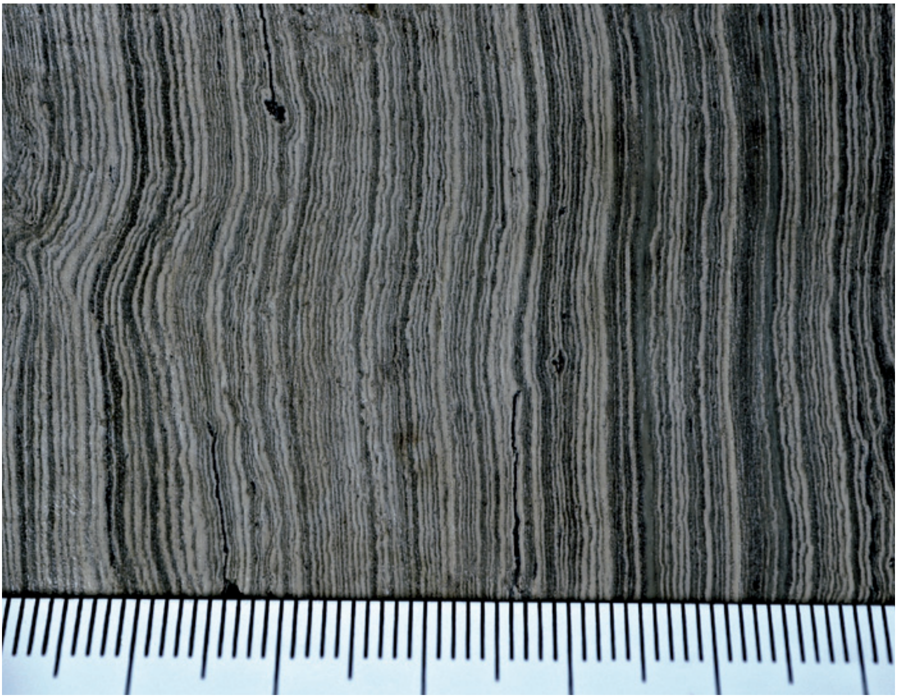
The 200 km long Salpausselkä III ridge in South-West Finland runs for about 200 km on the north-eastern side of Salpausselkä II. Salpausselkä end moraines can rise for 60–80 m over the surrounding landscape, but most commonly for about 20 m. The structure of Salpausselkä ridges shows that the glacier edge oscillated or moved forward and backward during the ridge formation. Till beds between and on top of glaciofluvial sediments serve as evidence of this process. In some places also silt and clay layers occur between other layers, which indicates that the glacier edge has been farther and the area has been under deep water.

Sand quarry at Kiikalannummi on the Salpausselkä III ridge

Waterlaid deposits

In front of the glacial margin large ice-dammed lakes were often formed. Although they are commonly tilted today as a result of crustal readjustments, these lacustrine deposits were once absolutely horizontal. The deposits are well stratified and consist mainly of sands and silts. In winter times, when the lakes were covered with ice and inflow of melting material was negligible, only the finest material was deposited in the bottom of lakes. In the summertime, when glacier melting was extensive, coarser material was deposited. Under suitable conditions a varved structure consisting of finer and coarser layers generated by the annual rhythm of melting was formed in the bottom sediment. By correlating different varved clay profiles a varved clay chronology can be established enabling dating different geological events.

Varved lake sediments.
Photo by Gennadi Baranov



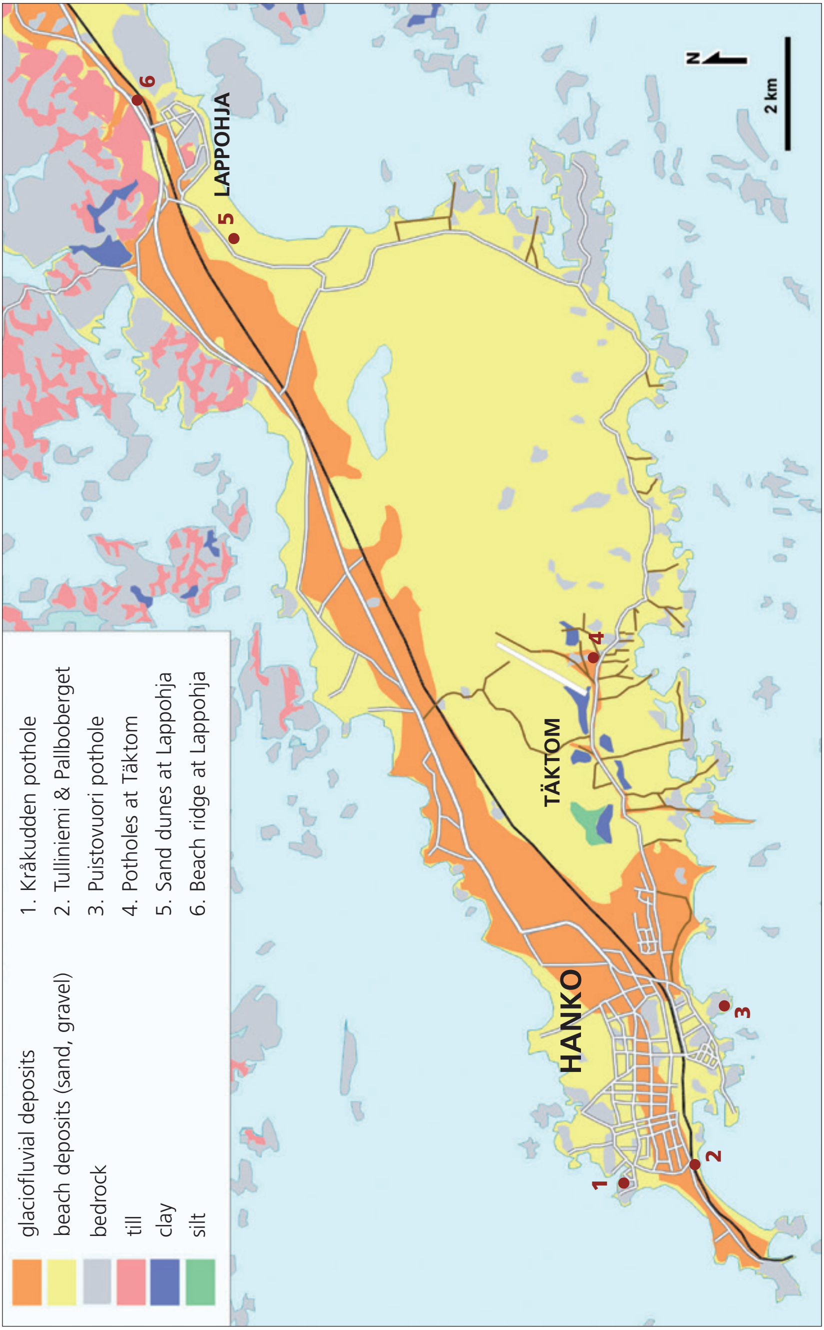
Southern Finland landscapes shaped by glacier

Hanko city area

The Salpausselkä I ridge, which was formed during the Baltic Ice Lake stage, rises up from the sea in the Tulliniemi beach in the south-western part of Hanko cape. The ridge has been strongly washed and shaped by currents and waves and is very flat. The loose material, washed away from Salpausselkä I ridge, has deposited as a wide belt of littoral deposits in the southern part of Hanko cape. The ridge extends through the city of Hanko, where a railway and Hankoniementie road proceed along it. However, as the ridge is very flat, it can be hardly distinguished from adjacent littoral deposits. The Tulliniemi beach area is represented mainly by littoral deposits, while the glaciofluvial sediments are found in the harbour area. To the south-west of Tulliniemi, Salpausselkä I continues for 15 km under the sea up to Bengtskär lighthouse, where it disappears under clays in the bottom of the sea at a depth of 40 m. In the north-east Salpausselkä I ridge extends from Hanko to Tammisaari and Lohja and through Hollola to Sairakkala where it turns eastwards.

The Tulliniemi coast displays a beach ridge, some erosional formations caused by the wind and deflation depressions. In this area it can be seen how vegetation has fixed the sandy soil rising up from the sea. On the eastern side of the coast there is Pallbobergets crystalline rock hill, where near the waterline some nice ice-polished surfaces can be observed.

View of Tulliniemi beach from Pallboberget cliff


glaciofluvial deposits
beach deposits (sand, gravel)
bedrock
till
clay
silt
1. Kråkudden pothole
2. Tulliniemi & Pallboberget
3. Puistovuori pothole
4. Potholes at Täktom
5. Sand dunes at Lappohja
6. Beach ridge at Lappohja
HANKO
TÄKTOM
LAPPOHJA
1
2
3
4
5
6
N
2 km

Some erratic boulders are also found on the coast, the most interesting of these being the rapakivi-boulder on the top of Pallboberget. Possibly the boulder may have been transported here from the Laitila rapakivi area over 100 km north of Turku.

Many basement outcrops exposing ice-polished structures occur in the Hanko city area. Nice glacial outcrops and striae are found almost everywhere, for example in the Puistovuori area and in the basement outcrops on the Kolaviken beach. In Puistovuori, there is an impressive pothole 1.2 m in diameter and 2.5 m deep. From the sand road that starts behind Hanko Casino a marked path leads to the pothole. A rock hill with the Kråkuddens pothole, 3 m in diameter and over 3 m deep, lies east of Kappelisatama harbour. A sign from Länsitie road directs towards the pothole.

Täktom area

The area south of Täktom displays good examples of how sea bays can turn into lakes due to land uplift. Kattrumpan, Västerfjärden, Österfjärden and Täktbukten are bays that are in different phases of separating from the sea. Some small roads proceeding from Täktomintie road to the south lead to these bays. Långörintie road on top of a small esker leads to Kattrumpan small harbour. In the harbour area the esker forms a narrow isthmus, which connects Långören rocky basement hill with the mainland. South of the basement outcrop area, the esker extends into the sea. Kattrumpan Bay has only a narrow connection to the sea, and in the course of several hundred years it had to be deepened from time to time so that boats could go to the sea from the harbour. The bays, which are slowly transforming into lakes, are called *fladas*.


Puistovuori pothole

Kobben road leads up to Kobben Hill, from where Täktbukten Bay and Österfjärden can be seen. Täktbukten is still an open sea bay, but west of Österfjärden it has already become separated forming a so-called *glo-lake*. A glo-lake is an ancient sea

Österfjärden glo-lake, separated from the sea due to land uplift. Photo by Atte Karhima

Potholes at Täktom

bay that has already turned into a lake, but during storms it may still have saline-water inflow. Between Kattrumpan and Österfjärden there is Västerfjärden glo-lake. Täktom bays are quite small, but also many large bays of the southern coast are slowly turning into lakes. It should be mentioned that a vast lake will form in the area of the Gulf of Bothnia within the next 2000 years in case the Kvarken area continues to rise.

Potholes are also found in the Täktom area. A sign from Täktomintie road directs towards Lövkullantie road, where ice-shaped basement with about 15 potholes is exposed. Most of these potholes are quite small, but the greatest one is 3 m deep and 1.6 m in diameter.

Stony beach ridge at Lappohja.
Photo by Atte Karhima

Lappohja area

In Hanko Lappohja, less than 1 km from Warmuseum towards Tammisaari, a stony beach ridge lies between Hankoniementie road and the railway. The area can be reached by turning at the Ruukki crossroad from Hankoniementie to Satamatie, and turning after that immediately to the left to the old road base. Here Salpausselkä I is observable as a relatively narrow ridge between crystalline basement outcrops. The ancient beach ridge, formed by abundant loose boulders and cobbles, runs in the same direction with Salpausselkä, continuing to the north-east for about 1.3 km. The shape and size of the boulders are variable: in the south-western part rocks are small and rounded, but commonly larger and angular elsewhere. Several large

erratic boulders are found in that area. The stony beach ridge formed in the beginning of the Litorina Sea stage. Nowadays it lies 20–25 m above sea level.

West of Lappohja village, Koverharintie road takes a visitor to the Lappohjanranta outdoor area. There is a large dune area, now covered by vegetation. The steep lee side of the sand dune rises up near the parking place and the path that leads to the beach crosses it. The dune ridge is 1.5 km long and 5–7 m high. It was formed by strong wind that took up sand from the beach and finally deposited it as an aeolian formation parallel to the shoreline. In windy areas dunes may be reshaped all the time, but finally they get fixed by vegetation. The wide flat sandy areas of Salpausselkä I that are emerging from the sea are perfect for the formation of drift sand and dunes. The Hanko cape area abounds in aeolian deposits, with dunes being especially numerous on its eastern side, between Lappohja, Sandöträsket and Tvärminne.

Kiikalannummi and Hyyppärä

The Salpausselkä III ridge was generated during the Yoldia Sea stage. Its type area is at Kiikalannummi, about 5 km east of Kiikala. The area is geologically very diverse, comprising various forms created by glacial processes – wide deltas, sandur fields, dead ice formations as well as supra-aquatic glacial clays and silts. There occur many sandpits where

Lammenharju esker at Hyyppärä

the structures of Salpausselkä III can be examined.

An impressive kettle area occurs at Hyyppärä, east of Lake Lammenjärvi. The easiest way to get there is from Kultalähde spring, following the signs from Oinasjärventie road that turns off Suomusjärvi–Kiikala road. The area is suitable for walking and perfect for hiking due to the large number of paths. Steep kettle holes and big sand and gravel hills are found in the Hyyppärä area. Kettle holes have been formed by dead ice after huge ice blocks were buried under glaciofluvial sediments. When the ice melted, large holes were left – kettle holes, which are particularly numerous in the area of end moraine formations and eskers. A path from Kultalähde spring leads to the Lammenharju esker north of Lammenjärvi. The esker has a shape typical of these landforms: it is long, narrow and its slopes are relatively steep. Its highest point rises up to 25 m above the surrounding landscape. The Lammenharju esker is oriented from north to south, in the direction of glacier movement. The esker is only a few kilometres long, but to the south-east and north-east of it there occur ridges of the same direction, indicating that the esker probably continues under younger clay, silt and peat deposits.

Northern Estonia landscapes shaped by glacier

Lake Uljaste and Uljaste esker

In North Estonia the most frequent glaciofluvial formations are marginal and radial eskers. The Uljaste radial esker ridge is 9 km long. It belongs to the Pandivere stade and consists of gravel (30–40%) and sand (40–55%), with some content of pebbles and cobbles (10–20%) and silt (less than 5%). On the rather wide (300–500 m) and more or less flat top of the esker there are glaciokarst hollows up to 12 m deep. The slopes are steep and the esker is symmetrical on both sides. The height of the esker is 18–22 m. The bedding is highly variable, whereas different types of cross-lamination prevail. The absence of till on the slopes and top of the esker suggests that eskers of that type were formed in open crevasses of dead ice. Intensive exploitation of sand and gravel in building and road construction has completely destroyed many eskers. Since 1957 the northern part of the Uljaste esker has been under nature protection.

Lake Uljaste is 60 ha in area, 5.6 m deep and has formed in a glaciokarst hollow. In the glacially reshaped area also several comet eskers occur, formed probably according to delta theory, showing annual retreat of the ice.

Uljaste comet esker

The Saadjärv Drumlin Field (Vooremaa)

The drumlin field is about 55 km long, 27 km wide at the proximal (NW) end and less than 5 km at the distal (SE) end. The field contains about 120 drumlins arranged in a distinct down-ice tapering funnel, indicating converging ice flow. Drumlins vary greatly in shape, size and spatial arrangement within the drumlin field. Besides typical drumlins with steep, high stoss sides and tapering low lee sides, there are strongly elongated isometric drumlins, reversed drumlins (with stoss ends facing down-ice) and complex drumlins (with irregular shapes, possibly consisting of multiple superimposed drumlins of different sizes). Several ridges have grown together at their proximal ends or in the middle, to form a huge drumlin shield. The NW portion of the drumlin field contains very large, yet relatively flat and less elongated drumlins. Here the drumlins are 7–13 km long, 1–3.5 km wide and up to 60 m high. The SE region is dominated by smaller and more elongated drumlins with steep slopes. This topography shows that ice moved at a high speed over the Pandivere Bedrock Upland with an altitude difference of 110 m over a distance of 60 km, which caused intensive erosion and accumulation of till.

The overall thickness of Quaternary deposits in drumlins is some 60–70 m. The Pleistocene sequence comprises Middle and Upper Pleistocene tills and outwash deposits with a thickness over 100 m in buried valleys. Four lithostratigraphical till units (Elsterian, Saalian and two Weichselian units) have been established. Interglacial deposits of Holsteinian age have been found at Kõrveküla in the distal end of the drumlin field. Holocene sediments, up to 15 m thick, are represented predominantly by sand, silt, gyttja, lake lime and peat. The distal margin of the Saadjärv ice stream is marked by a hummocky topography. The drumlin field abounds in nice elongated lakes between drumlins and many cultural monuments, often associated with the national hero Kalevipoeg.

Vaivara Sinimäed

The Ordovician limestone blocks forming the cores of hills called Vaivara Sinimäed were broken off the klint edge and transported for 4–5 km southwards by continental ice sheet. At their present site they mark the maximum extent of the Pandivere stade. These are the most famous rafts in Estonia, forming three elongated hills projecting for 40–50 m above the generally flat topography (Tornimägi 70 m, Põrguhauamägi 83 m and Pargimägi 85.5 m a.s.l.).

View of the Raigastvere drumlin from the observation tower. Photo by Anto Raukas

Strongly tilted Middle Ordovician limestones at Pargimägi

The Lower Ordovician rocks cropping out on the western slope of Tornimägi Hill are vertically bedded and folded in places. The details of bedding, revealing clear evidence of horizontally directed pressure as well as the existence of till lenses between the folds, point to the glaciotectonic origin of dislocations. Some geologists have treated the hills as tectonic forms. Actually, the hills are located on the tectonic horst occurring in the bedrock, but genetically, they constitute a clear complex of glacial marginal formations with a push end moraine, including fracturing, thrusting and rotation of bedrock blocks in the proximal and glaciofluvial delta in the distal parts of the formation, gradually transforming into a glaciolacustrine plain.

In summer 1944, the Estonian Legion fought fiercely against the advancing Soviet troops in the Vaivara Hills area. The graves of 15500 Soviet soldiers are found in the local cemetery. In total, the Red Army lost about 60000 soldiers here and in the surroundings. Now a memorial to Soviet soldiers stands on the southern slope of Tornimägi Hill, while a memorial on the slope of Põrguhauamägi Hill commemorates those who fell on the German side during World War II in the battles at Vaivara. The Vaivara Landscape Reserve (79 ha) was established in 1959 and reorganized in 1988 to protect the hills and the historical monuments.

View at Vaivara Sinimäed, Pargimägi Hill

TERMS

Ablation till – till that was transported and deposited on the top of or inside the glacier

Delta – the area where river discharges its load

Deflation depression – a pit in the ground made by wind erosion

Distal – the farthest side of the formation when looked in the direction of the glacier; opposite to the proximal side

Dune – aeolian formation deposited by wind

Erosion – soil or bedrock wearing caused by a geological process (glacier, waves, wind, etc.)

Erratic boulder – a large boulder, transported by glacial ice

Glaciofluvial deposits – material transported by glacial rivers

Glo-lake – an ancient bay, which has turned into a lake but may have brackish water inputs during storms

Interglacial – warm time between glaciations when most glaciers melt away

Interstadial – a cool stage inside glaciation when glaciers partly retreated

Oscillation – back and forward movement of the glacier margin

Sandur – accumulation of glaciofluvial material from braided rivers in dry land

Sub-aquatic – an area that was under water during glaciation or after it

Supra-aquatic – an area that was released from under the glacier as dry land

Varved clay chronology – timing method based on counting annual rhythms of varved clays

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