GEOLOGICAL HISTORY OF THE BALTIC SEA

TTÜ Geoloogia Instituut

TÖÖVERSIOON 28.04.2010

Materjal on valminud projekti “Ühendades Läänemerd – COBWEB / Communicating the Baltic – COBWEB” raames

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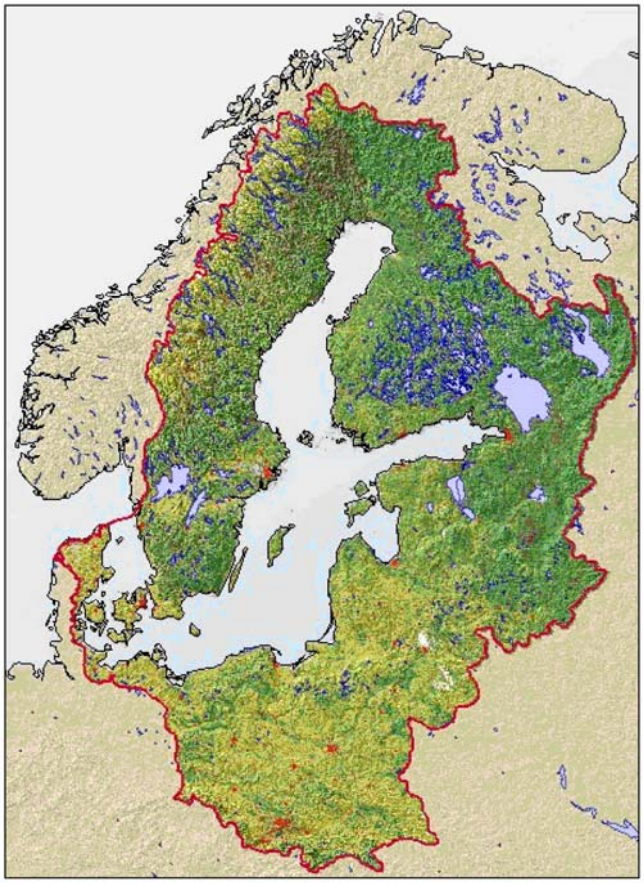
1.
Introduction

2.
Location of the Baltic Sea

TOPOKAART LISADA

The Baltic Sea is a brackish inland sea located in Northern Europe, from 53°N to 66°N latitude and from 20°E to 26°E longitude. It is bounded by the Scandinavian Peninsula, the mainland of Europe, and the Danish islands. It drains into the Kattegat by way of the Øresund, the Great Belt and the Little Belt. The Kattegat continues through Skagerrak into the North Sea and the Atlantic Ocean. The Baltic Sea is connected by man-made waterways to the White Sea via the White Sea Canal, and to the North Sea via the Kiel Canal. The Baltic Sea might be considered to be bordered on its northern edge by the Gulf of Bothnia, on its northeastern edge by the Gulf of Finland, and on its eastern edge by the Gulf of Riga. However, these various gulfs can be considered to be simply offshoots of the Baltic Sea, and therefore parts of it.

3.
INTRODUCTION
The Baltic catchment area



Watersheds of rivers falling into the Baltic Sea outline the present contours of the gentle topographic depression surrounding the sea. Watersheds correspond to Scandinavian Mountain chain in NW, Maanselkä hilly chain in NE, and Valdai and Belarus hills in SE. The catchment area is a depression around the Baltic Sea - the Baltic Depression sensu lato – BD. The Baltic Ice Lake (BIL) flooded the major lower area of BD. The area in contours of BIL has gradually emerged from the ice lake and, in the contours of the Yoldia Sea, from the sea. These emerged areas have been called as “virgin lands”. Thus, the new-born Baltic waterbody was much larger and deeper than present BS.

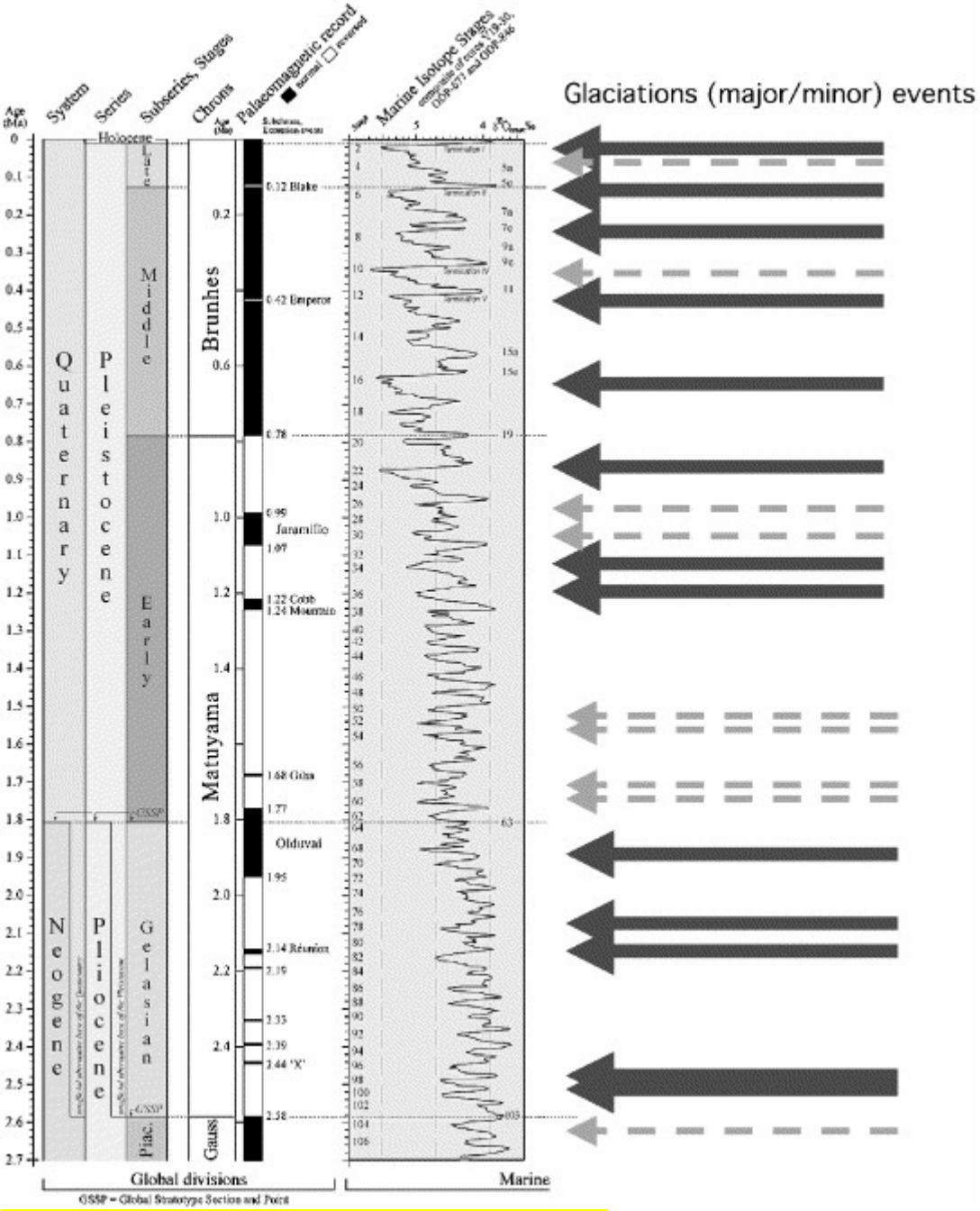
4.
Deep crustal roots of BD
JOONIS LISADA
The Baltic depression as a major morphostructure of the East European Craton (EEC) separated from the surrounding basins of great rivers White Sea, Arctic Ocean, Caspian Sea and Black Sea catchment areas in Early Cenozoic. NE and SE watersheds of the Batic cathment area follow the rifted and faulted boundaries of the 2 Bill years old Paleoproterozoic Svecofennian Crustal Domain. The interior of BD nestled upon the Svecofennian domain suggesting that differentiated tectonic movements of this domain favoured for the erosion of its central area and forming the depression opened to the SE border of EEC.

5.

THE GERAT ICE AGE, WAISTAGE OF GLACIERS AND BIRTH OF BIL

Late Cenozoic glaciations following the global cooling epochs

Oxygen isotope ratios in deep ocean sediments, especially in fossil sceleton reflect seawater temperature changes. Studies reveal that over 20 stages of minor and major glaciation events occurred since the continental glaciations started in northern hemisphere at about 2.6 M years ago.



TABELIST EEMALDADA MAGNET-STRATIGR

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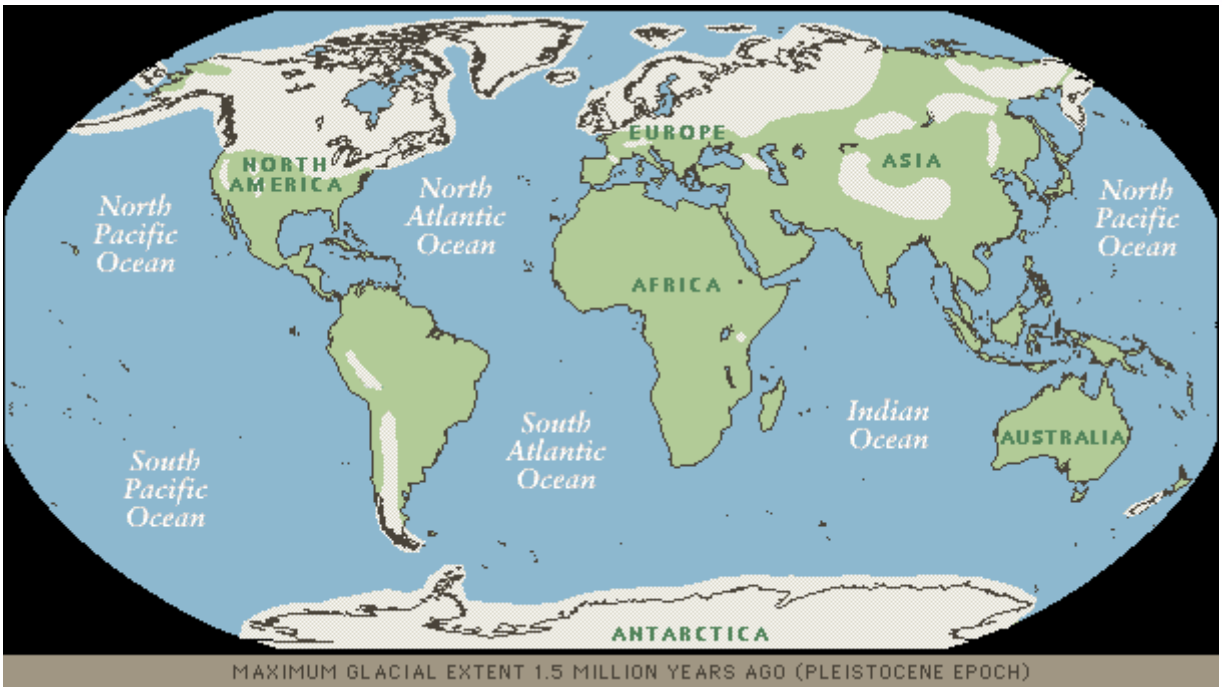
The Great Ice Age – Pleistocene Glaciation – a principal foreplay towards the Baltic Sea, its general and local features

An artist's impression of Ice age Earth at glacial maximum. Based on: "Ice age terrestrial carbon changes revisited" by Thomas J. Crowley.

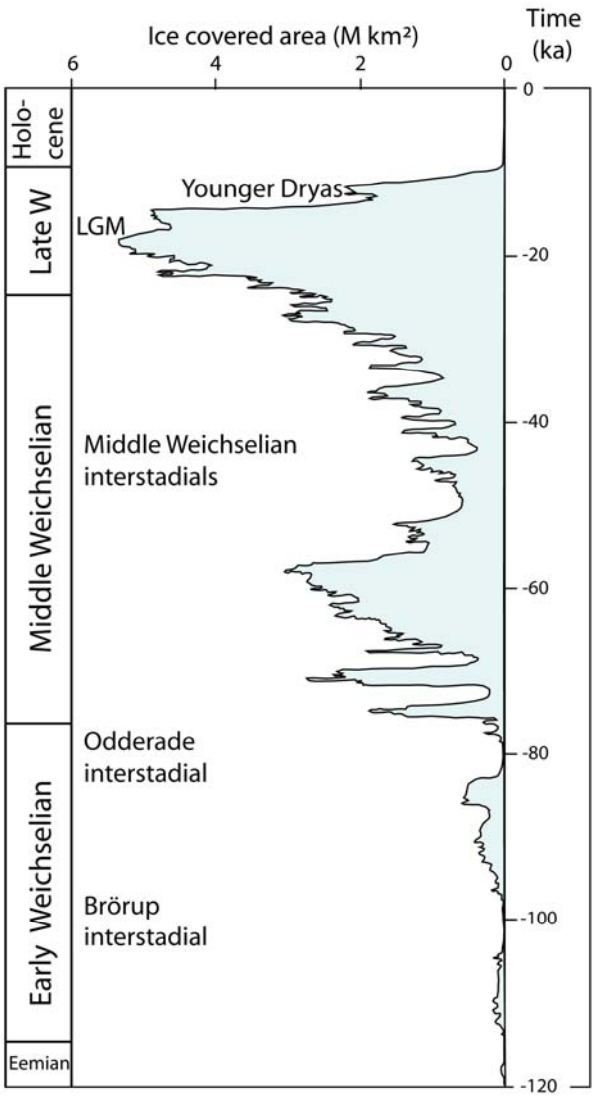
The great Ice Age – Pleistocene Glaciation - started 1.6 million years ago, causing widespread glaciation on northern continents. It was a period of global temperature reduction. In human history, this prehistoric era is commonly referred to as Paleolithic. Fennoscandia and surroundings were covered by an ice sheet then.

7.
A scientists` view to maximum glacial extent 1.5 Million years ago



The Baltic, Hudson and White seas shown in blue were actually overfilled with ice 2-3 km thick.
High ice plateaus of the Northern Hemisphere towered above the surrounding lowlands and ocean, the level of the last lowered some xxx m.
Under the ice sheet, the solid land surface had subsided some 200-300 m or more below its pre-glacial level.

8.
Modeling of changes in territorial extent of the ice sheet from Eemian through Weichselian to Holocene

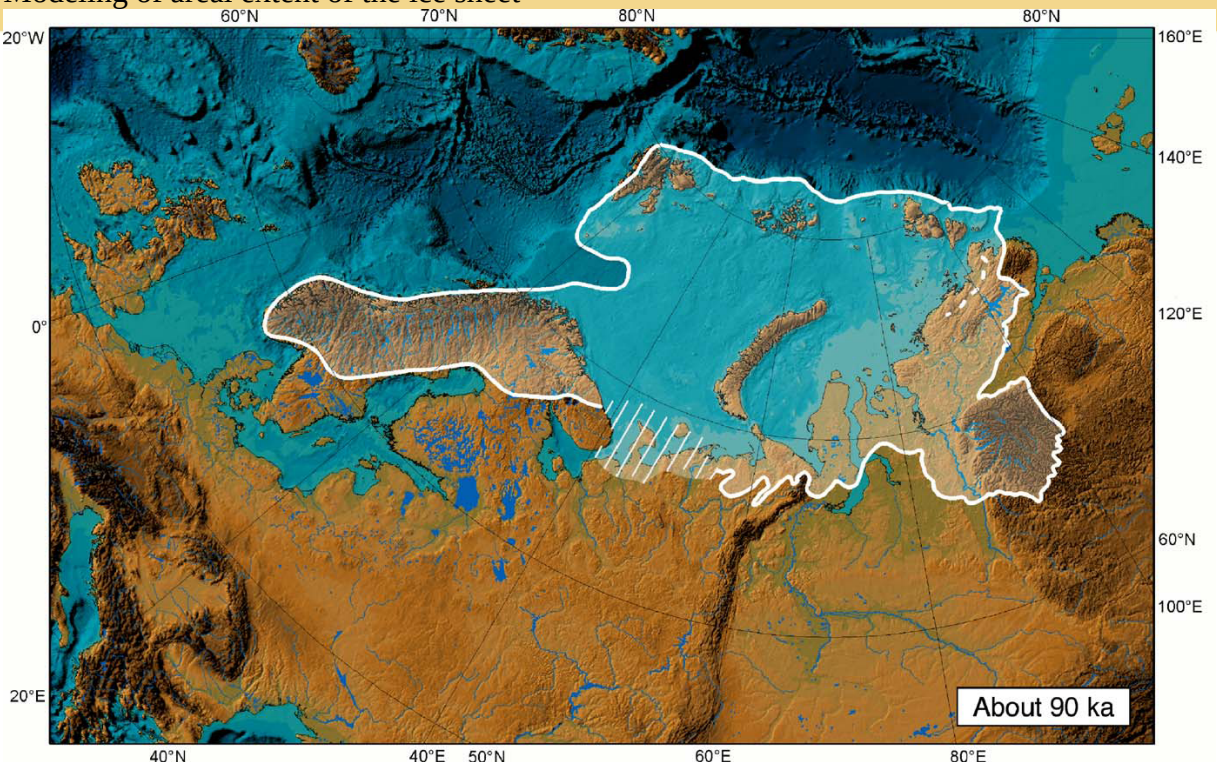


The largest ice sheet 5.5 M km^2 covered lowlands and shelf seas around Fennoscandia. It towered in Northern Europe during the Late Glacial Maximum (LGL) Late Weichselian at about 25 to 15 thousand years ago. During the Weichselian, usually less than 2 000 km^2 of the territory was covered with ice.

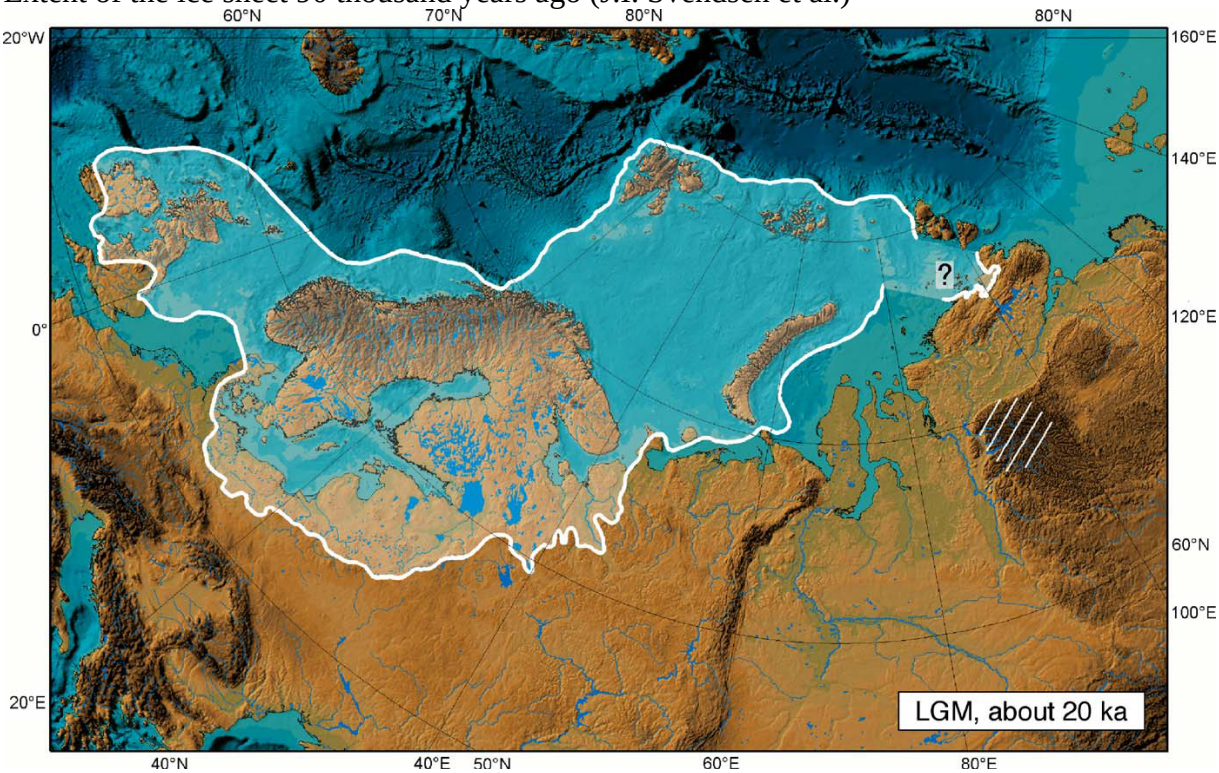
9.
Eeamian Sea
The ocean level during the Eemian interglacial, about 130-115 thousand years ago was ~2-5 m higher than any time during Holocene that left Scandinavia an island. The Eemian sea level flooded low areas including land bridges between the Gulf of Finland and White Sea. This precursor was larger than the present Baltic and obviously of higher salinity.

JOONIS LK
http://notendur.hi.is/oi/Historical%20Geology%20pdf/Fyrirlestur%2014%20-%20Pleistocene%20glaciations.pdf

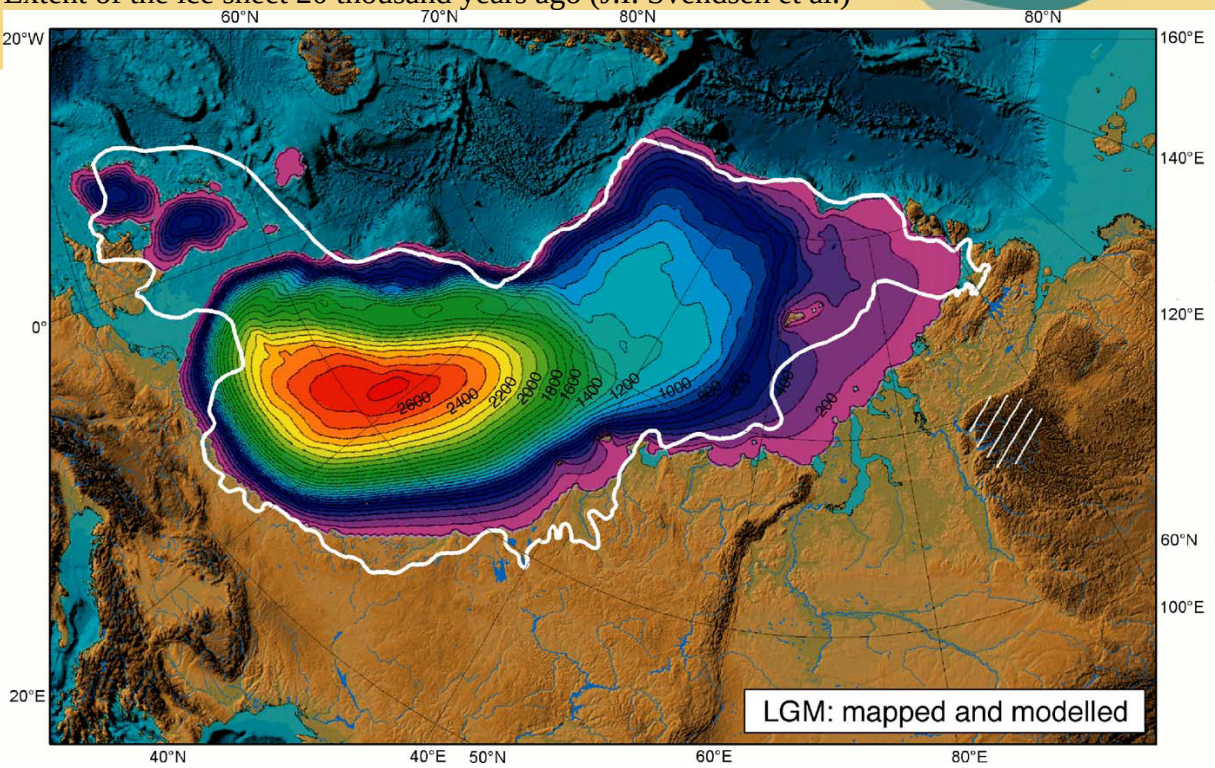
10.
Modeling of areal extent of the ice sheet



Extent of the ice sheet 90 thousand years ago (J.I. Svendsen et al.)



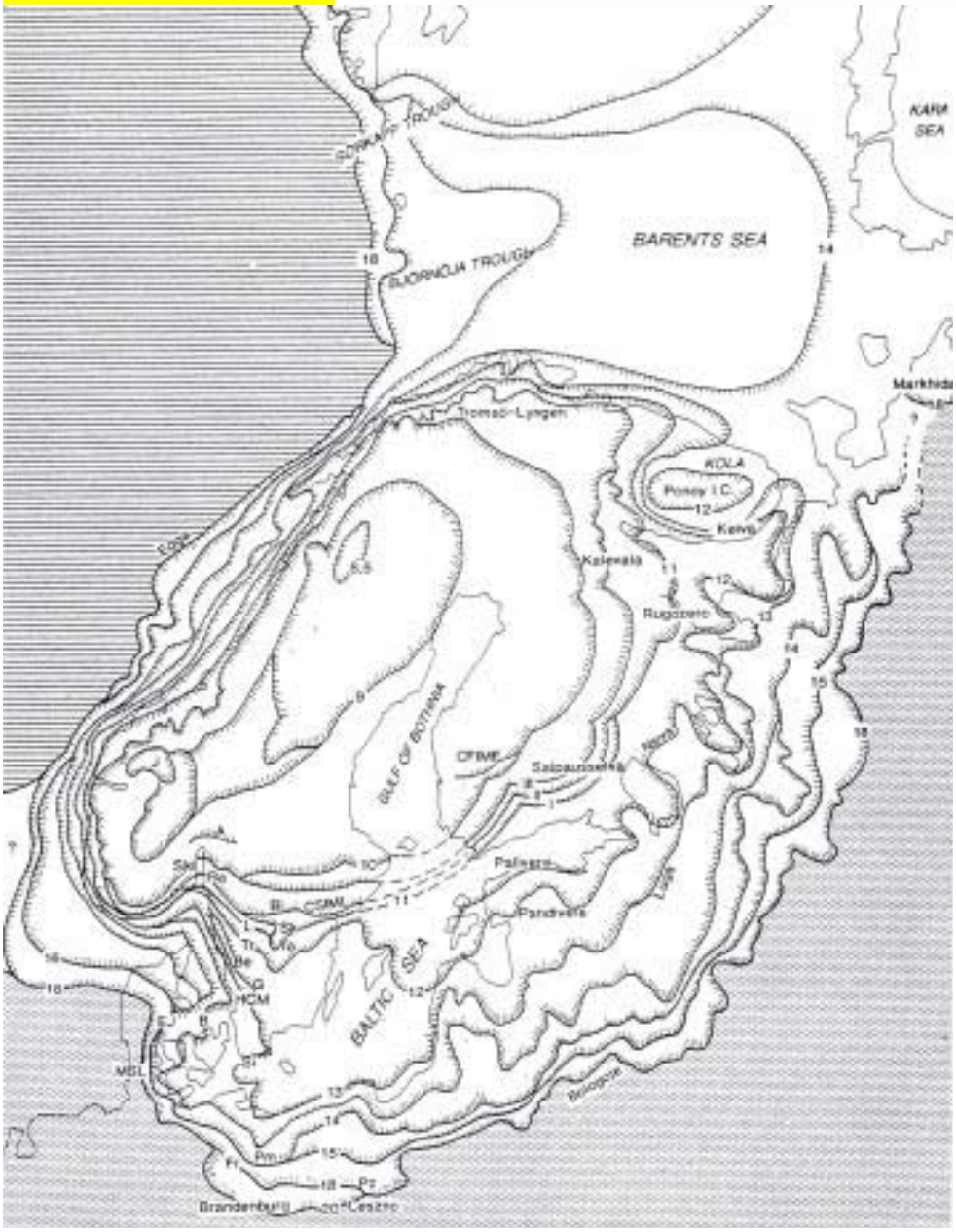
Extent of the ice sheet 20 thousand years ago (J.I. Svendsen et al.)



Ice sheet was thickest 20 thousand years ago in the Gulf of Bothnia area (J.I. Svendsen et al.).

The thickest centre of the largest ice sheet at LGM positioned in the Gulf of Bothnia area (Fig for 18 ka). However, during most of the Weichselian glaciation, the Fennoscandian ice sheet was limited only to restricted mountain areas (as on Fig 85 ka).

11.
Deglaciation of the Baltic Sea region
JOONIS ANIMEERIDA



Isochrons of retreat of the last European ice sheet. The retreat pattern shown in figure is translated into isochrons of retreat by calibration with the Swedish and Finnish varve timescales and available corrected 14C determinations (G.S. Boulton et al.).
Isochrons of waistage of Weicheselian ice sheet between 20 – 10 ka releasing the depression of the Baltic Sea from ice. Retreat of the Weichselian ice sheet from central Europe started some 20 thousand years ago when wastage exceeded accumulation due to rapid warming of climates. (i) Friction at bottom of ice mass and (ii) warming of surface during the summer months, as well as (iii)

evaporation from ice surface were the main processes of wastage. Remind, that even in the Holocene interglacial epoch, continental ice sheets still cover the polar lands and ice gaps occur in mountain ranges, including the Scandinavian mountains.

EELMIST JOONIST VÕRRELDA JOONISEGA 2.4

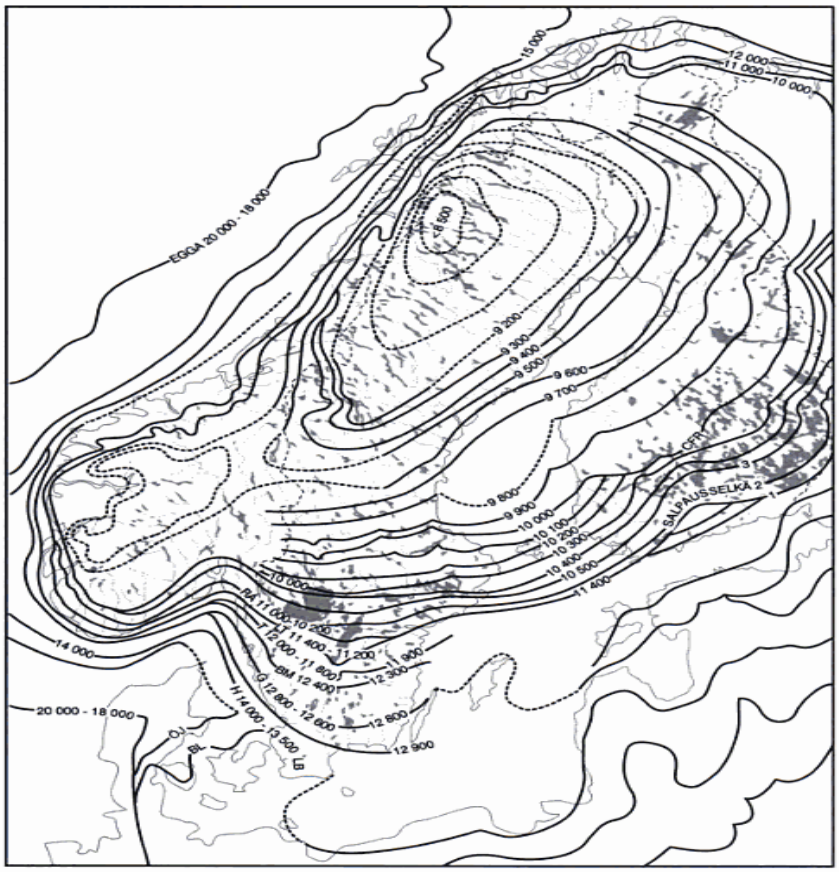


Fig. 2.4 Ice recession lines and the major ice-marginal formations in Fennoscandia
Abbreviations of moraines: B = Billingen; S = Skövde; LT = Levene–Taberg; T = Trollhätte; BM = Berghem–Moslätt; G = Göteborg; H = Halland's coast; LB = Low Baltic; CFR = Central Finland margin; BL = Belt; ÖJ = Eastern Jutland margin;
(*Source:* Adapted from Lindström *et al.* 2000.)

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12.

Glacial processes reshaping the land surface and birth of BIL

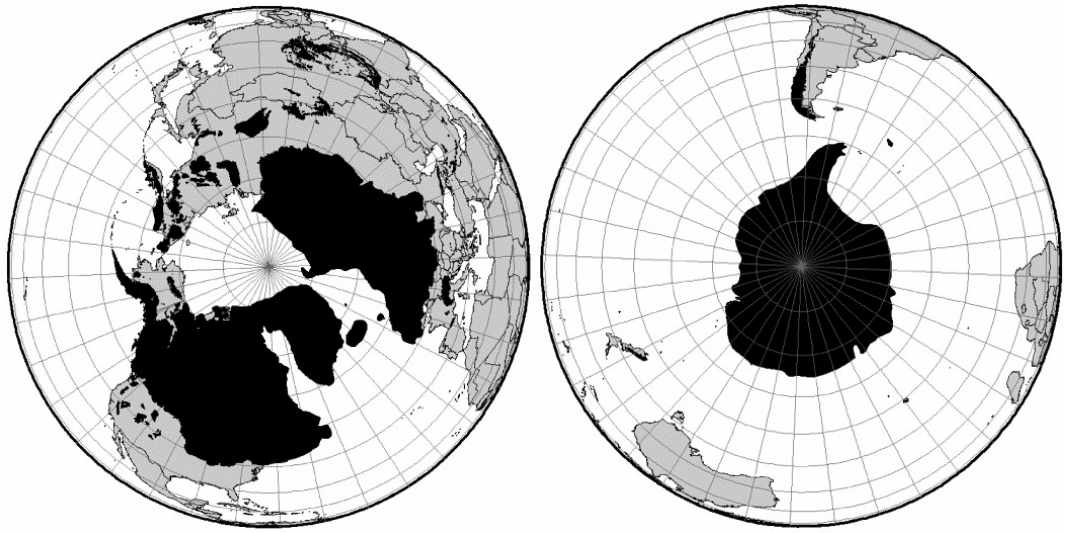
Alari varaseim BIL

The postglacial Baltic waterbody gradually grew out from the dammed ice melt water. It filled the depression on the earth surface that recently was loaded under up to 3 km thick, retreating ice sheet. The land surface in the depression was severely reworked by pre-glacial rivers and moving ice and melt waters during the waistage the glaciers, and subsided under the ice load. The fresh waterbody was born in the SW end of the present BS, close to to the Danish land-bridge, damming the new-born Baltic Ice Lake (BIL) from fatal drainage toward the Atlantic.

13.
MYSTERY OFGLACIATION AND DEGLACIATION

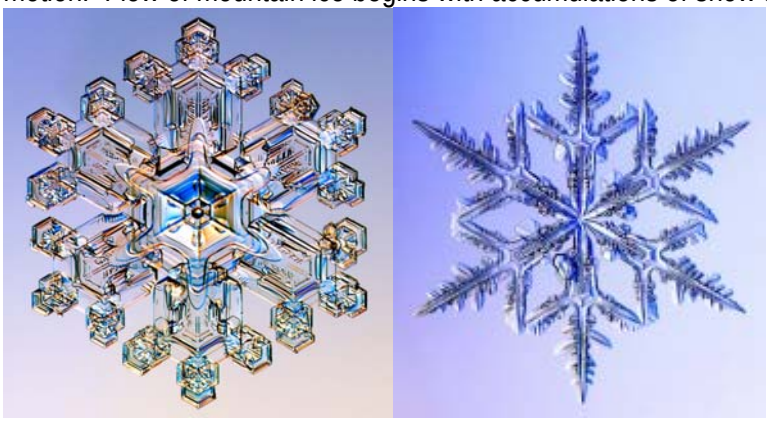
Glaciers, continental ice sheets and ice ages

Siia leida parimad pildid polaaralade laiadest jääkilpidest



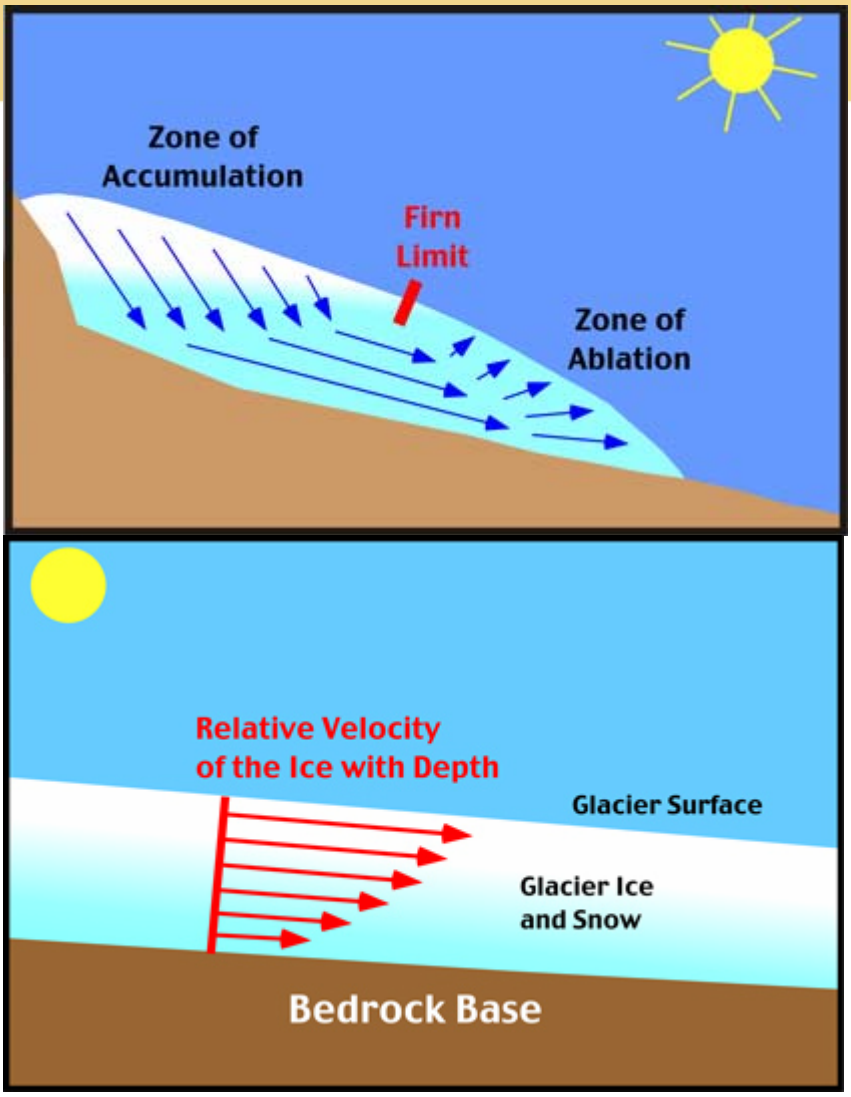
From snowing to glaciers

Snowflakes accumulating on frozen land start glaciations.The density of snow ranges from about 50 to 300 kilograms per cubic meter. After the snow falls, the crystals can be reduced by the effects of ablation (melting and sublimation). The original snowflakes are transformed into small round crystals. This partly melted, compressed snow is called firn, with density exceeding 500 kilograms per cubic meter. Transformation of firn into glacial ice may take 25 to 100 years. To become ice, this snow underwent modifications that caused it to become more compact and dense. Glacial ice has a density of about 850 kilograms per cubic meter. To be called a glacier, a mass of ice must be capable of motion. Flow of mountain ice begins with accumulations of snow and ice greater than 20 meters.



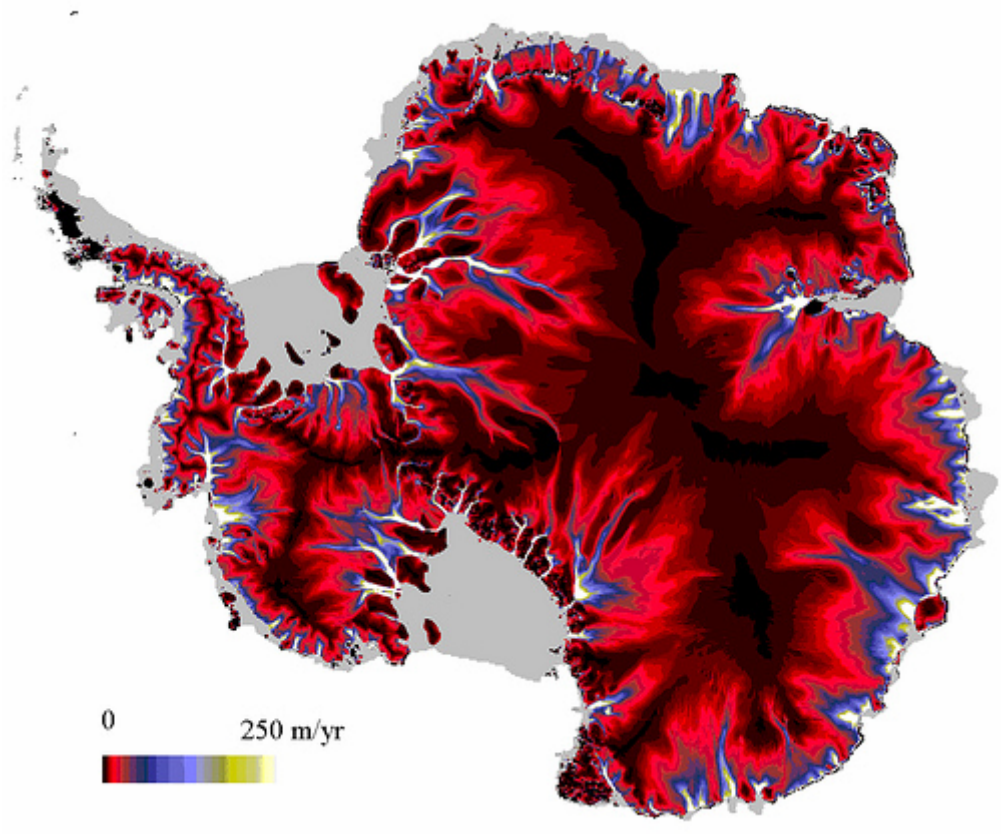
SnowCrystals.com was created by Kenneth G. Libbrecht

Floable ice of glaciers



The density of snow ranges from about 50 to 300 kilograms per cubic meter . After the snow falls, the crystals can be reduced by the effects of ablation (melting and sublimation). The original snowflakes are transformed into small round crystals. This partly melted, compressed snow is called firn, with density exceeding 500 kilograms per cubic meter. Transformation of firn into glacial ice may take 25 to 100 years. To become ice, this snow underwent modifications that caused it to become more compact and dense. Glacial ice has a density of about 850 kilograms per cubic meter. To be called a glacier, a mass of ice must be capable of motion. Flow of mountain ice begins with accumulations of snow and ice greater than 20 meters. Note: on frosen base, the cold ice flow velocity is the lowest.

14.
Ice streams and their velosity



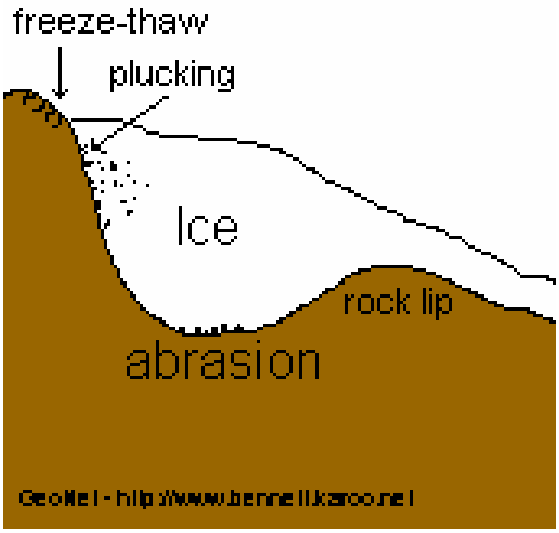
First of all, snow and ice accumulate in a broad basin high in mountains. As the glacier proceeds to move downslope, the flow lines of the ice begin to converge because of the narrowing of the valley. At the terminal end of the glacier, flow lines spread out as the ice is no long constricted by valley walls. In large comtinental sheets, many separate ice streams usually follow depressions of the base. The movement of ice over the ground in most temperate glaciers is enhanced by a process known as basal sliding. The weight of the overlying glacial mass causes the ice to melt because of pressure, despite subzero temperatures (pressure melting). Cold glaciers tend to move very slowly because there is no basal sliding.

15.

GLACIAL EROSION

Glacial erosion

Glacial erosion reshaping the land surface. Actually it very much sculptured the Baltic Sea bottom.



Stationary glaciers (cold-based glaciers) are much less erosive than warm based-glaciers. It is the mobility of warm-based glaciers, due to the presence of meltwater, and the material that they transport that facilitates greater amounts of erosion.

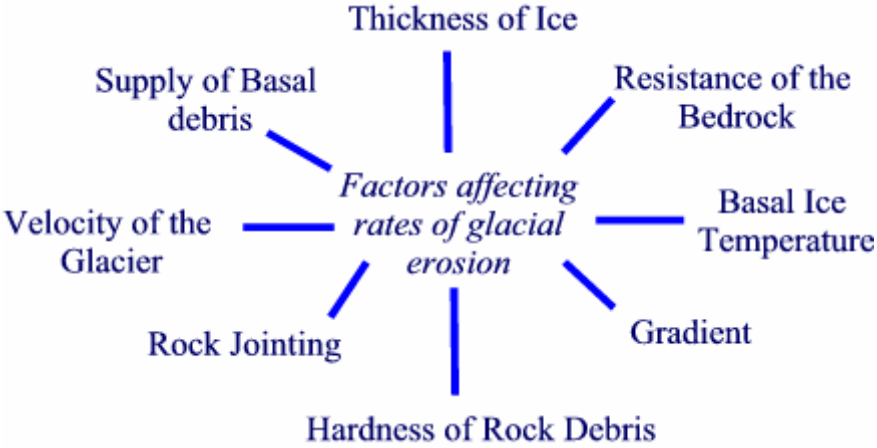
As glaciers move over the landscape, they are able to erode it. The rock that is removed by these processes (lowering and carving the primary relief) is then transported by the glacier and deposited elsewhere (accumulating positive landforms).

Three main processes of glacial erosion

VAJALIK FOTO EROSIOONIST

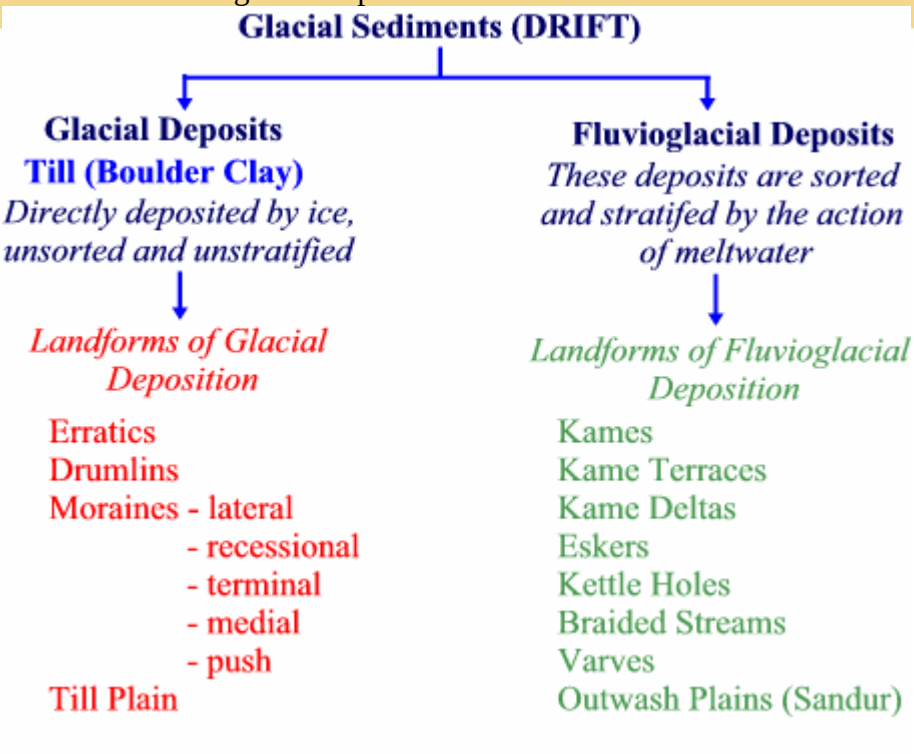
Abrasion. As the glacier moves over the bedrock, rock debris embedded in ice scrapes away at the rock like sandpaper wearing it away, leaving behind polished surfaces with striations. Fine material embedded in the base of the glacier will act to 'polish' and smooth the bedrock below. xxxxPlucking. The process of plucking (also known as quarrying), results in the removal of much larger fragments of bedrock than that undertaken by abrasion. The process is most effective on well jointed rock. Large erratic blocks transported by glaciers far from their place of occurrence are formed due to plucking. xxxx Sub-glacial meltwater erosion. Meltwater under the glacier is often travelling under pressure and may fluvially abrade the underlying bedrock using the sediment that it is carrying. This process is most effective where the suspended sediment is coarse.

16.
Factors affecting rates of glacial erosion



Stationary glaciers (freezen or cold-based glaciers) are much less erosive than warm based-glaciers. It is the mobility of warm-based glaciers, due to the presence of meltwater, and the material that they transport that facilitates greater amounts of erosion.

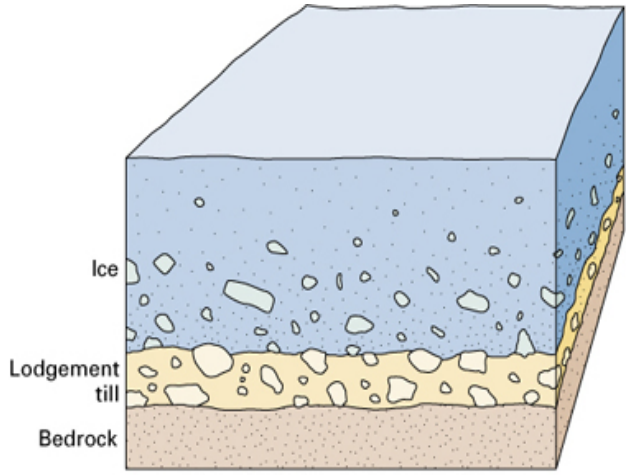
17.
Glacial and fluvioglacial deposits and landforms



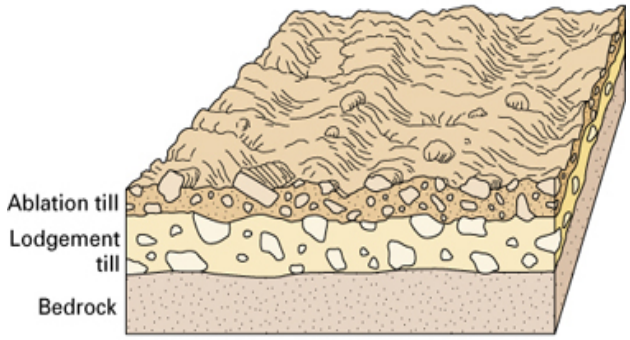
TABELI parempoolse tulba nimi anda täiendatud kujul:

Fluvioglacial and glaciolacustrine/-marine deposits

Glacial sediment is collectively known as ***drift***. Abundant drift is mixed into the glacier ice. Material that is deposited directly by ice is known as **till** (or **boulder clay**). Although depending in rock varieties of bedrock, glacial deposits are are generally alike because they are both unsorted and unstratified. A large portion of material may also be deposited by glacial meltwater streams. These deposits are known as **outwash deposits.** Fluvio-glacial deposits are well sorted due to the action of water, and a large variety of those are met in different landforms .



Glacial drift in ice sheet



Till plain

Moving glacier erodes its base and carries suspended fragmented and ground rock material, accumulating lodgement till on its lower contact as lodgement till. In course of ablation the suspended material concentrates on glacier surface ("dirty ice"). Till plain looks like hummocky flatland.

18.

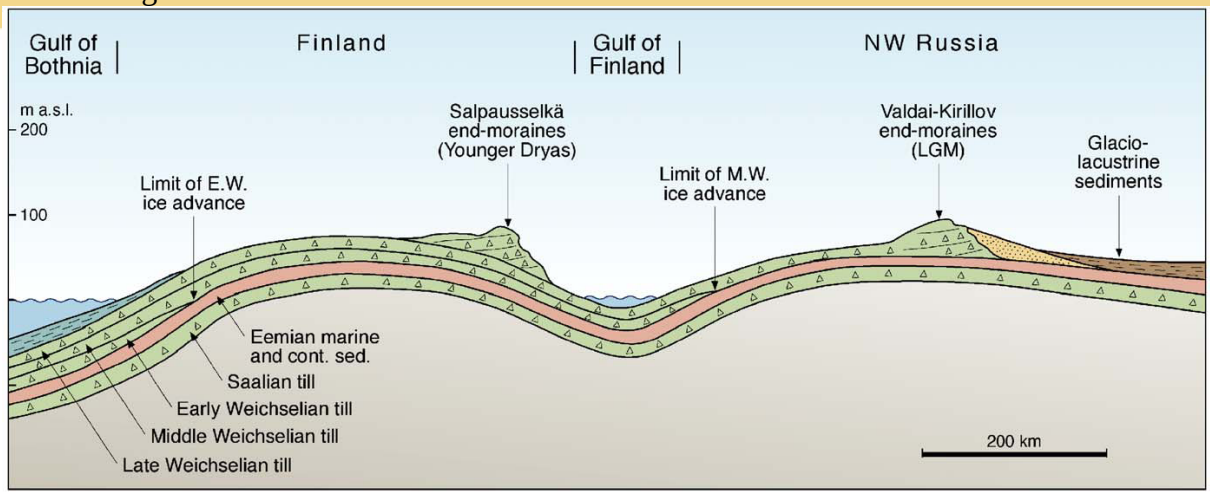
Ages of basal of glacial drift in BIL and BS

Ages, 10^3 years	Stages	SW Baltic, off Denmark	SE Baltic, off Poland	Southern Baltic , off Oland	Gotland Deep	Northern Baltic, off Hiiumaa	Bothnian Sea	Bothni Bay
0-4	Littorina Sea	BS: Marine silts and sands, muds						
4-8		BS: Marine silts and sands, muds						
8-10	Ancylus Lake, Yoldia Sea	AL silts and sands, muds BSY silts and sands, muds					AL, glacio-marine fluvial, till	
10-12	BIL	BIL silts and sands, muds, varves				AL, glacio-marine/-fluvial, till	till	
12-14		BIL silts and sands, muds, varves			AL, glacio-marine/-fluvial, till	till		
14-16		BIL silts and sands, muds, varves			till			
16-18	Glacier	Till						

BS – Baltic Sea, AL – Ancylus Lake, BSY - Baltic Sea Yoldia stage, BIL / BIL - Baltic Ise Lake

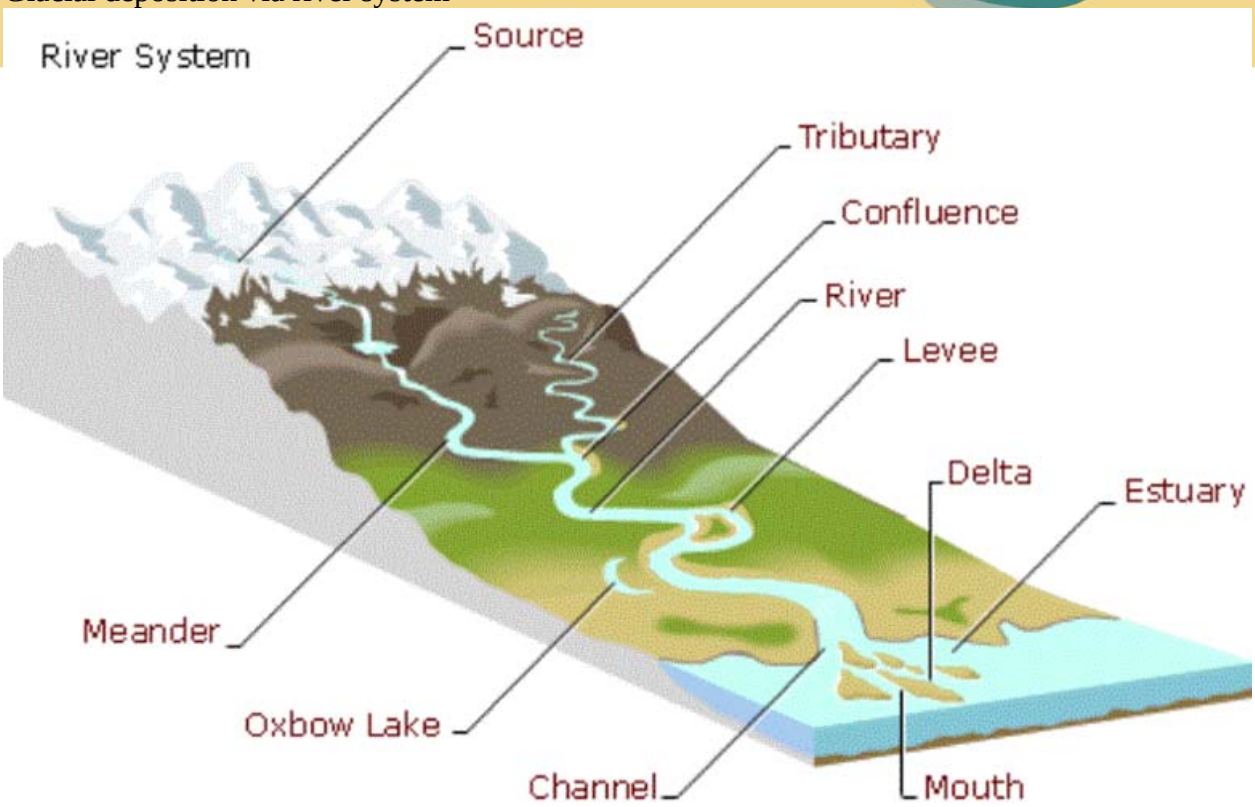
During 18 to 8 thousand years ago, the glacier margin gradually retreated and the Baltic waterbody extended. The zone of intense ice-marginal deposition of glacial and glaciofluvial/-lacustrine formations upon the base surface of smoothed by moving ice streams gradually migrated from the south to the north. Note that when Yoldia Sea established in the most of BS area, the northernmost Bothnian Bay was still filled with ice. Huge melt-water inflow carried masses of suspended rock debris from melting glaciers into BIL and BS. As a result, extensive moraine plains and positive ice-marginal landforms (oldest in the south and youngest in the north) sculpture both present seabed and surrounding “virgin lands”.

Principal cross section of Weichselian glacial deposits in Gulfs of Bothnia and Finland and surrounding offshore areas



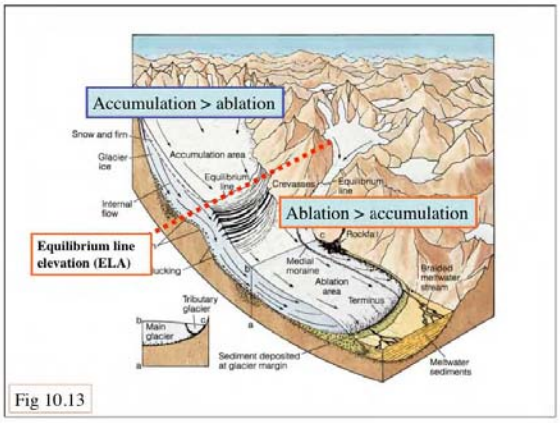
Holocene lacustrine, marine and continental sediments that overlie the glacial drift are omitted. Under the Late Weichselian, Middle Weichselian deposits are found in central and western parts of the profile, and Early Weichselian – in the westernmost part, reflecting lesser extension of respective glaciations phases. The underlying Eemian interglacial deposits and Saalian glacial deposits are actually only randomly survived, because they usually are eroded by Weichselian glacial movements.

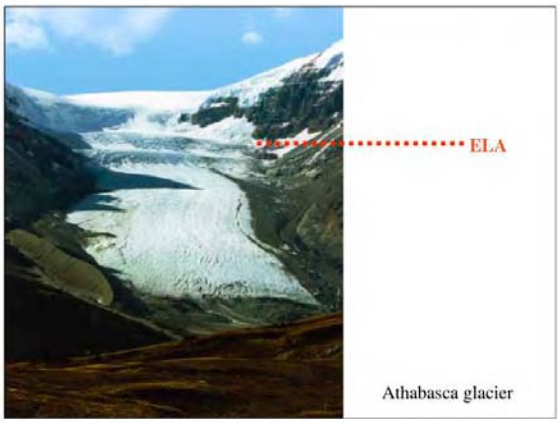
Glacial deposition via river system



JOONIS ANIMEERIDA

Long-lasting in early and middle Weichselian, and again in latest Weichselian, the Fennoscandian glacier was limited to Scandinavian mountain chain. Glaciers melted on mountain slopes supplying suspended material into Gulf of Bothnia and Baltic Sea via river system. Additional grinding and rounding of the debris occurred in the course of fluvial transportation before the final deposition in lake or sea environments.

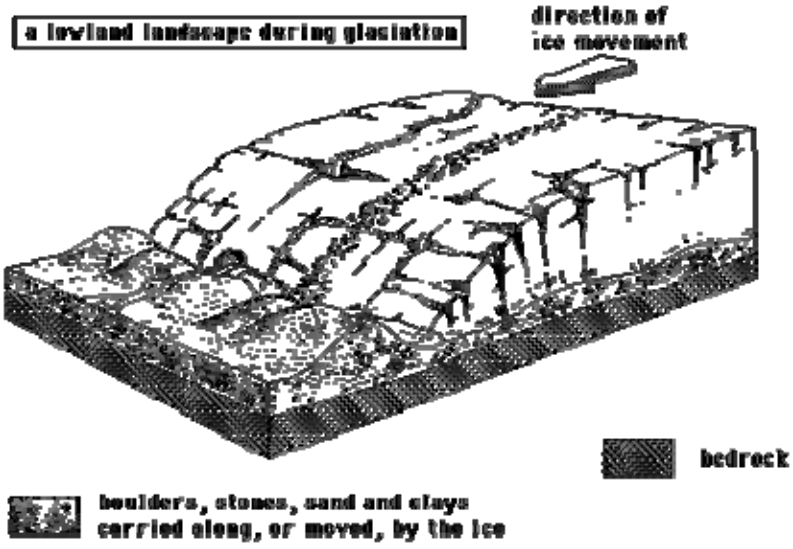


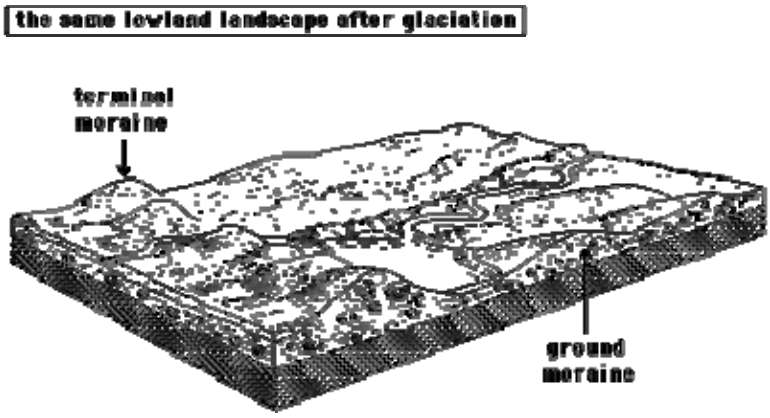


2

Most of the time the Weichselian glaciation in Scandinavia, many glaciers of southeastern slopes supplied meltwater streams with suspended material carried toward the Gulf of Bothnia and Baltic Sea. In mountain glaciers areas of accumulation and ablation/melting may position close to each other. However, in cold epochs like LGM, mountain glaciers together with direct accumulation of snow contributed to accumualtion of the huge ice sheet in Fennoscandia and surrounding area.

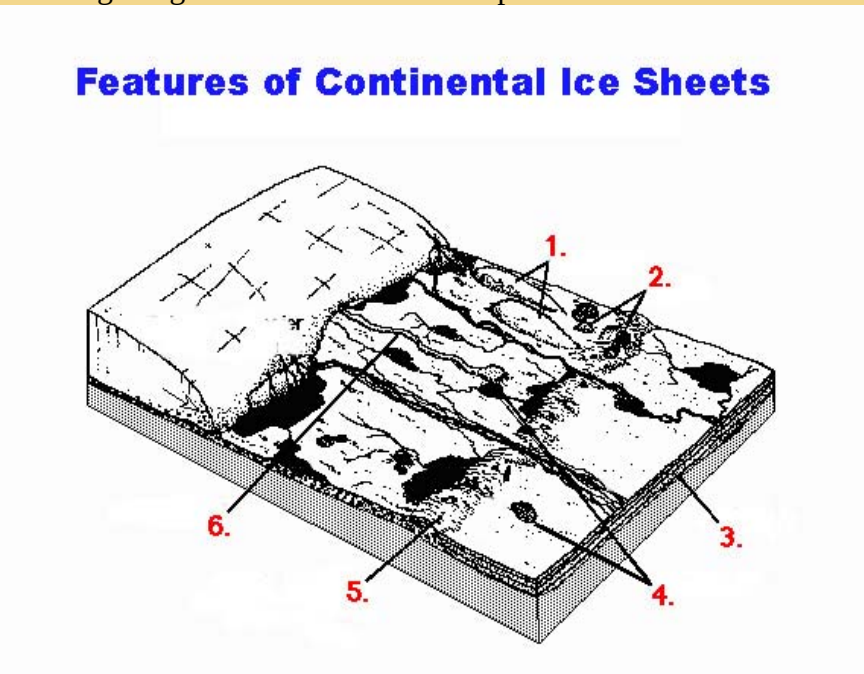
Ice marginal deposits and landforms of retreating continental glacial sheets





In the process of wastage and retreat, the collapse of a continental ice sheet margin may be fast: the Late Weichselian sheet covering an area more than 5 000 000 km² dissappeared during 10 000 years. Melt water streams in tunnels of collapsing ice sheet and at its base carried suspended material outside the glacier. Temporary stagnations of ice margin (weakining of melting of moving ice streams) caused accumulation of chains of terminal moraine hills on maps shown as ice-marginal zones. Temporary advance of ice margin could push, compress and terminal moraines and glaciofluvial esker, kame and other deposits. Parallel chains of marginal morains as positive landforms mark the order of stepwise retreat (recession) and temporary outage (stand) in deglaciation of a region.

Ice marginal glaciofluvial and other deposits and landforms



Ice marginal glaciofluvial and other deposits and landforms left by retreating continental glacial sheets substantially modify the hummocky till plain – the dominating landform of a glaciated area. Glaciofluvial deposts and landforms: 1, 2, 6 –supra-, infra- or underglacial formations settling in the course of ice melting, 3 and 5 – extra-glacial formations accumulated by meltwater streams, 4 – holes in outwash plain left after melting of buried dead ice blocks.

Märkide järjestust tuleb muuta loogilisemaks (numbrid sulgudes), lisades 7. Braided stream

1 drumlins (4)
2 kames (3)
3 outwash (5)
4 Kettles/kettle lakes (6)
5 terminal moraine (1)
6 esker (2)

Braided streams continue depositing outwash material (7)

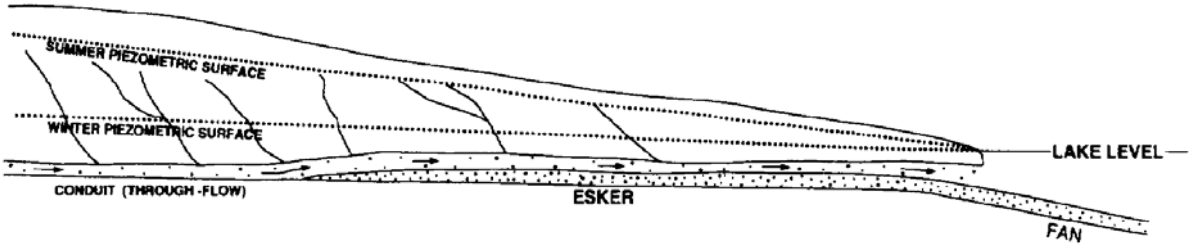


FIGURE 1 ….

Eskers are composed of fluvioglacial gravels and coarse sands**,** forming prolonged walls (at most hundreds km long, over 100 m high) in surface topography. They are typical for glaciated areas. Eskers may form on lands above surrounding water level. In the picture (1), esker gravels are supposed to accumulate in a water conduit. **Eskers deposits** accumulate in riverbeds on top of a glacier or in tunnels within or at the base or side of an ice sheet. In figure 1 melt-water conduit is active under the embracing lake level, in Fig (2) are shown parallel tunnels falling into the waterbody their outwash fans accumulating next to delta of a supra-glacial stream.

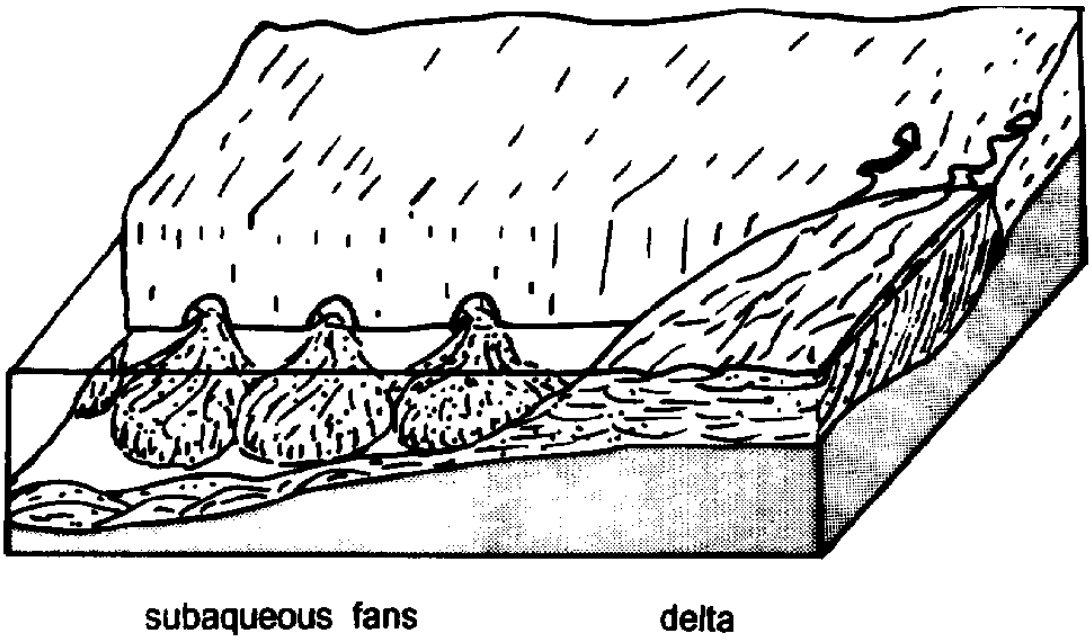


FIGURE 2

Typical stratified coarse sands of eskers, slightly deformed (flexured) in the course of melting of ice, and compaction. The picture characterizes a considerably stable composition surrounded by lenses and irregular bodies composed of pebbles or cobbles, or rich in fine sand and clay. Till cap layer may hide the esker interior.

Subglacial conditions in a branching Saalian esker in north-central Poland

Amir Mokhtari Fard and Beata Gruszka

© Matti Osara

FOTO VÄLJAVAHETADA: JUUNIS VÄLITÖÖD PILDISTADA

In Fennoscandian glaciation area, eskers are most wide-spread glacial landforms, especially in the shield area, including “virgin lands” and present Baltic seabed. They are equally abundant near ice-marginal zones and in-between. Orientation of eskers is close to directions of ice streams of the retreating ice sheet (illustrated below). Eskers have been of extraordinary importance as deposits of cheep high quality building material. Kaukolan-harju (harju = esker) is one of the 156 landscape areas, which was defined by the Finnish Government as nationally valuable landscapes.

Kames are also infra-glacier formations

On till plains, kames occur as steep-sided mounds of stratified sand and gravel. Large holes in melting glacier top layers (supraglacial) or in its interior (intraglacial) or at its base were filled with ice lake deposits. Infra-glacier meltwater streams have carried, sorted and redeposited drift material into holes acting as ice lakes. Coarse, well stratified sands are the most typical kame deposits. Also kames have presented extraordinary important deposits of building material.

Lithologies of sandar

Moving glaciers contain large amounts of fine sediment, picked up as they erode the underlying rocks. At the snout of the glacier, meltwater can carry this sediment away from the glacier and deposit it on a broad outwash plain forming sandars. Finest materials, like silt, are the most distantly re-deposited, whereas larger boulders, pebbles and gravels are the closest to the original terminus of the glacier. Surfacial braided streams rework the original deposits. Outwash plains may also contain kettle lakes, locations where blocks of ice have melted, leaving a depression that fills with water. Sandars are met on ’virgin lands’ and in Baltic seabed.

21.
Varves and dropstones

A single dropstone in glaciomarine varves

At sea or lake, near the glaciers margins varved deposits accumulated reflecting the yearly cycles of faster (summer) and slower (winter) sedimentation. Fine-grained sediments reliesed from the melting glacier. Single boulders, cobbles, gravel grains – dropstones – in varved clays suggest wandering and slowly melting of icebergs.

VAJALIK TEHA MOVIE KUIDAS KIVI KUKUB PANGALT

22.
Drumlins: drumlin fields and other glacial landforms in eastern Estonia
LISADA:
Fig 2 lk 19 Maris Rattas disser 2004
These oval or elongated hills are believed to have been formed by the streamlined movement of glacial ice sheets across rock debris, or till. Drumlins are generally found in broad lowland regions, with their long axes roughly parallel to the path of glacial flow. Although they come in a variety of shapes, the glacier side is always high and steep, while the lee side is smooth and tapers gently in the direction of ice movement. Drumlins can vary widely in size. They usually occur as drumlin fields on „virgin lands“ and as minor groups in seabed.

23.

BIRTH OF THE BALTIC SEA

Ocean level curve during the Late Weichselian and Holocene

29.jpg

Post-glacial sea level rise

Glacier collapse and advancing Baltic waterbody

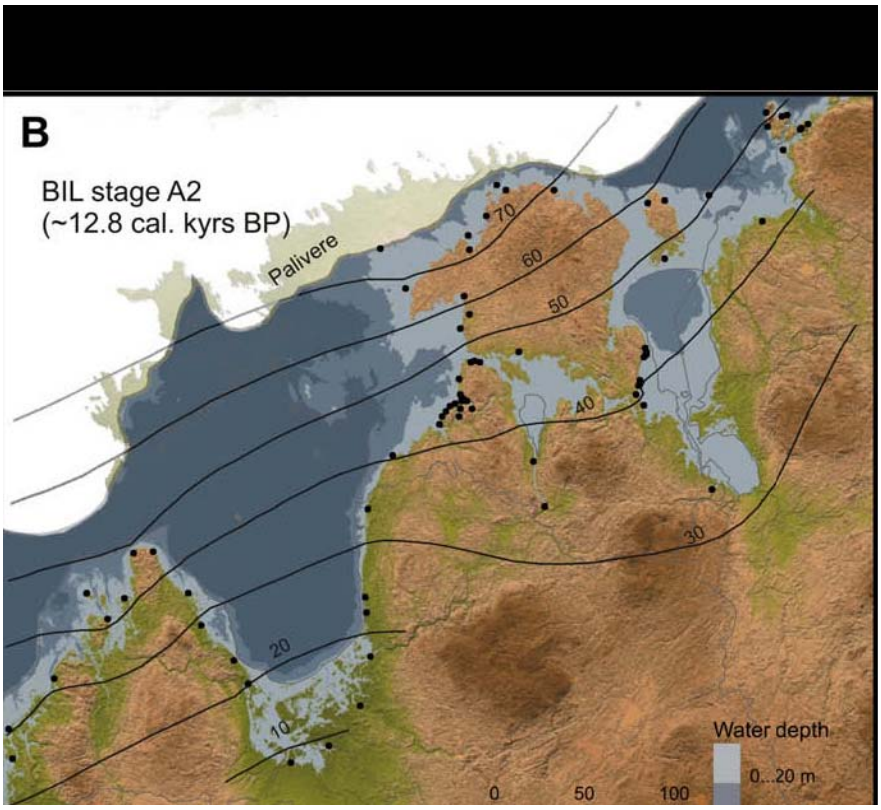
Glaciers stored more than 70 million km3 of water, lowering world ocean level 130 meters. During LGM, some 22 thousand years ago, the ocean level was lowest. The ocean level rapid rise, proved by the global studies, corresponds to the ubrupt climate warming during the latest Pleistocene. In the Baltic depression, meltwater started to replace the continental glacier at about 14 000 years ago when the ocean level was some 80 m below the present. The first ingression of the seawater giving birth to Yoldia Sea happened at about 11 700 years ago when the ocean level was some 60 m below the present. Littorina Sea established at about 8 000 years ago when the ocean level was some 10 m below the present, and at about 6000 years ago – 2 m below present. The second half of the Holocene only a gentle rise of the ocean level (as well as of the Baltic Sea level) has occurred. The first ingression of the salty seawater into the BaLtic Ice Lake at about (11 700) (10 thousands) years ago gave birth to brackish Yoldia Sea.

KONTROLLIDA TEKSTIS ÜLE ARVUD - AASTASKAALAD

In the very beginning of inundation of the future Baltic Sea basin at about 15 thousand years ago, a narrow channel-like along the glacier margin formed. This was the way for meltwater from the Privaldai Ice Lake (PL) toward the Glacial Lake Peipsi (GLP), inundated Kurland and southern Baltic Ice Lake (BIL). A river from BIL, which then had some xxx m lower water level than BIL. Influx of surface drainage to channel-like BIL was diverse. In the north, glacial streams from its surface and tunnels fed the lake. In the south, rivers draining the area recently left by glaciers transferred rich suspended material to the lake.

25.
The Baltic Ice Lake at ~ 12,8 cal kyrs BP

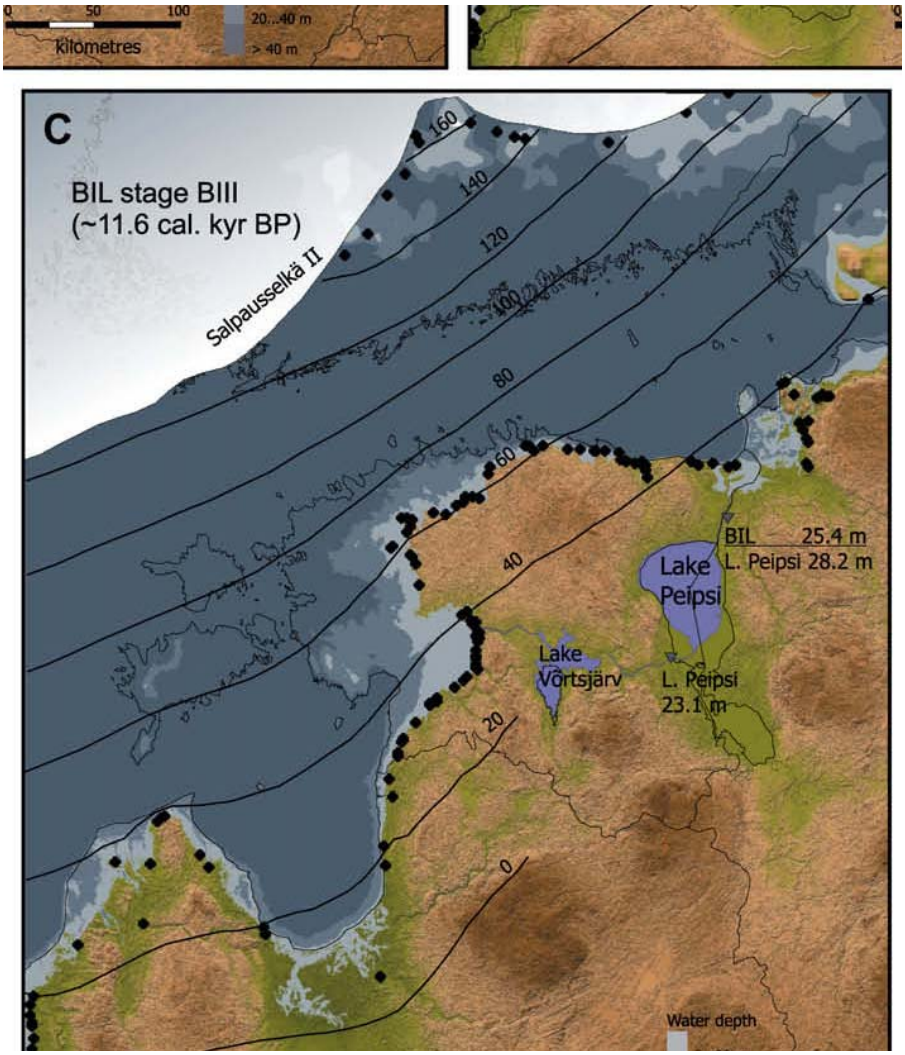
Rosentau et al Quat Int 206, p 19 Fig.3B – jpg/ eraldi saadetis



BIL flooded eastern parts of the Gulf of Finland, the NArva and Ojamaa lowlands in NE Estonia, Gulf of Riga with embracing mainland and deglaciated parts of Saaremaa and Hiiumaa. The outflow from Lake Peipsi toward Lake Vo~rtsja'rv and Gulf of Riga continued existence parallel to inundated zone along the ice margin. Note that the North Estonian Klint in NE Estonia was under water level, but in NW - still under ice sheet. The Pandivere, Otep''a'a and Sakala Uplands of Estonia already towered above the lake level.

26.
The Baltic Ice Lake at ~ 11,6 cal kyrs BP

Rosentau et al Quat Int 206, p 20 Fig.4c – jpg-eraldi saadetis



BIL flooded the Gulf of Finland and SE Baltic Sea together with W Estonia and west Estonian Islands, as well as a narrow low coastal zone of Latvia. Note the contours of Lake Peipsi, outflow from which was via Vo~rtsja”rv toward Gulf of P’arnu. The edge of North Estonian Klint appeared from the water, but in NW Estonia it still was underwater. Imagine, how would rivers of North Estonia look like having in mind the present waterfalls. A small stripe of ”virgin land” formed since 12,8 kyr BP (compare Fig 31) will continuously extend toward western coast of Estonia.

27.
Birth of the brackish Yoldia Sea

During 13-8 ka BP the melt-water lakes gradually extended along the southern margin of the glacial sheet. The lake system was drained through Sweden-Denmark land dridge by rivers that fell into North Sea via Skagerrak and Kattegat straits. Factors like (i) tectonic and glacioisostatic vertical movements of land, (ii) river erosion of land surface, (iii) rise of the ocean level as well as (iiii) retreat and temporary readvance of the nearby ice sheet changed the relative height of the threshold, causing recurrent openings and closures of straits for ingression of ocean water.The Yoldia Sea – a short lived connection with the sea across south-central Sweden through the Närke strait – approximately 10,000 to 9,600 BP. Note: (i) the seabed was formed in the course of recurrent glaciations, and the latest phase of its formation was sedimentation from ices lakes; (ii) the primary contours of the Ancylus Sea were much larger than the present Baltic coastline, therefore the early marine sediments are found also on present coastal lowlands.

Littorina Sea

PILTI VAJA

Since 8000 years BP, the Littorina Sea has receded most of all in the Gulf of Bothnia area and also in considerably low NW Estonia. Note that the highest points of Saaremaa and Hiiumaa as well as of Aland Islands have just emerged from the sea. No Hailuoto Island,Turku and Stockholm archipelagos and many small isles existed then. Non-existing then lower runs of present rivers are shaded. Larger straits toward Kattegat suggest richer inflow of ocean water.

Stages and key fossils of the postglacial Baltic waterbody

The factors that determined the sea's characteristics were the changes of ocean level, differentiated submergence or emergence of the region due to the weight of ice and subsequent isostatic readjustment, and the connecting channels to the North Sea-Atlantic, either through the straits of Denmark or at what are now the large lakes of Sweden, and the White Sea-Arctic Sea. A detailed time table of existence of waterbodies in the Baltic depression.

Fossils OSA PILTE PUUDU

- Post-littorina Sea or today's Baltic Sea 4,000–present
- Littorina Sea, 7,500–4,000
- Mastogloia Sea 8,000–7,500
- Ancylus Lake, 9,500–8,000
- Yoldia Sea, 10,300–9500
- Baltic ice lake, 12,600–10,300 peaks olema varasem algus? *Lisada mahajooksu aeg*
    - Weichselian Ice Sheet
- Eemian Sea, 130,000–115,000 (years ago)
- Limnaea Sea (Named after brackish snail L*ymnaea ovata*) PILT VAJA LEIDA

- Mya Sea (named after the brackish beach clam *Mya arenaria*)

Mya arenaria

Photo © Erkki Leppäkoski, Åbo Akademi University

Ancylus fluviatilis, minute conical gastropod

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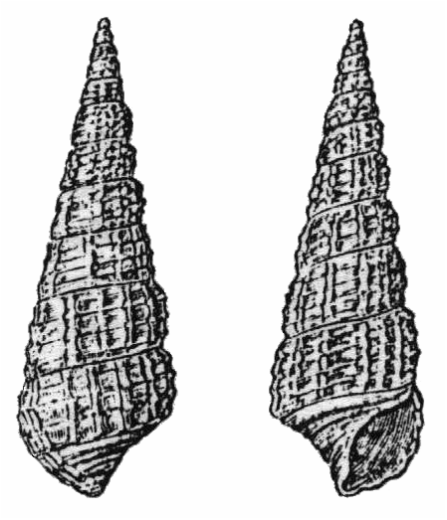
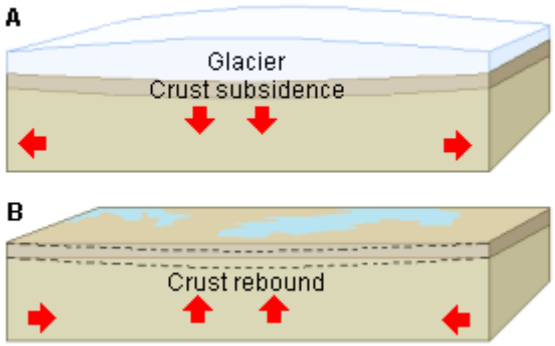
Yoldia Sea, named after the saltwater clam Portlandia *arctica* (previously known as *Yoldia arctica*)



Bittium reticulatum

Bittium reticulatum Picture from Harting (1886) assigned by him as 'Index fossil' for the Eemian

Isostatic reponse of the earth crust to glacial loading and unloading



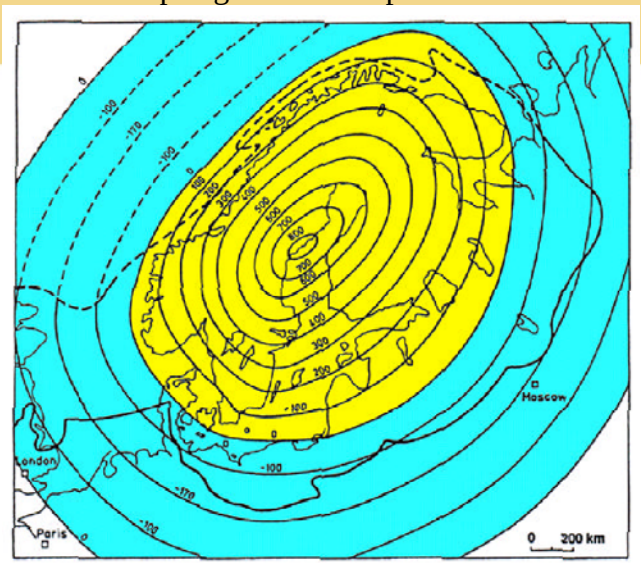
This simplified illustrations shows the crustal subsidence and subsequent rebound produced by variations of glaciers loads variations.

A: In Northern Canada and Scandinavia ice accumulated and bent the crust layer.
B: When ice started to melt down, the surface relocated back to its previous position.

JOONISE KÕRVALE JÄTTA A: ja B:, ülemine lõik ära

The first reaction to the loading of an ice sheet is subsidence of ground surface. The depression is about a third the thickness of the ice sheet. Expanding and decilining of an ice sheet cause respective deformations of the ground surface. Isostatic rebound occurs with a certain delay in time to the changes of ice load. Consequently, the land uplift as an isostatic adjustment of the Fennoscandian glaciation area has lasted already more than 10 thousand years and it is still in progress.

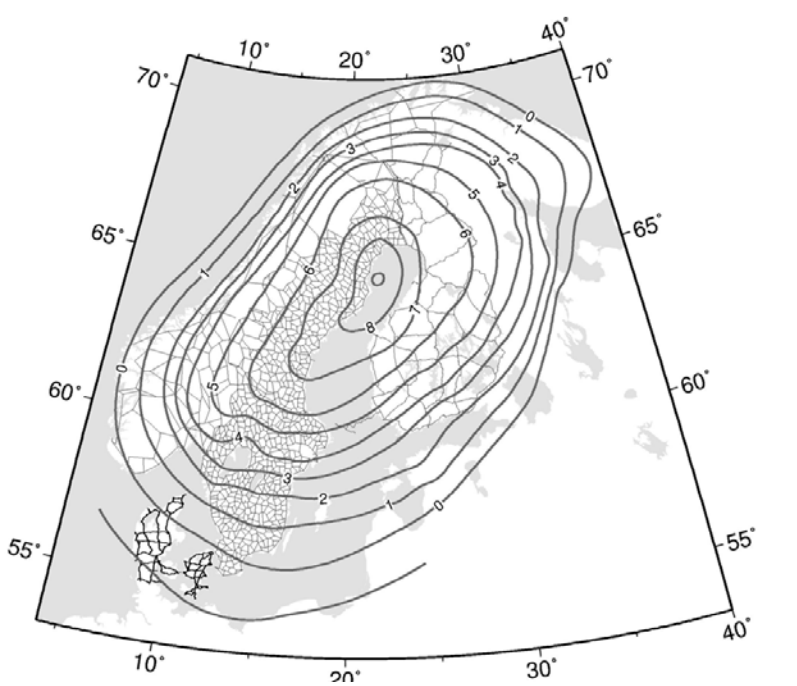
The total of postglacial land uplift in the centre of the last North European glaciation



Original from: Dr. Wolfram Lemke

The Baltic Sea depression was filled with seawater after and due to the retreat of the Late Weichselian continental glacier from NW Europe about 20 000 to 10 000 years ago. Its contours are still in contraction phase due to post-glacial land uplift. Model in Fig A is extrapolating the observed land uplift (yellow) data back to the start of glacier thinning. In consequence with the model, the blue area is supposed to be subsiding to compesate uplift of the central area. However, a very probable uplift of the marginal parts of the glaciated area due to early decay of ice sheet there is ignored in the model.

Present-day glacioisostatic land uplift in northern Europe



Geodetic leveling data reveal that the most intense land uplift almost 1 cm per year occurs continously in the Gulf of Bothnia area, it is in the centre of the past Fennoscandian glaciation. Along the ice sheet margins of some 12-14 thousand years ago the land surface is either stableor even gently sinking. In the centre of glaciation, velocity of land uplift was almost 10 cm per year in times of glacier decay. Since that, velocity of land uplift has decreased about ten times there.

? ERALDI PLOKINA PAIGUTADA:
BEDROCK UNDER THE QUATERNARY BLANKET AND EXPOSED IN OUTCROPS

Pre-glacial geology of the Baltic Sea and Baltic Depression
Lihtsustada, suurendada Baltimere osa, vähendada ala W, N ja E servades! Likvideerida inset/map, väike kaart ja kaardi nimi kaotada, kaardi sees lihtsustusi

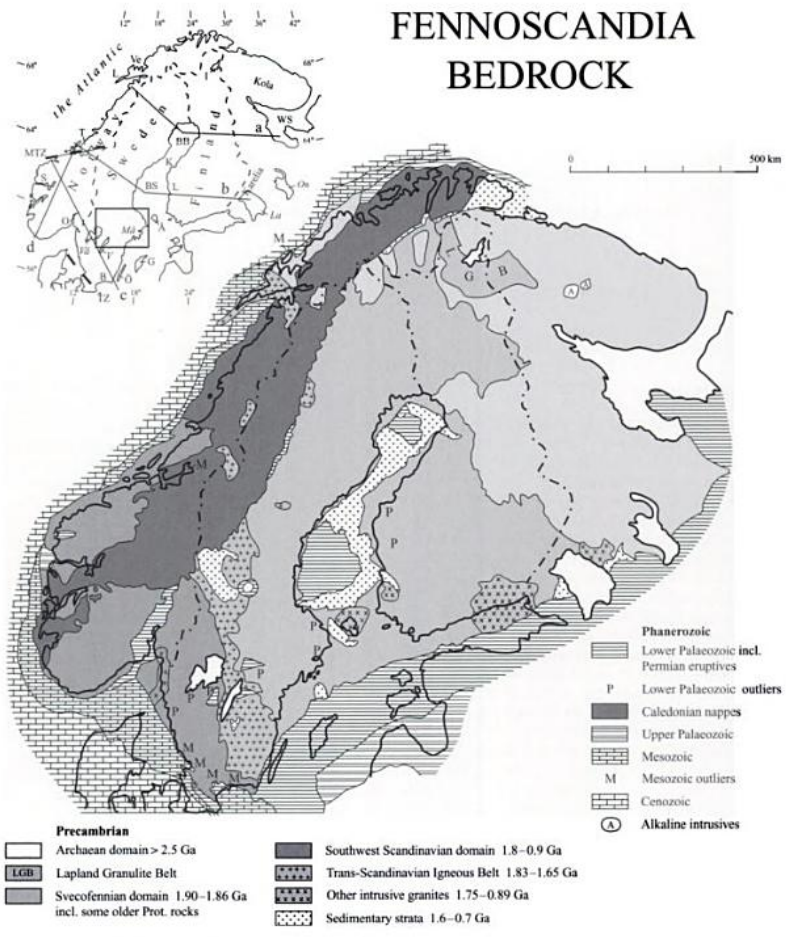


Fig. 1.1 Geology of Fennoscandia, basement and cover rocks

Note: Locations of map, Fig. 1.2, and profiles, Fig. 1.3, are indicated on insert map. Å = Åland; B = Blekinge; BB = Bothnian Bay; BS = Bothnian Sea; G = Gotland; K = Kvarken; L = Lofoten; La = Ladoga; Mä = Lake Mälaren; MTZ = Møre–Trøndelag Fault Zone; O = Oslo Graben; Ö = Öland; On = Onega; S = Sognefjorden; T = Trondheimsfjorden; TZ = Tornquist Tectonic Zone; V = Lake Vättern; Vä = Lake Vänern; Ve = Vesterålen; WS = White Sea.

(*Source:* Mainly based on Gorbunov and Papunen 1985, with additional information from Gaál and Gorbatschev 1987; Ahlberg 1986; Sigmond 1992; Gorbatschev and Bogdanova 1993; Balashov *et al.* 1993; Fredén 1994.)

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The Baltic Sea is located in north-western part of the East European Craton, along the contact of the Precambrian crystalline basement (exposed in north and west) and Phanerozoic sedimentary cover (in south-east). The Gulf of Bothnia is positioned in a Proterozoic to Paleozoic depression of the basement.

Geological columns of sea areas, data on dominant lithologies and approximate thicknesses (m)

Systems	Gdansk Bay, Poland	Hano“ Bay	SE Balti off Lithuania	Baltic Sea off Latvia	Riga Bay	Bothnian Sea	Bothnian Bay	Gulf of Finland West	Gulf of Finland East
Neo-gene	Continent Sandst, clays, 50 m								
Paleogene	Deltaic sandst, clays 50 m	0 m	0 m						
Cretaceous	**Marly chalk, clayey carbonates 300 m**	**Marly chalk, clayey carbonates 600 m**	**10 m**	**0 m**					
Jurassic	**Alternated sandst, clayst, carbon, 150 m**	**0 m**	**50 m**	**0 m**					
Triassic	**Clayst, gypsum, marlst, carbonates, 500 m**	**0 m**	**200 m**	**0 m**					
Per-mian	Salt, gypsum, **sandst, clayst, carbon** 300 m	**0 m**	59 m	0 m					
Carbo-niferous	0 m	0 m	0 m	50 m	0m				
Devo-nian	0 m	0 m	Sandst 1000 m	Sandst 400 m	Sandst300 m	0 m	0 m	0 m	0 m

Silurian	1600 m	0 m	Carbo-nates 1000 m	Carbon Carbo-nates 700 m	Carbo-nates 400 m	0 m	0 m	0 m	0 m
Ordovi-cian	80 m	Carbo-nates sandst 0 m	Carbo-nates sandst 100 m	Carbo-nates sandst 150 m	Carbo-nates sandst 150 m	Carbo-nates sandst	0m	0 m	0m
Cam-brian	350 m	Sandst, clayst 20 m	Sandst, clayst 200 m	Sandst, clayst2 50 m	Sandst, clayst 150 m	Sandst 100 m	Sandst, clayst ? m	0 m	0 m
Ediaca-rian		Great Precambrian Discontinuity							Sandst, clayst 50 m
Neopro-terozoic		Great Precambrian Discontinuity							
Meso-prote-rozoic		Meso prot basem			Rapakivi granites	Jotnian quartzose sandstones n x 100 m Rapakivi granites			
Late Paleo-prote-rozoic									Rapakivi granites
Mid-Paleo-prote-rozoic				Sveco-fennian	Sveco-fennian	Sveco-fennian	Sveco-fennian	Sveco-fennian	Sveco-fennian

Bornholmi geoloogia tahab kontrollida, teiste andmed Geologiya Balt Morja (Grig), Botnia lath Flodeni j'rgi

Systems	Bornholm	O"land	Gotland	Saaremaa	Ruhnu	Kotlin	Aland	Hailuoto
Neogene	0 m	0 m	0 m	0 m	0 m	0 m	0 m	0 m
Paleog e		0 m	0 m	0 m	0 m	0 m	0 m	0 m
Cretac	Chalk	0 m	0 m	0 m	0 m	0 m	0 m	0 m
Jurassic	Sandst	0 m	0 m	0 m	0 m	0 m	0 m	0 m
Triassic		0 m	0 m	0 m	0 m	0 m	0 m	0 m
Permian		0 m	0 m	0 m	0 m	0 m	0 m	0 m
Carbonif		0 m	0 m	0 m	0 m	0 m	0 m	0 m
Devonian		0 m	0 m	0 m	Sandst	0 m	0 m	0 m
Silurian		0 m	Carbon	Carbon	Carbonates	0 m	0 m	0 m
Ordovician	Carbon, shales	Carbon, sandst	Carbon, sandst	Carbon, sandst	Carbon, sandst	0 m	Carbon, sandst	0 m
Cambrian	Sandst, shales	Sandst, clayst	Sandst, clayst	Sandst, clayst	Sandst, clayst	Sandst, clayst	Sandst, clayst	Sandst, clayst
Ediacarian	Great Precambrian Discontinuity					Sandst, clayst	Gr Prcm Discont	Sandst, clayst
Neoprot	Great Precambrian Break							
Early Mesoprot- late Paleoproterozoic	granite	Great PCm Break		Rapakivi granites	Rapa-kivi gra-nites	Gr PCm Break	Rapakivi granites	Gr PCm Break
Late Paleoprot	No data	Great Precambrian Break						
Mid-Paleoprot		**Svecofennian basement**						

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Main territory of BSD										southern –most BSB area
Age		Regional and areal rock-forming within the Svecofennian crustal domain								
Neoproterozoic NP 542-1000 Ma	Latest NP	Ediacarian stratified sedimentary rocks in NE BSD: sandstones, siltstones, claystones								
	Great Precambrian Break									
Mesoproterozoic MP 1000- 1600 Ma	Mid-Late MP	Lo-cally			Dolerite dikes Jotnian quartzose sandstones					MP cryst basement
	Great Precambrian Break									
	Early MP	Unique volca-nic and intru-sive rock suites of rapakivi family				Quartz porphyries and plagioclase porphyrites,rapakivi granites, anorthosites, dolerite dikes				No data
Paleoproterozoic PP 1600-2500 Ma	Late PP				Quartz porphyries and plagioclase porphyrites, rapakivi granites, anorthosites, dolerite dikes					
	Mid-Late-PP	Great Precambrian Break								
	Mid-PP folded crystalline basement	Large variety of the Svecofennian crystalline hard rocks: Igneous rocks: microcline and plagio-microcline granites and migmatites, charnockites, granodiorites, diorites, gabbros, Metamorphized (sedimentary-)volcanic rocks: granite-gneisses, biotite, biotite-amphibole and pyroxene gneisses, amphibolites Metamorphized sedimentary rocks: biotite shists and gneisses, biotite-garnet-sillimanite-cordierite geisses, quartzites, marbles								
	Early PP	No data								

SIIA LISADA: Geological cross section between the south and north ends of the Baltic to Bothnian basin
- Gdanskist Tornioni üle Gotlandi süviku, Ahvenamaa, Botnia mere ja Botnia lahe
28.
GLACIAL SEDIMENTS: SOME EXAMPLES
VIRGIN LANDS EMERGED FROM THE BALTIC BASIN:
Virgin land emerging in central and southern Finland
Virgin landscape near Helsinki
Emergence of Saaremaa and Muhumaa
Vassiljevi pildid „Geoturism“ lk 20-21 LISADA
Ice-marginal accumulation zone of the Palivere stage (12.7-12.6 ka) towered above the Ancylus Lake at 9.2 ka. From the Littorina sea at 7 ka, also the bedrock-based Central Saaremaa upland emerged from the sea. Note that cliffs of Saaremaa were still under water level.

Postglacial sediments on islands
LÄÄNE EESTI SAARTE Q-GEOL KAART
Thin layers of glaciolacustrine, marine, lacustrine, alluvial, bog and other sediments cover the surface of glacial deposits and locally exposed bedrock.

29.

Boulder zones of BIL coastline in shield area

In glaciated shield area, a considerably poorly rounded loos fragments of mainly nearby crystalline rocks have accumulated in coastal zones. An exposed boulder field created by littoral forces on the slope of Lauhanvuori in South Ostrobothnia. The top of this hill lies slightly above the level of the highest shoreline of the Baltic Sea. (Photo by Matti Tikkanen, 07/95) ***Late Weichselian and Holocene shore displacement history of the Baltic Sea in Finland*** *MATTI TIKKANEN AND JUHA OKSANEN*

30.
Crystalline glacial erratics in “virgin lands”
Crystalline blocks plucked (quarried) and transferred from their original settings are found in the whole region reached by glacial streams once created in the Fennscandian Shield area. Crystalline erratics are considered as most spectacular natural monuments in the sedimentary provinces embracing the shield where no outcrops of such rocks exist. Coastal erosion of regressing BIL and BS washed the glacial deposits and removed the fines from it into deeper sedimentary traps, leaving the heavy blocks towering on the surface and cobbles and bebbles paving the past and present beaches.
Photo Käsmust põhjas / rahnud ja kivid

31.
Dispersal of erratics telling about the ice stream routes.
Ice-flow patterns and dispersal of erratics at the southwestern margin of the last Scandinavian Ice Sheet: signature of palaeo-ice streams
PILT LISADA

32.
Jägala River and Jägala waterfall in the North Estonian Klint zone
Jägala River and Jägala waterfall are products of the Baltic water level drop since xxxx years ago. Just after the retreat of glacier from Northern Estonia, rivers drained into the basin that flooded the plateau above the present North Estonian Klint (Cliff). Waterlevel drop during xxxx-xxxx years ago opened the edge of the North Estonian limestone plateau for the coastal erosion. Since that lowering waterlevel worked out the cliff – a vertical wall with hard limestones layers on top and softer sandstone and clay layers at base. Rivers and streams having their route across the limestone plateau met the cliff. Height increase of the cliff and of the new waterfall added power to fluvial erosion, and penetration of the river canyon started. During the last xxxx years, the Jägala waterfall has created an about 300 m long canyon with the rims of 12 - 14 m high. Presently the waterfall is 8 m high and in the wall from Middle Ordovician Lasnamägi limestones on the edge to lowermost Ordovician sandstones at the foot crop out. Narva and Keila river canyons and waterfalls and many other stream have principally similar histories of formation. The other type of rivers falling from cliff plateau is cut into the pre-Holocene buried valleys. Much faster erosion of tills and othe. r soft materials resulted in formation of km-s -long riffle in lower runs of rivers of Purtse, Pühajõgi, and many smaller streams

Southern Baltic as the homeland of Vikings

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Sea ports and sea transport at 2000 and 2015

Point	Number of ships crossing in 2000	Number of ships expected to cross in 2015
1	23 388	31 600
2	34 692	70 100
3	46 476	83 700
4	58 500	105 300
5	75 696	121 100
6	85 296	136 500

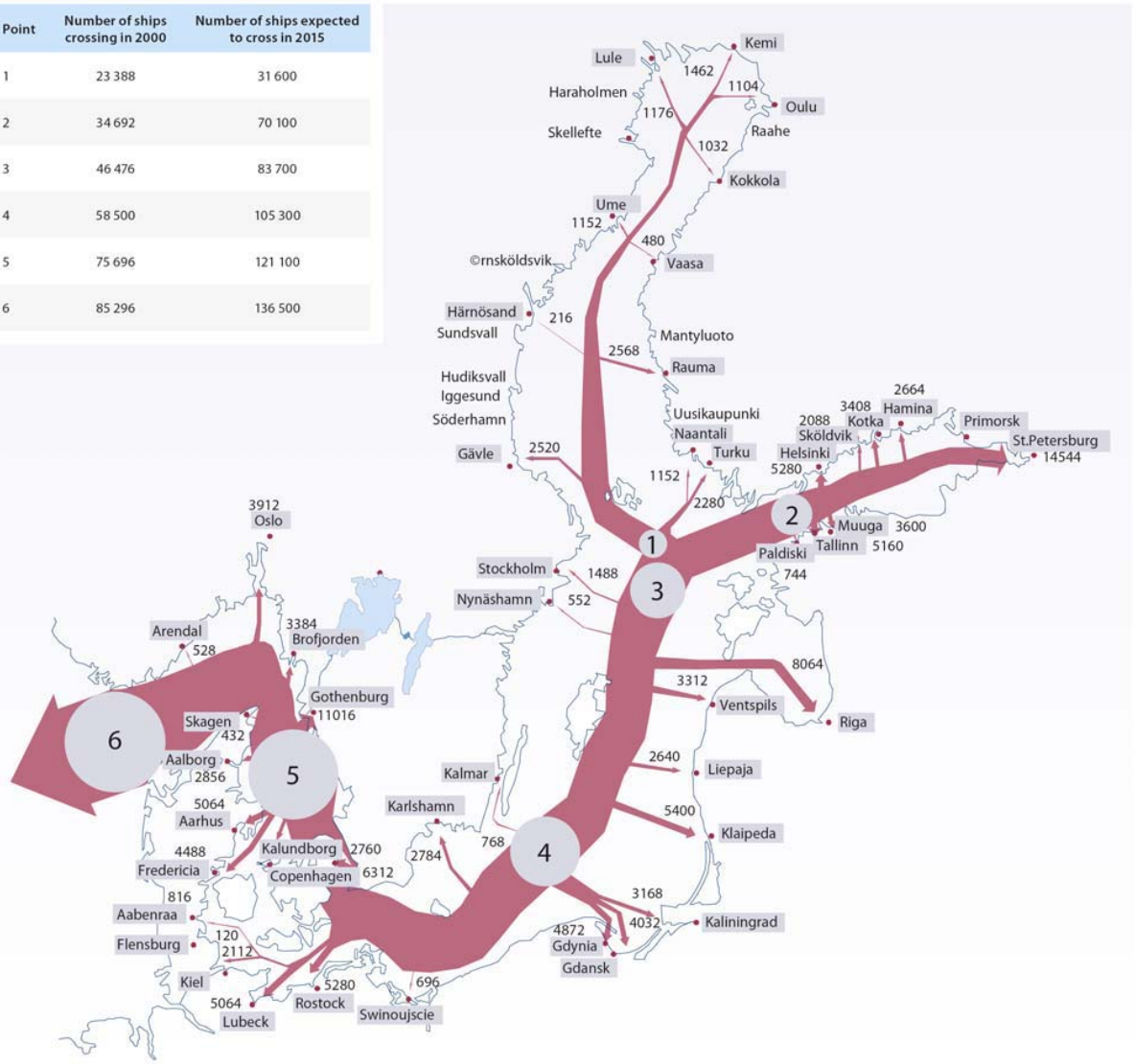
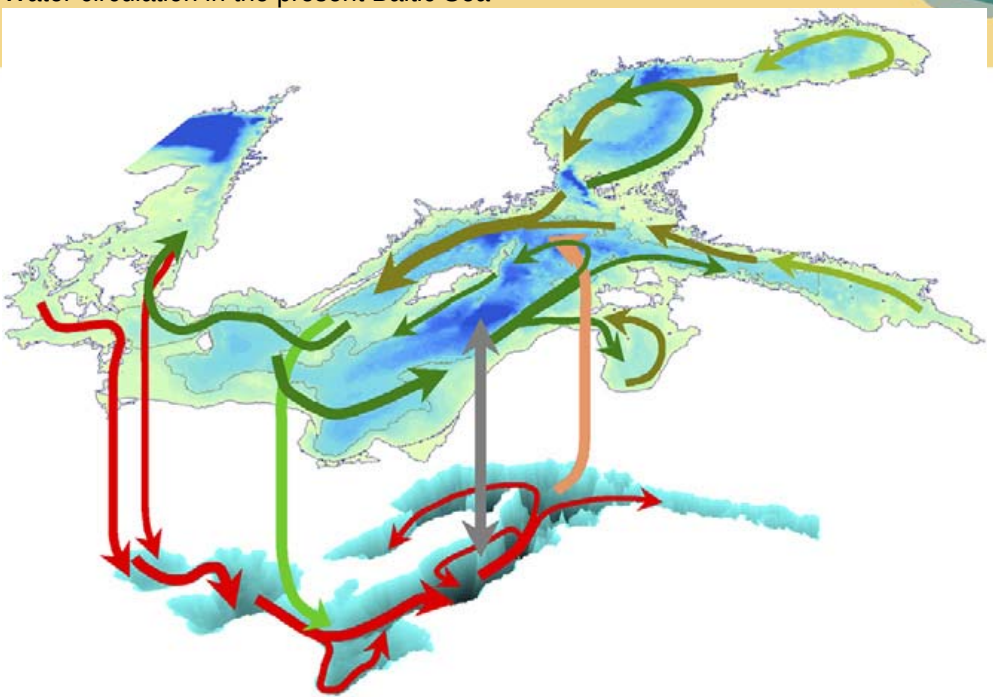


Figure 9 Number of ships, excluding ferry traffic, in the Baltic Sea 2000.
(Source: Rytkönen et al. 2002)

LISADA Paldiski, kavandatav Kaliningradi , Sillamäe jäätmehoidla

Water circulation in the present Baltic Sea



Salinity of the brackish Baltic Sea depends on the effiency of the ocean water inflow. Nowadays the bottom saline water circulation does not reach gulfs of Bothnia and Riga. Schematic view of the large-scale circulation in the Baltic Sea (from Elken and Mattha¨us). Green and red arrows denote the surface and bottom layer circulation, respectively. The light green and beige arrows show entrainment. The gray arrow denotes diffusion. Modeling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea

Summary

Geological structure and history of its formation is extraordinary complex because:

Fascinating observation of natural heritage….

- **The sea settled into an previously eroded depression, in the bed of which**

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