### Ice Age and Isostatic Land Uplift

*Photos: Dragos Alexandrescu, Patricia Rodas, if not otherwise mentioned.*

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<td><img src="" alt="Image" /></td>
<td>World Heritage in Cooperation 63°N High Coast Kvarken Archipelago Ice Age and Isostatic Land Uplift</td>
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<td>2</td>
<td><img src="" alt="Image" /></td>
<td>An icy story</td>
<td>The High Coast and the Kvarken Archipelago are unique in that they are characterised by the land uplift. This, in combination with the geological conditions, was the reason for the World Heritage nomination. The land uplift is due to the latest ice age - a long period when the area was covered by an ice sheet nearly three kilometres thick. Photo: Christina Knookala.</td>
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<td>3</td>
<td><img src="" alt="Image" /></td>
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<td>The land uplift and the waves have shaped the landscape in the World Heritage Site since the last ice age, and mean that the landscape is undergoing constant change.</td>
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<td><img src="" alt="Image" /></td>
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<td>During the long history of the Earth the climate has changed many times, fluctuating between colder and warmer periods. During the colder periods large ice sheets formed and spread. The number of ice ages is uncertain, but may be as many as 40. At the end of the Tertiary period (about 3 million years ago) the temperature fell and many small glaciers formed. About 2.5 million years ago, the rate of glacier formation started to accelerate and this</td>
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marked the change to the Quaternary period. This was a period with many fluctuations between long glacial periods and shorter interglacial periods. Ice ages have been the most common condition on Earth during the past 640,000 years.

Scientists don’t know much about the glaciations in Scandinavia before the last ice age, the Weichsel. The latter effectively erased all traces of its predecessors, such as the Elster and Saale ice ages.

In Ostrobothnia, traces from earlier ice ages have been found, such as ridges and moraine beds from the Saale ice age, the ice age before Weichsel that started about 200,000 years ago. In the World Heritage area there is mud from the Saale ice age underneath the Weichsel moraine.

| Glacial periods – in relation to the Sun | Cool summers and mild winters with a lot of precipitation cause glaciers to grow and ice sheets to form. The snow doesn’t melt during summer. The snow cap grows and the lower layers are converted to ice by the pressure of overlying layers.

Snow is formed from water in the atmosphere, which gets its water from the sea. Because the water is not returned to the sea, sea level falls. During the last ice age, the water levels in the oceans sank by about 100 metres.

Ice sheets grow slowly. During the last glaciations in Scandinavia, glaciers formed in the mountain range, spread and joined other glaciers to form ice sheets. That’s how the ice sheet of the Weichsel ice age was formed.

Climatic variations in a time scale of 10,000-100,000 years are mainly due to variations in the Earth’s position in relation to the Sun.

The theory was put forward by the Yugoslavian astronomer Milutin Milankovitch (1879-1958) at the beginning of the century.

Other reasons for climate change can be volcanic eruptions, meteorite impact or air pollution that blocks the Sun’s rays. There are also connections between the temperature and the amount of greenhouse gases in the atmosphere. Yet another theory is that climate may become colder if the
The last ice age, the Weichsel ice age, lasted for about 100,000 years. Its coldest phase, when the ice mass was at its maximum, occurred about 22,000 years ago. Northern Europe was covered by an ice sheet up to three kilometres thick. From its centre in Scandinavia, it spread out over the northern parts of Germany and western Russia.

During the same time period, much of present-day North America was also covered with ice, and glaciers also grew in the Southern Hemisphere. An ice sheet already covered Antarctica but grew during this period.

Like much of Scandinavia, the High Coast and the Kvarken Archipelago was not covered with ice throughout the Weichsel. The climate fluctuated between colder and warmer periods. During the warmer periods the ice partially melted and plants and animals could spread into the ice-free areas. When it became colder the ice reclaimed large areas. The last major glaciation started 30,000 years ago.

Extraction of ice cores from glaciers shows the layers of the ice and how much it has grown each year. Such cores also show pollution. Ice cores from Antarctica tell us about the climate on Earth over the past 740,000 years!

Photo: Ove Källström.

Humans during the Ice Age?

Varggrottan, located 100 km south of Vaasa, is one of the few known dwelling sites in the Nordic area originating from the last ice age. Finds of objects and a fireplace show that there were humans here, probably Neanderthal humans (*Homo Neanderthalensis*), during the warmer periods of the ice age. They had probably migrated from Central or Eastern Europe about 130,000- 74,000 years ago. In the Terranova exhibition at the Ostrobothnia Museum in Vaasa, there is a reconstruction of Varggrottan.

Neanderthal man became extinct about 30,000 years ago. The species lived in Europe parallel to the modern human (*Homo sapiens*) for about 10,000 years. Neanderthal man had a bigger head and was more...
Ice in constant motion

Ice sheets and glaciers form when snow accumulates for many years and, over time, is converted into ice. When the ice becomes sufficiently big it slowly starts moving, it becomes plastic. The bottom of the ice erodes the bedrock over which it passes and transports the loose material. The eroded material is transported with the ice towards the front and edges, where it is deposited as moraine. The ice masses disappear either through melting or when ice floes break off the front.

If the uppermost layer of the ice has areas moving at different speeds, large crevasses are formed. Sometimes these may be formed when the ice glides downhill over a cliff threshold, so the uppermost layer moves faster than the rest of the ice. The entire surface does not move at equal speed, and so the ice fractures. Even if the ice flows like a plastic, it is not all that elastic.

The temperature in the ice varies. In the lowest layers, it can be close to melting point. Heat from the rocks, combined with high pressure from above, causes the ice to melt from below. The ice mass is pressed towards the edge and at the same time the whole ice moves across the surface. So there is both internal movement and ice sliding along the rock underneath.

When the thickness of the ice is not sufficiently big for it to move it is called dead ice. A glacial kettle hole is formed when a block of dead ice buried in moraine melts.

Traces left behind by the ice flow

The movement of the ice sheet left traces in the landscape, such as striations (grooves) on the surface of bare rocks and cliffs, spindle-shaped drumlins and other moraine landforms, and glacial erratics.

What the ice eroded and transported, from small mud particles to large boulders, became visible when the ice melted. The composition of the deposits depends on what types of rock the ice has passed over, and what distance and how they have been transported, but also on the phase of the melting process when the moraine was deposited.

muscular than the modern human.

Photo: GTK
In the old days, large boulders in the landscape were called giant’s throws. There was no natural explanation for how the rocks ended up there, so it was assumed that giants had thrown them.

The direction of glacial striations and grooves makes it possible to see the direction in which the ice moved. In the Kvarken Archipelago there are indications that the older direction of movement was from northwest to southeast and the younger from northeast to southwest. The traces are especially visible on the smoother push side of bare rocks. On the more jagged lee sides of the rocks parts of shattered boulders can often be seen.

The soil types formed by the ice sheet and it’s melting are called glacial soil types.

| 9 | The ice melted quickly | About 18,000 years ago, after the maximum spread of the ice sheet, the climate became warmer and the ice sheet started melting faster. The ice sheet became thinner and the front retreated towards the north and northwest. The end of the ice age is often dated to 10,000 years before the present, although much of Norrland in Sweden was still covered with ice. About 10,500 years ago the High Coast and the Kvarken Archipelago were free from ice. The last remnants of ice east of the Scandinavian mountain range disappeared about 9,000 years ago.

During the subsequent warmer period the climate was probably milder than today and the Norwegian mountains were probably ice free for a long period.

The ice grew slowly during the last ice age, but melted much faster. The ice melted and retreated towards the Scandinavian mountain range. On land it became thinner and melted away.

Ice sheets that reach open water might break up during the melting process. Parts of the ice float in the seawater and chunks break off. Ice floes and icebergs are formed and they float away with the currents. They can be very big and pose a threat to shipping. The Titanic sank in 1912 after colliding with an iceberg. Only the top of the iceberg is visible, and about 90 percent is under water.

Photo: Thomas Birkö.
The melting of the ice also left traces in the present landscape, like eskers at the High Coast and the De Geer moraines characteristic of the Kvarken Archipelago. These “washboard moraines” are the youngest of the moraine formations and were formed at the ice edge during the end phase of the ice age.

When the ice melts a mixture of rock, gravel, sand and finer material is left on the surface as moraine, or is transported and sorted by the melt water to form sediment. The bedrock in both Sweden and Finland is mostly covered by moraine. Moraine is an unsorted soil type made up of everything from small mud particles to big blocks.

Moraine that has been under water has, with time, been washed out and redeposited by the waves. The line between outwash and unsorted moraine is very sharp at the High Coast.

At the end of the ice age, earthquakes and crustal movements resulting in faults occurred. In the sea huge water masses were displaced and huge waves hit the shores, strongly affecting the landscape.

The Kvarken and Bothnian Sea are a part of the Baltic Sea. The Baltic Sea has been affected by the ice melting and has experienced many phases during and after the Weichsel.

The earlier phase, the Baltic Ice Lake, never extended as far as the World Heritage area, which was then covered by ice. Starting from the east, the ice started to leave the Kvarken- High Coast area. The Baltic Sea was then called the Yoldia Sea, which was saltier than today’s Baltic Sea.

The meltwater from the ice transported large amounts of mud that were deposited as mud sediments. Analysis of the mud layers on the bottom of the Kvarken shows that the ice edge retreated about 200-500 metres per year in the Kvarken area.

The next phase in the development of the Baltic Sea was the Ancylus Lake - a freshwater lake covering much of Finland and Sweden. In the beginning of this stage there were still remains of the ice sheet in the World Heritage area. The highest coastline in
southern Ostrobothnia, 210-190 above sea level, was formed in the beginning of this stage.

When the ice sheets melted the water levels rose and the Danish sounds opened up, giving the Baltic Sea a connection to the Atlantic. Salt water entered and the sea became brackish again. The Littorina Sea can be clearly seen in the greenish mud and today these sediments make up the most fertile farmland in the coastal region of the Gulf of Bothnia. All former shorelines and outwash sediments on the Finnish side of the Kvarken originate from the Littorina Sea stage, from less than 8,000 years ago.

Since 2,500 years ago the Baltic Sea has been an inland sea, i.e. it is part of the Atlantic and North Sea through a very narrow connection, and has cold and brackish water.

Like the ice, the water has affected and contributed to the natural landforms we now see in the World Heritage Site, such as the bare cobble fields and till-capped hills. These have been shaped by the Yoldia Sea, Ancylus Lake, Littorina Sea and today’s Baltic Sea.

### Table

<p>| 12 | The ice pressed down the earth’s crust about 800 metres. This occurred where the Scandinavian ice sheet had its centre for a long time – the area that today contains both the High Coast and the Kvarken Archipelago. |
| 13 | The crust of the Earth is still rising | The extremely heavy ice sheet, up to 3 kilometres thick, pressed down the earth’s crust. When the pressure is released, the crust slowly returns to its original shape and level. Since the ice left the World Heritage area, the crust is now rising to its original level. |
| 14 | When the melting began the pressure gradually decreased. Already by the time the ice edge had reached the High Coast, the land had risen 500 metres. The land uplift was remarkably fast - 10-15 metres per 100 years! Since the ice edge left the High Coast 10,500 years ago, the land has so far risen another 286 metres, according to Swedish scientists. |</p>
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| 15   | ![Image](image1.png) | World record in land uplift!  
Skuleberget, High Coast 2009.  
The highest coastline (HC) is the highest level in the landscape that the Ancylus Lake reached when the ice was melting.  
The world’s highest coastline is on Skuleberget, in the heart of the High Coast. This is the biggest land uplift in the world - 286 metres in 10,000 years, which is also noted on Skuleberget. The High Coast is the only hilly land uplift area around the Baltic Sea with height variations 300 metres above sea level.  
In Finland the HC is at 210 metres above sea level in southern Ostrobothnia and central Finland- about 100 km east and southeast of the Kvarken Archipelago. |
| 16   | ![Image](image2.png) | At first the land uplift was very rapid, more than 100 millimetres per year, now the land in the World Heritage area is rising at about 8 millimetres per year.  
The displacement of the shoreline is also affected by the rising water levels. In the World Heritage area the land uplift has always been faster than the rise of the water level since the melting of ice sheet. During the last glaciations, much water was stored in the ice sheets and sea level was about 120 metres lower than today.  
Apart from global climate change, which affects how much of the earth’s water is stored in glaciers, sea level is also thought to be affected by changes in the gravitational force. It is slow displacements in the earth’s core that change the gravitational field.  
Changes in the flows of rivers and variations in water temperature also affect the volume of water in the oceans and seas. |
| 17   | ![Image](image3.png) | New land, new lake  
In about 2,000 years the land uplift will form a land bridge across Kvarken - and the Gulf of Bothnia will become the largest freshwater lake in Europe.  
The land will continue to rise for thousands of years, but the rate will slowly decrease with time. |
### Present

The High Coast will not change very much because the sea is deep offshore. However, some islands will join the mainland. Inlets will be cut off and form lakes. Many lakes will become smaller due to sedimentation and overgrowth.

### Future

**Lappören Islands, Kvarken Archipelago**

In contrast, changes in the shoreline, related to the land uplift are very visible in the shallow Kvarken Archipelago. New islands rise from the sea, islands join together, peninsulas grow, inlets become flads and, over time, turn into lakes and wetlands.

The Kvarken Archipelago is the most representative area in the world for studying the land uplift phenomenon in a flat moraine archipelago. Particularly spectacular are the large areas of De Geer moraines and glacial erratics.

*Photo: Helifoto, 2009*

**150 new football fields – every year**

Large land areas will continue to rise from the sea. Today the land area is growing by one square kilometre per year or 100 hectares, which is equivalent to 150 football fields per year.

In the course of a century, Finland grows by about 1,000 square kilometres. Two-thirds of the increase is due to the land uplift and the rest is explained by sedimentation. A third of the total increase in land area is in the county of Ostrobothnia.

*Photo: GTK.*

**Between two glacial periods**

We live in a geological era called the Holocene, an interglacial period whose length we don’t have exact information about. Earlier interglacials have lasted 10,000-20,000 years. Scientists think it will be a long time before the next ice age, around 50,000-60,000 years, based on a study predicting the variation in solar insolation in the future. This suggests that the natural climatic fluctuations make an ice age unlikely for the coming millennia, a view that has also been reinforced somewhat by the warming caused by CO₂ releases.

Since the melting of the last ice 9,000 years ago, the climate has been variable. During the warm period...
8,000-4,000 years ago, the average temperature was 1.5-2 degrees higher than today. The temperature then decreased and glaciers formed in mountain areas. The Little Ice Age took place in the mid-15th century and lasted until the mid-19th century. The climate became colder and the glaciers grew. Since then, the climate has become milder again and the glaciers are shrinking or have disappeared. The few remaining glacier ices are found in, for example, Sylarna and Norra Storfjället in the Swedish mountains.

“In the next 50,000 years we will have more constant solar insolation in our latitudes than we have had the last million years.”
André Berger, climate scientist