high coast kvarken archipelago



WORLD HERITAGE



Text: Liselott Nyström Forsén, Sigrid Sjösteen,

Patrik Bylund, Malin Henriksson, Anna Carlemalm,

Roosa Mikkola, Niko Putkinen.

Translation: Leslie Walke, Communicaid.

Illustrations in watercolour: Liselott Nyström Forsén.

Graphics: Rosanna Telaranta. **Cover images:** Fabiola de Graaf.

Layout: Consid Communication and KMG Turku.

Published in 2020 by County Administrative Board of Västernorrland and

Parks and Wildlife Finland.







Lystra - awareness and activities in the World Heritage Site High Coast/Kvarken Archipelago

The EU-funded transboundary Interreg Botnia-Atlantica project Lystra developed the High Coast/Kvarken Archipelago World Heritage Site in the time period of 1.1.2018–31.12.2020.

The project produced a nature interpretation plan, updated the knowledge on the geological values of the Site and classified them, produced digital solutions and renewed the pedagogical material on the World Heritage Site.

Project Lystra's lead beneficiary was Parks & Wildlife Finland, and other beneficiaries were the rest of the project partners: County Administrative Board of Västernorrland (Sweden), Geological Survey of Sweden (SGU), Geological Survey of Finland (GTK), Finnish Geospatial Research Institute (FGI) and City of Vaasa in Finland.

Project's total budget was 1,38 million euros. Besides the EU-funding, the other providers of funds in Finland were the Regional Council of Ostrobothnia, Association of the World Heritage Site of Kvarken Archipelago, and Visit Vaasa/ the City of Vaasa. In Sweden, the Swedish Environmental Protection Agency and the municipalities of Örnsköldvik and Kramfors funded the project.



Contents

In	troduction	9
1.	The World Heritage concept	10
	History of the World Heritage Convention	
	The selection process	12
	Threats to World Heritage Sites	12
	Infobox: UNESCO's ten criteria for World Heritage	13
	Infobox: UNESCO	15
1.1	Our World Heritage Site	15
	Infobox: World Heritage Site: High Coast/Kvarken Archipelago	16
	Threats to our World Heritage Site	16
2.	The Ice Age	18
	The ice sheet in motion	
	Traces of the Ice Age in the landscape	.20
	Infobox: Why was the ice sheet thickest over the area of the World	
	Heritage Site?	21
	Infobox: Difference between an ice age and glaciation	22
2.1	Bedrock, topography, and rock chasms	. 23
	Most common rock types in the World Heritage Site	23
	Weathered diabase cracks form chasms in the High Coast	. 26
	Why is the High Coast high and Kvarken Archipelago low?	27
	Infobox: What is the difference between moraine and till?	27
2.2	Roche moutonnées and striations	.29
	Roche moutonnées	. 29
	How roche moutonnées are formed	.30
	Striations	.30
	What stiations look like	31
2.3	Erratics and boulder terrain	.32
	Boulders frozen in the ice sheet and icebergs	32
	How erratics may be formed	. 33
	Boulder terrain	
	Infobox: Famous erratics in Sweden and Finland	.34
	Infobox: Thrown by giants	. 35
2.4	Different types of moraines	.36

	2.4.1 Ribbed moraines	37
	2.4.2 Moraine types formed by the ice streams	38
	Hummocky moraine	38
	Drumlins and flutings	39
	A mosaic of moraine formations	40
	2.4.3 De Geer moraines	40
	De Geer moraines formed at the ice margin	40
	How De Geer moraines are formed	42
	Infobox: Gerard De Geer	43
	Infobox: How people have used the moraines	43
3.	Land uplift and the effects of the sea	44
	Nine millimetres a year in the World Heritage area	
	Land uplift and the sea continue to shape the landscape	
	Infobox: Various ways of measuring the land uplift in the	
	High Coast/Kvarken Archipelago World Heritage Site	46
3.1	Detection of the land uplift phenomenon	
	The "diminishing water"	
	The land uplift phenomenon	
	The highest land uplift	
	Research continues	
3.2	The land uplift	
J.2	The highest coastline	
	One square kilometre of new land every year	
	Infobox: Land sinking	
	The land uplift in different time periods	
3.3	Highest coastline and till-capped hills	
	Forested till-capped hills	
	How a till-capped hill is formed	57
3.4	Beach deposits	
	Cobble fields	
	How cobble fields are formed	
	Beach ridges	61
	How beach ridges are formed	
	Infobox: Devil's fields	
	Infobox: Stone labyrinths	63
3.6	Tunnel caves	
	Tunnel caves are also called onion caves	
	How a tunnel cave is formed	
3.7	Lagoons, flads, gloes and glo-lakes	
	Topography determines the process	
	Dredging	

	Land uplift reflected in placenames	68
	3.7.1 Flads, gloes and glo-lakes in the Kvarken Archipelago	68
	From juvenile flad to glo-lake	70
	A pearl band of lakes	71
	3.7.2 Lakes in the High Coast	72
	Infobox: Remnant species reveal the origin of the lakes	72
8.8	Ravines in sediment	74
4.	Nature	76
	Topography significant for habitats	77
4.1	Ice Age relicts	79
	Stages in the development of the Baltic Sea	80
	Ice-age relicts came to the Baltic Sea at early stages	82
	Monoporeia affinis	82
	Saduria entomon	83
	Ringed seal	83
	Four-horned sculpin	84
4.2	Land uplift forest	84
	Plant succession	85
	Typical stages of shore succession in the Kvarken	
	Archipelago	85
	Succession varies on different shores	86
	Most common succession in the Kvarken Archipelago	86
	Plant succession on the rocky shores of the High Coast	87
i. 3	Kvarken Archipelago – abundant bird life	88
	A paradise for breeding birds	89
i. 4	Shell gravel ridges, south-facing slopes, and alpine flora	
	in the High Coast	90
	Shell gravel ridges provide nutrients for orchids	90
	South-facing slopes capture the heat	91
	Arctic flora of the hills and rock surfaces	92
4.5	Below the water surface	93
	Ability to adapt to brackish water crucial	93
	Sunlight and seabed material also exert an influence	94
	Bladderwrack and common mussel key species in the High Coas	t95
	Infobox: Bladderwrack	95
	Infobox: Common mussel	96
	Kvarken Archipelago important for Baltic Sea fish stocks	97
5.	Cultural history	100
	People pursue the fleeing shoreline	

5.1	Immigration after the Ice Age	105
	Settlement by the former shoreline	105
	The High Coast's oldest relicts are 8,000 years old	106
	Kvarken populated approximately 7,000 years later	107
	Settlement history in the High Coast	108
5.2	Pilots, lighthouses, and fairways	109
	Many different ways to mark the fairways	109
	The pilots	111
	Narrow channels for leisure boats	111
6.	High Coast / Kvarken	
	Archipelago: The future	112
6.1	Land uplift and the future	113
	90–130 metres remaining	113
	Apparent land uplift decreasing	113
	Next ice age?	114
	Infobox: How much sea levels will rise	114
6.2	Future scenarios in the High Coast/	
	Kvarken Archipelago World Heritage Site	115
	Scenario 1: Rise in sea level less than land uplift	115
	Scenario 2: Sea level rises at the same rate as land uplift	116
	Scenario 3: Rise in sea level greater than land uplift	116
	Other effects of climate change on the World Heritage Site	116
	No land bridge over Kvarken in sight	117
6.3	Protecting and preserving our World Heritage	117

Introduction

The High Coast was inscribed on the World Heritage List in 2000, and in 2006 the World Heritage Site was expanded to include the Kvarken Archipelago. Up to now, there has been no comprehensive knowledge base about the joint World Heritage Site and its values. Information can be found in books and brochures about the individual areas, but no descriptions of the entire site. In 2018-2020, the Lystra World Heritage Project worked on compiling factual material and communication regarding the World Heritage Site. This resultant publication from Lystra will hopefully address the need for a common description of the values of the entire site. The aim is to provide interesting in-depth information for anyone wishing to discover more about our fantastic World Heritage Site and what makes it unique in a global perspective.

We start by discussing the World Heritage concept, and what lies behind our large World Heritage family, which now has over 1100 sites spread over the entire world. In Chapter Two, we describe the most recent Ice Age and the traces it left that we can still see in the landscape, and the bedrock and topography. We also explain why the High Coast is high and the Kvarken Archipelago low. Chapter Three concerns the land uplift and how it is affecting the landscape, along with the effects of the sea. These two chapters explain much of our outstanding universal value (OUV), and why the High Coast/Kvarken Archipelago is a World Heritage Site. Chapter Four focuses on how nature must adapt to constantly changing conditions as the land rises. Chapter Five describes how, over time, people have had to adapt to changes in their living environment with the constant displacement of the shoreline. In the final chapter, we take a look into the future and see how the land uplift will continue to affect those who live here in the World Heritage Site.

Patrik Bylund, World Heritage Coordinator, High Coast Malin Henriksson, World Heritage Coordinator, Kvarken Archipelago



The World Heritage Concept

Photo: Fabiola de Graaf

The basic idea behind declaring certain special areas World Heritage Sites is to protect and preserve them, to ensure they are kept for both present and future generations to enjoy and learn from. World Heritage Sites are the heritage of all of us, all of humankind, regardless of which country the sites are in or who manages them. This is why we all have a duty to preserve the sites.

History of the World Heritage Convention

The idea of protecting and preserving places, buildings, objects, and ideas existed already in the Age of Enlightenment in the 18th century, when there were currents in society that wanted to strengthen people's cultural and national identity. Following the First World War, at approximately the same time as the forerunner of the United Nations was founded to secure world peace, an awareness grew that the wartime bombing had damaged or destroyed many valuable buildings. In the subsequent decades, various attempts were made to bring countries together in a common effort to preserve cultural heritage for present and future generations.

However, it was not until 1959, when the Aswan Dam in Egypt was to be built, that anything tangible was done on an international level. UNESCO (the United Nations Educational, Scientific and Cultural Organization) stepped in to help, through a large international rescue campaign to move buildings, such as the Abu Simbel temple, which would otherwise have been drowned by the water masses. When Venice and Florence were flooded in 1966, UNESCO started a campaign to save the cities' cultural treasures.

After these interventions, UNESCO started work on drawing up a formal convention on international protection for various types of cultural heritage. At the same time, a unique idea grew to extend the protection offered by the World Heritage Fund that had been set up, to also include natural areas. The Fund was to stimulate international collaboration to preserve the world's most magnificent natural and aesthetic areas, and historical sites, for present and future generations. The Convention Concerning the Protection of the World Cultural and Natural Heritage (generally called the World Heritage Convention) was adopted on 16 November 1972 by the UNESCO General Assembly. The first twelve World Heritage Sites were inscribed in 1978, including the Galapagos Islands, which was officially the first site.

The selection process

For a site to become a World Heritage Site, it must meet one or more of UNESCO's ten criteria (see infobox on the following page). Every country that is a signatory to the World Heritage Convention may nominate sites in their own country. Once a year, the UNESCO World Heritage Committee decides which of the nominated sites are to be granted World Heritage status. The World Heritage Committee comprises representatives from 21 of the countries that have signed the Convention, and membership of the committee alternates between the nearly 200 countries that are signatories to the Convention. All World Heritage Sites have equally high status and are equally valuable. The countries in which the World Heritage Sites are located have promised to manage and conserve them, and to collaborate internationally to protect all World Heritage Sites in the world, which aligns with the UN peacekeeping objective.

Finland and Sweden are two of the countries that have promised to follow this Convention. World Heritage Sites in Finland and Sweden include both cultural heritage and natural heritage.

Threats to World Heritage Sites

UNESCO has described the outstanding universal value (OUV) of each World Heritage Site, i.e. what it is that makes that particular site worthy of World Heritage status. Today, many World Heritage Sites are under threat from various factors that can have a negative impact on or destroy their particular outstanding universal value. Usually, the threats are caused by human actions or the consequences of them.

Climate change can threaten World Heritage Sites, for example through rising temperatures, drought, hurricanes, and floods. Similarly, urbanisation and uncontrolled tourism can both encroach upon and erode sensitive areas and properties. In wars and armed conflicts, valuable places or buildings can be destroyed, or it becomes difficult to protect species or habitats there. Natural disasters such as earthquakes and volcanic eruptions are another serious threat to many World Heritage Sites. Finally, accidents can occur, such as when an oil tanker ran aground and leaked oil near the East Rennell World Heritage Site, or when the Cathedral of Notre-Dame in Paris caught fire. If the outstanding universal value of a World Heritage Site is destroyed, it may lose its World Heritage status.



Figure 1. The World Heritage Emblem is the official emblem of the Convention. The circular shape of the emblem represents the globe we live on and the world's diversity. The symbols inside the emblem comprise an outer circle enclosing a square. The circle represents nature, and the square represents culture.



Figure 2. In 2019, the Nordic World Heritage Conference was arranged in Stockholm, gathering World Heritage workers from the entire Nordic region. The photo was taken at Drottningholm Palace (one of Sweden's World Heritage Sites).



Figure 3. Patrimonito is a small figure created with the World Heritage Emblem as a base, and is used in international teaching about World Heritage. Patrimonito or Patrimonita means 'small heritage' in Spanish and represents a young person working for World Heritage.

Photo: Raphael Stecksén / The Royal Palaces

Infobox: UNESCO's ten criteria for World Heritage. The site or object must:

- I Be a masterpiece of human creative genius.
- II Exhibit important changes in architecture, town planning, technology, monumental arts, or landscape design.
- III Bear a unique or incomparable testimony to a cultural tradition or to a civilization (living or extinct).
- IV Be an outstanding representative of one or more significant stages in human development.
- V Be an outstanding example of human settlement or use of land/water.
- VI Be completely or partly associated with events or living cultural traditions, with ideas or beliefs, or with outstanding artistic and literary works of significance for the whole world.
- VII Contain superlative natural phenomena or areas of exceptional natural beauty and aesthetic importance;
- VIII VIII Be an outstanding example that represents major stages in the Earth's history.
- IX Be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of ecosystems.
- X Contain the absolute most important and significant natural habitats for in-situ conservation of biological diversity.

Famous World Heritage Sites

Some famous Cultural Heritage Sites

World Heritage	Country
Sydney Opera House	Australia
Rapa Nui National Park	Chile
The Pyramids at Giza	Egypt
The Eiffel Tower	France
Palace and Park of Versailles	France
Acropolis	Greece
Taj Mahal	India
The Great Wall	China
Machu Picchu	Peru
Stonehenge	United Kingdom
Statue of Liberty	USA

Some famous Natural Heritage Sites

Great Barrier Reef	Australia
Amazonia	Brazil
Galapagos	Ecuador
Surtsey	Iceland
Etna	Italy (Sicily)
Serengeti	United Republic of Tanzania
Teide National Park	Spain (Tenerife)
Yellowstone	USA
Grand Canyon	USA
Victoria Falls	Zambia and Zimbabwe

Infobox: UNESCO

UNESCO stands for the United Nations Educational, Scientific and Cultural Organization, and also carries out other types of international preservation and protection activities. For example, countries can also nominate Intangible Cultural Heritage and Memories of the World. Examples of Intangible Cultural Heritage are the Lucia tradition in Sweden and sauna bathing in Finland. Memories of the World comprise documentary heritage — archives, papers, photos, etc. — that are significant for mankind and that need protection. Examples of Memories of the World are the Original Declaration of the Rights of Man and of the Citizen (France) and The Alfred Nobel Family Archives (Sweden).

1.1 Our World Heritage Site

The High Coast/Kvarken Archipelago World Heritage Site was awarded its World Heritage status by meeting UNESCO's eighth criterion, as an outstanding example of an important stage in the Earth's history. The High Coast was inscribed in the World Heritage List in 2000. Six years later, this World Heritage Site was expanded to include the Kvarken Archipelago.

One feature that justifies a joint World Heritage Site is a landscape where high meets low. Today, the undulating landscape of the High Coast, with its high islands, steep shores, smooth cliffs, deep sounds, and hills is the complete opposite of the Kvarken Archipelago, with its thousands of low islands, rocky reefs, shallow inlets and bays, moraine ridges, and massive fields of boulders. Together they form the best place in the world to experience and understand the land uplift that has taken place since the most recent Ice Age.

Here, it is easy to see geological traces in the landscape that were created by the ice sheet in the most recent Ice Age. The ice sheet was at its thickest here, approximately 3 kilometres, and pressed down the Earth's crust by up to a kilometre. The crust is still trying to regain the original position it occupied before the most recent Ice Age. The isostatic land uplift of 9 millimetres per year is constantly raising the Earth's crust and exposing more and more of the seabed. It

was in the High Coast that, in the 19th century, scientists were able to prove that it was the land that was rising and not the water disappearing. Nowhere else on the planet can the ongoing process be seen as clearly as here. It is also possible to see how both flora and fauna and people are affected by and have to adapt to the land uplift. This makes the High Coast and the Kvarken Archipelago a unique environment – a kind of open-air museum of the Ice Age and land uplift – an environment that forms the basis for the area's inscription as a World Heritage Site.

Threats to our World Heritage Site

Sweden and Finland have undertaken to protect and manage the High Coast/ Kvarken Archipelago World Heritage Site to preserve it for humankind, both now and in the future. Within the World Heritage area, individual attributes can be under threat from, for example, dredging, and in the future, the entire area can be impacted by, particularly, climate change. The isostatic land uplift will

Infobox: World Heritage Site: High Coast/Kvarken Archipelago

- The High Coast was inscribed on the World Heritage list in 2000, and in 2006 the site was expanded to include the Kvarken Archipelago.
- The official name is High Coast/Kvarken Archipelago World Heritage Site.
- The site is a marine, geological, and transnational World Heritage Site.
- The areas comprise the topographically most extreme land uplift landscapes (high and low) in the Baltic Sea.
- The World Heritage Site comprises three separate areas with a combined area of 3,464 square kilometres.
- High Coast: In Sweden, the Västernorrland County Administrative
 Board has main responsibility for managing the World Heritage
 Site. The area is in the municipalities of Kramfors and Örnsköldsvik,
 and comprises 1,520 square kilometres, of which 57% is land. The
 population of the area is approximately 5,500.
- Kvarken Archipelago: The Finnish part of the World Heritage Site
 comprises two smaller areas managed by Parks & Wildlife Finland,
 Coastal and Metropolitan Area. The areas are in the municipalities of
 Vörå, Korsholm, Vaasa, Malax and Korsnäs. The area of the Finnish part
 of the World Heritage Site is 1,944 square kilometres, of which 15% is
 land. The population of the area is approximately 2,500.

continue regardless of whether sea levels rise because of climate change, but the effects will become less visible. Particular habitats relating to the land uplift and biological succession processes, both on land and in the sea, are therefore at risk of disappearing in the future. Other threats, such as increased tourism, dredging, and land use, may have major consequences locally. The authorities in Sweden and Finland manage these areas according to management plans, and the World Heritage Site is protected by laws and ordinances to a certain extent. For example, parts of the Kvarken Archipelago are nature protection areas, and in the High Coast there is a national park and many nature reserves. However, everyone who lives and is active in the World Heritage Site can help to take care of the World Heritage Site. Small simple actions contribute to the management and care of our joint World Heritage Site, such as not building towers of stones on the cobble fields and beach ridges, because this destroys these geological traces.



Figure 4. The High Coast/Kvarken Archipelago World Heritage Site is a transnational site comprising three separate areas.

Illustration: Gunvor Ekström



The area that today comprises Sweden and Finland is the result of geological development over many billions of years. The ice ages gave this particular area a special character, by shaping the landscape we see today. In the warmer periods between the ice ages, wind, waves, winter ice, and flowing water continued to alter the landscape. However, we do not know much about the earlier ice ages, because the most recent ice age obliterated many of the traces they left. When people talk about "the Ice Age", they are referring to the most recent ice age, which in northern Europe is called the Weichsel.

Approximately 120,000 years ago, several phenomena, such as the angle of the Earth's axis in relation to the Sun, and the distance of the Earth from the Sun, led to the climate slowly becoming 5-10 degrees colder than it is today. Snow and ice did not melt in the short, chilly summers, and the glaciers in higher areas grew and grew until they joined to form many large ice sheets that spread over much of the Northern Hemisphere and parts of the Southern Hemisphere. The ice sheet that lay over northern Europe and the Nordic region has been named the Fennoscandian ice sheet. The ice sheet was at its maximum 18,000 years ago, and its southern edge ran from Ireland, over the northern parts of Central Europe, and as far as Siberia.

After the cold period, the climate once again became warm enough for the ice mass to melt and shrink. A period when the ice is melting and shrinking is called deglaciation. Researchers believe that, once the melting had started, the process went relatively quickly. The High Coast and Kvarken Archipelago are believed to have become ice-free around 10,500 years ago. Around 9,000 years ago, Finland and Sweden were, in principle, free of ice.

We are currently in a warmer period between Ice Ages, a so-called interglacial. Nobody can know when the next cold period will come, but previous warmer periods have lasted between 10,000 and 20,000 years.

The ice sheet in motion

The Fennoscandian ice sheet was not stationary – it could both move and vary in extent, just as glaciers do. The ice grew during cold periods, when the precipitation that fell in the winter did not melt in the summer. Its own weight constantly

pressed ice out from the centre and out towards the margin, causing an internal movement in the ice mass. During the melting phases, the ice reduced its mass both through calving (when large pieces of ice break off the ice margin) and by melting on the surface. Even during the melting phase, the ice continued to flow outwards from the centre, despite the ice mass shrinking.

The temperature inside an ice sheet is not the same everywhere, and there is a distinction between warm (active) and cold (passive) zones at the base of the ice. In colder zones, the ice is mostly stationary and often frozen to the underlying sediment and rock. Under this type of ice, the ground is not impacted so much, so the ice sheet leaves fewer traces in the landscape. In areas where the base of the ice is warm, the ice flows over the terrain. An ice sheet can probably flow anything from a few centimetres up to a hundred metres a day. The meltwater and the loose sediment layers under the ice act as a lubricant. The sediment under the ice consists of material of different grain sizes. The ice sheet and the sediment can be described as an enormous block of coarse sandpaper that smooths irregularities in its path as it flows over the terrain. It hollows out valleys and ravines, making them deeper and wider.

Traces of the Ice Age in the landscape

The Fennoscandian ice sheet flowed in slightly different directions in different periods. The boulders, rocks, gravel, and smaller particles (sediment) eroded by the ice were transported as the ice moved over the landscape. The rock debris and sediment could be transported frozen in the ice, on the surface, and under the ice, and could also be washed along in streams of meltwater, even large meltwater rivers that could also flow on, inside, or under the ice. At the ice margin, glacially transported rock debris of different sizes was deposited to form ridge-shaped geomorphological formations. When the ice sheet ended in a water basin, icebergs were released by calving. The icebergs floated away and later deposited their load elsewhere when they melted.

Through the above processes, the ice, rock debris, sediment, and meltwater shaped the underlying landscape, leaving behind the landforms that we can today recognise as, for example, eskers, giant potholes, kettle holes, and U-shaped valleys. In the High Coast and the Kvarken Archipelago, common traces from the glacial period include roche moutonnées with striations and De Geer moraines. These formations are also one of the reasons why these particular areas have been declared a World Heritage Site. This area offers the best opportunity to see how the last Ice Age shaped the landscape. The following section describes in more detail some of the traces left after the last Ice Age.



Figure 5. Extent of the Weichsel glaciation. The illustration shows the greatest extent of the ice sheet in Europe in the last Ice Age. The ice sheet was thickest, at most three kilometres, and heaviest over the High Coast – the Umeå region – Kvarken Archipelago, where it pressed down the Earth's crust approximately one kilometre.

Infobox: Why was the ice sheet thickest over the area of the World Heritage Site?

The current rate of land uplift can tell us a lot about the Fennoscandian ice sheet. When the continental ice sheet developed in the Scandinavian mountain range, most of the ice concentrated in the basin that is today the Gulf of Bothnia. This was the centre of the Fennoscandian ice sheet. Scientists get this information by comparing current land uplift rates in the area previously covered by the ice sheet. The highest land uplift rate today is where the ice was thickest during the Ice Age. The World Heritage Site is far from the margins of the Fennoscandian ice sheet in every direction, and it is believed that the most extreme conditions lasted longest here, causing the ice to be thickest in this area.

Infobox: Difference between an ice age and glaciation

An ice age is a period in the Earth's history that is characterised by large land areas being covered with ice. Continental ice sheets started to form when the climate was so cold that snow and ice on north-facing slopes and in mountainous areas, areas with high precipitation, did not melt during the summer. Many consecutive cold summers led to the ice cover slowly but surely growing, both in height and in extent. The light surface of the ice also reflected the Sun's heat, making the climate even colder.

During an ice age, there can be many periods of glaciation, when it is so cold that the ice sheet grows. Between glaciations, there are warmer periods when the continental ice sheet melts considerably more than it grows, and the ice may even disappear completely. These periods are called deglaciation. During the Weichsel glaciation, there were at least three glaciation periods, interspersed by warm periods.

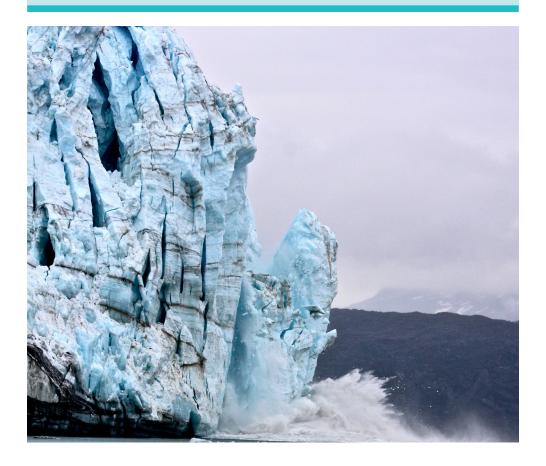


Figure 6. The World Heritage Site Kluane/Wrangell-St. Elias/Glacier Bay/Tatshenshini-Alsek shows how the landscape is shaped by glaciers. Here is a glacier that is calving.

Photo: fschaller/NPS image

2.1 Bedrock, topography, and rock chasms

Before we can identify and understand the traces of the last Ice Age and the subsequent land uplift in the World Heritage Site, we need to look in more detail at the landscape itself. The rock types that form the bedrock in the area are also part of the reason for both the height differences between the High Coast and Kvarken Archipelago, and local characteristic landforms like the rock chasms in the High Coast.

Most common rock types in the World Heritage Site

Rocks that consist of metamorphosed sediment dominate both in the central parts of Norrland and in the Kvarken Archipelago. However, in the High Coast area of the World Heritage Site, these rocks are subordinate. Approximately 2 billion years ago, a large sea covered the area, and the landscape was worn down by wind and water. Gravel, sand, and clay sediments, eroded from a nearby continent, were washed out into the sea, over a period of at least 100 million years. Eventually these sediments, especially those in the bottom layers, were subjected to enormous pressure and temperature on the seabed and became lithified. Movements in the Earth's crust caused the tectonic plates to move and eventually collide, approximately 1.8 billion years ago. When the tectonic plates were forced together, a subduction of the heavier plate occurred and the lighter continental crust was scraped off and compressed, eventually forming a mountain range. The sedimentary rock types were pressed deep inside the Earth, where they completely or partially melted. At a depth of 15 kilometres, the new rock types, granite, and gneiss, were formed.



Figure 7. Gneiss from Molpehällorna, Kvarken Archipelago.

Photo: Tuija Warén.

Gneiss, a metamorphic rock, is common in the Kvarken Archipelago. Gneiss can easily be identified by its veins – the rock type often shows irregular stripes, with alternating lighter and darker layers of mineral grains.

The granites are magmatic rock types that melted completely before solidifying again. The oldest is over 1.9 billion years old. Vaasa granite is one such old granite, and is only found in the Kvarken Archipelago. The rock was a popular building material when the city of Vaasa was built.



Figure 8. Vaasa granite from Vikarskat, Kvarken Archipelago.

Photo: Malin Henriksson

If the grey Vaasa granite with white spots can be said to be characteristic of the Finnish part of the World Heritage Site, then the reddish Nordingrå granite, a rapakivi granite, is characteristic of the High Coast. The Finnish name 'rapakivi' tells that the rock easily weathers, as can be seen on Slåttdalsberget. Nordingrå



Figure 9. Nordingrå granite at Norrfällsviken, High Coast.

Photo: Fabiola de Graaf

granite is a younger type of granite than the Vaasa granite. It was formed approximately 1.6 billion years ago. Nordingrå granite can be found, for example, on Skuleberget and in Norrfällsviken.

Around 1.6 billion years ago, the continental plate broke up again here, and magma, consisting of gabbro, was able to force its way up through the cracks in the granite. Gabbro and granite consist of different minerals and have different melting points, but the gabbro magma melted the granite that it passed on the way up towards the surface,



Figure 10. Nordingrå gabbro near Häggvik, High Coast

Photo: Patrik Bylund.

so the two rock types could be mixed. In the Nordingrå area in the High Coast, the special dark grey Nordingrå gabbro can be seen, which in some places contains sections of granite that solidified inside the gabbro.

The Jotnian sandstone accumulated as sediment in a sea approximately 1.3-1.2 billion years ago. The sandstone has since lithified into a yellowish or reddish sandstone. The sediment was deposited on top of older bedrock, and in the High Coast sandstone is found above Nordingrå granite and Nordingrå gabbro, which can be seen for example at Sörleviken and on the islands of Trysunda and Storön. Sometimes, the sandstone's surface still bears traces of how waves created ripple patterns in the sand that remained visible when the sandstone lithified later. Sandstone often contains darker layers of mudstone, varying from a few centimetres to a few decimetres thick. In the Kvarken Archipelago, sandstone can be found as individual boulders on the stony beaches.



Figure 11. Ripple marks in sandstone at Nyhamn, High Coast.

Photo: Lena Lundqvist, SGU

Weathered diabase cracks form chasms in the High Coast

Most of the sandstone in the High Coast has been protected from weathering by an overlying layer of diabase. Diabase was formed approximately 1.25 billion years ago, when a large quantity of magma was forced up into the Earth's crust where it solidified. It lay like a large, flat, plate-like rock mass, with a diameter in the High Coast area of approximately 50 kilometres. The diabase is called Ulvö diabase because this rock type dominates on the Ulvöarna islands. It appears in the High Coast area in an arc shape in the archipelago. Diabase from the same magma could also be forced upwards in vertical cracks in the bedrock, known as dikes. Skuleskogen's well-known Slåttdalsskrevan is a remnant of such a crack. Most of the diabase in the chasm has been eroded over time and washed away by running water, but diabase can still be seen at the bottom of the chasm. Most chasms in the High Coast have been formed in the same way.



Figure 12. The magnificent Slåttdalsskrevan chasm in the Skuleskogen National Park, High Coast, formed when a diabase dike was eroded, and the material washed away from the surrounding Nordingrå granite.

Photo: Erik Engelro

Why is the High Coast high and Kvarken Archipelago low?

Six hundred million years ago, the High Coast and Kvarken were part of the same smooth, flat rock surface, known as the sub-Cambrian peneplain. The sub-Cambrian peneplain was the result of millions of years of weathering and erosion. Because of tensions and movements in the Earth's crust, areas like what is today the High Coast were lifted up. This is why the High Coast is the only area around the Baltic Sea where high hills reach the coast.

The upland landscape was exposed to powerful erosion, and was worn down over time by running water, wind, and ice, which found their way into the large cracks in the bedrock. Together with the ice ages, these powerful forces eventually formed much of the undulating, rounded landscape of hills, deep valleys and inlets that characterise the High Coast. The tops of the hills in the High Coast are the remains of the same flat rock surface that is still visible in the Kvarken Archipelago.

The Kvarken Archipelago is low, with small topographical differences for two reasons: the part of the sub-Cambrian peneplain where the archipelago now lies was not lifted, and perhaps because it was subjected to the slowest erosion on Earth. In Kvarken, the water depth is, at most, 25 metres, and the highest point just over 20 metres above sea level, while the height differences in the High Coast area are more than ten times greater, with a sea depth of over 290 metres and hilltops of 350 metres.

Infobox: What is the difference between moraine and till?

- 1. The soil type known as till is a mixture of rock boulders, stones, gravel, sand, and fine-grained material loosened from the bedrock by the ice sheet. Till is typically unsorted, but in the World Heritage Site the material was often wave-washed, sorting the gravel and sand if the till lay under the sea surface during the land uplift. The finest material was completely washed out by the waves.
- 2. Moraines are geomorphological formations made of till, such as drumlins and De Geer moraines.

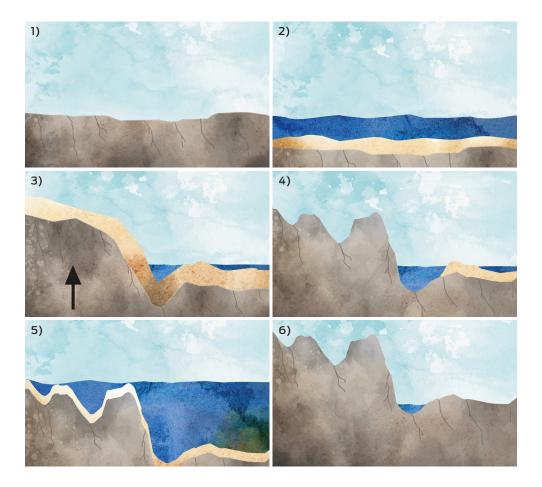


Figure 13. 1) Approximately 550 million years ago: The High Coast and the Kvarken Archipelago lay on the same flat erosion surface known as a peneplain. The bedrock of the peneplain contained cracks, which are zones of weakness where the bedrock can be eroded more easily. 2) 550-420 million years ago: Approximately 550 million years ago, the common peneplain was under water, and large quantities of sand, sludge and calcium accumulated on the seabed. These sediments were compressed and hardened into rock. There are no longer any known traces of these sedimentary rocks within the land area of the World Heritage Site, but there are remains of limestone, sandstone, and mudstone on the sea floor off the coast. 3) 420-50 million years ago: About the time the Atlantic was opening up in the west, movements in the Earth's crust raised some of the bedrock underlying the High Coast. The bedrock under the Kvarken Archipelago was not lifted in the same way. 4) 450-50 million years ago: Over a long period, movements in the crust gradually forced the two rock masses up and down. The sedimentary rocks were slowly eroded away in the High Coast land areas. Eventually, the erosion also started to attack the cracks in the crystalline basement rock. The cracks were eroded faster, as the rock was already weakened at these points. The characteristic hilly landscape of the High Coast started to take shape. 5) 450-50 million years ago: In the subsequent millions of years, the eroded hilly surface of the High Coast was alternately above and below water. When the land was covered by sea, new sedimentary rocks were formed that gave some protection against erosion. When the land was above the sea, the sedimentary rocks were once again eroded away. 6) 50 million years ago until the present day: When we are standing on what 's left of the old erosion surface that the High Coast and Kvarken Archipelago once shared. There is no trace of the ancient peneplane in Kvarken Archipelago anymore and it is also eroded away in the High Coast.

2.2 Roche moutonnées and striations

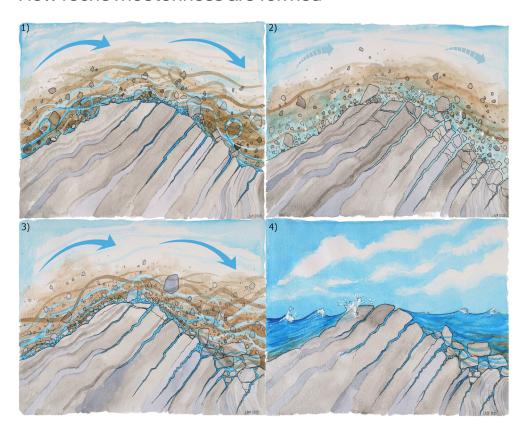
In the Nordic region, there is usually a layer of till above the bedrock. This layer can vary in thickness, typically only a few metres, but in certain parts of the Kvarken Archipelago the till layer can be tens of metres thick. Both the earlier and the most recent glaciations wore down hills and cliffs, and carried with them loose material that was deposited when the ice melted. In some places, the ice scraped away the till layer completely, exposing the bedrock. The ice acted like a very coarse sandpaper, wearing away the rough edges of the rock surfaces over which it passed.

Roche moutonnées

Under the ice sheet, there was tremendous pressure, which caused the lowest metres of ice and the upper part of the permafrost in the sediment below to melt. Subglacial sediment and water formed a thick slurry, acting as a film between the permafrost and the glacier, causing the ice to flow. This mass worked like coarse sandpaper on the underlying ground, and particularly the bedrock that lay exposed to the ice was worn away over time. Eventually, the formerly jagged and uneven rock surfaces became smoother and rounded, forming roche moutonnées. Researchers believe that the main erosion of roche moutonnées occurred right at the end of the last Ice Age, during the melting in the deglaciation phase.

The direction of ice movement can be seen on a roche moutonnée. The up-glacier side has a gentler slope and is rounded and streamlined. That side is called the stoss, and it absorbed the main impact of the ice.

On the down-glacier side, the ice had less effect on the rock. This is called the lee or plucked side. On that side, subglacial meltwater froze into cracks in the bedrock, causing the rock to shatter. The moving ice then plucked the loosened rock and transported it away. This is why the lee side is often craggy and fractured.



How roche moutonnées are formed

Figure 14. 1) A slurry of sediment and water flowed over the landscape under the enormous ice sheet. The stony material in the slurry was dragged over the rock surface and ground down irregularities in the exposed bedrock. 2) Occasionally the ice and slurry froze to the bedrock 's lee side for short moments and, as the ice moved, it could detach pieces of the bedrock. The process by which the ice broke off rocks and boulders and transporting them is called plucking or quarrying. 3) Glacier transportation occurred when the ice once again became active and started to move, and the flowing slurry of meltwater and sediment carried with it some of the loosened boulders. On the lee side, the rock became craggy and relatively unpolished, and some loosened rocks and boulders were left behind. 4) When the land uplift raised the roche moutonnée to sea level, it was further eroded by waves, currents and winter ice, and loose material was washed away.

Striations

In certain places, the underside of the ice worked like a block of sandpaper with different levels of coarseness. Large boulders could be frozen into the base of the ice, and large rocks could be found in the meltwater and sediment slurry. These rocks carved grooves or striations on the up-glacier side of a roche moutonnée when they were dragged over its surface. Often, many of these striations can be seen parallel with each other on a rock surface. Some are only a millimetre deep, while grooves can be up to a decimetre deep. What distinguishes striations and grooves from cracks in the rock surface is that striations were clearly formed by something scraping over

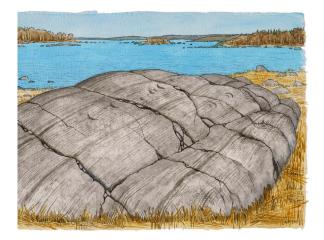
the rock surface and that they often rounded at the base, while cracks are irregular and deeper.

The striations can be used to work out the direction in which the ice was moving when they were created. Most striations in the High Coast and Kvarken Archipelago probably formed in the final phases of the last ice age, but in certain places striations can also be seen from earlier phases of the Weichsel glaciation or even from earlier ice ages. Some rock surfaces may have been carved by the underside of the ice several times, and striations may cross each other.

When the land uplift raised the roche moutonnées to the sea's surface, the waves and winter ice washed them completely free of loose material and polished them even smoother. These types of roche moutonnées are common in the High Coast. They can be found at different levels in the landscape, and sometimes in large areas or along long stretches of earlier or current shorelines. They are seen most clearly along the current coastline.

What stiations look like

Figure 15. The slurry of sediment and water that flowed under the ice sheet contained stone boulders. When these flowed over the rock, they carved long grooves on the smoother surfaces. Some of these striations could be barely a millimetre or so deep, while others could be more than a decimetre deep. The pressure from the ice could also cause various chips and crack formations in the rock surface. On some bare rock surfaces, striations can be seen that to form perpendicular to each other



or have a different orientation. They may have been created during earlier stages of the Weichsel glaciation.

Figure 16. Striations lie parallel with each other, and can be anything from a millimetre to a decimetre deep.

Photo: Patrik Bylund



2.3 Erratics and boulder terrain

In the Nordic region, large rock boulders can be seen, apparently scattered randomly in the landscape. These large boulders, which can be tens of metres in diameter, are called erratics. They can be found hundreds of kilometres away from the place they were situated before the most recent ice age.

Apart from its size, the characteristic feature of an erratic is that it is solitary or rather solitary in a certain area and that it has been transported to its position by an ice sheet. The erratic can also be made of a rock type that is not found in that particular area. Erratics can be found here and there in both Finland and Sweden. However, in the Kvarken Archipelago, large boulders are so common that far from all of them can be defined as erratics according to the above definition. Nevertheless, most of Kvarken's large boulders have probably been moved and deposited by the ice sheet in the last deglaciation.

Figure 17. In the Kvarken Archipelago, there are so many large boulders that it is difficult to define which of them are erratics.

Photo: Liselott Nyström Forsén



Boulders frozen in the ice sheet and icebergs

When the ice sheet advanced over the landscape over thousands of years, its enormous force combined with frost shattering could break off large pieces of the bedrock and carry them away. The ice sheet started to melt towards the end of the last ice age, and the deglaciation in the Kvarken area was relatively rapid. When the ice melted, the till was left on the land or on the seabed, often far from the location where the ice had broken away the rock material.

Giant icebergs could also break off from the front edge of the ice, probably similar to the way glaciers calve in Greenland or Alaska today. In the same way as ice cubes float in a glass of water, the icebergs could float, even while still carrying many tonnes of heavy rock boulders. An iceberg could float far from the ice sheet before it had melted so much that it could no longer hold the rock material. The rocks and stones then sank to the seabed wherever they happened to be at the time; many of them have now been lifted above sea level by the land uplift and become visible.

How erratics may be formed

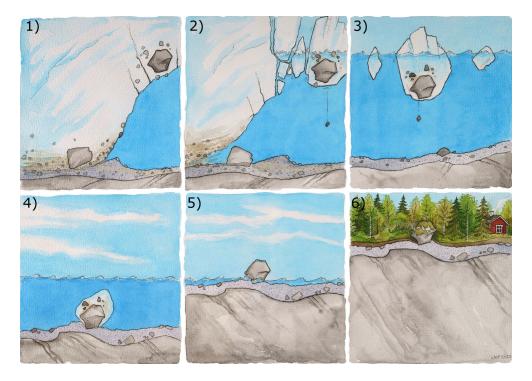


Figure 18. 1) The ice sheet could loosen large boulders from the bedrock and transport them inside the ice as it moved outwards from its centre. **2)** When the ice sheet melted over open sea, large overhanging ice shelves were formed, which later broke off to form smaller icebergs when they became too buoyant. Rocks and stones could also be released by the melting of the ice and sink directly to the seabed. **3)** Icebergs could float long distances on the sea currents and be blown by the wind. **4)** When the ice had melted so much that it could no longer bear the weight of the rock material frozen inside it, the iceberg sank to the seabed. **5)** Over time, the land uplift raised the erratics towards the sea surface. **6)** Erratics can be distinguished by comprising an exotic rock type or by being considerably larger than other rocks in the surroundings.

Boulder terrain

A common feature in Kvarken is groups of large rock boulders, even large fields with many large boulders together. Boulder terrain is most common in the southern part of the Kvarken Archipelago. There are several different theories about how these fields of rock have been created, depending on the location of these areas and their appearance. In some areas, large rocks and boulders seem to be randomly scattered on a flat surface. In other areas, the boulders have been pushed together to form small hills or ridges. In the boulder terrain, jagged and unpolished granite is the most common rock type, inspiring place names such as Bergö gaddarna, which means, freely translated, Bergö's fangs.



Figure 19. In the area around Södra and Norra Geren in the southern World Heritage area in the Kvarken Archipelago, navigation by boat is difficult, because there are so many boulders and rocks strewn around, with an apparently random distribution.

Photo: Hans Hästbacka

Infobox: Famous erratics in Sweden and Finland

Botmarksblocket outside Umeå has been measured to be $15 \times 30 \times 50$ metres and is regarded as Sweden's largest erratic. Lostenen in Pedersöre in Österbotten is $15 \times 30 \times 40$ metres, and therefore Finland's fourth largest erratic.



Figure 20. In Köklot the beaches are often higher than normal in the flat Kvarken Archipelago. The boulder terrain here seems to have been created by the ice sheet pressing together large boulders in the last Ice Age.

Photo: Seppo Lammi

Infobox: Thrown by giants

Earlier, people could not understand why individual enormous boulders could be so scattered in the landscape. Many believed they had been thrown by giants. Many sagas tell about how giants lived up here in the Nordic region in the past. One of them was called Finn.

According to the legend, Finn was driven out of Sweden by the other giants. He took a leather sack and filled it with large pieces of rock and stones. Some people thought he planned to take the rocks to build a new place to live somewhere else, while others thought he took them to defend himself with. Whatever the reason, he was wading across the sea when, halfway to Finland, the bottom of the sack ripped open. Some of the rocks and stones fell out, and they formed the island group we know as Valsörarna. A little further on, the bottom of the sack ripped completely open, and all the rocks fell out. That pile formed Panike. Finn then became so angry that he picked up the massive rocks from the pile and threw them around – forming Replot, Björkö and Vallgrund and their innumerable islets, skerries and shallows.

2.4 Different types of moraines

Common traces left after the most recent ice age are various features in the landscape made of the till deposited by the ice sheet. These landforms are called moraines and are categorised according to their shape. They include ribbed moraines, drumlins, flutings, and hummocky moraines. One of the more characteristic moraine formations is called De Geer moraines.

In some parts of the glacier, the base was cold, and the ice was frozen to the underlying rock surface. In other parts, the base was warm, and the ice was moving. In these warm areas, a slurry of wet rock debris and sediment lay between the ice and the underlying rock. Material in this active zone of slurry between the glacier and the solid rock or permafrost below acted like a conveyer belt, moving the ice out towards the margin while maintaining the ice velocity. This is the typical feature of an ice stream, which is a fast-flowing body of ice originating from the continental ice sheet during the deglaciation.

Ice streams played a significant role in the glacial erosion-transportation phenomena throughout the areas covered by the Fennoscandian ice sheet. During their life cycle, ice streams changed the underlying landscape when flowing over soft wet sediment or rock, leaving behind a characteristic footprint as seen across the Kvarken Archipelago. When an ice stream starts to develop and flow, this causes cracks in the surrounding cold ice. In these cracks, ribbed moraines are formed. Drumlins and flutings are created when the flow increases. In the last stage of the ice stream, when it reaches the ice margin, De Geer moraines are formed. When De Geer moraines cover a larger region, as in the Raippaluoto area, it suggests that the ice margin retreated rapidly during deglaciation across the region.

2.4.1 Ribbed moraines

Ribbed moraines appear in many different shapes, but typically these formations are broad, low ridges orientated perpendicular to the direction of ice flow.

In Kvarken archipelago, ribbed moraines formed deep inside the continental ice sheet where an ice stream started, also called the onset point, far from the ice margin. The flow of the ice stream exerted extensional forces on the cold ice surrounding it, causing it to crack. Ribbed moraine ridges are formed when the sediment is squeezed up into the ice cracks. Ribbed moraines are perpendicular to the direction of movement of the ice sheet. Ribbed moraines were previously called Rogen moraines in Scandinavia, but nowadays Rogen moraines are one type of ribbed moraine.



Figure 21. Ribbed moraines on the Valsörarna islands.

Photo: Christoffer Björklund

2.4.2 Moraine types formed by the ice streams

The most recent ice age — and all ice ages before that — left many different traces in the landscape. These traces can be found throughout Sweden and Finland, and in other parts of the world covered at some stage by ice. Some of these traces, such as giant potholes, terminal (end) moraines, and kettle holes, can still be seen clearly in the landscape, while others have been affected by or even destroyed by erosion or human activity. Here, we will consider in more depth some of the other types of moraines that can be seen in the High Coast/Kvarken Archipelago World Heritage Site.

Various moraine formations are common throughout Ostrobothnia and Ångermanland. They are exceptionally common in the Kvarken Archipelago, but quite rare in the High Coast area. The geographical delimitations in the Kvarken Archipelago World Heritage areas reflect the frequent occurrence and their well-preserved state in these particular areas.

Hummocky moraine

Hummocky moraine comprises many types of small or large hill-shaped moraine formations. They can be straight, oblong-shaped, curved, and round. They can also be mounds of till containing rocks of various sizes. These moraines have many subtypes depending on the size, shape, and composition. They can also be divided into sub-types depending on their origin.

Hummocky moraines often form large areas. The hills, 5-20 metres high, form a mosaic pattern, and are surrounded by sea, lakes, ponds, and peatlands. However, these areas can seem very irregular, because they may contain several different types of hummocky moraine shapes that were formed under different conditions. The hummocky moraine formations may even merge into each other.

Drumlins and flutings

Drumlins and flutings are 'cigar-shaped' moraine formations formed under fast-flowing ice. Drumlins are typically 5-10 metres high and hundreds of metres long, orientated parallel to the direction of ice flow. Flutings are smaller than drumlins and less significant in the landscape. They are typically only around 1 metre high, but can be as long as drumlins.

Loose wet material called subglacial sediment moved under the fast-flowing ice streams, making the terrain flatter and more streamlined. However, a protruding piece of rock or other obstacle could also remain, with sediment forming an elongated ridge behind it. Those long, elongated ridges are called drumlins, or flutings depending on their size.

Flutings are also streamlined features made by glaciers, but they are smaller than drumlins and typically needle-shaped. They are found in clusters, also parallel with the direction of movement of the ice. They are long, low ridges of till.

Figure 22. This illustration shows ribbed moraines on the Valsörarna islands. They were formed during the last Ice Age, perpendicular to the direction of movement of the ice sheet. On the Valsörarna islands, there is also a drumlin, which can be seen as an elongated rounded hill in the bottom left part of the illustration, and flutings, which are seen as narrow ridges on top of the ribbed moraines in the centre of the picture.



A mosaic of moraine formations



Figure 23. One of the reasons why the Kvarken Archipelago was added to the High Coast World Heritage Site was that the area contains a great number of traces left by the Ice Age and land uplift. Occasionally, these traces even overlap and merge into one another, which can make it difficult to identify different moraine formations in the landscape, for example at Boskär.

Photo: Christoffer Björklund

2.4.3 De Geer moraines

The De Geer moraines are made of till that was shaped into long, narrow ridges along the ice margin. They often appear in groups, giving a striped appearance to the landscape. De Geer moraines are found in much of the Nordic region, and in the Kvarken Archipelago alone there are over 14,000 above sea level, mainly in the World Heritage areas. They cover large areas, both above and below the sea surface. There are only a few De Geer moraines in the High Coast, but they are common in other parts of Sweden.

De Geer moraines formed at the ice margin

De Geer moraines are found mainly in flat areas, and only below the level of the highest coastline (see Chapter 3. Effects of the land uplift and the sea). Moraines of this type are formed during deglaciation when the ice sheet is shrinking rapidly. In Kvarken, they were formed under water, at a sea depth of more than 250 metres. The theory geologists work with today is that the De Geer moraines in Kvarken were formed by ice streams at the front of the retreating ice margin. The size of ice streams can vary considerably, but for example the Raippaluoto ice stream that formed De Geer moraines in Björkö was about 10 km wide and 40 km long.

When the subglacial ice stream, transporting wet sediment, reached the ice margin, the velocity suddenly decreased, and the sediment was deposited, forming a ridge. This long, relatively thin and narrow formation is called a De Geer moraine. The ridges often slope more gently on the side that faced the ice, and are steeper on the side facing the sea. De Geer moraines are usually 2-5 metres high and vary in length up to a kilometre.

When ice sheets end in the sea, long overhanging ice ledges often form along the top of the ice margin, extending far beyond the bottom edge. When the ice under the ledges melted during the deglaciation, this released sediment transported inside the ice sheet. Some of these rocks sank down onto the side of the De Geer moraines facing away from the ice sheet.

During the deglaciation, icebergs calved at relatively regular intervals, so the bottom edge could retreat by tens of metres or more at a time, after which a new De Geer moraine would start to form at the new position of the ice margin. The De Geer moraines outside Svedjehamn in the Kvarken Archipelago run in an approximately southwest-northeast direction, indicating that the ice margin here was retreating towards the northwest during the deglaciation. On the island groups, Mickelsörarna and Rödgrynnorna, the De Geer moraines have a different orientation, suggesting that the ice margin was curved. The ice melted at rates of 500-700 metres per year, and the speed of melting can be measured using the De Geer moraines. Every winter, one larger De Geer moraine seems to have been formed from material that flowed under the ice, and every summer 3-5 smaller moraine ridges can have formed when the ice calved. This corresponds with other calculations of how quickly the ice melted at the end of the Ice Age.

When the land uplift later raises the moraine ridges up to the sea surface, sea currents, waves, wind, and winter ice can reshape them. This process is still happening today, for example outside Svedjehamn, where the De Geer moraines can be seen as a cluster of long, narrow islands, resembling an old washboard – and innumerable De Geer moraines are still lying on the seabed waiting to go through this process. When the De Geer moraines are raised out of the sea, the waves wash out some of the fine-grained material from the moraine ridges, so it may look like only the larger rock material is left. However, when geologists cut sections in De Geer moraines, they could see that the formation comprises two different parts. The side facing the glacier consists of fine-grained till with sand, while the flank facing towards the sea at the time of deglaciation is much coarser grained with gravel and stones. The finer material was washed out of the till and deposited in valleys between the moraines, as well as further away. Many De Geer moraines have already been covered by forest, fields, or buildings, which can be seen clearly along the roads in Björköby.

Although the ribbed moraines and the De Geer moraines have the same orientation as the ice flow direction, the De Geer moraines were formed at the ice margin, while the ribbed moraines were formed deep inside the ice, far away from the ice margin. Because of their different origins, De Geer moraines can lie on top of ribbed moraines (for example, on the Valsörarna islands), but never vice versa.

How De Geer moraines are formed



Figure 24.1) Under the enormous ice sheet, pressure and ice movement created a thick slurry of water and sediment that flowed at great speed over the terrain. At the ice margin the flow ceased. Subglacial material that had been carried along by the flowing wet sediment was deposited as long moraine ridges. Melting under the ice ledges released rocks that sank down onto the ridges. 2) When the ice ledge became too buoyant, it broke off the edge of the ice sheet, and the ice margin retreated to a new position. At the new ice margin, glacially transported sediment started to accumulate in a new moraine ridge. 3) When the land uplift raised a moraine ridge to the sea surface, the waves started to wash out fine-grained sediment from the rock material on the De Geer moraine. The clay, silt and sand were deposited in basins far away from De Geer moraines. 4) When the land uplift raised the De Geer moraines higher up in the landscape, they often grew together to form larger islands and eventually become part of the mainland. Between the moraine ridges, flads (shallow inlets) are first formed, which gradually become lifted higher and eventually become fens. Some of the valleys have been cleared to produce fields and meadows, because the old seabed there is more fertile and less stony, while houses and roads were often built higher up on the drier and stonier ridges.



Figure 25. Where De Geer moraines can be seen. Outside Svedjehamn in Björköby, the De Geer moraines can be seen most clearly from the Saltkaret lookout tower, but large fields of De Geer moraines can be found, for example, in the inner archipelago between Replot and Björkö.

Photo: Christoffer Björklund

Infobox: Gerard De Geer

The moraine formations were named after Gerard De Geer, a Swedish geologist and Member of Parliament at the end of the 19th century. His theory on how these striking moraine ridges had been created was that the ice melted more during the summer half-year, so moraine was deposited along the edge of the ice, rather like growth rings in a tree. The distance between two moraine ridges would then show how much the ice melted in a year. Since then, geologists have found that 3-6 De Geer moraines could be formed per year in the Kvarken region, the largest of which was probably formed in the winter half-year.

Infobox: How people have used the moraines

In Björköby, it can be seen how people have adapted to the landscape, because they often built their farm buildings up on the dry moraine ridges and farmed the rather more fertile and somewhat less stony till soil between the moraines. Because the landscape in the Kvarken Archipelago is so stony, people were forced to clear stones from fields and meadows, so stone walls are a common sight in the archipelago villages.



Approximately 18,000 years ago, the climate became warmer and the Fennoscandian ice sheet started to melt, and deglaciation started. The ice cover became thinner, and the ice margin retreated towards the northwest through melting and calving. As the weight decreased, the Earth's crust, which had been pressed down, started to rebound upwards towards its original position. This is the concept of **postglacial isostatic land uplift**: the land rises back to its original position after an ice age.

It is hard to imagine the enormous size of the ice sheet when it was at its maximum, and how unfathomably heavy it was when it was resting on the thin, hard Earth's crust, the lithosphere. Under the crust is a thick layer of viscous magma. This is why the tremendous weight of the ice sheet could slowly press the crust downwards into the softer magma. The ice was thickest roughly inside the triangle formed by the High Coast – Umeå – Kvarken Archipelago, and was approximately three kilometres thick at its maximum. Here, the ice pressed the Earth's crust down by as much as 1,000 metres. Further away from the centre, the ice was thinner, so there was less weight pressing the crust down. In areas outside the edges of the ice sheet, for example in the Netherlands and on the seabed off the west coast of Norway, the Earth's crust was forced upwards instead by the displaced magma masses.

Nine millimetres a year in the World Heritage area

When the ice sheet started to melt, this released the pressure on the earth's crust. At first, the postglacial land uplift was rapid. Geologists believe that the High Coast had already risen 500 metres before all the ice in the area had melted 10,500 years ago. Since then, the rate of land uplift has slowed. In the High Coast/ Kvarken Archipelago World Heritage Site, calculations from 2016 showed that the land uplift in the area is 9 millimetres per year, which is somewhat higher than previous calculations. (See infobox for definition of land uplift.)

Land uplift occurs at many places in the world, and in certain places the rate of land uplift is greater than here in the World Heritage site. However, nowhere else has seen as much postglacial isostatic land uplift as has been measured here. Since the ice sheet melted at the end of the last Ice Age, the land has risen 286 metres.

Land uplift and the sea continue to shape the landscape

Just as the ice sheet shaped the landscape beneath it, the land uplift and the forces of the sea continue to shape the landscape in the High Coast/Kvarken Archipelago World Heritage Site. Where the land uplift has raised the seabed to the surface, the sea starts to alter the landforms left by the ice sheet or create new landforms. The waves wash and sort the till that was deposited by the glacier during the deglaciation, and erode rocks and cliffs even more. Winter ice moves rocks and can even shatter bedrock and boulders. The land uplift causes traces, such as cobble fields, to be lifted higher and higher in the landscape, and causes sea bays to become shallower. Eventually, they are cut off from the sea, forming first lagoons and then wetlands. This is an ongoing process that is expected to continue for several thousand years until the Earth's crust has regained its original position from before the most recent ice age. The following section describes in more detail some of the traces from and consequences of the isostatic land uplift.

Infobox: Various ways of measuring the land uplift in the High Coast/Kvarken Archipelago World Heritage Site

- Absolute land uplift = land uplift measured from the absolute centre of the Earth: 10 millimetres/year.
- Levelled land uplift = land uplift measured from the geoid (the shape the ocean surface would take under the influence of the Earth's gravity and rotation alone. The effects of winds and tides are therefore excluded) = 9 millimetres/year.
- Apparent land uplift (shoreline displacement) = land uplift measured from the geoid minus the rise in sea level in the Baltic Sea caused by climate change, which in the past 30 years has averaged 3.6 millimetres/year = 5-6 millimetres/year.
- Land area increase = land uplift + sedimentation + overgrown by
 vegetation = 1 square kilometre of new land in the Kvarken Archipelago.
- Previously, the land uplift in the High Coast/Kvarken Archipelago
 World Heritage Site was thought to be 8 millimetres/year. New
 measurements and models now show that the figure is closer to 9
 millimetres/year, calculated as levelled land uplift.
- In this document, land uplift refers to the levelled postglacial isostatic land uplift, unless stated otherwise.

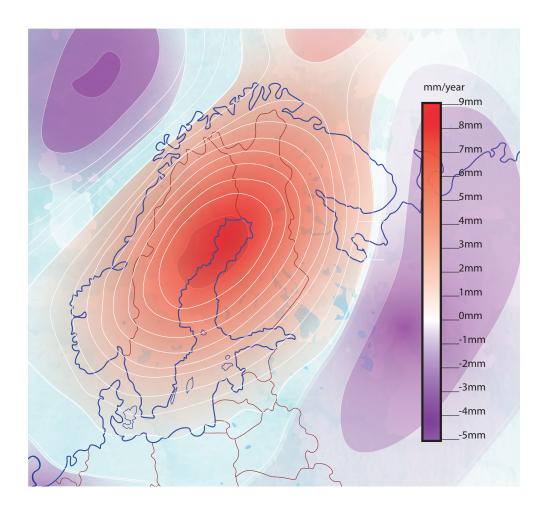


Figure 26. The map shows the extent and rate of land uplift in different areas. The dark red circle over Kvarken and the Gulf of Bothnia shows the highest rate of land uplift, approximately 9 millimetres per year. The purple areas, which were not covered by ice during the Weichsel, now have varying degrees of land sinking.





Figure 27. The effects of the land uplift can be seen particularly clearly and relatively quickly, particularly on the shores in the flat Kvarken Archipelago. At low water, it is possible to imagine what the shore could look like in only a few decades. These photos were taken on the Valsörarna islands at low water in 1984 and at normal water level in 2011.

Photo: Seppo Lammi

3.1 Detection of the land uplift phenomenon

One of the reasons why the High Coast was declared a World Heritage Site in 2000 is because extensive and definitive research about the land uplift phenomenon has been carried out in this area. The population along the coasts of the Baltic Sea has probably always been aware that shorelines are moving over time, and that new islands are appearing out of the sea. For a long time, it was believed that the amount of water in the Baltic Sea was decreasing, and in learned circles the term Wattuminskningen ("the diminishing water") was used. It was not until the mid-19th century that an association was observed between the most recent ice age and the land uplift. Research in the field continued tirelessly and, in recent years, new technology has given many new insights into what happened thousands of years ago.

The "diminishing water"

The first person to document the Fennoscandian land uplift was Ericus Erici Sorolainen, a Bishop of Turku, in 1621. In the 17th and 18th centuries, Swedish scientists tried to find explanations for the falling water levels in the Baltic Sea that, in one way or another, supported the Biblical version of the creation of the world. One example was the theory that the Biblical flood was still affecting the sea levels. However, the astronomer Anders Celsius believed that the water was either evaporating or disappearing through a hole in the bottom of the Baltic Sea. On his initiative, from 1731, a number of marks showing normal water level were carved in rock walls around Sweden. With the help of these, in 1765, both the Finnish land survey director E.O. Runeberg and the Swedish astronomer Bengt Ferrner, simultaneously and independently of each other, argued that it was the land rising, not the sea sinking. They realised that the causes of the difference in sea level lay in the movements in the Earth's crust, because the falls in sea level were not constant everywhere. Consequently, their explanation was that different rates of land uplift were the cause.

The land uplift phenomenon

However, why the land was rising in the Scandinavian peninsula and Finland remained a mystery, and various theories were put forward. Jakob Berzelius (1779-1848) stated that, at the start of the 1820s, most researchers no longer believed in the diminishing water explanation, and instead believed the cause was land uplift. Berzelius argued that the land uplift was caused by the Earth cooling, so it was shrinking and its diameter decreasing. The Earth's crust was crinkling as it adapted to its smaller diameter, causing the land to rise in northern Sweden and sink in the southern parts.

However, the now confirmed cause of the land uplift remained unknown until Scotsman Thomas Jamieson in 1865 connected the land uplift phenomenon with the theory of the Ice Age presented by the Swiss glaciologist Louis Agassiz in 1837. Agassiz had studied the glaciers in the Alps, and stated that much of the Northern Hemisphere had probably been covered by ice sheets. Not until the investigations of former Swedish shorelines by the Swedish geologist Gerard De Geer in 1890 did the theory of land uplift in the Nordic region being caused by the weight of the ice sheet in the most recent ice age become generally accepted.

The highest land uplift

Arvid Högbom (1857-1940) from Lövånger in Västerbotten tried to find the location of the highest coastline, and found it on Skuleberget, then measured to be 283 metres above the sea. In 1894, Högbom criticised De Geer's theories that the land uplift was greatest in central Sweden. Högbom argued that Norrland generally had risen more than the rest of Sweden, and that Norrland had not moved up and down but was solely in a land uplift phase. He placed the highest land uplift on the coast of Ångermanland.

Research continues

Technology moves continually forward, so we are still learning new things about the most recent ice age and the subsequent land uplift. By studying lidar data, geologists from the Geological Survey of Finland have been able to map, classify, count, and redefine certain moraine formations. Greater knowledge about the glacier footprint, i.e. different moraine formations that were deposited during the deglaciation of the ice sheet, also helps us understand what happens when an ice sheet melts. This knowledge can be used in research on modern climate change and the glaciers that are melting today, to find out more about how it will affect

us in the future. The fact that the ice sheets in Greenland and Antarctica are now melting rapidly also gives us new insights into how ice sheets affect the landscape. Researchers can study the processes in real time, giving useful information about behaviour of glaciers in the past. In 2016, the Nordic Commission of Geodesy developed a new model of the land uplift in northern Europe, which combines modelling with actual measurements to ensure the results are as realistic as possible. One of the findings is that the boundary between where the land is sinking and where it is rising does not run through Skåne and Denmark but further south, in northern Germany. However, studies of the land uplift do not just provide knowledge about the past and, to a certain extent, the future.

The land uplift is an effect of movements in the magma beneath the crust, so it is also the most important process for determining the viscosity of the Earth's mantle. Consequently, the land uplift can also teach us about phenomena that are otherwise difficult to study in-situ and in real time.



Figure 28. At the Ritgrund lighthouse in the Kvarken Archipelago, someone has carved the average water levels for the years 1900 and 1952.

Photo: Malin Henriksson

3.2 The land uplift

When the ice sheet started to melt 18,000 years ago, the pressure on the Earth's crust decreased, and the land started to rise again. In total, the land rose 500 metres during the 8,000 years it took for the ice sheet to melt completely in the World Heritage area. Around 10,500 years ago, the area became completely ice-free, and since then the World Heritage area has risen 286 metres. The rate of land uplift was much faster at the start, when the ice first melted, probably more than 10 cm per year. Now it is approximately 9 mm per year.

When the ice had melted in the Nordic region, two-thirds of Finland and one-third of Sweden was under water. When the ice had melted in the High Coast area 10,500 years ago, only about the top 9 metres of Skuleberget would have been above water, appearing as two small islands. The first two small skerries that appeared when the ice melted have now been raised by the uplift, so that they now comprise some of the highest hill tops near the sea in the undulating Ångermanland landscape.

The highest coastline

The coastline that formed when the area became ice-free, and that today has been lifted far above the current sea level, is called the highest coastline. On Skuleberget in 2020, this was 286 metres above sea level. This is the highest coastline found anywhere in the world – a world record! In the High Coast, traces of the highest coastline have been found at various levels in the landscape.

At the time when the High Coast comprised skerries and islands, the entire low-lying Kvarken Archipelago was still far beneath the water – and would remain so for another 8,500 years. This is why there is no highest coastline in Kvarken – it lies much further inland, 231 metres above the sea. The highest coastline in Finland is not as high as that in the High Coast, because the rate of land uplift is slower with greater distance from the triangle High Coast – the Umeå region – Kvarken Archipelago.

One square kilometre of new land every year

The isostatic land uplift is one of the main reasons why the High Coast/Kvarken Archipelago was declared a World Heritage Site by UNESCO. Here, one of the processes that shaped and developed our Earth – and that is continuing to do so – can be clearly seen. When the Earth's crust rises, the sea becomes shallower, and higher sections of the seabed become reefs that develop into skerries and then into islands. The islands become bigger, and perhaps grow together with nearby islands, and eventually become part of the mainland. Over time, the total land area in the High Coast/Kvarken Archipelago World Heritage Site has increased.

Using maps and aerial photos, the Geological Survey of Finland has calculated that approximately one square kilometre of land rises out of the sea in the Kvarken Archipelago every year. This is caused by the land uplift together with sedimentation and overgrowth with vegetation. The calculation also takes into account the rising sea water level in the Baltic Sea (see Chapter 6. World Heritage Site: The future).

This means that shorelines can be displaced many metres, and rocks, shallows, and even islands can rise out of the sea in just a few decades. Where children have walked on a beach when they were small, there can now be forest when they are older, and boathouses built on the shoreline can, over time, lie tens of metres higher up on the shore.

In the High Coast, where some shorelines are steep and rocky, the postglacial land uplift does not have such noticeable effects in the form of new land areas. Here, the shoreline is displaced mainly vertically, so a boathouse can still be close to the water's edge even though the land uplift has raised it a metre or more above the water level. In total, an estimated 7 square kilometres of new land rises out of the sea every year along the Baltic Sea shores.

Infobox: Land sinking

At the same time as much of the Nordic region is slowly rising, the areas that lay beyond the edge of the ice sheet at its maximum extent are sinking. When the weight of the ice sheet pressed down the Earth's crust here in Fennoscandia, large amounts of magma were displaced sideways, forcing the crust beyond the edges of the ice upwards. An isostatic equilibrium process is also taking place in these areas, but the opposite of what is happening in the World Heritage area. This is why the Netherlands is sinking by 1 mm every year, while the seabed in the North Atlantic off the coast of Norway is sinking by 5 mm a year. According to calculations in 2016, the equilibrium line, where the land is neither rising nor sinking, is near the coasts of Germany and Poland. In principle, the whole of Sweden and Finland are rising, but the further away from the triangle High Coast – Umeå – Kvarken Archipelago, the smaller the uplift in millimetres per year.

The land uplift in different time periods

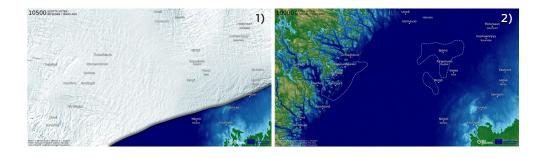


Figure 29. The maps show how the landscape has developed since the ice melted, and what it may look like in a thousand years' time. **1) 10,500 years ago:** At the end of the most recent ice age, the ice sheet is melting relatively quickly, and in just a few hundred years, it has melted away from both the Kvarken Archipelago and the High Coast. **2) 10,000 years ago:** The first small islands are already emerging from the sea in the High Coast, while the ice is still melting in the area. The Kvarken Archipelago is still at a depth of 260 metres.

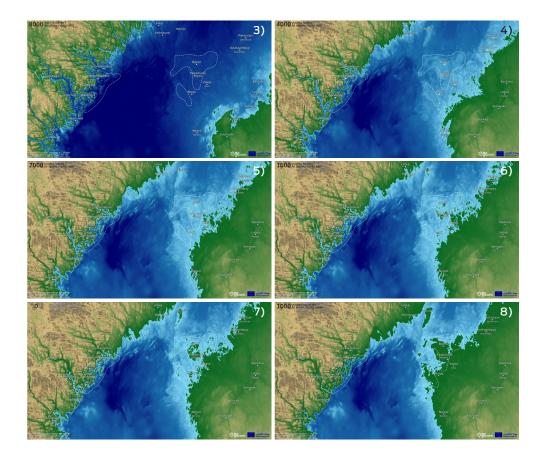


Figure 29.(cont) 3) 8,000 years ago: The Kvarken Archipelago is still under water, but the first people are starting to settle on the islands in the High Coast. They are hunters and not yet permanent settlers. Near the cave on Skuleberget they are building a camp near the beach. Today, there are traces of this camp 160 metres above sea level, the oldest known ancient relict in the World Heritage area. 4) 4,000 years ago: Approximately now, the first permanent settlers arrive in the sheltered bays of the High Coast. The area's Bronze Age burial grounds, which today are found 30-55 metres above sea level, are being built, and will be built over the next thousand years. In Finland, some land areas near the Kvarken Archipelago have emerged from the sea. 5) 2,000 years ago: Now the Iron Age longhouses and hillforts are being built in the High Coast. The lowest ancient relics from this time are today around 20 metres above the sea. In the Kvarken Archipelago, the first small islands are emerging from the sea. 6) 1,000 years ago: Now people are starting to arrive in the Kvarken Archipelago. The oldest ancient relicts are temporary seal hunting camps that are today 15 metres above the sea. 7) The present: Today, we find the world's highest coastline here in the World Heritage Site – at the top of Skuleberget, 286 metres above sea level. 8) 1,000 years in the future: If the land uplift continues to be greater than the rise in sea level, most island groups will become part of the mainland.

Diagram: ©2019 V. Perheentupa, V. Mäkinen & J. Oksanen Finnish Geospatial Research Institute FGI, NLS Data: HELCOM, Lantmäteriet, National Land Survey of Finland

3.3 Highest coastline and till-capped hills

The first shoreline that appeared during the final phases of the latest Ice Age is called the highest coastline. It is not so apparent everywhere, but on the till-capped hills the highest coastline can be seen in certain places as a clear boundary between a cap of till on the top and the smooth hillsides. The highest coastline in the world is 286 metres above sea level on Skuleberget.

When the ice sheet started to melt towards the end of the most recent ice age, this reduced the pressure on the Earth's crust, which started to rebound upwards again. Even before all the ice had melted, the land in the High Coast and Kvarken Archipelago had already risen approximately 500 metres, but the landscape was still pressed down compared with today. The very highest hilltops of today stuck out of the sea as small islands, but everything that today is lower than 281 metres above sea level was then under water.

The boundary between the forested hilltops and the wave-washed sides of the hills can still be seen clearly in many places today, over 10,000 years later. The postglacial highest level of the coast is generally called the highest coastline. It is thanks to the signs of the highest coastline in the landscape that, today, we can relatively accurately determine how great the land uplift has been in different places. In the High Coast, the highest coastline today is between 281 and 286 metres above sea level.



Figure 30. The world's highest coastline is at the top of Skuleberget, 286 metres above sea level.

Photo: Erik Engelro



Figure 31. The top of Skuleberget was probably the first two islands that appeared after the melting of the ice at the end of the last Ice Age. Above the highest coastline is a layer of till that the ice left. The sea was unable to wash away this till as it was above wave level.

Photo: Fabiola de Graaf

Forested till-capped hills

In the High Coast, there are 13 till-capped hills, with the highest coastline at different heights depending on when the hills were exposed by the melting ice. In contrast, in the Kvarken Archipelago, there is not a single till-capped hill because, when the ice melted there, all the low-lying area lay at least 260 metres below sea level.

When the ice sheet melted, it released a mass of rock material that had been frozen in the ice. This material, called till, is a mixture of large and small grain sizes, everything from silt, mud and sand to gravel, stones, rocks, and boulders mixed and deposited by the glacier.

Ice melts faster in water than over land. When the High Coast became ice-free at the end of the most recent ice age, the ice on the sea probably melted first. The hilltops that were above sea level, and the areas between the hilltops, were still covered with ice when the sea became ice-free. Then the ice between the hilltops melted, leaving just a very thin cover of ice on the hilltops. When ice on the hilltops melted, the rocks and sediment in the ice was deposited. The sea could not reach this material, so it was neither washed away nor sorted by the waves. However, further down the hillsides, the waves washed away most of the till to be redeposited out to sea. This is why the sides of the highest hills, but also the tops of the slightly lower hills, are washed bare, and largely comprise smooth bare rock.

The tops of the till-capped hills are covered with spruce forest, with blueberries and funnel chantarelle mushrooms growing in the undisturbed till. On the bare rock surfaces below the highest coastline, where there is hardly any soil to support plant life, the only vegetation that grows is small, hunched pines, heather, and lingonberries. These pines grow very slowly, but they are the oldest trees we have in the World Heritage Site, and can be over 500 years old. Over time, the finer till that was washed out into sea bays has been lifted by the land uplift. The former seabed is now covered with fertile fields, meadows, and forest.

How a till-capped hill is formed

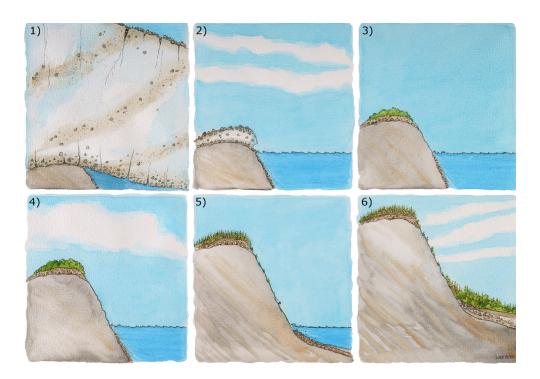


Figure 32.1) When the ice melted over the Bothnian Sea at the end of the last Ice Age, small islands were already protruding from the sea in the High Coast. 2) When the ice margin reached these islands, it melted faster around the islands than on top of them, leaving a cap of ice on the highest points. When this ice melted, it deposited all the till it had contained. 3) The waves then washed the till from the sides of the small islands, but did not reach the till left by the ice at the highest points. The line between the washed sides and the till cap on the tops marks the highest coastline. 4) Over time, the land uplift raised the small islands, which became higher and higher hilltops. At the same time, the sea washed the hillsides free of all fine-grained and loose material. 5) The till washed off the hill sides accumulated as layers of sediment on the seabed in the sheltered bays between the islands and in depressions on the seabed. 6) When the land uplift raised the seabed, crops could be planted on the nutrient-rich sediment in the valleys between the former islands. The maximum height of the highest coastline is now 286 metres above the sea.

Figure 33. Within the High Coast World Heritage area there are 13 till-capped hills. These hills are easily recognised because of the cap of spruce forest on the top, and the bare rocks below the highest coastline. The hill in the photo can be seen from Slåttdalsberget in the Skuleskogen National Park.



Photo: Tuija Warén

3.4 Beach deposits

In some places by the sea, large quantities of coarse material such as sand and gravel can accumulate and form beaches through the effects of waves and currents. These beaches are formed of material called wave-washed sediments.

When the ice sheet melted, it left large quantities of till, unsorted rock material in all grain sizes, both on land and on the seabed. Slowly but surely, the land uplift brings new parts of the seabed up to the surface. When the seabed approaches the water surface, it becomes exposed to the force of the waves and currents, and the till becomes wave-washed. The waves wash away the smaller particles, and transport them to sheltered positions on the seabed. The finest material, such as clay, mud, and silt, is transported furthest by the water before it is deposited. It sinks to the bottom at greater depth in the sea. After thousands of years, the land uplift has raised these deep areas out of the sea, and they now form today's fertile valleys. Coarser material, such as sand and gravel, is deposited closer to the shoreline, often in sloping areas.

On the Mjällomshalvön peninsula in the High Coast, there are many areas with large beach deposits. These can be tens of metres thick. These deposits are wave-washed sediments. On the beach deposits, despite them now lying far from the sea, typical beach traces can still be found, such as ancient beach ridges and beach cliffs.

3.5 Cobble fields

On exposed beaches, powerful waves can roll rocks and stones along the shoreline against each other, so that sharp edges and irregularities are worn away. Small ridges of these rounded cobble stones then occur along the beach, and are called cobble fields.

Waves and currents have transported away the finer material from the till. Left behind are the larger rocks and boulders that are too heavy for the waves to transport. These stones and boulders are rolled and rubbed against each other, becoming rounded by the wave action. The land uplift moves the rocks on the shoreline higher and higher in the terrain, and finally out of reach of the effects of the sea.

As long as more till is being lifted to the water surface, and as long as powerful waves can reach the material and sort and roll the rocks, cobble fields will continue to form. In some locations, only boulders nearly a metre in diameter remain, and all smaller material has been washed away, showing how powerful waves can be on unprotected beaches.

Large accumulations of cobble stones together form cobble fields, which in Finland are called 'devil's fields'. Some of the world's highest cobble fields, 270 metres above sea level, can be seen on the Högklinten and Mossaberget hills in the High Coast, while cobble fields are still being formed, for example on the shore at Bådamalen. In the High Coast, many cobble fields and other beach deposits are found in bays and valleys, where a lot of till has accumulated from the surrounding terrain.

Once the waves no longer reach the cobble fields, various lichens gradually start to grow on the stones. In this type of terrain, many crustose lichens, of which the map lichen is one of the most common, grow slowly but relatively steadily. By measuring the distribution of the lichen on the cobble fields, it is possible to determine roughly how long the cobble stones have been out of the range of the waves. It is often too difficult for other plants to take root among the stones on a cobble field, as the waves washed out the fine-grained material that is needed to provide firm support for plants and hold moisture and nutrients between the stones. Few animals can use the cobble fields as a habitat, but researchers in the Kvarken Archipelago have discovered, for example, the rare spider, Crustulina sticta. The cobble fields also seem to serve as a winter hibernation area for bats.

How cobble fields are formed

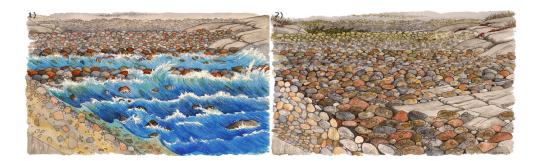


Figure 34.1) Cobble fields can be formed on beaches that are exposed to strong waves and currents and where there is a layer of till on a gently sloping seabed. At the water's edge, the waves roll the rocks against each other, smoothing and rounding them over time. The rounded stones are called cobble stones. **2)** As the land uplift raises more of the till-rich seabed to the surface, more cobble stones are formed. Waves push the stones into ridges. Where waves can no longer reach the stones, they gradually start to be covered by various lichens.



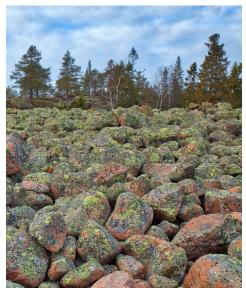


Figure 35. Cobble fields are formed on beaches, where waves and wind remove the gravel, sand, and finer material from the till, leaving only rocks and boulders. The waves rub the rocks against each other, so they become smoother and rounder. On a cobble field, it can sometimes be seen how the ice sheet carried different rock types far from their original locations.

Photo: Liselott Nyström Forsén

Figure 36. This cobble field at Högklinten in the High Coast lies at a height of 260 metres above the sea. The higher up in the landscape a cobble field is found, the older it is. This cobble field was formed only a few hundred years after the ice disappeared from the area.

Photo: Fabiola de Graaf

Beach ridges

Wave action or strong bottom currents can push the stones together to form beach ridges. They are made up of stones of roughly the same size, and can be seen as recurring ridges in the cobble fields. In the High Coast, these beach ridges can be seen in cobble fields high above the sea, where they were formed thousands of years ago. Beach ridges can also be formed in other beach deposits. Over time, the land uplift raises both cobble fields and beach ridges higher and higher in the terrain. Their height above the sea can help us calculate how long ago the shoreline was at this level.

How beach ridges are formed



Figure 37. On exposed beaches, where rocks, gravel and sand are present near the shoreline, waves, sea currents, and even wind, can pack the material into ridges. They can be seen as long strips along the beach, and may appear like a series of steps on sloping beaches. The land uplift gradually raises the ridges higher up from the sea, and when the coastline is displaced, a new ridge will form at the shoreline. In the lower areas between the ridges, green map lichen often grows, and sometimes crowberry, juniper, heather, and pine, while on the tops of the ridges, grey lichen grows, since it can tolerate rather drier conditions.



Figure 38. In Norrfällsviken in the High Coast, trees and brushwood grow in the depressions between the beach ridges.

Photo: Lena Lundqvist/SGU



Figure 39. On the large cobble field called Bådamalen in Norrfällsviken, new beach ridges will be constantly formed as long as there is coarse-grained material on the seabed near the shore and as long as the land continues to rise out of the sea. In areas where the waves can no longer reach the cobbles, the depressions are coloured green by map lichens, and the tops grey by other crustose lichens.

Photo: Erik Engelro

Infobox: Devil's fields

It is very difficult for plants to take root on a cobble field, because there is no suitable soil in which to grow. This also seems to be why, in Finland, these cobble fields are called devil's fields. The local word for cobble fields along the High Coast is 'mal', and this can be seen in place names such as Bådamalen.

Infobox: Stone labyrinths

Near cobble fields, ancient relicts and other traces of human activity can be seen, because these areas have not been overgrown by vegetation. The stones themselves in the cobble fields have also been a useful building material throughout history. One of the more mysterious relicts are the stone labyrinths found in the World Heritage area. Stone labyrinths are found in many places in the world and from different epochs, with the oldest being over 3,000 years old. The ones on the Baltic Sea coasts are thought to have been made by the Vikings. Here, they are usually made from rounded cobble stones that are placed on the ground in spirals to form a round or oval labyrinth. In the High Coast, there are beautiful stone labyrinths on the island of Storharaskär, and in the Kvarken Archipelago there are wellpreserved examples on the Valsörarna and Mickelsörarna island groups. In the Finnish-Swedish language, the labyrinths are called 'jungfrudanser' (virgin dances), and historians believe that the name derives from games in which a young man has to find his way to a young woman in the centre of the labyrinth. Sources in the High Coast suggest they may have been built to shut in the ghosts of drowned sailors, who people believed could haunt the coastal communities. The Finnish name 'jatulintarha' refers to the giants ('jatulin') that, according to legend, lived in the Nordic region in days gone by, and 'tarha' means field or farm. It is not known for certain why people built them, but they are believed to have magical or religious significance.



Figure 40. Beside this 'virgin dance' at Krokskär in the Kvarken Archipelago is a compass rose. Photo: Mikael Herrgård.

3.6 Tunnel caves

Tunnel caves are a typical land uplift feature, and over half of the world's 60 tunnel caves are found in the High Coast.

All land areas that have risen from the sea under the highest coastline of just over 280 metres have, at some time, been near the shoreline, where they were affected by the sea forces. Bedrock often contains cracks. If the crack is in a steep cliff exposed to the sea, powerful waves can start to erode the crack and hollow it out. Rocks and gravel, either thrown in by the waves or loosened from the walls and roof, accumulate in the crack. The rocks are thrown around by the waves and help to grind away the rock in the crack, deepening it until it becomes a deep cave.

Tunnel caves are also called onion caves

Tunnel caves are narrowest at the top, and become wider further down, because as more rocks accumulate on the floor of the cave they are used as grinding tools by the waves. At the same time, the land is still rising, so new parts of the crack are constantly being exposed to wave action, while the upper parts of the crack are lifted out of the range of the waves. If the land were not rising, the waves would simply hollow out the rock more and more until the entire cliff collapses. Over time, the land uplift raises the entire crack (which is now a cave) completely out of range of wave erosion, after which the cave usually retains its shape. Tunnel caves are also called onion caves because of their shape. Tunnel caves formed in this way are usually around 5 metres high and 10 metres deep.

This type of cave is unusual because their formation requires both land uplift and a steep cliff exposed to the waves. Tunnel caves of this type are only found in the Nordic region, and half of them are in the High Coast. Today, onion caves can be found, for example, at a height of 105 metres on the island of Mjältön. There are no onion caves in the Kvarken Archipelago because there are no steep cliffs exposed to the waves.

How a tunnel cave is formed

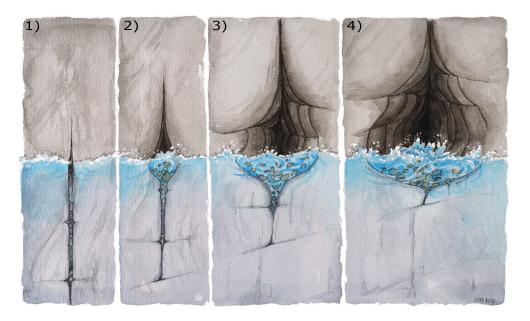


Figure 41. A tunnel cave can only form if there is a crack in a steep rock wall exposed to the waves on a land uplift coast. 1) At first, the crack is below water level. 2) When the land uplift raises the top part of the crack to water level, the waves can start to swirl around small stones and rocks that are loosened in the crack. 3) Over time, the stones and rocks deepen and widen the cave. As the land uplift raises the crack further up out of the sea, more is exposed to the force of the waves. 4) More rock material accumulates at the bottom of the crack, and the waves use this to wear away more of the walls. The base of the cave becomes wider and wider, and eventually becomes onion-shaped. When the entire crack has been lifted above water level, the hollowing out process ceases, and the cave dries out.



Figure 42. Tunnel caves, or onion caves as they are sometimes called, are usually around 5 metres high and 10 metres deep, but there are many variants. Inside the cave, the walls have been worn smooth by the sea and the abrasive effects of its load of rocks and stones.

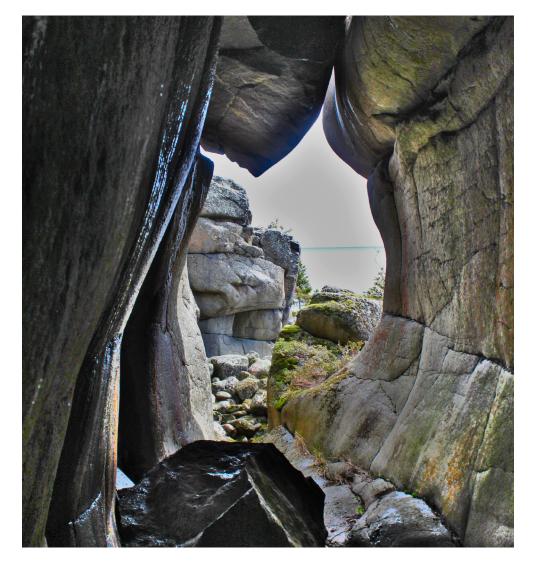


Figure 43. In this onion cave in the Rammberget Nature Reserve in the High Coast, parts of the roof have collapsed.

Photo: Liselott Nyström Forsén

3.7 Lagoons, flads, gloes and glo-lakes

At some stage after the most recent ice age, all the lakes and lagoons in the High Coast/Kvarken Archipelago World Heritage Site have been part of the sea. Over time, the postglacial land uplift has caused the sea bays to be gradually cut off from the sea.

One of the reasons why the High Coast/Kvarken Archipelago was declared a World Heritage Site is the constant change in the landscape. Every year, the land rises by nearly a centimetre, and 700 hectares of seabed emerge from the sea along the Baltic Sea shorelines. But the seabed is not flat – it is uneven, with hills, valleys, rocks, and moraine formations. When they are raised close to and above water level, these landscape formations appear as reefs, skerries and islands that grow in size as the land rises. At the same time, the intervening water areas shrink and become shallower as the seabed rises. In many parts of the World Heritage Site, the uplift causes sea bays to be gradually cut off from the sea, and these eventually develop into lagoons and wetlands.

Topography determines the process

This process varies slightly depending on the topography. On the steep and deep High Coast, the most common type of lake is found in large, deep basins with smooth rock walls. In the flat and shallow Kvarken Archipelago, the lagoons are commonly small and shallow, with shores of various moraine formations. They are formed in a process in which the main phases are called juvenile flad, flad, glo-flad, glo, and glo-lake. These shallow basins can also be formed in the High Coast, but are much less common there.

Dredging

Humans can also influence this process. Because of the land uplift, the shoreline is displaced outwards and downwards, so that over time harbours become too shallow or boat houses eventually lie too far from the water's edge. Another effect is that the passage between two islands becomes too shallow for boats. Previous generations have been forced to move harbours and boat passages, for example by building a new harbour further out near deeper water, but today both harbour basins and navigable channels are often dredged to enable continued use.

In some flads and lagoons, the threshold, which would otherwise have eventually cut off the bay from the sea, is dredged. This disrupts the succession process because the water connection to the sea is kept open artificially. In Ostrobothnia, a fifth of the 1,942 juvenile flads, flads, glo-flads, gloes and glo-lakes have been dredged, and another fifth has also been affected by ditching. Road embankments can accelerate the process of bays being cut off from the sea and overgrown by vegetation, despite bridges and road drums. Today, we know how vitally important flads and gloes in particular are for fish reproduction, and some areas have been restored to recreate fish spawning grounds (see more in Chapter 4.3 A paradise for birds and fish).

Land uplift reflected in placenames

The land uplift also has cultural manifestations in the High Coast and Kvarken Archipelago. Many placenames describe what a place looked like earlier. Everything from names of villages and farms to forest areas or fields can end in words such as *-viken* (bay or inlet), *-holmen* (islet), *-fjärden* (inlet), *-fladan* (flad) or *-ön* (island). In the middle of the forest in the Kvarken Archipelago, there are hills called Sandön or Gubbgrundet (*grund* = shallows), fields called Laxviken (*lax* = salmon) or Backfladan, and boggy areas called Trångsund (*trång* = narrow, *sund* = sound or strait) or Gammelgloet (*gammal* = old, *glo* = glo). In the High Coast, placenames that include Ön and Näs (peninsula) are common, despite the places now being on the mainland, and many isolated basins that are now lakes have names from earlier stages in their development, such as Järestaviken and Vågsfjärden. By looking at historical maps showing the shoreline, it is possible to see when the name corresponded to its landscape feature, thereby giving an indication of how old the name can be.



Figure 44. If the land uplift continues to be greater than the rise in sea level, Kråknäsfjärden will eventually be completely cut off from the sea and become a lagoon, which has already happened with Svarttjärnen (to the right in the photo). Holmen outside Häggvik would thereby grow to become part of the mainland.

Photo: Erik Engelro

3.7.1 Flads, gloes and glo-lakes in the Kvarken Archipelago

From the air, the Kvarken Archipelago looks like a conglomeration of islands, skerries and reefs. The islands often form island groups because of the different moraine formations created by the ice sheet. Over time, these can grow together and form bays and peninsulas. Because of the different moraine formations, a bay can often have a moraine ridge at its entrance. This is slowly raised to the water

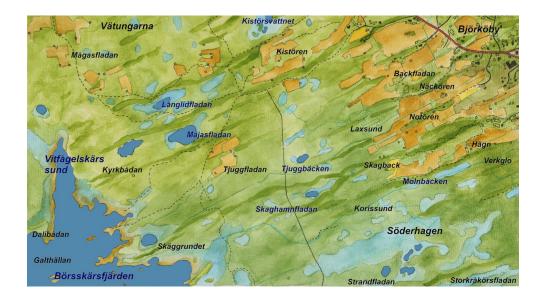


Figure 45. In the land uplift area, placenames can often reveal that the appearance of the landscape was previously different. The map shows the area around Björköby, where farmland can have names including the word 'flad' and places like Laxsund can lie in the middle of the forest. In the High Coast, names of lakes and hills containing the words 'fjärd' and 'ö' are common instead.

surface, forming a kind of threshold against the sea. The higher the threshold is raised, the more the bay is cut off, until it becomes a shallow lagoon, which in turn often becomes filled with sediment and overgrown with vegetation over time.

The first stage of this process is called a juvenile flad. At the entrance to the bay is an underwater threshold, for example a De Geer or ribbed moraine, but this has little effect on the water exchange between the bay and the sea.

In the next stage, the flad, the underwater threshold has been lifted so far that it limits the water exchange with the sea at low water level. However, even at low water levels, the threshold still prevents the flad from emptying and drying out. While the flad continues to rise because of the land uplift, it is gradually surrounded by dry land. The flads are generally only about a metre deep on average, so they often freeze during the winter.

The next stage is the glo-flad, which occurs when the bay has risen so much that the threshold, at normal sea water level, cuts off the bay from the sea. There is little water exchange with the sea. The threshold allows the water in the juvenile flad, flad, and glo-flad stages to warm up in the spring considerably faster than the sea, and to remain warmer during the summer half year. Spring-spawning fish such as perch and trout can still swim up over low parts of the threshold or along streams to breed in the relatively warm, nutrient-rich water (see more information in Chapter 4.3. A paradise for birds and fish).

In the fourth stage, when the threshold has risen so much that the bay only has contact with the sea at high water levels, it is called a glo. The glo still receives an inflow of brackish water when water levels are high or in storms. The glo often has a small stream or a lower area in the threshold where water flows either from the glo to the sea or vice versa, depending on the sea water level.

In the fifth stage, the glo-lake has lost all contact with the sea. The glo-lake is a lagoon that does not receive any brackish water inflow even at high water levels, so the water level in the lake is constant. Rain and runoff from the surrounding land increases the freshwater content of the glo-lake.

From juvenile flad to glo-lake



Figure 46. 1) Juvenile flad: The middle of the illustration shows how a moraine ridge can be seen as a threshold under the surface at the mouth of the bay. However, this does not affect the water exchange in the juvenile flad. 2) Flad: The land uplift has caused the moraine ridge at the mouth of the flad to rise so much that it partially limits the water exchange with the sea at normal sea level. It also prevents water discharging to the sea at low water level.

3) Glo-flad: The moraine ridge is now at the same level as the water level at normal sea level, and water exchange only takes place when sea levels are high. 4) Glo: The land has risen so much that the moraine ridge is above the water at normal sea level. The glo can only receive an inflow of seawater during storms and extremely high water levels through the otherwise dried stream. In the fifth stage, all contact with the sea has been lost, and a lagoon is formed, called a glo-lake.

A pearl band of lakes

Juvenile flads, flads, glo-flads, gloes and glo-lakes are often found together, sometimes as a series of lakes where the outer one still has contact with the sea. This is because the moraine formations can have a certain regularity in the landscape, for example the cluster of De Geer moraines in the Björkö archipelago. This often means that a new flad is formed outside the earlier flad, which by now has developed into a glo.

After a while, the glo-lake develops through various stages of wetland and becomes overgrown. This is why damp coastal groves, marshes, mires, and bogs are common in the Kvarken Archipelago, but all of them are young. Shallow bays that do not have a threshold can also quickly turn into swamps, often accelerated by broad belts of reeds in which sediment accumulates between the reeds and roots, so that the water fills with sediment faster.





Figure 47. On Lappörarna island in the Kvarken Archipelago there is a remarkable chain of gloes and glo-lakes. Outside the youngest glo, there are more moraine ridges. If the land uplift continues to be greater than the rise in sea level, more flads will eventually be added to the chain.

Photo: Seppo Lammi

Figure 48. In the Kvarken Archipelago, a survey of flads and their various stages of succession found over 800 juvenile flads, flads, glo-flads and gloes. At the mouth of this flad at Stenskär in Kvarken archipelago, moraine ridges on the seabed are gradually being raised towards the surface because of the land uplift.

Photo: Metsähallitus Jaakko Haapamäki

3.7.2 Lakes in the High Coast

The topography in the High Coast differs from that in the Kvarken Archipelago, and the process by which the land uplift causes bays to lose contact with the sea also differs. The bays in the High Coast are usually much deeper and the height differences greater. The result is that bays that are cut off in the High Coast are often larger than those cut off in the Kvarken Archipelago, and they are not affected as strongly by storms and other temporary high water levels. When they lose contact with the sea, they are isolated rather more quickly from the effects of the sea than is the case in the flat landscape of the Kvarken Archipelago.

Flads, gloes and glo-lakes in the same system are also less common. However, there are many areas with a series of lakes and wetlands of various types in valleys where the lakes lie at different heights above sea level. In such areas, it is possible to follow how the land uplift has created lakes from the bays in a process lasting over thousands of years.

Infobox: Remnant species reveal the origin of the lakes

When the land rises and sea bays are cut off from the sea, certain marine species can be enclosed in the new lakes. Examples are shrimps, the four-horned sculpin, and the crustacean Sadurias entomon. Some of these species derive from long ago, when the Baltic Sea, in earlier stages, had contact with the Atlantic Ocean westwards, right across central Sweden and with the Arctic Ocean to the northeast. Read more about glacial relicts in Chapter 4.1. Some of the lagoons gradually become overgrown and develop into mires. If the common reed grows by a mire, this is a sign that the wetland was formerly a lake.



Figure 49. On the island of Mjältön it can be seen that, over time, the Baggviken bay will be cut off if the land uplift continues to be greater than the rise in sea level Many of the lakes that have already formed in the High Coast, here Baggtjärnen on Mjältön, are becoming overgrown and are slowly becoming mires.

Photo: Erik Engelro



Figure 50. Over time in the hilly landscape in the High Coast, bays can be cut off from the sea through the land uplift process. 1) Many of the bays are shaped like a basin, with a kind of threshold at the mouth. 2) When the land rises, the threshold will eventually shut off the bay's contact with the sea, and the bay will become a lake. **3-4**) Many of the isolated basins continue to become overgrown, and develop through different stages of wetland until, finally, forest can grow on them.

3.8 Ravines in sediment

n the valleys of the High Coast, ravines can be seen as long furrows in the terrain. They are often a steep V-shape, tens or even hundreds of metres long, 10-20 metres deep, and are usually branched. Ravine formation is a continual process. Many of the ravines and ravine systems here may have formed quite early in the land uplift process after the last Ice Age, when the rate of land uplift was high. Many of the High Coast ravines in silty and till soils are today overgrown with thick vegetation.

Silt and mud that was deposited on the seabed during and after the Ice Age accumulated in layers that can be several metres thick. The land uplift has caused these sediments to be lifted above the water surface. Soils that contain silt are sensitive to erosion, because they are made up of small particles that do not stick to each other. The soil has a weak structure and can absorb and hold a lot of water. At high water flows, the soil is converted from a solid material to a flowing slurry, which means that landslips can occur easily in silt soils. But these properties also create the conditions in which ravines can form.

Ravines are usually formed when there is a more concentrated outflow of groundwater. The more the land rises in relation to the water level in the Baltic Sea, the more the groundwater flows. When the groundwater washes away parts of the easily eroded silt soils, the ravine eats its way backwards inland, often forming a network of ravines. Other water flows, such as heavy rain or meltwater from snow and spring thaw, can then flow downwards into this low-lying area and reinforce the process. Ravines can also be formed when a stream cuts down through the loose soil layers. Erosion continues until the ravine meets the underlying layer of more stable soil, such as till or gravel. In the High Coast, the ravines contain, at least periodically, streams.

The ravines and ravine systems in the High Coast have been formed after the areas were lifted up from the sea by the land uplift. Today, many of them are high above sea level, in fact not far below the highest coastline, and probably started to form while the ice sheet was still melting. New ravines are also being formed in the silt soils that lie closer to the current sea level. Today, the older ravines are usually covered with a damp, lush spruce forest, with elements of deciduous trees, bracken, and herbs. In the Kvarken Archipelago, the silt soils are not sufficiently thick for ravines to form.



Figure 51. Small ravine with a stream in the bottom, Skuleskogen National Park, High Coast. Photo: Patrik Bylund



Figure 52. The land that rose out of the sea is washed by the waves, which wash out all the fine-grained sediment. The sediment of silt, mud, or sand sinks to the seabed in sheltered bays, and can form layers many metres thick. Over time, the land uplift lifts these sediments above the water level. Under the right conditions, running water from groundwater, storms or snow melt can hollow out long furrows in the layers of sediment, particularly in silt. When a ravine has started to form, the water continues to cut downwards into the sediment layers until it meets the underlying, erosion-resistant till. Ravines can also be branched, and where the areas of sediment are extensive, large networks of ravines can be formed. Access to moving surface water and nutrients means that the vegetation around the ravines is often lush, with large trees, bracken, and tall herbs.



Since the World Heritage area was covered by ice until only 10,500 years ago, the nature in the High Coast and Kvarken Archipelago is young compared with the rest of the world. In general terms, the nature in both World Heritage areas is quite similar, since they lie on approximately the same latitude and with the same content of brackish water. However, the land uplift and the topography create special conditions for different habitats, which can vary within just a few metres.

The Ice Age and the land uplift have influenced, and continue to influence, the nature in the World Heritage area to a high degree. All organisms in Sweden and Finland have migrated into the area in the past 10,000 years, i.e. since the most recent ice age. Consequently, the High Coast and Kvarken Archipelago are relatively poor in terms of species. The changing landscape also forces flora and fauna to adapt rapidly, particularly in the flat Kvarken Archipelago where the land uplift causes changes in shoreline habitats over just decades. In addition, many species with their origins in either saltwater or freshwater are forced to adapt to brackish water conditions. There are few endemic species, i.e. species that are only found here.

In both Kvarken and the High Coast, the climate is milder than further inland because of the moderating effect of the sea. In spring, the sea does cool the climate, but the sun warms the sea during the summer, keeping the climate warm far into the autumn. Particularly in the flat and shallow Kvarken Archipelago, the sun warms both the shallow water and the seabed more easily.

Topography significant for habitats

What clearly distinguishes the High Coast from the Kvarken Archipelago are the height differences, which can create significant local variations in climate and thereby different conditions for flora and fauna. The topography of the High Coast creates both sheltered, warm, south-facing slopes as well as bare, cold hilltops and north-facing slopes. Consequently, a number of plants that are more common in southerly latitudes, such as hazel and lime, can be found on south-facing slopes, while other plants adapted to mountain environments, such as tufted saxifrage and purple saxifrage, are found on the north-facing slopes. The topographic differences also mean that higher areas, such as the hills in Skuleskogen, receive considerably more precipitation than the flatter, lower areas in the High Coast and Kvarken.

The Kvarken Archipelago is very flat and low-lying, with the highest points barely 20 metres above sea level. However, the archipelago is extensive, with approximately 5,600 islands whose position and shape create different microclimates. For example, an island in the outer archipelago can have both bare and windswept shores facing north, but lush coastal forests and warm flads in sheltered bays with a southerly aspect. Furthermore, the land uplift exposes a lot of new land every year, giving different vegetation zones with different habitats on the low shores.



Figure 53. The early marsh orchid (Dactylorhiza incarnata) is one of the orchids in the High Coast. They grow on many of the mires that are calcareous because of the inflow of leachate from the shell gravel ridges.

Photo: Sigrid Sjösteen



Figure 54. Razorbills thrive at the outer edge of the Kvarken Archipelago. On the bare skerries, they build their nests in holes between the stones.

Photo: Pekka Mäkynen



Figure 55. In the shallow, warm flads in the Kvarken Archipelago, large meadows of underwater vegetation can spread and provide both shelter and nutrients to juvenile fish.

Photo: Metsähallitus Maija Haukkala

4.1 Ice Age relicts

Today, the Baltic Sea is the world's second largest brackish water sea, with flora and fauna from both saltwater and freshwater. However, it is difficult for pure saltwater and freshwater species to live here, which makes the sea relatively poor in species. After the Ice Age, the Baltic Sea passed through various stages of development, where the sea intermittently had contact with both the Atlantic Ocean in the west or southwest and the White Sea in the northeast. At those times, certain species of saltwater fish, crustaceans and mammals migrated to the area, and were stranded when the area became cut off from the oceans. Examples of species that have adapted to the brackish water in the Baltic Sea and that are still found here are the crustaceans *Monoporeia affinis* and *Saduria entomon*, the four-horned sculpin, and ringed seals. Many of these species can also be found in lakes in the High Coast, because these are former bays cut off from the sea by the land uplift.

One feature that the World Heritage areas in the High Coast and the Kvarken Archipelago have in common is the brackish seawater in the Baltic Sea, where the salt content is only 0.4-0.5%, compared with 3% in the large oceans. The inland sea that we today call the Baltic Sea passed through four different stages during and after the melting of the most recent ice sheet. The various stages have been named after the different shellfish that were common here during each period.

Stages in the development of the Baltic Sea

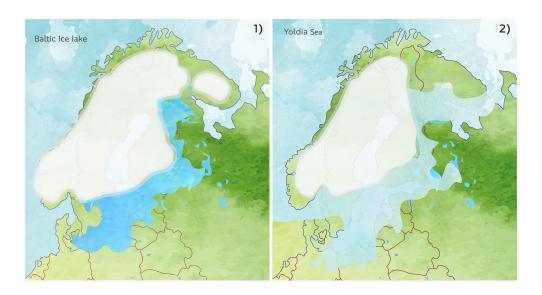
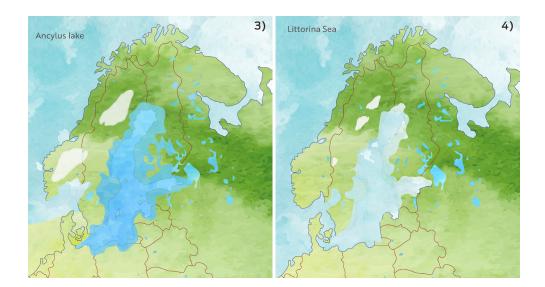


Figure 56. 1) The Baltic Ice Lake. Approximately 15,000-11,500 years ago. When the ice started to melt, the meltwater accumulated in a lake containing cold freshwater. Because a lot of water was still frozen in the large ice sheets, sea level was lower, and the sounds in Denmark were dry land. However, when the ice sheet melted away from southern Sweden, a passage opened up westwards at the southern end of today's Lake Vänern, and the freshwater could flow out from the lake via a 25-metre waterfall. In just a few years, the water level in the Baltic Ice Lake fell to the same level as that in the North Sea. This enormous emptying of the Baltic Ice Lake exposed much of the seabed, and a continuous land mass was formed from southern Sweden, over the whole of Denmark, and down to Germany.

2) Yoldia Sea 11,500-10,800 years ago. When the water level in the Baltic Ice Lake fell, saltwater could flow in from the North Sea, and the former ice lake became a cold sea of brackish water. At the same time, the Yoldia Sea became connected to the present White Sea in the northeast, which meant that more saltwater could enter, and saltwater organisms from the Arctic Ocean could migrate into the area. Eventually, the land uplift closed both the sound across central Sweden and the one to the White Sea. The High Coast and the Kvarken Archipelago were still under the ice sheet.



- **3)** The Ancylus Lake. 10,800-9,800 years ago. The sounds across central Sweden and Finland were now closed, and once again a lake was formed, but now containing warmer freshwater. A few centuries into this stage in the development of the Baltic Sea, the edge of the ice sheet reached the Kvarken Archipelago and then the High Coast. The ice sheet now melted, at such a rate that the water level in the southern part of the Ancylus Lake rose by 5-10 cm per year, which was faster than the rate of land uplift in Denmark. Finally, an outlet developed south of Sweden, probably over the Danish sounds. The water levels in the lake fell once again, and sea water could flow in.
- 4) The Littorina Sea. 9,800-3,000 years ago. More and more saltwater could flow in through the sounds in Denmark, because the land there was still sinking after being forced up outside the edge of the ice sheet. For a while, the climate was warmer than it is today, so an inland sea was formed, containing warmer brackish water than we have in the Baltic Sea today. It was mainly during this period that the mussels lived, whose shells are now found in the shell gravel ridges in the High Coast. Around 3,000 years ago, what we now call the Baltic Sea was formed, a sea containing cool brackish water. The stage from 3,000 years ago until the present is also called the Limnaea Sea. The first islands in the Kvarken Archipelago started to emerge from the sea about 2,000 years ago.

Ice-age relicts came to the Baltic Sea at early stages

The species that migrated into the Baltic Sea during the earlier stages of its development are called ice-age relicts. They are also called Arctic Ocean relicts and glacial relicts. They usually live in Arctic Ocean areas, and their continued presence here shows that the Baltic Sea, in earlier stages of development, had contact with the Arctic Ocean via the White Sea to the north. To survive here, the species have had to adapt to the lower salt content and the warmer water. We now look at four of these species in more detail.

Monoporeia affinis

Monoporeia affinis is found in the Baltic Sea, the Arctic Ocean, and lakes in the Nordic region. Monoporeia affinis are small, yellowish crustaceans that grow to about one-cm long and live for two to four years. Monoporeia affinis live in soft seabeds in large shoals, commonly a hundred to thousands of individuals per square metre, sometimes up to 20,000 in a shoal.



Figure 57. *Monoporeia affinis.* Illustration: Sarelika

Monoporeia affinis are important for mixing the sediment on the seabed and adding oxygen (bioturbation) and they eat phytoplankton and decomposed biomass. In turn, Monoporeia affinis becomes food for animals such as Saduria entomon. Monoporeia affinis can also be found in lakes below the highest coastline, indicating that these lakes must have had contact with the Baltic Sea before they were cut off by the land uplift. In recent decades, the oxygen content in the Baltic Sea has fallen. This is unfavourable for the Monoporeia affinis which, like most other crustaceans, is sensitive to low oxygen concentrations. The numbers of Monoporeia affinis are an indicator of the biological health of the Baltic Sea.

Another new threat to the *Monoporeia affinis* are the invasive sea brush worms from the *Marenzelleria* family. They entered the Baltic Sea in ballast water, and have now completely displaced the Monoporeia affinis as the most common species on soft seabeds.

Saduria entomon

Saduria entomon is a crustacean, a member of the isopoda order. It is found in the Arctic Ocean, and is common in deeper water in the Baltic Sea, but has been found in around ten Swedish lakes below the highest coastline. This is another indicator that the lakes must have had contact with the Baltic Sea before they were cut off by the land uplift. Saduria entomon is grey or grey-brown, and grows to up to 9 cm long. It has a flattened, oval body, with a pointed and triangular abdominal plate. Its food consists of other, smaller creatures scavenged from the seabed and becomes, in turn, food for animals such as grey seals, flounder, and small pike.



Figure 58. *Saduria entomon.*Photo: Metsähallitus Essi Keskinen



Figure 59. Ringed seal (*Pusa hispida*). Photo: Pekka Mäkynen

Ringed seal

The ringed seal (*Pusa hispida*) has typical, ring-shaped markings in its

fur. The seal is found throughout the Arctic area, but entered the Baltic Sea when the Yoldia Sea had contact with the White Sea approximately 10,000 years ago. The Saimaa ringed seal, which is found in Finland, and the Ladoga ringed seal in Russia are really ringed seals that were enclosed in the large bays that became lakes because of the land uplift. Now the ringed seal is also a relict here in the Gulf of Bothnia, Kvarken, and the Bothnian Sea. The ringed seal and the grey seal have been hunted for as long as people have lived here. It is believed that in the 19th century there were several hundred thousand ringed seals in the Gulf of Bothnia. However, when people started to hunt with rifles, the number of ringed seals fell considerably, and in the latter part of the 20th century the population fell even more because of environmental toxins. In recent years, the number of ringed seals has risen again and, today, a certain amount of protective hunting is permitted in both Sweden and Finland. However, climate change will pose a direct threat to the ringed seal, because it is dependent on thick winter ice for giving birth to their puppies.

Four-horned sculpin

The four-horned sculpin (Myoxocephalus quadricornis) is a member of the Cottidae family in the order Scorpaeniformes. It lives in fresh-, brackish, and saltwater. On the head of the brackish and saltwater types are four yellowish bony protuberances, hence the name. The four-horned sculpin is found in the sea and deep lakes, from shallow waters to depths of up to 100 metres. They swim deeper in the summer. The four-horned



Figure 60. Four-horned sculpin (*Myoxocephalus quadricornis*).

Photo: Anna-Lena Granlund

sculpin can be up to 40 cm long in Europe and 60 cm in North America, but in freshwater they are rarely more than 10 cm long.

They are found in deep lakes below the highest coastline in the High Coast, which indicates that the lakes were once sea bays, and the presence of the four-horned sculpin in these lakes is further evidence of the land uplift. The four-horned sculpin's food consists of epifauna and fish, and they can live for up to 14 years. The four-horned sculpin can make a growling sound, for example when males are fighting over territory.

4.2 Land uplift forest

When new land emerges from the sea because of the land uplift, it is the first time since before the most recent ice age that terrestrial plants can become established on these sites. This process, known as primary succession, is still taking place in the Kvarken Archipelago and the High Coast. In parts of the World Heritage area, it can be said that primary forest is being born.

In the Kvarken Archipelago, much of the forest can be classified as succession forest. This reflects the successive stages of forest that develop on the new land that has emerged from the sea. The first stage, nearest the shoreline, is a strip of alder. The next stage comprises deciduous forest dominated by birch, which finally develops into spruce forest in most areas.

Plant succession

When terrestrial vegetation starts to become established on the newly exposed land, a process called succession usually takes place, where different plants colonise the rising land in a particular order. The width of these vegetation zones depends on how flat the land is. In the flat Kvarken Archipelago the different zones can be several metres wide, even tens of metres, but in the steep High Coast the zones are generally much narrower and therefore less distinct.

Closest to the shoreline, species that can tolerate salt, wetness, and nutrient-poor soil become established, but they cannot tolerate much competition from other species. As the land rises, the shoreline is displaced outwards, and when a strip of land is lifted out of reach of the sea water, new species will start to colonise the area. The zone containing plants that tolerate salt, wetness, and nutrient-poor soil is constantly shifted outwards as the shoreline moves, because they cannot compete with the new species in their earlier growth site.

Typical stages of shore succession in the Kvarken Archipelago





Figure 61. 1) In shallow water, plants that can tolerate growing in brackish water can take root and spread easily as they do not require many nutrients. Examples are common reed, saltmarsh rush, slender spike-rush, and reed canary grass. Closest to the waterline, plants grow that can tolerate standing temporarily with their roots in brackish water at high water levels and storms. Examples include grass of Parnassus and red fescue. 2) On the shore meadow, many colourful herbs grow, such as purple loosestrife, beech speedwell, and Euphrasia bottnica. Further up the shore, taller herbs grow, such as meadowsweet, common tansy, and common valerian. Along with these, sea buckthorn bushes thrive, because they are tolerant but need light and space. 3) On many of the shores in the Kvarken Archipelago, a strip of alder grows before the birch forest takes over. Rowan and bird cherry can also grow among the birches. If the ground has been grazed by cattle, herbs such as lily-of-the-valley and various grass types dominate, but otherwise the ground is usually covered by blueberry brushwood. 4) The final coloniser is the spruce, and the ground vegetation in the spruce forest is usually dominated by blueberry and lingonberry brushwood, with elements of, for example, sorrel, chickweed wintergreen, and May lily.

Succession varies on different shores

Up the shore, the different succession zones can vary, depending on the nature of the ground surface. On exposed, very rocky or cliffed shores, and on islands in the outer archipelago, plants have more difficulty in taking root and obtaining sufficient nutrients. The shore vegetation is also more affected by differences in water level, wind, wave washing, and ice. Consequently, such shores have many fewer species than shores in sheltered bays or in the inner archipelago. Rocky shores are perhaps the most inhospitable, and only a few species can survive, such as stonecrop, raspberry and *Deschampsia bottnica*, while sandy shores favour other species, such as sea sandwort and wild rye. In the High Coast there is a greater variation of shore types than in the Kvarken Archipelago, and rocky and sandy shores are common.

Most common succession in the Kvarken Archipelago

Much of the Kvarken Archipelago follows the same pattern of succession. The gently sloping, shallow shores are often drowned temporarily by high water levels, and broad belts of reeds are common closest to the water's edge. This is succeeded by a strip of shore meadow, with species such as saltmarsh rush, slender spike-rush, and reed canary-grass. Slightly further up, the shore meadow or the stone shore is often colourful during the summer, since grass of Parnassus, crow vetch, loosestrife, meadowsweet, tansy, and beach speedwell thrive in this zone. A common sight in the Kvarken Archipelago is sea buckthorn bushes, which usually grow between the shore meadow and the strip of grey or black alder, which appear as the next zone. Both alder and sea buckthorn can withstand the salt and windy shores, and bind nitrogen in the soil. Sea buckthorn was also one of the first bush plants that colonised from the south in Sweden and Finland after the most recent ice age. Where alder starts to colonise over the lower shore vegetation, the succession forest according to the definition begins.

Figure 62. In summer, the low-lying shore meadows in the outer Kvarken Archipelago are covered with flowering herbs.

Photo: Seppo Lammi



Beyond the alder strip, where the land is no longer reached by the sea, the birch forest takes over, often with elements of rowan, bird cherry, juniper, and willow. In the coastal groves, sorrel, wood horsetail, bracken and various grasses thrive. The birch trees usually grow sparsely and are gnarled, because nutrient-rich soil is rare at this stage. In Kvarken's birch forests, large areas glow brightly in June when the lily-of-the-valley blooms. Finally, it is the turn of the spruce trees to dominate and thicken the forest. In the spruce forest, the undergrowth usually comprises brushwood such as blueberries, crowberries, and lingonberries. In the Kvarken Archipelago, there are few pines, which only grow on drier soils on some of the larger islands.

Plant succession on the rocky shores of the High Coast

Because the High Coast shores are more varied than those in the Kvarken Archipelago, the plant succession can vary greatly between different places. On the low-lying stony beaches, the succession follows largely the same pattern as in the Kvarken Archipelago, apart from the absence of sea buckthorn. However, many of the High Coast shores consist of wave-washed steep cliffs with small sand beaches in between, and here the succession is different.

On the rocks closest to the water, the only organisms are crustose lichen, such as tar lichen, orange lichen, and map lichen. Organic material accumulates in the rock cracks, enabling tolerant species of grass and brushwood to take root. Examples of plants in these zones are loosestrife, common stonecrop, wavy hair grass, crowberry, heather and, in Ångermanland, the endemic northern rock-cress. In sheltered positions far from the water, the crustose lichens cannot compete with bush lichens and, eventually, mosses. When the rocks have risen sufficiently far out of the water, and more organic material has accumulated, larger vascular plants become established, and eventually the sparse rock vegetation develops into pine forest. The field layer mainly comprises brushwood such as crowberry, lingonberry,

Figure 63. Northern rock-cress (Cardaminopsis petraea) is endemic in Ångermanland and grows here only on gravelly seashores and on cliffs and rocks near the beach.

Photo: Anna Carlemalm



heather, and blueberry, along with herbs such as cow wheat and twinflower. In the damper depressions, which were once tidal pools, spruce often grows. On the sandy shores, the vegetation is often sparse, mainly comprising reeds, fen violet, wild rye, and sand seawort. It is not until several metres from the water that the alder strip starts to develop, and then eventually becomes spruce forest.

4.3 Kvarken Archipelago – abundant bird life

The land uplift landscape in the Kvarken Archipelago is ideal for birds. There is a plentiful supply of food, partly because of the warm flads and glo-lakes that produce enormous quantities of fish fry and insects. The 5,600 islands offer many different types of habitats, and the area is a popular resting place for migrating birds.

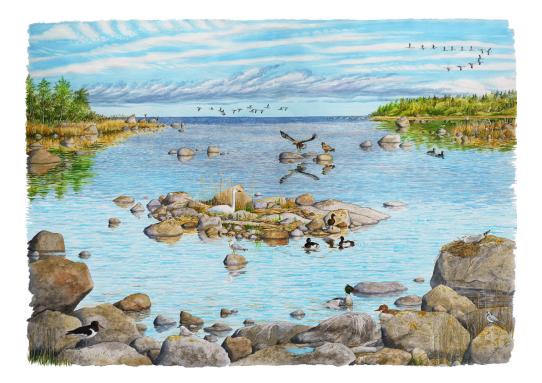


Figure 64. The varied landscape in the Kvarken Archipelago offers suitable habitats for many bird species. Most of the birds, such as the common crane (*Grus grus*), the Arctic tern (*Sterna paradisea*), the red-breasted merganser (*Mergus serrator*), the wagtail (*Motacilla alba*) and the whooper swan (*Cygnus cygnus*), return every year to breed in the archipelago, which teems with fish. Many sea eagles (*Haliaeetus albicilla*) are only seen here during the breeding period, but older eagles can remain in the archipelago all year round.

A paradise for breeding birds

The flat landscape and the constant land uplift create many types of nature in the Kvarken Archipelago. In just a few hundred metres, sometimes only tens of metres, the nature can vary from lush coastal groves in sheltered bays to bare heaths on exposed skerries. There is plenty of space for breeding and various habitats to suit different bird species. Many species thrive because of the rocky nature of the Kvarken Archipelago. For example, razorbills and black guillemots breed in holes between rocks, seagulls often build their nests on large rocks out in the water, and terns prefer the rocky skerries that, as yet, have only been colonised by grass. It has recently been confirmed that, in the winter, bats hibernate deep in the stones in the cobble fields of the outer archipelago.

The area is also an ideal resting place for migrating birds. Every spring and autumn, enormous numbers of birds pass the biological station on the Valsörarna islands on their journey over the Baltic Sea's narrowest passage. Particularly in April and May, the Kvarken Archipelago is filled with loons, ducks, swans, and cranes. Many of these species remain in the daytime to feed on the Eastern Bothnian fields, for example in the meteorite crater Söderfjärden, but they prefer to spend the night out in the sheltered skerries in the Kvarken Archipelago. An increasing number of whooper swans and cranes are also breeding in the Kvarken Archipelago, and many sea eagles remain here all year round.



Figure 65. In the Kvarken Archipelago, migrating cranes can rest safely overnight in the shallow bays.

Photo: Eero Murtomäki

4.4 Shell gravel ridges, south-facing slopes, and alpine flora in the High Coast

The High Coast has many varied habitats, and there are many different microclimates in a small area. This is mainly due to the topography, as the steep hills and rocks comprise both warm, sheltered parts and cold, windswept areas. This makes the High Coast the boundary for both the most northerly range for some species, and the most southerly limit for other species. In addition, the land uplift in particular has created a number of conditions for different habitats, such as shell gravel ridges and lakes at different heights.

Shell gravel ridges provide nutrients for orchids

Botanists in the High Coast have the land uplift to thank for the growth of the fairy slipper and other orchids in the World Heritage Site. Around 4,000-6,000 years ago, the climate here was temporarily warmer, and the salt content in the then Littorina Sea was considerably higher than it is in today's Baltic Sea. Under these conditions, mussels and snails thrived, forming colonies on the gently sloping underwater rock and the clay seabed outside the High Coast. Species here at that time included large populations of the common mussel, the Baltic bivalve, and the cockle. When the animals died, the shells were sorted by the waves, accumulating in thick bluish-purple piles in the depressions and on the lee side of rocks. When the rocks were then lifted out of the sea, the ridges were buried under metres of sand, gravel, and stone sediments. Today, the banks can be found 6-75 metres above sea level. Because the sediment has low water-holding capacity, rain and meltwater run straight through, leaching the calcium that the mussel shells are made of. Calcium then concentrates in the groundwater that seeps out in mires between the hills, creating conditions for plants that thrive on calcareous soils, such as the early-marsh orchid, the fairy slipper, the ghost orchid, broad-leaved cottongrass, cotton deergrass, white adder's tongue, and the lady's slipper orchid. In addition, many calciphilous moss and sedge species can be found in the mires whose water is influenced by shell sediment.

In the Kvarken Archipelago there are no shell gravel ridges, mainly because the area is so low and flat. Shell sediment is generally found higher up in the terrain, so the shell gravel ridges are found much further inland in Finland.

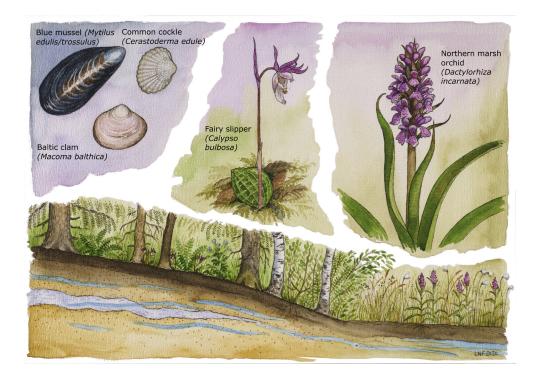


Figure 66. While the Baltic Sea underwent several development stages after the most recent ice age, mussels and snails lived on the steep rock walls below the water surface. When they died, their shells sank to the seabed, and the currents caused them to accumulate in thick banks. The land uplift then lifted these up in the terrain, where they can be seen today in layers up to several decimetres thick, as a pale bluish-purple layer of shell gravel embedded in layers of fine-grained sediment. Running water leaches the calcium out of the shell gravel, and washes it into streams and mires. In the calcium-rich soil layers, various orchids and other calciphilous plants thrive.

South-facing slopes capture the heat

The rocky slopes in the High Coast that face south, east, and west work like solar collectors, and provide shelter from the cold northerly wind. In addition, heat from the sun is stored in the steep rock walls during the day, and radiates out to the surroundings at night. These south-facing slopes provide a microclimate that is warmer than that in the surroundings, with a higher mean temperature and a shorter frost period. This means that species that are normally found further south can survive on these south-facing slopes. Plants that grow here are relicts from the period 4,000-6,000 years ago when the climate was warmer. This is why lime, hazel, maple, elm, spring pea, and spleenwort can be found in the High Coast. In combination with the old seabed raised by the land uplift into valleys and slopes, vegetation in these south-facing areas can be lush. For example, spruce increment expressed in cubic metres of wood can be more than double the rate of growth in Ångermanland generally.

Figure 67. In the shelter of the warm south-facing hills, species that normally grow much further south can be seen, such as this spring pea (Lathyrus vernus).

Photo: Fabiola de Graaf



Arctic flora of the hills and rock surfaces

On the wave-washed rock plateaus and hillsides below the highest coastline in the High Coast, there is hardly any soil for plants to grow in, and vegetation is sparse. Here, species can be found that occur more commonly in mountain areas much further west and north. For example, purple saxifrage and lady's mantle are alpine relicts, species left in the High Coast since the climate was almost alpine during a period after the last Ice Age. The alpine relicts grow on shaded, north-facing rock walls and in ravines high up in the landscape. An exception to this is the tufted saxifrage, which grows in cracks in almost vertical rock walls all the way down to sea level. On the thin-soiled rock surfaces, pines are the most common vegetation type, often low and gnarly, all the way up to 280 metres above the sea. Many of them are several hundred years old, with the oldest over 500 years old. These areas have seldom or never been subjected to forestry, because the small, gnarled pines lack economic value.

Figure 68. On the north sides of the hills, the local climate is colder than that of the surroundings, and plants that are otherwise found in mountain areas grow, such as this Alpine catchfly (Lychnis alpina L.).

Photo: Patrik Bylund



4.5 Below the water surface

The land uplift landscape shaped by the Ice Age continues under the water surface in the High Coast/Kvarken Archipelago World Heritage Site. Here too, the Finnish and Swedish parts of the World Heritage area differ, despite lying on the same latitude and both consisting mainly of coast and archipelago along the brackish Baltic Sea.

Much of the landscape shaped by the ice sheet still lies hidden under the surface of the Baltic Sea. Geologists estimate, for example, that there are as many De Geer moraines in the sea in the Kvarken Archipelago as there are now on land. From a depth of two metres downwards, the seabed is not affected by sea ice and waves.

Ability to adapt to brackish water crucial

Our inland sea is unique. It consists of brackish water, a mixture of saltwater and freshwater. The Baltic Sea is affected by both the saltwater pulses that enter via the Danish sounds and the freshwater delivered by rivers. Because the Baltic Sea is a young sea, its species are also young. The species have their origins either in saltwater or in freshwater, so none of them live in conditions that are optimal for them in the World Heritage area.

Many of the marine species spread to the Baltic Sea after the most recent ice age. The freshwater species, the perch, and the saltwater species, the herring, can be found here. Certain species have adapted better than others from the saltier oceans to a more freshwater environment.

The species that once were able to adapt to a life at the absolute limit of what they can tolerate, are once again facing challenges, as climate change is affecting the Baltic Sea. We can already observe that the salt content in the Bothnian Sea has fallen by 0.5 parts per thousand since the 1970s. This is because of increased precipitation, increasing the inflow of freshwater from streams and rivers. According to climate change predictions, the salt content will continue to decrease in the next hundred years. This would force species with low tolerance to freshwater to move southwards or die out if they cannot adapt.

At the same time as the salt content is changing, the sea is also becoming

warmer. It has already been observed that the temperature of the surface water has increased by an average of 1.5 degrees in the past thirty years. A temperature change has also been observed in deeper water. Many of the species in our sea are adapted to cold water, and their habitats will be affected by the increasing temperature of the water. Small organisms are affected rapidly by temperature changes that affect the composition of phytoplankton and zooplankton communities. These small organisms are an important source of food for fish fry, and can therefore affect entire fish populations.

Sunlight and seabed material also exert an influence

All photosynthesising plants, including those under water, require sunlight to survive. How much sunlight reaches a certain site determines which and how many plants can live there. Here, the topographical differences between the High Coast and Kvarken Archipelago play a role. Similarly, the amount of moraine determines the type of seabed that dominates in the different areas.

The low-lying and gently sloping Kvarken Archipelago lies in the north of the Kvarken area, which extends as a shallow shelf between Vaasa and Umeå. In Kvarken, the maximum depth is only 25 metres. Here, large areas can have approximately the same depth, so extensive underwater meadows of similar species are common. For example, in the flads and gloes, the water is often clear and the bottom soft. As a result, the bottom can resemble a jungle because of the dense carpets of charophytes, pondweed, and water milfoil. The underwater plants are a sizeable carbon sink, and another advantage is that they bind the sediment particles from the water and stabilise the sediment on the seabed. Otherwise, particularly in the Kvarken Archipelago, the waves are continually washing sediment out of the moraine ridges as the land uplift raises the seabed to the surface.

The bays and archipelago in the High Coast are usually deep, and the sea offshore is up to 300 metres deep. Consequently, the underwater landscape there is often steep, and the water becomes deep relatively quickly. The seabed is usually hard, comprising rocks and stones, and the species that live there differ considerably from the flora and fauna on the soft seabeds. These rocky shores are suitable for many algae species that attach themselves to the rocks and form plant belts at different depths depending on their ability to utilise the decreasing sunlight. Common algae types are filamentous algae (0-1 metres deep), bladderwrack (1-5 metres deep), and red algae (5 metres and deeper). The different habitats create narrow strips in the High Coast, both on land and under water.

The marine vegetation must also adapt to the land uplift slowly raising the seabed, as on the land uplift shores. Many of the marine species are sessile (immobile), so they are not able to escape changes that occur in their environment. Furthermore, algae and plants only spread a short distance in the water, approximately 1 km, and fish usually stay within a radius of approximately 5 km, which means that their ability to adapt to sudden changes is poor.

Bladderwrack and common mussel key species in the High Coast

In the World Heritage area, two marine species occur that are crucial for the ecosystem. Bladderwrack, and its endemic relative the brown algae narrow wrack

Infobox: Bladderwrack

Bladderwrack (*Fucus vesiculosus*) is a type of brown algae that creates a living environment for many organisms, either as a habitat or directly as food. In one square metre of bladderwrack in the World Heritage area, there can be up to 9,000 individuals of invertebrate animals. In turn, these are food for many small fish, and therefore comprise the start of the food chain of the marine species. Storms can uproot tufts of bladderwrack and wash them up on land, where they form banks. They are characterised by the gasfilled bladders on the stems, which lift the heavy plants up to the light. But bladderwrack can also lack these bladders. Throughout time, seaweed has been used as fertiliser and a colouring agent. The presence of bladderwrack tells us a lot about the state of the sea, as it is sensitive to eutrophication and is dependent on sunlight. In areas with clear, clean water in the High Coast, bladderwrack has been found at depths of up to 14 metres.



Figure 69. Bladderwrack (Fucus vesiculosus) in Västernorrland. Photo: Lotta Nygård

Infobox: Common mussel

The small, blue-black shells of the common mussel (Mytilus edulis/ trossulus) can sometimes be found on the beaches of the World Heritage area. The shells are small, approximately 1-2 cm, because the common mussel lives here on the limit of its range. In the large oceans of the world, the common mussel can be up to 9 cm long. This crustacean is a filter feeder, obtaining its food from the water, so it is not dependent on sunlight. What it does require though is a hard surface on which to attach itself, and it is one of the fast-growing species in the Baltic Sea that is found deepest in the water, at depths of up to 20 metres.

The common mussel cannot tolerate water with a lower salt content than that in the World Heritage area. Furthermore, it seems that unique populations of common mussels that are the ones that survive here. Genetic studies show that, in the High Coast, approximately 40% of individuals are the species Mytulis edulis, 15% are Mytulis trossulus and 45% are hybrids between these two species. Further south in the Baltic Sea, the proportion of hybrids and pure M. trossulus individuals decreases. In Bohuslän on the west coast of Sweden, the ratio is 95% M. edulis and 5% hybrids.

The common mussel is the dominant species on hard seabeds and, in certain areas in the Baltic Sea, there can be up to 10,000 individuals in a square metre. On the shell of the common mussel, red algae can also be found, where enormous numbers of invertebrates can hide. The common mussel comprises the main food of the eider, which is completely dependent on the mussel for its survival, but flounder also feed on the common mussel. The common mussel is a highly effective water filter, and a single individual can filter an average of two litres of water an hour.



Figure 70. Common mussel (Mytilus edulis/trossulus). Photo: Metsähallitus Anu Riihimäki

(*Fucus radicans*), and the common mussel are some of the key species in the Baltic Sea. Key species are those species that are of absolute importance for the entire ecosystem and its survival. Without them, the entire ecosystem can collapse.

These species are found on hard seabeds, so occur mainly in the High Coast. They are not completely adapted to conditions with low salt content, which can be seen for example in their small size and because they are not found any further north than the World Heritage area. Their limit of tolerance for salt lies near Kvarken, and they do not occur in the Gulf of Bothnia. Narrow wrack is an algae type that is similar to bladderwrack, and it was only recently found to be a separate species. It is endemic for the Baltic Sea.

Kvarken Archipelago important for Baltic Sea fish stocks

It is primarily spring-spawning fish, such as perch and pike, that benefit from the underwater landscape created by the moraine formations in the Kvarken Archipelago. The shallow flads, in various stages of succession, and particularly the gloes in the outer archipelago, warm up faster in the spring than the surrounding sea. In June, the temperature difference between a glo and the sea can be as much as 10 degrees in the outer archipelago. This difference is because the shallow areas warm up much faster than the surrounding water masses, and because the water exchange with the cold sea is limited. For fish fry, there is already plenty of shelter and food in the warmer water, as an average of 40% of the water surface in a flad is covered by aqueous plants, and many insects find their way to the warm, calm water to breed. Researchers have calculated that, from a single glo, the Käringsund glo on the Valsörarna islands, approximately 100,000 perch fry swam out in one hour.

The perch lives its life in a relatively small area around the flad or glo in which it was born, and over 90% stay within a 10-kilometre radius, giving the flads great local significance. New studies suggest that vibrant populations of large predatory fish help to reduce the symptoms of euthrophication in the Baltic Sea, by keeping down the stickleback population. Eutrophication causes, for example, large-scale algae bloom along many of the Baltic Sea coastal areas, because the filamentous and single-celled algae receives a lot of nutrients. The quantity of algae is kept down by the insect larvae, zooplankton, and crustaceans that eat them. The stickleback feeds on these algae eaters, and if the stickleback numbers increase too much, this also increases the risk of large-scale and harmful algae bloom. Vibrant populations of predatory fish like the perch are important for controlling the stickleback populations. This reduces the predation pressure on the stickleback's prey, and the algae population can be kept down by grazing. This is why initiatives

have been launched to restore many of the flads and gloes that have been dredged or ditched, thereby restoring these important spawning grounds and increasing the number of predatory fish.

For more information about underwater species in the Kvarken Archipelago and the High Coast, see Chapter 3.6 Lagoons, flads, gloes and glo-lakes, Chapter 4.1 Ice Age relicts, and Chapter 6. High Coast/Kvarken Archipelago: The future.



Figure 71. In the shallow flads and gloes in the Kvarken Archipelago, underwater plants can form thick, dense carpets.

Photo: Metsähallitus Maija Haukkala



Figure 72. The warm flads and gloes in the Kvarken Archipelago are perfect nurseries for spring-spawning fish like the perch and the pike. This small pike can find both food and shelter in the rich underwater vegetation.

Photo: Metsähallitus Anniina Saarinen



There has been a cultural and economic bridge between Ostrobothnia and Västerbotten and, to a certain extent, Västernorrland, for many hundreds of years. The first permanent settlers in the Kvarken Archipelago are said to have moved in from Sweden. For a long time, Korsholm Castle in Ostrobothnia was the administrative centre for the entire northern part of the kingdom of Sweden (to which Finland belonged until 1809), and trade over Kvarken and the Bothnian Sea has always been important. In the 20th century, there was lively passenger traffic between, for example, Vaasa and Örnsköldsvik. Even today, many people have relatives on the other side of the Baltic Sea and the contacts are good. We now also share a transnational World Heritage Site.

Again, there are both differences and similarities between the two World Heritage areas. The High Coast's cultural history is much older than that of the Kvarken Archipelago, which stretches over only a thousand years. However, the areas have two things in common that have influenced their populations: closeness to the sea, and the land uplift. The sea has been an important source of food, but also people's main transport route, because it was easier to travel over water or the winter ice than through forests and across high land.

People pursue the fleeing shoreline

The land uplift has affected where people have chosen to live, and where to build their fishing villages and harbours. The bays that offered shelter for harbours and settlements have, over time, gradually become shallower and eventually cut off from the sea, forcing people to move both harbours and fishing villages further out towards deeper water. This applies to both Kvarken and the High Coast, but the topographical differences mean that the changes in the coastline occur at different rates. In the low-lying Kvarken Archipelago, the shoreline can be displaced by many metres even during a person's lifetime, but on the steep shores of the High Coast, it can take hundreds of years before the land uplift has any effect on boat transport. By looking up the slopes from the sea, it is possible to see traces of human activity; the higher a settlement is in the terrain, the older it probably is. In the Kvarken Archipelago the effect of the land uplift on settlements can be better seen from a bird's-eye perspective, as people were often forced to move longer distances to regain access to a deeper harbour and navigable fishing waters. For example, the harbour in the city of Vaasa has been moved several times since it was founded in 1606 - and after the fire in Vaasa in 1852, the new city was rebuilt closer to a deeper harbour.



Figure 73. A good example of a harbour that had to be moved because of the land uplift is that at Björköby in the Kvarken Archipelago. The old harbour is at Bodback (in the bottomright corner of the photo) beside what is now a shallow glo-lake, where the water level is kept constant artificially. The harbour at Svedjehamn (top-centre) is situated further out towards the sea and, for a long time, was a centre for fishing, trading, and shipping, but today it is too shallow for anything larger than leisure boats. Fishermen have been forced to build a new deep harbour at Vikarskat, another couple of kilometres to the northeast.

Photo: Seppo Lammi



Figure 74. On the low-lying coastal meadows in the Kvarken Archipelago, residents in the archipelago harvested grass, reeds, and foliage as winter fodder for their cattle. The hay was stored in barns on the shores of the bays and flads, so that in winter they could easily fetch it by crossing the ice by horse and cart. However, over time, the land uplift has moved the shoreline far from the barns, and today hay barns can be found beside marshes and deep in the forest.

Photo: Liselott Nyström Forsén

Small-scale farming and cattle

The land uplift has also affected where people could farm and engage in other activities on the two coasts. Nutrient-rich fine-grained sediment accumulated on the former seabed, and now offers fine soil for cultivation. In the High Coast most people have been farmers, with fields in the nutrient-rich valleys. The Kvarken Archipelago, however, is generally very stony and therefore difficult to cultivate, so the fields have been small, often lying between the moraine ridges. Consequently, in the Kvarken Archipelago, fishing and trading have been the main activities, and, earlier, seal hunting.

Farmers were able to keep cattle on coastal meadows and out on the islands. Particularly in the Kvarken Archipelago, the wide, shallow shores and overgrown bays provided the archipelago residents with plenty of fodder for their cattle, such as reeds, various coastal grasses, and foliage from young deciduous trees. The winter fodder was stored in hay barns next to sheltered bays, from which hay could be fetched by travelling over the winter ice by horse and cart. The remains of these barns can be found today, far from the shores, beside glo-lakes that are now overgrown. Over the centuries, sheep and young cattle in the Kvarken Archipelago have been moved to the islands during the summer. This affected the landscape and nature out in the archipelago, as the grazing of sheep and cows kept brushwood and bushes down, but favoured the growth of grass and herbs. This has promoted the biodiversity, and given many of the archipelago forests a park-like appearance. Even today, summer-grazing sheep and Highland cattle affect the ground vegetation on beaches and islands in the Björkö archipelago.

For hundreds of years, the Sami people have lived in both the High Coast and the Kvarken Archipelago. Kungsgården in Korsholm had Sami people who hunted seal in the 16th century. In the 18th century, there were 35 sea and coastal Sami families in Nordingrå, in addition to the more well-known nomadic mountain

Figure 75. The Trysunda fishing hamlet was founded in the 16th century by fishermen from Gävle. But the name is older than that. Approximately 1000 years ago, there were three sounds, as indicated by the name Trysunda. Today, because of the land uplift, there is only one sound left.

Photo: Erik Engelro



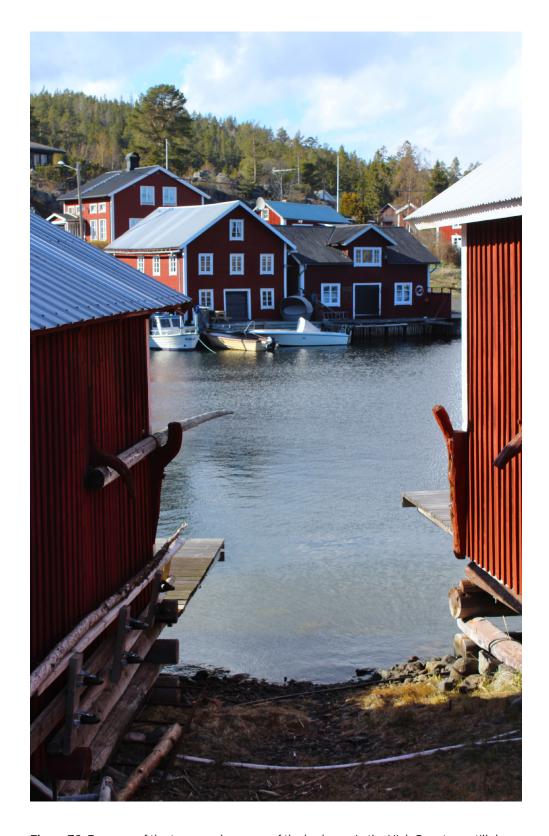


Figure 76. Because of the topography, many of the harbours in the High Coast are still deep. However, unlike the Kvarken Archipelago where the shoreline seems to creep outwards, in the High Coast it often seems to creep downwards. This can be seen clearly in the old fishing jetties in Bönhamn.

Photo: Liselott Nyström Forsén

Sami, who came down to the coast to collect winter fodder for their reindeer. Sami relicts are found in many places in the World Heritage Site, and many placenames indicate the Sami influence. An example is Lappudden by the Vågsfjärden water passage. As late as the 20th century, the Sami had reindeer out on the Ulvöarna islands.

5.1 Immigration after the Ice Age

The land uplift gives archaeologists, historians, and other interested persons a unique method for calculating the age of settlements along the entire Baltic Sea Coast. The rate of uplift is rapid in the World Heritage Site, so the method is more precise here.

The ice melted here 10,500 years ago, and the new ice-free land was an inhospitable, cold, wet tundra. A couple of thousand years later, the climate was warmer. The oldest ancient relicts found in the High Coast are at approximately 160 metres above sea level, corresponding to approximately 8,000 years ago. The Kvarken Archipelago lay under water until the start of our calendar, so the oldest relicts in the Kvarken Archipelago are situated only 15 metres above the sea, and are believed to be approximately a thousand years old.

Settlement by the former shoreline

Ancient relicts show that, historically, people have usually chosen to settle by the coasts, to be close to seals and fish, the main catch. Furthermore, it has always been easier to travel over water and along rivers, even on the winter ice, than through forest and over hills. This made the shore the natural place to live. In the Kvarken Archipelago and along the Swedish Norrland coast, boat landing sites have been found, areas on the shoreline where rocks have been removed to allow boats to be pulled up onto the beach. By establishing the height of these landing sites above the sea, we can calculate how old they are – the higher their position, the older they are.

The High Coast's oldest relicts are 8,000 years old

The area now called Sweden probably became populated soon after the melting of the ice sheet. The oldest evidence of human presence in the World Heritage area in the High Coast is a temporary camp near the cave on Skuleberget, approximately 8,000 years old. It may have been built by Stone Age people, who lived immediately south of the World Heritage area on the south side of the Angermanälven river, and who could have set up a camp there when out on a seal or seabird hunting or fishing trip. Seal hunting was important for the first immigrants here – 98% of the bone remains found in the Stone Age camps are from ringed and harp seals. The seal hunting settlements are found along the earlier shoreline, such as the Överveda settlement in Nordingrå, now 69-76 metres above the sea.

During the Bronze Age (3,800-2,600 years ago), people moved to the High Coast and built permanent settlements in sheltered, more cultivable locations. The large burial cairns that are found along the entire Norrland coast derive from that time, such as those at Sund in Vibyggerå. The cairns were built on bare cliffs by the beach, visible from afar to seafarers, but they are now 30-55 metres above the sea.

During the Iron Age (2,600-1,000 years ago) cultivation and cattle husbandry grew in importance on the easily worked and nutrient-rich former seabed. The climate during the Iron Age was approximately the same as today, and most people still lived by hunting and fishing. Settlements here became more permanent, and longhouses were built. Because the land was steadily rising out of the sea, people built new settlements nearer the coast, where they could benefit from both the sea and the fertile valleys. They built beacons (piles of wood and other incinerable material) on hilltops, and these could be lit when enemies were approaching. They also built hill forts where they could defend themselves from enemies. Iron Age farms and graves can be found approximately 20 metres above sea level.

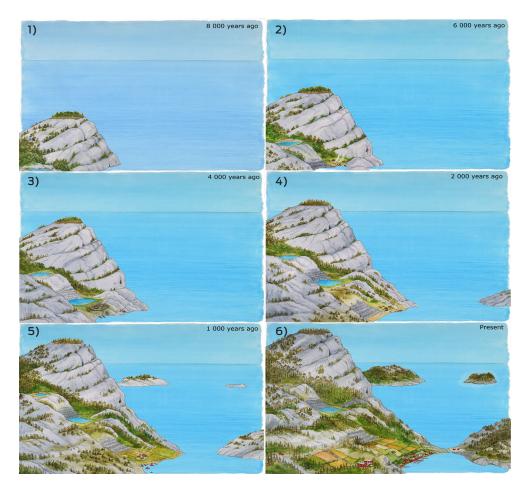
During the Middle Ages, the population in the High Coast increased, and more people became Christian. The oldest churches in the High Coast area are from the 13th century, and were built next to trading sites. At that time, the people paid tax with, for example, oil from seals, salmon, herring, and skins. Between 1557 and 1772, fishermen from more southerly towns, including Gävle, had sole rights to fish trading along the Ångermanland coast. These 'Gävle fishermen' built many of the High Coast's fishing villages. These were originally only used during the summer. At that time, the law required everyone to attend church services. However, it was often a long way to the churches from the villages, so the fishermen built small chapels in the villages. These chapels are usually the oldest preserved buildings. In the winter, when the fishing villages were empty, the chapel was used to store the fishing equipment. The sea entrance to many of the

old fishing villages has now become too shallow, or even cut off by the land uplift. Today, the buildings mostly comprise holiday homes and tourist accommodation.

Kvarken populated approximately 7,000 years later

The Kvarken Archipelago became populated much later. Around 2,000 years ago, the first skerries appeared out of the sea in the area that is now the Kvarken Archipelago World Heritage Site. After a while, people in Ostrobothnia and long-distance hunters from Norrbotten became aware that this area was rich in seals and fish. Consequently, the first signs of human presence here are temporary hunting camps. Relicts believed to be around a thousand years old have been found, for example, on Mickelsörarna. At Replot and in Vallgrund, old harbour structures and jewellery have been found that have been dated to the 10th century, i.e. Viking times.

More permanent settlements started to appear on the larger islands in the Kvarken Archipelago during the subsequent centuries, particularly during the 15th and 16th centuries, when people migrated from Sweden to Finland. It can also be seen from ancient documents that farmers from, for example, Kyro held the rights to fishing waters out in the Kvarken Archipelago during the Middle Ages. Evidence of this can still be seen in placenames in the archipelago, such as Finngrundet. The rich supply of seal and herring in the archipelago was an important part of the local economy of the Ostrobothnian coast right up to the middle of the 20th century. Even today there are 'fishing saunas', overnight huts for fishermen, far out in the outermost archipelago as testimony to the periodic fishing here, although most are used today as holiday homes.



Settlement history in the High Coast

Figure 77. The illustration represents a typical landscape based on the settlement history in the High Coast. Over thousands of years, people have preferred to build their camps and settlements along the shore in sheltered bays.

- 1) 8,000 years ago: Approximately the same time as Sweden became free of ice, the first people found their way to the islands in the High Coast. They were hunters, and were met by a climate that was warmer than the climate we have here today.
- 2) 6,000 years ago: For several thousand years, Stone Age people returned to the coast every autumn. In the rocky archipelago, they fished and hunted seals and seabirds.
- 3) 4,000 years ago: During the Bronze Age, people started to build permanent settlements in the High Coast. They were mainly hunters and fishermen. They lived along the shore in sheltered bays. Along the coast, they built burial cairns.
- 4) 2,000 years ago: Because the land was steadily rising out of the sea, people built new settlements nearer the shoreline. They cleared fields on the fertile land that had once been the seabed, and kept animals such as goats and dogs as pets.
- 5) 1,000 years ago: During the Viking period, people built large farms in the valleys. They planted crops in the fields and kept cattle on the coastal meadows and in the forest, but hunting and fishing were still important.
- 6) The present: Today, the oldest relicts from the Stone Age are found 160 metres above sea level. Old burial cairns from the Bronze Age are now 30-50 metres above sea level.

5.2 Pilots, lighthouses, and fairways

The dangers of the sea have always been a feature of everyday life in the archipelago landscapes of the High Coast and Kvarken. Randomly distributed moraine deposits from the Ice Age, and the continuous land uplift, together create a constantly changing and treacherous coastal landscape. Fairways become shallower and had to be rerouted. New reefs and rocks are lifted closer to the surface, and sea charts must be frequently updated to ensure they correspond with reality.

The people of the Baltic Sea coasts have always been a maritime folk that went on long voyages. During the Middle Ages, Kvarken was the most important trading centre in the entire Gulf of Bothnia. The most important fairways ran through the current World Heritage area. From Ostrobothnia, products such as seal oil, salt fish and skin were transported to Stockholm, Denmark and Lübeck, and salt was the main cargo transported back. Tar burning and wood transport gave industry and shipowners a golden age in both Kvarken and the High Coast.

Many different ways to mark the fairways

The Kvarken Archipelago is not just shallow (average depth 10 metres, but with a maximum depth of only 25 metres), it also contains shallows, reefs, skerries, rocks and boulders. Some parts of the archipelago consist quite simply of wide fields of large boulders that were left when the ice sheet melted at the end of the last Ice Age. In shallow bays, inlets and river estuaries, sedimentation speeds up the shallowing process, so in the course of just a few decades, a fairway in the Kvarken Archipelago can become unnavigable.

In contrast, in the High Coast, the fairways are relatively deep and free of rocks, so the effect of the land uplift is not so noticeable. The land uplift has caused some bays to be cut off from the sea. This has sometimes led to new settlements being built closer to the sea when the old harbours became too narrow and shallow.

Historically, many different methods have been used to ensure the safety of maritime transport in the World Heritage area. In the High Coast, the hills were probably used as natural landmarks for navigation for several thousands of years.

During the Bronze Age, the burial cairns built out on the cliffs were also used as landmarks, and later probably the hill forts too. In the Kvarken Archipelago, seafarers in the Middle Ages built cairns and set up beacons and navigation markers.





Figure 78. On Molpehällorna, Finland's first rocker beacon was erected in 1668. This type of beacon was a stand to hold a basket of burning wood that could be raised up ten metres up to mark dangerous shallows. In the memory of both lighthouse-keeper Jakob Rautio and the Finnish maritime history, a reconstruction of this rocker beacon was erected on Molpehällorna in the Kvarken Archipelago.

Photo: Malin Henriksson

Figure 79. The photo shows the second lightship in the Qvarken (Snipan) scheme. It was built and put in position in 1885 and was stationed west of Snipansgrund in Kvarken. The ship had an iron hull, no engine, only a sail, and the red lantern in the mast was run on oil. In 1944, when it was to be taken ashore to be scrapped, it ran aground in a snowstorm and could not be salvaged.

Photo: Finnish Lighthouse Society Lexikon

Figure 80. At various places in the outer archipelago in both the Kvarken Archipelago and the High Coast, lighthouses, pilot stations, and coastguard stations were built. All lighthouses are now automated, and pilots and coastguards monitor large areas of sea from a few remaining stations along the coasts. But for many decades, these officials lived for long periods in the outer archipelago, often cut off from the world and exposed to the forces of the weather and the sea. The lighthouse in the photo is on the island of Högbonden in the High Coast. It was built in 1909 and was operated by lighthouse-keepers until 1963 when it became automated. At most, 21 people lived here together, and the children went to school in the attic of the lighthouse-keeper's house.

Photo: Erik Engelro



The pilots

Since the early 18th century, the pilots who have guided incoming vessels to safe harbour berths have been an important professional group for sea traffic in the High Coast and the Kvarken Archipelago. In the High Coast, pilots were in operation, for example, in Skagshamn and on Ulvön. Lighthouse-keepers and pilots often lived together with their families in small communities on islands in the outer archipelago. In the 20th century, the lighthouse-keepers and pilots in the Kvarken Archipelago were joined by the coastguards, who were first appointed to control the extensive smuggling in the area. Then, after the Second World War, they were given the task of ensuring that no enemies reached Finland from the sea.

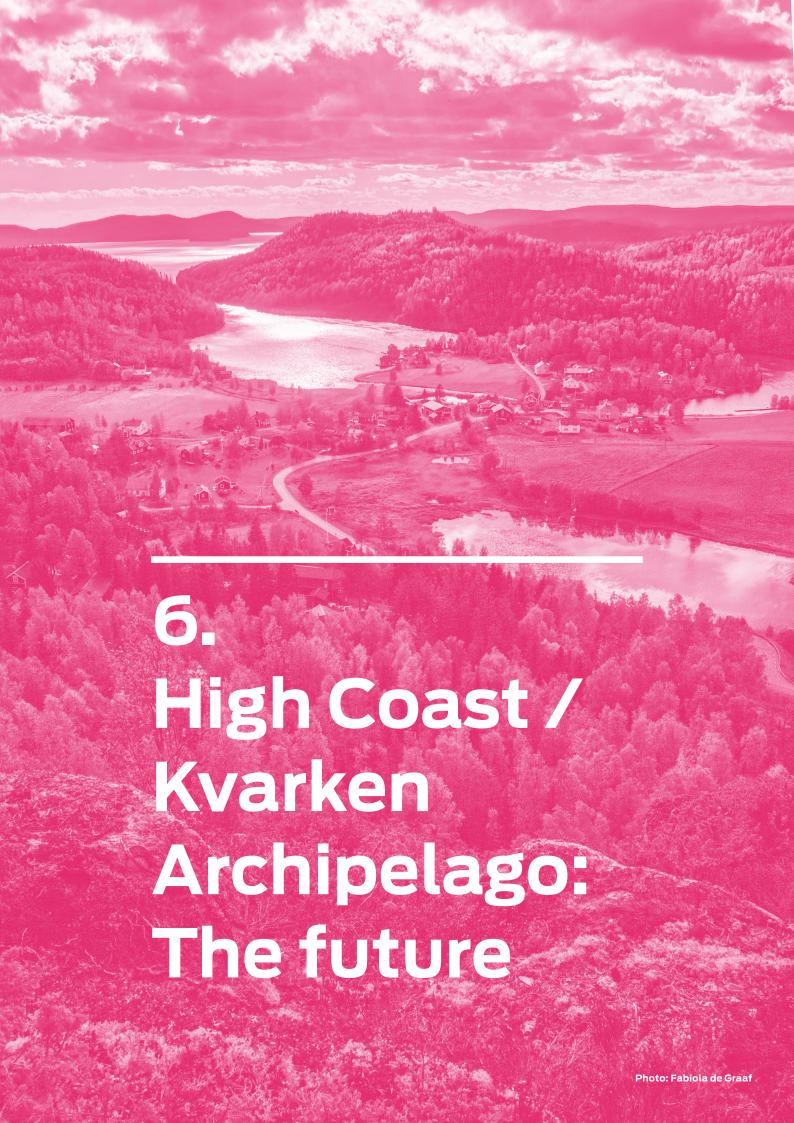
Narrow channels for leisure boats

In the inner parts of the Kvarken Archipelago, the traces of the Ice Age and the land uplift have caused problems for archipelago dwellers throughout history. For example, inlets became shallow and overgrown, and rocks were raised by the land uplift or moved by the winter ice. The navigation passages in the archipelago are often only a few metres wide, and at low water can be treacherously shallow. Today, it is mainly recreational fishermen and holiday home owners who use the leisure boat channels in the Kvarken Archipelago.



Figure 81. According to a Kvarken proverb, the trick of navigating here is not to know where the rocks and shallows are but to know where they are not. The traces of the Ice Age and the land uplift make the fairways rocky, shallow, and treacherous. Placenames in the archipelago also tell of the dangers. Bergö gaddarna really do look like a field of sharp rocky teeth, and many shallows have been named after people who sailed on them. Despite dredging, some of the leisure boat passages in Kvarken are so narrow that there is barely room to row boats through them.

Photo: Liselott Nyström Forsén



The land uplift will continue until the Earth's crust has regained the level it was at before the last Ice Age. The rate of uplift will slow, but the process will continue for tens of thousands of years. However, researchers calculate that climate change will also have consequences for the High Coast/Kvarken Archipelago World Heritage Site, for example because of rising sea levels in the Baltic Sea. This will mean that the apparent land uplift (see infobox in Chapter 3. The land uplift and effects of the sea) will decrease, which in turn will affect the World Heritage area.

6.1 Land uplift and the future

90-130 metres remaining

In the area covered by the Fennoscandian ice sheet, the land uplift will continue for another tens of thousands of years. According to comprehensive measurements from 2016, the Earth's crust in the High Coast-Umeå region-Kvarken Archipelago area is rising by 9 mm/year, measured from the geoid. The rate of land uplift is slowly decreasing as the Earth's crust approaches the level it occupied before the most recent ice age. Geologists estimate that 90-130 metres remain until the crust is restored to its original level.

Apparent land uplift decreasing

The actual land uplift that we see along the Baltic Sea shores depends on how quickly the sea level rises every year. This apparent land uplift is also called shoreline displacement. The more the sea levels rise, the smaller the apparent land uplift. In the past 30 years, the water level in the Earth's oceans has risen by an average of 3-4 millimetres per year. The sea level in the Baltic Sea is also rising by approximately the same rate, or even faster, than that in the oceans. Climate change is resulting in the Nordic region receiving more precipitation, which runs off the land into the Baltic Sea. Because the sounds that link the Baltic Sea and the Atlantic Ocean are narrow, some of this increase in precipitation will remain in the Baltic Sea, raising the sea level. The Baltic Sea is a relatively shallow sea, so the water warms up faster than in the oceans. This causes the water to expand and the sea level to rise. The increased inflow means that it will not be able to flow out through the sounds to the Atlantic.

According to the UN climate panel, The Intergovernmental Panel on Climate Change (IPCC), the water levels in the oceans will rise increasingly quickly. The main reason why the ocean levels are rising is because of the melting of the glaciers in Greenland and in Antarctica because of global warming. Heat causes water to expand. Ninety percent of the heat from global warming has so far been stored in the sea. Sea levels will therefore rise gradually, regardless of whether or not we succeed in stopping climate change. Both the air and the seas have already warmed up so much that the glaciers will continue to melt, and the volume of water in the oceans will continue to increase.

Next ice age?

When the next glaciation will occur is uncertain. We are currently in an interglacial period, and the previous warm periods between glaciations have lasted approximately 10,000-20,000 years. There are many theories on how the climate change will affect the climate in the future. Some researchers argue that the next glaciation may be delayed because of the warmer average temperatures in the world, but nobody can know for how long. Others predict that the next ice age will occur earlier if, for example, the warming Gulf Stream slows or stops as a result of climate change.

Infobox: How much sea levels will rise

In the IPCC report from 2019, researchers based their calculations on the best-case scenario, i.e. humankind will succeed in considerably reducing carbon dioxide emissions and keep global warming below 2° C. According to that forecast, it is believed that sea water level will rise by between 30 and 60 cm (4-9 mm/year) by the end of this century. In the worst-case scenario, where carbon dioxide emissions and global warming increase considerably, sea levels may rise by 60-110 cm (10-20 mm/year) by 2100. However, already by 2050, sea level will rise by between 24 and 32 cm, depending on which scenario is used for the calculations.

6.2 Future scenarios in the High Coast/ Kvarken Archipelago World Heritage Site

For a few hundred years, the High Coast and Kvarken will continue to rise by 9 millimetres per year, calculated from the geoid. However, climate change will cause the Baltic Sea to become warmer and its volume to increase, so it is probable that both the ecology and human life in the World Heritage Site will be affected. We can observe that certain changes have already occurred.

On the basis of statistics from the past century and researchers' forecasts regarding climate developments, it is hardly likely that the apparent land uplift will be unaffected by rising sea levels within the foreseeable future. In theory, the land uplift effects in the High Coast and the Kvarken Archipelago can be divided into three possible scenarios.

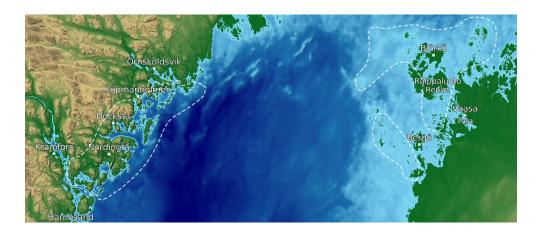


Figure 82. This was the shoreline in the World Heritage area a hundred years ago. If the sea levels start to rise faster than the land is being uplifted, the shoreline will eventually look like this again.

Scenario 1: Rise in sea level less than land uplift

Researchers have found that sea levels in the oceans rose by an average of 3.6 millimetres per year in the period 2005-2015. In all probability, the sea levels will continue to rise at the same rate or faster. In theory, this would virtually halve the apparent land uplift in the Kvarken Archipelago and the High Coast. In the World Heritage Site, this would not have much effect on the landscape, at least in the short term. To take a few examples, the succession in the flads would probably slow down, and the cobble stones in the cobble fields would perhaps have time to become slightly rounder.

Scenario 2: Sea level rises at the same rate as land uplift

If the land uplift and the rise in sea level balance each other out, the World Heritage area would see no apparent land uplift at all. All the changes that the land uplift can bring about together with the work of the sea would cease. For example, no new moraine ridges would be lifted to surface level in the Kvarken Archipelago. It would also mean that no new flads would form, while gloes and glo-lakes would probably continue to be overgrown by vegetation. This in turn would, for example, reduce the breeding grounds for important predatory fish. No new tunnel caves would be formed in the High Coast, and those tunnel caves currently being eroded would become deeper and their roofs would eventually collapse. No more cobble fields or beach ridges would form, but the shorelines would still be affected by waves, so cliffs and rocks would become even more polished and rounded. On land, the vegetation zones closest to the water's edge would no longer undergo succession. Where sea water and winter ice still reach, the same tolerant plants would remain, but higher up on the land, plants such as sea buckthorn and alder would quickly be forced out by birch and spruce.

Scenario 3: Rise in sea level greater than land uplift

If the sea water levels rise faster than the rate of land uplift, the shoreline would instead be displaced inland. It is probable that vegetation zones and lower areas would then be flooded, which would quickly result in certain vegetation zones disappearing. According to this scenario, the waterline would eventually reach the plants whose roots cannot tolerate brackish water. These plants would die and be replaced by more salt-tolerant plants. However, fish could return to some of the former flads to breed, because the sea water can reach them again.

Other effects of climate change on the World Heritage Site

Climate change will not only lead to raised water levels. According to researchers' predictions, global warming will probably result in poorer or no winter ice and less frozen ground. Finland and Sweden will probably get more precipitation than is the case today, and more frequent and more intense storms, as more moisture will evaporate in a warmer climate. The storms can temporarily cause extreme high water levels and high waves, causing flooding and shoreline erosion. Flooding due to increased precipitation would wash out even more nutrients from the fields and increase eutrophication. Many coastal towns and buildings close to the shore, infrastructure, and industries would all need to be protected by damming in the next decades, or moved to higher ground.

All these factors will affect many species and ecosystems in and around the Baltic Sea. Certain marine species may move further northwards towards cooler water, or southwards towards saltier water. However, if, for example, winter ice no longer reaches the northern parts of the Gulf of Bothnia, the ringed seal will not be able to give birth to its puppies on the ice. Other species such as the common mussel will neither be able to move any great distance nor have time to adapt to the rapid changes, and the numbers will either fall or species may even die out completely. If the Gulf Stream weakens so much that the climate in the Nordic region becomes colder, this would entail major challenges for other species instead.

No land bridge over Kvarken in sight

For many decades, there has been speculation in the land uplift discussion about when the land uplift could create a land bridge between Sweden and Finland over Kvarken. The water depth between the Valsörarna islands and Holmön is only 20-25 metres. However, because of climate change, sea level is rising, so the land bridge would form more slowly than was previously calculated. As things are now, it will take at least 4,000 years before a land bridge forms. However, according to some predictions, the sea level rise may be measured in centimetres instead of millimetres per year after 2100, so there may never be a land bridge.

6.3 Protecting and preserving our World Heritage

During the past decades, the Nordic region has done more to protect areas of sensitive nature, for example through various types of nature protection. Parts of the High Coast/Kvarken Archipelago World Heritage Site are protected by designating areas as, for example, national parks, nature protection areas, and nature reserves. Through the nature protection work, it is hoped that at least some of the negative effects caused by man, both directly and indirectly, can be reduced. In addition, public agencies and the third (voluntary) sector have also focused on disseminating knowledge and information about the many natural values to both the local population and visitors. This, together with greater environmental awareness in society, means that more people are developing a closer relationship with nature, which increases their inclination to protect and preserve it. In Västernorrland and Ostrobothnia, work is also taking place to disseminate knowledge about the geological values that gave the High Coast and Kvarken Archipelago World Heritage status. The hope is that, if more people are made aware of why this area is the best place in the world to experience and understand the land uplift since the last Ice Age, they will be more willing to actively work to protect and preserve it.



Figure 83. Tomorrow's nature conservationists?

Photo: Malin Henriksson

