Land uplift and its effects in Finland – the Bothnian Bay as an example

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Key words: land uplift, reliction

SUMMARY

During the coldest phase of the most recent Ice Age 18,000–20,000 years ago, the glacier was at its thickest in Scandinavia. It has been estimated that the ice sheet was 2.6 kilometres thick in the Bothnian Bay area. The crust of the earth was pressed down by the mass of ice for a period of thousands of years. Thawing of the glacier caused the land to begin to rise. Throughout the entire period following the Ice Age, land uplift has been most rapid in the Bothnian Bay area. Today the land rises in the Bothnian Bay at a rate of 7–9 mm per year Land uplift has previously been measured with precision levelling, but today satellite measurements can be used too. The land is rising more in the Bothnian Bay than on the mainland, and Finland is gradually tilting towards the southeast. Rivers emptying into the Bothnian Bay will get longer, their rate of flow will slow down and floods will grow. The discharge routes of inland lakes will change. The shoreline is moving further out to sea and land is being bared. Inlets will get shallower and some of them will be choked off from the sea, forming flads. Fishing places will change as the land rises. It has been estimated that the Bothnian Bay will become a lake about 2000 years from now. An estimated 150–200 metres of uplift is still left. Uplift will continuously get slower and will last thousands of years.

TIIVISTELMÄ

Viimeisen jääkauden kylmimmän vaiheen aikana 18 000-20 000 vuotta sitten mannerjäätikkö oli Skandinaviassa laajimmillaan. Perämeren kohdalla arvellaan olleen jäätä noin 2,6 kilometriä. Vuosituhansien aikana jäämassa painoi allaan olleen maankuoren lommolle. Mannerjään sulaminen käynnisti maankohoamisen. Maankohoaminen on ollut nopeinta Perämeren ympäristössä, jossa se kohoaa nykyisin 7-9 mm vuodessa. Maan kohoamista on aiemmin mitattu tarkkavaaituksilla, mutta nykyisin voidaan tehdä myös satelliittimittauksia. Maa kohoaa enemmän Perämerellä kuin mantereella ja Suomi kallistuu hiljalleen kaakkoa kohti. Perämereen laskevat joet pitenevät, niiden virtaus hidastuu ja tulvat kasvavat. Sisämaan järvet vaihtavat purkautumisreittejä. Rantaviiva siirtyy kauemmas merelle ja saaria tulee lisää. Perämeren lahdet mataloituvat ja niitä kuroutuu irti merestä. Myös kalastuspaikat muuttuvat maan kohotessa. On arvioitu, että Perämeri muuttuu järveksi 2000 vuoden kuluttua. Maankohoamista on jäljellä 150-200 metriä, se jatkuu hidastuen ja kestää tuhansia vuosia.

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1. LAND UPLIFT

During the coldest phase of the most recent Ice Age 18,000–20,000 years ago, the glacier was at its thickest in Scandinavia (Figure 1), and it has been estimated that the ice sheet was 2.6 kilometres thick in the Bothnian Bay area (Figure 2). The crust of the earth was pressed down by the mass of ice for a period of thousands of years. Thawing and thinning of the glacier caused the land to begin to rise; the crust of the earth began to rebound to a state of equilibrium.

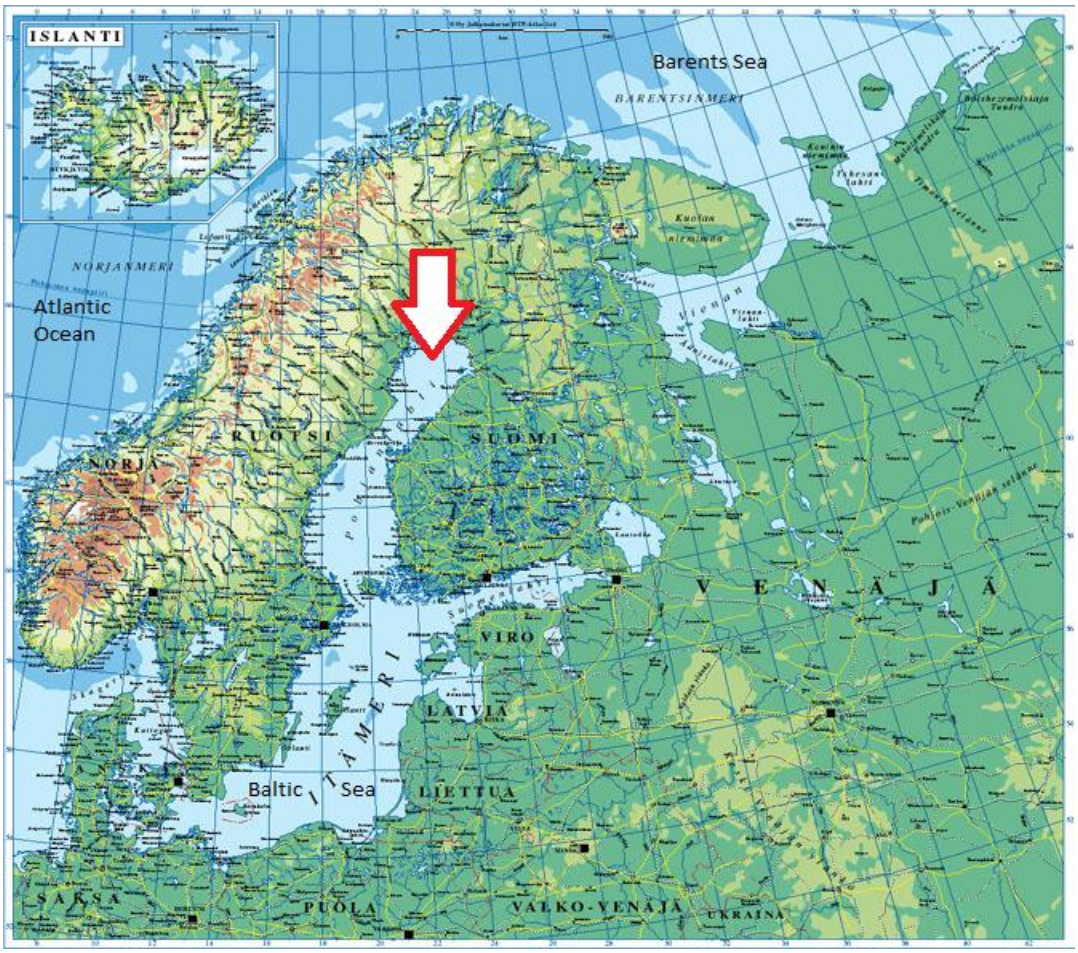

Figure 1. Bothnian Bay area

As the glacier melted, the Bothnian Bay area went through both lake and sea phases, the most recent being the Litorina Sea phase which began about 9000 years ago. The Litorina Sea period began when the rising sea level caused salty water to flow into the Baltic Sea through

the Strait of Denmark.

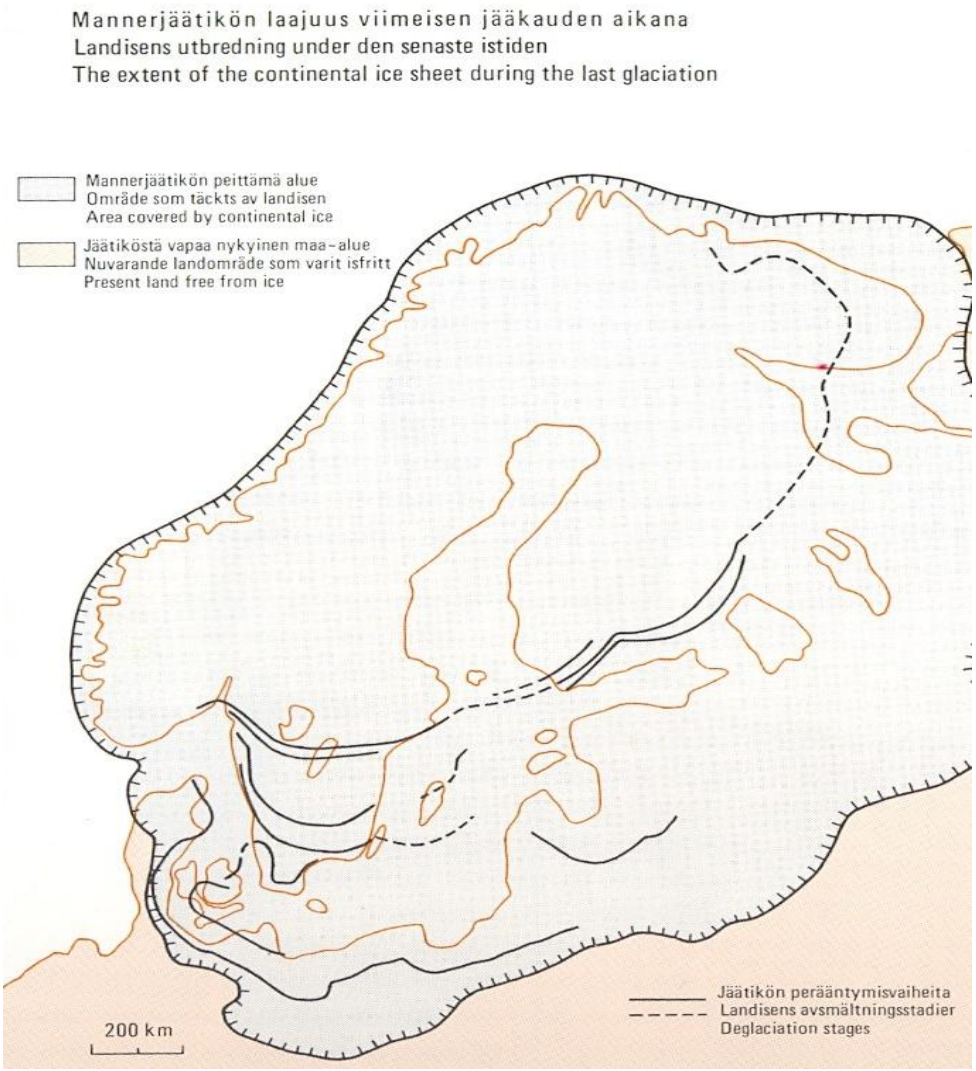

Figure 2. Extent of the glacier during the most recent Ice Age (Niemelä Jouko, Suomen Kartasto vihko 123-126 Geologia).

Throughout the entire period following the Ice Age, land uplift has been most rapid in the Bothnian Bay area. The last traces of the glacier disappeared from the Ylitornio-Kolari area in Finland a little less than 9000 years ago. An ice divide was situated in central Lapland. Today the highest post-glacial shores of the Baltic Sea in Finland are over 210 m above sea level.

Changes in sea level with respect to the shoreline are monitored with marigraphy. Changes in inland ground level are monitored with repeated precision levelling. Nationwide precision levelling has been done three times in Finland: in 1892–1910, 1935–1975 and 1978–2006. Land uplift is only one consequence of the global phenomenon of post-glacial rebound . This phenomenon not only affects the crust of the earth and the upper parts of the mantle, but also causes changes in sea level, glaciation and changes in gravity. Melting of glaciers raises sea

levels. Global sea level has been rising at a rate of slightly more than 1.5 millimetres a year, but the rate has nearly doubled in recent years. The rise in sea level lessens the amount of discernible land uplift along the coast. So far, the rise in sea level is lesser than land uplift along Finland's coast, so new land continues to become visible in the sea. The amount of land uplift in Finland is known precisely due to precision levelling and GPS observations. However, both the mechanism of land uplift and the changes it causes in gravity and the details of land uplift require further study. These topics are being studied by the Finnish Geodetic Institute.

The earth's gravitational field is mapped in Finland and globally. Changes caused by the earth's various geophysical phenomena are analysed. The tools used include gravimeters and data from satellite gravity missions such as GRACE and GOCE. The measurement results are used to calculate the theoretical shape of the ocean, or geoid, for GPS height determination and to analyse the effects of various geodynamic phenomena such as post-glacial rebound and global changes.

Pan-Nordic measurement of land uplift gravity lines was begun by the Finnish Geodetic Institute in 1966. East-west gravity profiles cover the entire area of land uplift in Scandinavia. Precise relative gravimetry is used to measure very small (0–2 microgal) yearly relative changes in gravity difference between line stations, depending on the origin of the land uplift phenomenon. International measurements coordinated by the Nordic Geodetic Commission have been carried out along line 63° N at five-year intervals. Measurements along other lines are conducted more seldom. Land uplift in Scandinavia is presented in Figure 3.

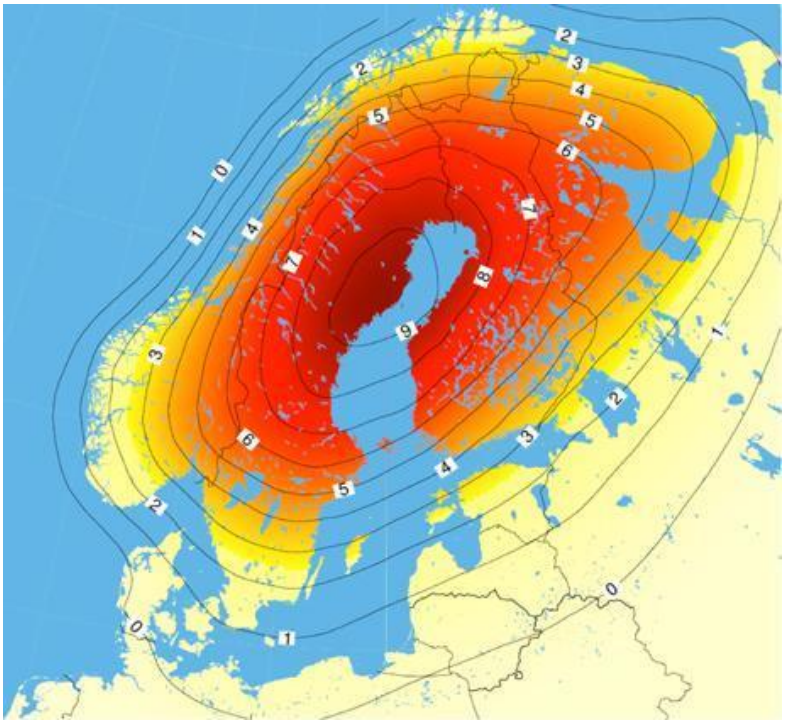

Figure 3. Land uplift in Skandinavia. (Finnish Geodetic Institute)

2. EFFECTS OF LAND UPLIFT

The land in Finland is rising more in the sea area than on the mainland. Thus, Finland is gradually tilting towards the southeast. The shoreline is moving further out to sea and land is being bared (Figure 4).

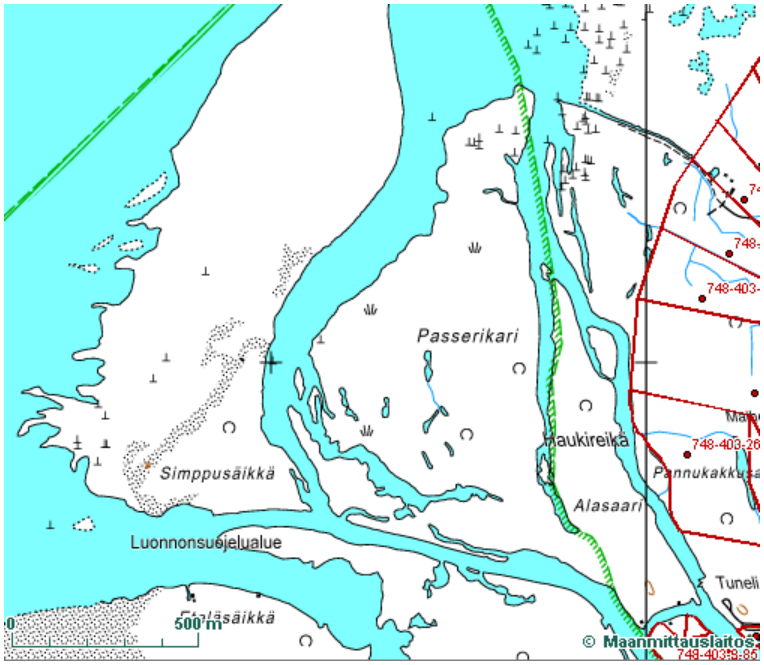

Figure 4. Reliction in Siikajoki. © National Land Survey of Finland; permit no. 51/MML/12.

Over time, houses that were on the shore will be left on dry land. Land that rises from the sea first grows hay and grass, and eventually bushes and trees. The first tree species that grow in the area are alder and birch, then spruce and in higher areas, pine. As the land rises, more

shoals and islands will appear, they will get bigger and finally they will be connected to the mainland (Figures 5 and 6). Land bared in front of coastal properties may be redeemed via real estate transactions if the prerequisite for redemption are fulfilled.

The prerequisite for redeeming newly bared land is that it is jointly owned land or privately owned land that has appeared after the property has been formed. An additional prerequisite is that the newly bared land significantly hinders use of the property or that it can be conveniently used only together with the property. If such land can be conveniently used only together with the property, the owner of the land may obligate the property owner to redeem all or part of the bared land.

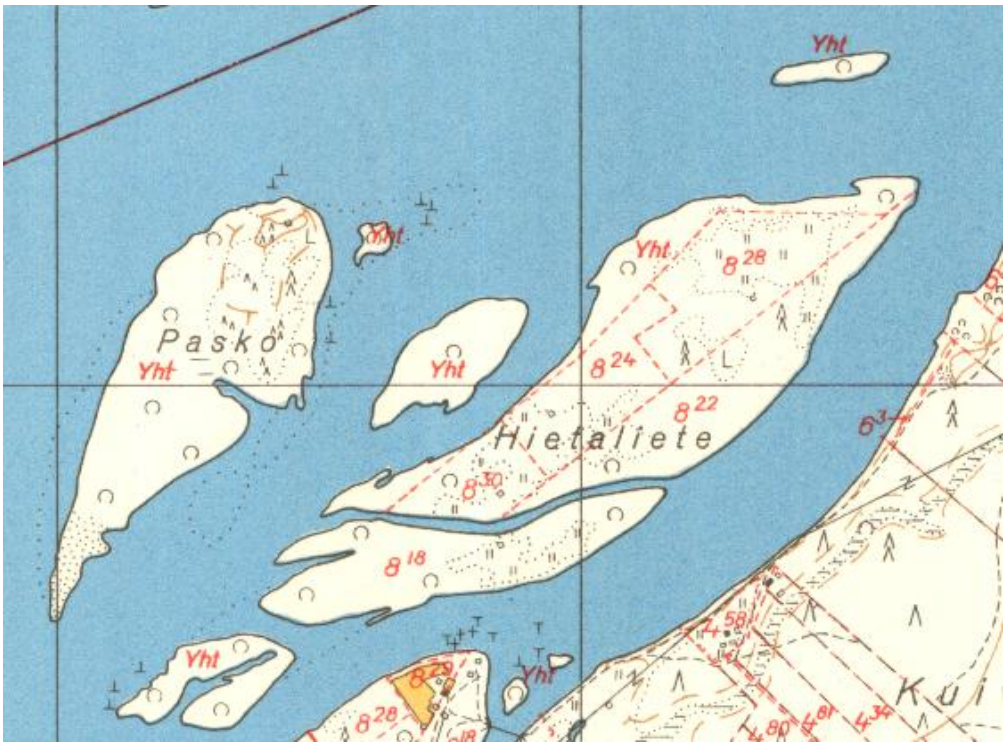

Figure 5. Islands and islets off the coast of Kemi in 1955, base map 2541 08. © National Land Survey of Finland; permit no. 51/MML/12.

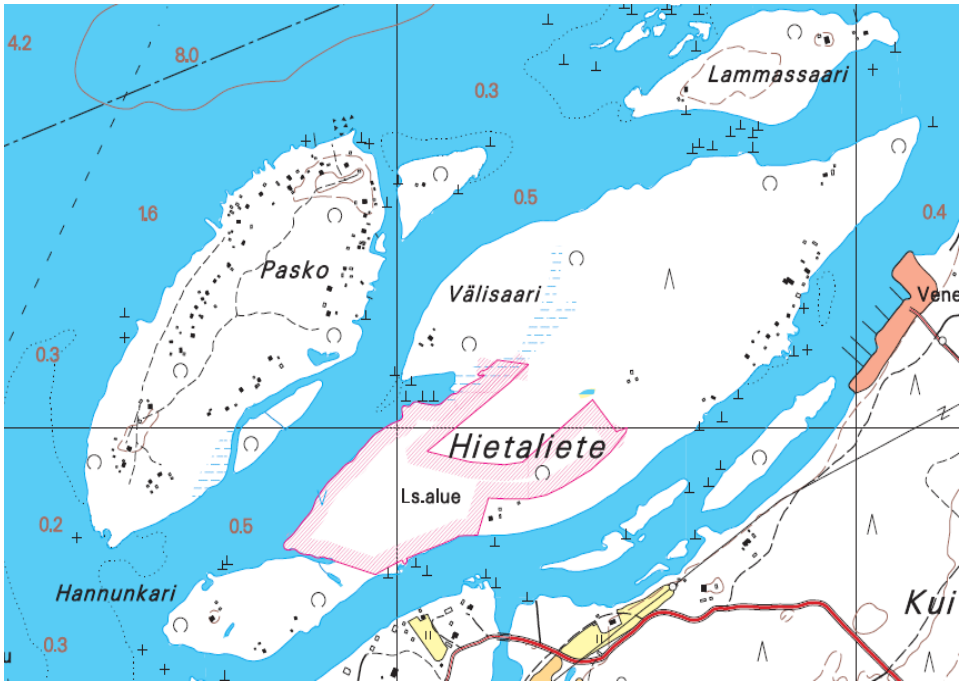

Figure 6. Islands and islets off the coast of Kemi in 2012, geographic material output from area 2541 08 of the base map. © National Land Survey of Finland; permit no. 51/MML/12.

As the land rises, boat landings and harbours will be left stranded on dry land and channels will need to be dredged to provide access to them (Figure 7). Eventually they will need to be moved closer to the sea. In Jakobstad, an area where land uplift is greatest, the land has risen about five metres in five hundred years. The location of the city's first harbour is now in the middle of the city, and the newest harbour is located about five kilometres closer to the sea. Another reason the harbour had to be moved was the need for deeper channels to accommodate today's larger vessels.

Figure 7. Dredged channels off the coast of Jakobstad. © Jakobstad stad.

Fishing places will also change. The Bothnian Bay has state-owned fishing places. The state leases these fyke net fishing places to professional fishermen. There are also special fishing rights as an usufruct in the area. Some of the fishing places have already been left on dry land or they have become so shallow that fishing is not possible. There is ambiguity regarding the use of existing fishing places.

Most waterways in northern and central Finland empty into the Bothnian Bay. These rivers will get longer, their rate of flow will slow down and flooding will increase. The discharge routes of inland lakes will change. This has already happened in Lake Päijänne and Lake Saimaa 6000–7000 years ago. Inlets of the Bothnian Bay will get shallower. Vegetation in them will need to be mowed more often and they will have to be dredged deeper to maintain water routes that serve recreation and fishing. Inlets will be choked off from the sea, forming flads. When an inlet is completely separated from the sea it becomes a gloe lake. At the same time its salt content and population change (Figure 8).

Figure 8. Flads and gloe lakes. (Olav Jern, Regional Council of Ostrobothnia & Metsähallitus)
It has been estimated that the Bothnian Bay will once again become a lake about 2000 years from now (Figure 9) when rifts in the Kvarken region rise above sea level. An estimated 150–200 metres of uplift will still occur. Uplift will continuously get slower and will last thousands of years.

Figure 9. The Bothnian Bay will become a lake in the future (Harri Kutvonen, Geological Survey of Finland).

3. FUTURE

It has been estimated that the Bothnian Bay will once again become a lake about 2000 years from now (Figure 9) when rifts in the Kvarken region rise above sea level. An estimated 150–200 metres of uplift will still occur. Uplift will continuously get slower and will last thousands of years.

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