

Small Publications in Historical Geophysics

No. 15

---

**The First Land Uplift Map that Could have been  
Constructed – but Never was**

**Martin Ekman**

Summer Institute for Historical Geophysics  
Åland Islands

2006

Small Publications in Historical Geophysics

No. 15

---

**The First Land Uplift Map that Could have been  
Constructed – but Never was**

**Martin Ekman**

*Contents*

1. Introduction
  2. Sea level data
  3. Land uplift rates
  4. The first land uplift map
  5. Comparisons with modern results
  6. Why was the land uplift map never constructed?
- References

Summer Institute for Historical Geophysics  
Åland Islands

2006

## 1. Introduction

The first map showing a part of the pattern of the present postglacial uplift of Fennoscandia was published by Blomqvist & Renqvist (1914). They calculated the land uplift rates at a number of sea level stations, all having been in operation from 1889 to 1912. The resultant land uplift map covered the Baltic Sea but no areas outside that. The sea level stations were stations with daily readings or mareographs with continuous recordings of the sea level.

However, long before the establishment of these stations there existed a more primitive kind of sea level stations, usually called sea level marks. These were merely horizontal lines cut into vertical parts of solid rock (or huge erratic blocks) to mark the approximate mean sea level around a certain year, the year being cut into the rock together with the mark itself. The first such sea level mark was cut in 1731 at the island of Lövgrund in the Gulf of Bothnia, on the initiative of Celsius; see Figure 1. His purpose was to create a reference mark for future determinations of the rate of the land uplift, or the lowering of the sea level as it was considered to be at that time; see Celsius (1743).

Obviously, the cutting of these marks in solid rock guaranteed their long-term stability (apart from the land uplift itself, of course). On the other hand, sea level was usually observed there only on rare occasions, with only primitive methods to estimate the mean sea level. The most important result obtained from these sea level marks was that the rate of change of the measured sea level was different in different parts of the Baltic, from which Lyell (1835) concluded that the phenomenon could not be a lowering of the sea level but had to be a land uplift.

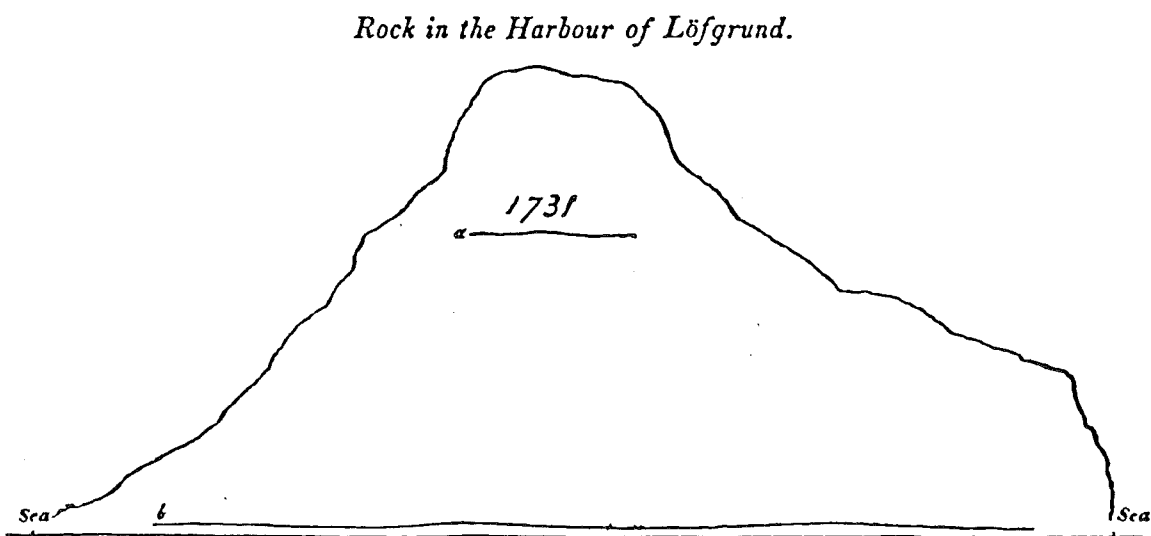


Figure 1. The Celsius rock at Lövgrund with its sea level mark from 1731 as depicted by Lyell (1835).

However, there was never any successful attempt made to establish a pattern of the vertical movements of the crust, i.e. to construct a land uplift map, at that time. Was it not possible to do so from the sparse data available? We will investigate this, trying to construct a land uplift map from the sea level data available around 1840, about 100 years after the first sea level marks were cut, but as early as 70 years before the first land uplift map was actually constructed.

## 2. Sea level data

At 1840 there were quite many sea level marks along the Swedish and Finnish coasts of the Baltic; see the overview by Holmström (1888) and some additional information in Bergsten (1954). However, many of these marks are not old enough for our purpose. We need our marks to have been established already in the 1700s to create a sufficiently long time span. Moreover, several of the reported sea level determinations were made under uncertain conditions or stem from anonymous people. We will confine ourselves to what we consider reasonably reliable data from known persons (most of them geodesists and hydrographers).

Altogether, this leaves us with 8 useful sea level marks. For each mark there are two useful sea level determinations, one at each end of a time span of about 50 - 100 years. In addition we have data from one sea level gauge with half a century of observations. In total we thus have 9 sea level stations; see Figure 2 and also Table 1.

We will now go through the sea level marks and their data, in chronological order according to the year of establishment of the mark. For this we will use original publications rather than the overviews above. At the end of the section we will treat the sea level gauge.

### *Lövgrund (1731)*

The mark at Lövgrund in the southwestern Gulf of Bothnia was cut in 1731 according to instructions by Celsius (Celsius, 1743). The mark refers to a summer sea level approximately equal to mean sea level. Sea level during summers is often close to normal here since the effect of winds on the Baltic sea level usually has its minimum in summer. A century later, in 1834, the mark was visited by Lyell from England (who was very surprised by the absence of tides in the Baltic). From a pilot at Lövgrund he got a personal estimate of the deviation of the instant sea level from the mean sea level. After correcting for this, Lyell found that mean sea level was 2 feet 10½ inches = 2.88 feet below the 1731 mark (Lyell, 1835). From Lyell's text it is not quite clear

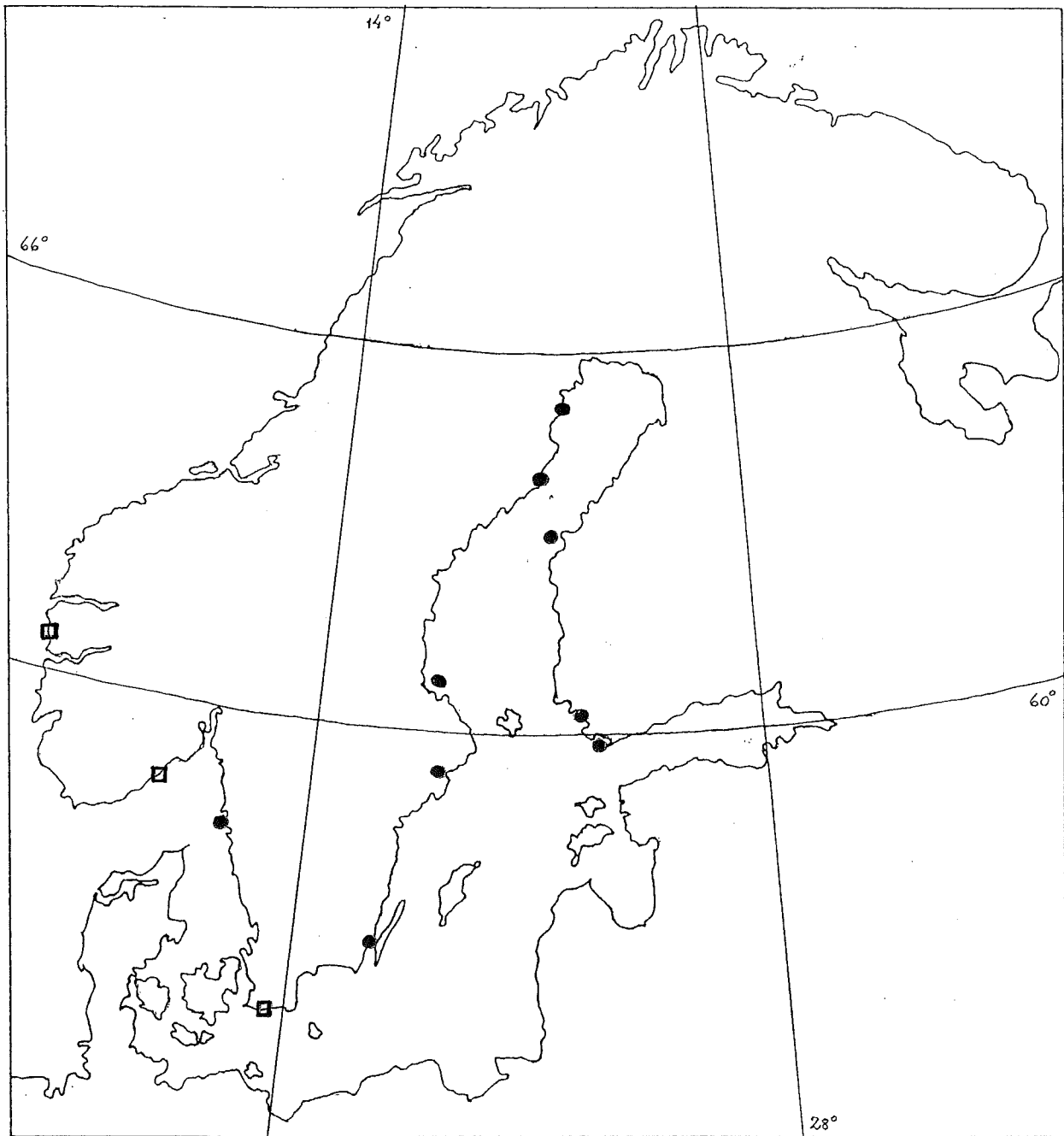


Figure 2. Sea level stations (mainly sea level marks) with a time span of 50 years or more around 1840, denoted by black dots. Coasts with other sea level information are indicated by squares.

whether he used English or Swedish feet but the difference is insignificant in our case.

*Ledskär (1749)*

The mark at Ledskär (close to Ratan) in the northwestern Gulf of Bothnia was established in 1749 by Chydenius (Chydenius & Lacman, 1749). In 1819 Hällström found the approximate mean sea level to be 2.60 feet below the 1749 mark (Hällström, 1823).

*Storrebben (1750)*

The mark at Storrebben in the northernmost part of the Gulf of Bothnia was established in 1750 by Hellant, who (according to a letter of his to the Royal Academy of Sciences) had developed some method for estimating mean sea level. In 1796 Hjort af Ornäs found the approximate mean sea level to be 1.90 feet below the 1750 mark (Hällström, 1823; year of mark erroneous there).

*Åbo slott (1750)*

At Åbo slott, i.e. the castle of Åbo (Turku), near the entrance to the Gulf of Finland, there is no ordinary sea level mark. Instead, the flat bedrock at the northwestern tower of the castle, close to the sea, served as a reference mark. This was levelled in 1750 by Gadolin, who found its height to be 24.2 feet above mean sea level as determined from some repeated sea level readings in the first half of the year (Gadolin, 1751). In 1841 Wallenius and Hällström (a brother of the above-mentioned Hällström) repeated the levelling, now obtaining the height 25.95 feet, i.e. an increase of 1.75 feet (Hällström, 1842; levelled height misprinted there).

*Hangöudd (1754)*

The mark at Hangöudd at the entrance to the Gulf of Finland was established in 1754 by Ehrensvärd, in connection with a hydrographic survey. In 1837 Nordenskiöld found the approximate mean sea level to be 1.67 feet below the 1754 mark (Hällström, 1842).

*Vargö (1755)*

The mark at Vargö (later Bergö) in the northeastern Gulf of Bothnia was established in 1755 by Klingius. Mean sea level as determined from some repeated sea level readings during the year was 0.2 feet below the mark

(Runeberg, 1765). In 1821 Brodd found mean sea level to be 2.87 feet below the mark, i.e. a lowering of 2.67 feet (Hällström, 1823).

*Skallö (1756)*

The mark at Skallö in the southern Baltic proper was established in 1756 by Wijkström. Mean sea level as determined from daily sea level readings 1754 – 1758 was 6.52 feet below the mark (Wijkström, 1757 & 1760; Siljeström, 1844). For 1800 Frigelius found mean sea level, on the basis of daily sea level readings during a couple of years, to be (probably) 6.56 feet below the mark, i.e. a lowering of 0.04 feet (Hällström, 1823; Siljeström, 1844).

*Marstrand (1770)*

The mark at Marstrand in the northeastern Kattegatt was established in 1770 by Cronstedt (Schultén, 1806; year of mark erroneous there). It was visited by Lyell in 1834, shortly after his visit to Lövgrund. From a person living close to the mark he got an indication that the instant sea level was not deviating too much from the mean sea level. This approximate mean sea level was found to be 0.83 feet below the 1770 mark (Lyell, 1835).

*Stockholm sea level gauge (commencing 1774)*

Systematic sea level observations at the Stockholm sluice, between the Baltic Sea and Lake Mälaren, started in 1774. The observations were performed, on an average, once a week. The data were stored by the sluice authority. The first (partly defective) compilation of annual means was published by Erdmann (1847). For a thorough treatment of the Stockholm sea level series, including a complete table of monthly and annual means calculated directly from the original data, see Ekman (2003). We will here use the data for 1774 – 1837, during which period the zero point of the sea level scale was kept unchanged.

### **3. Land uplift rates**

For the sea level marks the computation of land uplift rates from the sea level data in the last chapter is quite straightforward. Thereby, the measured height changes in feet have been transformed into mm through 1 Swedish foot = 296.9 mm. For the sea level gauge (Stockholm) the land uplift rate has been computed using linear regression of the annual means of the sea level. The results for all the stations are presented in Table 1. Here the stations are ordered anti-clockwise around the Baltic (with the Kattegatt at the end).

Table 1. Land uplift rates ( $U$ ) at sea level marks and one sea level gauge for the approximate period 1750 - 1830 (mm/yr).

Station	Lat.	Long.	Height change	Time span	$U$
Hangöudd	59.8	22.9	496	83	6.0
Åbo slott	60.4	22.2	520	91	5.7
Vargö	63.0	21.2	793	66	12.0
Storribben	65.2	21.7	564	46	12.3
Ledskär	64.0	20.9	772	70	11.0
Lövgrund	60.8	17.4	855	103	8.3
Stockholm	59.3	18.1	Lin. reg.	63	5.0
Skallö	56.7	16.4	12	44	0.3
Marstrand	57.9	11.5	246	64	3.8

The accuracy of the uplift rates at the sea level marks has to be more or less guessed. Whatever method was used to estimate the mean sea levels we might expect a standard error in the height change of about 10 cm. This would yield a standard error in the uplift rate of 1 - 2 mm/yr depending on the time span, the lower value for one century and the higher value for half a century. The accuracy of the uplift rate at the sea level gauge (Stockholm), on the other hand, can be calculated from the linear regression. The standard error there turns out to be 0.3 mm/yr, illustrating the tremendous improvement achieved by performing permanently repeated observations.

#### 4. The first land uplift map

Studying the land uplift values of Table 1 we note that they form some kind of pattern. They tend to increase from south to north, from 0 mm/yr in the southern Baltic to 12 mm/yr in the northern Gulf of Bothnia. Thus, at first glance the uplift seems to be latitude-dependent. However, counted from the maximum area nearly all stations are situated more or less to the south. We need to know something about the land uplift also in another direction. Fortunately, there is some information of that kind.

Keilhau (1838) tried to investigate if there was a land uplift along the Norwegian coast of the same kind as along the Swedish and Finnish ones. There were no old mean sea level marks to use, but he interviewed a lot of



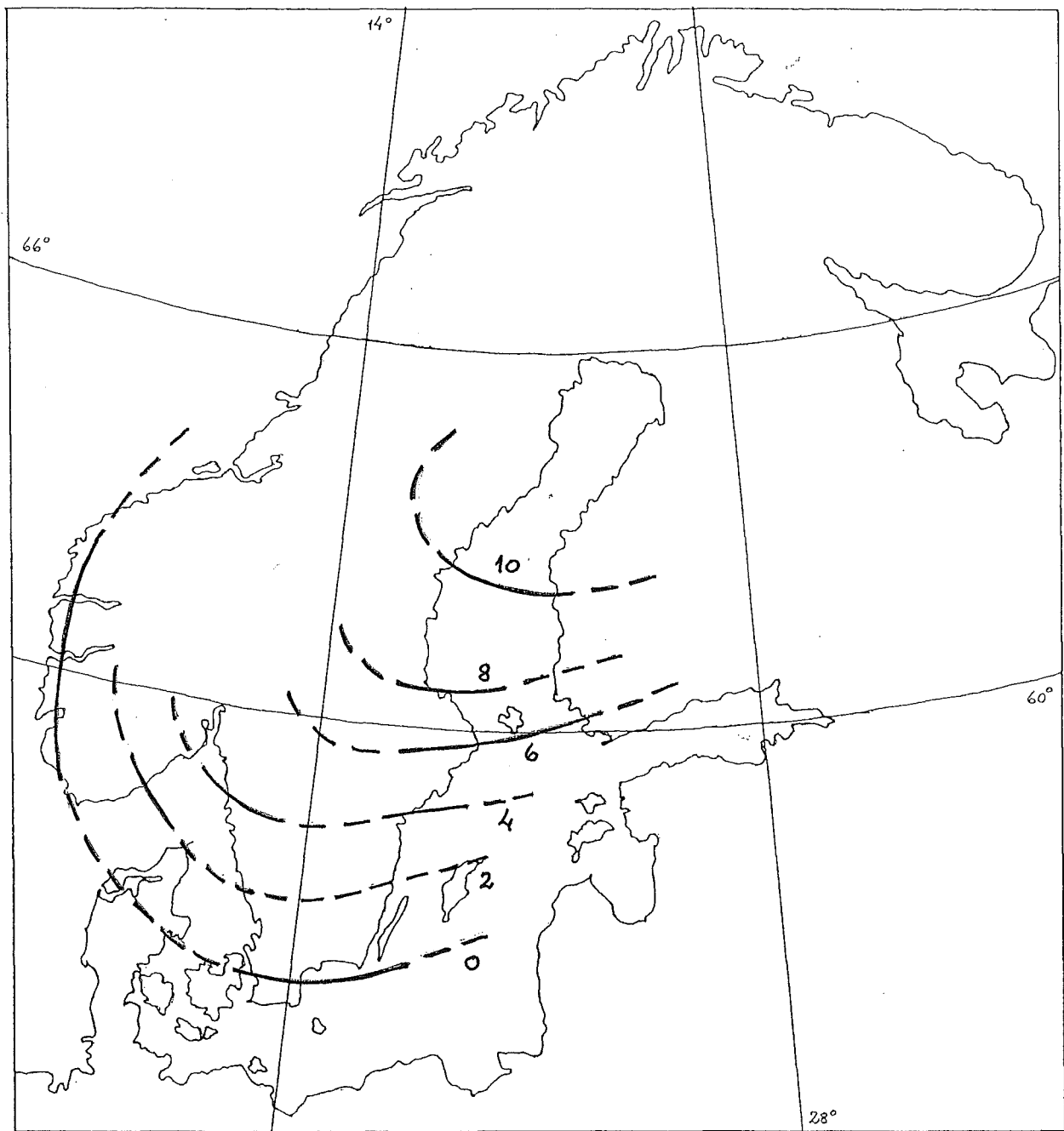


Figure 3. Land uplift of Fennoscandia based on sea level data c. 1750 - c. 1830 (mm/yr).

people living along the coast and studied some phenomena in nature. He found that there were signs of a moderate land uplift at least along the eastern part of the Norwegian south coast, i.e. in the northern Skagerrak. On the other hand, there was hardly any sign of a land uplift along the Norwegian west coast. These somewhat vaguely stated results are important complements to the numerical results above. In addition Lyell (1835), using the same methods, found that there was no sign of an uplift along the Swedish south coast.

We now are in the position to construct a land uplift map by drawing curves for every 2 mm/yr of uplift based on the data and information above. The result is presented in Figure 3. This is thus the very first land uplift map, based on data available in 1842. The map fairly clearly shows a phenomenon with a tendency of increasing uplift values from south as well as southwest and west towards the area around the northern half of the Gulf of Bothnia. In reality such a land uplift map was not constructed until more than 70 years later, as mentioned in the Introduction.

## 5. Comparisons with modern results

Let us now compare the land uplift rates on which the land uplift map is based, i.e. the uplift rates of Table 1, with modern results. Such a comparison is shown in Table 2. The modern uplift rates are basically taken from Ekman (1996). His values there represent the uplift of the crust relative to sea level during the 100-year-period 1892 – 1991. However, during this period sea level, due to warmer climate, has risen by close to 1.0 mm/yr, a sea level rise that did not occur during our period of approximately 1750 – 1830; see Ekman (2000). Therefore, the uplift rates of Ekman (1996) have all been increased by 1.0 mm/yr to relate to our time period.

The differences in Table 2 between old and modern uplift rates are consistent with our earlier approximate estimate of the standard error in the old uplift rates (the modern ones can be considered as error-free in this context). However, why are nearly all differences positive?

A possible explanation of the systematically positive differences could be the following. When the mean sea level marks were cut, mean sea level was often estimated using peoples general impression of this level at their coast. Such an impression might be based on their integrated memories from the last two decades or so, yielding a mean sea level referring to a year about one decade earlier than the year of the mark. If the remeasurement 50 – 100 years later was less biased, an error in the uplift rate would occur, yielding a positive difference of the order of 1 mm/yr in Table 2.

Table 2. Comparison of land uplift rates ( $U$ ) from Table 1 with modern land uplift rates ( $U_m$ ) according to text (mm/yr).

---

Station	$U$	$U_m$	Diff.
Hangöudd	6.0	4.0	+ 2.0
Åbo slott	5.7	5.0	+ 0.7
Vargö	12.0	8.5	+ 3.5
Storrebber	12.3	9.7	+ 2.6
Ledskär	11.0	9.2	+ 1.8
Lövgrund	8.3	7.2	+ 1.1
Stockholm	5.0	5.0	-
Skallö	0.3	1.6	- 1.3
Marstrand	3.8	2.6	+ 1.2

---

## 6. Why was the land uplift map never constructed?

We have seen that it was actually possible to construct a reasonable (partial) land uplift map already around 1840, based on uplift rates that are not too bad in comparison with modern ones. Why, then, was this map never constructed?

To find an answer to this question we need to understand how the knowledge of the behaviour of the sea level in the Baltic Sea has developed. The first mentioning of Baltic Sea level variations is in the land uplift paper by Celsius (1743). From this it is clear that there was some knowledge of seasonal variations in the sea level. A few years later Gissler (1747) discovered that there was a relation between air pressure and sea level, after having performed daily observations of both air pressure and sea level at the coast of the Gulf of Bothnia.

Half a century later Nordenankar (1792) claimed, on the basis of many years of experience from navigating in the Baltic, that winds were the main contributing factors to the sea level variations. He found that winds affected sea level in two different ways: Short-term winds tended to redistribute water within the Baltic, whereas long-term winds tended to increase or decrease the amount of water in the Baltic as a whole by transporting water from or to the North Sea. However, not much later Schultén (1806a) stressed the importance

of the air pressure again, an effect that, contrary to those of the winds, could be confirmed by precise measurements.

Thus, around 1840 all relevant ideas on the origin of the sea level variations in the Baltic had been put forward, but one could not judge their relative importance. As a consequence one tended to overestimate the importance of short-term variations which are easily visible and related to both winds and air pressure at the spot. The importance of wind-induced long-term variations, on the other hand, was not really understood.

This had consequences for the estimation of mean sea level at that time. The short-term variations could be more or less averaged out (or perhaps corrected for), but not really the long-term variations. Not even repeated sea level measurements during a year or so would be sufficient. To take care of the peculiar long-term sea level variations of the Baltic, repeated measurements performed during very many years would have been needed. In fact, the only way to solve the problem is actually to perform the measurements during such a long time that it seems more relevant to make them permanently, as at the Stockholm sluice. But this was not realized until much later.

As a result, land uplift rates at that time were calculated using all sorts of sea level marks and their sea level observations, without understanding the importance of selecting only those where the effects also of long-term variations were minimized. Therefore, one could not find a clear pattern in the uplift rates obtained and, consequently, one could hardly find any basis for drawing a land uplift map. (A typical example of this is the inconclusive investigation of Holmström (1888) based on about 60 sea level marks.) The pattern of the land uplift map was hidden behind large amounts of unreliable data.

## References

- Bergsten, F (1954): The land uplift in Sweden from the evidence of the old water marks. *Geografiska Annaler*, 36, 81-111.
- Blomqvist, E, & Renqvist, H (1914): Wasserstandsbeobachtungen an den Küsten Finlands. *Fennia*, 37/1, 1-433.
- Celsius, A (1743): Anmärkning om vatnets förminskande så i Östersjön som Vesterhafvet. *Kongl. Svenska Vetenskaps Academiens Handlingar*, 4, 33-50.
- Chydenius, S, & Lacman, S (1749): *De decrementis aquarum in sinu Bothnico*. Åbo, xx pp.
- Ekman, M (1996): A consistent map of the postglacial uplift of Fennoscandia. *Terra Nova*, 8, 158-165.
- Ekman, M (2000): Determination of global sea level rise and its change with time. *Small Publications in Historical Geophysics*, 7, 19 pp.
- Ekman, M (2003): The world's longest sea level series and a winter oscillation index for Northern Europe 1774 - 2000. *Small Publications in Historical Geophysics*, 12, 31 pp.
- Erdmann, A (1847): Svenska vallens höjning. *Öfversigt af Kongl. Vetenskaps-Akademiens Förhandlingar*, 4, 274-291.
- Gadolin, J (1751): Åbo slotts belägenhet öfver vattubrynet. *Kongl. Svenska Vetenskaps Academiens Handlingar*, 12, 219-224.
- Gissler, N (1747): Anledning at finna hafvets affall för vissa år. *Kongl. Svenska Vetenskaps Academiens Handlingar*, 8, 142-149.
- Hällström, C P (1823): Observationer öfver hafsyttans sänkning i Bottniska viken. *Kongl. Vetenskaps-Academiens Handlingar*, 1823, 30-41.
- Hällström, G G (1842): Ny mätning af Åbo slotts höjd öfver hafsyttan, jemte slutsatser om södra Finlands höjning öfver hafvet. *Acta Societatis Scientiarum Fennicae*, 1, 519-525.
- Holmström, L (1888): Om strandliniens förskjutning å Sveriges kuster. *Kongl. Svenska Vetenskaps-Akademiens Handlingar*, 22/9, 1-99.

- Keilhau, B M (1838): Undersögelser om hvorvidt i Norge, saaledes som i Sverrig, findes Tegn til en Fremstigning af Landjorden i den nyere og nyeste geologiske Tid. *Nyt Magazin for Naturvidenskaberne*, 1B, 105-254.
- Lyell, C (1835): On the proofs of a gradual rising of the land in certain parts of Sweden. *Philosophical Transactions of the Royal Society of London*, 125, 1-33.
- Nordenankar, J (1792): Om strömgångarne i Östersjön. Tal hållet för Kongl. Vetenskaps-Academien vid praesidii nedläggande, 13 pp.
- Runeberg, E O (1765): Anmärkningar, om någre förändringar på jord-ytan i allmänhet, och under de kalla climat i synnerhet. *Kongl. Vetenskaps Academiens Handlingar*, 26, 81-115.
- Schultén, N G (1806): Geographiska belägenheten af åtskilliga svenska orter, i synnerhet uti rikets södra och västra provinser. *Kongl. Vetenskaps Academiens Handlingar*, 27, 149-197.
- Schultén, N G (1806a): Försök att förklara orsaken till wattenets stigande och fallande, samt derigenom uppkommande strömdrag i Östersjön. *Kongl. Vetenskaps Academiens Handlingar*, 27, 77-94.
- Siljeström, P A (1844): Observationer rörande Östersjöns medel-vattenhöjd vid Calmar förr och nu. *Kongl. Vetenskaps-Akademiens Handlingar*, 1844, 329-345.
- Wijkström, A (1757 & 1760): Märke, at finna Östersjö vattu-högdens af eller tiltagande & Rön och märken på Östersjöns nu varande medelmåttiga vattu-högd. *Kongl. Vetenskaps Academiens Handlingar*, 18 & 21, 74-76 & 74-76.