

# The late Quaternary development of the Baltic Sea

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## INTRODUCTION

Since the last deglaciation of the Baltic basin, which began 15 000-17 000 cal yr BP (calibrated years Before Present) and ended 11 000-10 000 cal yr BP, the Baltic has undergone many very different phases. The nature of these phases were determined by a set of forcing factors: a gradually melting Scandinavian Ice Sheet ending up into an interglacial environment, the highly differential glacio-isostatic uplift within the basin (from 9 mm/yr to -1mm/yr; Ekman 1996), changing geographic position of the controlling sills (Fig. 1), varying depths and widths of the thresholds between the sea and the Baltic basin, and climate change. These factors have caused large variations in salinity and water exchange with the outer ocean, rapid to gradual paleographic alterations with considerable changes of the north-south depth profile with time. For example, the area north of southern Finland-Stockholm has never experienced transgressions, or land submergence, while the development south of that latitude has been very complex. The different controlling factors are also responsible for highly variable sedimentation rates, both in time and space, and variations of the aquatic productivity as well as faunal and floral changes. The basic ideas in this article follow the lengthy, but less up-dated version of the Baltic Sea history (Björck, 1995), a more complete reference list and, e.g., the calendar year chronology of the different Baltic

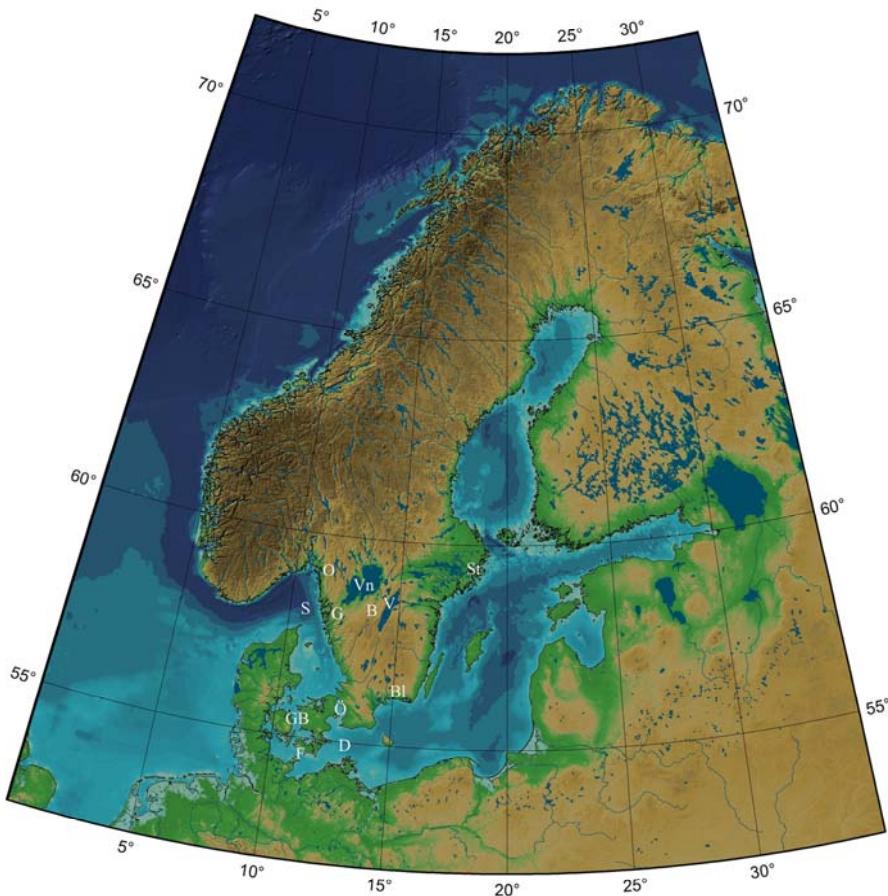
phases can be found on:

<http://www.geol.lu.se/personal/seb/Maps%20of%20the%20Baltic.htm>.

## THE GLACIAL TO LATE-GLACIAL BALTIC SEA

Due to repetitive, more or less erosive, glaciations during the last glacial cycle, little detailed evidence exists about the glacial conditions in the Baltic before 15 000-14 000 cal yr BP. Based on lithostratigraphic correlations and a large set of OSL (optically stimulated luminescence) and  $^{14}\text{C}$  dates, Houmark-Nielsen and Kjær (2003) have, however, indicated several ‘embryonic’ glacial stages of the Baltic Sea during MIS3 (Marine Isotope Stage 3 dated to c. 25 000-60 000 cal yr BP). According to their model the dynamic behavior of the southwestern part of the Scandinavian Ice Sheet between c. 40 000-17 000 cal yr BP, produced several proglacial Baltic Ice lakes before the last Baltic Ice Lake proper between c. 15 000-11 600 cal yr BP (Björck, 1995; Björck et al., 1996; Andrén et al., 1999). In-between glacial advances these proglacial stages have been dated to c. 40 000-35 000 and 33 000-27 000 cal yr BP, but with changing configurations during these stages (Houmark-Nielsen and Kjær, 2003). It is also postulated that the deep northwest-southeast trending Esrum-Alnarp valley, through Sjælland and Skåne, often functioned as the main connection between the Baltic basin and the (glacio)marine waters of the Kattegatt-Skagerrak. After the final advance some time between 17 000-16 000 cal yr BP - the Öresund lobe (Kjær et al., 2003) - a rapid deglaciation of the southern Baltic basin seems to have taken place (Björck, 1995; Lundqvist and Wohlfarth, 2001; Houmark-Nielsen and Kjær, 2003). A proglacial lake – the *Baltic Ice Lake* (BIL) – was developed in front of the receding ice sheet. Due to glacial in-filling of the Esrum-Alnarp

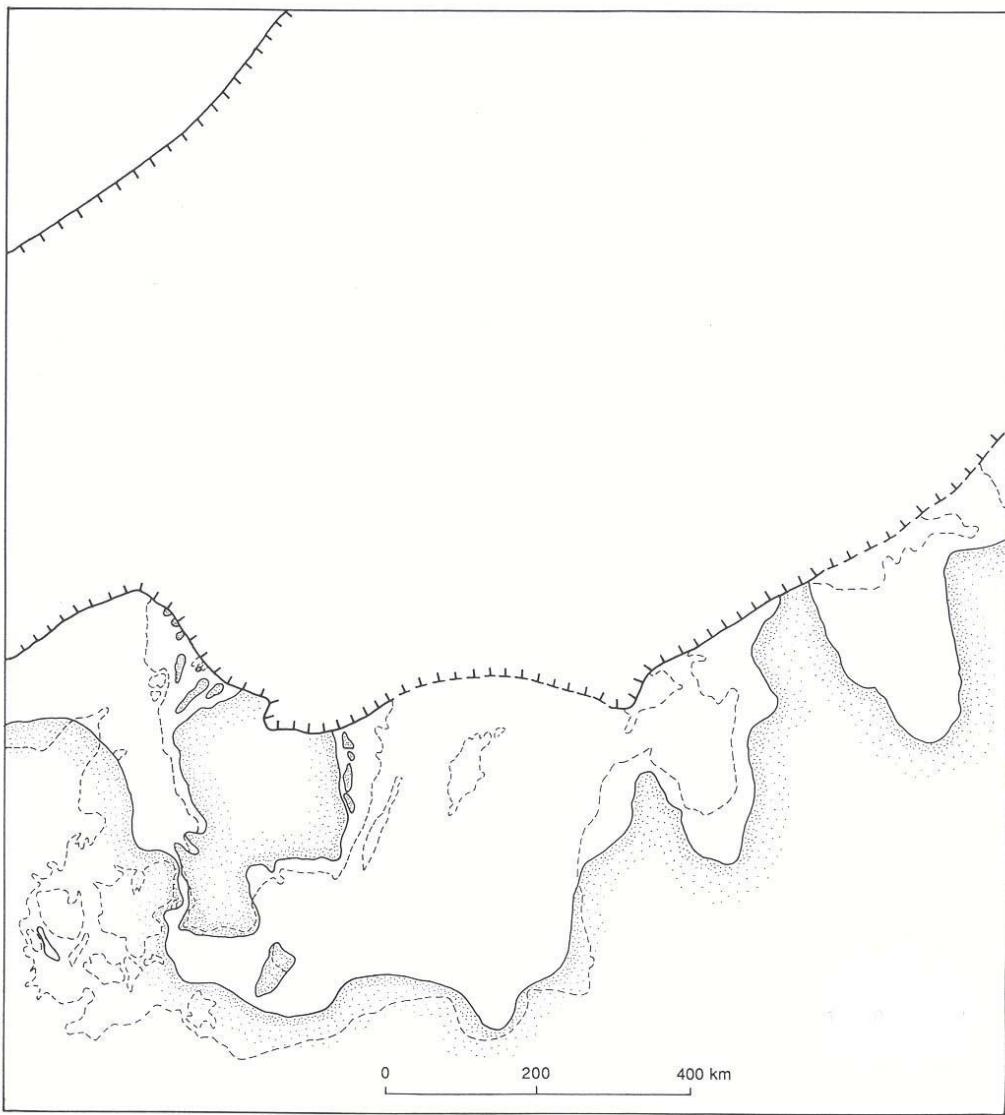
valley, the lowland in the Öresund region developed into the connecting channel between the Baltic and the sea in the northwest. Glaciolacustrine sediments, e.g., varved clays, were laid down in the Baltic as the ice sheet retreated northwards.



*Figure 1. The Baltic Sea region, showing both land and submarine topography. The letters denote geographical names used in the text. B=Billingen, Bl=Blekinge, D=Darss sill, F=Fehmarn Belt, G=Göta Älv river valley, GB=Great Belt, O=Otteid/Steinselva strait, S=Skagerrak, St=Stockholm, V=Lake Vättern and Vn=Lake Vänern.*

At this early stage of the BIL global sea level was situated at -100 m (Lambeck and Chappell, 2001); >2/3 of the last glacial maximum ice sheets still remained to be melted. Since the remaining rebound of the loading effect from the ice sheet was fairly small in the southernmost Baltic, the coast line was situated below today's sea level in southern Denmark, Germany and Poland. However, further north both the total and remaining unloading effect – glacial isostatic uplift - was larger than 100 m, and therefore the coast lines of Sweden and the Baltic republics were above today's sea level; the further north the higher.

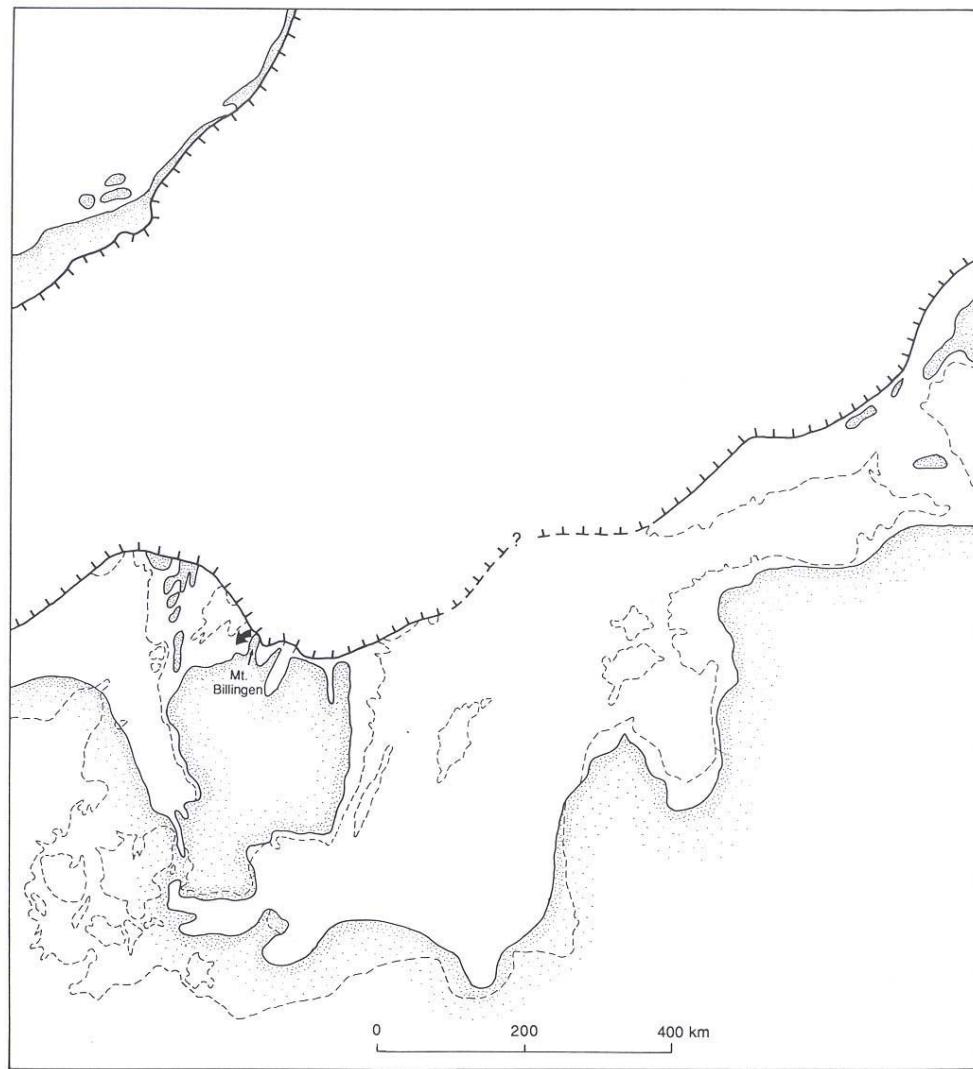
As a consequence of the uplift the Öresund area, which was now the threshold of the BIL, emerged faster than the rising sea level. This gradual shallowing of the outlet increased the velocity of the out-flowing water and thus also the erosion of the sill area. As long as loose Quaternary deposits could be eroded the erosion continued, and the present Öresund Strait was possibly shaped, with the island of Ven being an erosional remnant of a previous till-covered landscape. However, when the bedrock sill of flint-rich bedrock between Malmö and Copenhagen was exposed, erosion ceased. The consequence of this was that the continuing uplift made the threshold gradually shallower, until a critical water velocity was reached. At this stage, c. 14 000 cal yr BP (Fig. 2), the water level inside the threshold, i.e. the BIL level, had to rise to compensate for the decreased water depth of the sill. This caused the BIL to rise above sea level; a gradually higher water fall was created between the BIL level south of the threshold and sea level north of it. It also meant that coastal areas situated north of the Öresund isobase (isobases connect areas with the same uplift/shoreline) continued to emerge, while areas south of it submerged, the latter causing a transgression.



*Figure 2. The configuration of the Baltic Ice Lake at c. 14 000 cal yr BP. Note that the drainage through Öresund and that today's coast line is marked with a stipple line. After Björck (1995).*

The melting Scandinavian Ice Sheet had a strong impact on the aquatic and sedimentary conditions in the Baltic; fresh-water with a strong glacial influence produced clayey-silty sediments often of varved (annual layering) type and without organic material. Diatoms are rarely found in these sediments and it is doubtful if any fauna at all existed in this glacial lake. As the melting continued northwards, an important water shed

melted out of the retreating ice sheet: the Billingen bedrock ridge in south central Sweden between the two large lakes Vättern and Vänern. The Billingen area almost formed a ‘wall’ between the sea in the west and the up-dammed BIL in the east.



*Figure 3. The configuration of the Baltic Ice Lake at c. 13 000 cal yr BP. Note that it was drained north of Mt. Billingen and that Öresund was dry land. The arrow marks a possible subglacial drainage before Mt. Billingen was completely deglaciated. After Björck (1995).*

However, when the ice retreated to the northern tip of Billingen around 13 000 cal yr BP (Fig. 3), the BIL was drained west, initially beneath the ice. We think the BIL was

lowered some 10 m at this event, but any morphologic evidence about this drainage would later be destroyed by the ice. The effect of the sudden lowering was that Öresund was abandoned as the outflow and the BIL water flowed through the, at the time glaciomarine, Vänern basin and out into the Skagerrak through several different valleys/fiords. However, there is no evidence from sediments that saline water managed to penetrate into the Baltic, east of Billingen.

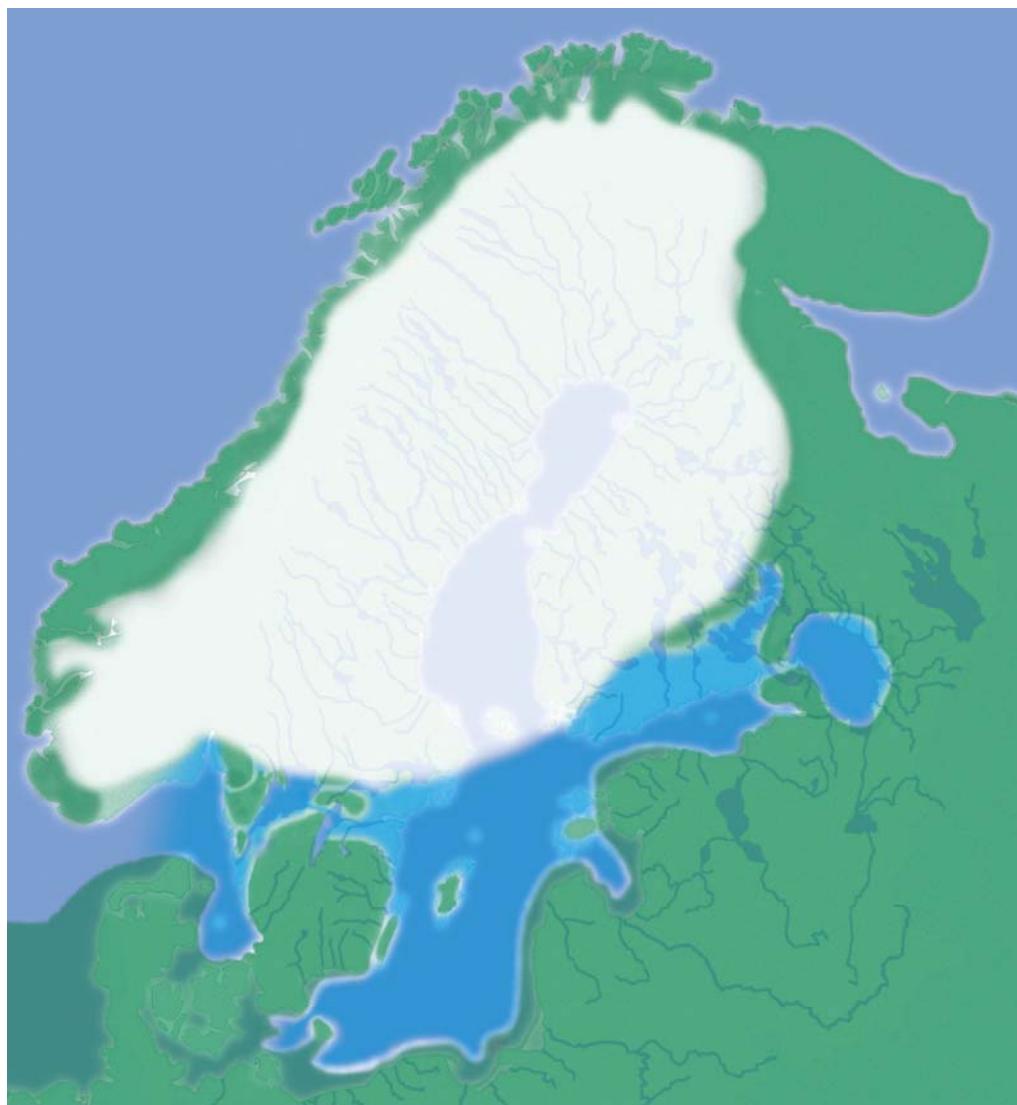


*Figure 4. The configuration of the Baltic Ice Lake just prior to the final drainage, 11 700 - 11 600 cal yr BP, which was to lower the Baltic with 25 m. From Andrén (2003a).*

At c. 12 800 cal yr BP the North Atlantic region experienced a fairly abrupt climatic change, the so-called Younger Dryas cooling. One effect of the lowered temperatures, especially in winter, was that the previously receding ice sheets of the region began to expand again, and the Scandinavian Ice Sheet advanced southwards to block Billingen again. This would have dramatic effects on the BIL: the water level would once again rise above sea level until Öresund began to function as the outlet (Fig. 4). This quick transgression would have continued slowly in areas south of the sill, while the remaining Baltic coasts experienced regression, or emergence. The outlet/sill area was still rising quicker than the rising sea, which meant that the BIL rose more and more above sea level; the water fall in Öresund became gradually higher. During this time the sediments in the Baltic were still very influenced by the glacial input, even in the southern Baltic.

At the end of the Younger Dryas cool period the ice sheet started to retreat again, and sometime between 11 700 and 11 600 cal yr BP a second, and very dramatic, drainage occurred at Billingen when the ice sheet receded north of the barrier. Since the Öresund threshold at this time had risen c. 25 m above sea level the water level within the Baltic basin fell with the same amount. It has been calculated that this drainage took 1-2 years and the main traces of it, huge sediment complexes of pebbles and boulders, can be found 5-7 km west of Billingen. As a consequence of the drainage the coast around the Baltic emerged out of the water and ‘fresh’ coasts were suddenly exposed. Especially in the southern Baltic large areas emerged and became land areas, which was of course also the case with the Öresund sill. A large land bridge between Skåne and Själland was

established, which favoured a rapid northward plant and animal colonization during the imminent Holocene interglacial period.



*Figure 5. The configuration of the Yoldia Sea stage at 11 400 - 11 300 cal yr BP, when a short saline phase is about to start. Note the large paleogeographic changes between Figures 4 and 5 with the huge land-bridge in the south and the Närke Strait in the north. From Andrén (2003b).*

## THE POST GLACIAL BALTIC SEA

### The *Yoldia* Sea stage

Obviously the final drainage of the BIL at 11 600 cal yr BP was a turning point in the late geologic development of the Baltic Sea: a sudden paleogeographic change, a warmer climate, a rapidly retreating ice sheet and direct contact with the saline sea in the west, incl. Vänern. This is also the starting point for the next Baltic stage, the *Yoldia* Sea stage, which would last c. 900 years.

The straits between Vänern and the Baltic were initially narrow, and saline water could not enter into the Baltic mainly due to the large amount of out-flowing water. It would take 250 years (Andrén et al., 1999) until the straits had opened up enough to allow eastward penetration of salt water (Fig. 5). This slightly brackish phase had its highest salinities in the low-lying areas between Vänern and Stockholm. However, brackish bottom-water also managed to penetrate down to the southern Baltic, creating periodically anoxic bottom conditions. Brackish conditions are shown by occurrences of foraminifera and the bivalve mollusk *Portlandia (Yoldia) arctica* as well as by the diatom flora of the sediments. This slightly saline phase only lasted for some 150 years until the straits between the marine water in Vänern and the Baltic became too shallow to allow saline inflow. Although the brackish conditions turned into fresh-water the Baltic was still at level with the sea, and the sediments during the complete *Yoldia* Sea stage were characterized by low organic content. As a contrast the western part of Vänern was a fairly fauna-rich marine embayment (Fredén, 1986).

Owing to the on-going and still rapid uplift in south central Sweden, the straits between Vänern and Skagerrak became gradually shallower, and even some of them

emerged above sea level. The out-flowing water from the Baltic had to pass through Vänern and these straits, and in the end only two straits functioned: the Göta Älv strait, which today is the Göta Älv river valley between Vänern and Göteborg, and the Otteid/Steinselva strait at the Swedish-Norwegian border east of Idefjorden.



*Figure 6. The configuration of the Akyllus Lake stage at c. 10 300 cal yr BP at the culmination of the Akyllus transgression. Note the outlets west and southwest of Lake Vänern. From Andrén (2003c).*

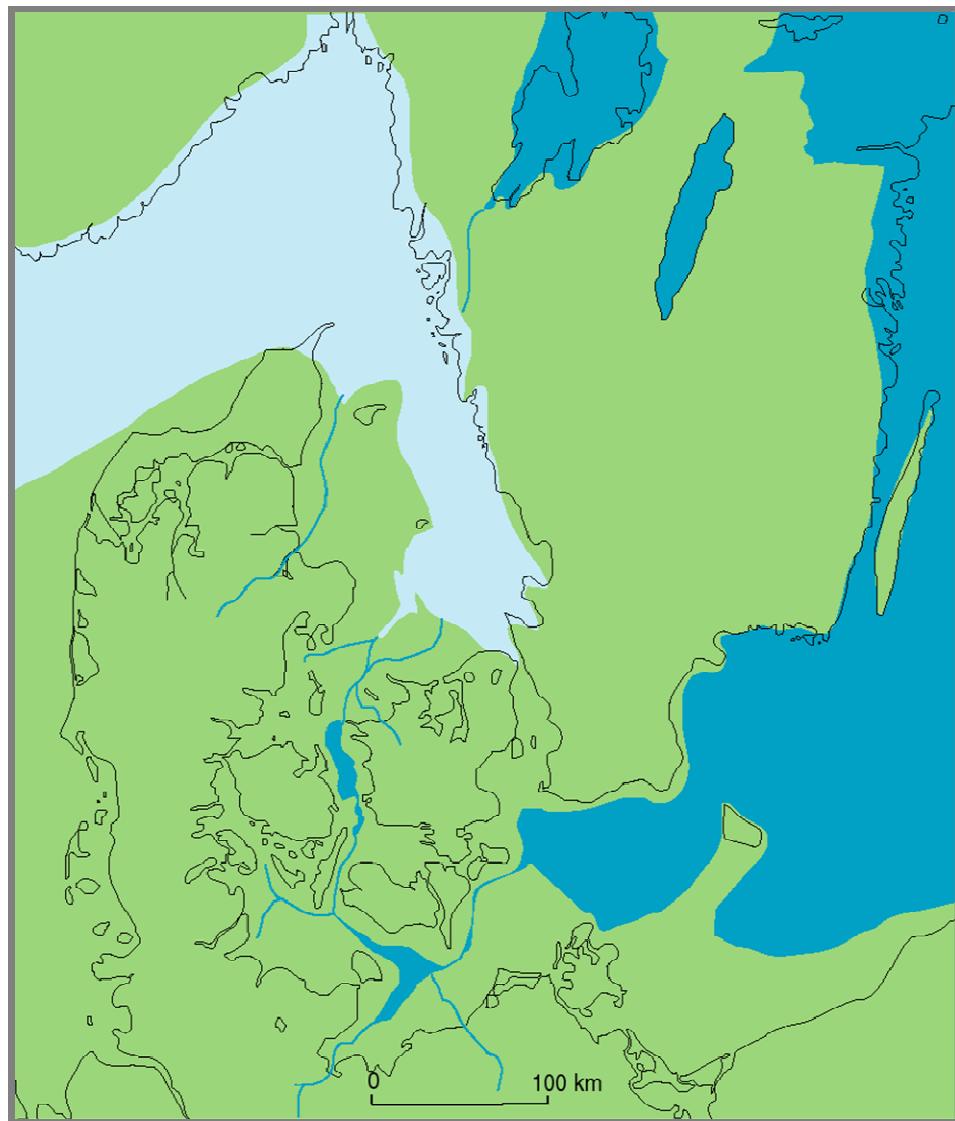
## The Ancylus Lake stage

The gradual shallowing and narrowing of these straits resulted in increased water velocity in these outlets until a maximum was reached when they could not ‘swallow’ the amount of water entering the Baltic basin (including melt-water from the melting ice sheet); the water level inside the narrow straits had to rise to compensate for the decreasing outflow area in the straits. Similar to the up-damming of the Baltic Ice Lake, the water level had to rise in pace with the uplift of the sills/straits. South of the isobases for the outlet region this would result in a transgression since the uplift here was smaller than the forced water level rise, while to the north the situation would be the opposite; a northwards increasing regression. This tilting effect is the onset of the *Ancylus Lake* transgression, which started around 10 700 cal yr BP. The possibly already submerging coasts in the southernmost Baltic experienced an increased flooding, while the previously emerging coasts of southern Sweden and the northern Baltic republics now changed into submergence. This sudden submergence, or transgression, is witnessed by, e.g., drowned pine forests east of Skåne and tree-ring analyses show rapidly deteriorated living conditions. The transgression is also clearly displayed by the *Ancylus* beach; a raised beach found in many places in, e.g., southeast Sweden, on the island of Gotland, and in Latvia/Estonia showing transgressive features. The fresh-water conditions with low primary productivity at the end of the *Yoldia Sea* and during the *Ancylus Lake*, named after the fresh-water limpet *Ancylus fluviatilis*, resulted in good mixing of water without permanent stratification. The sediments of the *Ancylus Lake* are also poor in organic material, and the further north the more glacially influenced they are. The amount of the *Ancylus* transgression varies between areas/regions depending on the local uplift. The maximum

transgression probably occurred outside the Polish coast and amounted to c. 20 m, while a transgression of 10-12 m characterized the *Ancylus* coast in the southwest, Denmark-Sweden-Germany. The latter amount was probably also how much the *Ancylus Lake* was finally dammed-up above sea level. The transgressive phase of the *Ancylus Lake* lasted c. 500 years, and was obviously governed by the possibility for the Baltic water to find an alternative outflow area. This meant that the transgression in the south continued as long as the constrained sills west of Vänern functioned as outlets (Fig. 6).

From independent studies we know that the *Ancylus* transgression ended abruptly with a fairly sudden lowering of the Baltic water level at c. 10 2000 cal yr BP. The rate of the lowering, or regression, strongly implies that it is not only a gradual isostatic effect that shows up in the shore displacement curves, but rather a forced regression; the absolute water level fell. The most likely explanation for such a regression would be that the *Ancylus Lake* level fell due to a lowering of the base level. Since the base level was determined by the sills/outlets, it would mean that the sill(s) was eroded. We do, however, also know that the sills west of Vänern consist of crystalline bedrock, and it is hardly possible for water to suddenly erode 10 m of hard bedrock. It has therefore been assumed that the water found a new outlet. Because of the transgression in the south, the most obvious threshold/outlet candidate should be situated in low-lying areas of the Danish-German area, which is also characterized by lose Quaternary deposits. For a long time it has therefore been postulated that the water found its way over Darss Sill, into Mecklenburg Bay, over Fehmarn Belt and finally through the deep Great Belt, between the islands of Sjælland and Fyn, the so-called Dana River. Parts of the submarine morphology along this path have been interpreted to be a remnant of such an erosive

event. However, recent German and Danish studies (e.g., Bennike et al., 1998; Jensen et al., 1999; Lemke et al., 1999) partly contradict such a scenario, although Bennike et al. (2004) recently dated river deposits in the Great Belt channel to c. 10 200 cal yr BP, surrounded by levée and lake sediments.



*Figure 7. The configuration of the Akyllus Lake just prior to the first minor saline ingression at c. 10 000 cal yr BP. In comparison with Figure 6, note the regressive shore line as a consequence of both isostatic uplift and the lowering caused by the Akyllus drainage. Also note that Lake Vänern was no longer a part of the Akyllus Lake. From Jensen et al. (2002).*

In fact, a compromise between the rather dramatic picture of the Ancylus drainage presented by Björck (1995) and Novak & Björck (1998) and the calm Danish-German solution may be possible: an initial regression was caused by a few metres of erosion of the Darss Sill and possibly also in the Great Belt channel lowering the Baltic by up to 5 m. This was followed by a fairly calm fluvial phase; the gradient between the Kattegatt sea level and the *Ancylus Lake* level was only perhaps 5 m. As the region was now characterized by a rising sea level/base level this gradient decreased and conditions gradually became even calmer. We also know that the area outside the mouth of the Great Belt channel in Kattegatt at this time was not characterized by marine conditions, but was very influenced by fresh water (Bennike et al., 2004). Since the uplift of the area had more or less ceased, conditions were now controlled by the rapidly rising sea level (2-2.5 cm/yr). It would therefore last only 200-300 years before sea level was at level with the *Ancylus Lake*, i.e. at c. 10 000 cal yr BP (Fig. 7).

The transitional stage between the fresh-water of the *Ancylus Lake* and the following brackish-marine *Littorina Sea* (named after the marine gastropod *Littorina littorea*), named the Early Littorina Sea by Andrén et al. (2000), is also partly an enigma. The first signs of marine influence have usually been seen in sediments with an age of c. 9000 cal yr BP, usually in the southern Baltic area. This is also in accordance with the time when we think that the Öresund Strait was flooded by the global marine transgression; at that time the sea level rise had exceeded the uplift rate in South Sweden. Therefore the younger limit of the *Ancylus Lake*, has often been set at c. 8500 cal yr BP, although geologists have been aware that the transition into the *Littorina Sea* is complex; the end of this transition stage has occasionally been named the Mastogloia Sea. Lately,

however, data from the Bornholm Basin and the archipelago of Blekinge in southeastern Sweden imply that the first saline influence may have occurred already at c. 9800 cal yr BP (Andrén et al., 2000; Berglund et al., 2005). This indicates that saline water from Kattegatt, through the Great Belt-Fehmarn-Mecklenburg-Darss channel, could occasionally penetrate into the Baltic fairly soon after the point in time when the rising sea level began to rise the Baltic level. However, this narrow and long outlet did never allow large amounts of salt water into the Baltic. It would take another c. 1500 years before a real marine influence was felt inside the Baltic; then sea level had finally reached up to the Öresund threshold between Limhamn and Dragør and a wide outlet/inlet area was created.

### *The Littorina Sea*

If we disregard some of the uncertainties about the initial outlet/inlet area during the Ancylus-Littorina transition, we can at least clearly document a rapid spread of saline influence throughout the Baltic basin around 8500 cal yr BP. When the first clear signs of marine water appear, usually defining the onset of the *Littorina Sea* in the related sediments, this is also usually reflected in the sediment composition as an increased organic content. This implies that with the increased saline influence the aquatic primary productivity clearly increased in the Baltic. In the beginning of this phase salinities were very low in the north, but between 8500-7500 cal yr BP the first and possibly most significant *Littorina* transgression set in. The reason that the southern Baltic, up to approximately the Stockholm-south Finland area, would experience transgressions during the forthcoming 2500-3000 years was that isostasy in this whole region was less rapid

than the on-going sea level rise. While the causes for most of the separate *Littorina* transgressions can possibly be related to sudden collapses of the Antarctic Ice Sheet and its huge ice shelves, the more or less steadily rising sea level until 6000 cal yr BP was mainly an effect of the still melting North American ice sheets. At this point in time the last remnants of the Labrador Ice Sheet melted.



Figure 8. The *Littorina* Sea stage at c. 7000 cal yr BP. Note the wide straits in the south and the still much remaining uplift in the north, especially conspicuous in lowland areas. From Andrén (2004).

During the first three successive *Littorina* transgressions the water depths increased considerably (Berglund et al., 2005) in the at the time two functioning inlets, Öresund and Great Belt. The extent of these transgressions was in the order of at least 10 m in the inlet areas, with a large increase in water depth at any critical sill. In turn this allowed a significant increase in the amount of inflowing saline water into the Baltic, with higher salinities as an important consequence. The increasing salinity, in combination with the warmer climate of the mid-Holocene, generated a fairly different aquatic environment, compared to before. In terms of richness and diversity of life, and therefore also primary productivity, the biological culmination of the Baltic was possibly reached between 7500-6000 cal yr BP (Fig. 8). The high productivity, in combination with increased stratification due to high salinities in the bottom water, caused anoxic conditions in the deeper (>100 m) parts of the Baltic (Sohlenius et al., 2001), especially in the central and northern parts with its larger distance to ‘fresh’ oxygenated Atlantic water.

A turning point in the Baltic development can be seen after c. 6000 cal yr BP: the transgressive trend is broken around a large part of the Baltic coast line, although minor transgressions may have occurred until c. 5000 cal yr BP. While sea level had, generally speaking, ceased to rise, the uplift pattern in the Baltic area was complex. In the southernmost Baltic area the submergence continued, which meant that the transgression rate became less extensive than during peak *Littorina* time. In Sweden and along the coast from northern Lithuania and northwards uplift was still going on, which meant that the end of sea level rise resulted in a renewed regression.

The regression caused shallower sills, which meant that a gradually less amount of marine water could enter the basin. Since the main sill areas, Öresund and Great Belt, today are situated around the isobase -0.4 mm/yr (Ekman, 1996), it implies that this shallowing ended perhaps a few hundred years ago. Since then the inlet areas have become slightly deeper, causing more inflow of Atlantic waters. Another consequence of the differential uplift is that a large part of the Baltic is rising, causing a shallowing effect, and a small part is sinking. If we are worried about a future reduced circulation/ventilation in the Baltic, it is fortunate, at least in the long-time perspective, that the deepest parts of the basin are situated in areas with fairly high uplift rates.

Generally speaking the Baltic sediments tell us that since peak *Littorina* time, some 6000 years ago, salinities in the Baltic have gone down. Three possible reasons for this decline can be postulated: less inflow of Atlantic waters from Skagerrak/Kattegatt, and decreased summer temperatures and increased precipitation in most of the Baltic region. All these three factors would by themselves have triggered reduced salinities, and it is very likely that they all are responsible for the long term trend.

According to several independent studies the last millennium of the Baltic Sea seems to have been characterized by at least two phases of high productivity and anoxic bottom conditions, the Medieval Warm Period and the last century, and one period with decreased productivity and oxygenated sediments, the Little Ice Age. Thus, the natural climatic variability seems to be a key player for the Baltic Sea and its often profound changes. Owing to the sudden appearance of the North American soft celled clam *Mya arenaria*, the youngest part of the Baltic Sea history have often been named the Mya Sea; it was thought to have been introduced in the bilges of European trade ships. However,

Petersen et al. (1992) dated such clams in Danish coastal deposits and found that they predate Columbus' discovery of America with several hundreds of years. This would be additional evidence that Vikings discovered America before Columbus and that their ships brought this 'stranger' and newcomer into the Baltic environment. This is a good example of how humans have been part of, and often were an important player of the natural environment. Today this is truer than ever.

**Acknowledgements:** With this article I would like to honor the friend and colleague Wolfram Lemke, who very sadly suddenly passed away when this article was being written.

## REFERENCES

- Andrén, T., Björck, J. & Johnsen, S. 1999: Correlation of Swedish glacial varves with the Greenland (GRIP) oxygen isotope record. *Journal of Quaternary Science* 14, 361-371.
- Andrén, E., Andrén, T., Sohlenius, G. 2000: The Holocene history of the southwestern Baltic Sea as reflected in a sediment core from the Bornholm Basin. *Boreas* 29, 233-250.
- Andrén, T. 2003a: Baltiska Issjön – eller hur det började. *Havsutsikt* 1, 2003, 4-5.
- Andrén, T. 2003b: Yoldiahavet – en viktig parentes. *Havsutsikt* 2, 2003, 6-7.
- Andrén, T. 2003c: Acyclussjön – fortfarande ett mysterium. *Havsutsikt* 3, 2003, 8-9.
- Andrén, T. 2004: Littorinahavet – en salt historia. *Havsutsikt* 1, 2004, 8-9.
- Bennike, O., Jensen, J.B. & Lemke, W. 1998: Fauna and flora in submarine early Holocene lake-marl deposits from the southwestern Baltic Sea. *The Holocene* 8, 353-358.
- Bennike, O., Jensen, J.B., Lemke, W., Kuijpers, A. & Lomholt, S. 2004: Late- and postglacial history of the Great Belt, Denmark. *Boreas* 33, 18-33.
- Berglund, B.E., Sandgren, P., Barnekow, L., Hannon, G., Jiang, H., Skog, G. & Yu, S. 2000: Early Holocene history of the Baltic Sea, as reflected in coastal sediments in Blekinge, southeastern Sweden. *Quaternary International* 130, 111-139.
- Björck, S. 1995: A review of the history of the Baltic Sea, 13.0-8.0 ka BP. *Quaternary International* 27, 19-40.
- Björck, S., Kromer, B., Johnsen, S., Bennike, O., Hammarlund, D., Lemdahl, G., Possnert, G., Rasmussen, T. L., Wohlfarth, B., Hammer, C. U. & Spurk, M. 1996:

- Synchronized Terrestrial-Atmospheric Deglacial Records Around the North Atlantic. *Science* 274, 1155-1160.
- Ekman, M. 1996: A consistent map of the postglacial uplift of Fennoscandia. *Terra Nova* 8, 158-165.
- Fredén, C. 1986: Quaternary marine shell deposits in the region of Uddevalla and Lake Vänern. *Sveriges Geologiska Undersökning. Rapporter och Meddelanden* 46, 192 pp.
- Houmark-Nielsen, M. & Kjær, K. 2003: Southwest Scandinavia, 40-15 kyr BP: paleogeography and environmental change. *Journal of Quaternary Science* 18, 1-18.
- Jensen, J.B., Bennike, O., Witkowski, A., Lemke, W. & Kuijpers, A. 1999: Early Holocene history of the southwestern Baltic Sea: the Ancylus Lake stage. *Boreas* 28, 437-453.
- Jensen, J.B., Kuijpers, A., Bennike, O. & Lemke, W. 2002: Balkat, The Baltic Sea without frontiers. *Geologi, nyt fra GEUS* 2002, 4, 19 pp.
- Kjær, K., Houmark-Nielsen, M. & Richardt, N. 2003: Ice-flow patterns and dispersal of Erratics at the southwestern margin of the last Scandinavian ice sheet: imprint after paleo ice-streams. *Boreas* 32, 130-148.
- Lambeck, K. & Chappell, J. 2001: Sea level change through the last glacial cycle. *Science* 292, 679-686.
- Lemke, W., Jensen, J.B., Bennike, O., Witkowski, A., & Kuijpers, A. 1999: No indication of a deeply incised Dana River between Arkona Basin and Mecklenburg Bay. *Baltica* 12, 66-70.

- Lundqvist, J. & Wohlfarth, B. 2001: Timing and east-west correlation of south Swedish ice marginal lines during the Late Weichselian. *Quaternary Science Reviews* 20, 1127-1148.
- Novak, B. & Björck, S. 1998: Marine seismic studies in southern Kattegatt, with special emphasis on longitudinal bars and their possible relationship to the drainage of the Ancylus Lake. *GFF* 120, 293-302.
- Petersen, K.S., Rasmussen, K.L., Heinemeier, J. & Rud, N. 1992: Clams before Columbus. *Nature* 359, 679.
- Sohlenius, G., Emeis, K.-C., Andrén, E., Andrén, T. & Kohly, A. 2001: Development of anoxia during the Holocene fresh-brackish water transition in the Baltic Sea, *Marine Geology* 177, 221-242.