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AN ATTEMPT TO RESOLVE THE PARTLY CONFLICTING DATA AND IDEAS ON THE ANCYLUS–LITTORINA TRANSITION

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Abstract. The transition phase between the Ancylus and Littorina stages of the Baltic Sea is an old controversial topic. With the newest data available we try to reach a compromise between the "dramatic" model, including a sudden and large drainage of the Ancylus Lake, and the idea of a non-existing Ancylus drainage through Denmark. This new model includes a minor, perhaps 5 m, sudden erosion and forced regression slightly before 10000 cal. yrs BP. This was followed by a 200–300 yr long period when the outlet through Denmark and Great Belt (Dana River) was characterized by a variable fluvial environment creating fluvial, levée and lacustrine deposits. During this period of rapidly rising sea level, we postulate that the gradient between the Ancylus Lake and sea level gradually decreased from some 5 m until sea level had reached the Ancylus and Darss Sill level. After this point in time occasional pulses of marine water could easier enter into the Baltic basin, which is seen as brackish pulses as early as 9800 cal. yrs BP in records from the Bornholm and Gotland basins, but also from Blekinge. It would, however, take another c. 1500 years before the Öresund threshold was flooded by the rising sea level, causing a significant rise in salinity sometime between 8500–8000 cal. yrs BP, and marking the true onset of the Littorina Sea.

Key words: sea level, Ancylus Lake, Littorina Sea, Baltic Sea.

INTRODUCTION

Research on the late- and postglacial development of the Baltic Sea has a long tradition in the circum-Baltic countries, but in spite of this more than century-long research, many questions remain to be solved. The reasons for this are many and the most obvious ones are presented below.

The length axis of the 1400–1500 km long Baltic basin is situated more or less perpendicular to the isostatic uplift isobases, which has created a very special relative sea level situation: while the coasts around southernmost Baltic sink c. 1 mm/yr, the coastal areas around the Bothnian Bay rise 8–9 mm/yr. This differential uplift has also varied over time and has been one of the reasons behind the complex development of the Baltic Sea. Furthermore, there are studies showing a variable isostasy within restricted areas, implying neotectonic movements, which have complicated shoreline correlations and sea level interpretations even more.

Owing to the deglaciation, differential uplift and shallow, often narrow, straits between the Baltic basin and the sea, the position of the water-level-controlling threshold has changed over time. In addition, sediment thresholds may have been eroded in pace with the ongoing uplift, until bedrock is exposed, preventing further erosion. Due to the differential, and often high, uplift rates such situations inevitably seem to have lead to new sill locations. We know that such threshold alterations often are related to important changes within the Baltic Sea region as well as to the water body itself; therefore the classic Baltic Sea stages can be attributed to different sills and thus different threshold depths as well as different levels in relation to sea level. This has created a Baltic Sea environment characterized by a variety of aquatic conditions: glaciolacustrine, glaciomarine, fresh-water and brackish-water conditions.

The processes of differential uplift in combination with the character of the sills have caused important paleogeographic changes in and around the Baltic basin. For example, high uplift rates of a non-erosive threshold in a basin like

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the Baltic, with its differential uplift, may lead to very different local "water-level-histories" within the basin: submerging coasts in one end while other remote coastal areas experience rapid emergence. On the other hand, erosion of the sill or a sudden change in the geographic position of the sill may in special situations lead to sudden lowerings of an up-dammed water level.

Since many of the important events and transitions in the Baltic Sea history have been fairly short and dramatic, another problem with obtaining a detailed enough Baltic Sea history is connected with dating problems: many different types of material from very different environments have been ^{14}C dated. Furthermore, the reservoir effect of the Baltic Sea is poorly known and with the changing salinities through time this has possibly also varied over time. Finally, a varying amount of reworked "old" carbon over time incorporated in bulk sediment samples due to the ongoing isostatic rebound further reduce the precision of ^{14}C dating.

Lately, much effort has been concentrated on finding new data from the transition between the Ancylus Lake regression and the initial Littorina Sea, to be able to arrive at a holistic solution. We will here try to present a first attempt to reconcile the different, partly opposing, views on this important part, of the Baltic Sea history; in fact the onset of the modern Baltic Sea.

THE ANCYLUS–LITTORINA TRANSITION "PROBLEMS"

Most geologists working with the Baltic Sea history agree that the Ancylus transgression is an anomaly in terms of glacial isostasy and eustasy; it precedes the expected postglacial transgression within marginal areas of glaciation (e.g. Clark *et al.*, 1978) with a few thousand years. Furthermore, this expected transgression, in the Baltic Sea case the Littorina transgression, did also occur. The Ancylus transgression rapidly followed the Yoldia Sea lowstand in the southern Baltic, with sometimes rather dramatic consequences. For example, a drowned pine forest in the Hanö Bay bears witness of this (Björck, Dennegård, 1988), and if the eleven ^{14}C dates of pine stumps are regarded to date one single event the pooled mean value of these dates is 9540 ±28 ^{14}C yr BP. Since this ^{14}C age is situated on the well-known 9500–9600 ^{14}C year plateau the calibrated age (2 σ) is much less confined: 11080–10940 (49.3%) and 10880–10710 (46.1%) cal. yrs BP (Reimer *et al.*, 2004). The tree-rings of the pines prior to the death of the trees show stress signs, which imply that the transgression began just before they died. The age of the onset of the transgression therefore lies slightly before 10700 cal. yrs BP, and an age of 10700–10900 cal. yrs BP seems rather likely considering the different records on this transition.

Because of ^{14}C plateaux at both the onset and end of the Ancylus transgression, the duration of the transgression is difficult to estimate in detail, but should be in the order of 600 years, with a culmination around 10200 cal. yrs BP (Björck *et al.*, 2001; Berglund *et al.*, 2005). The occurrence of the so-called Ancylus raised beach, especially on the islands of Öland and Gotland and in Latvia and Estonia, is a distinct feature of the Ancylus transgression maximum. The transgression is supposed to have been caused by the differential uplift between the outlet region west and southwest of Lake Vänern, south central Sweden, and the southern Baltic area, from Estonia and southwards (Björck, 1995); the further south the more extensive transgression. Independent records show that the transgression was followed by a distinct regression, summarized by Björck (1995) but also found in later studies (e.g. Berglund *et al.*, 2005), which is not only an implication that the Ancylus Lake was raised above sea level, but also that the (new) outlet threshold could be eroded (down to sea level). An Ancylus Lake outlet was placed through Denmark already in the late 1920´s (von Post, 1929), the so-called Dana River, and this concept was reviewed and discussed by Björck (1995) to be accommodated within the model originally described in Björck (1987) and further developed in Björck (1995). The basic idea was that a critical threshold in the Darss Sill area was reached, whereupon erosion began from the threshold and along an assumed pathway through lake basins and partly forming a river valley through the German–Danish area. This would at least partly have deepened, for example, the Great Belt and the area east of Langeland. Although Björck (1995) stated that this 10–15 m regression possibly lasted a couple of hundred years he also implied that it was characterized by high discharge and substantial erosion. This led Novak and Björck (1998) to relate high-energy longitudinal bars in southern Kattegatt to this event, and through hydrologic calculations they concluded that the regression could have taken place during 2–3 years. The latter model was immediately challenged by a set of Danish–German studies (e.g. Bennike *et al.*, 1998; Jensen *et al.*, 1999; Lemke *et al.*, 1999) showing that the postulated drainage area seems to have been characterized by fairly calm conditions during the time of the assumed drainage. These studies also implied that the amount of rapid regression, and thus erosion, was possibly not more than 7–10 m, and that the following marine ingression did not occur until 8500–8000 cal. yrs BP. Slightly later Andrén *et al.* (2000a) found indications of a first post-Ancylus brackish influence at c. 9800 cal. yrs BP in the Bornholm basin, which was later confirmed by a first brackish water peak in Blekinge, southeastern Sweden, dated to c. 9800 cal. yrs BP (Berglund *et al.*, 2005). An early brackish phase of the same age has also been documented reaching as far north into the Baltic basin as to the eastern Gotland basin, however, much weaker than in the southern part of the basin (Sohlenius *et al.*, 1996, Andrén *et al.*, 2000b). The question is: can these partly opposing views and data sets be reconciled. As you will see below, the answer is: Yes, they probably can.

A RECONCILABLE SOLUTION?

Firstly, let us postulate that the Ancylus Lake was dammed c. 10 m above sea level when Darss Sill began to function as a new threshold, in the beginning most likely together with the Göta Älv outlet in southwestern Lake Vänern. The assumed 10 m gradient between Darss Sill and the sea level at an outlet in southern Kattegatt is very low and would not in itself create high discharges. Furthermore, if the probable course of a Dana River is mapped out (Fig. 1) we find that the narrowest parts along the supposed river path have an outflow area of c. 500 x 10 m. In fact, with a water velocity of 3 m/s such a channel could 'swallow' all outflowing Ancylus water, without using the Göta Älv outlet. It is, however, very likely that the latter outlet functioned together with the Dana River in the initial stage. Depending on highly varying channel widths and depths this would have created a variable fluvial environment along the Dana River. This is also documented by Bennike *et al.* (2004) unit H1 in the Great Belt: it consists of lake, levée and fluvial deposits, showing initial erosion at some places and indications that the channel was filled up to critical depths at other places. A major fresh water

Fig. 1. Location map of the Baltic Sea area

Numbers refers to sites mentioned in the text: 1 – Öland, 2 – Gotland, 3 – Lake Vänern, 4 – Kattegatt, 5 – Bornholm basin, 6 – eastern Gotland basin, 7 – Blekinge, 8 – Göta Älv outflow in southern Kattegatt at this time is also shown by Bennike *et al.*'s (2000) study of a large submarine complex of brackish lagoonal deposits between Sjælland and the island of Anholt.

The independent evidence around the Baltic for a sudden regression following the Ancylus transgression can be explained by a very restricted forced regression of perhaps only 5 m, caused by fluvial erosion, followed by the 'normal' regression in the uplift regions. Regarding the Dana River it would mean that perhaps some 5 m difference between sea level and the Ancylus Lake remained to be equaled out before the Baltic was at level with the sea. At this time global sea level was rising c. 2 cm/yr (Lambeck, Chappell, 2001), and with an isostatic uplift that had ceased in the Darss Sill region (Björck, 1995), sea level would have reached the Ancylus Lake level within 200–300 years, i.e. slightly after 10000 cal. yrs BP. This would obviously have created even calmer fluvial-lacustrine environments along the Dana River, which is also documented in many of the Danish–German studies.

The first post-Ancylus brackish indications within the Baltic basin, dated to c. 9800 cal. yrs BP in both Blekinge (Berglund *et al.*, 2005) and in the Bornholm Basin (Andrén *et al.*, 2000a), have not been confirmed in sediments along the Dana River system. In fact they are challenged by fine grained, distinctly brackish sediments in the Darss Sill area (Jensen *et al.*, 1999, Witkowski *et al.*, 2005) dated to about 8500 cal. yrs BP.

However, three ^{14}C dates (Bennike, Jensen, unpublished) of terrestrial macrofossils in stratigraphically older parts of the supposedly brackish water sediments have yielded ages between 10300–9600 cal. yrs BP. They have previously been regarded as reworked macrofossils in much younger sediments, but with the new evidence from the Swedish studies it is possible that these finds in the Mecklenburg Bay show the same. This would indicate a surprisingly long period of slightly brackish conditions. After sea level had risen above the Darss Sill level it is possible that pulses of marine water could easier enter the Dana River system, causing occasional phases of more brackish water conditions in the southern Baltic. Such phases could have occurred during periods with dominating low-pressure systems over southern Scandinavia, such as during NAO+ conditions. It would, however, take another c. 1500 years before (more) saline conditions began to characterize the Great Belt (Bennike *et al.*, 2004), the southern Baltic (Andrén *et al.*, 2000a; Berglund *et al.*, 2005), but also the Baltic in general. This salinity rise was most likely related to a sea level flooding of the fairly wide threshold in the Öresund Strait sometime between 8500–8000 cal. yrs BP, as a consequence of the still rapidly rising sea level (Lambeck, Chappell, 2001). In comparison with the long and narrow Dana River, such a wide salt water ingression would have had a rather sudden impact on the whole Baltic environment, and we also know that the spread of saline bottom water conditions was rapid, from the south up to Finland (cf. Björck, 1995).

CONCLUSIONS AND RECOMMENDATIONS

The above outlined model shows that the final outlet for the Ancylus Lake could have been through the German–Danish area (Fig. 2), if a "calm" drainage model is applied. It also shows that it is possible that the transition between the Ancylus Lake and the Littorina Sea, named the Initial Littorina Sea and roughly corresponding to the former Mastogloia Sea, may have been a c. 1500 year long phase with occasional brackish water inflow through the Dana River system. This phase of very low and possibly fluctuating salinity (cf. Berglund *et al.*, 2005) did not turn into more marine conditions until the sea level rose above the Öresund Strait flint threshold area between Copenhagen (Dragør) and Malmö (Limhamn).

As so many times before in the past, the Darss Sill area turns up as a key area and near future work to solve the discussed problems should be carried out to make additional detailed interdisciplinary studies in this area to further clarify the possibly long brackish Mastogloia/Initial Littorina phase.

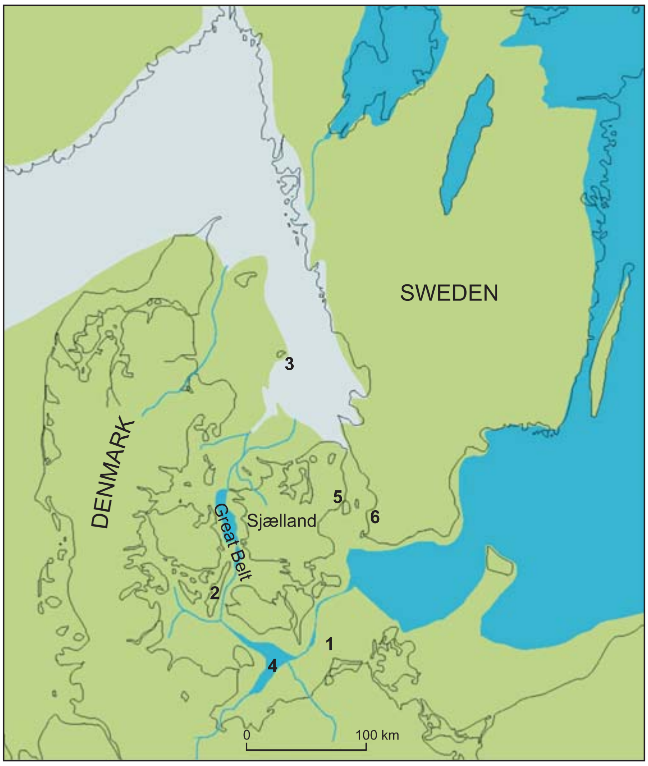

Fig. 2. The possible land-sea configuration in the southern Baltic ca. 10000 cal. yrs BP, including possible water routes through the German–Danish area, just prior to the onset of the transition from the Ancylus Lake to the Initial Littorina Sea

Modified from Jensen *et al.* (2002). Numbers refer to sites mentioned in the text; 1 – Darss Sill, 2 – Langeland, 3 – Anholt, 4 – Mecklenburg Bay, 5 – Copenhagen (Dragør), 6 – Malmö (Limhamn).

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