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Late Quaternary Coastal Records of Rapid Changes in the Eastern Baltic[1]

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ABSTRACT

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In the eastern Baltic area, comprising the countries of Estonia, Latvia and Lithuania, and the St. Petersburg and Kaliningrad Districts of Russia, there are a lot of phenomena suggesting rapid changes in sea level due to different factors. At the end of the Pleistocene, the present-day Baltic Sea was a big ice-dammed (local ice lakes) or ice-influenced (Baltic Ice Lake) lake with complicated water-level fluctuations. The drop of the Baltic Ice Lake at Billingen in Central Sweden about 10,300 yr BP resulted in the drainage of 25–30 m. A typical freshwater Ancylus Lake mollusc fauna, discovered beneath the brackish water Litorina Sea mollusc fauna in a tectonically rising area near the settlement of Partsi on the island of Hiiumaa, Estonia, provides evidence of the catastrophic lowering of the water level by at least 25–30 m at the end of the Ancylus stage about 8500 yr BP.

ADDITIONAL INDEX WORDS: *Baltic Sea, Eemian Sea, transgression, regression, sea-level change, Holocene, Lateglacial.*

INTRODUCTION

Rapid changes taking place in natural environments are of fundamental importance for better understanding of man-induced processes which should be recognized and managed. Shoreline displacements of the past provide a major key to understanding of on-going processes and assist in prediction of changes to be expected in the coastal area in the future. The rather small Baltic Sea poses problems characteristic of many inland seas. This almost land-locked area of brackish water (average salinity of surface water only 7–8‰), is separated from the ocean by the narrow and shallow Danish Straits and has a very sensitive eco-system which suffers from considerable pollution.

Technological developments and the ensuing progress in marine transport were accompanied by a dramatic increase in human impact which the Baltic has experienced more than any other sea in the world. Some changing environments in the Baltic reflect global trends, others only local and regional trends which, nevertheless, are important to compare with global scale processes.

The Baltic Sea is a young body of water which formed only some 12,000 years ago (KVASOV and RAUKAS, 1971). In the early stages of development, the present-day Baltic was a big ice-dammed (local ice lakes) or ice-influenced (the Baltic Ice Lake) body of water with complicated water-level fluctuations. Later it was twice connected with the ocean. This was accompanied by an abrupt lowering of the water level. The end of the Baltic Ice Lake and the formation of the Yoldia Sea are connected with the drainage caused by the recession of the ice from Billingen in Central Sweden some 10,300 yr BP (SVENSSON, 1991). In Estonia, near Pärnu (Figure 1), the fall in water level was some 25–30 m (TALVISTE, 1988). The rapid lowering of the Ancylus Lake level on Hiiumaa Island (Figures 1 and 2) and in NW Estonia has been estimated at 20–25 m (KESSEL and RAUKAS, 1967). After the connection of the Baltic Sea with the ocean at the beginning of the Litorina (Mastogloia) stage, the shore displacement became influenced by eustatic sea-level change which, in turn, was controlled by climate change and tectonic movements.

On the contemporary coasts of the eastern Baltic, the last decades have witnessed remarkable activation of erosion processes and longshore displacement of sediments has intensified. The frequency of extremely strong storms has increased. Storms cause especially great damage on sandy beaches which are least resistant to erosion. In the autumn-winter period, when the water level is relatively high, storms pile up great water masses and the coastal formations even on the backshore are subject to strong wave activity (ORVIKU and GRANÖ 1992). Therefore, long-term environmental monitoring in combination with research into the past processes in the eastern Baltic area will be of great importance.

GEOLOGICAL SETTING OF THE STUDY AREA

The study area, comprising the countries of Estonia, Latvia and Lithuania, and the St. Petersburg and Kaliningrad Districts of Russia (Figure 1), belongs structurally to the north-

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Figure 1. Location of the study area with the maximum shoreline of the Ancylus Lake (A_I).

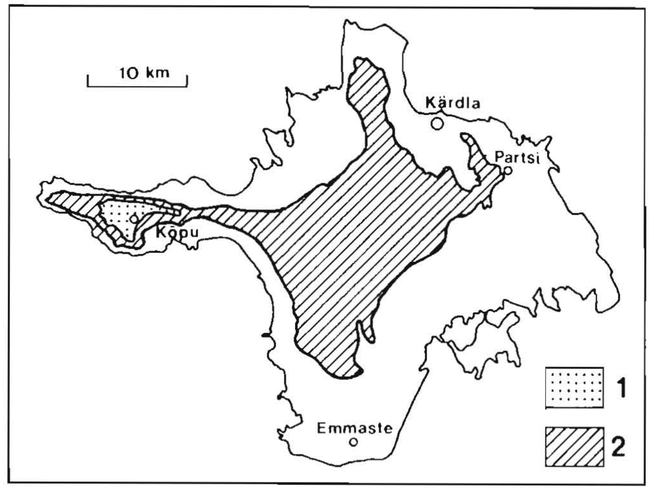

Figure 2. Ancylus shorelines on the Island of Hiiumaa (NW Estonia): (1) area above the Ancylus transgression (A_I); (2) area above the Ancylus regression (A_{VI}).

western part of the East-European Platform. The boundary between the Fennoscandian Shield and the Platform is defined by the northern limit of sedimentary rocks and it runs through the Gulf of Finland. Depending on tectonical peculiarities, the bedrock of different age crops out in the form of sublatitudinal belts, starting from Vendian and Cambrian rocks in the north (North Estonia) and ending with Mesozoic and Neogene rocks in the south (Lithuania). In the territory under consideration, the distribution of Quaternary sediments is controlled by the composition and topography of the bedrock (TAVAST and RAUKAS, 1982).

As part of the vast East-European Plain, the study area is characterized by a flat surface topography with small absolute and relative heights. The highest point of the area, the Suur-Munamägi Hill (317.6 m), is part of the Haanja Upland in Estonia (Figure 1). In the topography, hilly heights and slightly undulating plains dominate.

The sea-level history in the eastern Baltic region has been controlled by the unequal land uplift which has affected different areas in different ways. In the northern and central regions of the study area, the ancient coastal formations are located several tens of metres above water level; in the southern part of the area, correlative coastal formations lie at a depth of up to 60 metres below sea level (RAUKAS, 1991a). Several sinking and lifting blocks with anomalous heights are also encountered (MIIDEL, 1994). The present average rise of the world ocean level does not remarkably affect the evolution of the beaches in the northern part of the study area; in that area due to crustal uplift (2–4 mm per year), the coast is rising more rapidly than the level of the world ocean (about 1.5 mm annually). However, the sinking southern part of the study area would be endangered, especially due to accelerated sea-level rise resulting from the "greenhouse effect".

RAPID SEA-LEVEL CHANGES DURING THE EEMIAN INTERGLACIAL

In the territory under discussion, the Eemian period correlates with Stage 5e of the deep-sea record, which is dated roughly between 125 and 115 ka (SHACKLETON and OPDYKE, 1977). Several methods, including the counting of annual layers in fresh-water sediments (MÜLLER, 1974), suggest the duration of about 10,000 years for the Eemian interglacial period. Fauna and flora remains in Eemian deposits indicate considerably higher temperatures during the interglacial period compared to those at present. It is generally concluded that sea levels at/or close to the climatic optimum of the Eemian interglacial were 5–15 m higher than nowadays (SHACKLETON and MATTHEWS, 1977).

There are two basically different viewpoints in the eastern Baltic area as regards the contours of the Eemian Sea in the Baltic depression and the sounds through which it was connected with the Atlantic Ocean (RAUKAS, 1991b). According to GRICHUK (1989), the Baltic Sea basin was connected with the North Sea via the Danish Straits, through the present lake system of Vänern and Mälar in Central Sweden and the area of the current Kiel Canal on the Jutland Peninsula. Like LAVROVA (1961), he assumes a connection between the Baltic and White Sea basins through the system of shallow sounds and the lakes Onega and Ladoga. This means that the transgression of Eemian age must have been synchronous in the north of Eurasia as demonstrated by dating techniques, including the ESR-method (MOLODKOV and RAUKAS, 1988).

According to the second, less established reconstruction, the contours of the Eemian Sea in the Baltic basin closely coincided with the Litorina Sea limit, and therefore the connection with the ocean could have been via the Skagerrak, Kattegat and Danish Straits (BLAGOVOLIN *et al.*, 1982). Resolution of the problem concerning the connection of the Baltic Sea with the White Sea during the Eemian Interglacial is of principal importance from the standpoint of palaeogeographical and palaeoclimatological reconstructions and study of rapid coastal records.

In the Baltic Sea, Eemian marine beds are known from different heights (LIIVRAND, 1987). For instance, at Rybackoye and Sinjavino in the Neva River Lowland near St. Petersburg in Russia, they occur at a depth of 5–45 metres below sea level; while in the Mga section in St. Petersburg, they are at a height of 10 metres and in the Krasnoretskoye section (on the Karelian Isthmus between the Gulf of Finland and Lake Ladoga) 12 metres above sea level. The Eemian layers are at their deepest on the island of Prangli (north of Tallinn), where they lie at a depth of −61 to −75 m and in the mouth of the Luga River (−50 to −60 m). Thus great variations in elevations of similar deposits within the same pollen zones may be explained by glaciotectonics rather than the sedimentary history, because all the above-mentioned sections are situated in the zone of intensive glacial erosion. Because of the lack of disturbances, completeness of the profile and low altitudes (LIIVRAND, 1991), the Prangli (Figure 1) section seems to furnish the best standard for reconstructing the rapid shore-line changes for the Eemian Sea basin, but such calculations will be complicated due to the difficulty of establishing reliable accumulation rates.

FRESHWATER STAGES OF THE BALTIC

Although alternative successions of Baltic Sea stages have been suggested from time to time, the present concept of the development seems to be rather well established. The freshwater stages of local ice lakes and the Baltic Ice Lake were replaced by the Yoldia stage during which short-term brackish water conditions existed in the western and more or less freshwater conditions in the eastern part of the Baltic basin. The Yoldia Sea, in turn, was transformed into the freshwater Ancylus Lake. Around 8,500 ^{14}C years ago, the Baltic was reunited with the Atlantic via the Danish Straits (WINN *et al.*, 1986). Since then, all succeeding stages have been marine, beginning with the Litorina (or transitional Mastogloia) Sea.

The literature dealing with proglacial lakes in the study area is fairly extensive; but, in some respects, all the reconstructions are somewhat hypothetical, as they are frequently based on the contemporary topography. However, due to uneven neotectonic movements of the runoff threshold, the position of shorelines has changed beyond recognition since late glacial times. Similarly, one cannot always rely on coastal sediments of ancient lakes which are small in size and often simply lacking. Pronounced shoreline phenomena are absent due to the flatness of topography, the occurrence of relatively erosion-resistant rocks and deposits, and insufficient time to form shoreline features. In the shallow basin, waves were small and their destructive power inconsiderable. There was not any remarkable longshore drift either which might have contributed to the development of large beach formations (RAUKAS, 1992).

More information about the water-level fluctuations is available on the Baltic Ice Lake which was formed after the ice margin had retreated from the Pandivere Upland in North Estonia (Figure 1) about 12,000 yr BP (KVASOV and RAUKAS, 1971) and came to the end when the recession of the ice margin from the Central Swedish end moraines resulted in a drainage of the waters at Billingen. The drainage took place immediately or shortly after the formation of the Salpausselkä II in Finland and can be traced morphologically as a series of marginal deltas 27–28 m below the marginal deltas formed before the drainage, giving clear amplitudes for the extremely rapid shoreline change. As the history of the Baltic Ice Lake in the eastern Baltic area has recently been summarised in several publications (DONNER and RAUKAS, 1989, 1992), we shall focus on the somewhat more hypothetical drainage of the Ancylus Lake.

CATASTROPHIC LOWERING OF THE ANCYLUS LAKE

The classical theory of VON POST (1928) purports that the Ancylus Lake furiously drained its waters via the Svea River about 30 m down into Lake Vänern at Degerfors in Central Sweden, this thesis was later debated (FREDEN, 1979). BJÖRCK (1987) locates the discharge channels for the Ancylus Lake to the western side of Lake Vänern, where two long and narrow straits—Uddevalla and Otteid seem to have functioned. By his opinion, these narrow hydraulic dams had acted as thresholds which regulated the water level both in the Baltic basin and Lake Vänern.

IGNATIUS *et al.* (1981) subdivided the Baltic offshore sediments into three main lithological units repeatedly observed in cores from the different parts of the Baltic Sea: 1) glacial varved clays; 2) massive sulphide-rich clays, termed transition clays; and 3) massive or finely laminated muds with relatively high organic content, termed postglacial muds. The transition-clay unit is broadly correlative with the Ancylus stage. The deposition of postglacial muds started most probably with the establishment of brackish conditions at the beginning of the Litorina stage.

It is difficult to draw the lithostratigraphic and biostratigraphic borderlines between the Yoldia and Ancylus sediments, at least in the eastern part of the basin (AKER *et al.*, 1988; HAILA and RAUKAS, 1992). The boundary between the transition clays and postglacial muds, on the contrary, is extremely well defined and consistent. IGNATIUS *et al.*, (1981) consider it as a boundary between the Ancylus and Litorina stages. As the events of the catastrophic outflow of the Ancylus Lake are absent in Sweden, the question concerning the source of such a great and clear change in sedimentary conditions is still open.

WINTERHALTER (1992) explains it with the inflow of saline water, which caused massive flocculation and deposition of

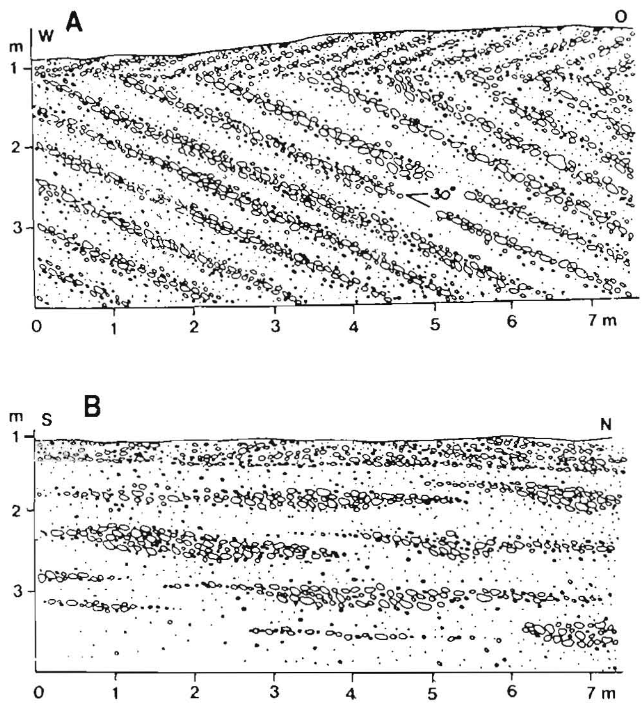

Figure 3. Lamination of Ancylus Lake sediments with rich subfossil mollusc fauna in the gravel pit at Partsi on the island of Hiiumaa, NW Estonia. Cross (A) and longitudinal (B) section of the spit. Compiled by R. Karukäpp.

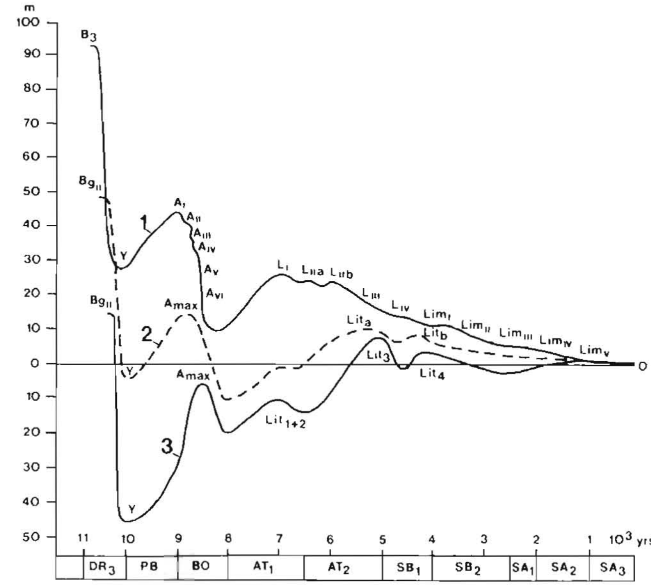

Figure 4. Water level changes of the Baltic Sea at Kôpu, Island of Hiiumaa in NW Estonia (1) western Latvia (2) and western Lithuania (3) with two clear rapid regressions: B_3 and B_{gII}—phases of the Baltic Ice Lake; A_I-A_{VI}—phases of the Ancylus Lake; L_I-L_{IV} and Lit_1-Lit_4—phases of the Litorina Sea; Lim_I-Lim_V—phases of the Limnea Sea. The indexes somewhat differ with the republics.

suspended mineral particles. The concentration of particulate material in suspension decreased, sunlight could reach greater depths and promote organic productivity. The abundance of organic matter in conjunction with a marked decrease in fluvial transported mineral matter led, in his opinion, to a drastic change in the character of accumulating sediments.

Such explanation is hardly plausible, because according to the diatom flora and mollusc fauna, the salinity changes in the Litorina Sea and the transitional Mastogloia Sea were not rapid at all (HYVÄRINEN *et al.*, 1992). As already mentioned, a new connection between the Ancylus Lake and the Atlantic Ocean formed around 8,500 yr BP (WINN *et al.*, 1986). In the Arcona depression and Rügen Island in the southernmost part of the Baltic Sea, the saline conditions formed about 500 years later (KLIEWE and JANKE, 1978), on the southwestern coast of Finland at about 7,400–7,300 yr BP (ERONEN, 1974), but at the head of the Gulf of Bothnia (ERONEN, 1982) and near the coasts of Estonia (KESSEL and RAUKAS, 1979) at about 7,000 yr BP only.

Already in the 1960's, KESSEL and RAUKAS (1967) established in Estonia a low Ancylus Lake level (A_{VI}). The related deposits and relief forms have only been partly preserved in the contemporary topography and are buried under the transgressive Litorina Sea sediments. The water level is believed to have sunk by 20–25 m. In some localities (Risti and Vihterpalu in the northwest of Estonian mainland, and at Võlla on Muhu Island) besides typical Ancylus Lake molluscs, including *Ancylus fluviatilis, Lymnaea peregra f. baltica, Bithynia tentaculata* and *Pisidium amnicum,* the slightly brackish-water species *Theodoxus fluviatilis f. littoralis* (at Vihterpalu 8%, Võlla 13.5% of all molluscs) has also been identified in the low-lying sediments. This is indicative of the opening of the connection with the ocean and transition to the Litorina Sea environment. Typical brackish-water forms in the above-mentioned localities are absent.

In 1994, a new locality was found in the vicinity of Partsi, Hiiumaa Island (Figure 2), where the typical Ancylus Lake mollusc fauna represented by *Lymnaea peregra f. baltica, Ancylus fluviatilis, Bithynia tentaculata* underlies the characteristic Litorina Sea mollusc fauna (different species of *Cerastoderma (Cardium), Macoma baltica* a.o.). As a result, the rate, timing and amplitudes of the Ancylus regression could be established for the first time with precision. In the upper part of a large quarry, there is a long section of obliquely laminated sandy gravels, shingles and cobbles with well-rounded but poorly sorted deposits (Figure 3) containing freshwater molluscs in its lower part (at an absolute height of 10–14 m) and brackish water molluscs in the topmost part (at an absolute height of 16–18 m). The evidence derived from the island of Hiiumaa suggests the water-level lowering by 30 metres (Figure 4). Assuming that the Ancylus transgression reached its maximum in the Hiiumaa area about 9,200 yr BP (HAILA and RAUKAS, 1992) and the Ancylus stage came to an end some 8,500 yr BP, when the oceanic waters penetrated into the Baltic basin (WINN *et al.*, 1986), the regression of the Ancylus Lake must have been very rapid (3.5–4.2 cm/year). Afterwards the ocean should have transgressed the

Danish Straits gradually and only a minor quantity of the oceanic water could have penetrated further to the east, where slightly brackish water conditions appeared around 8,000 ^{14}C yr BP as recorded by littoral diatoms (HYVÄRINEN *et al.*, 1992).

SHORELINE DISPLACEMENT DURING THE BRACKISH-WATER BALTIC SEA

Since the reunion of the Baltic Sea basin with the ocean at the beginning of the transitional Mastogloia stage, the shore displacement has been controlled by two factors: eustatic sea-level change and isostatic uplift. While the former ought to be uniform all over the Baltic, the latter varies with regions resulting in different patterns of shore displacement in different areas (HYVARINEN *et al.*, 1992). In the eastern Baltic area, the rate of uplift broadly diminishes from north to south and, in the area of the Gulf of Finland, from southwest to southeast being at its lowest in the St. Petersburg region.

In the Helsinki area, the isostatic uplift exceeded the eustatic sea-level rise but in Estonia, transgressive trends prevailed in Mastogloia and early Litorina times. The Litorina transgression appears to have culminated at different times in different areas, so that the peak is delayed towards the margins of the land uplift zone (KESSEL and RAUKAS, 1984). In Estonia, the transgression continued until at least 6,000 yr BP; in areas with zero uplift (northern Latvia), the transgressive trend most probably continued as long as eustatic sea level kept on rising; however, the rapid eustatic rise had probably ceased by about 5,000 yr BP, after which regressive trends in shore displacement became prevalent even in the marginal parts of the Baltic uplift area (HYVÄRINEN *et al.*, 1992). Short-term fluctuations in relative sea level have been registered in some areas and are considered to be local in origin. The tides with an amplitude of 1–5 cm are barely noticeable, and their geological effect is insignificant. More significant changes in the water level, ranging from 2 to 4.5 m, are caused by persistent winds and differences in the air pressure. It means that contemporary beach ridges may be a couple of metres higher above the normal water level and at some distance inland from the shore.

CONCLUDING REMARKS

In the eastern Baltic, there are a lot of phenomena suggesting rapid sea-level changes due to different factors. Research into those phenomena will be of primary importance for predicting ongoing processes and future environmental changes in the densely populated area with advanced industry and agriculture. The investigated Partsi section in Hiiumaa Island allows, for the first time in the Baltic region, the rate, timing and amplitudes of the Ancylus transgression to be established with a rather high precision. The high resolution studies in the Baltic will promote better understanding of the global coastal scenarios.

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