Middle and Late Holocene Transgressions of the Baltic Sea on the Central Polish Coast*

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ABSTRACT

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Poland's central coast faces the southern part of the Baltic. Over the past 8,000 years, this sea has been permanently connected with the world ocean, which explains why the extensive transgressions relate to factors outside the area.

The geotectonically rather stable nature of Poland's central coast during this period favors a study of eustatic changes of sea level. It also provides for calculation of the average rates of the sea-level rise in each particular phase of the transgression. The result of these studies is a curve of Baltic sea-level fluctuations during the Middle and Upper Holocene.

ADDITIONAL INDEX WORDS: Baltic Sea, Holocene, Littorina transgressions, eustatic sea-level fluctuations, rates of sea-level change.

INTRODUCTION

The study area embraces the central Polish coast, which faces the southern Baltic and extends over about 40 km between lakes Sarbsk and Zarzewic (Figure 1). For the Holocene terminology, the author has adopted the chronostratigraphic divisions (Figure 3) proposed by Starkel (1977). According to this scheme, the Early or “Eoholocene” (10,250–8,400 years BP in C-14 yr) is regarded as a period of steadily rising atmospheric temperature. The Middle or “Mesoholocene” (8,400–5,100 years BP) covers the climatic optimum of the Holocene (the warmest stage). Finally, the Late or “Neoholocene” (5,100–present day), is characterized by a gradual tendency towards climatic cooling. The present century is an exception marked by an increase in temperature, related perhaps in part to the so called “greenhouse effect.”

This paper presents evidence for transgression of the Baltic in the Mesoholocene and Neoholocene. Each transgressive phase is described and rates of sea-level rise are calculated. Also presented are some lithological characteristics of the coastal sediments. The results permit the drawing of a curve of eustatic fluctuations in the Baltic Sea for the Middle and Late Holocene. The author’s proposals as to the climatostratigraphic divisions are presented and compared with results from other Baltic countries.

Many authors have conducted studies of Poland’s central Baltic coast (Bulow, 1929, 1932; Brodniewicz and Rosa, 1967; Tobolski, 1972, 1975, 1979; Bogaczewicz-Adamczak et al., 1981; Miotk and Bogaczewicz-Adamczak, 1987), but their results covered only specific areas. More comprehensive studies under project MR-I-15 (Studies on the Geological History of the Baltic Sea led by Rosa, Gdańsk University), have brought a more integrated light on the question of Holocene transgressions (Kaszubowski, 1987).

MIDDLE HOLOCENE

A second phase of the Mesoholocene transgression (abbreviated MH2) is marked by the invasion of the Littorina Sea (phase L1). The Littorina transgression of the Baltic basin was mainly the result of progressive and accelerated melting of the Laurentide continental ice sheet. At this time the Baltic became connected with the North Sea through the Danish Straits. The name of the Littorina Sea originated from the marine gastropod *Littorina littorea*. The period was marked by a rapid increase in salinity, and appearance of saltwater diatoms such as *Campylodiscus clyp-
Figure 1. Map of study area. (1) moraine surface (Pleistocene); (2) area of fluvial sediments (Late Pleistocene); (3) glacial terrace sediments (Late Pleistocene); (4) inland dunes (Late Pleistocene); (5) coastal dunes (Holocene); (6) peat-bogs (Holocene); (7) interpreted seismic profiles of sea floor; and (8) geological profiles through the coastal plane.

eus, Amphora mexicana, Campylodiscus eche neis, Epithemia turgida, Nitzschia scalaris and Terpsinoe americana. This transgression corresponded to the “early Atlantic” chronozone re cognized in Scandinavia.

Fluctuations in the levels of the Littorina Sea constitute a complex question. According to some authors this was a single transgression interrupted only by short stabilization intervals, or very slight oscillations. According to a second point of view, there were many such transgressions separated by distinct periods of regression. The author favors the second concept, proposing four separate transgressive phases for this region.

The concept of multiple transgressions of the Littorina Sea was first developed in Denmark (Iversen, 1937; Troels-Smith, 1942), where four transgression phases were identified. Traces of four transgressions were later seen in Sweden (Miller, 1981; Persson, 1978). The first was the most extensive, especially in northern Sweden. The younger phases were recognized only in the south. According to Berglund (1964), however, there were six transgressions of the Littorina Sea in southern Sweden. Multiple transgressions of the Littorina Sea were also identified in Finland (Eronen, 1974, 1983, 1987).

Characteristic of the first transgression phase (L1) in the region of Poland’s central coast, was the rapid rate of sea-level rise, calculated at 65 mm/yr. This is the highest rate of sea-level rise found in the whole of the Middle or Upper Holocene in the Baltic. An even higher rate given previously by the author (Kaszubowski, 1987) was overestimated, as has been found following detailed analysis of seismic stratigraphic data from this part of the sea floor.

Rapid changes in the shoreline towards the south, together with marked coastal erosion took place during this transgression, resulting in al-
most flat erosional surfaces cut mainly in glacial tills (Figure 2) probably belonging to the Vartanian glaciation (220–130 kyr BP).

With each of the first four transgressive subphases the coastline shifted south a similar distance, about 1.7 to 2 km. During the maximum subphases L1a and L1b, as shown by seismic stratigraphic studies of sea floor off Sarbsk and allowing for isostatic adjustment, the corresponding sea levels were 24 m and 23 m below msl. Thin deposits of sand accumulated in the coastal zone corresponding to these first brief stages of the Littorina Sea (Figure 2).

In subphase L1c, the encroaching Littorina Sea encountered an area of a formerly extensive ice marginal valley which formed here in the Late Pleistocene. The existence of this marginal valley, which runs through a substantial area of the region was discussed in numerous papers (BULOW, 1928, 1932; HARTNACK, 1926, 1931; ROSA, 1968, 1969), but its exact position and extent was not well known (KASZUBOWSKI, 1988). Seismic studies delineated the exact position for this ancient land form.

After occupying the former valley the Littorina Sea moved even faster to the south. Simultaneously, the soft silty-clay sediments and loose sediments of the inland dunes formed in the Late Pleistocene underwent rapid marine erosion. The erosional surface is covered by a transgressive sequence of sandy sediments, which increases in thickness southward, reaching 5–6 m (Figure 2) in certain places. The situation on the sea floor off Lubiatowo is very similar. Here there is also a characteristically flat erosional surface.

During the maximum of this transgression, the sea-level rose to 13 m below msl (Figure 3). As a result of this, the coastline in the study area shifted southward over 8 to 14 km (KASZUBOWSKI, 1987). Finally, by the end of phase L1c, the shore of the Littorina Sea came very close (within 1–3 km) to the present-day shore of the Baltic Sea (Figure 4).

A regression followed, during which the sea-level fell to 17 m below msl (Figure 3). The coastline then shifted back about 2 km. A regressive sedimentary sequence formed, and is still well preserved on the present-day sea floor (Figure 2), with a regressive cliff at the minimum regression level. Sandy sediments were deposited in the shallow coastal zone to a depth of 7 m, and reached a thickness of 1.5 to 4 m.

**MH—The Littorina Sea (Phase Lm)**

The second eustatic rise was marked by the Littorina Lm transgression. An erosional surface was observed on the seismic profiles truncating the sediments of the previous transgression series (Figure 2), capped by the new transgression with a sandy series formed corresponding to phase Lm, as reported earlier (KASZUBOWSKI, 1987). In the Sarbsk region they consist of fine sands, moderately sorted. This moderate sorting is characteristic of the majority of recent marine sediments in the study area (Table 1). The sandy sediments are overlaid with a thin layer of mud (Figure 5), containing numerous examples of *Cardium edule* and *Macoma baltica* dated at 7590 ± 100 yr BP (MIOTK and BOGACZEWICZ-ADAMCZAK, 1987). A similar radiocarbon date was found near the Vis-
tula delta, where an upper layer of peat was dated at 7,580 ± 95 yr BP (MOJSKI, 1983), and the sequence terminates with eolian facies in the L_{11} phase.

A palynological analysis of the muddy sediments from the Sarbsk area indicates the "older Atlantic" pollen zone (MIOTK and BOGACZEWICZ-ADAMCZAK, 1987), with fairly numerous pollen grains from a mixed deciduous woodland, especially lime (Tilia), elm (Ulmus), pine (Pinus) and oak (Quercus). The diatom flora was represented by a rich mixture of species characteristic of the Littorina Sea, with *Euchalohbora* the predominant marine plankton in this sea water of ca. 20% salinity (MIOTK and BOGACZEWICZ-ADAMCZAK, 1987). Many *mesohalobus* were also found, as well as *Terpsinoe americana* (Beil.) Ralfs., an excellent index of the Littorina period. Fresh-water diatoms constitute only 7–12% of the total number of specimens.

In the region of Lubiatowo, the transgression is most frequently represented by moderately sorted medium sands (Figure 6). The erosional surface in the form of distinct platforms is cut in glacial tills. The sea-level rose at a mean rate of 50 mm/yr, reaching 7 m below msl (cf Figure 3), while the shore-line shifted 2–10 km landwards (cf Figure 4). Following the transgression maxi-

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Figure 3. Sea-level fluctuations of the Baltic Sea at the middle Polish coast according to the author. Climatostratigraphic division according to STARKEL (1977).
Figure 4. Early Middle Holocene paleogeographic reconstruction across the middle Polish coast; the Littorina transgression in phase L₂ (MH:J. (1) shoreline of maximum Littorina transgression in phase L₂; (2) shoreline of maximum Littorina transgression in phase L₃; (3) beach gravel; (4) medium-grain sands with marine fauna; (5) fine sands; (6) medium-grain sands; (7) muds with fauna of Cardium edule and Macoma baltica; (8) coastal zone (0-2 m below msl); (9) coastal zone (2-4 m below msl); (10) inland dunes (Late Pleistocene); (11) glacial terrace sediments (Late Pleistocene); (12) area of fluvial sediments (Late Pleistocene); and (13) morainic surface (Pleistocene).

Table 1. Range of reliance for the mean value and mean values of granulometric indices of the main lithogenetical units of research area (ancient deposits).

<table>
<thead>
<tr>
<th>Lithogenetical Characteristics</th>
<th>M₁ (phi)</th>
<th>M₂ (phi)</th>
<th>M₃ (phi)</th>
<th>C (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine deposits of shallow coastal zone (0-4 m b.s.l.)</td>
<td>1.85 ± 1.99</td>
<td>0.75 ± 0.79</td>
<td>-0.62 ± 0.44</td>
<td>1.19 ± 1.41</td>
</tr>
<tr>
<td>Beach deposits</td>
<td>1.92</td>
<td>0.77</td>
<td>-0.53</td>
<td>1.30</td>
</tr>
<tr>
<td>Inland and coastal dunes deposits</td>
<td>1.62 ± 2.10</td>
<td>0.74 ± 1.02</td>
<td>-0.95 ± 0.43</td>
<td>1.02 ± 5.34</td>
</tr>
<tr>
<td>Lagoon-lake deposits</td>
<td>1.86</td>
<td>0.88</td>
<td>-0.69</td>
<td>3.18</td>
</tr>
<tr>
<td>Fluvial deposits</td>
<td>2.03 ± 2.50</td>
<td>0.69 ± 0.81</td>
<td>-0.71 ± 0.23</td>
<td>0.53 ± 0.83</td>
</tr>
</tbody>
</table>

M₁ = mean diameter of grains; M₂ = sorting index of deposits; M₃ = asymmetry of grain distribution; C = index appearing in Passega’s diagram.
Figure 5. Geological profile through the Sarbsk coastal plain. I. Lithology: (a) fluvioglacial gravels and sands; (b) fluvioglacial coarse and medium sands; (c) marine medium sands; (d) marine fine sands; (e) lagoon and lacustrine fine-grain sands; (f) lagoon fine-grain sands; (g) marine transgression sediments; (h) marine regression sediments; (i) fine sands of inland dunes; (j) fine and medium sands of coastal dunes; (k) marine muds dated 7,590 ± 100 yr BP; (l) silty-clay sediments; (m) peat deposits, the base dated 5,480 ± 90 yr BP; and (n) ancient marine cliff. II. Stratigraphy: (1) Pleistocene; (2) Late Pleistocene; (3) Early Holocene; (4) Middle Holocene (MH); (5) Middle Holocene (MH, MH); (6) Late Holocene (first half); (7) Late Holocene (NH, NH, NH, NH); and (8) Present (NH).

Figure 6. Geological profile through the Lubiatowo coastal plain. I. Lithology: (a) glacial till deposits; (b) fluvial coarse and medium sands; (c) beach gravels; (d) marine medium-grain sands; (f) marine muds; (g) lagoon-lacustrine muds; (h) marine transgression sediments; (j) marine regression sediments; (k) fine and medium-grain sands of coastal dunes; (l) soil and glacial deposits; (m) peat deposits; (n) limnic sediments; and (o) ancient marine cliff. II. Stratigraphy: (1) Pleistocene; (2) Late Pleistocene; (3) Early Holocene; (4) Middle Holocene (MH); (5) Middle Holocene (MH, MH); (6) Late Holocene (first half); (7) Late Holocene (NH, NH, NH, NH); and (8) Present (NH).
Holocene Transgressions along the Polish Coast

Figure 7. Early Middle Holocene paleogeographic reconstruction across the middle Polish coast; the Littorina regression in phase LII (MH): (1) shoreline of maximum Littorina transgression in phase LII; (2) shoreline of coastal lakes; (3) coastal peat; (4) regressive sequence sediments; (5) fine and medium-grain sands of coastal dunes; (6) fine-grain sands of coastal lakes; (7) medium-grain sands of coastal lakes; (8) area of coastal lakes; (9) inland dunes (Late Pleistocene); (10) glacial terrace sediments (Late Pleistocene); (11) area of fluvial sediments (Late Pleistocene); and (12) morainic surface (Pleistocene).

Mum marine muds and fine sands were deposited (Figure 6).

During the regression of phase LII, a spit system developed but was later capped by eolian deposits, the oldest coastal dunes in the study area. The majority of the dunes have moderate sorting and low index C values (Table 1) reflecting their distinctive character (Kaszubowski, 1987). These early Littorina dunes form a fairly wide spit of up to 1.2 km (Figure 7), but it must have been wider originally before successive erosion and reworking by younger transgressions.

A lagoon formed behind the spit is marked by the accumulation of fine sands of moderate sorting and relatively low index C values (Table 1). Somewhat later, the lagoon becomes transformed into a lake basin with typical limnic facies. With the eustatic fall (to 10 m below msl) the coastline moved northwards (cf Figure 3) and coastal peat formed over the lagoon-spit system (cf Figure 7).

MHII—the Littorina Sea (Phase LIII)

Phase LIII corresponds to the second half of the Middle Holocene. The sea-level rise was now much slower, occurring at 10 mm/yr on average. Medium sands of moderate sorting accumulated in the coastal zone, with beach deposits often containing shells so there is a substantial increase in the C index (Table 1). Lagoon basins are marked by an accumulation of fine and medium sands that appear landward of the older spit systems (Figure 8). Slightly later, a lagoon facies in the Debki region was followed by a marine facies.

At the transgression maximum, the sea-level reached 3 m below msl (cf Figure 3), and in many places the shore shifted landward of the former
coastline. Following the eustatic peak the coastline shifted northwards once more to form a late Littorina spit. This spit became superposed on older spit structures, causing the fairly substantial expansion of the present area of the spit. It is believed that the lower layer of peat from the region of the Vistula delta, dated at 6,330 ± 60 yr BP (Morski, 1983) may indicate the beginning of the regression of phase $L_{III}$. The eustatic level fell to 7 m below msl (cf Figure 3).

MH$_{III}$—The Littorina Sea (Phase $L_{III}$)

Phase $L_{III}$ corresponds to the end of the Middle Holocene. Coastal peat formed in the Sarbsk region; its lower layer dated 5,480 ± 90 yr BP (Miotk and Bogaczewicz-Adamczak, 1987; Figure 5). During this stage, the shoreline shifted slightly in places (100–200 m southwards).

Fairly intensive eolian activity took place and a series of coastal dunes covered the earlier spit structures at this maximum when sea-level reached 1.7 m below msl (see Figure 3). A section of the earlier erosional surface and probably part of the coastline from the period of maximum transgression was observed in the Lubiatowo region (see Figure 6). The later regression caused a rapid retreat—a drop in water level to 4 m below msl. This process marked a new stage in the history of the Baltic Sea, the Late Holocene.

It may be noted that in the stratigraphic table the author has shifted the lower boundary of the Littorina Sea substantially downwards (Table 2). This is a preliminary proposal at present, as corresponding levels of this transgression phase have not yet been dated in Poland. Although dated as phase $L_{III}$, the marine silt with Littorina Sea fauna at Sarbsk (see Figure 5), indicate indirectly, such a shifting of the lower boundary of this basin. It is not, however, excluded that these silts belong to the first transgression phase and future studies
in this field should supply the solution to the problem. The question of the lower boundary of the Littorina sequence differs slightly in the various centers studying the Baltic Sea (Table 2). In some countries, the lower boundary was fixed at about 7,200 yr BP (BERGLUND, 1964; KOLP, 1979; KESSEL and RAUKAS, 1979). In some other centers, this boundary is placed substantially lower in the stratigraphic table (GUDELIS, 1976, 1979; ERONEN, 1983; KLIEWE, 1983), which seems to be confirmed by the author's studies.

**LATE HOLOCENE ("NEOHOLOCENE")**

In the region of the central Polish coast, the "Neoholocene" is divided distinctly into two parts. The first stage, falling into the Subboreal chronzone, is characterized here by terrestrial conditions (KASZUBOWSKI, 1988a). Coastal peat developed in the Sarbsk area (see Figure 5). Similar biogenic and limnic sediments occur elsewhere. So far, no marine sediments from this period have been found in the area. In view of this, no indication of sea-level can be shown.

The second half of the Late Holocene, corresponding to the Subatlantic chronzone, was associated with successive transgressions on Poland's central coast. The transgressions were of a cyclical character (cf Figure 3), with periods probably lasting about 300 years. These cycles will be the subject of further studies. It is believed that similar cycles occurred earlier during the Subboreal period, so an appropriate numbering was given to them for the second half of the Late Holocene (Table 2).

The first transgressive phase (NH 1) was the fastest in the Late Holocene, having a rate of 5 mm/yr (KASZUBOWSKI, 1988a). At that time the sea-level rose to 0.5 m below msl (see Figure 3). The effect of this transgression was the forming of a "fossil" marine cliff in the Sarbsk region (KASZUBOWSKI, 1989) 100 m south of the present-day Baltic shore (see Figure 5). This is cut in peat and eolian sediments. In the region of Lubiatowo a corresponding fossil cliff is situated slightly further from the present-day coastline (200 m southward; Figure 6). Coastal dunes, well preserved in the contemporary landscape, formed along the former shoreline (Figure 5 and 6).

The next three transgressive phases (NH 2, NH 3, and NH 4) were smaller and did not cause such major shifts in the coastline as NH 1. During that time the sea-level rose by 2.0–2.5 mm/yr, on average (KASZUBOWSKI, 1987). They left distinct traces in both deposits and landforms. A contemporary rise of sea-level (NH 5) is observed everywhere on the Polish coast, associated with considerable erosion of the coast. It is observed (from tide-gauge data) that sea-level is rising here at a rate of 1.0–1.9 mm/yr (DZIADZIUSZKO, 1979). The present transgression phase should end by about 2080 AD, but the greenhouse effect caused by the increasing accumulation of CO$_2$ in the atmosphere will presumably modify the process.

The reason for the Late Holocene changes in sea-level in the Baltic, which was permanently connected with the world ocean at that time, are mainly related to fluctuations in the global ice budget (glacio-eustatic). However, the influence of tectonic movements of the ocean floor and the supply of juvenile waters from active rift zones may also play some role.

**CONCLUSIONS**

Characteristic of the early Holocene were considerable fluctuations of global sea-level associated with both rapid transgressions and regressions which also affected the Baltic. Evidence of them may also be seen in the first half of the Middle Holocene during the first two phases of the Littorina Sea (MH 1 and MH 2). During these...
phases, sea-level rose at rates respectively of 65 and 50 mm/yr. These rates of sea-level rise are believed to reflect principally a glacio-eustatic response to Laurentide ice melting.

A slower rate of transgression and reduced fluctuations of sea-level characterized subsequent phases. The last two phases of the Littorina Sea (MHs and MHl), for example, were marked by sea-level rise at a mean rate of 10 mm/yr associated with smaller landward shifts of the shoreline.

Characteristic of the late Holocene were smaller fluctuations of sea-level which gradually approached the present-day level. This phenomenon also corresponded to the slow rate of transgressions during which the sea-levels rose at rates of 2.0—2.5 mm/yr (NHr, NHs, NH).}

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LITERATURE CITED


Klifwe, H., 1983. Entwicklung, Ergebnisse und Tendenzen der Spätglazial und Holozänforschung im nordöstlichen Küstenraum der DDR. Das Jungquar-
Holocene Transgressions along the Polish Coast


La costa central de Polonia enfrenta la parte sur del mar Báltico. Antes de las últimos 8.000 años, este mar estuvo conectado permanentemente con el océano mundial, lo cual explica, porque, los extensos transgresiones se relacionan con factores externos al área. La costa central de Polonia, de naturaleza, geotectonicamente estable, durante este período, favorece el estudio eustático de los cambios del nivel del mar. Ello permite también calcular la tasa promedio del ascenso del nivel del mar en cada fase particular de la transgresión. El resultado de estos estudios es una curva de fluctuación del nivel del mar del Báltico durante el Holoceno Medio y Superior.— Néstor W. Lanfredi, CIC-UNLP, La Plata, Argentina.