

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

Leszek Kaszubowski

Technical University of Szczecin  
Water Engineering Institute  
Al. Piastow 50a  
70-311 Szczecin, Poland



### ABSTRACT

KASZUBOWSKI, L., 1992. Middle and Late Holocene transgressions of the Baltic Sea on the central Polish coast. *Journal of Coastal Research*, 8(2), 301-311. Fort Lauderdale (Florida), ISSN 0749-0208.

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 a 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 Zarnowiec (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 (BÜLOW, 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 MH<sub>2</sub>) is marked by the invasion of the Littorina Sea (phase L<sub>1</sub>). 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-*

90085 received 18 July 1991; accepted in revision 27 September 1991.  
\* Contribution to IGCP Project 274: Coastal evolution in the Quaternary.

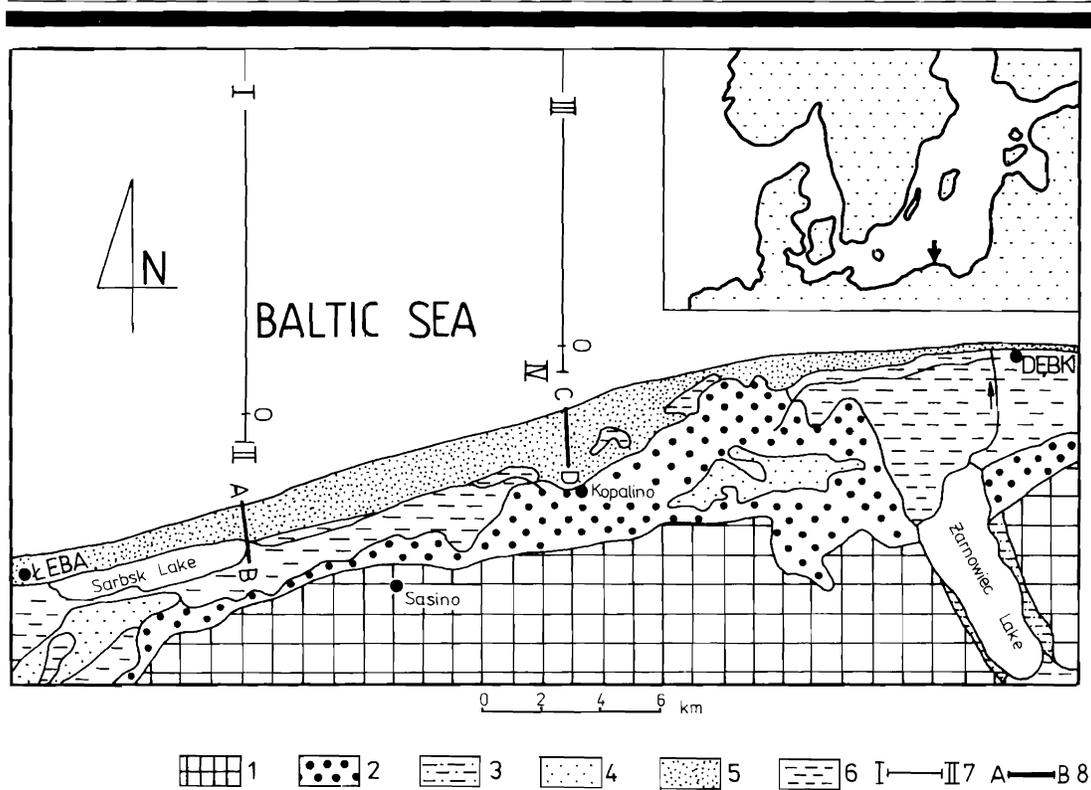


Figure 1. Map of study area. (1) moraine surface (Pleistocene); (2) area of fluvial sediments (Late Pleistocene); (3) glacial terrace sediments (Late Pleistocene); (4) inland dunes (Late Pleistocene); (5) coastal dunes (Holocene); (6) peat-bogs (Holocene); (7) interpreted seismic profiles of sea floor; 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 recognized 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 ( $L_1$ ) 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-

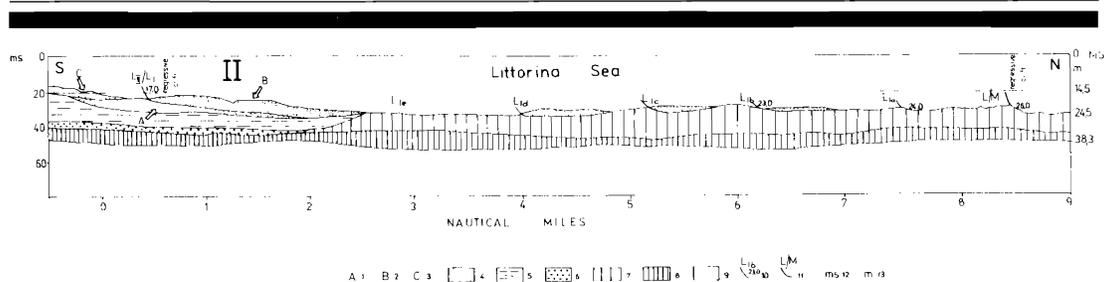


Figure 2. Geological profiles through the area of first Littorina Sea in the phase  $L_1$  ( $MH_2$ ). (1) sandy sediments of transgressive sequence maximum of phase  $L_1$  (Middle Holocene); (2) sandy sediments of regressive sequence of phase  $L_1$ ; (3) sandy sediments of transgressive sequence of phase  $L_{11}$  (Middle Holocene); (4) sandy sediments of former shallow coastal zones (Middle Holocene); (5) silty-clay sediments of the marginal valley (Late Pleistocene); (6) gravels and sands of the marginal valley (Late Pleistocene); (7) glacial till deposits (Vartanian glaciation: 220–130 kyr BP); (8) glacial till deposits (older glaciations); (9) substrate (Tertiary or Cretaceous); (10) Littorina Sea cliff and maximum sea level in subphase  $L_{1a}$  (m below msl); (11) Boundary between Mastogloia Sea and Littorina Sea; (12) two-way travel time in m.sec.; and (13) scale (meters).

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 sub-phases the coastline shifted south a similar distance, about 1.7 to 2 km. During the maximum subphases  $L_{1a}$  and  $L_{1b}$ , 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  $L_{1c}$  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 (BÜLOW, 1928, 1932; HARTNACK, 1926, 1931; ROSA, 1968, 1968), 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  $L_{11}$ , 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.

### $MH_3$ —The Littorina Sea (Phase $L_{11}$ )

The second eustatic rise was marked by the Littorina  $L_{11}$  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  $L_{11}$ , 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  $7590 \pm 100$  yr BP (MIOTK and BOGACZEWICZ-ADAMCZAK, 1987). A similar radiocarbon date was found near the Vis-

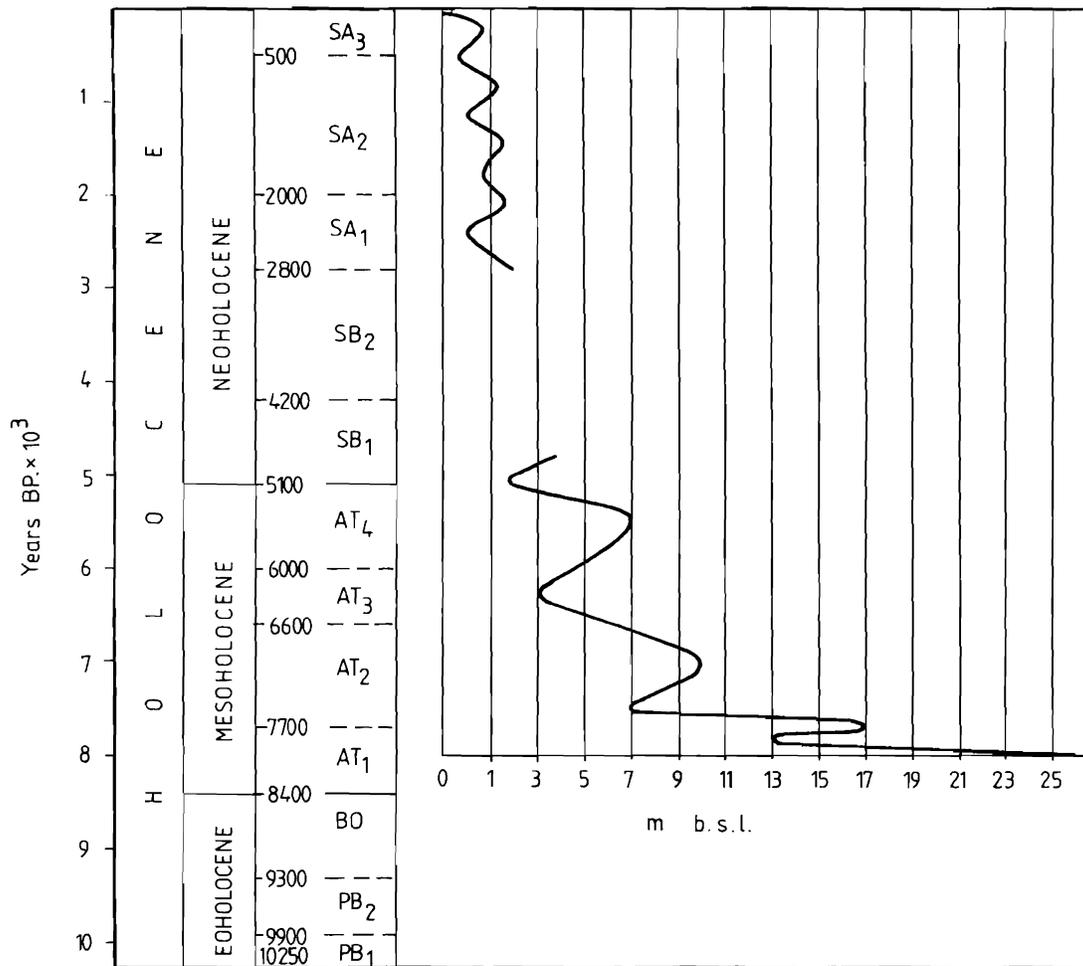


Figure 3. Sea-level fluctuations of the Baltic Sea at the middle Polish coast according to the author. Climatostratigraphic division according to STARKEL (1977).

tula delta, where an upper layer of peat was dated at  $7,580 \pm 95$  yr BP (MOJSKI, 1983), and the sequence terminates with eolian facies in the L<sub>II</sub> 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 *Euchalobour* the predominant marine plankton in this sea water of

ca. 20‰ salinity (MIOTK and BOGACZEWICZ-ADAMCZAK, 1987). Many *mesohalobous* 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-

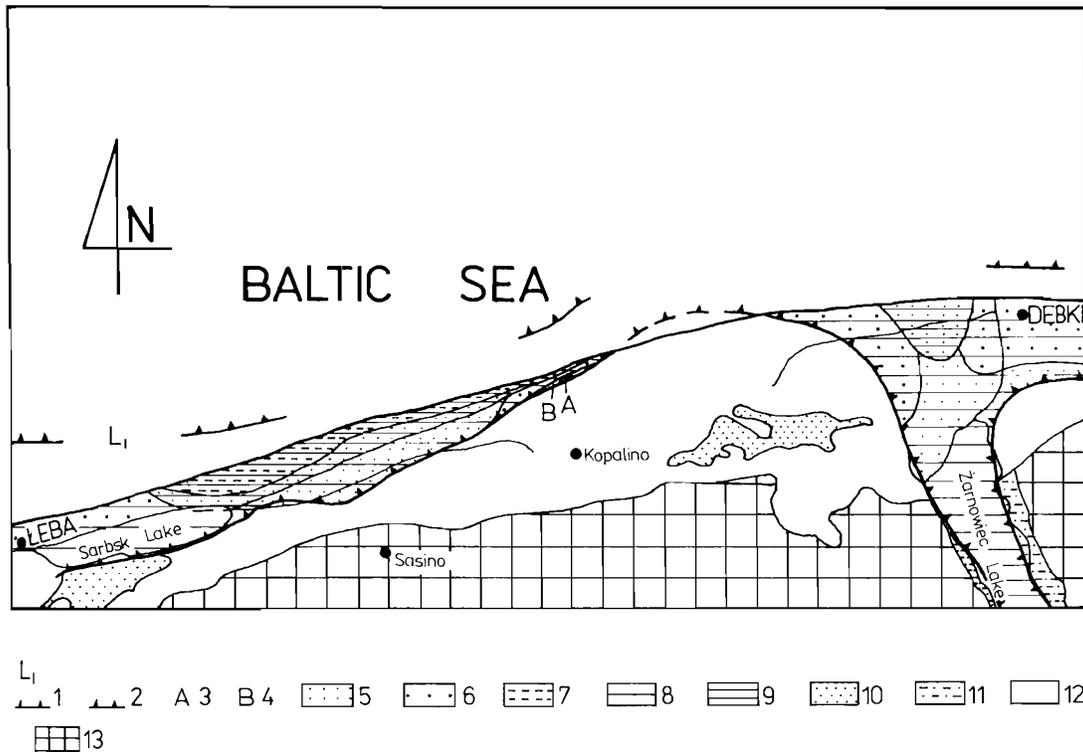


Figure 4. Early Middle Holocene paleogeographic reconstruction across the middle Polish coast; the Littorina transgression in phase  $L_{11}$  (MH.). (1) shoreline of maximum Littorina transgression in phase  $L_1$ ; (2) shoreline of maximum Littorina transgression in phase  $L_{11}$ ; (3) beach gravel; (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).

Lithogenetical Characteristics	$M_1$ (phi)	$M_2$ (phi)	$M_3$ (phi)	C (mm)
Marine deposits of shallow coastal zone (0–4 m b.s.l.)	1.85 ÷ 1.99	0.75 ÷ 0.79	-0.62 ÷ -0.44	1.19 ÷ 1.41
	1.92	0.77	-0.53	1.30
Beach deposits	1.62 ÷ 2.10	0.74 ÷ 1.02	-0.95 ÷ -0.43	1.02 ÷ 5.34
	1.86	0.88	-0.69	3.18
Inland and coastal dunes deposits	2.02 ÷ 2.08	0.53 ÷ 0.55	-0.15 ÷ 0.018	0.56 ÷ 0.60
	2.05	0.54	-0.07	0.58
Lagoon-lake deposits	2.30 ÷ 2.50	0.69 ÷ 0.81	-0.71 ÷ -0.23	0.53 ÷ 0.83
	2.40	0.75	-0.47	0.68
Fluvial deposits	1.17 ÷ 1.57	0.92 ÷ 1.02	-0.37 ÷ 0.07	1.96 ÷ 2.36
	1.37	0.97	-0.15	2.16

$M_1$  = mean diameter of grains;  $M_2$  = sorting index of deposits;  $M_3$  = asymmetry of grain distribution; C = index appearing in Passega's diagram

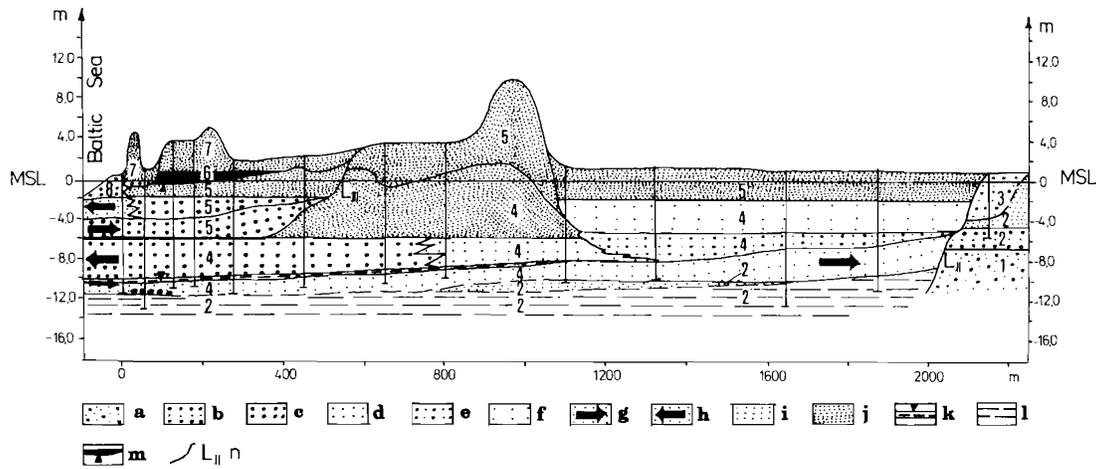


Figure 5. Geological profile through the Sarbsk coastal plain. I. Lithology: (a) fluvioglacial gravels and sands; (b) fluvial coarse and medium sands; (c) marine medium sands; (d) marine fine sands; (e) lagoon and lacustrine fine-grain sands; (f) lagoon fine-grain sands; (g) marine transgression sediments; (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<sub>1</sub>); (5) Middle Holocene (MH<sub>4</sub>, MH<sub>5</sub>); (6) Late Holocene (first half); (7) Late Holocene (NH<sub>4</sub>, NH<sub>5</sub>, NH<sub>6</sub>, NH<sub>7</sub>); and (8) Present (NH<sub>8</sub>).

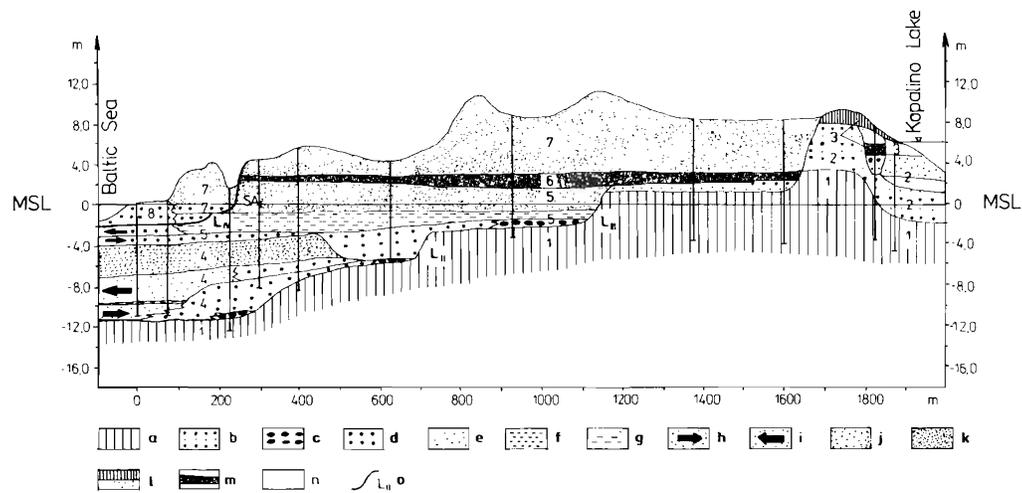


Figure 6. Geological profile through the Lubiatowo coastal plain. I. Lithology: (a) glacial till deposits; (b) fluvial coarse and medium sands; (c) beach gravels; (d) marine medium-grain sands; (e) marine muds; (f) lagoon-lacustrine muds; (g) marine regression sediments; (h) medium-grain sands of inland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

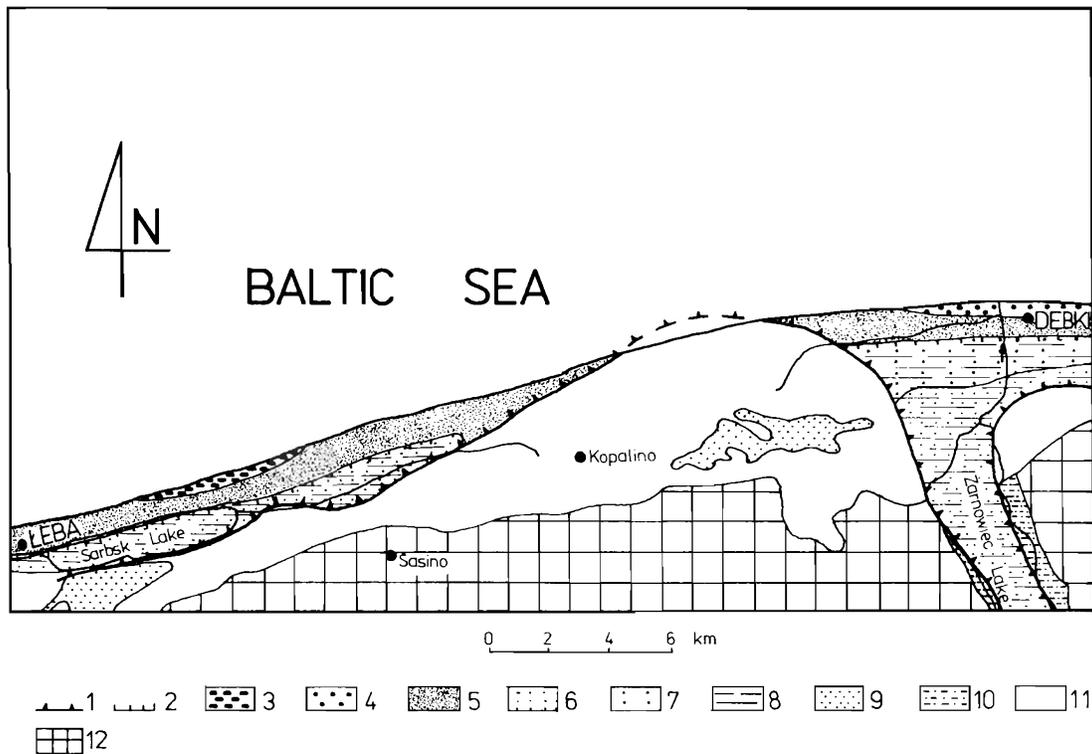


Figure 7. Early Middle Holocene paleogeographic reconstruction across the middle Polish coast; the Littorina regression in phase  $L_{II}$  ( $MH_1$ ). (1) shoreline of maximum Littorina transgression in phase  $L_{II}$ ; (2) shoreline of coastal lakes; (3) coastal peat; (4) regressive sequence sediments; (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).

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

During the regression of phase  $L_{II}$  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).

#### $MH_2$ —The Littorina Sea (Phase $L_{III}$ )

Phase  $L_{III}$  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

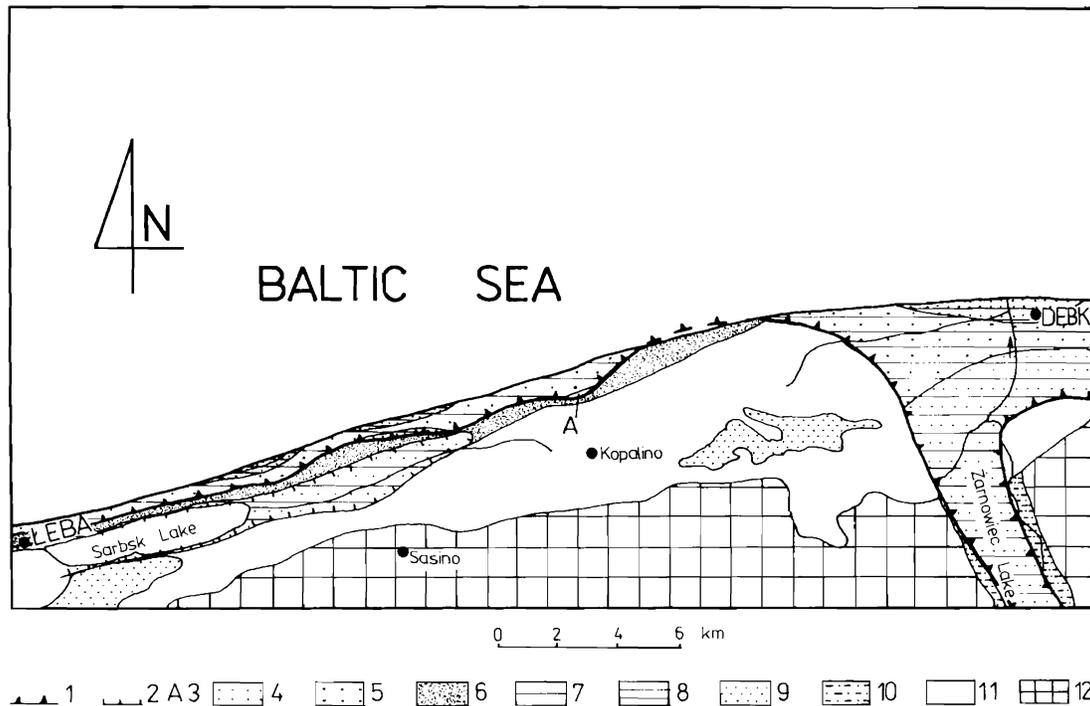


Figure 8. Late Middle Holocene paleogeographic reconstruction across the middle Polish coast; the Littorina transgression in phase  $L_{III}$  (MH<sub>5</sub>). (1) shoreline of maximum Littorina transgression in phase  $L_{III}$ ; (2) shoreline of lagoon basin; (3) beach gravels; (4) fine-grain sands; (5) medium-grain sands; (6) medium-grain sands of coastal dunes; (7) coastal zone (0–2 m below msl); (8) coastal zone (2–4 m below msl); (9) inland dunes (Late Pleistocene); (10) glacial terrace sediments (Late Pleistocene); (11) area of fluvial sediments (Late Pleistocene); and (12) morainic surface (Pleistocene).

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 as  $6,330 \pm 60$  yr BP (MOJSKI, 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<sub>5</sub>—The Littorina Sea (Phase $L_{IV}$ )

Phase  $L_{IV}$  corresponds to the end of the Middle Holocene. Coastal peat formed in the Sarbsk region; its lower layer dated  $5,480 \pm 90$  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  $L_{II}$ , 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 center 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 chronozone, 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 chronozone, 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<sub>4</sub>) 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<sub>5</sub>, NH<sub>6</sub>, and NH<sub>7</sub>) were smaller and did not cause such major shifts in the coastline as NH<sub>4</sub>. During that time the sea-level rose by 2.0–2.5 mm/yr, on average (KASZUBOWSKI, 1987). They left distinct

Table 2. Stratigraphic divisions in the Baltic Sea basin.

Years BP x 10 <sup>3</sup>	KLIEWE (1983) GERMANY east part	KASZUBOWSKI (1988a) POLAND middle part	GUDELIS (1979) LITHUANIA	KESSEL and RAUKAS (1979) ESTONIA	BERGLUND (1964) SWEDEN Blekinge	MILLER (1981) PERSON (1978) Stockholm
1		NH <sub>8</sub> NH <sub>7</sub>		Lim <sub>v</sub>		
2	PL	NH <sub>6</sub> NH <sub>5</sub>	PL	Lim <sub>iv</sub> Lim <sub>iii</sub>		
3	L <sub>III</sub>	NH <sub>4</sub>		Lim <sub>ii</sub> Lim <sub>i</sub>		
4					L <sub>VI</sub>	L <sub>IX</sub>
5	L <sub>II</sub>		L <sub>IV</sub>	L <sub>IV</sub> L <sub>III</sub>	L <sub>V</sub>	L <sub>II</sub>
6		MH <sub>2</sub> (L <sub>IV</sub> )		L <sub>IIb</sub> L <sub>IIc</sub>	L <sub>IV</sub> L <sub>III</sub>	L <sub>I</sub>
7	L <sub>Ib</sub>	MH <sub>1</sub> (L <sub>III</sub> )	L <sub>I</sub>	L <sub>I</sub>	L <sub>I</sub> L <sub>I</sub>	L <sub>I</sub>
8	L <sub>Ia</sub>	MH <sub>1</sub> (L <sub>II</sub> ) MH <sub>2</sub> (L <sub>I</sub> )	L <sub>I,II</sub>			

L<sub>I</sub>—Littorina Sea (marine transgressions)  
 MH<sub>1</sub>(L<sub>I</sub>)—Middle Holocene marine transgressions (Littorina Sea)  
 NH<sub>1</sub>—Late Holocene marine transgressions  
 Lim<sub>1</sub>—Limnaea Sea (marine transgressions)  
 PL—Post-Littorina Sea

traces in both deposits and landforms. A contemporary rise of sea-level (NH<sub>8</sub>) 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<sub>2</sub> 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<sub>2</sub> and MH<sub>3</sub>). 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 (MH<sub>4</sub> and MH<sub>5</sub>), 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 (NH<sub>5</sub>, NH<sub>6</sub>, NH<sub>7</sub>).

#### ACKNOWLEDGEMENTS

The author wishes to thank Professor B. Rosa of Gdańsk University for providing material and for numerous discussions. My thanks also to Dr. O. van de Plassche of the Free University of Amsterdam for his comments on the earlier version of the manuscript and useful suggestions. Appreciation is expressed to Professor Rhodes W. Fairbridge (Columbia University, New York City) who edited the final manuscript. The graphics were by Mrs. E. Nowak (Szczecin Technical University).

#### LITERATURE CITED

- BERGLUND, B.E., 1964. The post-glacial shore displacement in eastern Blekinge, Southeastern Sweden. *Sveriges Geologiska Undersökning* (Stockholm), ser. CNR 599.
- BOGACZEWICZ-ADAMCZAK, B.; FEDOROWICZ, S.; GOLEBIEWSKI, R., and MIOTK, G., 1981. Polodowcowa historia rejonu jeziora Gardno (The Postglacial History of the Lake Gardno Region). *Zeszyty Naukowe Wydziału BiNoZ* (Geografia, Gdańsk University), 12, 27–49.
- BRODNIWICZ, I. and ROSA, B., 1967. The Boring Hole and the Fauna at Czolpino, Poland. *Baltica* (Vilnius), 3, 61–85.
- BÜLOW, K., 1928. Entstehung und Ausfüllung eines jungglazialen Tales. *Jahrbuch der Preusschen Geologischen Landesanstalt zu Berlin*, 48.
- BÜLOW, K., 1929. Die Dünenzüge südlich Leba. *Jahrbuch der Preusschen Geologischen Landesanstalt zu Berlin*, 50.
- BÜLOW, K., 1932. Randlagen und Rückzug des Eises in Hinterpommern. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 84.
- DZIADZIUSZKO, Z., 1979. Średni poziom morza i jego wieloletnia zmienność u wybrzeży południowego Bałtyku (Mean sea-level and its fluctuations over many years on the southern Baltic coast). *Materiały Sesji Naukowej 60-lecie Państwowej Służby Hydrologiczno-Meteorologicznej* (Warszawa), pp. 246–260.
- ERONEN, M., 1974. The History of the Littorina Sea and Associated Holocene Events. *Societas Scientiarum Fennica, Commentationes Physico-Mathematicae*, 44, 79–195.
- ERONEN, M., 1983. Late Weichselian and Holocene shore displacement in Finland. In: SMITH, D.E. and DAWSON, A.G. (eds.), *Shorelines and Isostasy*. Institute of British Geographers, Special Publication 16, pp. 183–206.
- ERONEN, M., 1987. Global sea-level changes, crustal movements and Quaternary shorelines in Fennoscandia. In: M. Perttunen (ed.), *Fennoscandian Land Uplift*. Geological Survey of Finland, special Paper 2, pp. 31–36.
- GUDELIS, V., 1976. Istoria razwitija Baltijskogo Moria (The History of the Baltic Sea Development). *Geologia Baltijskogo Moria* (Vilnius), pp. 182–186.
- GUDELIS, V., 1979. The Quaternary History of the Baltic. Lithuania. In: GUDELIS, V. and KÖNIGSSON, L.K. (eds.), *The Quaternary History of the Baltic. Acta Universitatis Upsaliensis Symposia Universitatis Upsaliensis Annum Quingentesimum Celebrantis*, 1, pp. 159–173.
- HARTNACK, W., 1926. Die Küste Hinterpommerns unter besonderer Berücksichtigung der Morphologie. *Jahrbuch der Geographischen Gesellschaft zu Greifswald*, 43/44 (Beiheft II).
- HARTNACK, W., 1931. Oberflächengestaltung der Ostpommerschen Grenzmark. *Der Nordosten I*, Breslau.
- IVERSEN, J., 1937. Undersogelser over Litorina-Transgressioner i Danmark. *Meddelelser fra Dansk Geologisk Forening*, 9.
- KASZUBOWSKI, L., 1987. Rozwój paleogeograficzny obszaru pomiędzy jeziorem Sarbsk a jeziorem Żarnowiec w holocenie w świetle badań litologicznych (Paleogeographical Development of the Area between Lake Sarbsk and Lake Żarnowiec in the Holocene Revealed by Lithological Research). Doctoral Thesis. Maria Curie-Skłodowska University of Lublin (unpublished).
- KASZUBOWSKI, L., 1988. Późnoplejstocenska ewolucja Niziny Gardzieńsko-Lebskiej i Karwieńskiej (The Late-Pleistocene Evolution of the Gardno-Leba and Karwia Lowlands). *Prace Naukowe Politechniki Szczecińskiej, Geotechnika IV* (Technical University of Szczecin), pp. 35–67.
- KASZUBOWSKI, L., 1988a. The Holocene Transgression of the Baltic Sea on the Middle Sea Coast in Poland. International Symposium on: Theoretical and Applied Aspects of Coastal and Shelf Evolution, Past and Future. Amsterdam, the Netherlands, *Extended Abstracts*, pp. 60–63.
- KASZUBOWSKI, L., 1989. Holocenska ewolucja Mierzei Sarbskiej w świetle badań litologicznych (Holocene Evolution of the Sarbsk Spit, As Revealed by the Lithological Research). *Prace Naukowe Politechniki Szczecińskiej, Geotechnika V* (Technical University of Szczecin), 397, pp. 203–225.
- KESSEL, H. and RAUKAS, A., 1979. The Quaternary History of the Baltic Sea. Estonia. In: GUDELIS, V. and KÖNIGSSON, L.K. (eds.), *The Quaternary History of the Baltic. Acta Universitatis Upsaliensis Symposia Universitatis Upsaliensis Annum Quingentesimum Celebrantis*, 1, pp. 127–146.
- KLIEWE, H., 1983. Entwicklung, Ergebnisse und Tendenzen der Spätglazial und Holozänforschung im nordöstlichen Küstenraum der DDR. *Das Jungquar-*

- tär und seine Nutzung im Küsten und Binnentief-land der DDR und der VR Polen, No. 282.
- KOLP, O., 1979. Eustatische und isostatische Veränderungen des südlichen Ostseeraumes in Holozän. *Petermans Geographische Mitteilungen*, 123(3), 177-187.
- MILLER, U.A., 1981. Method of Reconstructing Changes in the Sedimentation Environment. *Report on the Meeting of Research Group Biology (24-25 March 1980, Paris) and Statements*, AS (Science) Pact (31) 3, pp. 40-52.
- MIOTK, G. and BOGACZEWICZ-ADAMCZAK, B., 1987. Marine transgressions on the basis of investigations of subfossil biogenic sediments in the Sarbska Bar, Southern Baltic. *Quaternary Studies in Poland*, 7, 65-72.
- MOJSKI, J.E., 1983. Lithostratigraphic units of the Holocene and the surface morphology of the bedrock in the north-western part of the Vistula Deltaic Plain (Żuławy Wiślane). *Geologische Jahrbuch R.A.*, 71, 171-186.
- PERSSON, CH., 1978. Dateringar av Ancylus-och Littorina transgressionerna på södra Gotland. *Sveriges Geologiska Undersökning*, C 745.
- ROSA, B., 1968. Obszar południowobałtycki w okresie ostatniego zlodowacenia i w holocenie (The Southern-Baltic Area in the Period of the Last Glaciation and in the Holocene). In: GALON, R. (ed.), *Ostatnie zlodowacenie skandynawskie w Polsce. Prace Geograficzne Instytutu Geografii PAN (Warszawa)*, 74, 121-155.
- STARKEŁ, L., 1977. Paleogeografia holocenu (The Holocene Paleogeography). *Państwowe Wydawnictwo Naukowe*, Warszawa.
- TOBOLSKI, K., 1972. Wiek i geneza wydmy przy południowo-zachodnim brzegu jeziora Lebsko (The Age and Origin of Dunes on the South-Western Banks of Lake Lebsko). *Badania Fizjograficzne nad Polską Zachodnią*, Vol. 25, ser. B, Biologia (Poznań), pp. 135-146.
- TOBOLSKI, K., 1975. Studium palinologiczne gleb kopalnych Mierzei Lebskiej w Słowińskim Parku Narodowym (Palynological Study of Fossil Soils of the Leba Spit in the Słowiński National Park). *Prace Komisji Biologii Poznańskiego Towarzystwa Przyjaciół Nauk*, Vol. 41, pp. 5-76, (Poznań).
- TOBOLSKI, K., 1979. Zmiany lokalnej szaty roślinnej na podstawie subfosalnych osadów biogenicznych w strefie plaży koło Leby (Changes of Local Vegetative Cover Basing on Subfossil Biogenic Sediments in the Beach Region near Leba). *Badania Fizjograficzne nad Polską Zachodnią*, Vol. 32, ser. A, Geografia fizyczna (Poznań), pp. 151-168.
- TROELS-SMITH, J., 1942. Geologisk datering av Dyrholm-fundet og Bemaerkninger om Litorinatidens Transgressionsfacer i Danmark. *Det Kgl. Danske Vidensk. Selskabs Archaeol.-Kuns.*, 1(1).

□ ZUSAMMENFASSUNG □

Die Hauptküste Polens begrenzt einen Teil der südlichen Ostsee. In den letzten 8.000 Jahren war dieses Meer ständig mit dem Weltmeer verbunden. Daher wurden die ausgedehnten Transgressionen von Faktoren außerhalb der Ostsee gesteuert. Weil die polnische Hauptküste im genannten Zeitraum geotektonisch relativ stabil war, lassen sich hier gut die eustatischen Meeresspiegelschwankungen studieren. Damit eröffnet sich auch die Möglichkeit, die durchschnittlichen Raten des Meeresspiegelanstiegs in den jeweiligen Abschnitten der Transgression zu berechnen. Als Resultat dieser Untersuchungen ergibt sich eine Meeresspiegelschwankungskurve der Ostsee für das Mittel- und Jungholozän.—*Helmut Brückner, Department of Geography, University of Marburg, Germany.*

□ RESUMEN □

La costa central de Polonia enfrenta la parte sur del mar Báltico. Antes de los últimos 8000 años, este mar estuvo conectado permanentemente con el océano mundial, lo cual explica, porque, las extensas transgresiones se relacionan con factores externos al área. La costa central de Polonia, de naturaleza, geotectónicamente 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.*