Geological Quarterly, Vol. 39, No. 3, 1995, p. 423–438

Elżbieta ZAWADZKA-KAHLAU

Lithodynamic processes along the Lake Jamno Spit

The contemporary trend of Lake Jamno Spit development is evaluated based on data from the periods 1889–1975, 1960–1983 and 1988–1991. During the last hundred years, erosion proceeded at a slow rate: 0.07 m/yr. The average rate of retreat in the period 1960–1983 was 0.57 m/yr.

Shallow-lying Pleistocene boulder till with uneven upper surface, on which there are peat and gyttja layers, is the direct substratum of a narrow zone of sandy bottom. The possibilities of reproducing the eroded coastal forms are limited, since the gyttja on the bottom surface is no source of sandy material, while the local outcrops of till in the activite zone of the nearshore bottom supply only small amounts of sand. During sea level rise from about 12 m at Littorina II, the whole upper surface of Holocene deposits was reworked. On the one hand, preserved erosional sills influence the dispersion of wave energy, on the other, they also exert a negative influence on the lithodynamic processes, strenghening the division in the sediment transport in the coastal zone. In transverse motion, after passing over the sills, the material is discharged directly into deep water, and has little chance of returning shorewards.

The average rate of coastline retreat during the last 6000 years was ca. 0.2 m/yr, and the average rate of sea level rise was ca. 2 mm/yr.

GEOMORPHOLOGICAL AND GEOLOGICAL CHARACTERISTIC OF INVESTIGATED AREA

The relief of the Lake Jamno area is the result of the Wolin – Gardzień Phase of the North Polish Glaciation and of contemporary relief-forming processes. Lake Jamno fills a depression in the Pleistocene surface, built of North Polish Glaciation boulder tills. In close vicinity to the lake, moraine highland reaches 4 to 28 m a.s.l. The southern part of the lake basin is filled by Holocene, peat and clay, lake muds and sands, river fen and Pleistocene clay and limnic muds. The lake is separated from the sea by a spit built of eolian sands and of eolian sands on dunes. The coastal zone adherent to the spit is built of various sized marine sands, originating from boulder tills. Locally, gravelly sands appear on boulder till.

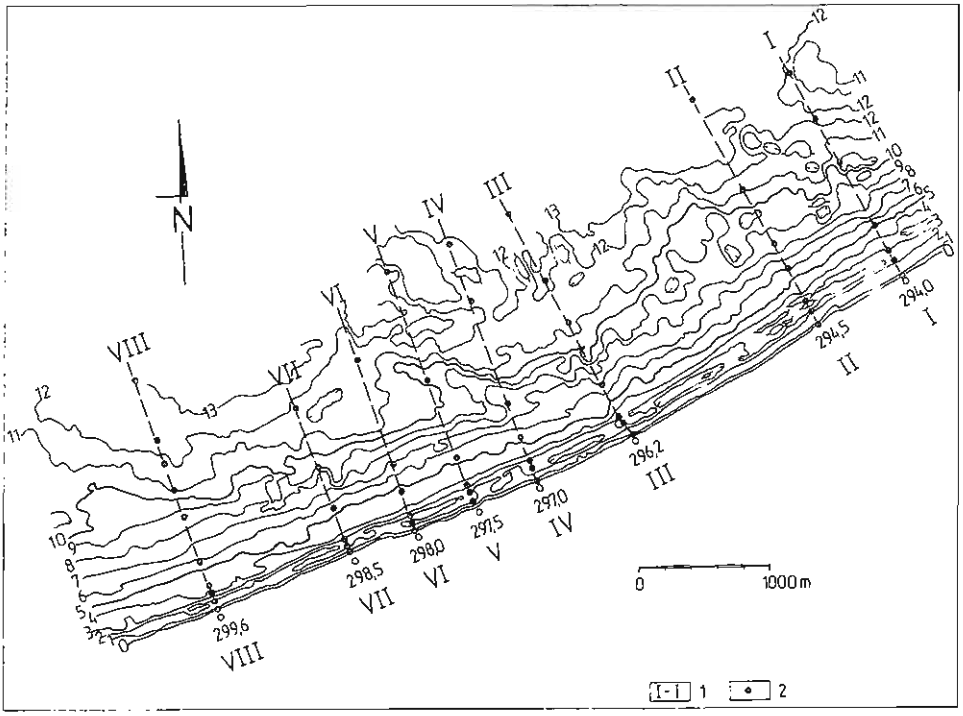


Fig. 1. Bathymetric plan Mielno – Unieście and localization of geological sections (kilometre 294.0–300.5)
1 — geological sections; 2 — hydrosoundings
Plan batymetryczny Mielna – Unieścia i lokalizacja przekrojów geologicznych (294.0–300.5 kilometr)
1 — przekroje geologiczne; 2 — sondy hydrogeologiczne

The sea bottom consists of sea originated forms, areas of polygenetic relief, and relicts of land originated forms. Outside the unerwater sea slope, but in its direct neighbourhood, there are areas with relicts of moraine hills and hills resulting from marine accumulation.

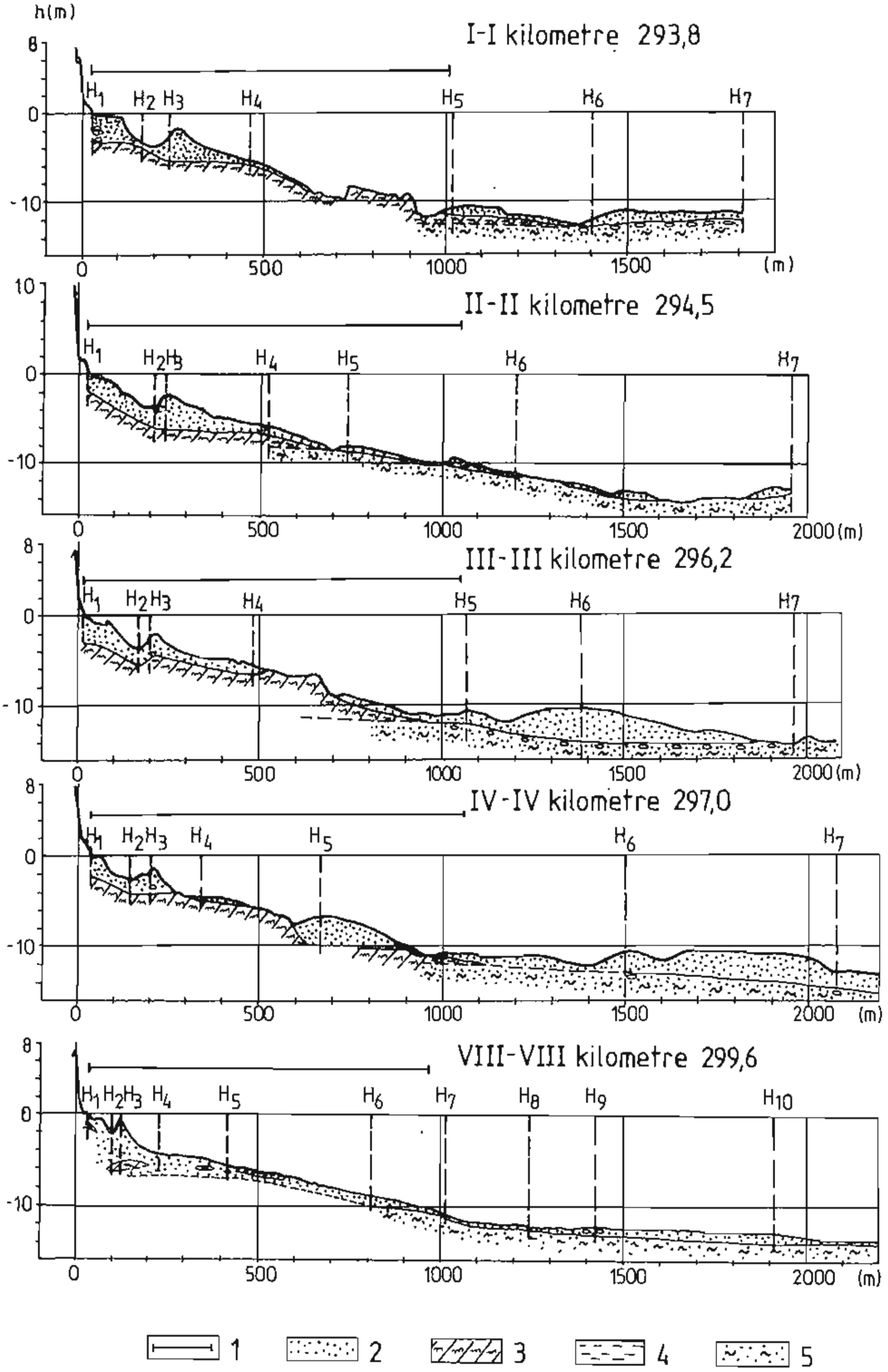
The geological build of the Lake Jamno area is connected with the post-glaciation history of South Baltic development. The pre-Jamno Lake appeared at the beginning of the Boreal Period (about 9300 BP). The whole area was a valley of some 7 km width, with a large slope to the north-west (M. Dąbrowski *et al.*, 1985). The depression in Pleistocene deposits was filled during the pre-Boreal with muddy sediments. Several deeper places filled with fresh-water existed in the depression. At the break of the Boreal and Atlantic Periods (about 7700–7900 BP), the bottom of the valley was covered by woods, bulrush complexes and shallow water basin plants. At that time sea level was 25 m lower than today. During the first phase of the Atlantic Period (over 7000 BP) sea level rose to 5.3 m below present m.s.l. From that time the Jamno valley was divided into an area of the Baltic and an area under the influence of land waters. Previously formed peats were flooded by sea water. The next transgression is dated at about 6200 BP, and sea level rose to 4.5 m below present m.s.l. From that moment, the internal division of the valley ceased to exist. The whole lake was a shallow sea bay. Sea level gradually rose to 3 m below m.s.l. In the sub-Boreal Period (4700–2800 BP), the spit dividing Lake Jamno from the sea started to close up. In the sub-Atlantic Period (about 2000 BP) there was another transgression, during which sea level reached today's level. The spit form became placed on lake deposits and gyttja (K. Wypych, 1973). In the substratum of the spit plain there are marine sands. Thickness of the sand layer varies from 6 to 10 m. At the bottom of the sand layer there are marine cobbles and gravel. Under them is lake gyttja resting on peat. These deposits occur in the substratum of the sea bottom down to the 15, 16 m depth contour (K. Wypych, 1973). Lake deposits, partly of marsh origin, pass downwards into muddy deposits with additions of organic matter. The muddy deposits belong to the pre-Boreal (about 10 000 BP), the peat and the lake deposits come from the Boreal (9100–7900 BP), possibly the Mastogloia sea phase (7600 BP) (K. Zaborowska, 1985).

Below the lake deposits there are deposits of the older, Pleistocene substratum in the form of boulder tills.

COASTAL ZONE MORPHOLOGY AND GEOLOGY

The Lake Jamno Spit is formed by dunes divided by a spit plain of 800 to 1000 m width. Large amounts of material accumulated on the coast are the result of accretion due to momentary stabilization of sea level after the Littorina transgression (B. Rosa, K. Wypych, 1980). The spit is about 10 km long. Nearly at the middle it is cut through by the Nurt Jamneński Lake outlet. Over long stretches the dune embankments are formed of only one, relatively low (5–10 m), dune line. On some stretches the dunes reach quite large height (up to 18 m at Unieście). Beach width, at mean sea level, is between 25 and 60–70 m, generally oscillating near the lower value. Morphometric data on the state of the Lake Jamno Spit, coming from 1972, from the stretch between kilometre 297 and 299 show existence of dunes reaching 4.9 to 10.7 m above m.s.l. Beach height was 1.2–3.2 m above m.s.l. Beach slope was between 1.7 and 4.7°. The seaward dune face sloped at an angle of 4 to 78°. Data on dune and beach parameters from 1988 show dunes with crest height 5.4–10.0 m. Average dune height was about 8 m above m.s.l. Beach height varied between 1 and 3.8 m above m.s.l. Lowest beaches were located along the kilometre 294.0–294.4 and 297.8–298.0 stretches. According to measurements from 1991, beach height was 1.5 to 2.7 m above m.s.l. Beach width varied from 19 to 49 m. Maximum dune height was 9.4 m. The lowest dunes (about 5 m above m.s.l.) were in the area of kilometre 295.0, 296.0 and 299.2.

The shape of the parent bed locally influence the shape of bottom forms. This is connected with gyttja, local peat outcrops or underlying boulder till which appear on the bottom surface or are covered by a thin layer of sandy sediments. Sandy sediments of larger thickness are present only in the region of kilometre 296.0–297.5 and also form a continuous belt in the zone of shallow depths, to the 3–4 m depth contour. Large thicknesses of the sand layer occur continuously only to the depth of 4 m, and tend to grow eastwards. Dynamic zone width depends on the presence and position of the gyttja sills. The narrowest layer of littoral cover was found in the area of the erosional bay at kilometre 297–298. Width of the sand layer, covering the gyttja, does not exceed 250–300 m. Nearest to shore uncovered gyttja was found at a distance of 175 m from the waterline. The general deficiency of sandy


h(m)
I-I kilometre 293,8
H1 H2 H3 H4 H5 H6 H7
8
0
-10
0 500 1000 1500 (m)
II-II kilometre 294,5
H1 H2 H3 H4 H5 H6 H7
10
0
-10
0 500 1000 1500 2000 (m)
III-III kilometre 296,2
H1 H2 H3 H4 H5 H6 H7
8
0
-10
0 500 1000 1500 2000 (m)
IV-IV kilometre 297,0
H1 H2 H3 H4 H5 H6 H7
8
0
-10
0 500 1000 1500 2000 (m)
VIII-VIII kilometre 299,6
H1 H2 H3 H4 H5 H6 H7 H8 H9 H10
8
0
-10
0 500 1000 1500 2000 (m)
1
2
3
4
5

sediments results not only from the ongoing process of bottom erosion — which is indicated by the appearance of substratum formations on the bottom surface — but also from the character of these formations. They is no (gyttja) or nearly no (moraine till) source of sandy material, and products of their erosion are flushed into deep water. Coarse material from the moraine till — gravel, cobble, boulders (depths of over 8–10 m) — remains at the site or in its vicinity.

Sea bottom shape is illustrated by bathymetric plans and profiles (I. Semrau, E. Zawadzka, 1990). Analysis of bathymetric plans points to an ongoing process of bottom profile formation on a scour-resistant substratum. This is shown by the existence of underwater platforms at various depths which are divided by sills of different height (0.2–2.0 m), in most cases with gyttja outcrops, though locally these are peat or moraine till. The process of levelling of the bottom is most advanced in the zone of shallow depths (to 4 m); this is indicated by a much more uniform alignment of depth contours.

However, even in that zone there are locally uncovered erosional platforms at depth of 0.5–1.0 m (kilometre 294.2, 296.4 and 300.5) and 2 m (kilometre 297.0, 297.4, 299.2, and 299.4). This, and an atypical alignment of sand bars with changing orientation, suggests that these are not classic bars of accumulative type, but accumulative forms of forced character, the position of which is determined by the run and level of the underlying erosion platforms. Also the 2.5 to 4.5 m deep trough in front of the sand bar is not conditioned only by wave dynamics, but is also the effect of cutting through the substratum underlying the sand. Presence of these troughs at a very small distance from the waterline (about 60 m at kilometre 298.0 — depth 2.5 m) may influence the character of changes occurring on the shore itself. Existence of erosional sills at larger depths may be connected with former stages of Baltic Sea development.

Investigations covered a segment of the coast, oriented WSW–ENE, 6.5 km long (kilometre 293.8–300.3) in a belt reaching maximally 2.2 km seaward from the waterline (Fig. 1). Geological information obtained from analysis of the hydrosoundings was used to draw geological sections (Fig. 2) and three block diagrams (Figs. 3–5), which give some insight into bottom morphology and geological structure of the investigated stretch.

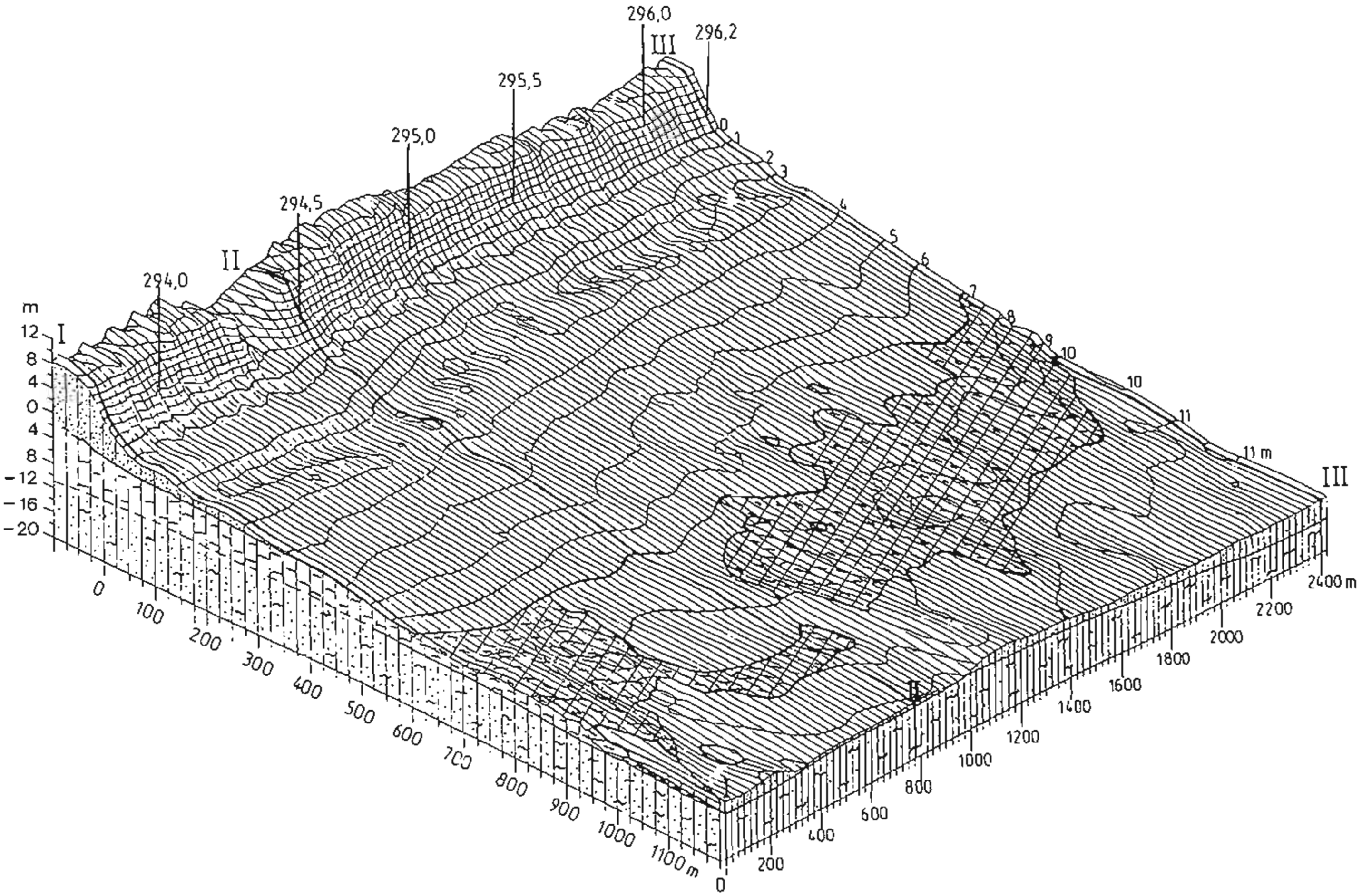
Results of hydrosoundings, bottom inspections, and studies of earlier archival material allow the distinction of two stratigraphic horizons within the Quaternary formations in the investigated area. These are the Holocene sand-gravel formations and organogenic deposits (peat, gyttja), and the Pleistocene formations of glacial origin (till and products of its scour — gravel and cobbles). Thickness of these formations varies from 4.0 m in the shallow water zone (Fig. 2) and decreases NNW-wards to 0.1 m. Sandy formations rest on a layer of organogenic deposits of gyttja and peat, which form the parent layer in the analysed segment of the coastal zone.

Fig. 2. Generalized geological sections

1 — segment of bottom inspected in 1989; 2 — fine, medium and coarse sand, gravel and cobble of marine accretion; 3 — gyttja; 4 — peat; 5 — boulder till; other explanations as in Fig. 1

Zgeneralizowane przekroje geologiczne

1 — zasięg przeglądów dna w 1989 r.; 2 — piasek drobny, średni i gruby, żwiry i otoczaki pochodzenia morskiego; 3 — gytia; 4 — torf; 5 — glina zwałowa; pozostałe objaśnienia jak na fig. 1


296,0
296,2
III
295,5
295,0
294,5
II
294,0
m
12
I
8
4
0
4
8
-12
-16
-20
0
100
200
300
400
500
600
700
800
900
1000
1100 m
0
1
2
3
4
5
6
7
8
9
10
10
11
11 m
III
II
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400 m

Based on analysis of the hydrosoundings and bottom inspections, it was found that gyttja outcrops have the form of large, wide platforms (Fig. 2) or of sills of smaller dimension. The height of the underwater sills is from about 2 m in the eastern part to 0.5 m in the western part of the investigated area. The sills are a relatively stable part of the nearshore zone. Gyttja is strongly compacted, and in the process of erosion becomes loosened in plates. Therefore, fragments of redeposited substratum appear on the sea bottom and on the beach in the form of plates found during inspections of the bottom.

HYDROMETEOROLOGIC AND HYDRODYNAMIC CONDITIONS

Hydrometeorologic conditions were analysed for the periods 1956–1970 and 1971–1989 (H. Boniecka, 1990). In the first period, the frequency of 15–17 m/s winds was 0.05%. 12–14 m/s winds appeared in that period 0.7% of the time. Average wind speed in the period 1971–1989 was calculated for 8 wind directions, showing a predominance of wind speeds from the west (4.98 m/s) and NW (4.31 m/s). Calculated probability of exceedance shows that winds with 9.96 m/s speed have 0.1% probability of occurrence in the autumn-winter season, and 8.08 m/s in the spring-summer season. Characteristics of sea levels in the period 1971–1989 showed that in the autumn-winter season sea levels of 495–500 cm (15.3%) (the datum level or "mean sea level" is 500 cm) and 501–510 cm (15.4%) are most frequent. Sea level varies between 370–635 cm. The absolute maximum sea level of 635 cm occurred in January 1983. Maximum mean sea levels in the autumn-winter season occurred during NW winds (524 cm) and N winds (529 cm). During the period 1971–1989, sea level of at least 630 cm appeared with a probability of 0.1% in the autumn-winter season. For the period 1956–1970 the 0.1% probability level was 580.9 cm. Generally, maximum sea level occurs winds from NW and W, and minimum level during winds from SW and S.

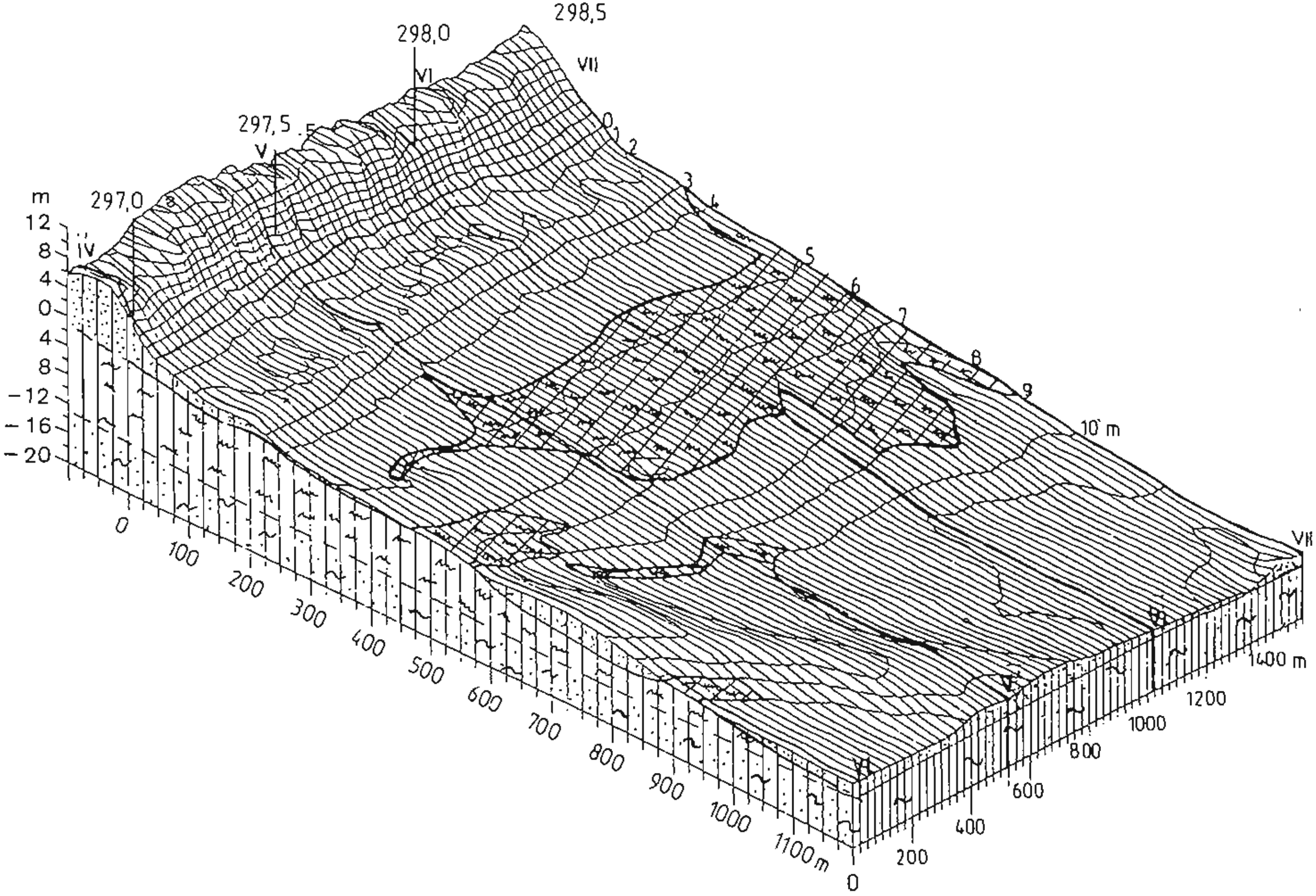
The reason for increasing erosion during the last 18 years was the more frequent and larger value of high sea levels than in the earlier period.

Parameters determined for the investigated region result from the weighted mean of energy of all waves, acting on the bottom at a given depth (A. Cieślak, 1990). They concern the significant wave (H_{33}). Waves constituting the highest danger to structures and coasts result from 18 m/s wind from NW. At the depth of 2 m wave height is evaluated at 1.5 m. At 1:15 beach slope, wave runup height was calculated at 0.7 m. Wind currents dominating in the coastal zone were evaluated using the I. Shadrin model (1972). Longshore components of wave currents were predicted using the LONG-CURR numerical model, developed by L. Gajewski *et al.* (1990). This model takes into account the real bottom relief and multiple breaking of waves approaching obliquely to the shoreline.

Calculations were made for the strongest storm that occurred during the 1971–1990 period, with 17 m/s mean wind speed from 290 degrees. The map of the longshore flow

←

Fig. 3. Coastal morphology and geology in Mielno area (kilometre 293.8–296.2)
Explanations as in Figs. 1 and 2
Morfologia i budowa geologiczna brzegu morskiego w rejonie Mielna (293.8–296.2 kilometr)
Objaśnienia jak na fig. 1 i 2


298,5
298,0
VII
VI
297,5
V
297,0
IV
m
12
8
4
0
4
8
−12
−16
−20
0
1
2
3
4
5
6
7
8
9
10 m
0
100
200
300
400
500
600
700
800
900
1000
1100 m
0
200
400
600
800
1000
1200
1400 m
VII
VI
V
IV

component shows significant variation, correlating with the bottom relief (Fig. 6) (L. Gajewski *et al.*, 1990). Longshore components of flow increase from 10 cm/s in the deep water zone to 160 cm/s in the main wave breaking zone. Three differing zones, characteristic of the distribution of longshore velocities have been distinguished. At a distance of about 600 m from the waterline, velocities do not exceed 26 cm/s. In that zone wind drift currents prevail. In the zone of the seaward slope of the bars, velocities increase from 20 to 50–90 cm/s. Along the main bar crest longshore velocities exceed 130 cm/s, and near the beach they reach 160 cm/s. Cross-shore components of flow (landward and seaward) have much smaller velocities. In the deep water zone they are about 2 cm/s, and in the zone of last wave breaking about 19 cm/s. The line of zero cross-shore velocity is located at a distance of about 600 m from the beach. The map of resultant flow vectors (Fig. 6) at the height of 0.5 m above bottom shows a distinct eastward longshore transport. The transporting force is largest in a belt of about 200 m width.

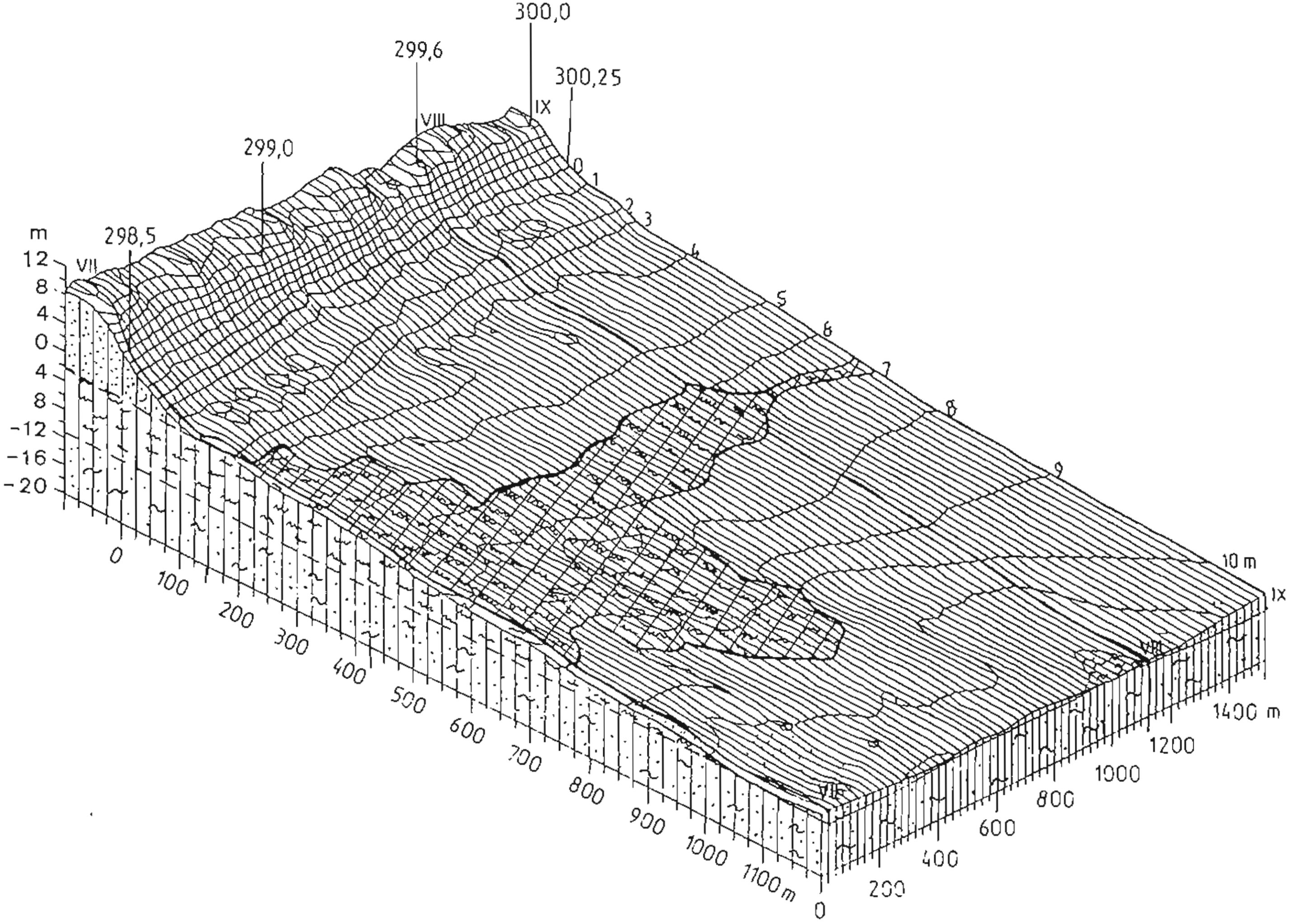
For a selected profile (kilometre 298.0), the distribution of wave and wind current components was modelled. Calculations were made for 8 wind directions and wind speeds of 10, 16 and 22 cm/s. During wind from S, SW, NW and W, flow to the east occurs over the whole section. In case of wind from W and NW, velocities near the bar tend to increase. When wind blows from SE and E, the longshore component is directed westwards. For winds from N and NE, flow is bilayered. At depth larger than 6 m, flow is directed to the east, in shallower water — to the west. Cross-shore components attain lower values than the longshore components. In the zone with depth exceeding 8 m, tri-layered flow was obtained. For wind from NW, NE, W and N, flow is directed shorewards at the water surface and near the bottom. A compensative current running in between is directed seawards. When the wind blows toward the sea, the flow pattern is reserved.

LITHODYNAMIC PROCESSES

Coastline changes were analysed based on cartographic material from the years 1889–1975 and for the period 1960–1983 (E. Zawadzka, 1993) also using results of geodetic surveys from the years 1988 and 1991 (I. Semrau, E. Zawadzka, 1990). Contemporary development of the spit has the character of cyclic changes, occurring with varying intensity in time and space. During the last hundred years (1889–1975) the rate of coastline displacement along the Lake Jamno Spit was relatively slower than along spits to the east and west. The average rate of retreat was 0.07 m/yr, while Bukowo Spit retreated at 0.47 m/yr, and Resko Spit — at 0.37 m/yr. Largest changes have been occurring west of the Lake Jamno outlet (0.1 to 0.5 m/yr). Small accumulative changes appeared east of the outlet (Fig.

←

Fig. 4. Coastal morphology and geology in Mielno area (kilometre 297.0–298.5)
Explanations as in Figs. 1 and 2
Morfologia i budowa geologiczna brzegu morskiego w rejonie Mielna (297.0–298.5 kilometr)
Objaśnienia jak na fig. 1 i 2


300,0
299,6
300,25
299,0
298,5
IX
VIII
VII
m
12
8
4
0
4
8
-12
-16
-20
0
1
2
3
4
5
6
7
8
9
10 m
IX
VIII
VII
0
100
200
300
400
500
600
700
800
900
1000
1100 m
0
200
400
600
800
1000
1200
1400 m

5). In the years 1960–1983, the average rate of coastline position change was 0.57 m/yr, and in the years 1972–1983 it was 0.84 m/yr.

The rhythm of coastline change between Mielno and Łazy was about 400–500 m. Regions with maximum change showed a 1000 m regularity.

Local accretion occurred within the groyne system of the spit as for east as the Mielno Channel. Erosion occurred east of the groyne system at rates from 0.1 to 3.2 m/yr. Areas with maximum changes appeared with about 1000 m regularity. East of kilometre 292.0, the rhythm of erosive bays was about 2000 m. Beach erosion increased in the years 1971–1983. Along the whole spit, the sea entered onto land. All stretches, along which during the former 11 years accretion was present, were subjected to erosion at rates from 0.1 to 2.5 m/yr. Regions with groyne were also eroded. Analysis of dune foot changes in the years 1960–1983 showed changes of at least 0.1 m/yr. Maximum change occurred at a rate of 1.3 m/yr. Accumulation appeared only in the vicinity of the Lake Jamno outlet. The latest, 1988–1990 period, was characterized by even more intensive erosion of the coastal zone. Comparison of averaged rates of coastline changes points to increasing erosive transformation of the spit. Analysis of short-term changes shows erosive displacement of the waterline proceeding at rates up to 6 m/yr, and of the dune foot at about 3 m/yr. Average rate along the whole stretch between kilometre 283.5 and 300.5 was 1.9 m/yr for the waterline, and 1.07 m/yr for the dune foot line. This is double the value for the 1971–1983 period. The most intensive change occurred east of the fishing slip at Unieście, on kilometre 297.7–298.0. Dune foot retreat was 1.7–8.9 m/yr.

Within the next erosive bay, the dune foot retreated by 3.2 to 7.5 m. The most endangered parts of the spit is between kilometre 295.0–295.4 and 297.6–297.7 because of terrain lying behind the dunes. Volumetric change, evaluated for the 1988–1991 period, varies between –2.5 and 69 m^3 per metre of coastline length (I. Semrau, E. Zawadzka, 1990). The balance of volumetric change above water level in 1988–1991 was –83 000 m^3. Total balance of change on shore and bottom to the 12 m depth contour was evaluated at –490 000 m^3. Therefore change above the waterline formed 16% of total loss. The seaward boundary of highly active erosion did not exceed outside the 6 m depth contour.

Based on investigations of surface sediments, carried out in the years 1989 and 1990, maps of median diameter and of sediment sorting were developed. Analysis of granulometry in relation to morphological forms of shore and bottom, indicates that the sediments are lithodynamically and genetically diverse. The bottom surface is built of products of scour of post-glacial formations, of organogenic formations, and of marine accumulation sediments. Significant diversification of sediments of the dynamic layer and of products of post-glacial formation scour are observed. Dynamic layer sediments, built of fine to coarse sands, show a zonal distribution, connected with cross-shore and longshore differentiation. The coastal dune and its foot is built of medium, well-sorted sand. On the beach, sand is coarser and more poorly sorted. Coarsest deposits occur at the crest of the beach embankment, and they are medium-sorted. Medium-sorted medium sands are associated with the

---

Fig. 5. Coastal morphology and geology in Mielno area (kilometre 298.5–300.0)
Explanations as in Figs. 1 and 2
Morfologia i budowa geologiczna brzegu morskiego w rejonie Mielna (298.5–300.0 kilometr)
Objaśnienia jak na fig. 1 i 2

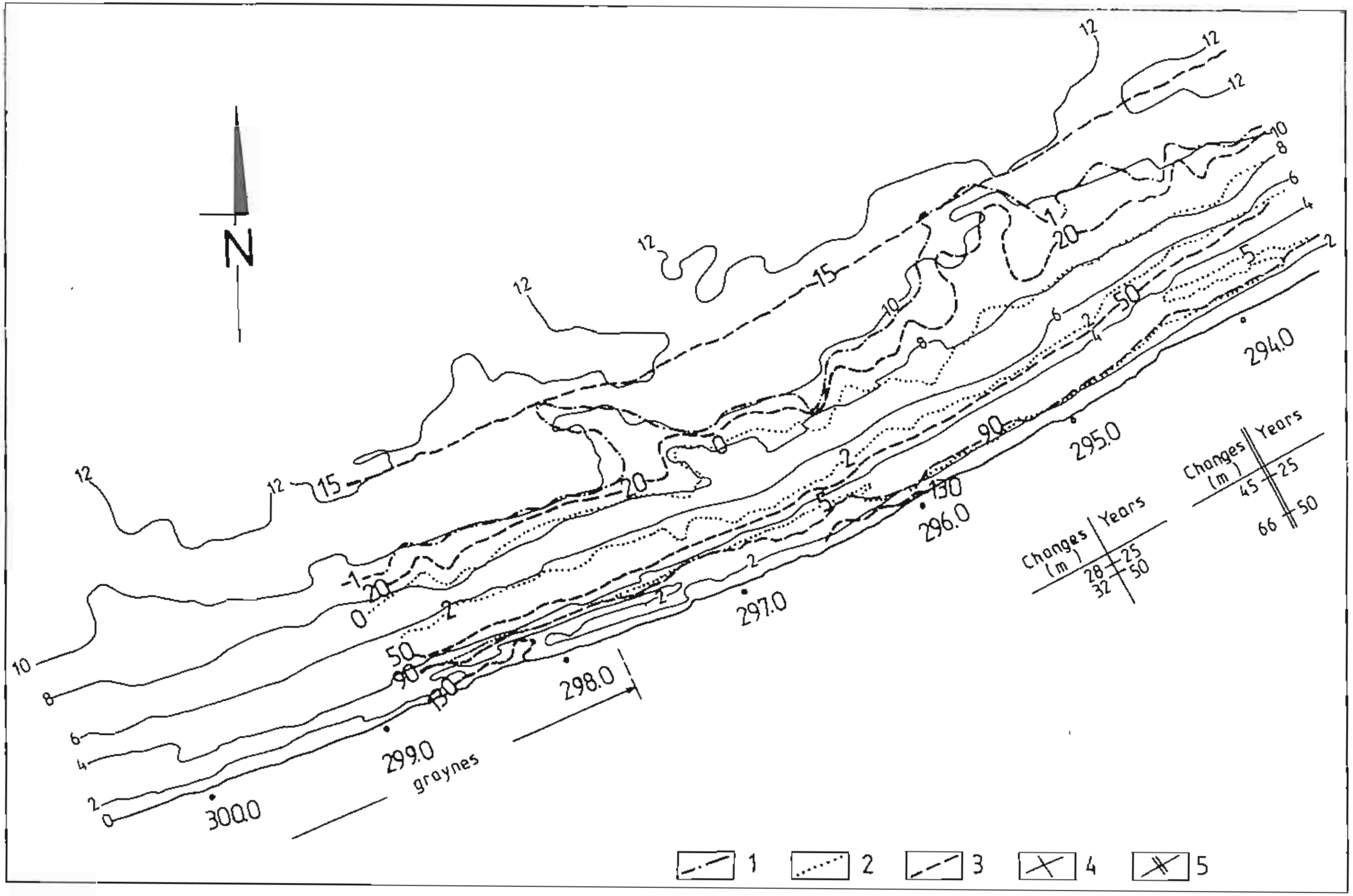

N
12
12
12
12
12
12
12
15
15
10
8
6
4
2
0
10
8
6
4
2
1
20
20
20
10
8
6
0
0
-1
2
2
2
2
2
5
5
50
50
90
90
130
130
294.0
295.0
296.0
297.0
298.0
299.0
300.0
groynes
Changes (m)
Years
28
32
25
50
Changes (m)
Years
45
66
25
50
1
2
3
4
5

Table 1

Average rates of waterline and dune foot line displacement on Lake Jamno Spit, in the period 1889–1991 (kilometre 289.5–300.5)

Period	Rate of change [m/yr]	
	waterline	dune foot line
1889–1975	–0.07	–
1960–1983	–0.57	–0.30
1972–1993	–0.84	–0.41
1989–1990*	–1.93	–0.07
1988–1991*	–1.02	–1.19

* — kilometre 293.0–300.5

waterline. Within the crests of bars and trough of the 1-st bar occurs medium-sorted fine sand. The landward slope of the 1-st and 2-nd bars built of medium sand, however sorting of the seaward slope of the 1-st bar is rather bad. Below the 10 m depth contour, sediments become coarser, indicating the presence of products of Pleistocene substratum scour.

On the background of the zonal differentiation of surface sediments, there appear areas suggesting a higher than average intensity of lithodynamic processes. In the erosive bay, kilometre 297.0–297.5, depth below 2 m, median diameter of grains approaches 1 mm. In the next bay the median diameter is over 1.5 mm. Areas with largest median diameters are connected with most intensive erosion of the shore. Areas of accretion kilometre 296.0–297.0 are characterized by median diameter within 0.1–0.2 mm and very good sorting of the sediments.

Comparison of granulometry of surface sediments from two periods, suggests that the bottom has become active in the region of kilometre 295.5–296.0 within the 8–10 m depth zone and in the region of kilometre 293.5–294.0 within the 6–8 m zone.

The spatial variability of erosional and accretional zones on shore and bottom, connected with averaged granulometric parameters, allows establishment of the directions of sediment transport. In the depth zone 0–6 m, eastward transport prevails. In the eastern part of the investigated stretch, in the 6–10 m water depth zone transport to the west predominates. The zone of convergence is located in the region of kilometre 296.0–297.0. Seaward transport is present in the whole analysed 6–8 m depth zone. From differences in compo-

Fig. 6. Longshore and cross-shore currents and forecast of coastline change

1 — landward flow component (cm/s); 2 — seaward flow component (cm/s); 3 — longshore flow component equal velocity lines (cm/s); 4 — predicted mean coastline retreat; 5 — predicted average value of coastline retreat taking into account sea level rise by 1 m in 100 years

Wzdłużbrzegowe i poprzeczne do brzegu wielkości prądów oraz prognoza zmian brzegowych

1 — dobrzegowe składowe przepływu (cm/s); 2 — odbrzegowe składowe przepływu (cm/s); 3 — wzdłużbrzegowe składowe izotachy przepływu (cm/s); 4 — prognozowane średnie wielkości zmian brzegowych; 5 — prognozowane średnie wielkości zmian brzegowych z uwzględnieniem przyrostu zmian poziomu morza (1 m/100 lat)

nents of the sand population results that particles with diameter exceeding 0.25 mm are transported shorewards in the wave transformation zone. Resultant movement of particles below 0.21 mm is directed seawards (K. Pawluk, 1990).

One of the reasons for the irretrievable loss of material, resulting among others in retreat of the coastline, is the cross-shore sediment transport. In a situation where the geological structure of the bottom is very complex due to the presence of underwater platforms built of gyttja, material eroded out of the shore and shallow water zone is irretrievably transported into the deep water zone (Fig. 2). The seaward oriented component of water flow causes grains with diameters below 0.15 mm to be flushed into the deep water zone event at current speed of 10–12 cm/s. Activating surfaces of the Pleistocene substratum lose their finer particles at water speeds of 15–20 cm/s.

In storm conditions, transport of sediments occurs over the surface of the bottom within the 10 m depth contour, and built of sand finer than 0.2 mm. Taking into account the maximum value of currents in depths smaller than 4 m, where currents of 50–130 cm/s occur, all sediments with diameter below 10 mm can be easily transported.

GENERAL CONCLUSIONS

Morpho- and lithodynamic processes, observed along the Lake Jamno Spit, are closely related with active hydrodynamics factors forming the shore and bottom, and with long-term factors proceeding in the Holocene. During Littorina transgression, the upper surfaces of Pleistocene and Holocene formations were reworked, depending on their resistance to shear abrasion. At the bottom surface, built of Pleistocene formations, products of scour remained in the form of sand and gravel. Holocene sediments took on the shape of gently sloping platforms or sharp erosional sills.

Assuming after B. Rosa (1991) that sea level at the break of Littorina III and II was at 10 to 12 m level (about 6000 years ago), occurring on the investigated stretch at a distance of 1000–1300 m from the present waterline, shear scour acted within the 8–12(14) m depth zone. According to Brunn theory, deposition of sediments should then proceed below the present 14 m depth. Maybe the massive accumulative forms at the foot of high sills are the remnants of the spit form built at a lower sea level, supplemented by sediments eroded at present out of the coastal zone.

Sea level rise to about 5.3 m caused that the gyttja surface started to be carved in the 3–8 m depth zone. The next sea level rise to 3 m acted on the 0.0–5.0 m depth zone. During sea level rise from about 12 m at Littorina II, the whole upper surface of Holocene deposits was reworked. Within the general sea level rise, periods of quicker rise can be distinguished, leading to the formation, and then preservation of erosional sills (zone 10 to 6 m depth).

From obtained results it is evalued that the average rate of coastline retreat during the last 6000 years was about 0.2 m/yr, and the average rate of sea level rise was about 2 mm/y. Pre-Jamno coasts reached at least 1300 m seaward of todays waterline.

At present, erosion of the coast is increasing because of increased rate of sea level rise, which is about 3 times higher than in the period 1950–1970, and 5 to 7 times higher in comparison to the period 1889–1975.

Instytut Morski
Gdańsk-Oliwa, ul. Abrahama 1
Received: 17.11.1994

REFERENCES

BONIECKA H. (1990) — Czynniki hydrometeorologiczne. In: Określenie stopnia zagrożenia, prognoza zmian oraz koncepcja ochrony brzegów na odcinku przystań rybacka w Unieściu — przetoka Jeziora Jamno, p. 11–36. WW-IM 4939. Gdańsk.

CIEŚLAK A. (1990) — Falowanie. In: Określenie stopnia zagrożenia, prognoza zmian oraz koncepcja ochrony brzegów na odcinku przystań rybacka w Unieściu — przetoka Jeziora Jamno, p. 46–47. WW-IM 4939. Gdańsk.

DĄBROWSKI M., LUBLINER-MIANOWSKA K., WYPYCH K., ZACHOWICZ J. (1985) — Bottom sediments of Lake Jamno in the light of palynological studies (in Polish with English summary). Peribalticum, 3, p. 37–52.

GAJEWSKI L., SZMYTKIEWICZ M., SKAJA M. (1990) — Rola prądów w przebudowie strefy brzegowej. In: Określenie stopnia zagrożenia, prognoza zmian oraz koncepcja ochrony brzegów na odcinku przystań rybacka w Unieściu — przetoka Jeziora Jamno, p. 48–75. WW-IM 4939. Gdańsk.

PAWLUK K. (1990) — Beach nourishment and sand population transported by waves landwards and seawards (in Polish with English summary). Rozpr. Hydrotech., 52, p. 71–106.

ROSA B. (1991) — The problem of sea level changes in South Baltic — present state of knowledge and prospects for future research (in Polish with English summary). Peribalticum, 5, p. 57–75.

ROSA B., WYPYCH K. (1980) — O mierzejach wybrzeża południowobałtyckiego. Peribalticum, 1, p. 31–44.

SEMRAU I., ZAWADZKA E. ed. (1990) — Określenie stopnia zagrożenia, prognoza zmian oraz koncepcja ochrony brzegów na odcinku przystań rybacka w Unieściu — przetoka Jeziora Jamno. WW-IM 4939. Gdańsk.

SHADRIN I. (1972) — Currents in the coastal zone of a nontidal sea. Izd. Nauka, Moscow.

WYPYCH K. (1973) — Geneza zalewów południowobałtyckich w świetle nowszych badań. Prz. Geof., 18, p. 111–120, no. 1–2.

ZABOROWSKA K. (1985) — Diatoms of Pre-Jamno (in Polish with English summary). Peribalticum, 3, p. 53–58.

ZAWADZKA E. (1993) — Tendencje rozwojowe brzegów południowobałtyckich w ostatnim stuleciu. Pr. Inst. Mors., no. 726.

Elżbieta ZAWADZKA-KAHLAU

PROCESY LITODYNAMICZNE NA MIERZEI JEZ. JAMNO

Streszczenie

Współczesny kierunek rozwoju mierzei Jez. Jamno został oceniony na podstawie danych kartograficznych z lat 1889–1975 i 1960–1983 oraz najnowszych pomiarów niwelacyjnych i batymetrycznych, a także badań budowy geologicznej prowadzonych w latach 1988–1991.

W sytuacji podnoszenia się poziomu morza, ocenionego dla rejonu Zatoki Koszalińskiej na ok. 14 cm/100 lat, akumulacyjna forma mierzejowa, która powstała w okresie przejściowej stabilizacji morza po transgresji litorynowej, podlega aktualnie erozji. W ostatnim stuleciu erozja zachodziła tu z małą prędkością (0,07 m/a). Znaczne przyspieszenie niszczenia stwierdzono po 1970 r. Średnie ubytki brzegu w latach 1960–1983 wynosiły 0,57 m/a, a w latach 1988–1991 — 1,0 m/a.

W badaniach nad kompleksem uwarunkowań i czynników kształtujących współczesne procesy lito- i morfodynamiczne na mierzei Jez. Jamno stwierdzono znaczny wpływ budowy geologicznej. Płytko leżące plejstoceńskie gliny zwałowe oraz holoceńskie gytie tworzą bezpośrednie podłoże wąskiej strefy piaszczystego dna. Możliwości odtwarzania niszczonych form brzegowych rejonu są ograniczone, ponieważ występujące na powierzchni dna gytie nie stanowią źródła materiału piaszczystego, a lokalne odsłonięcia glin w aktywnej strefie dna dostarczają niewielką jego ilość. Jest to jedna z przyczyn dużego deficytu osadów, podobnie jak w znacznej części Zatoki Koszalińskiej.

Formowanie się profilu dna w odpornym na rozmywanie podłożu przejawia się tworzeniem platform i progów na różnych głębokościach. Przebieg i rzędna tych form determinuje występowanie rew i przegłębień międzyrewowych. W zależności od zróżnicowania osadów i miąższości utworów podłoża, erozja dna ma charakter selektywny. Znaczna i zróżnicowana odporność podłoża na rozmywanie, mimo silnego deficytu osadów, dużej dynamiki falowania i silnego transportu wzdłużbrzegowego, jest powodem znacznego zróżnicowania przybrzeża. Rozpraszanie falowania przez układ progów podwodnych oceniane jest jako czynnik istotnie opóźniający niszczenie brzegów. Istnienie progów wywiera również pewien ujemny wpływ na przebieg procesów litodynamicznych. Pogłębiają one strefę rozdziału osadów transportowanych w pasie przybrzeżnym. Po przekroczeniu progów materiał w ruchu poprzecznym jest odprowadzany bezpowrotnie do strefy głębokowodnej.

W świetle przedstawionych badań stwierdzono wpływ budowy geologicznej na przebieg erozji brzegów mierzei Jez. Jamno. Uzyskane wyniki mają podstawowe znaczenie dla prognozowania rozwoju brzegów tego rejonu.