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Sopot

AN OUTLINE OF THE EVOLUTION OF THE SOUTHERN BALTIC AREA AT THE END OF THE LAST GLACIATION AND BEGINNING OF THE HOLOCENE

A b s t r a c t

The last Pleistocene ice sheet in Southern Baltic area moved from NNE to SSW, or in its western part, from east to west. The glacial erosion decreased westwards. One of the most important processes was drumlinisation and the appearance of the youngest generation of the subglacial channels, as well as the transformation of older large elevations. Especially interesting is the esker at the bottom of the Bornholm Basin.

The disappearance of the last Pleistocene ice sheet was areal deglaciation with blocks of dead ice and kames. The ice sheet decay developed from west to east. The western part of discussed area was ice free earlier than 14,060 years BP.

During the time period between 14.5 ka and 7.0 ka BP the discussed area was in part an inland. The main valley lead from east to the Bornholm Basin, but starting from the end of the Late Glacial, the Vistula flowed directly to the Gdański Basin. The maximum of the Litorina Sea along the Polish coast took place at 6.0 ka BP.

INTRODUCTION

The 1:200,000 Geological Map of the Baltic Sea Bottom, published in 1994 by the Polish Geological Institute, provides a new basis for studies of the development of Southern Baltic area during the period between the disappearance of the last Pleistocene continental ice sheet and present times. This new basis results both from the contents of the map itself, and from its additional parts, such as the geomorphological sketches, profiles from selected important boreholes and geological cross sections.

It is not the subject of the present paper to present even a short review of hitherto research achievements. Nevertheless, the pioneering results of the many years of investigations of ROSA (1967, 1987) cannot be overlooked. ROSA has determined the age and genesis of the Southern Baltic bottom, and has presented their development through time. His analysis was based mainly on studies of sea-floor relief, on interpretation of relatively scarce seismo-acouistic profiles, and only to a minimal degree on the interpretation of a few borehole profiles. Therefore many of his conclusions were of only hypothetical significance. Some problems investi-

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gated by ROSA were recently presented by the author of this paper (Mojski, 1989). Important additional information was supplied by investigation of the coastal zone carried out by the Polish Geological Institute (TOMCZAK, MOJSKI, 1990). The mentioned above map, the results of coastal zone investigations, and recent publications, form the basis for concepts formulated in the present paper.

THE SOUTHERN BALTIC AREA UNDER THE LAST PLEISTOCENE CONTINENTAL ICE SHEET

The last Pleistocene continental ice sheet probably covered the Southern Baltic area slightly before 20 ka BP. The development of the ice sheet caused changes in the relief of the area which are visible even now. This concerns mainly:

1. The deepening of earlier existing exaration depressions of the Lower Vistula and Lower Odra, and of several other smaller depressions (Fig. 1). This process destroyed the upper parts of sediments filling these depressions. Various investigations, carried out in the northern part of German Lowland and in Jutland, indicate that in the basin of present Baltic the continental ice sheet moved from NNE to SSW – or even from east

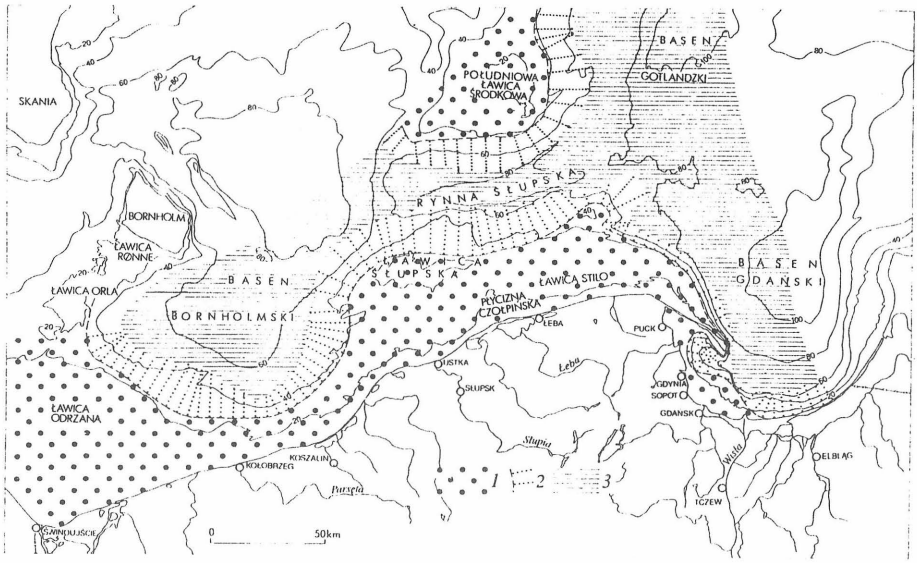

Fig. 1. Relief of the Baltic Sea bottom

1. plain in the shallow-water area; 2. slope of plain; 3. the deepest part of the Baltic Sea bottom

to west. The destructive force of the ice sheet decreased westwards, and for this reason also glacial erosion decreased in that direction. This is visible in the present relief of Baltic sea floor in the form of the deep Gdańsk Deep with its southward extension in the form of Vistula Delta, and in the lack of such deep forms in the Odra outlet area.

2. Generation of new, and renewal of earlier existing subglacial channels, which in some places cut through not only the Pleistocene cover, but also reach deep into the Mesozoic–Tertiary substratum. Some preliminary remarks on this have been presented in a separate paper (MOJSKI, TOMCZAK, 1994).

3. In many places the substratum became drumlinised, as it is at present visible in Western Pomerania in the Pomeranian Phase of the Odra lobe, in the hinterland of the marginal zone of the same phase of the less distinct Vistula lobe, and also in other places.

4. Smoothing of the shape of large old elevations, the core of which is built of Caenozoic formations with disturbed primary arrangement, and further disturbances of their structure (Bukowe Hills, Warszewo Hills, Koszalin Hills, Elbląg Hills, etc.).

5. Presence of distinct forms of glaciofluvial accumulation. This concerns especially the up to 35 km long esker (Fig. 2) in the bottom of the Bornholm Basin, oriented in the 220° azimuth direction (UŚCINOWICZ, ZACHOWICZ, 1990). This bank is clearly visible both in the sea-floor relief as separate long banks reaching a height of 22 m above the sea bottom, and in the geological structure (sands). Orientation of the esker corresponds with the direction in which the last Pleistocene continental ice sheet moved onto the area.

Probably into this group of forms should be included the marginal zone, which later became destroyed by transgression of the sea, and which is now visible in the form of the Słupsk Bank. In many places its surface is presently lying only about a dozen metres below sea level, and whole area is built of gravel and large amounts of stones. They form a thin coat of about 1 m thickness, covering older sediments.

The above mentioned forms – or their tranformations – are related to the development, and to a lesser degree to the disappearance, of the last Pleistocene continental ice sheet. At present they play a main role in the relief of the Southern Baltic bottom, and of the land directly southwards. In most cases they have been known for many years. However, the age of some of them could be determined more accurately only because of the recent geological survey of Southern Baltic.

The present coastal zone was distinct sill during the Vistulian. This sill separated the low lying area with reduced Tertiary and rather thin Qua-

ternary in the north, from the area to the south with high-lying Caenozoic formations of significantly greater thickness than in the area to north of the sill. It may be supposed that this sill separated the Baltic area with prevailing glacial erosion from the southern area in which glacial accumulation dominated during the whole glacial Quaternary. Such a sill either did not developed or was destroyed in zones of deep glacial erosion depressions (Lower Vistula, Lower Odra, Gardno–Łebsko Lowland, and others).

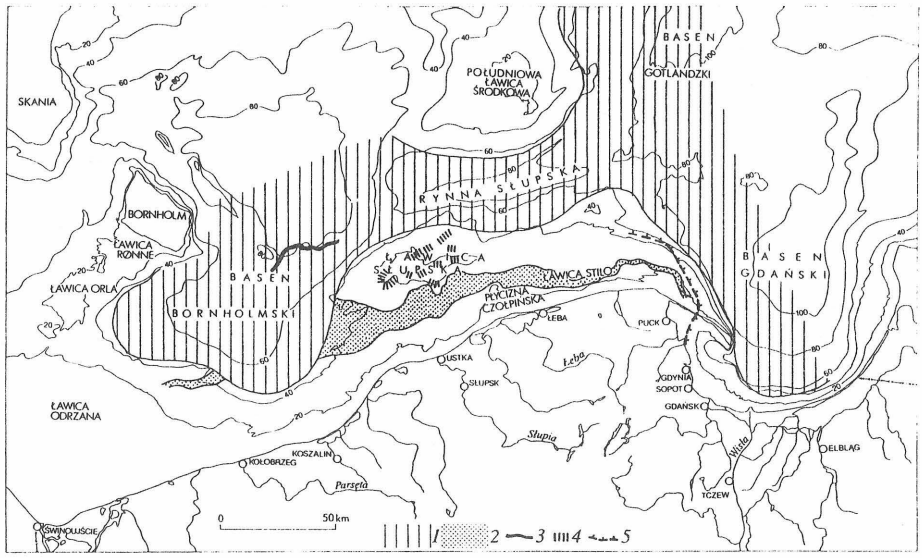

Fig. 2. Geomorphologic outline of the Baltic Sea bottom

1. area with dead-ice blocks during the last Vistulian ice-sheet decay; 2. ice-marginal valleys, latterly in the Vistula river valley (east of Bornholm Basin); 3. esker (see Fig. 3); 4. selected end-moraine ridges; 5. well documented coast-line before the Litorina transgression

The thickness of the last Scandinavian continental ice sheet was variable. Of course, it decreased southwards. However, it was different in the east and in the west. In the east it was much larger, and was facilitated by relative closeness to the ice sheet bowl, and to some degree by the meridionally-oriented zone of the low-lying forefield (present Gdańsk Deep, Gulf of Gdańsk and Vistula Delta). During the disappearance of the continental ice sheet this zone became the area in which for a long time first the stagnant ice stayed, and in which later large fields of dead ice were present.

TEMPORAL FRAMES OF CONTINENTAL ICE SHEET DISAPPEARANCE

Up to this time, the best conditions for dating ice sheet disappearance were found in the lines of terminal moraines. Such dating was done by KOZARSKI (1986), who used a wide range of dating methods. He determined the time at which the ice sheet front stayed in the marginal zone of the Pomeranian Phase to about 16.9 ka BP. The Gardno Phase marginal zone is without doubt present along the edge of the Gardno–Łebsko Lowland. However, its further extension – especially westwards – is only a hypothesis. There is no proof that the so-called Wolin terminal moraine connects with it. The author strongly believes that the "Wolin moraine" is mainly a system of large glacio-fluvial kames (MOJSKI, 1990).

During the last years, the Gardno Phase formations have been TL dated at about 13.2–12.9 ka BP (SYLWESTRZAK, 1984, 1986; ROSA, 1990). These dates are not in disagreement with KOZARSKI's estimations, though they could indicated a rather older age of the youngest marginal formations in this part of Polish Lowland.

There are no clearly visible lines of terminal moraines on the Southern Baltic floor. This is understandable, since either they never were there, or they were destroyed. Only the diversified of the latitudinally lying Słupsk Bank may suggest, as it was pointed out above its terminal-morainic origin. But there is no extension of this zone to the east or west – neither in relief nor in sediments. Therefore for the bottom of Southern Baltic there are at present no dates for marginal zones of the end of the Vistulian.

However, there are TL dated outwash fan and ice-dammed limnoglacial deposits (KRAMARSKA, TOMCZAK, 1988; KRAMARSKA, MASŁOWSKA *et al.*, 1990a; KRAMARSKA, MASŁOWSKA *et al.*, 1990b; PRÓSZYŃSKA-BORDAS, STAŃSKA-PRÓSZYŃSKA *et al.*, 1989). The largest number of the several dozen obtained dates falls within the period 15–10 ka BP (MOJSKI, 1993, 1994b), which corresponds with the generally accepted time for the end of the Vistulian.

But of much higher significance to the definition of the time at which the last continental ice sheet disappeared are ^{14}C dates determined in organic formations of the Pomeranian Bay and Gulf of Gdańsk. In the first area it is a series of dates falling in the period between 14,060 ± 220 years and 13,100 ± 300 years BP of peat samples taken from 10.5 and 9.21 m depth below bottom surface, in an area to SE of the Odra Bank (JUROWSKA, KRAMARSKA, 1990). In the second area, the dates are 10,650 ± 200 and 9,000 ± 260 years BP, taken from a profile at 6 m below bottom surface in the south-east part of the Gulf of Gdańsk, and 12,200 ± 240 BP at 5 m below bottom surface in the south-west part of the gulf (UŚCINOWICZ, ZACHOWICZ, 1992a, 1992b). These dates clearly show that the Pomeranian Bay was ice free of the sheet at least 14,000 years ago, and that even at

that time peat was forming in closed depressions on the land. Therefore, these dates prove that the south-west part of the Polish sector of the Baltic was free of the continental ice sheet earlier than it was hitherto thought. They also contradict the concept that the marginal zone of the Gardno Phase in the Gardno–Łebsko Lowland and the Wolin Hills are of the same age. It also may be supposed that the retreat of the ice sheet front in the Southern Baltic area did not proceed uniformly along its whole length. The author has stated earlier (MOJSKI, 1989) that the ice sheet in this area could have died and disappeared due to aeral deglaciation, leaving large blocks of stagnating, and later dead ice in such depressions as the Gdańsk, Gotland, and Bornholm Deeps, or the today's Gulf of Gdańsk. This would explain the isolated form of the Słupsk Bank and of other smaller forms of the same type. This also would explain the preservation of the deep Southern Baltic basins. It must be remembered that at present the Gulf of Gdańsk reaches 100 m depth, while depths in the Szczecin Bay do not reach 20 m. Therefore the continental ice sheet, or rather its large dead ice masses stayed longer in the east than in the west. Their disappearance proceeded not northward, but to the north-east. It may be assumed that the upper limit of ice disappearance – in form of large blocks – is 13.5 to 14.0 ka BP in the western part of the area, and about 12.5 ka BP in its eastern part.

THE SOUTHERN BALTIC AREA IN THE PERIOD BETWEEN 14.5–13.5 ka AND 7.5–7.0 ka BP

After the continental ice sheet disappeared, for about 7.0 ka the Southern Baltic area functioned mostly as land. Only depressions of the present Gdańsk, Gotland and Bornholm Basins were water reservoirs, alternately inland or marine. The Holocene evolution of the Baltic Sea basin is commonly known. Its traces are recorded in the bottom sediments of consecutive reservoirs, and – as many authors suppose – in traces of old coastlines, erosion platforms, etc. The first of the mentioned records is very well investigated, and consecutively generated deposits allow a far reaching reconstruction of palaeogeographic conditions. Their description can be found elsewhere. At this point it is much more important to draw attention to the possibilities of reconstructing the coastlines of former reservoirs, since only these lines allow the drawing of the boundaries of the water basins, which are the most important form of the Southern Baltic relief during Late Glacial and early Holocene. In this respect, much was attained by KOLP (1982). He formulated the theoretical principles of determining the location of various aged coastlines, taking into account the vertical movements of Earth's crust in the Fenno-Scandinavian area. However, results of investigations carried out for the needs of the 1 : 200,000

Geological Map of Baltic Sea Bottom do not allow for an unquestionable location of previous coastlines, especially coastlines of the Litorina age. On the other hand, the reach of earlier reservoirs can in some cases be analysed thanks to erosion terraces, which later did not become destroyed. This is the case, for example, of the southern slope of the Bornholm Basin. In the geophysical picture of that slope appear at a depth of 31–29 m distinct flattenings, formed during the maximum reach of the Baltic Ice Lake (PRZEŹDZIECKI, UŚCINOWICZ, 1989).

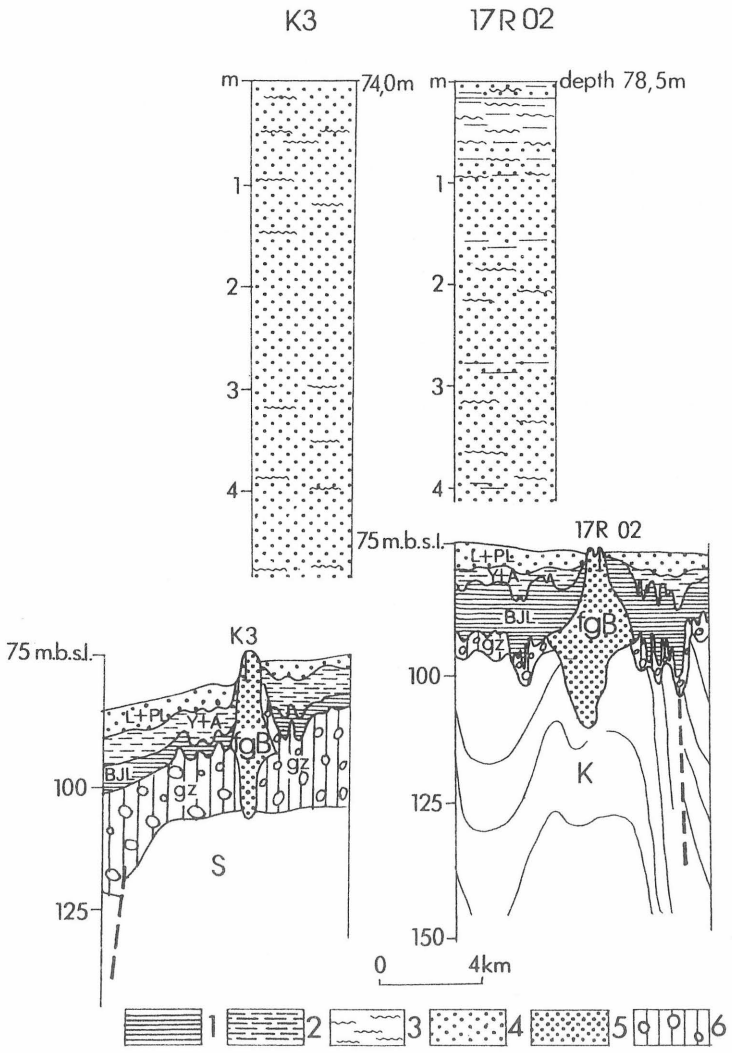

Fig. 3. Esker on the eastern slope of the Bornholm Basin

A – bore–hole profiles; B – geological cross-sections of the esker (acc. to S. UŚCINOWICZ, J. ZACHOWICZ, 1990); 1. varved clay; 2. clay; 3. silt; 4. sand; 5. esker sand; 6. till; S – Silurian; K – Cretaceous; gz – Vistulian till; fgB – esker deposits; BJL – Baltic Ice Lake; Y + A – Yoldia and Ancylus; L + PL – Litorina and Post-Litorina. Geology acc. to shallow seismic interpretation

The land part of the Southern Baltic area was subjected to the same relief-forming processes as the land adjacent from the south. Even at the beginning of Late Glacial, an ice-marginal valley functioned there (MOJSKI, 1989), which could have discharged water melted out of ice stagnating to the north and north-east, and water from the river in the south. The valley opened up into the gradually appearing form under the ice Bornholm Basin. Disappearance of ice caused the outlet to shift eastwards, finally reaching the developing Gulf of Gdańsk. North of the ice-marginal valley there was a freshly appearing form under the ice highland, with a distinctly marked marginal zone at the site of the present Słupsk Bank. An impressive form was esker in the west (Fig. 3). A live postglacial relief existed also to the south of the ice-marginal valley. Relatively small marginal forms were generated there, for example, in the Stilo Bank region; also melt-out basins developed, which at first were filled by ice dammed lake, and later by lacustrine formations – for example, in the Odra Bank region (JUROWSKA, KRAMARSKA, 1990). Both the area of the present Puck Lagoon and the area north of the Hel Peninsula base were land. The first beginnings of the peninsula appeared several kilometres northwards of the present north-west part. The genesis and evolution of the whole Hel Peninsula are the subject of several recent publications (TOMCZAK, 1990, 1991, 1993; TOMCZAK, DOMACHOWSKA, 1992; TOMCZAK, KRAMARSKA *et al.*, 1990).

About 7,000 years ago the Litorina transgression began in the Baltic basin, known in Western Europe as the Flandrian. Its maximum extent occurred about 6,000 years ago. This is supported by the dating of the highest part of peat, covered by Litorina marine deposits on the Vistula Spit which is 6,330 BP (MOJSKI, 1988, 1994a). The development of the transgression should be the subject of a separate paper.

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