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Southern Baltic area during the last deglaciation

Szymon UŚCINOWICZ

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In the Polish economical zone of the Baltic Sea there are boulder fields (residuum of end moraines), remnants of end moraines, glaciofluvial deltas, eskers, and ice-dam lake deposits formed during a decay of the last Scandinavian ice sheet. Landforms and deposits of three ice marginal zones were distinguished in the Southern Baltic. The Gardno Phase probably corresponds to the Halland–West Skåne Phase, dated at ca. 14 ka BP, and to the Middle Lithuanian Phase. The Słupsk Bank Phase is marked at a bottom of the Baltic Sea by boulder fields on the Słupsk Bank and by remnants of end moraines in the southern Bornholm Basin and the western Gdańsk Basin. It is to be correlated with the ice limit in Skåne, dated at 13.5 ka BP, and with the North Lithuanian Phase at ca. 13.2 ka BP. The Southern Middle Bank Phase, marked by glaciofluvial deltas on this bank and by end moraines in the central Bornholm Basin, most probably corresponds to the ice margin in Skåne, dated at 13.0–12.9 ka BP, and to the Otepää Phase in the east.

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Key words: Baltic Sea, Słupsk Bank, Southern Middle Bank, Pleistocene, Late Glacial, deglaciation.

INTRODUCTION

Many researchers have studied the last deglaciation. One of the earliest were the papers by G. De Geer (1940) and M. Sauramo (1958) in which correlation of the Salpausselka end moraines in southern Finland with the central Swedish moraines was presented on maps of ice sheet retreat. More complete outlines of deglaciation in the Baltic Sea area, the Southern Baltic included, were presented by V. K. Gudelis (1961), V. K. Gudelis, E. Emelyanov (1976), R. Galon (1968), N. A. Mörner *et al.* (1977), H. Ignatius *et al.* (1981), B. Rosa (1967, 1994), J. Lundqvist (1986), L. Lindner (1988), J. A. Ławruszyn (1993), J. E. Mojski (1993, 1995), and E. Lagerlund *et al.* (1995). Different number, shape and limit of individual phases, their age and correlation with ice marginal zones on the adjacent land result not only from insufficient data on landscape and geology of a sea bottom. Reconstruction of a deglaciation in the present Southern Baltic Sea, especially spatial and temporal correlation of landforms and deposits connected with a retreat of the last Scandinavian ice sheet, has been and to a large extent still is a problem which cannot be solved unequivocally due to several reasons. The first one rests in character of the surface, which became uncovered in the Southern Baltic area when the ice sheet retreated. After a retreat from the Pomeranian end moraines, a deglaciation changed due to a climatic transformation. The previously prevailing frontal deglaciation, reflected by a remaining distinct ice margin series, changed into aerial deglaciation (J. E. Mojski, 1993). A warming about 14.5 ka BP (L. Starkel, 1977) caused cutting of the ice sheet margin by the meltwaters, resulting in a disintegration into extensive dead ice blocks and development of a complex network of ice marginal valleys. Aerial deglaciation was prevalent in the Pomeranian coast area, with a prevailing deposition of tills, while end moraines and outwash plains (sandur) — if formed at all — were rather rare and not well developed (L. Roszko, 1968; A. Marsz, 1984). According to B. Augustowski (1972) such postglacial surface hinders determination of marginal zones during the ice sheet retreat. At least at the very beginning, a deglaciation of the Southern Baltic area was of a similar aerial character. As the ice sheet retreated from the Southern Baltic area and the northward sloping subglacial surface was uncovered, more numerous and larger ice-dam lakes were created, and a final deglaciation proceeded in partly subaqual conditions.

Another factor, making reconstruction of deglaciation in the Southern Baltic difficult, is that a sea appeared in this area. Ice marginal forms and deposits found themselves on a sea

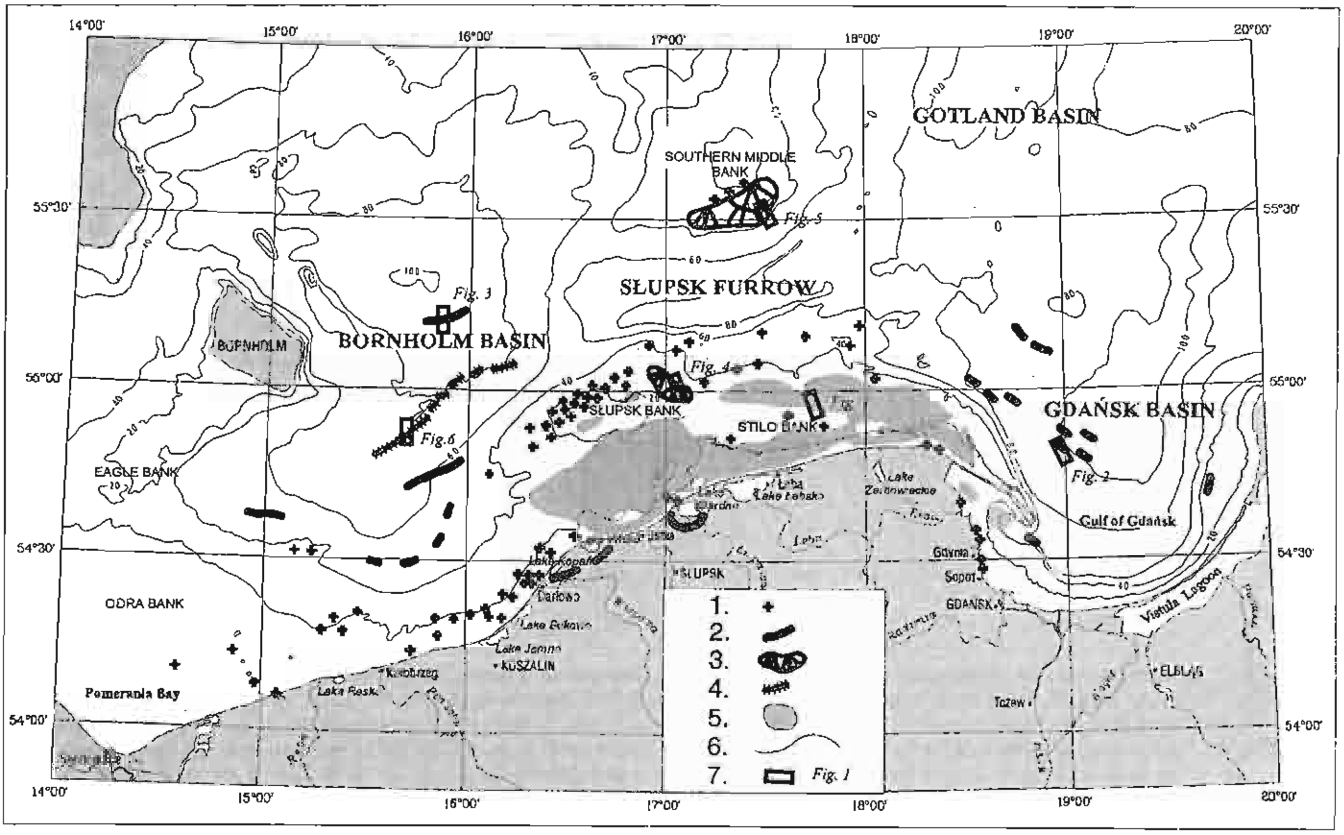


Fig. 1. Landforms and deposits of the last deglaciation in the Southern Baltic area after S. Uścinowicz (1996)

1 — boulders and boulder fields (lag deposits), 2 — ridges of marginal zones (remains of end moraines), 3 — glaciofluvial deltas, 4 — eskers, 5 — ice-dam lake sediments, 6 — isobath every 20 m, 7 — seismoacoustic profiles (*cf.* Figs. 2–7)

bottom. At depths smaller than 50 m, landforms and deposits were under influence of postglacial transgressions of the Southern Baltic, and became partly or completely destroyed by marine erosion. Deeper lying forms and deposits became masked considerably by a coating of the Baltic Sea sediments.

SEABED ICE MARGINAL LANDFORMS AND DEPOSITS

Despite the presented difficulties in reconstruction of deglaciation of the Southern Baltic area, the carried out geologic studies allowed to identify a number of landforms from the last deglaciation or their relics. They were based on a more than a dozen thousand kilometres of echo-sounding, 7000 km of seismoacoustic profiles, as well as sampling and analyses of several hundred cores. Seismoacoustic investigations created a basis for determination of seismostratigraphic units, resulting mainly from a comparative analysis of absorption by various sediments of acoustic energy. A recorded fabric of these deposits established extents of basic acoustic horizons and angular disconformities within the bedded sequences. The seismostratigraphic units are correlated with lithologic data from cores to establish the lithostratigraphic units.

Boulders, boulder fields and pebble-gravel deposits form a residuum, both of tills and frontal moraines. Boulders and boulder fields form commonly gentle hummocks on a seabed, but they occur also on abraded smoothed surfaces, e.g. on the southwestern Słupsk Bank. Most often the hills are gently sloped (1–2°) undulations, 200–500 m long and 2–3 m, occasionally more than 5 m high. Only the northern, the most shallow part of the Słupsk Bank is predominated by hummocks, locally 10–14 m high, and with slope angle of 5–7°(R. Kramarska, 1991*a*, *b*). Therefore, the idea of the nearly unchanged frontal moraine landscape on seabed of the banks (B. Rosa, 1967, 1987) seems incorrect. These hummocks are composed of a till and covered by coarse-grained residual material, and probably were formed due to locally different resistance of deposits. The areas, which were initially composed of a more compact, till and contain coarser material, occur higher than the lower-resistant ones, which were destroyed during a sea transgression.

In the Southern Baltic, a largest seabed area with boulders and boulder fields occurs in the northern and northwestern Słupsk Bank (Fig. 1). It forms a distinct zone, running in the NW–SE direction, with a depth of ca. 10 m in the north-east to 30 m in the south-west (R. Kramarska, 1991*a*, *b*, 1995*a*). There are also numerous boulders to the west and south-west of Jarosławiec and Darłowo at depths reaching 30 m (M.

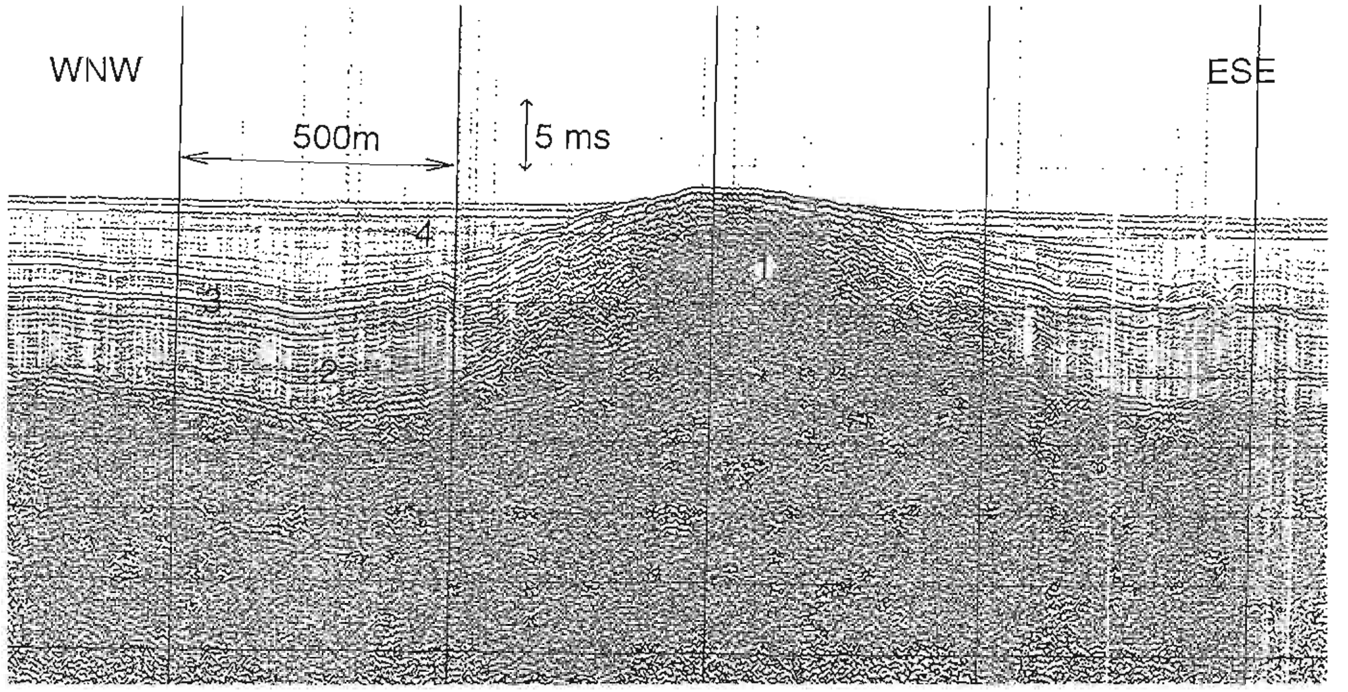


Fig. 2. Seismoacoustic profile of a buried end moraine in the western Gdańsk Basin, water depth 98–99 m, after S. Uścinowicz (1996)

1 — till, 2 — varved clays and micro-laminated clays of the Baltic Ice Lake, 3 — clays of the Yoldia Sea and the Ancylus Lake, 4 — muds of the Littorina and the post-Littorina Seas

Michałowska, R. Pikies, 1990, 1992). Smaller areas with boulders and pebble-gravel deposits were found on the Southern Middle Bank, at some sites to the north-west of Kołobrzeg, north of Ustronie Morskie and the Lake Jamno at depths up to 25 m, on the Stilo Bank and also to the north-east of the Słupsk Bank and to the north of the Stilo Bank at depths 35–45 m (S. Uścinowicz, J. Zachowicz, 1991*a*, *b*; R. Pikies, Z. Jurowska, 1994, 1995). Boulders occur also at foot of the cliffs, where glacial deposits have been destroyed.

Remnants of end moraines form rows of isolated hills or ridges. Summits of these hills, as proved by drillings, are composed of a till. Inner structure can be more complex (e.g. Figs. 2, 3), however, no information from cores is available. These landforms occur at depths below 50–55 m, therefore they have been only slightly changed by marine erosion. Often they are partly or completely covered by the Late Glacial and the Holocene deposits. These hills and ridges are from several hundred metres to ca. 10 km long, 200–1000 m wide, and 10–30 m high. They appear sometimes as elevations 0.5–8 m high on the contemporary flat bottom of deep-water basins (Figs. 2, 3).

The most distinct rows of ice marginal features occur in the southern Bornholm Basin (Fig. 1). The first arc is at depth 50–55 m, the second runs in NE–SW direction some distance to the north and slightly deeper. The third row looks like a push end moraine and lies in the central Bornholm Basin, east to the Bornholm Island (Fig. 3). Its WSW–ENE direction is concordant with a southwestern extension of the Southern Middle Bank (S. Uścinowicz, 1989, 1991; S. Uścinowicz, J. Zachowicz, 1992, 1993*a*). Elevations of the ice marginal zone in the Gdańsk Basin are less distinct, mainly due to a more thick cover of deposits, which mask a primary glacial relief. These elevations, arranged in one or two rows in NW–SW direction, occur in the western Gdańsk Basin (R. Pikies, Z. Jurowska, 1994, 1995; S. Uścinowicz, J. Zachowicz, 1993*b*, 1994).

Glaciofluvial deltas are composed of stratified gravel-sandy and sandy deposits. Large-scale oblique bedding is clearly visible on seismoacoustic records. Glaciofluvial deltas were found in the northeastern Słupsk Bank (S. Uścinowicz, J. Zachowicz, 1991*a*, *b*; R. Kramarska, 1991*a*, *b*) and in the southeastern part of the Southern Middle Bank (R. Pikies, 1992, 1995; M. Masłowska, M. Michałowska, 1995). On the Słupsk Bank, the glaciofluvial delta occurs at depth 20–30 m (Fig. 4). The delta bed of gravel and sands is 5–6 m thick, and the layers dip southwards. A seabed is inclined northwards, opposite to a slope of glaciofluvial deposits, and it suggests abrasive shearing of a delta surface during a transgression of a sea.

Much larger and better preserved are the glaciofluvial features in the Southern Middle Bank area (Fig. 5), where several superposed deltas occur at depths 20–40 m. Beds dip south-eastwards, and are about 15 m thick. Fine-grained limy sands and silty sands with shells of *Pisidum amnicum* (Müller), *P. milium* (Held), and of the snail *Limnea peregra* (Müller) (J. Krzymińska, 1990) occur on glaciofluvial deposits. They are most probably younger and were deposited during the Baltic Ice Lake Phase, when the Southern Middle Bank formed an island.

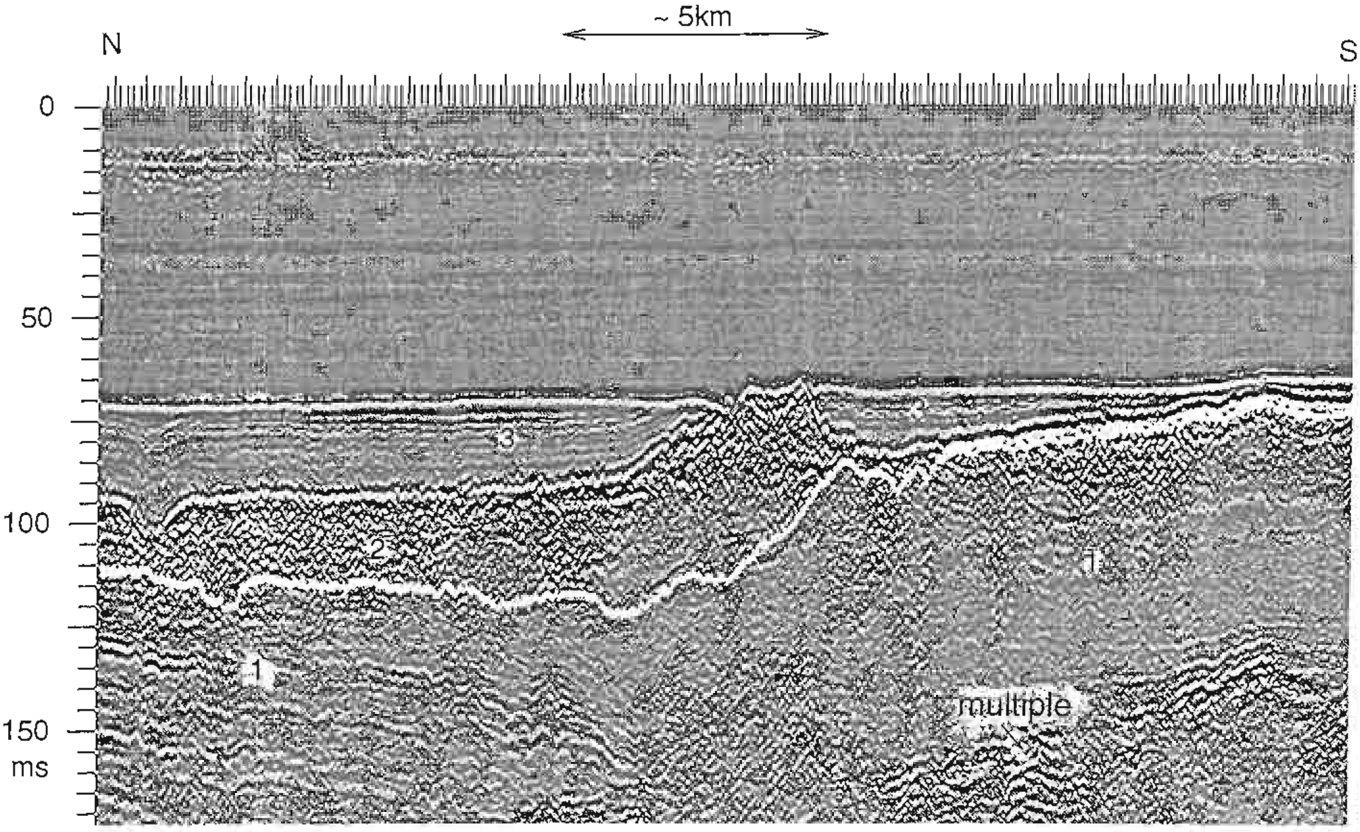


Fig 3. Seismic profile of a push end moraine in the central Bornholm Basin, water depth 97–98 m

1 — sub-Quaternary bedrock, 2 — till, 3 — postglacial clays and muds, different development phases of the Baltic Sea; multiple — secondary echo

Eskers occur in the Bornholm Basin (R. Kramarska, 1991*a*, *b*; S. Uścinowicz, J. Zachowicz, 1992, 1993*a*). They form a single row of partly overlapping ridges, with NE–SW orientation, parallel to a general direction of ice sheet movement (B. Ringberg, 1988; J. Lundqvist, 1994; J. E. Mojski, 1995). A location of the ridges is connected with faults and erosional cuts in the sub-Quaternary formations. Only locally the slopes of eskers enter onto a till. The ridges are 5–15 km long. The esker is a distinct seabed landform at distance of 50 km and it is 60–70 km long, together with a fragment buried

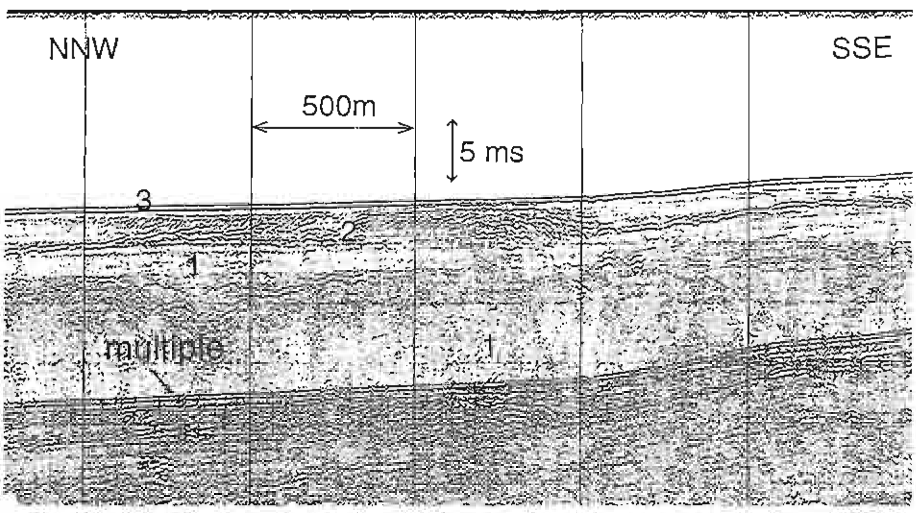
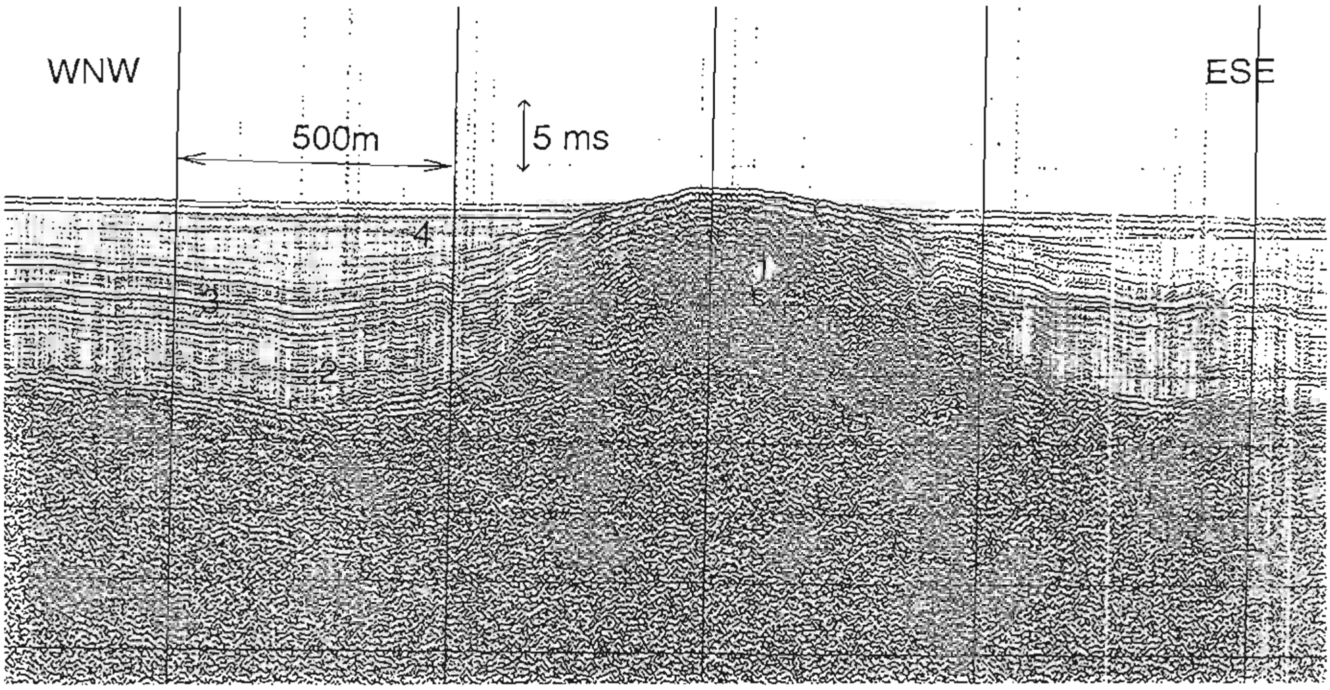


Fig. 4. Seismoacoustic profile of a partly eroded glaciofluvial delta in the eastern Slupsk Bank, water depth 20–25 m, after S. Uścinowicz (1996)

1 — till, 2 — sands and gravel of a glaciofluvial delta, 3 — sands of the Littorina and the post-Littorina Seas; multiple — secondary echo



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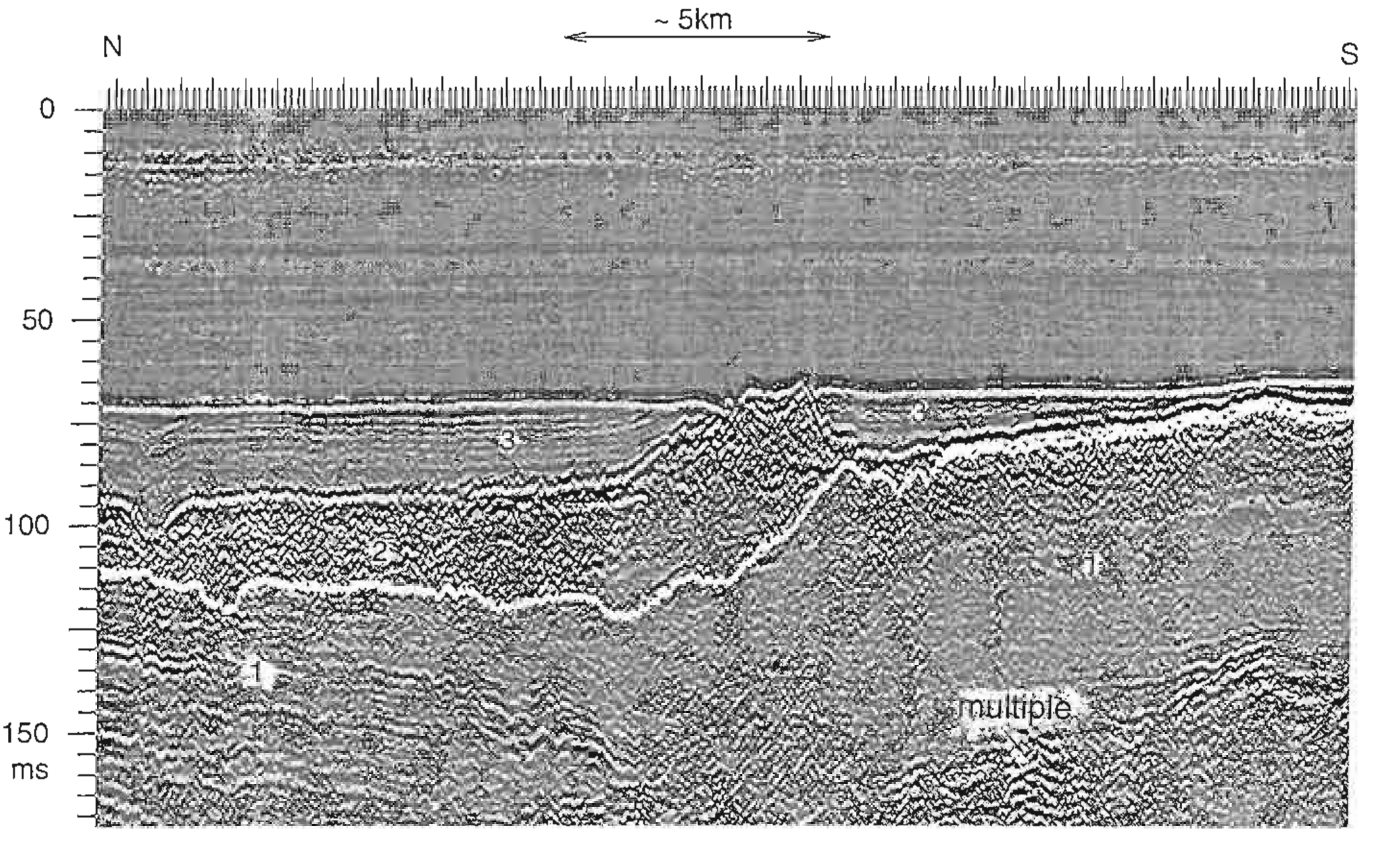

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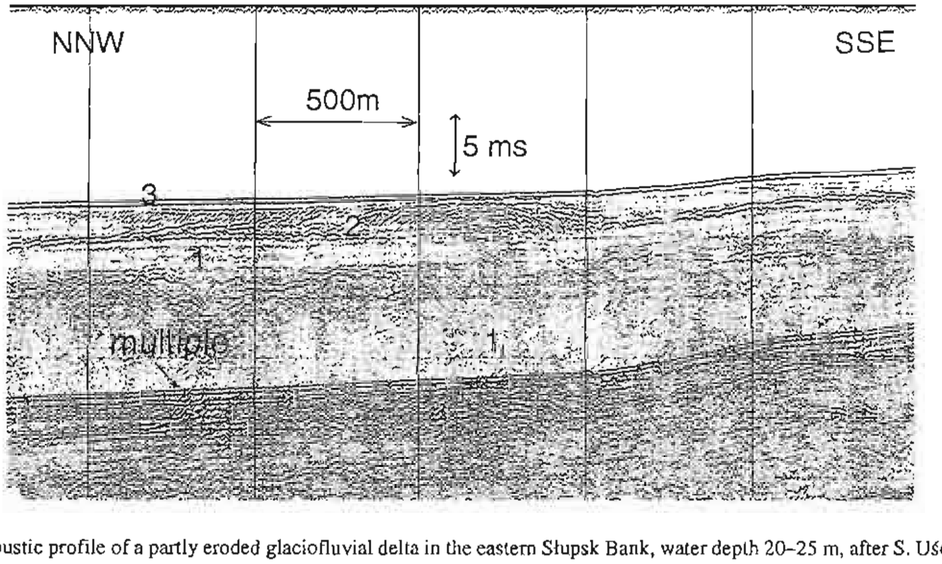

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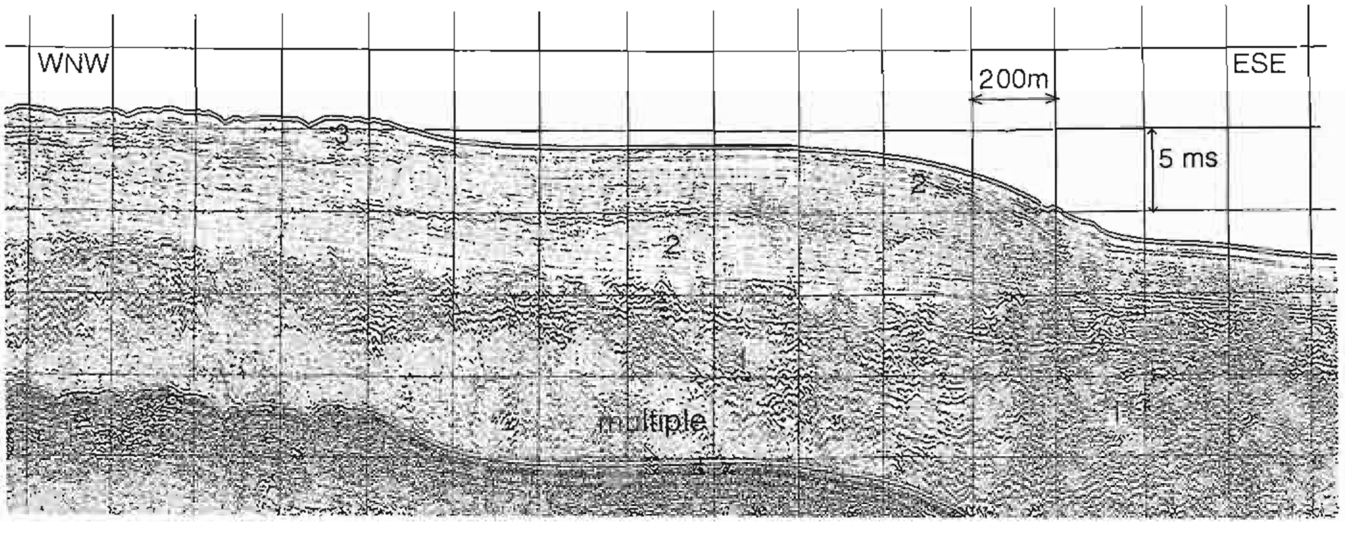


Fig. 5. Seismoacoustic profile of a glaciofluvial delta from the Southern Middle Bank, water depth 28–40 m, after S. Uścinowicz (1996)

1 — tills, 2 — sands and gravel of a glaciofluvial delta, 3 — sands of the Littorina and post-Littorina Seas; multiple — secondary echo

by the Late Glacial and the Holocene deposits of the Baltic Sea (Fig. 1). The esker is from 0.4 to 2 km width and 22 m high above a seabed, with a total height of 38 m (Fig. 6). A near-surface part of the esker (to 5–6 m depth) is composed of interbeddings of fine-grained or silty sands and sandy silts with clay inserts and laminations. Therefore, during a final stage of esker development, there was a low water discharge in crevasses within the ice body.

Ice marginal lake deposits were found at depth 10–40 m in the area between the western edge of the Słupsk Bank up to the Lake Wicko in the west and the Puck Bay in the east (Fig. 1). Grain size of these deposits is significantly varied; in most cases they consist of laminated silty clay, clayey and sandy silt, occasionally with sandy intercalations, and content of organic matter equal to about 1.5%. Locally there is silty and fine-grained sand. Post-sedimentary deformations are common. A thickness of ice marginal lake deposits depends

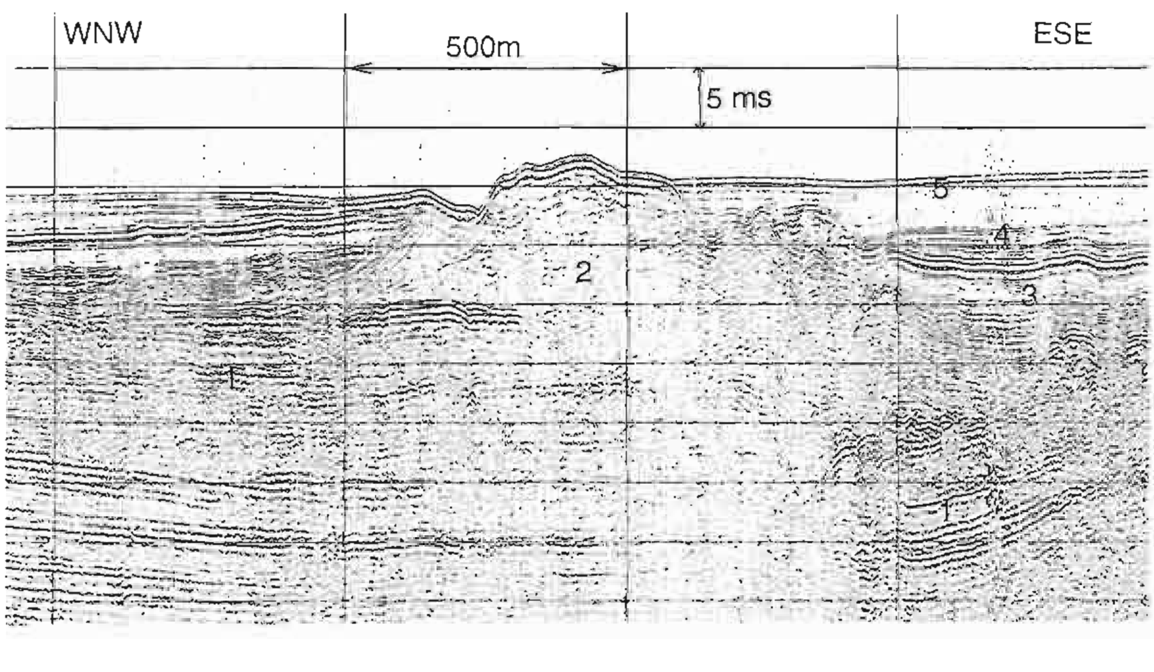


Fig. 6. Seismoacoustic profile of an esker from the southeastern Bornholm Basin, water depth 77–83 m, after S. Uścinowicz (1996)

1 — sub-Quaternary bedrock, 2 — sands, silty sands and sandy silts of an esker, 3 — varved clays and micro-laminated clays of the Baltic Ice Lake, 4 — clays of the Yoldia Sea and the Ancylus Lake, 5 — muds of the Littorina and the post-Littorina Seas

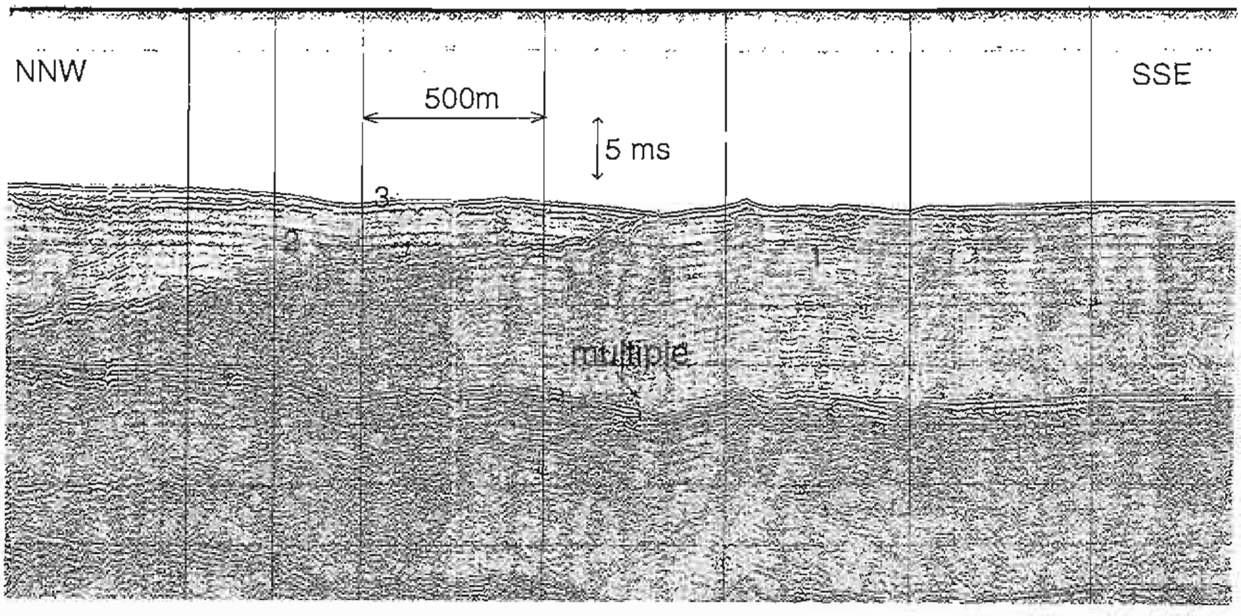


Fig. 7. Seismoacoustic profile from the Stilo Bank, water depth 22–25 m, after S. Uścinowicz (1996)

1 — till, 2 — ice-dam lake sediments, 3 — sands of the Littorina and the post-Littorina Seas; multiple — secondary echo

on a relief of the substrate, and varies from several dozen centimetres to 25 m (Fig. 7; R. Kramarska, 1991*a*, *b*; S. Uścinowicz, J. Zachowicz, 1991*a*, *b*; R. Pikies, Z. Jurowska, 1994, 1995). A radiocarbon age 18.82±0.4 ka BP (Gd-9332) of laminated silty-sand sediments with dispersed organic matter in the Puck Bay is presumably overestimated due to redeposited older plant detritus. In the boreholes on a coast of the Puck Bay, there were radiocarbon-dated peat and plant remains from the Grudziądz Interstadial. Similarly, a radiocarbon age of ice marginal lake deposits from the Gardno–Łeba Lowland, estimated at 14.3±0.15 ka BP (K. Rotnicki, K. Borówka, 1995*a*, *b*), may be slightly too old due to admixture of redeposited sediments from the Grudziądz Interstadial, found in several boreholes.

DEGLACIATION PHASES

At least three marginal zones corresponding to the Gardno, the Słupsk Bank and the Southern Middle Bank Phases were distinguished in connection with data from the surrounding terrestrial area, spatial mutual relations between coarse-grained residual deposits, remnants of end moraines, glaciofluvial deltas and ice marginal lake deposits in the Southern Baltic (Fig. 8).

GARDNO PHASE

The Gardno end moraines mark the last stop of the ice sheet in northern Poland. This phase was supposed previously to have occurred at 13.2 ka BP (*int. alia* S. Kozarski, 1986; J. E. Mojski, 1993) but recently, it was dated at 14.5–14.3 ka BP (K. Rotnicki, K. Borówka, 1995*a*, *b*) or about 14 ka BP (J. E. Mojski, 1995). A deglaciation of the Southern Baltic began a little earlier than 14 ka BP with a retreat of an ice sheet from the Velgast end moraines (Fig. 8). During the Gardno Phase, an ice sheet margin between Puck and Darłowo occurred slightly southwards from the present coastline. In the area between the Lake Kopań and Darłowo, an ice sheet margin crossed the present coast, running to the north of Kołobrzeg and the Odra Bank. The Pomeranian Bay was ice-free during this phase (Fig. 9A; S. Uścinowicz, 1995*b*). Ice marginal landforms of this phase are marked probably by coarse-grained deposits on the Baltic seabed to the north of the lakes Bukowo and Jamno, and to the north-west of Kołobrzeg (Fig. 1). On the basis of radiocarbon dating (K. Rotnicki, K. Borówka, 1995*a*, *b*), the Gardno Phase can be correlated with the Halland–West Skåne Phase in southwestern Sweden (E. Lagerlund, M. Houmark-Nielsen, 1993). In the Arkona Basin there are no traces of ice marginal forms (W. Lemke, 1998). Therefore, the Halland–West Skåne Phase and the Gardno Phase could be connected probably during the North Rügen Phase. To the east, the Gardno Phase corresponds to the Middle Lithuanian Phase (V. K. Gudelis, E. Emelyanov, 1976; A. Raukas *et al.*, 1995; Fig. 8). During the Gardno Phase, the ice sheet still occupied the Gdańsk Basin, and most probably covered a northern part of the present Vistula Delta Plain (Żuławy). The Vistula River since 14.5–14.0 ka BP could flow to the north (W. Niewiarowski, 1987; J. E. Mojski, 1990; L. Starkel, E. Wiśniewski, 1990), feeding an ice marginal lake in the Vistula Delta. Meltwaters were discharged at first through the Reda–Łeba ice marginal valley. As the ice sheet front retreated into the Baltic Sea area, a water discharge concentrated in the so-called coastal ice-marginal valley at the present coastal zone (S. Skompski, 1982, 1985). The youngest till was eroded, and the ice-marginal valleys were filled partly

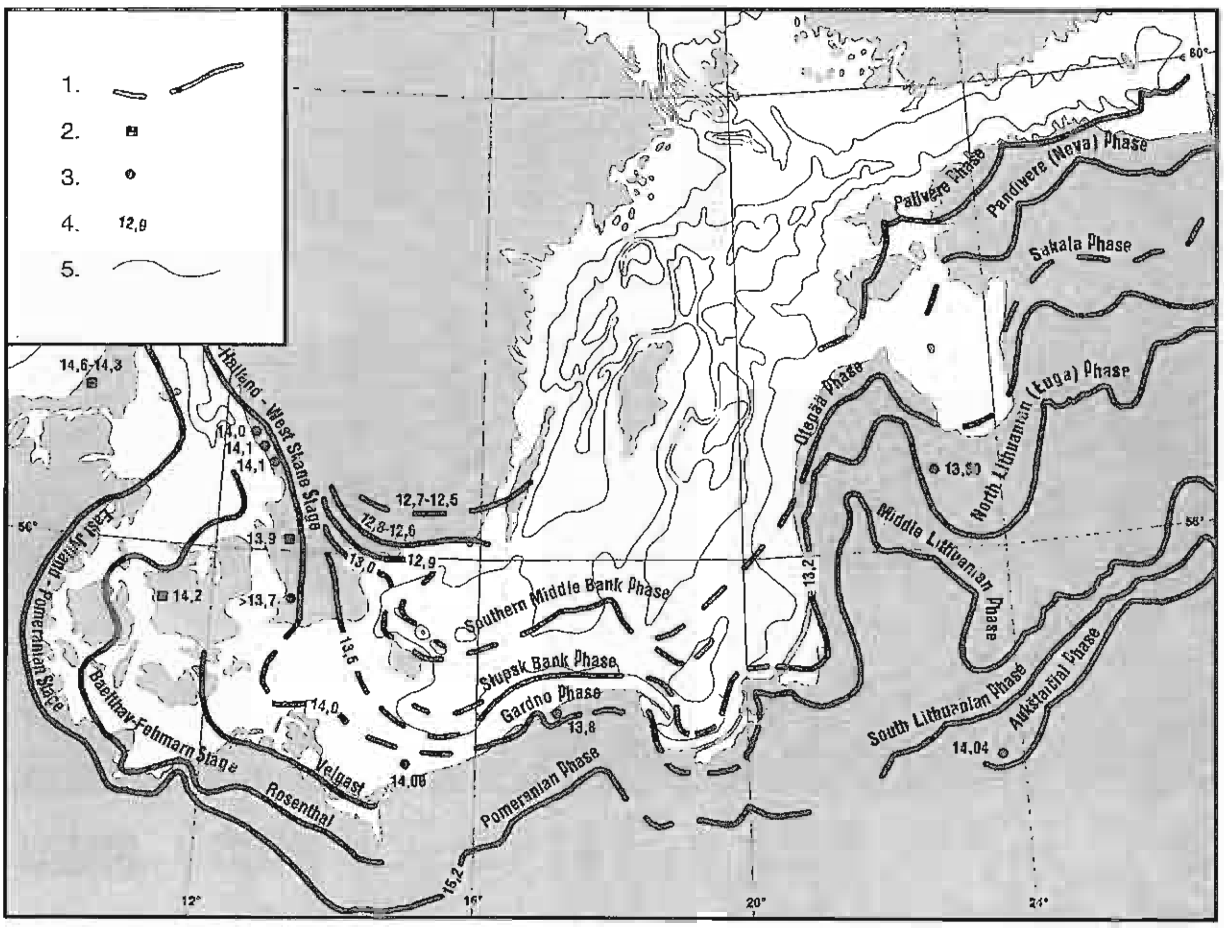


Fig. 8. Ice sheet marginal positions in the Southern Baltic area (after S. Uścinowicz, 1996, slightly changed), based on data after E. Lagerlund, M. Houmark-Nielsen (1993) for the Danish Straits and western Skåne, J. Lundqvist (1994) and S. Björck, P. Möller (1987) for Skåne and Blekinge, A. Raukas *et al.* (1995) and R. Pirrus, A. Raukas, (1996) for the Baltic States, J. E. Mojski (1993, 1995) for Pomerania; radiocarbon dates of the Gardno Phase on the Polish Coast after R. Kramarska, Z. Jurowska (1991), R. Kramarska (1998) and K. Rotnicki, K. Borówka (1995*a*, *b*)

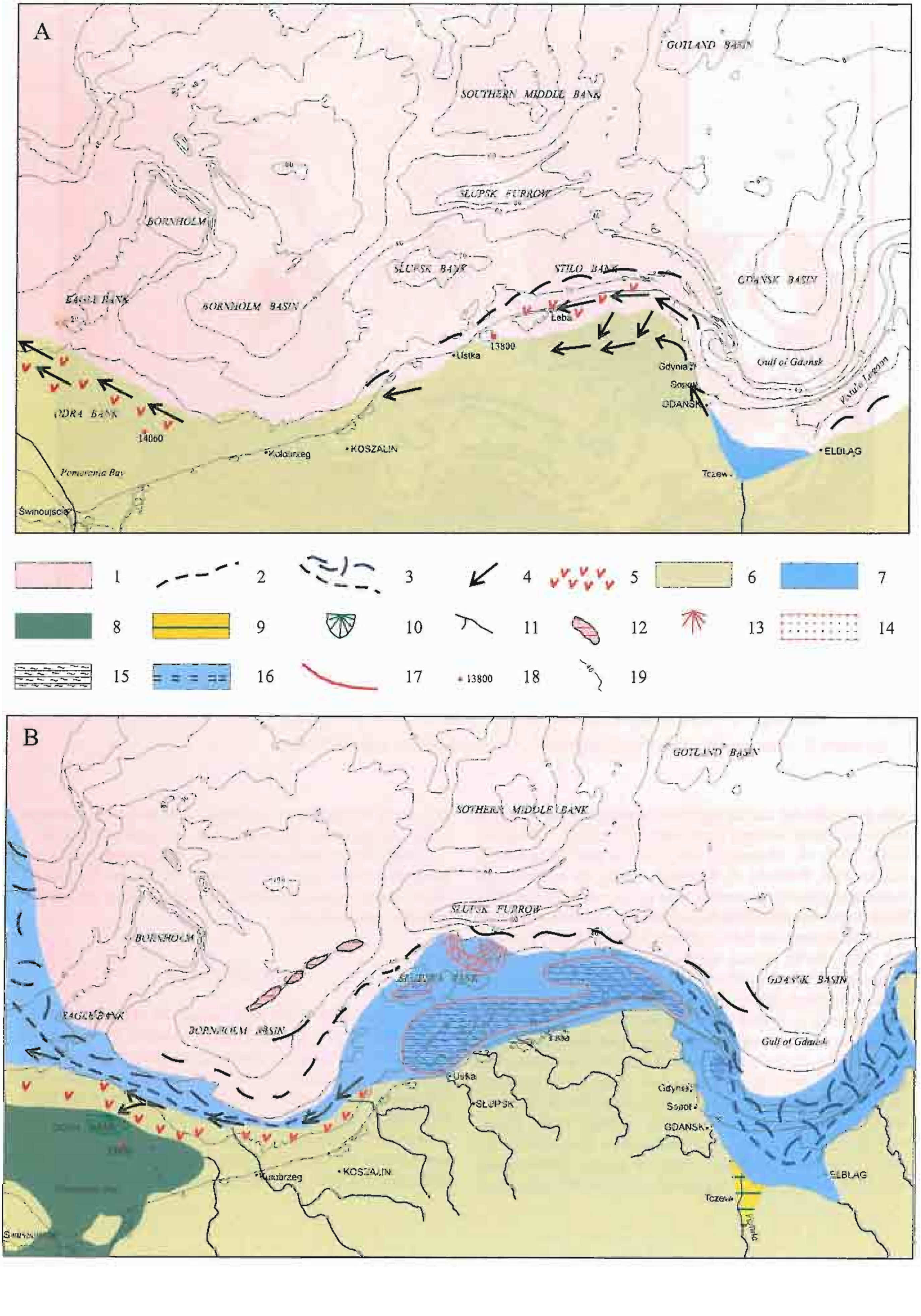
1 — ice margin, 2 — palaeomagnetic dates, 3 — radiocarbon dates, 4 — age in ka BP, 5 — isobath every 50 m

with glaciofluvial, fluvial and limnic sands and gravel, e.g. in the coastal zone between Żarnowiec and Łeba (S. Skompski, 1982, 1985; W. Morawski, 1987) and in the Gardno–Łeba Lowland (K. Rotnicki, K. Borówka, 1985*a*, *b*). An erosional meltwater activity is marked also to the north of the Odra Bank, where the Holocene marine sands are underlain directly by sandy deposits of the Grudziądz Interstadial (R. Kramarska, 1994, 1998). During the ice sheet retreat of the Gardno Phase, lake reservoirs and swamps developed to the south-east of the Odra Bank. The most complete sequence of marshy-lake sediments is known from the test borehole W-4 in the Pomeranian Bay. There are three peat layers in this section at depths 10.50–10.42, 9.80–9.69, and 9.23–9.21 m below a sea bottom, and they were radiocarbon dated at 14.06±0.22, 13.49±0.19, 13.35±0.27, and 13.10±0.30 ka BP (R. Kramarska, Z. Jurowska, 1991; R. Kramarska, 1995*b*, 1998). Therefore, the idea that the ice sheet occupied the Pomeranian Bay until 12.5 ka BP (J. B. Jensen, 1992; W. Lemke, 1998) cannot be accepted. A peat of a similar age (13.8 ka BP) was found also on the Gardno–Łeba Lowland, close to the end moraines of the Gardno Phase (K. Rotnicki, K. Borówka, 1995*a*, *b*).

Except for the predominant aerial deglaciation processes, an ice sheet front stopped for a short time on the Stilo Bank, where coarse-grained residual deposits indicate probably a previous marginal zone.

SŁUPSK BANK PHASE

The landforms of the next, longer ice sheet stop on the Słupsk Bank are far more distinct on a seabed. On the Słupsk Bank there is a hummocky landscape, with the largest relative heights and slope angles in the Southern Baltic Sea area. The hummocks are located in the northwestern part of the bank, and boulders are probably a relic end moraine. To the south-west of the Słupsk Bank, an ice sheet formed a lobe, which entered into the southern Bornholm Basin, where there are distinct semicircular rows of end moraines on a seabed. Thro-


A
GOTLAND BASIN
SOUTHERN MIDDLE BANK
SŁUPSK FURROW
BORNHOLM
SŁUPSK BANK
STILO BANK
GDAŃSK BASIN
BORNHOLM BASIN
Łeba
13800
Ustka
Gdynia
Sopot
GDAŃSK
Gulf of Gdańsk
Vistula Lagoon
ODRA BANK
14060
Kołobrzeg
KOSZALIN
Pomerania Bay
Tczew
ELBLĄG
Świnoujście
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
13800
18
19
B
SOTHERN MIDDLE BANK
SŁUPSK
Vistula

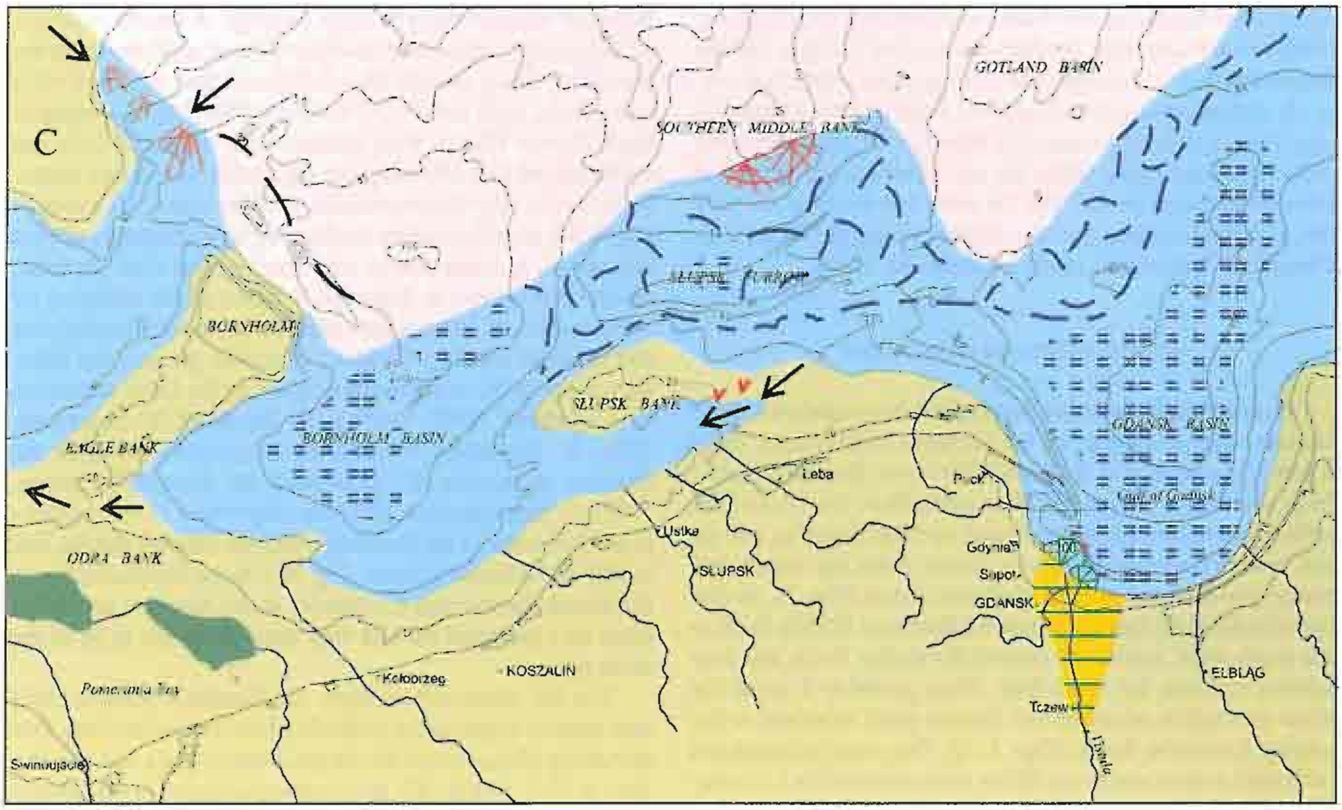


Fig. 9. Southern Baltic area during: A — Gardno Phase (ca. 14.0–13.8 ka BP), B — Słupsk Bank Phase (ca. 13.5–13.2 ka BP), C — Southern Middle Bank Phase (ca. 13.0–12.8 ka BP), after S. Uścinowicz (1995*b*), slightly changed

1 — ice sheet, 2 — lines of ice retreat, 3 — dead ice, 4 — direction of meltwater runoff, 5 — area of meltwater erosion, 6 — land area, 7 — ice-dam lakes, 8 — nearshore lakes and bogs, 9 — Vistula Delta, 10 — alluvial fan, 11 — rivers, 12 — esker, 13 — glaciofluvial delta, 14 — sands and gravel of glaciofluvial deltas, 15 — ice-dam lake sands, silts and clays, 16 — varved clays, 17 — present erosional boundary of glaciofluvial deltas and ice-dam lake sediments, 18 — main site with radiocarbon dating, 19 — isobath every 20 m

ugh the Eagle Bank (Adlergrund), this ice marginal series can be correlated with an ice sheet edge in Skåne at about 13.5 ka BP (J. Lundqvist, 1994). A similar lobe existed also in the Gdańsk Basin (Fig. 9B) and elevations in the western Gdańsk Basin are presumably the marginal formations of the North Lithuanian (Luga, Haanja, Linkuva) Phase, described by I. Veinbergs *et al.* (1995) in the northeastern Gdańsk Basin. The age of this phase is determined at *ca.* 13.2 ka BP (A. Raukas *et al.*, 1995), and corrected at 13.0 to 13.2±0.43 ka BP (R. Pirrus, A. Raukas, 1996), according to the Swedish varve chronology revised by I. Cato (1985). A presence of the lobe in the southern Bornholm Basin and of end moraines west of Darłowo partly blocked a meltwater discharge to the west. A large ice marginal lake was formed between the western part of the Gulf of Gdańsk and Darłowo. In the northern part of the lake, on the Słupsk Bank, a glaciofluvial delta was formed (Figs. 1, 9B). The Vistula discharged into a marginal lake in the present northern part of the Vistula Delta Plain (Żuławy) and the Gulf of Gdańsk, initiating a very beginning of delta development (S. Uścinowicz, 1995*a*; S. Uścinowicz, J. Zachowicz, 1994). The ice marginal lake was discharged westwards along the ice sheet front, eroding a morainic plateau to the north-west of Darłowo and to the north of Kołobrzeg (Fig. 9B; S. Uścinowicz, 1995*b*). There were extensive lakes and swamps without any direct connection with meltwaters to the south of the outwash train in the present Odra Bank and the Pomeranian Bay, but rivers flowing from the south supplied them. In contradistinction to the ice marginal lake deposits, with neither macro- nor microfossils, lake deposits from the Pomeranian Bay contain abundant molluscs, mainly snails and freshwater bivalves (R. Kramarska, Z. Jurowska, 1991; J. Krzymińska, 1990).

A short ice sheet stop during its general retreat from the Słupsk Bank end moraines is indicated by a second row of end moraines in the southern Bornholm Basin. Further quick melting of the ice sheet caused a discharge of meltwaters to the west and a drop of water level in the ice marginal lake. The areas to the south and east of the Słupsk Bank, i.e. at present in a shallow water zone, emerged above a water level. A drop of the water level in the ice marginal lake was probably due to intensive erosion due to increased water runoff. Such processes occurred *int. alia* on the eastern Słupsk Bank, where the Late Glacial peat covers directly a till, TL dated at 111±16.6 to 127±19 ka BP (S. Uścinowicz, J. Zachowicz, 1991*a*, *b*). During further deglaciation, a large esker system was formed in the Bornholm Basin. Similar NE–SW oriented eskers were formed also in Skåne and Blekinge (B. Ringberg, 1988). In the southern, ice-free parts of the Gdańsk and the Bornholm Basins, ice marginal lakes appeared simultaneously. A deglaciation increasingly has begun to be a subaqual one. Blocks of dead ice could be found in the shallower parts of the marginal lakes, while the ice sheet margin formed an ice cliff in deeper zones. The ice sheet has decayed not only due to surface melting, but also due to calving (K. Malmberg-Persson, E. Lagerlund, 1990; J. Lundqvist, 1994).

SOUTHERN MIDDLE BANK PHASE

Proceeding deglaciation was slowed down again when the ice sheet margin stopped on the Southern Middle Bank. Only a part of the bank is in the Polish Exclusive Economic Zone. In its shallowest part, at 15–20 m depth, there is a till covered with a thin layer of coarse-grained residual deposits, and on the southern and southeastern slopes there are sandy and sandy-gravel deposits of glaciofluvial deltas (Fig. 1). At that time the ice sheet front ran from the Southern Middle Bank to the south-west, across the central Bornholm Basin and then turning towards the Hanö Bay. Most probably a small ice sheet oscillation occurred and formed push moraines in the central Bornholm Basin (Figs. 1, 3). They can be correlated with the ice sheet margin in Skåne, reconstructed by J. Lundqvist (1994), and by S. Björck and P. Möller (1987), dated at 13.0–12.9 ka BP. East of the Southern Middle Bank, the ice sheet probably advanced into the southern Gotland Basin. Then, through the Gotland–Gdańsk Sill and the Klaipeda Bank its margin ran to the Latvian coast, where it is indicated by end moraines of the Otepää Phase (A. Raukas *et al.*, 1995; R. Pirrus, A. Raukas, 1996), called also the North Latvian Phase (V. K. Gudelis, E. Emelyanov, 1976).

A margin of the ice sheet remained on the Southern Middle Bank for a longer time as indicated by large, complex glaciofluvial deltas on the southern and southeastern slopes of the bank. Similar glaciofluvial deltas in the western part of the Hanö Bay (T. Andrén, K. Wannäs, 1988) were probably formed at the same time. Increasingly higher consecutive parts of the deltas on slopes of the Southern Middle Bank, allow to conclude that a water level in the ice marginal lake rose during this phase by about 10–15 m, while the ice sheet front shifted northwards very slightly only. The ice sheet retreat from the Southern Middle Bank, and a simultaneous rise of a water level in the ice marginal lake indicate a termination of glaciofluvial deposition. Referred to the ice sheet retreat in southwestern Sweden (S. Björck, P. Möller, 1987), it seems to have occurred about 12.7–12.6 ka BP.

The subaqual till layer in the Słupsk Furrow and the sills separating the Bornholm Basin from the Słupsk Furrow and the Gotland Basin from the Gdańsk Basin are also connected with the ice sheet retreat from the Southern Middle Bank. Until the ice sheet retreated from the Słupsk Bank, large dead ice blocks occurred in these areas. With a rise of water level, these blocks started to melt partly under water and partly as floating icebergs. Very complex sedimentary processes took place: deposition of clay from suspended matter was accompanied by gravitational flow of sediments from a dead ice and falling of material from floating icebergs. A thickness of this till is strongly varied, and reaches 40 m at a sill between the Bornholm Basin and the Słupsk Furrow. The subaqual till is soft plastic, light brown (5YR 6/4 or 5YR 5/6, according to Rock-Colour Chart) with distinct pale blue (5B 6/2) and moderate red (5R 4/6) irregular silt or clay lenses and lumps. Grain size is very heterogeneous. In most cases, it is a silty or clayey till, sometimes clay or silty clay with admixture of sand and gravel, in some places with sharp-edged rock particles, several centimetres in diameter. A fabric of the subaqual till is diversified, in some places random, often with laminations and irregular bedding. Deposits of similar genesis and lithology occur in the southwestern Skåne as the Lund diamicton (E. Lagerlund, 1987, 1995; B. E. Berglund, E. Lagerlund, 1981; K. Malmberg-Persson, E. Lagerlund, 1990) or the Öresund diamicton (E. Lagerlund, M. Houmark-Nielsen, 1993). At the same time, there was deposition of varved clays in ice-free areas of the Bornholm and the Gdańsk Basins, and locally in the Słupsk Furrow (Fig. 9C). In the Bornholm Basin, the Słupsk Furrow and the Gdańsk Basin there are no varved clays on a subaqual till and they seem therefore to be of the same age.

The ice sheet retreat from the Southern Middle Bank terminates a deglaciation of the Southern Baltic Sea area. Due to melting of dead ice in the Słupsk Furrow and a rise of water level at 12.7–12.6 ka BP, the ice marginal lakes in the Gdańsk Basin and the Bornholm Basin became connected with each other, initiating a development of the Baltic Ice Lake, i.e. the first phase of the Baltic Sea.

CONCLUSIONS

Several landforms and deposits have been recognised during mapping in 1977–1990 in the Polish Exclusive Economic Zone of the Baltic Sea. Boulders and boulder fields (residuum of moraine deposits), remains of end moraines, glaciofluvial deltas, eskers and ice marginal lake deposits are described and presented (Fig. 1). They are connected with a retreat of the last Scandinavian ice sheet in this area.

Landforms and deposits of three ice marginal zones were distinguished on the Southern Baltic seabed, referred to the Gardno Phase, the Słupsk Bank Phase and the Southern Middle Bank Phase. Spatial and temporal correlation of landforms on the Baltic seabed with ice margins on both sides of the Baltic Sea was based on the newer data.

The Gardno Phase, age of which is determined by radiocarbon dating of peat from the Gardno–Łeba Lowland (K. Rotnicki, K. Borówka, 1995*a*, *b*) and the Pomeranian Bay (R. Kramarska, Z. Jurowska, 1991), probably corresponds to the Halland–West Skåne Phase distinguished and dated at ca. 14 ka BP by E. Lagerlund and M. Houmark-Nielsen (1993), and to the Middle Lithuanian Phase in the east (A. Raukas *et al.*, 1995).

The Słupsk Bank Phase, marked by boulder fields on the Słupsk Bank and by end moraines in the southern Bornholm Basin and in the western Gdańsk Basin, is to be correlated with an ice sheet standstill in Skåne dated at 13.5 ka BP (J. Lundqvist, 1994), and with the North Lithuanian Phase (Luga) at 13.2 ka BP (A. Raukas *et al.*, 1995) or 13.0 to 13.2±0.43 ka BP (R. Pirrus, A. Raukas, 1996).

The Southern Middle Bank Phase is marked mainly by glaciofluvial deltas on this bank and by end moraines in the central Bornholm Basin. Most probably it corresponds to the ice marginal landforms in Skåne, dated at 13.0–12.9 ka BP (J. Lundqvist, 1994), and to the Otepää Phase in the east (A. Raukas *et al.*, 1995; R. Pirrus, A. Raukas, 1996), named also the North Latvian Phase (V. K. Gudelis, E. Emelyanov, 1976).

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OBSZAR POŁUDNIOWEGO BAŁTYKU W CZASIE OSTATNIEJ DEGLACJACJI

Streszczenie

W czasie prac kartograficznych prowadzonych w latach 1977–1990 przez Oddział Geologii Morza Państwowego Instytutu Geologicznego w obszarze polskiej strefy ekonomicznej Morza Bałtyckiego rozpoznano szereg form i osadów związanych z zanikiem ostatniego lądolodu skandynawskiego. Opisano i przedstawiono na mapie (fig. 1) rozmieszczenie głazów i głazowisk stanowiących rezyduum osadów morenowych, ostańców ciągów moren czołowych częściowo pogrzebanych pod młodszymi osadami (fig. 2, 3), delt glacifluwialnych (fig. 4, 5), ozów (fig. 6) i osadów zastoiskowych (fig. 7).

Na dnie południowego Bałtyku wyróżniono formy i osady trzech stref maginalnych: fazy Gardna, Ławicy Słupskiej i Południowej Ławiey Środkowej. Podjęto próbę korelacji przestrzennej i czasowej form zachowanych na dnie Bałtyku z ciągami marginalnymi występującymi po obu stronach Bałtyku (fig. 8).

Faza Gardna, której wiek w strefie polskiego wybrzeża wyznaczają daty radiowęglowe torfów z Niziny Gardzieńsko-Łebskiej (K. Rotnicki, K. Borówka, 1995*a, b*) i Zatoki Pomorskiej (R. Kramarska, Z. Jurowska, 1991; R. Kramarska, 1998), odpowiada najprawdopodobniej fazie Halland–West Skåne, wyróżnionej i datowanej na ok. 14 ka BP przez E. Lagerlunda i M. Houmark-Nielsena (1993), jak również fazie środkowolitewskiej na wschodzie (A. Raukas i in., 1995; R. Pirrus, A. Raukas, 1996).

Faza Ławicy Słupskiej, zaznaczająca się na dnie Bałtyku głazowiskami na Ławicy Słupskiej oraz ostańcami ciągów moren czołowych w południowej części Basenu Bornholmskiego i w zachodniej części Basenu Gdańskiego, może być korelowana z linią postoju krawędzi lądolodu w Skanii, datowaną na 13,5 ka BP (J. Lundqvist, 1994) i fazą północnolitewską (Luga), której wiek określa się na ok. 13,2 ka BP (A. Raukas i in., 1995; R. Pirrus, A. Raukas, 1996).

Faza Południowej Ławicy Środkowej, zaznaczona głównie przez delty glacifluwialne występujące na tej ławicy i moreny czołowe w środkowej części Basenu Bornholmskiego, odpowiada najprawdopodobniej strefie marginalnej w Skanii datowanej na 13.0–12.9 ka BP (J. Lundqvist, 1994), a na wschodzie fazie Otepää (A. Raukas i in., 1995), nazywanej też fazą północnolotewską (V. K. Gudelis, E. Emelyanov, 1976). Recesja lądolodu z obszaru Południowej Ławicy Środkowej kończy deglacjację obszaru południowego Bałtyku. Około 12,7–12,6 ka BP na skutek wytapiania się martwych lodów w Rynnie Słupskiej przy podnoszeniu się poziomu wody, następuje połączenie zastoisk Basenów Gdańskiego i Bornholmskiego dając początek bałtyckiemu jezioru lodowcemu — pierwszej fazie rozwojowej Morza Bałtyckiego.