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TERRESTRIAL DEPOSITS FROM THE SŁUPSK BANK AS AN EVIDENCE OF THE LATE GLACIAL AND EARLY HOLOCENE BALTIC SEA LEVEL

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Abstract. The site of Late Glacial and Early Holocene peat and limnic sediments at eastern part of Słupsk Bank were investigated by seismoacoustic profiling, lithological, pollen and molluscs analyses, and ^{14}C datings of 3 sediments cores. There is an evidence that from the last deglaciation to the beginning of the Littorina transgression *c.* 8000–7500 years BP, the Słupsk Bank was a land area, and the maximum water level of the Baltic Ice Lake and the Ancylus Lake was lower then 24–25 m below the present sea level.

Key words: peat and limnic deposits, pollen spectrum, ^{14}C dates, Late Glacial, Early Holocene, Słupsk Bank, Baltic Sea.

Abstrakt. Badania sejsmoakustyczne oraz analizy osadów (litologiczne, palinologiczne, malakologiczne), a zwłaszcza datowania radiowęglowe torfów, pozwoliły na szczegółową charakterystykę stanowiska późnoglacjalnych i wczesnoholoceńskich torfów i osadów jeziornych we wschodniej części Ławicy Słupskiej. Wykazano, że od deglacjacji do początków transgresji litorynowej, około 8000–7500 lat BP, Ławica Słupska była lądem, a maksymalny poziom wód w zbiornikach bałtyckiego jeziora lodowego i jeziora ancylusowego nie był wyższy niż 24–25 m poniżej współczesnego poziomu morza.

Słowa kluczowe: torfy i osady jeziorne, spektrum pyłkowe, daty ^{14}C, późny glacjał, wczesny holocen, Ławica Słupska, Bałtyk.

INTRODUCTION

Between 1984 and 1985, during work done by the Marine Geology Branch of the Polish Geological Institute for the purpose of the Geological Map of the Baltic Sea Bottom, scale 1:200,000 (GMBSB), a hollow in the top of till was identified in the eastern part of the Słupsk Bank, which was filled with Late Glacial and Early Holocene peat-bog and limnic sediments. These sediments were described in the comments to the Łeba sheet of the GMBSB and discussed at national conferences (Uścinowicz, Zachowicz, 1991, 1994).

The sites containing similar sediments known and described so far in the Southern Baltic are located in the coastal zone and at much smaller depths, mainly in the Vistula Lagoon (e.g. Bogaczewicz-Adamczak, Miotk, 1985; Zachowicz, 1985; Zachowicz, Uścinowicz, 1997) and the Puck Lagoon (Kramarska *et al.*, 1995), as well as in the Pomeranian Bight (e.g. Kramarska, 1998). The site in the Słupsk Bank is located in an open sea zone *c.* 23 km away from the shoreline (Fig. 1). Only limnic sediment sites with freshwater malacofauna in the Southern Middle Bank are located further north (Masłowska,

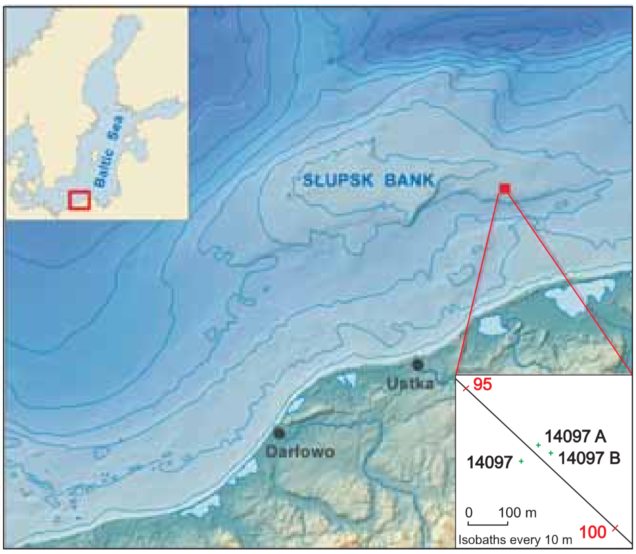

Fig. 1. Location of investigated site

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Michałowska, 1995). However, contrary to the Słupsk Bank site they do not have palynological documentation. Due to the good documentation and the importance of the Słupsk Bank site for the palaeogeographical reconstruction of the Southern Baltic, detailed findings of research and the conclusions following therefore have been presented in this article.

RESEARCH METHODS AND MATERIALS

Seismoacoustic profiling was performed using an EG&G boomer. Within the site located in the 14 ŁB seismoacoustic profile, 3 sediment cores were taken using a vibrocorer with a core tube length of 6 m and a diameter of 10 cm. Navigation was performed using a Syledis system with an accuracy of 5 m. The cores are located from 30 m south-west to 30 and 60 m north-east from the seismoacoustic profile line (Fig. 1).

Immediately after the cores had been taken, a macroscopic description was made; samples for examination were taken at the laboratory. The following analyses and designations were made:

– grain size distribution — 17 analyses in 3 cores
– petrographic composition of the 5–10 mm fraction — 2 analyses from 1 core
– composition and content of heavy minerals in the 0.125–0.25 fraction — 8 analyses in 1 core
– mineralogical and petrographic composition in the 0.5–1.0 mm fraction — 10 analyses in 2 cores
– roundness of quartz grains in the 0.25–0.5 mm fraction — 12 analyses in 2 cores
– organic matter and carbonate content — 8 analyses in 1 core
– palynological analyses — 22 samples from 2 cores
– malacological analyses — 6 samples from 1 core
– ^{14}C dating — 9 samples from 2 cores (Tab. 1)

Table 1

Results of designation with the ^{14}C method

Core No.	Sample position in core [m]	Material dated	Lab. code	^{14}C age [yr. BP]
14097	2.68–2.73	peat	Gd-3229	8950 ±70
14097	2.73–2.80	peat	Gd-1947	9850 ±80
14097 B	0.70–0.85	wood	Gd-5216	9240 ±90
14097 B	2.95–2.97	peat	Gd-4190	9320 ±150
14097 B	3.22–3.30	peat	Gd-5217	9320 ±90
14097 B	3.35–3.40	peat	Gd-4191	9620 ±160
14097 B	3.50–3.55	peat	Gd-2752	9720 ±160
14097 B	3.55–3.58	peat	Gd-2755	10060 ±130
14097 B	3.58–3.62	peat	Gd-4187	10510 ±170

All the lithological analyses were performed at the laboratory of the Marine Geology Branch of the Polish Geological Institute in accordance with the methodology adopted for the GMBSB. The palynological analyses were carried out by Zachowicz (1987), and the malacological analyses by Krzymińska (1987). Sediment age determination with the ^{14}C method was performed at the Radiocarbon Laboratory of the Silesian Technical University.

EXAMINATION FINDINGS

In the south-eastern part of the Słupsk Bank the top of till is levelled, gently sloping towards the south. Small and shallow hollows filled with postglacial sediments occur occasionally in the top of till. One of such hollows identified with seismoacoustic profiling (14ŁB profile), stretches along 500 m reaching a depth of *c.* 3–4 m (Fig. 2). The thickness of sediments which fill this hollow ranges from 3 to 3.65 m. A detailed description of sediment cores taken within this hollow is as follows (Figs. 3, 4, 5):

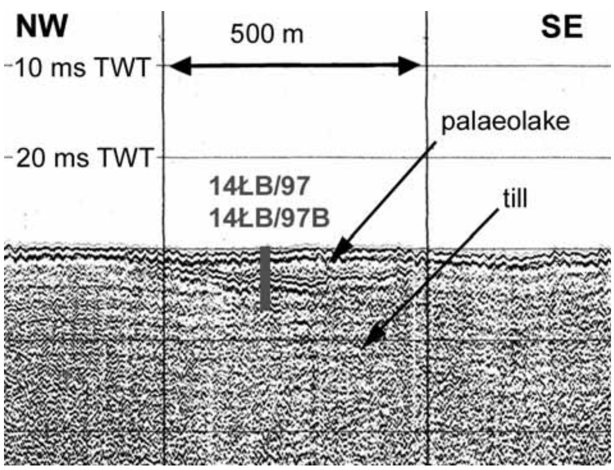

Fig. 2. Seismoacoustic profile (boomer record) across the investigated site

SEDIMENT LITHOLOGY

Based on macroscopic descriptions of the cores, ^{14}C dating and the results of laboratory tests, a lithological characteristics of the sequence of glacial, limnic and marine sediments are presented below (Fig. 6).

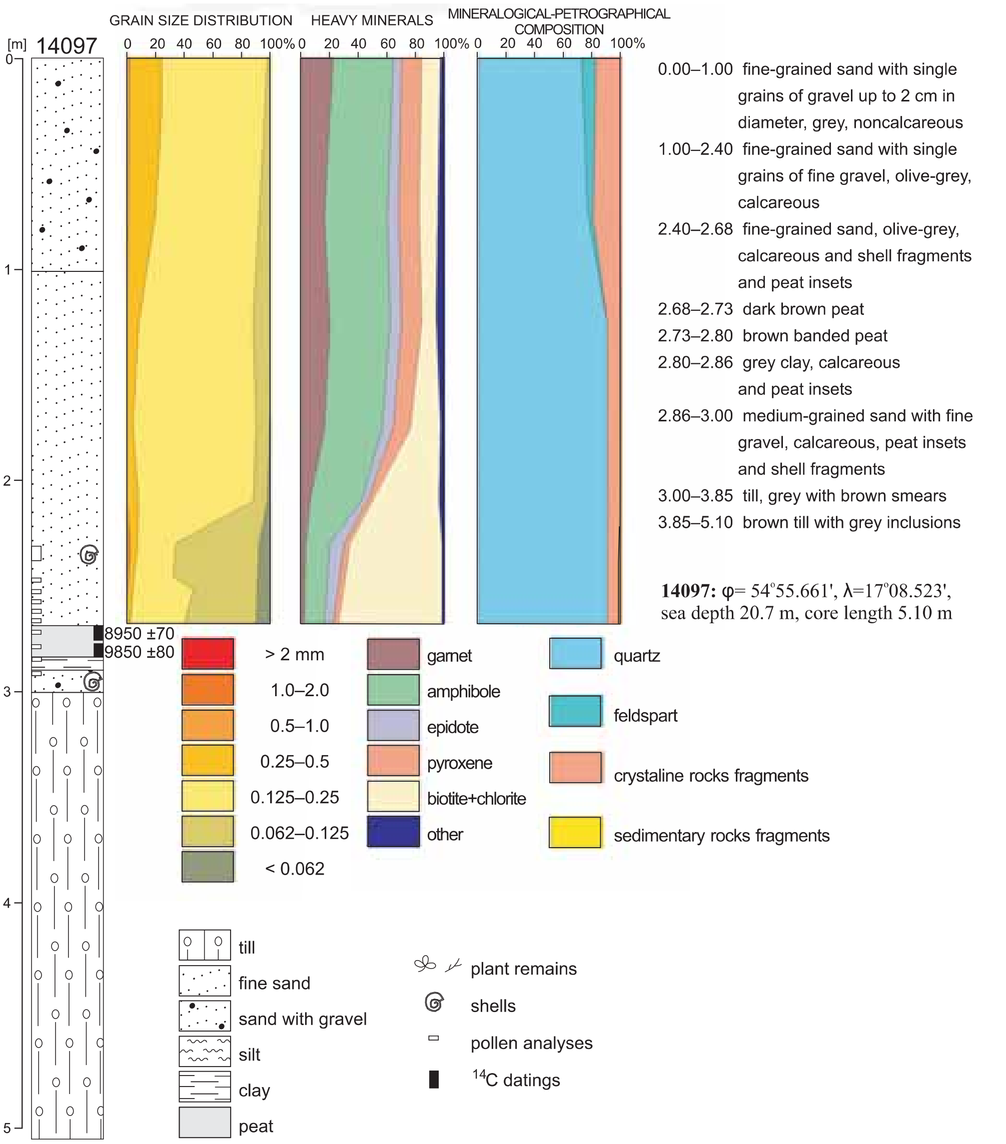

Fig. 3. Grain size distribution and mineralogical composition of sedimentary core 14097

Explanations to Figs. 4, 5, 7 and 8

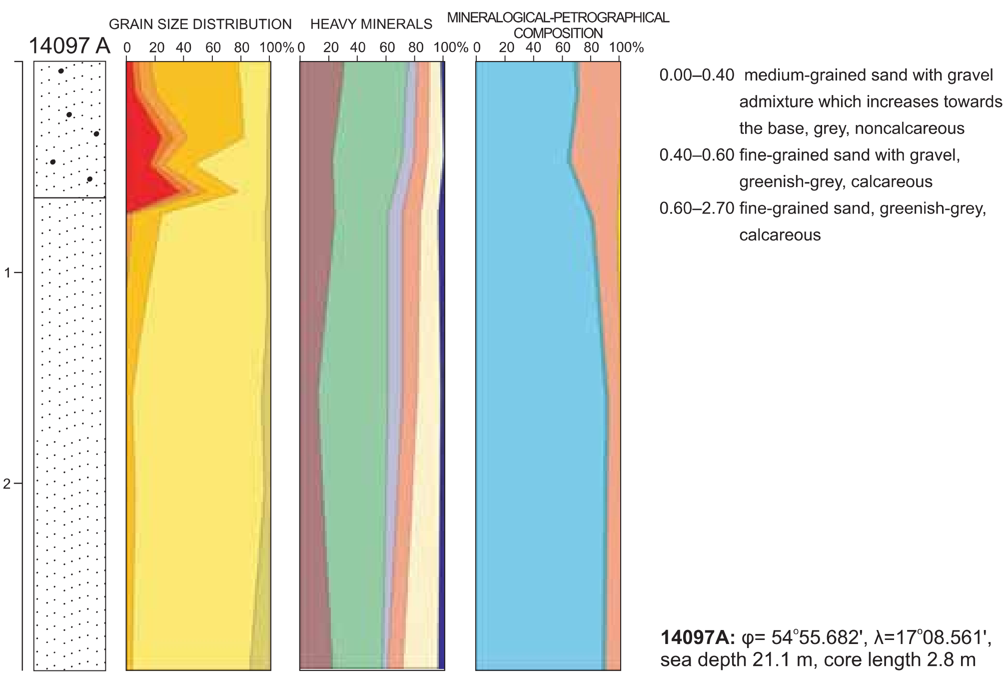

Fig. 4. Grain size distribution and mineralogical composition of sedimentary core 14097 A

For explanation see Fig. 3

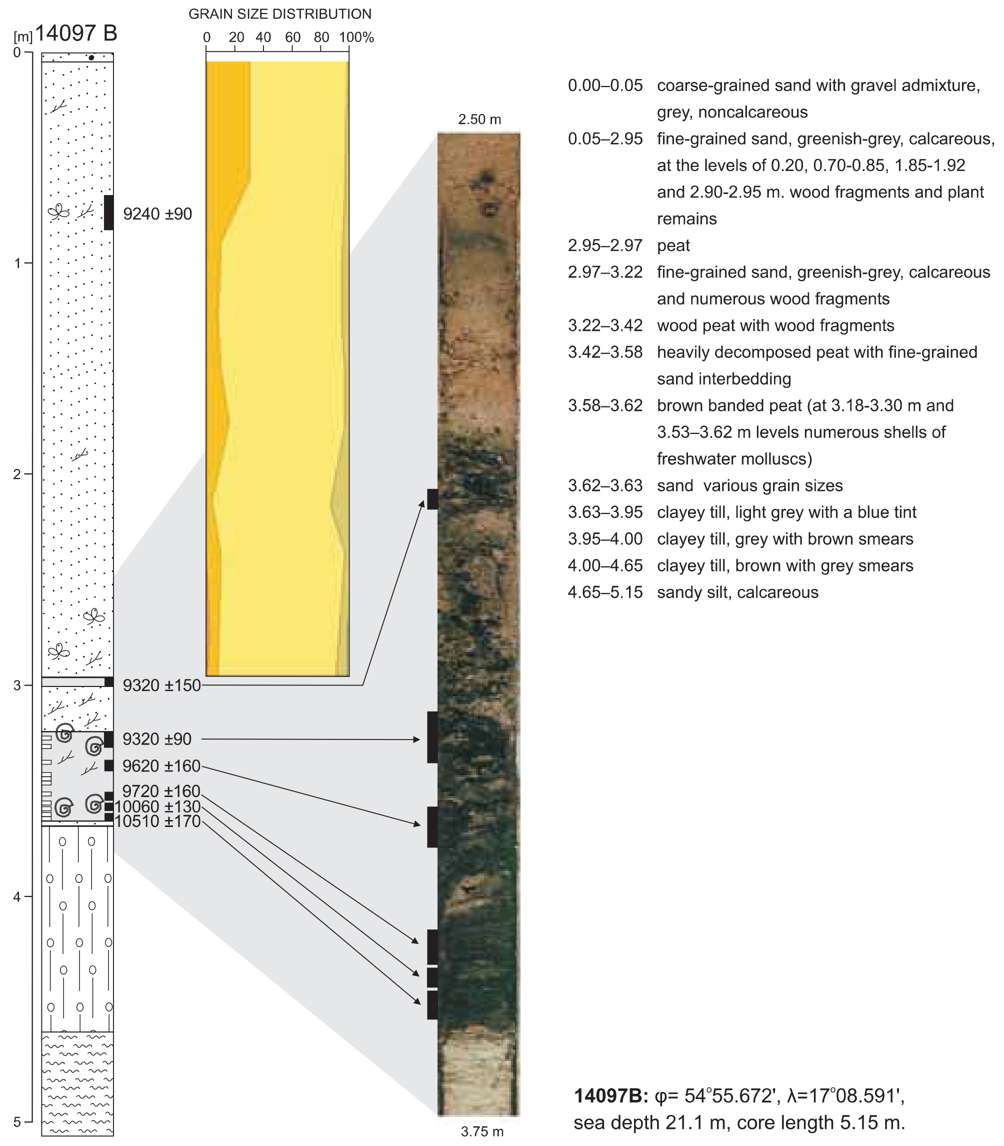

Fig. 5. Grain size distribution of sedimentary core 14097 B

For explanation see Fig. 3

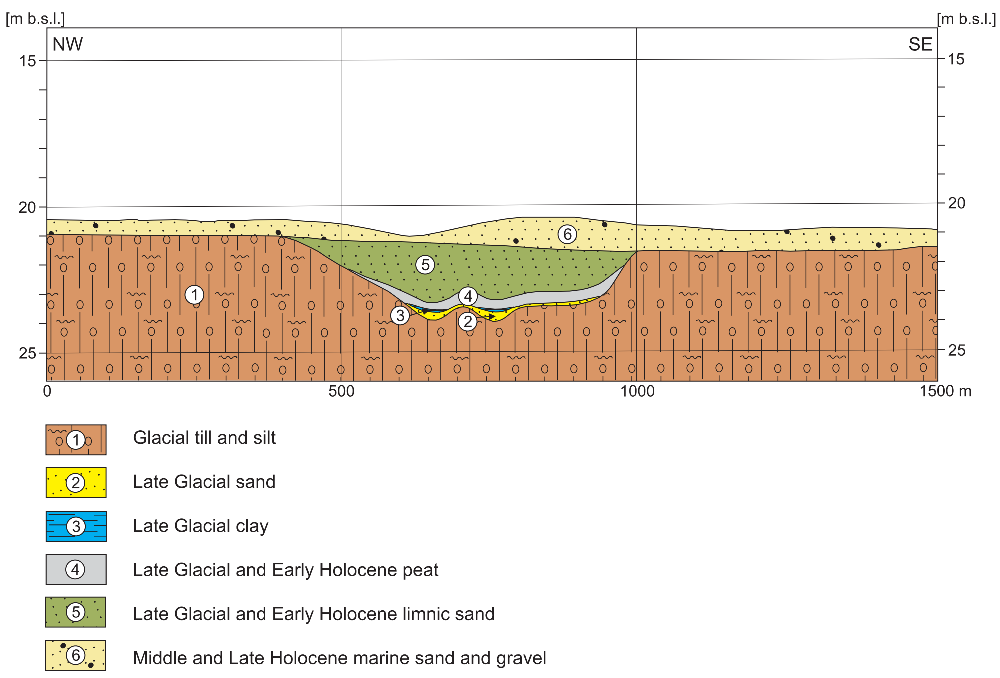

Fig. 6. Schematic geological cross-section along the investigated site

Glacial sediments — till and silt

Till from core 14097 contain small amounts of gravel fractions (2.1%). Sand fractions (0.063–2.0 mm) constitute 32.1–37.5%, silt fractions (0.004–0.063 mm) 31.9–33.7%, and clay fractions (<0.004 mm) from 28.5 to 32.1%. In the petrografic composition of the gravel fractions (core 14097) Scandinavian rocks decidedly predominate, crystalline rock fragments occur in quantities from 29.4 to 49.5%, palaeozoic calcareousstone — from 23.7 to 41.2%, and palaeozoic sandstone from 18.8 to 20.4%. Among the local components, only sandstone occurs in quantities from 3.2 to 7.1% and flint constitutes from 2.1 to 2.3%. In the mineralogical and petrographic composition of the 0.5–1.0 mm fraction, quartz predominates (44.7–48.3%), sedimentary rock fragments constitute 32.3–32.7%, and crystalline rock fragments account for 16.0–20.3%, feldspar admixtures constitute 2.7–3.0%. Among the quartz grains in the 0.25–0.5 mm fraction, angular or partly angular grains are dominant (50.3%), partly rounded grains constitute 35.7%, and the admixtures of rounded and well rounded grains — 14.0%. The composition of the transparent minerals which make up *c.* 50% of heavy minerals in the 0.125–0.25 mm fraction is as follows: garnets 14.0–17.7%, amphiboles 27.3–28.2%, epidotes 6.7–9.7%, pyroxenes 11.0–12.3%, biotite+chlorite 8.0–13.0%, disthene 8.0–13.0%, tourmaline 3.7–4.0%, staurolite 2.7–8.3%, circonium 2.7–4.3%. On the basis of petrographic indicators, this till was defined as Wartanian Glaciation till (Masłowska, Kramarska,, 1996), however, due to the limited quantity of data, their stratigraphic position is not certain.

Late Glacial sand and clay

These sediments form a thin layer in the top of till. The thickness of sand is from 1 cm in core 14097 B to 14 cm in core 14097. This sand is very calcareous (13.6% $CaCO_3$) and contains very small amounts of organic matter (1.1%). In core 14097 the sand is covered by a thin layer of clay, also very calcareous (13.4% $CaCO_3$) and with little organic matter (1.7%). According to the palynological analysis, both the sand and clay were deposited in the Late Glacial Period.

Peat

In core 14097, peat constitutes a 12-cm-thick layer which was formed in the period from 9850 ±80 to 8950 ±70 years BP (Tab. 1, Fig. 3). In core 14097 B the age of peat designated by ^{14}C dating ranges from 10510 ±170 to 9320 ±150 years BP (Tab. 1, Fig. 5), and their thickness is 40 cm. The base parts of peat in both cores are banded. Peat from core 14097 B contains sand laminas and numerous wooden fragments a few centimetres in size and shells of freshwater snails and clams.

Limnic sand

The thickness of fine-grained limnic sand ranges from 1.68 m in core 14097 to 3.17 m in core 14097 B, a their top is erosional. The 0.125–0.25 mm fraction predominates (Figs. 3, 4, 5). The sand is well- or very well sorted. The grain size distribution is symmetrical, meso- and leptokurtic. The variability of grain size distribution parameters is as follows: Mz from 2.52 to 2.58 φ , σ_I from 0.34 to 0.44 φ, Sk_I from 0.02 to 0.09, and K_G from 1.01 to 1.29. In the bottom part of the layer in core 14097, the 0.063–0.125 mm fraction predominates, and the admixture of finer fractions from 0.063 mm reaches 10% (Fig. 3). Fine-grained limnic sand is characterised by a high quartz content, which ranges from 80.4 to 90.0% in the 0.5–1.0 mm fraction. The share of crystalline rock fragments in this fraction is from 8.3 to 9.7%, sedimentary rock fragments and feldspars usually occur in quantities not larger than 1–2% (Figs. 3, 4). Quartz grains in the 0.25–0.5 mm fraction are angular and partly angular, their share oscillates from 46.7 to 57.0%. Also partly rounded grains are more numerous than rounded or well-rounded ones. Heavy mineral content in the 0.125–0.25 mm fraction ranges from 0.12 to 1.84%. The most frequently occurring minerals are transparent (22.8–39.5%) and altered (26.0–53.6%) ones. Among transparent minerals in fine-grained sand (domination of the 0.125–0.25 mm fraction), amphiboles predominate; their content is from 40.8 to 48.5%. Also numerous are garnets (12.5–23.1%), epidotes (6.1–7.9%), pyroxenes (9.5–13.2%), as well as biotite and chlorites (10.5–22.5%). In the bottom part of core 14097, together with the increase of the content of the 0.063–0.125 mm and <0.063 mm fractions, the content of amphiboles, garnets, epidotes and pyroxenes decreases, and the share of biotite and chlorites increases to 45.3–67.8% (Figs. 3, 4). The content of $CaCO_3$ in limnic sand ranges from 4.3 to 5.4%. Organic matter content is related to grain size distribution; in the base part of the layer it is 5.5%, dropping to 0.4% in the upper part.

Marine sand

Thickness and grain size distribution in marine sand changes considerably over small distances. In core 14097 it is fine-grained sand, 1 m thick, well sorted, with negative skewness and leptokurtic grain size distribution. The admixture of medium-grained sand fraction slightly exceeds 20%, and gravel fractions constitute 0.3–0.5% (Fig. 3). In core 14097 A the thickness of marine sediments is 0.4 m. In the top part, medium-grained sand occurs with *c.* 5% admixture of gravel fractions, in the base part gravelly sand is deposited, with the dominant 0,25–0,5 mm fraction of *c.* 40% and the admixture of *c.* 25% of the 2–8 mm fraction (Fig. 4). In core 14097 B, the thickness of marine coarse-grain sand with gravel admixture is only 5 cm. Marine sand is noncalcareous, only in the base — slightly calcareous. Quartz in the 0.5–1.0 mm fraction occurs in 64.0–75.7%, crystalline rock fragments constitute 18.7–32.0%, and feldspars from 2 to 7.7%. Sedimentary rock fragments occur in trace quantities, most often smaller than 1%

(Figs. 3, 4). Quartz grains, just like in till and limnic sand, are angular and partly angular (47.7–54.3%). Partly rounded grains constitute 32.7–41.0%, and rounded or well-rounded ones — 11.3–14.0%. Heavy minerals in the 0,125–0,25 mm fraction occur in 0.19–1.83%. Like in limnic sand, also in marine sand altered minerals (31.9–51.5%) and transparent minerals (32.9–46.1%) predominate among heavy minerals. Amphiboles (42.5–48.4%) and garnets (15.2–30.2%) are the most numerous among transparent minerals. Epidotes constitute 5.7–8.9%, pyroxenes 8.5–14.5%, while biotite and chlorites 6.4–15.1% (Figs. 3, 4). Organic matter in the marine sand of the discussed area constitutes less than 0.5%.

PALYNOLOGY OF PEAT-BOG AND LIMNIC SEDIMENTS

Eleven samples of peat and 1 sample of underlying sand from core 14097 B, as well as 10 sediment samples from core 14097 were subjected to pollen analysis; these included 2 peat samples, 6 samples of limnic sand which covers the peat, as well as clay and sand underlying the peat — one sample each (Figs. 7, 8).

The material for pollen analysis was treated by the standard KOH and acetolysis method (Faegri, Iversen, 1989). Pollen from terrestial plants, i.e. trees, shrubs, dwarf shrubs and herbs,

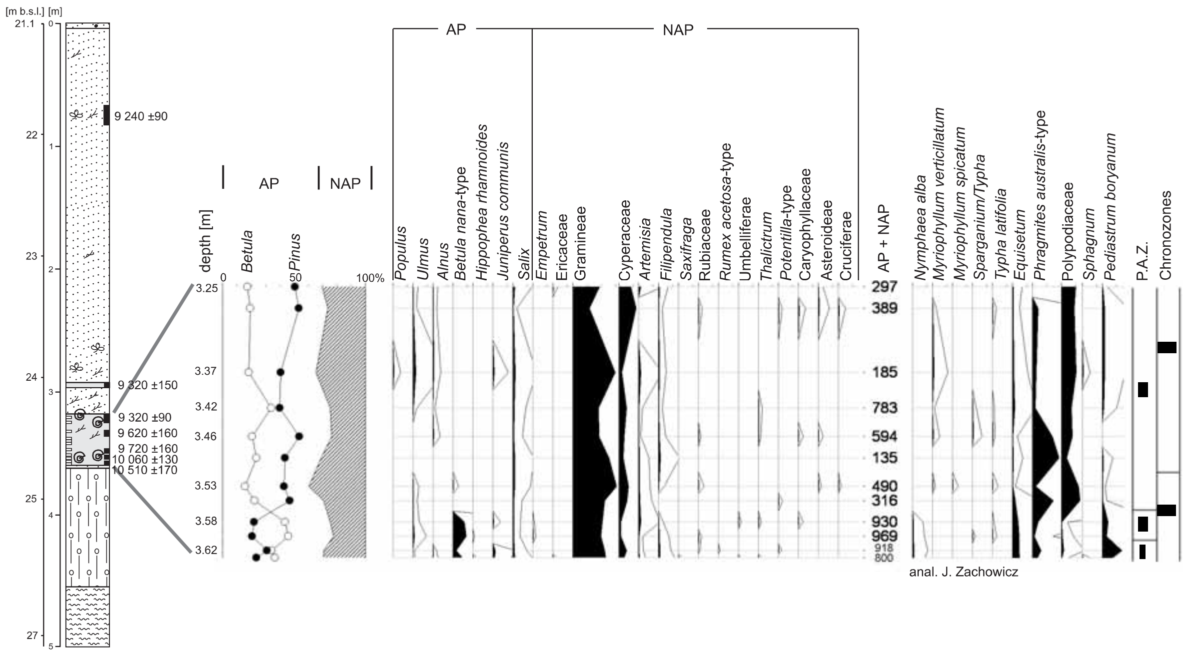

Fig. 7. Pollen diagram of sediments from core 14097 B (for explanation see Fig. 3)

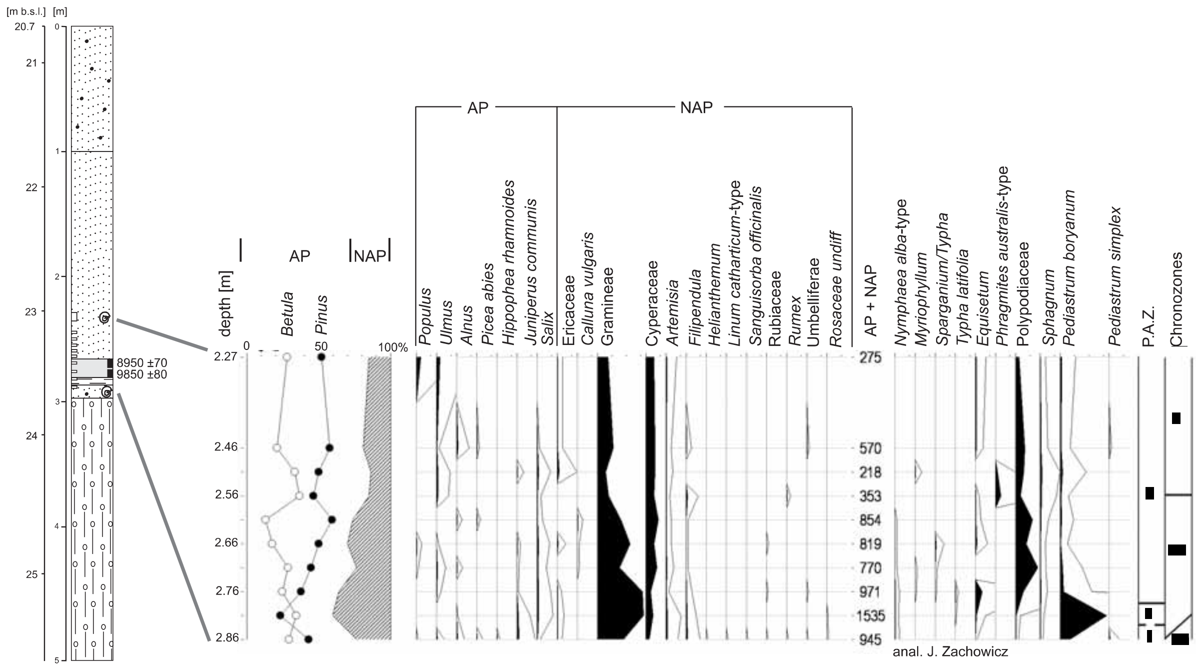

Fig. 8. Pollen diagram of sediments from core 14097 (for explanation see Fig. 3)

is included in the basic sum for percentage calculations. Pollen from telmatophytes, lymnophytes, green algae (*coenobia Pediastrum*) and spores is calculated outside the basic sum.

Three pollen assemblage zones have been distinguished in the pollen diagram of core 14097 B (Fig. 7, Tab. 2).

Table 2

Description of local pollen assemblages zones (core 14097 B)

Local PAZ	Name of PAZ	Depth [cm]	^{14}C dates [yr. BP]	Description of pollen spectra
1	*Betula–Pinus –Juniperus*	362–364	–	High frequencies of *Betula* (max. 37%), *Pinus* (max. 31%) and *Juniperus* (max. 1.5%)
2	*Betula nana –Betula*	356–362	10510, 10060	The characteristic features of this zone are the dominance of *Betula* (max. 46%) over the *Pinus*. *Betula nana* (max. 9.5%) played a significant role.
3	*Pinus–Betula*	325–356	9720, 9320	High frequencies of *Pinus* (max. 54%) and *Betula* (max. 34%).

A considerable amount of pollen grains of *Betula, Betula nana, Juniperus, Hippophae* and *Artemisia*, (Tab. 2) which are species characteristic of cold sub-arctic climate, in the sand underlying the peat and in the base parts of peat from core 14097 B indicates that the deposition of peat started in the Late Glacial period. Pollen spectra of the top parts of peat from core 14097 B are dominated by pollen grains of *Pinus* and *Betula* and herbs, mainly Gramineae and Cyperaceae with an almost complete lack of pollen of more demanding tree species, which suggests that peat deposition lasted also in the Preboreal period. (Fig. 7). Such an interpretation is compliant with the obtained ^{14}C dates. A similar composition of the pollen spectrum from core 14097 (Fig. 8, Tab. 3) also indicates that they were deposited in the end of Late Glacial period and Preboreal period, albeit the radiocarbon date of the top part of this peat is slightly younger. The pollen spectra of the base parts of limnic sand of this core, where a slight increase in the quantity of tree pollen grains occurs, especially of *Ulmus* and *Populus,* indicate that peat deposition was stopped at the beginning of the Boreal period (Fig. 8).

Table 3

Description of local pollen assemblages zones (core 14097)

Local PAZ	Name of PAZ	Depth [cm]	^{14}C dates [yr. BP]	Description of pollen spectra
1	*Pinus–Betula –Juniperus*	286	–	High frequencies of *Betula* (max. 29%), *Pinus* (max. 43%) and *Juniperus* (max. 1.3%)
2	*Betula–Pinus*	281	9850	Domination of *Betula* (34%) over *Pinus* (23%). The lack of *Betula nana*.
3	*Pinus–Betula*	227–281	9850, 8950	High frequencies of *Pinus* (max. 60%) and *Betula* (max. 36%).To the end of this zone increase in *Ulmus*.

The limnic reservoir in question was located in the vicinity of the shore of the then Baltic and most probably was hydraulically tied to it, and the level of groundwater altered along with the changes in the sea level. So changes in the composition of limnophytes and telmatophytes pollen spectra in peat from core 14097 B (Fig. 7) and from core 14097 (Fig. 8) coupled with radiocarbon dates can indirectly indicate the changes in the water level of the then Baltic. In Late Glacial peat which was radiocarbon dated at 10510 ±170 years BP, considerable quantities coenobia of *Pediastrum boryanum*, *Equisetum* spores and pollen of *Nymphaea alba* occur (Fig.7), which may be linked to the maximum water level in the Baltic Ice Lake, and thus with a higher groundwater level within the adjacent shore. A drop in the share of these species in pollen spectra coupled with an increase in the amount of *Phragmites australis-type* pollen grains in peat dated at 10060 ±130 and 9720 ±160 years BP, may be linked to the lowering of the groundwater level caused by the drainage of the water of the Baltic Ice Lake and a low water level in the early Preboreal Yoldia Sea. A repeated increase in the importance of *Pediastrum boryanum* and *Equisetum,* and a drop in *Phragmites australis-type* in peat dated at the second half of the Preboreal period (from 9620 ±160 to 9240 ±90lat BP, Tab. 1) may indicate an increase in groundwater level related to the transgression of the Yoldia Sea, and especially with the transgression and maximum water level of the Ancylus Lake.

MALACOFAUNA OF PEAT-BOG AND LIMNIC SEDIMENTS

The composition of malacofauna examined in four samples from core 14097 B is as follows (Krzymińska, 1987, 2001):

3.18–3.27 m *Pisidium amnicum* (Müller), *Pisidium casertanum* f. *ponderosum* (Stelfox),

3.27–3.30 m *Physa fontinalis* (Linnaeus), *Valvata cristata* (Müller), *Pisidium amnicum* (Müller), *Pisidium casertanum* f. *ponderosum* (Stelfox), *Pisidium milium* (Held),

3.56–3.58 m *Valvata* sp.,

3.58–3.62 m *Bithynia tentaculata* (Linnaeus), *Pisidium* sp.

Two groups of malacofauna were distinguished:

- a group from layers dated at 10510 ±170–10060 ±130 years BP (Younger Dryas) characterised by sparse species composition (*Valvata* sp., *Bithynia tentaculata* (Linnaeus), *Pisidium* sp.,
- a group from layers dated at 9320 ±90 years BP (Preboreal period) characterised by greater diversity, with the following dominating taxons: *Pisidium amnicum* (Müller) and *Pisidium casertanum* f. *ponderosum* (Stelfox), and the more sparsely occuring: *Physa fontinalis* (Linnaeus), *Valvata cristata* (Müller), *Pisidium milium* (Held).

Apart from a larger number of species occurring in sediments dated at the Preboreal period, one cannot see here regularities related to the changes in the species composition dependent on climatic changes. Both groups have species typical of the final stage of the last glaciation and the Preboreal period, such as: *Valvata cristata* (Müller), *Bithynia tentaculata* (Linnaeus), *Pisidium milium* (Held) (Alexandrowicz, 1987). The presence of a certain inversion is characteristic here; *Bithynia tentaculata* (Linnaeus) — a taxon with higher thermal requirements occurs in Young Dryas sediments, while a cold-loving species, according to Alexandrowicz (1987) characteristic of the final stage of the last glaciation — *Pisidium milium* (Held) occurs in Preboreal sediments.

SUMMARY AND CONCLUSIONS

The results of the research presented above allow us to attempt to recreate the processes which occurred in the Słupsk Bank in the Late Glacial Period and Early Holocene. A problem for discussion is the age of the till which underlies Late Glacial sediments. If we assume that the age of the till determined on the basis of petrographic factors is true, a question arises why the youngest till from the last glaciation does not occur here. One can assume that it was destroyed by meltwater during the last deglaciation or during the transgression and the first maximum of the Baltic Ice Lake (*c.* 11,200 years BP). If it had been so, the till from the last deglaciation would be very thin and it would contain very little gravel and sand material, as there is no residue after its washing-out. In the case of the till's being destroyed by meltwater, the hollow which is being discussed here would not be a lake basin but a fragment of a larger valley used by the meltwater.

It is an undeniable fact that peat forming processes commenced in the Słupsk Bank in the Younger Dryas and lasted until the end of the Preboreal period. During that time, a shallow, overgrowing water reservoir existed here. The variation in the pollen spectra of limnophytes and telmatophytes in the sediments deposited in this reservoir in the Late Glacial and in the Preboreal period also indicates indirectly changes in the water level located in the vicinity of the then Baltic, namely the maximum level of the Baltic Ice Lake, its draining at the end of the Pleistocene, the low water level of the Yoldia Sea at the beginning of the Preboreal period and the transgression of the Ancylus Lake at the end of this period (Figs. 9, 10).

The disruption of the peat forming process was caused by the increase in the water level in the reservoir and intensifying of the sedimentation of sandy sediments supplied probably be eolian processes. At the beginning of the Boreal period, very

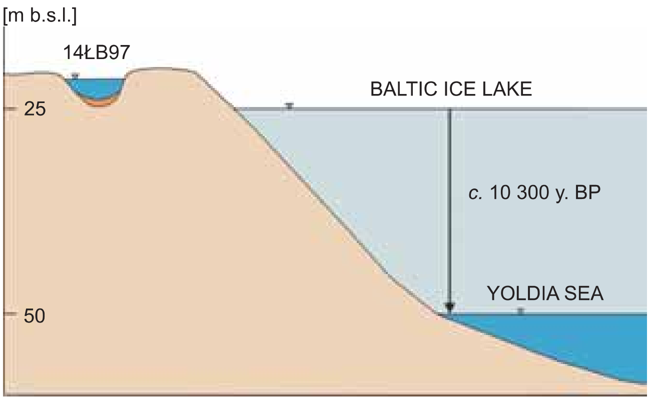

Fig. 9. Sketch of the discussed site and its vicinity during regression of the Baltic Ice Lake

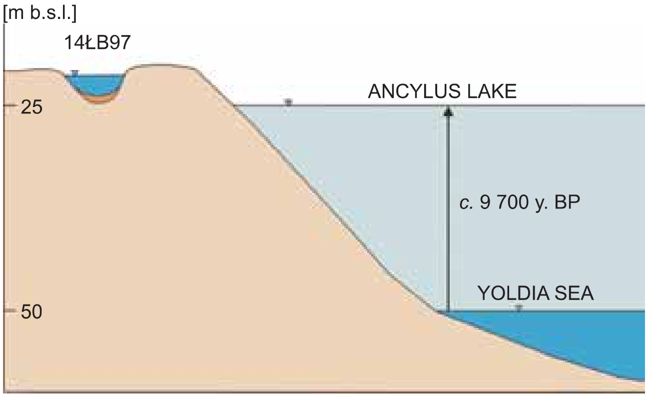

Fig. 10. Sketch of the discussed site and its vicinity during transgression of the Ancylus Lake

fine-grained sandy sediments were deposited in the reservoir; they contained plant remains and pollen grains. The change in the grain size distribution and the mineralogical composition of sediments (a clear drop in the content of the <0.125 mm fraction, and also chlorites and biotite) (Fig. 3) indicates that towards the end of the Boreal period there was a change in sedimentation conditions. An increase in the content of the 0.125–0.25 mm fraction, as well as garnets and amphiboles, suggests a closer location of the supply sources and a shorter transport route of the sediments. It took place most probably towards the end of the Boreal period and at the beginning of the Atlantic period, and was related to the raising of the sea level at the beginning of the Littorina transgression. The discussed limnic reservoir happened to be in a very close vicinity of the sea shore, possibly directly behind the dunes. The intrusion of the sea onto the Słupsk Bank *c.* 8000–7000 years BP stopped the processes of filling in the lake basin. The top part of the limnic sand was probably eroded during the transgression. Marine sand and gravel sediments deposited on limnic sand, particularly well developed in core 14097 A (Fig. 4) are a trace of the transgression. The limnic sediments were probably not destroyed completely because the sea entered this part of the Słupsk Bank from the south where originally there was a bay, and later a strait, of the Littorina Sea which separated the Słupsk Bay from the mainland. In such topographic conditions, the shoreline processes were considerably weaker than those occurring on the open sea shore from the northern side of the Słupsk Bank.

The most important conclusion from the presented documentation material is that from the deglaciation to the transgression of the sea at the beginning of the Atlantic period, the Słupsk Bank was a terrestrial area. In view of the above, one can say that during neither the maximum reach of the Baltic Ice Lake (*c.* 10 300 years BP) nor the Ancylus Lake (*c.* 9 200 years BP), the waters of these reservoirs in the Southern Baltic did not reach higher than *c.* 24–25 m below the present level. It is of vital importance for the reconstruction of the palaeoenvironmental conditions, especially those related to the magnitude of the level variation of the Southern Baltic in the Late Glacial and Early Holocene.

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