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A CRITICAL REVIEW AND REINTERPRETATION OF BIO-, LITHO- AND SEISMOSTRATIGRAPHIC DATA OF THE SOUTHERN BALTIC DEPOSITS

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Abstract. The aim of this study was the reinterpretation of the published and unpublished Late-Pleistocene and Holocene pollen and diatom diagrams of deposits from the sedimentary basins of the Southern Baltic Sea and the correlation of the distinguished biostratigraphic units with lithological parameters, seismostratigraphic units. Chronostratigraphic subdivision of the Late Pleistocene and Holocene was also made.

To facilitate the correlation and reinterpretation of the results of biostratigraphic (palynological and diatom) analyses, new unified and simplified diagrams were drawn using the POLPAL software. Such diagrams were constructed for all the sites under comparison, even for those of no numerical data. In such cases, the published diagrams were scanned and their percentage values were the basis for new diagrams.

A review and reinterpretation of biostratigraphic data show an almost complete lack of palynological documentation and diatom diagrams for the Late Pleistocene period and poor documentation for the Early Holocene. Middle and Late Holocene Baltic muds have the best biostratigraphic documentation and radiocarbon dating, which greatly facilitates their location on the geological time scale.

Among the Southern Baltic postglacial sediments three lithostratigraphic units were identified. They differ in their lithological features reflecting the conditions prevalent in the sedimentary basin during deposition. It should be noted that these units meet no formal criteria for distinguishing lithostratigraphic units. Similarly, within the Late Pleistocene and Holocene sediments of Southern Baltic deep-water basins, three main seismostratigraphic complexes have been identified.

The integrated analysis of seismoacoustic profiles, lithological profiles of cores and reinterpretated biostratigraphic data allow a correlation of the bio-, litho- and seismostratigraphic units with chronostratigraphic units and Baltic evolutionary phases.

Key words: pollen and diatoms diagrams, ^{14}C datings, bio-, litho- and seismostratigraphy, Late Pleistocene and Holocene, Southern Baltic Sea.

INTRODUCTION

The traditional Baltic evolutionary phases, such as the Baltic Ice Lake, Yoldia Sea, Ancylus Lake and Litorina Sea, established in various countries and by various authors and very often used in a stratigraphic sense, are not always comparable with one another. It is a serious problem that the index molluscs which were the basis for establishing the basic development phases of the Baltic in Sweden are absent in the sediments deposited in the Baltic Sea floor (Duphorn, 1979). Generally speaking, the development phases of the Baltic are determined by time intervals of open or closed connections of the Baltic with the ocean, and – as a consequence – mainly by changes in hydrological (ecological) conditions and, to a lesser degree, in sedimentary processes.

Towards the end of the 20th century, attempts were made both to systematise the separation of the Baltic development phases (Hyvärinen, 1988; Svensson, 1991; Björck, 1995) and to introduce formal lithostratigraphic (Ignatius *et al*., 1981; Kotliński, 1989, 1991; Winterhalter, 1992) and biostratigraphic schemes: diatomological (Alhonen, 1971) and malacological (Alexandrowicz, 1999). Despite this, the Baltic's evolutionary phases have not yet been defined correctly as geochronological units with generally accepted limits. So far,

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palynologic and chronostratigraphic stratotype sections have not been developed (Mangerud *et al*., 1974; Duphorn, 1979; Hyvärinen, 1988, 2000). More recent data (e.g. Andren *et al*., 2000) indicates that sedimentary profiles from Baltic deeps also contain information about climatic oscillations.

Polish research on the history of the Baltic Sea, recorded in deposits of deep-water sedimentatry basins, began at the turn of the 1960s. It was then that the first cores of deep-water deposits were taken in the Polish Exclusive Economic Zone of the Baltic Sea as part of international projects (Masicka, 1975; Pieczka, 1980). Earlier, expert biostratigraphic tests on the sea floor deposits by means of a pollen analysis method were made by Lubliner-Mianowska (1962, 1963, 1965). The first publications referred mainly to the lithological features of sediments (Masicka, 1975; Pieczka, 1980). Some time later, biostratigraphic studies of sediment cores collected from the offshore area were undertaken (Zaborowska, Zachowicz, 1982; Kępińska *et al*., 1986a, b; Pieczka, Zaborowska, 1989). In the 1980s, the Marine Geology Branch of the Polish Geological Institute conducted extensive geological research for the purpose of producing *Geological Map of the Baltic Sea Bottom* (Mojski, ed., 1989–1995). A few hundred sediment cores were taken and ca. 5,000 km of seismoacoustic profiling was performed at that time. The results of lithological analyses and radiocarbon dating were partly published in the *Notes* on *The Geological Map of the Baltic Sea Bottom* (e.g. Uścinowicz, Zachowicz, 1992, 1994), in *The Geological Atlas of Southern Baltic* (Zachowicz, 1995) and in a small number of original publications (e.g. Tomczak *et al*., 1999; Uścinowicz *et al*., 2000).

The rare published (Zaborowska, Zachowicz, 1982; Kępińska *et al*., 1986a, b; Pieczka, Zaborowska, 1989; Witkowski, 1994; Zachowicz, 1995) and archival pollen and diatom diagrams from deep-water basins of the Southern Baltic were analysed and discussed mainly in order to determine the development phases of the Baltic Sea and to specify their temporal limits.

The goal of this study is to reinterpret the published and unpublished Late-Pleistocene and Holocene pollen and diatom diagrams of clayey and silty deposits from the sedimentary basins of the Southern Baltic and the correlation of biostratigraphic units with lithological parameters and seismostratigraphic units.

THE CHARACTERISTICS OF THE RESEARCH AREA

The Baltic Sea is a shallow, tideless intracontinental sea with an area of 415,266 km^2 and average depth of 52 m, which has shallow and narrow connections with the Atlantic Ocean through the Danish Straits. The average depth of the Baltic is 56 m (Łomniewski *et al*., 1975). It is located between the temperate maritime and temperate continental climatic zones. Precipitation and river water inflow predominate over evaporation and oceanic water inflow.

Apart from the climate, the impeded water exchange with the ocean has a fundamental influence on the hydrological conditions in the Baltic. According to Łomniewski *et al*. (1975) and Majewski (1987), thermohalic stratification is an important feature of the Baltic waters. Deep layers in the Baltic basins are occupied by salt water with small temperature oscillations, the so-called isothermal salty layer, refreshed by the influx of oceanic waters and the movement of water to the neighbouring basins due to the varying water density. The top limit of the salty layer in the Southern Baltic is the 8‰ isohaline, which is located at the depth of 35–45 m in the Arkona Basin, at 45–50 m in the Bornholm Basin, and at 60–70 m in the Gdańsk and Gotland Basins. The top part of the salty layer is characterised by a quick increase in salinity (the so-called halocline) up to almost 17‰ in the Arkona Basin, 15‰ in the Bornholm Basin and 11–12‰ in the Gdańsk and Gotland basins. The oxygen saturation of this water layer is usually below 20%, and anaerobic conditions may occur periodically. The temperature of the saltwater layer is 4–6°C. Above the halocline, there is an isohaline layer, with more-or-less constantly balanced low salinity and varied, seasonally changeable thermal conditions. The salinity of this layer is 9–7 ‰ in the western part of Southern Baltic and decreases towards the east to 7–5‰ in the Gdańsk and Gotland basins. Oxygen saturation exceeds 90% in the near-surface layers and drops to 70% close to the halocline. The water temperature of the isohaline layer in the summer ranges from 16–17°C at its top to 5–6°C at its bottom. At a depth of 20–30 m there is a thermal jump layer (summer thermocline). In the autumn and spring, the whole isohaline layer profile has an isothermal arrangement with a temperature of 4–6°C. In the winter, a reversed arrangement occurs with the lowest water temperature (2– 3°C) in the surface water, which slowly increases with depth to 5–6°C (Łomniewski *et al*., 1975).

Summing up, the most important topographic and hydrological elements which influence the sedimentation processes include:

– location of the southern part of the Baltic Sea in a humid temperate climate zone,

– intracontinental location of the sea and impeded communication with the ocean,

– shallow-, brackish-water and tideless nature of the sea,

– occurrence of permanent density stratification,

– prevalence of undulation and currents from western directions,

– very high periodical water dynamics (during storms).

The terms “Southern Baltic” or “the Southern Baltic area” are not defined precisely, but they are used universally, especially in Polish publications – in articles, monographs and cartographic publications. In the Southern Baltic area, deep-water basins are clearly defined. These are the Arkona Basin (max depth 50 m), Bornholm Basin (max depth 105 m; in its Polish part – 95 m), Słupsk Channel (max depth 93 m), Gdańsk Basin (max depth 107 m) and Gotland Basin (max depth 249 m, in its

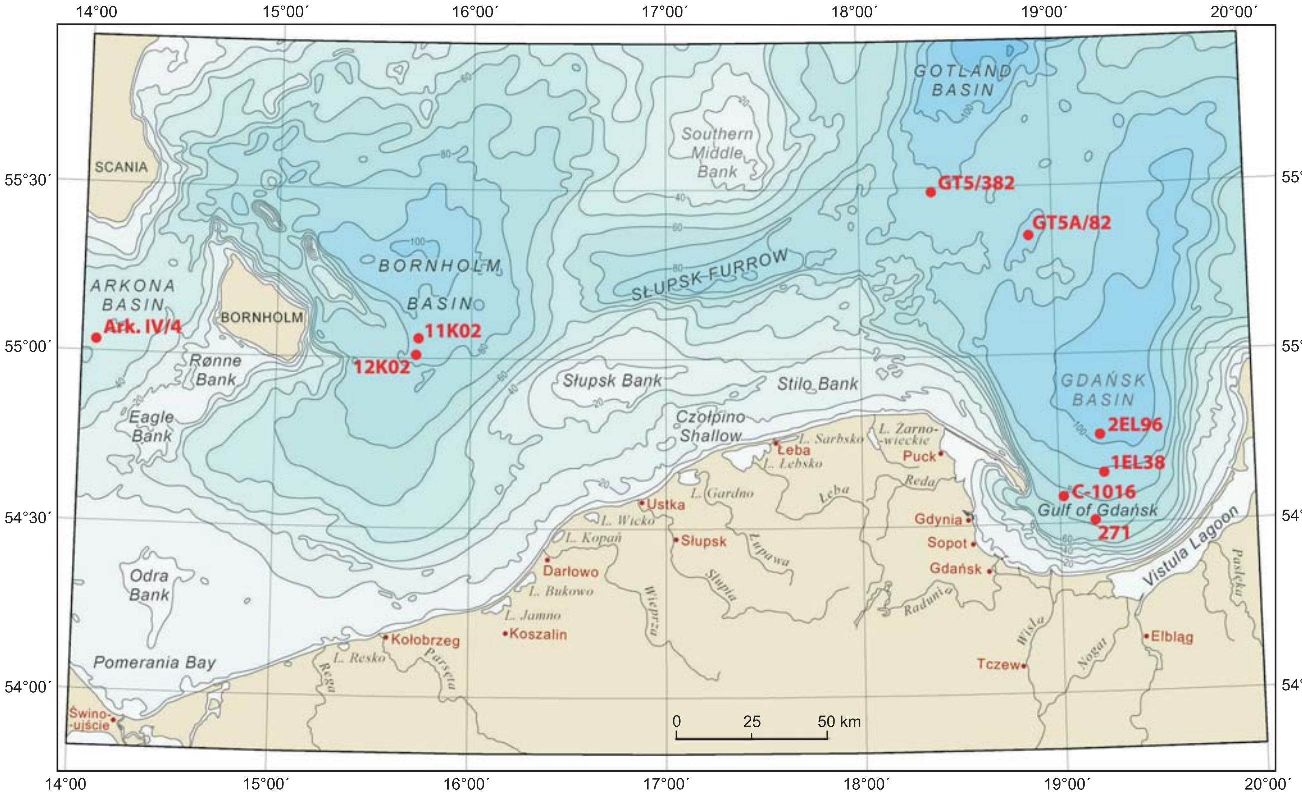


Fig. 1. The location of investigated cores

Polish part – 120 m) (Fig. 1). The basins are separated by sills with minimum depths of ca. 60 m on the sill separating the Bornholm Basin from the Słupsk Channel, and ca. 85 m between the Gdańsk and Gotland basins. South of the basins, there are coastal shallows with an elevated floor: the Odra Bank (min. depth 4.5 m), Słupsk Bank (min. depth 8 m), Czołpino Shallow (min. depth 14 m) and Stilo Bank (min. depth 18 m). The Rønne Bank (min. depth 12 m) and Eagle Bank (Adlergrund) (min. depth 5.1 m), the Southern Middle Bank (min. depth 14 m) and Klaipeda Bank are located far from the southern coast, often divided from them by sea-floor lowering.

Since the beginning of the Baltic Sea history, i.e. for almost 15,000 years, clay and silt deposits have been accumulating on the the basins' floor. The deposits now form a several to a few tens of metres thick layer. Together with the changes in climatic and hydrological conditions during the Baltic Sea evolution, also the lithological, physical and chemical features of the deposits have changed, and so have the diatom, macro- and microfauna associations, as well as the quantity and quality of pollen grains preserved in the deposits.

MATERIAL AND RESEARCH METHODS

The analysis covered the Southern Baltic area, mainly deep-water basins within the Polish Exclusive Economic Zone of the Baltic Sea: the Bornholm Basin, Gdańsk Basin and Gotland Basin. The few published (Zaborowska, Zachowicz, 1982; Kępińska *et al*., 1986a, b; Pieczka, Zaborowska, 1989; Witkowski, 1994; Zachowicz, 1995) and archival pollen and diatom diagrams from this area were taken into consideration. To facilitate the correlation of events in the Southern Baltic, the published pollen and diatom profiles from the Mecklenburg Bay and Arkona Basin were also taken into account (Kępińska *et al*., 1986a, b).

All sediment cores were described macroscopically. The type (grain-size distribution) of the deposit, its colour, consistency, smell, presence or lack of lamination and presence of mollusc shells were all taken into account as priority features. The fact that various deposit classifications and terminology are used by persons and institutions conducting research is the reason for a serious handicap in using macroscopic descriptions for core comparison and correlation. To a large degree, it also pertains to the results of lithological tests due to the diversity of laboratory testing methods used.

To facilitate the correlation and reinterpretation of the results of biostratigraphic (palynological and diatom) analyses, new unified and simplified diagrams were drawn using the POLPAL software. Pollen diagrams contain curves for particular tree species and cumulative curves for plants: those related to human economic activity, moist meadow plants, rushes, aquatic plants and *Pediastrum* green algae. In the diatom diagrams, only cumulative curves for ecological diatom groups were plotted in accordance with the division used by Hustedt and others (Przybyłowska-Lange, 1979) for saltwater (euhalobous), brackish-water (mesohalobous) and freshwater diatoms stimulated by small amounts of salt (halophilous) as well as indifferent ones. Such diagrams were drawn for all the sites under comparison, even for those of no numerical data. In such cases, the published diagrams were scanned and their percentage values were the basis for new diagrams.

Local pollen assemblage zones (levels) (LPAZ) were determined for all the selected and palynologically tested sites, according to Jańczyk-Kopikowa (1987). The duration period of each particular pollen zone was determined on the basis of the existing ^{14}C dates, but more often, due to the lack of any absolute dating, the palynological information at hand was compared with diagrams from the most fully documented sites in the Baltic coast (Latałowa, 1989; Latałowa, Tobolski, 1989). The isopollen maps of tree species (Huntley, Birks, 1983; Ralska-Jasiewiczowa *et al*., 2003, 2004) were also helpful in the reinterpretation of the earlier stratigraphic units. Simplified diatom diagrams were related to the time scale determined from palynological research (in the case of the same sediment core) and ^{14}C dating, or only from ^{14}C dating or from the comparison of changes in ecological conditions with those recorded in palynological research of the same water basin. In this study, chronostratigraphic units of the Late Pleistocene and Holocene have been adopted from Mangerud *et al*. (1974).

Among the analysed or reinterpreted sediment cores, only 6 of them were dated by radiocarbon methods. Either single core samples or sample sequences from an individual core were dated (Table 1). In total, a set of 17 radiocarbon dates was available.

Table 1

The list of radiocarbon datings

No	Site/core	Coordinates		Altitude [m b.s.l.]	Sample position in core [m]	Sample position [m b.s.l.]	^{14}C age BP	Lab. code	References	Locality
		φ	λ							
1	2 EL 96	54°45′22″	19°11′31″	101,50	1,80–1,90	103,30–103,40	3040 ± 120	Gd-6574	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
2	2 EL 96	54°45′22″	19°11′31″	101,50	3,80–3,90	105,30–105,40	6870 ± 130	Gd-6308	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
3	2 EL 96	54°45′22″	19°11′31″	101,50	4,10–4,32	105,60–105,82	7590 ± 140	Gd-6575	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
4	2 EL 96	54°45′22″	19°11′31″	101,50	4,52–4,66	106,02–106,16	8130 ± 160	Gd-6310	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
5	1 EL 38	54°38′16″	19°12′54″	88,00	0,60–0,80	88,60–88,80	1640 ± 90	Gd-4778	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
6	1 EL 38	54°38′16″	19°12′54″	88,00	2,60–2,80	90,60–90,80	4250 ± 130	Gd-6576	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
7	1 EL 38	54°38′16″	19°12′54″	88,00	4,60–4,80	92,60–92,80	6020 ± 120	Gd-4775	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
8	1 EL 38	54°38′16″	19°12′54″	88,00	5,60–5,80	93,60–93,80	8750 ± 170	Gd-6313	Uścinowicz, Zachowicz, 1992	Gdańsk Basin
9	11 K 02/A	55°02′21″	15°44′00″	85,50	3,10–3,20	88,60–88,70	7750 ± 140	Gd-6316	Zachowicz, 1995	Bornholm Basin
10	11 K 02/A	55°02′21″	15°44′00″	85,50	3,70–3,80	89,20–89,30	8680 ± 150	Gd-6324	Zachowicz, 1995	Bornholm Basin
11	11 K 02/A	55°02′21″	15°44′00″	85,50	3,80–3,90	89,30–8940	8800 ± 150	Gd-6317	Zachowicz, 1995	Bornholm Basin
12	12 K 02/A	55°01′69″	15°44′00″	85,50	2,90–3,05	88,40–88,55	7310 ± 150	Gd-6314	Uścinowicz, 2003	Bornholm Basin
13	12 K 02	55°01′68″	15°44′03″	85,50	2,90–3,10	82,60–82,40	6700 ± 90	Gd-2906	Uścinowicz, Zachowicz, 1992	Bornholm Basin
14	GT5A/82	55°21′95″	18°46′56″	87,80	1,80–1,90	89,60–89,70	7920 ± 150	Gd-10005	Zachowicz, 1995	Gotland Basin
15	GT5A/82	55°21′95″	18°46′56″	87,80	2,20–2,30	90,00–90,10	8160 ± 420	Gd-9173	Zachowicz, 1995	Gotland Basin
16	GT5A/82	55°21′95″	18°46′56″	87,80	2,30–2,40	90,10–90,20	8620 ± 200	Gd-9174	Zachowicz, 1995	Gotland Basin
17	GT5A/82	55°28′40″	18°20′60″	86,00	2,92–3,01	88,92–89,01	5850 ± 170	Gd-9170	Zachowicz, 1995	Gotland Basin

All the dates were established for olive-grey marine silt which contained organic matter in the amount from 5 to 10%. The silt samples contained no calcium carbonate. The dating was performed by means of a classical method at the Radiocarbon Laboratory of the Silesian University of Technology in Gliwice. The dates used were uncalibrated, the reservoir effect was not considered, either.

An attempt at correlating the bio- and chronostratigraphic units with lithological and seismostratigraphic units was also made. The reinterpreted pollen and diatom diagrams were correlated with lithological sections of cores, with regard mainly to the grain-size distribution of the deposits, organic matter and calcium carbonate contents, colour of the deposit and the presence or lack of lamination.

BIOSTRATIGRAPHY OF SOUTHERN BALTIC DEPOSITS

The following sites were selected, based on a review of the literature and the analysis and reinterpretation of available materials (Fig.1):

- in the Arkona Basin – one site (core IV/4, water depth – 43.6 m) with a palynological and diatom diagram (Kępińska *et al*., 1986a),
- in the Bornholm Basin – one site with a palynological diagram (core 12K02, water depth – 85.5 m, Zachowicz, 1995) and one site with a diatom diagram (core 11K02, water depth – 85.5 m, Witkowski, see Zachowicz, 1995),
- in the Gdańsk Basin – three sites with palynological and diatom diagrams (cores: 2 EL/96, water depth – 101.5 m and 1 EL/38 water depth – 88.0 m, Zachowicz, 1995, Witkowski, 1994 and core 271, water depth – 75.0 m; Zaborowska, Zachowicz, 1982) and one site with a palynological diagram (core C-1016, water depth – ca. 80.0 m; Miotk-Szpiganowicz – unpublished materials),
- in the Gotland Basin – one site with a palynological diagram (core GT5/382, water depth – 87.8 m, Noryśkiewicz, see Zachowicz 1995) and one site with a diatom diagram (core GT5A-82, water depth – 86.0 m; Witkowski, see Zachowicz, 1995).

THE ARKONA BASIN

The comparison of tree curves (Fig. 2) with the published isopollen data (Huntley, Birks, 1983; Ralska-Jasiewiczowa *et al*., 2004) did not cause any changes in the previous interpretation of the palynological image (Kępińska *et al*., 1986a). Only a minor correction of names of the youngest pollen levels (LPAZ) was made in order to unify the terminology and, through this, to facilitate correlation with other Southern Baltic sites.

The following local pollen levels were identified (Fig. 2):

- *Pinus–Betula* correlated with the Boreal period,
- *Pinus* corresponding to the last part of the Boreal period,
- *Quercus–Ulmus–Tilia* with the *Corylus* and *Fraxinus* subzones correlated with the Atlantic period,
- *Corylus–Quercus* singled out for the early and middle parts of the Subboreal period,
- *Pinus–Fagus–Carpinus* covering the last part of the Subboreal and the beginning of the Subatlantic period,
- *Fagus–Carpinus–Betula* associated with the middle part of the Subatlantic period.

The oldest deposits occurring in the bottom part of the tested core – represented by beige-grey clay – contain neither pollen grains nor diatoms. Palynological analyses indicate that the higher-lying green-grey silts were deposited towards the end of the Boreal period. Their bottom part (the *Pinus –Betula*, *Pinus* and *Quercus–Ulmus–Tilia* pollen levels – the *Corylus* subzone) is also devoid of diatoms. Diatom flora appears suddenly in the *Fraxinus* subzone of the *Quercus–Ulmus–Tilia* zone, which is correlated with the last part of the Atlantic period (Figs. 2, 3). Euhalobous diatoms predominate, with considerable addition of mesohalobous species. It is difficult to explain the absence of diatoms in the older deposits, very similar in terms of their lithology.

THE BORNHOLM BASIN

Two cores from the Bornholm Basin were investigated for pollen and diatoms. The diatom and pollen diagrams were made for different sites, ca. 1200 m away from each other (Fig. 1), therefore any mutual correlation of recorded events is not easy. When comparing the two cores, both the radiocarbon dates and lithological features of the deposits were taken into consideration.

The following local pollen levels (LPAZ) were identified (Fig. 4), and their previous names were partially changed (see Zachowicz, 1995):

- *Pinus* correlated with the Boreal period,
- *Quercus–Ulmus–Corylus* with the *Tilia* and *Fraxinus* subzones corresponding to the middle and last parts of the Atlantic period,
- *Pinus–Quercus* associated with the first half of the Subboreal period,
- *Carpinus–Quercus* corresponding to the second half of the Subboreal period,
- *Fagus–Carpinus* established for the first half of the Subatlantic period.

The oldest diatom-containing deposits are light-grey clays with a bluish tint (core 11K02). Freshwater diatoms predominate in these sediments, which are older than 8800 years BP according to radiocarbon dating (Fig. 5).

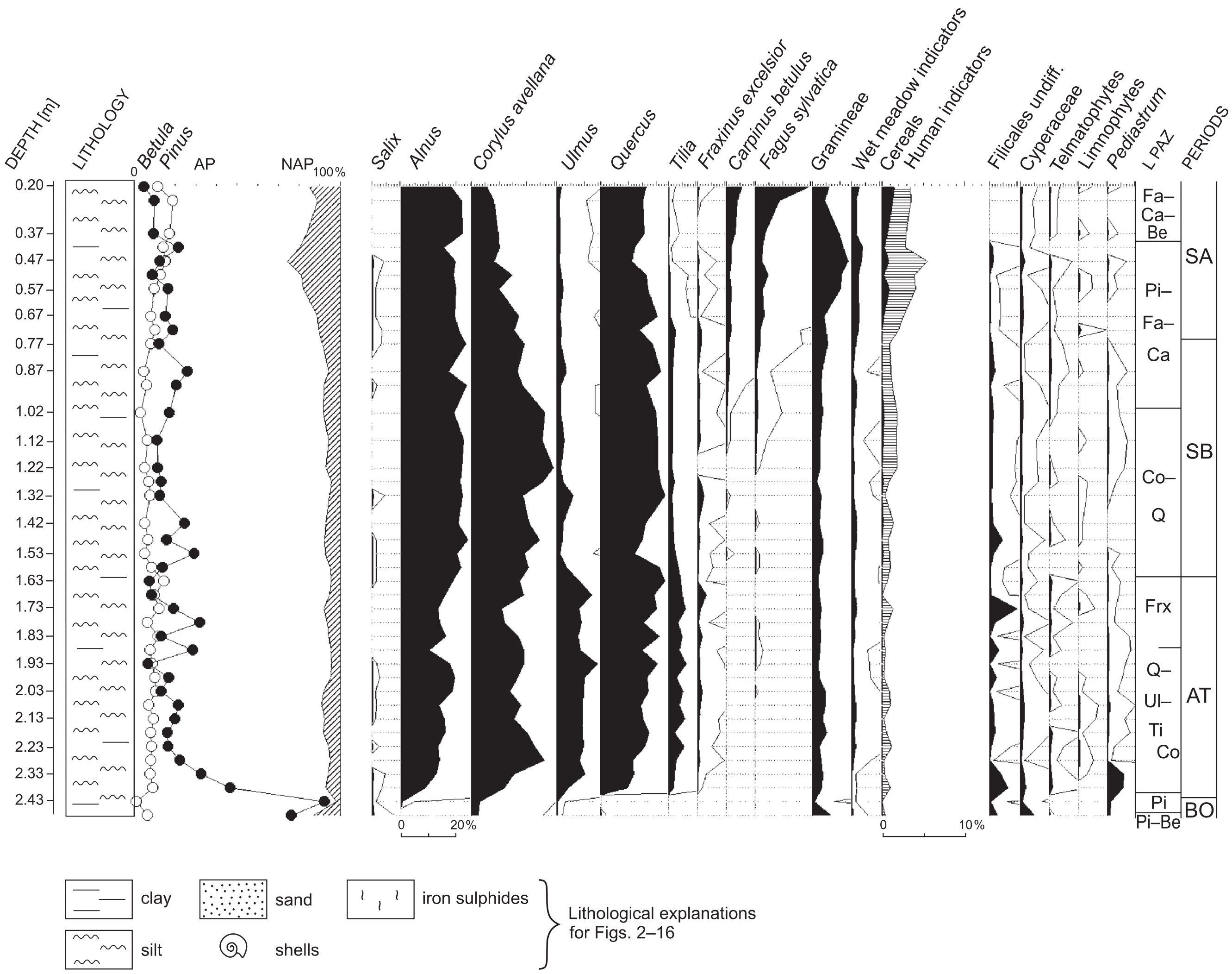


Fig. 2. The Arkona Basin, core IV/4 – simplified pollen diagram (after Kępińska *et al*., 1986a, modified)

Diatom (Fig. 5) and palynological (Fig. 4) analyses were performed on the higher-lying light-grey clays with an olive tint from both the drill cores. Freshwater diatoms with a clear addition of brackish-water ones were found (core 11K02, Fig. 5) togetherwith the index species of *Mastogloia* (Witkowski, Miller, 1999). Radiocarbon dating proves that these deposits accumulated from 8800 to 7750 years BP. They can be correlated with the younger part of Boreal deposits of the *Pinus* pollen zone from core 12K02 (Fig. 4). These deposits are overlain by the olive-grey silt and clay sediments containing a diatom association dominated by saltwater species (euhalobous) (Fig. 5). Palynological analyses (Fig. 4) suggest that they started to be deposited at least in the mid-Atlantic period (the *Quercus–Ulmus–Corylus* pollen zone). Radiocarbon dating shows that they were deposited between 7750 years BP (core 11K02, Fig. 5) and 6700 years BP (core 12K02, Fig. 4). The latter dating was repeated and yielded a result of 7310 ± 150 (Table 1, core 12K02A). Most probably, core 12K02 (Fig. 5) contains no deposits from the beginning of the Atlantic period.

THE GDAŃSK BASIN

The Gdańsk Basin is the best explored part of the Southern Baltic. Three 6 to 7-m long cores were analysed for pollen and diatoms. On one core, only palynological tests were made, and on a dozen or so cores – lithological analyses and radiocarbon dating were performed. The identification of pollen levels (LPAZ) for the previously published pollen diagrams (Zaborowska, Zachowicz, 1982; Zachowicz, 1995; Miotk-Szpiganowicz – unpublished materials) made it possible both

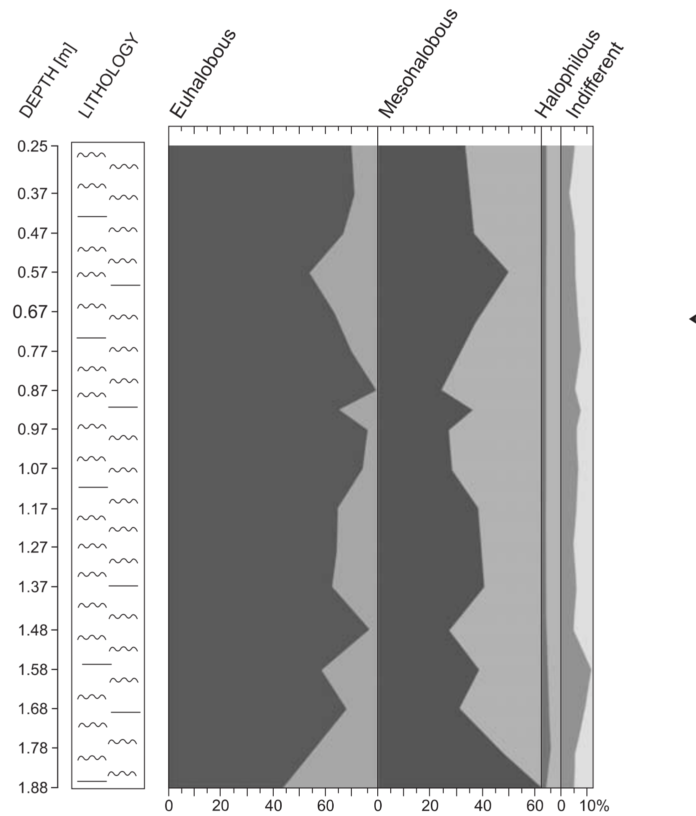


Fig. 3. The Arkona Basin, core IV/4 – simplified diatom diagram (after Kępińska *et al.*, 1986a, modified)

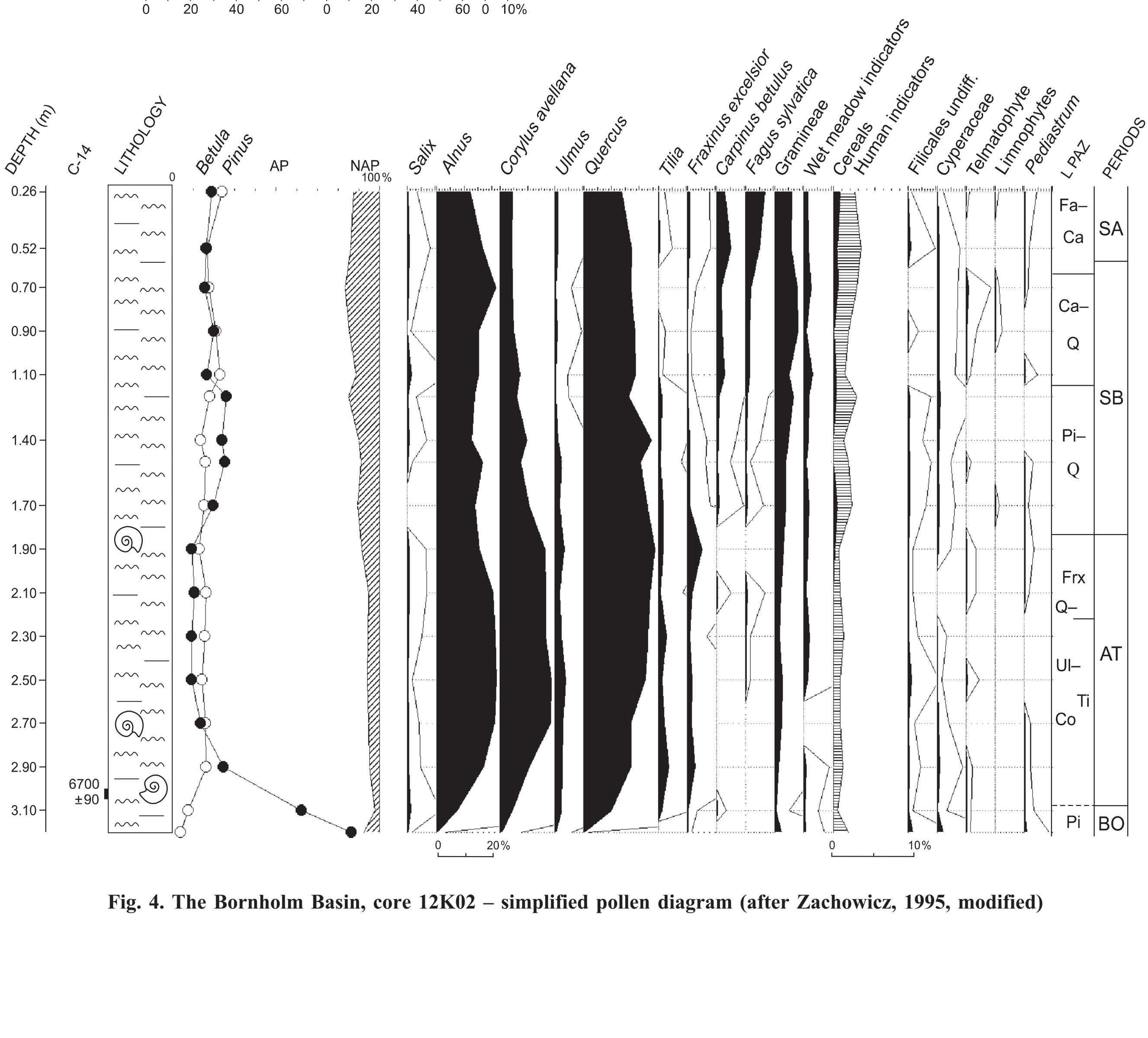


Fig. 4. The Bornholm Basin, core 12K02 – simplified pollen diagram (after Zachowicz, 1995, modified)

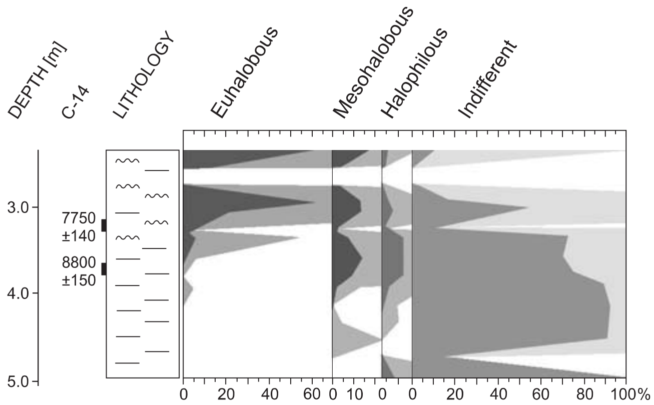


Fig. 5. The Bornholm Basin, core 11K02 – simplified diatom diagram (Witkowski, see Zachowicz, 1995)

to place the events more precisely on a time scale and to correlate them with radiocarbon-dated sites. The most complete pollen and diatom succession is recorded in core 271 (Fig. 6).

The following local pollen zones (LPAZ) were identified in core 271:

- *Pinus* correlated with the Allerød Period,
- *Juniperus*–Cyperaceae corresponding to the Younger Dryas period,
- *Pinus* correlated with the Preboreal period,
- *Pinus–Corylus* determined for the Boreal period,
- *Pinus–Tilia* covering the beginning of the Atlantic period,
- *Quercus–Ulmus–Corylus* correlated with the middle and last part of the Atlantic period,
- *Quercus–Corylus* corresponding to almost the whole of the Subboreal period,

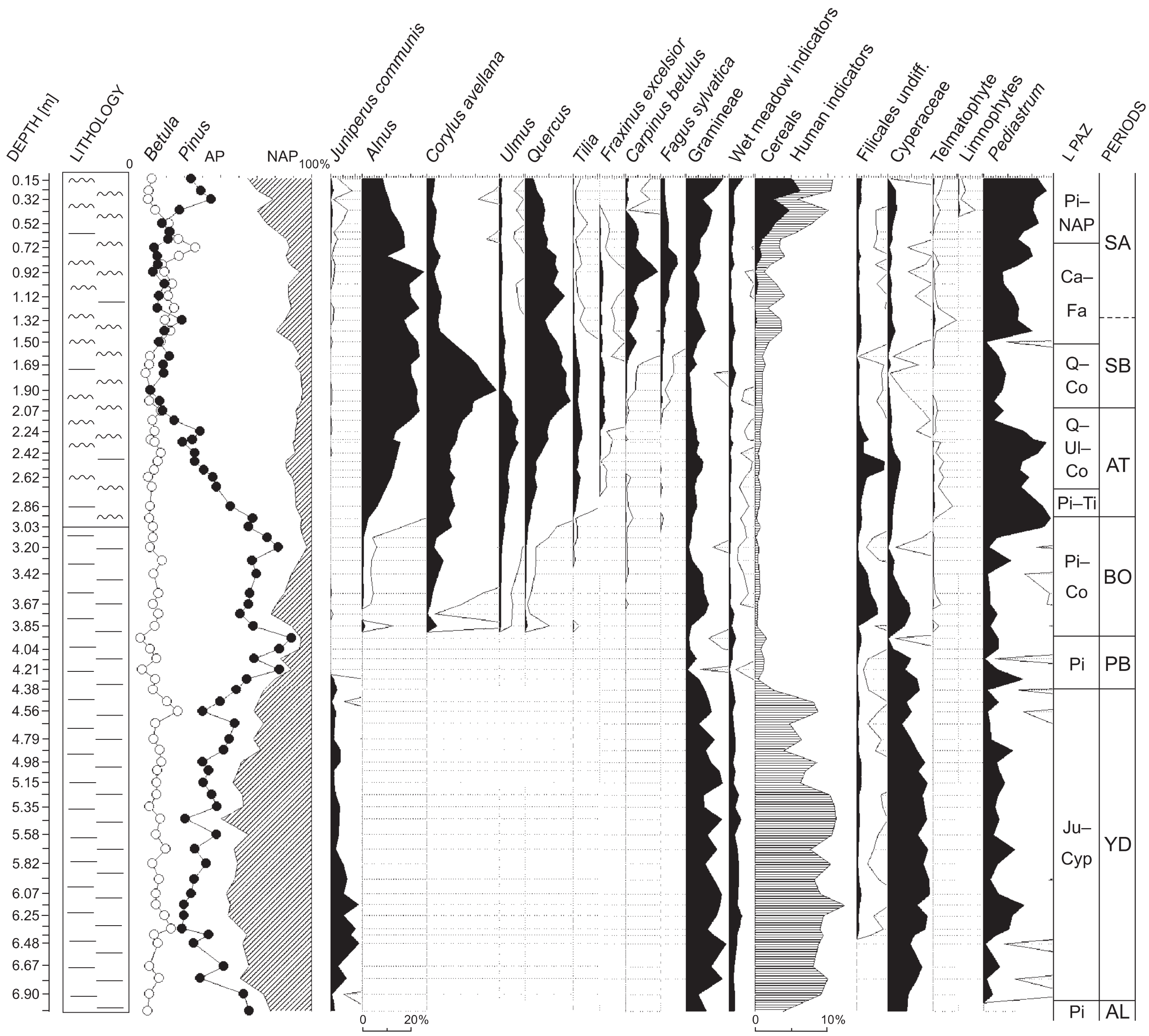


Fig. 6. The Gdańsk Basin, core 271 – simplified pollen diagram (after Zaborowska, Zachowicz, 1982, modified)

• *Carpinus–Fagus* for the last part of the Subboreal and the beginning of the Subatlantic period,

• *Pinus*–NAP typical of the last part of the Subatlantic period.

The pollen record in cores 2EL96 and 1EL38 is somewhat shorter and covers only the Boreal period (Fig. 7).

In core 2EL96, the following local pollen zones were identified:

• *Pinus–Betula* correlated with the beginning of the Boreal period,

• *Pinus–Corylus* determined for the last part of the Boreal period; the end of this zone was radiocarbon dated at 8130 ±160 years BP,

• *Quercus–Ulmus–Corylus* with the *Fraxinus* and *Tilia* subzones correlated with the Atlantic period. The subzone limits are radiocarbon dated at 7590 ± 140 years BP, while *Tilia* subzone deposits – at 6870 ±130 years BP,

• *Quercus–Corylus* covering the end of the Atlantic period and the first half of the Subboreal period,

• *Carpinus–Betula* with the *Corylus* and *Fagus* subzones correlated with the second half of Subboreal period (3040 ±120 years BP) and the first half of Subatlantic period respectively,

• *Pinus*–NAP typical of the last part of the Subatlantic period.

Similar local pollen zones were identified in core 1EL38 (Fig. 8):

• *Pinus–Corylus* correlated with the end of the Boreal period; the deposits of this pollen zone are radiocarbon dated at 8750 ± 170 years BP,

• *Quercus–Ulmus–Corylus* covering the first half of the Atlantic period; the deposits of the final part of this zone have a radiocarbon date of 6020±120 years BP,

• *Quercus–Corylus* corresponding to the last part of the Atlantic period and the beginning of the Subboreal period,

• *Carpinus* with the *Pinus* and *Fagus* subzones associated with the upper part of the Subboreal period (4250 ±130 years BP) and the lower part of the Subatlantic period (1640 ±90 years BP),

• *Pinus*–NAP characteristic of the last part of the Subatlantic period.The shortest palynological record, which covers deposits beginning from the end of the Atlantic period,

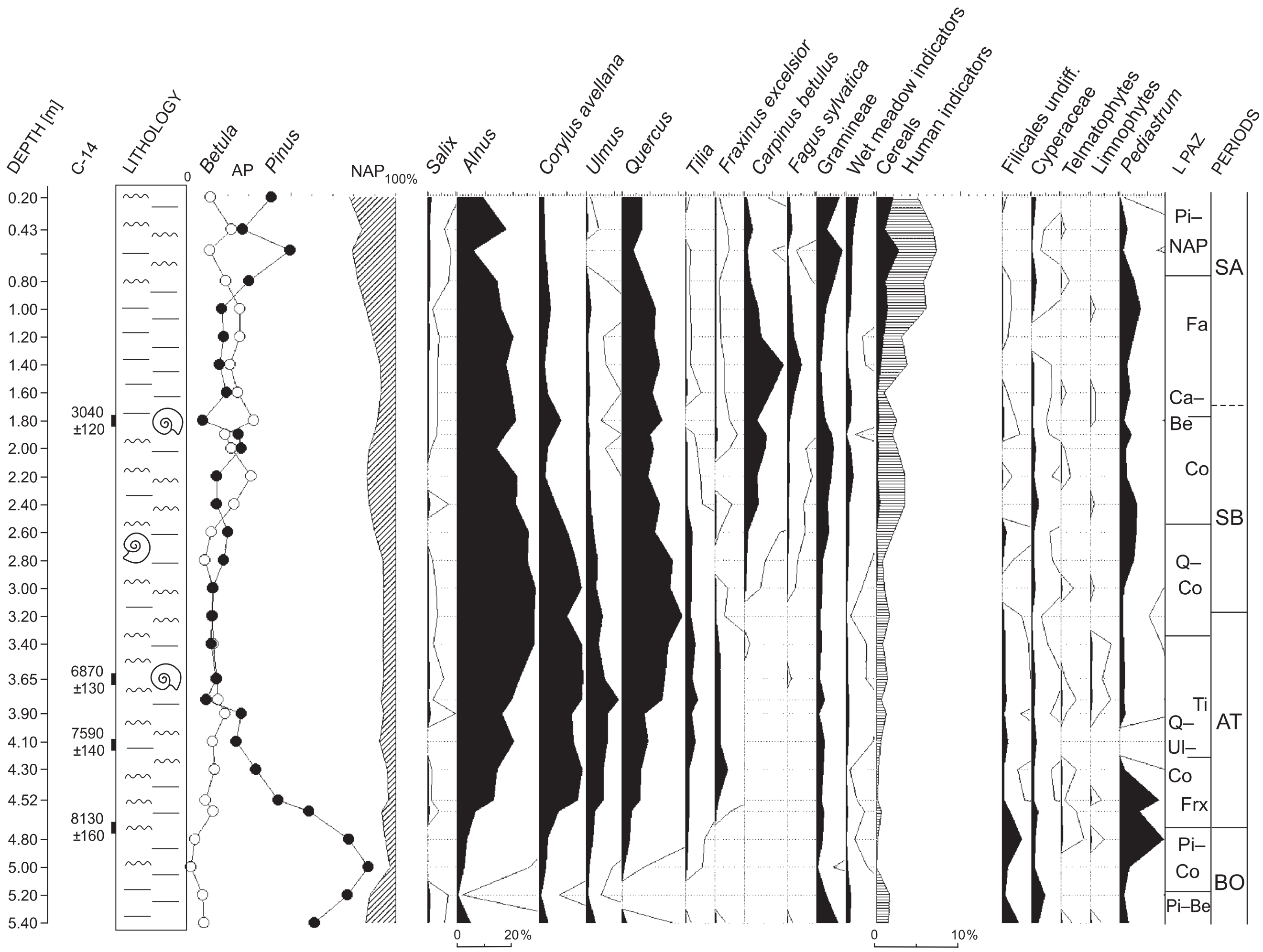


Fig. 7. The Gdańsk Basin, core 2EL/96 – simplified pollen diagram (after Zachowicz, 1995, modified)

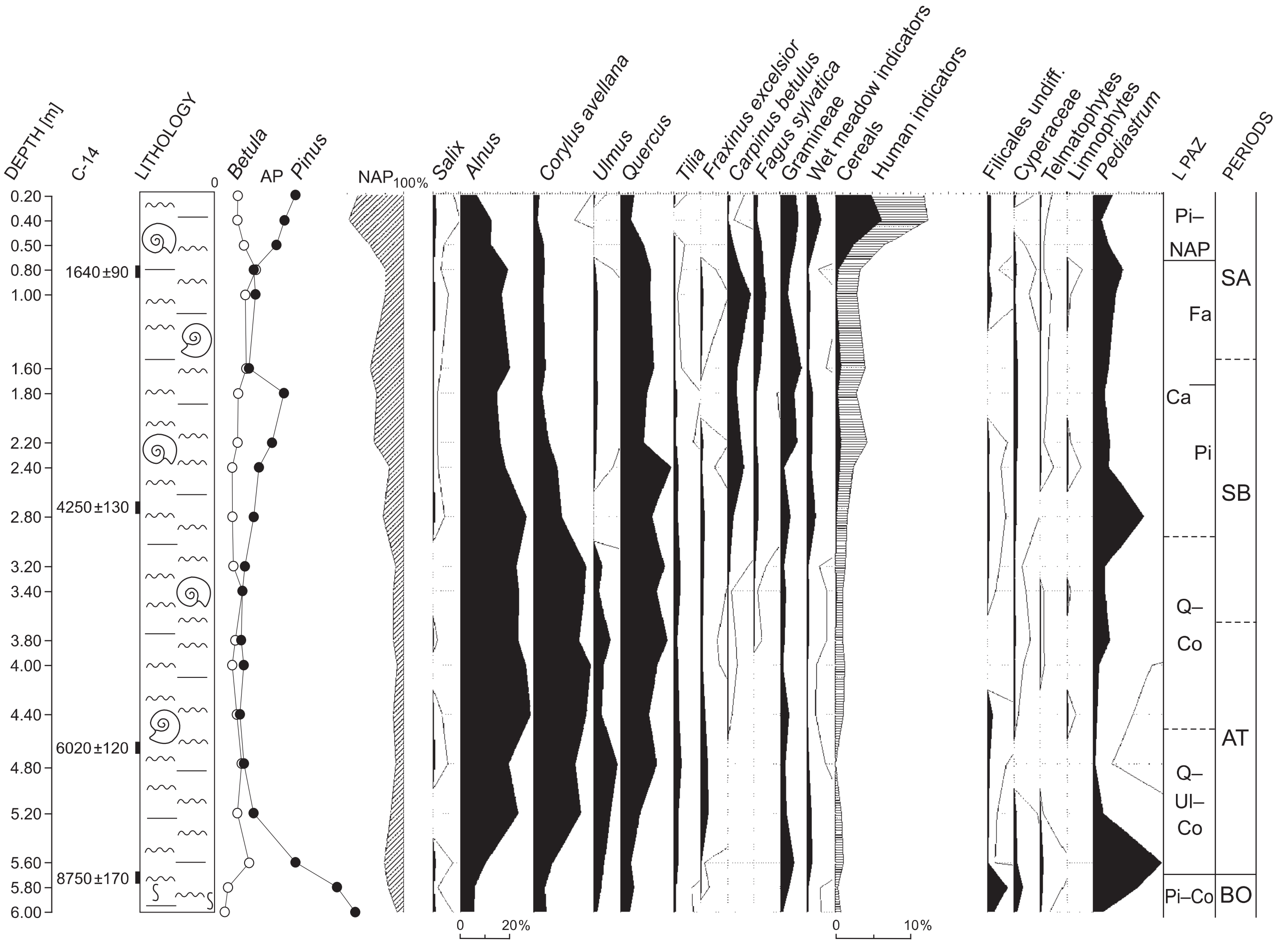


Fig. 8. The Gdańsk Basin, core 1EL/38 – simplified pollen diagram (after Zachowicz, 1995, modified)

was found in core C-1016 (Miotk-Szpiganowicz, unpublished) (Fig. 9).

The diagram of core C-1016 is almost identical as the upper part of core 271 diagram, hence the names of the identified local pollen levels are the same:

- *Quercus–Ulmus–Corylus* correlated with the Atlantic period,
- *Quercus–Corylus* corresponding to the Subboreal period,
- *Carpinus–Fagus* covering the beginning and middle part of the Subatlantic period,
- *Pinus*–NAP associated with the upper part of the Subatlantic period.

The results of palynological and diatom research in the Gdańsk Basin show that freshwater (indifferent) diatoms predominated (Fig. 10) in the Allerød, Younger Dryas and Preboreal deposits (Zaborowska, Zachowicz, 1982) dated by palynological method.

In the Boreal deposits (the *Pinus–Corylus* LPAZ) there is an increase in the contribution of brackish-water (mesohalobous) diatoms. Radiocarbon dating indicates that the increase occurred between 8750 and 7590 years BP (Figs. 10, 11). The dating also proves that, beginning with the Atlantic period, the diatom flora in the deposits younger than ca. 7500 years BP is marked by the predominance of brackish-water and marine species (mesohalobous and euhalobous) (Figs. 10, 11).

High similarity between the palynological and diatom diagrams from various sites (see Figs. 6–11) proves that at least in the Middle and Late Holocene, the deposition proceeded in similar hydrological and climatic conditions throughout the entire Gdańsk Basin.

THE GOTLAND BASIN

The palynological and diatom diagrams for the deposits of the southern part of the Gotland Basin were made, as in the case of the Bornholm Basin, for various sites located a few tens of kilometres apart (Fig. 1). Therefore, the mutual correlation of the data brings difficulties (Figs. 12, 13).

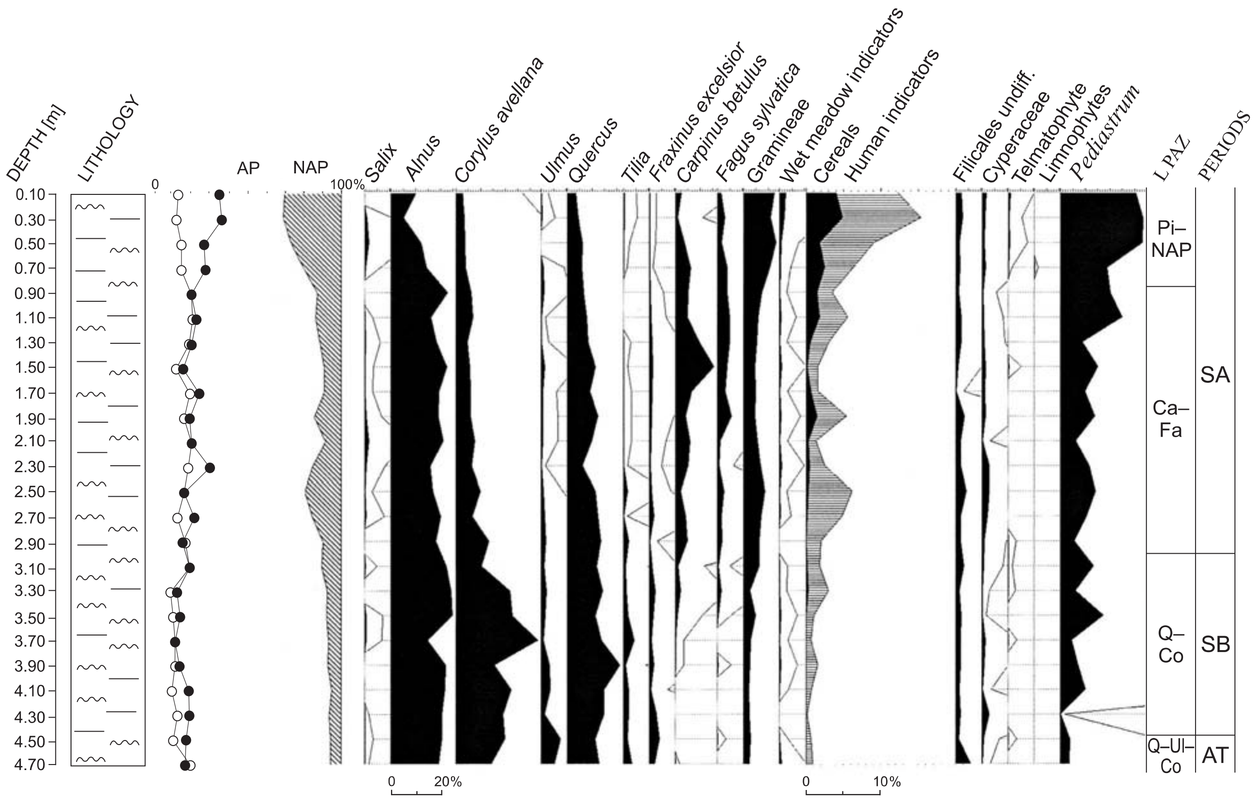


Fig. 9. The Gdańsk Basin, core C-1016 – simplified pollen diagram (Miotk-Szpiganowicz – unpublished materials)

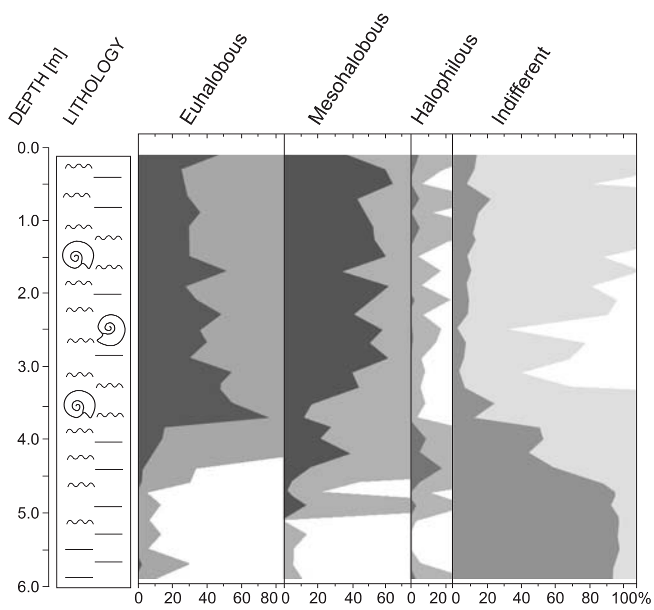


Fig. 10. The Gdańsk Basin, core 2EL/96 – simplified diatom diagram (Witkowski, 1994)

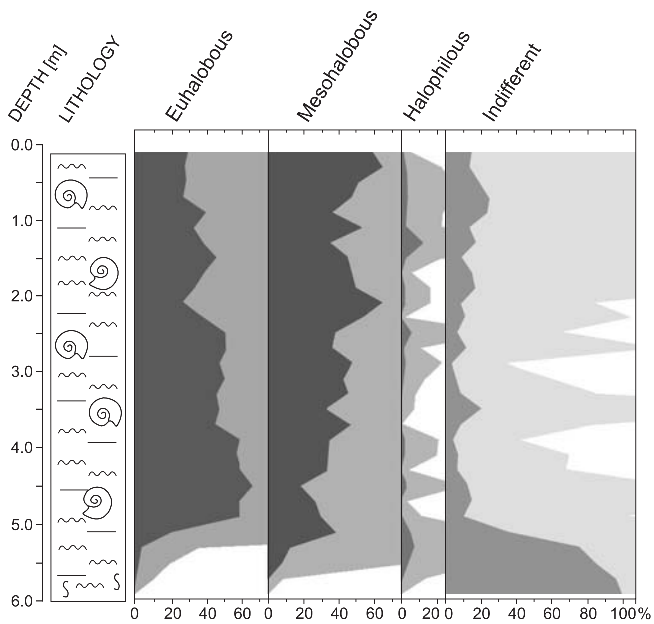


Fig. 11. The Gdańsk Basin, core 1EL/38 – simplified diatom diagram (Witkowski, 1994)

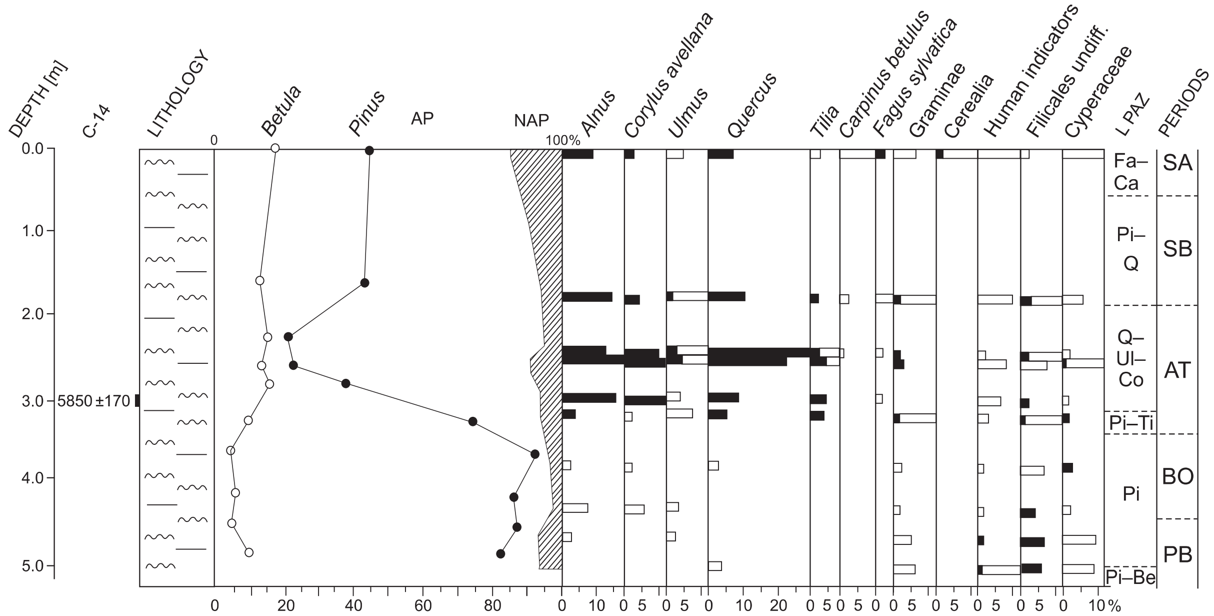


Fig. 12. The Gotland Basin, core GT 5-382 – simplified pollen diagram, (Noryśkiewicz, see Zachowicz, 1995)

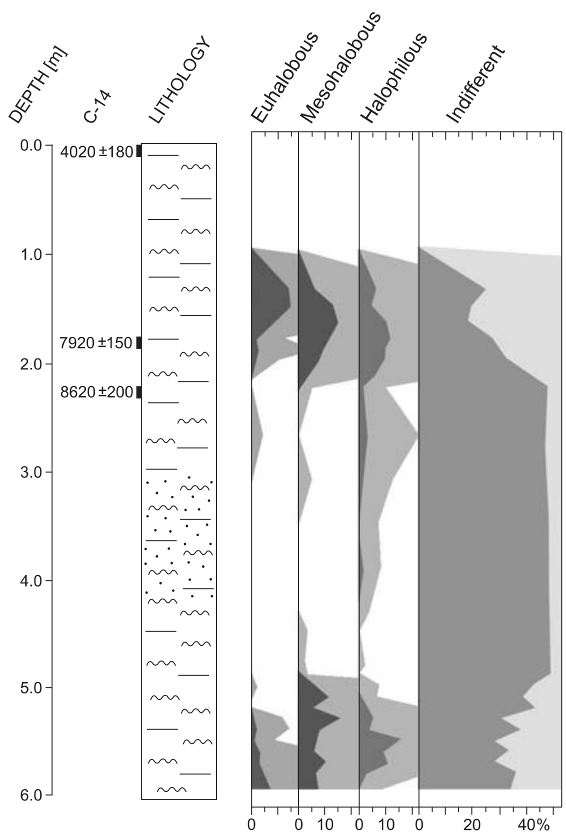


Fig. 13. Gotland Basin, core GT 5A-82 – simplified diatom diagram (Witkowski, see Zachowicz, 1995)

The palynological diagram (Fig. 12) (Noryśkiewicz, see Zachowicz 1995) indicates the lack of sporomorphs in the oldest deposits of the analysed core. The ages of the remaining deposits were determined palynologically at the Preboreal, Atlantic, Subboreal and Subatlantic periods. In these periods, the following local pollen zones (LPAZ) were identified:

- *Pinus–Betula*, correlated with the Preboreal period,
- *Pinus* distinguished for the end of the Preboreal period and the Boreal period,
- *Pinus–Tilia* corresponding to the beginning of the Atlantic period,
- *Quercus–Ulmus–Corylus* associated with the Atlantic period; it has a radiocarbon date of 5850 ±170 years BP,
- *Pinus–Quercus* characteristic of the Subboreal period,
- *Fagus–Carpinus* determined for the beginning of the Subatlantic period.

The diatom diagram (Fig. 13) distinctly reveals two periods of the presence of euhalobous diatoms. The older period is probably associated with Preboreal deposits, as evidenced by radiocarbon dating much older than 8620 ±170 years BP. The younger period is radiocarbon dated at the beginning of the Atlantic period (7920 ±150 years BP). It is preceded by a gradual disappearance of indifferent (freshwater) diatoms with an increase in the number of mesohalobous species (Fig. 13), which is recorded at the turn of the Boreal period to the Atlantic period.

Summing up, the reinterpretation of the palynological diagrams from the Holocene deposits of individual sedimentary basins from the Southern Baltic made it possible to identify local pollen zones (LPAZ) and to associate them with chronostratigraphic units. The correlation of diatom profiles with chronostratigraphic units and with radiocarbon dates made it possible to make a general reconstruction of the changes in environmental conditions, mainly in salinity, and to attempt to place these changes on an absolute time scale.

The results of palynological and diatom research of sediment cores from the Southern Baltic show that the present-day Baltic Sea was a freshwater basin in the Late Pleistocene, i.e. in the Allerød and Younger Dryas periods. It is, however, the least known period, as the Late Pleistocene sediments were documented palynologically and diatomologically only in one core from the Gulf of Gdańsk (Fig. 6). This period of the Baltic Sea history is commonly named the Baltic Ice Lake.

A short and poorly marked episode of low water salinity was recorded at the turn of the Late Pleistocene to the Holocene. Correlated with the Yoldia Sea phase, this event was clearly recorded by the presence of halophilous diatoms in the southern part of the Gotland Basin (Fig. 13). Most probably, evidence of that sea has also retained in the sediments of the Gdańsk Basin (Fig. 10).

At the end of the Preboreal and the beginning of the Boreal periods, there was a significant freshening of Southern Baltic waters (Figs. 5, 10, 11, 13). Recorded in the deposits of all the analysed basins, this period of the Baltic Sea history is called the Ancylus Lake.

The end of the freshwater phase in the Baltic evolution is palynologically dated at the end of the Boreal period. At that time, a gradual but distinct increase in the importance of brackish-water (mesohalobous) diatoms was marked in the sediment profiles from the Southern Baltic sedimentary basins. Radiocarbon dating indicates that the beginning of the deposition took place 8800 years BP (the Bornholm Basin), 8750 years BP (the Gdańsk Basin) and 8620 years BP (southern part of the Gotland Basin), i.e. at the beginning of the Boreal period. Taking into account the well-known fact, also described in literature (e.g. Andren *et al*., 2001), that radiocarbon dates from the silt deposits of the Southern Baltic were aged by ca. 300–400 years due to the addition of older redeposited organic matter, the radiocarbon dates cease to be in contradiction with palynological dating. Palynological analyses show that saltwater (euhalobous) diatoms predominate in the Southern Baltic sediments, starting from the end of the Boreal period. This is preceded by the appearance of brackish-water (meshalobous) species. Radiocarbon dating shows that the transition phase from freshwater to marine conditions, called the Mastogloia Sea phase, lasted ca. 1000 years, i.e. from 8800–8620 years BP to 7750–7590 years BP. In the light of the above-described facts, it can be stated that the marine phase in the Baltic history, called the Litorina Sea, began in the early Atlantic period. The changes in salinity are less clearly recorded in the deposits of younger periods. Meso- and euhalobous diatoms are predominant in these deposits (in varying proportions). A gradual change, related to an increase in importance of mesohalobous species, took place in the Subboreal period, younger than ca. 4000–3000 years BP. This period is often described as the Post-Litorina Sea.

THE LITHOSTRATIGRAPHY OF SOUTHERN BALTIC DEPOSITS

The composition and physical and chemical properties of each sedimentary rock depend on the character of the initial material and on the conditions prevailing in the sedimentary environment, i.e. climate, salinity, water temperature, pH, presence or absence of oxygen, strength of undulation and currents, etc. The features of the environment determine the physical and chemical properties of sediment layers, such as grain size, mineral composition, stratification, colour, etc.

The analysis of a few tens of sediment cores from deep-water sedimentary basins of the Southern Baltic made it possible to characterise both local stratigraphic profiles for the sedimentary basins and a regional profile for the Southern Baltic (Figs. 14, 15 and 16). Among the Southern Baltic postglacial sediments – deposited after the ice-sheet retreat – 3 sediment layers were identified, which differ in their lithological features reflecting the conditions prevalent in the sedimentary basin during deposition. It should be noted that these units meet no formal criteria for establishing lithostratigraphic units. Despite the attempts made (e.g. Kotliński, 1989, 1991), such units have not been defined or used so far for describing the deposits of the Baltic Sea.

In the deep-water sedimentary basins, the Baltic Sea deposits are underlain by glacial tills. Only locally, over small areas, the Baltic deposits rest on other Pleistocene sediments, such as sands, esker loams or directly on pre-Quarternary rocks.

THE BROWN BALTIC CLAY

A layer of brown Baltic clay comprises three lower-order lithological units: varved clays and silts which grade upwards into microlaminated (crypto-laminated) clays, and further into homogenous clays. Sandy intercalations and single gravel grains (drop stones) occur in the deposits. The total thickness of the varve, microlaminated and homogenous deposits concordantly overlying an undulated surface of glacial tills is ca. 10 m in the central parts of deep-water basins. The distinctive features of these deposits are low organic matter content, usually below 1.5%, and high (up to 20%) carbonate content. In the topmost section, the homogenous clay may be lime-free. In places, black laminae or spot clusters of iron sulphides occur in the brown limy Baltic clay and the colour changes towards the top from brown to light brown and brown-grey. The brown Baltic clay is in general palynological-

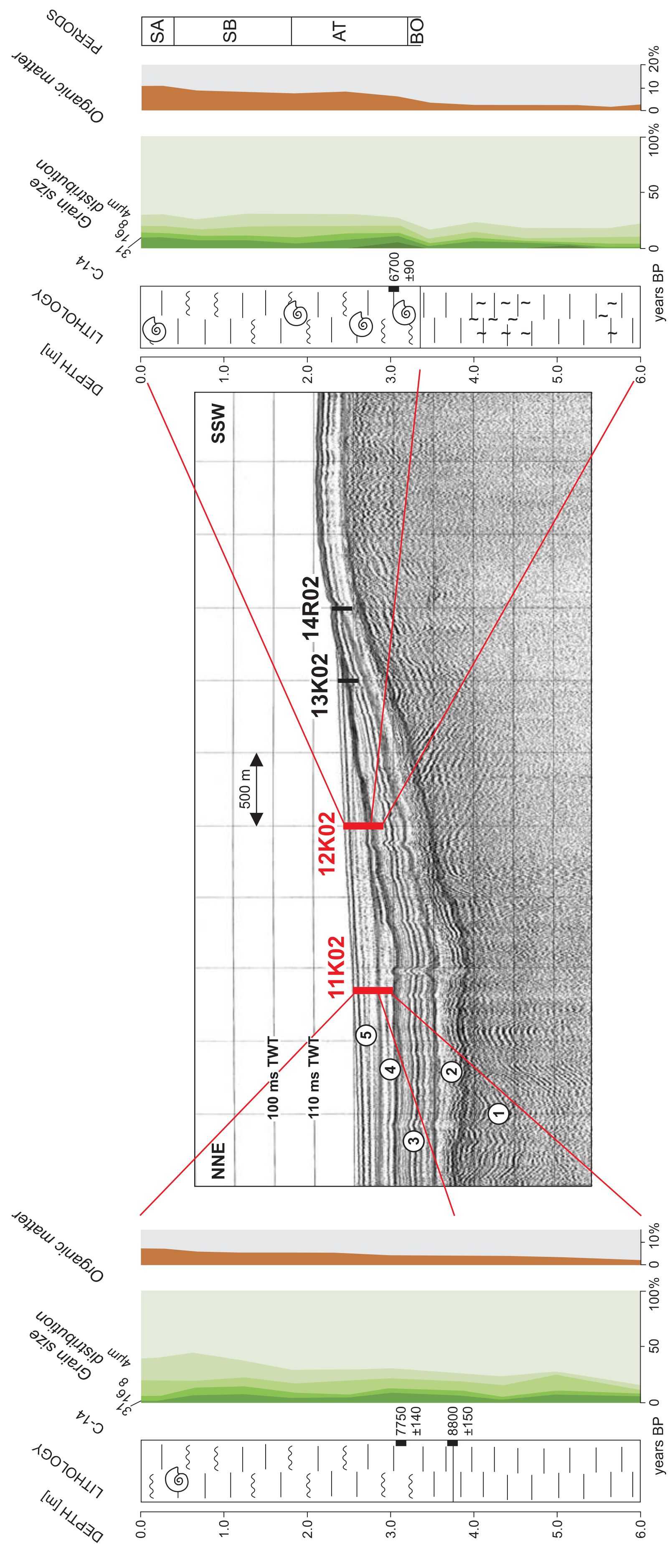


Fig. 14. The seismoacoustic profile of the Bornholm Basin across 11K02 and 12K02 coring sites

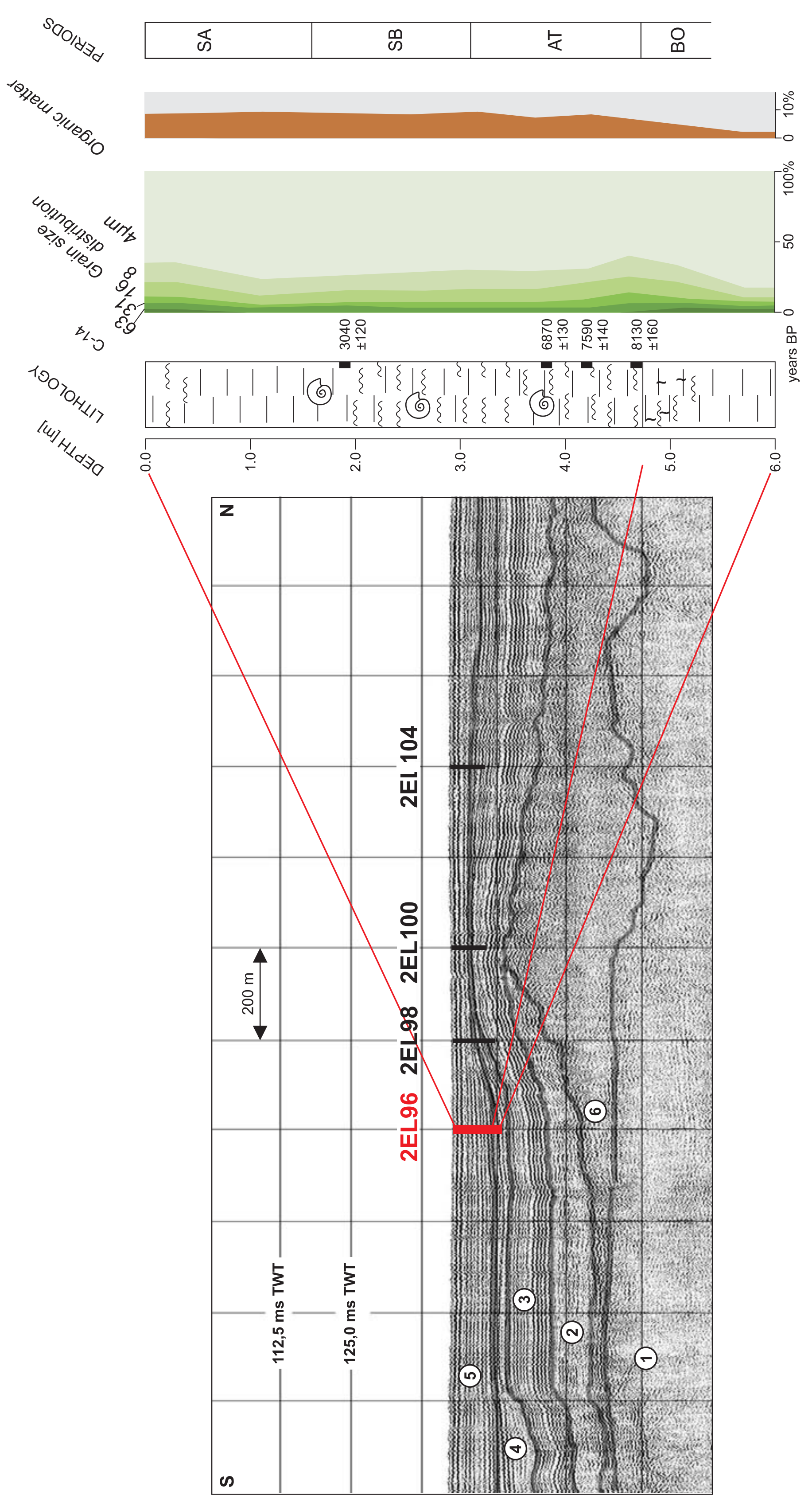


Fig. 15. The seismoacoustic profile of the Gdańsk Basin across 2EL/96 coring site

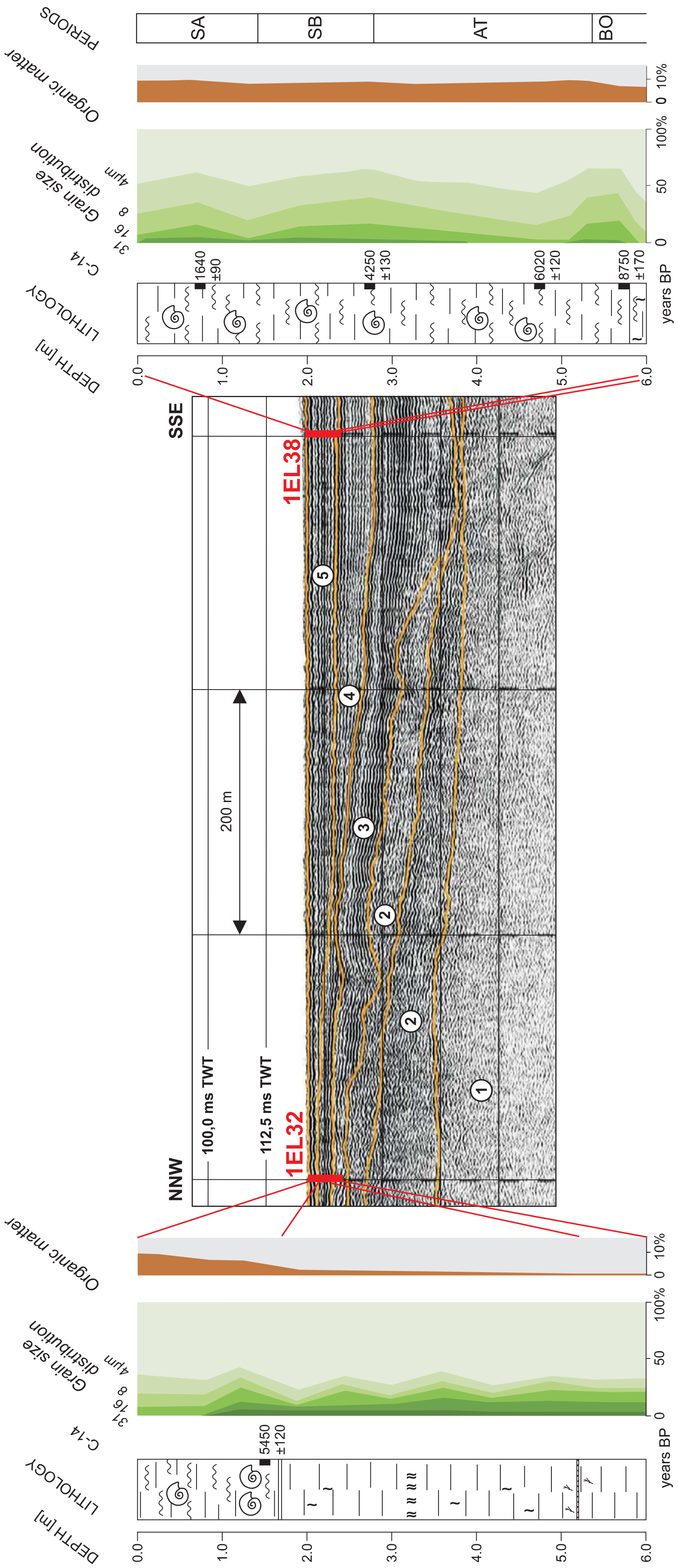


Fig. 16. The seismoacoustic profile of the Gdańsk Basin across 2EL/32 and 2EL/38 coring sites

ly barren; they commonly contain no diatoms either. The age position of this layer is determined mainly through its location in the stratigraphic profile: it was deposited in the Late Pleistocene. Although the brown Baltic clay layer is diachronic over the entire Baltic region: it is older (Late Pleistocene) in the southern part and younger (Early Holocene) in the northern part (Ignatius *et al.*, 1981; Winterhalter, 1992) of the area, it can be considered synchronous in the Southern Baltic area. It marks the deglaciation stages in the Southern Baltic (Mojski, 1993, 1995; Uścinowicz, 1999). Its sedimentation in this area started during the Bølling period. Its lithological features indicate deposition in the vicinity of a melting ice-sheet, first close by there where varve sediments were deposited, and as the deglaciation progressed – microlaminated and homogenous clays were deposited further from the ice-front. These sediments were deposited in the Baltic Ice Lake phase.

THE GREY BALTIC CLAY

The grey Baltic clay concordantly overlies the lightest brown clay. Due to this, the bottom limit of the layer is poorly expressed although the sedimentary continuity is retained. The typical features of this layer are: absence or a very low content of calcium carbonate, low (up to 2%) content of organic matter and the occurrence of black laminae and irregular clusters of iron sulphides. The colour of the sediments changes from grey-brown in the bottom parts of the layer to grey and light grey, often with a bluish tint in the top parts. Apart from the change in colour, there is also a slight increase in the organic matter content towards the top. The grey Baltic clay is characterised by a low pollen and diatom frequency, especially in the bottom parts of the layer. The frequency clearly grows upwards. Based on palynological analyses, the formation age of the grey Baltic clay layer was determined at the Early Holocene – Preboreal and Early Boreal. The diatom spectra show that these deposits were generally associated with a freshwater environment, and only during the Early Preboreal period a short episode of low salinity water was recorded, limited spatially to the north-eastern parts of the Southern Baltic (southern part of the Gotland Basin). The grey Baltic clay layer, just like the underlying brown clay, is diachronous in the entire Baltic area (Ignatius *et al.*, 1981; Winterhalter, 1992), but in the Southern Baltic it is definitely synchronous. The grey clay layer was deposited during the Yoldia Sea and Ancylus Lake phases.

The gradual transition, the lack of a clear lithological boundary with the lightest brown clay, and a similar sedimentation environment (a freshwater basin under the influence of the melting Scandinavian ice-sheet) may justify the combination of the brown and grey Baltic clay into one lithostratigraphic unit subdivided into a lower-order units of varve clays, brown microlaminated and homogenous clay, and grey homogenous clay with iron sulphides. The deposits accumulated in a limnoglacial environment with a short sedimentation period in a brackish environment, typical of the bottom part of this layer. The brackish environment is clearly marked in the southern part of the Gotland Basin, being poorly documented in the Gdańsk Basin and unknown from the Bornholm Basin.

THE OLIVE-GREY BALTIC MUD

The olive-grey Baltic mud discordantly overlies the grey Baltic clay. The olive-grey Baltic mud layer consists of two lower-order lithological units: grey laminated silts, with an olive tint, and silty and clayey dark-grey sediments, black in places, but also with the characteristic olive tint. The deposits of the second unit are usually homogenous with bioturbation signs, but they are also laminated in places. Both the layers contain no calcium carbonate and they are enriched with organic matter whose content reaches as much as 10%.

The olive-grey Baltic mud has the best biostratigraphic documentation and radiocarbon dating, which greatly facilitates their location on the geological time scale. According to palynological dating, the lower layer of grey laminated mud with an olive tint was deposited in the late Boreal and early Atlantic. Absolute ^{14}C dating indicates that it took place between 8800–8620 years BP and 7750–7590 years BP, although we must remember that the radiocarbon dates may be aged by ca. 300 years. This layer was deposited in a brackish-water environment, as evidenced by an increase in the content of brackish-water (mesohalobous) diatoms.

The beginning of the deposition of the upper olive-grey mud layer was determined to have occurred at the end of the early Atlantic. Euhalobous and mesohalobous diatoms predominate in this layer, indicating marine conditions prevailing during the deposition. The thickness of the olive-grey mud layer (the lower and upper one) reaches 4–5 m, and locally exceeds 6 m.

The boundary between grey clay and olive-grey mud often has an erosive nature. At the edges of sedimentary basins, on basement elevations within the basins and on the intervening sills, the beginning of the marine phase, an increase in salinity and the formation of haline stratification was marked by erosion, in places emphasised by a thin sand layer.

A clear lithological boundary between the underlying limnoglacial grey clay and the superjacent marine olive-grey mud, as well as a similar brackish or/and marine sedimentary environment prevailing in the Baltic Sea area from the late Boreal period may justify distinguishing a lithostratigraphic unit of the Baltic olive-grey mud. The olive-grey mud was deposited during marine evolutionary phases of the Baltic, i.e. during the Mastogloia Sea (transition phase from a freshwater to marine water basin), Litorina Sea and Post-Litorina Sea. The boundary between the Litorina and Post-Litorina Sea deposits is usually located at the turn of the early to middle Subboreal or in the middle Subboreal, i.e. ca. 4000–3000 years ago.

THE SEISMOSTRATIGRAPHY OF SOUTHERN BALTIC DEPOSITS

Seismoacoustic research is the basis for distinguishing seismostratigraphic units. The identification of these units is based mainly on a comparative analysis of acoustic features of sediments (degree of absorption of acoustic energy by various sediments, together with a record of characteristic texture), on tracing the basic acoustic horizons and on the analysis of an angular unconformity in stratified deposits. These features depend directly on lithological features of deposits, such as grain size, sediment density, and the presence or absence of stratification.

In seismoacoustic profiles, pre-Quarternary deposits are usually characterised by a distinct stratification with beds dipping at 2–3°, sporadically interrupted by discontinuity zones in fault areas. Deposits of various age display angular unconformities and differ in acoustic hardness and echo character. Only Tertiary deposits lie almost horizontally and show strong diversification of internal structure, from clearly stratified ones to almost structureless, poorly reflective strata. They are separated from older deposits by a remarkable boundary. The surface of pre-Quaternary sediments is usually well defined and determined by its glacial erosion origin. It is picked as a continuous, rather single-phase acoustic horizon, with strong reflection, which proves a rapid change in acoustic parameters.

Pleistocene deposits, mainly glacial tills, are marked as structureless layers, or layers with a chaotic internal structure, diversified in terms of reflection depending on grain size composition and the degree of plasticity. Numerous horizons are observed within the tills. The erosional top of pre-Vistulian tills is particularly sharply visible.

Within the postglacial (Late Pleistocene and Holocene) sediment cover of Southern Baltic deep-water basins, three main units are identifiable and defined as seismoacoustic complexes (Przezdziecki, 2004) (Figs. 14–16).

COMPLEX I

The sediments of Complex I are conspicuous by conformable deposition on a glacial till. The sediments are represented by three types of records characteristic of clayey deposits. The bottom parts are characterised by a record of a very fine and irregular arrangement of weak reflections suggesting stratification of the sediments. This layer turns smoothly into a characteristic white and poorly reflective, acoustically transparent zone. Towards the top, the non-reflection zone turns into regularly stratified deposits. The stratification repeats the profile of the till top. Various types of deformation structures are visible among the stratified deposits of Complex I. They are most probably associated with the melting of buried lumps of dead ice.

The sediments of seismoacoustic Complex I can easily be correlated with the formation of the limnoglacial brown Baltic clay with the members established within this formation. In terms of chronostratigraphy, Complex I clays belong to the Late Pleistocene spanning the Bølling to Younger Dryas periods, and they are related to the Baltic Ice Lake phase. Relatively well marked in seismoacoustic profiles, the top of Complex I deposits should be associated with the final drainage of the Baltic Ice Lake, which may have caused the formation of a discontinuity surface due to the lack of sedimentation or even erosional processes in shallower parts of the basins. A similar discontinuity surface related to the first drainage of the Baltic Ice Lake in the Allerød is probably reflected by one of the phases within Complex I.

COMPLEX II

Complex II sediments conformably overlie Complex I sediments. The seismoacoustic record of Complex II more or less clearly shows its stratification, depending on the research area and the recording parameters used. Complex II deposits are also characterised by higher acoustic transparency, showing much less clear stratification than those of Complex I. More distinct reflections are marked at the top sections of Complex II.

The deposits of seismoacoustic Complex II can easily be correlated with the formation of grey Baltic clay. In terms of chronostratigraphy, Complex II clays represent the early Holocene (Preboreal and early Boreal periods) and are related to the Yoldia Sea and Ancylus Lake phases. Relatively well outlined in seismoacoustic profiles, the top of Complex II deposits should be associated with the presence of laminae and clusters of iron monosulphides, as well as – in shallower regions of the basins, on their edges and seabed elevations – with the erosional surface related to the inflow of saline waters and the formation of haline stratification, and therefore with the occurrence of internal undulation at the contact of various-density water layers. In the central, deepest parts of the basins, the top of Complex II is often poorly marked.

COMPLEX III

Complex III sediments rest discordantly upon Complex II sediments. Theylevel out the hollows in the top surface of Complex II Complex III sediments are most often almost completely acoustically transparent, locally showing more or less clear reflectivity, depending on the research area and the recording parameters used, especially in zones of laminated deposits. Acoustic features of Complex III, especially in its top parts, are typical of highly hydrated and unconsolidated mud.

Based on the numerous sediment cores which were subject to lithological, palynological and diatom analysis, as well as radiocarbon dating, the sediments of seismoacoustic Complex III can be unambiguously correlated with the formation of Baltic marine mud and with the members of laminated grey, olive-tint mud (brackish-water silts) and dark-grey, olive-tint mud (marine mud). In terms of chronostratigraphy, Complex III mud represents the late Boreal and Middle–Late Holocene (Atlantic, Subboreal and Subatlantic periods). Correlated with the late Boreal and early Atlantic periods, the sediments of the bottom part of Complex III were deposited in the Mastogloia Sea, while the deposits of the upper parts of the Complex accumulated in the Litorina Sea and the Post-Litorina Sea. Locally, the transition from the laminated Mastogloia Sea mud to the Litorina Sea deposits is marked by a weak acoustic boundary. The boundary between the Litorina and Post-Litorina muds is not expressed in the seismoacoustic record.

THE CORRELATION OF BIO- AND CHRONOSTRATIGRAPHIC UNITS WITH THE LITHOLOGICAL FEATURES AND SEISMOSTRATIGRAPHIC UNITS

The analysis of seismoacoustic profiles, lithological profiles of cores and the reinterpretation of biostratigraphic data enabled an attempt to correlate the bio-, litho- and seismostratigraphic units with the chronostratigraphic units and Baltic evolutionary phases.

A list of all the identified local pollen assemblage zones (LPAZ) for all the sites under comparison is presented in Table 2. It also shows ^{14}C dates, the hiatuses in deposition (clearly marked in grey), and periods for which the diatom analyses recorded the beginning of an increase in salinity related to the Litorina and Yoldia Sea (red triangles). In creating the names of pollen zones, the oscillations in the alder (*Alnus*) values have not been used, as the occurrence of alder is mainly related to local hydrological changes. However, this species is often dominant in pollen spectra of the study areas and therefore the periods of its greater significance are marked in the Table (in green).

The brown Baltic clay was deposited in the Late Pleistocene period (Bølling, Older Dryas, Allrød, Younger Dryas) in the deep-water sedimentation basins of the Southern Baltic. Its structure changed from varve sediments through microlaminated sediments to homogenous ones. Palynological data is based on research of deposits from only one section, hence no satisfactory information is provided on the characteristic climate fluctuations during this period. The scarcity of organic matter makes it impossible to reconstruct the palaeoecological conditions in detail. It is known, however, that the sediments were deposited in a limnoglacial basin during the Baltic Ice Lake phase (e.g. Sauramo, 1958, de Geer, 1940). In the seismostratigraphic records, Complex I corresponds to the brown Baltic clay layer.

In the Early Holocene period (Preboreal and Boreal periods), the deep-water basins of the Southern Baltic were the deposition site of grey Baltic clay with clusters and laminae of iron sulphides at the top. Just like the Late Pleistocene period, the Preboreal period is poorly biostratigraphically documented and only few Preboreal sections were available. Much more data pertains to the Boreal period. It corresponds to the *Pinus* or *Pinus–Corylus* local pollen zones (LPAZ). The differences in the contribution of species in pollen spectra may be caused by the distance between the basins and the land.

The saltwater depositional environment at the beginning of the Holocene (the beginning of Preboreal period) is reflected by the presence of euhalobous diatom species. However, this pertains only to the Gotland Basin. For the remaining basins of the Southern Baltic there is no appropriate documentation in this respect so far. The end of the Preboreal period and the Boreal period have a more complete diatom documentation. Diatom associations indicate the existence of a freshwater basin at the Preboreal/Boreal transition. The Early Holocene grey Baltic clay was deposited in the Yoldia Sea and the Ancylus Lake. It makes up Complex II in the seismostratigraphic division.

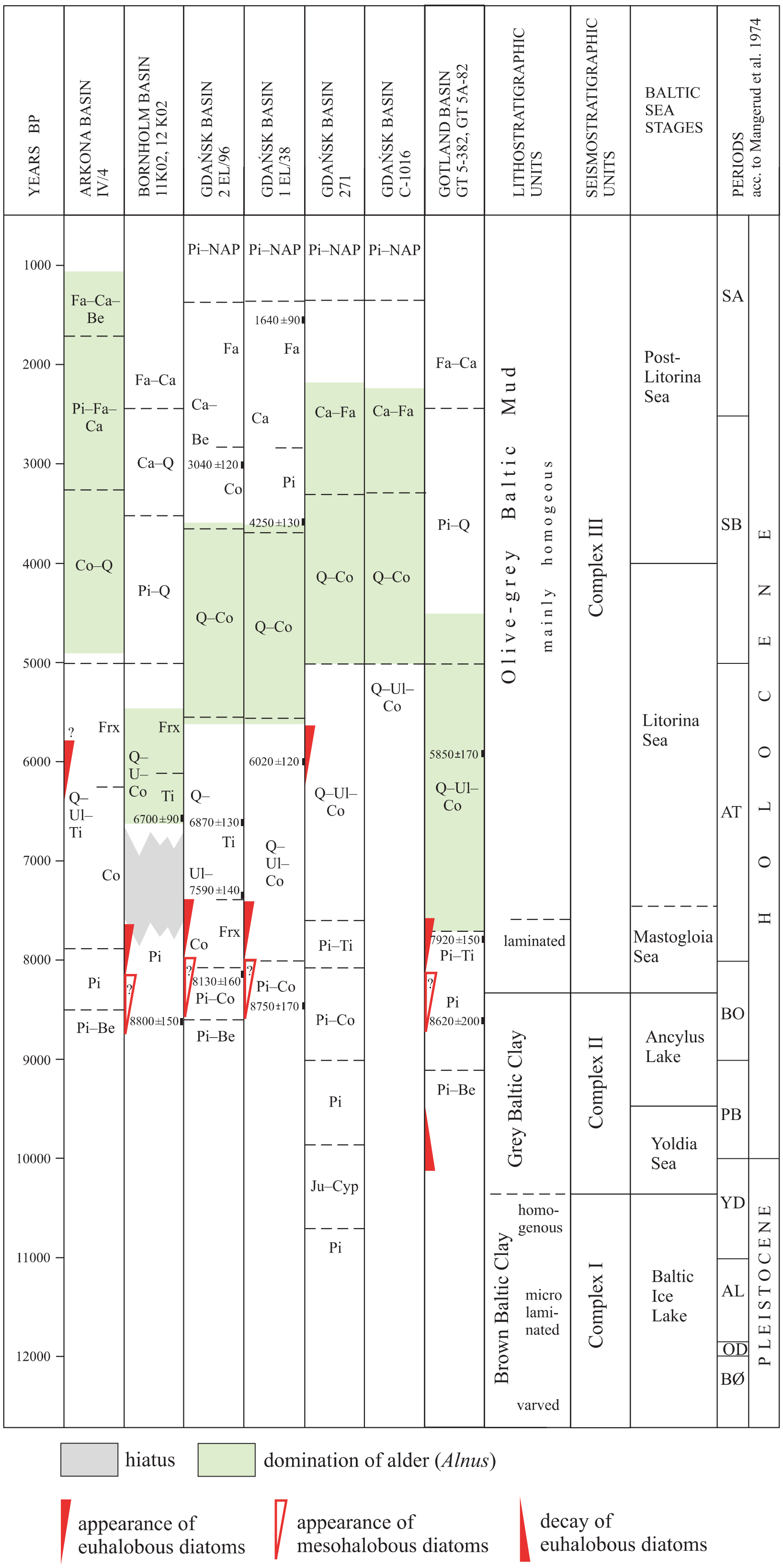
Sedimentation of the olive-grey Baltic mud began in the second half of the Boreal period. The clay is characterised by a gradual increase in organic matter content. A change in the lithological features of the deposits was related to the transformation of the freshwater basin into a brackish-water one. It was manifested by a change in the composition of diatom flora, in which brackish-water (mesohalobous) species appeared. Water salinity caused quicker sedimentation of suspended mineral matter and the expansion of a euphotic zone, and thus an increase in primary production (Winterhalter, 1992). The existence of the brackish-water basin is correlated with the Mastogloia Sea phase.

Sedimentation of the olive-grey Baltic mud was continued in the Middle Holocene (Atlantic period). A gradual change in colour from light olive-grey to dark olive-grey was caused by an increase in the amount of organic matter. It was an effect of a climate warming. This period has a good palynological and diatom documentation and correlates with the *Quercus–Ulmus–Tilia* or *Quercus–Ulmus–Corylus* pollen zones (LPAZ). At the beginning of the Atlantic period, an increase in salinity took place. It is manifested by the dominance of euhalobous species in diatom spectra. In the Baltic evolution phases, this period corresponds to the Litorina Sea.

Sedimentation of the olive-grey Baltic mud continued in the Post-Litorina Sea during the Late Holocene (Subboreal and Subatlantic periods). The greater diversification in the terminology of pollen zones in the second half of this period is the result of diversity in land habitat conditions. Diatom analyses show a gradual slight drop in salinity reflected in an increase in the number of mesohalobous species. In the seismostratigraphic division, the olive-grey Baltic mud makes up Complex III.

Tabela 2

Bio- litho- and seismostratigraphic units of the deposits from the Southern Baltic basins



FINAL REMARKS

In geological and paleogeographical studies on the Baltic Sea area, the problem of Quarternary stratigraphy, including that of the Late Pleistocene and Holocene periods, is one of the issues most poorly represented in the literature. The most advanced attempts to formalize the stratigraphy were made in the field of lithostratigraphy. However, neither bio- nor lithostratigraphic stratotype sections are known for the Baltic area, thus generally accepted stratigraphic units do not exist (Alhonen, 1971; Mangerud *et al*., 1974; Duphorn, 1979; Ignatius *et al*., 1981; Hyvärinen, 1988, 2000; Kotliński, 1989, 1991; Svensson, 1991; Winterhalter, 1992; Björck, 1995; Alexandrowicz, 1999; Andren *et al*., 2000). Traditionally, a stratigraphic meaning is given to the evolutionary phases of the Baltic. Generally speaking, the Baltic evolution phases define time intervals of open or closed connections of the Baltic with the ocean, and, as a consequence, mainly the changes in hydrological (ecological) conditions or, to a smaller degree, in sedimentary processes. Hence the litho- and biostratigraphic units have their specificity which not always corresponds to the principles of stratigraphic classification, terminology or nomenclature.

Both the quantity and quality of the available documentation materials have an additional importance for determining the separations, and, above all, for the correlation of the units established. A review and reinterpretation especially of biostratigraphic data have shown an almost complete lack of palynological evidence and diatom diagrams for Baltic sediments from the Late Pleistocene period. This is largely due to the low primary production caused by the cool climate and also because of the lack of appropriate research sections. Although the large similarity between the palynological and diatom diagrams from various sites in the Southern Baltic proves that deposition in the deep-water sedimentary basins of this region occurred in similar hydrological conditions during the Holocene period, there is no appropriate data for the Late Pleistocene to make any comparisons.

In many cases, the correlation is made difficult by the lack of stratotypical sections with a complete lithological, palynological and diatom documentation, and absolute age dating. A list of the existing biostratigraphic information from the Southern Baltic area shows that even within a single sedimentary basin the correlation of lithological changes with the record of ecological and climatic changes may be difficult if the data does not come from research on the same sections.

Therefore, there is a need to perform a full range of tests: lithostratigraphical, biostratigraphical (palynological, diatomological, malacological, etc.) and AMS radiocarbon dating for selected sediment sections from various areas of the Southern Baltic, which could become stratotypical sites.

REFERENCES

ALEXANDROWICZ S. W., 1999 — Malacofauna and stratigraphy of late vistulian and Holocene deposits in the Southern Baltic Coastal zone. Quaternary Studies in Poland, Special Issue 1999: 37–50.

ALHONEN P., 1971 — The stages of the Baltic Sea as indicated by the diatom stratigraphy. *Acta Botanica Fennica*, **92**: 1-18.

ANDRÉN E., ANDRÉN T., SOHLENIUS G., 2000 — The Holocene history of the southwestern Baltic Sea as reflected in a sediment core from the Bornholm Basin. *Boreas*, **29**: 233-250.

BJÖRCK S., 1995 — A review of the history of the Baltic Sea, 13.0–8.0 ka BP. *Quatern. Internat.*, **27**: 19–40.

De GEER G., 1940 — Geochronologia Suecica Principles. Kungliga Svenska Vetenskapsakademiens Handlingar. Ser. III, 18, 6.

DUPHORN K., 1979 — The ancient shorelines and the development of the Baltic coastal regions in Late Pleistocene and Holocene times: The German Federal Republic. *In*: The Quaternary history of the Baltic (ed. V. Gudelis, L.K. Königsson). Acta Univ. Ups. Symp. Univ. Ups. Annum Quingentesimum Celebrantis: 1: 195–206.

HUNTLEY B., BIRKS H.J.B., 1983 — An atlas of past and present pollen maps for Europe: 0–13 000 years ago. Cambridge Univ. Press.

HYVÄRINEN H., 1988 — Definition of the Baltic stages. *In*: Problems of the Baltic Sea History (eds. J. Donner, A. Raukas). *Ann. Acad. Scient. Fennicae*, *ser. A*, *3. Geol.–Geogr.*, **148**: 7–11.

HYVÄRINEN H., 2000 — The history of the Baltic Sea. *In*: Environmental changes in Fennoscandia during the Late Quaternary (ed. P. Sandgren): 45–54. LUNDQUA Report 37.

IGNATIUS H., AXBERG S., NIEMINTÖ L., WINTERHALTER B., 1981 — Quaternary geology of the Baltic Sea. *In*: The Baltic Sea (ed. A. Voipio): 54–104. Elsevier, Amsterdam.

JAŃCZYK-KOPIKOWA Z., 1987 — Uwagi na temat palinostratygrafii Czwartorzędu. *Kwart. Geol*., **31**: 155–163.

KĘPIŃSKA U., ZABOROWSKA K., ZACHOWICZ J., 1986a — Wyniki badań biostratygraficznych i geochemicznych osadów dennych Głębi Arkońskiej. Przyczynek do historii rozwoju Morza Bałtyckiego. *In*: Peribalticum IV. Z problematyki geologicznej dna Bałtyku Południowego: 25–34. Gdańskie Tow. Nauk. Wrocław, Ossolineum.

KĘPIŃSKA U., ZABOROWSKA K., ZACHOWICZ J., 1986b — Wyniki badań biostratygraficznych i geochemicznych osadów dennych z Zatoki Meklemburskiej. *In*: Peribalticum IV. Z problematyki geologicznej dna Bałtyku Południowego: 34–48. Gdańskie Tow. Nauk. Wrocław, Ossolineum.

KOTLIŃSKI R., 1989 — Lithostratigraphy of Late Glacial and Holocene deposits of the Southern Baltic [Eng. Summ.]. *Stud. Mater. Oceanolog*., **56**: 57–67.

KOTLIŃSKI R., 1991 — Sediments of the Southern Baltic Sea, their deposition and lithostratigraphy. *Kwart. Geol*., **35**, 1: 81–106.

LATAŁOWA M., 1989 — Type region P-t: Baltic Coastal Zone. *Acta Palaeobot.*, **29**, 2: 103–108.

LATAŁOWA M., TOBOLSKI K., 1989 — Type region P-u: Baltic Shore. *Acta Palaeobot.*, **29**, 2: 109–114.

LUBLINER-MIANOWSKA K., 1962 — Pollen analysis of the surface samples of bottom sediments in the Bay of Gdansk. *Acta Soc. Bot. Poloniae*, **31**, 2: 305–312.

LUBLINER-MIANOWSKA K., 1963 — Analiza pyłkowa dwu rdzeni z dna morskiego. *In*: Materiały do monografii polskiego brzegu Bałtyku. Zesz. 5, Geologia i zagadnienia pokrewne: 82–88. PWN, Warszawa.

LUBLINER-MIANOWSKA K., 1965 — Die Pollenanalyse einer Stechrohr-Probe aus der Mecklenburger Bucht. Beitrage zur Meereskunde: 12–14.

ŁOMNIEWSKI K., MAŃKOWSKI W., ZALESKI J., 1975 — Morze Bałtyckie. PWN, Warszawa.

MAJEWSKI A., 1987 — Characteristics of the southern Baltic waters. [Eng. Summ.]. *In*: Bałtyk Południowy (ed. B. Augustowski): 173–217. Ossolineum, Wrocław.

MANGERUD J., SVEND T., BERGLUND B.E., DONNER J.J., 1974 — Quaternary stratigraphy of Norden, a proposal for terminology and classification. *Boreas*, **3**: 109–128.

MASICKA H., 1975 — Stratyfikacja warwowa 10-metrowego rdzenia z dna Głębi Gdańskiej. [Eng. Summ.]. *Oceanologia*, **4**: 133–151.

MOJSKI J.E. (ed.), 1989–1995 — Geological Map of the Baltic Sea Bottom. Pol. Geol. Inst., Warszawa.

MOJSKI J.E., 1993 — Europa w plejstocenie. Wyd. PAE, Warszawa.

MOJSKI J.E., 1995 — The last Pleistocene ice-sheet and its decay. Pl. XXVI. *In*: Geological atlas of the Southern Baltic, 1:500000. (ed. J.E. Mojski *et al.*): 36–37. Państw. Inst. Geol. Sopot, Warszawa.

PIECZKA F.B., 1980 — Geomorfologia i osady denne Basenu Gdańskiego. *In*: Peribalticum. Problemy badawcze obszaru bałtyckiego (ed. B. Rosa): 79–118. Gdańskie Tow. Nauk., Gdańsk, Ossolineum.

PIECZKA F. B., ZABOROWSKA K., 1989 — Litologia i stratygrafia rdzenia 6/HI/67 z Basenu Gdańskiego. [Eng. Summ.]. *Stud. Mat. Ocean*., **56**, *Geologia morza*, 4: 323–330.

PRZEZDZIECKI P., 2004 — Seismostratigraphy of Quaternary sediments in the Polish part of the Baltic Sea [Eng. Summ.]. *Biul. Państw. Inst. Geol.*, **423**: 81–126.

PRZYBYŁOWSKA-LANGE W., 1979 — Diatoms of lake deposits from the Polish Baltic Coast. II Lake Jamno. *Acta Palaeobot*., **20,** 2: 227–244.

RALSKA-JASIEWICZOWA M., NALEPKA D., GOSLAR T., 2003 — Some problem of forest transformation at the transition to the oligocratic/Homo sapiens phase of the Holocene interglacial in the northern lowlands of central Europe. *Veget. Hist. Archaeobot*., **12**: 233–247.

RALSKA-JASIEWICZOWA M., LATAŁOWA M., WASYLIKOWA K., TOBOLSKI K., MADEYSKA E., WRIGHT H.E. Jr., TURNER Ch. (eds.), 2004 — Late Glacial and Holocene history of vegetation in Poland based on isopollen Maps. Isopollen history of trees and shrubs. W. Szafer Institute of Botany Polish Academy of Sciences, Kraków.

SAURAMO M., 1958 — Die Geschichte der Ostsee. *Ann.Acad. Sci. Fennicae*, *ser. A*, *3. Geol.–Geogr.*, **51**.

SVENSSON N.O., 1991 — Late Weichselian and Early Holocene shore displacement in the Central Baltic Sea. *Quatern. Internat*., **9**: 7–26.

TOMCZAK A., KRAMARSKA R., UŚCINOWICZ Sz., ZACHOWICZ J., PAZDUR A., MICHCZYŃSKI A., GOSLAR T., 1999 — Późny plejstocen i holocen polskiego brzegu i polskiej strefy ekonomicznej Bałtyku w świetle statystycznych analiz dat radiowęglowych. *In*: Geochronologia górnego czwartorzędu Polski w świetle datowania radiowęglowego i luminescencyjnego (eds. A. Pazdur, A. Bluszcz, W. Stankowski, L. Starkel): 251–263. Wind J. Wojewoda, Wrocław.

UŚCINOWICZ Sz., 1999 — Southern Baltic area during the last deglaciation. *Geol. Quart.*, **43**, 2: 137–148.

UŚCINOWICZ Sz., 2003 — Relative sea level changes, glacio-isostatic rebound and shoreline displacement in the sounthern Baltic. *Pol. Geol. Inst. Spec. Papers*, **10**.

UŚCINOWICZ Sz., ZACHOWICZ J., 1992 — Objaśnienia do mapy geologicznej dna Bałtyku 1: 200 000 (ed. J.E. Mojski). Arkusze Rønne, Nexø. Państw. Inst. Geol., Warszawa.

UŚCINOWICZ Sz., ZACHOWICZ J., 1994 — Objaśnienia do mapy geologicznej dna Bałtyku 1:200000, arkusze: Gdańsk, Elbląg, Głębia Gdańska. Państw. Inst. Geol. Warszawa.

UŚCINOWICZ Sz., KRAMARSKA R., TOMCZAK A., ZACHOWICZ J., 2000 — The radiocarbon age of marine and land deposits in the southern Baltic area. *Geologos*, **5**: 155–163.

WINTERHALTER B., 1992 — Late-Quaternary stratigraphy of Baltic Sea basins – a review. *Bull. Geol. Soc. Finland*, **64**, Part 2: 189–194.

WITKOWSKI A., 1994 — Recent and fossil diatom flora of the Gulf of Gdańsk, Southern Baltic Sea. *Biblioth. Diatomolog.*, **28**, Berlin–Stuttgard.

WITKOWSKI A., MILLER U., 1999 — Diatom flora of the Mastogloia Sea – an indicator of environmental changes in the recent Baltic Sea. *Quaternaria* A, **7**: 87–100.

ZABOROWSKA K., ZACHOWICZ J., 1982 — Woprosy biostratygrafii donnych otloženij Gdan'skoj Buchty. *In*: Peribalticum II. Problemy Badawcze Obszaru Bałtyckiego i Czarnomorskiego: 195–201. Gdańskie Tow. Nauk. Wrocław, Ossolineum.

ZACHOWICZ J., 1995 — Quaternary geological profiles (II). Pl. XVIII. *In*: Geological atlas of the Southern Baltic, 1:500000. (ed. J.E. Mojski *et al.*). Państw. Inst. Geol. Sopot, Warszawa.