Polish Geological Institute Special Papers, 23 (2008): 45–70
Proceedings of the Workshop “Relative sea level changes”

REVIEW AND REINTERPRETATION OF THE POLLEN AND DIATOM DATA FROM THE DEPOSITS OF THE SOUTHERN BALTIC LAGOONS

Grażyna MIOTK-SZPIGANOWICZ[1], Joanna ZACHOWICZ[1], Szymon UŚCINOWICZ[1]

Abstract. According to their origin, geomorphology and hydrology, the fresh/brackish-water bays and coastal lakes of the Southern Baltic coast can be treated as lagoons. They developed at the time of and as a result of the Atlantic (Litorina) transgression of the Southern Baltica. There are many publications about the origin and evolution of the lagoons and lakes along the Polish coast of the Southern Baltic (e.g. Przybyłowska-Lange, 1973a, b, 1974, 1979, 1981; Zaborowska, 1977; Zachowicz, 1977, 1985; Wypych, 1980a, b; Zachowicz *et al.*, 1982; Bogaczewicz-Adamczak, Miotk, 1985a, b; Dąbrowski *et al.*, 1985; Zachowicz, Zaborowska, 1985; Borówka *et al.*, 2001a, b, 2002). Nevertheless, the origin of the lagoons has not been fully explained. In the light of present-day information the results of earliest investigations often need to be reinterpreted. The aim of this work was the correlation of the published and unpublished pollen and diatom diagrams from Late Pleistocene and Holocene sediments of the Southern Baltic lagoons, and their relation with radiocarbon dating. The pollen and diatom diagrams from the area of north-east Germany and the Curonian Lagoon (Kabailienė, 1999; Jahns, 2000; Kaiser *et al.*, 2000; Endtmann, 2002; Bitinas *et al.*, 2002) have been used for comparison. For the palynological sites, the local pollen assemblage zones (L PAZ) have been identified according to Jańczyk-Kopikowa (1987). Comparison of the biostratigraphical data allowed us to define the approach time of the formation of the lagoons in their present-day position on the coast as well as to determine the periods of an accelerated sea-level rise and increased frequency of storm surges (so-called marine transgression phases) when the investigated areas had been under the direct influence of the sea. Such influences are visible about 7000, 6000, 5000 and 4000 years BP. This period of marine influences, about 1000-year long, corresponds very well to the same period of climate oscillations mentioned by Stuiver and Braziunas (1993), Stuiver *et al.* (1995) and Chapman and Shackelton (2000).
The influence of the sea in the Post-Litorina period was associated mainly with the inflow of sea water through more or less developed barriers, so they are not synchronous.

Key words: pollen and diatom analyses, lagoons, sea-level changes, Holocene, Baltic Sea.

INTRODUCTION

According to their origin, geomorphology and hydrology, lagoons and coastal lakes can be jointly defined as the lagoons of the southern coast of the Baltic because they were formed at the time of and due to the Atlantic (Litorina) transgression of the Southern Baltica.

The areas of the Southern Baltic lagoons were the subject of extensive research. The Vistula Lagoon is among those which are best studied; it was the subject of biological, hydrological and cartographic research as early as the beginning of the 20th century. A number of studies regarding the origin of this water body were also done (Sonntag, 1915–1918; Uhl, 1939). The first biostratigraphic (pollen and diatom) analyses were made by Gross (1941) and Brockmann (1954) (diatom analysis). From 1954 to 1964, a joint Polish and Russian research was performed within the Lagoon’s area. A monograph on this area, which also covered geological and geomorphological issues, including the origin and evolution of the water body, was the result of this research (Wypych, 1975). Biostratigraphic research of the water basin started in the 1970s (Przybyłowska, 1973a, b; Przybyłowska-Lange, 1974; Zachowicz *et al.*, 1982; Zachowicz, 1985).

[1] Polish Geological Institute, Marine Geology Branch, 5 Kościerska str., 80-328 Gdańsk, Poland; e-mail: grazyna.miotk-szpiganowicz@pgi.gov.pl; joanna.zachowicz@pgi.gov.pl; szymon.uscinowicz@pgi.gov.pl

As early as the 19th century, the Szczecin Lagoon was the object of much interest in the hydrology of this water body. In 1904, chemical/biological and bacteriological tests of the Lagoon's water were made (Brandt, 1906). In 1933, there was a report on the water salinity (Neuhaus, 1933). A number of hydrological works were developed in connection with the operation on fairways (Haack, 1960; Bauer, 1963). On the basis of the results of geological, meteorological and hydrological research performed from 1951 to 1970, a monograph on this water basin, which also included the results of biostratigraphic research, was created (Wypych, 1980a, b).

The other lagoons of the Polish coast were not given so much attention but also they were the areas of research related mainly to the Baltic transgressions (Rosa, 1963, 1968). In the 1970s and later, a number of reports were published, documenting various aspects of the formation and evolution of the lagoons and coastal lakes on the Polish coast of the Southern Baltic (e.g. Przybyłowska-Lange, 1973a, b, 1974, 1979, 1981; Zaborowska, 1977; Zachowicz, 1977, 1985; Wypych, 1980a, b; Zachowicz *et al.*, 1982; Bogaczewicz-Adamczak, Miotk, 1985a, b; Dąbrowski *et al.,* 1985; Zachowicz, Zaborowska, 1985; Borówka *et al.*, 2001a, b, 2002, 2005). Despite many publications, the issue of how the lagoons were formed is still not explained entirely. In the light of the current state of knowledge, the earlier research often needs reinterpreting and verifying through using more detailed biostratigraphic analyses and absolute dating. The lack of radiocarbon dates is felt especially acutely, as they would make it possible to place the events on an absolute time scale.

Furthermore, a number of general and basic issues regarding, for instance, the periodicity of transgression events, have not been resolved so far. The research on the periodicity of the changes in the Baltic water level dates back to 1937, when Iversen (1937) published a study on the Litorina transgression in Denmark. He distinguished four transgression phases in the Atlantic and Subboreal periods. The best documented research includes those of Berglund (1964, 1971) from the Blekinge area, of Digerfeldt (1975) from Skåne, and of Mörner (1976, 1980) from the Kattegat area. All these works indicate the occurrence of transgression-regression phases in the Atlantic and Subboreal periods. The impact of regional eustatic oscillations is poorly recognised on the southern coasts of the Baltic Sea and it still belongs to disputable problems.

THE AIM OF THE RESEARCH

The aim of this report is to reinterpret and correlate the published and unpublished pollen and diatom diagrams of the Late Pleistocene and Holocene sediments from the lagoons of the Southern Baltic, and their association with the results of radiocarbon dating. The reinterpretation of biostratigraphic data and its integration with the results of radiocarbon dating were made both to formalise stratigraphic units and to determine the possibilities of using this data for analysing climatic oscillations and transgression-regression phases. The area under analysis covers the Polish coast of the Southern Baltica.

THE FEATURES OF THE RESEARCH AREA

The Polish coast of the Southern Baltic is 500 km long, out of which 72 km constitute the Hel Peninsula coastline (Fig. 1).

During the Litorina Sea transgression, especially in its final phase, a system of coastal lakes and lagoons, separated from the open sea by barriers, was formed on the Southern Baltic coasts. The largest ones on the Polish coast include the Szczecin and Vistula lagoons and the Łebsko Lake. Although in Polish terminology, the names "lakes" and "lagoons" are traditionally used in relation to the landforms (basins) discussed here, the term "lagoon" is appropriate because of the morphology of the water bodies and the barriers (sandbars) which separate them from the sea, due to their hydrology, but most of all due to their origin.

SZCZECIN LAGOON

The Szczecin Lagoon is separated from the Gulf of Pomerania by sandy structures of the Świna Gate Barrier, the storm delta of the Świna and the morainic plateaux of the Wolin and Uznam islands. It is connected with the Gulf of Pomerania through three narrow straits of the Dziwna, Świna and Piana rivers (Fig. 2).

The area of the Szczecin Lagoon is 687 km^2. The largest river flowing into the Szczecin Lagoon is the Odra. The total average river water inflow is 478 m^3/s. The Lagoon is a shallow water body, with an average depth of 3.5 m and a maximum depth (apart from the artificially deepened fairway) of 8.5 m (Wypych, 1980a, b). The bed of the Szczecin Lagoon is flat and covered mainly with muddy deposits; only along the coastline a narrow belt of sand sediments occurs at the depth of 1.0–1.5 m.

JAMNO LAKE (LAGOON)

The Jamno Lake (Lagoon) is located in the western part of the Polish coast (Fig. 1). It is separated from the Baltic by the narrow sandy Jamno Barrier (Fig. 3) with low dunes reaching the height of 5 m. The width of the barrier ranges from 0.3 to 0.7 km.

Fig. 1. The research area

Lagoons discussed in text are marked in yellow

The total area of the Jamno Lake (Lagoon) is 22.4 km^2, its average depth – 1.4 m, and the maximum depth – 3.9 m. The lake is connected with the Baltic only through a narrow channel often blocked by beach sediments. During storm seasons, there is a periodical breach in the barrier and a discharge of sea water into the lake (Przybyłowska-Lange, 1979). The lake bed is flat and covered with muddy deposits.

GARDNO LAKE (LAGOON)

The Gardno Lake (Lagoon) is located in the middle of the Polish coast (Fig. 1), west of the Lake Łebsko. It is separated from the Baltic by the Gardno Barrier (Fig. 4), whose width reaches 1.5 km.

The barrier is covered by dunes reaching up to 35 m in height. The total area of the Gardno Lake (Lagoon) is 24.7 km^2. It is a shallow lake with the maximum water depth of 2.6 m, and the average depth not exceeding 1.3 m. The flat lake bed is covered mainly with muddy deposits, while outcrop tills occur only locally. The Łupawa River is the largest river flowing through the lake; it also connects the lake with the Baltica.

SARBSKO LAKE (LAGOON)

The Sarbsko Lake (Lagoon) is located in the middle of the Polish coast (Fig. 1), somewhat to the east of the Łebsko Lake. It is separated from the Baltic by the sandy Sarbsko Barrier (Fig. 5) with a width of ca. 1.5 km and high dunes of ca. 35 m.

The area of the Lake is 6.52 km^2, its average depth – 1.2 m, and the maximum depth – 3.2 m. The lake bed is flat, covered with muddy deposits. No watercourses flow into the Sarbsko Lake (Lagoon). It is only connected with the Łebsko Lake through a narrow channel.

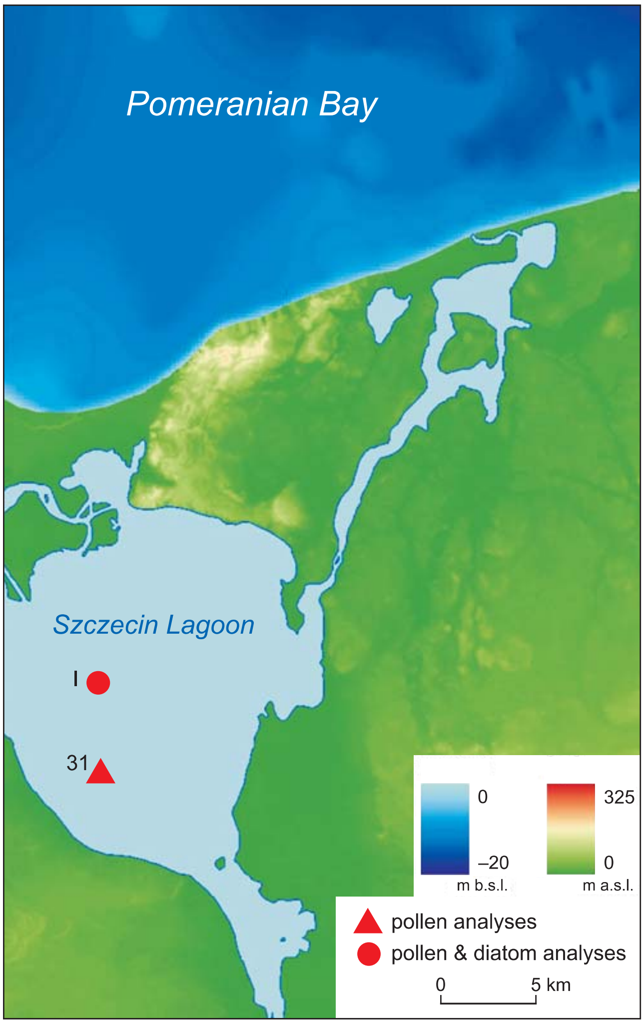


Fig. 2. Szczecin Lagoon – location of investigated cores

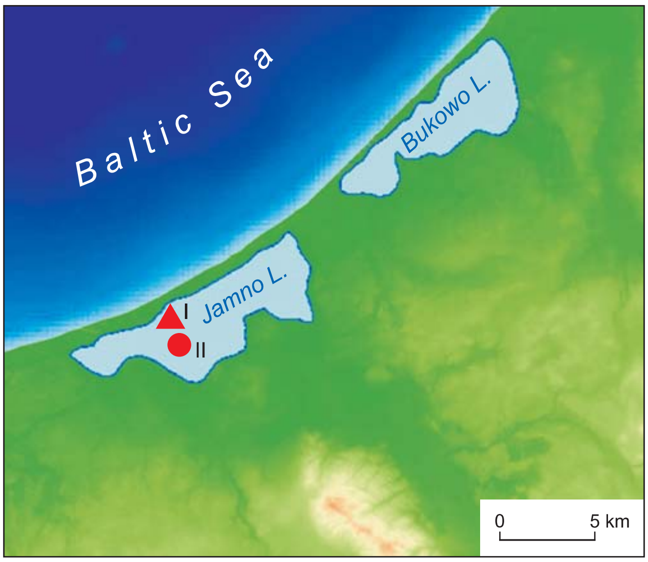


Fig. 3. Jamno Lake (Lagoon) – location of investigated cores

For explanations see Fig. 2

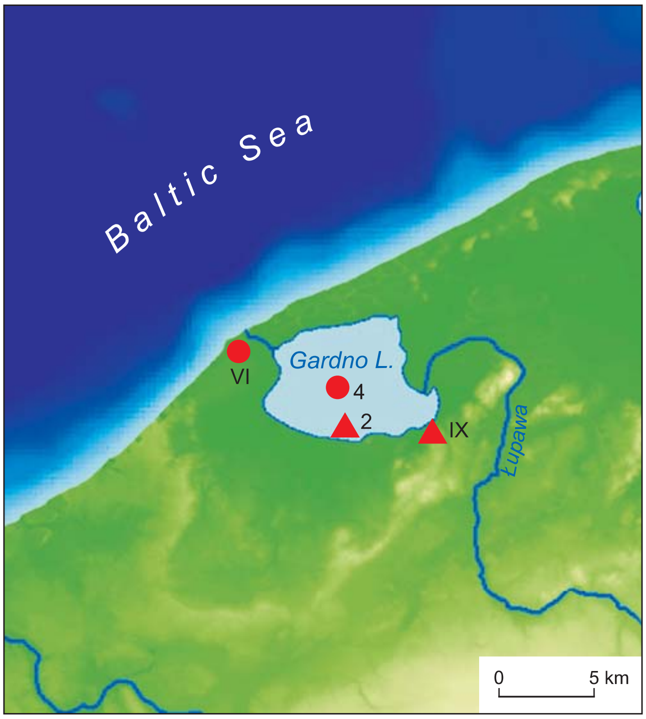


Fig. 4. Gardno Lake (Lagoon) – location of investigated cores

For explanations see Fig. 2

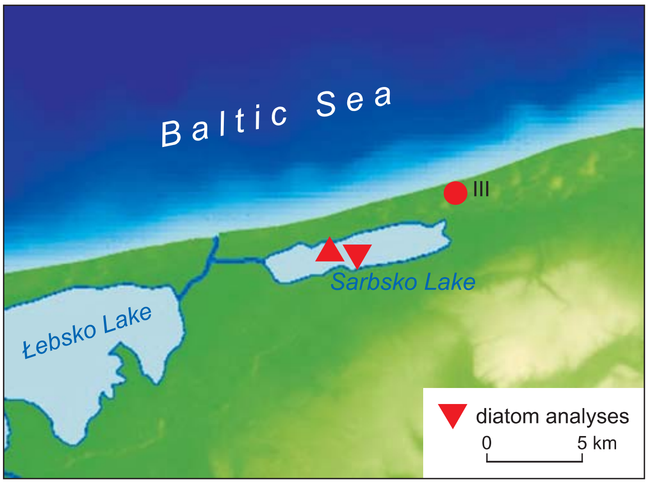


Fig. 5. Sarbsko Lake (Lagoon) – location of investigated cores

For other explanations see Fig. 2

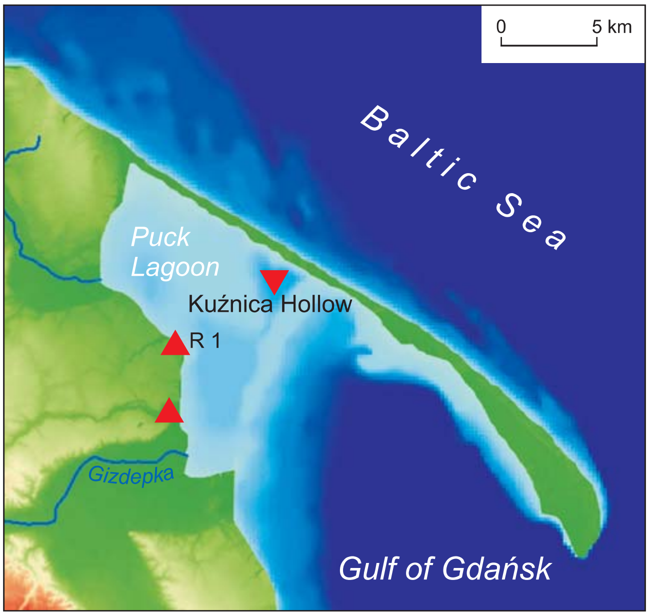


Fig. 6. Puck Lagoon – location of investigated cores

For explanations see Figs. 2 and 5

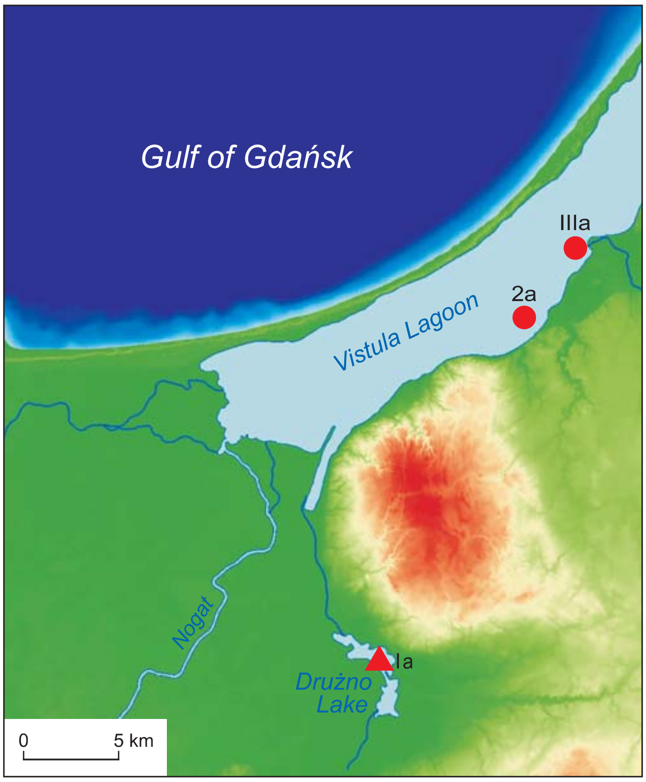


Fig. 7. Vistula Lagoon – location of investigated cores

For explanations see Figs. 2 and 5

PUCK LAGOON

The Puck Lagoon is situated in the north-western part of the Gulf of Gdańsk (Fig. 1). It is separated from the Gulf of Gdańsk in the north-east by a narrow, 100–200-m wide, low sandy barrier of the Hel Peninsula, and by dunes not exceeding 5–7 m in height. In the east, the Puck Lagoon is separated from the Gulf of Gdańsk by the partly submerged sandy Seagull Barrier (Fig. 6).

The area of the Puck Lagoon is 104 km^2. A few small rivers and streams flow into the Puck Lagoon, the largest of which is the Reda with the average discharge of ca. 4.5 m^3/s. The total average river water inflow to the Lagoon is ca. 10 m^3/s. The water exchange between the Puck Lagoon and the Gulf of Gdańsk occurs mainly through an artificially deepened strait. The average depth of the Lagoon is ca. 3 m (Nowacki, 1993). The relief of the lagoon bed is characterised by a number of depressions, the so-called hollows, with the maximum depths of 5.5, 5.7 and 9.2 m, filled with muddy sands and muds. There are also sand-covered elevations with the minimum depths of ca. 1–2 m.

VISTULA LAGOON

The Vistula Lagoon is situated on the south-eastern coast of the Gulf of Gdańsk and is separated from the sea by the Vistula Barrier (Fig.1). This sandy barrier is characterised by a considerable width (up to ca. 800 m) and a well-developed system of dunes up to 30 m high (Fig. 7).

The area of the Vistula Lagoon is 838 km^2. The total average river water inflow to the Vistula Lagoon is 300 m^3/s. The largest rivers which currently flow into the Lagoon are Pregoła and Pasłęka. Before 1914, also some of the Vistula waters flew into the Vistula Lagoon. The Vistula Lagoon is connected with the Gulf of Gdańsk by the Pilawa Strait. The bed of the Vistula Lagoon, with an average depth of 3 m, is flat and covered for the most part by mud. Sand sediments occur only as a narrow belt along the coastline (Uścinowicz, Zachowicz, 1996).

RESEARCH MATERIAL AND METHODS

The critical review and reinterpretation of pollen and diatom spectra from the lagoon deposits of the Southern Baltic began with a review of literature on biostratigraphic data. Then, those publications were selected which contained the most complete and best documented information on the changes in palaeoecological conditions. The priority was given to the studies concerning pollen and diatom analyses of sediments of the same core. Unfortunately, the results of biostratigraphic research were presented as diagrams not in all publications. Often, especially in older works, only tables of absolute or percentage values were published. For reinterpretation purposes, 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, plants from wet meadows, 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 zones (LPAZ) were established for all the selected sites of palynological research, according to Jańczyk-Kopikowa (1987). The duration of each 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 (Tobolski, 1987, 1989; Latałowa, 1989; Latałowa, Tobolski, 1989). The isopollen maps of tree species (Huntley, Birks, 1983; Ralska-Jasiewiczowa *et al.*, 2004) were also helpful in the reinterpretation of the earlier stratigraphic divisions. Simplified diatom diagrams were related to the time scale determined on the basis of palynological research (in the case of the same sediment core) and ^{14}C dating, or only on ^{14}C dating or on the comparison of changes in ecological conditions with those recorded in palynological research of the same water basin.

A list of all the identified pollen zones (LPAZ) for all the compared sites is presented in Table 1. This table also shows the ^{14}C dates and hiatuses in the sedimentary record (in grey), sand layers separating organic sediments (in yellow) and periods in which diatom analyses recorded an increase in salinity (red lines). The results of diatom tests were not available for all the sites, therefore, wherever possible, the periods of an increased number of rush species (blue lines) were plotted within the separated pollen zones, which can indirectly be associated with a low water level. In creating the names of the pollen zones, in order to facilitate the correlation with the most fully documented sites, it was attempted to take no account of the oscillations in the alder (*Alnus*) values, as the alder occurrence is related mainly to local hydrological changes. However, this species is often dominant in plant communities of the areas under research and therefore the periods of its greater significance in the local plant communities are also marked in the table (in green).

RESEARCH RESULTS

The following sites were selected as the result of literature review, as well as the analysis and reinterpretation of the available materials:

— for the Szczecin Lagoon – two sites (Fig. 2) – one with a pollen diagram (core 31) and the other with a pollen and diatom diagram (core I) (Wypych, 1980a, b). Biostratigraphic information from the works by Borówka *et al.* (2001a, b, 2002, 2005), Janke (2002), Latałowa and Borówka (2003), Latałowa and Święta (2003), Latałowa *et al.* (2003) and Witkowski *et al.* (2003, 2004) were also taken into consideration;

— for the Jamno Lake (Lagoon) – two sites (Fig. 3): one with a pollen diagram (core I) (Dąbrowski *et al.*, 1985) and one with a pollen and diatom diagram (core II) (Zachowicz, 1973; Przybyłowska-Lange, 1979);

— for the Gardno Lake (Lagoon) – from the contemporary lake area (Fig. 4): one site with a pollen and diatom diagram (core 4) and one with a pollen diagram (core 2) (Zachowicz, 1977; Zaborowska, 1977; Zachowicz, Zaborowska, 1985), one site from the Lake Gardno barrier with a pollen and diatom diagram (core Dębina–Rowy VI) and one site from the southern shore of the lake with a pollen diagram (core IX) (Bogaczewicz-Adamczak *et al.*, 1981; Bogaczewicz-Adamczak, Miotk, 1985b);

— for the Sarbsko Lake (Lagoon) – from the contemporary lake area (Fig. 5): one site with a pollen diagram (Tobolski, 1967), one – with a diatom diagram (Przybyłowska-Lange, 1981) and one site from the contemporary barrier area with a pollen and diatom diagram (Sarbsko III) (Miotk, Bogaczewicz-Adamczak, 1987);

— for the Puck Lagoon – two sites (Fig. 6) with pollen diagrams from the southern shore of the Lagoon (cores R 1 and Gizdepka) (Miotk-Szpiganowicz, 1997; Uścinowicz, Miotk-Szpiganowicz, 2003; Uścinowicz, Zachowicz, 2003) and one site with a diatom diagram (core IX) from Jama Kuźnicka (Kuźnica Hollow) (Witak, 2002). Other diatom studies were also taken into account (Witkowski, 1991; Witak, 2001);

— for the Vistula Lagoon – two sites (Fig. 7): one with combined diatom and palynological diagrams (cores 2a and IIIa) (Przybyłowska-Lange, 1973a, b, 1974; Bogaczewicz-Adamczak, 1980; Bogaczewicz-Adamczak, Miotk, 1985a; Zachowicz, 1985), and one site with a palynological diagram from Lake Druzno (core 1a) (Zachowicz *et al.*, 1982; Zachowicz, Kępińska, 1987).

SZCZECIN LAGOON

The new diagrams were drawn for this water body using the available numerical data: two palynological (Fig. 8 and 9) and one diatom diagram (Fig. 10). Constructed by K. Lubliner-Mianowska, J. Zachowicz (palynology) and K. Zaborowska (diatom analysis), these diagrams were included in the Wypych's report (1980a, b).

The presented pollen diagrams contain information on the history of the Szczecin Lagoon area starting from the Late Glacial period (Fig. 8). Silt and peat deposits document the existence of limnic and swampy environments probably from the Older Dryas period (Pre-Alleröd?) through the Atlantic period (Fig. 8). Frequent changes in sediment character also prove the equally frequent changes in the water level which caused the formation of gaps (hiatuses) in the deposition. In the *Quercus–Ulmus–Corylus* pollen zone of the Atlantic period (Fig. 9), whose duration in Wolin Island (Latałowa, 1989) is determined at 8300–6100 years BP, diatom analyses (Fig. 10) recorded a short increase in the number of brackish-water diatoms (mesohalobous). Then, after a brief disappearance, their repeated development took place. They were accompanied by euhalobous diatoms characteristic of the Litorina transgression in the Baltic region. Increased of sand and numerous *Cerastoderma* sp. shells also appear in the deposits. The results of pollen analyses prove a rapid disappearance of aquatic and rush plants at that time (Fig. 9). All these changes indicate the consolidation of marine conditions in the Szczecin Lagoon area. There is no presence of very characteristic for the marine episode of the Szczecin Lagoon, sandy layer described by Borówka *et al.* (2002, 2005) and Latałowa, Borówka (2003).

The deposits accumulated towards the end of the Atlantic and during the Subboreal period, contain almost no diatoms (Fig. 10). A similar problem is described by Witkowski (Witkowski *et al.*, 2003, 2004). The meso- and euhalobous diatoms appear again during the *Fagus–Carpinus* pollen zone in the beginning of the Subatlantic period (Figs. 9, 10)

Intensifying abrasion of the coastal cliffs on the islands of Uznam and Wolin at the beginning of the Subboreal initiated the formation of a sand bar in the area of the present-day Świna Barrier (Borówka *et al.*, 2002; Witkowski *et al.*, 2004). This is confirmed by the radiocarbon and palynological dates of peat deposits from the Świna Gate (Prusinkiewicz, Noryśkiewicz, 1966). The pollen profiles (Fig. 9) indicate that the building up of the bar due to sand accretion and the consequent isolation of the Szczecin Lagoon from the Baltic probably took place around 1500–1200 years BP. The diatom diagram for this period shows a fall in the numbers and abundance of meso- and euhalobous species (Fig. 10), while the pollen profile for the same period shows a distinct rise in the significance of human indicators connected with the early medieval economy (Fig. 9). In addition, studies of the dune forms in the Świna Gate area (Osadczuk, 2004) have shown that the yellow dunes began to form around 1500 years BP.

After this period, the isolation of this water body from the Baltic began. It is visible in the diatom diagram (Fig. 10) as an increase in the contribution of indifferent diatoms. This isolation was not always complete, as proved, for instance, by an increase in the number of saltwater diatoms in the upper part of the diagram.

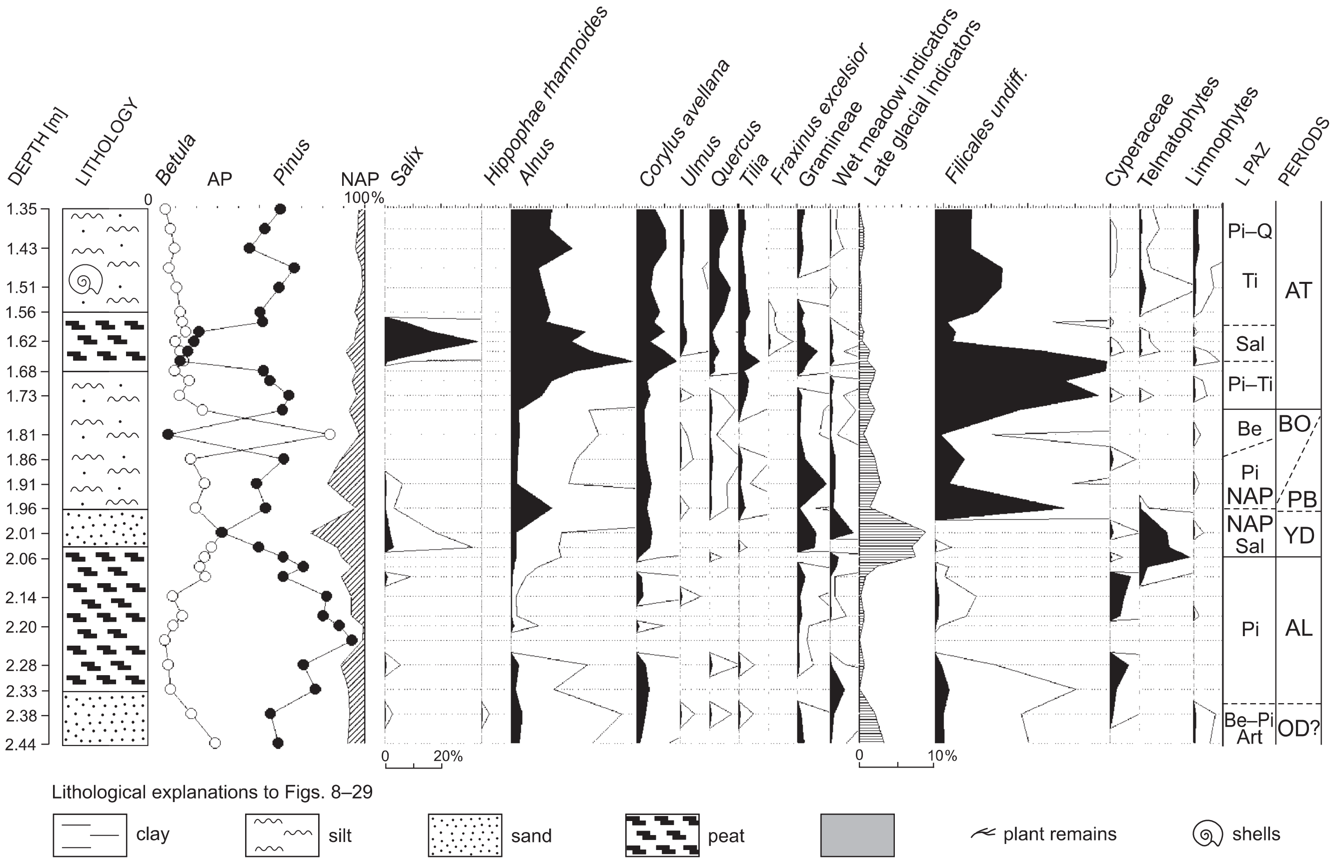


Fig. 8. Szczecin Lagoon 31 – simplified pollen diagram (after Wypych, 1980a; modified)

JAMNO LAKE (LAGOON)

The available numerical and percentage data made it possible to draw two simplified pollen diagrams (Figs. 11 and 12) and one diatom diagram (Fig. 13).

The identification of pollen zones for the diagrams published earlier made it possible to add more details to the data from literature. The basic difference appeared at the bottom limit of the Atlantic period. In relation to earlier studies (Zachowicz 1973, Przybyłowska-Lange 1979, Dąbrowski *et al.* 1985), it should be moved "downwards" and set there where the percentage values of lime (*Tilia*) appear. In the light of current data on the migration time of various tree species into the area of Poland, it is known that this species appeared in northern Poland not earlier than 8200–8100 years BP (Ralska-Jasiewiczowa *et al.* 2003, 2004); therefore its percentage values cannot be associated with the Boreal period (Zachowicz, 1973; Przybyłowska-Lange, 1979; Dąbrowski *et al.*, 1985). Taking into account the changes introduced in the running of the time limits between the identified pollen zones (LPAZ), it can be said that the oldest signs of marine influence recorded in the Jamno I core deposits in the northern part of the lake and related to the silt and sand layer (Dąbrowski *et al.*, 1985), occurred during the *Quercus–Ulmus–Corylus* zone (Fig. 11, Tab. 1). In the Jamno II core, this zone is related to the presence of meso- and euhalobous diatoms (Przybyłowska-Lange, 1979) in peat sediments (Fig. 13). After the change in the limits of the Atlantic period, the time in which the earliest recorded marine influence took place is also somewhat rejuvenated. It seems that it happened not "earlier than 7000 years BP" (Dąbrowski *et al.*, 1985), but ca. 7000 years BP. Another marine influence, manifested mainly by an increase in the quantity of brackish-water diatoms (mesohalobous), was recorded towards the end of the Atlantic period within the *Corylus–Quercus–Ulmus–Tilia* pollen zone (Figs. 11, 12, 13; Tab. 1). Another increase in the contribution of brackish-water (mesohalobous) and salt-water (euhalobous) diatoms (Fig. 13) took place also in the *Corylus–Quercus–Ulmus–Tilia* zone (Fig. 12) corresponding to the beginning of the Subboreal period. The youngest marine influence clearly visible in a diatom analysis was recorded within the *Fagus–Carpinus* (Fig. 12) or *Fagus–Carpinus–Pinus* zone (Fig. 11) and took place in the Subatlantic period. In the second half of this period (*Fagus–Carpinus* L PAZ), a clear freshening of the lake occurred, as indicated by an increase in the quantity of indifferent freshwater diatoms (Fig. 13). It was certainly related to the closure of the connec-

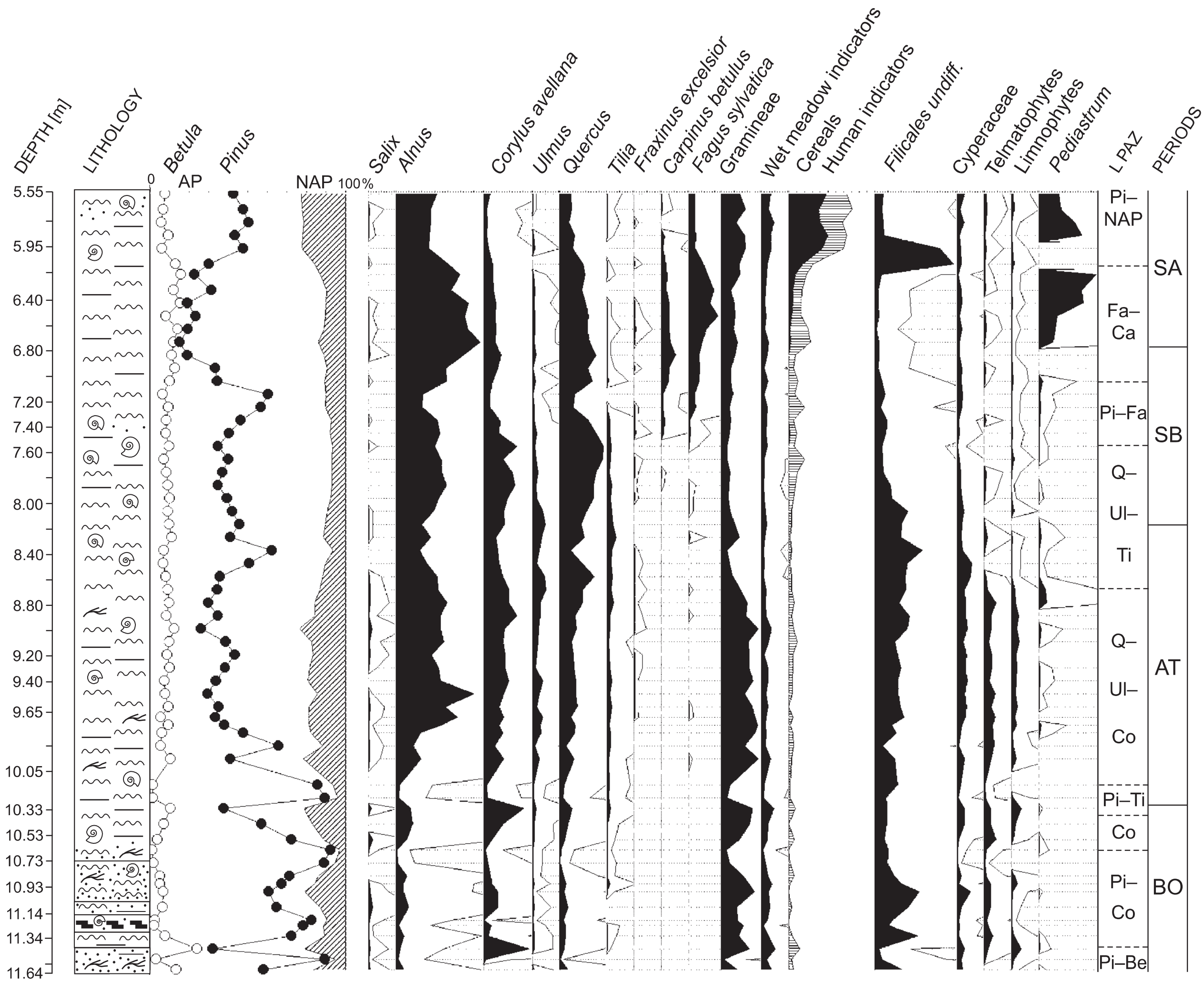


Fig. 9. Szczecin Lagoon I – simplified pollen diagram (after Wypych, 1980a; modified)

For explanations see Fig. 8

tion with the Baltica. The instances of increase in the quantity of euhalobous diatoms recorded in the youngest period of the basin's existence (Fig. 13) indicate brief influxes of sea water, presumably during storm overflows across the sandy barrier (Dąbrowski *et al.*, 1985).

GARDNO LAKE (LAGOON)

Using the available quantitative data regarding the pollen analyses and the percentage values obtained from the readouts of the scanned diatom diagrams, four abbreviated pollen diagrams (Figs. 14, 16, 17, 18) and two diatom diagrams (Figs. 15, 19) were drawn for the Gardno Lake (Lagoon) area.

Both the analysis of the diagrams and the position of the information on the time scale (Table 1) show that the earliest marine influence was recorded by the presence of eu- and mesohalobous diatoms in the silts of Dębina–Rowy VI core taken from the area of the present-day barrier (Fig. 19). It occurred during the Ulmus subzone of the *Quercus–Corylus* LPAZ (Fig. 18), i.e. at the Atlantic/Subboreal transition (Tab. 1). The clear presence of both euhalobous and mesohalobous diatoms (Fig. 19) indicates the existence of at least a brackish-water lagoon in this area. After this brief marine influence, a drop in water level occurred, as evidenced by the accumulation of wood peat (Fig. 18). Another increase in the amount of saltwater and brackish-water diatoms (Fig. 19) occurred within the Tilia subzone of the same pollen zone, in the middle part of the Subboreal period (Table 1, Figs. 18, 19). The diatom analysis of sediments from the present-day lake

Fig. 11. Jamno Lake (Lagoon) I – simplified pollen diagram (after Dąbrowski *et al.*, 1985; modified)

For explanations see Fig. 8

area shows that these marine influences are marked only by the occurrence of single brackish-water diatoms in peat deposits (Fig. 15). After placing the available biostratigraphic data on the time scale, it seems that the present-day water body formed in the second half of the Subboreal period during the *Corylus-Quercus-Ulmus-Tilia* zone (Figs. 14, 16, 17), not in the Subatlantic period (Bogaczewicz-Adamczak, Miotk, 1985b; Zachowicz, Zaborowska, 1985) as it was previously thought. The Subboreal age of the lake sediments, deposited directly on the Early Holocene peat (Figs. 14, 16), is proven first of all by the lack of considerable amount of pollen grains of plants related to human economic activity. Pollen grains of trees characteristic of the Subatlantic period are also absent, e.g. beech (*Fagus*) which, at the beginning of this period, usually reached values of as much as 3-5% in the pollen spectra from this area (Ralska-Jasiewiczowa *et al.*, 2004). This is particularly clear in a diagram from the southern shore of the present-day lake (Fig. 17). The dominance of indifferent oligohalobous diatoms with a small quantity of typical

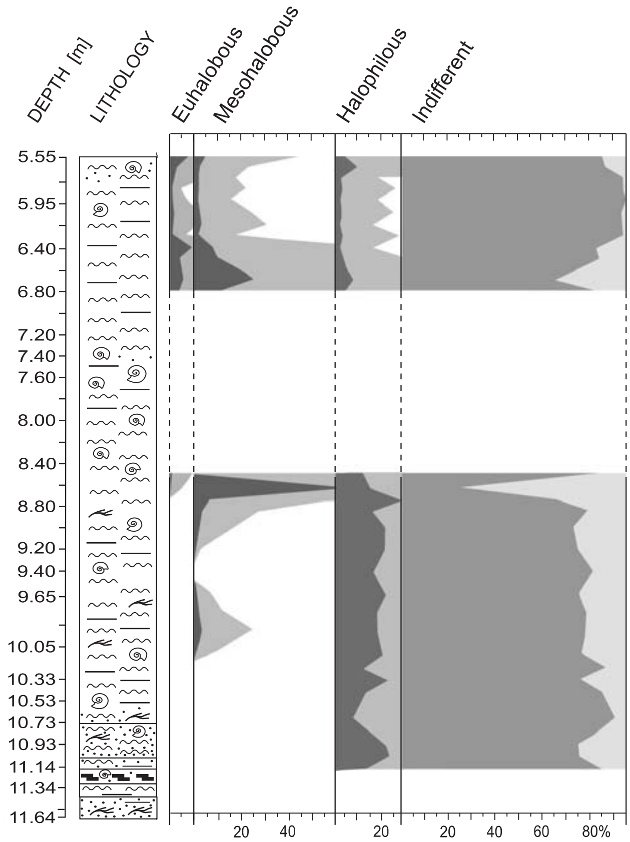
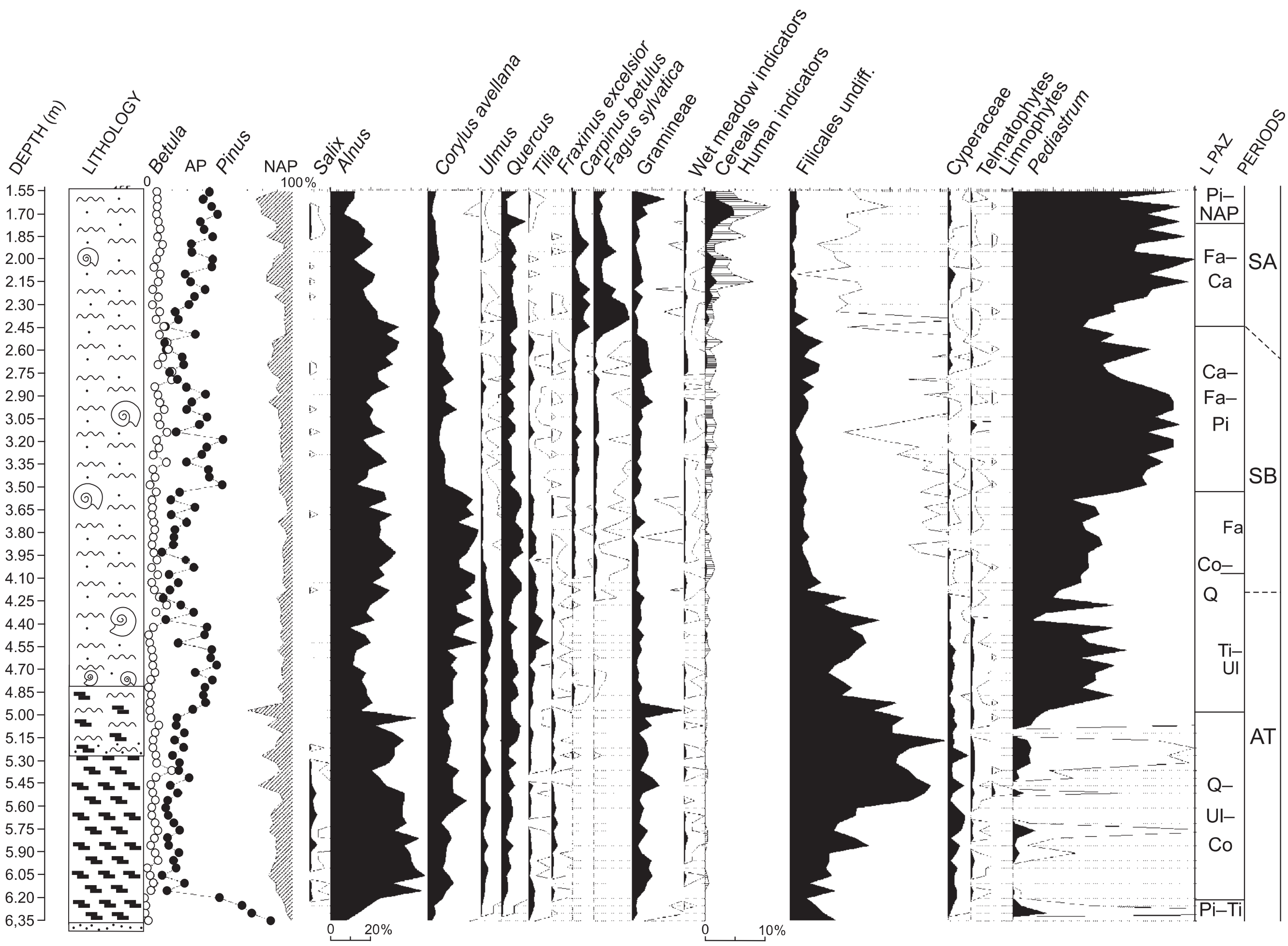


Fig. 10. Szczecin Lagoon I – simplified diatom diagram (after Wypych, 1980a; modified)

For explanations see Fig. 8



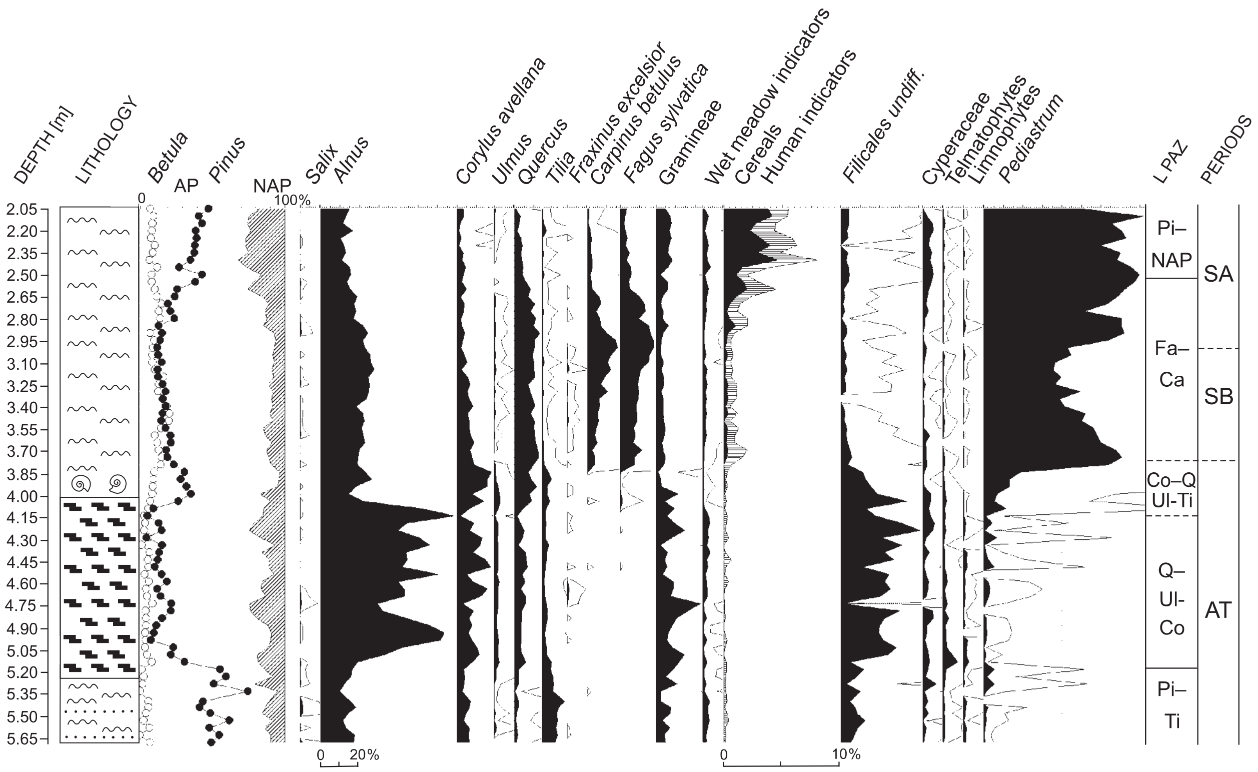


Fig. 12. Jamno Lake (Lagoon) II – simplified pollen diagram (after Dąbrowski *et al.*, 1985; modified)

For explanations see Fig. 8

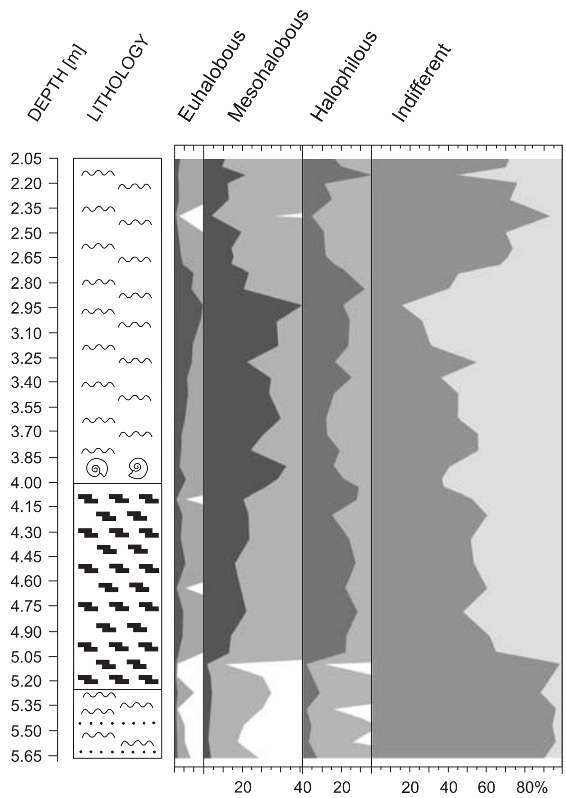
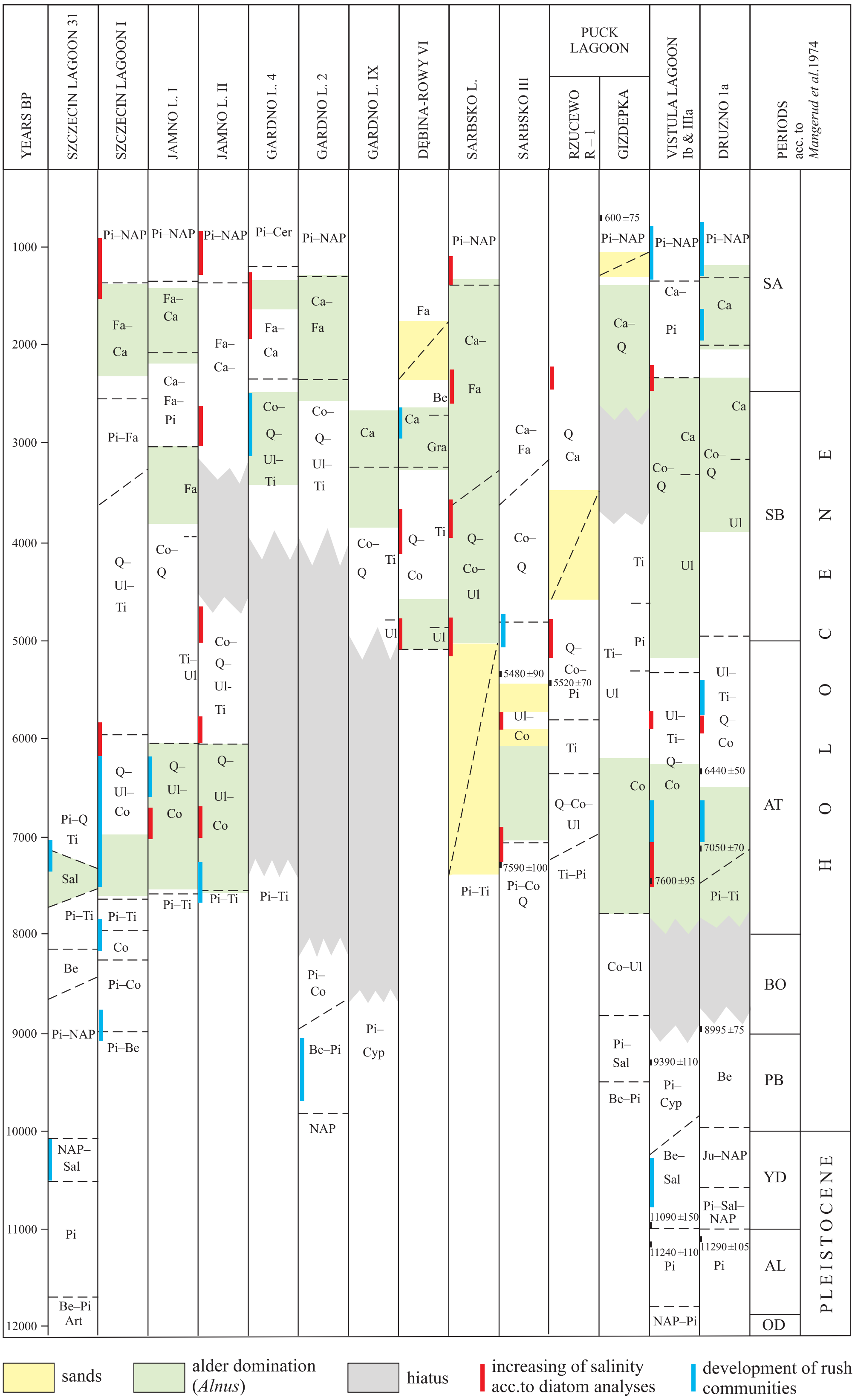


Fig. 13. Jamno Lake (Lagoon) II – simplified diatom diagram (after Dąbrowski *et al.*, 1985; modified)

For explanations see Fig. 8

T a b e l a 1

Bio- and chronostratigraphic units established for the sections from the Southern Baltic lagoons



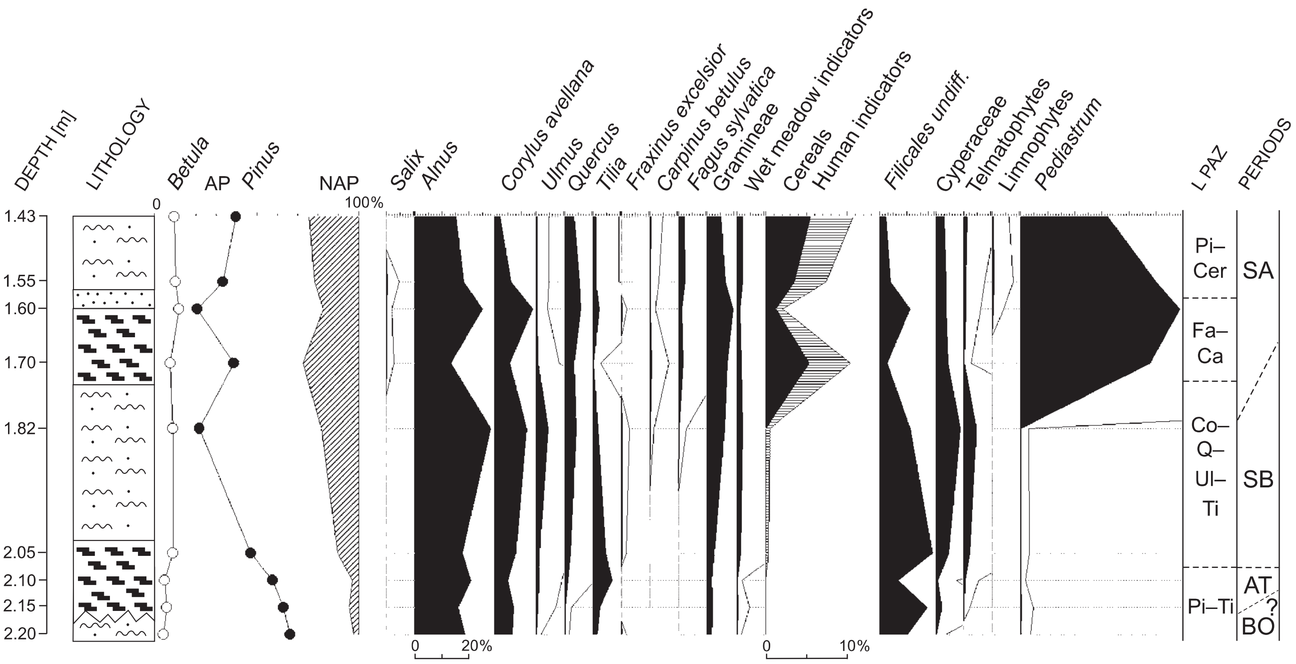


Fig. 14. Gardno Lake (Lagoon) 4 – simplified pollen diagram (after Zachowicz, Zaborowska, 1985; modified)

For explanations see Fig. 8

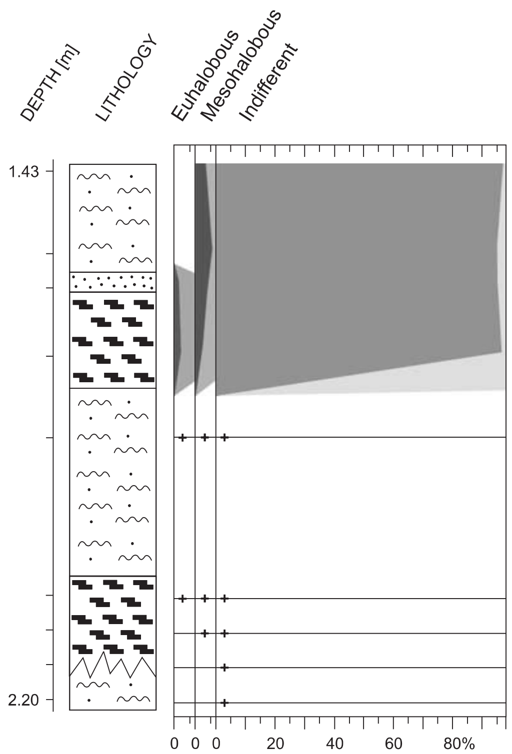


Fig. 15. Gardno Lake (Lagoon) 4 – simplified pollen diagram (after Zachowicz, Zaborowska, 1985; modified)

For explanations see Fig. 8

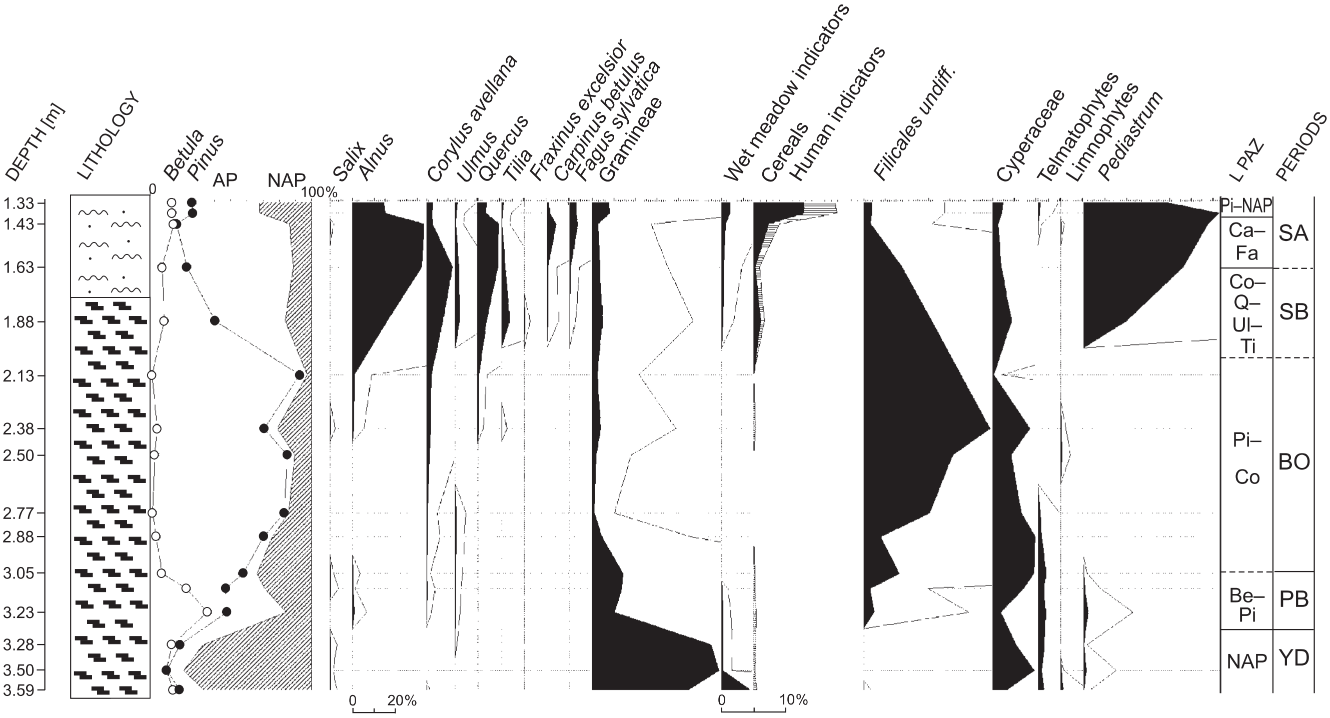


Fig. 16. Gardno Lake (Lagoon) 2 – simplified pollen diagram (after Zachowicz, Zaborowska, 1985; modified)

For explanations see Fig. 8

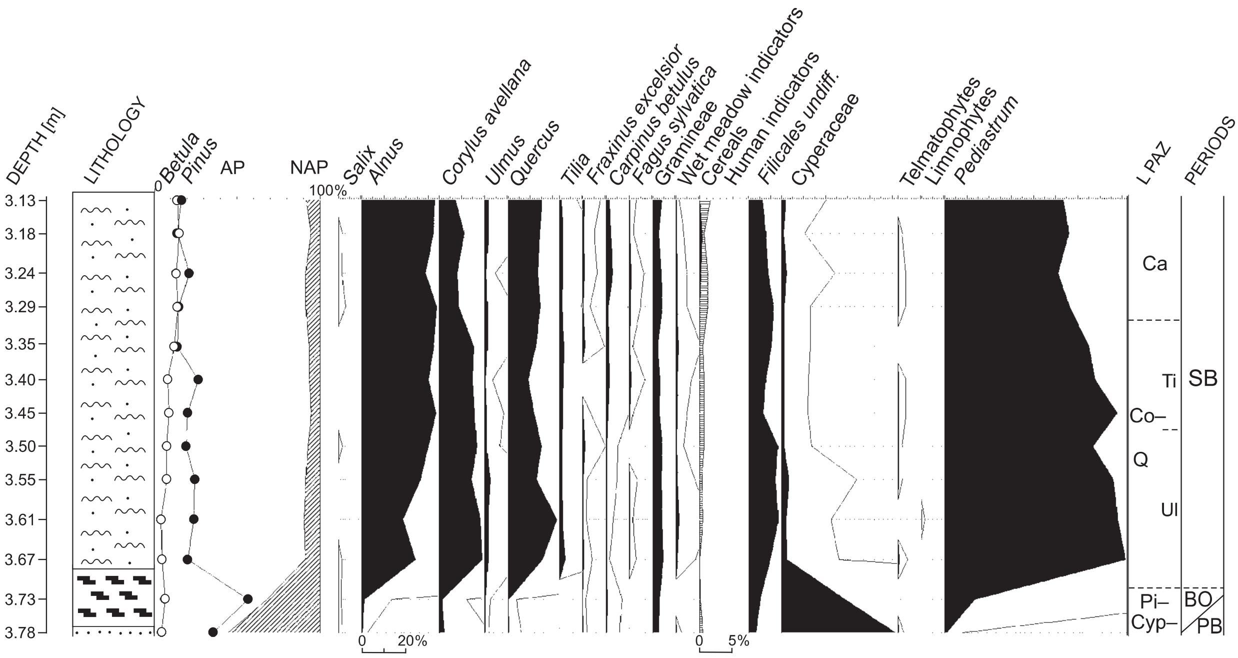


Fig. 17. Gardno Lake (Lagoon) IX – simplified pollen diagram (after Bogaczewicz-Adamczak, Miotk, 1985b; modified)

For explanations see Fig. 8

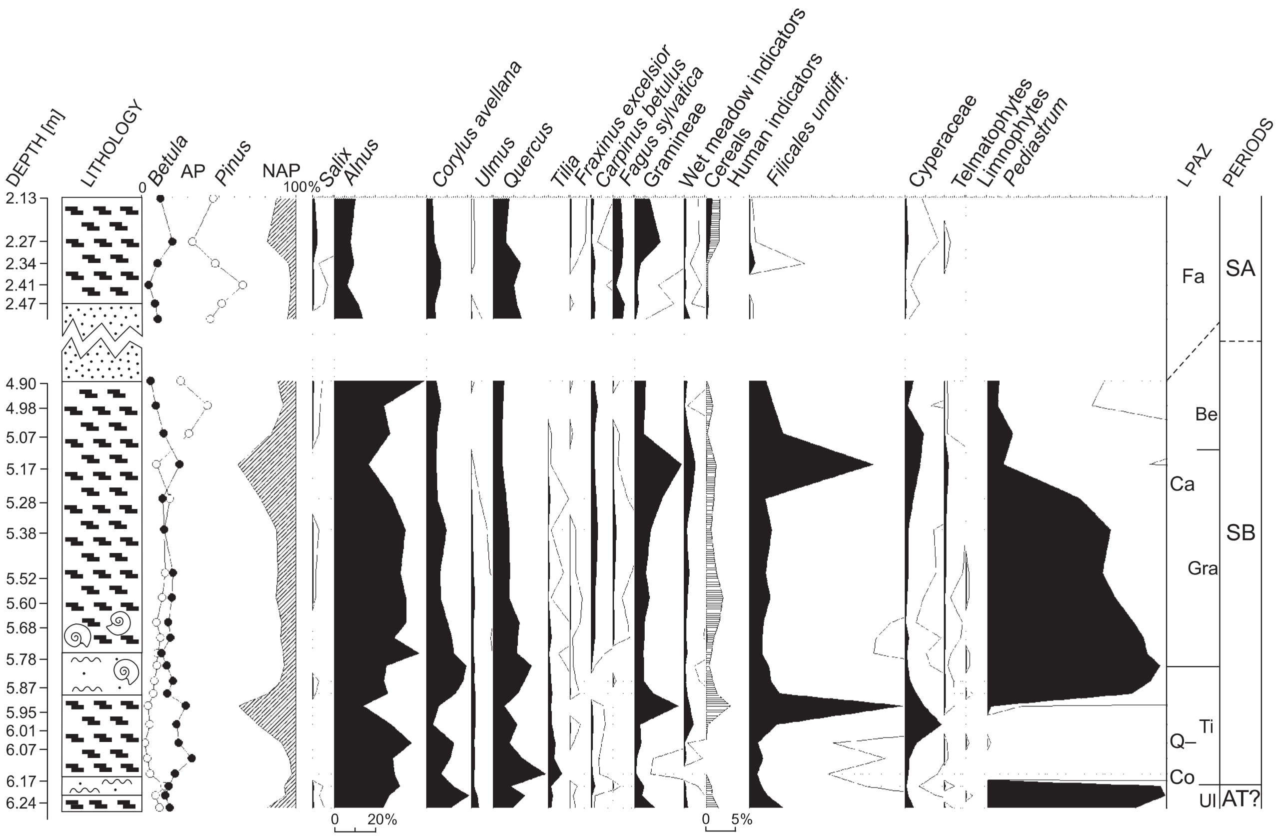


Fig. 18. Dębina–Rowy VI – simplified pollen diagram (after Bogaczewicz-Adamczak, Miotk, 1985b; modified)

For explanations see Fig. 8

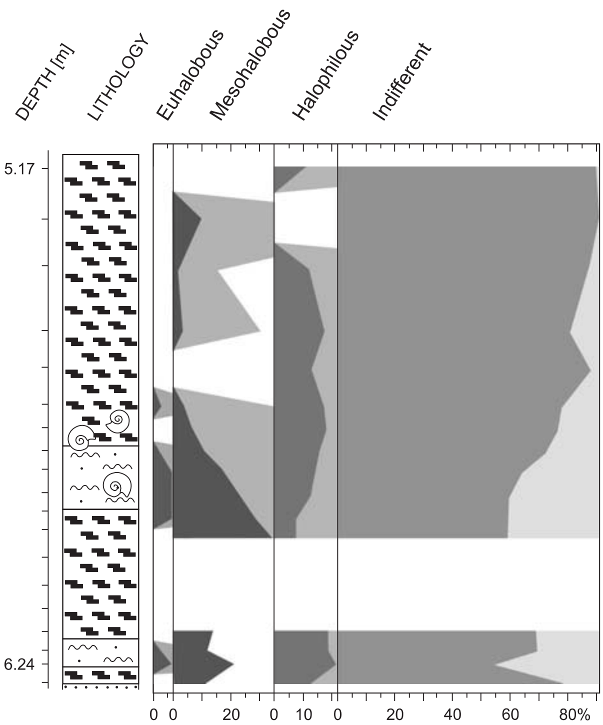


Fig. 19. Dębina–Rowy VI – simplified diatom diagram (after Bogaczewicz-Adamczak, Miotk, 1985b; modified)

For explanations see Fig. 8

euhalobous species (Fig. 15) indicates that it was a freshwater body with a poorly marked marine influence. At the same time, a peatland started developing again in the barrier area (Fig. 18).

SARBSKO LAKE (LAGOON)

Biostratigraphic data for this water body also comes from older literature (Tobolski, 1967; Przybyłowska-Lange, 1981; Miotk, Bogaczewicz-Adamczak, 1987). On the basis of our own numerical data and that published in literature (Tobolski, 1967), two new abbreviated pollen diagrams were drawn. Two other diatom diagrams were drawn based on the percentage data readouts (Figs. 20–23).

The analysis of the diagrams shows that the earliest marine influence recorded in the silt sediments of the present-day barrier by the occurrence of large quantities of saltwater (euhalobous) and brackish-water (mezohalobous) diatoms (Fig. 21) took place during the *Pinus–Corylus–Quercus* zone, as indicated by the radiocarbon date of 7550 ±100 years BP (Miotk, Bogaczewicz-Adamczak, 1987). Possibly this zone corresponds to the *Pinus–Tilia* zone identified in most sites at the beginning of the Atlantic period. It is more probable, however, that this date is slightly aged, as already suggested by the

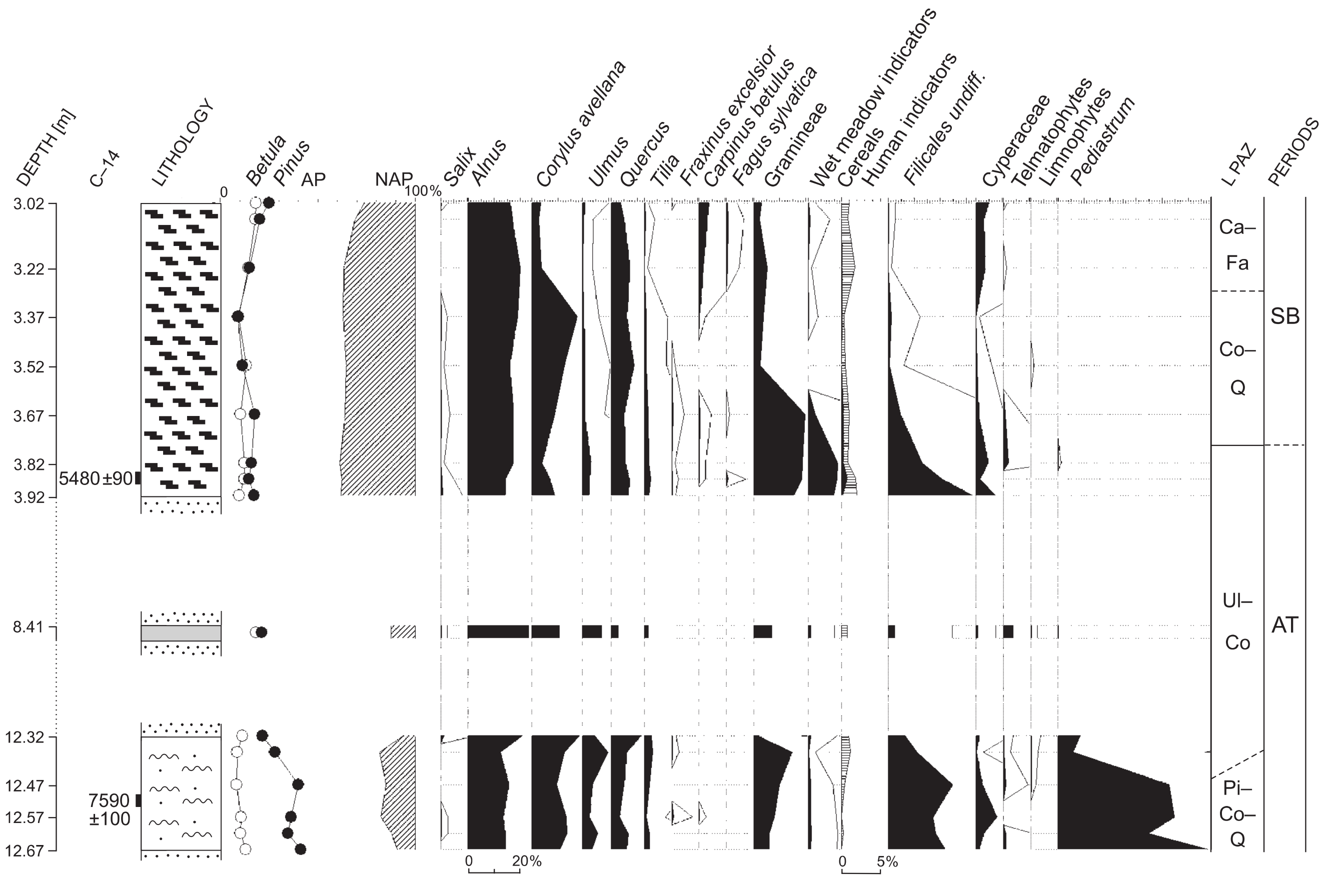


Fig. 20. Sarbsko III – simplified pollen diagram (after Miotk, Bogaczewicz-Adamczak, 1987; modified)

For explanations see Fig. 8

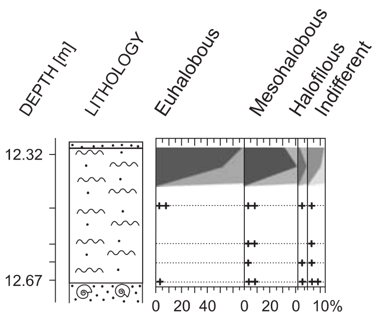


Fig. 21. Sarbsko III – simplified diatom diagram (after Miotk, Bogaczewicz-Adamczak, 1987; modified)

For explanations see Fig. 8

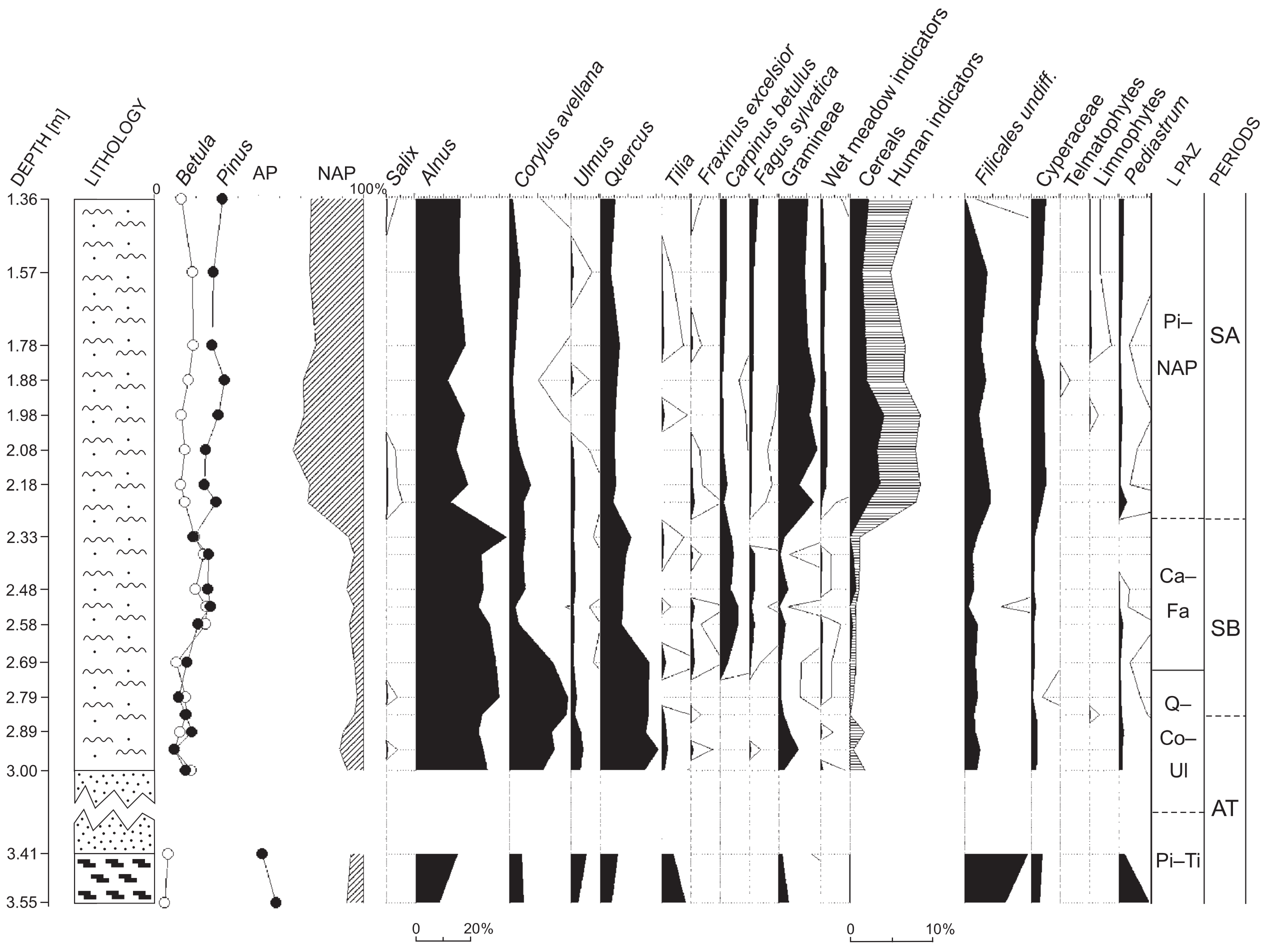


Fig. 22. Sarbsko Lake (Lagoon) – simplified pollen diagram (after Tobolski, 1967; modified)

For explanations see Fig. 8

present authors (Miotk, Bogaczewicz-Adamczak, 1987). Thereby, the formation of a saltwater lagoon in the present-day barrier area should be associated with the same influence of sea water recorded by a change in lithology in the northern part of Jamno Lake (Lagoon) (Fig. 11).

At the time of the occurrence of a shallow and saltwater basin in the present-day barrier area, peatlands developed over the area of the present-day lake (Tobolski, 1967). The presence of only singly occurring brackish-water and freshwater diatoms in a fossil soil (Fig. 20) of the barrier is obviously an insufficient evidence for identifying a marine transgression phase. The authors (Miotk, Bogaczewicz-Adamczak, 1987) suggest that the presence of the fossil soil may indicate an increase in the elevation of groundwater level as a result of the sea-level rise in the middle part of the Atlantic period (Fig. 20). Another event of marine influence noted at the end of the Atlantic period and at the beginning of the Subboreal period (Fig. 23) was recorded in the deposits of the present-day Sarbsko Lake (Lagoon). It is marked by a large contribution of euhalobous and mesohalobous diatoms. At that time, peatlands developed in the region of the then-forming barrier (Fig. 20). As the sandbar developed and the basin was being separated from the sea, a freshening of the basin occurred, as proved by the dominance of freshwater diatoms in lake deposits (Fig. 23). The periodical growth in the quantity of halophilous diatoms proves that this general tendency was being stopped by sea water inflows. The definite freshening took place in the youngest period of the water body's evolution (Fig. 23).

PUCK LAGOON

This water body was analysed in numerous biostratigraphic studies, both palynological (Miotk-Szpiganowicz, 1997; Pomian *et al.*, 2000; Latałowa, Badura, 2003; Uścinowicz, Miotk-Szpiganowicz, 2003; Uścinowicz, Zachowicz, 2003) and diatom researches (Witkowski, 1991; Witkowski, Witak, 1993; Witak, 2001, 2002). However, due to the numerous gaps in deposition and the frequent “enrichment” of the deposits with older material, there is no reliable

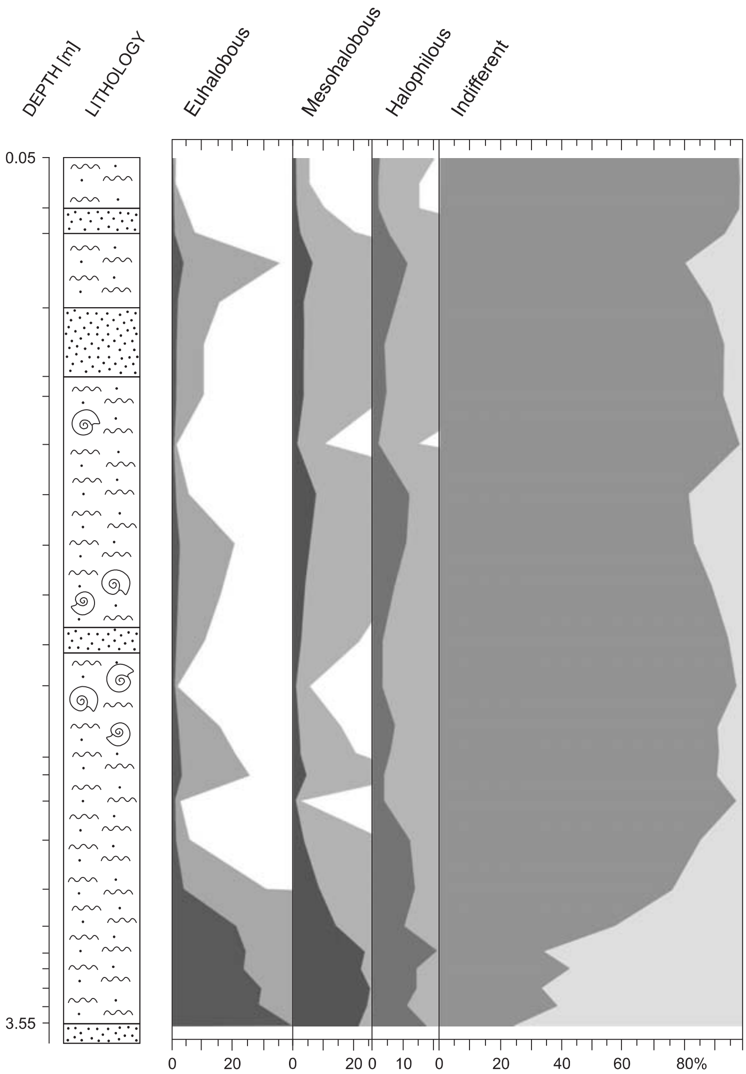


Fig. 23. Sarbsko Lake (Lagoon) – simplified diatom diagram (after Przybyłowska-Lange, 1981; modified)

For explanations see Fig. 8

section to document the complete history of the water basin. In order to illustrate the palaeogeography of this area in the most detailed way possible, it was decided to select land sites containing more complete biostratigraphic data.

Using the available absolute numerical values, two abbreviated pollen diagrams were drawn for the sites in the Rzucewo Headland (Fig. 24) and in the Gizdepka Valley (Fig. 25), and one diatom diagram constructed for the Kuźnica Hollow (Witak, 2002) (Fig. 26).

Both these pollen diagrams (Figs. 24, 25) treated together provide a lot of information on the history of vegetation in this area. A peat layer from the site in the Rzucewo Headland (Fig. 24) was radiocarbon dated at 5520 ±50 years BP (Uścinowicz, Miotk-Szpiganowicz, 2003). This date is confirmed by palynological data and falls within the *Quecus–Corylus–Pinus* zone (Fig. 24, Tab. 1) dated at the end of the Atlantic period. The presence of peat indicates that the shallower areas of the Lagoon were still land at that time (Uścinowicz, Miotk-Szpiganowicz, 2003). The results of diatom tests of core IX from Jama Kuźnicka (the Kuźnica Hollow) (Witak, 2002), presented in a simplified diagram (Fig. 26), indicate a significant contribution of euhalobous and mesohalobous diatoms in the Subboreal deposits (Kramarska *et al.*, 1995). It proves that during that period, there was a brackish-water body in the more deeply located areas of the Puck Lagoon (the Kuźnica Hollow and the Rzucewo Hollow), which owes its formation to the final phase of the Litorina transgression (Witkowski, Witak, 1993; Witak, 2002) extending onto the whole area of the Puck Lagoon (Uścinowicz, Miotk-Szpiganowicz, 2003). The shores of this water body were covered by peatlands (Miotk-Szpiganowicz, 1997).

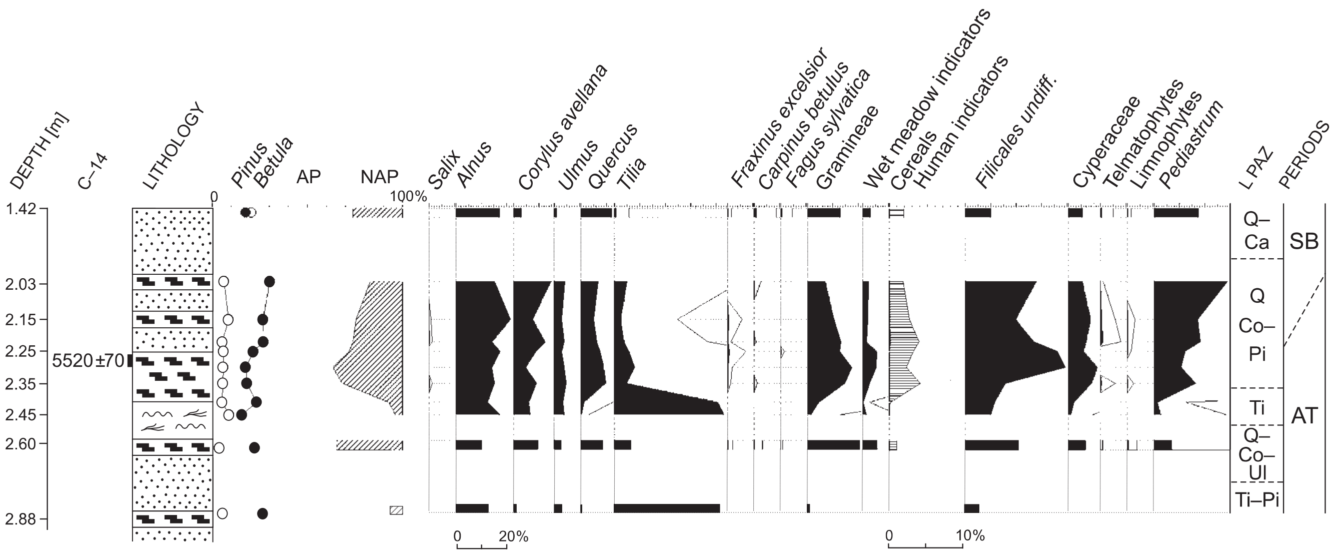


Fig. 24. Rzucewo Headland, R-1 – simplified pollen diagram (after Uścinowicz, Miotk-Szpiganowicz 2003, modified)

For explanations see Fig. 8

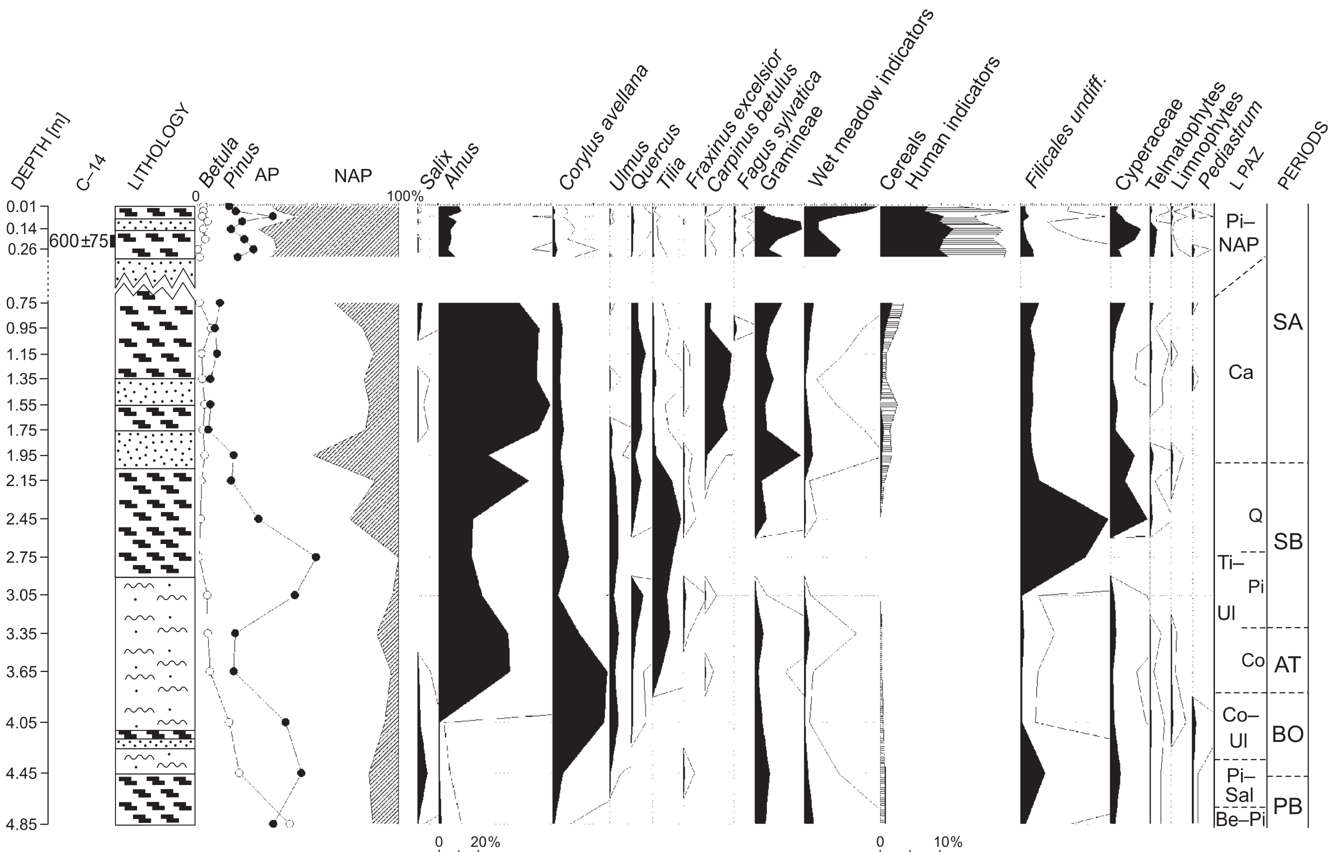


Fig. 25. Gizdepka Valley – simplified, combined pollen diagram (after Miotk-Szpiganowicz 1997, Uścinowicz, Zachowicz 2003, modified)

For explanations see Fig. 8

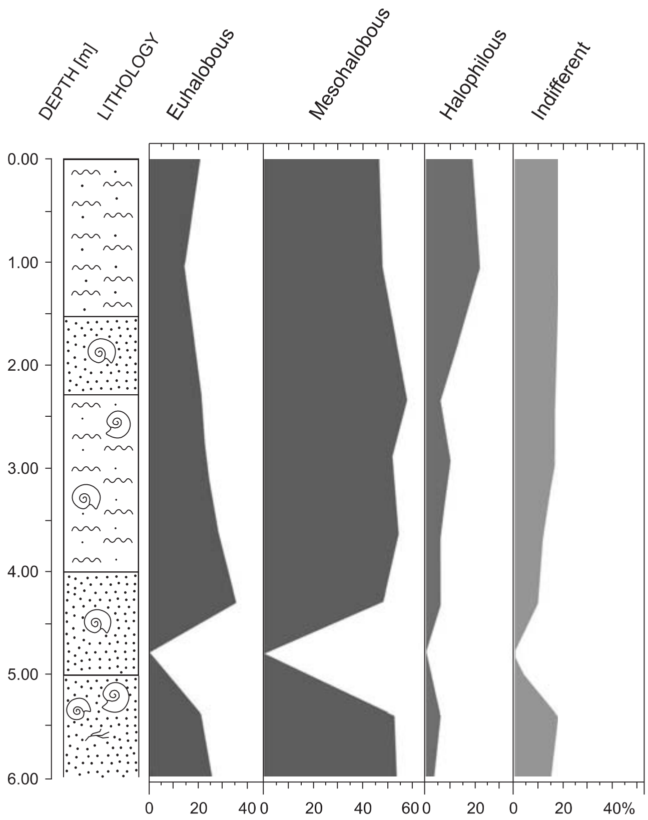


Fig. 26. Puck Lagoon, Kuźnica Hollow – simplified diatom diagram (after Witak 2002, modified)

For explanations see Fig. 8

VISTULA LAGOON

In order to present in more detail the history of vegetation in this area, a combined pollen diagram was drawn for cores Ib and IIIa (Fig. 27) for this water body using the available absolute numerical data (Bogaczewicz-Adamczak, Miotk, 1985a; Zachowicz, 1985). A diatom diagram (Fig. 28) was drawn with the use of percentage data read out from the published diagram (Przybyłowska-Lange, 1973a, b, 1974). A pollen diagram was also drawn for Lake Druzno – core Ia (Fig. 29) (Zachowicz, Kępińska, 1987).

The analysis of the diagrams confirms the previously published information. At the beginning of the Atlantic period, during the *Ulmus–Tilia–Quercus–Corylus* zone (Fig. 27), which began (according to radiocarbon dating) 7050 ±70 years BP in Lake Druzno and 7600 ±95 years BP in the Vistula Lagoon (Figs. 27, 29), an increase in the amount of saltwater and brackish-water diatoms is noted (Fig. 28). According to Zachowicz (1985), it was then that a brackish-water body was formed in place of the pre-existing shallow freshwater basin. The subsequent, both Subboreal and Atlantic, influxes of sea water, which resulted in a slight increase in the number of mesohalobous diatoms (Fig. 28), did not change the basin nature. This is proven by the permanent dominance of freshwater diatoms. The above-mentioned data, as well as the previous research (Zachowicz, 1985), showed that the area of the Vistula Lagoon had never been in the direct range of the Litorina Sea, while sea water got into it only through the Vistula Barrier, poorly developed at that time.

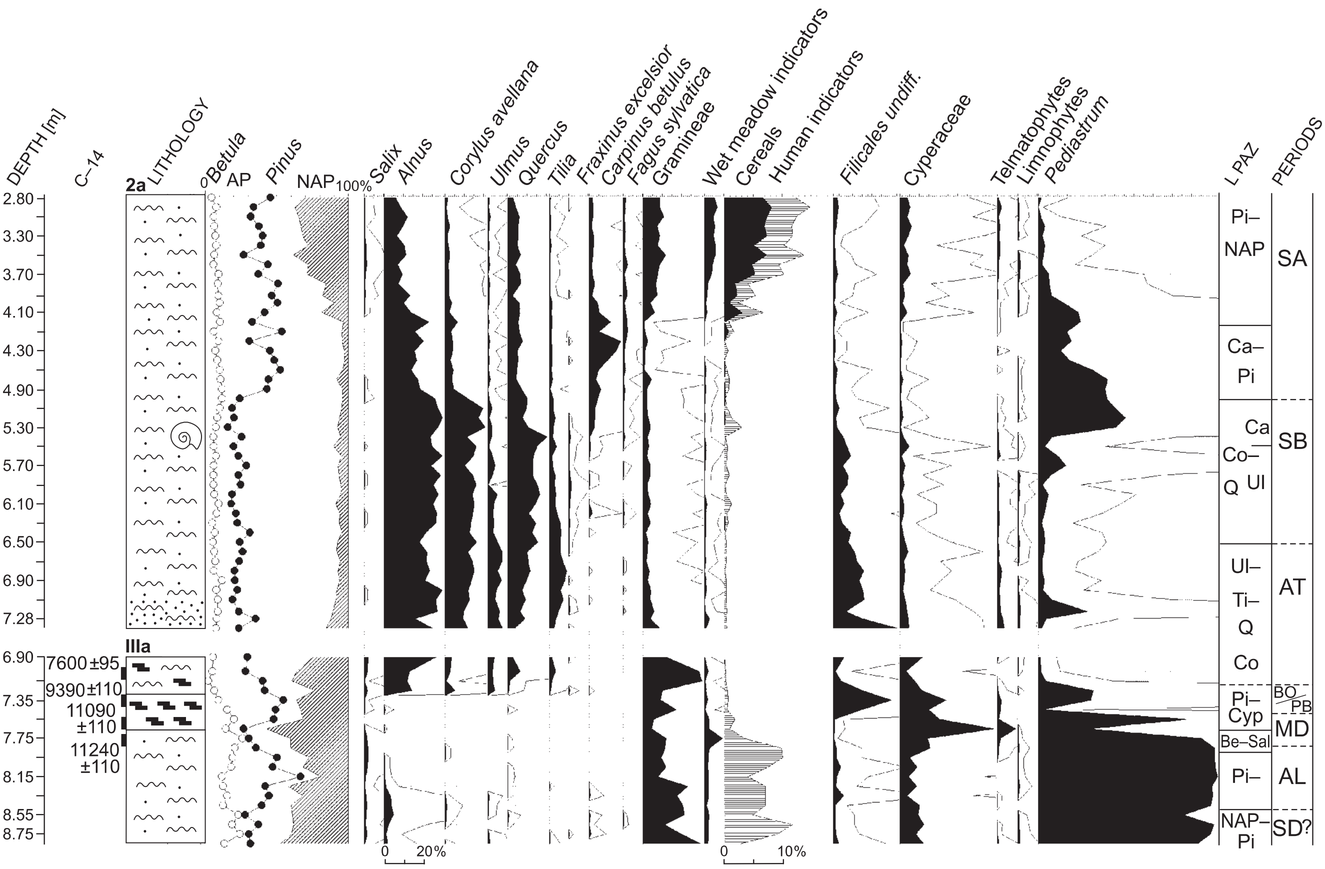


Fig. 27. Vistula Lagoon Ib and IIIa – simplified, combined pollen diagram (after Bogaczewicz-Adamczak, Miotk, 1985a; Zachowicz, 1985; modified)

For explanations see Fig. 8

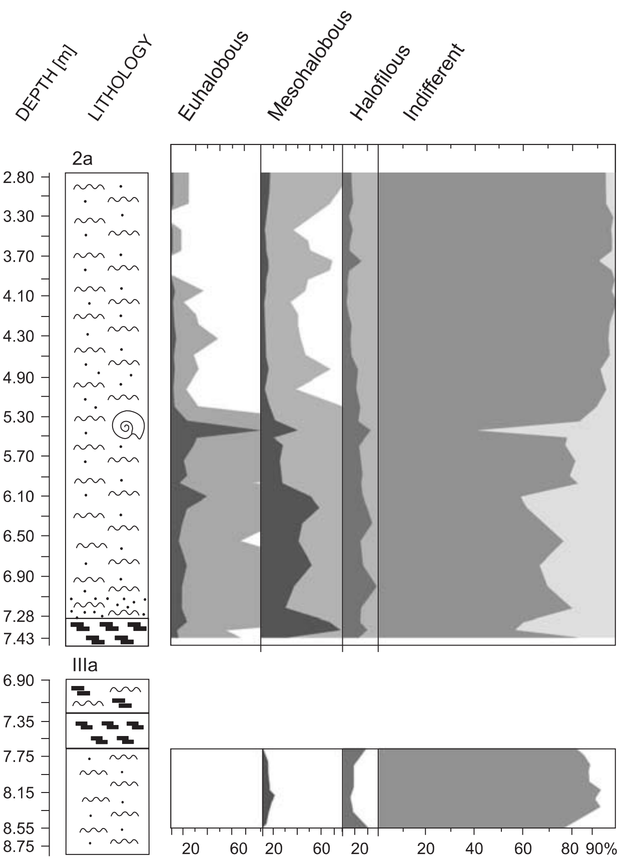


Fig. 28. Vistula Lagoon I – simplified, diatom diagram (after Przybyłowska-Lange, 1974; modified)

For explanations see Fig. 8

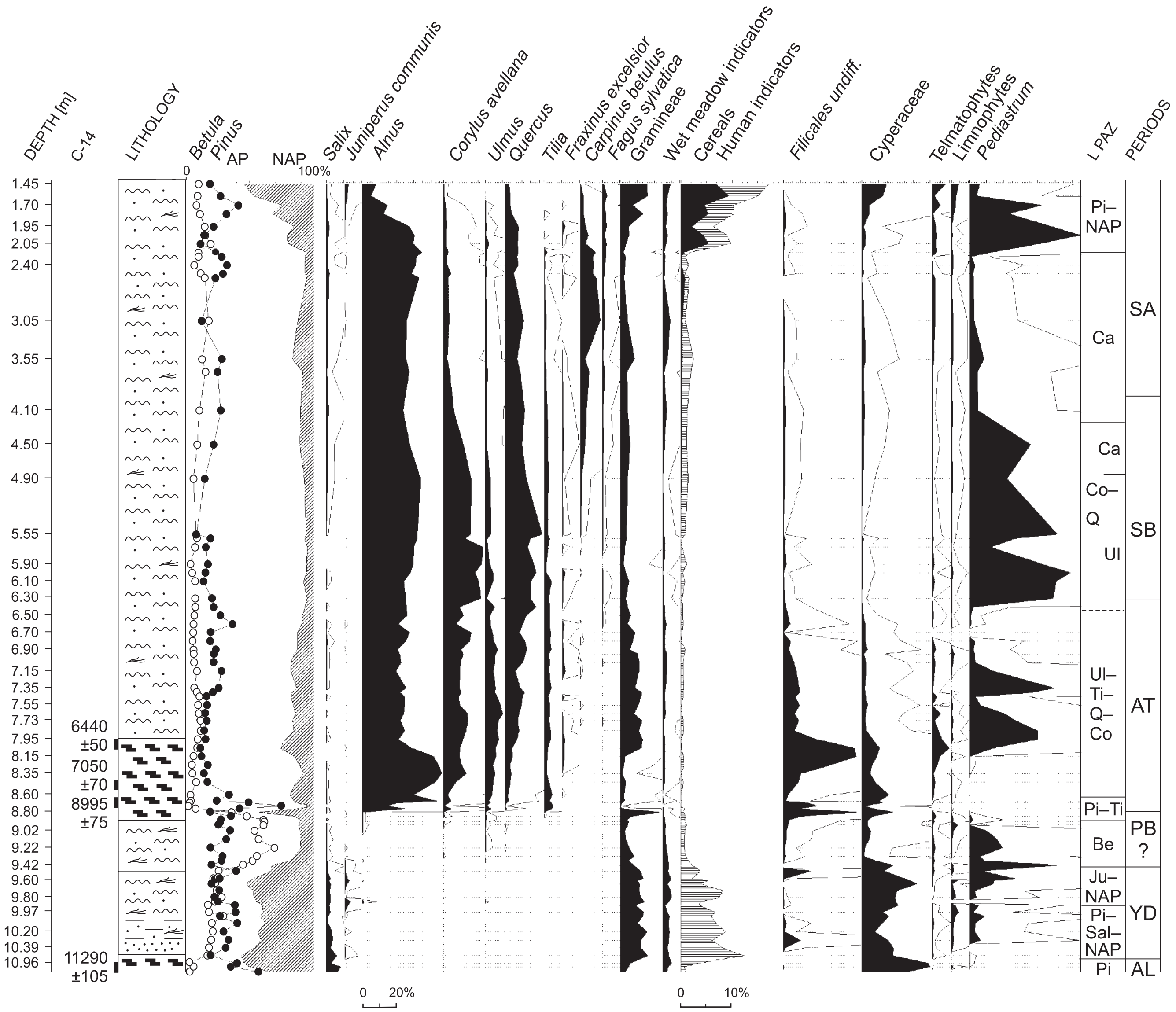


Fig. 29. Druzno Lake Ia – simplified pollen diagram (after Zachowicz, Kępinska, 1987; modified)

For explanations see Fig. 8

DISCUSSION OF RESULTS

The results of biostratigraphic research conducted in the area of Polish lagoon water bodies were compared with those from coastal areas of Germany, Russia and Lithuania (Kabailienė, 1999; Jahns, 2000; Kaiser *et al.*, 2000; Bitinas *et al.*, 2002; Endtmann, 2002; Juspina, Savukyniene, 2002). Thanks to a large number of both classical and AMS radiocarbon dates, diagrams from the German coast (Jahns, 2000; Kaiser *et al.*, 2000; Endtmann, 2002) enabled a relatively accurate placement of events which affected the transformations of plant communities in the north-western coast of Poland (primarily the Szczecin Lagoon), on the time scale.

Palynological information from the south-eastern part of the Curonian Lagoon or, more precisely, the already identified pollen zones from the area of chronozones characteristic of the Late Glacial and Holocene (Mangerud *et al.*, 1974; Kabailienė, 1998), were used for comparisons with the Vistula Lagoon.

For both the western and eastern lagoons of the Polish coast, an expected similarity in the nature of transformations of plant communities with the neighbouring areas located outside of Poland was marked. The differences refer only to a different development of local communities dependent to a large extent on hydrological conditions.

All the biostratigraphic data under comparison are included in Table 1. The comparison of pollen zones (L PAZ) clearly shows that those established for the Late Glacial and Early Holocene were very similar in the entire research area. At that time, these areas were completely covered by peatlands, mires and lakes. It indicates the predominance of similar conditions, not only thermal, but also hydrological ones. More remarkable differences were marked in the second half of the Atlantic period, and more considerable ones occurred in the Subboreal and Subatlantic periods. The composition of plant communities depended at those times to a larger extent on the directions and rate of tree species migration (Ralska-Jasiewiczowa *et al.*, 2004), the extent of the Atlantic climate influence, human economic activity (Latałowa, 1982a, b, 1994, 1995, 1997), and, especially in the study areas, on sea-level oscillations.

The comparison of all the biostratigraphic information shows that some distinct environmental changes are common to the entire study area or at least to its substantial part, while others are local in their character and are marked only within a single water body, although can be helpful in bio- and chronostratigraphic interpretations.

The first type, with a definitely wider range, includes information on the traces of marine influence. The earliest influence of salty water was marked ca. 7000 years BP. It is recorded in the sediments of Vistula Lagoon, Lake Druzno (Przybyłowska-Lange, 1974; Zachowicz *et al.*, 1982; Zachowicz, 1985), and Lake Sarbsko (Lagoon) (at present under the Sarbsko Barrier). In the last locality it is dated at 7590 ±100 years BP, however this date is certainly somewhat exaggerated (Miotk, Bogaczewicz-Adamczak, 1987). The beginning of marine influences recorded in the deposits of the northern part of Jamno Lake (Lagoon) was dated at a similar age (Dąbrowski *et al.*, 1985). It seems that this information needs to be confirmed by diatom flora and radiocarbon tests. In several sites (Jamno II, Szczecin Lagoon I, Szczecin Lagoon 31 – Table 1), a gradual disappearance of rush communities is noted for that time, which may also be associated with a water-level rise.

The first phase of the marine transgression is dated at the earliest period (8000–7800 years BP) only in the Curonian Lagoon barrier (Kabailienė, 1999).

Another marine influence was marked in biostratigraphic analyses in the majority of sites at ca. 6000 years BP or slightly earlier (Table 1). It is chiefly proved by the results of diatom tests from the Szczecin Lagoon (Fig. 10), Jamno Lake (Lagoon) (Fig. 13), indirectly in Sarbsko Lake (Lagoon) (Fig. 20), Lake Druzno (Przybyłowska-Lange 1974), the Nemunas delta (Bitinas *et al.*, 2002) and the Curonian Lagoon (6700–5700 years BP, after Kabailienė, 1999). The water level rise was accentuated in many sites by an increase in the contribution of alder (Alnus) in plant communities (Table 1).

The next marine influence took place ca. 5000 years ago. Diatom research shows that it occurred earliest in the Barther Bodden area (Kaiser *et al.*, 2000), where it is dated at 5520 ±60 years BP. At the same time (Table 1), in the present-day Sarbsko Barrier (Fig. 20) and the Puck Lagoon coast (Fig. 24), the development of peatlands took place (Table 1). Direct marine influence resulting in an increase in the quantity of saltwater and brackish-water diatoms in the deposits was recorded in Jamno Lake (Lagoon) (Fig. 13), Gardno Barrier (Dębina–Rowy VI – Fig. 19), Sarbsko Lake (Lagoon) (Fig. 23), Puck Lagoon (Fig. 26), Vistula Lagoon (Przybyłowska-Lange, 1974) and Curonian Lagoon (5200–4500 years BP, after Kabailienė, 1999).

For the Subboreal and Subatlantic periods there is no such a good time correlation between the successive marine influences observed in various sites documented by diatom tests. Only ca. 4000 years BP there was still an increase in the number of mesohalobous diatoms in the deposits of the Gardno Barrier (Dębina–Rowy, Fig. 19), Sarbsko Lake (Lagoon) (Fig. 23) and the Curonian Lagoon (4000–3500 years BP, after Kabailienė, 1999). The next marine influences were asynchronous indicating that they could be the result of water influxes during storm overflows. This was certainly related to a differentiated degree of isolation of the Baltic water bodies and dependent on the time and rate of the barriers development.

The local features include, for instance, an almost complete lack of diatoms in the Litorina transgression sediments of the present-day Szczecin Lagoon. It is reported in all the studies on diatom analyses from this area (Wypych, 1980a; Witkowski *et al.*, 2003, 2004). It is difficult to say if this absence of diatoms was caused by a high content of sand in the sediments, waves and currents, as Witkowski (Witkowski *et al.*, 2004) would have it, or by e.g. a high content of humus acids washed out from the peatlands flooded by sea water, which made it impossible for diatom flora to develop. Any-way, it seems that it may be a characteristic diagnostic feature in the palaeogeographic research of this area.

A comparison of all the biostratigraphic data also enabled a temporal reinterpretation. First of all in relation to the literature data on the history of Lake Jamno's evolution (Dąbrowski *et al.*, 1985), the decision was by "lowering" the limit of the Atlantic period. This allowed a more detailed specification of the age of palaeoenvironmental changes by distinguishing local pollen zones (L PAZ), and thus a more precise age determination of the observed (Fig. 13) marine influence phases (Tab. 1).

Besides, the comparison of the existing biostratigraphic data and the distinguishing of pollen zones (L PAZ) for all the sites under comparison gave rise to the statement that a large amount of information present in older literature requires verification by conducting palaeogeographic research using more modern research methods, such as for instance AMS radiocarbon dating. The information about the direct influence of the Early Atlantic marine transgression phase on the northern area of Lake Jamno (Lagoon) (Dąbrowski *et al.*, 1985) should also be confirmed. The palynological dating of this event still seems to be appropriate (Fig. 11, Table 1) although a certain rejuvenation of palaeogeographic events took place after the change in the timing of the Atlantic period. However, the correlation between the deposition of the sandy-silty layer and the sea water influence should be confirmed by diatom analyses. The area of Lake Gardno (Lagoon) also requires additional research. From the literature data (Bogaczewicz--Adamczak, Miotk, 1985b) it follows that at the turn of the Atlantic and Subboreal periods, a marine water body existed in the area of the present-day Gardno Barrier (Fig. 18, 19). At the same time, the present-day lake was taken up by a peatland. It was under the direct influence of sea water, as indicated by the presence of small quantities of mesohalobous diatoms characteristic of the Litorina transgression in the peat deposits (Zachowicz, Zaborowska, 1985). However, these events do not have absolute radiocarbon dating. The peat deposits of Lake Gardno (Lagoon) were radiocarbon dated (Wojciechowski, 1990), but it is difficult to correlate these dates with biostratigraphic data.

The coastal area of lakes and lagoons causes difficulties in biostratigraphic research due to numerous sedimentation gaps resulting from either erosional processes during transgressions or disturbances in peat deposition due to hydrological changes.

Within an individual reservoir, different types of biostratigraphic research were very often conducted in various sites, making it immensely difficult to interpret and compare the results. Such a situation is observed in the Puck Lagoon, where palynological and diatom research pertained to quite different sites. The diatom diagram comes from the Kuźnica Hollow (Witak, 2002), while the palynological diagrams was constructed for the southern part of the present-day water body (Miotk-Szpiganowicz, 1997; Uścinowicz, Miotk-Szpiganowicz, 2003; Uścinowicz, Zachowicz, 2003). Therefore, it is difficult to associate the changes in the water body character recorded in the diatom spectra with the results of palynological research and with the time scale.

Comparison of the existing biostratigraphic data and radiocarbon dating shows that, for some areas of the coastal lakes, practically no palaeogeographic studies have been made to date. The lakes include: Resko, Bukowo, Kopań, Wicko and Łebsko. The studies conducted in these areas with the use of modern research methods would certainly shed new light on the progress and duration of the individual marine transgression phases. It would also make it possible to learn the development of the coast, among others to determine the time in which Jamno and Bukowo lakes, as well as Gardno, Łebsko and Sarbsko lakes constituted conjoint water bodies.

CONCLUSIONS

The comparison of all the biostratigraphic data related to the development of the lagoons from the Poland's coast enabled a comprehensive insight into palaeogeography of this area. This created a possibility of capturing the common elements in the historical evolution of the discussed water bodies related to marine transgression phases.

Comparison of the available biostratigraphic data, identification of pollen zones and comparison with well-dated reference sites enabled determination of the approximate time of accelerated sea-level rise periods and increased frequency of storm surges – the subsequent marine transgressions, when the study areas were under direct marine influence. Such influence was marked ca. 7000, 6000, 5000 and 4000 years BP.

The observed period of ca. 1000 years of marine influence oscillations is well correlated with the periodicity of climatic changes discovered by Stuiver and Braziunas (1993), Stuiver *et al.* (1995), Chapman and Shackelton (2000).

Marine influences of the Post-Litorina period were associated predominantly with the influxes of sea water through more or less developed barriers. That is why these events are asynchronous, as they depend more on the degree of isolation of the water body from the sea, than on the sea-level rise.

The areas of coastal lakes, especially those which have never been the subject of palaeogeographic research, such as Bukowo, Kopań or Łebsko, require performing such research using modern methods for age determination of organic deposits. The research would enable a more precise determination and range of both the Litorina and Post-Litorina marine transgression phases.

REFERENCES

BAUER W., 1963 — Hydrographische Beobachtungen im Kleinem Haff und seinen Nebengewässern in den Jahren 1958–1960. *Z. f. Ficherei u. deren Hilfswiss.*, **11**, 7/8.

BERGLUND B.E., 1964 — The Postglacial shore displacement in eastern Blekinge, southeastern Sweden. *Sveriges Geologiska Undersökning*, **C599**.

BERGLUND B.E., 1971 — Litorina transgressions in Blekinge, south Sweden, a preliminary survey. *Geol. Fören. Stockholm – Forhandl.*, **93**: 625–652.

BITINAS A., DAMUSYTE A., STANCIKAITE M., ALEKSA P., 2002 — Geological development of the Nemunas River Delta and adjacent areas, West Lithuania. *Geol. Quart.*, **46**, 4: 375–389.

BOGACZEWICZ-ADAMCZAK B., 1980 — Późnoglacjalna i holoceńska flora okrzemek w osadach dennych Zalewu Wiślanego. Late-Glacial and Holocene diatom flora in bottom sediments from the Vistula Lagoon. *Zeszyty Nauk. Wydz. BiNoZ UG, Geografia*, **11**: 53–59.

BOGACZEWICZ-ADAMCZAK B., MIOTK G., 1985a — Z biostratygrafii osadów Zalewu Wiślanego. Peribalticum III, Gdańskie Towarzystwo Naukowe: 113–127.

BOGACZEWICZ-ADAMCZAK B., MIOTK G., 1985b — From biostratigraphical studies of sediment from the region of Lake Gardno [in Polish, Eng. summ.]. Peribalticum III, Gdańskie Towarzystwo Naukowe: 79–96.

BOGACZEWICZ-ADAMCZAK B., FEDOROWICZ S., GOŁĘBIEWSKI R., MIOTK G., 1981 — Polodowcowa historia jeziora Gardno. *Zesz. Nauk. Wydz. BiNoZ UG, Geografia*, **12**: 27–49.

BORÓWKA K.R., OSADCZUK A., WITKOWSKI A., 2001 — Late Glacial and Holocene stages of the Szczecin Lagoon development. *In*: 15 Treffen Deutschsprachiger Diatomologen (eds. A. Witkowski, W. Kowalski): 6–12. Uniwersytet Szczeciński, Szczecin.

BORÓWKA K.R., OSADCZUK A., WITKOWSKI A., WAWRZYNIAK-WYDROWSKA B., 2001 — The deposit sequences of the Szczecin Lagoon. *In*: 15 Treffen Deutschsprachiger Diatomologen (eds. A. Witkowski, W. Kowalski): 13–33. Uniwersytet Szczeciński, Szczecin.

BORÓWKA R., LATAŁOWA M., OSADCZUK A., ŚWIĘTA J., WITKOWSKI A., 2002 — Palaeogeography and palaeoecology of the Szczecin Lagoon. *Greifswalder Geographische Arbeiten*, **27**: 107–113.

BORÓWKA R., OSADCZUK A., LATAŁOWA M., DUDA T., WOZIŃSKI R., WITKOWSKI A., ŚWIĘTA-MUSZNICKA J., KOSIŃSKA B., 2005 — Pokrywa osadowa Zalewu Szczecińskiego i jej wymowa paleogeograficzna. *In*: Środowisko przyrodnicze wybrzeży Zatoki Pomorskiej i Zalewu Szczecińskiego (eds. R.K. Borówka, S. Musielak): 93–103. Wybrane aspekty. Szczecin.

BRANDT K., 1906 — Vergleichende Untersuchungen des Stettiner Haffes und des Papenwassers. Die Beteiligung Deutschlands an der Internationelen Meeresforschung **3**. Jahresber. Berlin.

BROCKMANN Chr., 1954 — Die Diatomeen in den Ablagerungen der ostpreussischen Haffe. Meyniana 3. Kiel.

CHAPMAN M.R., SHACKELTON N.J., 2000 — Evidence of 550-year and 1000-year cyclicities in North Atlantic circulation patterns during the Holocne. *The Holocene*, **10**, 3: 287–291.

DĄBROWSKI J., M., LUBLINER-MIANOWSKA K., ZACHOWICZ J., WYPYCH K., 1985 — Bottom sediments of Lake Jamno in the light of palynological studies [in Polish, Eng. summ.]): 37–52. Peribalticum III, Gdańskie Towarzystwo Naukowe.

DIGERFELDT G., 1975 — Investigations of Litorina transgessions in the ancient lagoon Barsebäckmossen, western Skåne. University of Lund. Department of Quaternary Geology. Report 7.

ENDTMANN E., 2002 — Das "Herthamoor" — ein palynostratigraphisches Leitprofil fűr das Holozän der Insel Rűgen. *Greifswalder Geographische Arbeiten*, **26**: 143–147.

GROSS H., 1941 — Beitrag zur Entwicklungsgeschichte des Frischen Haffs. *Geologie das Meere und Binnengewässer*, **5**, 4: 39–68.

HAACK E., 1960 — Das Achterwasser. Eine geomorphologische und Hydrographische Untersuchung. Neuere Arbeiten zur Mecklenb. Küstenforschung, **4**. Berlin.

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.

IVERSEN J., 1937 — Undersøgelser over Litorinatransgressioner i Danmark. (Foreløbelig Meddelelse). *Meddelelser fra Dansk Geologisk Forening*, **9**: 223–232.

JAHNS S., 2000 — Late-glacial and Holocene woodland dynamics and land-use history of the Lower Oder velley, north-eastern Germany, based on two, AMS 14C-dated, pollen profiles. *Veget. Hist. Archaeobot.*, **9**: 111–123.

JANKE W., 2002 — Pollen and diatom analyes from sediment cores of the Szczecin Lagoon. *Greifswalder Geographische Arbeiten*, **27**: 115–117.

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

JUSPINA L., SAVUKYNIENE N., 2002 — Pollen grains, spores and diatoms. *In*: Geology of the Gdansk Basin, Baltic sea. *In*: Holocene sediments of the Gdansk Basin (ed. E.E. Emelyanov): 118–134. Russian Academy of Sciences, Yantarny Skaz, Kaliningrad.

KABAILENĖ M., 1998 — Vegetation history and climate changes in Lithuania during the Late Glacial and Holocene, according pollen and diatom data. *PACT*, **54**: 13–30.

KABAILENĖ M., 1999 — Water level changes in SE Baltic based on diatom stratigraphy of Late Glacial and Holocene deposits. *Geologija*, **29**: 15–29.

KAISER K., ENDTMANN E., JANKE W., 2000 — Befunde zur Relief-, Vegetations- und Nutzungsgeschichte an Ackersöllen bei Barth, Lkr. Nordvorpommern. *Bodendenkmalpflage in Mecklenburg-Vorpommern*, **47**: 151–180.

KRAMARSKA R., USCINOWICZ Sz., ZACHOWICZ J., 1995 — Origin and evolution of the Puck Lagoon. *J. Coast. Res.*, Spec. Issue, **22**: 187–191.

LATAŁOWA M., 1982a — Major aspects of the vegetational history in the eastern Baltic coastal zone of Poland. *Acta Palaeobot.*, **22**, 1: 47–63.

LATAŁOWA M., 1982b — Postglacial vegetational changes in the eastern Baltic coastal zone of Poland. *Acta Palaeobot.*, **22**, 2: 179–249.

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

LATAŁOWA M., 1992 — Man and vegetation in the pollen diagrams from Wolin Island (NW Poland). *Acta Palaeobot.*, **32**, 1: 123–249.

LATAŁOWA M., 1994 — Gospodarka mezolityczna i początki rolnictwa na obszarze polskiego Pobrzeża Bałtyku w świetle danych palinologicznych. *Polish Botanical Studies, Guidebook Series*, **11**: 135–153.

LATAŁOWA M., 1995 — Zarys problematyki palinostratygrafii holocenu polskiego pobrzeża Bałtyku. *In*: Geologia i Geomorfologia Pobrzeża i Południowego Bałtyku 2 (ed. W. Florek): 111–125. WSP Słupsk.

LATAŁOWA M., 1997 — Impact of the late Bronze and early Iron Age settlement on the late Holocene history of forests in the Baltic coastal zone of Poland [in Polish, Eng. sum]. *In*: Dynamika i ochrona roślinności Pomorza (eds. W. Fałtynowicz *et al.*): 113–124. Bogucki Wyd. Nauk., Gdańsk–Poznań.

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

LATAŁOWA M., BORÓWKA R.K., 2003 — Palino- i chronostratygrafia osadów dennych Zalewu Szczecińskiego. Paleogeografia Zalewu Szczecińskiego w świetle badań interdyscyplinarnych. Sesja naukowa. Prace Komisji Paleogeografii Czwart. PAU. Tom I. Kraków: 105–108.

LATAŁOWA M., BADURA M., 2003 — Pollen and macrofossil analysis of the sediments in the area of the underwater medieval site at Puck. Rapid transgressions into semi-enclosed basins. 8–10 May 2003. Gdańsk–Jastarnia. PGI. Excursion Guide Book: 131–134.

LATAŁOWA M., ŚWIĘTA J., 2003 — Późnoglacjalna i holoceńska sukcesja roślinności lokalnej na obszarze Zalewu Szczecińskiego. *In*: Człowiek i środowisko przyrodnicze Pomorza Zachodniego. II Środowisko abiotyczne (eds. R.K.Borówka, A.Witkowski): 123–129. Oficyna IN PLUS, Szczecin.

LATAŁOWA M., WITKOWSKI A., WAWRZYNIAK-WYDROWSKA B., ŚWIĘTA J., WOZIŃSKI R. BORÓWKA R.K., 2003 — Ewolucja ekosystemów na obszarze Zalewu Szczecińskiego w późnym glacjale i holocenie. *In*: Człowiek i środowisko przyrodnicze Pomorza Zachodniego. II Środowisko abiotyczne (eds. R.K. Borówka, A. Witkowski): 119–122. Oficyna IN PLUS, Szczecin.

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.

MÖRNER N.A., 1976 — Eustatic changes during the last 8000 years in view of radiocarbon calibration and new information from the Kattegatt region and other northwestern European coastal areas. *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **19**: 63–85.

MÖRNER N. A. 1980 a — Late Quaternary sea-level changes in north-western Europe: a synthesis. *Geol. Förhandl.*, **100**: 381–400.

MIOTK G., BOGACZEWICZ-ADAMCZAK B., 1987 — Marine transgressions on the basis of investigations of subfossil biogenic sediments in the Sarbska Bar, Southern Baltica. *Quaternary Studies in Poland*, **7**: 65–72.

MIOTK-SZPIGANOWICZ G., 1997 — Results of palynological investigations in the Rzucewo area. *In*: The Built Environment of Coast Areas during the Stone Age (ed. D. Król): 153–162. The Baltic Sea-Coast Landscapes Seminar, Session No 1. Gdańsk.

NEUHAUS E., 1933 — Studien über das Stettiner Haff und seine Nebengewässer. I Untersuchungen über die allgemeinen hydrographischen und biologischen Verhältnisse. *Zeitsschrift f. Fischerei*, **31**: 1–92.

NOWACKI J., 1993 — Morfometria Zatoki. *In*: Zatoka Pucka (ed. K. Korzeniewski): 71–78. Instytut Oceanografii Uniwersytetu Gdanskiego, Gdańsk.

OSADCZUK K., 2004 — Geneza i rozwój wałów piaszczystych Bramy Świny w świetle badań morfometrycznych i sedymentologicznych. *Wydawnictwo Naukowe Uniwersytetu Szczecińskiego. Rozprawy i Studia*, **552**.

POMIAN I., LATAŁOWA M., ŁĘCZYŃSKI L., BADURA M., 2000 — Water or land? Preliminary results of interdisciplinary Project of palaeoenvironmental reconstruction At the site of the mediewal harbour In Puck (N. Poland). *In*: Down the river to the sea (ed. J. Litwin): 27–36. Proceedings of the Eighth International Symposium on Boat and Ship Archaeology, 1997, Gdańsk.

PRUSINKIEWICZ Z., NORYSKIEWICZ B., 1966 — Problem of age of podzols on brown dunes of bay bar of River Świna in the light of palynological analysis and dating by radiocarbon [Eng. summ.]. *Zeszyty Naukowe Uniwersytetu Mikołaja Kopernika w Toruniu, Geografia*, **5**: 75–88.

PRZYBYŁOWSKA W., 1973a — Analiza okrzemkowa osadów dennych Zalewu Wiślanego. *Prz. Geof.*, **18**, 1/2: 121–126.

PRZYBYŁOWSKA W., 1973b — Wyniki analizy okrzemkowej profilu osadów dennych Zalewu Wiślanego. *Prz. Geof.*, **18** (25), 1/2: 121–126.

PRZYBYŁOWSKA-LANGE W., 1974 — Development of the Vistula Firth in the light of diatom analysis [in Polish, Eng. summ.] *Pr. Inst. Met. Gosp. Wodnej*, **2**: 129–164.

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

PRZYBYŁOWSKA-LANGE W. 1981 — Diatoms of lake deposits from the Polish Baltic Coast. III Lake Sarbsko. *Acta Palaeobot.*, **21**, 2: 145–160.

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., TURNER CH. (eds.), 2004 — Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. Szafer Inst. Of Botany, Polish Academy of Sciences, Kraków.

ROSA B., 1963 — O rozwoju morfologicznym wybrzeża Polski w świetle dawnych form brzegowych. *Studia Societatis Scientiarum Torunensis*, **5**.

ROSA B., 1968 — The South Baltic area during the last glaciation and the Holocene [in Polish, Eng. summ.]. *In*: Last Scandinavian Glaciation in Poland (ed. R. Galon). *Pr. Geogr.*, **74**: 121–155.

SONNTAG P., 1915–1918 — Hela, die Frische Nehrung und das Haff. *Schriften d. Naturforschenden Ges.*, N.F., **14**, 1.

STUIVER M., BRAZIUNAS T.F., 1993 — Modeling atmospheric ^{14}C influences and 14C ages of marine samples to 10,000 BCA. *Radiocarbon*, **35**: 137–189.

STUIVER M., GROOTES P.M., BRAZIUNAS T.F., 1995 — The GISP2 δ^{18}O record of the past 16,500 years and the role of the sun, ocean, and volcanoes. *Quater. Res.*, **44**: 341–354.

TOBOLSKI K., 1967 — The palynological analysis of the deposits from the Lake of Sarbsko [in Polish, Eng. summ.]. *Bad. Fizjogr. Nad Polską Zach.*, **20**: 173–177.

TOBOLSKI K., 1987 — Holocene vegetational development based on the Kluki reference site in the Gardna–Łeba Plain, *Acta Palaeobot.*, **27**, 1: 179–222.

TOBOLSKI K., 1989 — Holoceńskie transgresje Bałtyku w świetle badań paleoekologicznych Niziny Gardzieńsko–Łebskiej. *Studia i Materiały Oceanologiczne*, **56**, Geologia Morza, 4: 257–265.

UHL I., 1939 — Neue Anschaungen üEntstehnung des Frischen Haffs und der Frischen Nehrung. *Geologie d.Meere und Binnegewässer*, **3**.

UŚCINOWICZ Sz., ZACHOWICZ J., 1996 — Geochemical Atlas of the Vistula Lagoon. Pol. Geol. Inst., Warszawa.

UŚCINOWICZ Sz., MIOTK-SZPIGANOWICZ G., 2003 — Holocene shoreline migrations In the Puck Lagoon (Southern Baltic Sea) based on the Rzucewo Headland case study. *Landform Analysis*, **4**: 83–97.

UŚCINOWICZ Sz., ZACHOWICZ J., 2003 — Environment around the Mediaeval harbor in Puck. *In*: Rapid transgressions into semi-enclosed basins (eds. Sz. Uścinowicz, J. Zachowicz):

121–130. Abstracts and excursion guidebook. Pol. Geol. Inst., Gdansk.

WITAK M., 2001 — A Late Glacial flora from lacustrine sediments of Puck Bay, Southern Baltic Sea, Poland. *In*: Studies on diatoms (ed. R. Jahn *et al.*): 457–475. Lange-Bertalot-Festschrift, Ganter, Rugell.

WITAK M., 2002 — Postglacial History of the development of the Puck Lagoon (the Gulf of Gdansk, Baltic Sea) based on the Diatom Flora. *Diatom Monogr.*, **2**: 1.

WITKOWSKI A., 1991 — Diatoms of the Puck Bay coastal shallows (Poland, Southern Baltic). *Nord. J. Bot.*, **11**: 689–701.

WITKOWSKI A., WITAK M., 1993 — Budowa geologiczna dna Zatoki. *In*: Zatoka Pucka (ed. K. Korzeniewski): 309–315. Inst. Oceanografii Uniwersytetu Gdanskiego, Gdansk.

WITKOWSKI A., BĄK M., LUTYŃSKA M., OLAS M., GREGOROWICZ P., BERNAT D., 2003 — Paleogeografia Zalewu Szczecińskiego w świetle badań interdyscyplinarnych. Sesja naukowa. Prace Komisji Paleogeografii Czwart. PAU. Tom I. Kraków: 113–117.

WITKOWSKI A., LATAŁOWA M., BORÓWKA R.K., GREGOROWICZ P., BĄK M., OSADCZUK A., ŚWIĘTA J., LUTYŃSKA M., WAWRZYNIAK-WYDROWSKA B., WOZIŃSKI R., 2004 — Palaeoenvironmental changes in the area of the Szczecin Lagoon (the south western Balic Sea) as recorded from diatoms. *Studia Quaternaria*, **21**: 153–165.

WOJCIECHOWSKI A., 1990 — Lithofacies analysis of Lake Gardno deposits [in Polish, Eng. summ.]. *Wydawnictwo Naukowe Uniwersytetu im. Adama Mickiewicza w Poznaniu, Geografia*, **49**: 1–120.

WYPYCH K., 1975 — Geologia, charakterystyka geomorfologiczna, ukształtowanie dann i osady denne zalewu. Historia zalewu. Hydrometeorologiczny ustrój Zalewu wiślanego. Wydawnictwa Komunikacji i Łączności, Warszawa.

WYPYCH K., 1980a — Osady denne Zalewu Szczecińskiego. *In*: Zalew Szczecinski (ed. A. Majewski): 54–72. Instytut Meteorologii i Gospodarki Wodnej, Wydawnictwa Komunikacji i Łączności, Warszawa.

WYPYCH K., 1980b — Powstanie i rozwój Zalewu Szczecińskiego. *In*: Zalew Szczeciński (ed. A. Majewski): 72–89. Instytut Meteorologii i Gospodarki Wodnej, Wydawnictwa Komunikacji i Łączności, Warszawa.

ZABOROWSKA K., 1977 — Analiza flory okrzemek osadów dennych jeziora Gardno. Studia i Materiały Oceanologiczne nr 19, Podstawy Gospodarki w środowisku morskim I. *Bad. Geol. Geof.*, **4**: 304–306.

ZACHOWICZ J., 1973 — Results of the pollen analysis of the profile no.2 from the Lake Jamno [in Polish, Eng. summ.]. *Prz. Geof.*, **18**, 1/2: 127–131.

ZACHOWICZ J., 1977 — Analiza palinologiczna osadów jeziora Gardno. Studia i Materiały Oceanologiczne, 19. Podstawy Gospodarki w Środowisku Morskim I. *Bad. Geol. Geof.*, 4: 299–303.

ZACHOWICZ J., 1985 — Z badań biostratygraficznych nad osadami Zalewu Wiślanego. Peribalticum III, Gdańskie Towarzystwo Naukowe: 97–111.

ZACHOWICZ J., PRZYBYŁOWSKA-LANGE W., NAGLER J., 1982 — The Late-Glacial and Holocene Vegetational History of the Żuławy Region, N. Poland. A biostratigraphic study of Lake Drużno sediments. *Acta Palaeobot.*, **22**, 1: 141–161.

ZACHOWICZ J., ZABOROWSKA K., 1985 — Bottom sediments of Lake Gardno in the light of biostratigraphical studies [in Polish, Eng. summ.]. Peribalticum III: 67–77. Gdańskie Towarzystwo Naukowe.

ZACHOWICZ J., KĘPIŃSKA U., 1987 — The Paleoecological Development of Lake Druzno (Vistula Deltaic Area). *Acta Palaeobot.*, **27**, 1: 227–249.