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A multidisciplinary study on the palaeoenvironmental history of the Resko Przymorskie Lake spit during the Late Glacial and Holocene (the southern Baltic coast, NW Poland)

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The paper presents the results of sedimentological and biostratigraphical analyses from the Resko Przymorskie Lake spit (NW Poland), supported by radiocarbon datings. The study has aimed to recognize the geological structure of the spit and its base and to recognize the palaeoenivronmental changes. Nine sedimentary series composing the Resko Przymorskie Lake spit have been distinguished (I–IX). The oldest sediments are the Vistulian Glaciation till (series I) and fluvioglacial sand and gravel (series II). In the Early Holocene, in the study area there was a river valley (series III) followed by a shallow water basin (series IV), which was replaced by a peat bog (series V). In the Atlantic (7.4 ka cal BP), the water level rose (Littorina transgression) and accumulation of lagoonal sediments started (series VI). Biostratigraphic analysis of deposits in series VI indicates a marine influence. In the Atlantic and Subboreal, the spit moved southwards and fine sand (series VII) was deposited on lagoonal gyttja and silt (series VI). In the western part of the study area, peat accumulated (series VIII), dated at 6.7 ka cal BP (Late Atlantic). The youngest series IX is composed of aeolian fine sand in white dunes that formed in the last 400 years.

Key words: sedimentology, pollen, diatom, ostracods, molluscs, Baltic Sea coast.

INTRODUCTION

Relative sea level changes are among the major objectives of the research into the southern Baltic Sea coast. Uścinowicz (2003) divided the history of sea level changes in the southern Baltic Sea into three stages. The first stage (13.0–8.5 ka BP) was characterized by large and rapid sea level changes within an amplitude as wide as 25–30 m. The second stage (8.5–5.0 ka BP) was characterized by a constant sea level rise (which was initially fast – 15 mm/yr). In the third stage (last 5000 years) the sea level slowly rose. Despite many studies (Kramarska et al., 1995; Rotnicki, 1999, 2001, 2009; Cedro, 2003, 2004, 2005, 2012; Uścinowicz, 2003, 2006; Uścinowicz and Miotk-Szpiganowicz, 2003; Bitinas and Damušytė, 2004; Berglund et al., 2005; Hoffmann et al., 2005; Lampe, 2005; Rotnicki et al., 2009; Lampe et al., 2011) the Holocene sea level changes are still poorly investigated in some areas of the southern Baltic Sea.

As a result of the sea level rising during the Littorina transgression, intense coast abrasion took place. In this way, a large amount of material was released that was then used to form the spits (Wypych, 1973; Tomczak, 1995). At the end of the Atlantic, the spits were narrow and low and they were rapidly evolving (Uścinowicz, 2003).

According to Uścinowicz (2003), two basic spit types can be discriminated during the Subboreal: stationary and landward-migrating spits. The first type with a well-developed dune system emerged in areas where sandy material was supplied in large amounts. This type is represented by the spits of Świna Gate and Łebsko Lake. The second type has poorly developed dune systems (frequently limited to a foredune) evolved in areas with deficiency of sandy material. These spits developed as transgressing spits, entering the lagoons in their hinterland. This type is represented by the spits of Jamno Lake and Bukowo Lake.

The geological structure and evolution of the spits in the southern Baltic Sea are also described in detail by Keilhack (1912, 1914), Rotnicki (1999), Hoffmann (2004), Osadczuk (2004, 2005), Hoffmann et al. (2005), Hoffmann and Barnasch (2005), Hoffmann and Lampe (2007), Janczak-Kostecka and Kostecki (2008) and Rotnicki et al. (2009).

The present article describes the results of detailed studies on the spit of Resko Przymorskie Lake located in the eastern

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coast of Pomeranian Bay. The objectives of the study were to recognize the geological structure of the spit and its base, as well as the palaeoenivronmental changes.

In order to solve this scientific problem, a sedimentological study along with ostracod, mollusc, diatom and pollen analyses and radiocarbon dating (^{14}C) were carried out. Application of the multiproxy approach provided better understanding of environmental changes in the area of Pomeranian Bay coast.

In the 1990s and 2000s, geological mapping was performed in the study area for the *Geodynamic Map of the Polish Coastal Zone in the Baltic Sea* at the scale of 1:10,000, Dźwirzyno Sheet (Dobracki and Zachowicz, 1997). One borehole was drilled in the area of the spit and another in the bottom of Resko Przymorskie Lake. Samples recovered from those boreholes provided information for a few publications describing this area. These papers focused mainly on lithofacies description, seismoacoustic research and fossil fauna present in the sediments (Krzymińska et al., 2003, 2011; Krzymińska and Przezdziecki, 2008). There were, however, no publications that based on a multiproxy approach.

Some information about the environs of the study area was presented in a number of publications from the Rega River valley near Mrzeżyno (Cedro, 2003, 2004, 2005, 2012; Mianowicz and Cedro, 2013), as well as in the study of the coast between Niechorze and Mrzeżyno (Sydor and Kotrys, 2013) and in the study of sediments exposed in the cliff near Niechorze (Kopczyńska-Lamparska, 1976; Brykczyńska, 1978; Cieśla and Marciniak, 1982; Kopczyńska-Lamparska et al., 1984; Ralska-Jasiewiczowa and Rzętkowska, 1987).

STUDY AREA

The study area is located in NW Poland on the coast of Pomeranian Bay (Fig. 1). The area is described as a spit coast with two dune ridges, 5 to 10 m in height. The average beach width is 55 m (Musielak et al., 2005). The area is adjacent to the southern shallow part of the Baltic Sea where the till is overlain by marine sand (fine to medium sand), with a thickness of less than 1 m (Kramarska et al., 1995; Kramarska, 1999).

On the coast, the dominant feature is a meltwater valley (0.5–1.0 m a.s.l.). Its lowest part is occupied by Resko Przymorskie Lake. The valley feeds the Rega and Błotnica rivers. The bottom of the valley is filled with peat. Directly to the south of the valley (and Resko Przymorskie Lake) there is a moraine upland elevated up to 20 m over the surrounding terrain. The central part of the upland is incised by the Samowo subglacial valley (Dobracka, 1990, 1992).

METHODS

Two boreholes were drilled in the study area. The total recovery was 9.6 m (borehole O4) and 15.6 m (borehole O8) (Fig. 1). The coordinates of the drill sites (Figs. 2 and 3) are provided in WGS84 Coordinate System. The boreholes were sampled for sedimentological, pollen, diatom, ostracod, mollusc analysis and radiocarbon dating (^{14}C). The following archival drilling profiles were used to process the results: borehole (Bh) 4T drilled for the *Geodynamic Map of the Polish Coastal Zone in the Baltic Sea* at the scale of 1:10,000, Dźwirzyno Sheet (Dobracki and Zachowicz, 1997) and water well profiles (Bh 780062, Bh 780143) from the Polish Geological Institute – National Research Institute hydrogeological database – the Hydro Data Bank.

SEDIMENTOLOGICAL ANALYSIS

The study was performed on 122 samples from sandy deposits (O4 and O8 boreholes), including a grain-size analysis (on 5 samples from the 4T borehole, published by Dobracki and Zachowicz, 1997) as well as observations of rounding and frosting of quartz grains from O4 and O8 boreholes.

Grain-size analysis. Samples were dried and sieved on the *Fritsch Vibratory Sieve Shaker Analysette 3 PRO*. The mesh interval of the sieves was 0.25 phi. For each sample, textural parameters were defined according to Folk and Ward (1957). Basic fractions were determined using the Wentworth (1922) classification. To distinguish sedimentary environments, diagrams of Folk and Ward textural parameters were made along with frequency and cumulative curves. The cumulative curves were placed on the probability scale. Their types were determined on the basis of the Sindowski (1958) classification.

Rounding and frosting of quartz grains. For each sample, a 0.5–0.8 mm fraction was obtained. To remove carbonate admixtures, the samples were washed with 10% HCl and then rinsed with distilled water. A hundred grains were selected under the binocular, which were then assigned to classes using the Cailleux (1942) classification modified by Balińska-Wuttke (1963) and Goździk (1995). According to this classification, quartz grain surfaces are divided into seven groups: shiny grains (EL), transitional shiny grains (EM/EL), frosted grains (RM), transitional frosted grains (EM/RM), angular grains (NU), broken grains (C) and others.

OSTRACOD AND MOLLUSC ANALYSIS

The analysis was performed on 46 samples from both boreholes (O4 and O8). The sediment was treated with 30% H_2O_2 (hydrogen peroxide) to digest all the organic matter, and then washed with water on a 0.1 mm sieve. A *Nikon* binocular was used to identify the species present in each of the samples. The number of shells for each mollusc and ostracod species was determined separately for each sample, with the boundary value of 100 specimens. The results were presented in diagrams prepared with the POLPAL application (Nalepka and Walanus, 2003).

DIATOM ANALYSIS

The analysis was performed for 40 samples from O4 and O8 boreholes. Microscopic slides were prepared according to the procedure proposed by Battarbee (1986). Calcium carbonate was removed by adding 10% HCl. The samples were treated with 30% H_2O_2 and boiled on a hot plate (until the reaction was completed) to digest all the organic matter. After several washings with distilled water, a few drops of diatom suspension were dried on a coverglass. Permanent microscope slides were mounted in Naphrax. The diatom identification was performed under a *Nikon Eclipse E-200* microscope. In each slide, up to 500 diatom valves were counted.

In order to identify the diatom flora, we followed Lange-Bertalot and Metzeltin (1996), Krammer and Lange-Bertalot (2008a, b, 2010, 2011), Hofmann et al. (2011). Ecological groups of diatoms were determined by means of the *Omnidia* software (version 4.2) (Lecointe et al., 1993) and then the resulting groups were distinguished according to Denys (1991/92) and van Dam et al. (1994). Planktonic and benthic groups were distinguished according to Round (1981). Salinity preferences

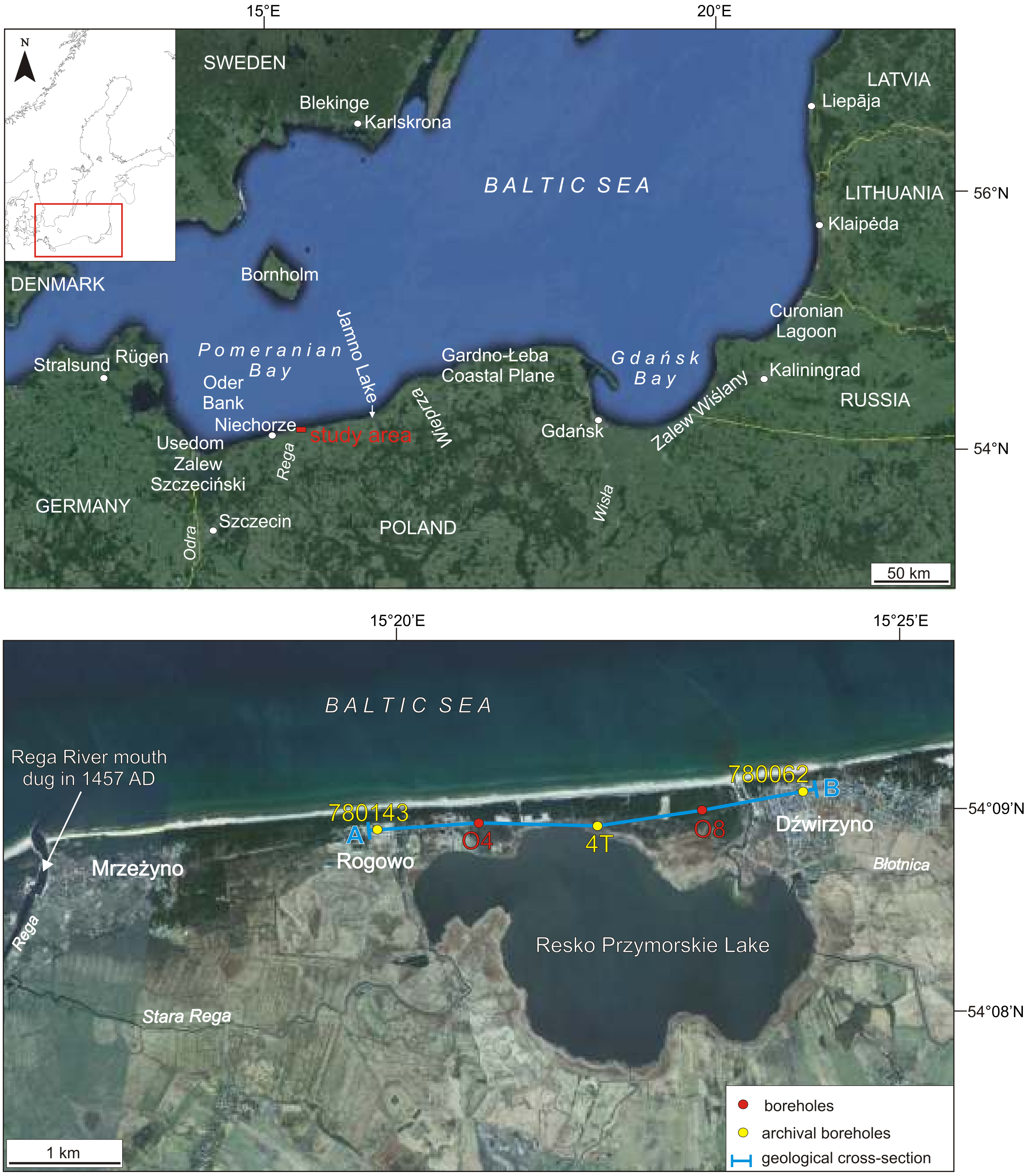


Fig. 1. Study area

Archival profiles taken from studies of Dobracki and Zachowicz (1997 – Bh 4T) and the HYDRO Data Bank (Bh 780062 and 780143)

of diatoms were based on the van der Werff (1958), van der Werff and Huls (1957–1974) classification – see Denys (1991/92). Ecological preferences of unspecified species in the classification of van der Werff (1958), van der Werff and Huls (1957–1974) – see Denys (1991/92), were supplemented from diatom literature (Witkowski, 1994; Witkowski et al., 2000; Kwadrans, 2007; Krammer and Lange-Bertalot, 2008a, b, 2010, 2011; Pliński and Witkowski, 2009, 2011, 2013a, b; Hassan, 2010; Hofmann et al., 2011). Diatom species were checked in electronic databases: www.algaebase.org (Guiry and Guiry, 2015) and www.marinespecies.org (WoRMS Editorial Board, 2015).

POLLEN ANALYSIS

As the material was poor in pollen grains, the analysis was made for 10 samples taken from O8 borehole. The pollen analysis in O4 borehole was not performed because of the lack of well-preserved pollen grains. The samples of organic deposits from O8 borehole were treated with 10% KOH and 10% HCl and then they were subjected to acetolysis (Faegri and Iversen, 1989). The analysis was performed by means of a *Leica DME* optical light microscope under 400× magnification. In each sample, consisting of two 22 × 22 mm microscopic slides, about 300 pollen grains and spores were counted. The basis for the quantitative calculation was the sum of all the identified pollen grains of trees and shrubs (AP) as well as herbs (NAP). Furthermore, *Pediastrum* algae and small pieces of charcoal were observed. Results were presented in a percentage diagram prepared with the POLPAL application (Nalepka and Walanus, 2003).

RADIOCARBON DATING (^{14}C)

Five bulk samples from O4 and O8 boreholes were dated. The dating was performed at the Laboratory of Absolute Dating in Cianowice. Because there is no data from the coastal lakes in the southern Baltic Sea area, we decided not to use the reservoir effect correction. All the radiocarbon dates were calibrated in the *OxCal v. 4.2.3.* program using the *Intcal13* radiocarbon age calibration curve (Reimer et al., 2013). An age-depth model was also constructed for O4, O8 and 4T boreholes.

In some of the cited publications (Prusinkiewicz and Noryśkiewicz, 1966; Kopczyńska-Lamparska, 1976; Brykczyńska, 1978; Cieśla and Marciniak, 1982; Kopczyńska-Lamparska et al., 1984; Ralska-Jasiewiczowa and Rzętkowska, 1987; Kramarska et al., 1995; Kramarska, 1999; Rotnicki, 1999; Witkowski et al., 2004; Cedro, 2004, 2005; Borówka et al., 2005a; Lutyńska, 2008; Mazurek et al., 2008; Miotk-Szpiganowicz et al., 2008) only conventional radiocarbon age (^{14}C years BP) was used. This may disturb the discussion of the results. Therefore, the discussion below involves the calibrated age (cal BP). In the brackets, we refer to conventional radiocarbon age and laboratory code of the sample.

RESULTS

SEDIMENTOLOGICAL ANALYSIS

Five lithofacies types (L1–L5) have been distinguished in the sandy deposits (Figs. 2 and 3) based on changes in grain size, textural parameters and their relationships, type and location of cumulative curves and frequency curves, admixture of carbonate rocks as well as rounding and frosting of quartz grains.

Lithofacies L1. This lithofacies was identified in O8 borehole at depths below 8.03 m. The deposits represent coarse, medium and fine sand, mostly moderately sorted. They are characterized by the greatest share of the coarse fraction among all described lithofacies. Sand and gravel of carbonate rocks are quite abundant. Skewness represents negatively skewed and nearly symmetrical curves. Kurtosis is typical for mesokurtic and leptokurtic curves (Figs. 3, 4 and 5Ba).

The analysis of the cumulative curves shows that lithofacies L1 is characterized by two types of curves: concave-convex (KV-KX type) and initially moderately inclined passing into convex-curved (MG-KX type) (Fig. 5Aa). Frequency curves show multimodal distributions. For most samples of this series, five modes are distinguishable, which are focused chiefly within the following particle sizes: 0.25, 1.0, 1.5, 2.25 and 3.25 phi (Fig. 5Ba).

The relationship between the mean size (Mz) and the standard deviation (σ_I) shows a trend where the increase of particle size diameter is accompanied by the decrease in sorting (Fig. 6A). Such a situation is typical for river-channel deposits – system 1 according to Mycielska-Dowgiałło (2007), with high variability of transport energy (Ludwikowska-Kędzia, 2000; Mycielska-Dowgiałło, 2007; Mycielska-Dowgiałło and Ludwikowska-Kędzia, 2011). For the pair of standard deviation (σ_I) and skewness (Sk_I), it can be seen that the points cluster in two loose groups characterized by an increase in deposit sorting with the increasing skewness (Fig. 6B). The relationship of skewness (Sk_I) and mean size (Mz) shows a loose point group characterized by a variable tendency – the decrease in particle size diameter and the decrease in skewness is followed by the skewness increase (Fig. 6C).

The analysis of rounding and frosting of quartz grains shows the dominance of two types of grains: EM/EL and NU. Despite the minor tendency of the upward increase in its proportion, the EM/RM type shows considerable fluctuations within the series. The increasing tendency is also shown by the RM type. The share of other types of grains is low (Fig. 3).

Lithofacies L2. The lithofacies was identified in O4 borehole at depths below 7.93 m and in O8 borehole at a depth of 7.57–8.03 m. It consists of medium and fine sand (Figs. 2 and 3) characterized by moderate sorting. Skewness is typical of negatively skewed and nearly symmetrical curves. Kurtosis for most samples of this lithofacies is typical of mesokurtic curves. Unlike lithofacies L1, these deposits are finer, better sorted and do not contain admixture of carbonate rocks (Figs. 2–4 and 5Bb).

Cumulative curves of lithofacies L2 represent the KV-MG type (concave-convex passing into moderately inclined in the middle and at the end) and the MG type (moderately inclined curves) (Fig. 5Ab). Frequency curves, as for the previous lithofacies, are multimodal with modes focused in the following fractions: 0.5, 1.0, 1.5, 2.25 and 3.0 phi (Fig. 5Bb).

The relationships of Folk and Ward parameters (Mz-σ_I, σ_I-Sk_I and Mz-Sk_I) show the same trends as in the case of lithofacies L1 (Fig. 6).

The analysis of rounding and frosting of quartz grains implies that NU and EM/EL grains are the most common in these lithofacies. Similarly to lithofacies L1, significant share fluctuations in the EM/RM type is observed. In comparison to lithofacies L1, the share of the EL and RM types is slightly greater. The smallest share is characteristic of C-type grains (Figs. 2 and 3).

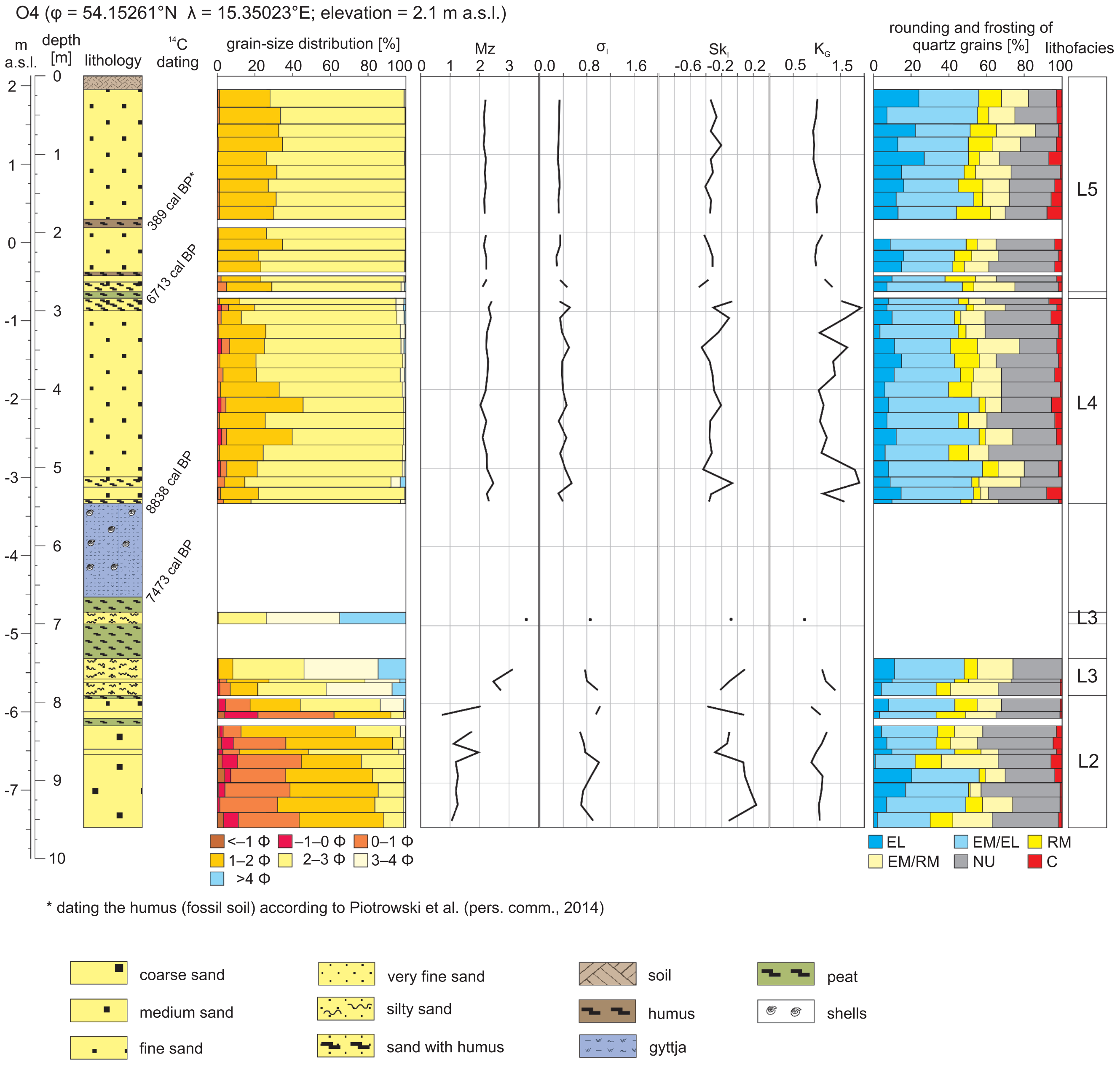
Lithofacies L3. This lithofacies was identified at depths of 6.85–7.0 and 7.45–7.9 m in O4 borehole and 6.65–7.45 m in O8 borehole. The lithofacies is represented mainly by very fine sand with admixture of silt. The O8 borehole contains interbeds of fine sand. Their thickness does not exceed 10 cm. The deposits are characterized by moderate sorting. These are the finest and most poorly sorted deposits of all the lithofacies discussed here, and show the predominance of nearly symmetrical curves with a considerable share of negatively skewed curves. Kurtosis is typical for leptokurtic, mesokurtic and platykurtic curves (Figs. 2–4 and 5Bc).

Cumulative curves represent the MG-KV type – initially moderately inclined curves passing into concave ones (Fig. 5Ac). Frequency curves are multimodal with 4 to 5 modes (Fig. 5Bc).

The relationship between the mean size and standard deviation shows a loose group of points without a clear trend (Fig. 6A). The standard deviation-skewness relationship shows a skewness increase with increasing sorting (i.e. decreasing standard deviation values; Fig. 6B). The third relationship, between the skewness and mean size, shows a trend of decreasing skewness and mean size (Fig. 6C).

The analysis of rounding and frosting of quartz grains shows the greatest share of EM/EL and NU grains. The lithofacies shows a topward increase of the share of the EM/RM type and a decrease in the share of the NU type (Figs. 2 and 3).

Lithofacies L4. The lithofacies was identified in O4 borehole at a depth of 2.8–5.47 m and in O8 borehole at 0.0–4.8 m. Deposits of this lithofacies are represented mainly by



* dating the humus (fossil soil) according to Piotrowski et al. (pers. comm., 2014)

Fig. 2. Lithostratigraphic profile of the O4 borehole, results of ^{14}C analysis, variability of sediment grain-size distribution, its main statistical parameters, rounding and frosting of quartz grains, and subdivision into lithofacies

C – broken grains, EL – shiny grains, EM/EL – transitional shiny grains, EM/RM – transitional frosted grains, NU – angular grains, RM – frosted grains

well-sorted fine and medium sand. The skewness is typical of very negatively skewed curves. Kurtosis is represented by mesokurtic curves (Figs. 2–4 and 5Bd).

Cumulative curves are of the SG-FG type – initially steeply inclined curves (for larger grains) pass into flat-inclined (Fig. 5Ad). Frequency curves are bimodal with the mode in the fractions 2.25 and 2.75 phi (Fig. 5Bd).

The mean size-standard deviation relationship shows a cloud of densely concentrated points with a trend of decreasing deposit sorting along with the increase in mean size (trend no. 1 according to Mycielska-Dowgiałło, 2007 as well as Mycielska-Dowgiałło and Ludwikowska-Kędzia, 2011; Fig. 6A). The relationship between the standard deviation and skewness shows a cloud of scattered points forming the shape of a flattened letter "U". Initially, one can observe a slight increase in deposit sorting, and then a slight decrease with a constant increase in skewness (Fig. 6B). The skewness-mean size relationship shows a cloud of points characterized by similar values of mean size and different values of skewness (Fig. 6C).

The analysis of rounding and frosting of quartz grains shows the continued dominance of the NU and EM/EL types. The EL type is the most common (as in the case of lithofacies E) within the series. Compared to the other lithofacies, the share of the EM/RM, RM, NU and C types (Fig. 3) is at a similar level.

Lithofacies L5. The lithofacies was identified only in O4 borehole at a depth of 0.0–2.75 m. It consist of very well-sorted fine sand. This deposit is characterized by negatively skewed

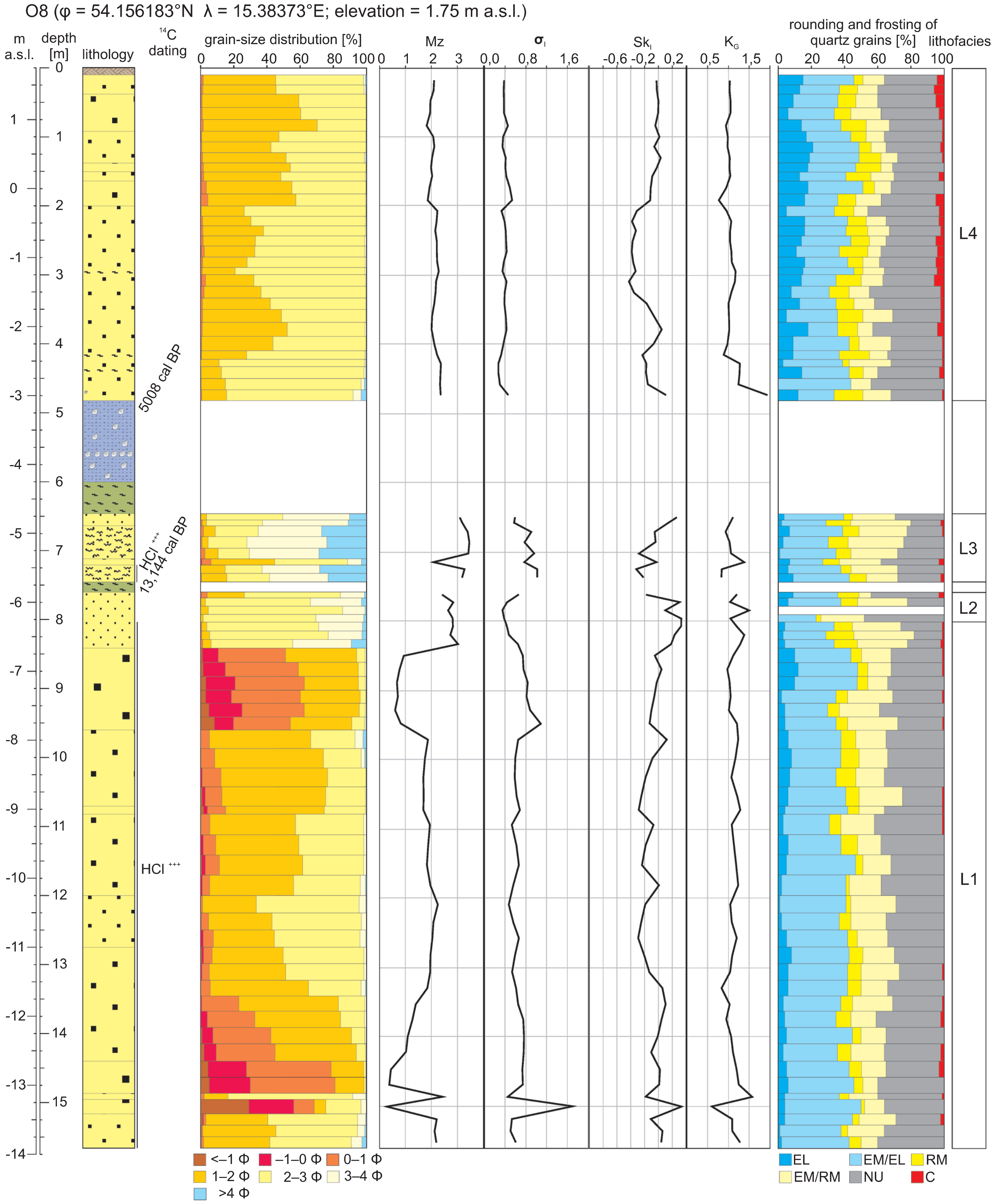


Fig. 3. Lithostratigraphic profile of the O8 borehole, results of ^{14}C analysis, variability of sediment grain-size distribution, its main statistical parameters, rounding and frosting of quartz grains, and subdivision into lithofacies

Symbol HCl^{+++} means long and intense reaction with 10% hydrochloric acid; for lithology explanation see Figure 2 curves and mesokurtic curves. Within this series, the deposits of lithofacies L5 are characterized by the best sorting.

Cumulative curves of the series represent type SG-FG. Frequency curves are bimodal with their modes in 2.25 and 2.75 phi (Fig. 5Be).

The relationship between the mean size and standard deviation is represented by a very dense cloud of points (Fig. 6A). This is the result of small dynamic changes of the environment. The standard deviation-skewness relationship shows a trend of increasing sediment sorting with the skewness increase (Fig. 6B). In the case of a pair of skewness mean size, skewness fluctuations that accompany small changes of the mean grain size can be observed (Fig. 6C).

The analysis of rounding and frosting of quartz grains shows the dominance of two types of grains: EM/EL and NU. The share of type EL is the greatest among all the discussed lithofacies. There is a noticeable increase towards the top of the series in the share of EL, EM/EL, RM and EM/RM types, and a decrease in NU and C types (Fig. 2).

OSTRACOD AND MOLLUSC ANALYSIS

In O4 borehole ostracods and molluscs were found at depth 5.50–6.37 m, in O8 borehole at depth 4.70–5.90 m. In the other intervals (both cores) there were no ostracods and molluscs. In O4 borehole 11 mollusc species (8 freshwater and 3 marine), and 4 ostracod species (2 freshwater and 2 marine) were identified, in O8 borehole – 10 mollusc species (7 freshwater and 3 marine), and 10 ostracod species (8 freshwater and 2 marine).

In the lower part of O4 profile (depth 6.15–6.37 m; Fig. 7) freshwater molluscs such as: *Bithynia tentaculata* (operculum), *Theodoxus fluviatilis*, *Valvata cristata*, *V. piscinalis* were found with a presence of marine fauna (*Hydrobia ulvae*, *Cerastoderma glaucum*, *Mytilus edulis*). The dominant species is the marine ostracod *Cyprideis torosa*. In the middle part of the profile (5.85–6.15 m) fauna was not observed. In the upper part (5.50–5.85 m) there was a mixed fauna (freshwater and marine) with a high share of *Cyprideis torosa*. The presence of mollusc

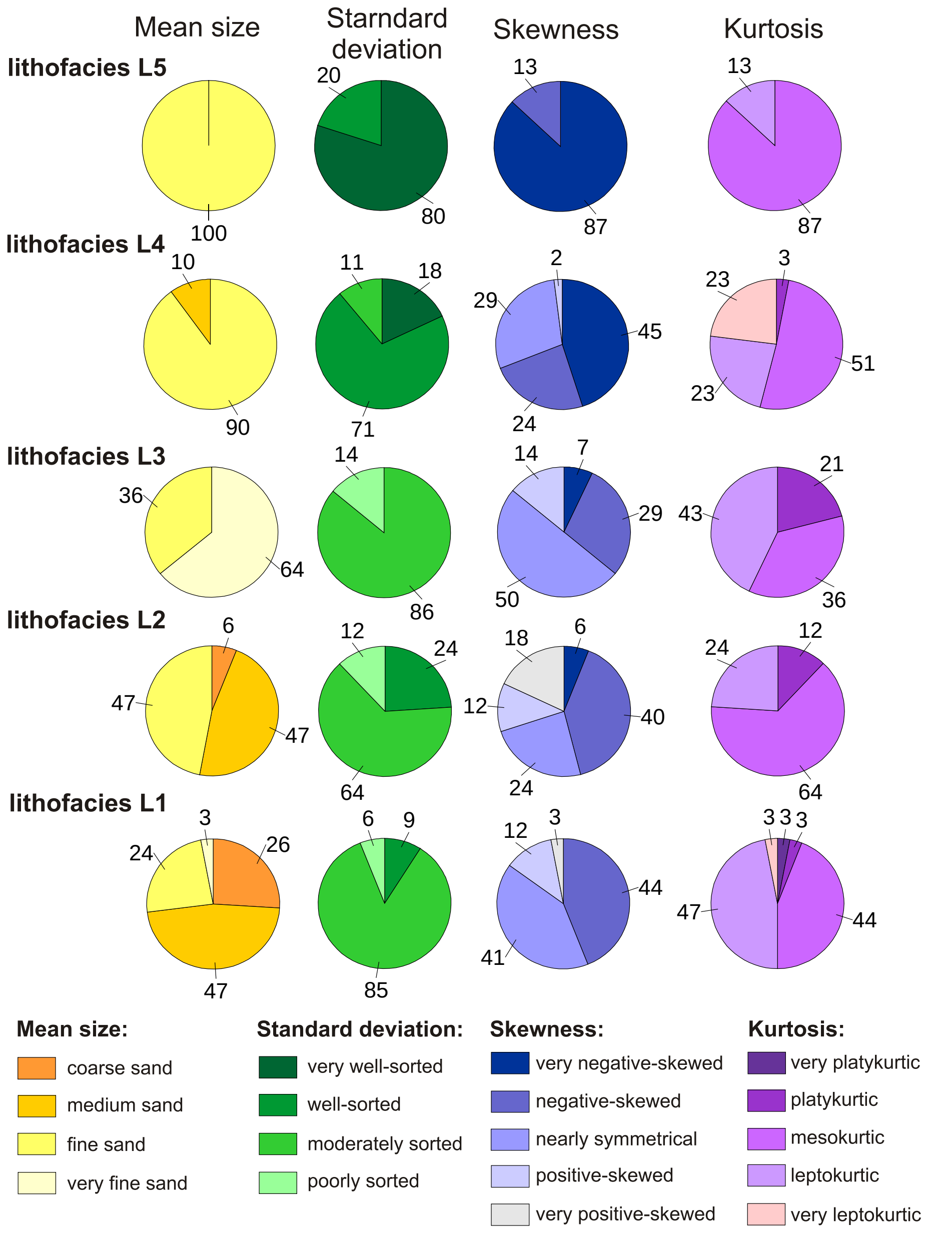


Fig. 4. Percentage of tested samples for different values of Folk and Ward textural parameters

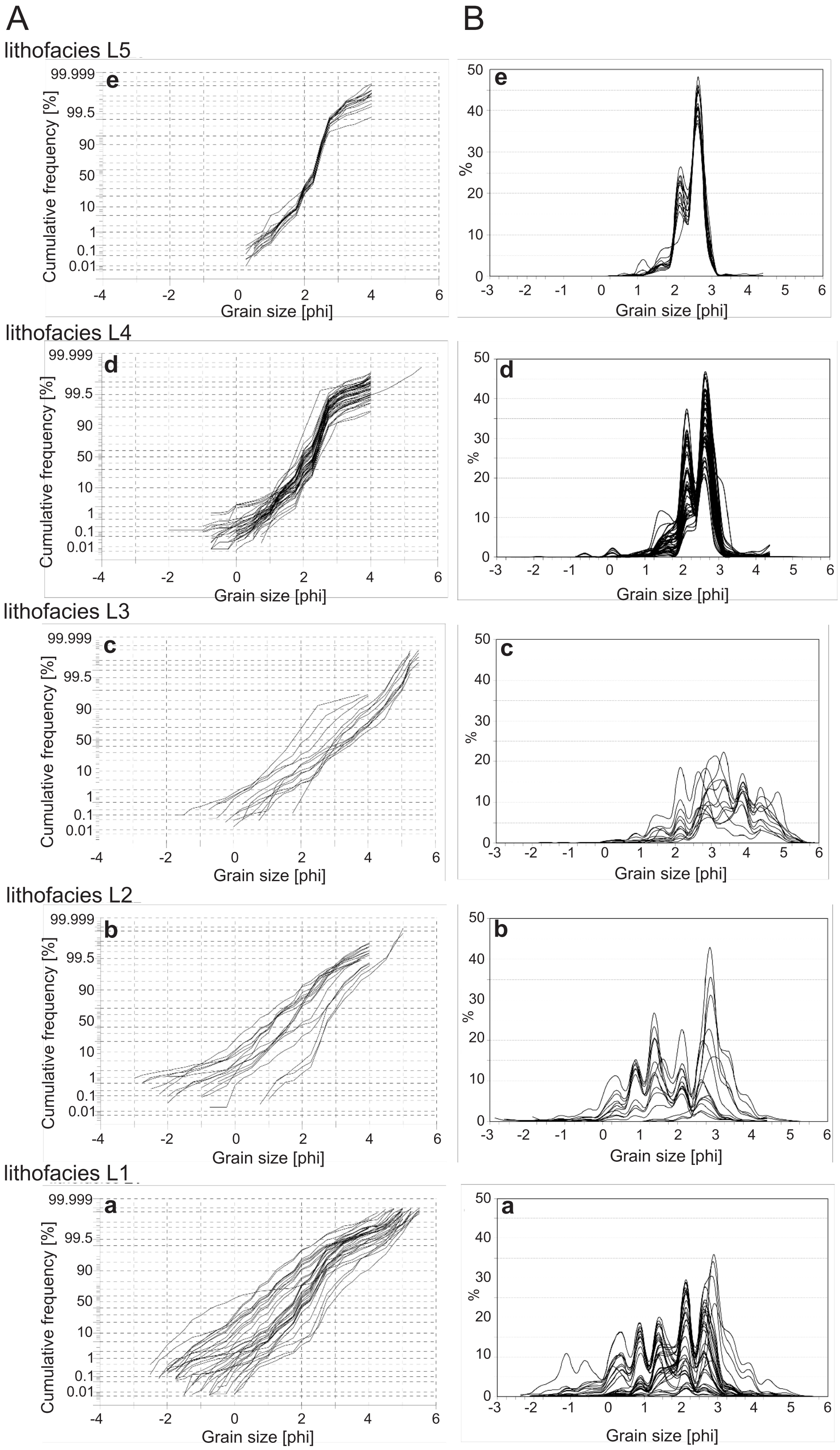


Fig. 5. Cumulative curves (A) and frequency curves (B) of the lithofacies

species such as *Theodoxus fluviatilis*, *Valvata piscinalis*, *Pisidium casertanum, Unio* sp. f. *ponderosa* may be indicative of riverbank.

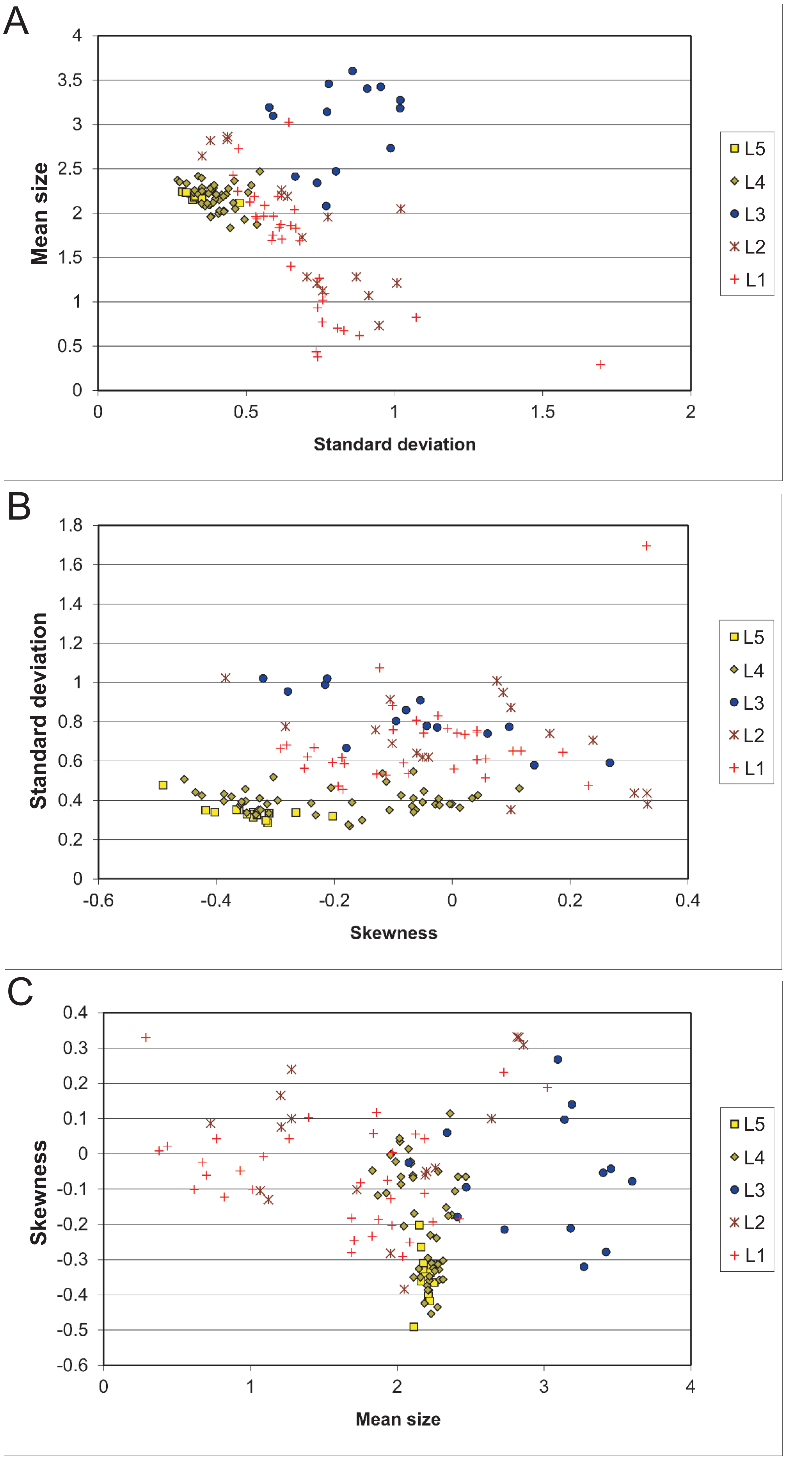


Fig. 6. Relationships of Folk and Ward textural parameters

In O8 borehole at a depth 4.70–5.90 m (Fig. 8) mixed fauna (freshwater and marine) was found. There were freshwater ostracods such as *Candona neglecta*, *Cyclocypris laevis*, *Darwinula stevensoni*, *Fabaeformiscandona caudata*, *Ilyocypris decipiens*, *I. lacustris*, *Limnocythere inopinata* and *Limnocytherina sanctipatricii* and collaterally molluscs *Valvata cristata*, *V. piscinalis*, *V. piscinalis* f. *antiqua*, *Theodoxus fluviatilis*, *Pisidium casertanum* f. *ponderosa*. The dominant species was marine ostracod *Cyprideis torosa*.

In the studied borehole sections (O4 and O8), we found both freshwater and marine forms. Freshwater forms included lake and fluvial species. Among the typical lake forms the gastropod species *Valvata piscinalis* f. *antique* was identified. Typical fluvial forms included the gastropod *Theodoxus fluviatilis* that lived on rocky bottom of rivers and lakes as well as a bivalve of the taxa *Unio* and *Pisidium casertanum* f. *ponderosa* which occupy silty bottom of the riverbank.

The presence of marine molluscs (*Hydrobia ulvae*, *Cerastoderma glaucum*, *Macoma baltica* and *Mytilus edulis*) and ostracods as well as high abundance of ostracod *Cyprideis torosa* and the presence of *Cytheromorpha fuscata* indicate a short-lived connection with the sea (inflow of marine waters).

DIATOM ANALYSIS

In O4 borehole, diatom valves were found at a depth of 2.50–6.54 m, in O8 borehole at 4.16–6.00 m. No diatom valves occur in the other intervals.

O4 borehole. The diatom analysis was performed on 24 samples. Diatoms were found in the following depth intervals: 2.50–3.20, 4.00–5.50 and 6.25–6.54 m. A total of 135 taxa have been identified. Based on the species composition and ecological data, 3 diatom assemblage zones (DAZ I-O4, DAZ II-O4, DAZ III-O4) have been distinguished (Fig. 9).

DAZ I-O4 covers a depth range of 6.25–6.54 m. Deposit representing this level is a dark grey gyttja with fragments of shells. At the bottom of this diatom zone, benthic diatoms are dominant, mainly *Staurosira construens* Ehrenberg and *Staurosira binodis* (Ehrenberg) Lange-Bertalot. At the depth of 6.44 m, there is an increase in the percentage of planktonic diatoms (up to 69%) represented mainly by *Aulacoseira ambigua* (Grunow) Simonsen (55.9% of the entire community). In the other samples of this level, plankton proper does not exceed 38%. DAZ I-O4 is characterized by the dominance of freshwater diatoms, such as: *Aulacoseira ambigua* (Grunow) Simonsen, *A. granulata* (Ehrenberg) Simonsen, *Pseudostaurosira brevistriata* (Grunow) Williams and Round and *Staurosira construens* Ehrenberg. In addition there are also halophilous [*Pseudostaurosira parasitica* (Smith) Morales], brackish-water [*Pseudostaurosiropsis geocollegarum* (Witkowski) Morales and *Pseudostaurosira subsalina* (Hustedt) Morales], and marine diatoms [*Cocconeis peltoides* Hustedt, *Catenula adhaerens* (Mereschkowsky) Mereschkowsky].

DAZ II-O4 is located at a depth of 4.00–5.50 m (sand with humus passing into grey fine sand). This level shows the greatest variability of diatoms with the dominant freshwater benthic flora represented mainly by *Amphora pediculus* (Kützing) Grunow ex Schmidt, *Staurosira construens* Ehrenberg, *Pseudostaurosira brevistriata* (Grunow) Williams and Round, *Amphora copulata* (Kützing) Schoeman and Archibald and *Karayevia*

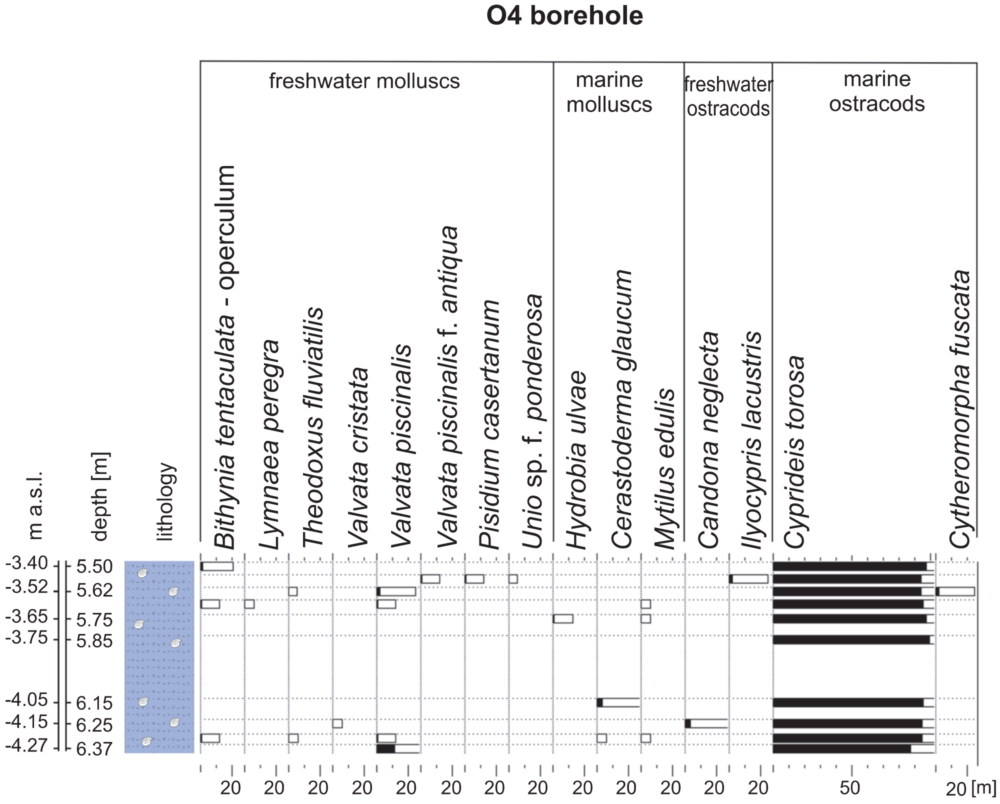


Fig. 7. Species composition and percentage content of ostracods and molluscs in O4 borehole

For lithology explanation see Figure 2

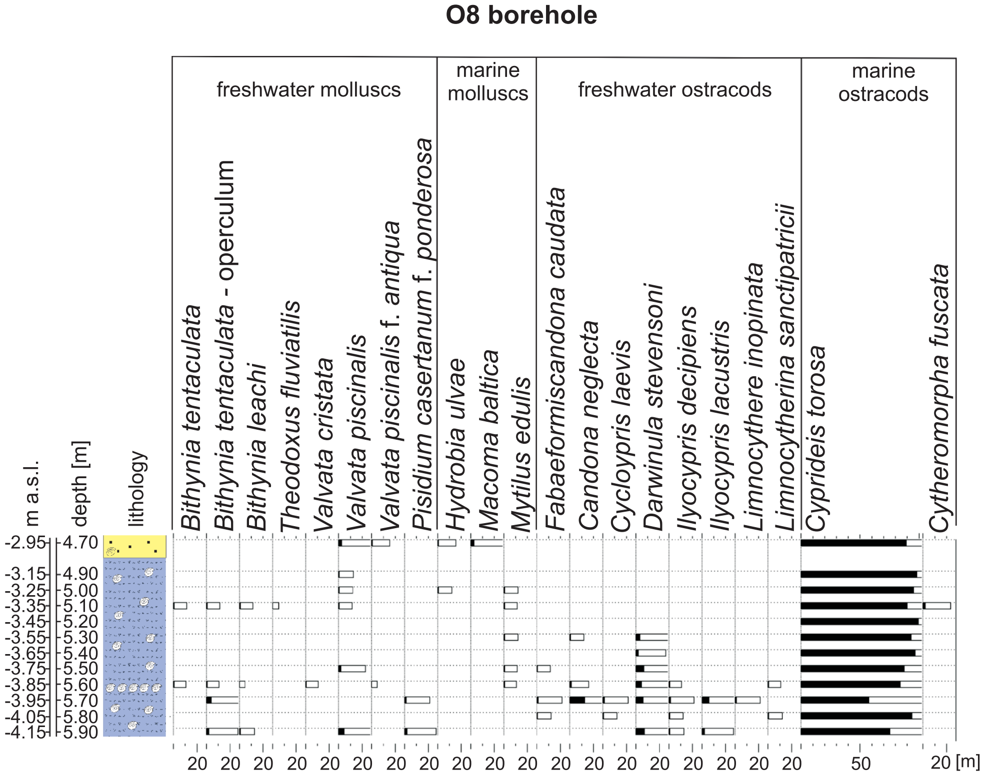


Fig. 8. Species composition and percentage content of ostracods and molluscs in O8 borehole

For lithology explanation see Figure 2

clevei (Grunow) Round and Bukhtiyarova. This phase is represented by many brackish-water taxa – about 20% [Pseudostaurosiropsis geocollegarum (Witkowski) Morales, *Fragilaria sopotensis* Witkowski and Lange-Bertalot, *Cocconeis hauniensis* Witkowski] and marine taxa (up to 22% of the community at a depth of 5.40 m). Marine diatoms are represented by *Catenula adhaerens* (Mereschkowsky) Mereschkowsky and *Cocconeis peltoides* Hustedt.

DAZ III-O4 (2.50–3.20 m) is represented by grey fine sand passing towards the top into sand with humus followed by peat and peat with fine sand interbeds. The 3.20 m depth sample differs from the other samples within the zone. The prevailing species is *Aulacoseira crenulata* (Ehrenberg) Thwaites, a freshwater planktonic species that commonly occurs in clean and calcium-rich waters, usually in small water basins, less frequently in the littoral zone of lakes (Krammer and Lange-Bertalot, 2008b; Pliński and Witkowski, 2009). In the interval of 2.50 to 3.00 m, benthic species are dominant (above 80%), accompanied by planktonic taxa such as *Aulacoseira ambigua* (Grunow) Simonsen and *A. granulata* (Ehrenberg). Both species are typical for eutrophic lake water (Krammer and Lange-Bertalot 2008b; Pliński and Witkowski, 2009). In terms of salinity, predominance of freshwater taxa is noticed. Towards the top of the zone, an increase in the share of brackish-water diatoms is observed (*Pseudostaurosira subsalina* (Hustedt) Morales, *Opephora mutabilis* (Grunow) Sabbe and Wyverman, *Fragilaria sopotensis* Witkowski and Lange-Bertalot). Single marine taxa have also been found [*Catenula adhaerens* (Mereschkowsky) Mereschkowsky and *Cocconeis peltoides* Hustedt].

O8 borehole. The diatom analysis was performed on 16 samples with 103 taxa identified. Diatoms were found in the intervals 4.16–4.65 and 5.60–6.00 m. The species composition and differences in ecological groups were used as a basis for distinguishing 4 diatom assemblage zones (DAZ I-O8, DAZ II-O8, DAZ III-O8, DAZ IV-O8; Fig. 10).

DAZ I-O8 is located at a depth of 5.90–6.00 m (dark grey gyttja with fragments of shells). Most common are freshwater benthic species, such as *Pseudostaurosira brevistriata* (Grunow) Williams and Round and *Staurosira construens* Ehrenberg, *Staurosirella pinnata* (Ehrenberg) Williams and Round. Moreover, they are accompanied by brackish-water species (about 20%): *Fragilaria sopo-*

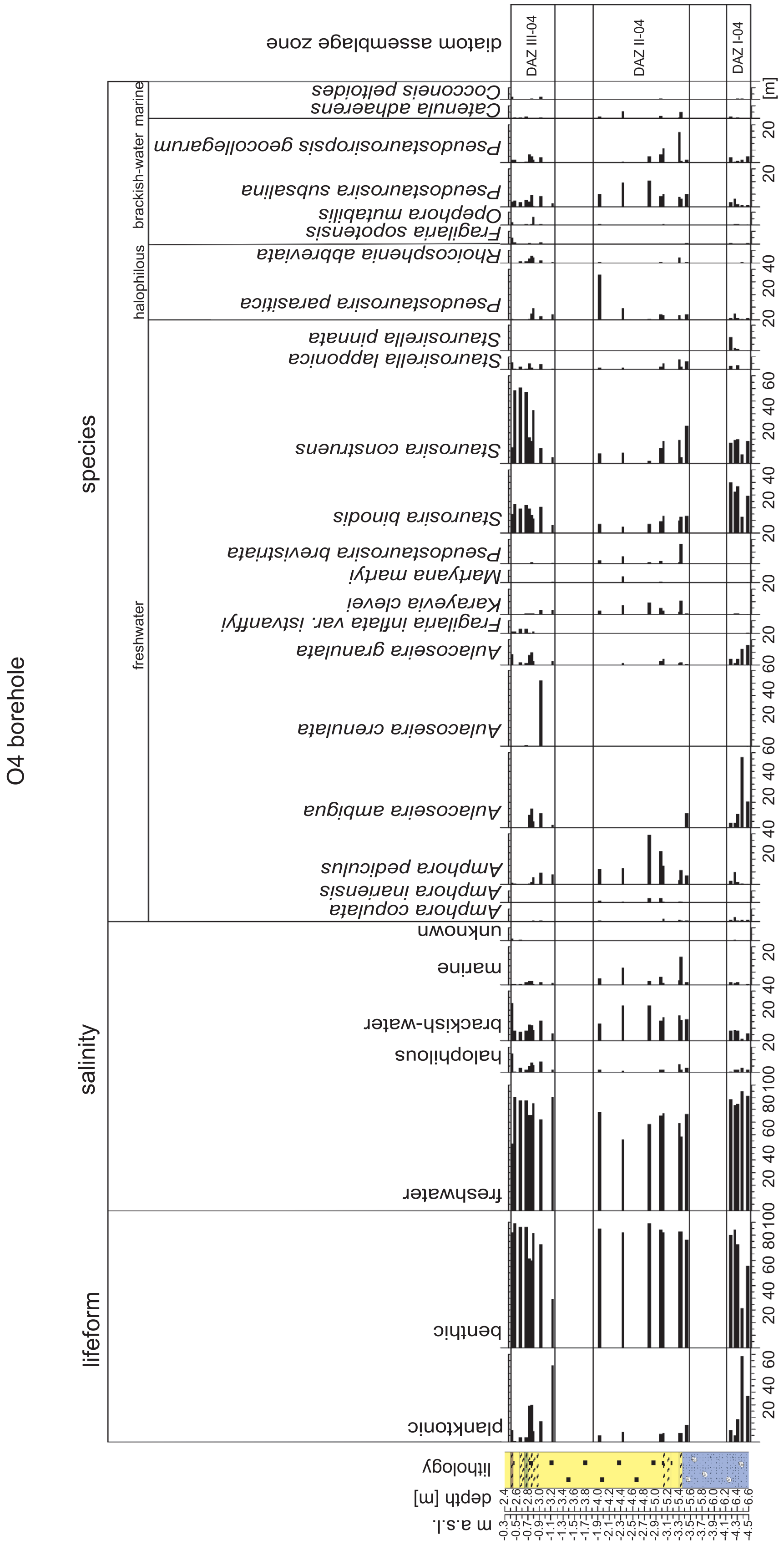


Fig. 9. Percentage content of various ecological groups and main diatom taxa in the sediments of O4 borehole

For lithology explanation see Figure 2

tensis Witkowski and Lange-Bertalot, *Pseudostaurosira subsalina* (Hustedt) Morales.

DAZ II-O8 (5.60–5.80 m) is represented by dark grey gyttja with fragments of shells. Benthic freshwater diatoms continue to dominate in this zone [e.g., *Pseudostaurosira brevistriata* (Grunow) Williams and Round, *Staurosira construens* Ehrenberg, *Staurosirella pinnata* (Ehrenberg) Williams and Round].

DAZ III-O8 covers a depth range of 4.40–4.65 m represented by fine sand with humus containing shell fragments. The dominant freshwater benthic flora (80–90%) is represented by *Pseudostaurosira brevistriata* (Grunow) Williams and Round, *Staurosira construens* Ehrenberg, *S. binodis* (Ehrenberg) Lange-Bertalot and *Staurosirella pinnata* (Ehrenberg) Williams and Round. Another group (10–20%) is brackish-water diatoms, mainly *Fragilaria sopotensis* Witkowski and Lange-Bertalot and *Pseudostaurosira subsalina* (Hustedt) Morales. Isolated valves of marine diatoms have been identified in DAZ III-O8 [*Catenula adhaerens* (Mereschkowsky) Mereschkowsky, *Cocconeis peltoides* Hustedt].

DAZ IV-O8 is located at a depth of 4.14–4.30 m (grey medium sand). Freshwater diatoms still prevail in this interval, including mainly *Pseudostaurosira brevistriata* (Grunow) Williams and Round, *Staurosira construens* Ehrenberg, *S. binodis* (Ehrenberg) Lange-Bertalot and *Staurosirella pinnata* (Ehrenberg) Williams and Round, but also halophilous, brackish-water specimens (about 20%, *Navicula menisculus* Schumann, *Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot) as well as marine species [about 10%; e.g., *Catenula adhaerens* (Mereschkowsky) Mereschkowsky, *Cocconeis peltoides* Hustedt] have been found.

POLLEN ANALYSIS

The pollen analysis on O8 borehole shows that pollen grains occur only at a depth of 5.84 to 6.29 m (Fig. 11). The lower part of this interval contains strongly dried peat. Drying could have had a destructive impact on pollen and spores. Gyttja sedimentation in the upper part of the interval was probably too slow for the pollen grains and spores to be preserved in good condition.

The study resulted in separation of 33 taxa and taxa groups within two local pollen assemblage zones (LPAZ 1 and LPAZ 2) distinguished according to the method proposed by Jańczyk-Kopikowa (1987), which correspond with the Holocene local vegetation and climatic changes.

LPAZ 1 (depth 6.24–6.29 m) is represented by relatively well-preserved material with the dominance of pine (*Pinus sylvestris* >50%) and an increasing percentage of alder (*Alnus glutinosa* type >20%). A large number of pine pollen can plausibly be attributable to

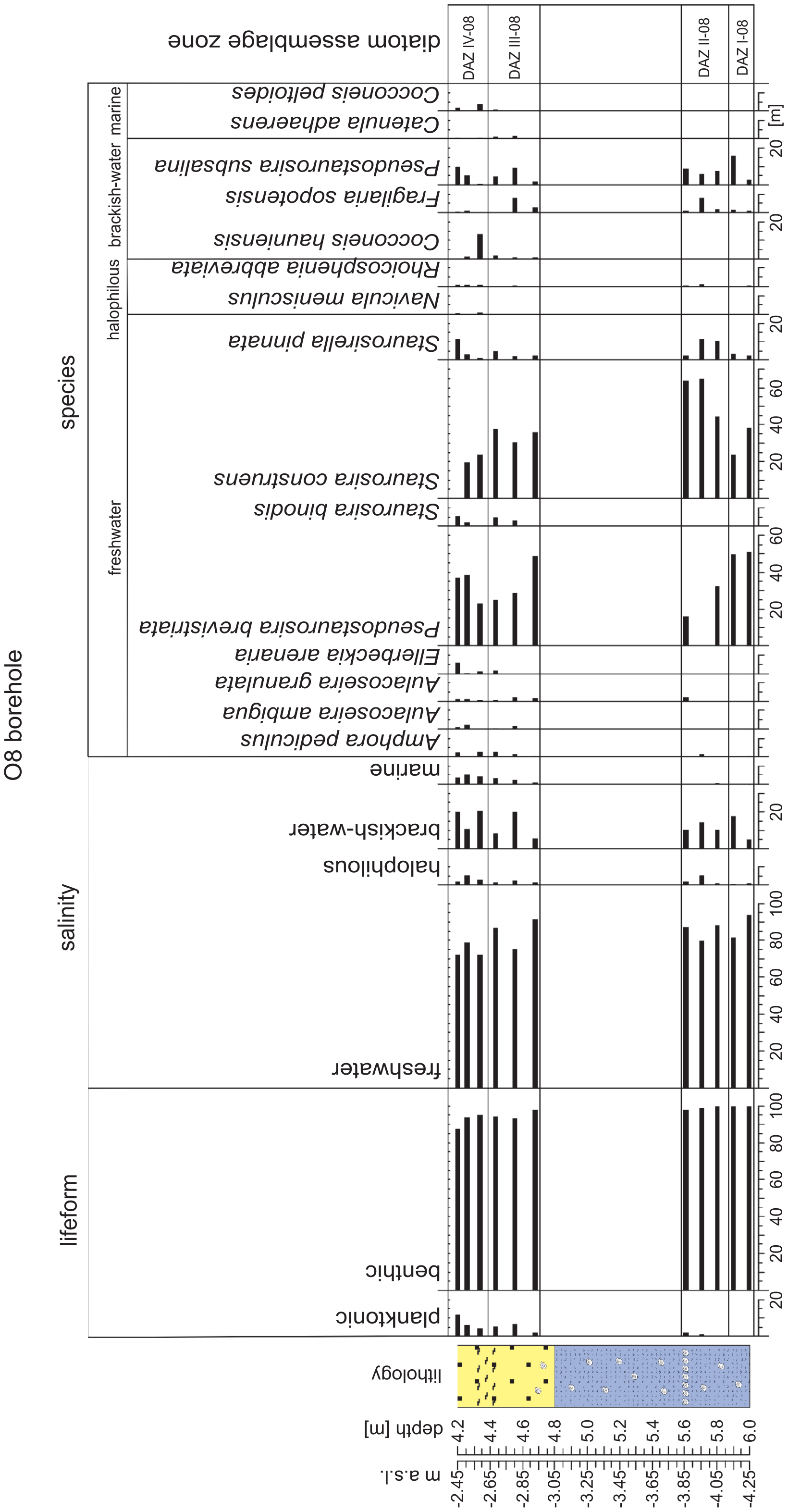


Fig. 10. Percentage content of various ecological groups and main diatom taxa in the sediments of O8 borehole

For lithology explanation see Figure 2

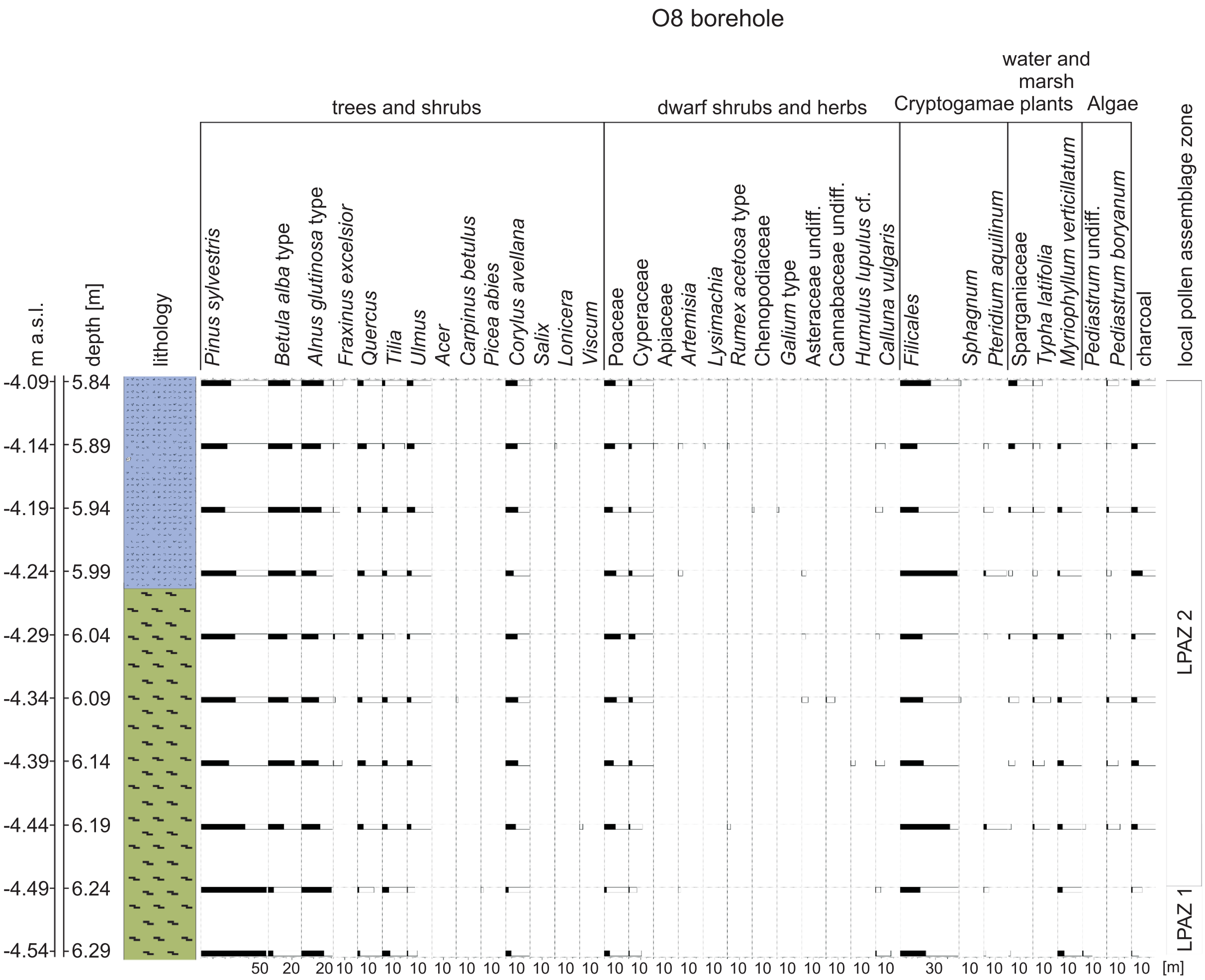


Fig. 11. Pollen diagram of deposits in the O8 borehole

For lithology explanation see Figure 2

distant transport. The percentage of other trees like oak (*Quercus*), elm (*Ulmus*) and hazel (*Corylus avellana*) in the LPAZ 1 is low and does not exceed 5%. The only exception is *Tilia*, whose share exceeds 6%. The other pollen grain assemblages demonstrate no distinct vegetation pattern. Very low percentage of the charcoal assemblage indicates infrequent fire events in the study region.

LPAZ 2 (depth 5.84–6.24 m) is characterized by a decrease in the share of pine to approximately 30%. The share of birch (*Betula alba* type) reaches a value of 20%. There is also a high share of oak, hazel and elm. *Fraxinus* excelsior can be clearly seen only in the middle of the LPAZ 2. Water plants of *Myriophyllum verticillatum*, *Typha latifolia* and Sparganiaceae occur throughout the whole study interval at a relatively low percentage. The highest amount of charcoal was found at a depth of 5.99 m and corresponds to the maximum occurrence of *Filicales* (>40%).

RADIOCARBON DATING (^{14}C)

To determine the age of the deposits, 3 samples of gyttja and 2 samples of peat were taken for ^{14}C dating. The samples were collected from the top and the bottom of the lacustrine sediments and from the peat layers in sands lying below and above the lacustrine sediments.

Furthermore, two radiocarbon dates from peat in 4T borehole (Dobracki and Zachowicz, 1997; Krzymińska et al., 2003) were also used along with one radiocarbon date (fossil soil) from O4 borehole made for the study “Geological prospecting and studies of fossil tsunami deposits on the Polish Coast of Baltic Sea” (Piotrowski et al., pers. comm., 2014).

Table 1 shows the results of datings. Besides the conventional ^{14}C dates, the Table shows calibrated years (cal BP). Figure 12 presents an age-depth model for O4, O8 and 4T boreholes.

In O4 borehole, one sample yielded an incorrect age. We think that sample MKL-1502 (gyttja, Table 1) is “older” than the deposition time. Organic matter might have originated from redeposition of older sediments.

DISCUSSION

The analysis of collected data has allowed us to reconstruct palaeoenvironmental history of the Resko Przymorskie Lake spit. The deposits were divided into nine sedimentary series (Figs. 13 and 14). The oldest series (I–III) in the study area were accumulated in the Late Glacial. Series I represents till accumulated during the Vistulian Glaciation (Dobracka, 1992). In the

Table 1

Radiocarbon dates of samples from the spit of Resko Przymorskie Lake

Borehole number	Laboratory code	Depth [m]	Metres [a.s.l.]	Dated material	^{14}C age [year BP]	68.2% probability [cal BP]	Mean [cal BP]
O4*	Poz-57665	1.85	0.25	humus (soil)	305 ± 25	429–375 (48.9%) 365–360 (3.1%) 325–306 (16.2%)	389
O4	MKL-1501	2.75	–0.65	peat	5890 ± 90	6848–6814 (7.0%) 6802–6627 (57.6%) 6586–6568 (3.6%)	6713
O4	MKL-1502	5.50	–3.40	gyttja	7970 ± 150	9010–8626 (67.0%) 8619–8610 (1.2%)	8838
O4	MKL-1503	6.60	–4.50	gyttja	6570 ± 100	7574–7418 (68.2%)	7473
O8	MKL-1497	4.80	–3.05	gyttja	4380 ± 110	5270–5184 (14.4%) 5119–5113 (1.1%) 5064–4844 (52.7%)	5008
O8	MKL-1498	7.57	–5.82	peat	11,280 ± 130	13,284–13,035 (68.2%)	13,144
4T**	Gd-7846	3.53	–3.28	peat	6210 ± 60	7240–7216 (7.4%) 7178–7143 (13.2%) 7130–7010 (47.6%)	7106
4T**	Gd-7845	4.00	–3.75	peat	6480 ± 60	7435–7323 (68.2%)	7383

* humus dating according to Piotrowski et al. (pers. comm., 2014); ** lithology and dating according to Dobracki and Zachowicz (1997) and Krzymińska et al. (2003)

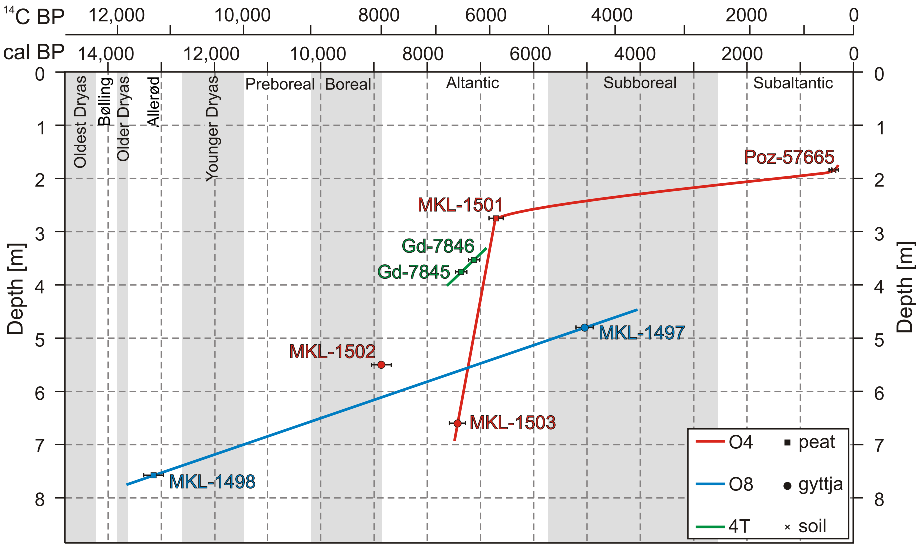
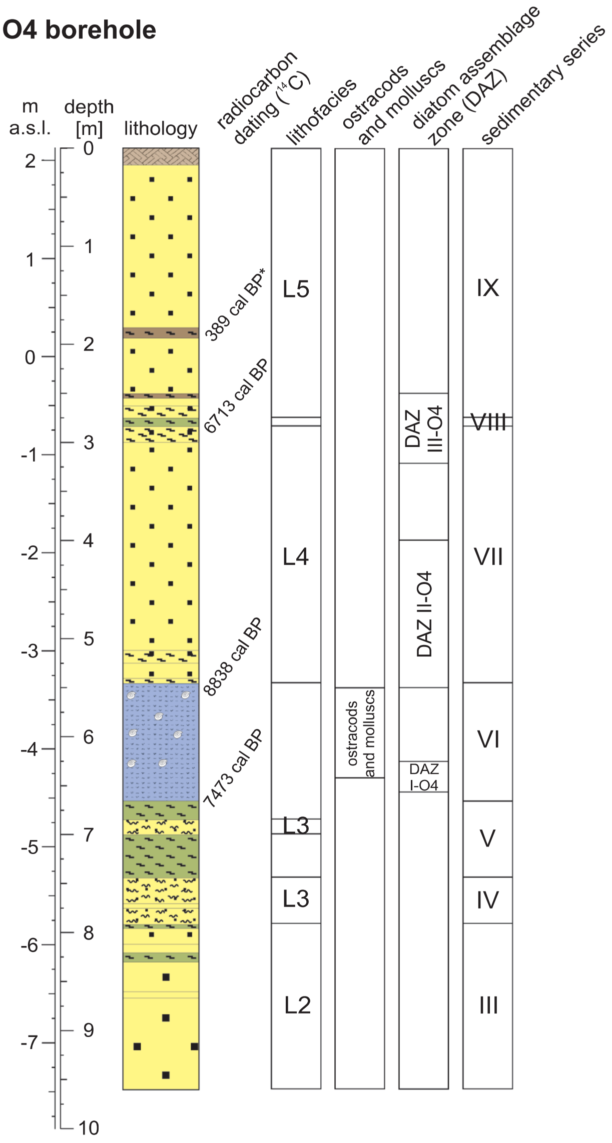


Fig. 12. Age-depth model for O4, O8 and 4T borehole

Late Pleistocene and Holocene subdivision after Mangerund et al. (1974) and Latałowa (2003)

eastern part of the study area, a depression formed, filled with fluvioglacial sand (series II).

As a result of the ice sheet deglaciation, the fluvioglacial accumulation (rich in fragments of carbonate rocks) was replaced by fluvial sand (series III). The radiocarbon date from the peat layer that covers the sand suggests that fluvial accumulation ended in the Allerød 13,144 cal BP (^{14}C 11,280 ± 130 BP, sample MKL-1498). At that time, fluvial sand was deposited in many places in the southern Baltic Sea area. In the Gardno-Łeba Coastal Plain area, similar deposits have been described as, for instance, Late Vistulian fluvial sand covered with a thin peat layer. The top of the layer is at an elevation of –7 to –10 m a.s.l. (Rotnicki, 1999, 2009; Rotnicki et al., 2009). In the Zalew Szczeciński (Szczecin Lagoon), it has been reported as fluvial deposits with a thin intercalation of limnic-swampy deposits dated to the Allerød. Their origin is related to the development of the Odra River valley from the end of the last glaciation to the Allerød. The top of the series is located at an elevation ranging from –11 m a.s.l. in the Zalew Wielki (Great Lagoon) to –6 m a.s.l. along the western coast of the Szczecin Lagoon



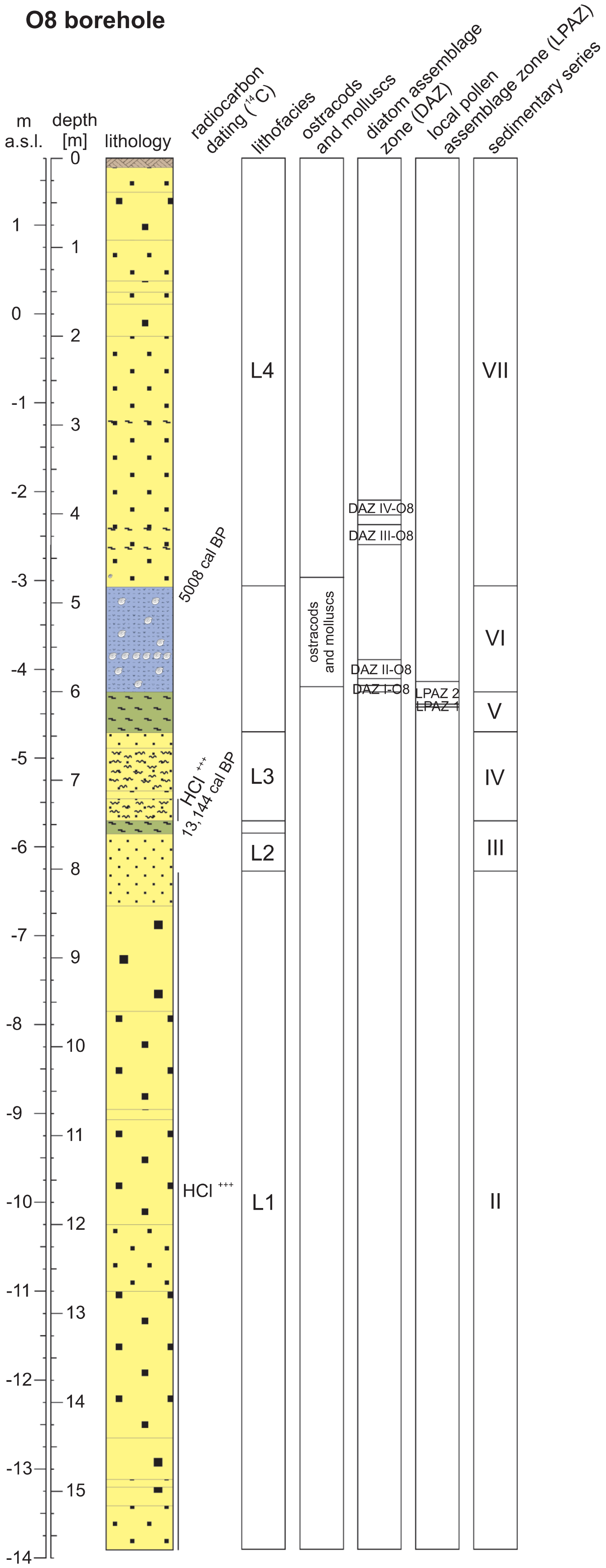


Fig. 13. Compilation of the results of sedimentological and biostratigraphical analysis from O4 and O8 boreholes, with the sedimentary series shown

For lithology explanation see Figure 2

HCl^{+++} - long and intensive reaction with 10% hydrochloric acid

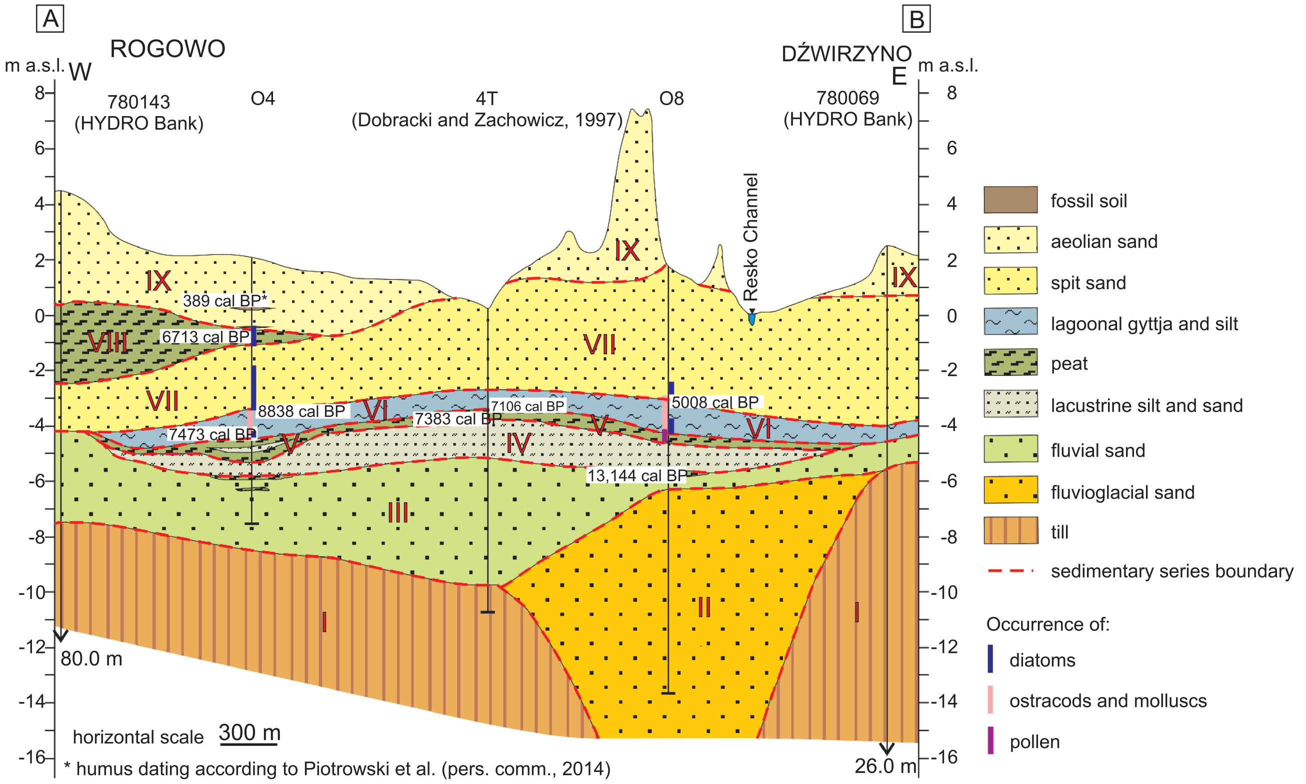


Fig. 14. Geological cross-section along the spit of Resko Przymorskie Lake

Roman numerals mark the sedimentary series; location of cross-section shown in Figure 1

(Borówkaet al., 2001a, b, 2002, 2003, 2005a, b). In Usedom Island (Pudagla Lowland and Peenemünde Lowand) and Rügen Island (Mönchgut Peninsula), Hoffman et al. (2005) found fine and medium sand with a peat layer whose radiocarbon age is ^{14}C 11,500 ± 65 BP. The top of the layer is located at an elevation ranging from –14 m a.s.l. in the Mönchgut Peninsula to –5 m a.s.l. in the Peenemünde Lowand.

From the Allerød to Middle Atlantic, the study area was covered by a shallow lake (series IV). The lack of diatom valves in the deposits suggests (acc. to Bradshaw et al., 2000) turbid conditions in the lake. At that time, the whole region was covered by lakes. Fossil lakes of similar age have been described in the studies on the Pomeranian Bay area between the Oder Bank and the Polish coast by Kramarska et al. (1995) and Kramarska (1999). Onshore, fossil lakes have been found in the Niechorze area – fossil lakes of Niechorze I and II (Kopczyńska-Lamparska, 1976; Brykczyńska, 1978; Cieśla and Marciniak, 1982; Kopczyńska-Lamparska et al., 1984; Ralska-Jasiewiczowa and Rzętkowska, 1987), as well as in the Rega River valley (Cedro, 2004, 2005). The prevailing environment of the Szczecin Lagoon area was limnic-swampy in character (Borówka et al., 2001a, b, 2002, 2003, 2005a, b; Witkowski et al., 2003a, b, 2004; Woziński et al., 2003).

In the Middle Atlantic 7473 cal BP (^{14}C 6570 ± 100 BP, sample MKL-1503), the lake started to shallow and overgrow (series V). The presence of whorled water milfoil, *Typha latifolia* and Sparganiaceae implies the existence of a swampy area (Fig. 11). A change of environmental conditions occurred during the Middle Atlantic. Alder was replaced by birch, oak, elm, hazel and ash. Such changes in vegetation may be indicative of a much lower water level.

In the Middle Atlantic during the Littorina transgression, the water level in the southern Baltic Sea rose (depending primarily on glacio-eustatic sea level changes) at a rate of about 11 mm/yr (Uścinowicz, 2003). As a result of this increase, a water basin developed in the study area, in which gyttja with shells and silt (series VI) was accumulated. The analysis of molluscs, ostracods and diatoms demonstrated that a variety of species (freshwater, brackish and marine) inhabited the basin. This type of association may imply the existence of a shallow-water lagoon in this area. A significant proportion of diatoms *Aulacoseira ambigua* (Grunow) Simonsen and *A. granulate* (Ehrenberg) Simonsen in the lower part of series VI (DAZ I-O4 – Fig. 9) may indicate a small water basin with alkalophilous eutrophic conditions, and water level fluctuations (Korhola, 1990; Sirviö and Kajander, 2003). Lagoonal conditions suggest that the lake was separated from the Baltic Sea by a spit that had already formed, but it must have been located to the north of its current position. From time to time, the spit was broken by storms. Interbeds of fine sand are the remnants of those episodes. The accumulation of series VI was associated with the Middle Holocene sea level rise called the Littorina transgression (Uścinowicz, 2003). The first traces of the Baltic Sea influence in the study area took place in the western part of the spit – 7473 cal BP (^{14}C 6570 ± 100 BP, sample MKL-1503). At that time, the sea level in the study area reached –4.5 m a.s.l. In the middle part of the spit, the sea influence occurred slightly later – at 7106 cal BP (^{14}C 6210 ± 60 BP, sample Gd-7846). It corresponded with the sea level rise reported for SE Rügen/Usedom Island (Hoffman et al., 2009), the Gardno-Łeba Coastal Plain (i2 transgression; Rotnicki, 2009), Vistula Lagoon (Uścinowicz and Miotk-Szpiganowicz, 2013) and Lithuanian Maritime Region (L2 Littorina Sea transgression; Bitinas and Damušytė, 2004). Furthermore, a marine influence (increase in salinity) of similar age (determined by means of biostratigraphic analyses and radiocarbon datings) was marked in the deposits from Jamno Lake (Miotk-Szpiganowicz et al., 2008), Szczecin Lagoon (Borówka et al., 2001a, b, 2002, 2003, 2005a, b; Witkowski et al. 2003a, b, 2004; Woziński et al., 2003; Miotk-Szpiganowicz et al., 2008; Borówka and Cedro, 2011) and Curonian Lagoon (Kabailienė, 1999). In the case of the Rega River valley, which is directly adjacent to the study area, traces of the sea ingression were marked earlier (^{14}C 7680 ± 40 BP – Cedro, 2004; Borówka and Cedro, 2011) than in the study area, by fine sand with marine mollusc shells (e.g., *Cerastoderma glaucum*). The base of these deposits was at –8 m a.s.l. (Cedro, 2004).

Along with an increasing sea level, the spit of Resko Przymorskie (series VII) migrated towards the south and covered the lagoon deposits. Initially, the spit deposits occurred only in the western part of the study area. The lower part of the spit deposits contain freshwater, brackish and marine diatom taxa. The presence of diatoms in these deposits implies that the initial phase of accumulation of series VII took place at the bottom of the lagoon. In the Late Atlantic, 6713 cal BP (^{14}C 5890 ± 90 BP, sample MKL-1501), the sea level in the study area rose to –0.75 m a.s.l. The western part of the spit stabilized and the accumulation of peat (series VIII) started. The presence of brackish and marine diatoms in the peat indicates inflows of marine waters (Lutyńska, 2005, 2008; Janczak-Kostecka and Kostecki, 2008; Mazurek et al., 2008).

In the Late Atlantic and Early Subboreal (6–5 ka BP), the rate of sea-level rise slowed down to about 2.5 mm/yr (Uścinowicz, 2003). In the Early Subboreal, 5008 cal BP (^{14}C 4380 ± 110 BP, sample MKL-1497), the spit sand (series VII) covered the lagoon deposits in the eastern part of the study area.

Peat and spit sand are covered by aeolian sand (series IX). The sand form dunes of a height of up to 8 m. Based on the radiocarbon date of fossil soil (Fig. 13 and Table 1), we can conclude that they are white dunes that developed over the last 400 years. It has been the time of intensified aeolian processes recorded in other places of the southern Baltic Sea coast such as the Świna Gate (Keilhack, 1912, 1914; Prusinkiewicz and Noryśkiewicz, 1966; Borówka, 2001; Osadczuk, 2004, 2005; Reimann et al., 2011), the Curonian Spit (Bitinas, 2004; Moe et al., 2005) and the Vistula Spit (Fedorowicz et al., 2009, 2012). This intensification was probably determined by a change of climatic conditions to LIA-type, expressed mainly by a decrease in mean temperature and an increase in the number of storms (Clemmensen et al., 2001a, b; Bitinas, 2004; Moe et al., 2005; Reimann et al., 2011; Fedorowicz et al., 2012).

CONCLUSIONS

The studies allowed us to recognize the geological structure of the spit and its base, as well as the palaeoenivronmental changes in the area of the Resko Przymorskie Lake spit.

The oldest sediments in the study area are Late Glacial deposits represented by the Vistulian Glaciation till, and fluvioglacial and fluvial sands. In the Allerød (13.1 ka cal BP), a shallow water body was formed, which was replaced by a swamp in the Middle Atlantic (7.3 ka cal BP). In the Middle Atlantic (ca. 7.5 ka cal BP), the water level was gradually rising (Littorina transgression), a lake developed at that time. Biostratigraphical analysis has shown the influence of marine waters (with brackish and marine species), but the lake never had a direct contact with the Baltic Sea. It was separated from the sea by a spit.

In the Atlantic, the spit migrated to the south. Spit deposits were accumulated upon lagoonal sediments. In the western part the spit, sand is covered by peat deposited in the Late Atlantic (6.7 ka cal BP). The youngest series in the study area is fine-grained aeolian sand composing white dunes that developed over the last 400 years.

The analysis of the sedimentary series and their spatial distribution in the study area allows us to draw a conclusion that the spit of Resko Przymorskie Lake belongs to the transgressing barriers entering the lagoons in their hinterland (Uścinowicz, 2003).

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REFERENCES

Balińska-Wuttke, K., 1963. Morphometric investigations of Pleistocene sand grains in the Rawka river basin (in Polish with English summary). Biuletyn Geologiczny Wydziału Geologicznego UW, **3**: 3–67.

Battarbee, R.W., 1986. Diatom Analysis. In: Handbook of Holocene Paleoecology and Paleohydrology (ed. B.E. Berglund): 527–570, John Wiley and Sons, London.

Berglund, B.E., Sandgren, P., Barnekow, L., Hannon, G., Jiang, H., Skog, G., Yu, S.-Y., 2005. Early Holocene history of the Baltic Sea as reflected in coastal sediments in Blekinge, southeastern Sweden. Quaternary International, **130**: 111–139.

Bitinas, A., 2004. The age of aeolian deposits in Lithuania (in Lithuanian with English summary). Geologija, **45**: 1–5.

Bitinas, A., Damušytė, A., 2004. The Littorina Sea at the Lithuanian Maritime region. Polish Geological Institute Special Papers, **11**: 37–46.

Borówka, R.K., 2001. Historia rozwoju wydm na Mierzei Łebskiej (in Polish). In: Przemiany środowiska geograficznego nizin nadmorskich Południowego Bałtyku w Vistulianie i holocenie (ed. K. Rotnicki): 81–84. Bogucki Wydawnictwo Naukowe, Poznań.

Borówka, R.K., Cedro, B., 2011. Holocene marine ingressions In the coastal zone of the Pomeranian Bay based on radiocarbon assays. Geochronometria, **38**: 85–92.

Borówka, R.K., Osadczuk, A., Witkowski, 2001a. Late Glacial and Holocene stages of the Szczecin Lagoon development. 15 Treffen Deutschsprachiger Diatomologen: 6–12.

Borówka, R.K., Osadczuk, A., Witkowski, A., Wawrzyniak-Wydrowska, B., 2001b. The deposit sequences of the Szczecin Lagoon. 15 Treffen Deutschsprachiger Diatomologen: 13–33.

Borówka, R.K., Latałowa, M., Osadczuk, A., Święta, J., Witkowski, A., 2002. Palaeogeography and palaeoecology of Szczecin Lagoon. Greifswalder Geographishe Arbeiten, **27**: 107–113.

Borówka, R.K., Osadczuk, A., Duda, T., Woziński, R., Kosińska, B., 2003. Pokrywa osadowa Zalewu Szczecińskiego oraz obszaru ujściowego Odry (in Polish). Prace Komisji Paleogeografii Czwartorzędu PAU, **1**: 99–103.

Borówka, R.K., Osadczuk, A., Latałowa, M., Duda, T., Woziński, R., Witkowski, A., Święta-Musznicka, J., Kosińska, B., 2005a. Pokrywa osadowa Zalewu Szczecińskiego i jej wymowa paleogeograficzna (in Polish). In: Środowisko przyrodnicze wybrzeży Zatoki pomorskiej i Zalewu Szczecińskiego (eds. R.K. Borówka and S. Musielak): 93–102. Oficyna InPlus, Szczecin.

Borówka, R.K., Osadczuk, A., Witkowski, A., Wawrzyniak-Wydrowska, B., Duda, T., 2005b. Late Glacial and Holocene depositional history in the eastern part of the Szczecin Lagoon (Great Lagoon) basin – NW Poland. Quaternary International, **130**: 87–96.

Bradshaw, E.G., Jones, V.J., Birks, H.J.B., Birks, H.H., 2000. Diatom responses to late-glacial and early-Holocene environmental changes at Kråkenes, western Norway. Journal of Paleolimnology, **23**: 21–34.

Brykczyńska, E., 1978. An attempt to reconstruct Late Glacial and Holocene history of vegetational cover from the Niechorze area in Western Pomerania (in Polish with English summary). Kwartalnik Geologiczny, **22** (2): 361–377.

Cailleux, A., 1942. Les actions éoliennes périglaciaires en Europe (in French). Sociéte Géologique de France Mémoire, **41**: 1–176.

Cedro, B., 2003. Postglacial and Holocene fluvial, swampy-limnic and marine sediments in the Rega river valley in vicinity of Mrzeżyno (in Polish with English summary). In: Człowiek i środowisko przyrodnicze Pomorza Zachodniego. II Środowisko abiotyczne (eds. R.K. Borówka and A. Witkowski): 47–49. Oficyna InPlus, Szczecin.

Cedro, B., 2004. Environmental changes reconstruction recorded in Vistulian and Holocene sediments of Rega Valley in Mrzeżyno vicinity (in Polish with English summary). Prace Geograficzne, **200**: 59–67.

Cedro, B., 2005. Wstępne uwagi o wieku osadów wypełniających dolinę Regi w rejonie Łobza oraz jej ujściowym odcinku w rejonie Mrzeżyna (in Polish). In: Plejstoceńskie i holoceńskie przemiany środowiska przyrodniczego Polski (ed. R.K. Borówka): 13–16. Oficyna InPlus, Szczecin.

Cedro, B., ed., 2012. Późnoglacjalne i holoceńskie przemiany środowiska przyrodniczego zarejestrowane w osadach profilu T28 z okolic Mrzeżyna na podstawie badań wielodyscyplinarnych. Wydawnictwo ZAPOL, Szczecin.

Cieśla, A., Marciniak, B., 1982. Development of Late Glacial lacustrine deposits at Niechorze (Western Pomerania) in the light of diatomological and geochemical data (in Polish with English summary). Kwartalnik Geologiczny, **26** (1): 191–215.

Clemmensen, L.B., Pye, K., Murray, A., Heinemeier, J., 2001a. Sedimentology, stratigraphy, and landscape evolution of a Holocene coastal dune system, Lodbjerg, NW Jutland, Denmark. Sedimentology, **48**: 3–27.

Clemmensen, L.B., Murray, A., Beck, J.H., Clausen, A., 2001b. Large-scale aeolian sand movement on the west coast of Jutland, Denmark in late Subboreal to early Subatlantic time – a record of climate change or cultural impact? Geologiska Föreningens i Stockholm Föhandlingar, **123**: 193–203.

Denys, L., 1991/92. A check-list of the diatoms in the Holocene deposits of the western Belgian coastal plain with a survey of their apparent ecological requirements. Service Geologique de Belgique.

Dobracka, E., 1990. Szczegółowa mapa geologiczna Polski w skali 1:50 000 arkusz Trzebiatów (in Polish). Państwowy Instytut Geologiczny, Warszawa.

Dobracka, E., 1992. Objaśnienia do Szczegółowej mapy geologicznej Polski skali 1:50 000 arkusz Trzebiatów (in Polish). Państwowy Instytut Geologiczny, Warszawa.

Dobracki, R., Zachowicz, J., 1997. Mapa geodynamiczna polskiej strefy brzegowej Bałtyku południowego w skali 1:10 000 arkusz Dźwirzyno (in Polish). Państwowy Instytut Geologiczny, Szczecin.

Faergi, K., Iversen, J., 1989. Textbook of Pollen Analysis. Wiley and Sons, New York.

Fedorowicz, S., Gołębiewski, R., Wysiecka, G., 2009. The age of the dunes of the Vistula Spit in the vicinity of Stegna. Geologija, **51**: 139–145.

Fedorowicz, S., Zieliński, P., Wysiecka, G., Hołub, B., 2012. Phases of aeolian accumulation on the Vistula Spit (Southern Baltic Sea) in the light of TL dating and analysis of a digital elevation model. Geological Quarterly, **56** (2): 345–352.

Folk, R.L., Ward, W.C., 1957. Brazos River bar, a study of significance of grain size parameters. Journal of Sedimentary Petrology, **27**: 3–26.

Goździk, J., 1995. Selected methods of analysis of the shape of the sand grains for paleogeographic and stratigraphic purposes (in Polish with English summary). In: Badania osadów czwartorzędowych. Wybrane metody i interpretacja wyników (eds. E. Mycielska-Dowgiałło and J. Rutkowski): 115–132. Uniwersytet Warszawski, Państwowy Instytut Geologiczny, Komitet Badań Czwartorzędu PAN, Warszawa.

Guiry, M.D., Guiry, G.M., 2015. Algae Base. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org; searched on 12 March 2015.

Hassan, S., 2010. Paleoecological Significance of Diatoms in Argentinean Estuaries. Nova Science Publishers Inc., New York, (E-book).

Hoffmann, G., 2004. Postglacial to Holocene sedimentation history and palaeogeographical development of a barrier spit (Pudagla lowland, Usedom Island, SW Baltic coast). Polish Geological Institute Special Papers, **11**: 83–90.

Hoffmann, G., Barnasch, J., 2005. Late Glacial to Holocene coastal changes of SE Rügen Island (Baltic Sea, NE Germany). Aquatic Sciences, **67**: 132–141.

Hoffmann, G., Lampe, R., 2007. Sediment budget calculation to estimate Holocene coastal changes on the southwest Baltic Sea. Marine Geology, **243**: 143–156.

Hoffmann, G., Lampe, R., Barnasch, J., 2005. Postglacial evolution of coastal barriers along the West Pomeranian coast, NE Germany. Quaternary International, **133–134**: 47–59.

Hoffmann, G., Schmedemann, N., Schafmeister, M.-T., 2009. Relative sea-level curve for SE Rügen and Usedom Island (SW Baltic Sea coast, Germany) using decompacted profiles. Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, **160**: 69–78.

Hofmann, G., Werum, M., Lange-Beralot, H., 2011. Diatommen im Süßwasser-Benthos von Mitteleuropa. ARG Gantner Verlag.

Janczak-Kostecka, B., Kostecki, R., 2008. Reconstruction of the Holocene environment in the Łeba Barrier in the light of diatomological and geochemical analysis (in Polish with English summary). In: Holoceńskie przemiany wybrzeży i wód południowego Bałtyku – przyczyny, uwarunkowania i skutki (eds. K. Rotnicki, J. Jasiewicz and M. Woszczyk): 17–23. Wydawnictwo Tekst, Poznań–Bydgoszcz.

Jańczyk-Kopikowa, Z., 1987. Remarks on palynostratigraphy of the Quaternary (in Polish with English summary). Kwartalnik Geologiczny, **31** (1): 155–162.

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

Keilhack, K., 1912. Die Verlandung der Swinepforte. Jahrbuch der Königlich Preussichen Geologischen Landesanstalt, **32**.

Keilhack, K., 1914. Erluterungen zur Geologischen Karten von Preussen und Benachbarten Bundesstaaten Blatt Swinemünde. Königlich Geologische Landesanstalt, Berlin.

Kopczyńska-Lamparska, K., 1976. Radiocarbon datings of the Late Glacial and Holocene deposits of western Pomerania. Acta Geologica Polonica, **26**: 413–418.

Kopczyńska-Lamparska, K., Cieśla, A., Skompski, S., 1984. Evolution of fossil lake basins of the Late Glacial and Holocene in the cliff near Niechorze (Pomeranian Lakeland, Poland). Quaternary Studies in Poland, **5**: 39–58.

Korhola, A., 1990. Paleolimnology and hydroseral development of the Kotasuo bog, southern Finland, with special reference to the Cladocera. Annales Academiae Scientiarum Fennicae, **155**: 1–40.

Kramarska, R., 1999. Zarys geologii czwartorzędu południowo-zachodniej części Bałtyku (in Polish). In: Problemy geologii, hydrogeologii i ochrony środowiska wybrzeża morskiego Pomorza Zachodniego. LXX Zjazd Naukowy Polskiego Towarzystwa

Geologicznego (eds. R.K. Borówka, A. Piotrowski and Z. Wiśniowski): 43–52. Państwowy Instytut Geologiczny, Szczecin.

Kramarska, R., Uścinowicz, Sz., Zachowicz, J., 1995. Atlas geologiczny południowego Bałtyku. Czwartorzęd (in Polish). Państwowy instytut Geologiczny, Sopot-Warszawa.

Krammer, K., Lange-Bertalot, H., 2008a. Bacillariophyceae 2, Ephitemiaceae, Bacillariaceae, Surirellaceae. In: Süsswasserflora von Mitteleuropa 2 (eds. H. Ettl, J. Gerloff, H. Heyning and D. Mollenhauer). T 2, 4th Edition, Fischer, Stuttgart.

Krammer, K., Lange-Bertalot, H., 2008b. Bacillariophyceae 3, Centrales, Fragilariaceae, Eunotiaceae. In: Süsswasserflora von Mitteleuropa 2 (eds. H. Ettl, J. Gerloff, H. Heyning and D. Mollenhauer). T 3, 3rd Edition, Fisher, Stuttgart.

Krammer, K., Lange-Bertalot, H., 2010. Bacillariophyceae 1, Naviculaceae. In: Süsswasserflora von Mitteleuropa 2 (eds. H. Ettl, J. Gerloff, H. Heyning and D. Mollenhauer). T 1, 4th Edition, Fischer, Stuttgart.

Krammer, K., Lange-Bertalot, H., 2011. Bacillariophyceae 4, Achnanthaceae. In: Süsswasserflora von Mitteleuropa 2 (eds. H. Ettl, J. Gerloff, H. Heyning and D. Mollenhauer). T 4, 3rd Edition, Fischer, Stuttgart.

Krzymińska, J., Przezdziecki, P., 2008. Wstępne dane o kopalnych jeziorach w okresie późnego glacjału i wczesnego holocenu w rejonie Mrzeżyna (in Polish). In: VIII Konferencja "Geologia i geomorfologia Pobrzeża i południowego Bałtyku": 31–32. Słupsk–Ustka, 12–14 czerwca 2008.

Krzymińska, J., Dobracki, R., Koszka-Maroń, D., 2003. Environmental changes in the western part of south Baltic Sea coast area in Late Glacial and Holocene according to malacological and ostracod analysis (in Polish with English summary). In: Geologia i geomorfologia pobrzeża i południowego Bałtyku cz. 5 (ed. W. Florek): 15–24. Pomorska Akademia Pedagogiczna w Słupsku.

Krzymińska, J., Dobracki, R., Miotk-Szpiganowicz, G., Seidler, J., Dobracki, K., 2011. Changes of palaeoenvironment recorded in the Late Glacial and Holocene deposits of the middle coast of the Southern Baltic Sea based on biostratigraphical research. Grzybowski Foundation Special Publications, **17**: 104–105.

Kwadrans, J., 2007. Diversity and ecology of benthic diatom communities in relation to acidity, acidification and recovery of lakes and rivers. Diatom Monographs, **8**: 1–169.

Lampe, R., 2005. Late glacial and Holocene water-level variations along the NE German Baltic Sea coast: review and new results. Quaternary International, **133–134**: 121–136.

Lampe, R., Naumann, M., Meyer, H., Janke, W., Ziekur, R., 2011. Holocene evolution of the Southern Baltic Sea coast and interplay of sea-level variation, isostasy, accommodation and sediment supply. In: The Baltic Sea Basin (eds. J. Harff, S. Björck and P. Hoth): 233–251. Springer.

Lange-Bertalot, H., Metzeltin, D., 1996. Indicators of oligotrophy. 800 taxa representative of three ecologically distinct lake types. In: Iconogrphia Diatomologica: Annotated Diatom Micrographs (ed. H. Lange-Bertalot). Koeltz Scientific Books, **2**.

Latałowa, M., 2003. Późny Vistulian (in Polish). In: Palinologia (eds. S. Dybova-Jachowicz and A. Sadowska): 266–273. Wydawnictwa Instytutu Botaniki Polskiej Akademii Nauk, Kraków.

Lecointe, C., Coste, M., Prygiel, J., 1993. "OMNIDIA": software for taxonomy, calculation of diatom indices and inventories management. Hydrobiologia, **269/270**: 509–513.

Ludwikowska-Kędzia, M., 2000. Ewolucja środkowego odcinka doliny rzeki Bielanki w późnym glacjale i holocenie. Wydawnictwo Akademickie DIALOG, Warszawa.

Lutyńska, M., 2005. Powstanie jeziora Gardno i jego zmiany paleoekologiczne a holoceńska transgresja Bałtyku Południowego w świetle analiz okrzemkowych i geochemicznych (in Polish). PhD Thesis, Archiwum Zakładu Geologii i Paleogeografii Czwartorzędu, Instytutu Geoekologii i Geoinformacji UAM w Poznaniu.

Lutyńska, M., 2008. Phases of development of Lake Gardno based on geochemical and diatomological analysis (in Polish with English summary). In: Holoceńskie przemiany wybrzeży i wód południowego Bałtyku – przyczyny, uwarunkowania i skutki (eds. K. Rotnicki, J. Jasiewicz and M. Woszczyk): 17–23. Wydawnictwo Tekst, Poznań-Bydgoszcz.

Mangerund, J., Andersen, S.T., Berglund, B.E., Donner, J.J., 1974. Quaternary stratigraphy of Norden, a proposal of terminology and classification. Boreas, **3**: 109–126.

Mazurek, T., Lutyńska, M., Rotnicki, K., 2008. Traces of young Holocene inflows of marine water to the Dołgie Wielkie Lake (in Polish with English summary). In: Holoceńskie przemiany wybrzeży i wód południowego Bałtyku – przyczyny, uwarunkowania i skutki (eds. K. Rotnicki, J. Jasiewicz and M. Woszczyk): 35–42. Wydawnictwo Tekst, Poznań-Bydgoszcz.

Mianowicz, K., Cedro, B., 2013. The Holocene palaeohydrological evets recorded in the subfossil deposits from Mrzeżyno (Trzebiatowskie Coast) on the basis of the results of the floral and faunal macrofossil analysis of T28 core (in Polish with English summary). In: Geologia i geomorfologia pobrzeża i południowego Bałtyku cz. 10 (ed. W. Florek): 99–117. Akademia Pomorska w Słupsku, Słupsk.

Miotk-Szpiganowicz, G., Zachowicz, J., Uścinowicz, Sz., 2008. Review and reinterpretation of the pollen and diatom data from the deposits of the Southern Baltic lagoons. Polish Geological Institute Special Papers, **23**: 45–70.

Moe, D., Savukynienė, N., Stančikaite, M., 2005. A new ^{14}C (AMS) date from former heathland soil horizons at KuršiĺNerija, Lithuania. Baltica, **18**: 23–28.

Musielak, S., Łabuz, T.A., Wochna, S., 2005. Współczesne procesy brzegowe na Wybrzeżu Trzebiatowskim. In: Środowisko przyrodnicze wybrzeży Zatoki Pomorskiej i Zalewu Szczecińskiego (eds. R.K. Borówka and S. Musielak): 61–71. Oficyna InPlus, Szczecin.

Mycielska-Dowgiałło, E., 2007. Metody badań cech teksturalnych osadów klastycznych i wartość interpretacyjna wyników (in Polish). In: Badania cech teksturalnych osadów czwartorzędowych i wybrane metody oznaczania ich wieku (eds. E. Mycielska-Dowgiałło and J. Rutkowski): 95–180. Wydawnictwo Szkoły Wyższej Przymierza Rodzin, Warszawa.

Mycielska-Dowgiałło, E., Ludwikowska-Kędzia, M., 2011. Alternative interpretations of grain-size data from Quaternary deposits. Geologos, **17**: 189–203.

Nalepka, D., Walanus, A., 2003. Data processing in pollen analysis. Acta Palaeobotanica, **43**: 125–134.

Osadczuk, K., 2004. Origin and evolution of the Świna Barrier spit in the light of morphometric and sedimentological research (in Polish with English summary). Uniwersytet Szczeciński. Rozprawy i Studia T. (DCXXVI) **552**.

Osadczuk, K., 2005. Wydmy Bramy Świny i ich wymowa paleogeograficzna (in Polish). In: Środowisko przyrodnicze wybrzeży Zatoki Pomorskiej i Zalewu Szczecińskiego (eds. R.K. Borówka and S. Musielak): 43–53. Oficyna InPlus, Szczecin.

Pliński, M., Witkowski, A., 2009. Okrzemki – Bacillariophyta (Diatoms) (with the English key for the identification to the genus), Cz. 1: Okrzemki Centryczne. Wydawnictwo Uniwersytetu Gdańskiego.

Pliński, M., Witkowski A., 2011. Okrzemki – Bacillariophyta (Diatoms) (with the English key for the identification to the genus), Cz. 2: Okrzemki Pierzaste. Wydawnictwo Uniwersytetu Gdańskiego.

Pliński, M., Witkowski, A., 2013a. Okrzemki – Bacillariophyta (Diatoms) (with the English key for the identification to the genus), Cz. 3: Okrzemki Pierzaste. Wydawnictwo Uniwersytetu Gdańskiego.

Pliński, M., Witkowski, A., 2013b. Okrzemki – Bacillariophyta (Diatoms) (with the English key for the identification to the genus), Cz. 4: Okrzemki pierzaste (Thalassiophysales, Rhopalodiales, Bacillariales, Surirellales). Wydawnictwo Uniwersytetu Gdańskiego.

Prusinkiewicz, Z., Noryśkiewicz, B., 1966. Problem of age of podzols on brown dunes of bay bars of river Świna in the light of a palynological analysis and dating by radiocarbon C^{14} (in Polish with English summary). Zeszyty Naukowe Uniwersytetu Mikołaja Kopernika w Toruniu, **14**: 75–88.

Ralska-Jasiewiczowa, M., Rzętkowska, A., 1987. Pollen and macrofossil stratigraphy of fossil lake sediments at Niechorze I, W Baltic Coast. Acta Palaeobotanica, **27**: 153–178.

Reimann, T., Tsukamoto, S., Harff, J., Osadczuk, K., Frechen, M., 2011. Reconstruction of Holocene coastal foredune progradation using luminescence dating – an example from the Świna barrier (southern Baltic Sea, NW Poland). Geomorphology, **132**: 1–16.

Reimer, P.J., Bard, E., Bayliss, A., Warren Beck, J., Blackwell, P.G., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R., L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, A.K., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. INTCAL13 and MARINE13 radiocarbon age calibration curves 0–50 000 years cal BP. Radiocarbon, **55**: 1869–1887.

Rotnicki, K., 1999. Problem of the Holocene transgressions at the Polish Baltic Middle Coast in the light of new data from the Gardno-Łeba Coastal Plain (in Polish with English summary). In: Ewolucja geosystemów nadmorskich południowego Bałtyku (eds. R.K. Borówka, Z. Młynarczyk and A. Wojciechowski): 131–139. Bogucki Wydawnictwo Naukowe, Poznań-Szczecin.

Rotnicki, K., 2001. Holocene relative sea level changes of the southern Batlic at the Polish middle coast (in Polish with English summary). In: Przemiany środowiska geograficznego nizin nadmorskich południowego Bałtyku w vistulianie i holocenie (ed. K. Rotnicki): 63–80. Bogucki Wydawnictwo Naukowe, Poznań.

Rotnicki, K., 2009. Identification, age and causes of the Holocene transgressions and regressions of the Baltic on the Polish Middle Coast (in Polish with English summary). Wydawnictwo Słowińskiego Parku Narodowego, Smołdzino.

Rotnicki, K., Alexandrowicz, S.W., Pazdur, A., Goslar, T., Borówka, R.K., 2009. Stages of the formation of the Łeba barrier-lagoon system on the basis of the geological cross-section near Rąbka (Southern Baltic Coast, Poland). Studia Quaternaria, **26**: 3–24.

Round, F.E., 1981. The Biology of Algae. Cambridge University Press, Cambridge.

Sindowski, K.-H., 1958. Die synoptische Methode des Kornkurven--Vergleiches zur Ausdeutung fosiller Sedimentationsräume. Geologisches Jahrbuch, **73**.

Sirviö, T., Kajander, M., 2003. Holocene development of the Pennala basin with special reference to the palaeoenvironment of Meso- and Neolithic dwelling sites, Lahti–Orimattila, Southern Finland. Fennia, **181**: 85–101.

Sydor, P., Kotrys, B., 2013. History of development of the former Rega River Valley deposits in Pogorzelica area in the light of sedimentological and palynological analysis (in Polish with English summary). In: Geologia i geomorfologia pobrzeża i południowego Bałtyku cz. 10 (ed. W. Florek): 179–193. Akademia Pomorska w Słupsku, Słupsk.

Tomczak, A., 1995. Budowa geologiczna i ewolucja polskiej strefy brzegowej (in Polish). In: Atlas geologiczny południowego Bałtyku (ed. E. Mojski). Państwowy Instytut Geologiczny, Sopot–Warszawa.

Uścinowicz, Sz., 2003. Relative sea level changes, glacio-isostatic rebound and shoreline displacement in the Southern Baltic. Polish Geological Institute Special Papers, **10**: 1–80.

Uścinowicz, Sz., 2006. A relative sea-level curve for the Polish Southern Baltic Sea. Quaternary International, **145–146**: 85–105.

Uścinowicz, Sz., Miotk-Szpiganowicz, G., 2003. Holocene shoreline migration in the Puck Lagoon (Southern Baltic Sea) based on the Rzucewo Headland case study. Landform Analysis, **4**: 81–95.

Uścinowicz, Sz., Miotk-Szpiganowicz, G., 2013. Zalew Wiślany i Mierzeja Wiślana (in Polish). In: Osady morskie, lagunowe i torfowisk nadbrzeżnych jako źródło informacji o paleośrodowiskach i klimacie. VI Polska Konferencja Paleobotaniki Czwartorzędu: 82–93. Krynica Morska, 11–13 czerwca 2013.

van Dam, H., Mertens, A., Sinkeldam, J., 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology, **28**: 117–133.

Wentworth, C.K., 1922. A scale of grade and class terms of clastic sediments. Journal of Geology, **30**: 377–392.

Witkowski, A., 1994. Recent and fossil diatom flora of the Gulf of Gdansk, Southern Baltic Sea. Bibliotheca Diatomologica, **28**.

Witkowski, A., Lange-Bertalot, H., Metzeltin, D., 2000. Diatom flora of marine coasts, 1. In: Iconographica Diatomologica: Annotated Diatom Micrographs, **7** (ed. H. Lange-Bertalot). A.R.G. Gantner.

Witkowski, A., Borówka, R.K., Bąk, M., Olas, M., Lutyńska, M., Wawrzyniak-Wydrowska, B., Osadczuk, A., Tomkowiak, J., 2003a. Environmental changes in the Szczecin Lagoon during the Late-Glacial and Holocene as inferred from diatom analysis (in Polish with English summary). In: Człowiek i środowisko przyrodnicze Pomorza Zachodniego. Cz. II Środowisko abiotyczne (eds. R.K. Borówka and A. Witkowski): 36–42, Wydawnictwo Oficyna In Plus.

Witkowski, A., Latałowa, M., Borówka, R.K., Gregorowicz, P., Bąk, M., Osadczuk, A., Święta, J., Lutyńska, M., Olas, M., Bernat, D., Wawrzyniak-Wydrowska, B., Woziński, R., 2003b. Succession of diatom (Bacillariophyceae) assemblages in the Holocene deposits of Szczecin Lagoon. Their relation to local vegetation and palaeogeographic development. Acta Botanica Warmiae et Masuriae, **3**: 167–180.

Witkowski, A., Latałowa, M., Borówka, R.K., Gregorowicz, P., Bąk, M., Osadczuk, A., Święta, J., Lutyńska, M., Olas, M., Wawrzyniak-Wydrowska, B., Woziński, R., 2004. Palaeoenvironmental changes in the area of the Szczecin Lagoon (the south western Baltic Sea) as recorded from diatoms. Studia Quaternaria, **21**: 153–165.

WoRMS Editorial Board, 2015. World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2015–03-12.

Woziński, R., Wawrzyniak-Wydrowska, B., Borówka, R.K., 2003. The subfossil malacofauna from the Holocene deposits of the Szczecin Lagoon (in Polish with English summary). In: Człowiek i środowisko przyrodnicze Pomorza Zachodniego. Cz. II Środowisko abiotyczne (eds. R.K. Borówka and A. Witkowski): 113–118. Wydawnictwo Oficyna In Plus.

Wypych, K., 1973. Geneza zalewów południowobałtyckich w świetle nowszych danych (in Polish). Przegląd Geofizyczny, **18**: 111–120.