Studia Quaternaria, vol. 27 (2010): 27–33.

DIATOMOLOGICAL AND GEOCHEMICAL EVIDENCE OF LITTORINA TRANSGRESSION IN POMERANIAN BAY, SOUTHERN BALTIC SEA

Robert Kostecki, Beata Janczak-Kostecka

Department of Quaternary Geology and Paleogeography, Adam Mickiewicz University, ul. Dzięgielowa 27, 61-680 Poznań, Poland, e-mail: kostecki@amu.edu.pl

Abstract

This article presents results of the analysis of 3 sediment cores taken from the bottom of Pomeranian Bay, southern Baltic Sea. These results are part of a larger project that aims to determine the characteristics and rate of the Atlantic marine ingression in the Pomeranian Bay area. The main geochemical elements and diatom assemblages from the cores were identified, revealing lacustrine sediments deposited during the time of Ancylus Lake and marine sediments deposited during the Littorina transgression. Distinct changes in the geochemical composition and diatom assemblages suggest that the Littorina transgression had a very large impact on the environment of Pomeranian Bay.

Key words: diatoms, geochemistry, Littorina transgression, Pomeranian Bay, southern Baltic Sea.

INTRODUCTION

Current knowledge of the transitional period between Ancylus Lake and Littorina Sea at the area of the modern Baltic Sea, is not sufficient to reconstruct the changes that occurred on past coastlines, especially in large lowland areas. The contemporary Pomeranian Bay of the southern Baltic Sea (Fig.1) was one such lowland. After the deglaciation, from the beginning of the Holocene till the Atlantic period, this area was a land. During the Baltic Ice Lake period, the water table rose to approximately 10 m below present sea level, creating a lagoon south of the Odra Bank (Lampe 2005). Kramarska (1998) reported the existence of a lagoon between Odra Bank and the Littorina Sea before about 7000 years ago. Before the Littorina transgression, Odra Bank may have been a sand barrier that separated the lagoon from the open sea. Previous studies found Early Holocene lacustrine and lagoon deposits north of Wolin Island in the Baltic Sea (Kramarska 1998; Krzymińska, Przeździecki 2001, Broszinski *et al.* 2005). According to Broszinski *et al.* (2005), numerous lakes existed in the southern part of Pomeranian Bay during the Ancylus and early Littorina periods. The land changed with the Late Atlantic transgression at ca. 7200 cal BP (Borówka *et al.* 2002, 2005), forming an open marine bay that extended southward into the lower Odra River valley. Researchers (Rosa 1963, Borówka *et al.* 2005) have suggested that this event may have been disastrous. The rapid ingression may have been caused by disruption and destruction of the sand bar between Odra Bank and the east coast of Pomeranian Bay during extremely strong storms.

The main goals of this study were to determine the characteristics and rate of the Late Atlantic ingression, and to ascertain the importance of coastal Pre-Littorina lagoons and lake basins in the development of the Baltic Sea ingression. Earlier geological studies of Pomeranian Bay were based on diatomological (Broszinski *et al.* 2005) and malacological (Krzymińska, Przeździecki 2001, Borówka *et al.* 2005) analyses of a few cores taken from the eastern part of the bight. These studies helped to distinguish transitional environmental phases. However, recent studies of the southern Baltic Sea have not fully explained the genesis and evolution of Pomeranian Bay during the Holocene. In particular, they have not determined the intensity of flooding of the former terrestrial environment caused by the Late Atlantic ingression, or the nature of the early Holocene depositional environments located in the terrestrial area.

MATERIALS AND METHODS

Site description

Pomeranian Bay (Fig.1) is a large and shallow basin situated in the south-western part of the Baltic Sea off the Polish and German coasts. The basin is limited to the south by the mouth of the Odra River between Uznam and Wolin Islands, to the west by the German island of Rugia, and to the north by Danish island of Bornholm. The bay is located in the vicinity of Arkona Basin, Eagle Bank and Bornholm Basin. Its depth is limited along the 30 m isobath. The main forms of bottom relief are the Odra Bank, which rises to 7 m below sea level (b.s.l.) in the central part of the basin, and the old Odra Valley, which descends to a depth of 20 m b.s.l in the western part of the basin.

Table 1

Radiocarbon and calendar ages of the material studied in the present work

Sample code	Type of material	Depth below bed surface (m)	Radiocarbon age ^{14}C (BP)	Calibrated age cal year	Laboratory code
246060/250	organic mud	2.50	7720 ± 50	8275-8139 (68.2%) 8315-8046 (95.4%)	Poz-33884
246060/280	gyttja	2.80	8300 ± 50	8961-8785 (68.2%) 8999-8660 (95.4%)	Poz-33885

Sample collection and analysis

We examined three sediment cores taken from Pomeranian Bay by the Institute for Baltic Sea Research (Warnemünde, Germany) aboard the research vessel FS "A. v. Humboldt". The cores were obtained from Prorer Wiek, situated 3.5 to 9 km from the east coast of Rugia in western Pomeranian Bay (Fig. 1). Distances between cores did not exceed 5 km. Cores 246040 and 246040 were collected at 16 m b.s.l. and had lengths of 540 cm and 485 cm, respectively. Core 246060 was drilled below 20 m b.s.l. and was 610 cm in length. The cores were sub-sampled to collect 5–10-cm-thick samples, depending on the lithology.

Geochemical analyses were conducted in entire samples to determine loss of ignition, terrigenous silica, biogenic silica, sodium, potassium, magnesium, calcium, iron, and manganese contents. Dried samples were combusted at 550 °C to determine loss of ignition. Terrigenous silica content was obtained by digestion on water bath in aqua regia, and biogenic silica content was determined by digestion in sodium hydroxide. The main elements were measured using flame atomic absorption spectrometry (AAS) on digested liquid samples.

Samples for diatom analysis were prepared according to the standard method described by Battarbee (1986). Analyses were conducted using an illuminating microscope Nikon Eclipse E200 with 100× objectives. Approximately 300 valves per sample were counted. Taxonomy and ecological grouping were determined according to Krammer and Lange-Bertalot (1991a, 1991b) and Witkowski *et al.* (2000).

Bulk sediment samples were dated at the Poznań Radiocarbon Laboratory by ^{14}C accelerator mass spectrometry (AMS) (Table 1). Radiocarbon dates were calibrated with the computer programme OxCal (Bronk Ramsey 1995) against the Marine09 data set (Reimer *et al.* 2009), using the Baltic Sea regional ΔR value of –100 ± 100.

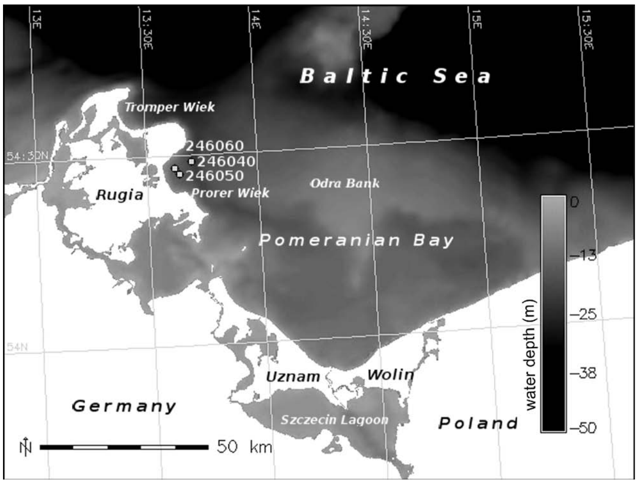

Fig. 1. Location of the study cores.

RESULTS

Geochemical analysis

Core 246060 was taken from the greatest water depth (20.7 m b.s.l.) of the three cores analysed in this study (Fig. 2). The geochemical composition of the core allowed identification of 3 chemical zones (Fig. 3). The lowest zone (L1 – 460–270 cm below sea floor) consisted of sandy and clayey silt of an olive-grey colour, with olive-black peat gyttja at the top. Terrigenous silica was the greatest contributor (90%); calcium constituted only 3% of this part of the core, and the contributions of loss of ignition, biogenic silica, magnesium, sodium, and iron were also low. The upper part (280 cm below bed surface) of this zone dated to 8999–8660 cal BP (8300 ± 50 ^{14}C years BP).

The next zone (M1 – 270–160 cm) consisted of olive-grey mud with marine shells (*Mytilus* sp. and *Cerastoderma* sp.) at the top. The sediments of this zone exhibited 12% loss of ignition and 8% biogenic silica content. Large contributions of magnesium (8%), sodium (0.4%), and iron (0.35%) we also were found. In contrast, contributions of terrigenous silica and calcium were low. Sediments from a depth of 250 cm are dated to *ca*. 8315–8046 cal BP (7720 ± 50 ^{14}C years BP).

The upper zone (M2) spanned a depth of 160 cm to the sea floor. It consisted mainly of olive-grey mud with shell debris and *Scrobicularia* sp. shells. Sediments of this zone contained more terrigenous silica than those of the M1 zone, but lower quantities of other components (loss of ignition did not exceed 3%, biogenic silica 4%, and magnesium 0.5%).

The interface between zones L1 and M1 (270 cm depth) represents a significant change in the environment. The chemical composition of zone L1 suggests a lacustrine environment, whereas the compositions of zones M1 and M2 appear to reflect a marine/brackish water environment. The observed differences between zones L1 and M1 thus suggest a shift from a lacustrine to marine environment.

Cores 246040 and 246050 were taken from the shallower parts of the basin. The sediments in these cores document also the transition between lacustrine/marine environment with a high quantity of calcium (maximum 6%) and low quantities of magnesium (1%) and iron (2%) (Fig. 3).

Diatom analysis

We found three diatom zones in the core (246060) taken from the deepest part of the study area (Fig. 4). The lowest

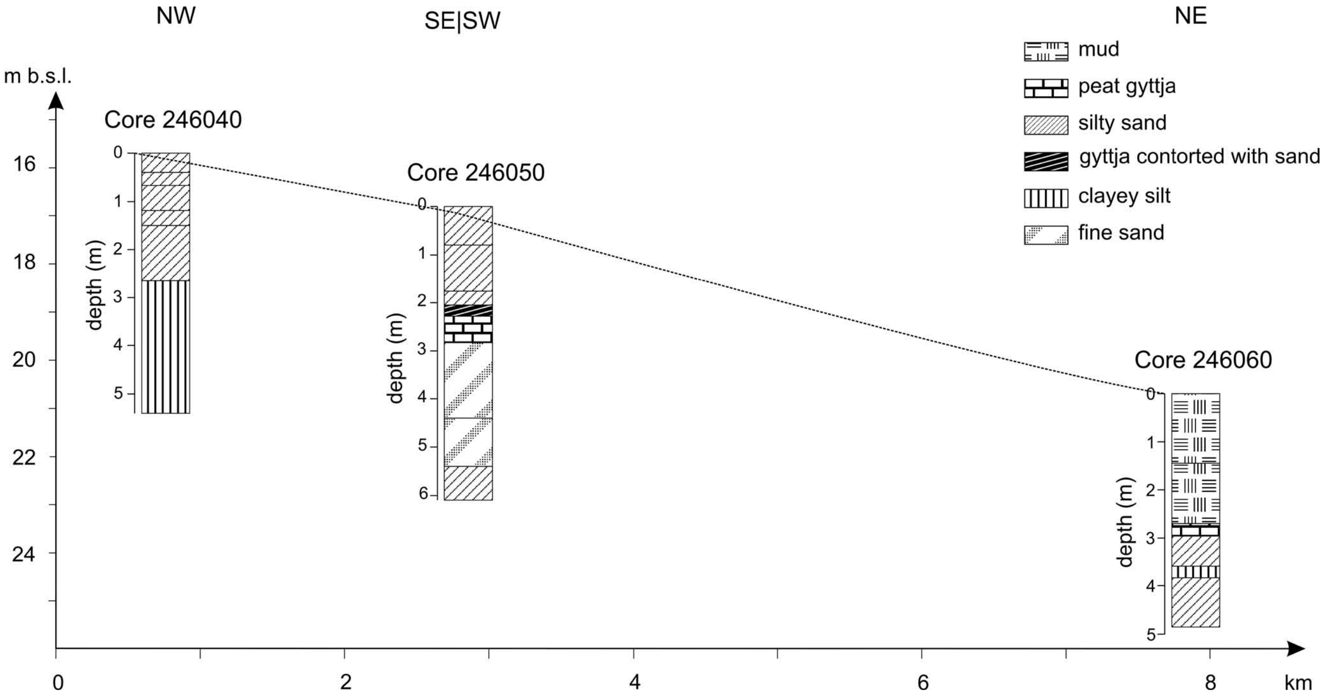

Fig. 2. Lithology and position of investigated cores.

zone (DAZI; 460–370 cm below sea floor) contained only a few freshwater diatoms valves. DAZII (370–270 cm) contained an abundant diatom flora dominated by freshwater species, including *Fragilaria lapponica*, *F. martyi*, and *Amphora pediculus*. Dominant brackish water forms included *F. guenter-grassi* and *F. fasciculata*.

Diatoms assemblages abruptly switched from freshwater to marine/brackish water species in the transitional layer (at 270 cm) between zones DAZII and DAZIII. This significant change is reflected in emergence of new marine diatom specimens and the disappearance of many freshwater species. Marine diatoms included species such as *Diploneis smithii*, *Cocconeis scutellum*, *Pseudosolenia calcar-avis*, and *Paralia sulcata*. The composition of the brackish water diatoms changed too, with the total disappearance of *F. fasciculata* and the emergence of *Chaetoceros* sp. spores. Other brackish water diatoms such as *F. guenter-grassii* and *F. geocollegarum* were present throughout the entire core. The abundance of *Chaeteceros* sp. spores (66 %) that form during the change of environment, explains the disappearance of many freshwater and brackish water species. Such a significant change in the diatom assemblages suggests that a marine environment appeared and that the freshwater basins became an open marine bay. Moreover, the greater abundance of plankton forms in zone DAZIII indicates greater basin depth during the marine period than during the lacustrine period.

In core 246050 taken from the shallowest part of the study area, diatoms were present only in the thin layer of gyttja. This gyttja contained benthic freshwater diatom species such as *Fragilaria martyi*, *F. brevistriata*, *F. pinnata* and *Amphora pediculus* and brackish water species such as *F. guenter-grassi* and *F. geocollegarum*. The limited distribution of diatoms may reflect a dynamic coastal environment in which diatom valves were not preserved.

DISCUSSION

Our investigations of sediment cores taken a few kilometres from the west coast of Rugia Island near Prorer Wiek suggest that the Littorina transgression had a very large impact on the environment of Pomeranian Bay. A sudden transgression at the beginning of the Littorina period is suggested by a shift of diatom assemblages from freshwater to marine taxa, and by the increasing levels of magnesium and iron in the sediment.

Core 246060 could be thus divided into two main units: a lower lacustrine unit containing geochemical zone L1 and diatom zones DAZI and DAZII; and an upper marine unit encompassing zones M1, M2 and DAZIII. The age, diatom assemblage and geochemical composition of the lower unit, deposited during the Ancylus Lake stage, correspond to sediments of unit "E4" found in Tromper Wiek (Lemke *et al.* 1998). Sediments of the upper marine unit were deposited during the Littorina Sea stage and they are equivalent to unit "E5" from Tromper Wiek (Lemke *et al.* 1998).

Dates obtained from the marine unit place the beginning of the Littorina transgression at *ca.* 8300 cal BP. Dates from the lower lacustrine unit (*ca.* 9000 cal BP) suggests that this environmental change occurred over a few centuries.

Previous studies have placed the beginning of the Littorina transgression into the Pomeranian area at *ca.* 7200 cal BP (Borówka *et al.* 2005). The similar ages of limnic deposits from Pomeranian Bay and Szczecin Lagoon (Kramarska 1998, Borówka *et al.* 2002, 2005) constitute further evidence for the rapid rate of this transgression. Kramarska (1998) reported the existence of a lagoon separated from the marine Littorina Sea Basin by the barrier of Odra Bank until *ca.* 5500 cal BP (5100 ± 200 ^{14}C BP, calibrated by authors). However, marine conditions could have affected this area at *ca.* 7000 BP (Kramarska 1998). Uścinowicz (2006) also described a

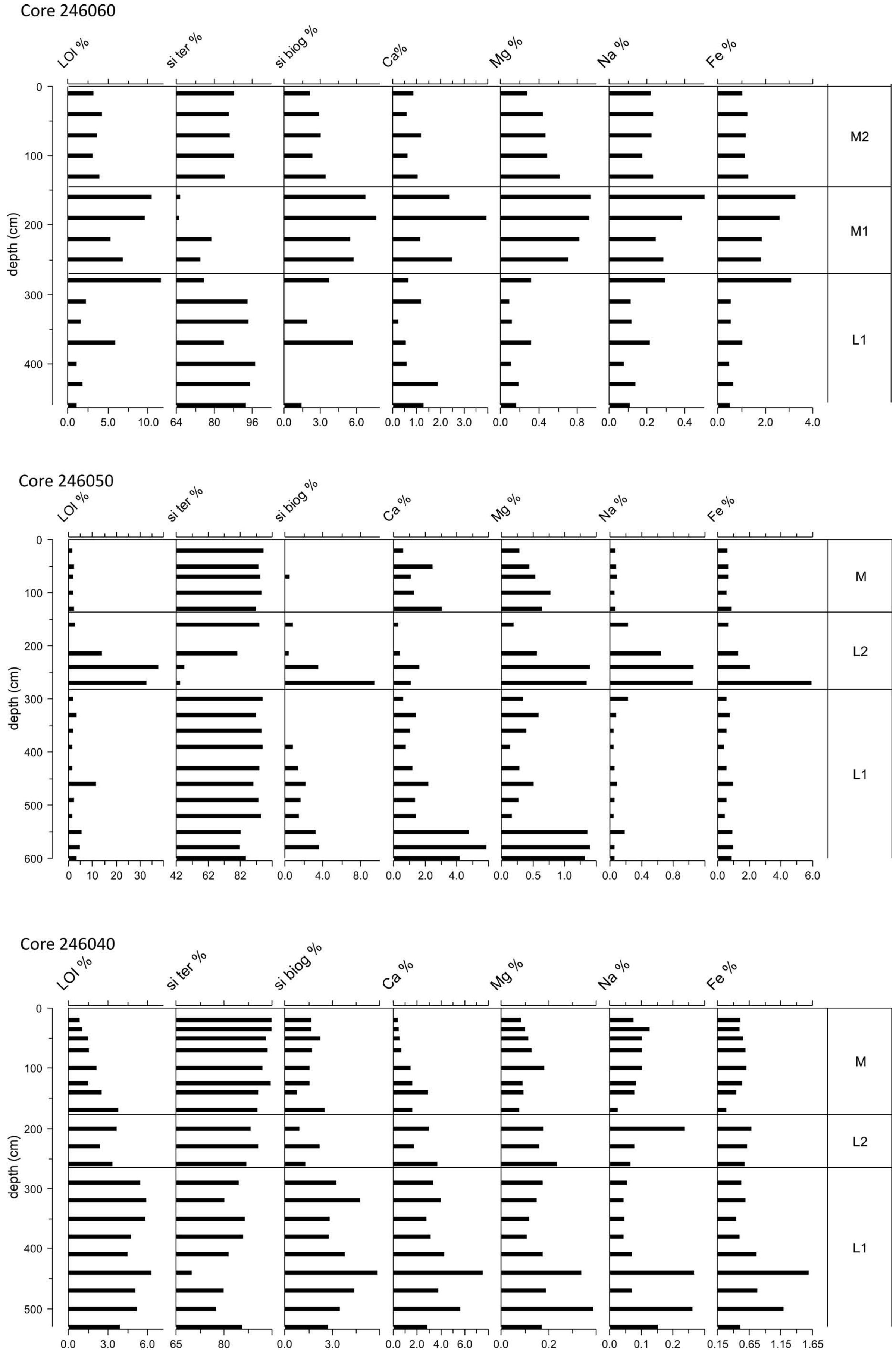

Fig. 3. Geochemical composition of the sediment in studied cores.

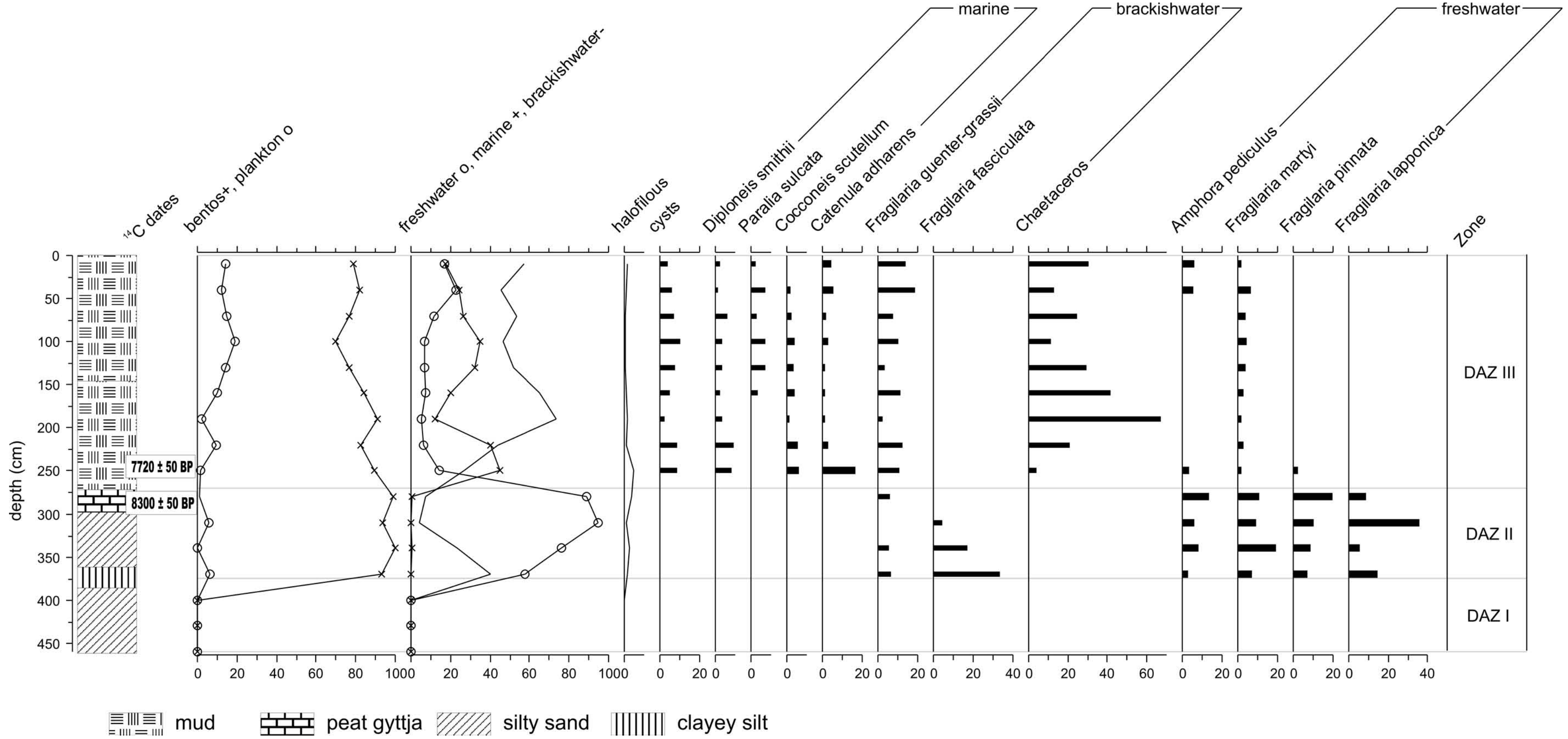

Fig. 4. Distribution of diatom ecological groups and the diatom species in core 246060.

rapid sea level rise in north-western Europe at *ca.* 8500 to 6500 cal BP.

The Littorina transgression strongly influenced the entire south Baltic coast, where it flooded formerly dry land in many places. For example Witkowski *et al.* (2009) found sediments of the first transgressive stage dated to 8640 cal BP in the area of the Rega River Valley. A similar date reported by Rotnicki (2008) for the Gardno–Łeba Plain, indicates the emergence of a marine environment at 8550 cal BP.

The beginning of the Littorina transgression is dated to 8650 cal BP on the German coast in Wismar Bay (Lübke 2002, Lampe *et al.* 2005, Schmölcke *et al.* 2006, Lübke, Lüth 2009). Lübke and Lüth (2009) discovered submerged prehistoric human settlements at a maximum depth of 11 m below modern sea level in this area. The earliest Mesolithic settlements date to 8350–7950 cal BP (Lübke, Lüth 2009). Apparently, sea level rise forced people to abandon earlier settlements (Schmölcke *et al.* 2006). The dates from Wismar Bay are similar to those from the Polish middle coast and Pomeranian Bay, but differ from those obtained from Szczecin Lagoon. These disparities in the timing of transgression in different sites could be because the tectonic activity of the coasts belongs to different neotectonic structural units (Witkowski *et al.* 2009).

Lemke (1998) and Witkowski *et al.* (2005) reported in Mecklenburg Bay dates of Littorina transgression similar to those from Szczecin Lagoon, where a drastic rise in water level and change into full marine conditions occurred from 8300 to 7800 cal BP. Our study of the sediment profiles from Pomeranian Bay, revealed diatom assemblages similar to that from Mecklenburg Bay. In both regions, freshwater zones of Ancylus Lake contained the same dominant diatom species, such as *F. martyi*, *F. brevistriata* and *A. pediculus*. Marine zones of the Littorina Sea contained the same brackish water and marine taxa, such as *D. smithii, P. sulcata* and *P. calcar-avis*. The strong similarities in diatom community changes at the beginning of the Littorina period in Pomeranian and Mecklenburg Bays suggest that the Littorina transgression drastically changed the environment over larger part of the southern Baltic coast. Marine diatom assemblages almost completely replaced freshwater communities. We suggest that this transgression in the Pomeranian Bay area occurred suddenly within a short time span during the Late-Atlantic period between 9000 and 8300 cal BP.

CONCLUSIONS

Our analysis of sediment cores from Pomeranian Bay identified two main units. The lower unit consisted of sediments such as silt and gyttja that were deposited in freshwater conditions. In contrast, the upper unit of sandy silts and mud was formed in marine conditions. The diatom communities and geochemical composition of the cores confirmed this division. The most important feature was the sharp transition layer between freshwater and marine periods, which occurred at a depth of 270 cm below the sea floor. In our opinion, such a distinct transition between environments could have been caused by a rapid marine transgression that took place during the Late-Atlantic period. This scenario agrees with data from other investigations conducted in Szczecin Lagoon and Wismar Bay.

Acknowledgments

The authors are grateful to Professor Andrzej Witkowski from Szczecin University and Matthias Moros from the Leibniz Institute for Baltic Sea Research in Warnemünde for their help in obtaining material. We also wish to thank Małgorzata Schade for sample preparation for the diatom and geochemical analyses. We thank Ryszard K. Borówka and Tomasz Goslar for their helpful comments on earlier version on the paper. The Polish Ministry of Science and Higher Education financed the study within the framework of project No. N N305 084235.

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