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Stable isotope composition of subfossil *Cerastoderma glaucum* shells from the Szczecin Bay brackish deposits and its palaeogeographical implications (South Baltic Coast, Poland)

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ABSTRACT

The environmental conditions of the Szczecin Bay, which existed prior to Szczecin Lagoon, have been reconstructed on the basis of the stable carbon and oxygen isotope (^{18}O and ^{13}C) analysis and radiocarbon dates obtained for subfossil shells of *Cerastoderma (Cardium) glaucum*. The shells in the collected core were well preserved in their life positions, representing a geochemical record of past temperature variation over the middle Holocene. Three major periods with different thermal conditions have been distinguished in the interval ~6000–4300 cal yr BP, when the important Littorina regional transgression took place. During the first period, 6000–5250 cal yr BP, water temperature decreased by 1.4°C, and then remained constant over the second period (5250–4750 cal yr BP). In contrast, during the third period (4750–4300 cal yr BP) both δ-values were highly variable and the mean summer temperature (March–November) increased by about 3.5°C. During first two periods, $\delta^{18}O$ and $\delta^{13}C$ were significantly correlated, indicating stability of the environmental conditions.

Introduction

The reconstruction of environmental conditions in the Baltic Sea has been attempted utilizing various paleoecological and paleogeographical methods by a number of researchers listed below. The late glacial and Holocene development of the Baltic Sea was controlled by varying temporally and spatially postglacial eustatic sea level and isostatic rebound of the areas previously covered by permanent ice (Björck, 1995; Harff and Meyer, 2011). In consequence, significant variations of the area and local sea level occurred, leading to serious changes of the whole marine ecosystem resulting from changes in water salinity, temperature and concentration of dissolved oxygen in deep water.

These changes, which were essentially induced by the amounts of water inflowing from the North Sea and climatic changes in the Baltic Sea basin, can be reconstructed utilizing cores of preserved sediments from deep basins (Sohlenius et al., 2001; Harff et al., 2011) alike those from the Baltic littoral zones (Borówka et al., 2005; Lampe, 2005; Uścinowicz, 2006; Miettinen et al., 2007; Kabailiene et al., 2009; Rotnicki, 2009).

For paleoecological reconstructions of salinity, temperature, and bottom-water oxygen content, various approaches have been used including paleobotanical (Witak, 2002; Witkowski et al., 2004; Brenner, 2005; Jankowska et al., 2005; Witak and Dunder, 2007; Leśniewska and Witak, 2008; Miotk-Szpiganowicz et al., 2008) paleozoological (Damušyte, 2009) and isotopic methods (Punning et al., 1988; Emeis et al., 2003; Widerlund and Andersson, 2006, 2011). Paleoclimatic studies based on the records from adjacent continental areas, particularly those used for modeling of temperature and precipitation during the late glacial period and the Holocene, were also important for understanding the environmental changes of the Baltic Sea. These studies used mainly palynological and isotopic methods (e.g. Seppä and Poska, 2004; Antonsson and Seppä, 2007; Skrzypek et al., 2009; Heikkilä and Seppä, 2010). Palynological studies performed in the areas of the South Scandinavia, Finland, Latvia and Estonia lead to conclusion that the Holocene Thermal Maximum occurred there ca. 8000–4000 cal yr BP, with the highest temperatures at the beginning of this period (Heikkilä and Seppä, 2010), while in the SW Poland the highest temperatures occurred ca. 5000 cal yr BP (Skrzypek et al., 2009).

One of the most accurate methods used for the reconstruction of physical-chemical properties of marine water is the analysis of stable carbon and oxygen isotope compositions of carbonates from recent and fossilized mollusk shells. This approach was successfully applied for paleotemperature studies of many basins (Epstein et al., 1953;

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Mook and Vogel, 1968; Mook, 1971; Schöne et al., 2005) and for tracing of their salinity (Keith and Parker, 1965; Punning et al., 1988; Emeis et al., 2003; Mueller-Lupp et al., 2003; Simstisch et al., 2005).

The reconstruction of water temperature in a basin may be used to infer atmospheric circulation in the past. Alheit and Hagen (1997) demonstrated that thermal conditions of littoral water in the South Baltic, including Szczecin Lagoon, are related in a significant degree to the atmospheric circulation in Europe. Winter temperatures of air (Marsz, 1999) and of water in the littoral zones of the South Baltic (Gierjatowicz, 2003, 2007, 2011) are significantly correlated with the fluctuations of North Atlantic Oscillation Index (NAO). The highest winter temperatures are related to the maxima of western circulation, i.e. with the inflow of warm air masses from Atlantic. In summer, the water temperatures are positively correlated with the frequency of air masses inflowing from the east, whereas they are negatively correlated with air masses inflows from the northwest and north (Girjatowicz et al., 2002). It is highly probable that recently observed regularities might be referred to the whole Holocene, therefore they might be useful in the interpretation of dominant types of air circulation in the littoral zone of the South Baltic. The purpose of the present study was to determine temperature variations in the formerly existed open-sea Szczecin Bay, which was replaced by the current Szczecin Lagoon. The open-sea Szczecin Bay existed between the Middle Atlantic and the Middle Subboreal periods (Borówka et al., 2002, 2005, 2009; Borówka and Osadczuk, 2003). During this period the sedimentation of sand with significant addition of mollusk shells was dominant in prevailing brackish conditions (Borówka et al., 2002, 2005; Woziński et al., 2003). Among numerous fossilized mollusk species, the dominant was *Cerastoderma (Cardium) glaucum*, however, other species, including *Macoma balthica, Hydrobia ventrosa* and *Hydrobia ulvae* were also common. The biometric analysis of *Cerastoderma glaucum* shells confirmed that the autochthonic population was very well developed, and displayed a typical age and size structure (Woziński et al., 2003). Many of *C. glaucum* shells have been observed in their typical living position, what proves in situ location at the bottom of the bay and prove that sediments have not been redeposited later on. Therefore, these unique well-preserved mollusk shells have been chosen for assessment of paleohabitat conditions based on the collected sediment core no. 35/99.

Study area

The core no. 35/99 selected for laboratory analyses of extracted shells was collected from central-western part of the Szczecin Lagoon (location: 53° 45′ 29″ N, 14° 19′ 26″ E, see Fig. 1). In the lowermost part of the core at −7.53 to −8.51 m with respect to the current sea level (a.s.l.) dominate fluvial sands deposited from the old Odra river valley at time of the late glacial (Borówka et al., 2002, 2005). Above these sands limnic formations such as gyttja and highly decomposed peats have been deposited (Table 1). The total thickness of the lacustrine–swampy formations is 60 cm. At the level of −6.93 m there appears a distinct erosional unconformity between peat and the cover of fine and very fine grained sands with marine and brackish mollusks. These sediments have total thickness of 147 cm and extend up to −5.44 m a.s.l. Those sediments are covered by 14 cm layer of fine-grained sands with admixture of fresh water mollusk shell, and also 29 cm layer of recently deposited shells of *Dreissena polymorpha*. The top of the bottom deposits reaches altitude of −5.01 m a.s.l. (Table 1).

According to the recent studies (Borówka et al., 2009) the radiocarbon dates of 66 shells of *C. glaucum* preserved in their living position, extracted from 14th profiles of sandy sediments, shows that the studied shells were accumulated at the bottom of the Szczecin Bay during the period between 6460 ± 40 and 3040 ± 35 cal yr BP (7378 ± 41 to 3269 ± 53 cal yr BP). About 4800 cal yr BP began the formation of the Uznam sandbar, which gradually isolated the Szczecin Bay from the direct influence of the Baltic Sea (Prusinkiewicz and Noryśkiewicz, 1966; Borówka et al., 1986; Osadczuk, 2002; Reimann et al., 2009). This process was completed about 3600 to 3300 cal yr BP, when a retrograde delta of the Świna river was developed between these sandbars (Borówka et al., 2009).

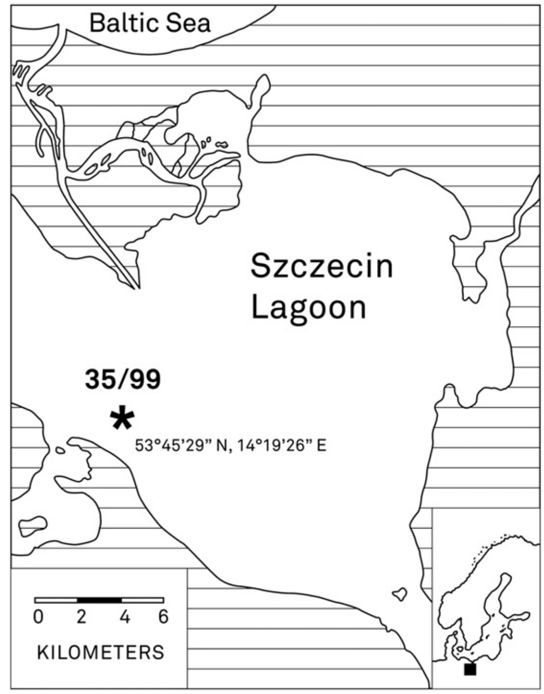

Figure 1. The study area map showing location of sediment core.

Table 1
The lithology of the core 35/99 from the Szczecin Lagoon.

Depth bellow bed surface (m)	Altitude (m a. s. l.)	Lithology
0.00–0.16	−5.01 to −5.17	Shell layer (*Dreissena polymorpha*)
0.16–0.29	−5.17 to −5.30	Shell layer (*Dreissena polymorpha*) with admixture of dark organic mud
0.29–0.43	−5.30 to −5.44	Fine-grained dark-gray sand with admixture of freshwater mollusks shell (*Bithynia tentaculata, Valvata piscinalis, Unio sp., Pisidium* sp.)
0.43–0.58	−5.44 to −5.59	Fine-grained light-gray sand with admixture of marine and brackish mollusks shell (*Cerastoderma glaucum, Hydrobia ventrosa, H. ulvae, Macoma balthica*)
0.58–0.86	−5.59 to −5.87	Fine-grained dark-gray sand with admixture of marine and brackish mollusks shell (*C. glaucum, H. ventrosa, H. ulvae, M. balthica*)
0.86–1.02	−5.87 to −6.03	Fine-grained light-gray sand with admixture of marine and brackish mollusks shell (*C. glaucum, H. ventrosa, H. ulvae, M. balthica*)
1.02–1.92	−6.03 to −6.93	Fine-grained gray sand with admixture of marine and brackish mollusks shell (*C. glaucum, H. ventrosa, H. ulvae, M. balthica*)
1.92–2.20	−6.93 to −7.21	Dark-brown peat
2.20–2.52	−7.21 to −7.53	Dark-brown detritus gyttja
2.52–3.00	−7.53 to −8.01	Fine-grained light-brown sand with a root traces
3.00–3.50	−8.01 to −8.51	Fine-grained light-gray sand, horizontally laminated