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Fossil lacustrine bodies in the Gulf of Gdańsk as recorded by seismoacoustic data and ostracodological analysis

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Abstract The studies were carried out in two testing grounds (*polygon-1 and polygon-2*) located in the western part of the Gulf of Gdańsk. They included lithological, biostratigraphic and seismoacoustic investigations of sediments, whose Late Glacial to Atlantic Period age was determined by the ^{14}C method and verified by palynological analyses. Ostracodological study indicates that the sediments represent both freshwater and marine environments. The species composition of freshwater ostracods from the sections confirms that the sediments were deposited in local lacustrine bodies. Seismoacoustic survey shows that these bodies are ca. 200 to 1000 m in size and with spaces of 2 to 5 km between them. They were deposited during the Late Glacial and developed up until the onset of marine transgression.

Keywords *Gulf of Gdańsk, Ostracods, seismoacoustic data, ostracodological analysis.*

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INTRODUCTION

The Gulf of Gdańsk is one of the classical areas for palaeogeographical researches of the southern Baltic due to well–preserved deltaic, lagoonal and berm sediments deposited during various periods of the Baltic Sea development. The area can be subdivided into the western part, covering the Puck Bay with underwater slopes of the Hel Peninsula, and the eastern part, covering the Vistula Spit forefield.

A shallow–water zone of this area slopes gently to a depth of 35–40 m b.s.l. It is separated from a deep–water zone by a slope that begins at a depth of 50–60 m and slopes gently further towards the Gdańsk Deep to a depth of ca. 100 m.

There is also diversity in the lithology of benthic sediments. The bottom of the deep–water zone is composed mainly of marine mud, whereas the shallow–water zone is represented by sand sediments (Atlas.... 1995).

The basic information about the geological structure of the bottom of the Gulf of Gdańsk is derived from “The geological map of the Baltic Sea bottom, 1:200 000” (Gdańsk, Elbląg and Głębia Gdańska sheets) (Uścinowicz, Zachowicz 1994) and other publications on the geology, geomorphology and palaeogeography of this area (Ignatius *et al.* 1981; Gudelis *et al.* 1982; Grigelis (ed.) 1991; Blazhchishin 1998; Gelumbauskaitė 2000, 2009).

Detailed research recently carried out (mainly for geotechnical purposes) in limited testing grounds significantly contributed to the recognition of the geological structure of this area. The research involved use of high-frequency seismoacoustic equipment that allows obtaining high-resolution images, in contrast to the previous research conducted in this area (Przezdziecki 2004). Ostracod diagrams, illustrating the percentage of the main association components, proved to be very useful in identification and direct comparison of sedimentary layers.

RESEARCH MATERIAL AND METHODS

Polygon-1 was surveyed using the X-STAR Chirp system. A regular grid of 21 profiles spaced at 500 m was developed over a 5x5 km area. Three profiles, with 50 m spacing, were run in *polygon-2,* parallel to the planned cable route. An ORETECH 8010 Subbottom Profiler (pinger type) was used in profiling, at the frequency of 3.5 kHz. Main geological boundaries were established from geophysical records. Analysis of the seismoacoustic data allowed us to locate remnants of ancient lacustrine bodies and to select core sampling sites.

Sediment cores were taken with a vibrocorer and subjected to a standard sieve analysis to determine lithology. In total, 108 samples of identical volume (200 cm^3) were taken from four cores for quantitative faunal analysis. The sediment was rinsed on a 0.1 mm mesh diameter sieve. The number of shells for each ostracod species was determined separately for each sample, with the top value of 150 specimens. In total, 18 freshwater and two marine taxa were identified. Ostracod spectra were developed to illustrate the percentage of the main components of the association. Ostracod species were identified according to the methodology of Sywula and Pietrzeniuk (1989) and Skompski (1991). All calculations were made using the POLPAL software.

RESEARCH RESULTS

Seismoacoustic investigations

The results presented in this paper come from two different testing grounds (*polygon-1* and *polygon-2*) of detailed research (Fig. 1). Both the polygons are located in the western part of the Gulf of Gdańsk, within a shallow–water zone. One of the testing grounds is located east of Gdynia at a 20–30 m water depth. The other one is situated between the ports of Gdynia and Gdańsk (surveyed before laying down the optical telecommunications cable). The water depth is about 10–15 m in this polygon.

The analysis of seismoacoustic data from the shallow–water zone of the Gulf of Gdańsk shows local hollows in its basement, filled at many places by a different type of sediment, and underlain by recent marine sands. The pattern of these infillings, observed on seismoacoustic records, indicates that they are composed of silt or clay, or partly fine grained sand. In *polygon-2,* two separate basins can be observed (Figs 2, 3). Three vibrocores were taken in this area. The seismoacoustic record from *polygon-1* shows few characteristic features. One core was acquired in this area (Fig. 4). The sampled cores prove that the sediments clearly differ from each other. Basement sediments are composed of

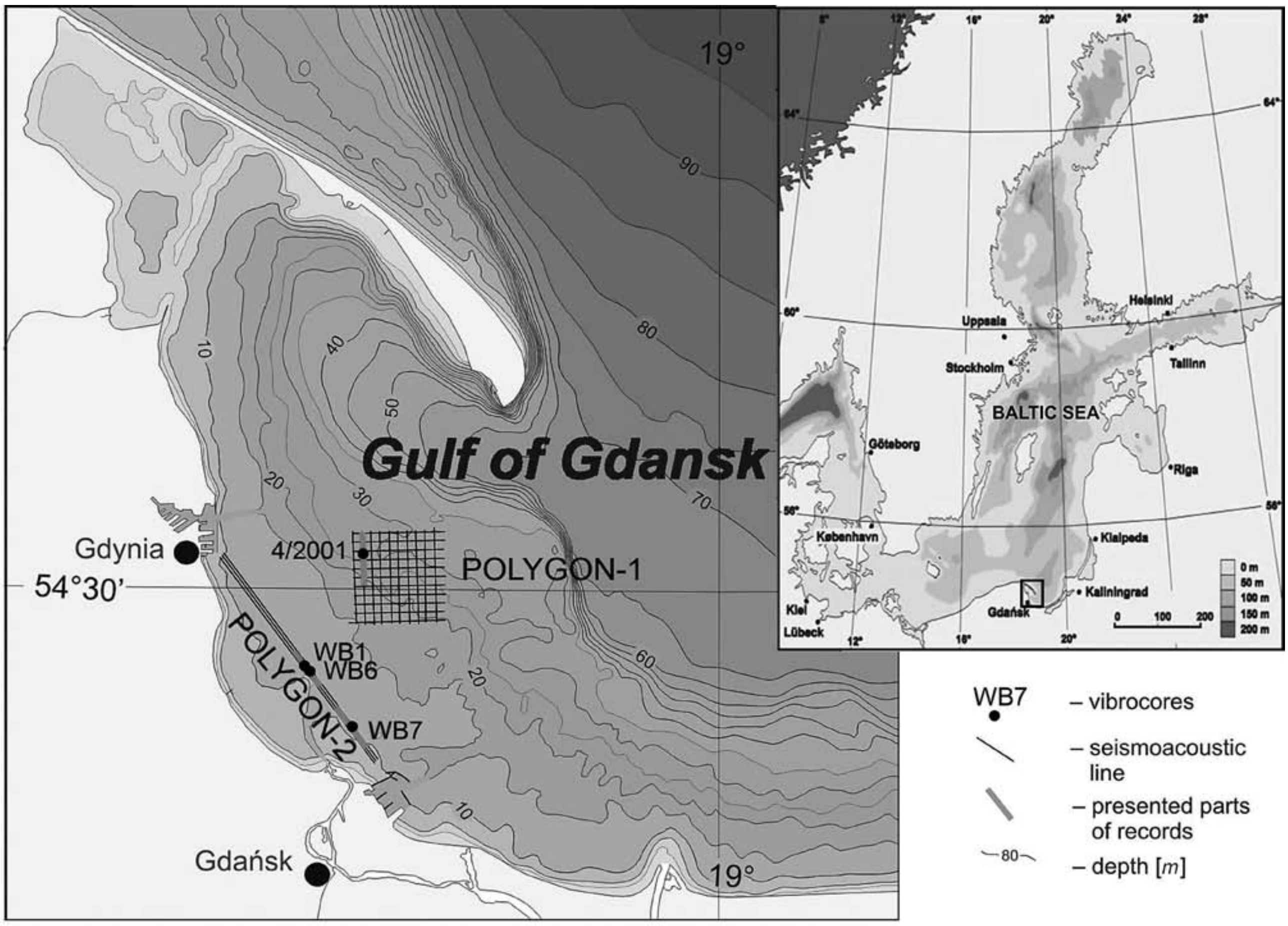


Fig.1. Location of investigation areas.

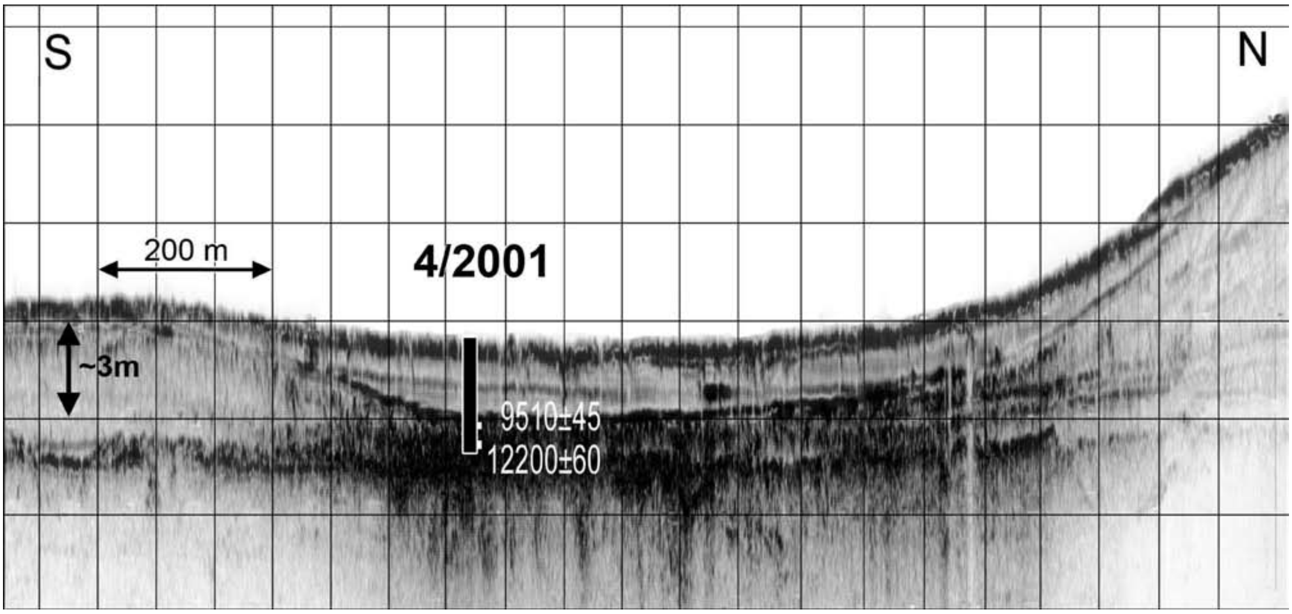


Fig.2. Chirp record with localization of core 4/2001.

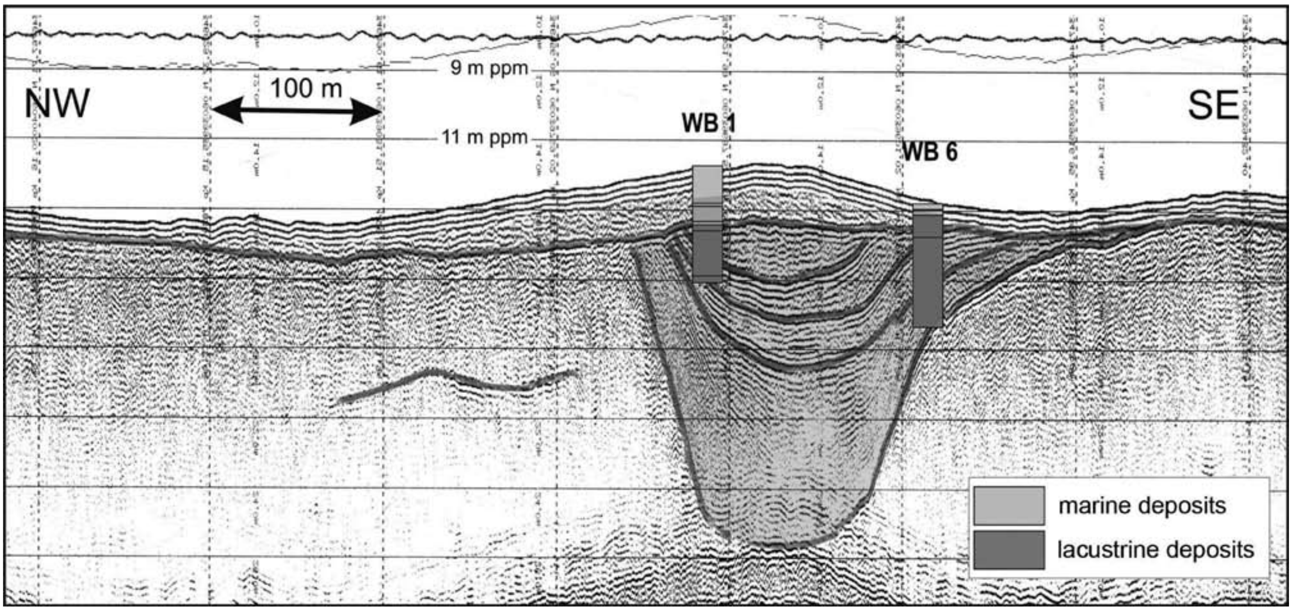


Fig.3. Interpretation of seismoacoustic record (subbottom profiler 3.5 kHz) with core WB1 and WB6.

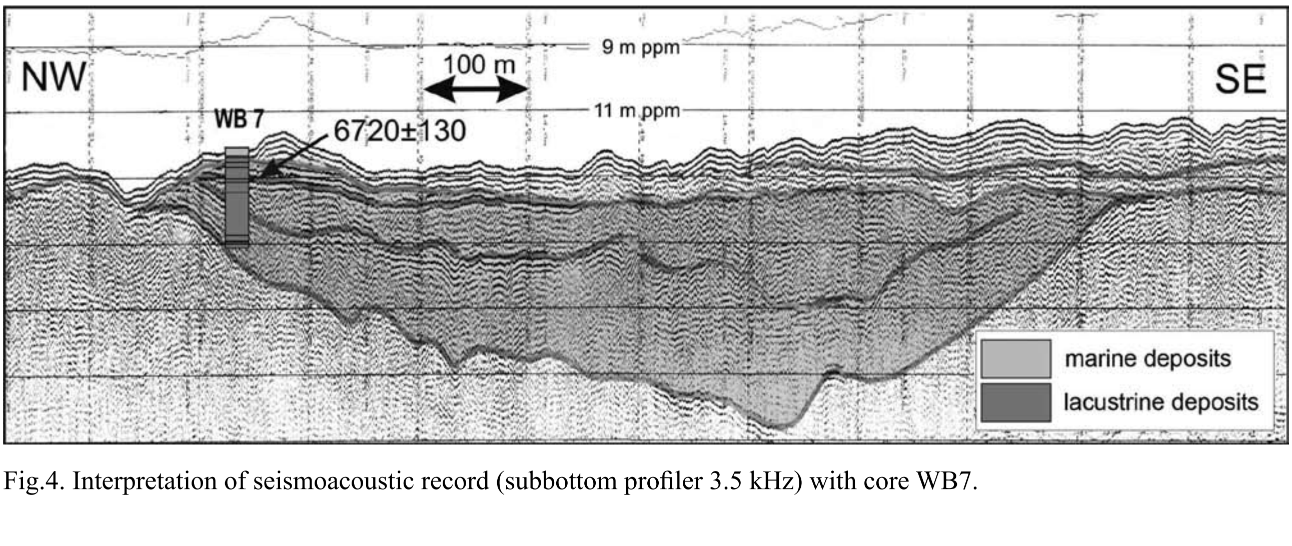


Fig.4. Interpretation of seismoacoustic record (subbottom profiler 3.5 kHz) with core WB7.

compact fine-grained sands, as evidenced from other cores being beyond the scope of this paper. To determine whether the sediments represent lacustrine basins, the samples were analysed for faunal remains. The observed structures and sediments indicate that these are remnants of smallish local water basins formed during a land period. The regular grid of seismoacoustic profiles in *polygon-1* enables presenting the location of the palaeolakes in this area (Fig. 5).

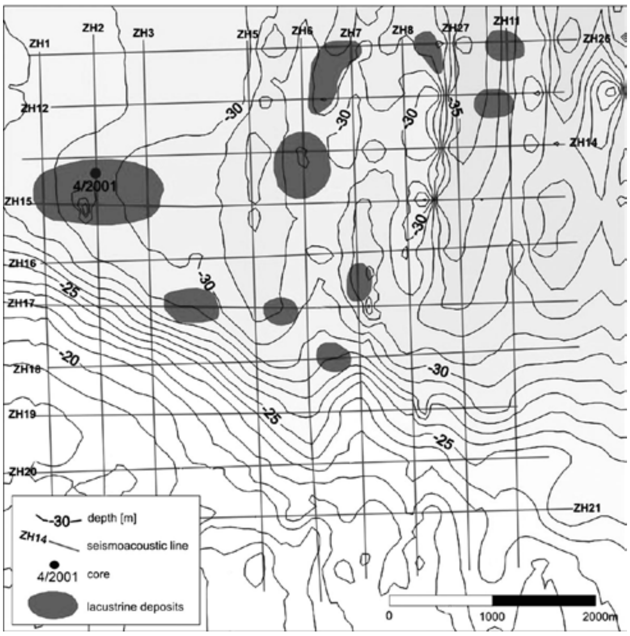


Fig.5. Exposure of palaeolakes on the recent bathymetry.

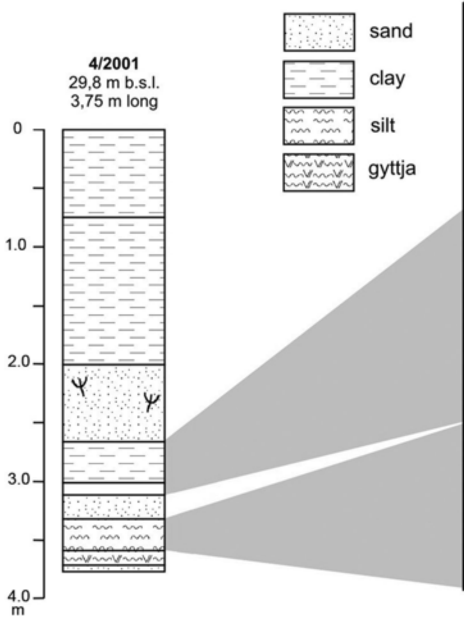
Ostracodological analysis

The sediments from the cores (4/2001, WB1, WB6 and WB7) are represented by gyttja, silt, silty sand and fine grained sand interbedded with organic matter. ^{14}C age determination, verified by palynological research, suggests the Late Glacial to Atlantic Period. The ostracodological study indicates that the sediments represent both freshwater and marine environments.

Polygon-1. The lower portion of core 4/2001 (from 3.58 to 2.65 cm) contains Late Pleistocene and Early Holocene gyttja and lacustrine silt, grading upwards into sand with clay interbeds (Fig. 6). Between the 2.65 cm to the top, there is Late Holocene clay containing marine bivalve shells. Ostracods are preserved only in the clay and lacustrine gyttja, dated at 12200±60 years BP. Single specimens of *Cytherissa lacustris* (Sars) were found here. Above, at a depth of 3.58–3.31 m, grey silt with organic matter (dated at 9,510±45 years BP) contains freshwater species, such as: *Candona alexandri* (Sywula), *Cytherissa lacustris* (Sars) and *Candona angulata* (Müller), *Candona neglecta* (Sars), *Cypridopsis vidua* (Müller), *Herpetocypris reptans* (Baird). All these species are cold stenothermal forms. Benthic diatoms represented almost exclusively by freshwater species predominate in the diatom flora. The results of pollen analysis indicate that the oldest sediments in this core were deposited in the Preboreal period (Krzymińska *et al.* 2005).

Polygon-2. At the base of section WB1 (Fig. 7), a large proportion of *Cytherissa lacustris* (Sars) with a low percentage of *Limnocythere inopinata* (Baird), *Candona neglecta* (Sars), *Candona angulata* (Müller), *Ilyocypris lacustris* (Kaufmann), *Cyclocypris laevis* (Müller), *Herpetocypris reptans* (Baird) was found in deltaic silty sand at a depth of 340 cm. The lacustrine sediments from a depth of 320 cm contain a smaller number of taxa. There is a drop in the proportion of *Cytherissa lacustris* (Sars). An increase in the proportion of *Candona neglecta* (Sars) and *Herpetocypris reptans* (Baird) indicates a change in environmental conditions within the basin. At depths of 270 and 230 cm, there is a drop in the proportion of *Cytherissa lacustris* (Sars), with constant contents of *Limnocythere sanctipatricii* (Brady and Robertson) and *Candona neglecta* (Sars). Another high percentage peak of *Cytherissa lacustris* (Sars) occurs at a depth of 180 cm.

In the basal portion of section WB 6 (Fig. 8), *Cytherissa lacustris* (Sars) also predominates in the lacustrine sediments, whereas the proportion of *Candona*



Core 4/2001	*Candona alexandri*	*Candona angulata*	*Candona neglecta*	*Candona candida*	*Cypridopsis vidua*	*Cytherissa lacustris*	*Herpetocypris reptans*	*Limnocythere inopinata*
2,65-2,70		X	X					
2,70-2,75			X					X
2,75-2,80		X	X			X		X
2,80-2,85		X	X			X		X
2,85-2,90		X	X			X		X
2,90-2,95			X			X		X
2,95-3,00			X			X		X
3,00-3,05			X			X		
3,05-3,10			X			X		
3,27-3,30			X			X		
3,30-3,35	X	X	X	X	X		X	
3,35-3,40	X		X					
3,40-3,45		X	X					
3,45-3,50		X	X					
3,50-3,55			X					
3,55-3,58						X		

Fig.6. Sediment profile and table of ostracods frequent of core 4/2001.

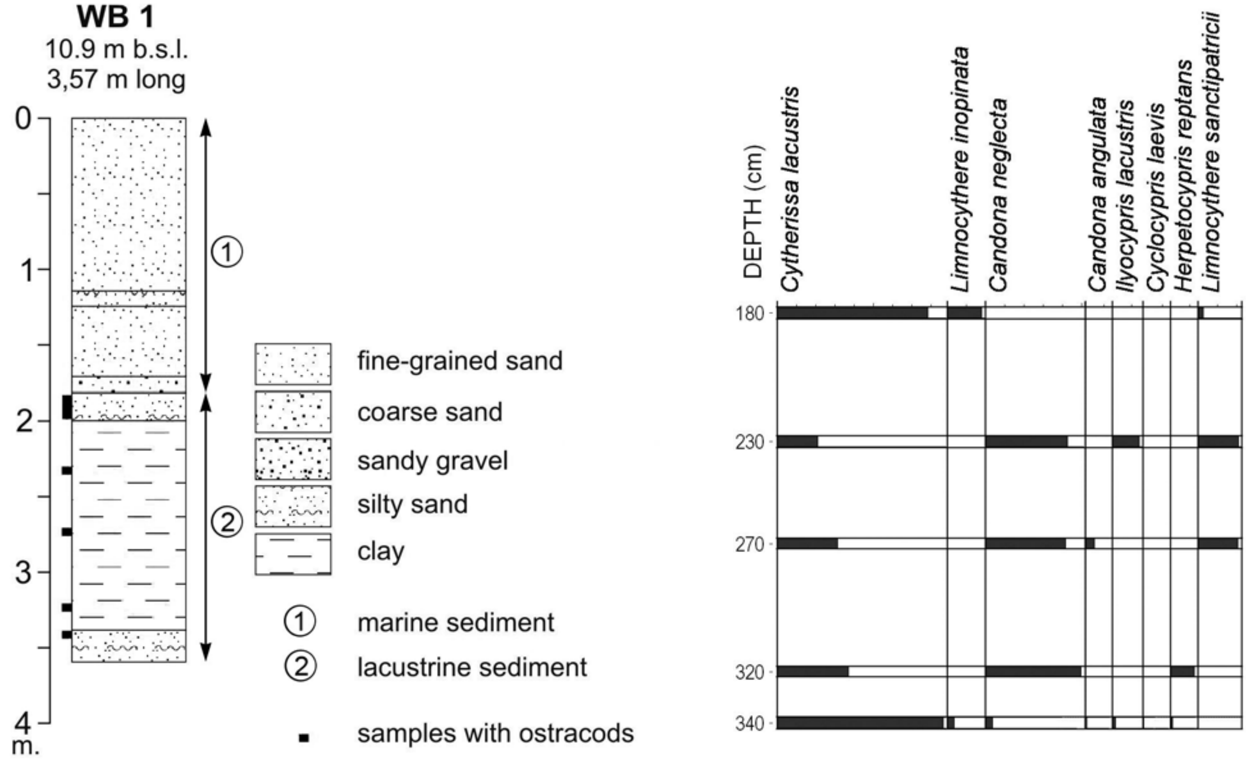


Fig.7. Sediment profile and ostracods diagram of core WB1.

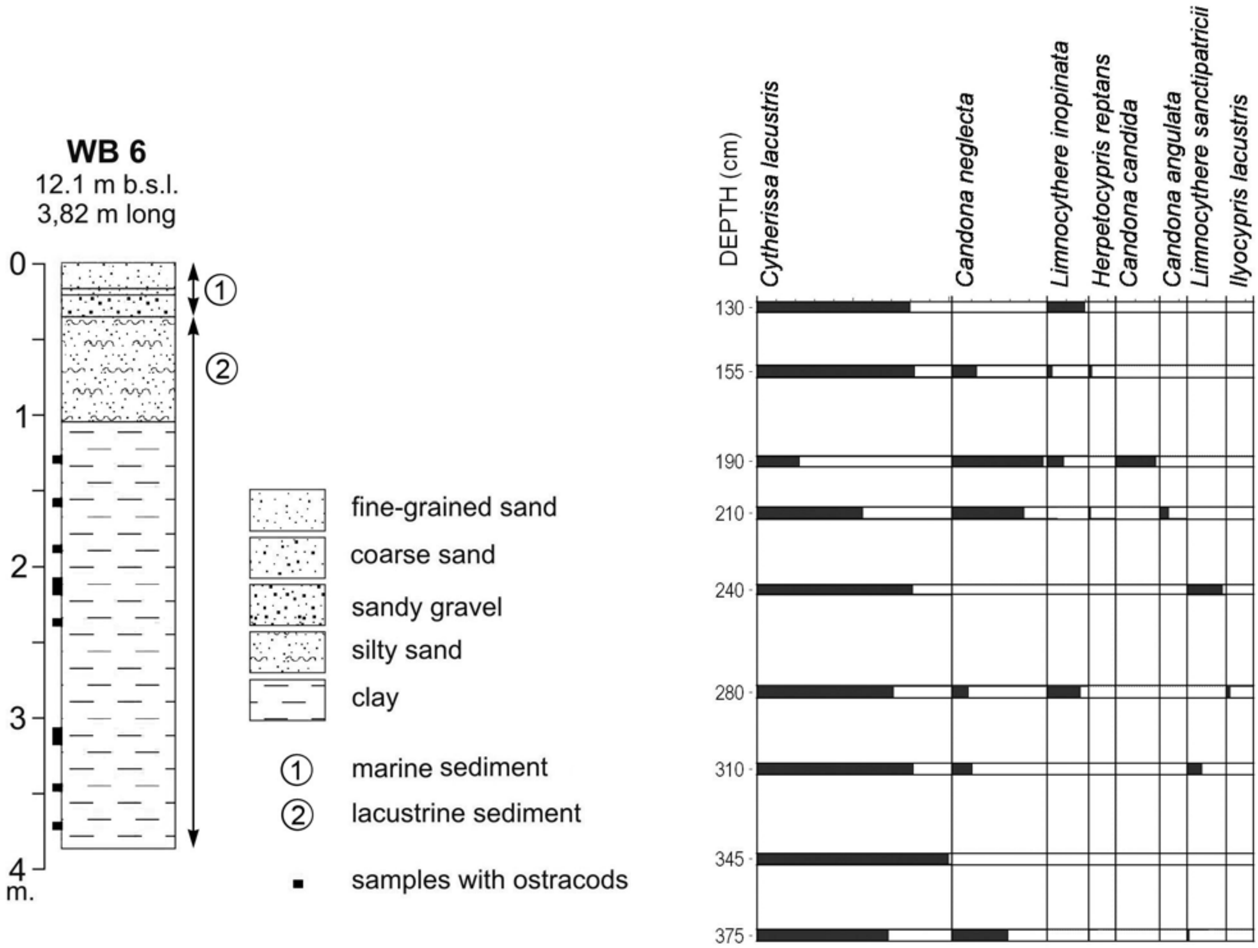


Fig.8. Sediment profile and ostracods diagram of core WB6.

neglecta (Sars) is smaller. *Limnocythere sanctiparicii* (Brady and Robertson) and *Herpetocypris reptans* (Baird) are even rarer. A high frequency of *Cytherissa lacustris* (Sars) was found at a depth of 345 cm. At a depth of 310 - 210 cm, the number of species increased with a continuously high percentage of *Cytherissa lacustris* (Sars). A decrease in the proportion of *Cytherissa lacustris* (Sars) is observed at a depth of 190 cm, accompanied by an increase in the frequency of *Candona neglecta* (Sars), *Candona candida* (Müller) and *Limnocythere inopinata* (Baird). A high proportion of *Cytherissa lacustris* (Sars) combined with a drop in the frequency of the accompanying taxa is observed at depths of 155 and 130 cm.

In both these sections (WB1 and WB6), *Cytherissa lacustris* (Sars) is the dominant species. Its presence in the sediment suggests that it found itself optimum development conditions to meet its environmental requirements. It occurs in lakes at various depths, mainly in the sublittoral and profundal zones, with a preference for oligotrophic lakes. Progressing lake eutrophication results in a retreat of this species. It is a eurythermal species with a preference for cold water and water salinity tolerance up to 1.5 PSU; this species is native to large water bodies (Danielopol *et al.* 1990). According to some researchers, *Cytherissa lacustris* (Sars) is considered to be an indicator of subarctic climate (Skompski 1991).

In the basal portion of section WB 7 (Fig. 9) (depth of 350 cm) is marked with a small percentage of typically lacustrine species, such as *Limnocythere sanctipatricii* (Brady and Robertson), *Ilyocypris lacustris* (Kaufmann). Lacustrine sediments from depths of 310 and 220 cm are characterised by a complete absence of ostracods. A marine (brackish-water) species of *Cyprideis torosa* (Jones) appeared at a depth of 150 cm. Its significant proportion may suggest a temporary intrusion of marine water. At a depth of 115 cm, radiocarbon dating suggests an age of 6,720±130 BP, however, the marine species retreated and freshwater species became more common with a relatively high frequency of *Candona compressa* (Koch), *Candona neglecta* (Sars), *Limnocythere inopinata* (Baird), *Metacypris cordata* (Brady and Robertson) and *Scottia tumida* (Jones). *Darwinula stevensoni* (Brady and Robertson) and a fluvial species of *Ilyocypris decipiens* (Masi) occur in smaller proportions. At a depth of 100 cm, there is the last occurrence of *Cyprideis torosa* (Jones) and an increase in the percentage of *Candona candida* (Müller) and *Darwinula stevensoni* (Brady and Robertson). The

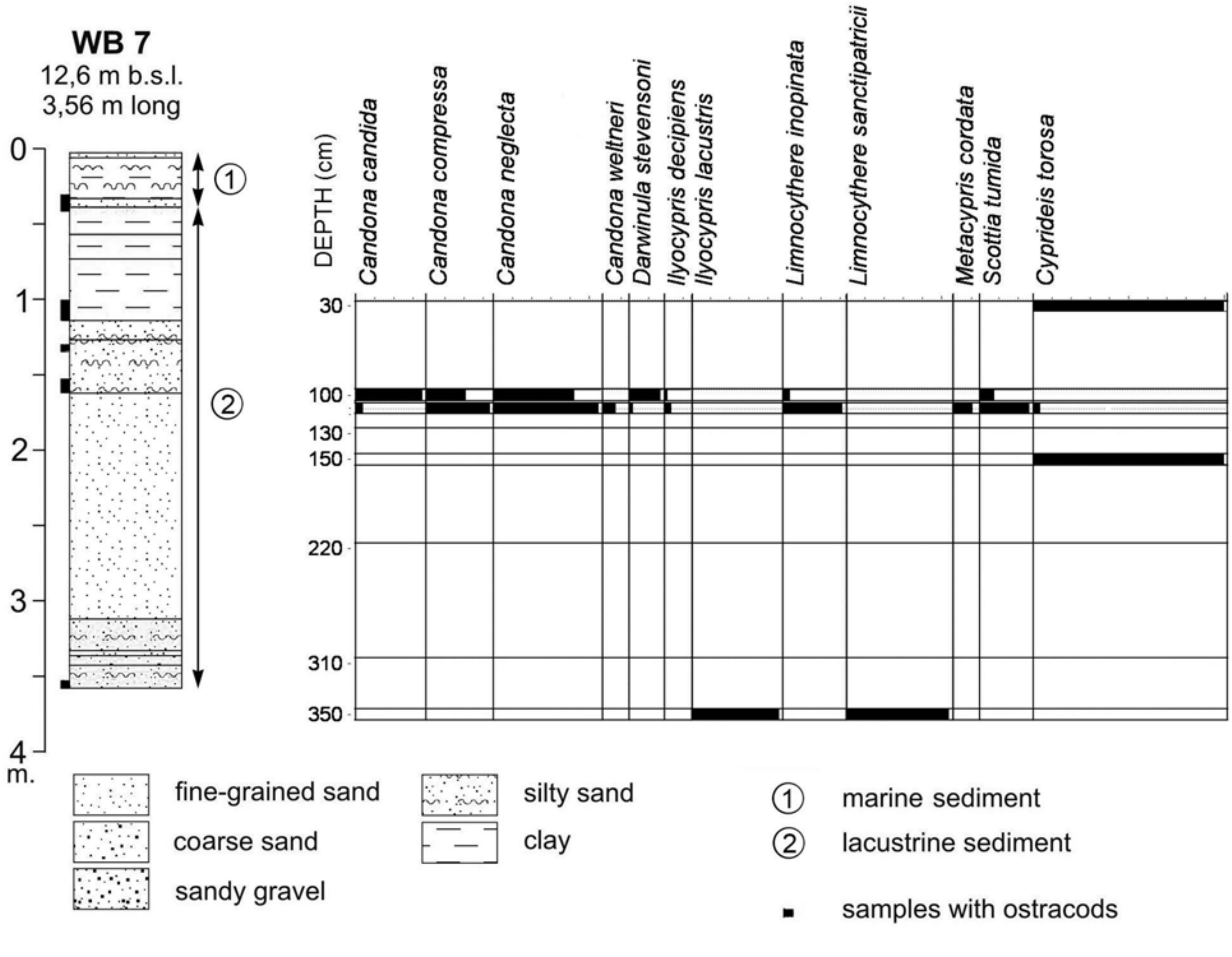


Fig. 9. Sediment profile and ostracods diagram of core WB7.

above-presented assemblage may suggest a lacustrine body, probably with a river flowing through it. This fact may be confirmed by the presence of river-inhabiting bivalves of *Pisidium moitessierianum* (Paladilhe) and *Pisidium supinum* (Schmidt). In the top portion of the section, a high percentage of *Cyprideis torosa* (Jones) is marked at a depth of 30 cm.

In this assemblage, *Scottia tumida* (Jones) is worthy of attention. This is a stratigraphically important freshwater species that commonly occurred during interglacial periods of the Lower and Middle Pleistocene, possibly suggesting redeposition of sediments.

DISCUSSION

The results of the research suggest two lake types. The first one (WB 1, WB 6 and 4/2001) is a deep oligotrophic lake. Its sediments contain ostracods typical of the Preboreal and Boreal periods: *Candona angulata* (Müller), *Candona candida* (Müller), *Candona neglecta* (Sars), *Cytherissa lacustris* (Sars), *Limnocythere inopinata* (Baird), *Limnocythere sanctipatricii* (Brady and Robertson) and *Herpetocypris reptans* (Baird). The other type (WB 7) is a shallow overgrowing lake with an ostracod assemblage enriched, in addition to the ones listed above, in the following species: *Candona compressa* (Koch), *Darwinula stevensoni* (Brady and Robertson), *Metacypris cordata* (Brady and Robertson), *Scottia tumida* (Jones), but lacking of *Cytherissa lacustris* (Sars). The ostracod assemblages display an extensive similarity to the well-known ostracod assemblages from ancient lakes of the southwestern part of the Odra Bank (Krzymińska 1994) and Dziwnów Spit (Krzymińska, Przezdziecki 2001).

The ostracod assemblages were also accompanied by freshwater snail species, such as *Acroloxus lacustris* (Linnaeus), *Anisus contortus* (Linnaeus), *Bithynia tentaculata* (Linnaeus), *Bithynia leachi* (Sheppard) and *Valvata piscinalis* (Müller), with the presence of bivalve species *Pisidium casertanum f. ponderosa* (Stelfox), *Pisidium milium* (Held), *Pisidium moitessierianum* (Paladilhe) and *Pisidium supinum* (Schmidt).

Cypridopsis vidua (Müller) and *Darwinula stevensoni* (Brady and Robertson) were found only in the basal portion of core 4/2001, indicating that it was initially a shallow water body. This is also confirmed by the predominance of benthic diatoms, with a particularly high proportion of epiphytic *Epithemia agnata* (Krzymińska et al. 2005). This species has stringent edaphic requirements, which may sugest abundance of food in this water body. *Fragilaria brevistriata*, dominant in Early Holocene sediments (3.40-2.60 m), has similar ecological requirements. This species occupies slightly alkaline, well-oxygenated mesotrophic and eutrophic waters. The ages of these sediments dated by radiocarbon are 12,200±60 and 9,510±45 years BP.

At the top of the sections, there are marine ostracods *Cyprideis torosa* (Jones) and *Cytheromorpha fuscata* (Brady), as well as marine bivalve species *Cerastoderma glaucum* (Poiret), *Macoma baltica* (Linnaeus) and *Mya arenaria* (Linnaeus).

The species composition of freshwater ostracods in the sections confirms that the sediments were deposited in local lacustrine bodies. Seismoacoustic survey shows that these bodies were ca. 200 to 1000 m in size, with spaces of 2 to 5 km between them. The water bodies came into existence in the Late Glacial and developed up until the onset of marine transgression. During the marine transgression, the lacustrine sediment was partly destroyed and covered by a layer of marine sands containing marine (brackish-water) ostracods.

CONCLUSIONS

High-resolution seismoacoustic survey enabled a discovery of sediments of ancient lakes, resting below a recently deposited marine sand cover in the shallow-water zone of the Gulf of Gdańsk.

Freshwater ostracod assemblages were found in the sediments whose lacustrine origin is inferred from seismoacoustic data. The species composition of the ostracod assemblages indicates that the lake water bodies developed in the Late Glacial and Early Holocene, which is supported by the presence of cold stenothermal species.

Top layers of acquired sediment cores contain marine (euryhaline) ostracods. The accompanying remains of marine bivalve shells confirm the boundary between the lacustrine and marine sediments, designated from the seismoacoustic records.

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