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PALAEOGEOGRAPHY OF LATE GLACIAL AND LOWER HOLOCENE LAKES IN THE POMERANIAN BAY ON THE BASIS OF MALACOFAUNA AND OSTRACODS AND SEISMOACOUSTIC DATA

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Abstract
Within a small (2.5 x 2.5 km) test field, located in the eastern part of the Pomeranian Bay, the geological structure was investigated in detail using seismoacoustic profiling and coring. In the cores, mineral grain size and micro- and macrofauna were analysed. Basing on seismoacoustic records, three main seismostratigraphic units were distinguished. The lowest unit is built of sand and muddy sand. Higher up lies the unit of sandy mud, in some places – of clay. Fauna assemblages indicate cold climate conditions, and clearly point to an existence of lacustrine reservoir of oligotrophic character. Analysis of cores shows that sedimentation began in bog conditions. The lakes in the area existed till the Atlantic period, when due to sea transgression they became filled with sandy sediments. The third unit is built mainly of fine sand, locally medium sand, even with addition of gravel. Basing on the presence of marine fauna, this unit is classified as marine sand.

Key words: Pomeranian Bay, malacofauna, ostracods, seismoacoustic data

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INTRODUCTION

The investigated area is located in the Pomeranian Bay (Fig. 1) SE of the Odra Bank, about 5 km eastwards of the present Dziwna river mouth. The objective of our research was to document sand resources for artificial beach nourishment. Over a small area of 6.25 km^2, a detailed survey of the geological structure of the sea bottom was carried out. The obtained material introduced new interesting data concerning the palaeogeographic development of the region.

Basic information about the geological structure of the Pomeranian Bay and eastern part of the Odra Bank was provided by earlier surveys of the Division of Marine Geology, Polish Geological Institute, carried out for preparation of 1:200,000 Geological Map of Baltic Sea Bottom. This information, in synthetic form was presented in the Geological Atlas of the Southern Baltic (ed. Mojski 1995). Recent measurements of heavy minerals concentrations on the Odra Bank introduced significant changes in the idea about the geological structure of the area (Kramarska 1998).

In the Pomeranian Bay, boulder till forms a noncontinuous, rather thin layer, below which sandy deposits of various origin appear. Higher up lacustrine deposits often occur, in most cases covered by marine sand. There is no morainic till in the investigated area, and the Southern Baltic sands directly underlay the lacustrine deposits. By analogy to the western coast, these deposits were formerly described as fluvioglacial sands and gravels of the Central Polish Glaciation (Jurowska, Kramarska 1991).

The closest location of lithologically similar sediments of the same age (covered by deposits of Younger Pleistocene) is known at the Gardno–Łeba Lowland (Rotnicki, Borówka 1994, Rotnicki 2001) and also at the Szczecin Lowland (Kurzawa 1993). In light of the latest investigations at least a part of them represents deposits of Interpleniglacial of the Vistulian Glaciation.

The region of the Pomeranian Bay became deglaciated about 14 thousand years ago. At that time, the edge of the ice sheet was situated northwards of Kołobrzeg and Odra Bank (Uścinowicz 1999). Therefore, the Pomeranian Bay and the Odra Bank were the first areas of the Southern Baltic which became free of the ice cover. On top of remaining patches of dead ice bogs were formed, and peat-generating processes developed. Gradually these bogs transformed into local lakes. These were shallow reservoirs, with slow sedimentation of mud, in some places mud/sand or mud/clay deposits. Radiocarbon dates from the Pomeranian Bay show that terrestrial environment in this area developed since the Late Glacial (the oldest radiocarbon date of peat is 14,060±220 years BP) and persisted until the Atlantic period (the young-

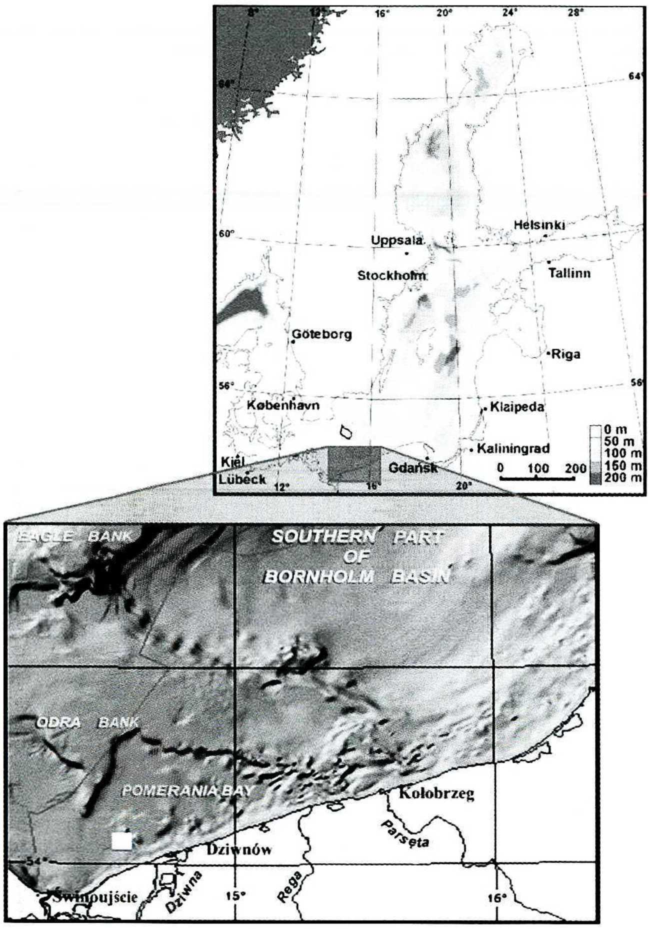


Fig. 1. Location of the study area (white rectangle) in the Pomeranian Bay.

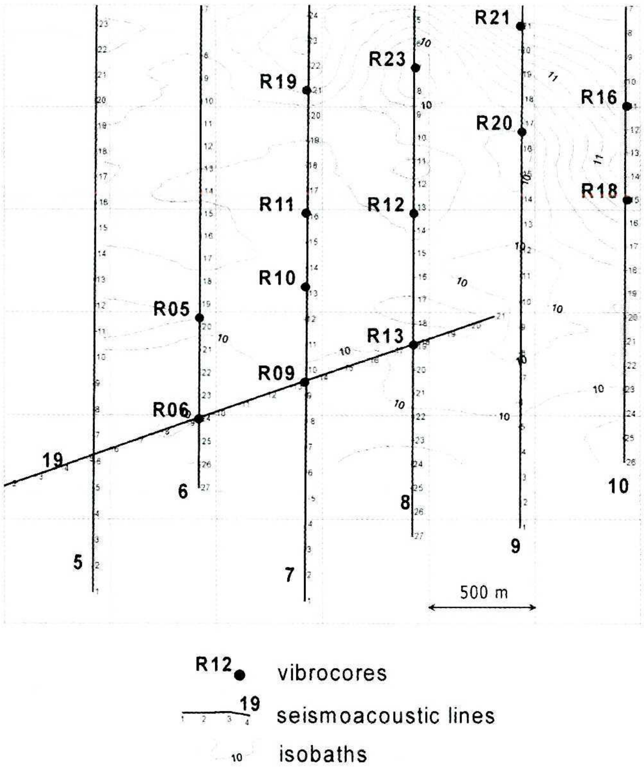


Fig. 2. Location of vibrocores and seismoacoustic cross-sections in the study area in the Pomeranian Bay.

est date is 5100±200 BP), when the sea transgressed onto the area (Kramarska 1998).

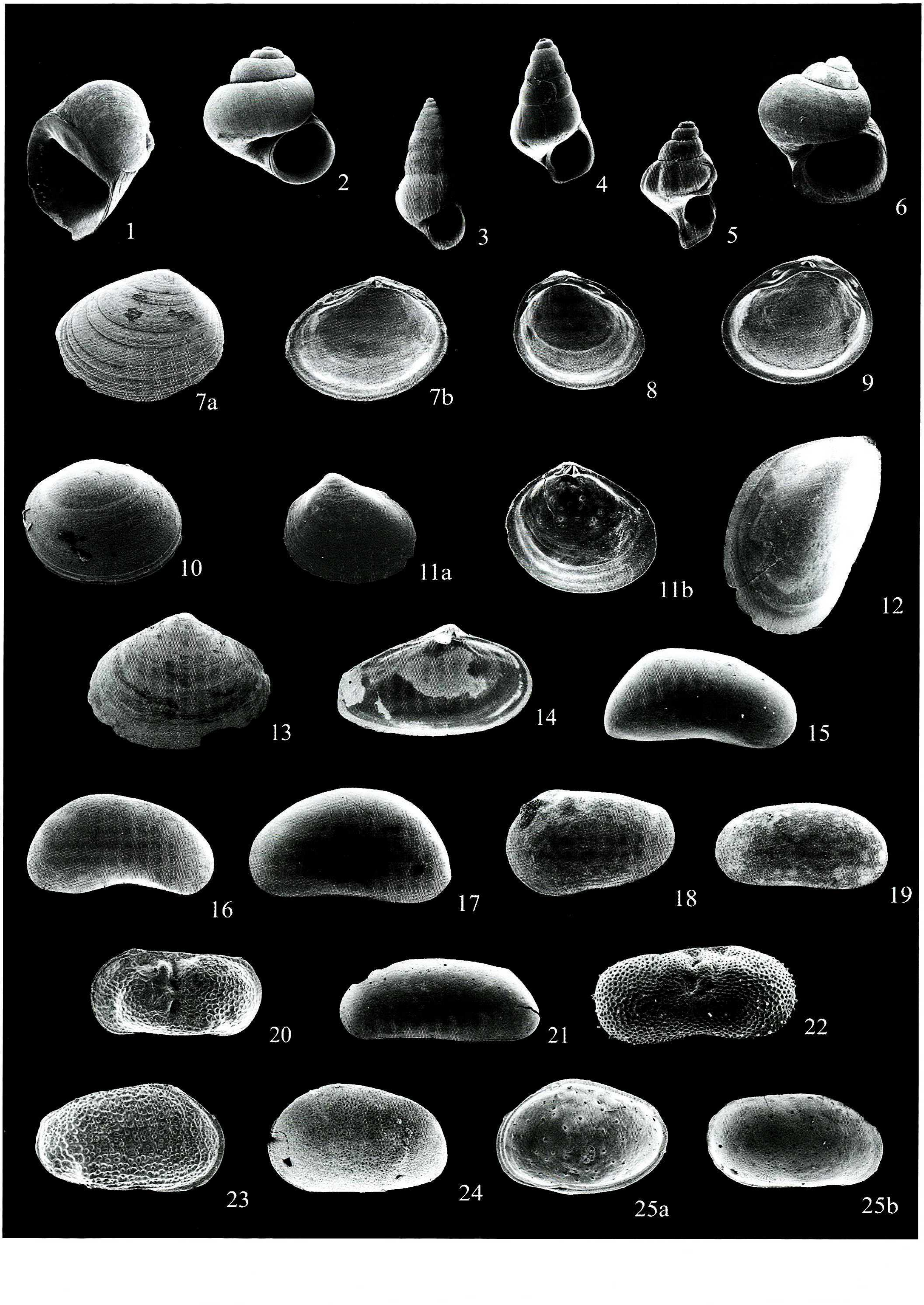
MATERIAL AND METHODS

The survey was carried out over a small area (2.5 x 2.5 km), about 3.5 km from the coast. In this area (Fig. 2), we took seven seismoacoustic profiles of total length 23 km, and pulled out 16 vibrocores of total length 62 m.

The seismoacoustic research was carried out with a high resolution ORTECH equipment of pipeliner type, using signal frequency of 3.5 kHz. Simultaneously, echosounding of the bottom was performed. The records were geophysically intepreted, and the main horizons were distinguished. The observed horizons were quite distinct, and along many stretches they were continuous or suggested continuity. Nevertheless, their character indicates only slight diversification of the deposits. The vertical range of readability of the records was about 10–11 m below the seafloor due to the water depth. Neither signals from the top of pre-Quaternary deposits nor those suggesting a presence of boulder till were recorded. In the seismoacoustic records, three main seismostratigraphic units were distinguished. Basing on these units, after correlating them with core profiles, geological transects were worked out. For construction of the transects, we assumed sound velocity of 1.6 m/ms in deposits and 1.45 m/ms in water. The transects were displayed after digitisation and further processing using AUTOCAD 2000.

The cores were sampled for grain size and fauna analyses. Grain size analysis was carried out by sieving on a – 4 to 2 Φ set with 1 Φ spacing. The median diameter and other parameters of grain size distribution were calculated using Folk-Ward formulas. Microfauna and malacofauna analyses were made for 88 samples from 16 profiles. 200 cm^3 samples were washed through a 0.1 mm sieve. 14 species of freshwater and 12 of marine molluscs, 10 species of freshwater and 3 of marine ostracods were distinguished (Plate 1).

Plate 1. **1** – *Theodoxus fluviatilis* (LINNAEUS), × 13.5; **2** – *Valvata piscinalis f. antiqua* (SOWERBY), × 10.5; **3** – *Hydrobia ventrosa* (MONTAGU), × 8.5; **4** – *Hydrobia ulvae* (PENNANT), × 20; **5** – *Turboella parva* (DA COSTA), × 22.5; **6** – *Littorina obtusata* (LINNAEUS), × 13; **7a, b** – *Pisidium amnicum* (MÜLLER), × 7.5; **8** – *Pisidium casertanum* (POLI), × 13.5; **9** – *Pisidium casertanum f. ponderosa* STELFOX, × 15; **10** – *Pisidium conventus* CLESSIN, × 30; **11** – *Macoma balthica* (LINNAEUS), × 37.5; **12** – *Mytilus edulis* LINNAEUS, × 5.5; **13** – *Scrobicularia plana* DA COSTA, × 8.5; **14** – *Mya truncata* LINNAEUS, × 12; **15** – *Candona angulata* MÜLLER, × 50; **16** – *Candona neglecta* SARS, × 50; **17** – *Candona candida* (MÜLLER), × 53; **18** – *Cytherissa lacustris* (SARS), × 75; **19** – *Candoniella subellipsoida* SHARAPOVA, × 75; **20** – *Limnocythere inopinata* (BAIRD), × 68; **21** – *Herpetocypris reptans* (BAIRD), × 22.5; **22** – *Ilyocypris lacustris* KAUFMANN, × 60; **23** – *Cytheromorpha fuscata* (BRADY), × 125; **24** – *Cyprideis torosa* (JONES), × 75; **25a, b** – *Loxoconcha elliptica* BRADY, × 87.5.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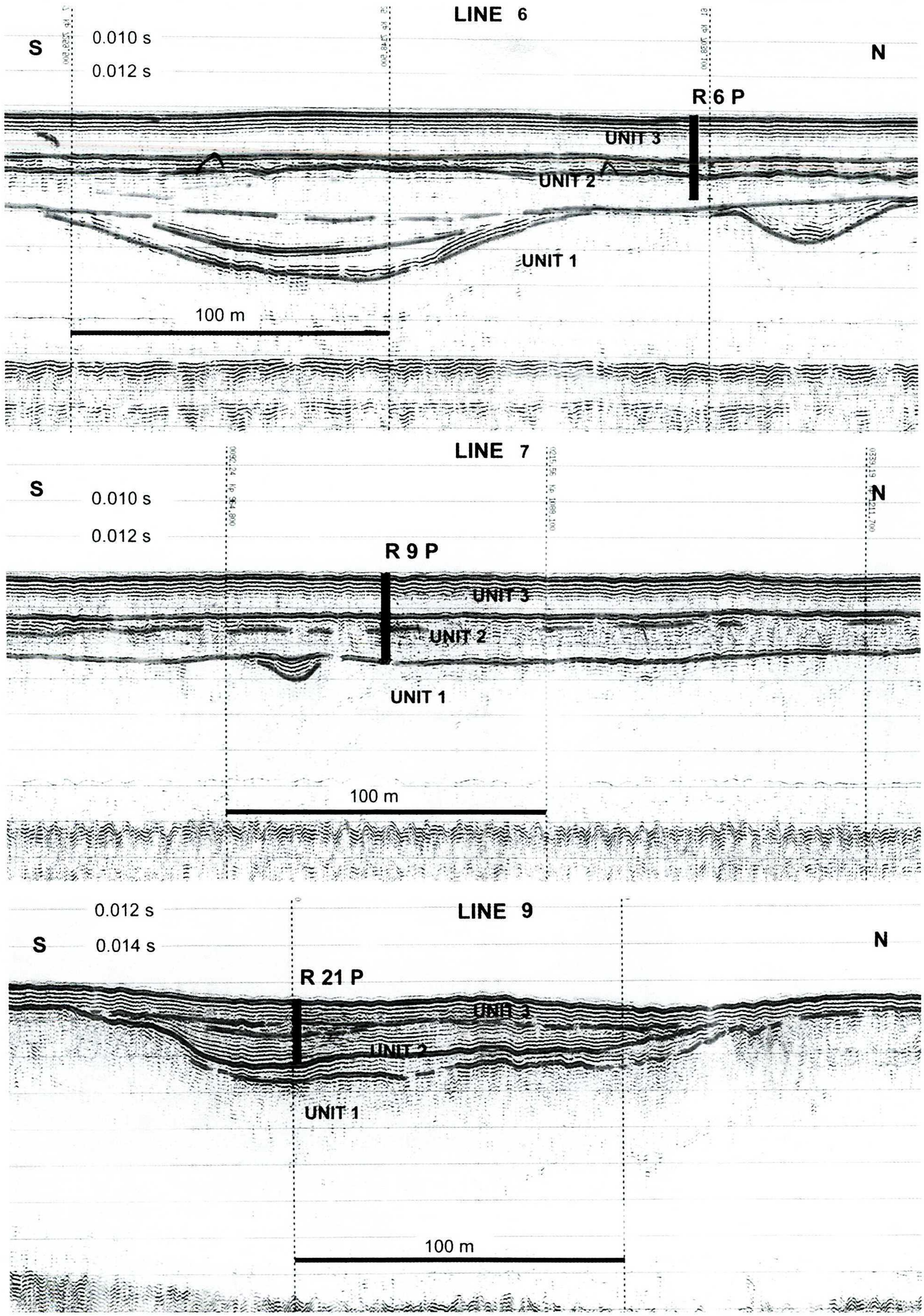

Fig. 3. Selected seismoacoustic cross sections of the Pomeranian Bay sediments.

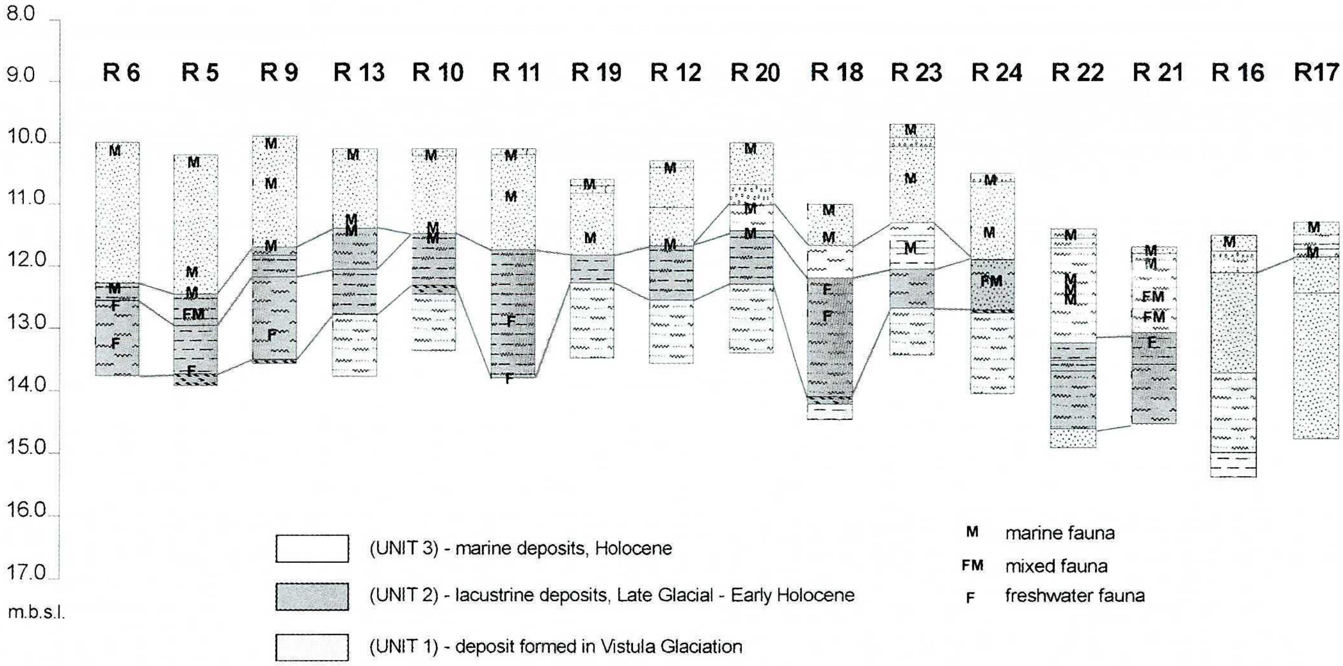

Fig. 4. Correlation of vibrocores pulled out in the study area (cf. Fig. 2).

The species of freshwater and marine molluscs were identified basing on Piechocki (1979), Piechocki, Dyduch-Falniowska (1993), Jagnow & Gosselck (1987), while the ostracods on the basis of Sywula (1974) and Sywula & Pietrzeniuk (1989).

RESULTS

Basing on the seismoacoustic records and their correlation with the cores, the distinguished seismostratigraphic units (Fig. 3) were interpreted as:

Unit 1 of uniform character of the records, with local large scale oblique layering. Judging from the cores, it contains sand and sand/mud deposits. By analogy to neighbouring regions they were classified as deposits of the Vistulian Glaciation. Lithologic characteristics and radiocarbon datings include generally sandy sediments, which together with the upper till constitute the upper part of the Quaternary layer – recognized more precisely. Sands and sands with silty admixtures of unidentified origin (possibly riverain) contain dispersed organic matter and carbonificated organic remains – radiocarbon dated from >45,000 to 21,480±440 years BP (Kramarska 1998).

Unit 2 consisting of deposits located in depressions of the upper surface of Unit 1. There are several horizons within this unit. The character of the records indicates local diversification of processes of its formation. Deposits of this unit are most diversified: it is built of sand, sandy mud, mud, and locally of clay and peat.

Unit 3, covering the two former units over the whole area, is the most uniform, and the character of the records is typical for marine sand. Most common here is fine sand with median diameter 0.18–0.20 mm. Only in the north-eastern part of the area medium sand (0.25–0.30 mm median diameter) occurs. This layer is 1.8 to 2.5 m thick.

In the investigated core profiles two fauna assemblages (fresh-water and salt-water) were found. No malacofauna or ostracods were found in the deposits of the Unit 1.

In the investigated area, freshwater fauna occurred in 7 cores (Fig. 4). Samples containing this fauna come from the Unit 2, the top of which is at 12.7–11.4 m below sea level. In these deposits sets of fauna typical for fresh-water environment occur. Some diversity of the assemblages was observed, suggesting differentiation of conditions during deposition of sediments.

In sandy mud in profiles R-5, R-6, R-9, R-11, R-18 (Fig. 4) there were numerous ostracods such as: *Candona angulata* Müller, *Candona candida* (Müller), *Candona neglecta* Sars, *Candoniella subellipsoida* Sharapova, *Cytherissa lacustris* (Sars) and a rich bivalves fauna, dominated by such species as: *Pisidium amnicum* (Müller), *Pisidium casertanum* Poli, *Pisidium casertanum f. ponderosa* Stelfox, *Pisidium milium* Held, *Pisidium nitidum* Jenyns, *Pisidium conventus* Clessin. This type of association may suggest that there was a shallow-water reservoir with stabilised conditions of sedimentation (Stelfox *et al.* 1972). The set of cold-adapted ostracods such as: *Candona candida*, *Candona neglecta*, *Candoniella subellipsoida*, *Cytherissa lacustris*, *Cyclocypris laevis*, points to an oligotrophic character of the reservoir (Winnicki, Skompski 1991, Skompski 1991, Hammarlund 1999). They live on a muddy bottom. In the upper part of the Unit 2, apart from beside freshwater species, occur also marine ostracods such as: *Cyprideis torosa* (Jones), *Cytheromorpha fuscata* (Brady) and *Loxoconcha elliptica* Brady. This may reflect a lagoon, separated by the present Odra Bank from the sea, and supplied with salt water only periodically.

In profile R-21, solely freshwater ostracods were present: *Candona candida*, *Candona neglecta*, *Candoniella subellipsoida*, *Limnocythere inopinata* (Baird), *Herpetocypris* *reptans* (Baird) with an addition of marine molluscs *Cerastoderma glaucum* Poiret, *Mya truncata* Linnaeus.

On the other hand, in profile R-24, besides *Candona neglecta* and *Limnocythere inopinata*, mass occurrence of *Valvata piscinalis* (Müller) and of *Bithynia tentaculata* (Linnaeus) and *Bithynia leachi* (Sheppard) operculum with some participation of such mollusc species as *Pisidium amnicum*, *Pisidium casertanum* (Poli), *Pisidium casertanum f. ponderosa*, *Pisidium milium*, *Pisidium nitidum*, and *Pisidium conventus* was observed. Sporadically, *Gyraulus laevis* (Alder), *Valvata piscinalis f. antiqua* Sowerby, *Sphaerium corneum* (Linnaeus), and *Pisidium moitessierianum* Paladilhe, were found. The composition of the malacocenosis indicates a shallow, overgrown reservoir, while the presence of *Valvata piscinalis f. antiqua* and of *Pisidium conventus* points to a typical lake.

In deposits of Unit 3 only marine molluscs and ostracods are present. In marine sand (profiles R-10, R-13, R-17, R-20, R-22, R-23) predominate marine species such as: *Hydrobia ulvae*, *Hydrobia ventrosa*, *Cerastoderma glaucum*, *Mytilus edulis*, and *Macoma balthica*. Sporadically, *Littorina obtusata* (Linnaeus), *Turboella parva* (Da Costa), *Mysella bidentata* (Montagu), *Scrobicularia plana* (Da Costa), and freshwater taxa *Theodoxus fluviatilis* (Linnaeus) (tolerating 19 PSU) occur. This set of marine species means a high ecological valency. These are euryhaline species, which inhabit bottoms covered with algae. Attention is drawn to *Littorina obtusata, Turboella parva* (Da Costa), *Mysella bidentata* and *Scrobicularia plana* (Da Costa), since these species do not inhabit the Southern Baltic at present but occur in Western Baltic and in White Sea waters where salinity exceeds 12 PSU (Jagnow, Gosselck 1987). The mentioned mollusc species may come from littorinian deposits, because their ecological requirements indicate higher salinity of the Southern Baltic than presently. It can probably be connected with littorinian phase of the Baltic Sea. Some of the species from these assemblage have already been described by Brodniewicz & Rosa (1967), and Petersen (1993).

DISCUSSION OF RESULTS

The analysed deposits (Fig. 5) contain layers corresponding to the Vistulian Glaciation (Unit 1), and lacustrine (Unit 2) and marine sedimentation (Unit 3). The bottom of lacustrine deposits is not continuous. The cross-sections indicate that their top is locally convex, so probably partly destroyed (Fig. 5) during the transgression of the sea. This could explain the presence of marine fauna in typically lacustrine deposits in the upper parts of cores R-24, R-5 and R-6, suggesting transformation from lacustrine into lagoon environment.

In the map (Fig. 6), two small patches of lacustrine deposits of 0.30 and 0.25 km^2, and one large, covering significant part of the investigated region (of about 2.5 km diameter and 4.6 km^2 area) are shown.

Within Unit 2 there is a duality of deposits. Quite distinct is the lower layer of deposits containing a set of cold water molluscs and ostracods such as: *Pisidium milium*, *Pisidium nitidum*, *Pisidium conventus*, *Candona neglecta*, *Candona candida*, *Cytherissa lacustris*, which lived during the Late Glacial. In the rest of the deposits (main part of Unit 2) a set of molluscs with higher thermal requirements was distinguished: *Bithynia tentaculata*, *B. leachi*, *Valvata piscinalis f. antiqua*, *Pisidium moitessierianum*, which suggest warming of climate during the early Holocene. This issue has already been described by Alexandrowicz (1999) and Wojciechowski (1995) in the papers on Late Glacial and Holocene lake sediments.

The presence of marine fauna in this layer does not support the statement that it was solely built of lagoon deposits. Development of lakes in this area began from a small reservoir in the southern part. This reservoir was formed during Late Glacial and continued to grow until the transgression of the sea. During sea transgression the lacustrine deposits were partly destroyed and subsequently covered by marine sands.

Similar situation of occurrence of Late Glacial and Lower Holocene lakes the Pomeranian Bay appeared in the area of Odra Bank. During fauna analysis (Krzymińska 1990, 1996, 2001) freshwater molluscs and ostracods were found. The deposits dated between 14,060 and 12,010 years BP in this area contained abundance of such molluscs: *Armiger crista f. cristatus* Draparnaud, *Gyraulus laevis* (Alder), *Lymnaea peregra* (Müller), *Pisidium amnicum* (Müller), *Pisidium casertanum* (Poli), *Pisidium casertanum* f. *ponderosa* Stelfox, *Pisidium milium* Held, *Pisidium nitidum* Jenyns, *Pisidium obtusale f. lapponicum* (Lamarck) and ostracods: *Cytherissa lacustris* (Sars), *Candona neglecta* Sars, *Candona candida* (Müller), *Candoniella subellipsoida* Sharapova. This assemblage tolerating cold climatic conditions indicates lacustrine sedimentation. Along with freshwater fauna, marine fauna appeared. Mixed fauna deposits occurred directly over the organic layer dated at 7240 years BP (Kramarska 1998). Along with sea level rise and sea transgression, sand cover built mainly of fine sands started to form. The date 5190 years BP (Kramarska 1998) documents the littorinian sea transgression in the area of the Odra Bank.

CONCLUSIONS

1. In the investigated region, both in cores and in seismoacoustic records, neither pre -Quaternary deposits nor boulder tills were found.

2. The lowest investigated bedding (Unit 1) is probably built of Vistulian Glaciation deposits, and it is represented by sandy and sand/mud deposits, in which no fauna was found.

3. In the overlying sandy muds and clays (Unit 2) a typical lacustrine fauna, characteristic for the Late Glacial and early Holocene, was observed. Seismoacoustic records show that these sediments fill depressions in the top of older deposits.

4. Basing on the distribution of Unit 2 deposits, the contours of the paleolakes were determined. The top of these deposits is locally convex, as they were subject to destruction during the sea transgression. This is especially distinct near profile R-24.

5. The marine fauna in the upper layers of the lacustrine deposits reflects sea transgression.

6. The boundary between the second (Unit 2) and third (Unit 3) seismoacoustic unit does not correspond exactly with the change between typically fresh-water and marine

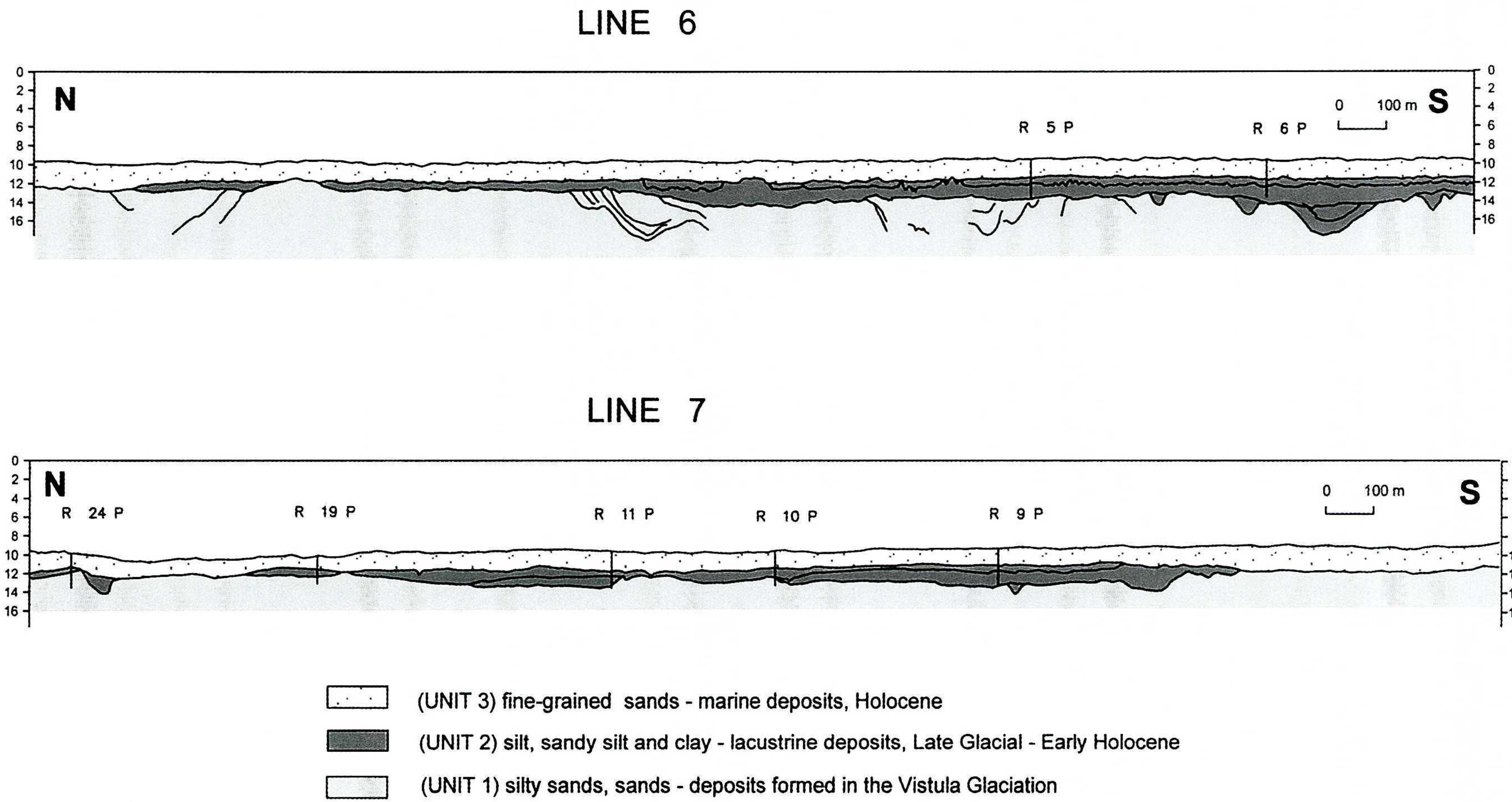

Fig. 5. Selected geological cross-sections of the Pomeranian Bay sediments (cf. Fig. 2).

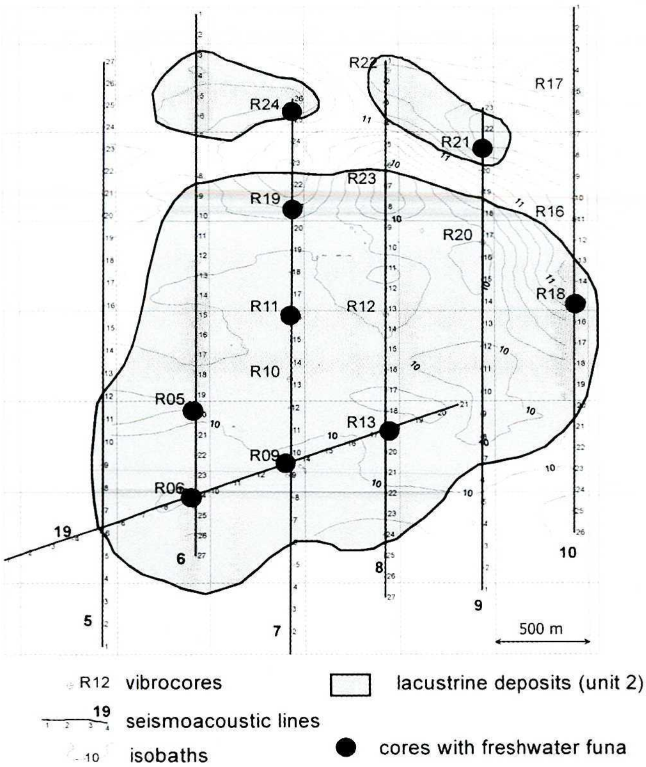

Fig. 6. Distribution of lacustrine deposits in the study area in the Pomeranian Bay.

fauna assemblages.

7. Development of lakes in the area began during Late Glacial and lasted until the sea transgression. During the transgression, lacustrine deposits were partly destroyed and were covered by a layer of marine sand.

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