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Late Glacial and Holocene subfossil mollusc shells on the Lithuanian Baltic Sea coast

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Abstract Late Glacial and Holocene subfossil molluscs along the Lithuanian Baltic Sea coast are found in the outcrops of Ventės Ragas Cape and squeezed lagoon gyttja at Nida and in offshore boreholes at Būtingė, north of Klaipėda, Smiltynė, Nida on the Curonian Spit. They are also found in boreholes drilled in the Curonian Lagoon and River Nemunas delta water areas. During the Late Glacial and the first Litorina Sea transgression, a small shallow freshwater basin or a semi-enclosed lagoon of the larger basin covered an area of the recent Curonian Spit and Lagoon. Subfossil molluscs of the Litorina Sea discovered near Būtingė, Melnragė and Smiltynė are typical of shallow littoral zones with sandy and somewhat muddy bottoms. As concerns the Yoldia Sea and Ancylus Lake periods, the water level was considerably lower than present sea level, thus sediments and subfossil molluscs of these basins are absent along the Lithuanian coast.

Keywords *Subfossil molluscs, Baltic Sea, Litorina Sea, Nemunas delta, Curonian Lagoon, Curonian Spit.*

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INTRODUCTION

The Baltic is an inland sea bounded by the Scandinavian and Jutland peninsulas. It drains via the Kattegat and Skagerrak into the North Sea and the Atlantic Ocean. Development of the Baltic Sea during the Holocene was predetermined by the water level dynamics of the World Ocean, climate changes and by the tectonic evolution of the Danish straits region (Andrén *et al.* 2000; Jensen *et al.* 2002). During the Late Glacial (Weichselian) and Holocene, climate warming and the increasing amount of precipitation triggered melting of the Last Glaciation ice sheets and drove global glacio–eustatic sea level rise in the oceans. These events also resulted in concomitant changes in peripheral basins. Although the Baltic Sea extends deep into the continent it also has been influenced by the global changes. The water level, temperature and salinity of the Baltic Sea basins have changed during the Late Glacial and Holocene (Berglund *et al.* 2005). Inevitably the organisms that inhabited the Baltic Basin, including the molluscs, strongly reacted to these changes, and in particular to the water salinity variations.

Aquatic molluscs are reliable indicators of environmental conditions in a basin. The importance of molluscs for reconstruction of palaeoenvironmental conditions at different stages of the Baltic Sea basin development has been demonstrated repeatedly by many researchers who have studied subfossil Mollusca in Estonia (Kessel 1958; Tavast 2000), Poland (Skompski 1991), Denmark (Petersen 2004), Germany (Glöer, Meier–Brook 1998) and Russia (Danilovskij 1955). There is a large literature in which information concerning the composition of molluscan assemblages, assessments of climatic conditions and reconstructions of the palaeoenvironment of the basins has been discussed.

The first comprehensive description of recent molluscs (including those from the marine environment) found in Lithuania was made by P. Šivickis (1960). However, subfossil molluscan studies, especially the marine taxa, have not become more widely studied because of the lack of finds. The only outcrops from which subfossil molluscs are known in Lithuania are on the Ventės Ragas Cape and on the Curonian Lagoon coast, near to the settlement of Nida. An attempt to relate these subfossil mollusc assemblages to the Baltic palaeobasins was made by V. Gudelis (1988). During the geological mapping, at a scale of 1:50 000, which was undertaken during the last decade of the 20th century, subfossil mollusc faunal material was recovered from core samples. These finds encouraged their full–scale study. The new material served as a basis for a more detailed investigation of the Baltic Sea development stages and for a closer examination of the biota in general.

The proglacial lakes and the subsequent Baltic Ice Lake (c. 12–10 ^{14}C kyr BP) that formed in the Baltic Sea basin, filled by melt water from the retreating ice sheet, are considered the beginning of the modern Baltic Sea (Jensen *et al.* 1997; Kabailienė 1999). They were cold freshwater lakes inhabited by sub–arctic flora and fauna. Although the basin shoreline can be identified on the present Lithuanian coast, nothing can be said about the molluscs that inhabited the Baltic Ice Lake because their shells have not been found in the lake sediments. The water level of the subsequent Baltic Sea basins — the Yoldia Sea (c. 10–9.6 ^{14}C kyr BP; Schoning 2001) and the Ancylus Lake (c. 9.6–8 ^{14}C kyr BP; Jensen *et al.* 1999) — was considerably lower than the present sea level. This therefore explains why molluscs typical either of the Yoldia Sea or Ancylus Lake are not found on the Lithuanian coast. The available data allows only the full–scale characteristics of the molluscan assemblage and therefore the reconstruction of the palaeoecological conditions of the younger Litorina Sea (c. 8–4 ^{14}C kyr BP (Bitinas, Damušytė 2004) to be determined.

The molluscs of the youngest Post–Litorina Baltic Sea stage actually do not differ from those occurring today and they are therefore not analysed in this paper.

METHODS

Subfossil mollusc shells have been collected from the Lithuanian coastal area on the mainland seacoast, on the Nemunas River delta, the Curonian Lagoon, and the Curonian Spit. Two outcrops are known which contain subfossil mollusc shells: one is close to the Ventės Ragas Cape (eastern coast of the Curonian Lagoon), and the other is at the base of Parnidis dune (Parnidis kopa outcrop, the Curonian Spit, Nida environs) (Fig. 1). The other mollusc sites have been recovered from the offshore boreholes (further – bh.) at Būtingė (bh. 18/4), north of Klaipėda (bh. 91, 93) and Smiltynė (bh. 165), Nida environs (bh. 28/1), Curonian Lagoon water area (bh. 5, 6), and Nemunas delta (bh. 16, 25) (Fig. 1, Fig. 2, Fig. 3).

Subfossil mollusc shells were recovered from the core samples. They were separated from the sand by sieving (mesh diameter up to 1 mm) or by soaking and mechanically disaggregating other sediment types (e. g. gyttja). The volume of the sediments (V, in m^3) taken from the core samples was calculated using the

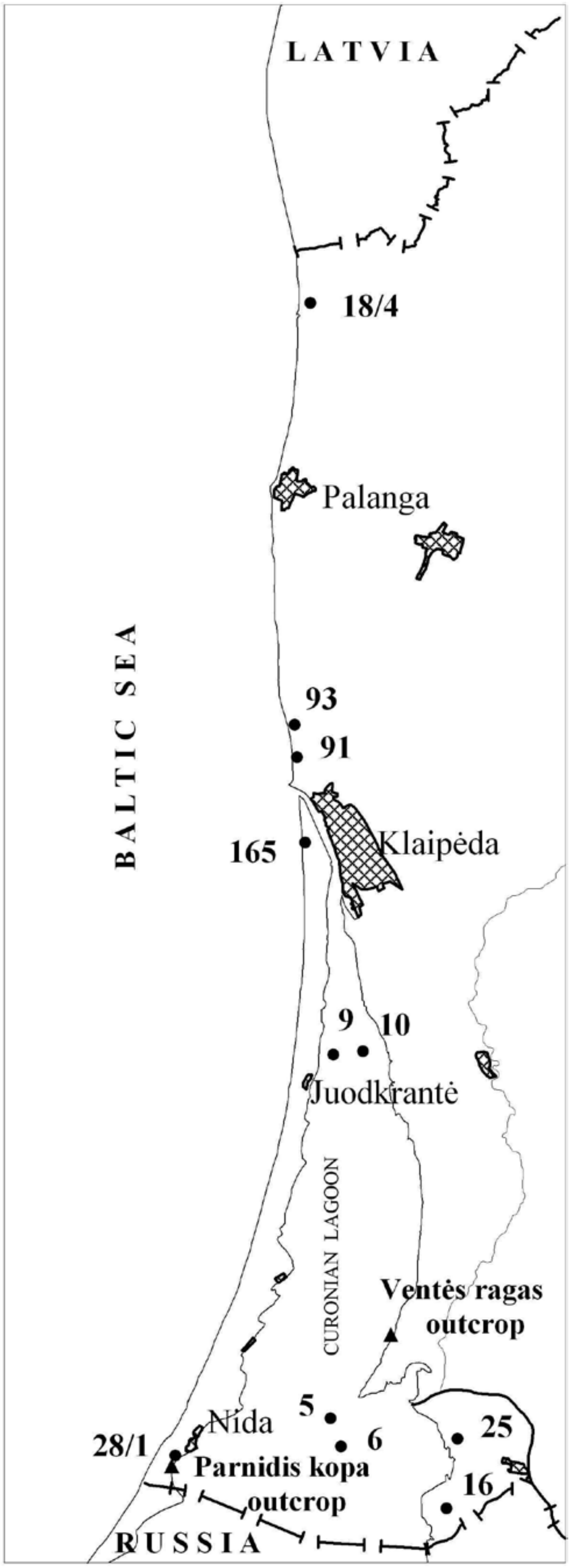

Fig. 1. Location map showing the sections studied: ● 91 - borehole number; ▲ - outcrop.

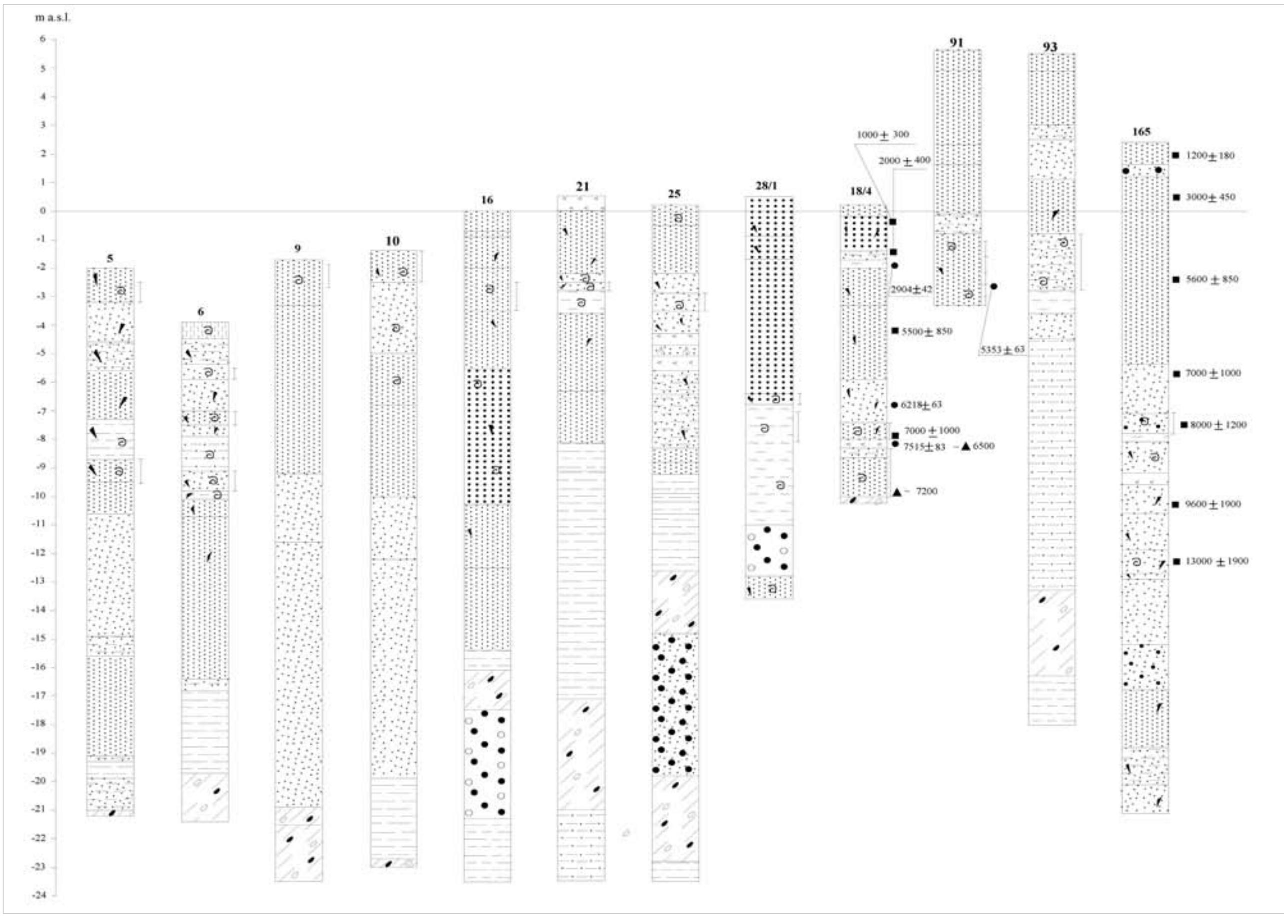

Fig. 2. Geological cross sections from the boreholes investigated.

formula V=πr²h, where *r* is the radius of the borehole (m) and *h* is sampling interval (m). From outcrops the subfossil mollusc shells were taken from 5–7 kg of sediment mass. The separation of shells from the sediments was difficult because of the high compression of the gyttja and the fragility of shells. Therefore, it is possible that all the individuals of some species could not be identified.

The number of full Bivalvia molluscs was used for calculations and the diagrams, thus, the frequency of the collected shells was divided by two. Because the number of specimens of different species was very unequal (from a few to a few hundred), logarithmic diagrams of species composition of molluscs were used to provide a more vivid demonstration of the peculiarities of mollusc species distribution. The determined subfossil molluscs belong to two classes: Gastropoda and Bivalvia, 15 families, 22 genera and 46 species. All mollusc species determined are listed in the Table 1.

The shells of subfossil molluscs collected were dated at the Laboratory of Radiometric Dating of the Estonian Institute of Geology at Tallinn Technical University using the electron spin resonance method (ESR; G. Hütt, 1996), and radiocarbon dating (^{14}C; R. Rajamäe, 1996); shells of *Cardium* Linnaeus,

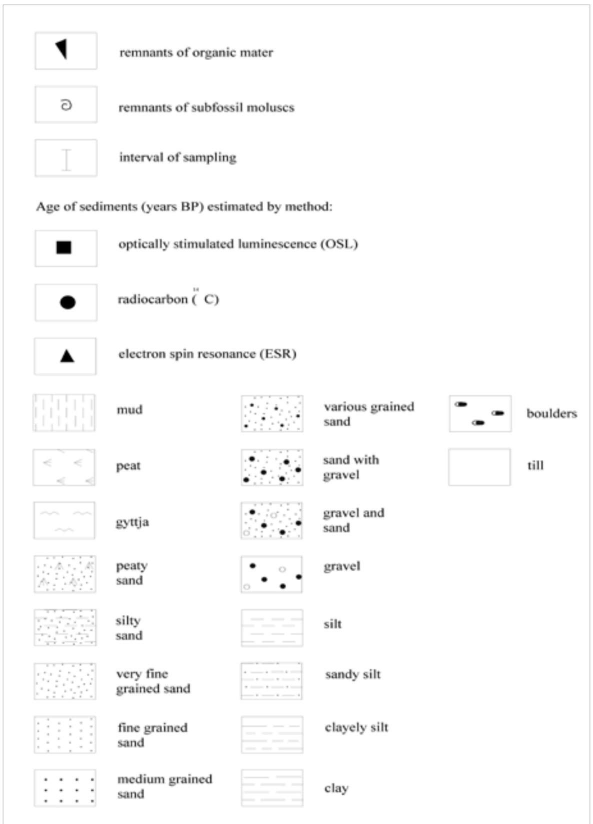

Fig. 3. Legend.

Table 1. The summary list of mollusc species identified.

Species	Bore-hole	5	6		9	10	16	21	25	28/1		Ventės ragas outcrop	Parnidis kopa outcrop	18/4	91	93	165
	depth, m	7.75-9.45	3.1-3.6	7.0-7.5	0.2-1.0	0.0-1.1	1.6-3.1	3.0-3.3	3.2-3.7	6.9-8.6	13.0-13.3			6,0-9,1	7,1-9,3	6,3-8,3	9,5-10,2
Gastropoda																	
Acroloxus lacustris (Linnaeus, 1758)									+								
Amnicola steini (Martens, 1858)						+	+		+	+			+				
Armiger crista f. *cristatus* (Draparnaud, 1905)												+					
Bithynia tentaculata (Linnaeus, 1758)		+	+	+	+	+	+	+	+	+			+	+	+		+
Galba truncatula (O.F.Müller, 1774)					+	+									+		+
Gyraulus albus (Müller, 1774)												+					
Gyraulus laevis (Alder, 1838)												+					
Lithoglyphus naticoides (C.Pfeiffer, 1828)		+															
Lymnaea auricularia (Westerlund, 1885)													+				
Lymnaea ovata (Westerlund, 1885)													+				
Lymnaea peregra (Müller, 1774)												+	+				
Lymnaea stagnalis (Linnaeus, 1758)												+					
Succinea putris (Linnaeus, 1758)										+			+				
Valvata alpestris (Küster, 1853)										+							
Valvata naticina (Menke, 1845)		+	+	+	+	+	+	+	+	+	+		+				
Valvata piscinalis (Müller, 1774)		+													+		+
Valvata piscinalis f. *antiqua* (Sowerby, 1838)		+	+	+	+	+	+	+	+				+		+		
Valvata pulchella (Studer, 1820)		+	+	+	+	+	+	+	+	+	+		+		+		+
Viviparus fasciatus (Müller, 1774)			+	+									+				
Viviparus fluviatilis (Schlesch, 1939)			+	+													
Viviparus viviparus (Linnaeus, 1758)			+	+									+				
Hydrobia ulvae (Pennant, 1777)														+	+	+	+
Littorina littorea (Linnaeus, 1758)															+		+
Theodoxus fluviatilis (Linnaeus, 1758)																	+
Bivalvia																	
Dreissena polymorpha (Pallas, 1771)		+	+	+	+	+							+				
Musculium lacustre (O.F.Müller, 1774)		+	+	+			+			+		+	+				
Pisidium amnicum (Müller, 1774)			+	+	+	+	+	+	+	+	+	+	+		+		+
Pisidium henslowanum (Sheppard, 1823)			+	+		+	+	+	+	+		+	+				

Pisidium lilljeborgi (Clessin, 1886)							+	+	+	+	+	+	+				
Pisidium milium (Held, 1836)		+	+	+	+	+	+	+		+		+	+				
Pisidium moitessierianum (Paladilhe, 1866)			+	+	+	+	+	+	+	+		+	+				
Pisidium nitidum (Jenyns, 1832)		+	+						+			+					
Pisidium obtusale (C.Pfeiffer, 1821)							+										
Pisidium obtusale lapponicum (Clessin, 1886)												+					
Pisidium pulchellum (Jenyns, 1832)				+			+	+		+			+				
Pisidium subtruncatum (Malm, 1855)		+					+										
Pisidium supinum (Schmidt, 1851)			+	+	+	+	+	+	+	+	+	+	+				
Pisidium tenuilineatum (Stelfox, 1918)		+					+		+								
Sphaerium lacustre (Müller, 1774)												+					
Sphaerium rivicola (Lamarck, 1881)												+					
Sphaerium solidum (Normand, 1884)		+	+	+			+					+					
Unio sp.		+	+	+			+		+								
Macoma balthica (Linnaeus, 1758)														+	+	+	+
Macoma calcarea (Gmelin, 1790)														+	+	+	+
Cerastoderma glaucum (Poiret, 1789)														+	+	+	+
Cerastoderma edule (Linnaeus, 1758)														+	+	+	+
Cerastoderma crassum (Gmelin, 1791)															+	+	+
Mytilus edulis (Linnaeus, 1758)														+	+	+	+

1758, were selected for dating. The content of isotopes d^{13}C and d^{18}O were also determined at this laboratory (T. Martma, 1996); for this purpose shells of *Cardium* Linnaeus, 1758 (bh. 91, 165), *Macoma* Leach, 1819, and *Mytilus edulis* Linnaeus*,* 1758 (bh. 18/4, 91, 165) were selected (Bitinas *et al.* 2000).

The organic sediments containing subfossil mollusc shells have already been dated by the radiocarbon method (peat from the Ventės ragas outcrop and the lagoon gyttja at Nida, bh. 28/1; H. Jungner, Dating Laboratory of the University of Helsinki, 1998; and J. Mažeika, Radioisotope Research Laboratory of the Institute of Geology and Geography, 1998, respectively). Sandy sediments from some sections have been dated using optically stimulated luminescence (OSL) in the Tallinn laboratory by G. Hütt (1996).

RESULTS

Ventės ragas outcrop

Subfossil mollusc shells were discovered on the Ventės ragas outcrop (Fig. 4) in lacustrine sediments at a depth of 2.68–2.73 m from the earth surface (NN 3.12–3.07 m). This 5 cm thick layer of greenish peaty gyttja directly overlies the till of the Late Nemunas (Late Weichselian) Formation. According to radiocarbon dating (11 700±180–11 190±120 ^{14}C years BP, or 13830 – 12930 cal years BP), these sediments were deposited in Alleröd (AL) (Bitinas *et al.* 2002). A 10 cm thick layer of black and brownish black slightly decomposed and compressed peat accumulated above the gyttja at the beginning of Younger Dryas (YD) (10 740±100–10 460±150 ^{14}C years BP, or 12810–12080 cal years BP) (Bitinas *et al.* 2002).

The subfossil mollusc shells were collected from a 5 kg of sediment block. The gyttja deposited during the Late Glacial contains 1341 subfossil mollusc shells (Fig. 5). The genera *Musculium* Link, 1807, *Pisidium* C. Pfeiffer, 1821, and *Sphaerium* Scopoli, 1777, belong to the Sphaeriidae, Bivalvia; the genus *Lymnaea* Lamark, 1799, belongs to the Lymnaidae, the genera *Armiger* Hartmann, 1843, and the *Gyraulus* (Agassiz) Charpentier, 1827, belong to the Planorbidae, Gastropoda.

Fig. 4. Outcrop of Ventės ragas; photo A. Bitinas, 1998.

The bivalve molluscs from the Sphaeriidae dominate the sediments studied, and the shells of *Sphaerium* Scopoli, 1777, *Musculium* Link, 1807, and *Pisidium* C. Pfeiffer, 1821, were also recovered. *Musculium* Link, 1807, is represented by only one species, *Musculium lacustre*, but the fragments of shells were rare; presumably as a consequence of their high fragility. *Sphaerium rivicola, S. solidum* and *S. lacustre* (*Sphaerium* Scopoli, 1777) were also relatively scarce. The shells of *Pisidium* C. Pfeiffer, 1821 were found in great abundance on the Ventės ragas outcrop exposure, where *Pisidium amnicum* is dominant, together with the other species (*P. henslowanum, P. supinum, P. lilljeborgi, P. milium, P. nitidum* and *P. obtusale lapponicum*) of this genus.

Gastropoda are represented by two families: the Lymnaeidae and Planorbidae. The former is represented by a few specimens of *Lymnaea stagnalis* and *L. peregra* (*Lymnaea* Lamarck, 1799). The Planorbidae is represented by the genera *Armiger* Hartmann, 1843 and *Gyraulus* (Agassiz) Charpentier, 1827, whereas *Armiger crista* f. *cristatus* is uncommon, but *Gyraulus albus* and *G. leavis* are found in abundance.

Nida environs

Subfossil mollusc shells also were found in lacustrine sediments close to Nida and at the foot of the Parnidis dune (Fig. 6). Here organic deposits of two metres thick are composed by dark greyish green, black, blackish brown or greenish grey gyttja, clayey gyttja and gyttja–bearing clay ('lagoon marl'). This layer is found in the borehole 28/1 at the depth of 8.0–10.0 m below the present water surface. At this depth the gyttja stratum is also fixed by the geophysical investigations (ground penetrating radar survey) (see Fig. 2). As a result of gravitation processes of the

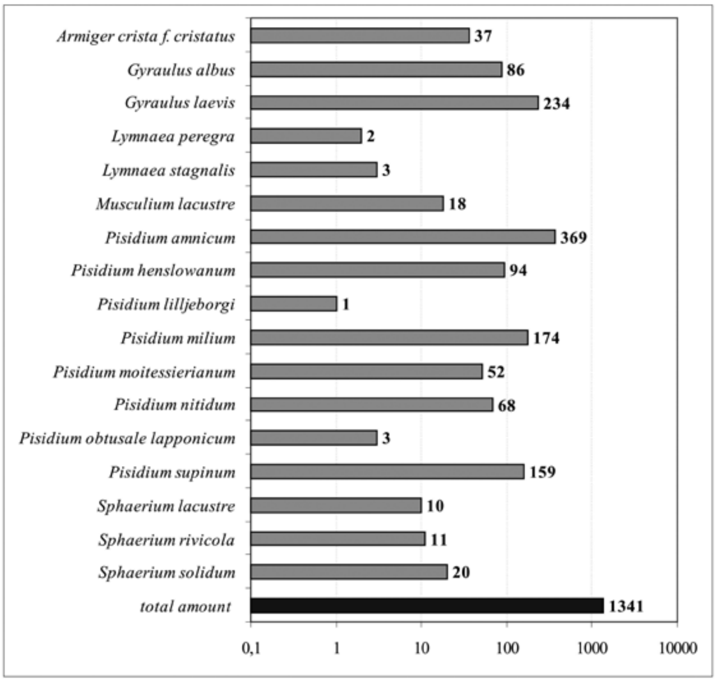

Fig. 5. Numbers of Mollusca identified in sample Ventės ragas outcrop plotted on a logarithmic scale.

Fig. 6. Outcrop of 'lagoon marl' at the bottom of Parnidis dune; photo A. Bitinas, 1998.

moving dunes, the gyttja deposits are squeezed in places. The ages of gyttja from the bottom of Parnidis dune determined by radiocarbon dating vary from 7380±105 ^{14}C years BP (8135±125 cal years BP) to 6130±100 ^{14}C years BP (6965±70 cal years BP) (Bitinas, Damušytė 2004).

The subfossil mollusc shells were sampled from the exposure (from a 7 kg sediment block; Table 1) and from a borehole (bh. 28/1) on the Curonian Lagoon coast, situated 200 m NNW of the entire outcrop. The mollusc shells for species determination were taken from 0.06 m^3 core sample (bh. 28/1; depth 6.9–8.6 m), and 1865 mollusc shells were counted (Fig. 7). The deposits were clearly dominated by subfossil Gastropoda shells, of which representatives of the families Succineidae, Hydrobiidae and Valvatidae were found. The Succineidae is represented by a few specimens of *Succinea putris*, genus *Succinea* Draparnaud, 1801, whilst the Hydrobiidae is represented by a few tens of specimens *Amnicola steini*, genus *Amnicola* Gould et Haldeman, 1841, and by abundant shells of *Bithynia tentaculata,* genus *Bithynia* Leach, 1818. The Valvatidae genus *Valvata* O. F. Müller, 1774, is dominant in these lake deposits, comprising numerous *Valvata naticina* and *V. pulchella*, and less abundant *V. piscinalis* f. *antiqua* and *V. alpestris*. Bivalvia subfossil mollusc shells are represented by two genera of the Sphaeriidae: *Musculium* Link, 1807, by *Musculium lacustre,* and *Pisidium* C. Pfeiffer, 1821 by greatest abundance of *Pisidium amnicum* (dominant), *P. henslowanum, P. supinum, P. lilljeborgi, P. milium,* and *P. pulchellum*.

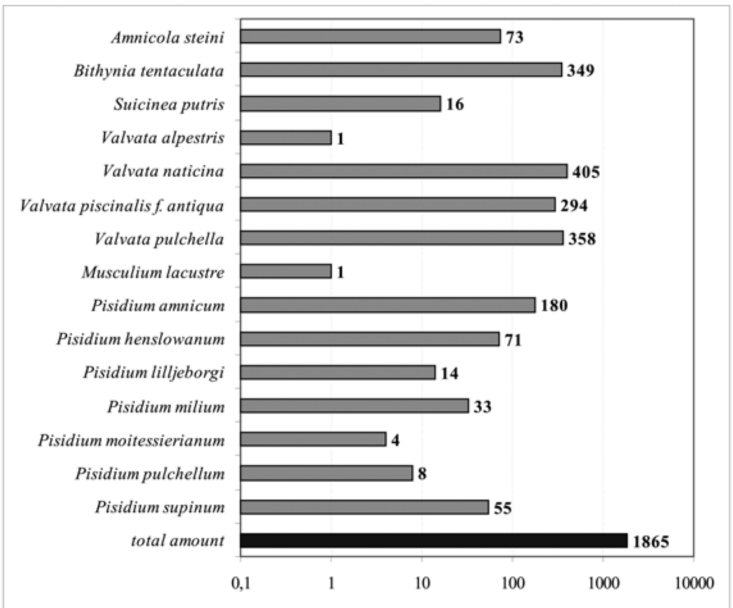

Fig. 7. Numbers of Mollusca identified in sample bh. 28/1 (depth 6.9-8.6 m) plotted on a logarithmic scale.

Būtingė environs

Borehole 18/4 near Būtingė was drilled on the eastern slope of foredune ridge (see Fig. 1). Here subfossil mollusc shells were found in fine–grained, well–sorted feldspar–quartz sand at a depth of 6.0–9.1 m (NN 3.5–4.6 m; Fig. 2) and taken from 0.07 m^3 of sediments. Optically stimulated luminescence dating (OSL) gave an age for this stratum of 7000±1000 years BP (Bitinas *et al.* 2000). The age of mollusc shell *Cerastoderma* from the borehole, determined by the Electron Spin Resonance (ESR) method, is about 6500–7200 years BP (Bitinas *et al.* 2000).

The frequency of mollusc shells is not abundant at this locality (195 specimens), and the number of species represented is also limited (Fig. 8). Here, the Bivalvia are represented by one genus each of the Tellinidae,

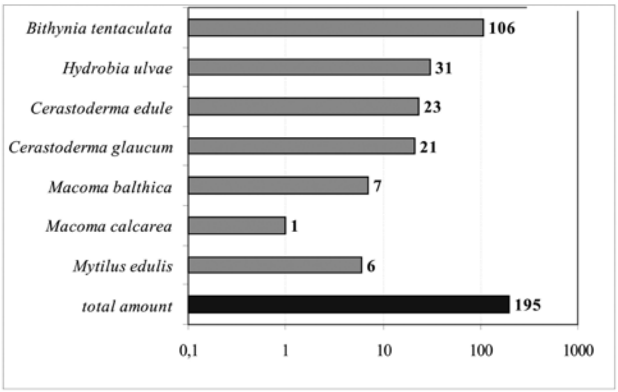

Fig. 8. Numbers of Mollusca identified in sample bh. 18/4 (depth 6.0-9.1 m) plotted on a logarithmic scale.

Cardiidae and Mytilidae. Shells of *Cardium* Linnaeus, 1758, and their fragments were found in the greatest abundance. The specimens of *Cerastoderma edule* and *C. glaucum* are present in almost equal quantities. The *Macoma* Leach, 1819, of Tellinidae, is sparsely represented by *Macoma balthica* and *M. calcarea*. A few shells of *Mytilus edulis*, of *Mytilus* Linnaeus, 1758, were also found. The Gastropoda are represented by genera of Hydrobiidae—*Bithynia* Leach, 1818, and *Hydrobia* Hartmann, 1821—by one species each. The abundance of *Hydrobia ulvae* is comparatively low at this site, whereas the quantity of *Bithynia tentaculata* was considerably higher.

Melnragė environs

Subfossil mollusc shells were found in borehole 91 (see Fig. 2), drilled on the Litorina Sea terrace east of the foredune ridge. Mollusc shells were found in a layer of fine–grained grey feldspar–quartz sand at a depth of 7.1–9.3 m (NN -2.1– -4.3 m) underlying organic sediments, which were dated to 5353±63 ^{14}C years BP (6138±97 cal years BP). 3334 mollusc specimens were collected from 0.05 m^3 of these deposits (Fig. 9).

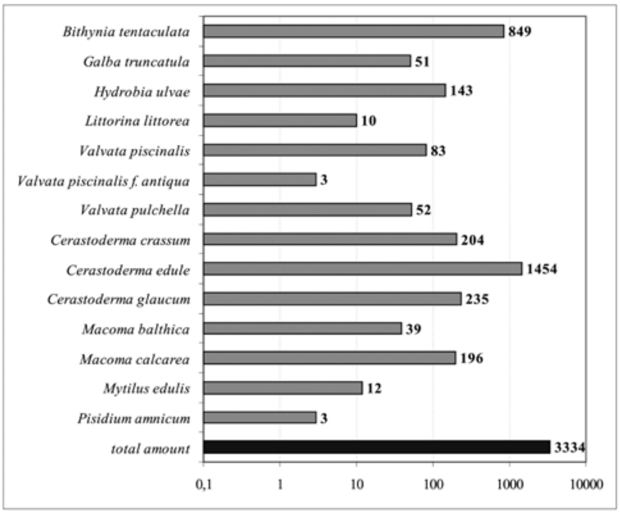

Fig. 9. Numbers of Mollusca identified in sample bh. 91 (depth 7.1-9.3 m) plotted on a logarithmic scale.

Here, members of the Bivalvia were the most common. Among the families Tellinidae, Cardiidae, Mytilidae, and Sphaeriidae, shells of *Cardium* Linnaeus, 1758, Cardiidae, predominate: *Cerastoderma crassum* and *C. glaucum* species are slightly fewer, whereas well–preserved shells of *Cardium edule* were especially abundant. *Macoma calcarea* and *M. balthica*, *Macoma* Leach, 1819, represent the Tellinidae. The Mytilidae comprises several shells of *Mytilus edulis, Mytilus* Linnaeus, 1758, and the Sphaeriidae is represented by a few shells of *Pisidium amnicum, Pisidium* C. Pfeiffer, 1758.

The stratum studied also yields many subfossil Gastropoda from the families Littorinidae, Hydrobiidae, Valvatiidae and Lymnaeidae. *Bithynia* Leach, 1818, and *Hydrobia* Hartmann, 1821, represent the Hydrobiidae. Specimens of *Bithynia tentaculata* are most common, but *Hydrobia ulvae* was found in considerably lower numbers. Shells even of *Valvata piscinalis, V. piscinalis* f. *antiqua* and *V. pulchella, Valvata* O. F. Müller, 1774, represent Valvatidae. A few shells each represent *Galba truncatula* of *Galba* Schrank, 1803, from the Lymnaeidae and *Littorina littorea* of *Littorina* Férussac, 1822, from Littorinidae.

Curonian Spit Smiltynė environs

Borehole 165 was drilled in the northern part of Curonian Spit at the eastern foot of foredune ridge near Smiltynė (see Fig. 1). Here, subfossil mollusc shells were found in fine–grained grey feldspar–quartz sand at a depth of 9.5–10.2 m (NN -7.1– -7.8 m; Fig. 2). The remains of 1458 shells were collected from 0.02 m^3 of deposits (Fig. 10). Based on OSL determination, the mollusc–bearing sand dates from 8 000±1 200 years BP (Bitinas *et al.* 2000). The sediments in borehole 165 contain the same mollusc species as those from the borehole near Melnragė (bh. 91; Fig. 2, Fig. 9). A few specimens *Theodoxus fluviatilis* of *Theodoxus*

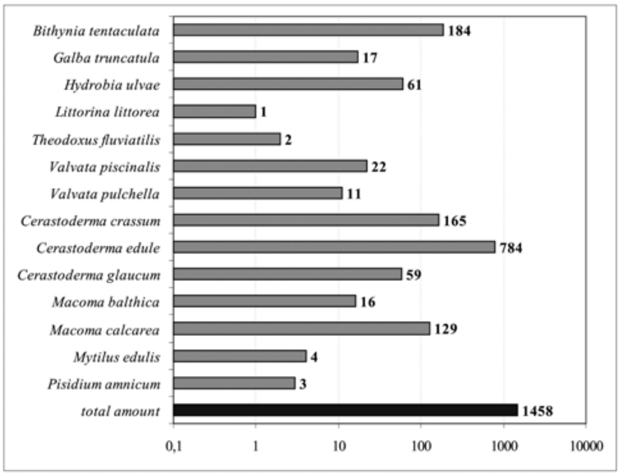

Fig. 10. Numbers of Mollusca identified in sample bh. 165 (depth 9.5-10.2 m) plotted on a logarithmic scale.

Montfort, 1810, from Neritidae and a considerably smaller number of other subfossil Gastropoda shells are the only difference between the two assemblages.

Curonian Lagoon

Similar mollusc species assemblages (Fig. 11, Fig. 12) were found in boreholes from the Curonian Lagoon water area (bh. 5, 6; Fig. 1, Fig .2) in a fine–grained grey feldspar–quartz sand layer deposited at a depth of 7.5–9.8 m below the present sea level.

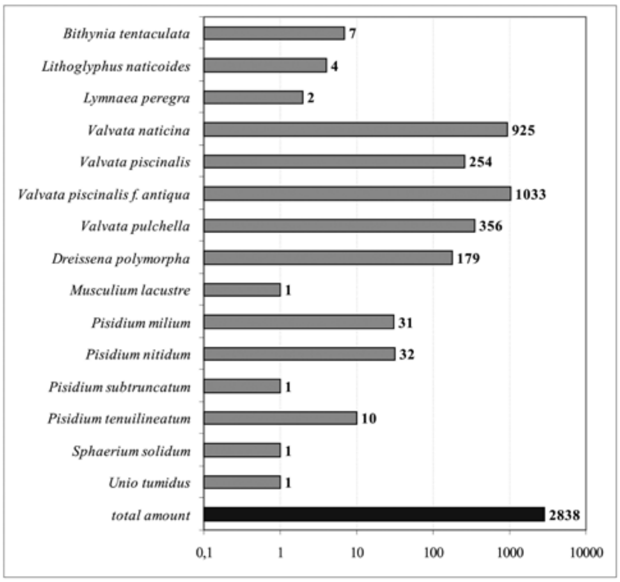

Fig. 11. Numbers of Mollusca identified in sample bh. 5 (depth 7.75 - 9.45 m) plotted on a logarithmic scale.

Borehole 5 was drilled in the Curonian Lagoon, east of Nida. Here, subfossil mollusc shells were collected at a depth of 7.75–9.45 m from 0.04 m^3 of sand. 2838 mollusc specimens were counted from this sample (Fig. 11). The deposits contain relatively few mollusc shells of Bivalvia, yet Gastropoda were found in high concentrations. The Bivalvia are represented by only one species each from *Sphaerium* Scopoli, 1777 (*Sphaerium solidum*) and *Musculium* Link, 1807 (*Musculium lacustre*). Shells of *Pisidium* C. Pfeiffer, 1821 were slightly more abundant, a few specimens of *Pisidium subtruncatum* and *P. tenuilineatum,* and a few tens of specimens of *P. nitidum* and *P. milium*. The deposits also contain fragments of *Unio tumidus* shells of the Margaritanidae (*Unio* Retzius, 1788) and shells of *Dreissena polymorpha* of *Dreissena* V. Beneden, 1835, from the Dreissenidae.

Snail shells represent the majority of subfossil molluscs of the Valvatidae Gastropoda. The shells of *Valvata piscinalis* f. *antiqua* and *V. naticina* dominated among the identified species of *Valvata* O. F. Müller, 1774, whilst those of *V. pulchella* and *V. piscinalis* were slightly rarer. A few shells of the Lymnaeidae (*Lymnaea peregra* of *Lymnaea* Lamarck, 1799) and Hydrobiidae (*Lithoglyphus naticoides* of *Lithoglyphus* Hartmann, 1821, and *Bithynia tentaculata* of *Bithynia* Leach, 1818) were also identified.

Borehole 6 was drilled in the Curonian Lagoon southwest of the Ventės Ragas Cape. Here, subfossil mollusc shells were collected from 0.01 m^3 of sand deposited at a depth of 7.0–7.5 m. This unit yielded 510 shell fragments, i.e. almost equal numbers of Bivalvia and Gastropoda specimens (Fig. 12). The Bivalvia are represented by prevalenting *Dreissena polymorpha* of *Dreissena* V. Beneden, 1835 from Dreissenidae. Sphaeriidae are represented by *Sphaerium* Scopoli, 1777 (*Sphaerium solidum*) and *Musculium* Link, 1807 (*Musculium lacustre*); one example from species each. Mollusc shells of *Pisidium* C. Pfeiffer, 1821 are slightly

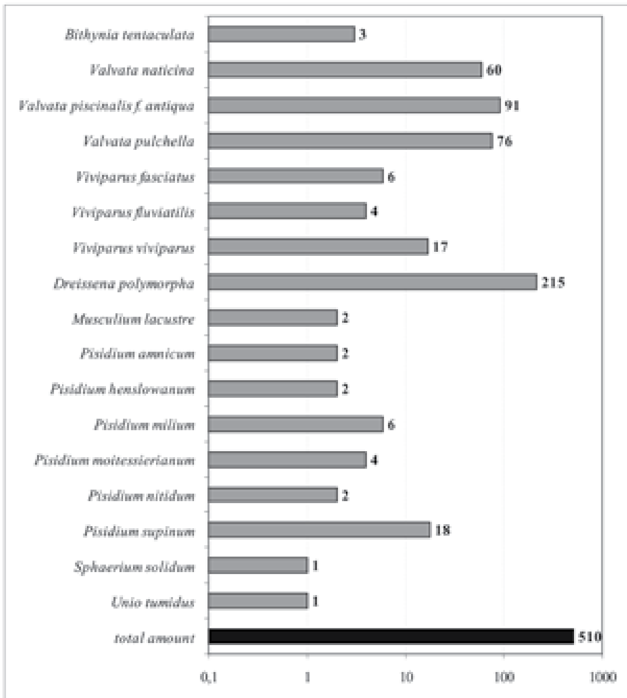

Fig. 12. Numbers of Mollusca identified in sample bh. 6 (depth 7.0 - 7.5 m) plotted on a logarithmic scale.

more abundant, comprising a few shells of *Pisidium nitidum, P. milium, P. henslowanum* and *P. amnicum* and some shells of *P. supinum*. The sediments also contain a few fragments of *Unio tumidus* shell from Margaritanidae (*Unio* Retzius, 1788).

As in the borehole 5, Gastropoda shells are principally represented by members of the Valvatidae. *Valvata piscinalis* f. *antiqua*_is dominant among the three *Valvata* O. F. Müller, 1774 species identified of *V. naticina* and *V. pulchella* shells were found in almost equal quantities. Shells of the Viviparidae (*Viviparus* Montford, 1810, *Viviparus viviparus, V. fasciatus* and *V. fluviatilis*) were represented from a few to occasional examples. Shells of *Bithynia tentaculata* (*Bithynia* Leach, 1818) of the Hydrobiidae were also found.

DISCUSSION: PALAEOENVIRONMENT OF BASINS

To date, subfossil mollusc shells have only been found in the outcrop of Ventės Ragas Cape on the Lithuanian coastal area (see Fig. 4). The analysis of mollusc shells has shown that they inhabited a closed freshwater basin, which existed in this area during the Weichselian, i.e. 11.7–11.2 radiocarbon kyr BP. During this time the Baltic Ice Lake shoreline was situated west of the Ventės Ragas Cape, and small lakes presumably occurred on the present land area after the fall of the water level of this cold, freshwater basin. Some authors consider that the basin probably represented a semi–enclosed embayment of the Baltic Ice Lake on the margin of which the deposits studied accumulated. This opinion is supported by the results of diatom analysis from sediments found in the environs of Ventės Ragas Cape (Kabailienė 2006). The concentration of *Pisidium amnicum* (O. F. Müller, 1774) shells implies the existence of a littoral zone of a small basin. Although the basin water was still cold (judging from *P. obtusale lapponicum* (Clessin, 1886) mollusc shells) and muddy (*Sphaerium solidum* (Normand, 1844), *Musculium lacustre* (O. F. Müller, 1774), *Pisidium milium* (Held, 1836) and other subfossil molluscs), its bottom was already overgrown by water plants. *Lymnaea stagnalis* (Linnaeus, 1758), *Armiger crista* f. *cristatus* (Draparnaud, 1905) implying gradual shallowing and eutrophication of the basin.

The later Yoldia Sea shoreline was situated west of the present Baltic Sea coast. The water level of the Yoldia Sea phase was roughly –40 m below the present sea level (Schoning 2001; Kabailienė 1999; Raukas 1995) in this region. This explains why deposits of this basin are not found on the Lithuanian Baltic Sea coast.

Researchers disagree about the water level and shoreline position of the subsequent Ancylus Lake. Some attempt to identify the sediments of this phase in the Curonian Spit area on the basis of diatom analyses (Jensen *et al.* 1999; Kabailienė 1999), yet subfossil mollusc shells that typify this large freshwater body have not been found in Lithuania.

During the Early Atlantic, the water level of Litorina Sea was considerably lower than that of the present Baltic Sea. Therefore, 8–6 000 ^{14}C years ago, the recent area of Curonian Lagoon was covered by a shallow freshwater lagoon in which sediments accumulated that today can be found beneath Parnidis dune on the Curonian Spit. These organic deposits abound in freshwater mollusc shells (see Fig. 6) that inhabited a small shallow closed water basin.

The existence of a small freshwater basin (possibly a lagoon) with a muddy bottom is demonstrated by the finds of subfossil molluscs *Pisidium milium* (Held, 1836), *P. henslowanum* (Sheppard, 1823), *Valvata piscinalis* f. *antiqua* (Sowerby, 1838). The edge of this shallow water body was presumably situated at the foot of modern Parnidis dune. This opinion is supported by the abundant littoral subfossil mollusc shells *Pisidium amnicum* (O. F. Müller, 1774) and *P. pulchellum* (Jenyns, 1832), which stringly favour the reed belts of littoral zones. It is also confirmed by the presence of the shells of the land snail, *Suicinea putris* (Linnaeus, 1758), that inhabits the trees and shrubs by the edges of water basins. Some researchers consider that the water body might have been a lagoon of the Litorina Sea because the deposits contain diatoms that only typify the Litorina Sea phase (Kabailienė 1999). The explanation of the source of these brackish water (halophilous?) diatoms remains: was this their true habitat or were they imported with the storm water from the open sea surging across the then narrow spit?

Subfossil mollusc shells from the Litorina Sea phase (8.0–4.0 radiocarbon kyr BP) were discovered in the boreholes drilled on the Curonian Spit near Smiltynė and on the mainland coast of the Baltic Sea north of Klaipėda. The boreholes from south of Klaipėda (on the Baltic Sea coast and on both the coast and floor of the Curonian Lagoon) did not contain subfossil mollusc shells typical of the Litorina Sea. At this time (8.0–4.0 radiocarbon kyr BP) a shallow littoral zone existed south of Klaipėda in which an intensive wave breaking regime occurred; or that the area was most likely already occupied by a shallow freshwater lagoon.

Litorina Sea phase mollusc shells found in the boreholes described show that their communities were rather similar. The Bivalvia shells of *Cerastoderma edule* (Linnaeus, 1758) are found in the greatest abundance, whilst those of *C. crassum* (Gmelin, 1791) and *C. glaucum* (Poiret, 1789). *Macoma calcarea* (Gmelin, 1790) and *M. balthica* (Linnaeus, 1758) were slightly less frequent. The Gastropoda were represented by a few specimens each of *Theodoxus fluviatilis* (Linnaeus, 1758) (bh. 165) and *Littorina littorea* (Linnaeus, 1758) (bh. 91, 165). The occurrence of *Hydrobia ulvae* (Pennant, 1777) was slightly higher. This mollusc community are typical of shallow (up to 5–10 m in depth) marine littoral zones with a sandy, and in places a muddy bottom.

It is notable that only a few halophilic molluscs *Littorina littorea* (Linnaeus, 1758) were found in the area studied. This taxon is generally regarded as typifying the Litorina Sea phase inhabitants (they flourish in basins of water salinity at least 12 ‰; Kessel 1958). This indicates that the Litorina Sea water was not as salty today in the present central and southern Baltic, i.e. the salinity value was only 8–10 ‰. This has been demonstrated by isotopic analysis (d^{13}C and d^{18}O) of mollusc shells (Bitinas *et al.* 2000). Small shells of freshwater molluscs *Valvata* sp., *Galba truncatula* (O. F. Müller, 1774) found in sediments in boreholes 91 and 165 were presumably transported from land to sea by rivers.

Mollusc shells (see Fig. 11, Fig. 12) are found in boreholes 5 and 6 in the Curonian Lagoon water area recovered from deposits, that according to palynological analyses accumulated during the Atlantic (bh. 6; depth 7.0–7.5 m) and pre-Boreal–Boreal (bh. 5; depth 7.75–9.45 m) periods. Analysis of these shells shows them to be of freshwater taxa, implying that during the time under consideration the water in the Curonian lagoonal basin already was almost completely fresh. In particular the deposits contain shells of Valvatidae, Sphaeriidae and, in the upper parts of the studied sections, of Dreissenidae families. Snail species of *Valvata* O. F. Müller, 1774 [*V. naticina* (Menke, 1845*), V. piscinalis* (O. F. Müller, 1774), *V. pulchella* (Studer, 1820), and *V. piscinalis* f. *antiqua* (Sowerby, 1838)], usually inhabit the sandy or silty bottom of shallow stagnant water bodies, were determined.

The species assemblage of bivalve molluscs belonging to *Pisidium* C. Pfeiffer, 1821 [*P. amnicum* (O. F. Müller, 1774), *P. henslowanum* (Sheppard, 1823), *P. lilljeborgi* (Clessin, 1886), *P. milium* (Held, 1836), *P. nitidum* (Jenyns, 1832), *P. supinum* (A. Schmidt, 1851)] is also typical of the shallow freshwater lagoon (lake) environment. Thus, the mollusc shells recovered (Fig. 11, Fig. 12) indicate that this mollusc community inhabited a small, shallow water basin or a semi–closed lagoon of a larger water body where the muddy bottom was partly overgrown by water plants. The shells of *Dreissena polymorpha* (Pallas, 1771) found still require detailed analysis in order to understand better their development history on the Baltic Sea coast (Buinevich *et al.* 2009).

CONCLUSIONS

Shells of subfossil molluscs that inhabited the Baltic Ice Lake are absent from sites along the modern Lithuanian Baltic Sea coast. During the Weichselian Late Glacial, either the present basin of Curonian Lagoon was occupied by a small, shallow lake or it formed the peripheral zone of a semi–enclosed lagoon of the Baltic Ice Lake. Subfossil mollusc shells typical of the Yoldia Sea and Ancylus Lake basins are absent from sites on the Lithuanian coast.

During the first Litorina Sea transgression, the coast south of the present Klaipėda was situated considerably further west of the recent Baltic Sea coast. The area of the recent Curonian Spit and Curonian Lagoon was occupied by a small, shallow, freshwater basin (or basins) or a semi–enclosed lagoon of a larger basin. The Litorina Sea molluscan community discovered from sites near Būtingė, Melnragė and Smiltynė is typical of a shallow (up to 5–10 m in depth) littoral zone with a sandy and in places, muddy bottom. The Litorina Sea water that washed the Lithuanian coast was not as salty as in the central and southern Baltic, i.e. the salinity value was only 8 – 10‰.

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References

Andrén, E., Andrén, T. & Sohlenius, G. 2000. The Holocene history of the southwestern Baltic Sea as reflected in a sediment core from the Bornholm Basin. *Boreas 29,* 233-250.

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., Damušytė, A. 2004. The Littorina Sea at the Lithuanian maritime region. Proceedings of the Conference "Rapid transgressions into semi–enclosed basin", *Polish Geological Institute Special Papers 11*, 37-46.

Bitinas, A., Damušytė, A., Hütt, G., Martma, T., Ruplėnaitė, G., Stančikaitė, M., Ūsaitytė, D., Vaikmäe, R. 2000. Stratigraphic correlation of Late Weichselian and Holocene deposits in the Lithuanian coastal region. *Proceedings of the Estonian Academy of Sciences, Geology 49 (3),* 200-217.

Bitinas, A., Damušytė, A., Stančikaitė, M., Aleksa, P. 2002. Geological development of the Nemunas River Delta and adjacent areas, West Lithuania. *Geological Quarterly 46 (4),* 375-389.

Buynevich, I. V., Damušytė, A., Bitinas, A., Olenin, S., Mažeika, J., Petrošius, R. 2009. Pontic–Baltic pathways for invasive aquatic species: geological implications. *GSA Special paper (in press).*

Danilovskij, I. V. 1955. *Key–section of sediments of the Scandinavian Glaciation of Russian Plain and Quaternary molluscs.* Gosgeoltehizdat, Moscow, 202 pp. [In Russian].

Glöer, P., Meier-Brook, C. 1998. *Süsswassermollusken. Deutscher Jugendbund für Naturbeobachtung.* Hamburg, 136 pp.

Gudelis, V. 1988. *The Lithuanian offshore and coast of the Baltic sea.* Lietuvos mokslas, 444 pp. [In Lithuanian].

Jensen, J. B., Bennike, O., Witkowski, A., Lemke, W. & Kuijpers, A. 1997. The Baltic Ice Lake in the southwestern Baltic: sequence-, chrono- and biostratigraphy. *Boreas 26*, 217-236.

Jensen, J. B., Bennike, O., Witkowski, A., Lemke, W., Kuijpers, A. 1999. Early Holocene history of the southwestern Baltic Sea: the Ancylus Lake stage. *Boreas 28*, 437-453.

Jensen, J. B., Petersen, K. S., Konradi, P., Kuijpers, A., Bennike, O., Lemke, W. & Endler, R. 2002. Neotectonics, sea-level changes and biological evolution in the Fennoscandian border zone of the southern Kattegat Sea. *Boreas 31*, 133-150.

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

Kabailienė, M. 2006. *Environmental evolution in the Lithuania during 14 000 years.* Vilniaus universiteto leidykla, 471 pp. [In Lithuanian].

Kessel, H. 1958. Neue Angaben über die Fauna subfossiler und recenter Mollusken der Esthnischen SSR. *Geoloogia Instituudi Uurimused III*, 253-268. [In Russian with summary in German].

Petersen, K. S. 2004. *Late Quaternary environmental changes recorded in the Danish marine molluscan faunas*. Geological Survey of Denmark and Greenland Bulletin, 268 pp.

Raukas, A. 1995. Evolution of the Yoldia Sea in the eastern Baltic. *Quaternary International 27,* 99-102.

Schoning, K. 2001. The brackish Baltic Sea Yoldia Stage – palaeoenvironmental implications from marine benthic fauna and stable oxygen isotopes. *Boreas 30*, 290-298.

Skompski, S. 1991. *Quaternary fauna of the Poland. Invertebrate*. Wydawnictwa Universytetu Warszawskiego, 239 pp. [In Polish].

Šivickis, P. 1960. *Molluscs of the Lithuania and their descriptions.* Valstybinė politinės ir mokslinės literatūros leidykla, 351 pp. [In Lithuanian].

Tavast, E. 2000. Subfossil molluscs shells of the Baltic Sea and the possibilities of their usage in the stratigraphy and correlation of the Baltic Sea sediments. *Geologos 5,* 31-40.