Studia Quaternaria, vol. 30, no. 1 (2013): 5–17. DOI: 10.2478/squa-2013-0001

LATE GLACIAL AND HOLOCENE MOLLUSCAN ASSEMBLAGES IN DEPOSITS FILLING PALAEOLAKES IN NORTHERN POLAND

Witold Paweł Alexandrowicz

AGH University of Science and Technology, Faculty of Geology, Geophysics and Environment Protection, Chair of Geology and Geoturism, Al Mickiewicza 30, 30-059 Cracow; e.mail: wpalex@geol.agh.edu.pl

Abstract

Late Glacial and Holocene carbonate lacustrine deposits developed as lacustrine chalk and calcareous gyttja are fairly widespread across northern Poland. They form fillings of palaeolakes which developed during the deglaciation. These formations are usually covered by peat. Rich and diversified malacofauna has been found in the aforementioned sediments. The profiles from 154 sites described and published by various authors were subjected to malacological analysis. In the whole material, 18 molluscan assemblages were distinguished, representing three types of habitats: terrestrial, of temporary water bodies, and of permanent water bodies. The composition and structure of these assemblages allows characterizing climate and differentiating habitats. The time-sequences of malacological assemblages provided possibility to define three types of malacological sequences. On the basis of these successions, a scheme of the lake water bodies evolution during Late Glacial and in northern Poland was elaborated.

Key words: lacustrine chalk, calcareous gyttja, palaeolakes, molluscan assemblages, Late Glacial, Holocene, northern Poland

INTRODUCTION

The lacustrine chalk and calcareous gyttja form the fillings of palaeolakes which developed in high numbers during the deglaciation. These may also be found on the coasts of present-day lakes where they mark their previous wider extents. The accumulation of these lake sediments occurred chiefly during transitional periods between cold glacial phases and warm interglacials when dead ice blocks, trapped earlier in moraine or glaciofluvial sediments have melted. Drainage-less depressions of various sizes, depths and shapes were formed, and became stagnant bodies of freshwaters, subjected to complex evolution during the Late Glacial and Holocene. Some of them transformed into permanent lakes, others were filled with deposits and became peat bogs, and finally, terrestrial habitats with various moisture levels. The course of sediment-filling and disappearance of these depressions was reconstructed and described by numerous authors. The age of great majority of the sites with carbonate or mineral deposits filling palaeolakes is linked to declining phase of the last glaciation and with the Holocene. Also known are the occurrences of these sediments of the earlier interglacials, mainly Eemian and Mazovian (Holsteinian) (e.g. Skompski, 1996; S. W. Alexandrowicz and W. P. Alexandrowicz, 2010).

Palaeolakes are filled with various types of sediments. Common, and the most important from the viewpoint of malacological studies, are lacustrine chalk and calcareous gyttja.

Lacustrine chalk is a carbonate sediment occurring as a result of precipitation of $CaCO_3$ in water. This process is particularly intensive in the water bodies with abundant vegetation which can be associated with uptake of carbon dioxide by plants during photosynthesis. The calcium carbonate content exceeds 80%. The sediments are white, grey, sometimes yellowish or brownish. Some of them contain small lumps of calcium carbonate, and sometimes oolith or stromatolith-type structures (e.g. Rzepecki, 1983; Rutkowski *et al.*, 2002; Freytet and Verrecchia, 2002). Very often, the lacustrine chalk contain remnants of molluscs and ostracods.

The name of calcareous gyttja is given to these lake sediments that contain from 50 to 80% of calcium carbonate. Depending on the proportions of other components e.g.: mineral or organic substances, or organic detritus, a number of types are distinguished among calcareous gyttja. The classification of theses sediments were taken up by many studies (e.g. Markowski, 1980; Rzepecki, 1983; Freytet and Verrecchia, 2002).

The carbonate deposits are accompanied by mineral deposits: sands and silts, and more rarely – gravels. Among the gravels, cobbles of Scandinavian rocks are represented most often by granites, gneisses or porphyries. In terms of their origin these are either moraine or glaciofluvial formations. In many sites these deposits occur at the bottom of palaeolake sequences.

Peats are of essential importance. They are associated with boggy environments and usually develop in the final stage of evolution of lake water bodies. They therefore occur at the top of depositional sequences and testify to overgrowing of lakes and their transformation into moist terrestrial environments. Thin interlayers or lenticles of peats are sometimes found also within the lake sediments. Their presence proves temporary shallowing of the lakes.

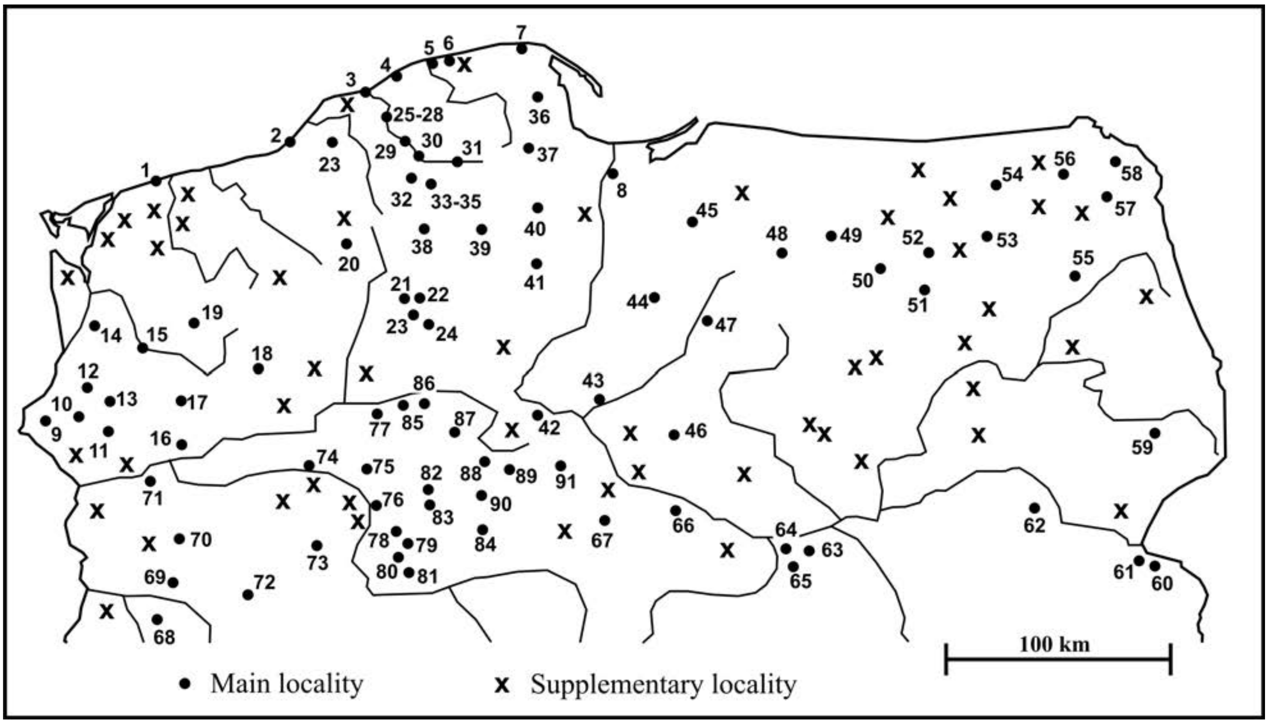

Fig. 1. Localization of mollusc-bearing calcareous lake sediments in Northern Poland. For explanations of numbers of localities (1–91) see Table 1.

The internal structures of the palaeolake fillings is often very complicated due to varying proportions and mutual relationships between the aforementioned principal genetic types of sediments. A total thickness of formations of the palaeolakes is from 0.5 to over 10 m.

Lacustrine chalk and calcareous gyttja often abound in shells of snails and bivalves. It is principally caused by high content of $CaCO_3$ in the sediments. Remnants of mollusk shells, usually less preserved and often bearing the traces of chemical dissolution may sometimes appear also within peats that accompany the carbonate sediments. Presence of molluscan shells in the lake sediments of Late Glacial and in northern Poland was recorded as early as in the 19th century and the early 20th by German geologists (e.g. Keilhack, 1888; Menzel, 1911). More detailed analyses of molluscan fauna in lacustrine chalk were undertaken by Dembińska (1924) during inter-war period. After WWII, a great progress was made in research of carbonate lake sediments. During the wide-range mapping and deposit documentation works, more than ten thousand sites with lacustrine chalk and calcareous gyttja were located and catalogued. Some of them became the topics of detailed and interdisciplinary studies, but huge majority still awaits a more elaborated research. Despite the fact that shells of snails and bivalves commonly occur in lacustrine chalk and calcareous gyttja, the state of recognition of malacocoenoses is far for being sufficient. In voluminous references there are many mentions on presence of malacofauna but without species identification. One can even assume that in many cases the shells of molluscs have been omitted or gone completely unnoticed. The studies listing faunas, sometimes with number of individuals of particular species are rare, and only exceptionally a full malacological analysis has been done, accompanied by palaeoecological and palaeogeographical reconstruction based on such data. There are rather few more general studies nature, presenting changes and evolution of molluscan assemblages over larger areas (S. W. Alexandrowicz, 1989; W. P. Alexandrowicz, 1999, 2007).

MATERIAL AND METHOD

In order to describe the properties of changes in sequences of molluscan assemblages and to carry out reconstruction of the evolution of sedimentary in lake carbonate sediments, 91 sites were selected. Additionally, the data from 32 sites with fragmentary malacological data were used as well as those from 31 sites described in the early 20th century by German geologists. This last group of sites can be treated as a supplement only, as they contain very general data, and locations of most of these sites cannot be practically identified at present. Owing to this large number of sites, however, it was possible to characterise particular types of assemblages of the fauna as well as their compositions and structures. Results of these studies were published in a number of scientific articles (e.g. S. W. Alexandrowicz, 1989; W. P. Alexandrowicz, 1999, 2007). The study presented here represents an attempt to generalise results of studies completed at various sites and to present characteristics of main faunistic assemblages and their relationship with climate changes and evolution of water bodies during Late Glacial and Holocene. The most important sites which provided the basis for the presented analysis are compiled (Table 1, Fig. 1).

On the sites of lacustrine chalk and calcareous gyttja (Table 1), rich and diversified malacofauna was identified. The habitat and climatic requirements of particular species were discussed in detail in many publications. Several papers

Table 1

Main localities of mollusc-bearing calcareous lake sediments in Northern Poland. For location of particular profiles see Fig. 1

No	Locality	References
1	Niechorze	Kopczyńska-Lamparska *et al.* (1984); S.W. Alexandrowicz (1989)
2	Dąbki	S.W. Alexandrowicz (1991)
3	Ustka	Brodniewicz (1979); S.W. Alexandrowicz *et al.* (1989, 1990); S.W. Alexandrowicz (1998); Wojciechowski (2012)
4	Poddąbie	Krzyszkowski *et al.* (1998); S.W. Alexandrowicz (1999b)
5	Kluki	Wojciechowski (1995, 2011); S.W. Alexandrowicz (1999b)
6	Jezioro Łebsko	
7	Karwia	S.W. Alexandrowicz (1999b)
8	Skowarcz	W.P. Alexandrowicz (1999, 2002, 2005)
9	Chojna	Czepiec (1998)
10	Brzesko	Kowalkowski and Berger (1966)
11	Płoń	S.W. Alexandrowicz (1989)
12	Okrzeszyce	Kowalkowski and Berger (1971/72)
13	Żabów	
14	Zelewo	S.W. Alexandrowicz (1989)
15	Lubiatowo	
16	Osiek	S.W. Alexandrowicz (1980, 1989)
17	Prostynia	S.W. Alexandrowicz (1980); S.W. Alexandrowicz and Tchórzewska (1981)
18	Zdbice	S.W. Alexandrowicz and Tchórzewska (1981)
19	Zacisze	S.W. Alexandrowicz (1989)
20	Marcelin	S.W. Alexandrowicz and Tchórzewska (1981)
21	Jezioro Duże Głuche	Nowaczyk *et al.* (1999); Nowaczyk and S.W. Alexandrowicz (2008)
22	Jezioro Małe Głuche	
23	Jezioro Charzykowskie	
24	Jezioro Ostrowite	
25	Grabowo	S.W. Alexandrowicz and Tchórzewska (1981); Filonowicz and Krzymińska (1989); S.W. Alexandrowicz (1995b, 1999b)
26	Słupsk Słowiańska	S.W. Alexandrowicz *et al.* (1989, 1990)
27	Słupsk Racławicka	
28	Słupsk Południe	
29	Stożek Glaźny	
30	Dębica Kaszubska	
31	Gałęźnia Mała	
32	Borzytuchom	S.W. Alexandrowicz and Tchórzewska (1981)
33	Jezioro Jasień	Florek *et al.* (1999)
34	Kozin	
35	Zawiaty	
36	Orle	S.W. Alexandrowicz (1988, 1999b)
37	Dolina Wierzycy	Błaszkiewicz and Krzymińska (1992)
38	Nowe Polaszki	S.W. Alexandrowicz (1989)
39	Sulęczyno	S.W. Alexandrowicz, Tchórzewska (1981)
40	Siwiałka	S.W. Alexandrowicz (1989)
41	Łubiana	S.W. Alexandrowicz, Tchórzewska (1981)
42	Fordon	Skompski (1961)
43	Lubicz	Urbański (1952)
44	Malinowo	S.W. Alexandrowicz (1989)
45	Florczaki	
46	Żuchowo	Urbański (1957)
47	Kurzętnik	Brodniewicz (1966)
48	Woryty	Dąbrowski ed. (1981); W.P. Alexandrowicz (1999)
49	Tłokowo	W.P. Alexandrowicz (1999)
50	Bezławki	Świerczyński (1958)
51	Szestno	Skompski (1996)
52	Rudkowo	S.W. Alexandrowicz (1989)
53	Sołdany	
54	Kruklin	Stasiak (1963); Czepiec (1997)
55	Kulwasy	Żurek and Dzięczkowski (1971)
56	Jezioro Głębokie	W.P. Alexandrowicz (1999)
57	Jezioro Wigry	W.P. Alexandrowicz (2000, 2009)
58	Jezioro Gajlik	W.P. Alexandrowicz and Żurek (2010)
59	Kurowo	S.W. Alexandrowicz and Żurek (2005)
60	Zaczopki	W.P. Alexandrowicz and Kusznerczuk (2012)
61	Woroblin	
62	Radzików	Dobrowolski et al. (2012)
63	Olszewickie Błoto	S.W. Alexandrowicz (1983b)
64	Cisowe	S.W. Alexandrowicz and Żurek (1998)
65	Zamość	
66	Głowina	Brykczyński and Skompski (1979)
67	Osłonki	S.W. Alexandrowicz (2005, 2008)
68	Zabór	
69	Pomorsko	S.W. Alexandrowicz (1980); S.W. Alexandrowicz and Nowaczyk (1982)
70	Szumiąca	S.W. Alexandrowicz (1980)
71	Zacisze	
72	Kiełkowo	S.W. Alexandrowicz and Żurek (1991)
73	Niepruszewo-Cieśle	Apolinarska and Ciszewska (2006)
74	Bogdanowo	Skompski (1994)
75	Miętkowo	Kasprzak and Berger (1978)
76	Oz Budzyński	Dzięczkowski (1982)
77	Smuszewo	
78	Jezioro Bnin	Wojciechowski (1999, 2000)
79	Jezioro Jeziory Wielkie	
80	Jezioro Kurnickie	Wojciechowski (1999, 2000)
81	Jezioro Raczyńskie	
82	Imiołki	Apolinarska and Ciszewska (2006)
83	Rybitwy	
84	Jóźwin	Ciszewska (1996)
85	Krucz	Dembińska (1924)
86	Chodzież	
87	Strzelce	
88	Byszkowice	
89	Szarlej	
90	Bytyń	
91	Bożejowice	Makohonienko et al. (1998)

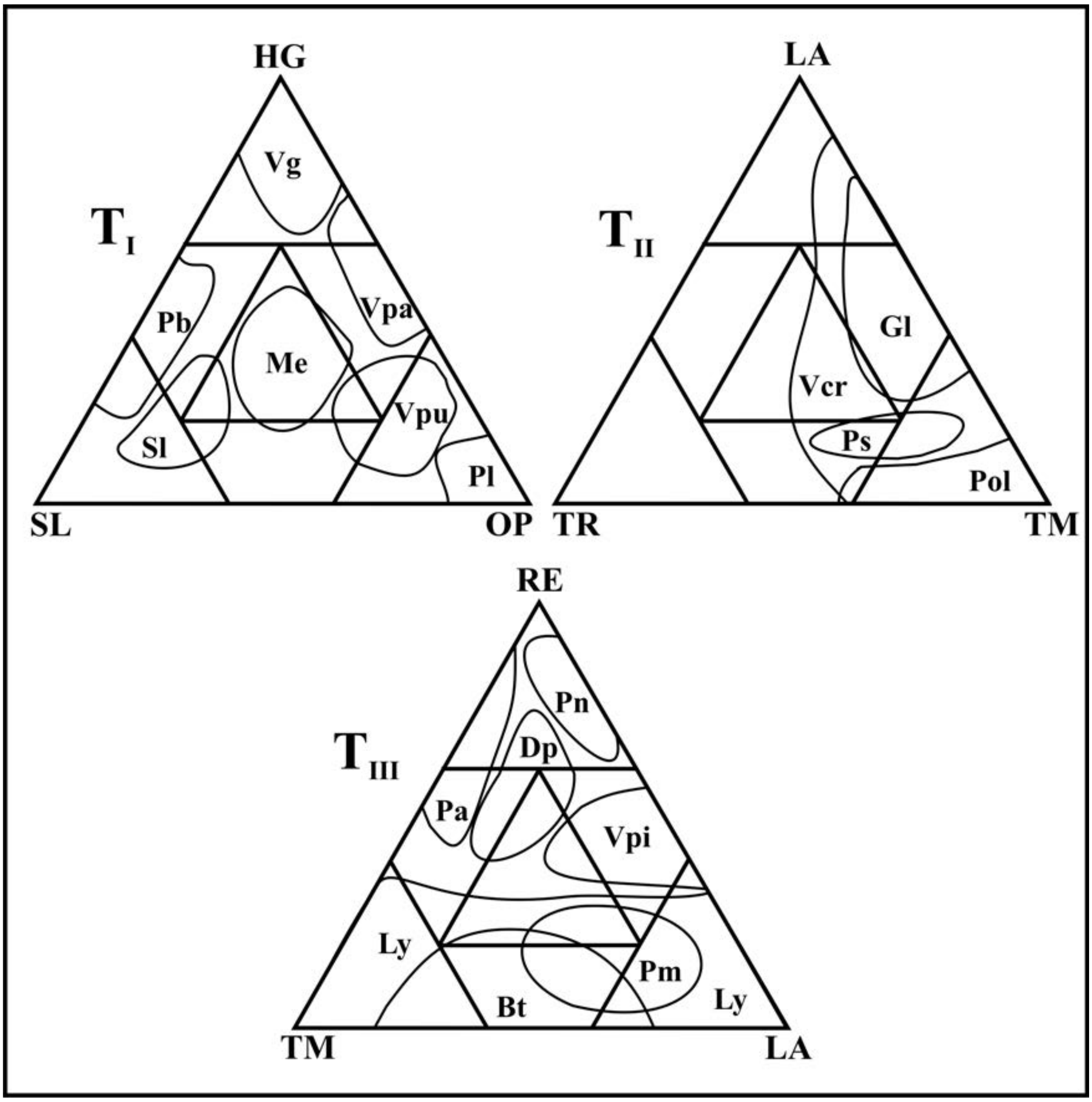

Fig. 2. Ecological structure of molluscan assemblages. T_I . Terrestrial habitats: SL – shady environments, OP – open environments, HG – moist environments: T_{II}. Temporary bodies of water: TR – terrestrial environments, TM – temporary bodies of water, LA – permanent bodies of water, T_{III}. Permanent bodies of water (lakes): TM – temporary bodies of water, LA – permanent bodies of water (lakes), RE – flowing water; explanations of symbols mollusc assemblages in text.

were used for this review of bivalves (Piechocki and Dyduch-Falniowska, 1993), aquatic (Piechocki, 1979) and terrestrial snails (Wiktor, 2004). The species were classified into ecological groups defined and described in detail by Lozek (1964), S. W. Alexandrowicz (1987), and S. W. Alexandrowicz and W. P. Alexandrowicz (2011). The last of the cited papers gave also the basic principles for grouping species and defining assemblages. Stratigraphic setting of particular assemblages was determined on the basis of their location in the sections, results of other published studies and analyses (palynological, diatomological, and radiocarbon dating) as well as stratigraphic characteristics of individual taxa of molluscs (Lozek, 1964; S. W. Alexandrowicz, 1987; W. P. Alexandrowicz, 2004). Index species for particular assemblages represent either the most typical forms (characteristic of certain types of habitats or certain climatic phases) or the taxa occurring in the highest numbers. This method for distinguishing the assemblages was described by W. P. Alexandrowicz (2004) and S. W. Alexandrowicz and W. P. Alexandrowicz (2011).

RESULTS

Owing to the abundant material it has been possible to distinguish faunistic assemblages. Their structure and composition closely match the conditions under which the deposition of sediments filling the palaeolakes occurred. It should, nevertheless, be stressed that the malacological associations defined below can be much diversified. This diversification is caused by specific regional conditions as well as by various local factors. The assemblages of molluscs identified in Late Glacial and Holocene lake carbonate sediments can be allocated to one of three groups: assemblages with predominant terrestrial species, assemblages with predomi-

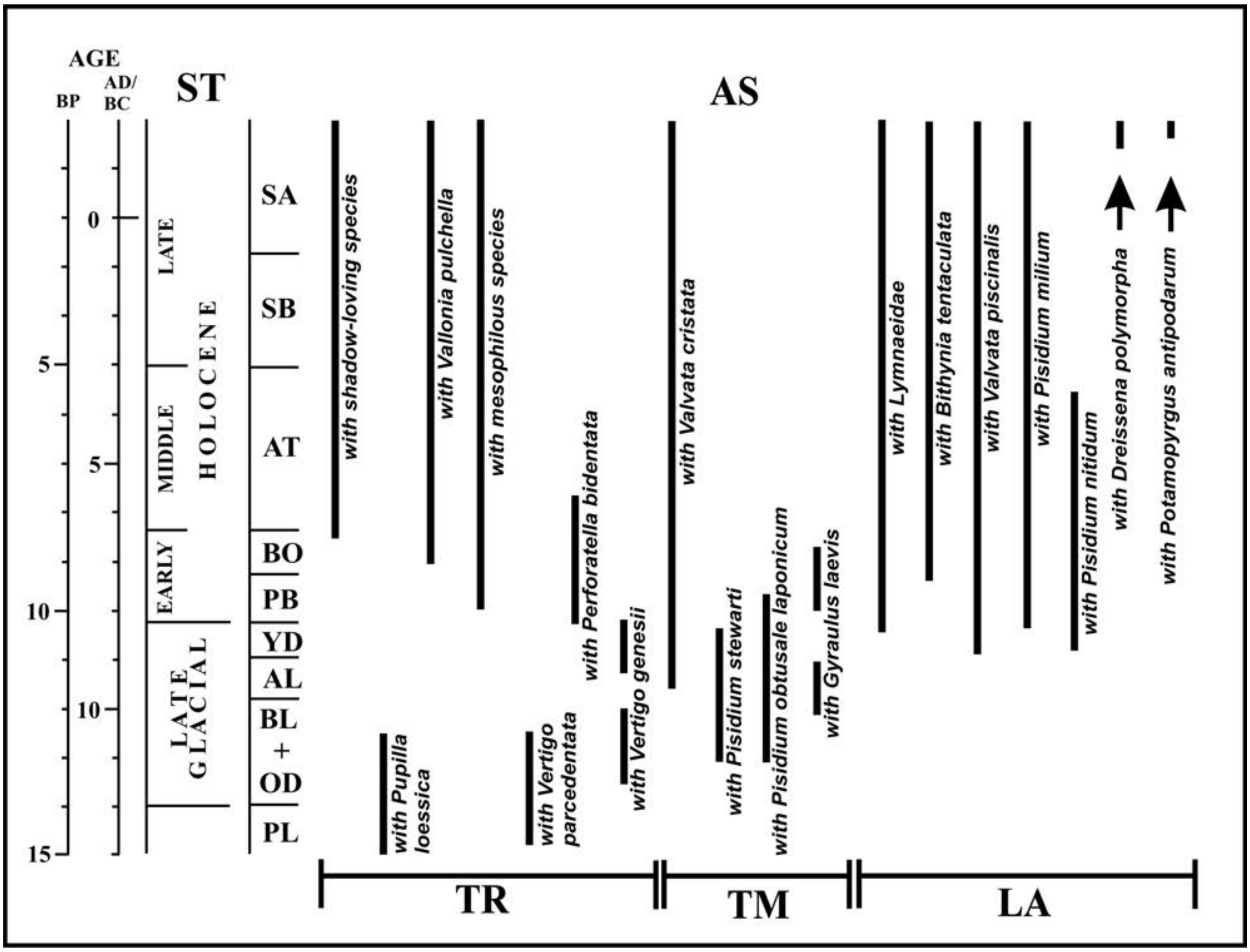

Fig. 3. Stratigraphic range of molluscan assemblages from calcareous lake sediments. ST. stratigraphy: PL – Pleniglacial, BL+OD – Older Dryas and Brlling AL – Alleröd, YD – Younger Dryas, PB – Preboreal Phase, BO – Boreal Phase, AT – Atlantic Phase, SB – Subboreal Phase, SA – Subatlantic Phase (subdivision of Holocene based on Starkel (1977)); AS. molluscan assemblages, TR – terrestrial habitats, TM – temporary bodies of water, LA – permanent bodies of water (lakes).

nant species typical of temporary or overgrowing water bodies, and assemblages with predominant species typical of permanent, open water bodies.

Assemblages with predominant terrestrial species (TR)

They are characterised by great diversity in both structure and composition. In the fillings of palaeolakes these assemblages are of little importance. They appear rarely and were recorded only in some sites. Usually, they occur in the bottom or at the top of sequences, indicating the preliminary or final phases of lake evolution.

The assemblage with shade-loving species (Sl) is characterised by great species diversity. The dominant group is composed of shade-loving forms, among them both forest taxa: *Discus ruderatus* (Fér.), *Cochlodina laminata* (Mont.), and snails preferring slightly more open habitats (open forests, brush zones) – *Cepaea hortensis* (Müll.), *Bradybaena fruticum* (Müll.). A proportion of forms of shaded habitats usually reaches up to 50%. The supplementing elements include taxa with wide ecological tolerance: *Cochlicopa lubrica* (Müll.), *Euconulus fulvus* (Müll.). Other ecological groups usually occur in minor proportions (Fig. $2T_I$). The mentioned association has been found in few sites only and occurs within the sediments above the lake sequence, thus indicating a final phase of filling of lake basins. This association can be correlated with the period from a decline of Boreal Phase untill the present (Fig. 3).

The assemblage with *Pupilla loessica* (Pl) is a fauna of very poor species composition. The nominal taxon, *Pupilla muscorum* (L.) are accompanied by *Vallonia tenuilabris* (Brown) and occasionally, by the oligothermic bivalve species of *Pisidium hibernicum* (West.). Such faunas are typical for a very cold glacial climate and habitats of a polar steppe type with many small and shallow water bodies (Fig. $2T_I$). Similar malacocenoses are commonly recorded in loess formations widespread throughout Central Europe (S. W. Alexandrowicz, 1995a; W. P. Alexandrowicz *et al.*, 2002). In northern Poland, this assemblage was found at Kurzętnik (Brodniewicz, 1966; W. P. Alexandrowicz, 1999, 2007), and in sediments underlying lake formations only. The association with *Pupilla loessica* represents a declining part of Pleniglacial and the earliest part of Late Glacial (Fig. 3).

The assemblage with *Vallonia pulchella* (Vpu) is marked by a predominant proportion of snails of open grassland habitats with variable moisture contents: *Vallonia pulchella* (Müll.), *Vallonia costata* (Müll.), and *Pupilla muscorum* (L.) (Fig. $2T_I$). They are supplemented by mesophilous taxa: *Cochlicopa lubrica* (Müll.), *Euconulus fulvus* (Müll.), and hygrophilous taxa: *Succinea putris* (L.), *Carychium minimum* (Müll.). At some sites, an essential component of the aforementioned association is formed by aquatic molluscs living in small and temporarily disappearing water bodies: *Planorbis planorbis* (L.), *Galba truncatula* (Müll.). The shade-loving species are practically absent. At many sites, the fauna with *Vallonia pulchella* appears at the top of lake deposits, indicating the phases of disappearance of water bodies and their transformation into moist grasslands. This malacocoenosis is characteristic for mid-and late Holocene (Fig. 3).

The assemblage with mesophilous species (Me) is marked by presence of all ecological groups, although the forest and brush species, and aquatic forms are of secondary importance (Fig. $2T_I$). The most important, however, are mesophilous forms: *Cochlicopa lubrica* (Müll.), *Euconulus fulvus* (Müll.), *Nesovitrea hammonis* (Ström), and *Vertigo angustior* (Jeffr.). These are supplemented by taxa of open: *Vallonia pulchella* (Müll.), *Vallonia costata* (Müll.), and of moist environments: *Succinea putris* (L.). The fauna hereby described represents the phases of disappearance of water bodies and is typical for the whole Holocene, and it occurs particularly often during Boreal and Atlantic Phases of the Holocene (Fig. 3).

The assemblage with *Vertigo parcedentata* (Vpa) is a very rare malacocoenosis, marked by presence of oligothermic hygrophilous species: nominal taxon, *Vertigo genesii* (Gredl.), and mesophilous species: *Columella columella* (G. Mart.). Also present are aquatic species with wide thermal tolerance – *Gyraulus laevis* (Ald.) (Fig. $2T_I$). The taxa of open and shaded environments are absent. This fauna represents the tundra with moist substrate, very cold, polar climate and is correlated with the Pleniglacial and early Late Glacial (Fig. 3).

The assemblage with *Perforatella bidentata* (Pb) is a malacocoenosis poor in terms of species composition, marked by predominance of nominal species. *Perforatella bidentata* (Gmel.) is a shade-loving taxon, inhabiting forests of alder swamp type, growing on waterlogged sites (Fig. $2T_I$). Besides the nominal species, hygrophilous forms: *Succinea putris* (L.), *Zonitoides nitidus* (Müll.), and aquatic molluscs living in temporary water bodies: *Galba truncatula* (Müll.), *Anisus leucostomus* (Mill.) are also important. Remaining ecological groups are represented sporadically only. The assemblage with *Perforatella bidentata* is typical for early Holocene, and particularly for Boreal Phase (Fig. 3). This association developed most often on shores of major lakes during low water level periods, in sediments that form inserts in gyttja and lacustrine chalk.

The assemblage with *Vertigo genesii* (Vg) is common and, at the same time, one of the most characteristic. The species preferring moist, sometimes waterlogged biotopes, developing under cold continental climate: *Vertigo genesii* (Gredl.), *Vertigo geyeri* (Lindh.), *Columella columella* (G. Mart.) and *Vertigo parcedentata* (Braun.) are of primary importance (Fig. $2T_I$). The second essential component includes euryecological mesophilous forms: *Euconulus fulvus* (Müll.) and *Nesovitrea hammonis* (Ström). The assemblage can be supplemented by oligothermic taxa characteristic for shaded habitats: *Semilimax kotulae* (West.) and *Arianta arbustorum* (L.). Occurrence of aquatic molluscs such as: *Gyraulus laevis* (Ald.), *Pisidium obtusale lapponicum* (Cless.) and *Galba truncatula* (Müll.) indicates presence of small, much overgrown or temporary water bodies. The malacocoenosis with *Vertigo genesii* is indicative of cold climate and domination of moist, usually open habitats of tundra type, and is characteristic for Late Glacial, and particularly the Younger Dryas. The upper limit of its occurrence is marked by the phase of rapid warming, manifested in the Preboreal Phase of the Holocene (Fig. 3).

The associations of similar compositions were described in many sections of genetically diverse sediments throughout Europe (e.g. Lozek, 1964; S. W. Alexandrowicz, 1987; Limondin-Lozouet, 1992; Krolopp and Sümegi, 1993; S. W. Alexandrowicz and W. P. Alexandrowicz, 1995; W. P. Alexandrowicz, 1997, 1999, 2004).

Assemblages with predominant species typical for temporary or overgrowing water bodies (TM)

The assemblage with *Valvata cristata* (Vcr) is a rich and diversified malacocoenosis in which two groups of aquatic molluscs predominate. The first, and usually more numerous group consists of species that are typical for shallow, small and much overgrown water bodies: *Valvata cristata* (Müll.), *Valvata macrostoma* (Mörch), *Acroloxus lacustris* (L.), and other species. The second group includes forms characteristic for temporarily disappearing water bodies: *Galba truncatula* (Müll.) and *Anisus leucostomus* (Mill.). There are often also euryecological aquatic molluscs: *Pisidium casertanum* (Poli.), *Radix baltica* (L.), and even rheophilous taxa as *Pisidium amnicum* (Müll.). The admixture of terrestrial species, chiefly hygrophilous, is usually fairly significant. More open biotopes are indicated by occurrence of *Succinea putris* (L.) and *Zonitoides nitidus* (Müll.) while in more shaded habitats, mesophilous species are common: *Vertigo angustior* (Jeffr.) and *Vertigo substriata* (Jeffr.) along with forms typical of waterlogged woods as *Perforatella bidentata* (Gmel.) (Fig. $2T_{II}$). The presented malacocoenosis is typical for a biotope with a small, shallow water body, gradually filled with sediments. The characteristic feature of such small lake is an abundant development of vegetation, composed mostly of immersed plants. The composition of terrestrial fauna accompanying the aquatic species depends closely on features of the environment surrounding the water body. The malacocoenosis is composed of species with great thermal tolerance and can appear in various climatic stages of the Holocene, and even in the Late Glacial sediments (Fig. 3).

The assemblage with *Pisidium stewarti* (Pst) is indicated by dominance of bivalves. Along with the nominal species, there are also: *Pisidium lilljeborgii* (Cless.), *Pisidium obtusale lapponicum* (Cless.), and sometimes *Pisidium hibernicum* (West.). Snails are represented by oligothermic aquatic forms as *Gyraulus laevis* (Ald.) as well as by hygrophilous species: *Vertigo genesii* (Gredl.) and *Vertigo geyeri* (Lindh.).

This fauna developed in shallow and intensively overgrown, permanent lakes (Fig. $2T_{II}$). It is characteristic of cold climate andcorresponds to the Late Glacial (Fig. 3).

The assemblage with *Pisidium obtusale lapponicum* (Pol) is a malacocoenosis poor in species composition, consisting chiefly of aquatic species, among which the forms living in small, very shallow, intensively overgrown and temporarily disappearing water bodies, typical for a cold climate. Apart from the nominal taxon, there are also oligothermic forms: *Pisidium lilljeborgii* (Cless.) and *Pisidium stewarti* (Pat.) as well as species of wide thermal tolerance: *Galba truncatula* (Müll.) and *Radix baltica* (L.). Terrestrial species are few and they are most often represented by hygrophilous and oligothermic snails as *Vertigo genesii* (Gredl.) (Fig. $2T_{II}$). This malacocoenosis is typical of Late Glacial, particularly of the Younger Dryas. It also occurs rarely at the beginning of the Holocene. It does not appear in its ypunger part, starting from the Boreal Phase (Fig. 3).

The assemblage with *Gyraulus laevis* (Gl) is characterised for its abundant occurrence of oligothermic aquatic snails. Apart from the most characteristic nominal taxon, there are also *Pisidium obtusale lapponicum* (Cless.) as well as other species of wide thermal tolerance such as: *Radix balthica* (L.), *Galba truncatula* (Müll.) and others. The terrestrial fauna with prevalence of oligothermic species: *Vertigo genesii* (Gredl.), *Vertigo geyeri* (Lindh.) and mesophilous species usually appears as admixture, although even up to 40% (Fig. $2T_{II}$). This assemblage is characteristic for small, shallow but not drying lakes of a cold climate. The assemblage with *Gyraulus laevis* is characteristic for warmer phases of the Late Glacial or the beginning of the Holocene. In the upper part of the Holocene, the nominal species occurs extraordinarily rarely (Fig. 3).

Assemblages with predominant of species typical for permanent open water bodies (LA)

The assemblage with Lymneaidae (Ly) is a rich and diversified malacocoenosis, consisting chiefly of aquatic species of wide ecological tolerance, inhabiting permanent water bodies: *Radix baltica* (L.), *Stagnicola turricula* (Held), *Stagnicola palustris* (Müll.), *Pisidium casertanum* (Poli.), and many other species. Forms typical of small water bodies: *Acroloxus lacustris* (L.), *Gyraulus albus* (Müll.), and sometimes even forms typical for temporarily drying zones: *Galba truncatula* (Müll.) appear as admixture. Terrestrial species are either absent or appear only as single shells (Fig. $2T_{III}$). The composition and structure of this association are very variable and depend closely on nature of the water body. The assemblage with Lymnaeidae develops during the whole Holocene, both in small, shallow and intensively overgrown lakes and in larger lakes of different trophism (Fig. 3).

The assemblage with *Bithynia tentaculata* (Bt) is one of the most characteristic and most commonly occurring associations in lake carbonate sediments. In this malacocoenosis, the most important species is *Bithynia tentaculata* (L.) which is sometimes accompanied by numerous forms characteristic for permanent water bodies (Fig. $2T_{III}$). The fauna with *Bithynia tentaculata* is typical for semi-open lakes, partly overgrown with reeds. There are 2 types of it. The first one is characterized by predominance of opercula over shells and is indicative of presence of compact reeds. The second type indicates prevalence of shell over opercula and corresponds to the littoral zone of the lake (Steenberg, 1917; S. W. Alexandrowicz, 1999a). The admixture of terrestrial fauna is usually minor. This assemblage is often found in early and mid-Holocene deposits. It occurs only occasionally in the Late Glacial formations (Fig. 3).

The assemblage with *Valvata piscinalis* (Vpi) has a poor composition indicated by predominance of nominal species, accompanied by euryecological bivalves: *Pisidium casertanum* (Poli.), *Pisidium subtruncatum* (Malm), and snails – *Bithynia tentaculata* (L.) (both shells and opercula). Terrestrial species are practically absent (Fig. $2T_{III}$). This association usually develops in deeper parts of the lakes, on a muddy bottom without rooted vegetation. The fauna with *Valvata piscinalis* occurs both in Late Glacial and Holocene sediments. In the latter case, it is usually more diversified in its species composition (Fig. 3).

The assemblage with *Pisidium milium* (Pm) is predominated by bivalves of the *Sphaeridae* family. Apart from the nominal taxon, the most frequently are: *Pisidium casertanum* (Poli.), *Pisidium subtruncatum* (Malm), and *Sphaerium corneum* (L.) as well as *Pisidium henslowanum* (Shep.) and *Pisidium supinum* (A. Schmidt). Warmer phases are indicated by presence of *Pisidium moitessierianum* (Pal.). Aquatic snails are more rare and are represented by lake forms: *Bithynia tentaculata* (L.) and *Stagnicola turricula* (Held), while terrestrial species are absent (Fig. $2T_{III}$). This assemblage is typical of open lake water bodies where it lives in the zones characterized by poor vegetation, both above the water surface and immersed. The malacocoenosis with *Pisidium milium* occurs exclusively in the Holocene sediments (Fig. 3).

The assemblage with *Pisidium nitidum* (Pn) is indicated by major proportion of bivalves among which a major role is played by *Pisidium nitidum* (Jen.), *Pisidium amnicum* (Müll.), *Pisidium casertanum* (Poli.) and *Pisidium subtruncatum* (Malm). Aquatic snails are rare while the admixture of terrestrial forms does not exceed 20% (Fig. $2T_{III}$). This malacocoenosis is distinct for its large contents of species that require running water. Such fauna develops in lowland rivers with slow current, or in bottom parts of large lakes, in the zones in which the currents occur. The assemblage with *Pisidium nitidum* was found in the sediments allocated to Late Glacial, and to early and mid-Holocene (Fig. 3).

The assemblage with *Dreissena polymorpha* (Dp) is predominated by the nominal species up to 95%. This assemblage occurs in lakes, characteristic for its different nature and trophy. The nominal species is remarkably euryecological, but it prefers particularly to colonise hard surface zones (cobbles, shells of large bivalves as *Unio* or *Anodonta* genera, anthropogenic hydrotechnical structures) where it develops huge populations (Stańczykowska, 1977) (Fig. $2T_{III}$). Presence of *Dreissena polymorpha* (Pall.) in the sediments indicates their young age. This form was introduced accidentally into Poland and has been recorded there since the beginning of the 19th century (W.P. Alexandrowicz and S.W. Alexandrowicz, 2010) (Fig. 3).

The assemblage with *Potamopyrgus antipodarum* (Pa) forms a poor association, predominated by the nominal species, accompanied by other aquatic forms typical for lakes: *Radix baltica* (L.), *Stagnicola turricula* (Held), *Bithynia tentaculata* (L.), as well as species typical for temporarily dried-up zones as *Galba truncatula* (Müll.) (Fig. $2T_{III}$). *Potamopyrgus antipodarum* (Gray) is a young immigrant, recorded in Poland since 1933 (W.P. Alexandrowicz and S.W. Alexandrowicz, 2010) and it is therefore a good age indicator (Fig. 3).

DISCUSSION

The mollusc assemblages develop in definite habitats. Their nature depends on two principal factors. The first one is climate which determines geological processes and living conditions in a regional scale. Within the most recent 15 000 years, two periods, utterly different from the viewpoint of climatic conditions, can be distinguished. The older period covers a termination of the last glaciation i.e. the Late Glacial. It was a cold phase with two warmer fluctuations (Bølling and Alleröd) which were only very weakly indicated in malacological successions of carbonate lake sediments. This period was associated with progressing deglaciation, when massive melting of dead ice blocks led to the emergence of lakes and swamps. The younger period corresponds with the Holocene when several colder stages are occurred, separated by warmer fluctuations. The Holocene is not only represented by developing lakes but, in many cases, also by their overgrowing, shallowing and gradual disappearance (e.g. Starkel, 1977; Ralska-Jasiewiczowa and Starkel, 1988; Ralska-Jasiewiczowa, 1989; Birks and Birks, 1989).

Local conditions are the second principal factor that determines development and variability of malacocoenoses. Great diversity of habitats can result in occurrence of utterly different faunistic assemblages in sediments of the same age. The Late Glacial is associated with occurrence of relatively poor malacoenoses. These are characterised by significant proportion of oligothermic species and forms of wide ecological tolerance as well as with occurrence of high numbers of molluscs living in shallow water bodies, boggy zones and open terrestrial habitats. The faunas of the Holocene are usually more diversified and include also species with high ecological requirements. The taxa associated with large water bodies and shaded terrestrial habitats are also common.

It is possible to distinguish three types of malacological successions in the analysed material, indicating diversification of habitats and stratigraphic sequences of fauna assemblages. These analyses of such sequences were attempted only rarely (S. W. Alexandrowicz, 1983a; W. P. Alexandrowicz, 1997, 2004), although they provide ample grounds for interpretations and reconstructions of palaeoenvironments as well as their changes in time.

Type A is indicated by domination of assemblages with major proportion of terrestrial molluscs. They are rare un lake deposits, but much more often in calcareous tufas in northern Poland (Skompski, 1961; Brykczyński and Skompski, 1979) as well as in the south (W. P. Alexandrowicz, 2004). The sequence starts with a malacocoenosis predominated by oligothermic terrestrial species preferring open habitats (assemblage with *Pupilla loessica*). In the final part of the Late Glacial, the hygrophilous assemblages (chiefly the fauna with *Vertigo genesii*) became increasingly important as well as associations typical for small, shallow and densely overgrown water bodies (assemblage with *Pisidium stewarti* and with *Pisidium obtusale lapponicum*). Starting from the early Holocene, the proportion of aquatic and swamp taxa declines gradually and shadow-loving, open-country and mesophilous snails take over (Fig. 4).

The aforementioned sequence is a record of evolution of small water bodies which emerged at the end of the Late Glacial as an effect of melting of small dead ice blocks. Small and shallow lakes were rapidly filled with sediments and transformed into swamps. Such transformation took place during the Younger Dryas or during the early Holocene. From the beginning of the Atlantic Phase, progressive drying and replacement of moist swampy habitats by drier grassland and/or forest habitats occurred (Fig. 4).

Type B is the most frequent one of the malacofauna assemblage in carbonate lake sediments (W.P. Alexandrowicz, 1999, 2007). This sequence begins with a phase predominated by open terrestrial habitats of tundra type. Characteristic features of this interval include occurrence of oligothermic assemblages with *Pupilla loessica* (on drier sites) or with *Vertigo parcedentata* (moist and waterlogged biotopes). In younger Late Glacial, a phase of peat bog development is commonly observed. Presence of characteristic malacocoenosis with *Vertigo genesii* is linked to this period. In waterlogged areas, there were small, shallow and much overgrown melt-out lakes, inhabited by associations with *Pisidium stewarti* and *Pisidium obtusale lapponicum*. Progressive melting of large dead ice blocks during the Younger Dryas and at the beginning of the Holocene led to transformation of these habitats into major lakes. This stage is associated with occurrence of rich assemblages of aquatic molluscs, particularly with *Bithynia tentaculata*. It is also a stage of intensive accumulation of carbonate sediments, a thickness of which may even exceed 10 m. Lacustrine chalk and calcareous gyttja gradually filled lake basins, leading to their disappearance. The final stage of filling of the lakes resulted in their transformation into peat bogs. This is confirmed by presence of peat layers overlying the carbonate sediments. The molluscan communities show also evident changes. The assemblages with prevalence of species typical of lakes are replaced by associations dominated by taxa of shallow and intensively overgrown, sometimes even episodic water bodies (assemblage with *Valvata cristata*). In the late Holocene, these waterlogged zones were transformed into terrestrial habitats, either open (assemblage with *Vallonia pulchella*) or shaded (assemblage with shadow-loving species) (Fig. 4).

Type C succession is characteristic for large lakes. These water bodies developed from extensive cave-in lakes, resulting from melting dead ice blocks and formed as late as in the Late Glacial. This stage is associated with occurrence of assemblages with minor proportion of terrestrial species e.g. fauna with *Valvata piscinalis*. A domination of aquatic molluscs maintains throughout the whole Holocene. The changes of water level in lakes (Ralska-Jasiewiczowa and Starkel, 1988; Wojciechowski, 1999, 2000) were marked by periodic occurrence of assemblages with greater proportions of taxa typical of shallow water bodies (assemblage with *Valvata cristata*) or even waterlogged terrestrial habitats (assem-

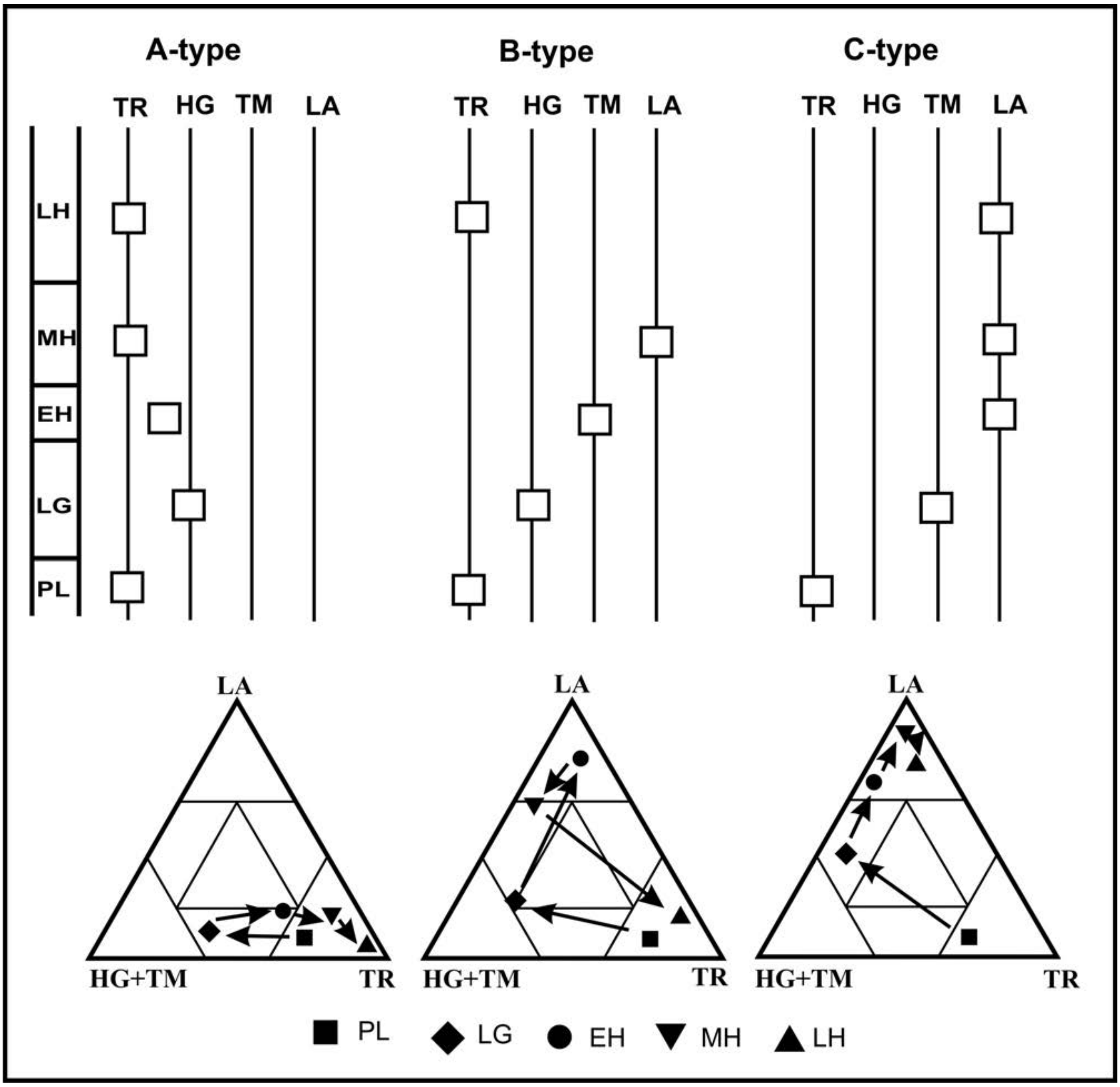

Fig. 4. Successions of molluscan assemblages from lake sediments in North Poland. A-type, B-type, C-type – successions of assemblages described in text: PL – Pleniglacial, LG – Late Glacial, EH – Early Holocene, MH – Middle Holocene, LH – Late Holocene, TR – terrestrial environments, HG – moist environments, TM – temporary bodies of water, LA – permanent bodies of water (lakes).

blage with *Perforatella bidentata*). In the top part of the sequence of lake sediments, the assemblages with *Potamopyrgus antipodarum* and with *Dreissena polymorpha* occur and indicate a human impact (Fig. 4).

CONCLUSIONS

On the basis of the analysis of features and sequences pertaining to molluscan assemblages occurring in lacustrine chalk and calcarous gyttja, it was possible to compile the scheme of evolution of lake water bodies. The oldest molluscan assemblages document the pre-lacustrine terrestrial phase, corresponding to the end of Pleniglacial, and with early Late Glacial. The malacoenoses indicate presence of open habitats with varying moisture levels, from dry Arctic steppe-like habitats to moist and waterlogged tundra biotopes. The first stage of lake development is connected with a warming of the Alleröd Interphase. Massive melting of dead ice blocks led to emergence of numerous melt-out lakes (e.g. W. P. Alexandrowicz, 1999, 2007; Wojciechowski, 1999, 2000). Thus extensive but shallow and intensively overgrowing water bodies were inhabited by relatively poor molluscan assemblages with predominant oligothermic species. During the Younger Dryas, many of these water bodies were completely filled with sediments and transformed into peat bogs. A characteristic assemblage with *Vertigo genesii* regarded as indicator of the aforementioned phase is associated with these habitats (Lozek, 1964; S. W. Alexandrowicz, 1987; Limondin-Lozouet, 1992; Krolopp and Sümegi, 1993; S. W. Alexandrowicz and W. P. Alexandrowicz, 1995; W. P.

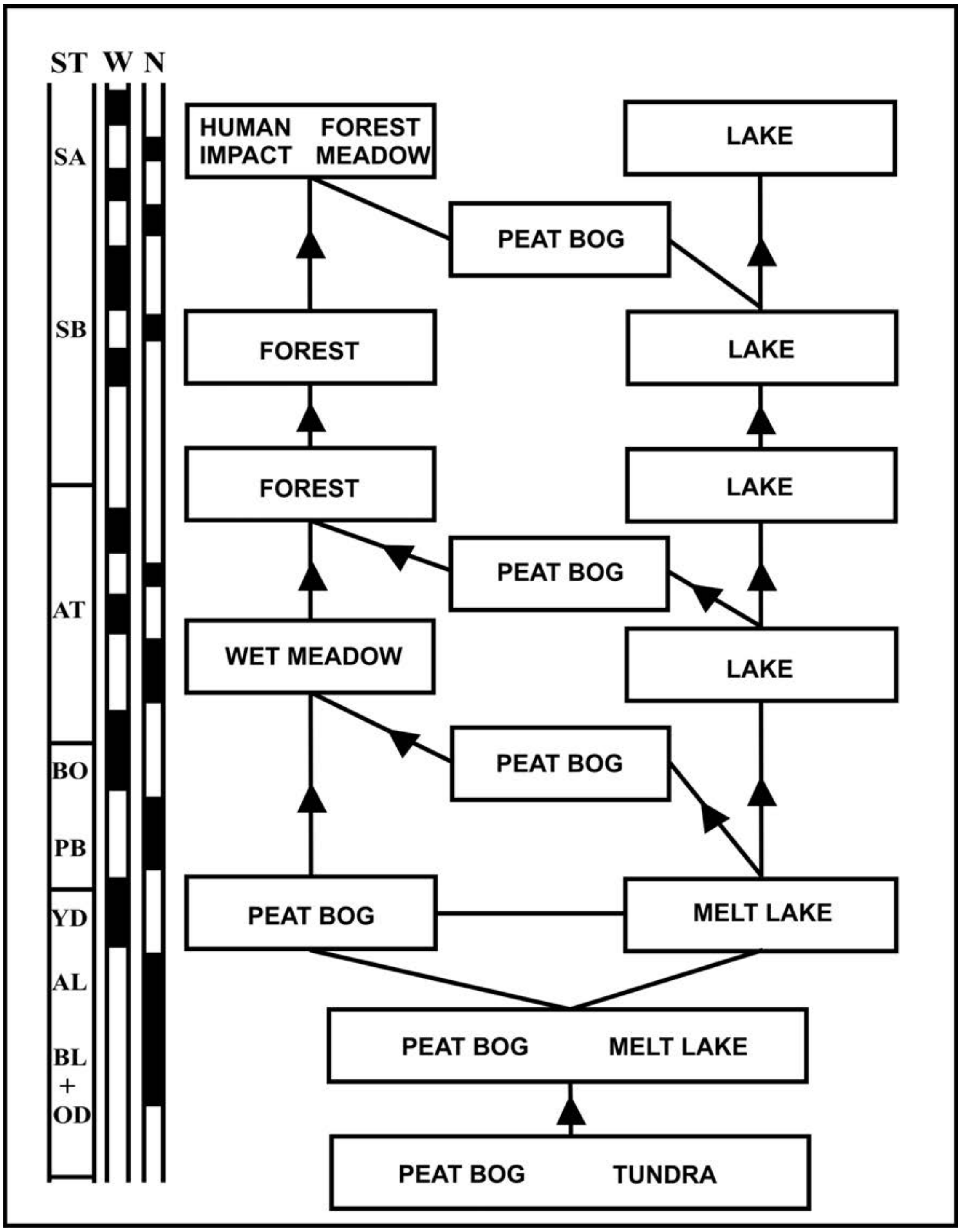

Fig. 5. Fig. 5. Late Glacial and Holocene environmental changes in North Poland in the light of malacological analysis of calcareous lake sediments. ST. stratigraphy: BL+OD – Older Dryas and Brlling AL – Alleröd, YD – Younger Dryas, PB – Preboreal Phase, BO – Boreal Phase, AT – Atlantic Phase, SB – Subboreal Phase, SA – Subatlantic Phase (subdivision of Holocene based on Starkel (1977)); W – high-level water periods (after: Wojciechowski, 1999, 2000), N – low-level water (after: Wojciechowski, 1999, 2000).

Alexandrowicz, 1997, 1999, 2004). On the other hand, however, the declining period of the Late Glacial was indicated by rising water levels in lakes. This phenomenon, observed in almost entire northern Poland (Wojciechowski, 1999, 2000) can be connected with gradually moister climate. Owing to that, many melt-out lakes were transformed into larger and deeper lakes, in which carbonate deposition was initiated. A beginning of the Holocene was indicated by rapid warming that determined a subsequent stage of lake water bodies. Decreasing precipitation resulted in a drop of water level in lakes (Ralska-Jasiewiczowa and Starkel, 1988; Wojciechowski, 1999, 2000). This fact, in combination with gradual fillings of lake basins with sediments resulted in disappearance of many shallow lakes and in peat bogs emerging in their places. During mid- and late Holocene these peat bogs were transformed into grassland and forest biotopes. The aforementioned drop of water level were much less pronounced in large lakes, in which deposition of lacustrine chalk and calcareous gyttja with rich and diverse molluscan assemblages has been continued throughout early and mid-Holocene. During late Holocene, a remarkable slowing down and in many cases, disappearance of carbonate sedimentation occurred. Climate changes reflected in changing water levels in lakes are also common during this period (Ralska-Jasiewiczowa and Starkel, 1988; Wojciechowski, 1999, 2000). During the last one hundred years, human impact has become more and more noticeable in the environment. It is marked in malacocoenoses n lake sediments either by impoverishment of species composition resulting from progressive eutrophication or by occurrence of expansive species alien to Polish fauna that indicate anthropogenic migrations (Fig. 5).

Changes in molluscan assemblages enable distinguishing of several episodes of peat bog development and disappearance of lake water bodies. These occurred in the declining part of the Younger Dryas, beginning of the Atlantic Phase and in the Subatlantic Phase (Fig. 5). These episodes evidently coincide with phases of lower water levels in lakes (e.g. Starkel, 1977; Ralska-Jasiewiczowa and Starkel, 1988; Wojciechowski, 1999, 2000).

Reconstruction of the evolution of lake water bodies in northern Poland, based on analysis of molluscan assemblages, supplements similar reconstructions and patterns defined under different methods and published in numerous studies, both in Poland (e.g. Goslar *et al.*, 1993; Starkel *et al.*, 1996; Żurek and Pazdur, 1999; Wojciechowski, 1999, 2000) and in northern Europe (e.g. Mania, 1973; Mania and Toepfer, 1973; Sunderlau, 1975; Griffiths *et al.*, 1994; Magny and Ruffaldi, 1995).

Acknowledgments

This study has been sponsored by the AGH University of Science and Technology through the University grant no. 11.11. 140.173.

REFERENCES

Alexandrowicz, S.W. 1980. Molluscan assemblages in lacustrine chalk of Lubusz Land. *Kreda jeziorna i gytie* 2, 24–32 (in Polish with English summary).

Alexandrowicz, S.W., 1983a. Malacofauna of the Holocene calcareous sediments of the Cracow Upland. *Acta Geologica Polonica* 33, 117–158.

Alexandrowicz, S.W., 1983b. Malacologic analysis of the soil profile in the southern strip of swamp in the Kampinos Primeval Forest. In: Wpływ działalności człowieka na środowisko glebowe w Kampinoskim Parku Narodowym. Wydawnictwa SGGW, 215–227 (in Polish with English summary).

Alexandrowicz, S.W., 1987. Malacological analysis in Quaternary research. *Geologia, Kwartalnik AGH* 12, 3–240 (in Polish with English summary).

Alexandrowicz, S.W., 1988. Molluscan assemblages of the lake sediments in the ancient melt-lake Orle. *Folia Quaternaria* 58, 59–67.

Alexandrowicz, S.W., 1989. Molluscs associations in Late Quaternary lake deposits of northern Poland. *Studia i Materiały Oceanologiczne* 56, 267–276 (in Polish with English summary).

Alexandrowicz, S.W., 1991. The malacofauna of the Holocene lacustrine sediments of Dąbki near Darłowo. *Przegląd Archeologiczny* 28, 19–24.

Alexandrowicz S.W., 1995a. Malacofauna of the Vistulian loess in Cracow Region (S Poland). *Annales Universitatis Mariae Curie-Skłodowska* B, 50, 1–28.

Alexandrowicz, S.W., 1995b. Malacofauna of the Holocene sediments in Grabowo near Koszalin (Pomerania, North Poland). *Questiones Geographicae* 4, 13–20.

Alexandrowicz, S.W., 1998. Radiocarbon-dated assemblages of molluscs in the Polish Costal Zone near Łeba and Ustka. Field symposium on glacial geology at the Baltic See Coast in Northern Poland. Excursion guide, 54–56.

Alexandrowicz, S.W., 1999a. *Bithynia tentaculata* (Linnaeus, 1758) as an indicator of age and deposition environment of Quaternary sediments. *Folia Malacologica* 7, 79–88.

Alexandrowicz, S.W., 1999b. Malacofauna and stratigraphy of Late Vistulian and Holocene deposits in the Southern Baltic coastal zone. *Quaternary Studies in Poland*, special issue, 37–50.

Alexandrowicz, S.W., 2005. Molluscs assemblages of Late Glacial and Holocene sediments in Southern Kujawy. *Prace Komisji Paleogeografii Czwartorzędu PAU* 3, 147–152 (in Polish with English summary).

Alexandrowicz, S.W., 2008. Malacofauna of Late Quaternary lacustrine deposits at Osłonki (Kujawy, Central Poalnd. *Folia Quaternaria* 78, 51–69.

Alexandrowicz, S.W., Alexandrowicz, W.P., 1995. Molluscan fauna of the Upper Vistulian and Early Holocene sediments of South Poland. *Biuletyn Peryglacjalny* 34, 5–19.

Alexandrowicz, S.W., Alexandrowicz, W.P., 2010. Molluscs of the Eemian Interglacial in Poland. *Annales Societatis Geologorum Poloniae* 80, 69–87.

Alexandrowicz, S.W., Alexandrowicz, W.P., 2011, Malacological analysis – method of research and interpretations. *Rozprawy Wydziału Przyrodniczego PAU* 3, 5–302 (in Polish).

Alexandrowicz, S.W., Cichosz-Kostecka, A., Florek, E., Florek, W., Orłowski, A., Rączkowski, W., Zachowicz, J., 1989. The evolution of the Słupia River Valley in the Late Vistulian and Holocene. *Geologia, Kwartalnik AGH* 15, 5–218 (in Polish with English summary).

Alexandrowicz, W.P., Florek, W., Zaborowska, K., Zachowicz, J., 1990. The Słupia upper floodplain in the vicinity of Słupsk, Pomerania, Poland. *Quaestiones Geographicae* 11/12, 5–27.

Alexandrowicz, S.W., Nowaczyk, B., 1982. Late Glacial and Holocene lake sediments at Pomorsko near Sulechów. *Questiones Geographicae* 8, 5–17.

Alexandrowicz, S.W., Tchórzewska, D., 1981. Bog lime in Quaternary deposits of the Middle Pomerania. *Geologia, Kwartalnik AGH* 7, 59–71(in Polish with English summary).

Alexandrowicz, S.W., Żurek, S., 1991. Malacofauna od Holocene lacustrine sediments and peat-bogs in the vicinity of Wolsztyn (Western Poland). *Geologia, Kwartalnik AGH* 17, 221–234 (in Polish with English summary).

Alexandrowicz, S.W., Żurek, S., 1998. Holocene lacustrine sediments in the Middle Swamp Strip of the Kampinos Forest. *Geologia, Kwartalnik AGH* 24, 333–351 (in Polish with English summary).

Alexandrowicz, S.W., Żurek, S., 2005. Landscape and peatlands of the Narew National Park. *Chrońmy Przyrodę Ojczystą* 61, 5–18 (in Polish with English summary).

Alexandrowicz, W. P., 1997. Malacofauna of Quaternary deposits and environmental changes of the Podhale Basin during the Late Vistulian and Holocene. *Folia Quaternaria* 68, 7–132 (in Polish with English summary).

Alexandrowicz, W.P., 1999. Evolution of the malacological assemblages in North Poland during the Late Glacial and Early Holocene. *Folia Quaternaria* 70, 39–69.

Alexandrowicz, W.P., 2000. The malacofauna of the Upper Holocene lacustrine sediments of Wigry Lake. *Folia Malacologica* 8, 141–149.

Alexandrowicz, W.P., 2002. Mollusc assemblages of an ancient lake in Różyny near Skowarcz (Żuławy Wiślane, North Poland). *Folia Malacologica* 10, 215–224.

Alexandrowicz, W.P., 2004. Molluscan assemblages of Late Glacial and Holocene calcareous tufa in Southern Poland. *Folia Quaternaria* 75, 3–309.

Alexandrowicz W.P., 2005. Assemblages of molluscs from lacustrine chalk in Skowarcz in Żuławy Wislane. *Prace Komisji Paleogeografii Czwartorzędu PAU* 3, 107–115 (in Polish with English summary).

Alexandrowicz, W.P., 2007. Malacofauna of the Late Glacial and Holocene calcareous lake deposits in northern Poland. *Geologia, Kwartalnik AGH* 33, 395–421(in Polish with English summary).

Alexandrowicz W.P., 2009. Changes of environment of Wigry Lake during Late Glacial and Holocene in the light of molluscan analyses. In: Rutkowski, J., Krzyszkofiak, L., (eds), Jezioro Wigry. Historia jeziora w świetle badań geologicznych i paleoekologicznych. Stowarzyszenie "Człowiek i Przyroda", 227–240 (in Polish with English summary).

Alexandrowicz W.P., Alexandrowicz S.W., 2010. Expansive migrations of molluscs during the historic period. *Biological Invasions in Poland* 1, 23–48.

Alexandrowicz W.P., Boguckyj A., Dmitruk R. & Łanczont M., 2002. Molluscs of loess deposits in the Halyc Prydniestrov'ja region. *Studia Geologica Polonica* 119, 253–290 (in Polish with English summary).

Alexandrowicz, W.P., Kusznerczuk, M., 2012. Evolution of the Bug River Valley during the Holocene in the environs of Janów Podlaski (Eastern Poland) in the light of malacological analysis of oxbow lake deposits. *Folia Malacologica* 20, 295–304.

Alexandrowicz, W.P., Żurek, S. 2010. Malacofauna of Gajlik mire's Lake deposits in the Sejny Lake District (North-Eastern Poland). *Geologia, Kwartalnik AGH* 36, 491–504 (in Polish with English summary).

Apolinarska, K., Ciszewska, M., 2006. Late Glacial and Holocene lacustrine molluscs from Wielkopolska (central Poland) and their environmental significance. *Acta Geologica Polonica* 56, 51–66.

Birks, H.J., Birks, H.H., 1989. Quaternary Palaeoecology. Arnold Ltd. Publications, 1–298, London.

Błaszkiewicz, M., Krzymińska, J., 1992. The late-glacial lake stage in the Wierzyca Valley. *Przegląd Geograficzny* 64, 369–380 (in Polish with English summary).

Brodniewicz I., 1966. Faunal analysis of freshwater intermorainic deposits from Kurzętnik near Nowe Miasto. *Zeszyty Naukowe UMK, Nauki Matematyczno-Przyrodnicze* 14, 17–36 (in Polish with English summary).

Brodniewicz, I., 1979. Faunistic analysis of Late Glacial fresh water deposits from the sea-cliff near Ustka Town (Poland). *Wydawnictwa Uniwersytetu Adama Mickiewicza, Geologia* 9, 3–27 (in Polish with English summary).

Brykczyński, M., Skompski, S., 1979. Holocene molluscan fauna and calcareous sinter from Głowina near Dobrzyń on Vistula. *Kwartalnik Geologiczny* 23, 429–434 (in Polish with English summary).

Ciszewska, M., 1996. Fossil molluscs fauna from the "Józwin 84" site in the Konin coal basin. *Geologos* 1, 176–192 (in Polish with English summary).

Czepiec, I., 1997. Malacofauna and depositional conditions of Lake sediments in Kruklin (NE Poland). *Geologia, Kwartalnik AGH* 23, 121–129 (in Polish with English summary).

Czepiec, I., 1998. Sequences of molluscan assemblages on the background of palynological subdivision of Quaternary deposits in Chojna (NW Poland). *Sprawozdania z Czynności i Posiedzeń PAU* 52, 128–130 (in Polish).

Dąbrowski, J. (ed.)., 1981. Woryty – an archaeological and naturalistic study of the settlement complex of Lusatian Culture. *Polskie Badania Archeologiczne* 20, 1–256 (in Polish with English summary).

Dembińska, M., 1924. La faune malacologique dans la craie lacustre de quelques localites de la Grande Pologne. *Prace Towarzystwa Przyjaciół Nauk* A, 1, 191–205 (in Polish with French summary).

Dobrowolski, R., Pidek, I.A., Alexandrowicz, W.P., Hałas, S., Pazdur, A., Piotrowska, N., Buczek, A., Urban, D., Melke, J., 2012. Interdisciplinary studies of spring mire deposits from Radzików (South Podlasie Lowland, East Poland) and their significance for palaeoenvironmental reconstructions. *Geochronometria* 39, 10–29.

Dzięczkowski, A., 1974. Subfossil molluscs from organic deposits near Czeszewskie Lake by Smuszewo, District Wągrowiec. *Badania Fizjograficzne nad Polską Zachodnią* 27, 113–116 (in Polish with English summary).

Dzięczkowski A., 1982. Subfossil molluscs from organic deposits near Budzyński Esker in Wielkopolski National Park. *Badania Fizjograficzne nad Polską Zachodnią* 33, 147–157 (in Polish with English summary).

Filonowicz, P., Krzymińska, J., 1989. Older Holocene in the Grabowa valley near Koszalin. *Studia i Materiały Oceanograficzne* 56, 331–337(in Polish with English summary).

Florek W., Alexandrowicz S.W. & Pazdur A., 1999. Changes of water level of Jasień Lake during Late Glacial and Holocene. In: Pazdur, A., Bluszcz, A., Stankowski, W., Starkel, L., (eds): Geochronologia górnego czwartorzędu Polski w świetle datowania radiowęglowego i luminescencyjnego, 199–206 (in Polsh).

Freytet, P., Verrecchia, E.P., 2002. Lacustrine and palustrine carbonate petrography: an overview. *Journal of Paleolimnology* 27, 221–237.

Goslar, T., Kuc, T., Ralska-Jasiewiczowa, M., Różański, K., Arnold, M., Bard, E., Van Gees, B., Pazdur, M.F., Szeroczyńska, K., Wicik, B., Więckowski, K., Walanus, A., 1993. High-resolution lacustrine record of the Late Glacial/Holocene transition in Central Europe. *Quaternary Science Review* 12, 295–305.

Griffiths, H.J., Ringwood, V., Evans, J.G., 1994. Weichselian Late-glacial and early Holocene molluscan and ostracod sequences from lake sediments at Stellmoor, north Germany. *Hydrobiologia* 3, 357–380.

Kasprzak, K., Berger, L., 1978. Subfossil molluscs of the Miętkowo profil near Poznań. *Przegląd Zoologiczny* 22, 7–24 (in Polish with English summary).

Keilhack, K., 1888. Die Gastropodenfauna einiger Kalkhaltiger Alluvialbildungen Norddeutschlands. *Jahrbuch der Königlich Preußischen Geologischen Landesanstalt und Bergakademie zu Berlin* 8, 134–149.

Kopczyńska-Lamparska, K., Cieśla, A. & Skompski, S., 1984. Evolution of fossil lake basins of the Late Glacial and Holocene in the cliff near Niechorze (Pomeranian Lakeland, Poland). *Quaternary Studies in Poland* 5, 39–58.

Kowalkowski, A., Berger, L., 1966. Paleomalacological analysis in investigations on development of soils in Holocene. *Folia Quaternaria* 23, 1–17.

Kowalkowski, A., Berger, L., 1971/72. Die Bedeutung der Conchylienfauna für die Spätpleistozäne und Holozäne Sediment- und Bodenstratigraphie. *Bulletin de la Societe des Amis des Sci-*

ences et des Lettres D, 12–13, 215–224.

Krolopp, E., Sümegi, P., 1993. *Vertigo modesta* (Say), *Vertigo geyeri* Lindholm 1925 and *Vertigo genesii* (Gredler 1856) species in Pleistocene formations of Hungary. *Malacological Newsletter* 12, 9–14.

Krzyszkowski, D., Alexandrowicz, S.W., Kuszell, T., Dyrcz, M., Gostkowska, M., Grzegorczyk, B., 1998. Stop 11 – Poddąbie. Stratigraphy and sedimentary environments of the Late Pleistocene deposits. Field symposium on glacial geology at the Baltic See Coast in Northern Poland. Excursion guide, 65–79.

Limondin-Lozouet, N., 1992. Biogeographie Holocene de Vertiginidae (*Mollusca – Gastropoda*) Europeens: relations la derniere deglaciation. *Compte Rendus de Academie Science Paris* 315, 1281–1287.

Lozek, V., 1964. Quartärmollusken der Tschechoslovakei. *Rozpravy Ustredniho Ustavu Geologického* 31, 3–374.

Magny, M., Ruffaldi, P., 1995. Younger Dryas and early Holocene lake-level fluctuations in the Jura mountains, France. *Boreas* 24, 155–172.

Makohonienko, M., Schubert, T., Wojciechowski, A., 1998. Palaecological study of Late Glacial sediments in Bożejowice (Kujawy). Geneza, Litologia i Stratygrafia Utworów Czwartorzędowych. III Seminarium, 71–76 (in Polish).

Mania, D., 1973. Paläoekologie, Faunenentwicklung und Stratigraphie des Eiszetalters im mittleren Elbe-Saalegebiet auf Grund von Molluskengesellschaften. *Geologie, Beiheft* 78–79, 1–175.

Mania, D., Toepfer, V. 1973. Königsaue – Gliederung, Ekologie und mittelpaläolitische Fund des letzten Eiszeit. *Veröffen Landmuseum Halle* 26, 1–164.

Markowski, S., 1980. Structure and properties of peatlands' bottom lake sediments of frequent occurrence in West Pomerania region as a basis for their identification and classification. *Kreda jeziorna i gytie* 2, 45–55 (in Polish with English summary).

Menzel, H., 1911. Die Binnenmollusken als Leitfossilen der deutschen Quartärbildungen. *Wochenschrift, Neue Folge* 10, 1–14.

Nowaczyk B, Alexandrowicz S.W., Hałas S. & Pazdur A., 1999. Development of glacial trough of Małe Głuche and Duże Głuche lakes. In: Pazdur, A., Bluszcz, A., Stankowski, W., Starkel, L., (eds): Geochronologia górnego czwartorzędu Polski w świetle datowania radiowęglowego i luminescencyjnego, 207–213 (in Polish).

Nowaczyk, B., Alexandrowicz, S.W., 2008. Evolution of lakes in the Chojnice region in the light of investigations of Late Glacial and Holocene littoral sediments and mollusk fauna. *Prace Komisji Paleogeografii PAU* 6, 7–17 (in Polish with English summary).

Piechocki, A. 1979., Molluscs (*Mollusca*). Gastropod (*Gastropoda*). *Fauna słodkowodna Polski* 7, 7–187 (in Polish).

Piechocki, A., Dyduch-Falniowska, A., 1993. Molluscs (*Mollusca*). Bivalves (*Bivalvia*). *Fauna słodkowodna Polski* 7a, 7–204 (in Polish).

Ralska-Jasiewiczowa, M., 1989. Environmental changes recorded in lakes and mires of Poland during the last 13 000 years. *Acta Palaeobotanica* 29, 1–120.

Ralska-Jasiewiczowa, M., Starkel, L., 1988. Record of the hydrological changes during the Holocene in the lake, mire, and fluvial deposits of Poland. *Folia Quaternaria* 57, 91–127.

Rzepecki, P., 1983. Classification and main lithological types of lacustrine deposits. *Geologia, Kwartalnik AGH* 9, 73–94 (in Polish with English summary).

Rutkowski, J., Król, K., Krzysztofiak, L., Prosowicz D., 2002. Recent sediments of the Wigry Lake (Bryzgiel Basin). *Limnological Review* 2, 353–362.

Skompski, S., 1961. Quaternary calcareous travertine near Fordon. *Kwartalnik Geologiczny* 5, 478–487 (in Polish with English summary).

Skompski, S., 1994. Quaternary geology near Oborniki, Central Great Poland Lowland, with references to palaeontological data. *Folia Quaternaria* 65, 285–302.

Skompski, S., 1996. Standard assemblages of malacofauna in different Quaternary stratigraphic units. *Prace Państwowego Instytutu Geologicznego* 151, 5–47 (in Polish with English summary).

Stańczykowska, A., 1977. Ecology of *Dreissena polymorpha* (Pall.) (*Bivalvia*) in lakes. *Polskie Archiwum Hydrobiologii* 24, 461–530.

Starkel, L., 1977. Palaeogeography of the Holocene. PWN, 5–362 (in Polish).

Starkel, L., Pazdur, A., Pazdur, M.F., Wicik, B., Więckowski, B., 1996. Lake-level and groundwater-level changes in the Gościąż area, Poland: palaeoclimatic implications. *The Holocene* 6, 213–224.

Stasiak, J., 1963. History of Kruklin Lake as revealet by deposits of its litoral zone. *Prace Geograficzne PAN* 32, 1–96 (in Polish with English summary).

Steenberg, C.M., 1917. Furesöens molluskenfauna. Kongelige Danske Videnskabernes Selskab Skrifter, *Naturvidenske og Mathematisk* 8, 78–200.

Sunderlau, G., 1975. Jungquartäre Ablagerungen in den Semken des Raumes Eisleben-Artern, Bad Frankenhausen. *Hercynit* 12, 228–255.

Świerczyński, K., 1958. The youngest substage locus within Masurian Lakes District. *Przegląd Geograficzny*, 30, 273–281 (in Polish with English summary).

Urbański, J., 1952. Early Post-glacial molluscs in Lubicz on Drwęca. *Z Badań Czwartorzędu* 2, 515–541(in Polish with English summary).

Urbański, J., 1957. Molluscs of Holocene deposits in Żuchów near Kanarków (Dobrzyń Land). *Z Badań Czwartorzędu* 8, 233–262 (in Polish with English summary).

Wiktor A., 2004. Terrestrial snails of Poland, 5–302, Wydawnictwo Mantis, Olsztyn (in Polish).

Wojciechowski, A., 1995. Holocene deposits and molluscan assemblages in Lake Łebsko, Gardno-Łeba Coastal Plain. *Journal of Coastal Research*, special issue 22, 237–243.

Wojciechowski, A., 1999. Late Glacial and Holocene lake-level fluctuations in the Kórnik-Zaniemyśl lakes area, Great Poland Lowland. *Quaternary Studies in Poland* 16, 81–101.

Wojciechowski, A., 2000. Palaeohydrological changes in the central Wielkopolska Lowland during the last 12 000 years on the basis of deposits of the Kórnik-Zaniemyśl lakes Wydawnictwo Naukowe Uniwersytetu Adama Mickiewicza, 5–236 (in Polish with English summary).

Wojciechowski, A., 2011. Stages of the evolution of the South Baltic coast as recorded in the molluscan fauna. *Journal of Coastal Research*, special issue 64, 711–715.

Wojciechoowski, A., 2012. Malacofauna of the Late Glacial freshwater sediments in the Orzechowo cliff. In: Florek, W., (Ed.): Geologia i geomorfologia Pobrzeża południowego Bałtyku 9, 219–229 (in Polish with English summary).

Żurek, S., Dzięczkowski, A., 1971. Tentative reconstruction of evolution of fossil lakes in "Biebrza" peat bog. *Przegląd Geograficzny* 43, 404–425 (in Polish with English summary).

Żurek, S., Pazdur, A., 1999. Records of palaeohydrological changes in peat bogs of Polish Territory. In: Pazdur, A., Bluszcz, A., Stankowski, W., Starkel, L. (Eds): Geochronologia górnego czwartorzędu Polski w świetle datowania radiowęglowego i luminescencyjnego, 215–228 (in Polish).