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Late Glacial and Holocene lacustrine molluscs from Wielkopolska (central Poland) and their environmental significance

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ABSTRACT:

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Late Glacial and Holocene lacustrine molluscs occurring in three sites from the Gniezno and Poznań Lake Districts in central Poland are described. The mollusc fauna present in the sites is composed mainly of aquatic species with an accessory content of terrestrial snails inhabiting damp or very damp, periodically flooded sites. Ecological preferences of species, changes in their composition and frequency together with shell dimensions are used as indicators of palaeoenvironment and palaeoclimate. Infrequent shells present in the Imiołki and Rybitwy sites are small and thin-walled in consequence of the cold climate prevailing in the Late Glacial when the sediments in question were deposited. In the Imiołki site *Pisidium lilljeborgii* CLESSIN, a species indicative of low temperatures, occurs. Deposits in the Niepruszewo-Cieśle site were accumulated through most of the Holocene, thus warmer conditions resulted in considerably more abundant and larger shells with thicker walls.

Key words: Poland, Late Glacial, Holocene, Lacustrine deposits, Molluscs, Palaeoclimate, Palaeoenvironment.

INTRODUCTION

Numerous lakes of glacial origin are present in Poland, in the area that was covered by the last Pleistocene continental ice sheet. Since its retreat the extent and volume of these lakes have decreased significantly, due to infilling with sediments. In addition, many of the small water reservoirs have remained overgrown. Lacustrine deposits constitute a rich source of proxy data for palaeoenvironmental and palaeoclimatic reconstructions, among which mollusc shells are very useful. The composition of subrecent mollusc fauna and its changes enable the recognition of the environmental conditions prevailing in lakes, changes in the water level and/or extent of vegetation, in particular. This is because most species found in the Late Glacial and Holocene deposits are still present in the recent environments. Hence, their ecological and environmental requirements are well known. Aquatic molluscs can also record temperature fluctuations although they are less sensitive to climatic changes than terrestrial species (ALEXANDROWICZ 1987).

The present study describes assemblages of lacustrine molluscs occurring in Late Glacial and Holocene deposits in Wielkopolska (central Poland) that were drilled in the 1980s close to the lakes Lednica and Niepruszewskie (Text-fig. 1). Except for a brief description by MAZUREK (1990), who mentioned the occurrence of molluscs in sediments at Rybitwy and Imiołki, Lake Lednica, the mollusc fauna remained unstudied. The purpose of this study was to recognize the taxonomical

Fig. 1. Location of the investigated sites. Dotted line in the inset shows the maximal extent of the last continental ice sheet in Poland. Triangles indicate location of the investigated sites

composition of fauna as well as its stratigraphical and environmental significance.

Investigation of the mollusc fauna described in the present paper was initiated by Marta CISZEWSKA M.Sc. This research project was interrupted by her premature death in September 1997. Since 2002 investigations have been carried out by Karina APOLINARSKA, who prepared the present paper. The senior author provided also new palaeoenvironmental and palaeoclimatological reconstructions of the fauna.

GEOLOGICAL BACKGROUND AND LOCATION

The Lake Lednica is situated in the southern part of the Gniezno Lake District (Text-figs 1-2). It is a water reservoir filling the southern part of a tunnel valley running between Janowiec and Lednogóra. The relief of the study area was formed during the last Pleistocene glaciation. The recession of the ice sheet of the Poznań Glaciation Phase was interrupted by periods of aggradation (KOZARSKI 1962). The tunnel valley of the Lake Lednica was formed as a result of subglacial erosion about 18 000 BP during the Dzwonowsko-Lednogórska oscillation (KOZARSKI 1962, STANKOWSKI 1989). After the disappearance of the continental ice sheet from the study area, the deepest parts of depressions remained filled with blocks of dead ice (KOZARSKI 1962). The earliest limnic sediments with remnants of periglacial tundra flora, filling numerous lake reservoirs in the area and shallower parts of the present Lake Lednica basin, were deposited two to three thousand years before the Alleröd, i.e. about 15 000 BP (LITT 1988, MAKOHONIENKO & TOBOLSKI 1991, TOBOLSKI 1998). In the

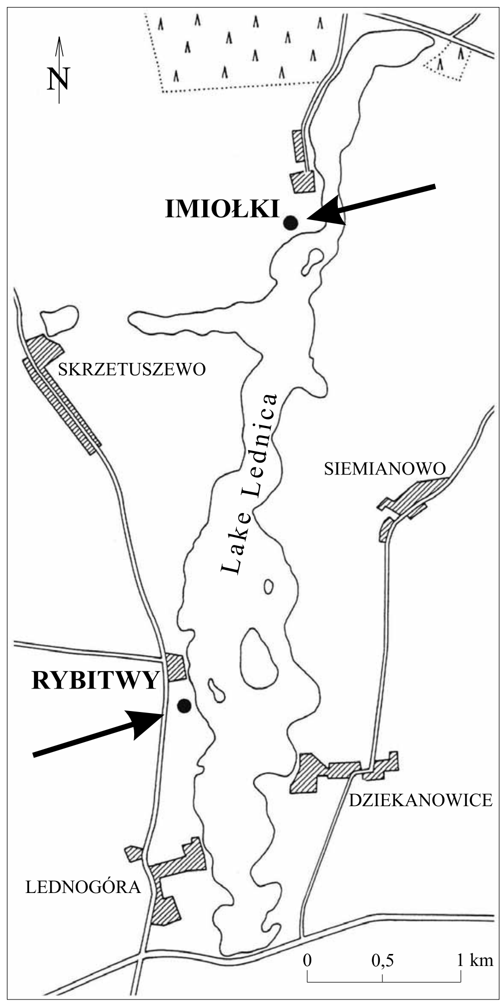

Fig. 2. Topographic map of the Lake Lednica. Arrowed are investigated sites at Imiołki and Rybitwy

deepest parts of the Lake Lednica the oldest lacustrine deposits accumulated at the beginning of the Holocene (TOBOLSKI 2000). This indicates that the deepest parts of the tunnel valley were still filled with dead ice throughout Late Glacial time.

The Imiołki site was drilled next to the northwest shore of the Lake Lednica, about 300 metres south of the village of Imiołki (Text-fig. 2), where an elongated ridge of sandy clays separates the biogenic deposits of the ancient Imiołki reservoir from the present day littoral of the Lake Lednica (GŁUSZAK 1998). In the past, this small reservoir was regarded as a shelf of the Lake Lednica (MAZUREK 1988, 1990, KOLENDOWICZ 1992). The top surface of the biogenic accumulation of the Imiołki reservoir is situated about one metre above the present water surface of the Lake Lednica (TOBOLSKI 1998).

The Rybitwy site is located close to the southwest shore of the Lake Lednica, about 300 metres south of the village of Rybitwy (Text-fig. 2). It is situated on the lower accumulative terrace of the lake (MAZUREK 1990), approximately one metre above the present water surface.

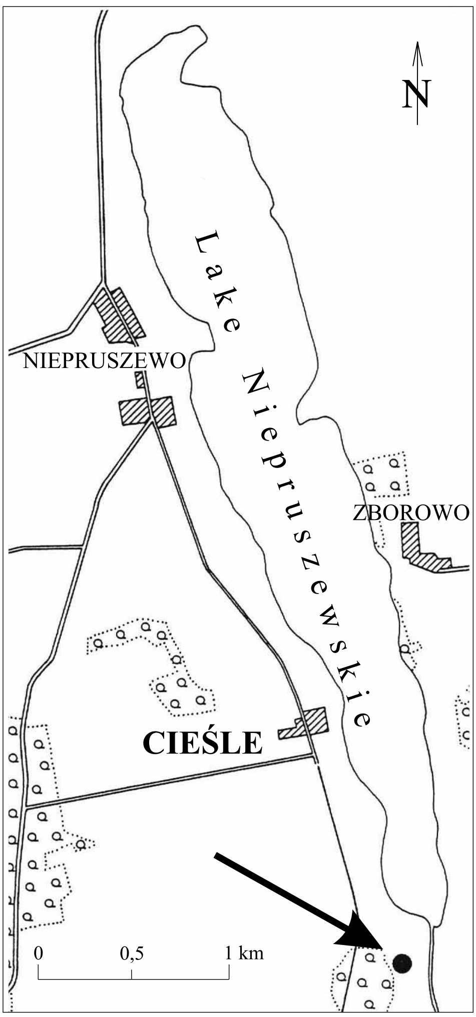

Fig. 3. Topographic map of the Lake Niepruszewskie. Arrowed is investigated site Niepruszewo-Cieśle

The palaeoecology of the Late Glacial sediments of the Lake Lednica at Imiołki was extensively studied by a group of scientists lead by TOBOLSKI (1998). Papers by MAZUREK (1988, 1990), STANKOWSKI (1989) and KOLENDOWICZ (1992) dealt with changes in water level of the Lake Lednica based on lacustrine deposits accumulated on the lake shores.

The Lake Niepruszewskie belongs to the central part of the Poznań Lake District and separates the Opalenica Plain in the west from the Poznań Plain in the east (KONDRACKI 2000). It is a water reservoir filling the northern part of the Niepruszewo-Strykowo tunnel valley formed as a result of subglacial erosion during the Early Leszno Phase and filled with fluvioglacial sands and gravels of the same age (GOGOŁEK 1993). Degradation of the tunnel valley during the successive aggradation of the continental ice-sheet was prevented by the dead ice present in depressions (BARTKOWSKI 1957). According to GOGOŁEK (1993), the intense organic accumulation in water reservoirs occurring in the tunnel valleys in the study area began during the transition from the Younger Dryas to the Preboreal. Because there is a gap between these organic sediments and the underlying fluvioglacial deposits of the Early Leszno Phase, it is evident that the tunnel valley of the Lake Niepruszewskie was filled with dead ice nearly until the beginning of the Holocene.

The Niepruszewo-Cieśle site is located on the southern bank of the Lake Niepruszewskie, about 1.5 km south of the village of Cieśle, ca. 200 metres south of the recent lake shore, in the lacustrine chalk mine (Text-figs 1, 3). The surface of the meadow where the section starts is situated ca. 0.7 m above the present water level of the lake. The lower part of the succession (samples 1-8) was sampled from a borehole core, whereas the upper part (samples 9-27) was sampled from an outcrop. The volume of the former samples constitute approximately 80% of the latter.

In contrast to the Lake Lednica, studies dealing with the Lake Niepruszewskie were rare and restricted primarily to the genesis of the lake (e.g. BARTKOWSKI 1957, ROTNICKI 1960).

MATERIAL

The mollusc fauna investigated during this study was derived from gyttjas, calcium carbonate gyttjas and lacustrine chalk. The preservation of the shells was good or very good. Shells with the periostracum preserved were

Species	A	B	C	D	E	F
Valvata cristata	11	Wp	-	PW	Pl	N_5
Valvata pulchella	10	WP	l	-	Es	N_5
Valvata piscinalis	11	We	-	-	Pl	N_5
Bithynia tentaculata	11	We	-	SW	Pl	N_4
Carychium minimum	9	WD	G	LF	Es	N_4
Physa fontinalis	11	WL	-	SW	Hl	N_4
Lymnaea stagnalis	11	WL	-	PW	Hl	N_5
Lymnaea palustris	11	Wp	l	PW	Hl	N_4
Lymnaea peregra	10	Wd	-	SW	Pl	N_5
Lymnaea peregra ovata	11	Wl	-	-	Pl	N_5
Lymnaea auricularia	11	WL	-	BW	Pl	N_3
Lymnaea glabra	11	Wp	l	-	Ew	N_3
Lymnaea truncatula	10	Wd	l	AM	Hl	N_5
Planorbis planorbis	10	WP	l	SW	Pl	N_4
Anisus leucostomus	10	WP	l	PW	Pl	N_4
Anisus vortex	11	Wp	-	PW	Es	N_4
Anisus contortus	11	Wl	-	SW	Pl	N_5
Gyraulus albus	11	We	-	-	Hl	N_3
Gyraulus laevis	11	WL	l	PW	Pl	N_5
Armiger crista	11	WL	-	PW	Hl	N_4
Hippeutis complanatus	11	Wl	-	PW	Pl	N_4
Acroloxus lacustris	11	WL	-	PW	Pl	N_3
Succinea putris	9	WD	l	LF	Es	N_5
Succinea oblonga	8	MD	L	LF	Es	N_4
Sphaerium corneum	11	We	-	-	Pl	N_5
Pisidium lilljeborgii	11	WL	g	-	Hl	N_5
Pisidium milium	11	We	-	SW	Hl	N_5
Pisidium obtusale	10	WP	-	PW	Hl	N_5
Pisidium nitidum	12	We	-	BW	Hl	N_5
Pisidium subtruncatum	11	We	-	SW	Es	N_5
Pisidium casertanum	11	We	g	SW	Hl	N_5

Table 1. Ecologial valence of molluscs present in sections described

A - ecological groups (after LOŽEK 1964, supplemented by ALEXANDROWICZ 1987): 8 – species typical of damp, but not wet sites, shaded to different degrees, 9 – snails inhabiting very damp, swampy, periodically flooded sites, 10 – molluscs inhabiting small, episodic, strongly overgrown reservoirs, 11 – aquatic species typical of stable, stagnating water basins, e.g. ponds, lakes, bays, 12 – species inhabiting running waters, rivers, streams or places with wave activity;

B – supplementary ecological symbols (after LOŽEK 1964, 1974, 1982, modified according to KÖRNIG 1966 and PIECHOCKI 1979): MD – mesophyllic species inhabiting damp sites, WD – snails typical for very damp and wet sites, inhabiting swamps, flooded meadows, shores of reservoirs, Wd – molluscs inhabiting shallow, episodic basins and marshy environment, WP – molluscs typical of episodic, periodically drying out water reservoirs, Wp – molluscs inhabiting stable, shallow, strongly overgrown water reservoirs, Wl – molluscs inhabiting reservoirs with stagnating or very slowly flowing waters, WL – species inhabiting stable water reservoirs of various size, We – species present both in rivers and lakes, in flowing and stagnating waters;

C - facies-stratigraphical and palaeoclimatical symbols (after LOŽEK 1964, 1976, 1982): **L** – typically loess snails, **l** – species found in assemblages of loess snails, **G** – species living during cold periods outside zones of loess accumulation, g – species surviving during cold periods, outside zones of loess accumulation as relicts;

D - ecological groups symbolizing major site types (after ZEISSLER 1962, 1975, 1977), BW – waters remaining in motion (currents, waves), SW – stagnating or poorly mobile waters, PW – stagnating waters, shallow, strongly overgrown reservoirs, AM – transitional terrestrial-aquatic environment, LF – damp terrestrial sites;

E - zoogeographical units (after JAECKEL 1962, LOŽEK 1964, KÖRNIG 1966), Hl – holoarctic species, Pl – paleoarctic species, Es – Euro-Siberian species, Ew – West-European species;

F - distribution to the north on the basis of Recent distribution in Europe (after SPARKS 1961, JAECKEL 1962) N_2 – species present on the European Lowlands, reaching southern coasts of the Scandinavian Peninsula, N_3 – species present up to latitude 60-61°N, N_4 – species present up to latitude 63°N, N_5 – species extending beyond the Arctic Circle, reaching northern coasts of the Scandinavian Peninsula found commonly. The molluscs were not transported and constituted in situ assemblages in each section studied. All the species recognized are well known from Pleistocene and Holocene lacustrine deposits in Poland, i.e. URBAŃSKI (1957), ALEXANDROWICZ & TCHÓRZEWSKA (1981), ALEXANDROWICZ & DOLECKI (1991), ALEXANDROWICZ & ŻUREK (1991), SKOMPSKI (1989). They have been classified into ecological groups (Table 1) introduced by LOŽEK (1964) and supplemented by ALEXANDROWICZ (1987). The composition of the investigated fauna is therefore presented in the form of malacological spectra (MS), which show the percentage number of species (MSS) or the percentage number of individuals (MSI) in each sample studied (Text-figs 4-6). Fluctuations in the number of taxa and number of specimens in the successions can reveal long-term changes in the living conditions of the mollusc fauna. The ecological preferences of snail and bivalve species described in the present paper are presented in Table 1.

Mollusc shells were very numerous in all three sites. At Imiołki 3733 snails (15 species) and 1330 bivalves (7 species) were found. At Rybitwy the fauna contained 3592 snails (16 species) and 968 bivalves (5 species). The mollusc fauna from the Niepruszewo-Cieśle site was extremely rich, 96175 snails (16 species) and 1579 bivalves (4 species) were collected.

Oxygen and carbon stable isotopes in the shells of several species of snails and bivalves occurring in sections described in the present paper are currently being analysed and will constitute a part of the doctoral thesis prepared by the senior author.

THE IMIOŁKI SITE

Faunal content

Light, calcareous gyttja and blue-grey, clayey silt contain 15 species of snails (13 aquatic and 2 terrestrial species) and 7 species of bivalves (Table 2). The mollusc shells are relatively small and thin-walled. A general increase both in the number of taxa and number of specimens can be observed in the sequence. Only in its middle part is there a significant decline in the fauna (Text-fig. 4).

The mollusc fauna present in the Imiołki succession is dominated by *Valvata pulchella* STUDER, *Valvata cristata* MÜLLER and *Lymnaea peregra ovata* (DRAPARNAUD). Other relatively abundant species are *Valvata piscinalis* (MÜLLER), *Sphaerium corneum* (LINNAEUS) and *Pisidium nitidum* JENYNS (Table 2). The gastropod species *V. pulchella* is most numerous in the lower part of the section (samples 2-5), while in the upper part (samples 8-12) its occurrence decreases in favour of *L. peregra ovata* (Table 2). In sample 12, *V. cristata* forms almost half of the mollusc fauna and represents the highest number of specimens in the succession (Table 2). Two snails, *Armiger crista* (LINNAEUS) and *Hippeutis complanatus* (LINNAEUS), scarcely present in the lower part of the site (samples 2-7), almost disappear from samples 8-10, but become more abundant in the uppermost gyttja (samples 11 and 12) (Table 2). Samples 5-10 contain considerable amounts of bivalve shells, most significantly in samples 9 and 10, with *S. corneum* and *P. nitidum* being the most numerous species (Table 2).

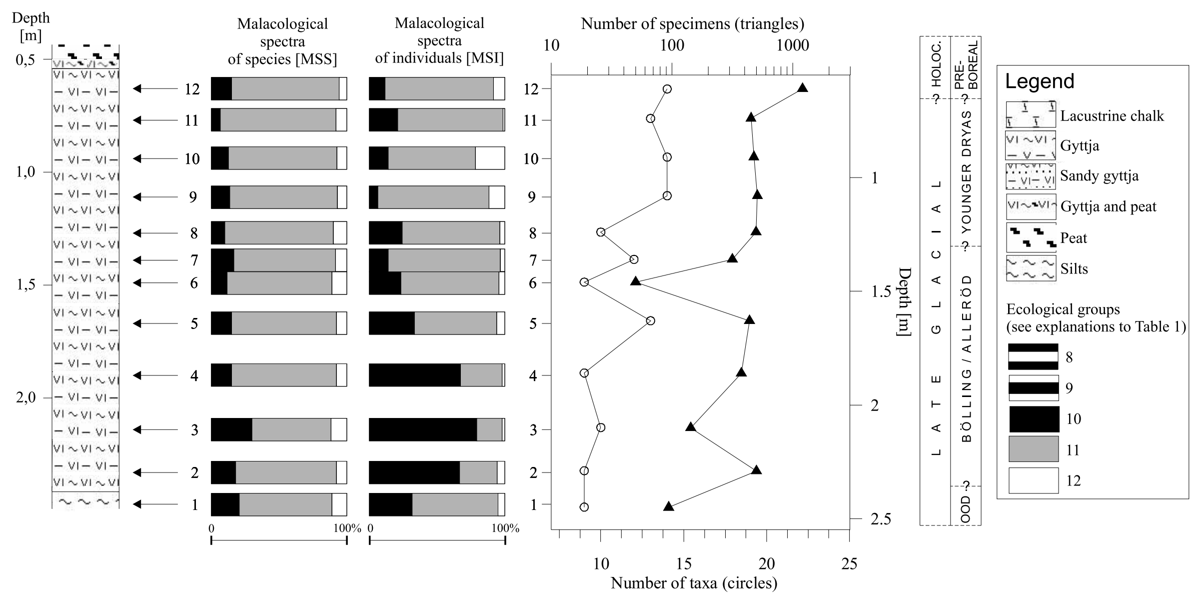

Fig. 4. Distribution of mollusc fauna in the Imiołki section. Stratigraphy on the basis of interpretation presented by TOBOLSKI (1998) and malacological investigations in the present paper. OOD – Oldest Dryas. For detailed lithological log see Appendix

Interpretation

The blue-grey silts in the lowermost part of the section contain a relatively poor mollusc fauna, in which species characteristic of stable water reservoirs (ecological group 11 sensu LOŽEK 1964 and ALEXANDROWICZ 1987) are dominant (Text-fig. 4, Table 2). The significant increase in the number of specimens observed in sample 2 is caused primarily by a high abundance of *V. pulchella*, a species indicative of shallow waters with well-developed vegetation, ecological group 10 (Text-fig. 4, Table 2). The frequency and predominance of *V. pulchella* suggest that the Imiołki reservoir remained relatively shallow during the time covered by samples 2-4. Although *V. pulchella* also remains dominant in sample 5, *L. peregra ovata* and bivalves, especially *S. corneum* and *P. nitidum*, become more numerous (Table 2). This marks the onset of the dominance of ecological group 11 in the fauna (Text-fig. 4), which characterizes the upper part of the section and indicates a higher water level than that covered by samples 2-4. Samples 8-10 are characterized by the highest number of bivalves in the succession. An increase in the numbers of *Pisidium lilljeborgii* CLESSIN (samples 8-10, Table 2), a bivalve species characteristic of a cold climate, accompanied by the disappearance of *A. crista* and *H. complanatus*, gastropods living among water plants, indicates a colder climate that contributed to a decrease in aquatic vegetation. A significant increase in the abundance of molluscs is noted in the uppermost gyttja (sample 12). The fauna is composed primarily of snails indicative of rich vegetation, of which *V. pulchella*, *A. crista*, *H. complanatus* and *V. cristata* are the most numerous. The abundance of gastropods living on water plants may have resulted from shallowing of the water basin and/or warming of the climate.

The lithology and thickness of the deposits drilled in the Imiołki site is similar to the succession of site No. 1 described by TOBOLSKI (1998). Therefore, it is justified to compare changes in the mollusc fauna noted in the Imiołki succession with the palaeoecological observations made by TOBOLSKI (1998). Data on water level changes of the Lake Lednica described by STANKOWSKI (1989) were also taken into consideration. Although most of the events recorded in the mollusc assemblages correspond well to observations made during the above-mentioned studies, I realize that not all of them must be simultaneous.

	Depth in cm	2,57 – 2,62	2,42 – 2,47	2,26 – 2,31	2,07 – 2,12	1,83 – 1,88	1,60 – 1,65	1,43 – 1,48	1,33 – 1,38	1,21 – 1,26	1,05 – 1,10	0,88 – 0,93	0,71 – 0,76	Total amount of specimens
IMIOŁKI		silts	gyttja											
	Samples	1	2	3	4	5	6	7	8	9	10	11	12	
Gastropods	*Valvata cristata*			○	◎	⊙	○	◎	◎	○	⊙	◎	✱	901
	Valvata pulchella	◎	✱	◘	◘	◘	⊙	◎	◘	⊙	◎	◎	◘	1316
	Valvata piscinalis	◎	◎	○		⊙	○	⊙	◎	⊙	○	◎	◎	329
	Physa fontinalis												◦	1
	Lymnaea palustris										○			7
	Lymnaea glabra	◦									◦	◦		6
	Lymnaea peregra ovata	⊙	⊙	○	⊙	◎	⊙	◎	◎	◎	◘	◘	◘	746
	Anisus leucostomus			◦										1
	Anisus vortex													1
	Gyraulus albus	○	⊙							◦				21
	Gyraulus laevis			◦		○	◦		◦	○	○	⊙	◘	180
	Armiger crista		⊙	◦	⊙	○		○		◦	◦	◎	◘	183
	Hippeutis complanatus				◦			○				◦	⊙	36
Bivalves	*Sphaerium corneum*	○	⊙			◎	○	◎	◎	◘	✱	⊙	⊙	443
	Pisidium casertanum		⊙	○	⊙	⊙		○	⊙	⊙	◎	○	○	132
	Pisidium lilljeborgii	○	○		◦	⊙		◦	⊙	◎	⊙	⊙	○	123
	Pisidium milium		◦		○	○	○	⊙	◎	⊙	◎	⊙	⊙	207
	Pisidium nitidum	○	◎	○	⊙	◎	◦	⊙	⊙	◎	◎	⊙	⊙	301
	Pisidium obtusale	◦	◦	◦	○	⊙		○		○	⊙		○	50
	Pisidium subtruncatum				◦	○	◦			○	◎			74
Total amount of specimens		94	500	143	376	438	50	316	498	511	476	451	1201	**5058**

Table 2. Molluscs identified in the Imiołki section. 1-28 – numbers of samples; symbols shown indicate classes of frequency of mollusc shells (logarithmic scale): ◦ – 1-3 specimens, ○ – 4-10, ⊙ – 11-31, ◎ – 32-100, ◘ – 101-316, ✱ – 317-1000, ● – 1001-3162, ■ – 3163-10 000 specimens

Palynological data (TOBOLSKI 1998) revealed that the Imiołki reservoir comprises lacustrine deposits formed in the Late Glacial and at the beginning of the Holocene. The earliest sediments were accumulated about 15 000 BP. The organic sedimentation lasted until Preboreal time, when the reservoir was overgrown by a peat bog.

Blue-grey silt (sample 1) at the base of the succession studied, was also found in numerous small reservoirs surrounding the Lake Lednica. LITT (1988) reported it at Dziekanowice and MAKOHONIENKO & TOBOLSKI (1991) in shallow parts of the Lake Lednica basin in Waliszewo. Its accumulation has been dated as Oldest Dryas (e.g. TOBOLSKI 2000). Thus, the rare molluscs found in sample 1 (Text-fig. 4) represent an initial stage of faunal development that took place in a cold climate. An increase in the number of specimens in sample 2 may be attributable to the climate warming that is known for the transition from the Oldest Dryas to the Bölling-Alleröd interstadial complex, which most probably comprises samples 2-7. An increase in the numbers of *P. lilljeborgi,* accompanied by the disappearance of *A. crista* and *H. complanatus* in samples 8-10 (Text-fig. 4, Table 2), indicate the Younger Dryas time, recognized earlier by TOBOLSKI (1998) in the site No. 1 succession. HAMMARLUND, the author of a chapter describing the content of oxygen and carbon stable isotopes in inorganic carbonates in the publication edited by TOBOLSKI (1998), suggested a more stable albeit colder climate for this period, which resulted in almost constant numbers of specimens in samples 8-10. The high abundance of molluscs connected with rich vegetation, observed in sample 12, is in agreement with the lowering of the Lake Lednica water level at the transition from the Late Glacial to the Holocene proposed by STANKOWSKI (1989). According to TOBOLSKI (1998), the highest part of the calcareous gyttja accumulated at the threshold of the Preboreal, thus indicating a warmer climate that could also have been responsible for the high faunal abundance in the highest sample.

THE RYBITWY SITE

Faunal content

Among small, thin-walled mollusc shells derived from sandy gyttja, calcareous gyttja and gyttja intercalat-

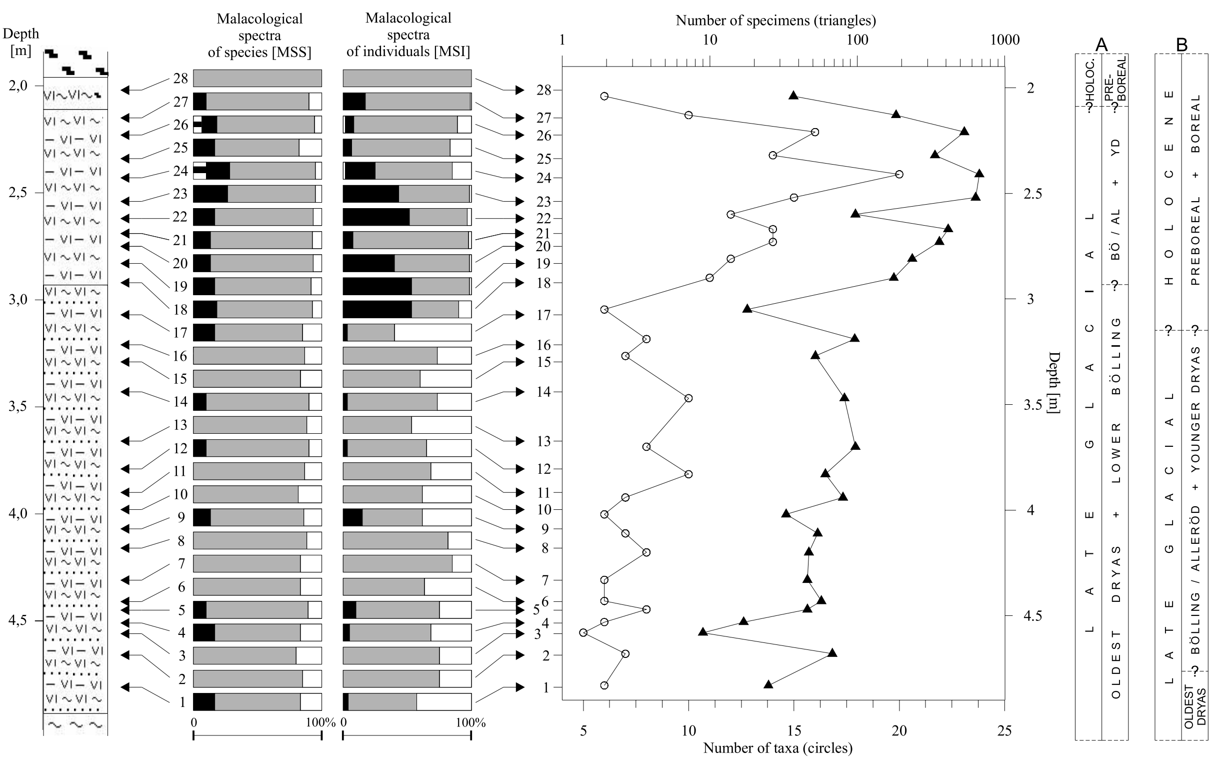

Fig. 5. Distribution of molluscs in the Rybitwy section. Note a significant change in the composition and frequency of mollusc fauna between sandy and calcareous gyttja (for legend see Text-fig. 4). A – Stratigraphy on the basis of observations made by STANKOWSKI (1989). BÖ/AL – interstadial complex Bölling/Alleröd; YD – Younger Dryas. B – Alternative stratigraphy suggested by preliminary results of oxygen and carbon stable isotope analyses in lacustrine carbonates. For detailed lithological log see Appendix

ed with peat 16 aquatic and 2 land species of snails together with 5 species of bivalves were recognized. The faunal diversity and numbers increase upwards, with a few strong decreases. After the decrease recorded in sample 3, the mollusc fauna shows a general increasing trend up to the highest sample from the sandy gyttja (sample 17), which records a considerable reduction in numbers of both gastropod and bivalve shells. This is followed by significant increase in diversity and numbers (samples 18-21), with a marked decrease in numbers in sample 22 (Text-fig. 5, Table 3). The most numerous assemblage occurs in samples 23-26, followed by a gradual but substantial decrease in the mollusc fauna in the highest two samples.

Bivalves, mainly *Pisidium nitidum* JENYNS, *Pisidium subtruncatum* MALM and *Sphaerium corneum* (LINNAEUS), dominate the relatively poor mollusc fauna occurring in sandy gyttja in the lower portion of the section. Sparse snails are represented mainly by *Valvata piscinalis* (MÜLLER) and *Lymnaea peregra* (MÜLLER), which are present in most of the samples (Table 3). The mollusc fauna occurring in the calcareous gyttja is more diversified and numerous (Text-fig. 5, Table 3). The species *Valvata pulchella* STUDER, *Armiger crista* (LINNAEUS), *V. piscinalis* and *Gyraulus laevis* ALDER are the most abundant snails. In contrast to their numbers in the sandy gyttja, the number of bivalve shells in the calcareous gyttja is very low. Of these, *P. nitidum* is the only species that occurs in significant numbers. Two snails that inhabit very damp, swampy sites, *Carychium minimum* MÜLLER and *Succinea putris* (LINNAEUS), which are sparsely represented in samples 24 and 26, were probably blown or washed out from the surrounding land.

Interpretation

The rare bivalve-dominated fauna occurring in the sandy gyttja (samples 1-17) is similar to the mollusc assemblage for which ALEXANDROWICZ (1987) suggested a deep zone in the lake. Representatives of ecological group 11, species characteristic of stable water reservoirs, are the most numerous. The considerable increase in the number of taxa and specimens in the calcareous gyttja is most probably attributable to a fall in the water level of the lake (Text-fig. 5, Table 3). The mollusc fauna present in samples 18-23 consists of approximately equal quantities of species belonging to ecological groups 10 and 11 (Text-fig. 5). The most abundant species, *V. pulchella*, *A. crista* and *V. piscinalis,* indicate a shallow but stable water basin with well developed vegetation. Beginning with sample 24, species belonging to ecological group 11 become most numerous, indicating a probable rise in the water level. The presence of *V. pulchella*, *A. crista* and *G. laevis* suggests that the extent of vegetation did not decrease significantly despite a possible deepening of the inhabited environment. In samples 24-26 a substantial increase in the numbers of *P. nitidum*, a species preferring running waters, is noted (Table 3). This may be connected with proximity to an inflow of a water-course or more intense wave activity. Sample 28, where a significant decrease in the mollusc fauna is noted (Text-fig. 5, Table 3), was derived from gyttja intercalated with peat, a record of an initial phase of peat-bog formation, indicative of a substantial shallowing of the lake.

Depositional development and stratigraphy

In the earliest stage of reservoir development, following the recession of the Pleistocene continental ice sheet, blue-grey lacustrine silts barren of molluscs accumulated (MAZUREK 1988, 1990, STANKOWSKI 1989). It can be assumed that those are coeval with the silts containing a Dryas flora that are found in numerous sites in the Lednicki Landscape Park (e.g. Imiołki, TOBOLSKI 1998). This indicates that as in the case of the Imiołki reservoir, an initial phase of sedimentation in Rybitwy began about 15 000 years ago (TOBOLSKI 1998). According to MAZUREK (1990), the sandy gyttja overlying the silts contains little $CaCO_3$ and organic matter but is greatly enriched in inorganic detritus. Thus, its deposition took place when the land surrounding the Lake Lednica was devoid of dense vegetation and open to intensive erosion resulting from the lack of stabilization of the soil surface. The conditions described caused a substantial transport of material eroded in the catchment area into the basin (MAZUREK 1988, 1990, STANKOWSKI 1989). The lithological and faunal features of the sandy gyttja indicate its accumulation during the Oldest Dryas and at the beginning of the Bölling-Alleröd interstadial complex (L PAZ NAP 1 and Salix-Hippophaë (TOBOLSKI 1998)), before the first dense vegetation in the form of birch forests developed in the study area (L PAZ Betula-Salix) (TOBOLSKI 1998). For the accumulation of the blue-grey lacustrine silts and sandy gyttja STANKOWSKI (1989) suggested a high lake water level. This is in agreement with the poor mollusc assemblage observed in samples 1-17 (Text-fig. 5).

The sharp transition from sandy gyttja to calcareous gyttja may reflect an abrupt change in the water level of the lake, as suggested by STANKOWSKI (1989) and MAZUREK (1990). A reduction of the inorganic detritus in gyttja (MAZUREK 1988, 1990) indicates stabilization of soils by terrestrial vegetation. A high content of organic detritus (samples 18-22) suggests a shallow environment with well developed aquatic plants. A subsequent gradual rise in the water level resulted in a higher $CaCO_3$ content, with lower amounts of organic substances (samples 23-27,

	Depth in cm	4,80 – 4,85	4,65 – 4,70	4,56 – 4,60	4,50 – 4,55	4,46 – 4,49	4,40 – 4,45	4,30 – 4,35	4,17 – 4,22	4,08 – 4,13	3,99 – 4,04	3,91 – 3,96	3,80 – 3,85	3,67 – 3,72	3,44 – 3,49	3,24 – 3,29	3,16 – 3,21	3,02 – 3,07	2,87 – 2,92	2,78 – 2,83	2,70 – 2,75	2,64 – 2,69	2,57 – 2,62	2,49 – 2,54	2,38 – 2,43	2,29 – 2,34	2,18 – 2,23	2,11 – 2,15	2,01 – 2,06	Total amount of specimens
	RYBITWY	sandy gyttja																	calcareous gyttja										gyttja /peat	
	Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	
Gastropods	*Valvata cristata*		◦				◦						◦	◦	◦		⊙		⊙	◦	⊙	⊙	◦	⊙	⊙	◦	○	◦		130
	Valvata pulchella	◦			◦	○				○					◦				**○**	▣	▣	⊙	**○**	▣	▣	⊙	**○**	**○**		975
	Valvata piscinalis	◦	◦		◦	○	○	○	○	◦	◦	○	○	⊙	⊙		⊙	◦	○	**○**	**○**	▣	○	**○**	**○**	**○**	**○**	**○**	⊙	635
	Bithynia tentaculata												◦				◦		◦	○	⊙	○	○	⊙	⊙	◦	○	◦	◦	71
	operculum															◦				⊙	⊙	⊙	◦	⊙	⊙	○	○	◦		(88)
	Carychium minimum																								◦					1
	Lymnaea stagnalis																								⊙	◦	○	○		21
	Lymnaea glabra																								◦					1
	Lymnaea truncatula												◦						◦	◦	◦	◦	◦	◦	○					19
	Lymnaea auricularia								◦							◦	○		◦		○	○	◦	◦	○	○	○			47
	Lymnaea peregra	○	⊙	◦	○	○		⊙	○	○	○	⊙	○	○	○	○	○	◦	◦	◦	◦	◦	◦	◦	⊙	○	⊙	○	◦	169
	Planorbis planorbis																							○	○					11
	Anisus leucostomus																							◦	○		○			9
	Gyraulus albus																			◦	◦	○		⊙	⊙	○	○			91
	Gyraulus laevis			◦		◦			◦			◦	◦		◦				⊙	◦	⊙	**○**	○	**○**	▣	**○**	▣	**○**	○	487
	Armiger crista													◦	◦			◦	⊙	**○**	**○**	▣	⊙	▣	▣	**○**	▣	**○**	⊙	859
	Hippeutis complanatus																			◦	○	○	◦	○	⊙		○		◦	36
	Acroloxus lacustris																				◦	◦			○	◦	◦			15
	Succinea putris																								○		○			15
Bivalves	*Sphaerium corneum*		⊙	◦	◦	○	⊙	⊙	○	○	○	⊙	◦	⊙	⊙	⊙	⊙								○	○				146
	Pisidium milium	◦	◦			◦	◦	○	○	◦	◦	○	◦	◦	○	○														48
	Pisidium nitidum	⊙	⊙	◦	○	⊙	⊙	○	○	⊙	⊙	⊙	⊙	**○**	⊙	⊙	⊙	⊙	⊙	◦	○	◦	◦	○	▣	**○**	**○**	◦		523
	Pisidium obtusale																	◦												1
	Pisidium subtruncatum	○	⊙	◦	◦	⊙	⊙	○	○	○	○	⊙	⊙	⊙	⊙	○	⊙	◦	◦	◦	◦	◦	◦	◦	○	⊙	**○**	◦		250
	Total amount of specimens	25	68	9	17	46	57	46	47	54	33	80	61	97	82	52	96	18	177	236	360	414	97	636	672	336	533	183	37	**4569**

Table 3. Mollusc fauna recognized in the Rybitwy section (for explanations see Table 2). Note the significant difference in fauna between sandy gyttja and calcareous gyttja

depth 2.54-2.11) (MAZUREK 1990). The significantly richer mollusc assemblage in the calcareous gyttja, with the most numerous species being characteristic of stable, stagnating water basins, probably inhabited a shallow but permanent reservoir. As in the case of the Imiołki site, the initial phase of peat-bog formation began at the beginning of the Preboreal (TOBOLSKI 1998), the calcareous gyttja accumulated during the Bölling-Alleröd interstadial complex and the Younger Dryas. A similarity of the events recorded in the Imiołki and the Rybitwy sites is possible because both are situated on the sloping western shore of the Lake Lednica, approximately one metre above the water level of the lake. Although the Imiołki reservoir is separated from the present day littoral of the Lake Lednica by an elongated ridge of sandy clays, a significant shallowing at the beginning of the Preboreal would have affected both of them. However, this interpretation requires a considerably faster sedimentation rate during the Oldest Dryas than during the Bölling-Alleröd interstadial complex and the Younger Dryas. Such a situation is possible due to sparse terrestrial vegetation in the Oldest Dryas allowing stronger detrital input into the lake than during the Bölling-Alleröd interstadial complex, but is less probable for a cold phase of the Younger Dryas.

The preliminary results of oxygen and carbon stable isotope analyses (by the senior author) indicate a different stratigraphy (Text-fig. 5). According to the $\delta^{18}O$ and $\delta^{13}C$ values recorded in the lacustrine carbonates, samples 16 and above constitute a record of the Holocene, probably the Preboreal and the Boreal time. This suggests that the transition from sandy to calcareous gyttja (noted between samples 17 and 18), which was most probably a result of considerable lowering of the water level in the lake, may be synchronous with the time of transformation of the Imiołki reservoir into a peat-bog. This would agree well with the occurrence of *Bithynia tentaculata* (LINNAEUS) (Table 3), a species considered to be an indicator of warming at the beginning of the Holocene (ALEXANDROWICZ 1987). Interpretation based on the preliminary results of oxygen and carbon stable isotope analyses seems more accurate and probable but needs further work. The complete results will constitute a part of the doctoral thesis by the senior author.

THE NIEPRUSZEWO-CIEŚLE SITE

Faunal content

Samples derived from gyttja and lacustrine chalk contain over 97 000 shells belonging to 16 species of snails (1 terrestrial species), four species of bivalves, and

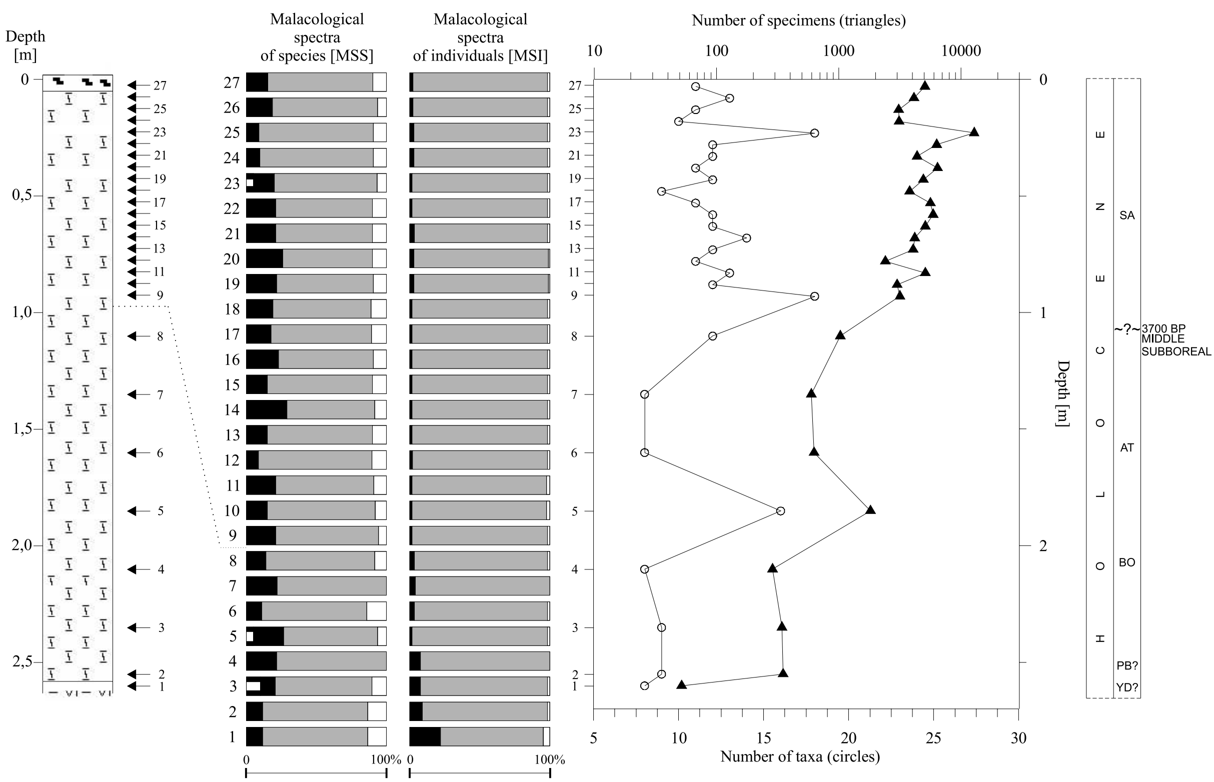

Fig. 6. Distribution of mollusc shells in the Niepruszewo-Cieśle section (for legend see Text-fig. 4). YD – Younger Dryas; PB – Preboreal; BO – Boreal; AT – Atlantic; SA – Subatlantic. For detailed lithological log see Appendix

some unidentified large bivalves which are probably *Anodonta* or *Unio* (Table 4). The diversity and numbers of the molluscs increase gradually toward the upper part of the section. The poorest and least diversified mollusc fauna is present in samples 1-8, with sample 5 being the only exception (Table 4, Text-fig. 6). Starting with sample 9, a marked increase both in numbers of taxa and numbers of specimens is noted (Text-fig. 6). The diversity is relatively constant, with the exception of samples 9 and 23, where a significant increase in species number is observed, and samples 18 and 24 with the lowest number of taxa. The numbers of molluscs increase gradually, reaching a maximum of 12810 shells in sample 23. A few fluctuations occur, with the most significant decrease in samples 12, 24 and 25 (Text-fig. 6).

The mollusc assemblages are dominated by *Valvata piscinalis* (MÜLLER), *Valvata piscinalis antiqua* SOWERBY, *Lymnaea auricularia* (LINNAEUS) and *Gyraulus laevis* ALDER. Each of these species is abundant in most of the samples (Table 4). The remaining mollusc fauna is subordinate. There is a characteristic trend in that high numbers of *L. auricularia* are associated with lower numbers of *G. laevis* whereas the latter species occurs abundantly in samples 1-8, 12, 16, 18, 19, 21-27, where *L. auricularia* is less numerous (Table 4). Scarce *Succinea oblonga* DRAPARNAUD, a species found frequently on the shores of water reservoirs (ecological group 8), occurs in samples 3, 5 and 23. It was probably washed out from the surrounding land.

Interpretation

Both the MSS and MSI malacological spectra indicate a permanent water reservoir with very stable ecological conditions (Text-fig. 6). The most numerous species, *V. piscinalis,* usually inhabits the littoral and sublittoral zone of stable water reservoirs with well oxygenated waters. *V. piscinalis antiqua*, a typically lacustrine subspecies of *V. piscinalis*, lives in sublittoral and deep zones of lakes. It is characteristic of larger water reservoirs where overgrowing by vegetation is insignificant (URBAŃSKI 1954). The constant predominance of *V. piscinalis* over *V. piscinalis antiqua* indicates that their habitat was not particularly deep, probably the littoral or sublittoral zone of the lake. The scarcity of species characteristic of shallow reservoirs with well developed vegetation, i.e. *Valvata pulchella* STUDER, *Valvata cristata* MÜLLER, *Armiger crista* (LINNAEUS) and *Planorbis planorbis* (LINNAEUS), precludes a very shallow environment. Two other dominant gastropod species, *L. auricularia* and *G. laevis,* are thought to be indicative of a reed zone (ALEXANDROWICZ 1987).

Prosobranch gastropods outnumber Planorbid snails in most of the samples, indicating a depth of accumulation below 2-3 metres, as suggested by ALEXANDROWICZ (1987) for mollusc assemblages where the latter snails dominate the former. The predominance of planorbids in samples 9 and 11 is connected with increased abundance of *L. auricularia* and *G. laevis* over *V. piscinalis.* A simultaneous rise in the number of *S. corneum* and *A. crista*, species living among water plants, suggests an increase in aquatic vegetation and a possible lowering of the water level.

The ecological preferences of the species described above indicate that the gyttja and lacustrine chalk accumulated in a permanent water reservoir with very stable environmental conditions. Most probably it was a deeper part of the littoral and sublittoral zone of the lake with a well developed reed zone. In the initial phase of reservoir development (samples 1, 2) molluscs were very sparse (Table 4). The relatively high content of Planorbid gastropods and absence of *V. piscinalis antiqua* indicates a shallow environment. In samples 3-8, a gradual increase in the number of specimens is observed, with a significant rise noted in sample 5, which represents one of the richest species assemblages in the section. Although in samples 9-24 the mollusc fauna shows exceptional constancy, some changes in its composition and richness (samples 12, 18) indicate fluctuations of the water level and/or a climate (Text-fig. 6, Table 4). Gradual overgrowing of the bay (samples 25-27) is reflected in a higher ratio of *V. piscinalis* to *V. piscinalis antiqua* (Table 4). The change from lacustrine chalk to peat had no influence on the mollusc assemblage initially. In the 5 cm thick peat layer, species characteristic of stagnant waters remain dominant (Text-fig. 6). Nevertheless the occurrence of a peat bog indicates considerable shallowing and overgrowing of the reservoir.

Stratigraphy

According to GOGOŁEK (1993), an intense organic accumulation in water reservoirs filling tunnel valleys in the area of Lake Niepruszewskie began at the beginning of the Holocene, thus the lowermost sediments of the Niepruszewo-Cieśle succession were deposited at the end of the Late Glacial or at the beginning of the Preboreal (Text-fig. 6). The shallow environment indicated by molluscs occurring in samples 1 and 2 agrees with the low water stand of lakes in central Poland suggested for the Preboreal (RALSKA-JASIEWICZOWA & STARKEL 1988).

At a distance of ca. 50 metres to the southeast from the section analysed, three pales, probably the remains of an on-shore construction, and a boat hollowed out of a tree trunk were found in the lacustrine chalk at a depth of 1.15 m (PRINKE & PRINKE 2001). The age of both the boat and the pales was determined by two independent

	Depth in meters	2,58 – 2,63	2,50 – 2,58	2,25 – 2,50	2,00 – 2,25	1,75 – 2,00	1,50 – 1,75	1,25 – 1,50	0,95 – 1,25	0,90 – 0,95	0,85 – 0,90	0,80 – 0,85	0,75 – 0,80	0,70 – 0,75	0,65 - 0,70	0,60 – 0,65	0,55 – 0,60	0,50 – 0,55	0,45 – 0,50	0,40 – 0,45	0,35 – 0,40	0,30 – 0,35	0,25 – 0,30	0,20 – 0,25	0,15 – 0,20	0,10 – 0,15	0,05 – 0,10	0 – 0,05	Total amount of specimens
	NIEPRUSZEWO-CIEŚLE	gyttja	Lacustrine chalk																									peat	
		grey	grey	pink															yellow-creme					cre-me	grey	grey			
	Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Gastropods	*Valvata cristata*		∘	∘		○	○	∘	∘	○		∘	∘	∘	∘	∘	∘			∘				⊙	∘	∘		○	77
	Valvata pulchella	⊙	◯	⊙	⊙	⊙	⊙	⊙	◯	⊙	⊙	◯	◯	⊙	⊙	⊙	⊙	⊙	○	◘	◘	◘	◘	◘	◯	◯	◯	◯	1448
	Valvata piscinalis	⊙	◘	◘	◘	✱	◘	◘	✱	✱	●	●	●	●	●	■	■	●	●	●	●	●	●	■	●	●	●	■	48671
	Valvata piscinalis antiqua			⊙	◯	◘	◯	◘	◯	◘	✱	◘	◘	◘	✱	✱	●	●	●	●	✱	✱	✱	●	✱	✱	◘	◘	13592
	Bithynia tentaculata	∘	∘			○		∘	⊙	○	⊙	∘	∘	∘	○	○	∘	○	∘	○	∘	○	⊙	◯	⊙	○	○	⊙	262
	operculum		○	○	∘	⊙	∘	∘	○	⊙	⊙	⊙	⊙	∘	○	○	⊙	⊙	○	∘	∘	○	⊙	◯	⊙	○	⊙	◯	(341)
	Physa fontinalis									∘																∘			3
	Lymnaea peregra				∘	○			∘	○	○	○			∘					∘	∘	○	∘	⊙			∘	○	65
	Lymnaea auricularia	○	◯	⊙	○	◘	◯	○	⊙	✱	✱	●	◯	●	●	●	◘	●	✱	✱	●	◘	✱	✱	✱	◘	◘	○	14762
	Planorbis planorbis					○		○		○		○			∘	○	∘	○	∘	∘	○	∘	∘						51
	Anisus leucostomus					∘				○				∘	∘		∘							○			∘		17
	Anisus contortus					∘				∘	∘													∘				∘	6
	Gyraulus albus				⊙						○													◯					92
	Gyraulus laevis	∘	◯	◯	⊙	✱	◘	◘	✱	✱	✱	✱	✱	◘	◘	◘	●	✱	●	●	✱	●	●	●	✱	✱	●	●	16708
	Armiger crista	⊙	⊙	⊙	○	◯	∘		○	◯	⊙	⊙	○	∘	∘	○	∘	∘		∘	∘	∘	∘	◯	○	○	○	○	387
	Hippeutis complanatus												∘					∘						∘	∘		∘		7
	Acroloxus lacustris					∘				∘														∘			∘		5
	Succinea oblonga			∘		○																		⊙					22
Bivalves	*Unio sp., Anodonta sp.*																							∘			∘		
	Sphaerium corneum								∘	◘		◯		⊙	⊙	∘						◯	◯	◯					367
	Pisidium casertanum	∘				○			○	⊙	∘	○	⊙	⊙	⊙	⊙	⊙	⊙	∘	∘	⊙	◯	◯	◯		∘	⊙		397
	Pisidium milium									∘																			1
	Pisidium nitidum	∘	∘	∘		⊙	∘		⊙	◯	⊙	◯	⊙	⊙	◯	⊙	◯	◯	○	○	◯	◯	◯	◘	○	∘	◯	∘	814
	Total amount of specimens	52	351	344	287	1820	629	598	1029	3169	2996	5114	2409	4058	4183	5115	5929	5614	3810	4910	6428	4370	6314	12810	3112	3096	4125	5084	**97756**

Table 4. Molluscs present in the Niepruszewo-Cieśle section (for explanations see Table 2). Note the considerable predominance of *Valvata piscinalis, Valvata piscinalis antiqua, Lymnaea auricularia, Gyraulus laevis* and their constant presence in the section

methods, dendrochronological and radiocarbon, at ca. 1 700 BC, the beginning of the Bronze Age (PRINKE & PRINKE 2001). Detailed analyses (KRĄPIEC 2001) proved that both the boat and the pales were made of trees growing around the lake at the same time. The location of the site where the boat was found may indicate that in the Early Bronze Age the southern shore of the lake was about 250 metres distant from the present shore. The mollusc fauna found in the boat was examined by the late Marta CISZEWSKA (unpublished data). It did not differ from that in the Niepruszewo-Cieśle site. Assuming that the depth of 1.15 m, at which the boat was found, corresponds to a similar depth in the succession described, samples 1-8 (depths 2.63-1.25 m) and samples 9-27 (depths 0.95-0.5 m) accumulated before and after 1 700 BC respectively. The date 1700 BC, the Early Bronze Age, refers to the middle Subboreal (Text-fig. 6).

Summing up, the accumulation of gyttja and lacustrine chalk probably started at the end of the Late Glacial (GOGOŁEK 1993) and lasted throughout the Preboreal, Boreal and Atlantic, until the middle Subboreal when the boat was made (PRINKE & PRINKE 2001). According to the assumptions made above, samples 9-27 accumulated after the middle Subboreal. Sedimentation continued until peat-bog developed in the study area.

CLIMATIC SIGNIFICANCE OF THE FAUNA

The mollusc fauna occurring in the Imiołki, Rybitwy and Niepruszewo-Cieśle sections exhibits wide climatic tolerance. It is composed of Holoarctic, Palaearctic and Eurosiberian species (Tables 1-3). The range of the species to the north, based on their recent distribution in Europe (sensu SPARKS 1961 and JAECKEL 1962 *In*: ALEXANDROWICZ 1987, Table 1), reveals the predominance of group N_5, i.e. molluscs extending beyond the Arctic Circle and reaching the northern coasts of the Scandinavian Peninsula, in all three sections (Tables 1-3). The elevated content of groups N_4 and N_3, i.e. species present up to latitudes 63°N and 60-61°N respectively, in calcareous gyttja at the Rybitwy site may result from a combination of more numerous species inhabiting shallower waters and a rise in the mean annual temperature. As for the Niepruszewo-Cieśle site, the presence of snails classified as group N_2, i.e. species inhabiting the European Lowlands and reaching the southern coasts of the Scandinavian Peninsula (samples 5, 9, 14, 16, 23), is consistent with an increased quantity of the mollusc fauna. The changes in richness between *Lymnaea auricularia* (LINNAEUS) and *Gyraulus laevis* ALDER (Table 4), observed in the Niepruszewo-Cieśle section, may reflect climatic fluctuations. An increased abundance of *L. auricularia*, a species showing a more restricted distribution to the north (N_3) than *G. laevis* (N_5) (Table 1), may indicate warmer conditions. This means higher temperatures for the middle unit of the section, (samples 9-20, depths 0.95-0.40 m), except for samples 12 and 16, where a sharp decrease in the numbers of *L. auricularia* is noted. According to the data presented above (see The Niepruszewo-Cieśle site, Stratigraphy), sediments covered by samples 9-20 most probably accumulated in the Upper Subboreal and the Lower Atlantic, for which an increase in the air temperature was noted (PAZDUR et al. 1988). The size of mollusc shells was clearly controlled by temperature. In the Imiołki and Rybitwy sites, all the mollusc shells were small and had thin walls indicative of a relatively low temperature, which is consistent with the Late Glacial age of both successions. In contrast, the numerous, large, well-developed shells with thick walls occurring in the Niepruszewo-Cieśle site indicate the much warmer climate during the Holocene.

CONCLUSIONS

The mollusc fauna occurring in the Imiołki, Rybitwy and the Niepruszewo-Cieśle sites is composed of species well-known from Pleistocene and Holocene lacustrine deposits in Poland. On the basis of the ecological preferences of species, and changes in their composition and numbers, it was possible to infer the environmental conditions that obtained during the accumulation of the successions described. The mollusc faunas present in the Imiołki and Rybitwy sites show that faunal composition and frequency may differ considerably between two closely adjacent sites yielding deposits that accumulated at the same time. Such a situation indicates local differences in the environments in which the molluscs lived. Local environmental conditions in the small, shallow water reservoir where the Imiołki sequence was accumulated were different from conditions in the deep and littoral zones of the Lake Lednica, where the Rybitwy sequence was deposited. The case of the Niepruszewo-Cieśle site, where only four mollusc species are abundantly present proves that large number of specimens may not be connected with a highly diversified assemblage. The molluscs occurring in this succession also show that temperatures higher than those at the Imiołki and Rybitwy sites did not result in a greater faunal diversity. A connection between size and wall-thickness of mollusc shells and climate has been noted. Mollusc shells present in the Rybitwy and Imiołki sections are considerably smaller and thin-walled in contrast to specimens occurring in the Niepruszewo-Cieśle site. The warmer climate that prevailed during the deposition of the Niepruszewo-Cieśle succession resulted in larger shells with thicker walls. The age of the Imiołki site was established as Late Glacial and the same is probably true for the Rybitwy site. Deposits in the Niepruszewo-Cieśle site probably accumulated through most of the Holocene.

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Appendix

Lithology of the investigated sites:

1. Imiołki

0 – 0.3 m – recent soil;
0.3 – 0.5 m – peat, initially brown, fen peat and moss peat, transiting into black peat;
0.5 – 0.54 m - mixed peat and gyttja;
0.54 – 2.39 m - light calcareous gyttja;
> 2.39 m - grey-blue, clayey silt;

2. Rybitwy

0 – 0.2 m – recent soil;
0.2 – 1.96 m – peat, initially brown than black and moss peat;
1.96 – 2.11 m - gyttja intercalated with peat;
2.11 – 2.93 m - calcareous gyttja, with colour changing from light to dark grey;
2.93 – 4.9 m - sandy gyttja;
> 4.9 m – blue-grey silt;

3. Niepruszewo-Cieśle

0 – 0.05 m – peat;
0.05 – 2.58 m – lacustrine chalk; successive units differ in colour from grey, trough pink, yellow-grey to cream and grey;
2.58 – 2.63 m – grey gyttja;