Acta Geologica Polonica, Vol. 66 (2016), No. 1, pp. 85–98
DOI: 10.1515/agp-2016-0004

DE G DE GRUYTER OPEN

Changes of sedimentation in the Drużno Lake based on geoarchaeological data from the Teutonic fortress in Elbląg, North Poland

JERZY NITYCHORUK[1], MARCIN SZYMANEK[2], KRZYSZTOF BIŃKA[2], MARIA KASPRZYCKA[3] and ŁUKASZ ZBUCKI[1]

[1]*Department of Geology, Pope John Paul II State School of Higher Education in Biała Podlaska, Sidorska 95/97, PL-21-500 Biała Podlaska, Poland.*
E-mail: jerzy.nitychoruk@pswbp.pl
[2]*Institute of Geology, University of Warsaw, Żwirki i Wigury 93, 02-089 Warszawa, Poland.*
[3]*Museum of Archaeology and History in Elbląg, Bulwar Zygmunta Augusta 11, 82-300 Elbląg, Poland.*

ABSTRACT:

Nitychoruk, J., Szymanek, M., Bińka, K., Kasprzycka, M. and Zbucki, Ł. 2016. Changes of sedimentation in the Drużno Lake based on geoarchaeological data from the Teutonic fortress in Elbląg, North Poland. *Acta Geologica Polonica*, **66** (1), 85–98. Warszawa.

The wooden structures unearthed in 2012 during archaeological excavation in the courtyard of the Museum of Archaeology and History in Elbląg have been dated using the dendrochronological method to the period between 1245 and 1302, which allows them to be considered to be parts of a Teutonic fortress. The remains of the wooden building located directly on the prehistoric lacustrine sediments created a unique opportunity to reconstruct the near-shore sedimentation of the Drużno Lake. Geological, malacological and palynological methods were applied during the investigation. The results, compared with the ranges of both the Drużno Lake and the Vistula Lagoon, known from previous studies of the region, allowed the correlation of a phase of a deep lake with the "Roman Period". Rapid shallowing of the lake occurred in the "Migration Period". The final disappearance of the lake in the area of modern Elbląg occurred in the early Middle Ages.

Key words: Lacustrine sediments; Teutonic fortress; Malacology; Palynology .

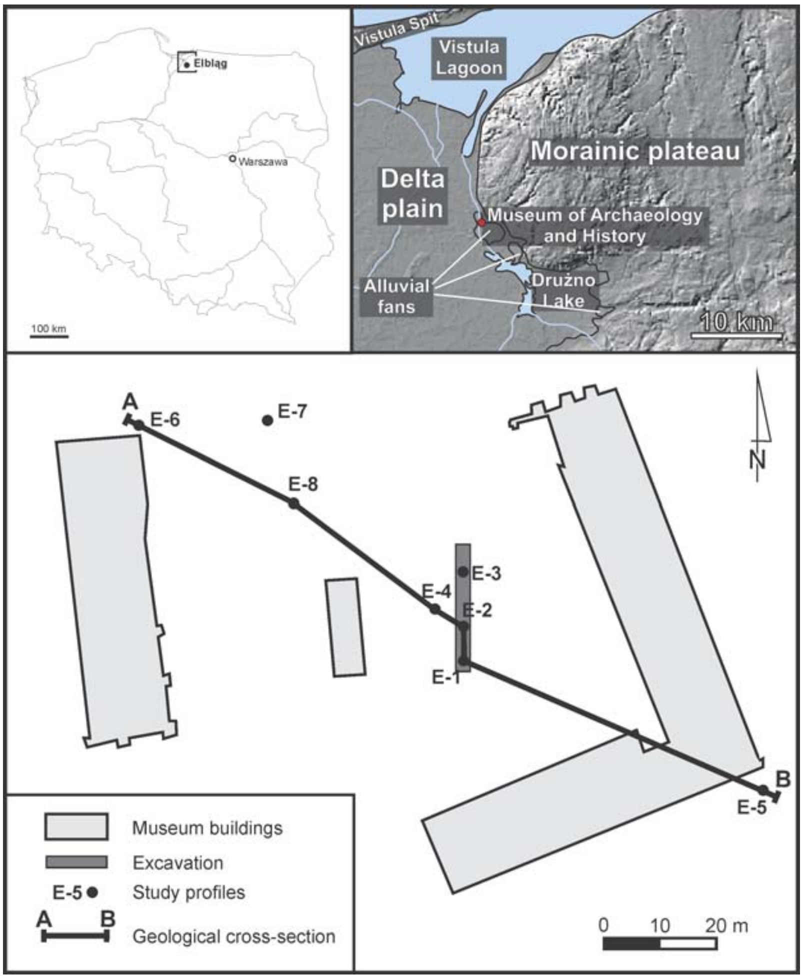
INTRODUCTION

The described Teutonic fortress at Elbląg is located at the Żuławy marshland, which is a part of the Vistula delta, north-central Poland. Delta habitats, counted among the most dynamic ones, involve an intense deposition of alluvia. River deltas are also the most commonly populated areas due to the fertility of the soil and the transport facilitated. The development of the delta and human activity are closely associated with each other, which allows for reconstruction of the settlement in the delta as well as dating the stages of alluvial sedimentation. The development of the Vistula delta is very interesting in the context of man colonising the area.

A number of scientific papers on the development of the Vistula delta have been written so far, based on the study of lacustrine sediment cores collected from the Drużno Lake and from the Vistula Lagoon. These papers allowed the reconstruction of the stages of increased salinity associated with the Littorina transgression and the subsequent influence of saline water from the Baltic Sea. Strengthening of the Vistula Spit at the beginning of the Subatlantic period resulted in an isolation of the Vistula Lagoon water (Przybyłowska 1973a, b; Przybyłowska-Lange 1974; Bogaczewicz-Adamczak 1980; Zachowicz *et al*. 1982; Bogaczewicz-Adamczak and Miotk 1985; Zachowicz 1985; Zachowicz and Kępińska 1987; Miotk-Szpiganowicz *et al*. 2007; Uścinowicz *et al*. 2013). The aforementioned studies did not present specific changes in the ranges of the Vistula Lagoon and of the Drużno Lake during the Holocene. The latter were determined amongst other by Bertram (1924) and Długokęcki (1992), but mostly with respect to the last millenium and archaeological and historical sources. In the 1990s, the first reconstructions of the range of the Drużno Lake and the Vistula Lagoon were conducted based mainly on geological research with the support of archaeological data (Kasprzycka *et al*. 1996, 1997; Kasprzycka 1999).

In 2012 in the courtyard of the Museum of Archaeology and History in Elbląg (Text-fig. 1) an archaeological excavation revealed huge wooden structures for which dendrochronological dating was performed (Ważny 2012). The oldest piece of the oak foundations was dated to the year 1245, and the newest to 1302, which identify the study site as the fragments of a Teutonic fortress dating back to the mid-thirteenth century, situated near the location where a stone castle was later erected. The Teutonic Knights moved here from an island on the Elblg River following the destruction by the Pogesanians of a wooden and earthen fortified settlement existing since 1237 (Kozłowska 2005). Archaeological investigations carried out in 2013 found evidence that the wooden fortress existed before and while the stone castle was being built. Afterwards this became a castle borough with temporary wooden or both wooden and stone buildings.

The remains of the wooden structure in the courtyard of the Museum of Archaeology and History in Elbląg



Text-fig. 1. Location of the study area, including the location of boreholes and geological cross-section through the courtyard of the Museum of Archaeology and History in Elbląg are located directly on the prehistoric lacustrine sediments, creating a unique opportunity to reconstruct the near-shore sedimentation and possible changes in the shoreline. In this paper a geological, geomorphological, malacological and palynological analyses has been conducted with respect to the sediments constituting the direct substrate of the timber structures. They allowed for the reconstruction of the changes in the lake depth and for an analysis of the changes in vegetation caused by human activity.

MATERIALS AND METHODS

The image of the geological structure visible in the archaeological excavation (Text-fig. 2) was supplemented by 8 fully cored boreholes performed with the use of an Eijkelkamp percussion drilling equipment in both the bottom of the excavation and its surroundings, and used for the preparation of the A–B geological cross-section (Text-fig. 3). Fourteen samples obtained from the boreholes were subjected to palynological and malacological analyses which allowed for a detailed reconstruction of the environment during the deposition of sediments.

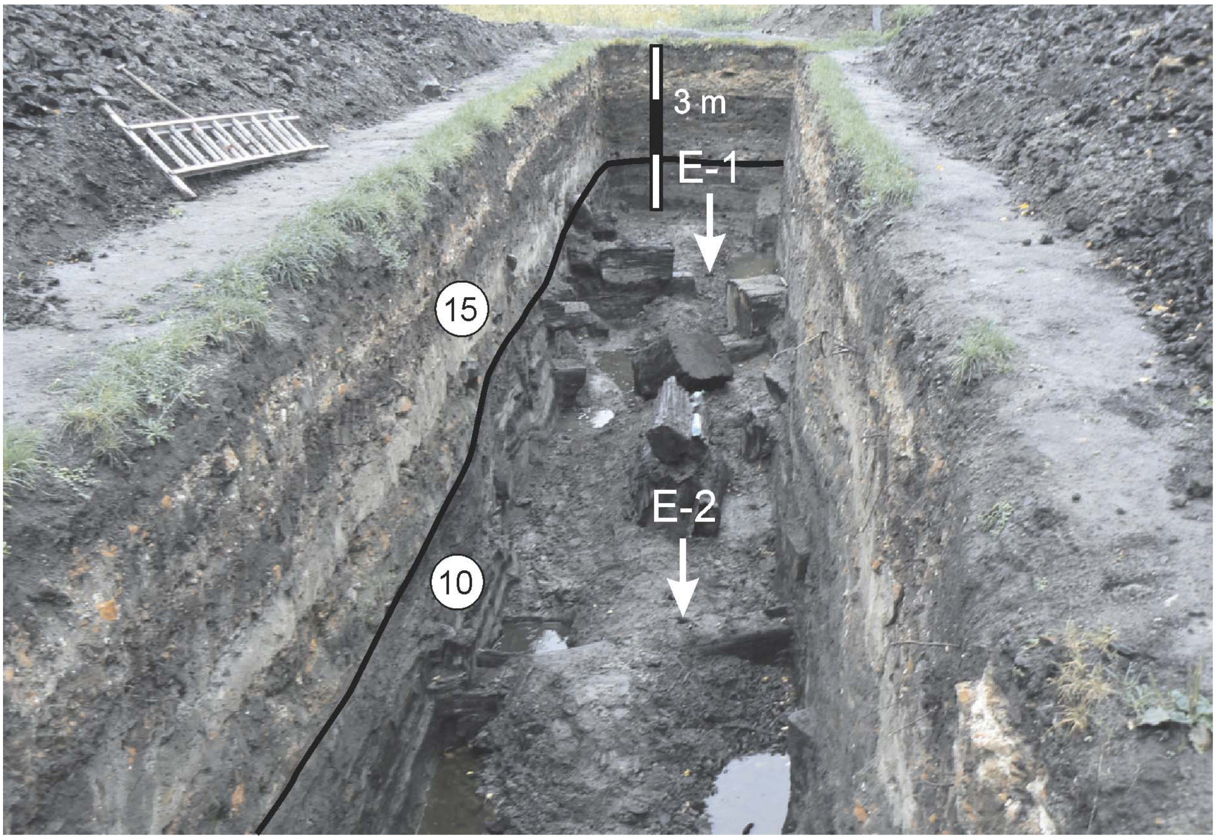
DENDROCHRONOLOGICAL DATING

Altogether 19 wood samples taken at the courtyard of the Museum of Archaeology and History in Elbląg were subjected to dendrochronolgical analysis (Ważny 2012). Annual tree-ring widths were measured with a LINTAB measuring equipment with the accuracy of 0.01 mm. Cross-dating was done with the use of CATRAS v. 4.20 (Aniol 1983), TSAPWin (Rinn 1989-1999) and DENDRO for WINDOWS applications. The results are illustrated in the bar chart (Text-fig. 4).

MOLLUSC ANALYSIS

A total of 6 samples collected from 5 boreholes (E-1, E-2, E-4, E-5, E-6) were subjected to malacological investigation at Elbląg. Deposit samples covered 10, 15 and 20 cm intervals and had a volume of 50–130 cm^3. Despite the relatively small volume of samples, mollusc shells were abundant and well preserved.

Standard malacological procedures described by Ložek (1964), Alexandrowicz (1987) and Alexandrowicz and Alexandrowicz (2011) were applied in the analysis. Deposits were sieved (mesh size 0.5 mm) to collect



Text-fig. 2. View of the wooden structure exposed in the archaeological excavation conducted in the courtyard of the Museum of Archaeology and History in Elbląg all mollusc shells and identifiable shell fragments. After identification and counting, all the species were grouped according to their ecological demands (after Ložek 1964; Alexandrowicz 1987; Alexandrowicz and Alexandrowicz 2011) (Table 1). Changes in the mollusc assemblage were illustrated on malacological spectra (Text-fig. 5) and a synthetic malacological diagram (Text-fig. 6). The latter consists of the lowermost sample (E-4, from the altitude of -2.8 – -3.0 m a.s.l.), the unit of three samples from the E-4, E-5, E-6 profiles, sample E-1 and sample E-2 on the top.

POLLEN ANALYSIS

Pollen analysis was conducted for eight samples, including one sample from the E-1 borehole from the altitude of -1.6 – -1.7 m a.s.l., one sample from the E-2 borehole (-1.4 – -1.5 m a.s.l.), three samples from the E-6 borehole from altitudes of -0.7 – -0.8, -1.5 – -1.7 and -1.7 – -2.0 m a.s.l. and three samples from the E-8 borehole from altitudes of -0.5 – -0.7, -0.8 – -0.9 and -1.7 – -1.8 m a.s.l. (Text-fig. 3). The floristic succession of both the E-6 and E-8 profiles was illustrated by pollen diagrams (Text-figs 7, 8).

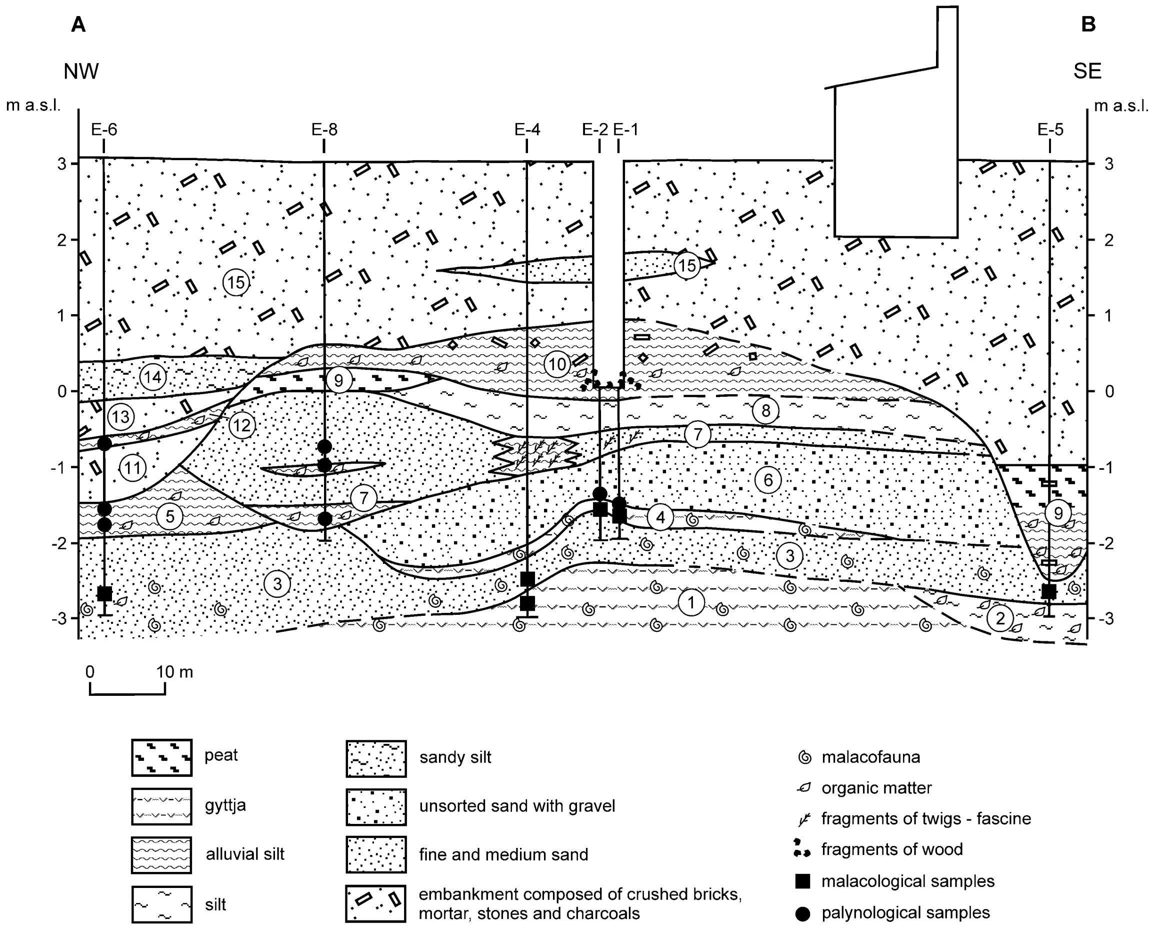
Because the aim of the pollen research was to characterise the environmental conditions in certain parts of the profiles rather than to reconstruct the full floristic succession in the region, only individual samples were investigated.

Samples for pollen analysis were treated with a cold HF and washed with 10% HCl, boiled in 10% KOH and finally treated by the traditional Erdtman's acetolysis. About 800 grains at x 400 magnification were counted in each sample.

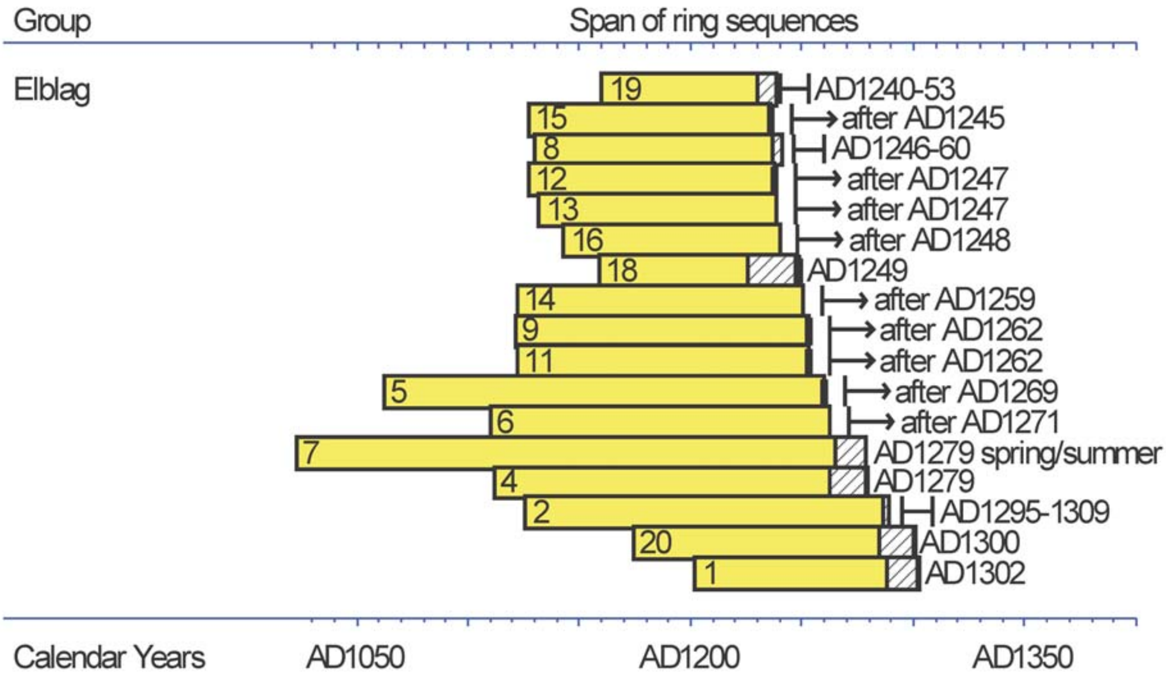
RESULTS

The geological structure of the courtyard of the Museum of Archaeology and history in Elbląg

During the geological investigation of the Elbląg site altogether 15 layers of deposits have been distinguished. They represent lacustrine and alluvial sedimentation and are characterised by a significant human impact in the uppermost part of the section (Text-fig. 3).



Text-fig. 3. Geological cross-section through the courtyard of the Museum of Archaeology and History in Elbląg along the A–B line



Text-fig. 4. Tree-ring chronology of the Old Town at Elbląg (after Ważny 2012)

The layers marked on the A–B geological cross-section (Text-fig. 3) as 1 to 4, which formed as gyttjas, silts with organic matter and fine sands with malacofauna, represent typical lacustrine sediments. Their variability is characteristic of the shoreline of a lake of varying depth.

Alluvial silts in layer 5 indicate a steady sedimentation with traces of flows. Layers marked as 6 to 8 on the geological cross-section, composed of sands with sparse gravel, sands with inserts of silts with organic matter as well as by silts, were formed as a result of flow with periods of steady sedimentation (layer 8). Within layer 7 there is a fascine, which is a product of human activity, used to stabilise the land as a foundation for the wooden structure visible in the archaeological excavation.

Deposits of steady biogenic sedimentation (alluvial silts with organic matter, peats) have been recorded in layer 9. The occurrence of fragments of bricks and mortar (E-5 borehole) are evidence of human activity during their deposition. The nature of this series originating from a small water body with no outflow probably indicates the sedimentation in a moat.

Alluvial silts with organic matter connected probably with water level changes are present in layer 10. The occurrence of crushed bricks in its upper part as well as in layers 11 and 13 is evidence of human activity.

Layer 12 (alluvial silts with organic matter) is devoid of brick fragments, but its position between horizons with crushed bricks suggests the accumulation during periods of high water level or that they had flowed down the slope.

Layer 14 consists of sand with bedding characteristic of the conditions of natural sedimentation.

The most modern series of sediments (number 15 on the geological section) is an embankment consisting of crushed bricks, mortar, stones and charcoal and may be dated to the 20th century.

Dendrochronology

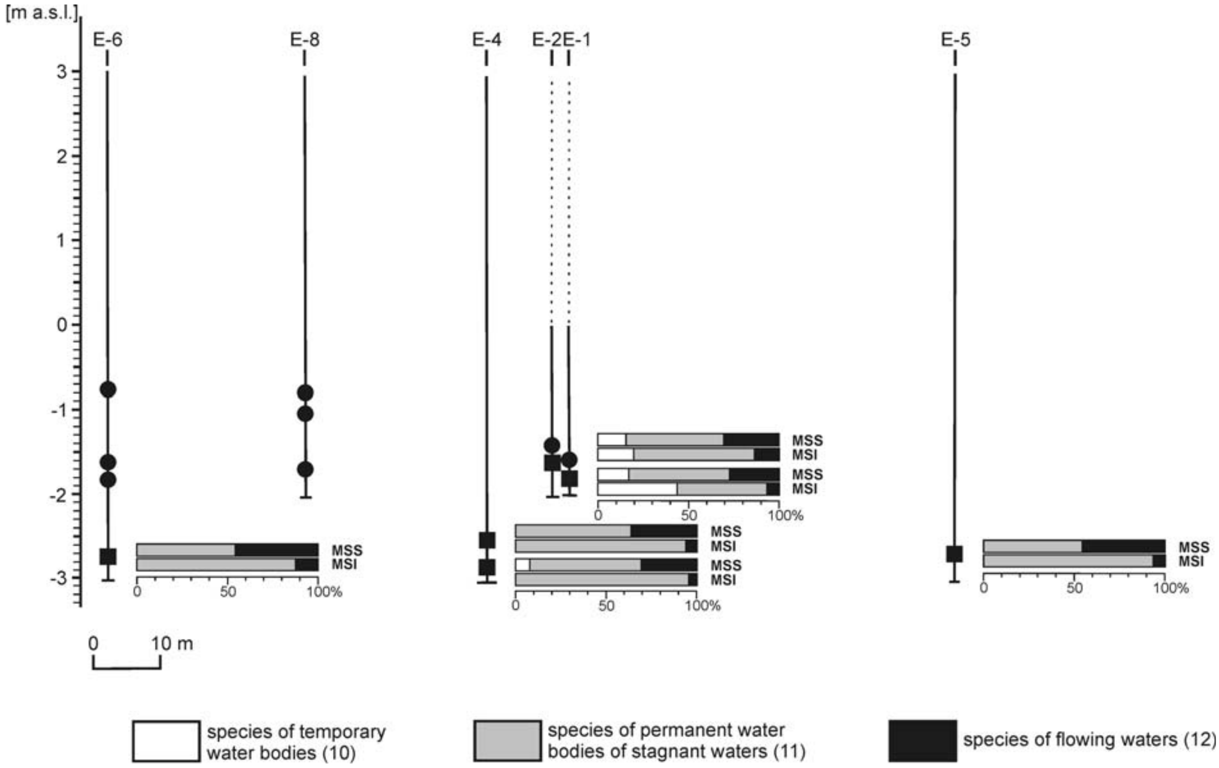
Among the 19 tested samples, 18 represented oak and 1 alder. Altogether 17 oak elements were dated successfully. All samples were assigned to the 13th century and the beginning of the 14th century (Text-fig. 4). Samples 9 and 11 were taken from the same tree trunk. The oak wood under investigation is characterised by a high quality and very regular structure of annual tree-rings. It appears that 150–250 year old oaks were cut down to build the Teutonic fortress at Elbląg.

Mollusc assemblage at Elbląg

The mollusc assemblage at Elbląg is composed of 33 taxa with a total of 3362 specimens. They represent 17 taxa of snails and 16 of bivalves. The number of taxa and specimens varies from 13 to 24 and from 330 to 837 per sample respectively. The most abundant are molluscs from the E-5 and E-1 boreholes, with the number of specimens exceeding 800. The malacocoenosis from the E-1 profile is also the most diverse

I	II	Taxa	Samples					
			E1 -1.7 -1.8 m a.s.l.	**E2 -1.55 -1.7 m a.s.l.**	**E4 -2.5 -2.6 m a.s.l.**	**E4 -2.8 -3.0 m a.s.l.**	**E5 -2.6 -2.8 m a.s.l.**	**E6 -2.7 -2.8 m a.s.l.**
10	Wp	*Bithynia leachi* (Sheppard, 1823) (+operculum)	24 (77)	5 (24)				
10	Wp	*Valvata cristata* Müller, 1774	209	21		1		
10	WP	*Segmentina nitida* (Müller, 1774)	4					
11	We	*Bithynia tentaculata* (Linnaeus, 1758) (+operculum)	22 (211)	12 (63)	4 (5)	2 (1)	7 (1)	5 (1)
11	We	*Marstoniopsis scholtzi* (Schmidt, 1856)	1					
11	We	*Valvata piscinalis* (Müller, 1774)	45	50	228	337	676	274
11	WL	*Valvata piscinalis* f. *antiqua* Sowerby, 1838				14	2	
11	WL	*Acroloxus lacustris* (Linnaeus, 1758)	23	3				
11	We	*Gyraulus albus* (Müller, 1774)	12					
11	Wl	*Hippeutis complanatus* (Linnaeus, 1758)	19	4				
11	We	*Sphaerium corneum* (Linnaeus, 1758)	2		1			
11	We	*Pisidium casertanum* (Poli, 1791)				2		1
11	We	*Pisidium casertanum* f. *ponderosa* Stelfox, 1918		4	4	2	3	4
11	We	*Pisidium henslowanum* (Sheppard, 1823)	12	22	15	4	21	50
11	WL	*Pisidium lilljeborgii* Esmark & Hoyer, 1886			1	2	4	2
11	We	*Pisidium moitessierianum* Paladilhe, 1866	2	7	3	8	9	9
11	We	*Pisidium crassum* Stelfox, 1918	2					
12	Wc	*Theodoxus fluviatilis* (Linnaeus, 1758)	1					1
12	Wc	*Borysthenia naticina* (Menke, 1845)	6	12	8	1	20	26
12	We	*Unio tumidus* Philipsson, 1788					2	
12	We	*Sphaerium rivicola* (Lamarck, 1818)		1				
12	Wc	*Sphaerium solidum* (Normand, 1844)			2		5	2
12	Wc	*Pisidium supinum* Schmidt, 1851	2		2	1	6	11
12	We	*Pisidium nitidum* Jenyns, 1832	30	16	4	11	13	6
12	We	*Pisidium subtruncatum* Malm, 1855	6	5		2	3	3
		Bithynia sp.	52	17				
		Valvata sp.	41	51	113	89	49	75
		Sphaerium sp.	k			k	4	4
		Radix sp.	1	1				
		Pisidium sp.	25	12	6	6	11	12
		Clausiliidae					1	
		Planorbidae				1		
		Unionidae	d	d			d	
Total			829	330	396	484	837	486

Table 1. Malacofauna of the Elbląg site. I – ecological groups (after Ložek 1964; Alexandrowicz1987; Alexandrowicz and Alexandrowicz 2011): 10 – species of temporary water bodies, 11 – species of permanent water bodies of stagnant waters, 12 – species of flowing waters; II – supplementary ecological symbols (after Ložek, 1964, 1976, 1982; Körnig 1966; Piechocki 1979): WP – molluscs of episodic, periodically drying out water bodies, Wp – molluscs of shallow, intensively overgrown water bodies, Wl – molluscs of stagnant and slowly flowing waters, WL – species of permanent water bodies of various size, species present both in rivers and lakes, in stagnant and flowing waters, Wc – species preferring flowing waters with weak current; k – a few bits of shell, d – shell detritus.

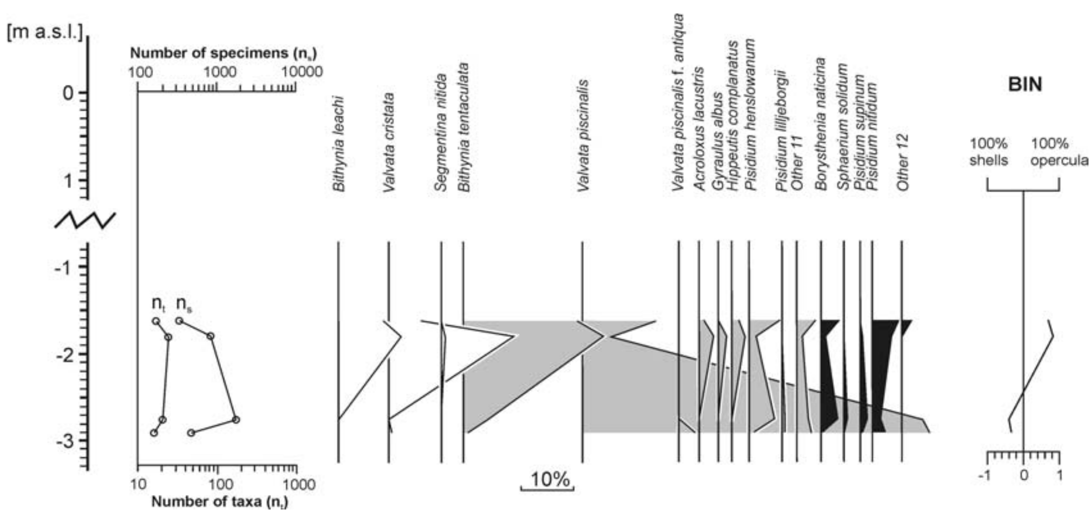


Text-fig. 5. Malacological spectra of species (MSS) and specimens (MSI) of the Elbląg site. For other explanations see Fig. 3

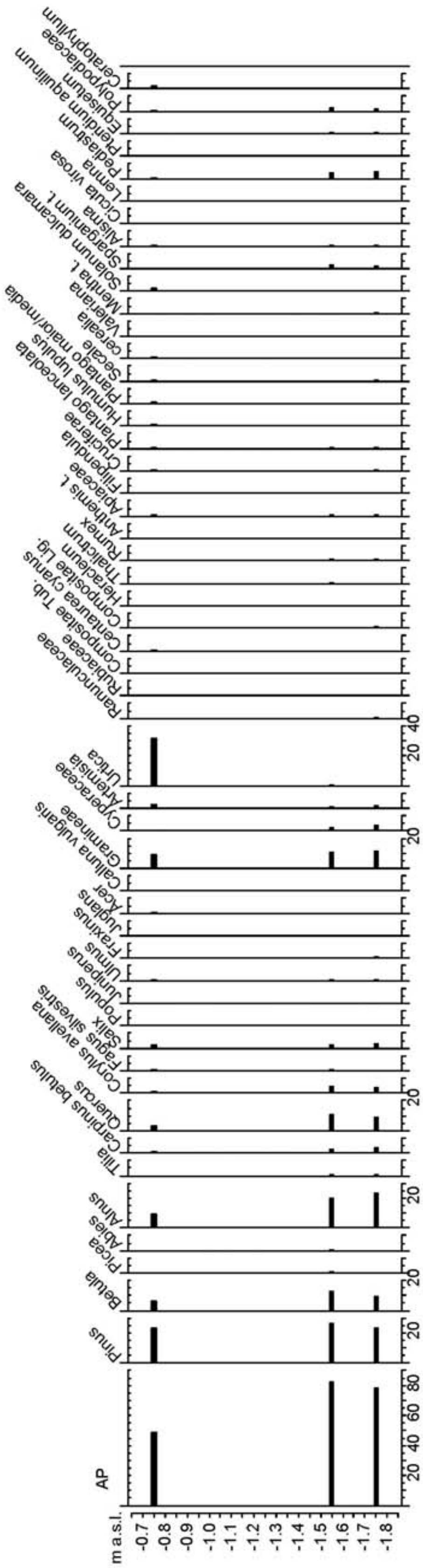
and comprises 24 taxa. Only 13 taxa and 396 specimens were found at the E-4 profile (-2.5 – -2.6 m a.s.l.), whereas the lowest number of species is noted at the E-2 profile (Table 1).

Except for a single shell fragment of land clausiliid snail, all the determined mollusc species inhabit freshwater environments. They represent three ecological groups: species of temporary water bodies (10), species of permanent water bodies of stagnant waters (11) and species of flowing waters (12), supplemented by 6 classes (Table 1). Rheophile species (group 12) make up to 46% of the studied malacocoenoses, but they are clearly outnumbered by specimens characteristic of permanent water bodies of various sizes (group 11), which play a dominant role in the assemblage with proportions of 49–96% (Text-fig. 5).

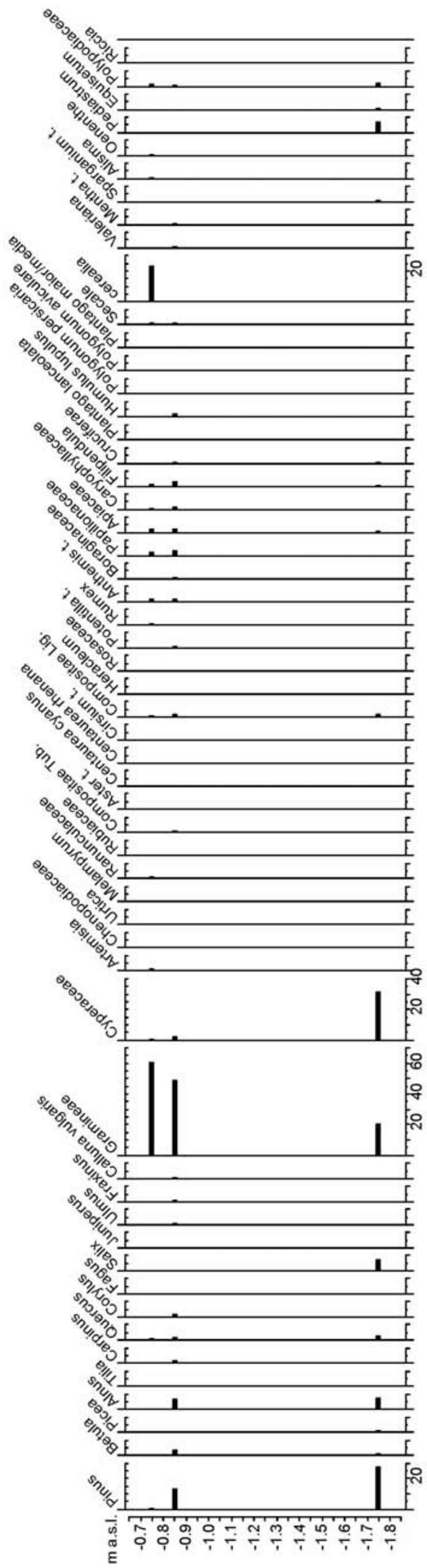
Molluscs of temporary water bodies (group 10) occur in the lowermost and uppermost parts of the succession. At the bottom of the section only one specimen is noted. Considerable amounts of this group appear at



Text-fig. 6. Synthetic malacological diagram and the Bithynia-index (BIN) of the Elbląg site



Text-fig. 7. Pollen histogram for the sediment samples from the E-6 borehole



8. Pollen histogram for the sediment samples from the E-8 borehole

the altitude of -1.55 – -1.8 m a.s.l. (profiles E-1 and E-2). They constitute 15–17% of all species and even 44% of all specimens (Text-fig. 5). As evidenced by the malacological spectra, the basis of the assemblage is formed by lacustrine species, with *Valvata piscinalis* f. *antiqua*, *Acroloxus lacustris* and *Pisidium lilljeborgii*. Shallow, overgrown water bodies or the near-shore zones of lakes are often inhabited by *Bithynia leachi* and *Valvata cristata* (Piechocki 1979; Glöer 2002; Welter-Schultes 2012). Higher energy conditions are suitable for, among others, *Theodoxus fluviatilis*, *Borysthenia naticina*, *Sphaerium solidum* and *Pisidium supinum*. They are most common in rivers, but may sometimes occur in lakes in habitats with distinct water movements – e.g. currents, wave action or overflow (Piechocki 1979; Piechocki and Dyduch-Falniowska 1993; Glöer 2002; Welter-Schultes 2012).

Mollusc communities from the lower part of the succession (profiles E-4, E-5, E-6, altitudes of -2.6 – -3 m a.s.l.) reflect fewer species in comparison with the uppermost samples (E-1, E-2) (Table 1). The characteristic feature is a mass occurrence of the snail *Valvata piscinalis* with its lake form *V. piscinalis* f. *antiqua*. Among the accompanying species, *B. naticina*, *Pisidium henslowanum* and *P. supinum* are frequently found. Noteworthy is an insignificant participation of *Bithynia tentaculata*, with shells outnumbering the opercula (the Bithynia-index (BIN) from -0.75 to -0.11; Text-fig. 6).

Expansion of this species is noted in the E1 and E2 profiles (-1.7 – -1.8 m a.s.l. and -1.55 – -1.7 m a.s.l.). It replaces *V. piscinalis* and becomes the main element of the assemblage with a significant predominance of opercula over shells (BIN in the range of 0.61–0.89). The structure of the malacocoenoses distinctly changes. The fauna is more diverse, with abundant snails typical of shallow, dense overgrown bodies of water: *V. cristata*, *B. leachi*, *A. lacustris*, *Gyraulus albus*, and *Hippeutis complanatus*, which are absent in the lower part of the succession. Nevertheless, considerable amounts of *P. henslowanum*, *P. nitidum* and other rheophile species are still noted in the assemblage (Table 1, Text-figs 5, 6).

Mollusc shells in the E1 profile (-1.7 – -1.8 m a.s.l.) are accompanied by single ostracods. One specimen of *Limnocytherina sanctipatricii* (Brady et Robertson), *Herpetocypris reptans* (Baird) as well as two valves of *Candona* sp. are present. *L. sanctipatricii* is a lake species, whereas *H. reptans* inhabits small, permanent water bodies or near-shore zones of lakes with dense vegetation and muddy bottom (Sywula 1974), which is in accordance with malacological data.

Pollen analysis

Three samples obtained from the E-6 borehole from altitudes of -0.7 – -0.8, -1.5 – -1.7 and -1.7 – -2.0 m a.s.l. are characterised by the presence of abundant herbaceous vegetation (Text-fig. 7).

Pollen spectra of the E-6 borehole are characterised by the low frequency of AP pollen (arboreal pollen) with the most abundant *Alnus* (alder), *Quercus* (oak), *Pinus* (pine), *Betula* (birch), *Carpinus betulus* (hornbeam) and a high content of NAP (non-arboreal pollen). The AP frequency decreases in the uppermost part of the section, from ca. 80% to ca. 50%. The NAP is represented mostly by *Gramineae* (grasses), *Cyperaceae* (sedges), *Artemisia* (mugwort) and numerous types of herbaceous pollen. In the uppermost sample (-0.7 – -0.8 m a.s.l.) we find the highest content of pollen of the *Urtica* (nettle) and Scrophulariaceae family. This over-representation of pollen confirms partly the occurrence of numerous nettle seeds (apart from elder) in this sample.

In addition, the pollen of *Secale* (rye), other unidentified cereals and accompanying weeds such as *Centaurea cyanus* (cornflower) are noted, pointing to some form of agriculture. The frequency of cereals, although somewhat higher in the uppermost sample, does not prove its cultivation. Rich herbaceous vegetation is also emphasised by the appearance of *Plantago lanceolata* (plantain), *Heracleum* (hogweed), *Rumex* (sorrel) and other plants.

The pollen spectra are completed by some water plants and forms connected with the shore zones of water bodies and wetlands, such as *Urtica* (nettle), *Solanum dulcamara* (nightshade), *Humulus lupulus* (hop), *Filipendula* (dropwort), *Sparganium* (bur-reed), *Pediastrum*, *Lemna* (duckweed), *Ceratophyllum* (hornwort), *Alismataceae*, and *Nymphoides peltata* (Fig. 7).

Three samples subjected to pollen analysis were obtained from the E-8 borehole from depths of -0.5 – -0.7, -0.8 – -0.9 and -1.7 – -1.8 m a.s.l. (Text-fig. 8).

The bottommost sample from the altitude of -1.7 – -1.8 m a.s.l. was probably affected by dry conditions, which resulted in poor pollen preservation, especially corrosion of the exine and general destruction of organic matter. The pollen content is low. The relative AP frequency (*Pinus*, *Alnus*, *Quercus*, *Salix*) is slightly higher than in the samples from the upper part of the section. The NAP is dominated by *Gramineae* and *Cyperaceae*. Particularly interesting are two genera - *Cyperus* and *Riccia*, indicating the existence of the muddy lake shores, drying in the late summer. This lake was surrounded by a band of shore plants (single pollen of *Sparganium* and *Filipendula*). In turn, coenobia of *Pediastrum* show the lake with a rather low water level.

The low number of pollen types constituting the NAP is also noteworthy.

The two topmost samples are characterised by a minimal frequency of arboreal pollen. Non-arboreal pollen is dominated by *Gramineae* and cereals (rye, however, appears only occasionally). The pollen concentration is higher in the topmost sample from the altitude of -0.5 – -0.7 m a.s.l. Similarly, more numerous types of pollen of herbaceous plants are noted in this sample than in the one from the altitude of -0.8 – -0.9 m a.s.l. In the spectra there are quite numerous weeds with two pollen types of plantains, *Polygonum aviculare* (knot-grass), *Heracleum*, two types of cornflower and a number of other plants. Wetland plants are only represented by those scantly appearing in the shoreline communities or on the surrounding wetland areas – *Filipendula*, *Humulus lupulus*, *Alismataceae* and *Oenanthe* (Text-fig. 8).

The sample collected from the E-2 borehole from the altitude of -1.4 – -1.5 m a.s.l. has a very low pollen content, the pollen being highly corroded and often with degraded exine, with an addition of Tertiary pollen.

The pollen grains present in the sample from the E-1 borehole at the depth of -1.7 – -1.8 m a.s.l. are well preserved, having been accumulated in a humid environment. The spectrum is dominated by the pollen of *Alnus*, *Pinus silvestris*, *Betula*, and *Quercus*, as well as by *Gramineae*, *Cyperaceae* and *Pediastrum*, *Sparganium*, *Sagittaria*, and *Alisma*.

DISCUSSION

Both the type of sediment and the structure of the mollusc assemblage at Elbląg point to freshwater environments. The mollusc composition as well as the numerous and constant occurrence of bivalve *Pisidium henslowanum* suggest that it was a lake with an overflow. At least two distinct phases of variable conditions and lake development are reflected in the faunal changes.

An older phase (the altitude interval of -2.6 – -3 m a.s.l.) is characterised by a high proportion of *V. piscinalis* and low abundance of *B. tentaculata*, which may document a deeper part of the lake with relatively poor aquatic vegetation. *Valvata piscinalis* is usually the most frequent at depths of 8–10 m, whereas *B. tentaculata* usually inhabits shallower zones – circa 0.7–1.8 m (Piechocki 1979; Alexandrowicz 1987, 1999a; Alexandrowicz and Alexandrowicz 2011). It is worth noting that non-synchronous occurrence of these species is quite common in lake deposits and often *V. piscinalis* covers the main phases of lake development and subsequently *B. tentaculata* appears (Alexandrowicz 1999a, b, 2002, 2007, 2009; Wojciechowski 2000; Alexandrowicz and Alexandrowicz 2010). A predominance of *B. tentaculata* shells over the opercula (very low values of BIN) points to the lack of dense reeds and bulrush and/or the overflow through the lake (Steenberg 1917; Sparks 1964; Gilbertson and Hawkins 1978; Alexandrowicz 1999a; Sanko *et al*. 2011). The latter is also supported by a significant number of *Pisidium supinum* and *Borysthenia naticina* in the assemblage (Table 1, Text-fig. 6).

The high number of opercula of the predominant *B. tentaculata* suggests intensive growth of reeds in the younger phase of the lake's existence (altitude of -1.55 – -1.8 m a.s.l.). Abundant species of shallow, temporary water bodies, the plant-associated forms (e.g. *Bithynia leachi*, *Valvata cristata*, *Acroloxus lacustris*), and ostracods *Limnocytherina sanctipatricii* and *Herpetocypris reptans* indicate the low water level, a very rich vegetation and probably a limited extent of the lake, which may support the increase of its trophy. This may have influenced the disappearance of *Pisidium lilljeborgii*, which avoids eutrophic waters (Piechocki and Dyduch-Falniowska 1993) and the expansion of *V. cristata*, which prefers such habitats (Welter-Schultes 2012). The lake was still (at least temporarily) fed by running waters, as evidenced by abundant *P. henslowanum*, *P. nitidum* and other rheophile species (Table 1, Text-figs 5, 6).

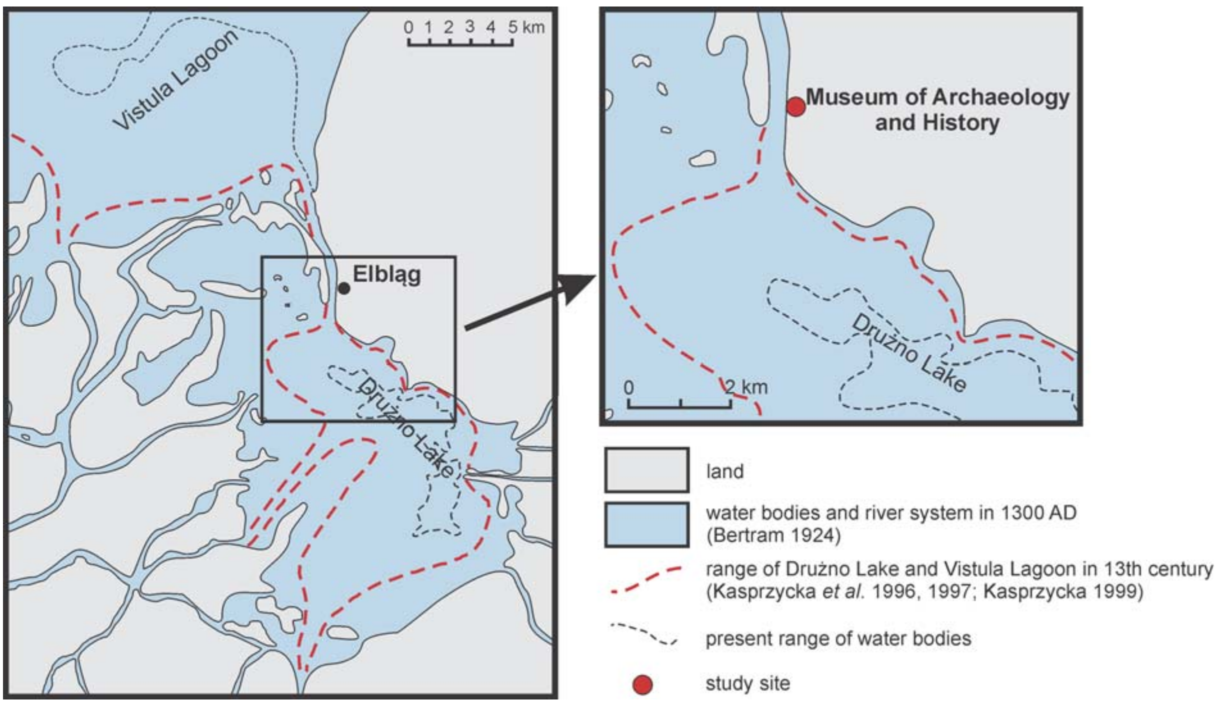
None of the occurring species has stratigraphical significance. Most of them have wide climatic tolerance; however, the presence of thermophilous *B. leachi*, *B. tentaculata*, *B. naticina*, and *P. moitessierianum* suggests a temperate climate and conditions suitable for fauna development. Worth noting is the occurrence of *Pisidium lilljeborgii*, regarded as a post-glacial relict. There is no data about its presence in the Vistula delta, but it seems to be quite common in lakes of northern Poland, especially the Pomerania region, where it has recently been noted at over a dozen sites (Piechocki 1985, 1989; Piechocki and Dyduch-Falniowska 1993; Welter-Schultes 2012).

Based on both the malacological analysis and the type of the deposits, it can be concluded that during the sedimentation of layers 1 to 4 the study area was a lake which had evolved from a deeper body of water (1) through a shallowing flow-through pool (2 and 3) to a shallow overgrown lake with malacofauna characteristic of the coastal zone (4) (Text-fig. 3). A typical freshwater malacofauna association, the absence of species of brackish and sea water as well as the earlier reconstructions of the range of the Drużno Lake may indicate that the Elbląg site represents the waterside of this body of water.

The multi-disciplinary reconstructions of Holocene palaeoenvironmental and palaeohydrological changes based on other lakes of Poland, including malacological investigations (e.g. Wojciechowski 1999, 2000), indicate the phases of high water level ca. 9500–8500 BP, 7000–6500 BP, 6000–5500 BP, 2500–2000 BP and 1700–1200 BP. A water level drop recorded in malacological successions is correlated with the intervals of ca. 10000–9300 BP, 8000–7200 BP, 6400–6100 BP, 4800–4100 BP, 3500–2800 BP, and 2000–1800 BP and was continued with some fluctuations until the Mediaeval Warm Period (10^{th}–13^{th} century) (Wojciechowski 1999, 2000). The unequivocal correlation of molluscs from Elbląg with one of these events is practically impossible, but during previously conducted research on the ranges of the Drużno Lake and the Vistula Lagoon (Kasprzycka *et al*. 1996, 1997; Kasprzycka 1999) the period of a deep lake was dated approximately to the "Roman period" or ca. 2100 years BP. The progressive shallowing of the lake was related to the "Migration Period", whereas its final overgrowing probably occurred in the Early Middle Ages (Kasprzycka *et al*. 1996, 1997; Kasprzycka 1999). The latter is also suggested by dendrochronological dating (Ważny 2012). In general, such chronology, including the accumulation of layers 1–4, appears to be in accordance with palaeohydrological changes reconstructed by Wojciechowski (1999, 2000) in central and western Poland.

The subsequent layers (from 5 to 7) were probably accumulated during the historical period. Their pollen spectra indicate the presence of abundant herbaceous vegetation. The low percentage of arboreal pollen (layer 5) indicates a rather treeless landscape locally with sparse clusters of alder, oak, birch, pine and hornbeam. Macroremains of *Sambucus nigra* and *Urtica* indicate the relatively wet and nitrogenic habitats. A number of plants associated with the open water, lakeshores or wet areas suggest a periodic flooding of the study site and gradual withdrawing of the lake.

Higher in the succession (layer 7), a cyclic drying in the near-shore zone of the lake is evidenced. The floristic composition is probably typical of a forest with an overabundance of grasses and sedges, although the presence of open areas cannot be ruled out. The low percentages of arboreal pollen point to the existence of intense deforestation and large open spaces, especially in a later phase of the accumulation of layer 7. Numerous cereals and weeds (two pollen types of plantains, knot-grass, two types of cornflower and others**)** indicate the existence of fields and pastures. The area was probably no longer plagued by flooding, although there were wet areas nearby, indicated by the *Oenanthe*, *Humulus* and *Alisma*. This fascine-bearing horizon appears to be a good foundation for a wooden fortress being built at that time. Cereal pollen indicates the intensification of agriculture in the region, but it is dif-



Text-fig. 9. The range of the Drużno Lake in 1300 according to Bertram (1924) and in the 13^{th} century determined on the basis of geological studies conducted by Kasprzycka *et al*. (1996, 1997) and Kasprzycka (1999) ficult to resolve whether this was early mediaeval or mediaeval activity.

The oak pollen content varying between 13.0 and 0.8 % in analysed samples may suggest that the intensification of human activities was followed by logging of oaks. The most spectacular example of that is the oak structure visible in the archaeological excavation in the courtyard of the Museum. The construction of the oak building might have been accompanied by digging a surrounding moat documented in the geological cross-section (Text-fig. 3, layer 9).

Abundant crushed bricks also occur in layers 11, 13 and 15, and only sands from layer 14 appear to represent the conditions of natural sedimentation. The ceramic finds of the 17th and 18th centuries in layers 11 and 13 may suggest that these sands were accumulated later, probably as a result of the catastrophic flood of 1888.

To sum up the geological, faunal and floristic investigations, it appears that the sediments which underlie the courtyard of the Museum of Archaeology and History in Elbląg document the evolution of this area from a relatively deep lake, through a shallowing water body, to a waterside zone allowing for the foundation of the oak building, and later of the brick castle.

According to the historical data (Kozłowska 2005) the establishment of the castle in Elbląg was one of the stages of the conquest of Prussia by the Teutonic Order, which in 1236 took over the area of the Drużno Lake. A fortified settlement was built where the Elbląg River flowed into the Vistula Lagoon and was then probably conquered by infidels and moved to its present location (Kozłowska 2005). Historical reports may also reflect some environmental conditions as, after Kozłowska (2005), it can be assumed that the river island, on which the first settlement was founded was not suitable for the construction of more permanent fortifications and did not provide natural defensive conditions. Thus in 1237 the settlement was moved to a new location on the eastern bank of the river, and in the 1280s wooden and earthen fortifications began to be replaced with stone and brick walls (Kozłowska 2005).

The above description is an accurate representation of changes in the environment resulting from geological and paleontological studies and it indicates changes in the water level of the Drużno Lake and of the Vistula Lagoon during the Middle Ages, which forced the relocation of the settlement. The analysis of the maps depicting changes in the ranges of both waterbodies 2200, 1100 and 1000 years ago (Kasprzycka *et al*. 1996, 1997; Kasprzycka 1999) shows that the dynamicity of changes of the shoreline was significant. The maps (Text-fig. 9) constructed by historians and archaeologists are very divergent regarding the presentation of the range of the Drużno Lake and of the Vistula Lagoon in the 13th/14th centuries (Długokęcki 1992; Bertram 1924). The reconstruction of water bodies in the area of Żuławy marshland shown on Bertram's map (1924) appears incompatible with geological research carried out in the 1990s (Kasprzycka *et al*. 1996, 1997; Kasprzycka 1999). Based on this research and the data from the present paper, it can be assumed that the range of the Drużno Lake was much smaller than that presented on Bertram's map (Text-fig. 9).

CONCLUSIONS

The principal conclusions of the research in the courtyard of the Museum of Archaeology and History in Elbląg may be summarised as follows:

1. Geoarchaeological and palaeontological investigations at Elbląg site document lacustrine deposits, locally with abundant malacofauna.
2. Mollusc-bearing deposits were accumulated in the Drużno Lake and appear to record the lake development between the "Roman Period" and the Early Middle Ages.
3. The mollusc assemblage records notable lake-level fluctuations and finally the shallowing of the lake and the development of wet meadows in the adjacent areas.
4. Enhanced human activity and a period of deforestation partly due to clearance for agriculture has been documented as an environmental background for the foundation of the oak building, and later of the brick castle in the Mediaeval Warm Period (10th–13th centuries). It appears that open areas, fields and pastures dominated the landscape of the study region at that time.
5. The results may imply the somewhat restricted range of the Drużno Lake with regard to the previous works.

Acknowledgements

This research was funded by a grant from Pope John Paul II State School of Higher Education in Biała Podlaska and the Museum of Archaeology and History in Elbląg. We also thank the Innovation Research Centre and Research Centre "Eko-Agro-Tech" of Pope John Paul II State School of Higher Education in Biała Podlaska.

REFERENCES

Alexandrowicz, S.W. 1987. Analiza malakologiczna osadów czwartorzędowych. *Kwartalnik Akademii Górniczo-Hutniczej, Geologia*, **12**, 1–240.

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

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. 2007. Malacofauna of Late Glacial and Holocene calcareous lake deposits in North Poland (in Polish with English abstract). *Kwartalnik AGH, Geologia*, **33**, 395–420.

Alexandrowicz, W.P. 2009. Changes of environment of Lake Wigry during Late Glacial and Holocene in the light of molluscan analyses. In: J. Rutkowski and L. Krzysztofiak (Eds), Wigry Lake. History of the lake in the light of geological and paleoecological studies, pp. 227–240. Man and Nature Association; Suwałki.

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

Alexandrowicz, S.W. and Alexandrowicz, W.P. 2011. Analiza malakologiczna. Metody badań i interpretacji. Rozprawy Wydziału Przyrodniczego PAU, **3**. Wydawnictwa PAU. Kraków.

Aniol, R.W. 1983. Tree-ring Rusing CATRAS. *Dendrochronologia* **1**, 45–53.

Bertram, H. 1924. Die physikalische Geschichte der Weichseldeltas (In:) Das Weichsel – Nogat – Delta. Danzig.

Bogaczewicz-Adamczak, B. 1980. Późnoglacjalna i holoceńska flora okrzemek w osadach dennych Zalewu Wiślanego. *Zeszyty Nauk. Wydz. BiNoZ Uniw. Gdańskiego, Geografia* **11**, 53–59.

Bogaczewicz-Adamczak, B. and Miotk, G. 1985. Z biostratygrafii osadów Zalewu Wiślanego. Peribalticum III, Gdańskie Towarzystwo Naukowe, pp. 113–127.

Długokęcki, W. 1992. Osadnictwo na Żuławach w XIII i początkach XIV wieku. Malbork.

Gilbertson, D.D. and Hawkins, A.B. 1978. The Pleistocene succession at Kenn, Somerset. *Bulletin of the Geological Survey of Great Britain*, **66**, 1–41.

Glöer, P. 2002. Die Süßwassergastropoden Nord- und Mitteleuropas. Bestimmungsschlüssel, Lebensweise, Verbreitung. *Die Tierwelt Deutschlands*, 73. ConchBooks; Hackenheim.

Kasprzycka, M. 1999. Tło paleogeograficzne osadnictwa Żuław Elbląskich w pierwszym tysiącleciu naszej ery. In: P. Urbańczyk (Ed.), Adalbertus, **5**, Warszawa.

Kasprzycka, M., Nitychoruk, J. and Roniewicz, P. 1996. Rekonstrukcja środowiska naturalnego w Zatoce Żuławskiej dla okresu 1000 lat BP, etap I część III. Archiwum Instytutu Archeologii i Etnologii Polskiej Akademii Nauk w Warszawie; Warszawa.

Kasprzycka, M., Nitychoruk, J. and Roniewicz, P. 1997. Rekonstrukcja środowiska naturalnego Żuław Elbląskich dla okresu 1000 lat BP, etap II część III. Archiwum Instytutu Archeologii i Etnologii Polskiej Akademii Nauk w Warszawie; Warszawa.

Kozłowska, J. 2005. Księga elbląska cz. III, Przewodnik historyczno-krajoznawczy. Fortyfikacje Elbląga. Praca zbiorowa pod redakcją J. Zaskiewicza, pp. 1–400.

Körnig, G. 1966. Die Molluskengessellschaften des mitteldeutschen Hügellandes. *Malak. Abhandl.*, **11**, 57–85.

Ložek, V. 1964. Quartärmollusken der Tschechoslowakei. *Rozpravy Ústředního ústavu geologického*, **31**, 1–374.

Ložek, V. 1976. Klimaabhängige Zyklen der Sedimentation und Bodenbildung während Quartärs im Lichte malakozoologischer Untersuchungen. *Rozpr. Československ. Akad. Věd.*, **86** (8), 1–97.

Ložek, V. 1982. Fauenengeschichtliche Grundlinien zur spät- und nacheiszeitlichen

Entwicklung der Molluskenbestände in Mitteleuropa. *Rozpr. Československ. Akad. Věd.*, **92**, 1–106.

Miotk-Szpiganowicz, G., Zachowicz, J. and Uścinowicz, S. 2007. Nowe spojrzenie na rozwój zbiorników przybrzeżnych południowego Bałtyku. *Studia Limnologica et Telmatica*, **1**, 127–136.

Piechocki, A. 1979. Mięczaki (Mollusca). Ślimaki (Gastropoda). Fauna słodkowodna Polski, *Zakład Biologii Rolnej PAN*, *Poznań*. **7**, 7–173.

Piechocki, A. 1985. Reliktowe stanowiska występowania *Pisidium lilljeborgii* Cless. (*Bivalvia*, *Sphaeriidae*) w Polsce. *Przegląd Zoologiczny*, **29**, 481–486.

Piechocki, A. 1989. The *Sphaeriidae* of Poland (*Bivalvia*, Eulamellibranchiata). *Annales Zoologici Fennici*, **42**, 249–320.

Piechocki, A. and Dyduch-Falniowska, A. 1993. Mięczaki (Mollusca). Małże (Bivalvia). *Fauna słodkowodna Polski*, **7A**, 7–185.

Przybyłowska, W. 1973a. Analiza okrzemkowa osadów dennych Zalewu Wiślanego. *Przegląd Geofizyczny*, **18**, 121-126.

Przybyłowska, W. 1973b. Wyniki analizy okrzemkowej profilu osadów dennych Zalewu Wiślanego. *Przegląd Geofizyczny*, **18**, 121–126.

Przybyłowska-Lange, W. 1974. Development of the Vistula Firth in the light of diatom analysis (in Polish with English summary). *Prace IMGW*, **2**, 129–164.

Rinn, F. 1989–1999. TSAP version 3.0. Reference Manual. Heidelberg.

Sanko, A., Gaigalas, A. and Yelovicheva, Y. 2011. Paleoclimatic and stratigraphic significance of Belgrandia marginata (Michaud) in Late Quaternary malacofauna of Belarus and Lithuania. *Quaternary International*, **241**, 68–78.

Sparks, B.W. 1964. Non-marine Mollusca and Quaternary ecology. *Journal of Animal Ecology*, **33**, 87–98.

Steenberg, C.M. 1917. Furesoens molluskenfauna. *Köngelige Danske Viden skabernes Selskab Skrifter*, **8** (III-1), 78–200.

Sywula, T. 1974. Małżoraczki (Ostracoda). *Fauna słodkowodna Polski*, **24**, 5–315.

Uścinowicz, Sz., Miotk-Szpiganowicz, G., Gałka, M., Pawlyta, J., Piotrowska, N., Pomian, I. and Witak, M. 2013. The rise, development and destruction of the medieval port in Puck in the light of palaeoclimatic and sea level changes research. *Archaeologia Polona*, **49**, 87–104.

Ważny, T. 2012. Analiza dendrochronologiczna drewna ze Starego Miasta w Elblągu (badania 2012). Archiwum Muzeum Archeologicznego i Historycznego w Elblągu, 1–3.

Welter-Schultes, F.W. 2012. European non-marine molluscs, a guide for species identification. Planet Poster Editions, 1–679. Göttingen.

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 UAM; Poznań.

Zachowicz, J. 1985. Z badań biostratygraficznych nad osadami Zalewu Wiślanego. Peribalticum III, Gdańskie Towarzystwo Naukowe, pp. 97–111.

Zachowicz, J., Przybyłowska-Lange, W. and Nagler, J. 1982. The Late-Glacial and Holocene vegetational history of the Żuławy Region, N. Poland. A biostratigraphic study of Lake Drużno sediments. *Acta Palaeobotanica*, **22**, 141–161.

Zachowicz, J. and Kępińska, U. 1987. The paleoecological development of Lake Drużno (Vistula Deltoic Area). *Acta Palaeobotanica*, **27**, 227–249.

Manuscript submitted: 8th December 2014
Revised version accepted: 10th December 2015