Carpathian Journal of Earth and Environmental Sciences, August 2019, Vol. 14, No. 2, p. 367 - 384; DOI:10.26471/cjees/2019/014/087

MALACOLOGICAL EVIDENCE OF THE NATURAL AND ANTHROPOGENIC CHANGES OF THE ENVIRONMENT IN THE EASTERN PART OF THE CARPATHIAN FORELAND: THE STUDIES IN THE GLINNE STREAM VALLEY NEAR RZESZÓW (SOUTHERN POLAND)

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

Abstract: The molluscan assemblages identified at the location in the Glinne Stream in the eastern part of the Polish Carpathian foreland were subjected to malacological analysis. The detailed studies pertained to seven profiles with thicknesses of up to 6 metres. Within them, three series were distinguished: gravel, peat-mud-tufa, and silts. The malacological analysis enabled separation of six distinct fauna assemblages of diversified compositions and structures. Their sequence in the profiles provided the basis of reconstruction of the environmental changes associated with climatic fluctuations and human activities. The lowermost section of the sequence, containing gravels, did not contain the remains of molluscs, and its emergence can be linked to the Late Glacial. The peat, muds, and calcareous tufas overlaying them contained rich malacofauna with the predominance of forest species. The composition of the assemblages and the results of radiocarbon dating indicate their emergence during the Early and Middle Holocene, as well as during the older part of the Subboreal Phase. The silty series, which forms the roof sections of profiles, contained poor assemblages with open-country species. The nature of the sediment and the results of radiocarbon dating testify to the anthropogenic deforestation of the area which occurred at the beginning of Subatlantic Phase. The changes in the environment observed in the Glinne Stream valley correspond closely to the changes described in other river valleys of the Carpathian foreland.

Key words: malacofauna, molluscan assemblages, environmental changes, human activity, Holocene, Carpathian foreland, southern Poland

1. INTRODUCTION

The degree to which the Holocene molluscan assemblages in the Polish part of the Carpathians are identified is diverse. Many locations of sediments have been analysed within the Podhale Basin and the Pieniny Mountains (Alexandrowicz, 1997, 2004; Alexandrowicz et al., 2014, 2016). A considerably lower number of profiles have been described in the area of the Flysch Carpathians. This fact has been undoubtedly affected by the rarer occurrence of rocks containing calcium carbonate in the bedrock. The decreased content of carbonates in the Quaternary sediments preventing the preservation of molluscan shells in a subfossil state is the consequence of that fact. There is a particular deficit in the studies of the Quaternary malacocoenoses in the eastern part of the Flysch Carpathians and their foreland. Among the profiles studied there, the locations lacustrine chalk near Jasło (Alexandrowicz, 1987) as well as loess and alluvial sediment outcrops in the area of Przemyśl (Alexandrowicz & Łanczont, 1995) warrant particular attention. Against that background, the profiles found in the Glinne Stream valley south of Łańcut should be deemed particularly interesting. The molluscan assemblages occurring there have been the subject of malacological studies since the 1990s. Then, one profile was described covering the faunistic sequence representing the end of the Late Glacial (Younger Dryas) and Holocene (Alexandrowicz et al., 1992). The studies continued in subsequent years and bore fruit in the form of research of two more profiles, and their generalised results were published in the proceedings of the VI Conference Pleistocene Stratigraphy of Poland (Alexandrowicz, 1999; Mamakowa & Wójcik, 1999). These results were also included in the monograph on the molluscs found in the Quaternary calcareous tufas as one of the several dozen locations presented there (Alexandrowicz, 2004). During the most recent years, four more profiles with abundant malacofauna have been described, and samples for radiocarbon dating have been collected. The materials enhanced in that way enabled the detailed analysis on the natural and anthropogenic changes in the environment in the area, covering the time from the end of the Late Glacial until the present. Owing to that, the location in the valley of the Glinne Stream may be regarded as a benchmark malacological profile in the eastern part of the Polish Carpathians.

2. GEOLOGICAL SETTING

The study area is situated between Markowa, Husów and Lipnik villages, approx. 25 km east of Rzeszów, and 10 km southeast of Łańcut. The area covers a fragment of the valley of the Glinne Stream, in the catchment basin of the Markówka River, a right bank tributary of the Wisłok River (Fig. 1). The study area has a mild, hilly relief with deeply cut stream valleys. It is a part of the so-called Kańczucka Upland (Klimaszewski, 1972; Starkel, 1972). The substrate of Quatenary deposits is made by Krakowiec clays representing the Miocene, at some places cut through by the layer of a Lower Sarmatian storm shell beds. The Miocene deposits are tectonically disturbed declining south at a small angle. Those are linked to the Stebnik unit or Zgłobice unit (Połtowicz, 2004). In the upper course of the Glinne Stream, there is a distinct morphological threshold whose course is marked by the edge of the Carpathian overthrust. In the area, its front is composed of Cretaceous and Paleogene flysch sediments of the Skole unit. Somewhat to the north of the edge of overthrust, there is an outcrop layer of the Lower Sarmatian storm shell bed, which is several meters thick (Uchman et al., 1992). The layer is a source of calcium carbonate for the Quaternary sediments with malacofauna, occurring in the lower part of the Glinne Stream valley (Fig. 2). The crushed fragments of molluscan shells found in the Quatenary deposits as well as the sporomorphs and cysts of Dinoflagellata identified during palynological analyses also originate from this layer (Mamakowa & Wójcik, 1999).

The profiles of Quaternary deposits are situated in the middle part of the Glinne Stream, on the 400-metre long section of it as well as in its right-bank tributary (GPS: N 50°0’32”; E 22°18’04”) (Fig. 2). Both streams have the shape of deep, with steep slopes cutting through the plateau up to the depth of about 6-8 metres.

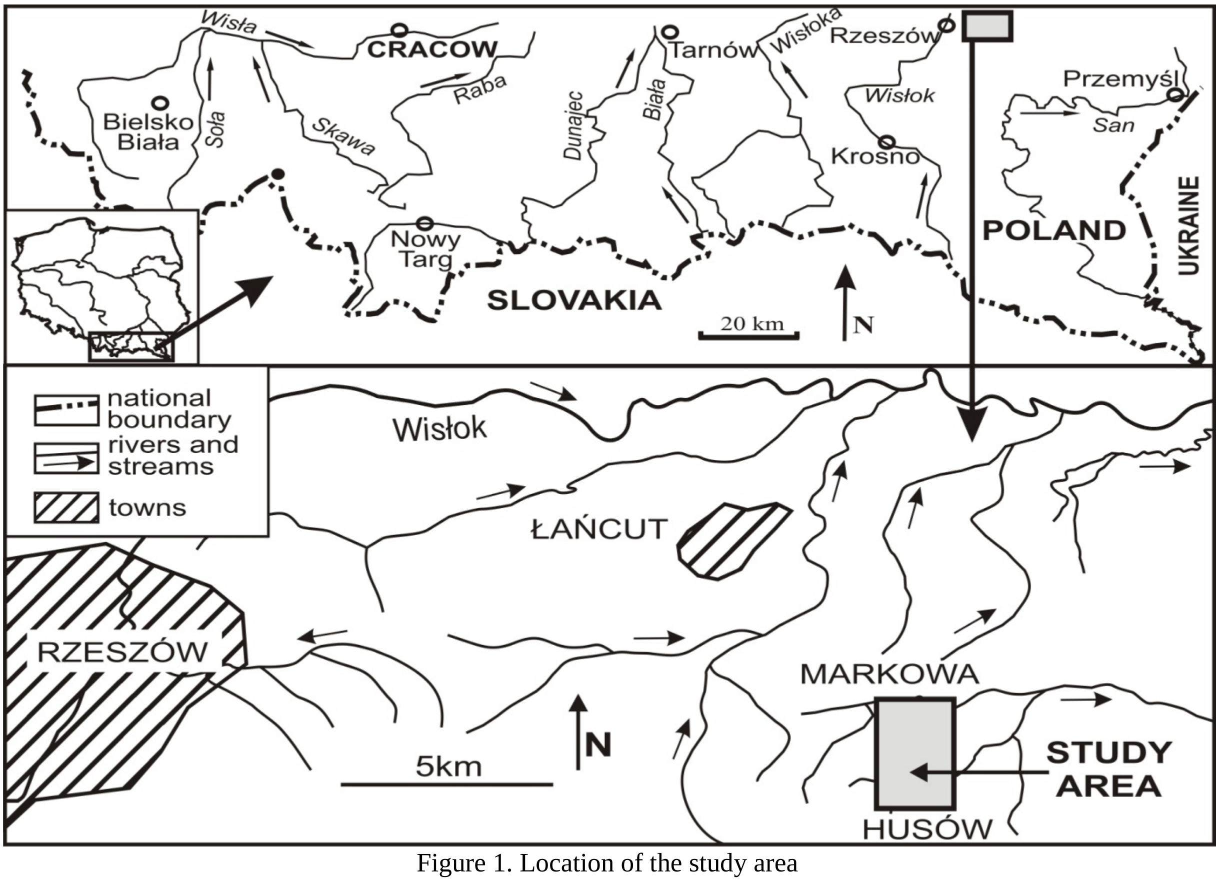

Figure 1. Location of the study area

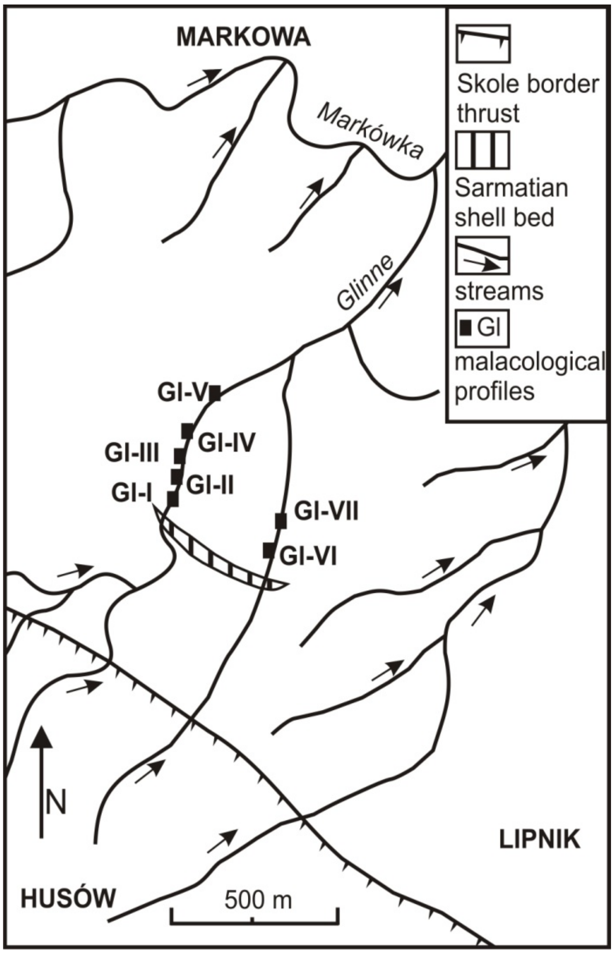

Figure 2. Location of profiles of mollusc-bearing deposits in Glinne Stream valley

The profiles identified in the valley of the Glinne Stream (Gl-I – Gl-V; Figs 2, 3) have a similar lithological form. Within it, three different elements can be distinguished. In the bottom section, fine- and medium-grained gravels formed by the sandstones of the Carpathian flysch of the Skole unit occur. Crushed, redeposited shells of Miocene molluscs are often contained there. The gravels are characterised by abundant sandy matrix, and sometimes they are overlaid by the several-centimetre thick layer of sand. The roof of gravels is 1-2 m above the present streambed and is clearly of an erosive nature (Fig. 3). Above the gravel series, there are black peat, dark calcareous muds, and calcareous tufas. In all these sediments, molluscan shells appear, sometimes in great numbers. Within the peat, muds, and calcareous tufas, there are visible traces of erosion underlined by insertions of sand, sometimes also of fine gravels. The total thickness of the aforementioned series ranges from one to three metres, depending on the profile, and its top is of an erosive nature (Fig. 3). The sediments that are overlaid above are formed as grey and yellowish silts sometimes containing gravel stones; whereas, the top layer often contains plant remnants, particularly potato leaves. The remnants of molluscs are few; whereas, in the uppermost section, they are entirely absent. The thickness of the silty series ranges between one and three metres. The aforementioned sediments are covered by a thin layer of present soil (Fig. 3).

The profiles in the right-bank tributary of the Glinne Stream (Fig. 2) are similarly formed. On the gravel series with 1 m of visible thickness, lay grey calcareous tufas interbedded by the insertions of dark-grey calcareous muds of up to 0.5 m in total thickness. The top of the profiles is composed of yellowish silts overlaid by present soil.

3. MATERIAL AND METHOD

The material for analyses was collected from seven profiles Gl-I – Gl-V in the Glinne Stream valley, and Gl-VI and Gl-VII profiles in the valley of its right-bank tributary (Fig. 2). The malacological analysis employed 115 samples of which 70 contained identifiable remnants of molluscs. Particular samples had a mass of approx. 2.0 kg and covered 10-15 cm intervals, depending on the types of sediments and the thickness of profiles. The determinations were performed on the basis of identification keys (e.g. Kerney et al., 1983; Wiktor, 2004; Walter-Schultes, 2012; Horsák et al., 2013), and reference collections. In the samples, the numbers of species and specimens were determined.

The malacological analysis followed the standard methods described by Ložek, (1964) and Alexandrowicz & Alexandrowicz, (2011). Particular species were classified into the following ecological groups: F – shadow-lowing species, O – open-country species, M – mesophilous species, H – hygrophilous species, and W – water species. The diversification of species composition as well as the proportions of particular ecological groups provided the basis to distinguish six fauna assemblages whose sequences in the profiles allowed the reconstruction of the changes in the environment. The age of sediments was determined directly and indirectly. In the former case, the foundation for conclusions was the comparison of the compositions and structures of malacoenoses with other stratigraphically documented profiles previously reported from the Carpathians.

The direct determination of the age of sediments was made possible using radiocarbon dating. The dating was based on the remains of plants occurring in the peat and silts. The radiometric analyses were performed in the Department of Radioisotopes, Institute of Physics of the Silesian University of Technology (laboratory code Gd). The results of age determination were calibrated on the basis of calibration curve (Stuiver et al., 1998), with

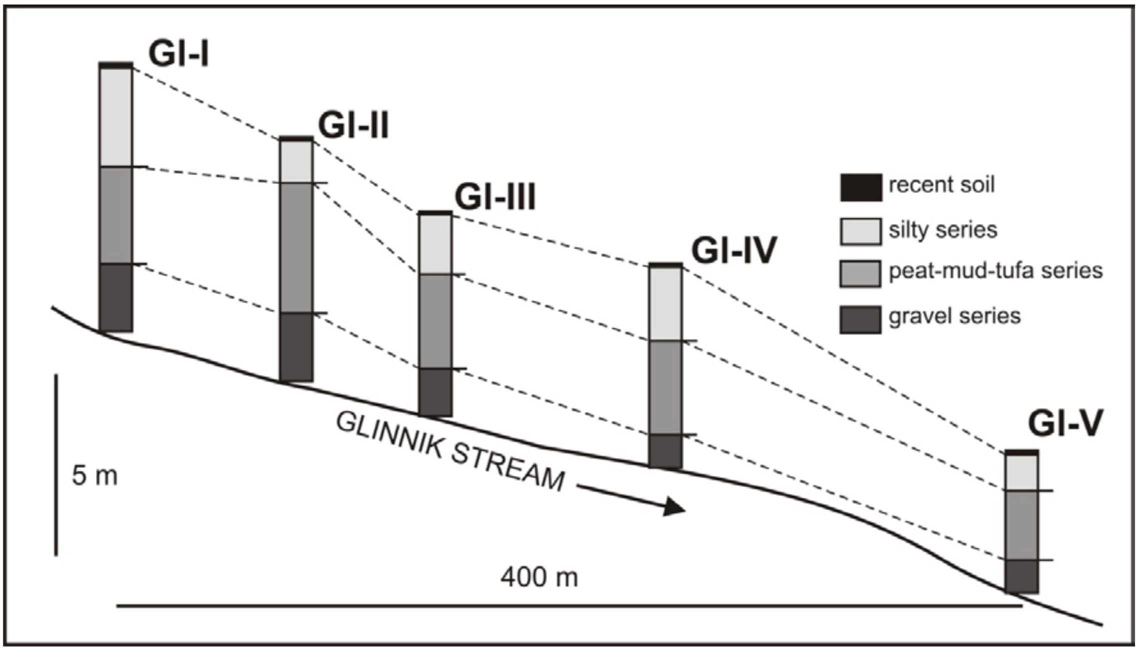

Figure 3. Profiles and lithology of mollusc-bearing deposits in Glinne Stream valley

the use of OxCal V 3.9 software (Bronk Ramsey, 2003). Additionally, the results of lithological studies (profiles Gl-II and Gl-III), and palynological studies (profile Gl-II) (Mamakowa & Wójcik, 1999) were used.

4. RESULTS

4.1. Malacofauna

The recognized malacofauna was rich and diverse. The number of species in particular samples ranged from 7 to 39; whereas, the number of individuals changed from 100 to 968. All in all, the whole analysed material included nearly a total of 14,000 specimens of 64 taxa (54 taxa of land snails, 6 taxa of water snails, and 4 of bivalves). The plates of slugs were included in a category *Limacidae*. Additionally, the examined material contained near 2000 unidentifiable shell fragments (Table 1).

The malacofauna identified in the profiles of the Glinne Stream valley has species living in the various types of habitats. Shadow-loving snails (group F) are the most numerous group, including 28 species. The forms typical of compact forests, both coniferous (*Discus rotundatus*) as well as deciduous and mixed (*Discus perspectivus, Ruthenica filograna*) occur commonly.

The shadow-loving taxa living in moist and very moist biotops (*Perforatella bidentata*, *Vitrea crystallina*) are also of essential importance. The first species among those listed above is the most numerous species found in the whole material analysed. The shadow-loving snails appear principally within the deposits of the peat-mud-tufa series, where they constitute the predominant group. In the roofs of profiles (silty series), their proportion falls markedly. The open-country taxa (group O) consist of five species, with *Vallonia pulchella* and *Vallonia costata* occurring in the greatest numbers.

They appear in all profiles, particularly in silty series, where they are the most important components of the malacofauna. The important component of fauna are snails with high ecological tolerance (mesophilous – group M), represented by 14 taxa, living in moist and very moist biotopes. The presence of cold-loving taxon, *Columella columella,* appearing in the floor sections of profiles, is also noteworthy. Mesophilous snails occur in high numbers both in peat-mud-tufa and silty series. The hygrophilous species (group H) (7 species) are also an important component of the malacofauna. Particularly noteworthy is the abundant occurrence of cold-loving tundra forms (*Vertigo genesii* and *Vertigo geyeri*) in the floor sections of profiles. The water molluscs (group W) (10 species) consist of both molluscs typical of running waters (*Pisidium personatum*, *Pisidium amnicum*) and those of the shallow, periodically dried bodies of water (*Anisus leucostoma*, *Galba truncatula*) (Table 1).

4.2. Molluscan assemblages

The diversification of species composition and the proportions of particular ecological groups observed in profiles was a basis used to distinguish fauna assemblages. They enabled us to characterise the conditions for the deposition of sediments that were controlled principally by the climate and human activities. They also allow drawing the stratigraphic conclusions backed up by the results of radiocarbon analyses as well as by the conclusions resulting from

Table 1. List of species recognized in profiles of mollusc-bearing deposits in Glinne Stream valley.

E	Taxon	Molluscan assemblages (described in text and Figs 4-6)						Total
		Vg+Dr	Dr	Dp	Pb	Vp	Wa	
		8 samples	10 samples	10 samlpes	20 samples	15 samples	7 samples	
F	*Platylla polita* (Hartm.)		3	2		2	2	9
	Acanthinula aculeata (Müll.)			13	11			24
	Daudebardia brevipes (Drap.)			8	12			20
	Carpathica callophana (West.)			4	15			19
	Semilimax kotulae (Drap.)	26	18					44
	Discus perspectivus (M. von Mühl.)		16	307	107	2		432
	Discus ruderatus (Hartm.)	205	273	94				572
	Vitrea diaphana (Stud.)		7	57	14	2	1	81
	Vitrea subrimata (Reinh.)			25	4			29
	Vitrea crystallina (Müll.)	26	31	118	97	18	5	295
	Aegopinella minor (Stab.)	6		41	29		2	78
	Aegopinella pura ((Ald.)		29	180	66			275
	Ruthenica filograna (Rossm.)		37	132	32			201
	Cochlodina laminata (Mont.)		9	97	42	5		153
	Cochlodina orthostoma (Menke)		2	19	7			28
	Macrogastra tumida (Rossm.)		14	22	12			48
	Macrogastra borealis (Boett.)			35	16		5	56
	Macrogastra plicatula (Drap.)		25	68	27			120
	Clausilia cruciata (Stud.)			13	3			16
	Vestia gulo (Bielz)				8			8
	Fruticicola fruticum (Müll.)	11	38	65	129	73	8	324
	Perforatella bidentata (Gmel.)	194	259	195	434	299	134	1515
	Monachoides incarnatus (Müll.)	3	31	71	9	3		117
	Monachoides vicinus (Rossm.)	14	32	62	62	16		186
	Petasina unidentata (Drap.)	7	12	40	13			72
	Isognomostoma isognomostomos (Schr.)	3	13	65	32			113
	Faustina faustina (Rossm.)	6	19	35	18			78
	Arianta arbustorum (L.)	56	37	42	70	14	8	227
O	*Vertigo pygmaea* (Drap.)		2	2	2	37		43
	Pupilla muscorum (L.)			9	1	59		69
	Vallonia costata (Müll.)	9	33	9	36	359	6	452
	Vallonia pulchella (Müll.)	27	132	68	176	611	31	1045
	Euomphalia strigella (Drap.)				7	10		17
M	*Carychium tridentatum* (Risso)	9	57	36	83	181	22	388
	Cochlicopa lubrica (Müll.)	33	60	42	50	140	22	347
	Succinella oblonga (Drap.)	107	43	141	95	21		407
	Columella columella (Mart.)	70	8					78
	Vertigo angustior Jeff.		77	10	101	337	10	535
	Vertigo modesta (Wall.)	20						20
	Vertigo substriata (Jeff.)	37	201	120			8	366
	Punctum pygmaeum (Drap.)	5	10	4	13	64		96
	Perpolita hammonis (Ström)	9	32	5	59	102	6	213
	Vitrina pellucida (Müll.)		2	2	2	4		10
	Limacidae	22	38	16	114	116	40	346
	Euconulus fulvus (Müll.)		31	3	10	43	2	89
	Clausilia dubia Drap.	10	6		2	1	5	24
	Trochulus hispidus (L.)	11		2	5		9	27
H	*Carychium minimum* Müll.	17	208	16	138	367	43	789
	Succinea putris (L.)	22	68	5	122	220	47	484
	Vertigo antivertigo (Drap.)	6	39	1	78	273	50	447
	Vertigo genesii (Gred.)	60	7					67
	Vertigo geyeri Lind.	120	25					145
	Zonitoides nitidus (Müll.)		59	3	7	69	15	153
	Pseudotrichia rubiginosa (Rossm)	5				15	12	32
W	*Valvata cristata* (Müll.)	1	28		33	114	89	265
	Bithynia tentaculata (L.)				8	8	14	30
	Stagnicola pallustris (Müll.)		7		5	43		55
	Galba truncatula (Müll.)	18	49	28	70	161	106	432
	Anisus leucostoma (Mill.)		32	12	77	317	231	669
	Segmentina nitida Müll.					8		8
	Pisidium amnicum (Müll.)				29	12	19	60
	Pisidium casertanum (Poli)		2		117	33	44	196
	Pisidium personatum Malm	14	28	58	158	66	57	381
	Pisidium obtusale (Lam.)	18	10		7	7	29	71
Total species		35	49	48	61	44	32	**64**
Total individuals		1207	2200	2402	2874	4232	1082	**13997**
Shells fragments (indeterminate)		146	268	371	348	449	217	**1799**

E. ecological groups of molluscs (after: Ložek 1964; Alexandrowicz and Alexandrowicz 2011): F – shade-loving snails, O – open-country snails, M – mesophilous snails, H – hygrophilous snails, W – water snails

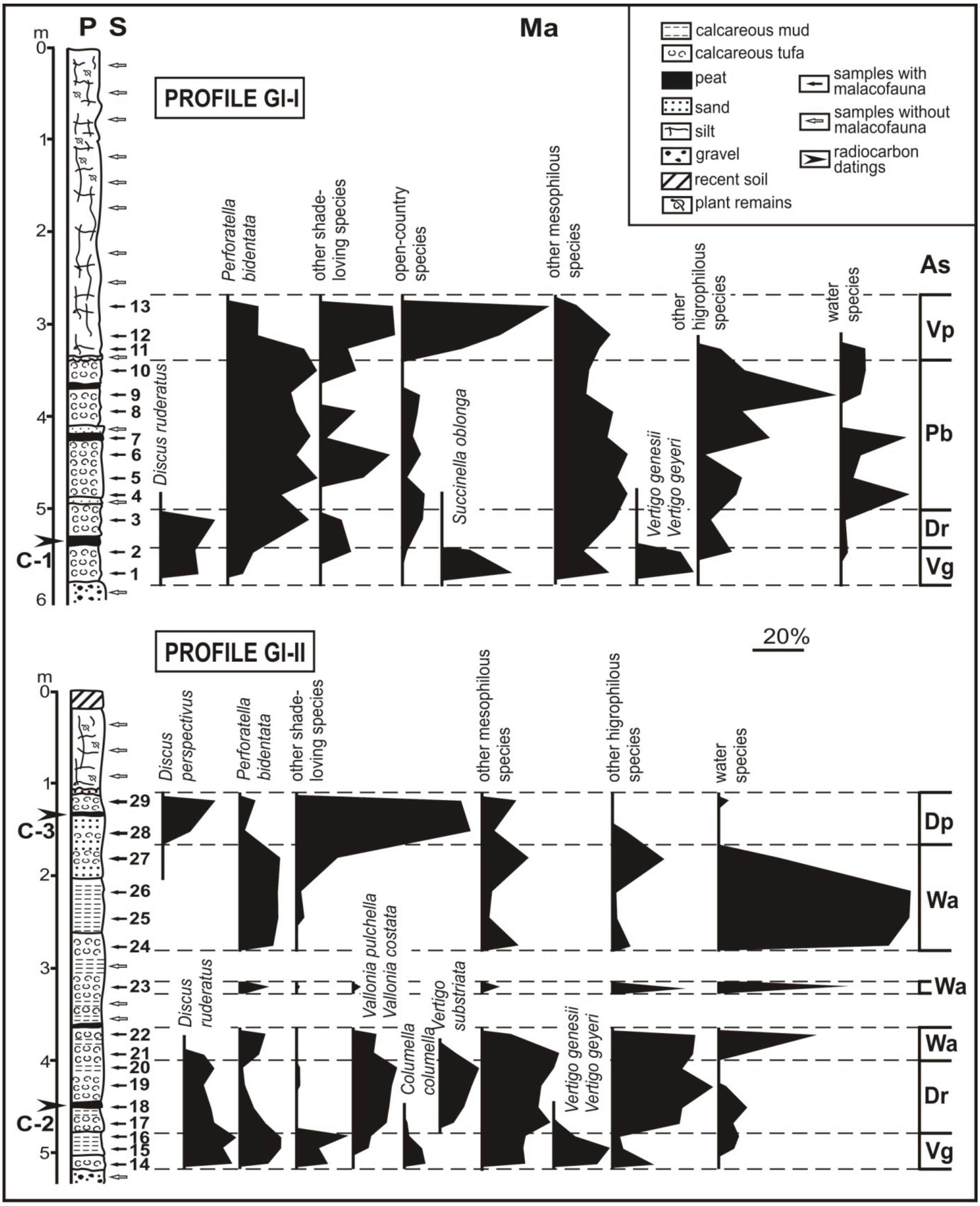

Figure 4. Lithology and malacological percentage diagram of profiles Gl-I and Gl-II
P. lithology of profiles, S. samples, Ma. malacology, As. molluscan assemblages (described in text)

completed palynological and sedimentological studies (Mamakowa & Wójcik, 1999). The studied material enabled the identification of six such assemblages.

The assemblage with *Vertigo genesii* and *Discus ruderatus* (Vg+Dr) – occurs in the floor sections of Gl-I, Gl-II, Gl-IV, and Gl-V profiles (Figs 2, 4-6). Two groups of species play the most important role in this fauna. The first includes the forms typical of the Late Glacial, often found in the sediments of that age throughout Central and Western Europe: *Vertigo genesii*, *Vertigo geyeri*, and *Columella columella*. They characterise the cold climate and open- and semi-open habitats with high humidity. The second group consists of shadow-loving species showing great thermal tolerance.

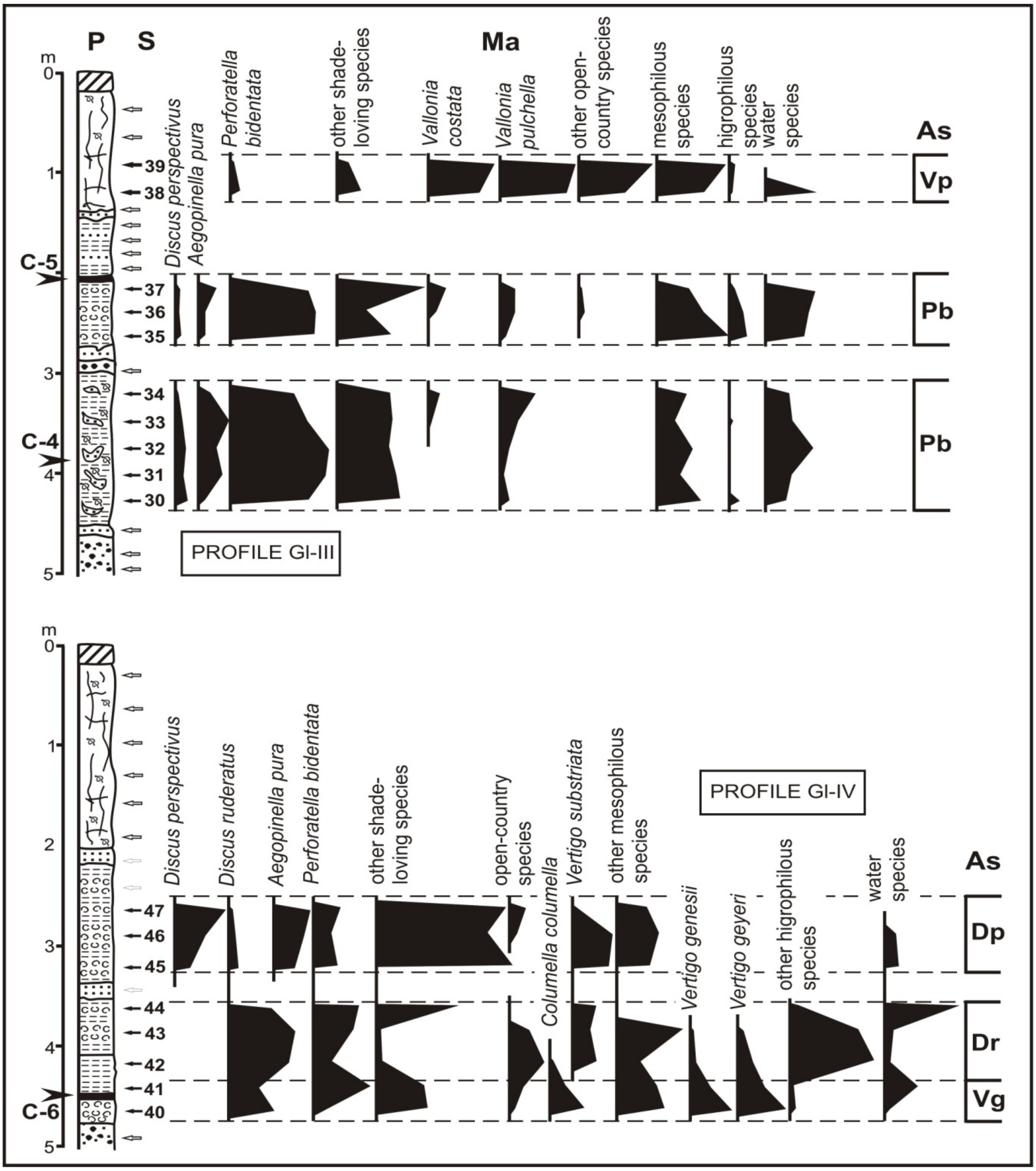

Figure 5. Lithology and malacological percentage diagram of profiles Gl-III and Gl-IV
For explanations see Figure 4

The presence of *Discus ruderatus* indicates the occurrence of coniferous forests; whereas, that of *Perforatella bidentata* indicates the occurrence of bush with a high proportion of alder growing on moist locations. The mesophilous and hygrophilous taxa supplement the assemblage; whereas, the snails of open-country species and water molluscs are less important components. These observations, as well as the results of radiometric dating (profile Gl-IV – 10130±140 BP; 10427 cal BC – 9303 cal BC; Gd-2639; c-6; Fig. 5, Table 2) of the sediments containing the aforementioned assembly, indicate that it represents the youngest part of the Younger Dryas or/and the older part of the Preboreal Phase.

The assemblage with *Discus ruderatus* (Dr) appears in floor intervals of the profiles Gl-I, Gl-II, Gl-IV, and Gl-V (Figs 2, 4-6). Two groups of species play the most important role in this assembly. The first consists of shadow-loving forms, represented primarily by *Discus ruderatus* and *Perforatella bidentata*. The second includes mesophilous snails (*Vertigo substriata*). The assembly has the features typical of "*Ruderatus*-fauna" (Dehm, 1967) and indicates the predomination of shadowed habitats with significant levels of the moisture of substrate, and also points to the development of coniferous forests. The described malacoenose characterise cold climate with fairly evident continental features. The presence of cold-loving taxa (*Columella columella*, *Vertigo genesii* and *Vertigo geyeri*) was of significant importance to the fauna in question. These species were common components of the assemblages associated with the Late Glacial, and – in line with warming climate during the Holocene – their ranges gradually shrank so that, at present, they are known only in single isolated locations (Pokryszko, 1990; Limondin-Lozouet, 1992; Horsák & Hájek, 2005; Schenková et al., 2012; Schenková & Horsák, 2013). The association of the fauna under discussion with the younger part of Preboreal Phase and Boreal Phase is confirmed by the determinations of age in Gl-I profile: 9720±130 BP (9650 cal BC – 8726 cal BC; Gd-10564; c-1, Fig. 4, Table 2, and Gl-II: 9790±100 BP (9655 cal BC – 8837 cal BC; Gd-6605; c-2, Fig. 4, Table 2).

The assemblage with *Discus perspectivus* (Dp) appears in the middle sections of the profiles Gl-II, Gl-IV, and Gl-V (Figs 2, 4-6). It is a rich and very diversified fauna with the predominance of shadow-loving species whose share exceeds 50%. *Discus perspectivus* is a characteristic species of the assemblage, accompanied by other therophilous forest species, e.g., *Ruthenica filograna* and *Aegopinella pura*. The mesophilous and hygrophilous snails complement the fauna; whereas, the forms typical of open-country habitats are practically absent. The assemblage under discussion has the composition and structure similar to the "*Perspectivus*-fauna" (Dehm, 1987). The assemblage is characteristic of species-diverse forest communities with a high proportion of deciduous trees, developing under warm and humid climate. The sediments containing the assemblage with *Discus perspectivus* were dated in the Gl-II profile at 6490±90 BP (5617 cal BC – 5311 cal BC; Gd-6069; c-3, Fig. 4, Table 2), which is indicative of their association with the Atlantic Phase.

In the Glinne Stream valley, the assemblage with *Perforatella bidentata* (Pb) occurs in the mid-sections of Gl-I and Gl-III profiles (Figs 2, 4, 5). It also appears in floor intervals of Gl-VI and Gl-VII locations in the tributary of the Glinne Stream (Figs 2, 6). The high frequency of *Perforatella bidentata* is a characteristic feature of this fauna. The species can even consist of more than 30% of the assemblage. Other shadow-loving forms occur more rarely; whereas, the mesophilous snails are numerous, particularly those which prefer moist biotopes (*Vertigo angustior*, *Succinella oblonga*). The hygrophilous species (*Carychium minimum*, *Succinea putris*) are usually common. Water molluscs, including both rheophilous forms (*Pisidium personatum*) and species of the temporary bodies of water (*Galba truncatula*, *Anisus leucostoma*), also constitute a frequent component of the aforementioned fauna. The presented fauna characterises very moist and boggy habitats typical of the valley bottom. The situation of the sediments containing the discussed malacoenose as well as the results of radiocarbon dating in the profile Gl-III (3450±160 BP; 2266 cal BC – 1410 cal BC; Gd-9821; c-4, 2800±70 BP, 1154 cal BC – 811 cal BC; Gd-12010, c-5 (Fig. 4, Table 2)) indicate the association of the malacoenose with the relatively cold and moist Subboreal Phase. This interpretation is also supported by the observed changes in species composition, particularly by the reduced importance of shadow-loving species, and the disappearance of thermophilous forms typical of the Atlantic Phase (*Discus perspectivus*, *Ruthenica filograna*).

The assemblage with *Vallonia pulchella* (Vp) occurs in the upper intervals of the profiles Gl-I, Gl-III, Gl-V, Gl-VI, and Gl-VII (Figs 2, 4-6) within the lower section of silty series. It is a poor malacoenose, where the most important role is that of open-country species, principally *Vallonia pulchella* and *Vallonia costata*, accompanied by mesophilous forms. The frequency of shadow-loving taxa decreases very rapidly, with *Perforatella bidentata* being the only representative occurring somewhat more often. The hygrophilous and aquatic mollusc usually have only accessory importance. The silts, forming the roof of the profiles Gl-I, Gl-III, and Gl-V, are devoid of molluscan shells.

Table 2. Results of radiocarbon datings

Date		Profile	Material	Age BP	Laboratory code	Calibrated age (BC/AD)
c-1		Gl-I	peat	9720±130	Gd-10564	9650 – 8726 cal BC
c-2		Gl-II	peat	9790±100	Gd-6605	9655 – 8837 cal BC
c-3		Gl-II	peat	6490±90	Gd-6069	5617 – 5311 cal BC
c-4		Gl-III	peat	3450±160	Gd-9821	2266 – 1410 cal BC
c-5		Gl-III	peat	2800±70	Gd-12010	1154 – 811 cal BC
c-6		Gl-IV	peat	10130±140	Gd-2639	10427 – 9303 cal BC
c-7		Gl-V	Plant remains	480±40	Gd-4253	1327 – 1343 cal AD 1394 – 1476 cal AD

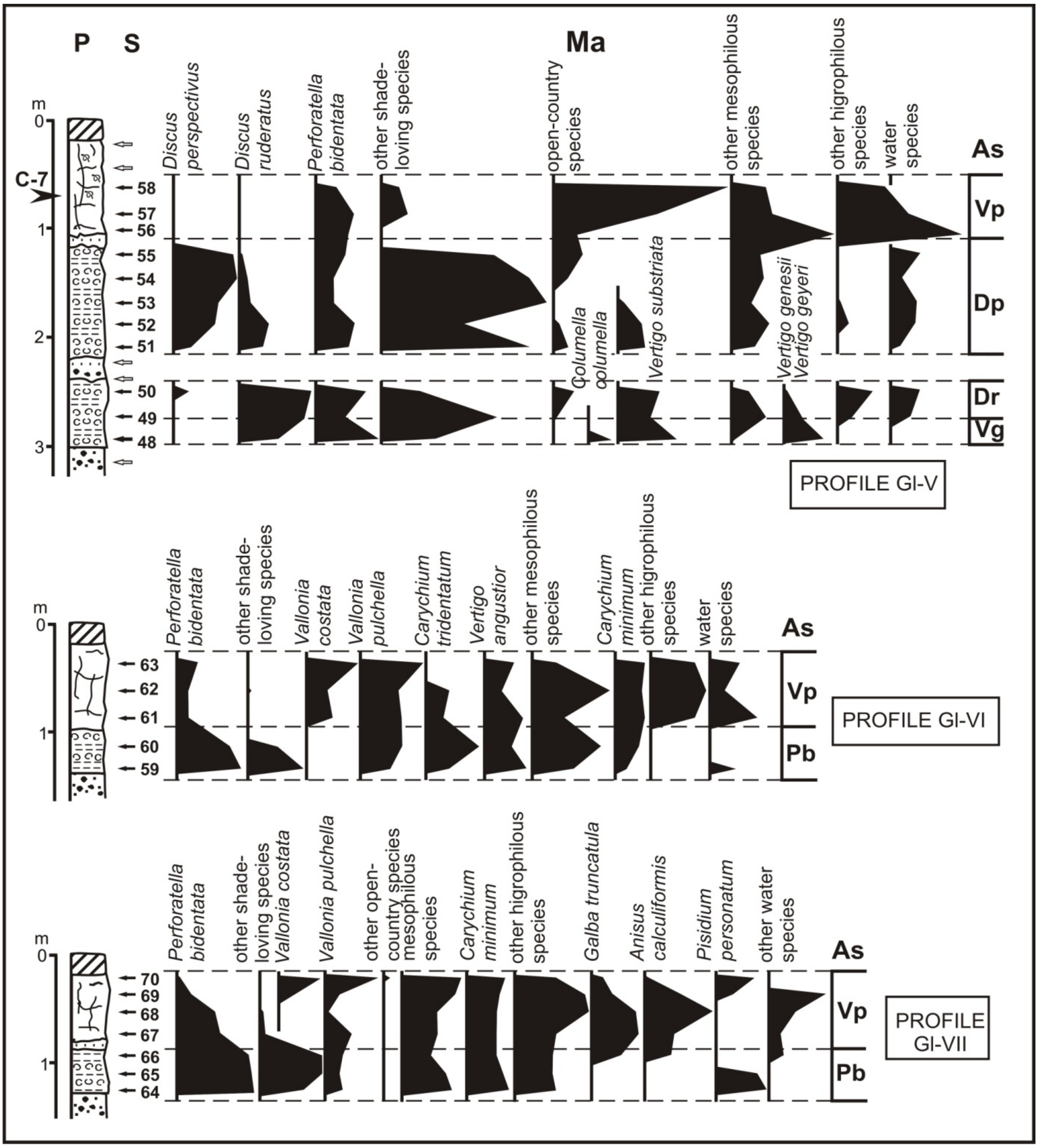

Figure 6. Lithology and malacological percentage diagram of profiles Gl-V, Gl-Vi and Gl-VII For explanations see Figure 4

The fauna with the composition described above indicates open, deforested grassland habitats, corresponding to the anthropogenic deforestation associated with the Subatlantic Phase and the historic period. The radiocarbon dating (profile Gl-V: 480±40 BP, 1327 cal AD – 1343 cal AD, and 1394 cal AD – 1476 cal AD; Gd-4253, c-7 (Fig. 5, Table 2) confirms this stratigraphic position.

The assemblage with water species (Wa) was identified in the profile Gl-II (Figs 2, 4). The characteristic feature of this fauna is that it contains a very great proportion of water species, particularly the snails typical of small, temporary bodies of water: *Anisus leucostoma*, *Galba truncatula*, and *Valvata cristata*, accompanied by euryecological bivalves, *Pisidium casertanum*, and *Pisidium subtruncatum*. The hygrophilous species (*Carychium minimum*, *Succinea putris*, and *Perforatella bidentata*) as well as the mesophilous forms typical of moist habitats (*Vertigo substriata* and *Vertigo angustior*) complement the composition. Other ecological groups are of much less significance. The discussed malacoenose indicates the presence of a small body of water. It was undoubtedly shallow and much overgrown, and it probably periodically dries up. The appearance and development of that body of water may be associated with the Boreal Phase, or with the older part of the Atlantic Phase. Despite the lack of radiocarbon dating, such an interpretation is indicated by the position of the assemblage with water species below the sediments containing the Middle Holocene fauna with *Discus perspectivus*.

5. DISCUSSION

5.1. Development of the Glinne Stream Valley

The collected malacological data, supplemented by palynological and lithological studies (Mamakowa & Wójcik, 1999), permit the reconstruction of natural and anthropogenic phases of the environment in the study area. It is possible to distinguish several stages of valley development. The oldest stage is represented by gravel series. These sediments do not contain either malacofauna or pollen, and their only organic components are crushed shells of Miocene molluscs washed down from the Lower Sarmatian storm shell bed situated higher in the stream valley. These are riverine deposits deposited during the Late Glacial period. Their roof is of an erosional nature. The dissection of the Late Glacial gravel series occurred near the end of the Younger Dryas. This phenomenon is very commonly observed in river valleys throughout Central Europe. Its record is visible both in large lowland rivers as well as in smaller mountain streams (Starkel, 1991, 2007; Starkel et al., 2007, 2015; Gębica et al., 2015). The causes of this phenomenon are complex. On the one hand, they are linked to climate changes, and on the other hand, they are linked to the marine regression resulting in the lowering of an erosion base (e.g., Lericolais et al., 2010; Feourdean et al., 2014; Starkel et al., 2015). The muds, peat, and calcareous tufas lying above the gravels contain abundant molluscan fauna as well as pollens of plants described in the Gl-II profile (Mamakowa & Wójcik, 1999). The tufas and dark muds exposed in the floors of the Gl-I, Gl-II, Gl-IV, and Gl-V profiles should be considered the oldest (Figs 2, 4-6). Within them, the assemblage with *Vertigo genesii* and *Discus ruderatus* occurs. The palynological analysis of this interval revealed a great frequency of *Pinus* and *Picea*, with admixtures of *Betula*, *Salix*, *Alnus*, and *Ulmus*. The proportion of the pollen of herbs (NAP) is relatively high and amounts up to 20%. The numerous occurrences of cold-loving species (*Vertigo genesii*, *Vertigo geyeri*, and *Columella columella*) testifies to cold climate. The composition and structure of malacoenosis demonstrates transitional features between the fauna with Vertigo genesii, typical of the Younger Dryas (Ložek, 1964, 1972; Alexandrowicz, 1983, 1997, 2001, 2004, 2013a, 2015; Limondin-Lozouet & Rousseau, 1991; Limondin-Lozouet, 1992; Krolopp & Sümegi, 1993; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Mania, 1995; Preece, 1998; Meyrick, 2001, 2002; Meyrick & Preece, 2001; Gedda, 2001, 2006; Alexandrowicz et al., 2014) and the fauna with *Discus ruderatus*, characteristic of the Early Holocene (Ložek, 1964, 1972; Dehm, 1967; Alexandrowicz, 1983, 1997, 2001, 2004, 2013a, 2015; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Preece, 1998; Preece & Bridgland, 1999; Gedda, 2001, 2006; Žak et al., 2002; Meyrick, 2002; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet, 2011; Alexandrowicz et al., 2014, 2016). From the first of the faunas, it differs in much greater species diversity and major proportion of shadow-loving species; whereas, from the second fauna, it differs in a much greater presence of the taxa typical of a cold climate. The assemblage in question characterises moist, even locally boggy habitats, typical of floor valleys with patches of forest with the predominance of coniferous trees (Fig. 7). The expansion of forests in the Carpathians at the break between the Late Glacial and the Early Holocene is well-documented in various outcrops, from the viewpoint of the lithological features of sediments (e.g. Starkel, 1991; Starkel et al., 2007, 2015; Gębica et al., 2015), the presence of pollen (e.g. Ralska-Jasiewiczowa, 1980; Obidowicz, 1990; Madeyska, 1998; Feourdean et al., 2014), and their malacological content (Alexandrowicz, 2004;

Alexandrowicz et al., 2014, 2016; Juřičková et al., 2014; Horáčková et al., 2015). The age of sediments containing the described fauna was determined by radiocarbon dating at 10130±140 BP; 10427 cal BC – 9303 cal BC; Gd-2639; c-6; (Fig. 5, Table 2). In the deposits lying above, a characteristic assemblage with *Discus ruderatus* occurs (the Gl-I, Gl-II, Gl-IV, and Gl-V profiles; Figs 2, 4-6). The palynological analysis has shown a major proportion of the pollen from coniferous trees, primarily of *Pinus* and *Picea*, reaching up to 70%. At the same time, the disappearance of herbs has been noted (NAP – 5-8%) (Mamakowa & Wójcik, 1999). This data points to the presence of compact coniferous forests overgrowing both the stream valley and its surroundings. The ecological structure of the molluscan assemblage is characteristic of similar habitat types. The predomination of shade-loving forms, particularly the numerous occurrences of *Discus ruderatus* indicates the development of coniferous forests (Fig. 7). The presence of hygrophilous species (*Perforatella bidentata*, *Vertigo substriata*) indicates the occurrence of shaded habitats with great humidity,

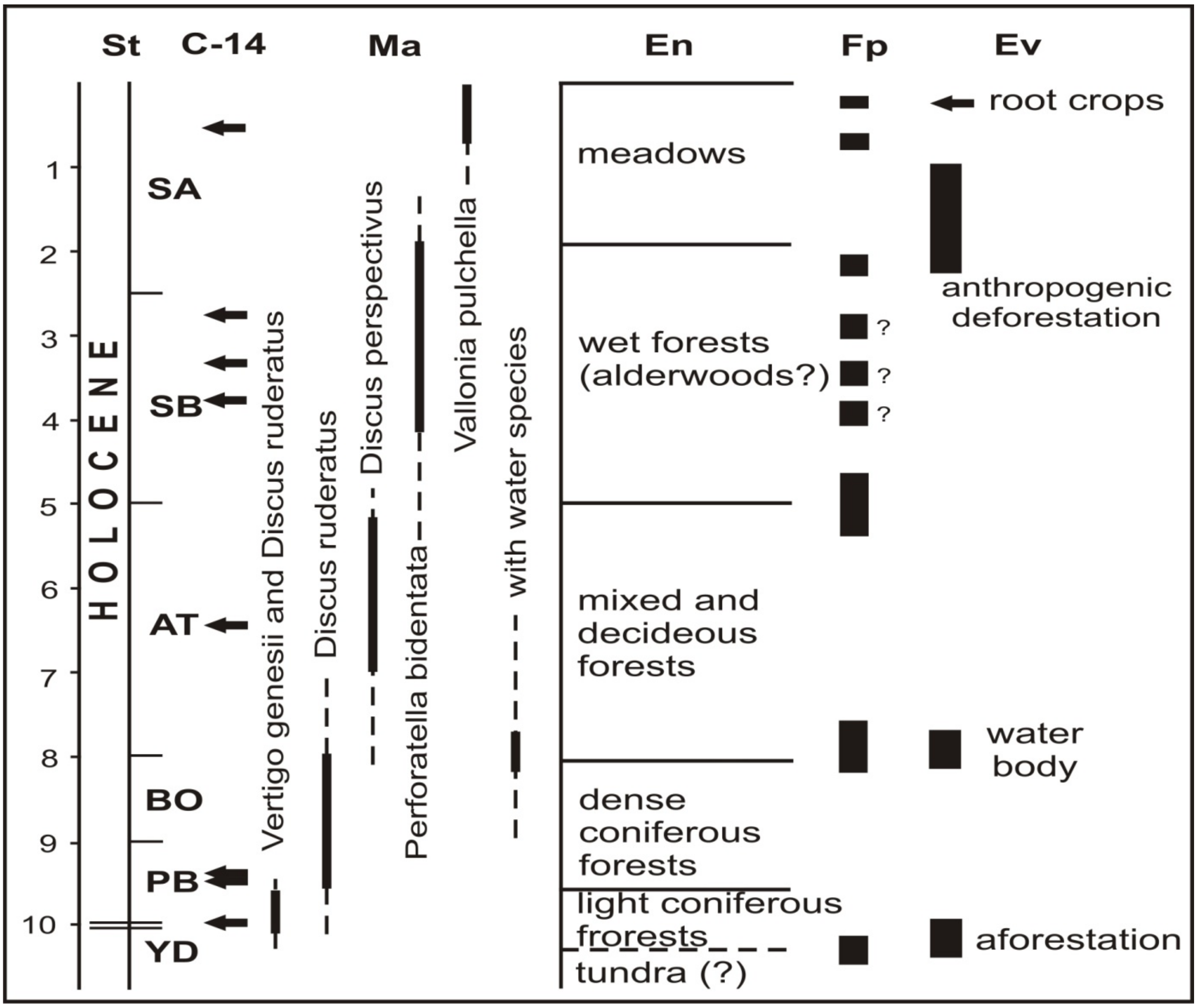

Figure 7. Environmental changes and startigraphy of profiles of mollusc-bearing deposits in Glinne Stream valley
ST. stratigraphical subdivision of Holocene (after: Walanus & Nalepka, 2010): PB – Preboreal Phase, BO – Boreal Phase, AT – Atlantic Phase, SB – Subboreal Phase, SA – Subatlantic Phase, C-14 – radiocarbon datings, Ma – molluscan assemblages described in text, En. environment, Fp. flood phases, Ev. events

probably associated with the bottom of the valley. The composition of the fauna in question typifies a relatively cold climate. The assemblage with *Discus ruderatus* is regarded as a characteristic malacoenose for the Early Holocene (Preboreal and Boreal Phases), and it has been described in this stratigraphic position in very numerous locations within Central and Western Europe (Ložek, 1964, 1972; Dehm, 1967; Alexandrowicz, 1983, 1997, 2001, 2004, 2013a, 2015; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Preece, 1998; Preece & Bridgland, 1999; Gedda, 2001, 2006; Žak et al., 2002; Meyrick, 2002; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet, 2011; Alexandrowicz et al., 2014, 2016; Juřičková et al., 2014; Horáčková et al., 2015). Towards the top, there are increasingly numerous species showing higher environmental requirements. It testifies to gradual warming of the climate and to the change of atmospheric circulation from continental to oceanic, typical of the ending of the Boreal Phase (Birks, 1990; Mackay et al., 2003; Mayewski et al., 2004). In the profile Gl-II (Figs 2, 4), above the sediments containing the fauna with *Discus ruderatus*, there are the calcareous tufas interbedded with dark muds and peat. In these sediments, there are numerous shells of water species (assemblage with water species). The fauna of such composition does not appear in other profiles, which is an indication of its local nature. The ecological composition of molluscs is indicative of a small, shallow, periodically drying body of water, which probably emerged as a result of separating a stream by a barrier (perhaps associated with a local landslide from the banks of the valley). The present interbeddings of muds usually do not contain snail shells, but they are enriched by re-deposited sporomorphs, pre-Quaternary crushed shells of Miocene bivalves, and the cysts of *Dinoflagellata* (Mamakowa & Wójcik, 1999). The palynological data indicates that the surroundings of the water body were overgrown by solid forests with a relatively great proportion of deciduous trees. Also abundantly present is the pollen of hygrophilous plants: *Salix*, *Alnus*, *Viburnum*, and *Phragmites*. The development of the said body of water can possibly be linked with the end of the Boreal Phase and/or the beginning of the Atlantic Phase. The interbeddings of muds containing redeposited Miocene material correspond to the phase of intensive flooding reconstructed in a number of river valleys within the Carpathian foreland (e.g. Starkel et al., 2006, 2015; Gębica, 2011, 2013a, b; Gębica et al., 2015). The presence of rich and diversified assemblage with *Discus perspectivus* is associated with the Atlantic Phase. That fauna was identified in the Gl-II, Gl-IV, and Gl-V profiles (Figs. 4-6). The malacoenose shows the predomination of shadow-loving species, as well as the presence of forms with high ecological requirements. The pollen analysis (Mamakowa & Wójcik, 1999) demonstrated the presence of compact forests with the major proportion of deciduous species. The presented assemblage has the features of "*Perspectivus*-fauna", which is characteristic of the Middle Holocene (Dehm, 1987) (radiocarbon date: 6490±90 BP, 5617 cal BC – 5311 cal BC; Gd-6069; c-3, Fig. 3, Table 2). Its connection with the Holocene Climatic Optimum was documented in many malacological profiles of Central and Western Europe (e.g. Ložek, 1972; Füköh, 1993, 1995; Alexandrowicz, 1997, 2001, 2004, 2015; Meyrick, 2002; Žak et al., 2002; Alexandrowicz & Rybska, 2013; Alexandrowicz et al., 2014, 2016; Juřičková et al., 2014; Horáčková et al., 2015). In the floor part of the deposits containing the said fauna, muds devoid of remnants of molluscs appear, containing redeposited Miocene material (the Gl-IV and Gl-V profiles; Figs. 5-6). It is a record of the abovementioned phase of intensified fluvial processes falling in the older part of the Atlantic Phase. In the top part of the interval in question, interbeddings of sands and gravels with crushed Miocene molluscs appear. They testify to a next erosion phase, which can be associated with the turn between the Atlantic and Subboreal Phases. Both of these phases are well documented in many locations of alluvial deposits in the Carpathian foreland (e.g. Starkel et al., 2006, 2015; Gębica, 2011, 2013a, b; Gębica et al., 2015). The sediments situated above them and identified in the profiles Gl-I, Gl-III and in locations of a tributary to the Glinne Stream (Gl-VI and Gl-VII) contain markedly poorer malacofauna with the major proportion of *Perforatella bidentata*. Palynological analysis indicates the numerous occurrences of hygrophilous plants, primarily *Salix* and *Alnus*. The data points at humid, shadowed habitats typical of valley floor, and the disappearance of forest species with high thermal requirements indicate the cooling of climate. The aforementioned sediments can be linked to the Subboreal Phase. Such an interpretation is also suggested by both their position in the profile, and by the results of radiocarbon dating: 3450±160 BP; 2266 cal BC – 1410 cal BC; Gd-9821; c-4, 2800±70 BP, 1154 cal BC – 811 cal BC; Gd-12010, c-5 (Fig. 4, Table 2). Within the sequence, several interbeddings of sands and gravels appear, suggesting the periods of intense floods. The detailed finding of their age and assigning them to the phases of intense fluvial activities defined in the Carpathian foreland (e.g. Starkel et al., 2006, 2015; Gębica, 2011, 2013a, b; Gębica et al., 2015) is very difficult because of the lack of a sufficient amount of data. The roof of the sediments containing the assemblage with *Perforatella bidentata* is of an erosional nature. Additionally, there is a marked change in the nature of sediments as well as in malacofauna they contain; the peat-mud-tufa sediments are replaced by silty formation. A poor assemblage with *Vallonia pulchella* is indicative of open, deforested habitats with a relatively dry substrate. Such changes in the features of the fauna indicate turbulent and rapid changes in the environment reflected primarily in the disappearance of forests. Similar processes have been documented in very many locations in river valleys, and they are reflected in the changed features of sediments (e.g. Starkel et al., 2015; Gębica, 2011, 2013a, b; Gębica, et al. 2015), their palynological content (e.g. Mamakowa & Starkel, 1974; Ralska-Jasiewiczowa, 1980, 1983), and malacological content (e.g. Alexandrowicz, 2004, 2013b, Horsák et al., 2007; Alexandrowicz et al., 2014, 2016). They are interpreted as representing the effects of anthropogenic deforestation leading to a rapid increase in the slope-related processes. In the top part of the silty series exposed in the profiles of the Glinne stream, molluscan shells are absent. However, the potato leaves occur in large numbers, which indicates the cultivation of root crops, particularly enhancing the washing down processes (Święchowicz, 2010; Łajczak et al., 2014). The deposits in question should be linked to the period of increased settlement activities, and with the intensification of accumulation in river valleys associated with it during the Middle Ages (Gębica & Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). The results of radiocarbon dating: 480±40 BP, 1327 cal AD – 1343 cal AD, and 1394 cal AD – 1476 cal AD; Gd-4253, c-7, Fig. 5, Table 2) confirms this interpretation.

5.2. Regional implications – environmental

The presence of a many phases with intensified fluvial activities of the rivers during the Holocene was frequently found in profiles of alluvial sediments in the Carpathians and their foreland (e.g. Starkel et al., 2006, 2015; Gębica & Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). The prevalent number of those profiles is situated in the valleys of major rivers. In this respect, minor streams were analysed on much rarer occasions. The hydrological conditions occurring in their valleys result in erosion processes during floods to be very intensive, therefore they are well-reflected in the sediments. In turn, this allows their use for reconstructions and correlations with the phases identified in large valleys. In the prevailing number of profiles described in professional publications, the malacological records were not preserved. There can be different reasons for the aforementioned phenomenon. On the one hand, they are associated with the great dynamics of water leading to breaking and removing the shell material. On the other hand, it is the lack of calcium carbonate observed in the majority of exposed alluvial sediments identified in the Flysch Carpathians and their foothills. It is a factor which decides about rapid destruction and dissolution of shells and, subsequently, leads to their elimination from sediments.

The malacological sequence in the sediments studied in the Glinne Stream valley represents the period spanning from the Late Glacial to the present. However, it is not continuous. Within particular profiles, there are interbeddings of sands, and sometimes also gravels without molluscan shells, while containing the redeposited fragments of Miocene bivalves. They mark the periods of intensified fluvial activity of the stream, and they testify to the development of erosional processes; therefore, some gaps occur in the malacological sequence. The analysis of profiles exposed in the valley of the Glinne Stream allowed the separation of several such periods. They correspond to the late part of the Younger Dryas, the transition of Boreal and Atlantic Phases, the upper part of Atlantic Phase, and the middle part of the Subboreal Phase. During the Subatlantic Phase, at least two subsequent periods of intensified erosion can be distinguished: the older, associated with its early part (Iron Age Cold Epoh?), and the younger, corresponding to the Early Middle Ages (Dark Ages Cold Epoh?). It is very likely that the final cutting of alluvial covers occurred during the last two hundred years (Fig. 7). Long-term studies conducted on the basis of fluvial sediments in the valleys of the Carpathian foreland allowed the identification of several distinct phases of the intensified fluvial activity of rivers and streams, as well as to identify precisely their time ranges (e.g. Starkel et al., 2006, 2015; Gębica & Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). When the stages of the development of the Glinne Stream valley is compared with data obtained in the studies of other valleys, great congruity in the sequence of erosion and accumulation phases is noted. That proves the existence of some regional connotations of these processes. The intensified fluvial activity of rivers, associated with the Middle and Late Holocene, was conditioned primarily by climatic conditions and occurred chiefly in more humid periods (e.g. Starkel et al., 2006, 2015; Gębica & Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). In the Late Holocene, climatic fluctuation coincided with anthropogenic activities, and with the passage of time, the latter become a predominant factor (Gębica, 2011, 2013a, b; Gębica et al., 2013). Deforestation should be deemed the most important factor affecting the course of geological processes. On the one hand, the deforestation leads to the intensification of slope processes and to the great supply of material to river valleys while, on the other hand, to the increased frequency and intensity of floods and, hence, to the intensification of erosion. The area of the Carpathian foreland was colonised by human groups relatively early. Nevertheless, it was only after the arrival in the area of agricultural groups from the Lusatian culture circle that led to the essential changes in the environment (Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). The vast deforestation significantly affected the intensity of geological processes, principally slope phenomena and fluvial processes. In the Glinne Stream valley, the manifestations of all these phenomena were noted in all profiles as erosion processes followed by the rapid accumulation of silty cover containing poor malacological assemblage (the fauna with *Vallonia pulchella*) without plant pollen. Similar phenomena can be observed in a number of river valleys in the northern foreland of the Carpathians both in Poland and Ukraine (Starkel et al., 2006, 2015; Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). The subsequent settlement phases have intensified these processes. As an effect, the covers were developed whose thickness can even reach several metres (Gębica, 2011, 2013a, b; Gębica et al., 2013, 2015). In the Glinne Stream, the silty series, linked to the aforementioned phase, is approx. 2 m thick, and the time of its deposition lasted no more than 2000 years. To compare, the underlying peat-mud-tufa series of similar thickness has developed in approx. 8000 years. The roof sections of the profiles represent the record of even more intensive accumulation. The presence of potato leaves is the characteristic feature of sediments that form them. The widespread introduction of root crops coupled with the arrangement of cultivated fields (narrow arable fields ploughed along with the slopes) were the reasons for the rapid erosion of soil and the major shifts of material to river valleys. During this period, lasting only 200 most recent years, the covers obtained a thickness of up to one metre. It should be emphasised that the record of such rapid anthropogenic changes in the environment is readable more easily in the valleys of small streams, which are much more vulnerable to the changes of the environment in their immediate surroundings than the valleys of major rivers (Gębica, 2011, 2013a, b; Cojoc et al., 2015). The Glinne Stream valley thus constitutes a magnificent example of the role of human activities and their impact on the environment.

5.3. Regional implications – malacological

The malacological sequence described in the sediments of the Glinne Stream valley shows many features common with the sequences described in other locations in the Carpathians and in their northern foreland. The sequence of faunistic assemblages was identified within the sediments of late glacial period, and Early and Middle Holocene. It includes initially cold-loving, Late Glacial assemblages with abundant occurrence of *Vertigo genesii*, *Vertigo geyeri*, *Columella columella*, and *Semilimax kotulae*. Along with progressive warming, they are replaced by faunas with major proportions of forest species, initially with *Discus ruderatus*, and later with *Discus perspectivus*. Such a pattern was described in very numerous malacological profiles in Central and Western Europe (e.g. Ložek, 1964, 1972; Dehm, 1967, 1987; Alexandrowicz, 1983, 1997, 2001, 2004, 2013a, 2015; Füköh, 1993, 1995; Preece & Day, 1994; Alexandrowicz & Alexandrowicz, 1995a, b; Preece, 1998; Preece & Bridgland, 1999; Gedda, 2001, 2006; Žak et al., 2002; Meyrick, 2002; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet, 2011; Alexandrowicz et al., 2014, 2016; Juřičková et al., 2014; Horáčková et al., 2015). It proves the existence of the climatic tendency of regional, or even continental, extent. The composition and structure of assemblages in particular locations are modified, in greater or lesser extent, by local factors. The clear testimony to that is the persistence of cold-loving species that sometimes occur in the sediments of the Boreal Phase, or even the Subatlantic Phase. It pertains particularly to the profiles situated in higher mountains and intermountain basins that typically have slightly cooler climate than the surrounding areas (e.g. Alexandrowicz, 1997, 2001, 2004, 2013a, 2015; Alexandrowicz et al., 2014, 2016; Juřičková et al., 2014; Horáčková et al., 2015). These forms are glacial relicts. In extreme cases, they can also be the components of contemporary faunas (e.g. *Semilimax kotulae* and *Vertigo geyeri* in the Podhale Basin (Horsák & Hájek, 2005; Schenková et al., 2012; Schenková & Horsák, 2013). In many profiles, the characteristic sequence of three species of *Discus* genus is found: *Discus ruderatus*, *Discus rotundatus*, and *Discus perspectivus*. They often appear in the sediments in just that order, testifying to the progressing warming of climate. This phenomenon is described in both Western and Central Europe; nevertheless, it is evidently diachronic. In the west of Europe, *Discus perspectivus* and *Discus rotundatus* appears in the sediments of the Boreal Phase, and sometimes even in its lower part (Preece & Day, 1994; Preece, 1998; Preece & Bridgland, 1999; Gedda, 2001, 2006; Žak et al., 2002; Meyrick, 2001, 2002; Limondin-Lozouet & Preece, 2004; Limondin-Lozouet, 2011); whereas, in Central Europe, it is noted from the beginning of the Atlantic Phase (e.g. Alexandrowicz, 1997, 2001, 2004, 2013a, 2015; Alexandrowicz et al., 2014, 2016; Juřičková et al., 2014; Horáčková et al., 2015). In the Glinne Stream valley, the occurrence of *Discus perspectivus* was found only as late as the middle part of the Atlantic Phase (radiocarbon date: 6490±90 BP, 5617 cal BC – 5311 cal BC; Gd-6069; c-3, Fig. 3, Table 2). It is similarly noted late in the profiles situated in intermountain valleys (Alexandrowicz, 1997, 2001, 2004, 2013a, 2015; Alexandrowicz et al., 2014). These observations incline towards the conclusion of the existence of a climatic gradient in Europe.

6. CONCLUSIONS

Malacological studies supplemented by lithological and palynological data, conducted in the Glinne Stream valley, allowed the reconstruction of the environmental changes covering the period of approx. 10,000 years. The specific conditions prevailing in the Glinne stream valley, particularly the availability of calcium carbonate, contributed to the preservation of abundant assemblages of molluscs. This situation permitted the reconstruction of the phases of intensified activities of the stream, emphasized by the presence of erosion surfaces, gravel insertions, and stratigraphic gaps. During the periods of quieter sedimentation, fine-grain sediments with the high calcium carbonate content were formed, as well as peats. The first type of sediments had many molluscan shells providing the basis to palaeoenvironmental reconstructions. The second type of sediments provided the basis for radiocarbon dating and thus permitted the identification of their stratigraphic positions. The sum of these elements translates into the great cognitive value of the discussed location.

The results indicate that during the Early and Middle Holocene, these changes were generated by natural factors. A characteristic sequence of fauna and flora assemblages can be observed there. The palynological data shows that, from the beginning of the Holocene, forest environments have predominated in the area. Initially, these were coniferous forests, later, along with the warming of climate; they were gradually replaced by more species-diverse mixed forests. Similar conclusions can also be drawn from the analysis of the molluscan assemblages. The fauna with Vertigo genesii and Discus ruderatus, containing numerous cold-loving species is associated with the cool period of the end of Late Glacial and the Preboreal Phase. In line with the progress of climate warming, these forms disappear with a simultaneous increase in taxa characteristic of compact coniferous forests (the assemblage with *Discus ruderatus*). As an effect of further warming, the assemblage with *Discus perspectivus*, an indicator of the Atlantic Phase containing many forest species with high thermal requirements, is found. In the concerned interval, several phases of erosion are marked that can be correlated with the periods of the increased humidity of climate. The analogous phases are reconstructed in a number of river valleys in the Carpathian foreland. The significant changes of the environment are marked in the upper parts of profiles. These are emphasised by both the change in the nature of sediments and by marked shake-up of the species composition of molluscan assemblages. A rapid acceleration of sedimentation as well as the disappearance of shadow-loving species and their replacement by open-country forms indicate the deforestation of the area connected with anthropogenic pressure and the development of agriculture. The changes fell into the end of Subboreal Phase and the older part of the Subatlantic Phase, and, like many other locations within the Carpathian foothills, it can be associated with the Lusatian settlements. The periods of marked acceleration of the sediment deposition interspaced by erosion episodes indicate the subsequent phases of intensified anthropogenic pressure, which can be associated with the intensive settlement activities as well as with the introduction of root crops (18^{th} and 19^{th} centuries). The final cutting of the sediments of the Glinne Stream sediments took place in the last 200 years.

The natural and anthropogenic changes of the environment reconstructed on the basis of profiles exposed in the Glinne Stream valley correspond to the results of similar analyses conducted in other valleys in eastern Poland and western Ukraine. It testifies to the existence of regional trends in such changes. It should also be emphasised that the discussed location is the sole object in this area where such detailed malacological analysis was completed. This fact permits obtaining new and unique data pertaining to the development and evolution of the environment in the Carpathian foreland during the Holocene.

Acknowledgements

This study has been sponsored by AGH University of Science and Technology through the University grant no 11.11.140.005.

REFERENCES

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

Alexandrowicz, S.W., 1987. *Malacofauna of the Late Vistulian and Early Holocene lacustrine chalk from Roztoki near Jasło (Jasło-Sanok Depression).* Acta Palaeobotanica, 27, 67-74.

Alexandrowicz, S.W. & Alexandrowicz, W.P., 1995a. *Quaternary molluscan assemblages of the Polish Carpathians*. Studia Geomorphologica Carpatho-Balcanica, 29, 41-54.

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

Alexandrowicz, S.W. & Alexandrowicz, W.P., 2011. *Malacological analysis – methods of investigation and interpretation.* Rozprawy Wydziału Przyrodniczego PAU 3, 5-302. (in Polish).

Alexandrowicz, S.W. & Łanczont, M., 1995. *Loesses and alluvia in the Krzeczkowski Stream valley in Przemyśl environs (SE Poland).* Annales UMCS B, 50, 29-50.

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

Alexandrowicz, W.P., 1999. Results of malacological analysis in Markowa site. Excursion Guide Book. VI Conference Pleistocene Stratigraphy of Poland. Czudec 31 VIII – 4 IX 1999, 141-146. (in Polish).

Alexandrowicz, W.P., 2001. *Late Vistulian and Holocene molluscan assemblages from calcareous tufa at Ostrysz Hill (Podhale Basin).* Folia Malacologica, 9, 159-169.

Alexandrowicz, W.P., 2004. *Molluscan assemblabes of Late Glacial and Holocene calcareous tufas in Southern Poland.* Folia Ouaternaria, 75, 1-309.

Alexandrowicz, W.P., 2013a. *Malacological sequence from profile of calcareous tufa in Groń (Podhale Basin, southern Poland) as an indicator of the Late Glacial/Holocene boundary*. Quaternary

International, 293, 196-206.
Alexandrowicz, W.P., 2013b. *Molluscan communities in Late Holocene fluvial deposits as an indicator of human activity: a study in Podhale Basin in South Poland*. Ekologia Bratislava, 32, 111-125.
Alexandrowicz, W.P., 2015. *The application of malacological analysis in the study of slope deposits: Late Pleistocene and Holocene of the Podhale Basin (Carpathians, Poland).* Acta Geologica Polonica, 65, 245-261.
Alexandrowicz, W.P. & Rybska, E., 2013. *Environmental changes of intramontane basins derived from malacological analysis of profile of calcareous tufa in Niedzica (Podhale Basin, Southern Poland).* Carpathian Journal of Earth and Environmental Sciences, 8, 13-26.
Alexandrowicz, W.P., Szymanek, M. & Rybska, E., 2014. *Changes to the environment of intramontane basins in the light of malacological research of calcareous tufa: Pohdale Basin (Carpathians, Southern Poland).* Quaternary International, 353, 250-265.
Alexandrowicz, W.P., Szymanek, M. & Rybska, E., 2016. *Molluscan assemblages from Holocene calcareous tufa and their significance for palaeoenvironmental reconstructions. A study in the Pieniny Mountains (Carpathians, Southern Poland).* Carpathian Journal of Earth and Environmental Sciences, 11, 73-54.
Alexandrowicz, W.P., Uchman, A. & Zuchiewicz, W., 1992. *On young calcareous tufas at Husów, Dynów Foothills, West Carpathians, South Poland*. Bulletin of the Polish Academy of Sciences, Earth Sciences, 40, 43-53.
Birks, H.J.B., 1990. *Changes in Vegetation and Climate during the Holocene of Europe*, 133-158. In: Boer, M.M. & de Groot, R.S., (Eds), Landscape-Ecological Impact of Climatic Change. IOS Press, Amsterdam.
Bronk Ramsey, C., 2003. OxCal Program 3.9. University of Oxford. Radiocarbon Accelerator Unit.
Cojoc, G.M., Romanescu, G. & Tirnovan, A., 2015. *Exceptional floods on a development river: a case study for the Bistrica River from the Eastern Carpathians (Romania).* Natural Hazards, 77, 1421-1451.
Dehm, R., 1967. *Die landschnecke Discus ruderatus im Postglazial Sddeutschlands*. Mitteilungen der Bayerische Staatssammlung für Paläontologie und Historische Geologie, 7, 135-155.
Dehm, R., 1987. *Die landschnecke Discus perspectivus im Postglazial Sdbayerns*. Mitteilungen der Bayerische Staatssammlung für Paläontologie und Historische Geologie, 27, 21-30.
Feurdean, A., Perşoiu, A., Tantau, I., Stevens, T., Magyari, E.K., Onac, B.P., Markovic, S., Andric, M., Connor, S., Farcas, S., Gałka, M., Gaudeny, T., Hoek, W., Kolaczek, P., Kunes, P., Lamentowicz, M., Marinova, E., Michczyńska, D.J., Persoiu, I, Płóciennik, M., Słowiński, M., Stancikaite, M., Sümegi, P, Svensson, A., Tamas, T., Timar, A., Tonkov, S., Toth, M., Veski, S., Willis, K.J. & Zernitskaya, V., 2014. *Climate variability and associated vegetation response throughout Central and Eastern Europe (CEE) between 60 and 8 ka.* Quaternary Science Reviews, 106, 206-224.
Füköh, L., 1993. *Holocene malacofaunal assemblages in Hungary*. Scripta Geologica, Special Issue, 2, 121-125.
Füköh, L., 1995. *History of the Hungarian Holocene mollusc fauna.* Geojournal, 36, 255-259.
Gedda, B., 2001. *Environmental and climatic aspects of the Early and Mid Holocene calcareous tufa and land mollusc fauna in southern Sweden*. Lundqua Thesis, 45, 1-50.
Gedda, B., 2006. *Terrestrial mollusc succession and stratigraphy of a Holocene calcareous tufa deposit from the Fyledalen valley, southern Sweden*. The Holocene, 16, 137-147.
Gębica, P., 2011. *Stratigraphy of alluvial fills and phases of the Holocene floods in the lower Wisłok river.* Geographia Polonica, Special Issue I, 39-60.
Gębica, P., 2013a. *Chronostratigraphy of alluvia and age of fluvial landforms in the Carpathians foreland during the Vistulian*. Studia Quaternaria, 30, 19-27.
Gębica, P., 2013b. *Geomorphological records of human activity reflected in fluvial sediments in the Carpathians and their foreland*. Landform Analysis, 22, 21-31.
Gębica, P. & Krąpiec, M., 2009. *Young Holocene alluvia and dendrochronology of subfossil trunks in the san river valley.* Studia Geomorphologica Carpatho-Balcanica, 43, 63-75.
Gębica, P., Michczyńska, D.J. & Starkel, L., 2015. *Fluvial history of the Sub-Carpathian Basins (Poland) during the last cold stage (60–8 cal ka BP).* Quaternary International, 388, 119-141.
Gębica, P., Starkel, L., Jacyszyn, A. & Krąpiec, M., 2013. *Mideval accumulation in the Upper Dniestr River Valley: the role of human impact and climate change in the Carpathian Foreland.* Quarternary International, 293, 207-218.
Horáčková, J., Ložek, V. & Juřičková, L., 2015. *List of malacologically treated Holocene sites with brief review of palaeomalacological research in Czech and Slovak Republics.* Quaternary International, 357, 207-211.
Horsák, M. & Hájek, M., 2005. *Habitat requirements and distribution of Vertigo geyeri (Gastropoda: Pulmonata) in Western Carpathian rich fens.* Journal of Conchology, 38, 683-700.
Horsák, M., Hájek, M., Dítě, D. & Tichy, L., 2007. *Modern distribution patterns of snails and plants in the western Carpathian spring fens: is it a result of historical development?* Journal of Molluscan Studies, 73, 53-60.
Horsák, M., Juřičková, L. & Picka, J., 2013. *Molluscs of the Czech and Slovak Republics*. 264 pp. Kabourek, Zlín.

Juřičková, L., Horáčková, J. & Ložek, V., 2014. *Direct evidence of Central European forest refugia during the Last Glacial Period based on mollusc fossils*. Quaternary Research, 82, 222-228.

Klimaszewski, M., 1972. *Goemorphology of Poland, Southern Poland – mountains and uplands*. 384 pp. PWN Warszawa. (in Polish).

Kerney, M.P., Cameron, R.A.D. & Jungbluth, J.H., 1983. *Die Landschnecken Nord- und Mitteleuropas*. 384 pp. Verlag P. Parey, Hamburg-Berlin.

Krolopp, E. & Sümegi, P., 1993. *Vertigo modesta (Say 1924), Vertigo geyeri Lindholm 1925 and Vertigo genesii (Gredler 1856) species in Pleistocene formations of Hungary*. Malakological Newsletter, 12, 9-14.

Lericolais, G., Guichard, F., Morigi, C., Minereau, A., Popescu, I. & Radan, S., 2010. *A post Younger Dryas Black Sea regression identified from sequence stratigraphy correlated to core analysis and dating.* Quaternary International, 255, 199-209.

Limondin-Lozouet, N., 1992. *Biogeographie Holocene de Vertiginidae (Mollusca - Gastropoda) Europeens: relations la derniere deglaciation*. Compest Rendus de l'Académie des Sciences Paris, 315, 1281-1287.

Limondin-Lozouet, N., 2011. *Successions malacologiques à la charnière Glaciaire/Interglaciaire: du modèle Tardiglaciaire-Holocène aux transitions du Pleistocène.* Quaternaire, 22, 211-220.

Limondin-Lozouet, N. & Preece, R.C., 2004. *Molluscan successions from the Holocene tufa of St Germain-le-Vasson, Normandy (France) and their biogeographical significance.* Journal of Quaternary Science, 19, 55-71.

Limondin-Lozouet, N. & Rousseau, D.D., 1991. *Holocene climate as reflected by a malacological sequence at Verriers, France*. Boreas, 20, 207-229.

Ložek, V., 1964. *Quartärmollusken der Tschechoslowakei.* Rozpravy Ustředniho Ustavu Geologického, 31, 1-374.

Ložek, V., 1972. *Holocene Interglacial in Central Europe and its land snails*. Quaternary Research, 2, 327-334.

Łajczak, A., Margielewski, W., Rączkowska, Z. & Święchowicz, J., 2014. Contemporary geomorphic processes in the Polish Carpathians under changing human impact. Episodes, 37, 21-32.

Mackay, A., Battarbee, R., Birks, J. & Oldfield, F., (Eds), 2003. *Global Change in the Holocene*. pp. 528. Edward Arnold, London.

Madeyska, T., 1998. *Vegetation in Poland at the close of the last glaciation.* Studia Geologica Polonica, 113, 137-180. (in Polish with English summary).

Mamakowa, K. & Starkel, L., 1974. *New data about the profile of Young Quaternary deposits at Brzeźnica in Wisłoka valley, Sandomierz Basin*. Studia Geomorphologica Carpatho-Balcanica, 8, 47-59.

Mamakowa, K. & Wójcik, A., 1999. Markowa site. Excursion Guide Book. VI Conference Pleistocene Stratigraphy of Poland. Czudec 31 VIII – 4 IX 1999, 130-141. (in Polish).

Mania, D., 1995. *The influence of Quaternary Climatic development on the Central European mollusc fauna.* Acta Zoologica Cracoviensis, 38, 17-34.

Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlen, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R. & Steig, E.J., 2004. *Holocene climate variability.* Quaternary Research, 62, 243-255.

Meyrick, R.A., 2001. *The development of terrestial mollusc faunas in the 'Rheinland region' (western Germany and Luxembourg) during the Lateglacial and Holocene.* Quaternary Science Reviews, 20 16–17, 1667-1675.

Meyrick, R.A., 2002. *Holocene molluscan faunal history and environmental change at Kloster Mühle, Rheinland-Pfalz, western Germany*. Journal of Quaternary Science, 18, 121-132.

Meyrick, R.A. & Preece, R.C., 2001. *Molluscan succesions from two Holocene tufas near Northampton, English Midlands.* Journal of Biogeography, 28, 77-93.

Obidowicz, A., 1990. *Eine pollenanalytische und moorkundlische Studie zur Vegetationgeschichte des Podhale-Gebietes (West-Karpaten).* Acta Palaeobotanica, 30, 147-219.

Pokryszko, B., 1990. The Vertiginidae of Poland (Gastropoda: Pulmonata: Pupillidae) – a systematic minograph. Annales Zoologici, 43, 133-257.

Połtowicz, S., 2004. *The Stebnik and Zgłobice Units in the Polish Carpathians structure*. Geologia Kwartalnik AGH, 30, 85-120. (in Polish with English summary).

Preece, R.C., 1998. *Mollusca*. In: Preece, R.C. & Bridgland D.R., (Eds), Late Quaternary environmental change in North-West Europe: excavations at Holywell Coombe, South-West England, 158-212. Chapman & Hall, London.

Preece, R.C. & Bridgland, D.R., 1999. *Holywell Coombe, Folkestone: a 13,000 year history of an English chalkland valley.* Quaternary Science Review, 18, 1075-1125.

Preece, R.C. & Day, S.P., 1994. *Comparison of Post-glacial molluscan and vegetational successions from a radiocarbon-dated tufa sequence in Oxfordshire*. Journal of Biogeography, 21, 463-468.

Ralska-Jasiewiczowa, M., 1980. *Late-glacial and Holocene vegetation of the Bieszczady Mts. (Polish Eastern Carparthians).* Acta Palaeobotanica, 20, 1-202.

Ralska-Jasiewiczowa, M., 1983. *The relationship between river activity and development of peat bogs on valley floors in the Polish Eastern Carpathians.* Geologishes Jahrbuch A, 41, 149-160.

Schenková, V. & Horsák, M., 2013. *Refugial populations of Vertigo lilljeborgi and V. genesii (Vertiginidae): new isolated occurrences in Central Europe, ecology and distribution.* American Malacological

Bulletin, 31, 323-329.
Schenková, V., Horsák, M., Plesková, Z. & Pawlikowski, P., 2012. *Habitat preferences and conservation of Vertigo geyeri (Gastropoda: Pulmonata) in Slovakia and Poland.* Journal of Molluscan Studies, 78, 105–111.
Starkel, L., 1972. *Sandomierz Basin*. In: Klimaszewski, M., (Ed.), Geomorphology of Poland, 2, 138-166. PWN Warszawa. (in Polish).
Starkel, L., 1991. *Environmental changes at the Younger Dryas-Preboreal transition and during the early Holocene: some distinctive aspects in central Europe.* The Holocene, 1, 234-242.
Starkel, L., 2007. *The diversity of fluvial system response to the Holocene hydrological changes using the Vistula river catchment as an example.* Annales Societatis Geologorum Poloniae, 77, 193-205.
Starkel, L., Gębica, P. & Superson, J., 2007. *Last Glacial-Interglacial cycle in the evolution of river valleys in southern and central Poland.* Quaternary Science Reviews, 26, 2924-2936.
Starkel, L., Michczyńska, D.J., Gębica, P., Kiss, T., Panin, A. & Perşoiu, I., 2015. *Climatic fluctuations reflected in the evolution of fluvial systems of Central-Eastern Europe (60–8 ka cal BP).* Quaternary International, 338, 97-118.
Starkel, L., Soja, R. & Michczyńska, D. J., 2006. *Past hydrological events reflected in Holocene history of Polish Rivers.* Catena, 66, 24-33.
Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, F.G., van der Plicht, J. & Spurk, M., 1998. *INTCAL98 Radiocarbon age calibration 24,000–0 cal BP.* Radiocarbon, 40, 1083-1127.
Święchowicz, J., 2010. *Extreme sheet and rill erosion on agricultural slopes in the flysch Polish Carpathians.* Prace i Studia Geograficzne, 45, 29-48. (in Polish with English summary).
Uchman, A., Krobicki, M. & Gonera, M., 1992. *A Miocene (Lower Sarmatian) storm shell bed In the Carpathian Foredeep at Husów, SE Poland.* Bulletin of the Polish Academy of Sciences, Earth Sciences, 40, 15-21.
Walanus, A. & Nalepka, D., 2010. *Calibration of Mangerud's boundaries.* Radiocarbon, 52, 1639-1644.
Walter-Schultes, F., 2012. *European non-marine molluscs, a guide for species identification*. pp. 674. Planet Poster Editions, Göttingen.
Wiktor, A., 2004. Land snails of Poland. pp. 302. Mantis, Olsztyn. (in Polish).
Žak, K., Ložek, V., Kadlec, J., Hladikova, J. & Cilek, V., 2002. *Climate-inducted changes in Holocene calcareous tufa formations, Bohemian Karst, Czech Republic.* Quaternary International, 91, 137-152.

Received at: 12. 03. 2018
Revised at: 06. 03. 2019
Accepted for publication at: 16. 05. 2019
Published online at: 20. 05. 2019