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RECORD OF ENVIRONMENTAL CHANGES DURING THE HOLOCENE IN THE LIGHT OF MALACOLOGICAL STUDIES OF RIVER SEDIMENTS IN THE ŁAPSZANKA STREAM VALLEY (SPISZ AREA, CARPATHIANS, SOUTHERN POLAND)

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Abstract: The analysis included alluvial sediments in the Łapszanka Stream valley in the Spisz area (Carpathians, Southern Poland). Seven gravel levels were distinguished in the sedimentary sequence, which is a record of periods of intense fluvial activity correlated with wet climate phases. They fall in the Early Holocene (10 100–8900 y BP), the beginning of the Middle Holocene (7900–6600 y BP), the Middle Holocene (6100–5900 y BP), the beginning of the Late Holocene (5100–4000 y BP), the Iron Age Cold Epoch, the Dark Ages Cold Period and the Little Ice Age. The gravels are separated by layers of mud, containing an abundant mollusc fauna. It was possible to distinguish five types of fauna assemblages corresponding to the environmental changes in the Spisz area during the Holocene. The malacofauna indicates that forests covered this area to a large extent during almost the entire period analysed. During the Early Holocene, the area was dominated by coniferous forests, and the fauna contained numerous cold-tolerant taxa. The Middle Holocene saw the emergence of mixed forests inhabited by mollusc communities that included species with high ecological tolerance. A malacofauna containing moisture-loving forest assemblages is characteristic of the sediments of the Late Holocene. The occurrence of muds (agricultural muds) with open-country snails at the top of the sequence indicates increased anthropogenic impact and associated deforestation during the last 500 years.

Key words: Fluvial deposits, molluscs, flood phases, environmental changes, Holocene, Spisz area.

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INTRODUCTION

Climatic fluctuations that usually lasted several hundred years took place during the Holocene (e.g., Bond *et al*., 2001; Mayewski *et al*., 2004; Wanner *et al*., 2011, 2014). They were triggered by various factors, among which changes in atmospheric and oceanic circulation and solar activity should be considered the most relevant (e.g., Mauri *et al*., 2015; Demény *et al*., 2021). As a result, colder and wetter phases, punctuated by warmer and drier periods, can be distinguished. The climate changes impacted on the course of geological processes as well as the nature of faunal and floral assemblages. Climate fluctuations are closely reflected in fluvial systems. During cooler and wetter periods, there was an increase in the fluvial activity of rivers and streams, resulting in the deposition of coarse-grained sediments (gravels). The accumulation of fine-grained sediments (sands and muds) is usually attributed to warmer and drier phases (e.g., Starkel *et al*., 2006, 2013; Hoffmann *et al*., 2008; Gębica, 2011, 2013a, b; Wirth *et al*., 2013; Benito *et al*., 2015; Gębica *et al*., 2016; Perşoiu and Perşoiu, 2019; Rădoane *et al*., 2019).

River sediments often contain organic residues. Large plant fragments – branches and even tree trunks – appear in the gravel series. In fine-grained sediments, fine plant detritus and mollusc shells are frequently found. In the sediments deposited by large rivers, the malacofauna contains mainly aquatic or wetland species living on the valley floor. In the smaller valleys, mollusc assemblages are enriched in terrestrial species, representing both the valley floor and the valley slopes. Human impact on the course of fluvial processes and also on the composition and structure of floral and faunal assemblages varies. It is particularly evident in highly transformed areas, mainly as a result of settlement, deforestation, and agricultural activity.

The study presented here demonstrates the potential for using malacological analysis to reconstruct environmental change concerning the phases of climatic fluctuations during the Holocene. Another objective of the study was to determine the role of humans as a factor that has a considerable impact on the characteristics of the natural environment and to determine the phases of increased anthropogenic impact.

SITE DESCRIPTION

The studies were conducted in the Spisz area, in the valley of the Łapszanka Stream, about 3 km west of the village of Niedzica (GPS: N49º24′04″; E20º16′30″; Fig. 1). In this section, the stream flows through a wide valley on a small slope. At the mouth of one of the tributaries (the Złatny Stream), an alluvial fan, cut by both the Łapszanka and the Złatny Streams, has formed (Fig. 2). Two terrace levels are visible there. The lower one rises about 1–1.5 m above the level of the modern riverbed of the Łapszanka Stream and forms a narrow (up to 15 m wide) strip, with a flat surface overgrown with dense vegetation (moisture-loving forest with the predominance of alder and willow; Fig. 2). The higher terrace is the alluvial fan of the Złatny Stream. In the proximal part, this cone is only slightly cut and rises about 0.5–1 m above the modern level of the Złatny Stream. In the distal part, the indentation is much larger, reaching a height of up to 5 m above the modern Łapszanka riverbed. The higher terrace forms an extensive (approximately 1 km wide) flat area and it is completely deforested and occupied by arable fields and pastures (Fig. 2). Both terrace slopes expose fluvial sediments, formed as layers of gravels, separated by fine-grained sand and mud deposits. The profile presented had already been analysed preliminarily from a malacological perspective (Alexandrowicz, 1997a). These data were supplemented by more detailed sampling of the profile and the collection of materials to enable radiocarbon dating.

MATERIAL AND METHODS

The analysis covered the sediments exposed in the two terrace slopes mentioned above. Observations of the lithological variability of the sediments were made and samples were taken in the field for malacological studies and age determinations. A total of 49 samples were obtained from both sites (profiles Lp-I and Lp-II), 26 of which contained mollusc shells. The samples were sectional, closely associated with the lithology of the sediments, and had a weight of ca.

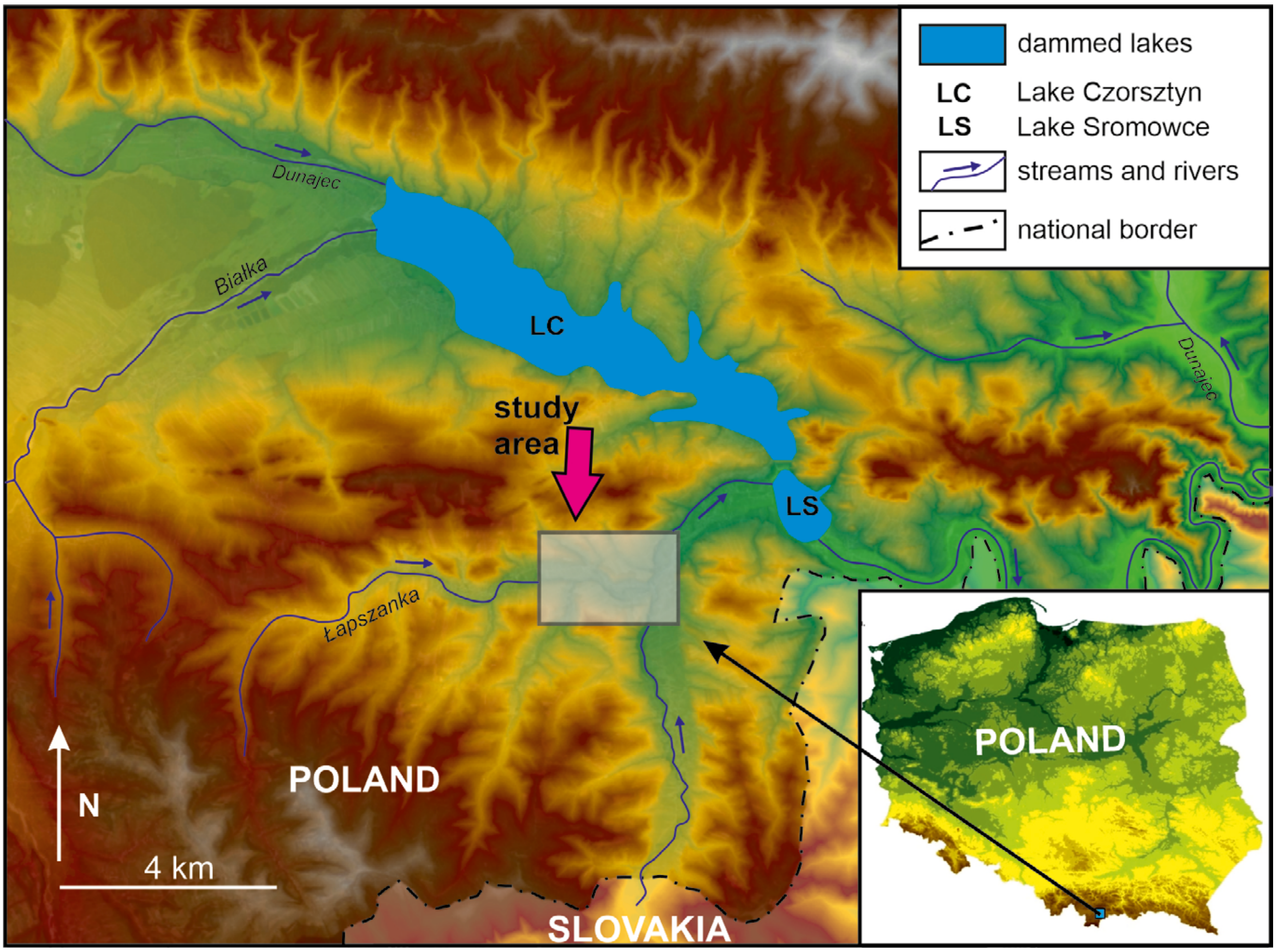

Fig. 1. General location of the study area (map base: www. polska.e-mapa.net).

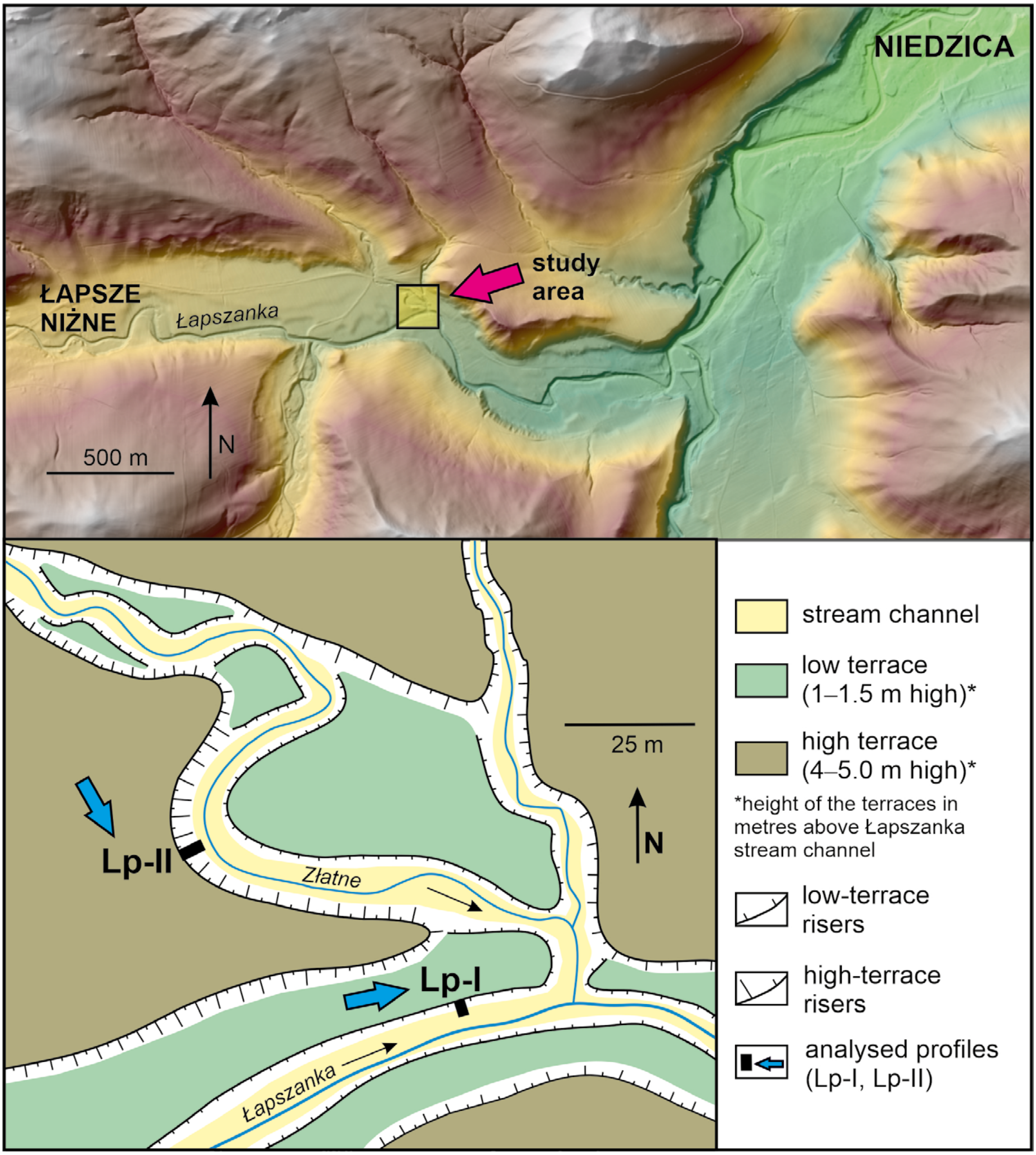

Fig. 2. Detail location of profiles of fluvial deposits in the Łapszanka Stream valley (map base: www. polska.e-mapa.net).

3 kg each. Shell material occurred only in the fine-grained deposits. Malacofauna selected from the sediments was determined using keys (Wiktor, 2004; Welter-Schultes, 2012; Horsák *et al.*, 2013) and comparative collection. Particular taxa are classified into ecological groups according to the scheme developed by Ložek (1964) with its modifications (Alexandrowicz and Alexandrowicz, 2011; Juřičkova *et al.*, 2014a). The calculated percentages of species and ecological groups enabled the compilation of malacological diagrams. Using a dendrogram of similarities (UPGMA clustering method and Morisita's algorithm, Morisita, 1959), five malacological assemblages were distinguished. Statistical analysis was carried out, using the statistical program PAST (Hammer *et al.*, 2001). Carrying out radiocarbon dating (at the Radiocarbon Laboratory of the Ukrainian Academy of Sciences in Kyiv, laboratory reference number: Ki) of six samples made it possible to determine the age of individual units of the sedimentary succession. The basis for C-14 analyses was plant remains found in the sediments. The results of age determination were calibrated using

OxCal software (Bronk Ramsey, 2017) and IntCal20 calibration data (Reimer *et al*., 2020). In addition, a coin found in one of the gravel layers (an Austrian Kreuzer from 1810) was used. The lithological, malacological, and stratigraphic data allowed the recognition of phases of environmental change and the correlation of them with the climatic phases of the Holocene.

RESULTS

Lithology of sediments

In the profile of the lower terrace (profile Lp-I), it is possible to distinguish four layers of fine- to medium-grained gravels formed by discoidal, well-rounded pebbles. The dominant components of the gravels are sandstones representing the Podhale Flysch. The pebbles of rocks of the Pieniny Klippen Belt are much rarer and are usually smaller in size. The matrix is sandy and abundant. The thickness of individual layers varies from 12 to 20 cm. Gravels are separated by layers of fine-grained, dark grey mud, containing mollusc shells and local accumulations of fine plant detritus. Four layers of such deposits with thicknesses between 15 and 25 cm were distinguished in this profile. The total thickness of the fluvial sequence in profile Lp-I is 1.25 m. Profile Lp-II represents the sedimentary sequence, comprising the higher terrace (the alluvial fan of the Złatne Stream) and has a thickness of 5 m. Within it, six gravel layers were distinguished. They are composed of fine-grained gravels formed from Oligocene sandstones of the Podhale Flysch. There are also numerous pebbles of rocks of the Pieniny Klippen Belt, forming the upper part of the Złatny Stream catchment. The sizes of the pebbles decrease towards the top of the profile, whereas the proportion of rocks representing the Pieniny Klippen Belt increases. The gravels are characterized by a very abundant, sandy matrix. The thickness of individual gravel layers varies from 10 to 80 cm. As in the lower terrace, the gravels are separated by layers of fine-grained sediments. Two variations of these appear in the Lp-II profile. Dark grey, sandy muds with abundant mollusc shells are present in the bottom part. Yellow muds (agricultural muds) are present in the upper part. The last-mentioned deposits include intercalations, enriched in pebbles of fine sandstone, accumulations of plant detritus, and shells of molluscs. In the lower part of the Lp-II profile, there are three thin (up to 10 cm) layers of peat with very abundant plant remains and mollusc shells. The sequences of lithological types of sediments are shown in Figures 3 and 4.

Malacofauna

A rich and diverse malacofauna was found in both profiles. A total of more than 16,000 specimens belonging to 69 species (62 land snails, 4 aquatic snails, and 3 bivalves) were determined in twenty-six samples. A few calcareous plates of slugs were also found. In individual samples, the number of specimens varied from 149 to 2,620, and the number of species from 9 to 52 (Tab. 1; Supplementary Material 1, 2). Shadow-loving snails (ecological groups F_F, F_B, and F_H) are the most abundant component of the fauna (36 species). Among these, forest taxa (group F_F) play a prominent role. These include both forms with high thermal tolerance, inhabiting coniferous and mixed forests (*Discus ruderatus*, *Aegopinella pura*), and species preferring a warm climate, living in deciduous forests (*Discus perspectivus*, *Ruthenica filograna*, *Clausilia cruciata*). Of note is the occurrence of a relict form of *Semilimax kotulae* in the bottom part of the Lp-II profile. In the Lp-I profile, taxa typical for shady habitats with high humidity are abundant: *Vitrea crystallina*, *Vestia gulo*, and *Vestia turgida*. The percentage of shadow-loving taxa in the analysed fauna reaches 60%. Only in the upper part of the Lp-II profile, shadow-loving species are not present (Figs 3, 4; Tab. 1; Supplementary Material 1, 2). Open-country snails (ecological group O_O) are present virtually in all the analysed samples. Usually, their share is small and does not exceed 10-15% of the assemblage. The exceptions are the top two samples from the Lp-II profile, where they are the dominant group and their contribution to the assemblage approaches 90%. The most prevalent taxa are *Vallonia pulchella* and *Vallonia costata*. Noteworthy is the cold-loving species: *Columella columella*, the shells of which were found in the bottom part of the Lp-II profile (Figs 3, 4; Tab. 1; Supplementary Material 1, 2). Mesophilous taxa (ecological groups M_I and M_H) appear in abundance in all samples (except in the upper interval of the Lp-II profile), and their proportion in the assemblages usually varies between 20 and 30%. They are an additional component of the assemblage. In the Lp-I profile, *Arianta arbustorum* and *Perforatella bidentata* play a particularly important role. They are typical of shady and moist habitats and are often found in damp woodland and scrub, overgrowing valley bottoms (Figs 3, 4; Tab. 1; Supplementary Material 1, 2). Hygrophilous species (ecological group H) are represented by 6 taxa. They are found in almost all samples (except in the upper section of the Lp-II profile), but their proportion in the assemblages rarely exceeds 10%. In addition to the relatively abundant *Carychium minimum* and *Zonitoides nitidus*, the presence of two cold-loving taxa, i.e., *Vertigo genesii* and *Vertigo geyeri,* in the bottom part of the Lp-II profile is noteworthy (Figs 3, 4; Tab. 1; Supplementary Material 1, 2). Aquatic molluscs (ecological group W) play a minor role, and the proportion of them in the assemblages is usually less than 5%. They are only more prominent in three samples from the Lp-II profile. This group includes the taxa of periodic water bodies (*Galba truncatula*), species with high ecological tolerance (*Pisidium casertanum*) as well as reophilous forms (*Pisidium personatum*) (Figs 3, 4; Tab. 1; Supplementary Material 1, 2).

DISCUSSION

Molluscan assemblages

Analysis of the similarity dendrogram made it possible to distinguish five faunal assemblages, characterising different phases of sediment deposition (Fig. 5).

Assemblage Dru (*Discus ruderatus*). This fauna is present in the bottom part of the Lp-II profile. Its characteristic feature is the presence of shadow-loving species, preferring coniferous (*Discus ruderatus*) or mixed forests (*Aegopinella*

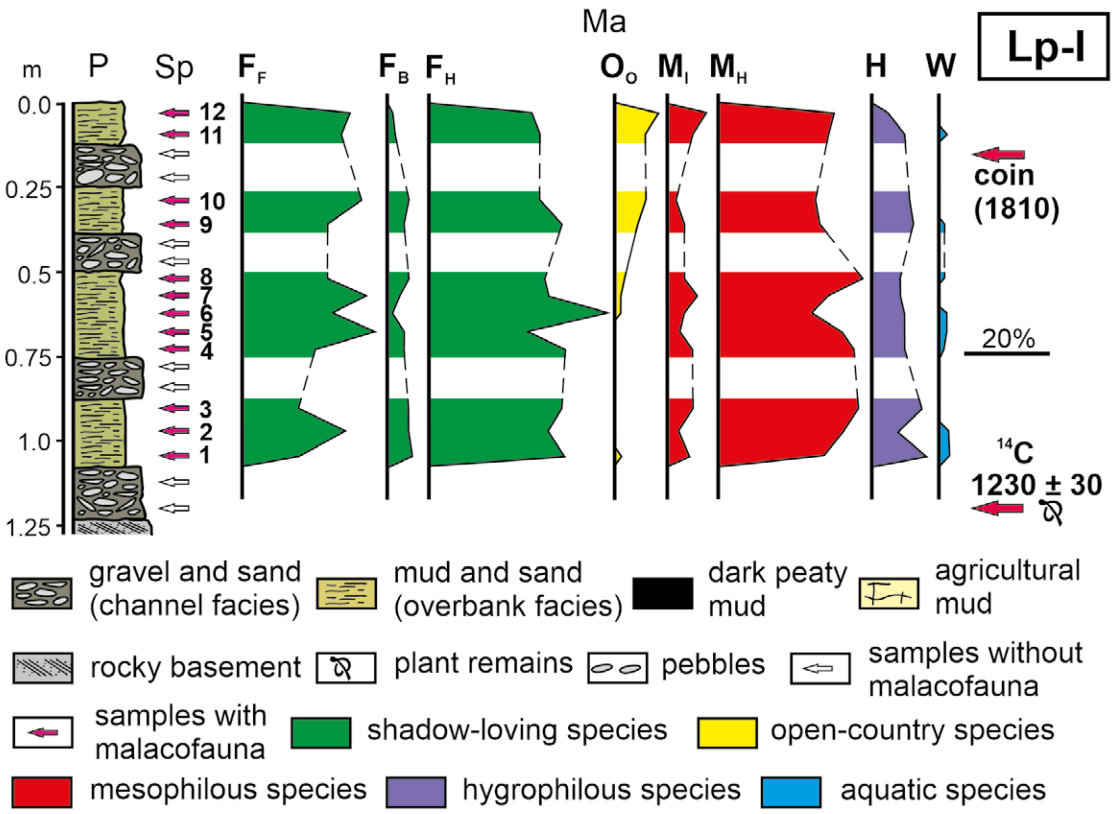

Fig. 3. Lithology of fluvial sediments and the mollusc fauna in the Łapszanka Stream valley (profile Lp-I). P – lithological profile; Sp – samples; Ma – malacofauna; Ecological groups of molluscs after: Ložek (1964), Alexandrowicz and Alexandrowicz (2011) and Juřičková *et al.* (2014a); F_F – forest species; F_B – shadow-loving species of rare forests and shrub zones; F_H – shadow-loving, moist forest species; O_O – open-country species; M_I – mesophilous species of medium humid habitats; M_H – mesophilous species of humid habitats; H – hygrophilous species; W – aquatic species.

pura), and taxa inhabiting shady biotopes with high moisture (*Vitrea crystallina*). The proportion of the shadow-loving component in the assemblage under consideration exceeds 50%. Another feature of this fauna is the presence of cold-tolerant species (*Semilimax kotulae*, *Columella columella*, *Vertigo genesii,* and *Vertigo geyeri*). This fauna is complemented by mesophilous taxa. The remaining ecological groups form an accessory component. The assemblage corresponds to the *Ruderatus*-fauna (Dehm, 1967). It is common in Early Holocene sediments and has been frequently recorded in numerous profiles in central and western Europe (e.g., Meyrick, 2001, 2002; Limondin-Lozouet and Preece, 2004, 2014; Gedda, 2006; Limondin-Lozouet, 2011; Juřičková *et al*., 2014b, 2020; Horáčková *et al*., 2015; Horsák *et al*., 2019; Granai *et al*., 2020; Frodlová and Horsák, 2021). Similar malacocenoses have also been found in Early Holocene sediments in the Podhale Basin (Alexandrowicz, 1997a, 2013a, 2022; Alexandrowicz *et al*., 2014). Currently, *Semilimax kotulae* and *Vertigo geyeri* occur in the Podhale region as relict species (Alexandrowicz, 1997a; Schenková *et al*., 2012, Schenková and Horsák, 2013). *Columella columella* and *Vertigo genesii* are currently not present in the area. The malacofauna under consideration is characteristic of a coniferous forest with moist substrates and a cool climate. Within this interval, an interlayer of peat containing numerous aquatic molluscs occurs. Rheophilous species (*Pisidium personatum*) are present, but the taxa of temporary water bodies (*Galba truncatula*) are the most abundant. The presence of aquatic molluscs indicates the appearance of a small and shallow, probably periodically drying, water body (Fig. 4).

Assemblage Dpe (*Discus perspectivus*). This type of fauna is found in the lower part of the Lp-II profile. It is characterised by high taxonomic diversity and the dominance of shadow-loving species, the proportion of which reaches 60%. A characteristic component of the assemblage is *Discus perspectivus*, accompanied by other thermophilous forest species (*Ruthenica filograna*, *Aegopinella pura*). The fauna is complemented by mesophilous and moisture-loving snails. The assemblage under consideration has a similar composition and structure to the *Perspectivus* fauna (Dehm, 1987). It is characteristic of species-diverse woodland communities, with a significant proportion of deciduous trees, developing under conditions of a warm and humid climate with oceanic influences. The assemblage with *Discus perspectivus* is indicative of the Middle Holocene and has been found in this stratigraphic setting, both in the Podhale region and many other areas in Europe (e.g., Alexandrowicz, 1997a; 2013a, 2022; Meyrick, 2002; Limondin-Lozouet and Preece, 2004, 2014; Gedda, 2006; Limondin-Lozouet, 2011; Alexandrowicz *et al*., 2014; Juřičková *et al*., 2014b; Horáčková *et al*., 2015; Horsák *et al*., 2019, Granai *et al*.,

Table 1

List of species recognised in profiles of fluvial deposits in the Łapszanka Stream valley; for sample locations, see Figure 3; Vpu, Dpe, Vcr, Pbi, Dru – molluscan assemblages (described in the text); E – ecological group of molluscs after: Ložek (1964), Alexandrowicz and Alexandrowicz (2011) and Juřičková *et al.* (2014a).

E	Taxon	Pbi	Dru	Dpe	Vcr	Vpu
		Lp-1–12	Lp-13–15	Lp-16–21	Lp-22–24	Lp-25, 26
F_F	*Platyla polita* (Hartm.)	49	80	257	44	
	Acanthinula aculeata (Müll.)		2	18		
	Vertigo pusilla Müll.		15	202	34	
	Ena montana (Drap.)	51	28	113	8	
	Cochlodina laminata (Mont.)	2	10	97	8	
	Ruthenica filograna (Rossm.)	5		227		
	Calusilia cruciata (Stud.)			140		
	Macrogastra plicatula (Drap.)		9	57		
	Macrogastra borealis (Boett.)			20		
	Bulgarica cana (Held)			9		
	Discus ruderatus (Hartm.)	99	489	56	12	
	Discus perspectivus (Mühlf.)			498		
	Vitrea diaphana (Stud.)	53	22	125	21	
	Vitrea transsylvanica (Cless.)		27	119	12	
	Mediterranea depressa (Sterki)	15		8	2	
	Aegopinella pura (Ald.)	96	125	544	21	
	Aegopinella nitens (Mich.)		7	76		
	Eucobresia nivalis (Dum et Mort)	2		3	5	
	Semilimax semilimax (Fér.)	5	1	23	4	
	Monachoides incarnatus (Müll.)	132	45	151	20	
	Petasina unidentata (Drap.)	58	25	85	5	
	Faustina faustina (Rossm.)	34	32	75		
	Isognomostoma isognomostomos (Schröt.)	54	41	161	20	
F_B	*Vertigo alpestris* Ald.		6	16		
	Alinda biplicata (Mont.)		7	15	2	
	Discus rotundatus (Müll.)			119		
	Aegopinella minor (Stab.)	13	1	150		
	Semilimax kotulae West.		116	15		
	Fruticicola fruticum (Müll.)	101	40	114	4	1
F_H	*Macrogastra tumida* (Rossm.)			26		
	Macrogastra ventricosa (Drap.)	35				
	Vestia turgida (Rossm.)		6	35		
	Vestia gulo (Bielz)	24		19		
	Vitrea crystallina (Müll.)	414	391	847	110	
	Monachoides vicinus (Rossm.)	259	81	275	44	
	Urticicola umbrosus (C.Pfe.)	128	15	106		
O_O	*Vallonia costata* (Müll.)	43	16	98	3	140
	Vallonia pulchella (Müll.)	72	15	95	11	229
	Columella columella (Mart.)		53			
	Vertigo pygmaea (Drap.)			10		22
	Pupilla muscorum (L.)		6	20		27

E	Taxon	Pbi	Dru	Dpe	Vcr	Vpu
		Lp-1–12	Lp-13–15	Lp-16–21	Lp-22–24	Lp-25, 26
M_I	*Cochlicopa lubrica* (Müll.)	65	133	148	35	20
	Clausilia dubia Drap.		8	76	5	
	Punctum pygmaeum (Drap.)	18	63	110	8	8
	Euconulus fulvus (Müll.)	15	47	60	8	3
	Perpolita hammonis (Ström)	25	79	241	32	7
	Vitrina pellucida (Müll.)	12	3	8	2	
M_H	*Carychium tridentatum* (Risso)	90	145	773	50	11
	Succinella oblonga (Drap.)	59	82	126	17	1
	Columella edentula (Drap.)	119				
	Vertigo substriata (Jeffr.)		137	45		
	Vertigo angustior Jeffr.	16		117	7	
	Perpolita petronella (L.Pfe.)		39	152	2	
	Trochulus villosulus (Rossm.)		25	27		
	Perforatella bidentata (Gmel.)	310	120	320	39	
	Arianta arbustorum (L.)	221	81	173	16	
H	*Carychium minimum* Müll.	160	203	520	53	
	Succinea putris (L.)	10	5	1		
	Zonitoides nitidus (Müll.)	87	38	124		
	Vertigo antivertigo (Drap.)			23		
	Vertigo genesii (Gred.)		62			
	Vertigo geyeri Lindh.		47			
W	*Galba truncatula* (Müll.)	37	167	236		
	Stagnicola palustris (Müll.)		16	8		
	Radix balthica (L.)		54	113		
	Anisus leucostoma (Mill.)		89	203		
	Pisidium casertanum (Poli)		22	26		
	Pisidium obtusale (Lam.)		41	41		
	Pisidium personatum Malm	3	21	83		
Total species		39	54	64	33	11
Total individuals		3012	3439	8781	664	480
Indeterminate shells fragments						
	Vertiginidae	5	41	56	2	1
	Clausiliidae	31	52	159	14	3
	Zonitidae	29	59	211	26	14
	Helicidae	42	66	193	44	11
	Other fragments	173	298	488	81	29
Total shell fragments		280	516	1107	167	58
	Plates of slugs	24	1	3	4	1

2020; Frodlová and Horsák, 2021). In the interval with the *Discus perspectivus* fauna, there were two additional peat interlayers, containing an admixture of aquatic snails and bivalves (Fig. 4).

Assemblage Vcr (*Vitrea crystallina*). It is a low-diversity fauna, identified in the upper part of the Lp-II profile (Fig. 4). Shadow-loving taxa that prefer moist habitats (*Vitrea crystallina*, *Monachoides vicinus*) play a dominant role here. Also, a significant reduction in taxonomic diversity (relative to the assemblage with *Discus perspectivus*) is apparent, especially concerning forest taxa. Mesophilous snails, especially those preferring moist habitats (*Carychium tridentatum*, *Perforatella bidentata*), and hygrophilous species (*Carychium minimum*) are important additions to the assemblage. The fauna discussed represents forest environments that develop on moist ground. Similar faunas have been described from a small number of sites, dating as Late Holocene in the Podhale Basin (Fig. 4; Alexandrowicz, 1997a, 2020, 2022; Alexandrowicz *et al*., 2014).

Assemblage Vpu (*Vallonia pulchella*). This fauna is located in the upper section of the Lp-II profile (Fig. 4). It is characterised by low species diversity. The main component

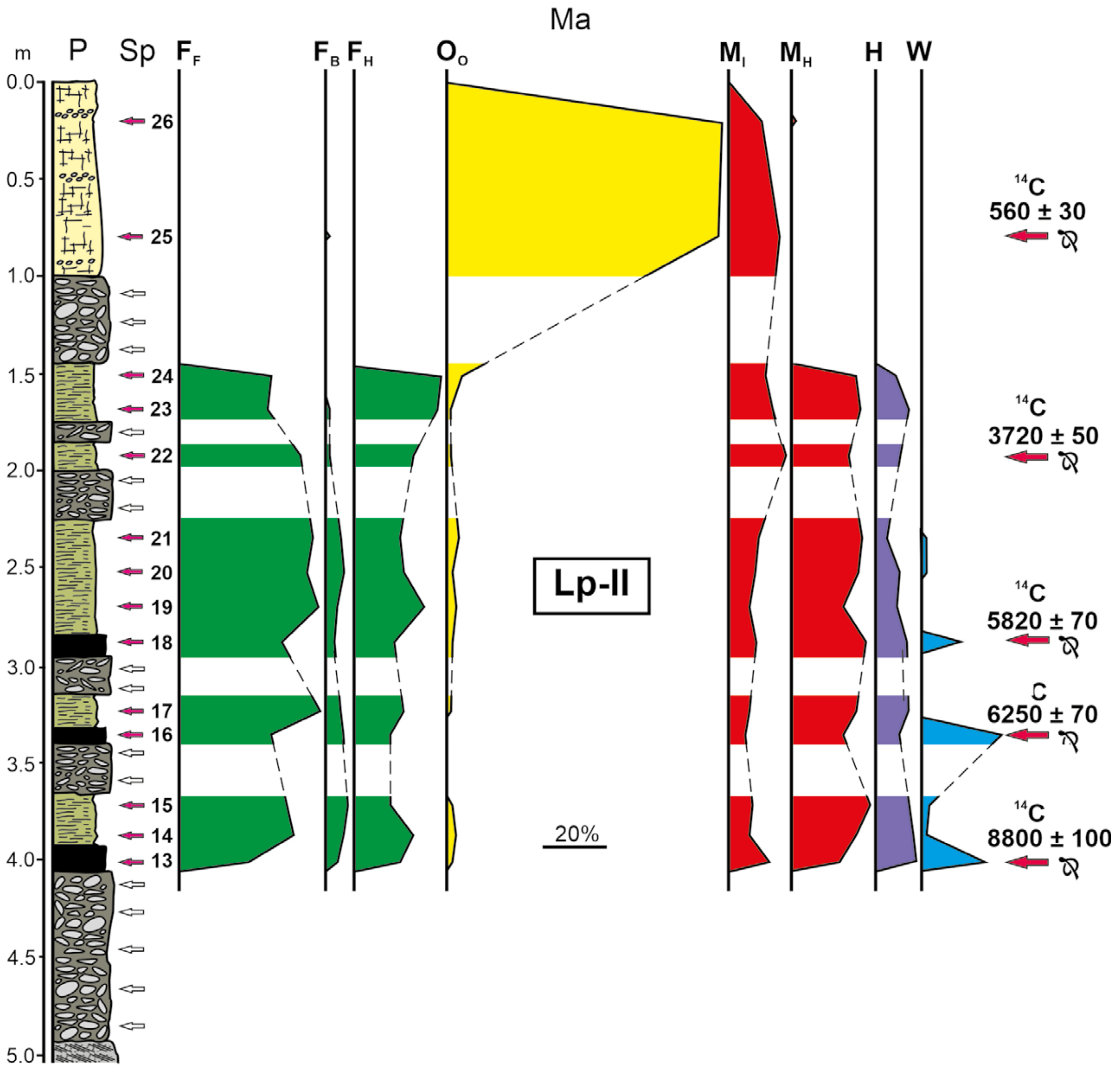

Fig. 4. Lithology of fluvial sediments and the mollusc fauna in the Łapszanka Stream valley (profile Lp-II); for explanations see Figure 3.

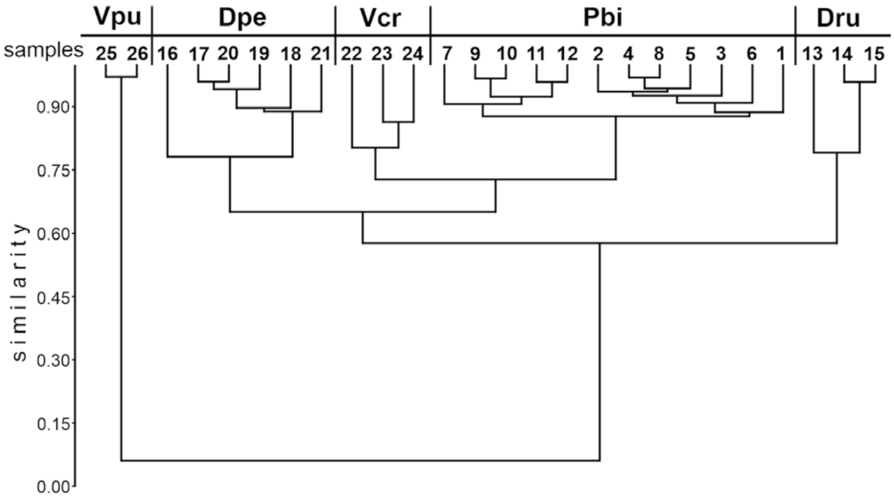

Fig. 5. Dendrogram showing similarities of malacofauna of fluvial deposits from the Łapszanka Stream valley. Vpu, Dpe, Vcr, Pbi, Dru – molluscan assemblages (described in the text).

is open-country snails (*Vallonia pulchella*, *Vallonia costata*). Their proportion of the assemblage is very high and exceeds 80%. The fauna is complemented by mesophilous taxa. Shadow-loving and moisture-loving snails are not present. This assemblage represents a semi-dry meadow. Faunas of similar composition have been recorded at numerous sites in the Carpathians (e.g., Alexandrowicz and Skoczylas, 2017; Alexandrowicz, 2019a, b, 2020, 2023; Alexandrowicz *et al*., 2019, 2023; Horsák *et al*., 2019) representing the last 500 years (Fig. 4).

Assemblage Pbi (*Preforatella bidentata*). This fauna was found in profile Lp-I (Fig. 3). It is characterised by the presence of shadow-loving and mesophilous species, typical of habitats with significant moisture. The major components of the assemblage under consideration are *Perforatella bidentata*, *Arianta arbustorum,* and *Vitrea crystallina*. The assemblage is complemented by hygrophilous snails (*Carychium minimum*, *Zonitoides nitidus*). Assemblages of similar composition are characteristic of shaded and humid valley bottoms. The abundant presence of *Perforatella bidentata* may indicate the presence of alder scrub. The assemblage under consideration represents the Late Holocene (Fig. 3).

Correlation of profiles

The profiles under study are located close to each other but represent two different terraces. The formation and genesis of the sediments at the two analysed sites are quite similar. However, attention should be paid to the differences in the petrographic composition of the gravels. In the Lp-I profile, pebbles of the Podhale Flysch sandstones predominate, and the proportion of other rocks is small, while in the Lp-II profile, the rocks of the Pieniny Klippen Belt are very numerous. These differences are related to the geological structure of the alimentation areas. The valley of the Łapszanka Stream cuts through the area of the Podhale Flysch rocks, while in the upper part of the Złatny Stream catchment, the bedrock is formed by the Pieniny Klippen Belt (Kulka *et al*., 1991). Despite their lithological similarities, the analysed profiles revealed the presence of significantly different malacofauna assemblages. Radiocarbon dating and the coin find made it possible to correlate the lithological sequences of the Lp-I and Lp-II profiles. The timeframe of deposition of the sediments that make up the Lp-I profile is determined by the radiocarbon date of the bottom layer of gravels: 1230 ± 30 y BP (1269–1206 and 1190–1066 cal BP) and an 1810-minted Austrian coin (Kreuzer) found in the top section of the profile (Fig. 6). This indicates that the sedimentary sequence, exposed in the Lp-I profile, was entirely deposited during the last few hundred years. The upper part of the Lp-II profile consists of yellow mud (agricultural mud). The dating of plant material recovered from the middle part of this layer yielded 560 ± 30 y BP (639–589 and 564–523 cal BP). This allows us to assume, with a high degree of probability, that the layer of gravels underlying the aforementioned agricultural muds corresponds to the bottom layer of gravels exposed in the profile Lp-I (Fig. 6). Consequently, the three pebble interlayers, visible in the upper part of the Lp-II profile, may correspond to the gravel layers, visible in the Lp-I profile (Fig. 6).

Phases of environmental changes

The profiles of river deposits in the Łapszanka Stream valley represent a complete sequence of Holocene sediments. This age range is indicated by both the succession of mollusc assemblages and the results of dating. The gravels distinguished within the sedimentary sequence correspond to periods of increased fluvial activity of the stream correlated with wetter climate phases. Such a correlation has been confirmed by numerous studies of river sediments in various mountainous areas throughout Europe (e.g., Starkel *et al*., 2006, 2013; Hoffmann *et al*., 2008; Gębica, 2011, 2013a, b; Wirth *et al*., 2013; Benito *et al*., 2015; Gębica *et al*., 2016; Perşoiu and Perşoiu, 2019; Rădoane *et al*., 2019).

The oldest component of the sequence is a layer of gravel, exposed in the bottom part of the Lp-II profile (layer G-1, Fig. 7). The location in the profile, below the layer of peat dated as 8800 ± 100 y BP (10 159–9554 cal BP; Tab. 2), shows that the G-1 horizon was formed during the Early

Table 2

Results of radiocarbon datings.

No	Profile/sample	Date (y BP)	Date (y cal BP)	Material	Lab. code
C-1	Lp-I/1	1230 ± 30	1269–1206 (27.7%) 1190–1066 (67.7%)	Plant remains	Ki-10088
C-2	Lp-II/9	8800 ± 100	10 159–9554 (95.4%)	Plant remains	Gd-5109
C-3	Lp-II/12	6250 ± 70	7316–6977 (95.0%) 6969–6964 (0.4%)	Plant remains	Ki-10089
C-4	Lp-II/14	5820 ± 70	6787–6450 (95.4%)	Plant remains	Ki-10095
C-5	Lp-II/18	3720 ± 50	4234–4196 (5,7%) 4185–3910 (89.7%)	Plant remains	Ki-10122
C-6	Lp-II/21	560 ± 30	639–589 (48,6%) 564–523 (46.8%)	Plant remains	Ki-10127

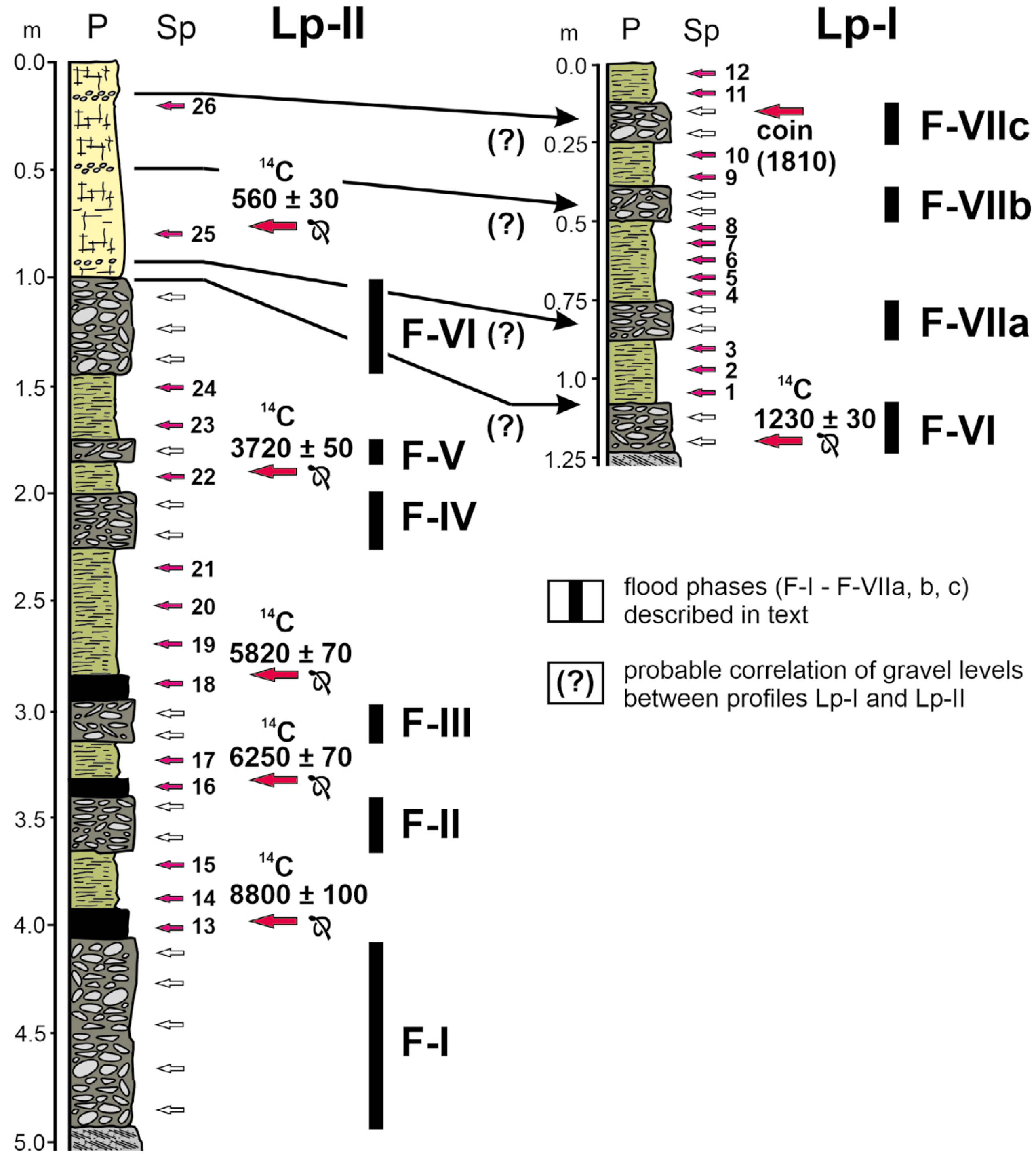

Fig. 6. Correlation between profiles Lp-I and Lp-II; for explanations see Figure 3.

Holocene. It corresponds to the oldest phase of enhanced fluvial activity (phase F-I; Fig. 7). The deposition of gravel during this period has been recorded in many river valleys in both the Polish and Ukrainian parts of the Carpathians (Starkel *et al*., 2006, 2013; Gębica and Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica *et al*., 2016; Olszak et al., 2019, 2023; Rădoane *et al*., 2019; Hrynowiecka et al., 2022) and in the Alps (Hoffmann *et al*., 2008; Wirth *et al*., 2013; Benito *et al*., 2015; Fig. 8). It is also a period of high-intensity mass movement in many European mountain areas (Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Dapples *et al*., 2002; Soldati *et al*., 2004; Prager *et al*., 2008; Pánek *et al*., 2013) and the development of glaciers in the Alps (Venediger phase (Joerin *et al*., 2006; Ivy-Ochs *et al*., 2009; Nussbaumer *et al*., 2011) and in Norway (Erdalen event; Shakesby *et al*., 2020). The period considered can be correlated with climatic fluctuations during the Early Holocene (Bond Event 6; Fig. 8; Bond *et al*., 2001).

Above this lies a thin layer of peat containing numerous mollusc shells (layer T_1; Fig. 7). In the assemblage found

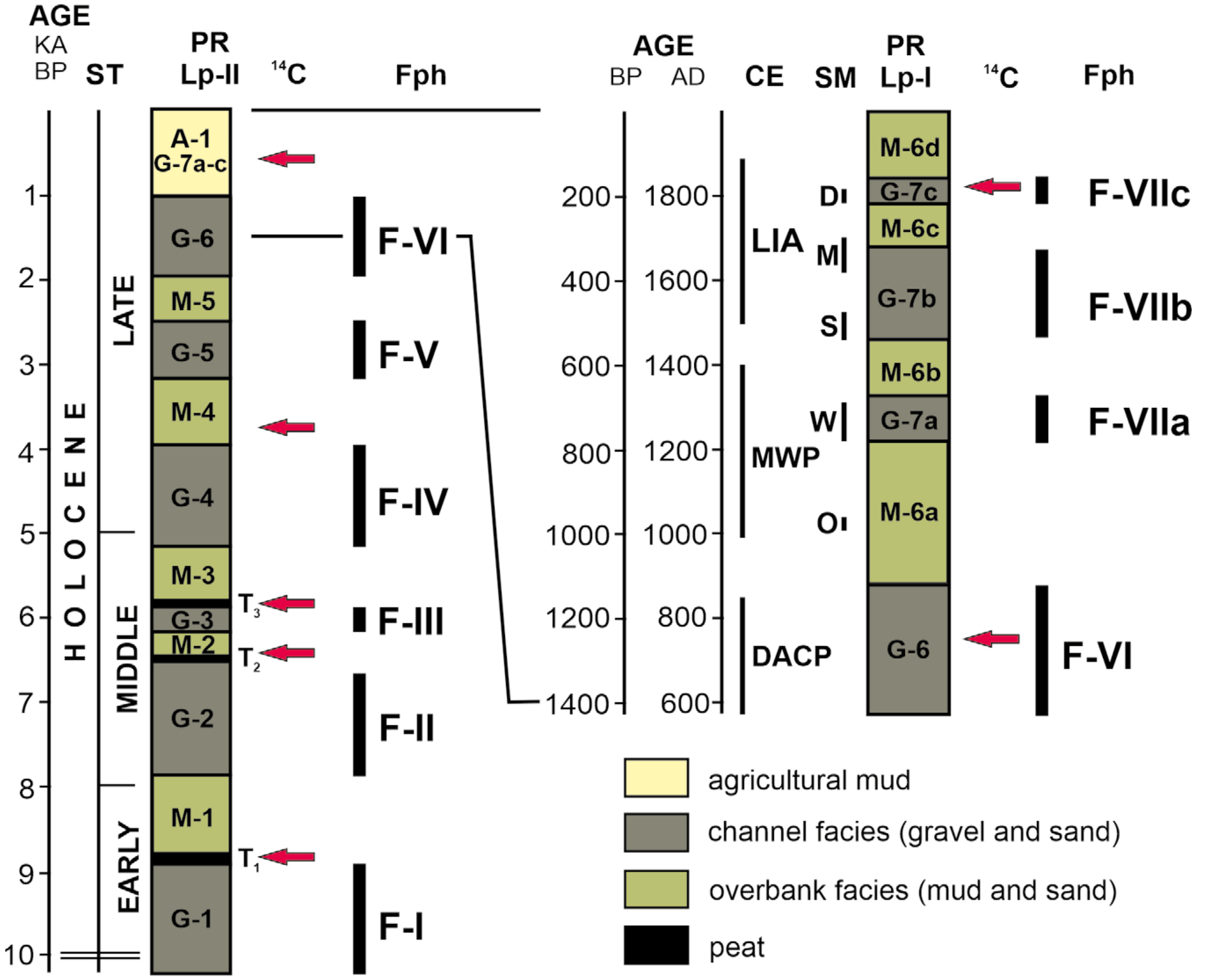

Fig. 7. Chronology of the sequence of fluvial deposits in the Łapszanka Stream valley. ST – stratigraphy (after Walker *et al.*, 2019); PR – lithological profiles; G1 – G-7a,b,c – gravel horizons; M-1 – M-6 a, b, c, d – mud horizons; T_1 – T_3 – peat; A-1 – agricultural mud; ^{14}C – radiocarbon dating; Fph – flood phases; CE – climatic events (after Mayewski *et al.,* 2004; Plunkett and Swindles, 2008; Mauri *et al.*, 2015); DACP – Dark Ages Cold Period; MCO – Medieval Climatic Optimum; LIA – Little Ice Age; SM – solar minima (after Mayewski *et al.*, 2004, Kudsk *et al.*, 2022); O – Oort; W – Wolf; S – Spörer; M – Maunder; D – Dalton.

here, the presence of cold-loving taxa (*Semilimax kotulae*, *Columella columella*, *Vertigo genesii,* and *Vertigo geyeri*) is characteristic, as is the abundant occurrence of *Discus ruderatus*. This fauna is typical of the Early Holocene (assemblage with *Discus ruderatus*) and indicates the presence of shaded habitats with significant moisture and a cool climate. Also of note are aquatic species. Their presence is indicative of the existence of a water body, probably temporary. The appearance of such reservoirs within river valleys indicates the periodic blockage of stream flow. This may be related to mass movements or beaver activity. However, based on the material collected, it is impossible to determine the cause of such a water body. The correlation of layer T_1 with the Early Holocene is suggested by radiocarbon dating 8800 ± 100 y BP (10 159–9554 cal BP; date C-2; Figs 4, 6, 7; Tab. 2).

A similar fauna, containing numerous *Discus ruderatus* shells and cold-tolerant species, was found in the mud layer, covering the T_1 horizon (layer M-1; Fig. 7). The composition of the fauna and the location within the sequence indicates that the layer discussed was formed in the younger part of the Early Holocene. Noteworthy is the gradual upward disappearance of the cold-tolerant taxa and the concomitant increase in the proportion of species with stricter ecological requirements. This is indicative of a gradual warming of the climate.

The next layer of gravel (G-2; Fig. 7) corresponds to the phase of enhanced fluvial processes in the older part of the Middle Holocene (phase F-II). This layer is relatively indistinct in the valleys of the Carpathian rivers and is only clearly distinguishable in a few profiles in Poland and Ukraine (Starkel *et al.*, 2006, 2013; Gębica, 2011, 2013a, b; Gębica *et al.*, 2016). At this time, the development of landslides and the advance of glaciers in the Alps also are marked (Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Joerin *et al.*, 2006; Prager *et al.*, 2008; Ivy-Ochs *et al.*, 2009; Nussbaumer *et al.*, 2011). The phase under

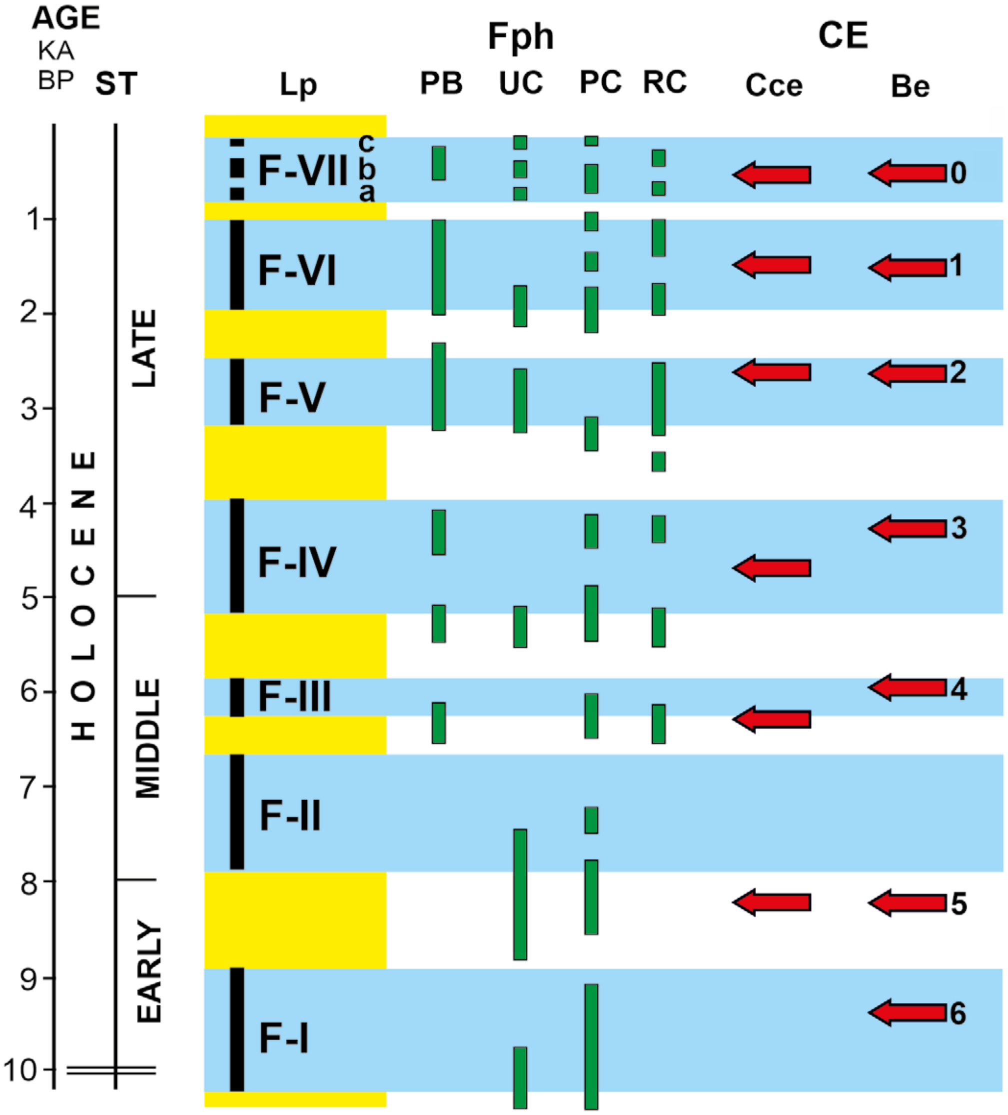

Fig. 8. Local and regional correlation of periods of increased fluvial activity in the Łapszanka Stream valley; ST – stratigraphy (after Walker *et al.*, 2019); Fph – flood phases; Lp – flood phases in the Łapszanka Stream valley (F-I – F-VIIa, b, c – described in the text); PB – flood phases in Podhale Basin (compilation after Alexandrowicz, 2019b, 2023); UC – flood phases in Ukrainian Carpathians (compilation after Gębica, 2011, 2013a, b; Gębica *et al.,* 2016); PC – flood phases in Polish Carpathians (after Starkel *et al.*, 2006, 2013); RC – flood phases in Romanian Carpathians (after Perşoiu and Perşoiu, 2019; Rădoane *et al.*, 2019); CE – climate events; Cce – Holocene cold climate events (after Wanner *et al.*, 2011); Be – Bond cold events (after Bond *et al.*, 2001).

consideration seems slightly younger than the cooling, correlated with Bond Event 5 (Fig. 8; Bond *et al.*, 2001).

Above layer G-2 lies peat with an aquatic fauna, which indicates the appearance of a small body of water (layer T_2; Fig. 7). The results of radiocarbon dating 6250 ± 50 (7316–6977 and 6969–6964; date C-3; Figs 4, 6, 7; Tab. 2) are indicative of its Middle Holocene age.

Another indication is the occurrence of dark muds with abundant malacofauna (layer M-2; Fig. 7). Shadow-loving forest taxa (*Discus perspectivus*, *Aegopinella pura*) play a dominant role there. This fauna (assemblage with *Discus perspectivus*) is indicative of a warm climate and shaded, forested habitats and corresponds to the Middle Holocene. During this period, the area analysed was covered with dense, mixed forests, with a significant proportion of thermophilous trees. This is well documented in both the malacological and the palynological profiles of peatlands in the Podhale Basin (*Ulmus-Tilia-Quercus-Fraxinus* local pollen zone; e.g., Obidowicz, 1990; Alexandrowicz, 1997a, 2013a, 2019b, 2023; Rybniček and Rybničková, 2002; Alexandrowicz *et al.*, 2014, 2023; Krąpiec *et al.*, 2016; Alexandrowicz and Skoczylas 2017).

Another gravel horizon (layer G-3; Fig. 7) indicates a deterioration of the climate and an increase in fluvial activity (phase F-III), which can be correlated with Bond Event 4 (Bond *et al.*, 2001) and cooling in the northern hemisphere (Wanner *et al.*, 2011). Associated with this climatic phase is the deposition of a gravel series in stream valleys in the Podhale region (Alexandrowicz, 2019b, 2023; Olszak *et al.*, 2019, 2023; Hrynowiecka *et al.*, 2022; Alexandrowicz *et al.*, 2023), the Polish, Ukrainian and Romanian Carpathians (Starkel *et al.*, 2006, 2013; Gębica and Krąpiec, 2009;

Gębica, 2011, 2013a, b; Gębica, *et al.*, 2016; Rădoane *et al.*, 2019) and in the Alps (Hoffmann *et al.*, 2008; Wirth *et al.*, 2013; Benito *et al.*, 2015). This interval is associated with more active slope processes (Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Dapples *et al.*, 2002; Soldati *et al.*, 2004; Prager *et al.*, 2008; Pánek *et al.*, 2013) and glacier advance in the Alps (Joerin *et al.*, 2006; Ivy-Ochs *et al.*, 2009; Nussbaumer *et al.*, 2011; Fig. 8).

The Middle Holocene section of the Łp-II profile is terminated by peat (layer T_3) and grey muds (layer M-3), containing a rich and diverse malacofauna (Fig. 7). Layer T_3 contains aquatic species that indicate the existence of a small, temporary water body. Radiocarbon dating carried out within this level gave the result of 5820 ± 70 y BP (6787–6450 cal BP; date C-4; Figs 4, 6, 7; Tab. 2). Shadow-loving taxa, however, are dominant here, accounting for up to 60% of the assemblage. An assemblage with *Discus perspectivus*, typical of the warm period at the end of the Middle Holocene, is found here. Such assemblages of molluscs in sediments of similar age were recorded from numerous profiles in the area of the Podhale as well as in other areas of the Carpathians (Alexandrowicz, 1997a, 2019b, 2023; Alexandrowicz *et al.*, 2014, 2023; Juřičková *et al.*, 2014b, 2020; Horáčková *et al.*, 2015; Horsák *et al.*, 2019; Frodlová and Horsák, 2021). The dominant vegetation type at the time was mixed woodland with deciduous trees (*Ulmus-Tilia-Quercus-Fraxinus* local pollen zone; Obidowicz, 1990; Rybniček and Rybničková, 2002; Krąpiec *et al.*, 2016).

The subsequent gravel level (layer G-4) indicates a change in climatic conditions. Increased fluvial activity (phase F-IV; Fig. 7) in the earlier part of the Late Holocene and the associated deposition of gravel series are common features in stream valleys in the Podhale region (Alexandrowicz, 2019b, 2022, 2023; Olszak *et al.*, 2019, 2023; Hrynowiecka *et al.*, 2022; Alexandrowicz *et al.*, 2023) and in numerous sites of fluvial sediments in the Carpathians and Alps (Starkel *et al.*, 2006, 2013; Hoffmann *et al.*, 2008; Gębica and Krąpiec, 2009; Gębica, 2011, 2013a, b; Wirth *et al.*, 2013; Benito *et al.*, 2015; Gębica *et al.*, 2016; Rădoane *et al.*, 2019; Fig. 8). This period also is marked by the activation of slope processes (Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Dapples *et al.*, 2002; Soldati *et al.*, 2004; Prager *et al.*, 2008; Pánek *et al.*, 2013) and the development of glaciers in the Alps (Joerin *et al.*, 2006; Ivy-Ochs *et al.*, 2009; Nussbaumer *et al.*, 2011). The climatic fluctuation under consideration can be correlated with the 4.2 ka event, documented in numerous profiles throughout the northern hemisphere (Wanner *et al.*, 2011) and corresponds to Bond Event 3 (Bond *et al.*, 2001; Fig. 8).

A malacofauna, characterised by a high proportion of moisture-loving species (assemblage with *Vitrea crystallina*), was found in the mud level (layer M-4; Fig. 7). This malacocenosis is characteristic of the environment of wet forests, growing on the valley floor. Significant changes in the characteristics of vegetation types at the beginning of the Late Holocene are evidenced by the results of palynological studies of the Podhale peatlands (*Picea* and *Carpinus-Abies* local pollen zones (Obidowicz, 1990; Rybniček and Rybničková, 2002; Krąpiec *et al.*, 2016). Dating carried out within the layer under analysis gave the result of 3720 ± 50 y BP (4234–4196 and 4185–3910 cal BP; date C-5; Figs 4, 6, 7; Tab. 2), indicating the correlation of it with the middle part of the Late Holocene (Fig. 8).

Gravel horizon G-5 represents a period of increased fluvial activity (phase F-V) in the middle part of the Late Holocene (Fig. 7). It probably can be correlated with a cool climatic fluctuation – the Iron Age Cold Epoch (Mayewski *et al.*, 2004; Plunkett and Swindles, 2008; Wanner *et al.*, 2011, 2014; Mauri *et al.*, 2015) and Bond Event 2 (Bond *et al.*, 2001; Fig. 8). The enhanced fluvial processes, observed at this time, left the gravel covers, described for many valleys throughout the Carpathians (Starkel *et al.*, 2006, 2013; Gębica and Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica *et al.*, 2016; Rădoane *et al.*, 2019), including the Podhale region (Alexandrowicz, 2019b, 2023; Olszak *et al.*, 2019, 2023; Hrynowiecka *et al.*, 2022; Alexandrowicz *et al.*, 2023; Fig. 8). This is also a period of increasing mass movements (Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Dapples *et al.*, 2002; Soldati *et al.*, 2004; Prager *et al.*, 2008; Pánek *et al.*, 2013) and glacial advance in the Alps (Löbben and Göschenen I phases; Holzhauser *et al.*, 2005; Joerin *et al.*, 2006; Ivy-Ochs *et al.*, 2009; Nussbaumer *et al.*, 2011).

In the subsequent level of fine-grained sediments (layer M-5; Fig. 7), an assemblage with *Vitrea crystallina* also occurs. The M-5 level most probably is related to the climatic warming, continuing in Europe between 250 BC and 300 AD (the Roman Warm Period; Mayewski *et al.*, 2004; Plunkett and Swindles, 2008; Mauri *et al.*, 2015). The Spisz area was covered with dense forests at that time. Faunas of analogous age were also described at numerous sites in the Podhale region (Alexandrowicz, 1997a, 2019b, 2022, 2023; Alexandrowicz *et al.*, 2014, 2023), as well as in profiles identified in other parts of the Carpathian Mountains (Juřičková *et al.*, 2014b, 2020; Horáčková *et al.*, 2015; Frodlová and Horsák, 2021). Also, the results of palynological analyses of Podhale peat-bogs confirm the presence of extensive forest complexes at that time (*Fagus-Abies* and *Carpinus-Abies-Fagus* local pollen zones; Obidowicz, 1990; Rybniček and Rybničková, 2002; Krąpiec *et al.*, 2016).

The G-6 gravel level appears in the upper part of the Lp-II profile; it also makes up the bottom of the Lp-I profile (Fig. 7). It represents a period of increased fluvial activity and can be correlated with climatic cooling – the Dark Ages Cold Period (Mayewski *et al.*, 2004; Helama *et al.*, 2017). Such an age interpretation is confirmed by the result of radiocarbon dating of plant material recovered in the bottom part of the Łp-I profile: 1230 ± 30 y BP (1190–1066 and 1269–1206 cal BP; date C-1; Figs 3, 6, 7; Tab. 2). The intensification of fluvial activity led to the cutting of the higher terrace of the Łapszanka Stream and the formation of the lowest terrace strip in the valley bottom. The deposition of gravel occurred during the aforementioned cooling. This phenomenon has been described in many valleys in the Podhale Basin (Alexandrowicz, 2019b, 2022, 2023; Olszak *et al.*, 2019, 2023; Hrynowiecka *et al.*, 2022; Alexandrowicz *et al.*, 2023), the Carpathians (Starkel *et al.*, 2006, 2013; Gębica and Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica *et al.*, 2016; Alexandrowicz *et al.*, 2019, Rădoane *et al.*, 2019) and the Alps (Hoffmann *et al.*, 2008; Wirth *et al.*, 2013; Benito *et al.*, 2015). The mountainous areas of Europe are marked by intensified slope processes and the advances of Alpine glaciers (Göschenen II phase; Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Dapples *et al.*, 2002; Soldati *et al.*, 2004; Holzhauser *et al.*, 2005; Joerin *et al.*, 2006; Prager *et al.*, 2008; Ivy-Ochs *et al.*, 2009; Nussbaumer *et al.*, 2011; Pánek *et al.*, 2013). This cold period correlates with Bond Event 1 (Fig. 8; Bond *et al.*, 2001; Wanner *et al.*, 2011).

The sediments lying above layer G-6, although having corresponding ages, clearly differ in the two profiles, both in terms of lithological composition and malacological content. The Lp-II profile consists of yellow muds (agricultural muds, layer A-1) containing three intercalations, enriched in pebbles of fine sandstone (G-7a-c; Fig. 7). The muds contain poor malacofauna, dominated by open-habitat species (assemblage with *Vallonia pulchella*). This is indicative of a forest-free, open environment. The sudden disappearance of forests is a common phenomenon in the Podhale region and has been recorded since the 13th century (Alexandrowicz, 2019b, 2022, 2023; Alexandrowicz *et al.*, 2023). It is linked to the expansion of settlements and the related need to convert forested areas into agricultural ones. Particularly intense deforestation occurred during the Medieval Climate Optimum. The record of these processes is visible in both the numerous malacological and palynological profiles (e.g., Obidowicz, 1990; Rybniček and Rybničková, 2002; Łajczak *et al.*, 2014; Alexandrowicz, 2019b, 2020, 2023; Krąpiec *et al.*, 2016; Alexandrowicz *et al.*, 2023). A similar, rapid change in character of habitat during the Medieval Climate Optimum is also evident in many fluvial sediment profiles in the Carpathians (e.g., Starkel *et al.*, 2006, 2013; Gębica and Krąpiec, 2009; Gębica, 2011, 2013a, b; Gębica *et al.*, 2016; Alexandrowicz, 2019a; Alexandrowicz *et al.*, 2019; Perşoiu and Perşoiu, 2019; Rădoane *et al.*, 2019; Olszak *et al.*, 2019, 2023; Hrynowiecka *et al.*, 2022). The pebble-enriched intercalations observed in the A-I layer could have been associated with periods of increased stream activity, coinciding with the cool period of the Little Ice Age (e.g., Mayewski *et al.*, 2004; Matthews and Briffa, 2005). The result of the dating, done with material extracted from the middle part of layer A-I: 560 ± 30 y BP; 639–589 and 564–523 cal BP; date C-6, Figs 4, 6, 7; Tab. 2), points to its relation to that historical period (Fig. 8).

The age equivalent of the A-I layer in the Lp-II profile is the profile of the low terrace of the Łapszanka Stream (Lp-I). However, the lithological nature of the sediments is different here. There are four levels of dark mud (layers M-6a - d), separated by three interlayers of gravel (layers G-7a-c). These gravel interlayers can be correlated with the pebble-enriched intercalations, visible within layer A-I in profile Lp-II (Figs 6, 7). These correspond to phases of increased stream activity during the Little Ice Age and probably also can be correlated with phases of minimum solar activity: the Spörer minimum (layer G-7a), the Maunder minimum (layer G-7b and the Dalton minimum (layer G-7c; Mayewski *et al.*, 2004; Kudsk *et al.*, 2022). This interpretation is supported by the 1810 coin, found in the uppermost gravel horizon. The periodic intensification of fluvial processes during the LIA and the associated accumulation of a gravel cover is commonly recorded in stream valleys in the Podhale region (Alexandrowicz, 2019b, 2020, 2023; Alexandrowicz *et al.*, 2023) and also in the Carpathians and Alps (Starkel *et al.*, 2006, 2013; Hoffmann *et al.*, 2008; Gębica and Krąpiec, 2009; Gębica, 2011, 2013a, b; Wirth *et al.*, 2013; Benito *et al.*, 2015; Gębica *et al.*, 2016; Olszak *et al.*, 2019, 2023; Perşoiu and Perşoiu, 2019; Rădoane *et al.*, 2019; Hrynowiecka et al., 2022; Fig. 7). This is also the time, when mass movements (Alexandrowicz, 1997b, 2013b; Starkel, 1997; Margielewski, 1998, 2018; Dapples *et al.*, 2002; Soldati *et al.*, 2004; Prager *et al.*, 2008; Pánek *et al.*, 2013) intensified and glacier advance in the Alps (Holzhauser *et al.*, 2005; Joerin *et al.*, 2006; Ivy-Ochs *et al.*, 2009; Nussbaumer *et al.*, 2011) occurred. LIA cooling was felt across the northern hemisphere (Wanner *et al.*, 2011) and is correlated with Bond Event 0 (Fig. 8; Bond *et al.*, 2001). The malacofauna, found in the fine-grained sediments of the Lp-I profiles, is characterised by the predominance of shadow- and moisture-loving species (assemblage with *Perforatella bidentata*) and is characteristic for shaded river valley bottoms. Its presence indicates that the surface of the low terrace of the Łapszanka Stream has not been deforested anthropogenically. The terrace is narrow, waterlogged, and flooded during periods of high water in the stream. For these reasons, it is not and has not been used for agricultural purposes.

CONCLUSIONS

The fluvial sediment sequences, exposed in profiles in the Łapszanka stream, represent a complete succession of Holocene sediments. The presence of gravel layers makes it possible to distinguish periods of enhanced intensity of fluvial processes. The abundant and diverse malacofauna found in fine-grained deposits permits the reconstruction of the environment and recognizes a period of strong anthropopressure.

Seven phases of intense fluvial activity have been identified. These are related to periods of the cooler climate and occur during seven phases: F-I, the beginning of the Holocene (10 100–8900 y BP); F-II, the older part of the Middle Holocene (7900–6600 y BP); F-III, the Middle Holocene (6100–5900 y BP); F-IV, the beginning of the Late Holocene (5100–4000 y BP); F-V, the Iron Age Cold Epoch; F-VI, the Dark Ages Cold Period; and F-VII, the Little Ice Age. In the latter phase, it was possible to distinguish three levels of gravels that probably correspond in age to the periods of the climatic minima of Spörer (F-VIIa), Maunder (F-VIIb), and Dalton (FVIIc).

The highlighted phases of intensive stream activity correlate well with the periods of deposition of gravel covers in stream valleys in the Podhale region and, more widely, in the Carpathians.

The occurrence of mollusc shells in fine-grained sediments allowed the reconstruction of environmental conditions. Five fauna assemblages have been identified, the succession and ecological characteristics of which indicate that the area discussed was forested for almost the entire period of sediment deposition. Initially (in the Early Holocene), coniferous forests predominated, and the malacofauna contained numerous cold-tolerant species (assemblage with *Discus ruderatus*). In the Middle Holocene, as the climate continued to warm, mixed forests with a high proportion of thermophilous deciduous trees appeared. The associated mollusc fauna is characterised by a very significant proportion of shadow-loving species with high thermal requirements (assemblage with *Discus perspectivus*). The cooling at the beginning of the Late Holocene led to a restructuring of the taxonomic composition of mollusc assemblages; an assemblage with *Vitrea crystallina*, containing mainly shadow- and moisture-loving taxa, emerged. There has been significant habitat diversification over the last few hundred years. The flat surface of the upper terrace was deforested anthropogenically. As a result, the disappearance of shadow-loving species is evident, and they are replaced by the taxa of open environments (assemblage with *Vallonia pulchella*). There are no signs of human activity on the lower terrace. It is home to the *Perforatella bidentata* assemblage, typical of river valley bottoms and is characterised by the dominance of shadow-loving species, preferring moist habitats.

Three interlayers of dark, peaty silts are visible within the Łp-II profile. Within these, numerous shells of desiccation-resistant aquatic species appear. Their presence indicates the emergence of small water bodies, which were created by the damming of the stream bed, either as a result of landslides of rock material from the valley slopes or as a result of beaver activity.

The succession of faunal assemblages in the profiles presented corresponds well with malacological sequences reported from valleys in the Podhale region.

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