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Late Pleistocene (MIS-2–MIS-4) mollusc assemblages of the loess-palaeosol sequence in Zalesie near Przemyśl (southern Poland)

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Lithological and malacological analysis was carried out at the loess site in Zalesie near Przemyśl. The profile exposed here comprises the last glacial loess-palaeosol sequence L-1 and is correlated with the Pleniglacial (MIS-2–MIS-4) of the Weichselian glaciation. Three loess layers separated by interstadial palaeosols are recognised here. Within the two younger loess layers, corresponding to the younger middle loess (LMs) and the younger upper loess (LMg), and in the soil horizon (Gi/LMs) separating them, numerous mollusc shells were found. The diversity of the mollusc assemblages allowed five types of faunal assemblages to be distinguished. The main faunal components in the younger middle loess were open-country species typical of dry subarctic steppe. The interstadial palaeosol horizon developed on this loess was dominated by hygrophilous taxa characteristic of the subarctic tundra environment. The molluscs of the youngest part of the loess bed comprise mainly mesophilous snails, indicating the presence of open but relatively humid biotopes. The profile in Zalesie belongs to a tiny group of loess sites in Poland with a complete malacological sequence preserved, encompassing both the younger upper and middle loesses and the palaeosol horizon separating them.

Key words: loess-palaeosol sequence, malacofauna, mollusc assemblages, Weichselian, Przemyśl Foothills, S. Poland.

INTRODUCTION

The loesses of southern Poland constitute the northern part of the European loess belt located north of two large mountain ranges, the Carpathians and Sudetes (Hasse et al., 2007; Lehmkuhl et al., 2021). Their distribution is closely related to the extraglacial zone of the Pleistocene glaciations. In southern Poland, loess deposits form patches of various sizes and thicknesses, and their distribution patterns have been described in detail (e.g., Malicki, 1950; Maruszczak, 1987, 1991, 2001; Jary, 2007). In general, an increase in the thickness, compactness and extent of the loess patches is noticeable towards the east. In the western part, their thickness usually does not exceed 10 m, while in the eastern part, it reaches up to 40 m (e.g., Jersak, 1973; Maruszczak, 1987, 1991, 2001; Jary, 2007). An increase in stratigraphic diversity is also observed. In western Poland, there is almost exclusively younger loess (LM) representing the Weichselian glaciation. By contrast, in the eastern part, there are known exposures of deposits corresponding to older cold stages correlated with MIS-6, MIS-8 and even MIS-12 (e.g., Maruszczak, 1987, 1991, 2001).

The younger loess (LM) is widespread in southern Poland, including the northern margin of the Carpathians as the so-called Carpathian (mountain) variety of loess (Gerlach et al., 1991). This occurs as separate islands and smaller patches, mainly along the larger valleys of Carpathian rivers, incorporated into a mosaic of genetically different Pleistocene deposits, or directly adjacent to outcrops of the flysch bedrock. The upper boundary of the Carpathian loess reaches 280–320 m a.s.l. Its thickness varies from 5–10 m to 20 m (Łanczont, 1995).

According to the stratigraphic subdivision of the younger loess (LM) (Maruszczak, 1980, 1991, 2001; Dolecki and Łanczont, 1998; Lindner et al., 2002, 2006; Jary, 2007), four loess units: younger upper loess (LMg), younger middle loess (LMs), younger lower loess (LMd) and younger lowest loess (LMn) are distinguished They are separated by horizons of more or less well developed interstadial palaeosols (Gi/LMs, Gi/LMd, Gi/LMn and Gi/GJ1). The equivalent of the younger loess (LM) in the global loess stratigraphy, derived from the Chinese loess stratigraphy, is the unit L1, falling between the Holocene S0 soil and the Early Glacial–Eemian pedocomplex (S1), correlated with MIS-5 (Kukla and An, 1989; Markovič et al., 2015; Cohen and Gibbard, 2019). A simplified pattern of

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Table 1

Correlation of Upper Pleistocene (Weichselian) loess-palaeosol stratigraphic schemes with marine isotope stages

AGE [ka]: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130

MIS	STRATIGRAPHY				LOESS-PALAEOSOL STRATIGRAPHY A	LOESS-PALAEOSOL STRATIGRAPHY B	
MIS-1		H	Holocene		S0	recent forest soil	GH
		LG	Late Glacial				
MIS-2	UPPER PLEISTOCENE	WEICHSELIAN	Upper Pleniglacial		L1	upper younger loess	LMg
MIS-3			Middle Pleniglacial			interstadial soil	Gi/LMs
						middle younger loess	LMs
						interstadial soil	Gi/LMd
MIS-4			Lower Pleniglacial			lower younger loess	LMd
MIS-5a			Odderade	Early Glacial		interstadial soil	Gi/LMn
MIS-5b			Rederstall			lowest younger loess	LMn
MIS-5c			Brørup			interstadial humus horizons	Gi/GJ1
MIS-5d			Herning				
MIS-5e		E	Eemian Interglacial		S1	interglacial forest soil	GJ1

MIS – marine isotope stages (after Cohen and Gibbard, 2019), loess-palaeosol stratigraphy: A – global loess stratigraphy (after Kukla and An, 1989), B – Polish regional stratigraphy (after Maruszczak, 1991, 2001)

stratigraphic correlation of Upper Pleistocene loess and palaeosols in Poland with marine isotopic stages (MIS) is given in Table 1.

In the loess, the remains of organisms that inhabited the depositional zones of these sediments are well preserved. Particularly important are the numerous mollusc shells found, especially in deposits with a high content of calcium carbonate. The theoretical basis for the malacological analysis of these deposits was formulated by Ložek (1965). He introduced the term "loess species", which included a relatively small group of taxa commonly found at many loess sites. Moreover, Ložek (1965, 1991) characterised the basic types of mollusc assemblages and indicated their usefulness for palaeoecological and stratigraphic reconstructions. Since then, malacological studies and the resulting palaeoenvironmental reconstructions have been carried out at many sections throughout Europe. There are also regional studies covering up to tens of sites. Synthetic analyses of this type have been carried out in Western Europe (e.g., Rousseau, 2001; Moine, 2008; Schirmer, 2016), southern Europe (e.g., Ložek, 2001; Sümegi and Krolopp, 2002; Sümegi, 2005; Marković et al., 2006, 2007, 2008; Sümegi et al., 2016) as well as in Ukraine (Alexandrowicz et al., 2002) and Poland (Alexandrowicz, 1995). The vast majority of these sites are associated with the youngest loess of the last cold stage, i.e. from LMg (MIS-2) *sensu* Maruszczak (2001). Mollusc shells in the older layers of the younger loess, such as the younger middle loess (LMs), younger lower loess (LMd) and younger lowest loess (LMn) corresponding to MIS-3–MIS 5a-d have been found and described at only a few sites in Poland (Alexandrowicz et al., 1989; Alexandrowicz and Łanczont, 1995; Alexandrowicz, 2014). The profile in Zalesie, being the subject of this study, belongs to this narrow group. Preliminary studies of the mollusc assemblages in Zalesie were made by Alexandrowicz and Łanczont (2001).

SITE DESCRIPTION

The loess deposits site in Zalesie is located in the eastern part of the Carpathian Foothills, in the Przemyśl Foothills (Fig. 1A). It is situated in the area of a now abandoned and overgrown brickyard pit, on the north-western slope of the Zalesiański Stream valley, flowing into the Cisowa (Olszanka) River, a tributary of the San River. The valley is approx. 3 km long, narrow and asymmetrical (Fig. 1B). The top of the exposure studied, which is about 7 m high, rises 260 m a.s.l. (Alexandrowicz and Łanczont, 1995).

The valley cuts obliquely through an area composed of north-south oriented flysch strata of the Scole Unit (Kotlarczyk, 1988). The bedrock includes sandstones, shales, siliceous marls and also Miocene clays (Gucik and Wójcik, 1982). The top and steep parts of the slopes are covered by a thin layer of weathered rock, the physical characteristics of which depend on the bedrock. The lower parts of the gentler slopes with an inclination of 3–6° and SE exposure in the site area are covered by loess. As regards the topoclimatic differentiation of the Olszanka basin, the slope has a moderately warm exposure (Łanczont et al., 1983).

The catchment area of the Zalesiański Stream is characterised by high relief energy; the gradients range from 403 m a.s.l. at the Zaleska Góra watershed to ~220 m a.s.l. at the mouth. Analysis of Quaterary deposits carried out for the Olszanka catchment shows their high variability near the site (Łanczont et al., 1983). The exposure analysed is located within the area of a disused brickyard on the right slope of the Zaleśniański Potok valley, ~200 m above its confluence with the Olszanka stream (GPS: 49°44'28" N; 22°38'46" E; Fig. 1C).

MATERIAL AND METHODS

LITHOLOGICAL AND MINERALOGICAL ANALYSES

During field investigations at the brickyard in Zalesie, material was collected for laboratory analyses. Measurements of grain size distribution were taken using the standard Casagrande areometric method modified by Prószyński (PN 88/B-04481). Particle size measurements were used to calculate basic grain size indices based on Folk and Ward (1957): mean grain size (Mz), sorting (s_1), skewness (S_k) and kurtosis (K_G). Additionally, the percentage of humus (by the Tiurin method), Fe_2O_3 (by the colorimetric method) and $CaCO_3$ (by a volumetric method using the Scheibler apparatus) were determined for the samples.

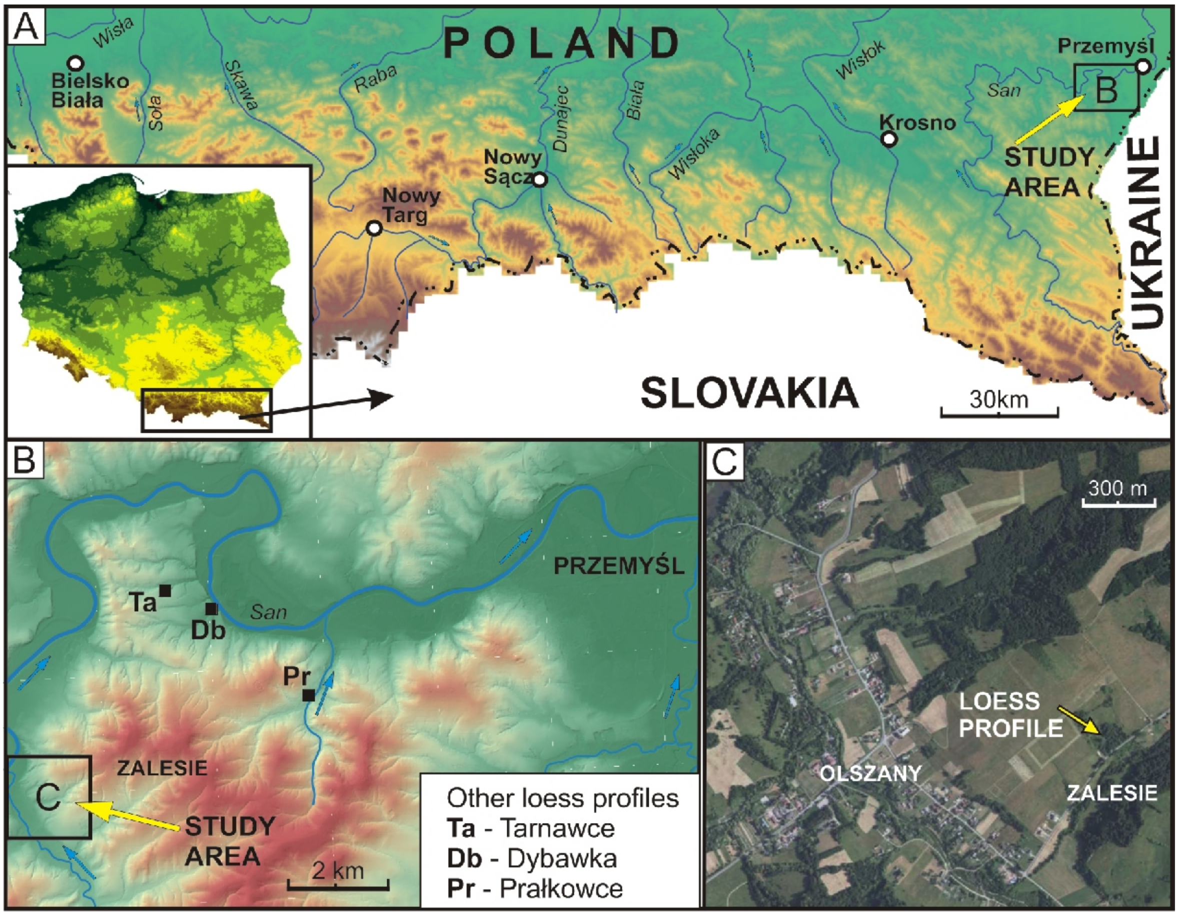

Fig. 1. Location of the loess profile in Zalesie (map base: www. polska.e-mapa.net)

Five loess and soil samples representing the lower and upper part of the section were also analysed for the composition of heavy minerals in the 0.06–0.01 mm fraction. Transparent minerals were determined; the proportion of glauconite, muscovite and opaque minerals was determined separately (Łanczont and Wilgat, 1994).

MALACOLOGICAL ANALYSES

Samples for malacological analysis taken from the profile in Zalesie represented intervals of about 10 cm each, representative of the lithological levels distinguished in the sedimentary sequence. In some sections of the profile, no mollusc shells were found. Overall, the malacological analyses were based on 13 samples containing abundant and well-preserved malacofauna.

After sieving on a 0.5 mm mesh sieve and drying, all completely preserved shells and their fragments, allowing determinations to species rank, were selected from the remaining material. Shell fragments were converted into whole specimens according to the scheme described by Alexandrowicz and Alexandrowicz (2011). Shell fragments of the genus *Pupilla* were separated according to the method proposed by Puisségur (1976). The shell material included ten species of terrestrial snails and one aquatic taxon. There were more than 3,200 specimens in the material analysed and numerous shell fragments that could not be determined. The number of taxa in each sample varied from 6 to 9, and specimens from 154 to 411. Identifications were made based on specialist guides (Wiktor, 2004; Welter-Schultes, 2012; Horsák et al., 2013) and our own comparative collection. Individual species were classified into ecological groups according to the scheme developed by Ložek (1964) with later modifications (Alexandrowicz and Alexandrowicz, 2011; Juřičkova et al., 2014). The percentages of ecological groups in the samples were the basis for compiling the malacological diagram. In the material analysed, five types of mollusc assemblages were defined. These were distinguished based on a similarity dendrogram analysis using the UPGMA clustering method and Morisita's algorithm (Morisita, 1959). Principal component analysis (PCA) and projection triangle analysis indicated differences in the ecological preferences of the assemblages and the most characteristic species. Statistical analyses were conducted using the *PAST* programme (Hammer et al., 2001).

RESULTS

LITHOLOGY

The sedimentary sequence in the Zalesie profile and its lithological characteristics are shown in Figure 2 and Table 2.

MALACOFAUNA

The mollusc fauna identified in the loess profile at Zalesie is characterised by low taxonomic and ecological diversity. Open-country species (ecological group O) are represented by four taxa, among which *Pupilla loessica* and *Pupilla muscorum* are the most prevalent. They are particularly abundant in the lower interval of the profile, where their proportion can exceed

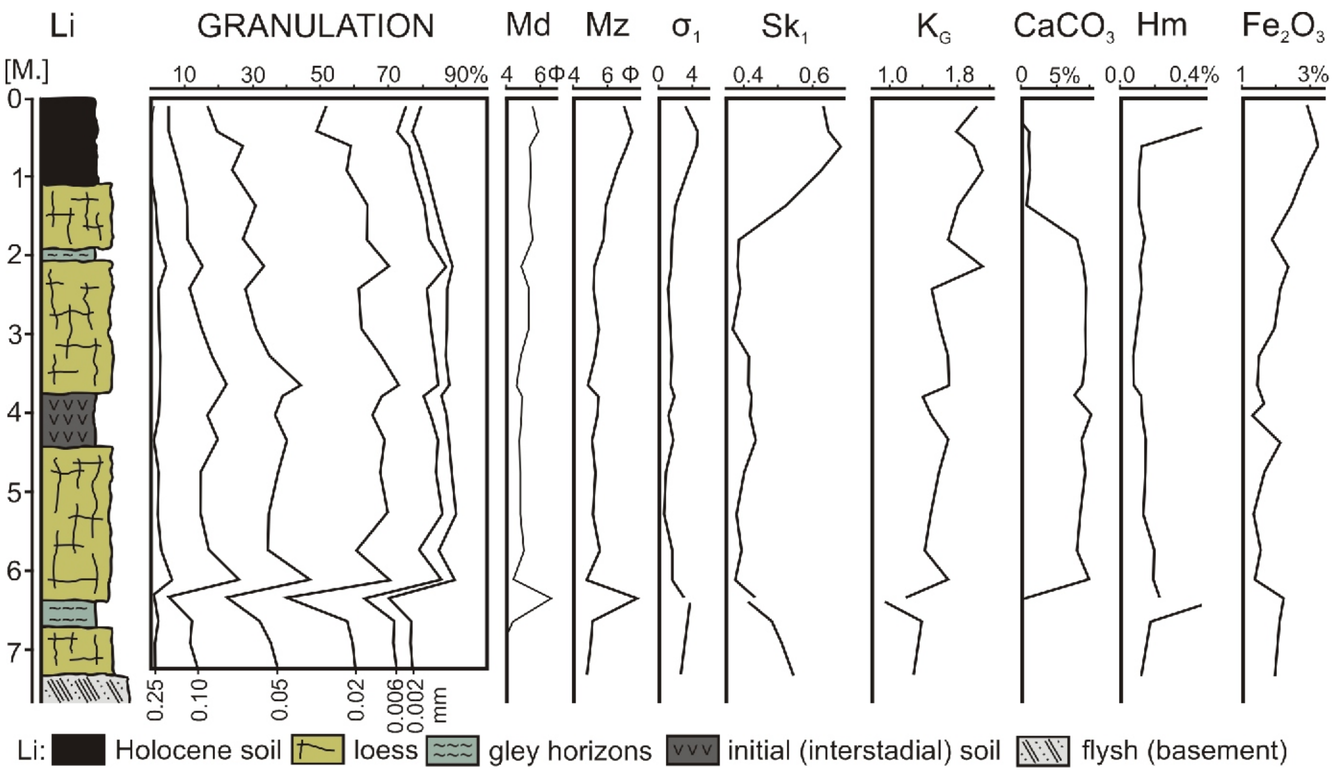

Fig. 2. Lithology, grain size and selected chemical properties of the loess-palaeosol section in Zalesie

Md – average grain size, Mz – mean diameter, $_1$ – inclusive standard deviation, Sk_1 – inclusive skewness, K_G – kurtosis (after Folk and Ward, 1957), $CaCO_3$ – calcium carbonate content, Hm – humus content, Fe_2O_3 – iron oxides content

60%, while they appear much less frequently in the uppermost part of the profile, accounting for up to 20% of the assemblage. Other species belonging to this group: *Columella columella* and *Vallonia tenuilabris*, are scarce. Four taxa are included in the mesophilous snails (ecological group M). Three of them: *Succinella oblonga elongata*, *Clausilia dubia* and *Trochulus hispidus*, were found in all samples and reached the highest abundances in the upper part of the profile where their proportion in the assemblage exceeds 70%, reaching a maximum of up to 90%. A fourth mesophilous species, *Euconulus fulvus*, appears only in three samples as single specimens. Hygrophilous taxa (ecological group H) represented by *Vertigo genesii* and *Vertigo geyeri* are abundant only in the middle interval of the sequence, with a maximum of up to 60% of the assemblage. In other parts of the profile, hygrophilous forms are scarce. This fauna is complemented by *Galba truncatula*. It is an amphibiotic

Table 2

Lithology and stratigraphy of the Zalesie profile

Depth [m]	Sediment description	Soils	Stratigraphic interpretation		MIS
			A	B	
0–1.10	Brownish-grey silt, carbonate-free, and below it, rusty-yellowish clayey silt, weakly calcareous.	Cambisol	S0	GH	1
1.10–3.75	Yellowish and greyish silt, indistinctly layered, calcareous. At a depth of 1.80-2.20 m, there is a vegetation horizon with gley spots; in the lower part, fine sandy interlayers are highlighted with ferruginous pseudofibres. Loess of aeolian-slope facies.			LMg	2
3.75–4.55	Sandy, grey, clumpy, calcareous silt with numerous small concentrations of Mn and Fe compounds.	Weak gleysol		Gi/LMs	
4.55–6.30	Greyish silt, below it, is grey and yellow-grey clayey silt, in the bottom (lower 0.55 m), enriched with products of denudation of the underlying soil. The lower border is clear (decalcification). Loess of slope facies.		L1	LMs	3
6.30–7.00	Blue-grey silty clay, compact plastic, clearly enriched with humus and iron oxides, carbonate-free. The thickness of this layer varies laterally and increases down the slope.	Gleysol		Gl/LMd	
7.00–7.50	Silt and silty clay with a scattered admixture of fine flysch rock detritus, carbonate-free.			LMd	4
7.50	Clay shales and fine-grained grey-greenish sandstones (Cretaceous).				

Stratigraphy: A – global loess stratigraphy (after Kukla and An, 1989; Marković et al., 2015), B – Polish regional stratigraphy (after Maruszczak, 1991, 2001), MIS – marine isotope stages (after Cohen and Gibbard, 2019)

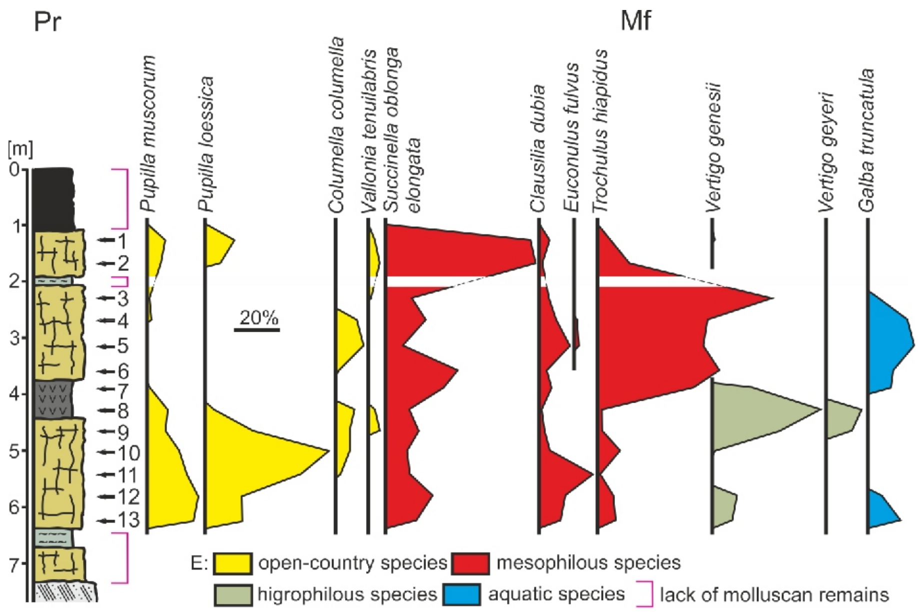

Fig. 3. Percentage diagram of molluscan fauna from the Zalesie profile

Pr – lithology of the profile (for explanations see Fig. 2), Mf – malacofauna

taxon inhabiting drying water bodies or very wet terrestrial biotopes. It appears in the middle and lowest part of the profile, and its proportion in the assemblage is <20%. All species identified in the profile in Zalesie are characterised by high ecological tolerance, especially of thermal conditions. They are frequent or even dominant components of malacocenoses occurring in loess. According to Ložek, they can be classified as so-called "loess snails" (Ložek, 1965, 1991). The taxonomic composition of the malacofauna and its diversity within the profile are illustrated in Figure 3 and Table 3.

MOLLUSCAN ASSEMBLAGES

The malacofauna identified in the loess profile in Zalesie bears typical features of loess faunas. It is characterised by the presence of snails typical of cold climates with continental features and low taxonomic diversity. It shows, however, considerable variability in the vertical profile. Similarity dendrogram analysis allows the distinction of five faunal assemblages appearing at different intervals of the sedimentary sequence (Fig. 4). Principal component analysis allows the indicator species for each assemblage to be distinguished (Fig. 5).

Assemblage A. This fauna is characterised by the abundance of *Pupilla muscorum* (nearly 50% of the assemblage; Fig. 3). The other common species is *P. loessica*. This is complemented by mesophilous snails, particularly *Succinella oblonga elongata*. Less abundant are taxa preferring wet habitats: *Vertigo genesii* and *Galba truncatula*. Principal component analysis indicates that the most characteristic species for the fauna discussed is *P. muscorum* (Fig. 5), which indicates open and relatively dry habitats of the Arctic steppe type. The presence of an admixture of hygrophilous taxa suggests the presence of zones of elevated humidity. Assemblage A was recognised in the lowest part of the malacological sequence (sam-

Table 3

Taxonomical composition of malacofauna from the Zalesie profile

E	Taxon	1	2	3	4	5	6	7	8	9	10	11	12	13
O	*Pupilla muscorum* (L.)	20	17	4	8			3	35	24	23	31	47	43
	Pupilla loessica Ložek	31	21						17	59	91	65	29	27
	Columella columella (G.Mart.)				39	42	2		30	17	10	3		
	Vallonia tenuilabris (Standb.)	7	14	3					12	15				
M	*Succinella oblonga elongata* Drap.	158	189	38	74	27	51	58	42	42	17	17	39	22
	Clausilia dubia Drap.	12	7	17	31	48	6	13	3	10	8	37	21	15
	Euconulus fulvus (Müll.)			1		5	2							
	Trochulus hispidus (L.)	15	40	243	199	157	84	95	5	7	17	2	14	14
H	*Vertigo genesii* (Gredl.)	2						38	174	79	3		19	14
	Vertigo geyeri Lindh.								52	31				
W	*Galba truncatula* (Müll.)			14	60	62	13	17					11	19
Total species		7	6	7	6	6	6	6	9	9	7	6	7	7
Total individuals		245	288	320	411	341	158	224	370	284	169	155	180	154

E – ecological groups of molluscs (after Ložek, 1964; Alexandrowicz and Alexandrowicz, 2011; Juřičkova et al., 2014): O – open-country species, M – mesophilous species, H – hygrophilous species, W – aquatic species

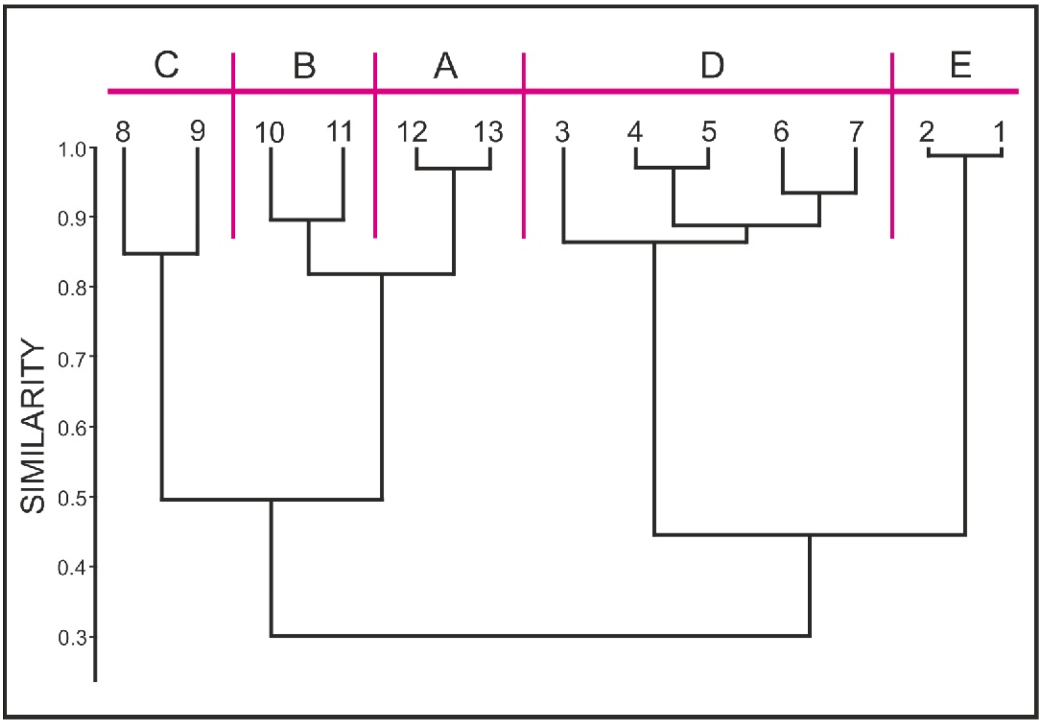

Fig. 4. Cluster analysis of malacofauna from the Zalesie profile

A–E – molluscan assemblages described in the text

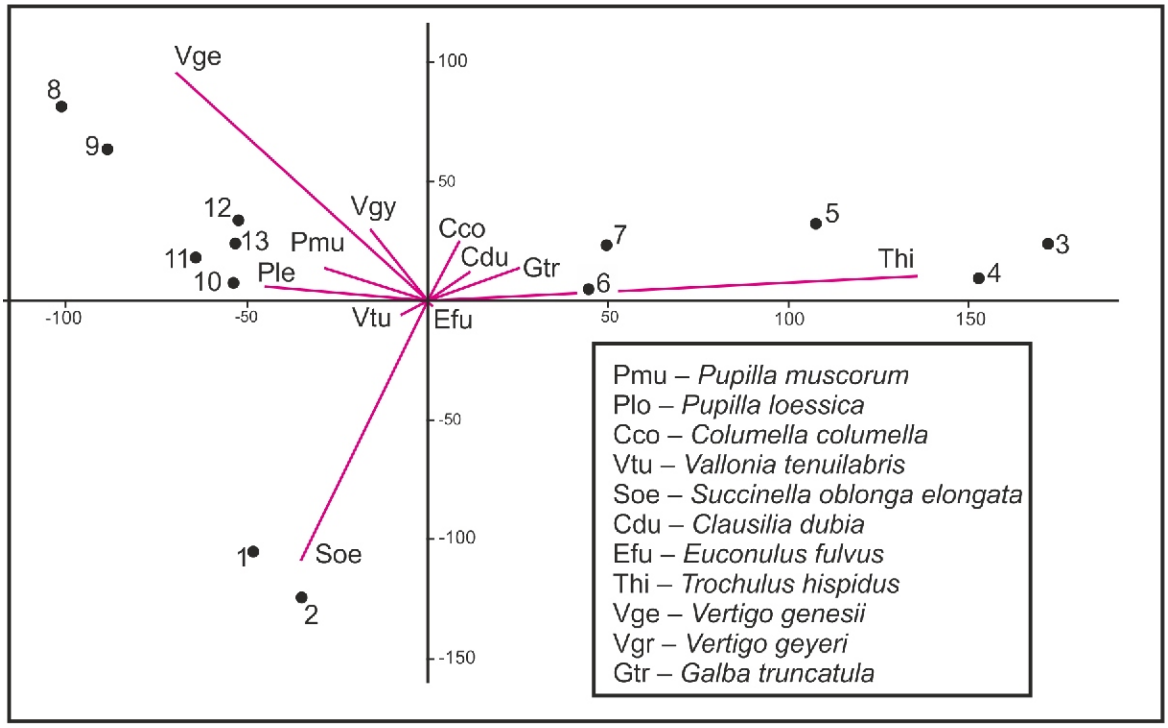

Fig. 5. Principal component analysis (PCA) of malacofauna from the Zalesie profile

ples 12 and 13; Fig. 4). Malacocenoses of similar composition and structure have frequently been recorded from loess profiles described from both southern Poland and western Ukraine (e.g., Rousseau, 1987, 2001; Alexandrowicz et al., 1989; Alexandrowicz, 1995, 2011a, b; Rousseau et al., 2001, 2002, 2013, 2014; Alexandrowicz and Dmytruk, 2007) and southern and western Europe (e.g., Ložek, 1965, 1991, 2001; Puissegur, 1976, 1978; Krolopp and Sümegi, 1995; Sümegi, 1995, 2005; Antoine et al., 2001, 2009; Sümegi and Krolopp, 2002; Rousseau et al., 2002; Limondin-Lozouet and Gauthier, 2003; Moine et al., 2005; Marković et al., 2007, 2008; Moine, 2008; Schirmer, 2016; Sümegi et al., 2016).

Assemblage B. The most prominent and indicative component of this fauna is *Pupilla loessica*, which can exceed 50% of the assemblage (Figs. 3 and 5). This is complemented by other taxa representing open and dry habitats: *Pupilla muscorum* and *Vallonia tenuilabris*. Species typical of wetter biotopes (*Succinella oblonga elongata*) are much less abundant. The assemblage in question bears the characteristics of a *Pupilla*-fauna (Ložek. 1965, 1991). It is one of the most characteristic assemblages found in loess sequences. It is typical of dry, completely open habitats of Arctic steppe type. The high proportion of *Pupilla loessica* indicates periods of rapid loess accumulation (Ložek, 1954, 1965, 1991; Puissegur, 1976, 1978; Alexandrowicz, 1995, 2014; Rousseau, 2001). *Pupilla*-fauna type assemblages have been described from very many profiles throughout Europe (e.g., Ložek, 1965, 1991, 2001; Rousseau, 1987, 2001; Alexandrowicz and Łanczont 1995; Alexandrowicz, 1995, 2011a, b, 2014; Sümegi, 1995, 2005; Krolopp and Sümegi, 1995; Antoine et al., 2001, 2009; Rousseau et al., 2002; Sümegi and Krolopp, 2002; Alexandrowicz et al., 2002, 2013, 2014; Limondin-Lozouet and Gauthier, 2003; Moine et al., 2005; Marković et al., 2006, 2008; Alexandrowicz and Dmytruk, 2007; Moine, 2008; Schirmer, 2016; Sümegi et al., 2016). Regional analyses indicate that the importance and frequency of occurrence of this faunal assemblage is higher in profiles from Central and Eastern Europe (e.g., Ložek, 1965, 1991; Alexandrowicz, 1995; Rousseau, 2001; Rousseau et al., 2001; Alexandrowicz et al., 2014). In the Zalesie profile, assemblage B was recognised in the higher part of the older loess cover (samples 10 and 11; Fig. 4).

Assemblage C. This fauna is characterised by the abundance of species typical of very wet or even marshy biotopes: *Vertigo genesii* and *V. geyeri*. Other taxa preferring moist habitats (*Succinea oblonga elongata*, *Columella columella*) often co-occur with them. Snails preferring drier habitats are in the minority. The assemblage in question is characteristic of Arctic tundra developing under cold climate conditions, often during phases of reduced rates of aeolian dust accumulation and the development of initial pedogenesis. The indicator species for assemblage C is *Vertigo genesii* (Fig. 5). The fauna discussed here occurs relatively rarely in loess sequences but has been recorded in several loess sites in southern Poland and western Ukraine (Alexandrowicz, 1995, 2014; Alexandrowicz et al., 2002, 2014). At the Zalesie site, assemblage C occurs in the middle part of the profile and is associated with a horizon of initial soils (samples 8 and 9; Fig. 4).

Assemblage D. The indicator species for this malacocoenosis is *Trochulus hispidus* (Fig. 5). This taxon is abundant and can exceed 70% of the assemblage. Complementary components are taxa preferring habitats with higher humidity: *Succinella oblonga elongata* and *Columella columella*. An interesting component of this fauna is the amphibiotic taxon *Galba truncatula*, which indicates the presence of very humid or even periodically flooded biotopes. The proportion of species typical of dry habitats is low. The assemblage can represent various habitat types, from fairly dry to distinctly wet. It does not occur during the coldest glacial phases, indicated by the accessory presence of species with considerably higher thermal requirements (*Euconulus fulvus*). Assemblages with a high proportion of *Trochulus hispidus* have been recorded at many sites throughout western and central Europe (e.g., Ložek, 1965, 1991, 2001; Rousseau, 1987, 2001; Alexandrowicz and Łanczont, 1995; Alexandrowicz, 1995, 2011a, b, 2014; Sümegi, 1995, 2005; Krolopp and Sümegi, 1995; Antoine et al., 2001, 2009; Rousseau et al., 2002; Sümegi and Krolopp, 2002; Alexandrowicz et al., 2002, 2013, 2014; Limondin-Lozouet and Gauthier, 2003; Moine et al., 2005; Marković et al., 2006, 2007, 2008; Alexandrowicz and Dmytruk, 2007; Moine, 2008; Schirmer, 2016; Sümegi et al., 2016). The fauna discussed here has been recognised in the lower interval of the younger loess cover (samples 3–7; Fig. 4).

Assemblage E. The dominant and most important component of this assemblage is *Succinella oblonga elongata* (Fig. 5). Its proportion is very high, exceeding 60%. The fauna is complemented by the mesophilic species *Trochulus hispidus* and *Clausilia dubia*. Taxa typical of dry and open habitats (*Pupilla muscorum* and *P. loessica*) are less prominent. The assemblage in question is characteristic of open habitats with moist soil. Faunas with such characteristics are common in loess profiles and described from very many sites throughout Europe (e.g., Ložek, 1965, 1991, 2001; Rousseau, 1987, 2001; Alexandrowicz and Łanczont, 1995; Alexandrowicz, 1995, 2011, 2014; Sümegi, 1995, 2005; Krolopp and Sümegi, 1995; Antoine et al., 2001, 2002; Rousseau et al., 2002; Sümegi and Krolopp, 2002; Alexandrowicz et al., 2002, 2013, 2014; Limondin-Lozouet and Gauthier, 2003; Moine et al., 2005; Alexandrowicz and Dmytruk, 2007; Marković et al., 2008; Moine, 2008; Schirmer, 2016; Sümegi et al., 2016). In the profile in Zalesie, the assemblage discussed is found in the uppermost interval of the younger loess cover (samples 1 and 2; Fig. 4).

DISCUSSION

The loess-palaeosol sequence in the Zalesie profile is characterised by relatively low thickness and correlates with the Pleniglacial period of the last glaciation (MIS-2–MIS-4). The mollusc assemblages within the sequence exhibit a diverse ecological structure indicative of changes in environmental characteristics during deposition. The succession of these changes is shown in Figures 6 and 7.

The sequence studied rests directly on the Carpathian flysch bedrock. Its deep decalcification is associated with intensive weathering preceding loess sedimentation, probably during MIS-5 (Eemian-Early Glacial). Thus, between the top of the weathered rocks and the bottom part of the loess cover, there is a hiatus related to erosion and denudation processes at the transition of MIS-5 and MIS-4. The cooling at the beginning of the Pleniglacial period resulted in changes in the plant cover. This has been documented at a nearby loess site in Tarnawce located on the high Pleistocene terrace of the San (Fig. 1B). The palynological analyses performed showed the disappearance of deciduous trees and the appearance of cold-loving species (*Selaginella selaginoides*, *Betula nana,* and *Hippophae rhamnoides*; Komar and Łanczont, 2002).

The oldest element of the loess cover in Zalesie is a relatively thin (~0.5 m thick) layer of silty and silty-clay deposits containing admixtures of sand and flysch rock detritus interpreted as younger lower loess (LMd) from the Lower Pleniglacial (MIS-4). The grain size characteristics and sediment structure indicate a substantial contribution of slope processes, accom-

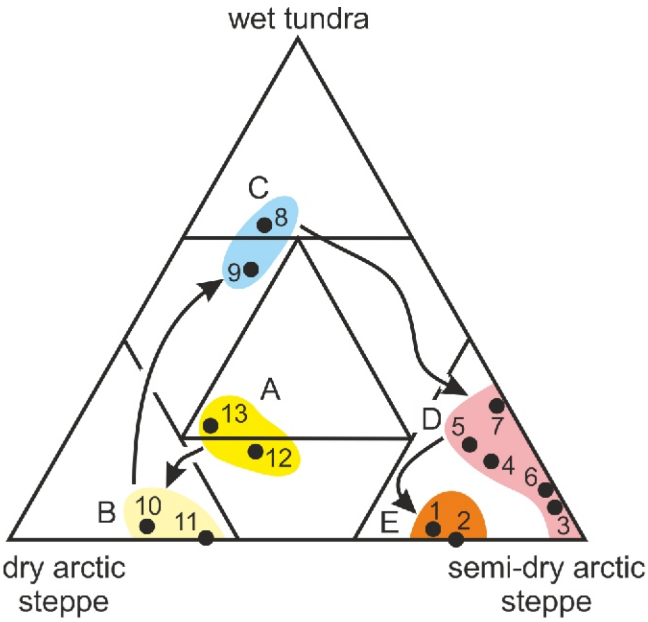

Fig. 6. Succession of mollusc assemblages in the Zalesie profile

panied by slow aeolian input of loess dust. The area was dominated at this time by an open landscape with a mosaic of tundra, grass steppe and rushes in river valley bottoms in a cold climate (Komar et al., 2015).

Another element of the profile is a well-developed gley palaeosol ~0.7 m thick (Fig. 2). It is rich in humic compounds and iron oxides, and represents a period of inhibition of aeolian dust deposition and the development of pedogenesis. In terms of age, it corresponds to the interstadial at the onset of the Middle Pleniglacial and can be correlated with the Gi/LMd soil horizon (Maruszczak, 1991, 2001). Similar soils appearing in neighbouring loess profiles in Poland and western Ukraine have been dated by the TL/OSL method at ~50 ka (Łanczont, 1991, 1995; Łanczont et al., 2021). According to palynological studies of the profile at Tarnawce, open birch and pine woodlands with spruce, fir, and more hardy deciduous trees and shrubs, with moist habitats occupied by willow and alder, were dominant at that time. This vegetation grew under boreal climate conditions (Komar and Łanczont, 2002).

Analyses of heavy minerals performed for the LMd-Gi/LMd sequence (Łanczont and Wilgat, 1994) showed a significant proportion of zircons (28–44%), garnets (18–38%), rutile (16–29%) and epidote (3–6%). This composition is similar to that identified within the nearby flysch rocks. It indicates a local sediment source, with much of the material coming from the washing and slope weathering of local material. The high content of heavy resistant minerals and the fact that a significant proportion of the garnet grains (40–50%) are damaged by corrosion and contain iron oxides is an indication that an essential source of material of this loess was soil material displaced from the higher slopes and deposited simultaneously with fresh dust (Łanczont and Wilgat, 1994). This may indicate that residual sediments formed during the younger part of MIS 5 are incorporated into this layer. The deposits forming this part of the loess-palaeosol sequence at Zalesie are decalcified and contain no mollusc shells.

The next profile segment corresponds to the younger middle loess (LMs), with a thickness of less than 2 m. Granulometric indices and structural features indicate that aeolian deposition and slope processes played a significant role in their formation (Łanczont, 1995). The sedimentary environment of the loess LMs was drier than in the earlier period, as shown by the high proportion of the dust fraction in the grain size distribution, the lower proportion of iron oxides, and the increase in carbonate content to around 10% (Fig. 2). This resulted in the preservation of mollusc shells. The younger middle loess correlates with the middle or older part of MIS-3 (Fig. 2). Its stratigraphic position (~40 ka) has been demonstrated by dating of other sites in southern Poland (Łanczont, 1995; Mroczek et al., 2023; Fedorowicz and Łanczont, 2004). In Central and Eastern Eu-

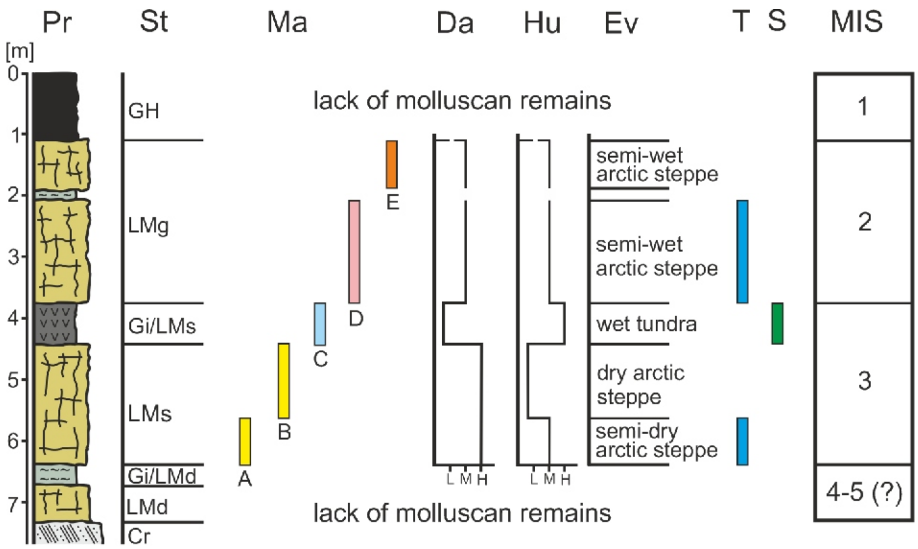

Fig. 7. Stratigraphy and environmental changes recognised in the Zalesie profile

Pr – lithology of the profile (for explanation see Fig. 2), St – stratigraphy (after Maruszczak, 1991, 2001), Ma – molluscan assemblages A–E (described in the text), Da – rate of dust accumulation (L – low, M – medium, H – high), Hu – humidity (L – low, M – medium, H – high), Ev – environment, T – temporary water bodies, S – swamps, MIS – marine isotope stages (after Cohen and Gibbard, 2019) rope, this period was characterised by a relatively low rate of loess deposition with a suggested dominance of winds from the west (Bokhorst et al., 2011).

Two mollusc assemblages were found within the younger middle loess at the site in Zalesie. The abundance of *Pupilla muscorum* and *Pupilla loessica* characterises the older one (assemblage A). Both of these taxa are characteristic of dry to moderately wet habitats of Arctic steppe type (Figs. 6 and 7). The high frequency of *Pupilla loessica* may indicate rapid aeolian dust accumulation (Ložek, 1954, 1965, 1991; Alexandrowicz, 1995, 2014; Rousseau, 2001). On the other hand, the fauna in question includes snails that prefer moist and even waterlogged habitats: *Glaba truncatula* and *Vertigo genesii*; their occurrence indicates the presence of moist biotopes. The coexistence of two distinct groups of molluscs (dry-loving and moisture-loving) may indicate limited redeposition of shell material due to flushing processes. The results of lithological data cited above also lead to similar conclusions.

In the upper section of the LMs loess, a change in the character of the malacofauna is noticeable. Hygrophilous taxa disappear, while *Pupilla loessica* (assemblage B) plays a dominant role. This change indicates the development of dry, open habitats of subarctic steppe type and an increase in the rate of aeolian deposition with a reduction in the role of slope processes (Figs. 6 and 7).

The top part of the LMs is pedogenically transformed; traces of soil-forming processes are modest. They result in a thicker (0.8 m) Gi/LMs horizon with gley soil features strongly enriched in manganese and ferruginous concretions. This likely corresponds to warming in the younger part of MIS-3 (luminescence age ~34–28 ka; Łanczont, 1995; Fedorowicz and Łanczont, 2004). At that time, reconstructions of the vegetation cover of the area (Komar et al., 2015) documented patches of widespread mixed forests surrounded by various meadows and areas subjected to erosion-denudation processes and colonised by pioneer plants. The climate was moderately cool.

Mollusc shells (assemblage C) are abundant within this palaeosol horizon (Figs. 6 and 7). This fauna is significantly different from the malacocenoses recognised in the older silty deposits in terms of taxonomic composition and ecological structure. Of note are the prominence of hygrophilous taxa typical of humid and even waterlogged tundra environments (*Vertigo genesii*, *Vertigo geyeri*; Figs. 6 and 7). This fauna indicates the development of swampy habitats while aeolian dust deposition was significantly reduced or even stopped (Fig. 7).

The upper part of the loess-palaeosol sequence at the site in Zalesie is represented by upper younger upper loess (LMg), which corresponds to MIS-2 (Fig. 7). Its deposition occurred with north and north-easterly winds (Łanczont, 1993; Pańczyk et al., 2020), undoubtedly modified by the local orography and orientation of the valleys, as northwesterly winds are reconstructed for central and eastern Europe during the LGM (Nawrocki et al., 2006; Bokhorst et al., 2011). The sedimentary structures of the lower part of this loess (LMg2) indicate that during the early phase of MIS-2, aeolian deposition still took place with some contribution from flushing processes. Abundant mollusc shells (assemblage D) are present in the LMg2 loess. The dominant taxon is *Trochulus hispidus*, accompanied by *Succinella oblonga elongata*. Also noteworthy is the presence of *Glaba truncatula*, indicating the existence of humid habitats. The ecological characteristics of this assemblage also indicate medium-humid subpolar steppe environments. The low proportion of dryland taxa and the absence of *Pupilla loessica* indicate a low rate of aeolian accumulation (Figs. 6 and 7).

Within the LMg deposit, there is a vegetation horizon 0.6 m thick, with the accumulation of numerous manganese-iron concretions, signalling its dichotomy. Analysis of heavy minerals carried out for this deposit (Łanczont and Wilgat, 1994) showed abundant garnet (up to 40%) and zircon (up to 30%), which may be an indication of admixture of the dust also from disseminated fluvioperiglacial deposits, as shown in the Prałkowce profile (Fig. 1B; Krysowska-Iwaszkiewicz and Łanczont, 1992). Regarding the vegetation cover, it was a period of dominance of an open landscape with a mosaic of grassland steppe and tundra and with scattered coniferous and deciduous trees (Komar et al., 2015). No mollusc shells were found in this horizon.

An assemblage showing a high frequency of *Succinella oblonga elongata* (assemblage E) is present in the upper part of the younger upper loess (LMg1) in Zalesie. It indicates relatively wet habitats (Figs. 6 and 7). Faunas of such composition are very common in the upper horizons of LMg, indicating less severe climate conditions, higher humidity of the topoclimate and lower rates of aeolian accumulation (Ložek, 1954, 1965, 1991; Puissegur, 1976, 1978; Alexandrowicz, 1995, 2014; Rousseau, 2001). By contrast, in neighbouring Dybawka, on the mid-San terrace (Fig. 1B) in loess LMg1 of arguably similar stratigraphic position (IRSL age ~16 ka; Bokhorst et al., 2011) an almost complete absence of *Succinella oblonga elongata* shells of this species, but with additional contributions of *Trochulus hispidus* and *Clausilia dubia*, was recorded, within a generally quite similar loess faunal composition, indicating in turn a relatively dry habitat for mollusc development under similar topoclimatic conditions (Łanczont, 1991; Figs. 6 and 7). These observations confirm the high spatial variability of habitats in the part of the Przemyśl Foothills adjacent to the San and indirectly corroborate the high local variability of the loess sedimentation rate assessed by the MAR index (Fedorowicz and Łanczont, 2007). In the Tarnawce site, this indicator is about 500 g/cm^2/year, while in the neighbouring Dybawka site, it is more than twice as high (about 1200 g/cm^2/year).

The ceiling of the profile in Zalesie is a well-developed Holocene soil without mollusc shells (Fig. 3).

CONCLUSIONS

1. The loess-palaeosol sequence profile in Zalesie is characterised by a relatively low thickness (~7 m), but represents the Pleniglacial of the Last Glacial cycle correlated with MIS-2–MIS-4.

2. The granulometric characteristics of this loess, the array of sedimentary structures indicating the important role, besides aeolian accumulation, of slope processes in its deposition, and the composition of heavy minerals, reflecting flysch rocks directly and indirectly, provide an argument for the mostly local provenence of the loess in Zalesie.

3. Within the lithological sequence, interstadial soil horizons corresponding to Gi/LMd and Gi/LMs and a gleyed vegetation horizon dividing the LMg loess into two soil subunits were distinguished.

4. Mollusc remains in the LM loess of Zalesie occur irregularly. The lower part of the sequence, which is decalcified, including the Gi/LMd palaeosol horizon, is devoid of mollusc shells. By contrast, mollusc shells are abundant in the LMs and LMg loesses and in the Gi/LMs palaeosol.

5. The malacocoenoses identified within the loess LMs are characterised by a high proportion of species typical of dry habitats, indicating an environment of subarctic steppe type. The abundant occurrence of *Pupilla loessica* shells in this interval indicates a moderate intensity of aeolian accumulation.

6. The assemblage of molluscs identified within the Gi/LMs palaeosol indicates considerable wetting of the habitats and inhibition of aeolian dust deposition, favouring the development of soil-forming processes.

7. The younger part of the loess cover (LMg loess) is dominated by mesophilous species preferring moderately moist soil, and the low proportion of *Pupilla loessica* indicates a locally low rate of aeolian accumulation.

8. The profile in Zalesie is one of the few sites in southern Poland where an almost complete malacological sequence of LMs and LMg loesses is preserved, representing the pleniglacial of the last glaciation.

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