Late Pleistocene climate history of the Baranja loess plateau – evidence from the Zmajevac loess-paleosol section (northeastern Croatia)

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ABSTRACT

The Zmajevac loess-palaeosol succession (LPS) of the northeastern Baranja loess plateau is exposed along the southern slope of Bansko Brdo, on the western bank of the Danube River. The investigated 17.5-m-thick section shows 4 palaeosol, 1 loess-like and 6 loess horizons. Their integrative palaeoenvironmental analysis combines quantified data from the mollusc record, magnetic susceptibility, grain-size, calcimetry and mineral abundances to reconstruct the pattern of regional palaeoclimate evolution. This result combined with infrared optically stimulated luminescence age estimates by GALOVIĆ et al. (2009) enabled correlation of the depositional units to Middle to the Late Pleistocene Marine Isotope Stages (MIS) 6 to 2. Magnetic susceptibility measurements show strong peaks in the palaeosol horizons pointing to increased concentrations of pedogenic ferrimagnetic minerals. Sedimentological and mineralogical parameters are in good agreement with other Pannonian Basin LPS. Terrestrial gastropod palaeoecology based on 1705 specimens of 13 species counted from loess and loess-like horizons documents cyclic transitions between cryophilous to cold resistant and mesophilous to thermophilous assemblage types. Whereas *Helicopsis striata*, *Arianta arbustorum* and *Chondrula tridens* are common throughout the succession, the typical loess representatives *Pupilla* sp., *Vallonia tenuilabris* and *Columella columella* are abundant only in certain horizons. Nevertheless, species tolerating open and dry habitats are abundant throughout the succession. The faunal spectra for the samples prove the dominance of transitional palaeoecological assemblage types, whereas uniformly defined types are rare. One of these, the *Columella columella* assemblage from the base of the section proved to be indicative of the Penultimate Glacial Maximum.

Keywords: mollusc palaeoecology, magnetic susceptibility, grain-size, modal analysis, loess, climate change, Danube, Croatia

1. INTRODUCTION

Loess is terrestrial clastic sediment, composed predominantly of silt-size particles, formed by the accumulation of wind-blown dust (PYE, 1995). The Pleistocene loess deposits show two main genetic types: (1) loess formed under periglacial conditions, commonly in front of the ice caps and (2) loess built up by small particles formed in the mountain areas. The second type of loess is present in the study area and also in the wider region (MARKOVIĆ et al., 2005, 2008, 2009; GALOVIĆ et al., 2009, 2011; SMALLEY et al., 2011, WACHA & FRECHEN, 2011). Actually, loess covers up to
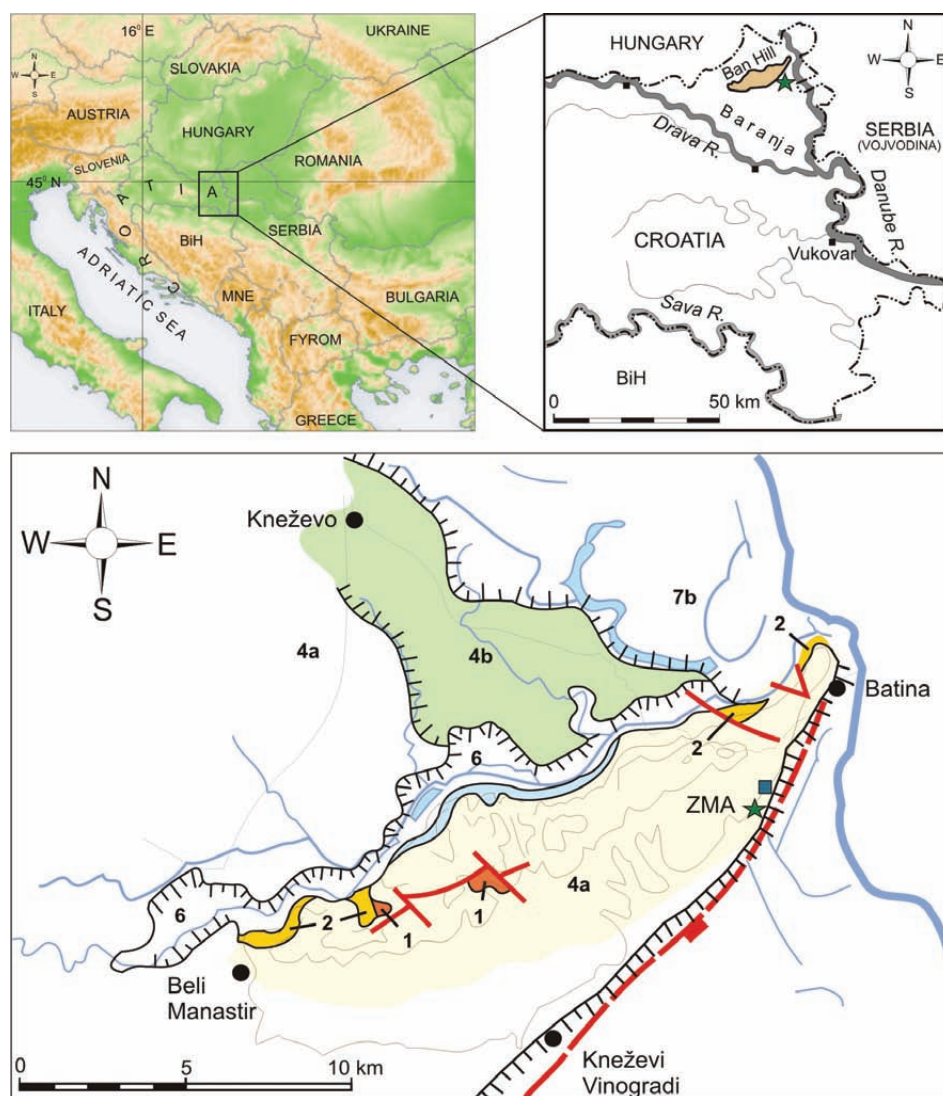
Figure 1: Map showing the geographic position of the Baranja region in Croatia and investigated loess profile at the Zmajevac locality, Bansko Brdo (shown by the star mark). The locality previously investigated by GALOVIĆ et al. (2009) is indicated by the square. Geology is from Croatian Geological Survey (2009): 1. Miocene andesite and rhyolite, 2. Badenian (Middle Miocene) limestone and marl with igneous clastics, 3. Pleistocene fluvial sediments, 4. Pleistocene loess (a) and loess-like sediments (b), 6. Holocene marshy sediments, 7b. Holocene proluvial sediments.

10% of the world's surface area (PÉCSI, 1968), and is usually inter-bedded with soil horizons. Such successions provide very detailed terrestrial records of Pleistocene climatic fluctuations (KUKLA, 1987; GUO et al., 2002).

Pleistocene sediments are widespread in Croatia covering about 35.7% of its territory (BOGNAR, 1976). In the southern Pannonian Basin (Northern Croatia) they dominantly cover large continuous areas, whereas in the Dinaride Mountains and Adriatic Islands (Southern Croatia), Pleistocene deposits are restricted to small areas. Aeolian silt and sand were blown into the lowland steppe, lakes, marshes and swamps (BAČANI et al., 1999). The region of Baranja in northeastern Croatia (Fig. 1) is almost completely covered with Pleistocene and Holocene sediments. In particular, some of the thickest loess successions of Croatia are exposed along the Danube River. The total thickness of these loess and loess-like deposits probably exceeds 50 m.

Loess-palaeosol successions of Baranja and northeastern Croatia have long history of investigation (WACHA & FRECHEN, 2011 and references therein). MALEZ (1965) analysed periglacial phenomena in eastern Croatia. RU-KAVINA (1983) investigated loess-palaeosol successions and their mollusc fauna, providing an overview on warm periods in the Late Pleistocene of northeastern Croatia. POJE (1982, 1985, 1986) focused on the molluscan fauna from loess-palaeosol sequences at the Vukovar and Đakovo loess plateaus, south of Baranja. BRONGER (1976, 2003) correlated loess-palaeosol sequences in East and Central Asia with others in south-east Central Europe, which are very close to the Baranja region. GALOVIĆ et al. (2009) focused on the chronostratigraphy of loess deposits of Zmajevac on the southern slopes of the Bansko Brdo in Baranja. From the same section MOLNÁR et al. (2010) investigated mollusc abundance from three palaeosol-related horizons. Finally, WACHA & FRECHEN (2011) provided luminescence dating for Middle to Late Pleistocene sections of Vukovar, while GALOVIĆ et al. (2011) investigated a loess-palaeosol section in Šarengrad.

The aim of this study is the reconstruction of climate changes during the latest Middle and Late Pleistocene based on the mollusc composition of different loess horizons of the Zmajevac PLS. This data will be integrated with magnetic susceptibility measurements, grain size analyses, mineral

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abundances (modal analysis), and calcimetry to provide a better control on palaeoclimate interpretations. The infrared stimulated luminescence (IRSL) data of Galović et al. (2009) will be finally compared with present results and integrated into a chronological framework for the Zmajevac LPS whereby a correlation of its depositional units with the Marine Isotope Stages of MARTINSON et al. (1987) will be discussed.

2. GEOLOGICAL SETTING

The surface geomorphology of Baranja is monotonous consisting largely of Pleistocene and Holocene sediments, with some minor outcrops of Miocene and Pliocene sedimentary and magmatic rocks (VELIĆ & VLAHOVIĆ, 2009) (Fig. 1). Tectonically it belongs to the Pannonian Basin, accommodating first Central Paratethys marine deposits during the Middle Miocene, then Lake Pannon brackish deposits in the Late Miocene and finally fresh water sediments of Lake Slavonia in the Pliocene completing the subaquatic deposition (ROYDEN, 1988; PILLER et al., 2007; HARZHAUSER & MANDIC, 2008; MANDIC et al., 2011).

Bansko Brdo is the only morphological high in the area and represents part of a tectonic horst stretching 20 km in a NE-SW direction, reaching the banks of the Danube River to the NE end. Its elevation reaches 244 m (Fig. 1). A combination of active neotectonic uplifting and Danube river erosion exposed large outcrops of a Pleistocene loess-palaeosol succession on Bansko Brdo. The hill is surrounded by a Holocene fluvial, oxbow lake, and marsh deposits.

The oldest exposed rocks at Bansko Brdo belong to the Miocene volcano-sedimentary complex, and include basalt-andesite and pyroclastic rocks comprising volcanic and tuffaceous breccia and conglomerates. K-Ar radiometric, whole-rock measurements indicate an early Middle Miocene age (13.8±0.4 and 14.5±0.4 Ma, PAMIĆ & PÉCSKAY, 1996). This complex probably originated from partial melting of the heterogeneous lower crust due to continental rifting processes during Pannonian Basin extension (HORVÁTH, 1995, PAMIĆ, 1997; PAVELIĆ, 2001; MANDIC et al., 2011). The basalt-andesite intercalates Middle Miocene (Badenian) marine calcareous sand and marl, indicating the synsedimentary character of the volcanic activity (PAMIĆ & PIKIJA, 1987; LUGOVIĆ et al., 1990). Furthermore few outcrops of Pliocene fresh-water, coarse-grained clastic deposits occur at Bansko Brdo.

The Pleistocene loess is the most dominant deposit in the geological pattern of Bansko Brdo (VELIĆ & VLAHOVIĆ, 2009). The mean thickness of the loess-palaeosol sequence is 28 m for the outcrop section. The oldest loess at the Zmajevac locality produced an infrared optically stimulated luminescence (IRSL) age of 217±22 ka, while the youngest loess has an IRSL age of 16.7±1.8 ka (GALOVIĆ et al., 2009).

3. SAMPLING AND METHODS

Section logging and sampling was carried out in 2009 and 2010. Thereby the depositional units and their internal sedi-

mentary characteristics have been described including photographic and GPS documentation. Data on the vertical changes of magnetic mineral content in the section was gathered from 44 samples collected into 200 ml plastic containers (KUKLA, 1987). Magnetic susceptibility measurements were performed using a Bartington MS 2 laboratory device. Sample material was decanted into, 100 ml plastic containers before fixing to the measuring module with a calibrated standard. Each sample was measured three times for precision. Data was processed with the Bartington software. In general palaeosol horizons show enhanced MS values due to increased concentrations of pedogenic ferrimagnetic minerals (GEISS & ZANNER, 2006), while the loess units are marked by a significantly decreased signal. The variations are related to soil forming processes and reflect differences in composition, concentration, and particle size of the magnetic minerals, between interglacial/interstadial and glacial/stadial sediments (KUKLA, 1987; EVANS & HELLER, 2001). Therefore magnetic susceptibility may reveal patterns congruent to the SPECMAP marine oxygen-isotope record (MARTINSON et al., 1987), and can provide an excellent stratigraphic correlation tool (MARKOVIĆ et al., 2008, 2009, 2011).

Thirteen bulk sediment samples (8–10 kg) were collected from loess and loess-like horizons for every 1.5 m of the Zmajevac LPS with at least one sample per defined lithostratigraphic unit. Grain-size analyses combined wet sieving and the pipette method. Classification of the grain size distribution follows WENTWORTH (1922). Mineral abundances (modal analyses) used the 0.063–0.125 mm calcite-free fraction. Heavy and light mineral fraction (HMF and LMF) were separated in bromoform liquid (CHBr$_3$, δ=2.86 gcm^{-3}) by gravity. Qualitative and quantitative analyses of the fractions were based on 300–350 grains per sample and were conducted using a polarizing light microscope (MENGE & MAURER, 1992). The carbonate (CaCO$_3$) content was calculated from the weight difference before and after cold hydrochloric acid (5 %) treatment. Mollusc shells were derived from samples by screen-washing in distilled water, using a 0.7 mm mesh sieve. As proposed by LOŽEK (1964), beside completely preserved shells only larger fragments including apices and apertures were picked out and counted. Identifications are based on comparison with collection material at Natural History Museum in Vienna, following the taxonomic concepts of LOŽEK (1964) and FRANK (2006). Assemblage analysis follows LOŽEK (1964).

4. RESULTS

4.1. Description of the section

The loess-palaeosol succession is situated 450 m south of the Zmajevac section of GALOVIĆ et al. (2009) and MÓLNAR et al. (2010). It outcrops in the vertical wall beside the road from Beli Manastir to Batina (Fig. 1). GPS coordinates of the bottom point of the section are 45° 48' 38'' N and 18° 49' 7'' E. Its altitude is 92 m. The 17.5-m-thick section exposess 6 loess, 1 loess-like and 4 palaeosol horizons
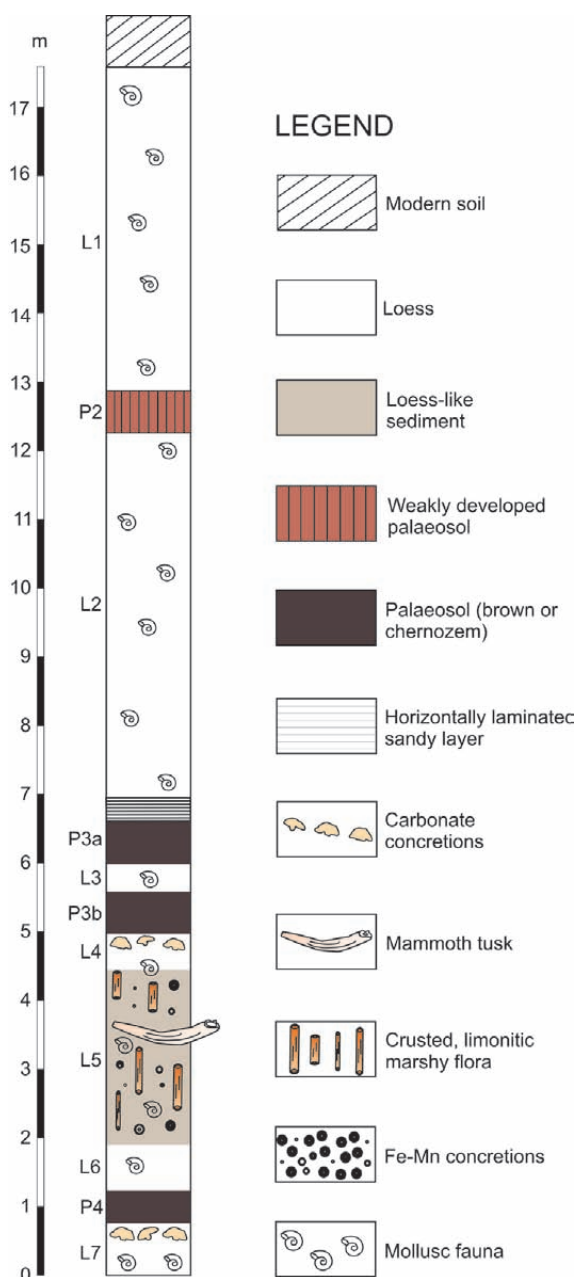
Figure 2: Lithology of the investigated loess-palaeosol succession at Zmajevac (45° 48' 38" N, 18° 49' 7" E).

(Fig. 2). The lithostratigraphically defined loess/loess-like horizons are coded from top to the base as L1 to L7, the palaeosol horizons – from P2 to P4. The third palaeosol representing the loess L3 intercalated doublet, received codes P3a and P3b. F1 marks the Holocene soil.

The lowermost unit of the section is the 80 cm-thick light yellowish brown loess **L7**. In the upper part of the unit carbonate concretions are concentrated. They attain 15–20 cm in diameter, are rounded and somewhat flattened. Mollusc remains and carbonate root casts are also present. The overlying palaeosol horizon **P4** is 50 cm thick and light brown to yellowish brown in colour, somewhat lighter in its basal part. **L6** follows upsection represented by the 60 cm-thick, light yellowish brown loess. The unit contains relatively

abundant mollusc fauna, and a small amount of Fe-Mn concretions and nodules 1–2 mm in diameter.

The light grey to pale yellowish 240 cm-thick loess-like unit **L5** follows upsection. Dark brown Fe-Mn nodules and small concretions 1–2 mm in diameter are common. Stems tentatively ascribed to a fossil reed are preserved as limonitized, pale orange to light brown tubes 5–10 cm in length and 0.5–1 cm in diameter. Molluscs are rare in this unit, but several fragments of mammoth tusk (up to 30 cm x 8–10 cm in size) were discovered in its middle part. The surface of the tusks is pale brown to yellowish brown in colour, while the core is white to pale yellow. Laterally, some smaller, 5–6 cm-long tusk fragments were also discovered.

The next loess unit **L4** is 40–50 cm thick and light yellowish in colour. It bears abundant white to pale yellowish, carbonate concretions measuring up to 10–15 cm in diameter, with variable, but mostly rounded form. Mollusc remains are rare. A well developed, 180 cm thick pedocomplex follows consisting of two palaeoesol horizons (**P3a** and **P3b**) separated by a 40–50 cm-thick light, yellowish brown, loess horizon **L3,** with a fairly rich mollusc fauna. The top 50 cm of the upper paleosol F3a is brown to light brown, and for the lower 30 cm light brown, to yellowish brown in colour. F3b is brownish in its upper 40 cm and light brown to yellowish brown in its lower 40 cm.

The next horizon **L2** is composed of 480 cm light yellowish loess, rich in molluscs underlain by 50 cm horizontally laminated sand, which is fine-grained and light yellow in colour. The stratification is represented by laminae-separated into 1–3 cm-thick sediment packages. L2 is overlain by a 60 cm thick, weakly developed, olive brown to yellowish brown palaeosol horizon **P2**, with no mollusc remains. Finally, the uppermost 450 cm-thick unit **L1** is composed by light yellowish brown silty loess. This unit is rich in mollusc fauna and bears carbonate filled tubes of fossilized root remains.

4.2. Grain-size, carbonate content and mineral distribution

Grain-size analyses indicate silt as the dominant grain-size fraction in all 13 studied loess samples (Fig. 3). Of these, seven (mostly from loess horizons L1 and L2) contain small amounts of clay-sized minerals. The abundance of sand-sized particles ranges from 5.5% to 15%. The laminated unit in the base of L2 is composed of 81% sand, 11% silt and 8% clay, with a median grain-size of 0.22 mm. The four lowermost loess samples indicate a higher percentage of coarse silt and sand-sized particles in reference to all loess samples. Median grain-size is largely constant between 0.025–0.03 mm, with exception for 4 lowermost samples showing significant increase, with the peak in L5 horizon (72% large coarse-silt and sand-sized fraction). Skewness is fairly constant in all 13 samples, averaging of 0.78. Sorting is dominantly poor, with an average value around 1.5.

$CaCO_3$ content of the samples ranges between 2.9% and 23.3% (Fig. 3), with an average value of 9.3%. The highest

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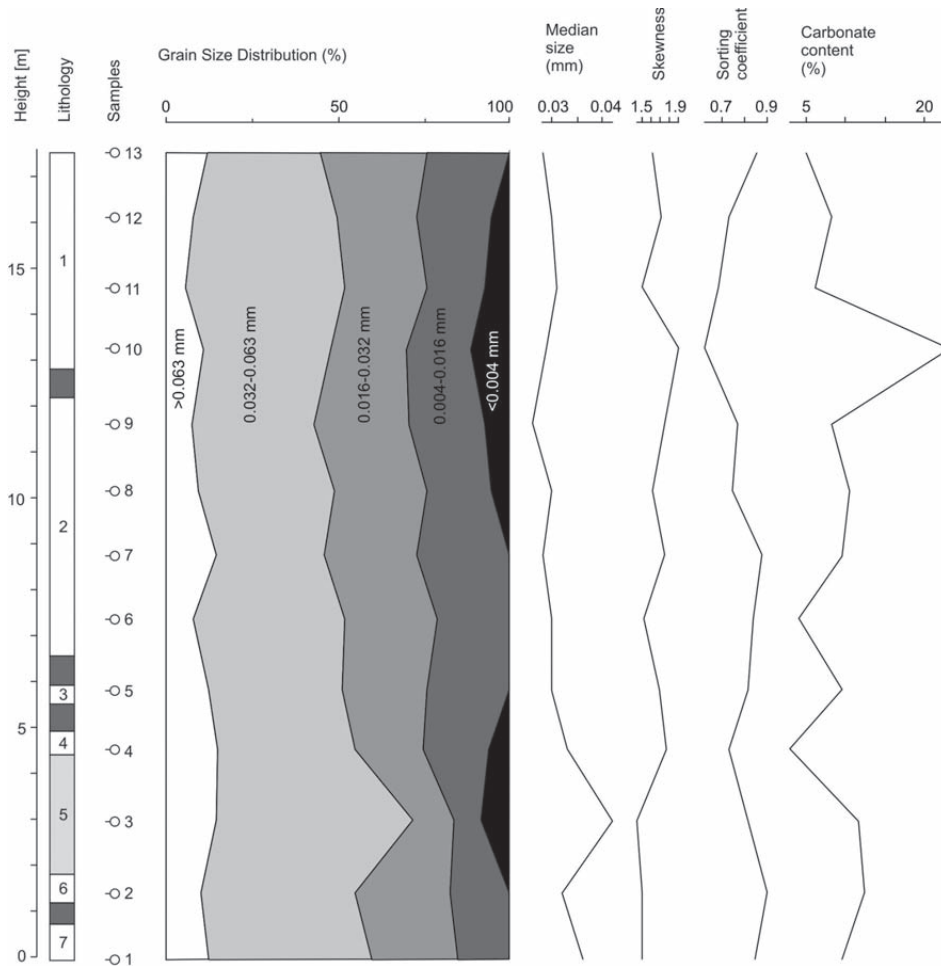
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Figure 3: Sedimentological data and CaCO₃ content from 13 bulk samples documenting facies changes of loess and loess-like horizons. Please note that palaeosol horizons have not been sampled.

Table 1: Mineral assemblage from loess samples. op – opaque minerals, do – dolomite, bi – biotite, ch – chlorite, thm – transparent heavy minerals, tu – tourmaline, zr – zirconium, ru – rutile, am – amphibole, py – pyroxene, ep – epidote, ga – garnet, cy – cyanite, st – staurolite, tit – titanite, czt – clinocoisite, cto – chloritoide, csp – cromespinel, si – silimanite, x – undetermined, q – quartz, f – feldspar, rf – rock fragments, mu – muscovite

| Sample | Heavy mineral fraction (%) | | | | | | | | | | | | | | | | | | | | | | | Light mineral fraction (%) | | | |
	(%)	op	do	bi	eh	thm	Transparent heavy minerals																	P	f	rf	m
							tu	zr	ru	ap	am	py	ep	ga	cy	St	tit	czt	eto	csp	si	X				
13	9.83	15			2	83	2	+	1		26	1	30	28	1	5	1	2	+			2		50	32	13	5
12	8.88	12		+	7	81	4	1	3		39		24	19	+	3	1	3		+		1		54	16	22	6
11	8.18	12			10	78	3	1	1		31		27	22	1	6	2	3	+			2		67	20	9	4
10	6.76	14			6	82	1	1	1	+	29		32	21	2	6	2	2				2		61	23	11	5
9	11.11	12	4	+	4	79	3	1	2	1	24	2	23	27	2	7	3	3				2		59	27	22	2
8	6.14	13			6	81	3	+	3		26	+	26	24	1	5		3		+		2		54	19	20	7
7	5.31	13			6	81	2		2		32	+	28	22	5	6	+	1		+		2		60	18	19	3
6	10.1	11			14	75	2	+	+		35	+	26	23	4	4	+	2	+	+		2		56	15	23	6
5	4.15	20		+	3	76	1	2	2		18	2	23	38	1	8	2	+				2		50	25	18	7
4	11.21	14			1	85	3	2	1	2	23	1	29	25	1	6	1	3	+			1		63	21	14	2
3	11.4	11			+	88	4	+	+	1	27		29	22	1	10	+	2				2		68	10	20	2
2	6.85	13			3	83	1	+	4	+	31		29	25	1	5	+	1	+			1		62	17	15	7
1	6.54	26			1	73	3	2	3		12		22	41	3	11	1					1		55	28	16	1
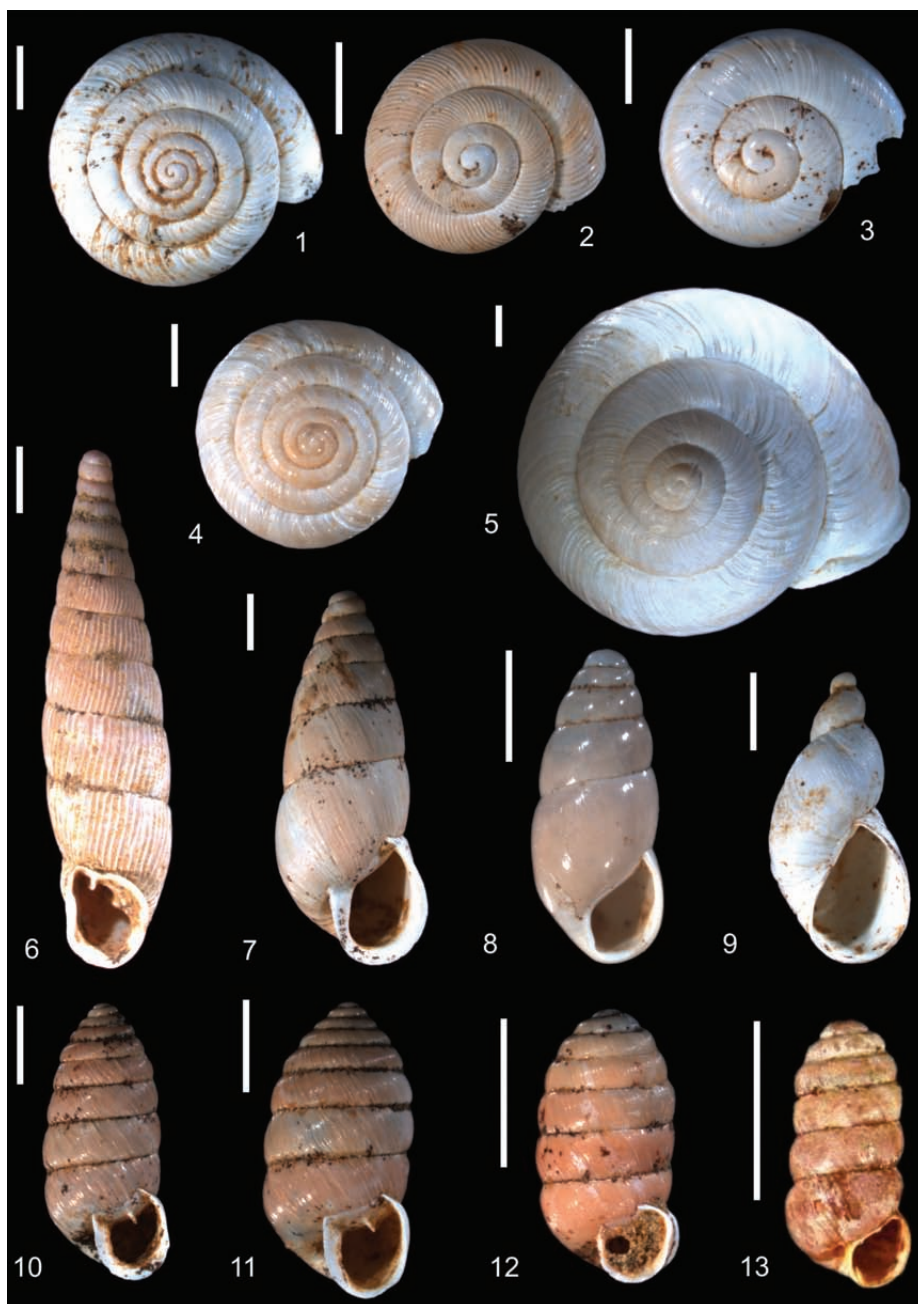
Figure 4: Species occurring in studied samples of the Zmajevac section. Scale bar is 2 mm. **1.** *Helicopsis hungarica* (SOÓS & WAGNER, 1935). **2.** *Vallonia tenuilabris* (A. BRAUN, 1843). **3.** *Vitrea contracta* (WESTERLUND, 1871). **4.** *Helicopsis striata* (O.F. MÜLLER, 1774). **5.** *Arianta arbustorum* (LINNAEUS, 1758). **6.** *Clausilia* (*Andrea*) *dubia* DRAPARNAUD, 1805. **7.** *Chondrula tridens* (O.F. MÜLLER, 1774). **8.** *Cochlicopa lubrica* (O.F. MÜLLER, 1774). **9.** *Succinea oblonga* (DRAPARNAUD, 1801). **10.** *Orcula dolium* (DRAPARNAUD, 1801). **11** *Pupilla muscorum* (LINNAEUS, 1758) **12.** *Pupilla loessica* (LOŽEK, 1954). **13.** *Columella columella* (MARTENS, 1830).

value is measured in the base of the uppermost L1 loess horizon, while the lowest (2.9%) was measured in the L4 loess horizon, bellow the F3b palaeosol. The $CaCO_3$ content is in accordance with typical values for loess deposits, with the exception of 23.3% in the upper part of the L2 loess unit.

Modal analysis pointed out that the light mineral fraction (LMF) is dominant in all samples, whereas the heavy mineral fraction (HMF) range, from 4.15% to 11.21% (Table 1). Quartz is the dominant LMF mineral ranging between 50% and 74% (mean = 59.5%). The feldspar group is the second most abundant ranging between 6% and 32% (mean = 17.1%). The rock particle content is between 9% and 24% (mean = 16.7%). Muscovite is present in all the analysed samples ranging from 1% to 21% (mean = 7.1%). In the HMF, the transparent heavy minerals (THM) are more common than opaque ones, whilst chlorite and dolomite are rare. The most common THM are the mineral groups of epidote, garnet and amphibole. The epidote group is most abundant and ranges from 17% to 37% (mean = 27.5%), garnet group ranges from 16% to 61% (mean = 26.5%), amphibole group from 1% to 35% (mean = 26.1%). Chlorite is present in all samples ranging from 1% to 14% (mean = 4.92%), with mean in L1, L2, and L3 distinctly higher (6.44%), than in L4, L5, L6 and L7 (1.5%).

4.3. Magnetic susceptibility

Magnetic susceptibility (MS) values from loess and loess-like sediment range from 5 to 28.5 x 10^{-6} SI (Fig. 6). L1 horizon from the upper part of the section ranges from 15 to 20 x 10^{-6} SI. The uppermost palaeosol horizon (F2) shows the

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Table 2: Palaeoecological ranges of recorded mollusc species after KROLOPP & SÜMEGI (1995) and SÜMEGI & KROLOPP (2002). C – Cryophilous, H – Hygrophilous, T – thermophilous, M – mesophilous, W – woodland preference, Cr – cold resistant, Sh – subhygrophilous, O – open habitat preference, W/O – intermediate habitat, D – aridity tolerant.

Species	Paleoclimate group	Paleohumidity group	Paleovegetation group	Biogeographical group
Helicopsis striata (O.F. MULLER, 1774)	T	D	0	Central European
Helicopsis hungarica (SOOS & VVAGNER, 1935)	T	D	0	Central and SE European
Chondrula tridens (O.F. MULLER 1774)	T	D	0	Central and SE European
Vallonia tenuilabris (A. BRAUN, 1843)	C	D	0	N and Central Asian
Arianta arbustorum (LINNAEUS, 1758)	Cr	H	w	W and central European
Pupilla muscorum (LINNAEUS, 1758)	M	M	0	Holarctic
Pupilla loessica (LOŽEK, 1954)	C	D	0	Extinct
Orcula dolium (DRAPARNAUD, 1801)	M	H	w	Central European
Succineaoblonga (DRAPARNAUD, 1801)	Cr	H	0	Eurosiberian
Columella columella (MARTENS, 1830)	C	H	0	Boreo-Alpine
Clausilia dubia (DRAPARNAUD, 1805)	M	Sh	w	Central European
Vitrea contracta (VVESTERLUND, 1871)	M	Sh	w/o	European
Cochlicopa lubrica (O.F. MULLER, 1774)	M	M	w/o	Holarctic

highest measured values within the section (82.5 x 10^{-6} SI). Values in the loess unit L2 are again much lower, with a mean of 14 x 10^{-6} SI. A notable peak within this horizon is 28.5 X 10^{-6} SI. The pedo-complex constituents P3a and P3b are marked by significant peaks that are however lower than in the F2 horizon. Upper palaeosol F3a attains 67.7 x 10^{-6} SI, the underlying P3b 53.2 x 10^{-6} SI. The lowermost palaeosol P4 shows again a somewhat higher MS of 58.3 x 10^{-6} SI.

4.4. Mollusc palaeontology

A total of 1705 terrestrial gastropod specimens classified to 13 species (Tab. 2 and Fig. 4) were obtained from 13 samples. Specimen richness, related to mollusc density within the samples varies upsection (Fig. 5). Hence, the mollusc densities are moderate in horizons L7 (85) and L6 (117), strongly decreased in L5 (5) and L4 (7), and strongly increased in L3 (90), L2 (213), and L1 (136).

Helicopsis striata, *H. hungarica* and *Arianta arbustorum* are present in all horizons (Fig. 5), except for L4 and L5. *Columella columella* is rare in all horizons showing peak abundance in L2 (3.29%, and 4.44%). The mean abundance of *Pupilla muscorum* and *P. loessica* is 11.34% with the highest abundance of 14.6% in L2. The latter horizon also produced the greatest number of individuals, representing all 13 species identified in the section.

5. DISCUSSION

5.1. Sedimentary facies and provenance of loess

The grain-size distribution is in good accordance with other loess localities in the Pannonian Basin (GALOVIĆ et al., 2009; BOKHORST et al., 2011). The studied locality shows the predominance of fine and medium silt in loess. Three lowermost loess units (L7, L6, L5) display an increase in the me-

dian grain-size, and coarse silt and sand exceed 50 %. The horizontally stratified fine-grained sand in the base of the L2 unit may be compared with aeolian sands with plane bed lamination (HUNTER, 1977) and are probably wind ripple deposits (HUNTER, 1977; CLEMMENSEN & ABRAHAMSEN, 1983).

THAMÓ-BOZSÓ & KOVÁCS (2007) published valuable data about the heavy mineral composition of flood plain sediments of the Palaeo-Danube and Tisza. The garnet and epidote mineral groups, amphiboles and chlorite are the most abundant heavy minerals in samples collected near the Danube River. The river Tisza and its tributaries drain abundant volcanic rocks, contrasting with those of the largely metamorphic and granitoid complex of the Danube. Comparing heavy mineral assemblage from Zmajevac LPS, with that data, it is obvious, that the main source area for loess in Baranja is from the Danube flood plain sediments. The main transport direction was from the North or North-West. Nevertheless, the higher concentration of amphiboles in the Zmajevac LPS (if compared with those from the Danube plain in Central Hungary), suggests an additional source area. The Western Carpathians with Neogene calc-alkaline volcanic rocks is the major source for amphiboles (THAMÓ-BOZSÓ & KOVÁCS, 2007). The percentage of amphiboles in the HMF of the Zmajevac LPS is fairly constant, averaging 28.8% in the three uppermost loess horizons and 23.25% in the lowermost four. Alternatively those minerals could also be denudation products from locally exposed volcanic and metamorphic rocks of the southward neighboring Slavonian Mts. (JAMIČIĆ et al., 1987). Mt. Krndija and Mt. Papuk, which are the closest to Baranja of all the Slavonian Mts., consist of amphibolites. Furthermore, Pliocene sands from the northern slopes of Mt. Krndija and Mt. Papuk are of local origin and contain abundant amphiboles (JAMIČIĆ et al., 1987).
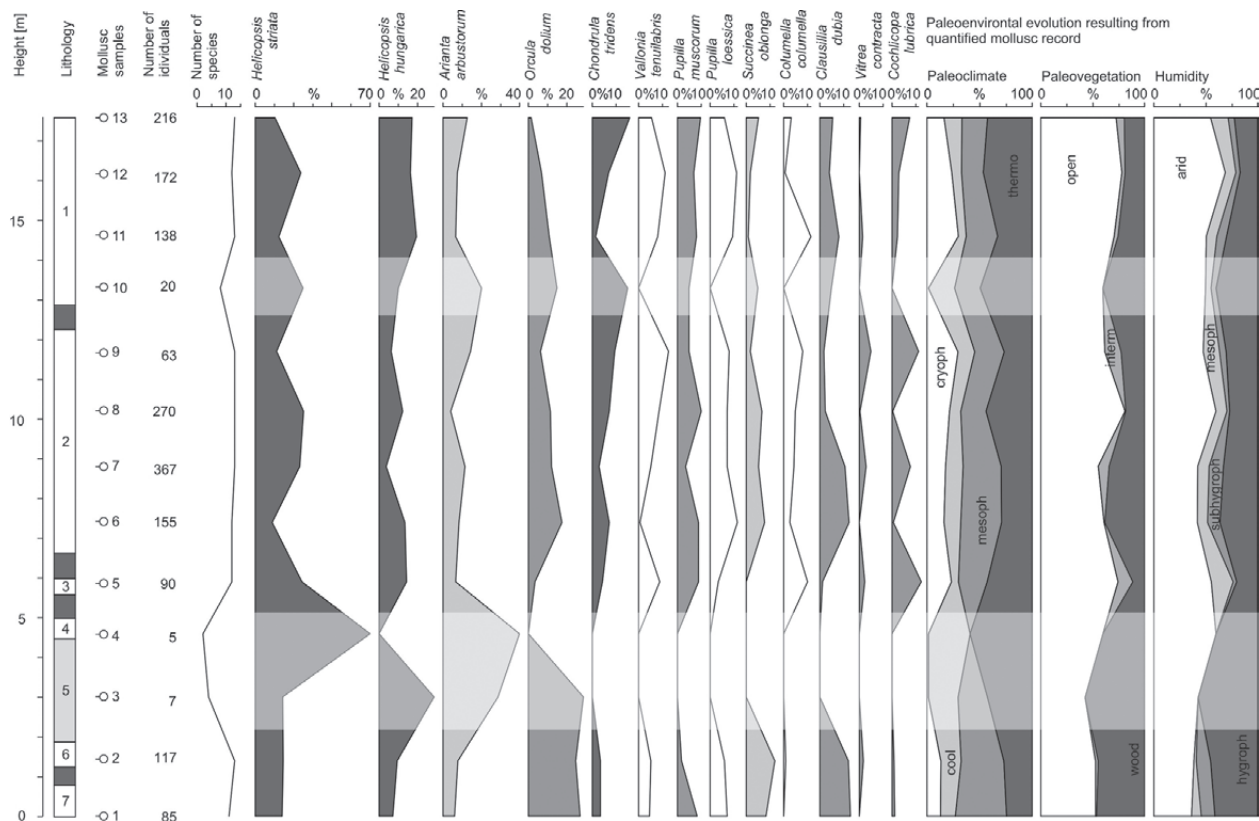
Figure 5: The individual abundances of 13 mollusc species from Zmajevac LPS samples. Palaeoenvironmental proxy curves result from abundance data for the palaeoecological categories presented in Table 2.

5.2. Palaeoclimate, palaeohumidity and palaeovegetation

The identified mollusc species have been classified according to their palaeoenvironmental preferences following KROLOPP & SÜMEGI (1995) and SÜMEGI & KROLOPP (2002) (Tab. 2). The presence and abundance of each species in the sample is considered thereby as a function of available palaeoclimate and palaeohumidity conditions and/or type of palaeovegetation (Fig. 5).

Thermophilous and mesophilous species are dominant in terms of paleotemperature (74–55% abundance, Fig. 5), although none of the warm-climate representatives, typical for interglacial periods, such as *Helicigona banatica*, *Mastus bielzi* or *Discus perspectivus* have been observed. Nevertheless, compared to the Holocene, detected species compositions suggest unfavourable regional climate conditions during loess deposition in the late Pleistocene. Thereby arid climate species are common in all horizons with a mean abundance of 50.49%. Finally open habitat representatives likely dominate the section with mean abundance of 66.81% and peak in L5 loess horizon (71.4%).

The species distribution shows similarities with the Irig section on the southern slope of Fruška Gora in NW Serbia (MARKOVIĆ et al., 2007). The lowermost palaeosol of the Zmajevac section can be compared with palaeosol horizon V-S1 in Irig, which is barren of terrestrial molluscs representing the Last interglacial (MIS5) climate phase. In the Zmajevac section, corresponding loess horizon may be rep-

resented by fossil poor samples 3 and 4. Above this, in both the Irig and Zmajevac sections the dominant *Helicopsis striata* fauna reflects the Late Pleistocene Central European "warm" loess environmental conditions described by LOŽEK (1964). In contrast, the lowermost samples in both sections bear common cooler climate representatives such as *Clausilia dubia* reflecting the Middle Pleistocene Penultimate Glacial (MIS6) conditions.

The Late Pleistocene assemblages from Petrovaradin show, in contrast, colder and more humid conditions than in either Irig or Zmajevac, probably due to the palaeogeographic position at the northern slope of Fruška Gora (MARKOVIĆ et al., 2005, 2008). In adition to the Irig locality, the Zmajevac section also represents the more sun-exposed southeastern side of Banovo Brdo.

5.3. Mollusc assemblage analysis

Species compositions of the samples reveal the presence of five glacial type assemblages defined in LOŽEK (1964), including *Chondrula tridens*, *Helicopsis striata*, *Pupilla loessica*, *Columella collumella* and *Arianta arbustorum*. Therefore, of the six originally introduced assemblage types only those with *Bradybaena fruticum* marking the warmest glacial episodes (LOŽEK, 1964) have not been found in the studied samples of the Zmajevac LPS (Fig. 6).

Horizon L7 displays a *Columella columella* Assemblage with depleted nominal species but with a high percentage of concurrent *Orcula dolium* (27.05%) and *Clausilia dubia*
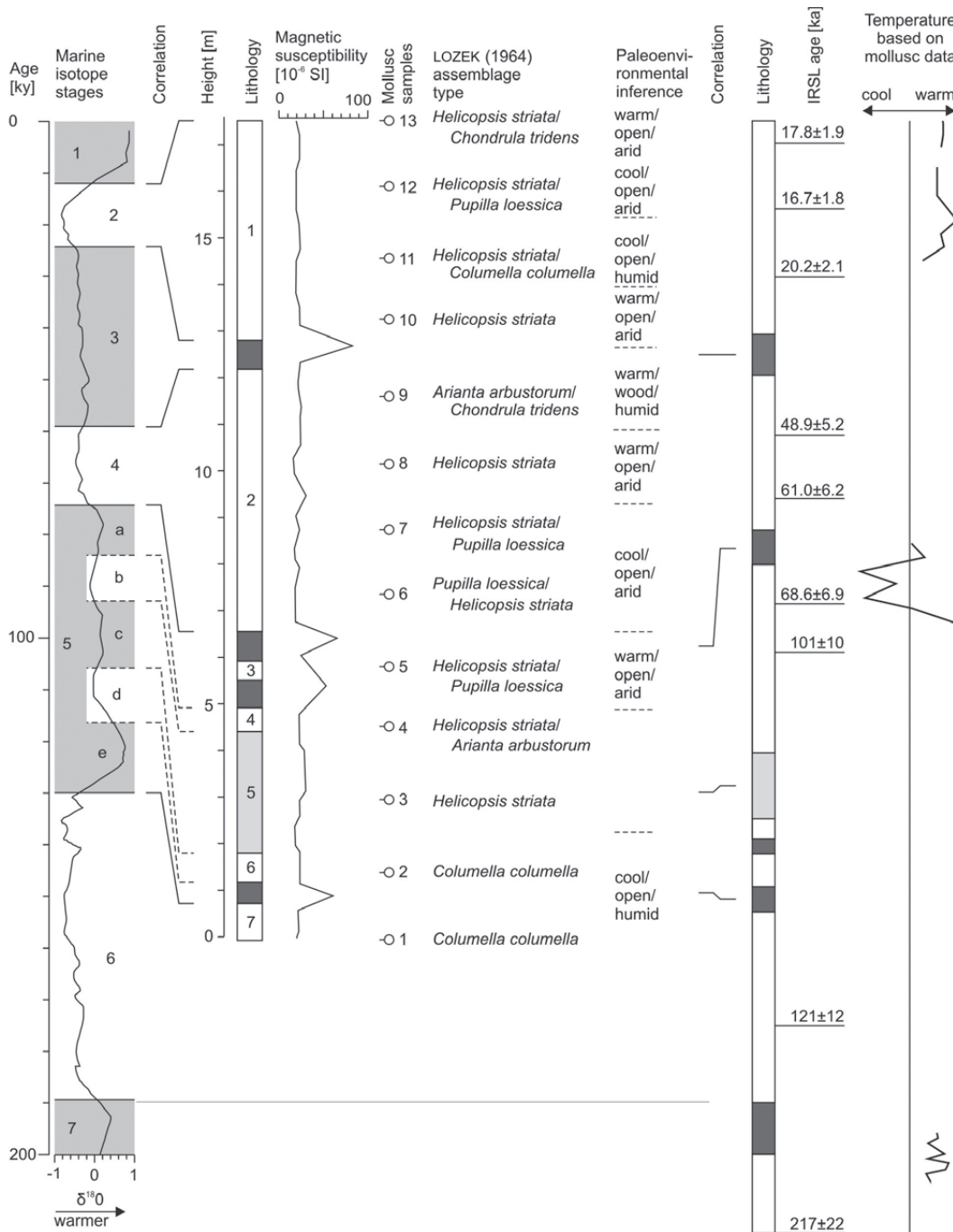
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Figure 6: Correlation of the studied section with Marine Isotope Stages (modified after MARTINSON et al., 1987 and AITKEN & STOKES, 1997) and Zmajevac Section of GALOVIĆ et al. (2009) and MÓLNÁR et al. (2010). The IRSL age estimates are by the mollusc paleotemperature inference by MÓLNÁR et al. (2010). Palaeosol positions are indicated in the lithological columns by dark gray colour. Loess (white) and loess-like (light gray) horizons are numbered in their order of appearance (from top to base). The lithological columns have the same scale.

(12.94%). Horizon L6 displays a similar faunal composition (Fig. 5). Thus it is likely classified as *Columella columella* Assemblage.

Horizons L4 and L5 yielded few molluscs so a determination of mollusc assemblage type is highly speculative. The small number of shells obtained results from strong fragmentation of mollusc shells in that horizons. The L4 horizon is tentatively attributed to transitional *Helicopsis striata – Arianta arbustorum* Assemblage, whereas L5 is defined as a *Helicopsis striata* Assemblage.

The L3 horizon is marked by a transitional *Helicopsis striata – Pupilla loessica* Assemblage. The position of this horizon between two palaeosols of a pedo-complex indicates abrupt cooling during a period of warm and humid climate. In this sample a significant percentage of *Cochlicopa lubrica* was detected (12.2%), which is often a part of typical loess faunas.

Horizon L2 is characterized by the highest densities of mollusc remains in the section. In its lowermost part, a transitional *Pupilla loessica – Helicopsis striata* Assemblage with almost equal number of *Pupilla* sp. and *Helicopsis* sp. indi-

viduals is present. A *Helicopsis striata – Pupilla loessica* Assemblage follows above. The middle part of the horizon produced a *Helicopsis striata* Assemblage with common *Vallonia tenuilabris* (6.59%). Finally the uppermost part bears a transitional *Arianta arbustorum – Chondrula tridens* Assemblage.

The L1 horizon is characterized by common representatives of a *Helicopsis striata* Assemblage commonly developed as transitional assemblage types. A sample from the base of L1 contains a typical *Helicopsis striata* Assemblage, followed by the transitional *Helicopsis striata – Columella columella* Assemblage. Above, a *Helicopsis striata – Pupilla loessica* Assemblage was detected. Along with *Pupilla* sp., *Vallonia tenuilabris* is also abundant (11%). Finally the uppermost part of horizon L1 belongs to the transitional *Helicopsis striata – Chondrula tridens* Assemblage.

A *Helicopsis striata* assemblage is dominant throughout the LPS Zmajevac, with transition to colder and warmer climate conditions, as recorded by the *Pupilla loessica – Columella columella* and *Arianta arbustorum – Chondrula tridens* Assemblages. The *Helicopsis striata* Assemblage indicates climate conditions preceding the last glacial/stadial maximum. *Chondrula tridens* and *Arianta arbustorum* are generally abundant species, but their abundance is never high enough for definition of a *Chondrula tridens* or *Arianta arbustorum* assemblage. Actually these were defined through abundance of typical concurrent species as defined by LOŽEK (1964). Both assemblages mark slightly humid steppe conditions, whereas, the first one is bounded by phases of chernozem formation. The *Pupilla loessica* and *Columella columella* assemblages are typical loess faunas and exponents of glacial/stadial maximum. Arid and cold climate conditions are indicated by the *Pupilla loessica* assemblage, more humid conditions by the presence of the *Columella columella* assemblage. *Pupilla muscorum*, *Helicopsis striata*, *Vallonia tenuilabris* and *Succinella oblonga* are concurrent species in *Pupilla loessica* assemblages, while *Orcula dolium*, *Clausilia dubia* and *Arianta arbustorum alpicola* are additional species in a *Columella columella* assemblage.

Interestingly the best known NE Croatian terrestrial mollusc assemblage (POJE, 1984) from the well dated (WACHA & FRECHEN, 2011) section of Vukovar reflects a similar cold spell around the MIS 5 lower boundary. Yet, the recorded assemblages seem to reflect somewhat more arid microclimate conditions.

5.4. Stratigraphic correlation and palaeoclimate history

Based on IRSL age estimate of 20.2±2.1 ka, GALOVIĆ et al. (2009) correlated the uppermost part of the loess-palaeosol succession at Zmajevac with the Upper Pleniglacial MIS 2. The base of the succession represented by a loess horizon yielded an IRSL age estimate of 217±22 ka and was tentatively correlated with the Middle Pleistocene MIS 8. However the lowermost 6 m of the Zmajevac succession are not exposed in the present outcrop (Fig. 6) that starts with the loess unit L7. The latter unit yielded the IRSL age estimate

of 121±12 ka and was tentatively correlated with the Penultimate Glacial MIS 6 by GALOVIĆ et al. (2009).

The loess horizon L7 is overlain by palaeosol P4 and followed immediately by the next loess unit (L6). Those two lowermost loess horizons (L6 and L7) are characterized by the presence of a *Columella columella* assemblage (Fig. 6). Its equivalent is a *Pupilla loessica* Assemblage indicated in horizons L3 and L2 and likely a typical loess fauna representing however more arid climate conditions. In contrast, the *Columella columella* Assemblage is an indicator of the glacial maximum (LOŽEK, 1964), with dominantly humid climate conditions. Compared with malacofaunal results from Irig and Ruma LPS in Vojvodina (MARKOVIĆ et al., 2006, 2007), that fauna represents palaeoenvironment of open grassland, and a cold, wet climate. Hence the presence of a *Columella columella* Assemblage in the basal part of the section strongly supports its correlation with the MIS 6 stage proposed by GALOVIĆ et al. (2009).

Sedimentological and magnetic susceptibility (MS) data obtained from Zmajevac LPS show similarities with other loess-palaeosol sequences in the Pannonian Basin investigated recently (MARKOVIĆ et al., 2006, 2007; GALOVIĆ et al., 2009; MOLNÁR et al., 2010; WACHA & FRECHEN, 2011). MS values are in the expected range, especially in loess horizons. MS values from four palaeosols are comparable with those from Irig in neighboring Vojvodina (MARKOVIĆ et al., 2007). The lowermost P4 palaeosol, displays significantly weaker signals, than the P2 palaeosol, but stronger than the overlying P3b palaeosol horizon (Fig. 6).

The MS value of 58.3 x 10^{-6} SI in the P4 palaeosol is lower than expected for an interglacial period and a fully developed soil. Even though it is the oldest palaeosol, a weaker signal than in the youngest F2 may indicate that iron is present in oxidized form in limonitic minerals. It is most likely that the low MS values result from mineral leaching. Such a decrease in the MS signal in clayey horizons was also detected in Germany by ROUSSEAU et al. (2002) and in Hungary by NOVOTHNY et al. (2009). It is very likely that similar processes affected the P4 palaeosol horizon in Zmajevac. In agreement with data by GALOVIĆ et al. (2009) the P4 horizon is correlated with the MIS 5e interglacial period.

The pedo-complex forming palaeosol horizons P3a and P3b is similar to a pedo-complex from the Vojvodina (MARKOVIĆ et al., 2007) and Hungary. Reminiscent of synchronous horizon of Hungarian Sütto LPS (NOVOTHNY et al., 2011), the signal from the P3 pedo-comlex is higher than the one measured in Vojvodina. Finally, the strongly increased MS value of 82.5 x 10^{-6} SI suggests that the uppermost palaeosol P2 represents an interglacial, rather than an interstadial phase. The chronostratigraphic data obtained by GALOVIĆ et al. (2009) imply the straight forward correlation of this horizon with the MIS 3 stage (Fig. 6).

The integration of palaeontological results with IRSL age estimates fixed the correlation of loess L7 with MIS 6. Through correlation of loess L2 with the Lower Pleniglacial MIS 4, (based likely on integrated palaeontological and chronostratigraphical data (GALOVIĆ et al., 2009)), the interchanging facies character between units L7 and L2 sug-

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gests climate forcing reflecting the five-folded pattern of MIS 5 (Fig. 6). The loess-like horizon L5 could thereby correlate with the warmer MIS 5c, while L6 and L4 loess units would correspond to MIS 5d and MIS 5b cooling events, respectively. If this correlation proves true the whole studied succession, except for the lowermost loess L7 would have been deposited during the Late Pleistocene (Fig. 6).

6. CONCLUSION

The present investigation of the Zmajevac loess-palaeosol sequence (LPS) established valuable palaeontological data for palaeoclimate and palaeoenvironmental reconstruction of Baranja during the latest Middle and Late Pleistocene. The recorded mollusc compositions display small but important differences to other Pannonian basin LPSs, especially for horizons L7, L6 and L3. Hence the later assemblages indicate still cooler and more humid climate conditions than previously known (POJE, 1984). This difference is probably a consequence of local geomorphology and microclimate conditions. Indeed the mollusc fauna from the rest of the samples is in very good agreement with the previous Pannonian basin record. Additional data obtained from sedimentological and magnetic susceptibility analyses, seem to show fairly good congruence with results from other LPS in the Pannonian basin (MARKOVIĆ et al., 2006, 2007; NOVOTHNY et al., 2011; WACHA & FRECHEN, 2011), although low sampling frequency prevent their use for more comprehensive correlation.

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