The late and middle pleniglacial malacofauna of the Zemun loess-paleosol sequence

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Abstract

The aim of our study was to describe the succession of malacological assemblages along the exposed loess profile located in Belgrade, at the Danube river bank (municipality of Zemun). Deposits which belong to the composite loess unit L1 were sampled. Loess unit L1 included two subunits: L1SS1 – the middle pleniglacial subunit with two weakly developed initial pedogenic horizons and L1LL1 – late pleniglacial loess subunit. Three malacological zones were identified. The molluscs indicate the environment with moderate warm and dry climate and mosaic vegetation type composed of grasslands and forest steppe. Gradual cooling was observed towards the end of the upper last glacial period. Our findings concur with results of earlier studies that the Zemun site and the adjacent area served as a transition zone between the refuge areas within the southeastern part of the Carpathian Basin during late Pleistocene.

Key words: loess, mallacofauna, Pleistocene, Serbia, Zemun

1. Introduction

Loess deposits cover 10% of the world's continents and even much larger parts of Eurasia (Pécsi, 1990), and represent some of the most important continental climate archives available (Porter, 2001). During the last decade loess-paleosol sequences (LPS) in Vojvodina region (Northern Serbia) have been established as the most complete European continental environmental terrestrial record during the last 1 Ma (Marković et al., 2009, 2011).

Previous studies of loess sections at various exposures in Northern Serbia have used lithological, pedogenetic and magnetic susceptibility (χ) data, along with variations in amino acid racemization geochronology (Marković et al. 2004, 2005, 2006, 2007, 2009, 2014), all combined with luminescence dating, as the primary basis for correlation (e.g. Fuchs et al., 2008; Schmidt et al., 2010; Stevens et al. 2011; Murray et al., 2014; Timar-Gabor et al., 2015). The result has been the establishment of a chronostratigraphy for various loess-paleosol units in Vojvodina region, and the southeastern part of the Carpathian Basin.

Because mollusc shells are usually well preserved in the loess layers, examination of malacofauna can produce very detailed information about paleoenvironmental and paleoclimatological conditions during Quaternary. Composition of mollusc taxa is influenced by many factors that exist in their habitat, but primarily by macro- and microclimatic conditions and vegetation structure (Sümegi and Krolopp, 2002). Many previous studies indicated that the last glacial land snails assemblages in the LPS in the Vojvodina region provide opportunity for sensitive temporal and spatial paleoenvironmental reconstructions (Marković et al., 2004, 2005, 2006, 2007, 2008, 2013, accepted; Sümegi et al., 2016).

In this study we analyzed the late and middle pleniglacial land snails in scope to better understanding of spatial environmental dynamics in southeastern part of the Carpathian Basin during the last glacial period.

2. Material and methods

LPS near Zemun are nicely exposed along steep cliffs at the Danube river bank (Figure 1). The LPS located near the Criminalistic Police Academy (N 44°51'28", E 20°23'13", 105 m a.s.l.), was sampled during 2015. The thickness of the analyzed section was approximately 500 cm. Lower part of exposure is completely covered by colluvial material making investigations of older LPS impossible.

The nomenclature for chronostratigraphy follows the Chinese loess stratigraphic system, with one exception – we used the prefix "V-" to refer to the standard Pleistocene loess-palaeosol stratigraphy in Vojvodina (Marković et al., 2008). Recently, a Danubian loess stratigraphic model (Marković et al., 2015) has been developed to correlate the loess paleosol units of the Danube Basin with the Chinese loess stratotype sections. Nonetheless, in our paper the use of the Chinese “L and S” labels are applied similarly (e.g. Kukla, 1987) without using any regional prefix.

Samples for the low filed magnetic susceptibility (χ) variations have been collected over the whole investigated sections with step each 5 cm. Measurements were obtained using a Bartington MS2 susceptibility meter in Laboratory for paleoenvironmetal reconstruction, Faculty of Sciences, University of Novi Sad.

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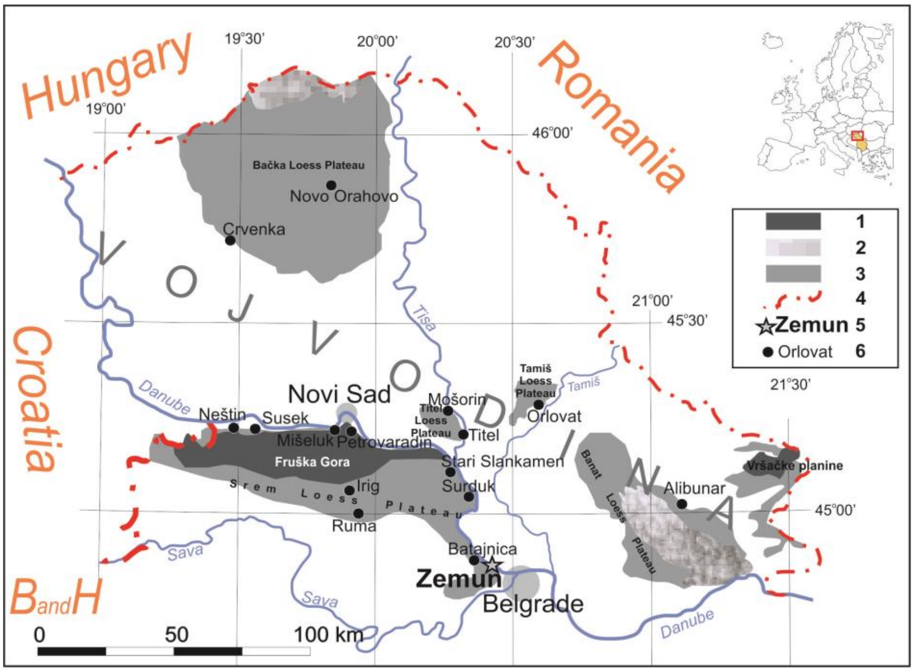

Figure 1 Study area. A) Geographic location of the Crvenka brickyard exposure and other relevant sites in the Vojvodinian loess area. Legend: 1. loess plateau; 2. sandy area; 3. mountain; 4; state border; 5. Zemun KPA site; 6. main loess sections.

Samples were taken within the last glacial loess layers (L1), while the top soil cover (S0) was omitted. For the purpose of malacological studies samples of approximately 10 kg were taken continuously at 20 cm intervals. Individual fossils were extracted from loess sediments by washing samples through sieves (0.5–1 mm) in field conditions and then air-dried. Individual shells and shell fragments were further sorted and identified on a dissecting stereo microscope. The abundance was given by the number of complete shells plus the number of apices or apertures which were considered as equivalent to one shell when taken together (Ložek, 1964; Moine et al., 2008; Osipova et al., 2013). Small fragments (lateral shell fragments, collumelae and parts of apertures or apices) were taken into account for counting according to the scheme proposed by Ložek (1964).

Identification was done using various malacological literature: Kerney et al. (1983), Pfleger (2000), Fehér et al. (2010), Welter-Schultes (2012) and Nekola et al. (2015). Classification of mollusc taxa according to their ecological preferences (temperature, humidity and vegetation structure) was done by comparison with the interpretations of Ložek (1964), Alexandrowicz (1987), Willis et al. (2000), Sümegi and Krolopp (2002), Sysoev and Shileyko (2009) and Juřičková et al. (2014).

Delineation of malacological zones was done using cluster analysis and non-metric multidimensional scaling (NMDS) ordination with PAST software (Hammer et al., 2001). Before Ward's method was selected for clustering, principal coordinates analysis with Bray-Curtis index was performed and original data were replaced with the PCoA scores. The same similarity measure (Bray-Curtis) was chosen for NMDS.

3. Results

3.1 Litho-, pedo-stratigraphy and magnetic susceptibility record

Zemun profile covers the Holocene soil (S0) and the sequence of last glacial units (L1). Two pleniglacial periods were observed within which we characterized three loess and three paleosol layers.

The middle pleniglacial period is represented by two weakly developed initial pedogenic horizons L1SS1SSS2 (10 YR 8/2 5/4) and L1SS1SSS1 (10 YR 8/2 5/5) separated by a thin inter loess layer L1SS1LLL1 (10 YR 8/2 5/3). The middle pleniglacial LPS at Zemun site have a typical χ record characterized by two slightly increased magnetic signals approximately 30 10^{-8} m^3/kg, like in many other sections in the Vojvodina region (e.g. Marković et al., 2008, 2009, 2011, 2015; Antoine et al., 2009; Bokhorst et al., 2009), associated with pedogenesis initial interstadial paleosols. Remarkable krotovinas around 3 m of profile depth indicate domination of dry steppic environmental conditions (Fig. 1).

The uppermost late pleniglacial loess subunit L1LL1 (10 YR 8/2 4/4) is less cemented and very porous. This loess stratigraphic subunit at Zemun loess section is separated by a thin initial weakly developed paleosol L1LL1SSS1 (10 YR 8/2 5/3). The lowest values of magnetic susceptibility (MS) is observed in subunit L1LL2LLL2 about 20 10^{-8} m^3/kg. However, MS values gradually increase from paleosol L1LL1SSS1 towards modern soil. Presence of many bioturbations in the uppermost part of L1LL1LLL1 loess layer, close to contact with modern soil (S0), indicate strong impact of post depositional process and more visible variations of MS (Fig. 1).

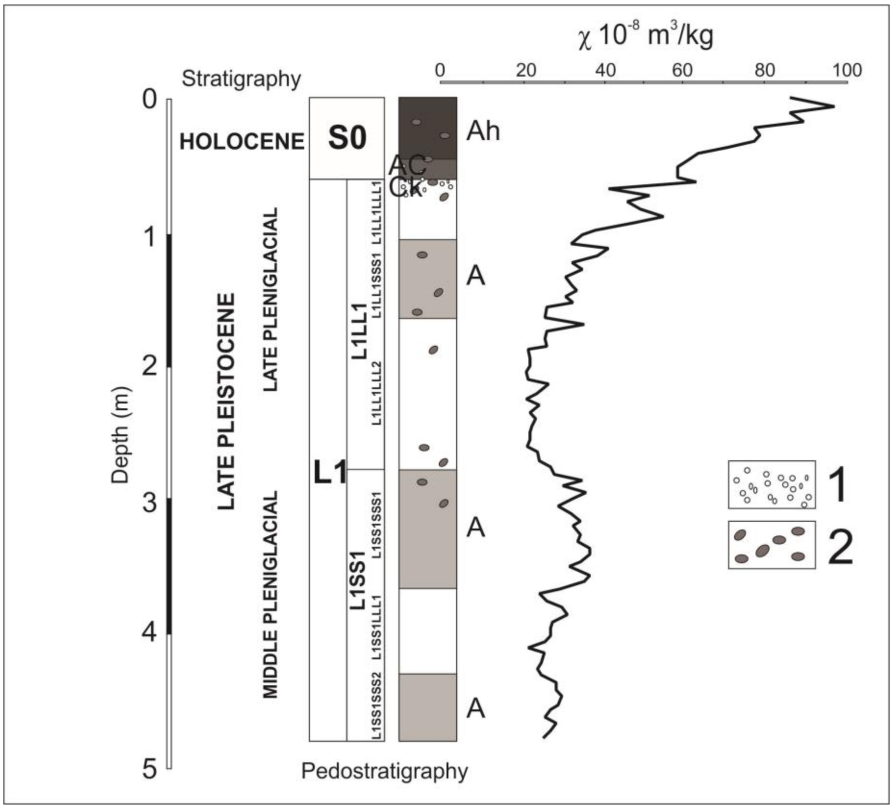

Figure 2 Litho- and pedostratigraphy of the Zemun loess section related to general stratigraphic interpretations and magnetic susceptibility record. Legend: 1 – Krotovinas; 2 – Carbonate concretions.

At the top of the investigated section, the modern soil is a 60 cm thick carbonate chernozem. The lower Ck horizon contains many $CaCO_3$ nodules of 1 to 3 cm in diameter, numerous krotovinas and root channels filled with humic material. A transitional AC horizon (10 YR 5/1 3/3) is a 15 cm thick, very porous, silty loam with fine granular structure. The uppermost Ah horizon (10 YR 6/3 3/3) is a 40 cm thick silty loam with typical granular structure and some carbonate pseudomycelia. Magnetic susceptibility values gradually in increase in modern soil S0 from 40 to almost 100 30 10^{-8} m^3/kg.

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3.2 Malacofaunistical investigations

Twenty two samples of the Zemun loess profile were taken for malacological analyses. A total of 3684 whole fossil shells of adult individuals were extracted from the sediment, together with 3757 apertures, 2969 apices and 2843 various small fragments. Complete and reconstructed shells (combined apertures and apices, together with calculated number of whole shells based on small fragments) produced 8846 identifiable mollusc shells. Eighteen species from 14 genera were identified. Rudimental slug shells (163 shells) could not be identified but belonged to species of Milacidae, Limacidae or Agriolimacidae. Shells of *Cecilioides acicula* (O. F. Müller, 1774) were omitted from analyses. This recent species is subterranean and can bury themselves 20–40 cm (up to 2 m) into the sediment (Welter-Schultes, 2012). Furthermore specimens of this species can also be secondarily deposited in the loess material by the process of bioturbation (Ložek, 1985). Only one shell of the juvenile individual that appeared to be *Quickella arenaria* was found and was excluded from analysis as well.

The loess sequence at Zemun contained terrestrial mollusc assemblages that share relatively high abundance of *Pupilla triplicata* and *Vallonia costata*, but differed in the presence of other species with vast range of ecological preferences. Based on changes in species richness and abundance (Fig. 2), as well as on the results of cluster and ordination analyses (Fig. 3, 4) three malacological zones can be distinguished. Snail fauna of each of these zones have a specific set of ecological preferences (Fig. 5).

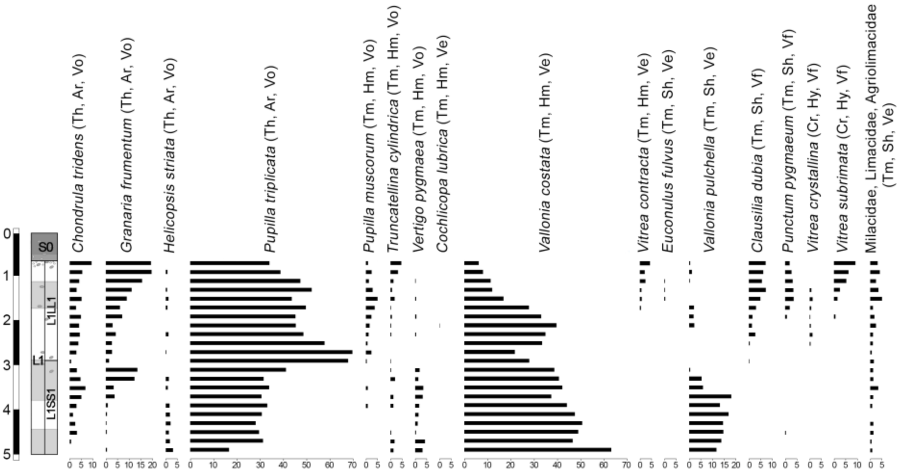

Fig. 2. Species abundance diagram of the loess section. The values represent the percentages of total number of taxa found in a sample. Abbreviations in parentheses are as follows: Temperature: thermophilous – Th, mesophilous – Tm, cold resistant – Cr; Humidity: aridity resistant – Ar, mesophilous – Hm, Subhygrophilous – Sh, Hygrophilous – Hy; Vegetation: open vegetation – Vo; ecotone vegetation – Ve; forest – Vf.

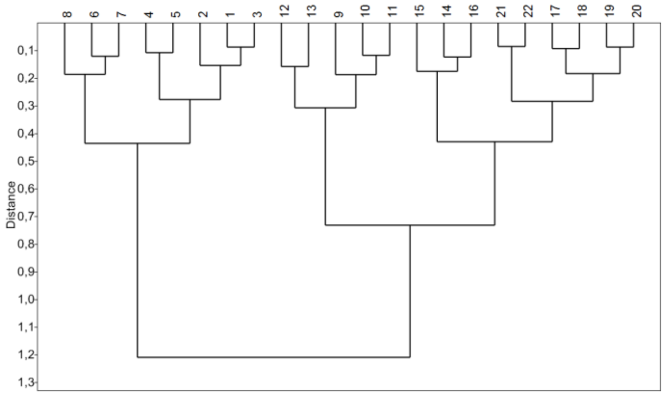

Fig. 3. The results of the cluster analysis of the malacocoenosis from the Zemun loess profile.

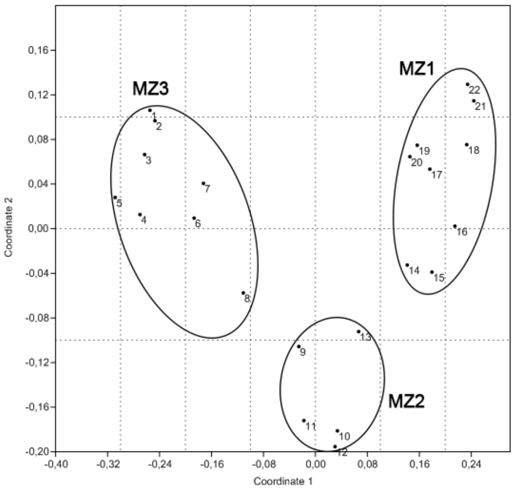

Fig. 4. The results of the NMDS analysis of the fossile mollusc fauna from the Zemun loess profile.

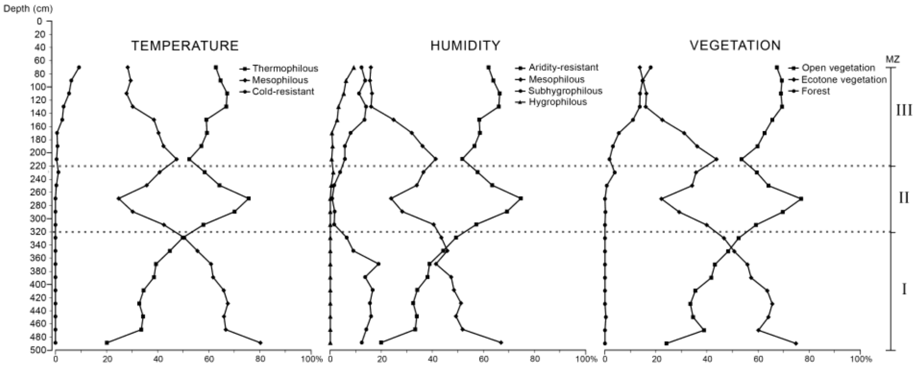

Fig. 5. Ecological preferences of the loess malacofauna.

Paleoenvironment as recorded at Zemun LPS is characterized by the continuous presence of two mollusc species – *Valonia costata* and *Pupilla triplicata*. Although their numbers fluctuated, they remained dominant elements that shaped the assemblage.

First mollusc zone (MZ1) is placed between 500 and 320 cm, into the middle pleniglacial period. High presence of *V. costata* in this zone indicates a mesophilous open or semiopen environment, such as a forest steppe ecotone. *Vertigo pygmaea* that is typical for low grassland areas was also commonly found in this zone. Thermophilous and xerophilous species remained at low numbers throughout MZ1, which also point to mesophilous conditions.

Second mollusc zone (MZ2) developed between 320 and 220 cm. It includes parts of the middle and late pleniglacials. The most important change is a drastic increase in the proportions of *Pupilla triplicata*. *P. triplicata* is dry open vegetation preferring species that is representative of steppe environment. An increase in the abundance of the xerophilous and open habitat species *Chondrula tridens* was also noted. The faunal change in MZ2 point to a transition from mild humid to drier conditions. Low grasslands were the prevailing type of vegetation during this period.

Third mallacological zone (MZ3) is located between 220 and 60 cm, and stretches all the way to the top layer of the Holocene soil (S0). This zone is placed in the late pleniglacial period. A pronounced faunal change can be observed in this zone. The ratio of thermophilous and xerophilous species decreased, while cold-loving species, characteristic for more humid habitats, started to increase in number. Mollusc fauna of this zone is considerably more diverse, however only a few species achieved dominance in the assemblage. The appearance of *Vitrea subrimata* and *V. crystallina* indicate forest and ecotone environment. Other shade-loving species, such as *Vitrea contracta*, *Truncatellina cylindrica* and *Clausilia dubia* also increased in abundance. The faunistic change of MZ3 suggest an increase of vegetation cover and an onset of colder climatic period in the study area.

4 Discussion

Due to climatic fluctuations during late Pleistocene the structure of the last glacial loess (L1) varies in different loess localities across the Vojvodina region (Marković *et al.*, 2008). Nevertheless, stratigraphy of the Zemun LPS show close similarities with the Batajnica loess profile, probably because sites are spatially close to each other and both are positioned at the Danube river bank (Marković *et al.*, 2008; Osipova *et al.*, 2013). We observed similar magnetic susceptibility (MS) pattern in L1 of the Zemun and Batajnica sections. MS values are related to marine isotope stages (MIS) 3 to 1. Both sections are characterized with two weakly developed interstadial paleosols that formed within L1SS1 during the middle pleniglacial interval. MS values of those pedocomplexes are only slightly higher than loess. The youngest loess layer L1LL1 accumulated during dry and temperate stadial in the late pleniglacial. Sedimentary proxies also suggest that conditions at Zemun site were similar to Batajnica (Marković *et al.*, 2008; Osipova *et al.*, 2013).

Malacological results imply a change in climatic conditions and subsequently in vegetation structure. Relatively monotonous and poorly diversified malacocoenosis of the mollusc zone 1 (MZ1) was characterized by the paleoassociation of *Vallonia costata* and *Vertigo pygmaea*. Mesic elements are replaced by xeric associations of *Pupilla triplicata* and *Chondrula tridens* in MZ2. Following gradual cooling, open vegetation (steppe) that extended during mild climatic periods was partially replaced with closed vegetation cover (forest). The vegetation structure was probably mosaic, with grasslands and patches of forested areas (forest steppe). In the southern part of the Great Hungarian Plain similar change was observed under arid local conditions, where short-grassed steppe vegetation developed during the interstadials of the last glacial, while during cold periods, vegetation density increased and forest steppe (mosaic-like vegetation) and long-grassed steppe became dominant (Sümegi *et al.*, 2016). It is know that the mosaic-like vegetation is capable of supporting high faunal diversity (Olff *et al.*, 1999; Adler *et al.*, 2001). Our observation of the increase in the number of species in the MZ3 (upper last glacial) is also in compliance with this statement.

Mollusc assemblage of the Zemun LPS show a constant presence of certain warm loving and xerophilic species (*Pupilla triplicata*, *Granaria frumentum*, *Chondrula tridens*). Even though their abundance is higher during interstadials, and is generally lower toward the end of the late pleniglacial, they maintained high presence. This suggests that the late Pleistocene climate in the analyzed region was dry and relatively warm. The cooling that started towards the end of the upper last glacial period was not as intense at the Zemun locality compared with glacial periods at other sites in Central Europe. Paleoclimatic and paleoenvironmental reconstructions indicate that the Vojvodina region was located at the northern edge of a southeastern European "warm" glacial province and was under Submediterranean influence (Marković, 2007). Therefore, continental climatic conditions were somewhat mitigated.

The most significant change in mollusc fauna occurred at the end of the glacial (in MZ3). Species associated with an increased vegetation cover and elevated levels of humidity appeared. Forest steppe vegetation existed during this period. It is believed that grassland and forest steppe mosaics that existed in the Vojvodina region served as a transition zone that mollusc species used while seeking refuges in nearby areas (Sümegi *et al.*, 2016).

5 Conclusions

Investigations of the loess-paleosol sequence at Zemun have established the importance of this site as a record of late Pleistocene paleoclimate and paleoenvironment in Serbia. Sedimentological, pedological, magnetic, and mallacological evidence suggest a relatively dry and warm conditions in this region. Gradual cooling was observed toward the end of the late pleniglacial period, however it was less pronounced than in other parts of Central Europe.

Identified malacofauna revealed important paleoclimatic and paleoenvironmental interpretations: 1) loess of MZ1 formed in a mild forest steppe environment; 2) loess of MZ2 formed in a typical dry and temperate steppe environment; 3) loess of MZ3 formed in a cooler and more humid forest steppe environment with a denser vegetation cover. During the last glacial Zemun and other adjacent localities probably served as a transition zone used by molluscs during their migrations between refuge areas. We can speculate that one such migration route leaded towards the Fruška Gora mountain which sheltered terrestrial snails from unfavorable conditions at the end of the Pleistocene.

Acknowledgements

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