An Introduction to the Late Pleistocene Loess-paleosol Sequence at Susek (Vojvodina, Serbia)

Slobodan B. Marković1, Ulrich Hambach2, Tivadar Gaudényi1, Mladjen Jovanović3, Ludwig Zöller2, Björn Machalett1,2, Stevan Savić1, Jovan Romelić1, Jovan Plavša1, Minučer Mesaroš1

Abstract
The Susek loess-paleosol sequence is located in the western part of the north slope of the Fruška Gora mountain, in the Vojvodina region, Serbia. Three loess units and two fossil pedo-complexes, and recent soil are preserved in the ~7.5-m thick Susek exposure document about the environmental changes during the Late Pleistocene and Holocene. Detailed magnetic susceptibility and sedimentological evidence of the Susek loess-paleosol sequence are used for correlation with the SPECMAP paleoclimatic record, as well as, with other Late Pleistocene loess sites in the Vojvodina region. Primary climatic and environmental records of the loess unit L1-L2 are disturbed by post-depositional hydromorphic processes. Our investigations confirm previous malacological results from the northern slope of Fruška Gora mountain which demonstrated significant similarities to the Paleoprelliyrian fauna of the southern Transdanubia region in Hungary and suggested that the Susek site also has a refugial character during the last glacial.

Key words: paleoclimate, paleoenvironment, Late Pleistocene, loess, Serbia, Susek, grain size, magnetic susceptibility

1 Department of Geography, Tourism and Hotel Management, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia and Montenegro; zbivim.ns.ac.yu
2 Chair of Geomorphology, University of Bayreuth, D-95440 Bayreuth, Germany;
3 Leibniz Institute for Applied Geosciences (GGA-Institute), S3: Geochronology and Isotope Hydrology, Stilleweg 2, D-30655 Hannover, Germany

Introduction
The rich loess records from the Vojvodina region (Northern Serbia) (Marković, 2000, 2001; Marković et al., 2003, 2004a, 2006), located in the southeastern part of the Carpathian (Pannonian) Basin (Fig. 1), provide important information for the comparison of the European loess stratigraphies. Loess accumulation in the Vojvodina province started in the late Lower Pleistocene (Marković et al., 2003) and culminated during the Late Pleistocene. Due to the high accumulation rates and widespread occurrence, the last glacial-interglacial loess-paleosol sequences in the Vojvodina region have preserved a detailed record of Late Pleistocene climate dynamics and environmental changes (Marković, 2000, 2001; Marković et al., 2003, 2004b, 2005, 2006).

Material and Methods
Investigations into the loess-paleosol sequences of the Susek exposure began in 2004. Samples were collected at 5-cm intervals for MS measurements and sedimentological analysis, and at 10-cm intervals for malacological studies.

Dry and moist colors were recorded using Munsell Soil Color Charts.

The measurements of the low-field magnetic susceptibility (MS) were performed at the paleo- and rock-magnetic laboratory of the Chair of Geomorphology, University of Bayreuth, using a KLY-2 susceptibility bridge (AGICO, Brno, Czech Republic).

10-kg bulk sediment samples for malacological investigations were sieved through a 0.7 mm mesh. After fossil gastropod shells were identified, paleoenvironmental classification and interpretation were done and they are based on the methods of Lošek (1964), but also extended with some local variants defined by Krolop and Sümegi (1995) and Sümegi and Krolop (2002).

Results
Litho- and pedostratigraphy and correlations
The loess stratigraphy is quite uniform in the Vojvodina region because of mostly...
plateau depositional conditions (Marković, 2000, 2001; Marković et al., 2003, 2006) similar to the ones in the central Chinese loess plateau (e.g. Liu et al., 1985; Kukla, 1987; Kukla and An, 1989). Recent stratigraphic studies of loess and paleosols at various exposures in this area region have used lithologic and pedogenic criteria and MS variations as the primary bases for correlation. Marković et al. (2003; 2004a; 2004b; 2006) designated the Vojvodinian loess-paleosol chronostratigraphic units as the labels that follow the Chinese loess stratigraphic system (e.g. Liu et al., 1985; Kukla, 1987; Kukla and An, 1989).

According to the current chronostratigraphic model (Marković et al. 2004b, 2005) of the Late Pleistocene loess-paleosol sequences in the Vojvodina region, the last interglacial – early glacial paleosol S1 correlates with MIS 5. This paleosol is overlain by composite loess unit L1, correlated with MIS 4-2. The structure of the last glacial loess L1 varies in different loess localities across the Vojvodina region (Marković et al., 2004a, 2005a, 2006). The lower sub-horizon of the upper loess, L1L2, accumulated above paleosol S1. The middle pedon is represented in the area by a weakly developed soil complex L1S1. The youngest loess layer L1L1 accumulated during the upper pedon period.

Loess-paleosol sequences distinguished at the Sussek exposure are presented in fig. 3. Table 1 shows the morphological description of the loess and paleosol units.

The oldest pale yellow (5Y 7/3, 5/4) loess unit L1 is uncovered only at lowest 10 cm of the profile. Many carbonate concretions (3-10 cm diameter) and humus infillings appear near the contact of the St soil complex and the underlying L1 loess. The reddish-brown fossil soil St is 135 cm thick. The lower darker transitional A(B) horizon (10YR 5/4 4/4) with many carbonate concretions 1-3 cm in diameter, and an upper weak incipient pedolohorizon L1S1S1 (10YR 5/4 4/4) with the granular structure and small soft carbonate spots.

Loess layer L1L1 is 195 cm thick, very porous and in some parts intensively bioturbated. Many spherical, relatively soft carbonate nodules and humus infillations in old root channels are found at the contact zone with the modern soil V-S0.

The Holocene soils developed on the loess plateau surface in the area surrounding the Sussek exposure are miceral and calcareous chernozem, and slightly melanized chernozem. At the top of the investigated section, the modern soil is a 55-cm thick slightly melanized chernozem. The lower Ck horizon contains many CaCO3 nodules of 2-5 cm in diameter and numerous krotovinas and root channels filled with humic material. A transitional AC horizon (10YR 5/1-5/3) is 15-cm thick, very porous silt loam with fine blocky structure. The A(B) horizon is 20 cm thick, reddish-

---

The superimposed paleopedocomplex horizon L1S1 is 140 cm thick and contains a lower chernozem-like pedological horizon L1S1S2 with carbonate pseudomycelia, loess inter-stratum L1S1L1 (10YR 6/3 4/2) with many carbonate concretions 1-3 cm in diameter, and an upper weak incipient pedolohorizon L1S1S1 (10YR 5/4 4/4) with the granular structure and small soft carbonate spots.

Loess layer L1L1 is 195 cm thick, very porous and in some parts intensively bioturbated. Many spherical, relatively soft carbonate nodules and humus infillations in old root channels are found at the contact zone with the modern soil V-S0.

---

### Table 1 Morphological description of loess-paleosol sequences at the Sussek exposure

<table>
<thead>
<tr>
<th>Unit / subunit</th>
<th>Thickness (cm)</th>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>S0</td>
<td>55</td>
<td>0-55</td>
<td>Modern soil, 55-cm thick chernozem slightly melanized with weak blocky structure</td>
</tr>
<tr>
<td>L1</td>
<td>560</td>
<td>55-615</td>
<td>Very porous, pale yellow loess (10YR 7/4-5/3) with many humic infiltrations and carbonate concretions (ø 2-5 cm), intensively bioturbated.</td>
</tr>
<tr>
<td>L1S1L1</td>
<td>195</td>
<td>55-245</td>
<td>L1S1S1: the upper lighter (10YR 5/4-4/4) part is a weakly developed incipient (A) horizon with granular structure. L1S1L1: thin loess layer (10YR 6/3 4/2) with carbonate concretions (ø 1-3 cm). L1S1S2: the lower darker (10YR 6/3-4/2) mollic Chernozem-like A horizon with carbonate pseudomycelia.</td>
</tr>
<tr>
<td>L1S1</td>
<td>160</td>
<td>245-385</td>
<td>Yellowish brown (10YR 5/3, 4/3) porous, loosely cemented calcareous loess only upper 20 cm, bellow are strongly developed hydromorphic features (manganese, iron coatings, iron oxide patches)</td>
</tr>
<tr>
<td>L1S1S1</td>
<td>230</td>
<td>385-615</td>
<td>Thick transitional Cambisol-Chernozem pedocomplex: the lower transitional AB horizon has weak platy structure (10YR 5/2-3); the upper mollic Ah horizon with brighter colour (10YR 6/2-4) and carbonate pseudomycelia.</td>
</tr>
<tr>
<td>S1</td>
<td>135</td>
<td>615-740</td>
<td>Porous yellow (5YR 7/3, 5/4) loess with many humus infiltrations and carbonate concretions (ø 3-7 cm).</td>
</tr>
<tr>
<td>L2</td>
<td>10</td>
<td>740-765</td>
<td></td>
</tr>
</tbody>
</table>
subunit L1L2: ~ 45 x 10⁻⁶m³kg⁻¹. The L1S1S1 shows higher, also stable values (range of 41.6 x 10⁻⁶m³kg⁻¹ to 56.3 x 10⁻⁶m³kg⁻¹). MS of the youngest loess layer L1L1 is the lowest with a minimal value of 19.5 x 10⁻⁶m³kg⁻¹. The Holocene soil S0 shows an increasing trend from ~ 50 x 10⁻⁶m³kg⁻¹ units at the base to more than ~ 65 x 10⁻⁶m³kg⁻¹ in its middle part (fig. 4).

Grain-size (GS) Distribution and Carbonate content (CC)

Measured variations in GS distribution also coincide well with the pedostratigraphy of the Susek loess-paleosol sequence. Generally, the pedogenic horizons have a lower proportion of coarse material than the loess layers (e.g. Vandenberghe and Nugteren, 2001). Variability in clay content (< 2μm) mostly parallels the MS record. The highest value of clay content is observed in lower part of paleosol S1 (more than 30 %) in contrast to relatively low values detected in loess layer L1L1 (less than 10 %). Loess horizon L1L2 with strongly developed hydromorphic features shows stable values of clay content from 20 to 25 %. Within the section, the middle part shows the highest variability of clay content: the lower part of loess L1L1 (9-27 %) and fossil soil L1S1S2 (11-32 %). Contribution of the clay fraction continuously increases from the middle part of loess L1L1 (about 20 %) to the recent soil S0 (more than 25 %) (fig. 4).

The coarse material (>20 μm) content shows many abrupt small amplitude fluctuations. High values of >20 μm content are also associated with the several peaks of coarse sand (>200 μm) deposition indicating periods associated with the dynamic environments typified by strong winds and cold climatic conditions (fig. 4).

Higher values of CC are detected in the upper part of profile: the recent soil S0 contains 15 to 25 %, the upper part of the loess unit L1L1 has higher values (33-20 %) than the lower part (20-10 %), and upper part of paleosol L1S1 has more than 5 %. However, very low values of carbonate (less than 5 %) are registered in the middle and lower parts of the section (fig. 4). This is a consequence of post-depositional gleification in the loess layer L1L2 and strong pedogenesis of the paleosol S1.

Malacology

Shells of 13,444 individuals of land snails representing 31 species (29 genera) were found in 75 samples taken from the Susek section. Generally, the terrestrial malacological assemblages reflect humid and relatively cold environmental conditions with mosaic vegetation.

No land snails were recovered from the loess horizon L1L2 and from paleosol S1. Because of intensive gleification in loess layer L1L2 and poor preservation and leaching in the fossil soil S1, these units were not valuable for malacological investigations.

The snail assemblages of the youngest paleosol L1S1S1 and loess L1L1 provided different environmental conditions. Domination of woodland environmental conditions represented by the presence of the forest snails such as Agagopinella ressmannii, Orcula dolium and Clausiliidae detected in the paleosol L1S1S1 and in upper part of loess L1L1 indicates relative humid climatic conditions. However, in the lower part of loess unit L1L1 dominance of steppe environmental conditions characterized by the presence of aridity-tolerant snails such as Pupilla triplicata, P. muscorum, Chondrusa tridens, and Granaria frumentum is observed.

During the last glacial period we note the presence of several relatively cold episodes. The coldest one was during the accumulation of loess layer L1L1 indicated by the presence of the cryptophilous species Columella collumella and Vallonia tenu...

![Fig. 3](image-url) Description and stratigraphy of the Susek loess-paleosol sequence.

1. Loess;
2. Embryonic pedogenetic layer (incipient soil horizon);
3. Chernozem-like A horizon;
4. Ah horizon;
5. Transitional AB horizon;
6. Krotovinas;
7. Hydromorphic features;
8. Carbonate concretions;
9. Humus infiltrations;
10. Position of samples for sedimentological and rock magnetic measurements;

brown (10YR 6/3, 7.5YR 4/2), and porous with blocky structure. The Ah horizon (10YR 6/3-4/4) is a 20 cm thick silt loam with the granular structure and carbonate pseudomycelia in the lower part.

Low-Field Magnetic Susceptibility (MS)

According to our investigations, the variations in the low-field MS are related to the pedostratigraphy in the Susek section. MS values observed in soils S0 (average 62.3 x 10⁻⁶m³kg⁻¹), L1S1 (average 50.1 x 10⁻⁶m³kg⁻¹), and S1 (average 105.7 x 10⁻⁶m³kg⁻¹) are higher than in the loess units L1L1 (average 28.2 x 10⁻⁶m³kg⁻¹), L1L2 (average 45.6 x 10⁻⁶m³kg⁻¹), and L2 (average 47.4 x 10⁻⁶m³kg⁻¹) (figure 5). This type of MS pattern that reflects magnetic enhancement via pedogenesis is similar to the one in Chinese and Central Asian loess deposits (e.g. Heller and Liu, 1986; Maher and Thomson, 1999).

The basal penultimate glacial loess unit L2 shows relative high MS values: close to 50 x 10⁻⁶m³kg⁻¹. MS values in the middle part of the paleosol S1 increase to 140.4 x 10⁻⁶m³kg⁻¹ where it is the highest in the whole column. Above that MS values continuously decrease to relatively low values in loess.
The stratigraphic pattern of the Susek site is generally similar to other Late Pleistocene loess-paleosol sequences in Europe (e.g. Kukla, 1975; Vandenberghe et al., 1998; Rousseau et al., 1998, 2001; Antoine et al., 1999, 2001; Horvath, 2001). However, all analysed proxies at Susek and other loess exposures in the Vojvodina region (Gaudenyi et al., 2003; Marković et al., 2004b, 2005, 2006) indicate that the Late Pleistocene palaeoclimatic and palaeoenvironmental evolution was relatively uniform compared to equivalent central, western and eastern European loess records (e.g. Kukla, 1975; Vandenberghe et al., 1998; Rousseau et al., 1998, 2001; Antoine et al., 1999, 2001; Horvath, 2001).

The multi-proxy data set and identified pedostratigraphy in the Susek sequence indicate the following climatic and environmental changes. Pedological interpretation of pedocomplex S1 shows a palaeoenvironmental succession from interglacial forest-like to steppe conditions during the early peniglacial. Intensive post-depositional hydromorphic conditions disturbed the primary climatic record of loess unit L1L1. Similar hydromorphic features are not observed in any other investigated Late Pleistocene loess sequence in the Vojvodina region (Marković, et al. 2004a, 2004b, 2005, 2006). Detailed evidence of middle and upper peniglacial environmental changes is preserved in the pedocomplex LiS1 and loess LiL1. At the Susek loess sequence, the first phase of climatic improvement of the middle peniglacial is indicated by the pedogenesis of chernozem-like fossil soil LiS1S1. During deposition of the loess sub-unit LiS1L1, the mean rate of dust deposition was relatively high, and the intensity of pedogenic activity was restricted. The weakly developed paleosol LiS1S1 provides mostly dry steppe environment.

Data from the youngest loess layer LiL1 indicates the coldest conditions during the last interglacial-glacial cycle. The rich upper peniglacial snail fauna witnesses humid forest-steppe-like environmental conditions. The lower part of loess LiL1 represents a steppe-like environment. By contrast, the upper part of this loess unit shows an increase of woodland elements and coldest climatic conditions. The increase of cryophilous and cold-resistant snails in the upper part of loess LiL1 agrees with other interpretations of the last glacial maximum recorded in the European loess sediments (e.g.; Antoine et al., 1999; Ložek, 2001; Sümegi and Kroloff, 2002). Finally, the Holocene soil So indicates the return to an interglacial climatic mode.

Generally, the snail assemblage of Susek’s loess sequence is similar to other investigated sections on the northern slope of Fruska Gora mountain (Marković et al., 2004b, 2005). All of these mollusc records show more humid and relatively cooler environments than in other investigated sites in the Vojvodina region (Marković et al., 2000, 2006; Gaudenyi et al., 2003). Therefore, we think that it was perhaps a refuge, i.e. one of those rare places in the south-eastern part of the Carpathian Basin where the Palaeopreillyrian snail assemblage (e.g. Aegopinella ressmanni, Ena Montan, Macrogaster ventricosa and Trichia edentula) survived (Sümegi and Kroloff, 2002). Palaeoclimatic gradients were similar as under actual climatic conditions. Present mean annual rainfall is approximately 10% higher on the north-western slopes of Fruska Gora mountain than the average precipitation in the other parts of the Vojvodina region.

Conclusions

The multidisciplinary study of the loess-paleosol sequence reveals a detailed Late Pleistocene record at the Susek section. The soil complex S1 shows a stable pedo-sedimentary evolution similar to other investigated loess sites in the region. Intensive post-depositional processes disturbed the primary environmental record of loess layer L1L2. By contrast, paleosol LiS1 and loess L1L1 preserved high-resolution evidence of palaeoclimatic changes. These results have established the importance of this site as a record of the last interglacial-glacial palaeoclimatic and palaeoenvironmental conditions in the southeastern part of the Carpathian Basin.

The identified mollusk record provides several rhythmic changes of the environmental conditions characterized by alternating domination of steppe and woodland elements. These fossil snail assemblages indicate more humid environmental conditions in this area than in other parts of the Vojvodina region (Northern Serbia) during the last glacial. Because of that the northern slope of the Fruska Gora mountain was a biogeographical “island” during the last two glacial; i.e. a refuge where the Palaeopreillyrian snail assemblage survived.

Acknowledgements

This work is supported by the Ministry of science and nature protection, Republic of Serbia (grant 146009). This is part of Marković’s research project supported by a Humboldt fellowship. Funding for malacological analysis was provided by the Inter-national Visegrad Fund (grant S–084–2005–IVF).

References


Marković S.B. 2000. Paleogeography of Vojvodina region during the Quater-
An Introduction to the Late Pleistocene Loess-paleosol Sequence at Susek (Vojvodina, Serbia)