JOURNAL OF QUATERNARY SCIENCE (2008) 23(1) 73–84

Published online 13 August 2007 in Wiley InterScience
(www.interscience.wiley.com) DOI: 10.1002/jqs.1124

Late Pleistocene loess-palaeosol sequences in the Vojvodina region, north Serbia

SLOBODAN B. MARKOVIĆ,[1]* MARK P. BOKHORST,[2] JEF VANDENBERGHE,[2] WILLIAM D. McCOY,[3] ERIC A. OCHES,[4] URLICH HAMBACH,[5] TIVADAR GAUDENYI,[1] MLADJEN JOVANOVIĆ,[1] LUDWIG ZÖLLER,[5] THOMAS STEVENS[6] and BJÖRN MACHALETT[5,7]

[1] Chair of Physical Geography, University of Novi Sad, Novi Sad, Serbia
[2] Faculty of Earth and Life Sciences, Free University, Amsterdam, The Netherlands
[3] Department of Geosciences, University of Massachusetts, Amherst, MA, USA
[4] Department of Geology, University of South Florida, Tampa, FL, USA
[5] Chair of Geomorphology, University of Bayreuth, Bayreuth, Germany
[6] Oxford Luminescence Research Group, School of Geography and the Environment, University of Oxford, Oxford, UK
[7] Leibniz Institute for Applied Geosciences (GGA-Institut), S3: Geochronology and Isotope Hydrology, Hannover, Germany

Marković, S. B., Bokhorst, M. P., Vandenberghe, J., McCoy, W. D., Oches, E. A., Hambach, U., Gaudenyi, T., Jovanović, M., Zöller, L., Stevens, T. and Machalett, B. 2007. Late Pleistocene loess-palaeosol sequences in the Vojvodina region, north Serbia. *J. Quaternary Sci.*, **Vol. 23** pp. 73–84. ISSN 0267-8179.

Received 8 September 2006; Revised 30 January 2007; Accepted 8 February 2007

ABSTRACT: Late Pleistocene loess-palaeosol sequences are widespread in the Vojvodina region, with thicknesses reaching a maximum of about 20 m. Our investigations include more than 40 of these loess sections. Geochronology of the last glacial loess-palaeosol sequences, based on luminescence dating and amino acid racemisation, provides correlations between Upper Pleistocene loess-palaeosol sediments in Vojvodina and comparable deposits at other European localities. Sedimentary logs of magnetic susceptibility, grain-size measurements and carbonate content, combined with malacological evidence, indicate two main relatively cold and arid phases during the last glacial period, related to intensive accumulation of loess units L1L1 and L1L2, as well as many brief episodes of dry and windy climatic conditions, suggesting a possible relationship with cold events recorded in the North Atlantic region. Generally, late Pleistocene climate in the region was dry and relatively warm, compared with glacial period sites in central Europe, and was characterised by sharp differences between glacial and interglacial modes.

New data and interpretations presented in this study emphasise the significance of loess-palaeosol sequences in Vojvodina for the reconstruction of the temporal and spatial evolution of late Pleistocene palaeoclimate in this part of Europe. Copyright © 2007 John Wiley & Sons, Ltd.

Journal of Quaternary Science

KEYWORDS: late Pleistocene; loess; palaeoclimate; Vojvodina; Serbia.

Introduction

Vojvodina is a region in northern Serbia, located in the southeastern part of the Carpathian (Pannonian) Basin, and encompassing the confluence area of the Danube, Sava and Tisa rivers (Fig. 1). More than 60% of this lowland area is covered with loess and loess-like sediments. Aeolian silt accumulation in Vojvodina began in the late early Pleistocene (Marković *et al.*, 2003) and culminated during the late Pleistocene. As a result of high accumulation rates and widespread occurrence, the late Pleistocene loess-palaeosol sequences preserve a record of late Pleistocene climate and environmental changes (Marković *et al.*, 2000, 2004b, 2005, 2006, in press; Bokhorst *et al.*, submitted).

In this paper we discuss analytical data from more than 40 loess sections, all of which are located on loess plateaus within Vojvodina (Fig. 1). Special emphasis is given to 12 sites: Susek, Petrovaradin, Mišeluk, Ruma, Irig, Batajnica, Stari Slankamen, Mošorin, Titel, Bačka Topola, Crvenka and Orlovat (Fig. 1). The aim of this study is to propose new ways of investigating late Pleistocene loess-palaeosol sequences in the Vojvodina region and to summarise palaeoclimatic inferences derived from these diverse exposures, as well as to compare climatic conditions in Vojvodina with climatic changes recorded in other parts of the Eurasian loess belt.

Loess distribution and methods

The complex relief of the Vojvodina region determined conditions of loessic silt deposition as well as post-depositional processes. In general, syngenetic or typical loess varieties are

* Correspondence to: S. B. Marković, Chair of Physical Geography, University of Novi Sad, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia.
E-mail: zbir@im.ns.ac.yu

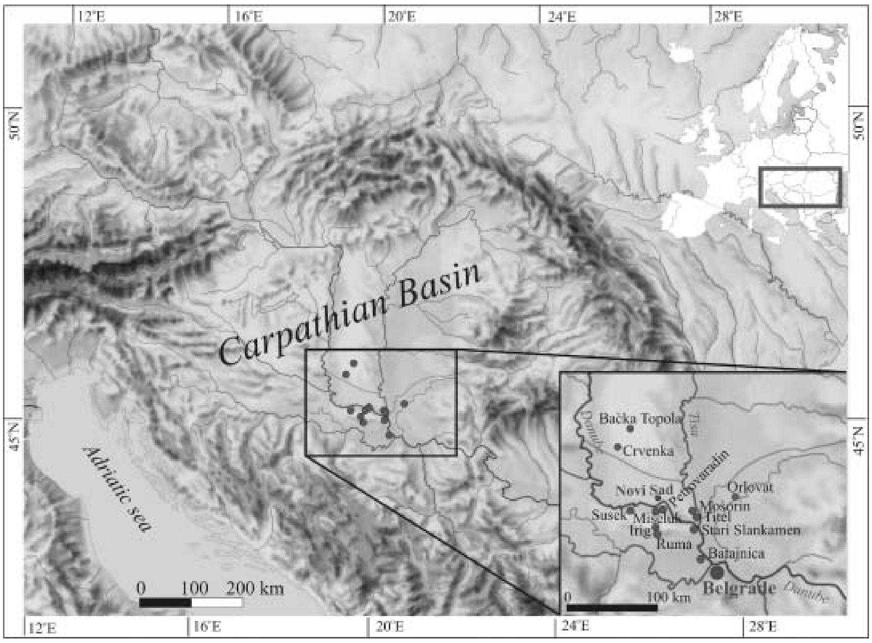

Figure 1 Morphological map of the Carpathian Basin and Vojvodina province showing the geographic positions of significant loess exposures

preserved in the loess plateaus, while loess-derived sediments are deposited in river valleys, on slopes and in sub-aquatic settings (e.g. Pecsi, 1990).

Typical loess is found on six discontinuous plateau uplands between alluvial plains of the Danube, Tisa, Sava and Tamiš rivers. In this study we investigated only the typical loess formed on loess plateaus. These are the most representative loess sequences of regional palaeoenvironments and preserve mostly undistributed palaeoclimatic records.

The last glacial-interglacial loess-palaeosol sequence reaches a maximum thickness of about 20 m at the Titel plateau and the southeastern part of the Srem loess plateau. Most of our investigated sections representing the last glacial-interglacial cycle are 7 to 12.5 m thick. The thinnest late Pleistocene sequences are found on the slopes of the Fruška Gora and Vršačke Planine mountains. Given the potential for erosion and redeposition of sediment, these slope profiles are not represented in this investigation.

Isopachs of the last glacial loess L1 generally indicate two possible predominant dust deposition directions: northerly and southeasterly (Fig. 2). However, differences in the thickness of loess L1 also indicate that loess thickness depends on local

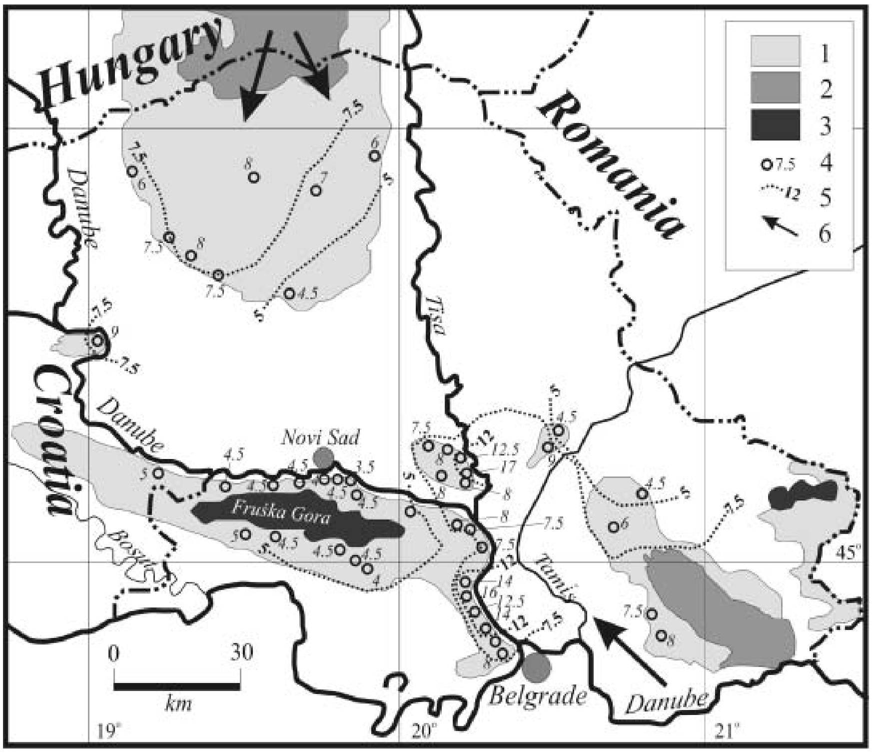

Figure 2 Map of loess distribution in Vojvodina and adjacent regions showing variations in thickness of the last glacial loess L1. 1, Loess plateau; 2, sandy area; 3, mountain; 4, observed exposures; 5, isopachs; 6, predominant direction of dust transport

DOI: 10.1002/jqs

relief. These observations support the previous interpretation that the main dust source for loess formation in the Carpathian Basin is sedimentary material from distant and diverse sources, delivered to and (re)transported by the Danube River system (Smalley and Leach, 1978).

Our multidisciplinary approach consists of detailed investigations of litho- and pedostratigraphy, low-field magnetic susceptibility (MS), grain size (GS) and carbonate content (CC) variations, amino acid racemisation (AAR) measurements in fossil mollusc shells and fossil mollusc assemblages. The sampling interval for magnetic and sedimentological analyses was 5 cm at each exposure. Samples for malacological investigations were collected at 25 cm (Irig, Ruma, Petrovaradin and Mišeluk) or 10 cm (Susek) regular intervals.

The MS variations were measured in the field (Irig, Ruma, Petrovaradin, Crvenka and Mišeluk) using a portable Bartington MS2 susceptibility meter. At each measured level, 10 independent readings were taken and averaged. Bulk sediment was collected for laboratory measurements of MS from profiles at Susek, Batajnica, Bačka Topola, Mošorin and Titel, and measured with a KLY2- and KLY3-kappabridge (AGICO, Brno, CZ), respectively. For inter-profile correlation and for comparison the MS values for each section were normalised to their mean value.

The GS distribution was measured by sieving and pipetting (four fractions: <2, 2–20, 20–200, $>200\,\mu$m), except for bulk samples from two sections, Mošorin and Titel, which were measured using a FRITSCH A22 laser GS analyser. Details of sample preparation and analytical methodology of laser GS analysis and comparison between results determined by laser diffraction size analysis and combined sieve and pipette method are presented in Konert and Vandenberghe (1997). The CC content was measured by gas volumetric analysis.

Gastropod shells were collected from four loess exposures (Irig, Ruma, Petrovaradin and Mišeluk) for AAR analysis in order to correlate independently the stratigraphy with loess-palaeosol units elsewhere in Europe. Samples were prepared and analysed by reverse-phase liquid chromatography following the methods of Kaufman and Manley (1998).

For malacological analyses, 10 kg bulk sediment samples were collected and sieved through 0.7 mm mesh. After fossil gastropod shells were identified, palaeoenvironmental classification and interpretation were done based on the methods of Ložek (1964), but also extended with some local variants defined by Krolopp and Sümegi (1995) and Sümegi and Krolopp (2002).

Results

Litho- and pedostratigraphy

Our stratigraphic model, based on investigations at various loess exposures in Vojvodina, uses lithologic and pedogenic criteria, MS variations, luminescence dating and amino acid geochronology as the primary bases for correlation (Marković *et al.*, 2004a,b, 2005, 2006). We designate the Vojvodinian L (loess) and S (palaeosol) stratigraphic units, numbered in order of increasing age. In previous publications, we used the prefix 'SL', referring to the Stari Slankamen site as a standard section for the region in our stratigraphic labelling scheme (Marković *et al.*, 2003, 2004a, 2006). However, to avoid confusion in our loess and palaeosol labelling system, we now use the prefix 'V' to refer to the standard Pleistocene loess-palaeosol stratigraphy in Vojvodina. According to our current chronostratigraphic interpretation (Marković *et al.*, 2004a,b, 2005, 2006) the last interglacial-early glacial palaeosol S1 (equivalent to fossil soil F2 of Bronger's nomenclature) correlates with Marine Oxygen Isotope Stage (MIS) 5 (Table 1). This palaeosol is overlain by a composite loess unit L1, correlated with MIS 4-2. In some profiles L1 is subdivided by weak interstadial palaeosols (Marković, 2000, 2001; Marković *et al.*, 2004b, 2005, 2006).

Pedostratigraphic descriptions of the main loess sections in the Vojvodina are presented in Fig. 3. Generally, the late Pleistocene pedostratigraphy is similar throughout the region, although the structure of L1 varies in some sections. The polygenetic palaeosol S1 is well expressed and composed of several welded pedological horizons, which represent a gradual palaeoclimatic transition from the last interglacial to the early pleniglacial phase. Pedocomplex S1 contains a well expressed basal B, AB or Ah horizon, overlain by a middle lighter Ah horizon and an uppermost, weakly developed A horizon characterised by many crotovinas (Marković *et al.*, 2004a,b, 2005, in press). The thickness of palaeosol S1 varies from 1 to 3.5 m at different exposures. The S1 pedocomplex in Vojvodina proceeded without interruptions represented by loess marker horizons, which are thin, fine-grained, light-coloured, homogeneous silt beds that are reported in last interglacial palaeosols elsewhere in central, western and eastern Europe (Kukla, 1975; Kukla and Cilek, 1996; Rousseau *et al.*, 1998, 2001).

The lower sub-horizon of the upper loess, L1L2, accumulated above palaeosol S1. This sandy loess layer is porous, loosely cemented and in some parts finely laminated with thin, fine sand beds.

Table 1 Chronostratigraphic models of the loess-palaeosol sequences in Vojvodina, Serbia

Bronger (1976)		Singhvi *et al.* (1989)	Bronger (2003)	Our model	
Palaeosol name	Alpine stratigraphy	MIS	MIS	Stratigraphic unit	MIS
				V L1L1	2
F1	Würm fossil soils			V L1S1	3
				V L1L2	4
F2		5a	5a	V S1	5
				V L2	6
F3		5e	5e	V S2	7
				V L3	8
F4			7	V S3	9
				V L4	10
F5	Riss-Würm soil		9 or 11	V S4	11

DOI: 10.1002/jqs

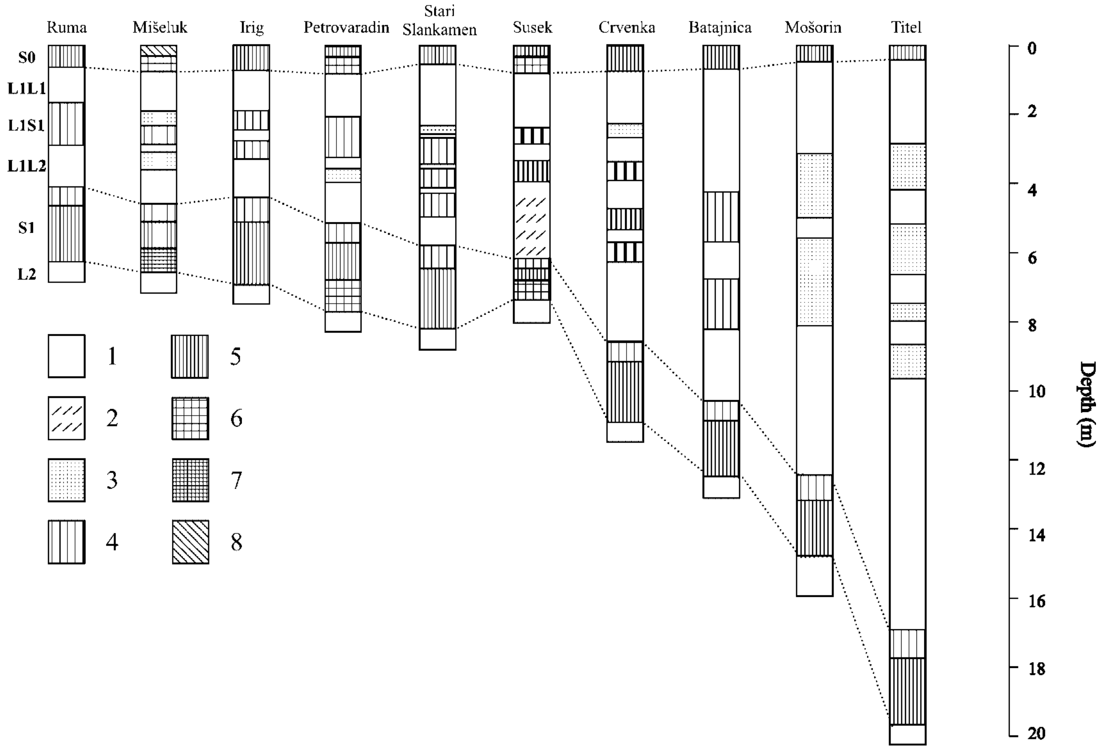

Figure 3 Lithostratigraphy of the main upper Pleistocene loess-palaeosol sections. 1, Loess; 2, hydromorphic features; 3, embryonic pedogenic layer; 4, a horizon; 5, Ah horizon; 6, transitional AB horizon; 7, B horizon; 8, horizon disturbed by human activity

The middle pleniglacial interval is represented in the region by a weakly developed soil complex L1S1, which appears either as a single, complete pedohorizon (Ruma site), or as double (Batajnica, Irig, Mišeluk, Susek and Petrovaradin) or multiple (Stari Slankamen, Titel and Crvenka) palaeosols.

The uppermost loess layer L1L1 accumulated during the late pleniglacial period (Table 1, Fig. 3). Loess layer L1L1 is very porous and in some parts intensively bioturbated. Many spherical, relatively soft carbonate nodules and humus infiltrations in old root channels are found at the contact zone with the modern soil S0. No cryogenic features have been observed in the last glacial loess layers of the Vojvodina region.

Amino-acid geochronology

AAR geochronology using fossil gastropod shells has been successfully applied to the stratigraphic correlation of loess-palaeosol sequences in different regions of the world (Oches and McCoy, 2001). Results of AAR geochronology obtained from different sections in Vojvodina provide the basis for our proposed chronostratigraphic interpretations. Nine different genera of terrestrial gastropod shells have been analysed, including samples from six levels within the loess sequences at four sites: Mišeluk, Petrovaradin, Irig and Ruma. Sampled genera include *Clausilia, Chondrula, Granaria, Helicopsis, Ena, Pupilla, Succinea, Trichia* and *Vallonia*. Measurements of alloisoleucine/isoleucine in the total acid hydrolysate (A/I – HYD) of representative samples are shown in Fig. 4. These data show that the method can clearly distinguish between loess units of the last two glacial cycles. The HYD A/I values from shells in the last glacial loess L1 (above soil S1) indicate small differences between samples above, within and below interstadial palaeosol L1S1. Our experience has shown that this can only be possible if the soil does not represent an interglacial period. A warm interglacial period would induce much more epimerisation, as is demonstrated by the significantly higher HYD A/I ratios in shells from penultimate loess L2 below the last interglacial palaeosol S1.

According to the AAR-derived chronostratigraphic model, loess and palaeosol units L1 and S1, respectively, formed during glacial cycle B (Kukla, 1975), corresponding to MIS 2, 3, 4 and 5. The L2 loess horizon was deposited during the later part of glacial cycle C and MIS 6. Shells of the terrestrial gastropod genera *Pupilla* and *Trichia* are the most abundant and offer the most direct aminostratigraphic comparison with data from loess units elsewhere in Europe (Zöller *et al.*, 1994; Oches and McCoy, 1995a,b, 2001; Oches *et al.*, 2000) (Fig. 5).

Current mean annual temperatures in Vojvodina ($\sim$11°C) region are higher than at other sampled European localities (8–10°C). Racemisation data suggest that effective palaeotemperatures are also higher in Serbia than at sites further to the north.

MS

Measurements of MS have played a central role in both chronostratigraphic and palaeoclimatic aspects of loess research. This is because climatic information is encoded into the stratigraphic variations in magnetic properties (Heller and Evans, 1995; Evans and Heller, 2001), which allows us to make palaeoclimatic inferences and correlate loess sequences regionally based on MS profiles.

Figure 6 shows the relationship between low-field MS records of ten investigated loess sites in Vojvodina and their correlation with the SPECMAP oxygen-isotope stratigraphy (Martinson *et al.*, 1987). Variations in MS correlate closely with the pedostratigraphy of the analysed exposures. Generally, all analysed MS records provide a similar pattern of variation, and the main MS peaks can be easily correlated among the sections. High MS values observed in palaeosol S1 and recent soil S0 are,

DOI: 10.1002/jqs

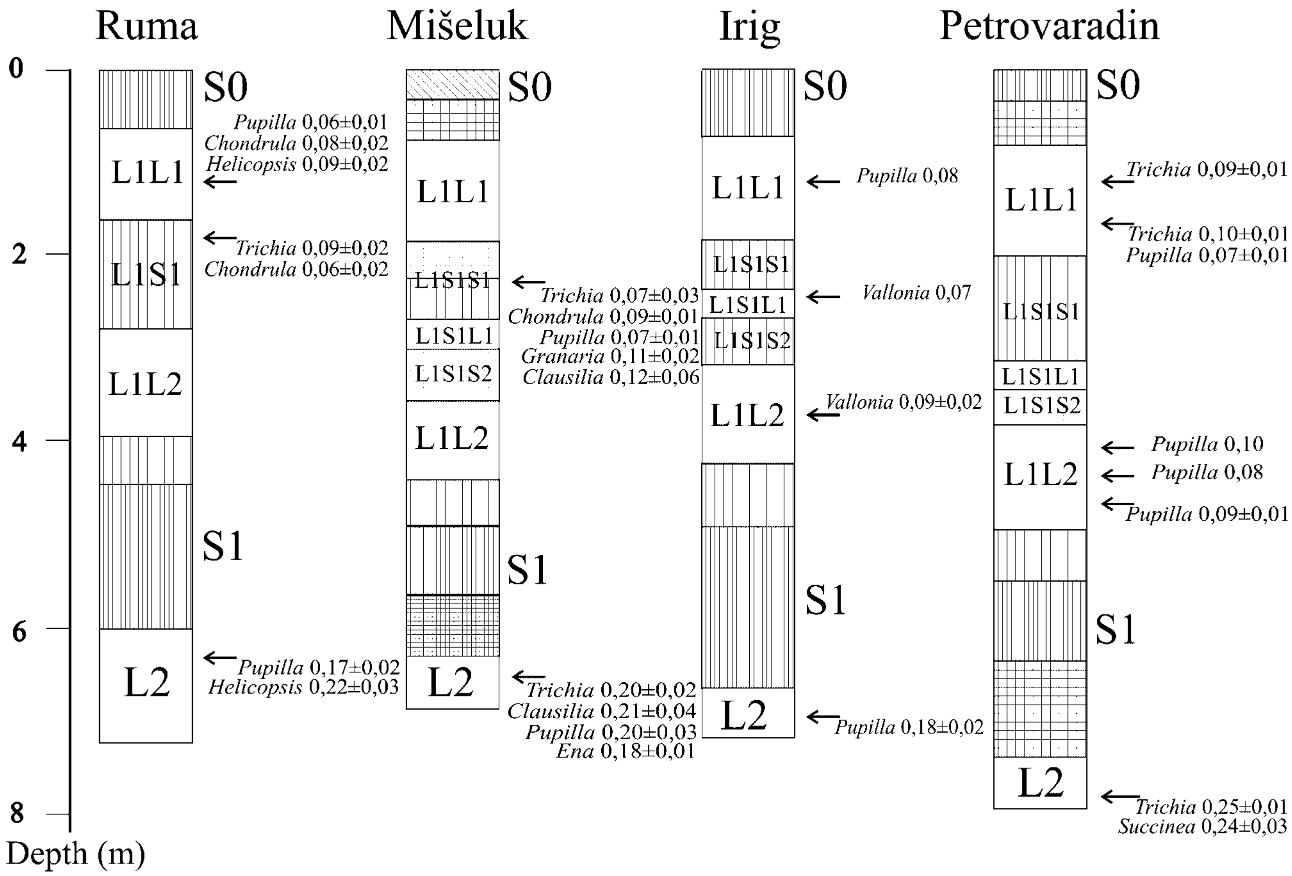

Figure 4 Position of samples for amino acid analyses at investigated sites, as well as HYD A/I values for selected gastropod genera. Pedostratigraphy is the same as shown in Figure 3

on average, more than twice as high as in loess unit L1. The unexpectedly high MS values recorded in recent soils S0 at Batajnica section are caused by influence of an intensive Neolithic occupation of this site. The lowest MS values were measured in loess layers L1L1 and L1L2. This type of MS pattern reflects magnetic enhancement in soils due to pedogenesis and is similar to that found in Chinese and Central Asian loess deposits (e.g. Heller and Liu, 1986; Maher and Thompson, 1999).

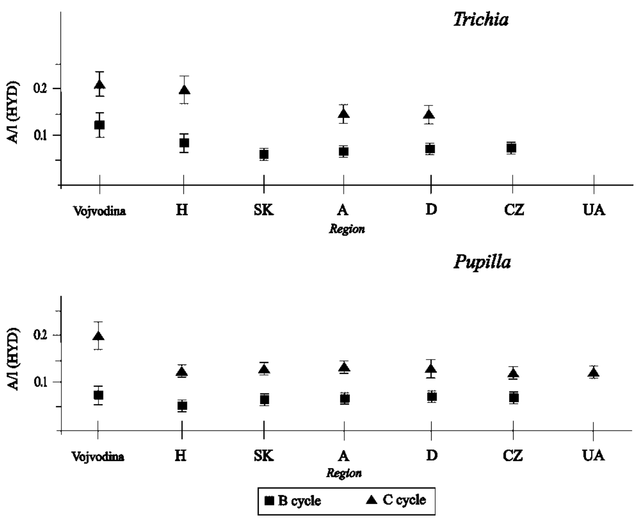

Figure 5 Aminostratigraphy of L1 and L2 loess in Vojvodina compared with other European localities for glacial cycles B (MIS 5-2) and C (MIS 6), for the terrestrial land snail genera *Trichia* and *Pupilla*. H = Hungary, SK = Slovakia, A = Austria, D = Germany; CZ = Czech Republic and UA = Ukraine (Oches and McCoy, 2001). The Vojvodina A/I data have been measured using reverse-phase liquid chromatography (RPLC), as opposed to cation-exchange HPLC, which was used for the comparative data. Analysis of standards shows that the RPLC results are about 4% higher in A/I ratios than the HPLC results. These numbers have not been adjusted for that difference, but it would be imperceptible on this figure

GS distribution and CC

Measured variations in GS distribution also coincide well with the pedostratigraphy, MS and CC records of the investigated sections (Marković *et al.*, 2004b, 2005, 2006). Figure 7 presents this relationship based on data from the Crvenka loess-palaeosol sequence. Variability in clay content (<2 μm) recorded at investigated sections generally parallels the MS record. Generally, the pedogenic horizons have a higher proportion of clay-sized material than the loess layers (e.g. Vandenberghe and Nugteren, 2001). High values of CC are measured in loess units, in contrast to very low values of carbonate in fossil soils. Variations of GS distribution show many abrupt, small amplitude changes possibly linked to wind transport intensity.

Late Pleistocene loess-palaeosol sequences in the Vojvodina region may preserve evidence of many abrupt, short-term climatic oscillations during glacial, as well as interglacial, intervals, as evidenced by coarse-fraction GS data (Fig. 8). The most detailed signature of the last glacial palaeoclimatic instability is preserved with high resolution in the loess exposures at Titel, Mošorin, Crvenka and Bačka Topola (Fig. 8). Within these profiles, high-frequency GS variability observed in individual sections is probably the result of local depositional factors, while trends traceable among profiles from across the study area suggest regional palaeoclimatic influence on sediment transport.

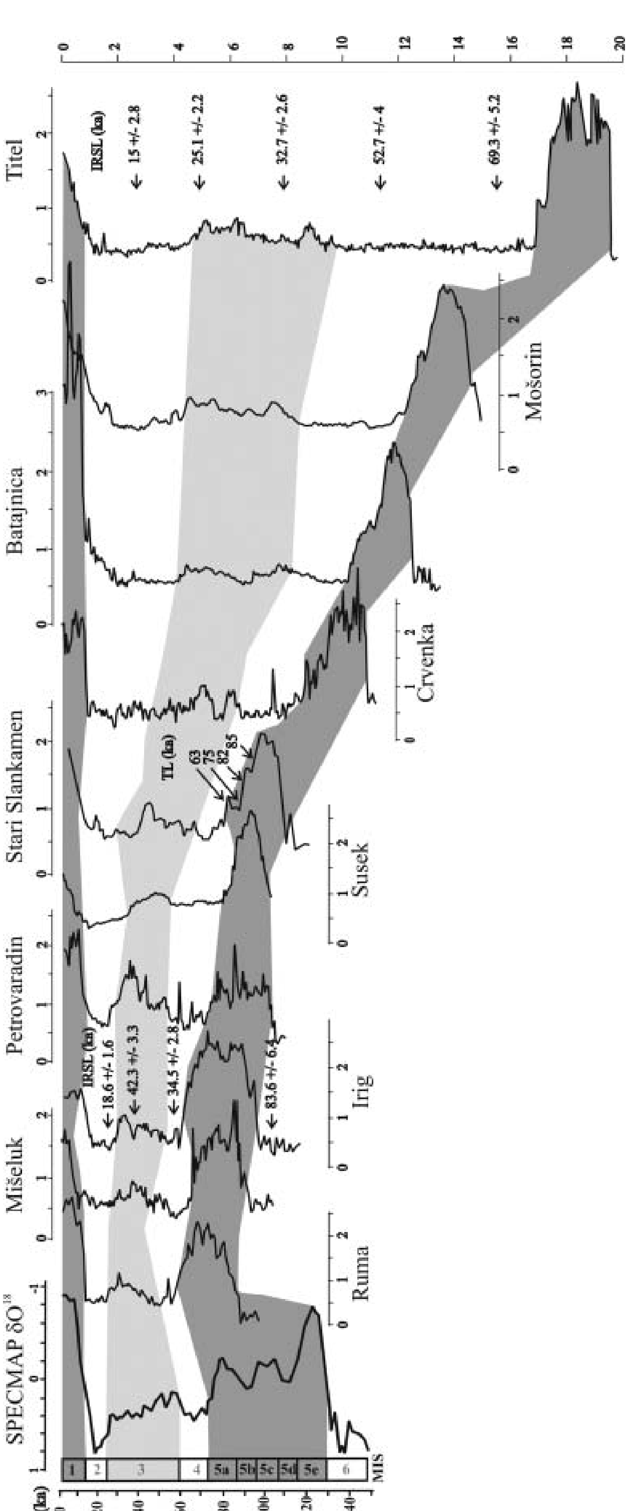

Figure 6 Relationship between low-field MS records of loess-palaeosol sequences in the Vojvodina region correlated with the SPECMAP palaeoclimatic model (Martinson *et al.*, 1987). Luminescence ages presented are from Singhvi *et al.* (1989) for Stari Slankamen, Marković *et al.* (in press) for Irig and Bokhorst *et al.* (submitted) for the Titel site. MS data of each section are normalised to their mean values

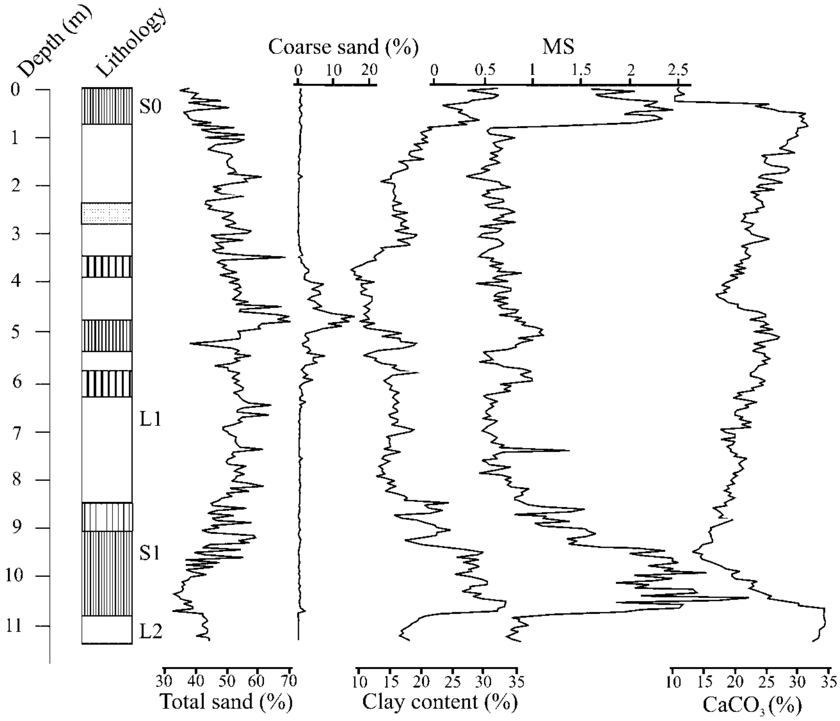

Figure 7 Depth plots of particle size fractions of coarse sand (>200 μm) and total sand (>20 μm), clay content (<2 μm) and normalised MS values to their mean value at the Crvenka exposure. Pedostratigraphy is the same as shown in Figure 3

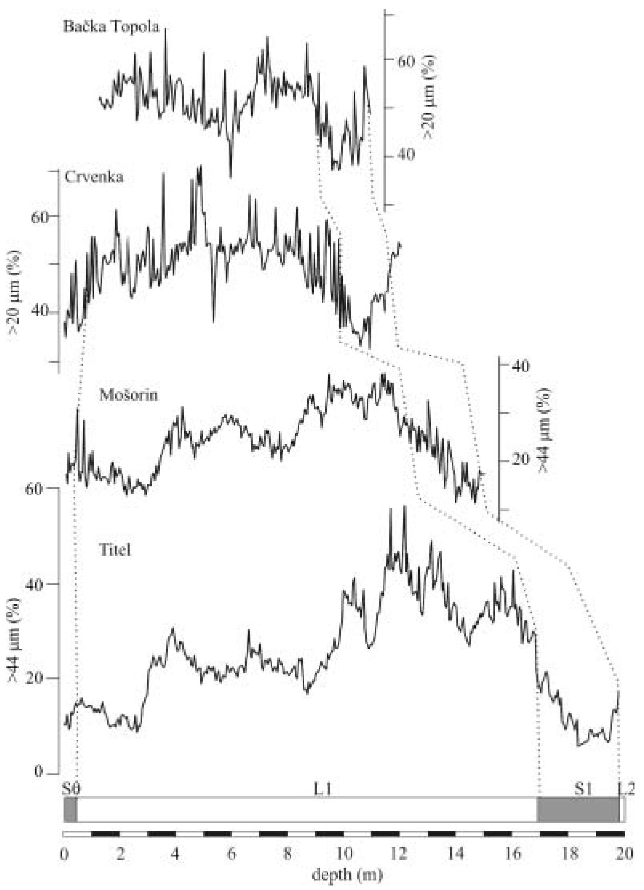

Figure 8 Grain size variations measured in loess profiles on the Bačka Loess Plateau (Bačka Topola and Crvenka) and Titel Loess Plateau (Titel and Mošorin) from the last interglacial to the Holocene expressed as the relative amount of coarser material. Boundaries corresponding with the main stratigraphic units are indicated by dashed lines

Malacology

About 25,000 individuals representing 36 species (27 genera) of molluscs were identified from more than 180 samples from the Vojvodina loess-palaeosol sequences. Generally, the late Pleistocene snail assemblages identified in Vojvodina suggest a drier and warmer climate in this region (Marković *et al.*, 2004a, 2005, 2006) than in other parts of the Carpathian Basin during the last glacial cycle (e.g. Krolopp and Sümegi, 1995; Willis *et al.*, 2000; Sümegi and Krolopp, 2002).

At Ruma land snails were identified only from the middle and upper parts of palaeosol S1, which has developed in a palaeodepression (Fig. 9) (Marković *et al.*, 2006). The interglacial species *Helix pomatia* was found in the middle part of palaeosol S1. In the upper part of this fossil soil the dominant snail assemblage is related to the *Chondrula tridens* fauna (Ložek, 1964, 2001). At other investigated sites, palaeosol S1 was not useful for malacological investigations, because of poor preservation and leaching in the more strongly developed fossil soil.

The fossil mollusc assemblage of loess horizon L1L2 is dominated by the aridity tolerant, open-vegetation and temperate species *Helicopsis striata*, *Pupilla muscorum*, *P. triplicata* and *Vallonia costata* (Fig. 9). This is a typical assemblage of a ‘warm’ loess steppe environment characterised by *H. striata* fauna (Ložek, 1964, 2001). Alternating presence of thermophilous species, including *C. tridens* and *Granaria frumentum*, and very rare cryophilous taxa, such as *V. tenuilabris*, reflect short-term palaeoclimatic oscillations during formation of L1L2 loess.

The snails identified in weakly developed palaeosol L1S1 are of an assemblage equivalent to the *C. tridens* fauna (Ložek, 1964) (Fig. 9). The poor snail fauna of intercalated loess inter-layers L1S1L1 and L1S1L2 indicates a dry and relatively cold environment.

The land snail assemblage of loess horizon L1L1 represents increasing hygrophilous and sub-hygrophilous elements, as well as a higher frequency of cold resistant species (Fig. 9). The presence of frigophilous species *Columella columella*,

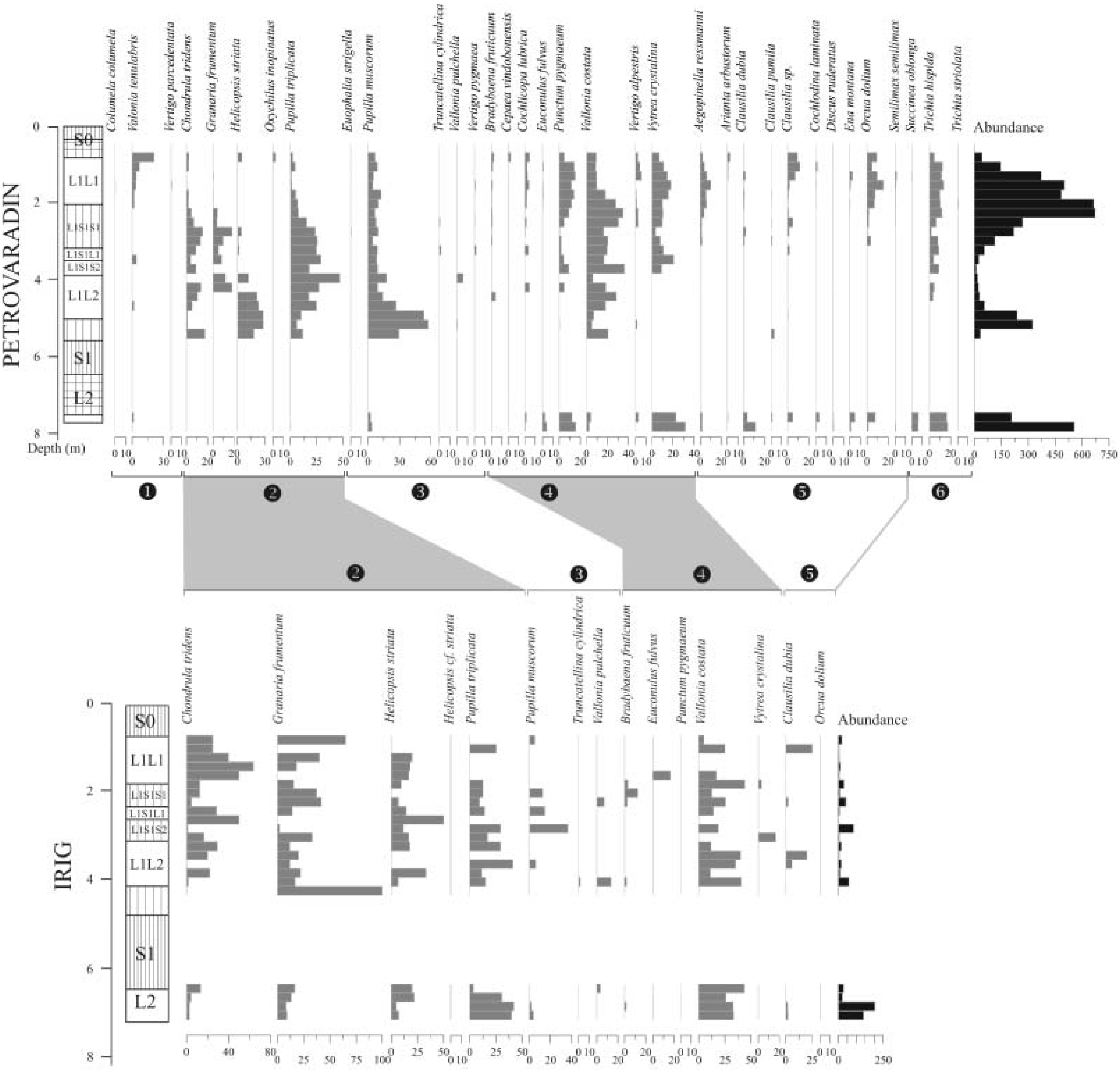

Figure 9 Relative abundance of identified mollusc species in the Petrovaradin (Marković *et al*., 2005) and Irig (Marković *et al*., in press) loess exposures. The species are clustered in ecological groups, as defined by Ložek (1964), but also extended with some local variations defined by Krolopp and Sümegi (1995) and Sümegi and Krolopp (2002): 1, Tundra-like; 2, dry steppe; 3, grassland; 4, transitional zone; 5, forest; 6, wetland. Pedostratigraphy is the same as shown in Figure 3

Vertigo parcedenta, V. tenuilabris and *Aegopinella ressmani* observed at some of the sites (Susek, Mišeluk and Petrovaradin) reflects the coldest conditions of the last glacial maximum (Fig. 9).

Fossil mollusc assemblages also provide information about local palaeoenvironmental conditions. The land snail assemblages of the loess belt around Fruška Gora show sharp environmental differences across short distances. Figure 9 compares malacological records at Petrovaradin and Irig sites illustrating differences between climatic and environmental evolution at the northern and southern margins of Fruška Gora. The mollusc association of the north side of Fruška Gora shows a more humid and relatively colder environment than at other sites in the Vojvodina region and indicates that the north slopes of Fruška Gora served an important role during the late Pleistocene. As a refugium, Fruška Gora served as one of the rare places in the southeastern part of the Carpathian Basin (Marković *et al*., 2004b) in which the *Palaeopreillyrian* gastropod assemblage survived (including, for example, *A. ressmanni, Ena montana* and *Euophailia strigella*) (Sümegi and Krolopp, 2002). In contrast, the mollusc fauna of the southern slope of the Fruska Gora range suggests that parts of it were a refugium for warm-loving and xerophilus mollusc taxa, where these elements could survive during the unfavourable climatic periods of the late Pleistocene. This is reflected in the continuous presence of *G. frumentum* specimens in the loess samples (Gaudenyi *et al*., 2003; Marković *et al*., 2006, in press).

Discussion

Data presented in Table 1 summarise existing chonostratigraphic models of Vojvodinian loess-palaeosol sequences. Bronger (1976) correlated palaeosols F1 to F4 with the last glacial period (Würm) and fossil soil F5 with the Riß-Würm

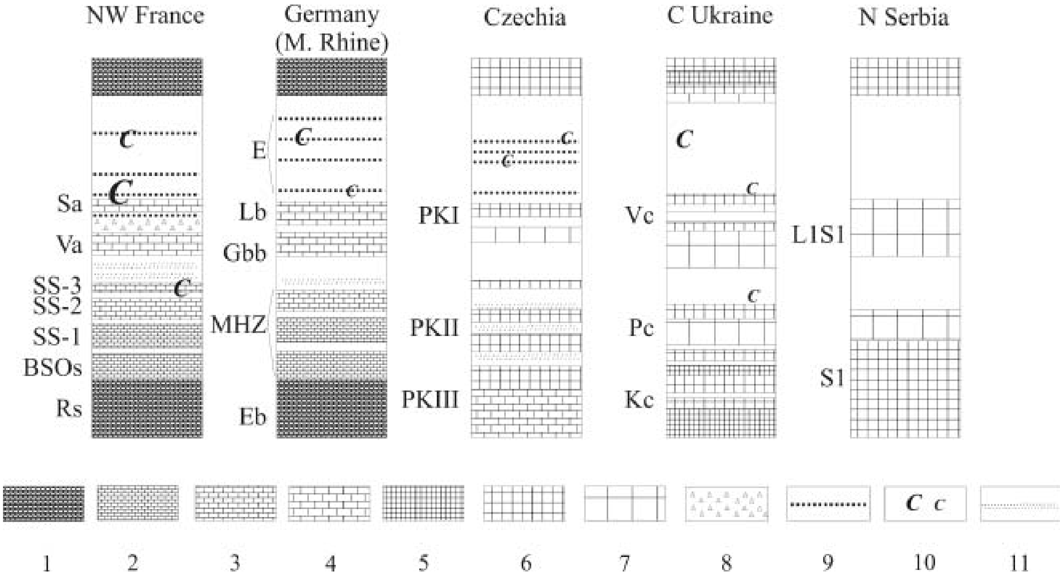

Figure 10 Principal stratigraphic subdivision of the lithologic record of the last 130 k-yr in loess sections of Vojvodina, compared with composite loess-palaeosol stratigraphic models in northwestern France (Antoine *et al.*, 1999), Germany (Zöller and Semmel, 2001), Czech Republic (Kukla, 1975; Kukla and Cilek, 1996) and central Ukraine (Rousseau *et al.*, 2001). Palaeosol names: NW France: SaVa = Saint-Acheul/Villiers-Adam Soil complex, SS-1, SS-2 and SS-3 = Saint-Sauflieu Early-Glacial Soil complex, BSOs = Bettencourt Saint-Ouen soil and Rs = Rocourt soil; Germany, Middle Rhine: E = Erbenheimer Nassboden, Lb = Lohner Boden, Gbb = Gräselberger Boden, MHZ = Mosbacher Humuszone and Eb = Erbacher Boden; Ukraine: Vc = Vytachiv complex, Pc = Pryluky complex and Kc = Kaydaky complex. 1, Truncated Bt horizon of Luvisol; 2, Bth or Ah horizon of Greyzem/Chernozem; 3, undifferentiated Ah horizon corresponding to steppe soil; 4, Bw horizon of Cambisol; 5, B horizon of boreal brown soil; 6, Ah horizon of typical thick Chernozem; 7, weakly developed A horizon; 8, humic layer/arctic meadow soil; 9, gelic gleysol/tundra gley; 10, cryogenic features; 11, pellet sand. Palaeosol designations follow interpretations of Antoine *et al.* (1999,2001), Semmel (1997), Kukla (1975), Rousseau *et al.* (2001) and Marković (2004b, 2005)

(last) interglacial period. Early thermoluminescence (TL) age estimates of loess-palaeosol sequences in the Vojvodina region suggested that fossil chernozems F2 and F3 formed during MIS 5a and 5e (Singhvi *et al.*, 1989). Their chronostratigraphic interpretation is still followed in some instances (e.g. Bronger, 2003). However, more recent luminescence dating techniques, including newer, more light-sensitive techniques such as optically stimulated luminescence and infrared optically stimulated luminescence (IRSL) are still not enough adequate for age estimations older than 100 k-yr (e.g. Singhvi *et al.*, 2001) and cannot be used for valid geochronologic assignments in such situations. The IRSL age estimate of 83.6 ± 6.4 k-yr for the uppermost part of penultimate glacial loess L2 at Irig is likely to be significantly underestimated by 50% (Marković *et al.*, in press). Results for samples from the penultimate glacial loess in Hungary (Wintle and Packman, 1988; Frechen *et al.*, 1997), Germany (Frechen, 1999) or Kazakhstan (Machalett *et al.*, 2006) give similar age underestimates. Anomalous fading could be the reason for these age underestimations, although short-time fading tests have not indicated a significant fading rate. The most recent results of IRSL dating provide ages of 120.7 ± 12.7 k-yr for the uppermost part of the penultimate loess L2 at the Surduk section (Fuchs *et al.*, submitted). The Surduk loess section is located on the right bank of the Danube River between the Stari Slankamen and Batajnica sites.

Late Pleistocene palaeoclimatic and environmental evolution

According to palaeopedological interpretations and identified land snail fauna, compared with other central European sites, the late Pleistocene interval in Vojvodina was characterised by relative small, but distinct environmental changes ranging from temperate, warm, interglacial steppe-forest to dry, lower and middle pleniglacial grassland, with a temperate, cold and humid mosaic environment towards the end of the penultimate glacial and late pleniglacial intervals.

A mostly continental climate regime determined the sharp climatic contrast between glacial and interglacial phases. During cold, dry stadial intervals, the mean rate of dust deposition was high, and the intensity of pedogenic activity was restricted. In contrast, during interstades and interglacials, the climate was warmer and generally wetter, which led to enhanced pedogenesis, accompanied by minor dust influx. Interglacial soil S1 tends to be well expressed, but the intensity of interstadial pedogesis (L1S1) is relatively weak.

Interglacial and early pleniglacial climatic conditions, represented by high values of MS and clay content, are recorded in the decalcified palaeosol S1. Based on pedological, sedimentological and malacological evidence from S1 aridity of the climate gradually increased.

At a number of localities in the Vojvodinian loess plateau, the boundary between palaeosol S1 and overlying loess unit L1 is sharp. The values of colour, granulometric composition, CC and low-field MS change abruptly. Rapid aeolian silt deposition began in the investigated area at about 75 k-yr and terminated during the late Pleistocene-Holocene transition. Two periods of loess formation occurred from about 70–50 k-yr (L1L2) and 30–10 k-yr (L1L1), separated by a period of contemporaneous pedogenesis (L1S1). With an absence of preserved cryogenic features and snail assemblages containing only a few cold-resistant species, the last glacial loess deposits in Vojvodina are regarded as representing mostly dry and relatively warm glacial period climatic conditions, compared with other European sites.

The oldest unit L1L2 of the last glacial loess L1 records early pleniglacial palaeoclimatic oscillations. The early pleniglacial snail assemblages represent mostly dry and relatively warm climatic conditions with dominance of grassland vegetation.

DOI: 10.1002/jqs

Woolly mammoth (*Mammuthus primigenius*) skeletal fragments at the base of loess layer L1L2 at the Mišeluk, Ruma and Crvenka sites (Milić, 1978; Marković *et al.*, 2004b, 2006) add to the palaeoecological picture of Vojvodina's early pleniglacial environment.

The middle pleniglacial warm and relatively moist climatic conditions are reflected in an increase in clay content and MS values in weakly developed pedocomplex L1S1. Depending on local conditions, the middle pleniglacial palaeosol L1S1 developed as a single, double or multiple pedocomplex. Loess sub-layers intercalated into L1S1 have preserved evidence of sudden cooling and increasing aridity. In contrast (Zöller *et al.*, 1994; Kukla and Cilek, 1996; Vandenberghe *et al.*, 1998; Antoine *et al.*, 1999, 2001; Rousseau *et al.*, 1998, 2001), the middle pleniglacial palaeosol L1S1 (Marković, 2001; Marković *et al.*, 2004a,b, 2005) is relatively weakly developed in the Vojvodina region.

The uppermost loess stratum L1L1 provides detailed evidence of late pleniglacial climatic fluctuations. Low values of field MS and clay content, plus high values of CC and the presence of frigophilous and cold-resistant snails record the coldest palaeoclimatic interval of the last glacial period. Composite mollusc associations in loess unit L1L1 suggest a high diversity of environments, from open grassland to closed boreal forest ecotones.

Besides climatic changes related to interglacial-glacial and interstadial-stadial conditions, especially, GS variations (Fig. 8) in the loess unit L1 recorded palaeoclimatic instability characterised by many episodes of abrupt climatic fluctuations. Evidence of similar abrupt high frequency fluctuations during the last glacial period appears in loess throughout much of Eurasia (e.g. Chen *et al.*, 1997; Porter, 2001; Vandenberghe and Nugteren, 2001; Rousseau *et al.*, 2002). Those authors linked continental climatic fluctuations with cooling events in the North Atlantic Ocean, partly associated with large-scale iceberg-rafting, as well as with cold phases of Dansgaard/Oeschger cycles recorded in Greenland ice (e.g. Bond *et al.*, 1993). Despite the possible common climatic origin of dust accumulation peaks recorded in the last glacial loess of the Vojvodina region and cooling episodes recorded in the North Atlantic region, establishing direct correlation between these palaeoclimatic records still requires a more precise chronological framework.

More intensive deposition of coarser material during the relatively cold early pleniglacial than during the coldest late pleniglacial period can be the consequence of changes in general atmospheric circulation, as well as changes in depositional regime of the Danube fluvial system (Fig. 7). During the late pleniglacial maximal extension of the ice sheets in northern Europe may have partially blocked penetration of the Atlantic air mass transfer to the east (e.g. Dodonov and Baiguzina, 1995). Model results of Van Huissteden and Pollard (2003) indicate a strong anticyclonal circulation over the Scandinavian ice cap and low wind intensity in the middle Danube Basin during the last glacial maximum. At the same time in the Danube Basin, the massive Alpine ice cap played an important role in the water regime as well as in the production and transport of source material for later aeolian deposition.

Relation to other late Pleistocene Eurasian loess records

The investigations of late Pleistocene loess-palaeosol sequences in Vojvodina provide detailed evidence of palaeoclimatic and environmental evolution. These results are comparable with recent high-resolution studies of climatic oscillations during the last glacial period recorded in Eurasian loess-palaeosol sequences (e.g. Derbyshire *et al.*, 1995; Kukla and Cilek, 1996; Chen *et al.*, 1997; Kemp *et al.*, 1999; Frechen and Dodonov, 1998; Antoine *et al.*, 1999, 2001; Porter, 2001; Rousseau *et al.*, 1998, 2001, 2002).

The investigated area is positioned in an important geographic location, being close enough to the Atlantic Ocean to record its weak influence, but at the same time isolated inland by surrounding mountains and protected from intensive cold Arctic air masses. Because of the geographic setting, the last interglacial-glacial climate and environmental conditions in the Vojvodina region were more stable than those elsewhere, as indicated by other European late Pleistocene loess-palaeosol records (Vandenberghe *et al.*, 1998; Antoine *et al.*, 1999, 2001; Rousseau *et al.*, 1998, 2001). Marker horizons (Kukla, 1975) are not observed in palaeosol S1 of Vojvodina, as they are in many exposures of corresponding European pedocomplexes (Kukla, 1975; Rousseau *et al.*, 1998, 2001; Zöller *et al.*, 2004; Gerasimenko, 2006). Furthermore, while cryogenic features are identified in the last glacial loess of many European sites (Vandenberghe *et al.*, 1998; Antoine *et al.*, 1999, 2001; Velichko *et al.*, 1995), none have been found in loess from the Vojvodina region (Fig. 10). This is a direct consequence of the appearance of the continuous dry continental climatic conditions modified by the temperate sub-Mediterranean climatic influence (Sümegi and Krolopp, 2002).

Late Pleistocene loess stratigraphy in the Vojvodina region, represented by the distinct pedocomplex S1, weakly developed palaeosol L1S1 and two thick loess horizons L1L1 and L1L2, shows similarities with the temporally equivalent loess record of the lower Danube Basin (Jordanova and Petersen, 1999; Panaiotu *et al.*, 2001) and the Black Sea coast (Dodonov *et al.*, 2006). This 'temperate' warm and semi-arid, southeastern European loess province is part of a transcontinental loess belt which is the most westerly extension of the Central Asian (e.g. Dodonov and Baizugina, 1985; Bronger *et al.*, 1995; Machalett *et al.*, 2006) and Chinese loess provinces (e.g. Kukla, 1987; Kukla and An, 1989; Porter, 2001).

Conclusions

Investigations conducted during the last decade have improved knowledge and understanding of the distribution, chronostratigraphy, palaeoclimatic and palaeoenvironmental record of the late Pleistocene loess-palaeosol sequences in the Vojvodina region. The most important advances presented in this paper are a suggested revision of previous chronostratigraphic interpretations, and the provision of more detailed evidence of late Pleistocene palaeoclimatic and palaeoenvironmental fluctuations.

The Vojvodina region is the warmest and driest part of the Carpathian Basin, and a similar climatic gradient existed during the late Pleistocene. Late Pleistocene climate changes recorded in the Vojvodina loess-palaeosol sequences varied from a temperate, humid and warm interglacial to an arid and temperate, cold glacial. This relatively small palaeoclimatic amplitude reduced the last glacial-interglacial environmental diversity of the investigated area. The last-glacial palaeoclimatic record indicates two main cold and dry periods, corresponding with deposition of two loess layers L1L1 and L1L2. Short-term variations of MS and sedimentological proxies may be an expression of abrupt, brief, cold and dry episodes, suggesting possible teleconnections with corresponding climatic variations in the North Atlantic region.

Results presented in this study emphasise the importance of understanding mechanisms of late Pleistocene climate change recorded in the Vojvodina loess-palaeosol sequences, as a contribution toward a more detailed spatial and temporal reconstruction of environmental dynamics across the Eurasian continents during the last 130 k-yr.

Acknowledgements We are grateful to Edward Derbyshire, Ian Smalley and two anonymous reviewers for their helpful discussion and constructive comments that greatly improved the quality of the manuscript. We thank Stevan Savić for his help during the fieldwork and assistance with the laboratory analyses. We also thank Paul Sanford for his assistance in the USF Amino Acid Geochronology laboratory. This work was supported by project 146019 of the Serbian Ministry of Science and Environmental Protection, US National Science Foundation (grants ATM-0081754 to Oches and ATM-0811115 to McCoy), and the Scientific and Technical Cooperation Program (WTZ) of the Federal German Ministry of Education and Research (BMBF, grant MOE 04/R01).

References

Antoine P, Rousseau DD, Lautridou JP, Hatté C. 1999. Last interglacial-glacial climatic cycle in loess-paleosol successions of northwestern France. *Boreas* **28**: 551–563.

Antoine P, Rousseau DD, Zöller L, Lang A, Manaut AV, Hatté C, Fontugne M. 2001. High resolution record of the last interglacial-glacial cycle in loess palaeosol sequences of Nussloch (Rhine Valley–Germany). *Quaternary International* **76/77**: 211–229.

Bokhorst MP, Beets CJ, Marković SB, Gerasimenko N, Matvviishina Z, Frechen M. In press. Late Pleistocene geochemical variations recorded in Serbian and Ukrainian loess-paleosol sequences. *Quaternary International.*

Bond G, Broecker W, Johnsen S, McManus J, Labeyrie L, Jouzel J, Bonani G. 1993. Correlations between climate records from North Atlantic sediments and Greenland ice. *Nature* **365**: 143–147.

Bronger A. 1976. *Zur quartären Klima - und Landschaftsentwicklung des Karpatenbeckens auf (paläo-) pedologisher und bodengeographischer Grundlage.* Kieler Geographische Schriften - Band 45. Selbstverlag, Geographisches Institut der Universität Kiel.

Bronger A. 2003. Correlation of loess-paleosol sequences in East and Central Asia with SE Central Europe - Towards a continental Quaternary pedostratigraphy and paleoclimatic history. *Quaternary International* **106–107**: 11–31.

Bronger A, Winter R, Derevjanko O, Aldag S. 1995. Loess-paleosol sequences in Tadjikistan as a paleoclimatic record of the Quaternary in Central Asia. *Quaternary Proceedings* **4**: 69–81.

Chen FH, Blomendal J, Wanng JM, Li JJ, Oldfield F. 1997. High-resolution multi-proxy climate records from Chinese loess: evidence for rapid climatic changes over the last 75 kyr. *Palaeogeography, Palaeoclimatology, Palaeoecology* **130**: 323–335.

Derbyshire E, Keen DH, Kemp RA, Rolph TA, Shaw J, Meng XM. 1995. Loess-paleosol sequences as recorders of paleoclimatic variations during the last glacial interglacial cycle: some problems of correlation in north-central China. *Quaternary Proceedings* **4**: 7–18.

Dodonov AE, Baiguzina LL. 1995. Loess stratigraphy of Central Asia: Paleoclimatic and paleoenvironmental aspects. *Quaternary Science Reviews* **14**: 707–720.

Dodonov AE, Zhou LP, Markova AK, Tchepalyga AL, Trubikhin VM, Aleksandrovski AL, Simakova AN. 2006. Middle–Upper Pleistocene bio-climatic and magnetic records of the northern Black Sea coastal area. *Quaternary International* **149**: 44–54.

Evans M, Heller F. 2001. Magnetism of loess/palaeosol sequences: recent developments. *Earth Science Reviews* **54**: 129–144.

Frechen M. 1999. Upper Pleistocene loess stratigraphy in southern Germany. *Quaternary Sciences Reviews* **18**: 243–269.

Frechen M, Dodonov AE. 1998. Loess chronology of middle and upper Pleistocene in Tadjikistan, Central Asia. *Geologische Rundschau* **87**: 2–20.

Frechen M, Horváth E, Gábris G. 1997. Geochronology of middle and upper Pleistocene loess sections in Hungary. *Quaternary Research* **48**: 291–312.

Fuchs M, Rousseau DD, Antoine P, Hatte C, Marković SB, Zöller L. Submitted. High resolution chonology of the upper Pleistocene loess/paleosol sequence at Surduk, Vojvodina, Serbia. *Boreas.*

Gaudenyi T, Jovanović M, Sümegi P, Marković SB. 2003. The north boundary of the Mediterranean paleoclimate influences during the late Pleistocene at southeastern part of Carpathian basin based on assemblages of mollusca (Vojvodina, Yugoslavia). In *Quaternary Climatic Changes and Environmental Crises in the Mediterranean Region*, Blanca Ruiz Zapata M *et al.* (eds). Universidad de Alcalá: Alcalá de Henares; 41–47.

Gerasimenko N. 2006. Upper Pleistocene loess-paleosol and vegetational successsions in the Middle Dnieper Area, Ukraine. *Quaternary International* **149**: 55–66.

Heller F, Evans M. 1995. Loess magnetism. *Reviews of Geophysics* **33**: 211–240.

Heller F, Liu TS. 1986. Paleoclimatic and sedimentary history from magnetic susceptibility of loess in China. *Geophysical Research Letters* **13**: 1169–1172.

Jordanova D, Petersen N. 1999. Paleoclimatic record from a loess-soil profile in northeastern Bulgaria II. Correlation with global climatic events during the Pleistocene. *Geophysical Journal International* **138**: 533–540.

Kaufman D, Manley W. 1998. A new procedure for determining DL amino acid ratios in fossils using reverse phase liquid chromatography. *Quaternary Science Reviews* **17**: 987–1000.

Kemp R, Derbyshire E, Meng X. 1999. Comparison of proxy records of Late Pleistocene climate change from a high resolution loess-paleosol sequence in north-central China. *Journal of Quaternary Science* **14**: 91–96.

Konert M, Vandenberghe J. 1997. Comparison of laser grain size analysis with pipette and sieve analysis: a solution for underestimation of the clay fraction. *Sedimetology* **44**: 523–535.

Krolopp E, Sümegi P. 1995. Paleoecological reconstruction of the late Pleistocene, based on loess malacofauna in Hungary. *Geojournal* **36**: 213–222.

Kukla GJ. 1975. Loess stratigraphy of central Europe. In *After Australopithecines*, Butzer KW, Isaac LI (eds). Mouton Publishers: The Hague; 99–187.

Kukla GJ. 1987. Loess Stratigraphy in central China. *Quaternary Science Reviews* **6**: 191–219.

Kukla GJ, An Z. 1989. Loess Stratigraphy in central China. *Palaeogeography, Palaeoclimatology, Palaeoecology* **72**: 203–225.

Kukla GJ, Cilek V. 1996. Plio-Pleistocene megacycles: record of climate and tectonics. *Palaeogeography, Palaeoclimatology, Palaeoecology* **120**: 171–194.

Ložek V. 1964. *Quartärmollusken der Tschechoslowakei. Rozpravý Ustrediniho Ústavu Geologické* **31**, Praha: 374 pp.

Ložek V. 2001. Molluscan fauna from the loess series of Bohemia and Moravia. *Quaternary International* **76/77**: 141–156.

Machalett B, Frechen M, Hambach U, Oches EA, Zöller L, Marković SB. 2006. The loess sequence from Remisowka (northern boundary of the Tien Shan Mountains, Kazakhstan)—Part I: Luminescence dating. *Quaternary International* **152–153**: 203–212.

Maher BA, Thompson R. 1999. Paleomonsoons I: the magnetic record of palaeoclimate in the terrestrial loess and palaeosol sequences. In *Quaternary Climates, Environment and Magnetism*, Maher B, Thompson R (eds). Cambridge University Press: Cambridge; 81–125.

Marković SB. 2000. *Paleogeography of Vojvodina region during the Quaternary.* PhD thesis (in Serbian), Institut za geografiju, University of Novi Sad.

Marković SB. 2001. Paleosols of Srem region. In *Soils of Srem region (Vojvodina, Yugoslavia)*, Miljković N, Marković SB (eds). Institut za geografiju, University of Novi Sad: 133–155 (in Serbian with English summary).

Marković SB, Kukla GJ, Sümegi P, Miljković LJ, Jovanović M, Gaudenyi T. 2000. The last glacial cycle paleoclimatic record of Ruma loess section (Vojvodina, Yugoslavia). *Zbornik radova Instituta za geografiju* **30**: 5–13 (in Serbian with English summary).

Marković SB, Heller F, Kukla GJ, Gaudenyi T, Jovanović M, Miljković LJ. 2003. Magnetostratigraphy of Stari Slankamen loess section. *Zbornik radova Instituta za geografiju* **32**: 20–28 (in Serbian with English summary).

Marković SB, Kostić N, Oches EA. 2004a. Paleosols in the Ruma loess section. *Revista Mexicana de Ciencias Geológicas* **21**: 79–87.

Marković SB, Oches EA, Gaudenyi T, Jovanović M, Hambach U, Zöller L, Sümegi P. 2004b. Paleoclimate record in the Late Pleistocene loess-palesol sequence at Miseluk (Vojvodina, Serbia). *Quaternaire* **15**: 361–368.

Marković SB, McCoy WD, Oches EA, Savić S, Gaudenyi T, Jovanović M, Stevens T, Walther R, Ivanišević P, Galović Z. 2005. Paleoclimate record in the Late Pleistocene loess-paleosol sequence at Petrovaradin Brickyard (Vojvodina, Serbia). *Geologica Carpathica* **56**: 545–552.

Marković SB, Oches EA, Sümegi P, Jovanović M, Gaudenyi T. 2006. An introduction to the Upper and Middle Pleistocene loess-paleosol sequences in Ruma section (Vojvodina, Serbia). *Quaternary International* **149**: 80–86.

Marković SB, Oches EA, McCoy WD, Frechen M, Gaudenyi T. In press. ''Warm'' Glacial climate recorded in the loess-paleosol seqence at Irig Brickyard Exposure (Vojvodina, Serbia). *Geochemistry, Geophysics and Geosystems* 2006GC001565.

Martinson D, Pisias MG, Hays JD, Imbrie J, Moorre TC, Shackleton NJ. 1987. Age dating and the orbital theory of ice ages: development of a high-resolution 0 to 300,000-year chronostratigraphy. *Quaternary Research* **27**: 1–30.

Milić R. 1978. Novi nalazi *Elephas primigenis Blum.* u Sremu, Vojvodina. *Priroda Vojvodine* **4**: 49–50.

Oches EA, McCoy WD. 1995a. Amino acid geochronology applied to the correlation and dating of central European loess deposits. *Quaternary Science Reviews* **14**: 767–782.

Oches EA, McCoy WD. 1995b. Aminostratigraphic evaluation of conflicting age estimates for the ''Young Loess'' of Hungary. *Quaternary Research* **44**: 767–782.

Oches EA, McCoy WD. 2001. Historical developments and recent advances in amino acid geochronology applied to loess research: examples from North America, Europe and China. *Earth Science Reviews* **54**: 173–192.

Oches EA, McCoy WD, Gnieser D. 2000. Aminostratigraphic correlation of loess-paleosol sequences across Europe. In *Perspectives in Amino Acid and Protein Geochemistry*, Goodfried GA, Collins MJ, Fogel ML, Macko SA, Wehmiller F (eds). Oxford University Press: NY; 331–348.

Panaiotu CG, Panaiotu CE, Grama A, Necula C. 2001. Paleoclimatic record from a loess-paleosol profile in southeastern Romania. *Physics and Chemistry of the Earth (A)* **26**: 893–898.

Pecsi M. 1990. Loess is not just the accumulation of dust. *Quaternary International* **7/8**: 1–21.

Porter SC. 2001. Chinese loess record of monsoon climate during the last glacial-interglacial cycle. *Earth Science Reviews* **54**: 115–128.

Rousseau DD, Zöller L, Valet JP. 1998. Climatic variations in the upper Pleistocene loess sequence at Achenheim (Alsace, France) based on a magnetic susceptibility and TL chronology of loess. *Quaternary Research* **49**: 255–263.

Rousseau DD, Gerasimaenko N, Matvviishina Z, Kukla GJ. 2001. Late Pleistocene environments of central Ukraine. *Quaternary Research* **56**: 349–356.

Rousseau DD, Antoine P, Hatté C, Lang A, Zöller L, Fontugne M, Ben Othman D, Luck JM, Moine O, Labonne M, Bentlaeb I, Jolly D. 2002. Abrupt millennial climatic changes from Nussloch (Germany) upper Weichselian eolian records during the last glaciation. *Quaternary Science Reviews* **21**: 1577–1582.

Semmel A. 1997. Referenzprofile des Würmlösses im Rhein-Main-Gebiet. *Jahresberichte der Wetterauischen Gesellschaft für die gesamte Naturkunde* **148**: 37–47.

Singhvi AK, Bronger A, Sauer W, Pant RK. 1989. Thermoluminescence dating of loess - paleosol sequences in the Carpatian Basin. *Chemical Geology* **73**: 307–317.

Singhvi AK, Bluszcz A, Bateman MD, Someshwar Rao M. 2001. Luminescence dating of loess–palaeosol sequences and coversands: methodological aspects and palaeoclimatic implications. *Earth Science Reviews* **54**: 193–212.

Smalley I, Leach JA. 1978. The origin and distribution of the loess in the Danube basin associated regions of east-central Europe – A review. *Sedimentary Geology* **21**: 1–26.

Sümegi P, Krolopp E. 2002. Quatermalacological analysis for modeling the upper Weichselian palaeoenvironmental changes in the Carpathian Basin. *Quaternary International* **91**: 53–63.

Vandenberghe J, Nugteren G. 2001. Rapid changes in loess successions. *Global and Planetary Change* **28**: 1–9.

Vandenberghe J, Hujizer B, Mücher H, Laan W. 1998. Short climatic oscillations in a western European loess sequence (Kesselt, Belgium). *Journal of Quaternary Science* **13**: 35–38.

Van Huissteden K, Pollard D. 2003. Oxygen isotope stage 3 fluvial and eolian successions in Europe compared with climate model results. *Quaternary Research* **59**: 223–233.

Velichko AA, Nechayev VP, Prozhnakova. 1995. Palaeocryogenic analysis of loess-paleosol sequences. *GeoJournal* **36**: 133–138.

Willis KJ, Rudner E, Sümegi P. 2000. The full-glacial forests of central and southeastern Europe. *Quaternary Research* **53**: 203–213.

Wintle AG, Packman SC. 1988. Thermoluminescence ages for three sections in Hungary. *Quaternary Science Reviews* **7**: 315–320.

Zöller L, Semmel A. 2001. 175 years of loess research in Germany-long records and ''unconformities''. *Earth Science Reviews* **54**: 19–28.

Zöller L, Oches EA, McCoy WD. 1994. Towards a revised chronostratigraphy of loess in Austria with respect to key sections in the Czech Republic and in Hungary. *Quaternary Science Reviews* **13**: 465–472.

Zöller L, Rousseau DD, Jäger KD, Kukla GJ. 2004. Last interglacial, lower and middle Weichselian – a comparative study from Upper Rhine and Thuringian loess areas. *Zeitschrift für Geomorphologie, N.F.* **48**: 1–24.

DOI: 10.1002/jqs