Paleosols in the Ruma loess section (Vojvodina, Serbia)

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ABSTRACT

The Ruma loess section, located in the central part of the south slope of Fruška Gora Mountain, exposes a 20 m thick series of loess and paleosols in the local brickyard. Results of amino acid racemization geochronology confirmed middle- and late-Pleistocene ages of Ruma's loess-paleosol sequences, and correlates with aminostratigraphic subdivisions at other Central European sites. Paleopedological analyses describe morphology, mineralogy, grain-size distribution and carbonate content of the sediments and paleosols. Five paleosol levels represent the environmental transition from humid forest environments to relatively dry steppe interglacial landscapes during the last about 350 ka. Especially interesting are thick pedogenic layers formed in distinct paleo-depressions, which were created during the last glacial cycle. These horizons provide proxy data useful in the detailed reconstruction of environmental conditions during marine oxygen-isotope stages 5 and 3.

Key words: loess-paleosol sequences, paleopedology, Ruma section, Serbia.

RESUMEN

La sección de loess Ruma, localizada en la parte central del talud meridional de la montaña Fruska Gora, expone una serie de loess y paleosuelos de 20 m de espesor en un depósito localizado en la fábrica local de ladrillo. Los resultados de la geocronología de racemización de aminoácidos, confirmaron las edades del Pleistoceno medio y tardío de las secuencias loess-paleosuelos de Ruma y correlacionan con las subdivisiones aminoestratigráficas en otros sitios de Europa Central. Los análisis paleopedológicos describen la morfología, mineralogía, distribución del tamaño de grano y contenido de carbonato de sedimentos y paleosuelos. La transición ambiental de ambientes boscosos húmedos a paisajes de estepas interglaciales, relativamente secas, durante los últimos 350 ka, está representada por cinco niveles de paleosuelos. Son especialmente interesantes los estratos pedogénicos gruesos, formados en diferentes paleo-depresiones, que fueron creados durante el último ciclo glacial. Estos horizontes suministran una aproximación a los datos, útiles en la reconstrucción detallada de condiciones ambientales durante las etapas 5 y 3 de isótopos de oxígeno marinas.

Palabras clave: secuencias loess-paleosuelos, paleopedología, sección Ruma, Serbia.

INTRODUCTION

Loess-paleosol exposures along the Panonnian part of the Danube River valley were first described by Marsigli (1726) (Figure 1). Since the pioneering study of Marsigli, many authors have described paleosols in loess sections of this region in varying degrees of detail. Bronger (1976) made the most important paleopedological study of key loess sections in the Carpathian (Panonnian) Basin region. These investigations established buried soils in Central European loess sites as being the most representative archives of middle Pleistocene paleoclimatic fluctuations on land (Bronger and Heinkele, 1989). The Ruma loess-paleosol sequences, which are the basis of significant new paleopedological investigations (Marković, 2001), are exposed in a quarry of a local brick factory in the central part of the south slope of Fruška Gora Mountain. Geographical coordinates of the Ruma site are 45°00' N Latitude and 19°51' E Longitude (Figure 2). The profile is nearly 20 m thick and includes 5 paleosols formed during the younger part of middle and upper Pleistocene (Marković *et al.*, in press). The aim of this study is the reconstruction of paleoenvironmental conditions based on paleopedological investigations.

MATERIALS AND METHODS

Investigations of the loess-paleosol sequences of the Ruma quarry began in 1997. There are two exploitation levels of about 10 m thickness; samples were collected from each paleosol horizon in the northeast part of the quarry. Pedological samples were air-dried and gently ground to pass a 2 mm sieve, and then split into subsamples by the cone-and-quarter method. Sieving and the pipette methods were used to determine particle size distribution of decalcified (by 0.25 N HCl) samples after destruction of organic material by 6% H_2O_2, and dispersion by boiling and overnight shaking in 0.4M $Na_4P_2O_7$. The analytical methods used were taken from Klute (1986). The $CaCO_3$ content was determined with a Scheibler calcimeter. Dry and moist colors were recorded using Munsell Soil Color Charts (1975).

The mineralogical composition of bulk samples was obtained by X-ray diffraction of randomly oriented powder samples. Clay fractions (<2 μm) were separated by centrifugal sedimentation and analyzed mineralogically by X-ray diffraction with a SIMENS D-500 diffractometer using CuKα radiation and a 45-kV tube voltage. Oriented specimens were scanned over the 2–45° 2θ range and step scanning at 0.02° 2θ/min. The DRX Win 1.4 software was used to quantify proportions of individual minerals in both the bulk samples and clay fractions.

The hydrolytic alteration index of Thorez (1985) was calculated by multiplying the percent of each mineral in the clay fractions by its phase number: 7 for kaolinite, 5 for smectite, 3 for vermiculite, and so forth, then dividing the sum of these by the percentage of illite. The extent of mineral weathering was also estimated by comparing illite/(illite + quartz), and orthoclase/(orthoclase + quartz) ratios in the ground bulk samples. All data were analyzed statistically by the Statistica for Windows 4.3b package (Statsoft, 1996).

Amino acid racemization (AAR) geochronology was used to evaluate the age and regional correlations of the stratigraphic units. Gastropod shells were collected from six loess layers and two paleosols for amino acid racemization analysis in order to independently correlate the stratigraphy at Vojvodina with loess-paleosol units elsewhere in Europe. Details of the sample preparation and analytical methodology are presented in Oches and McCoy (2001).

CHRONOSTRATIGRAPHY

Previous chronostratigraphic investigations of loess-paleosol sequences in Vojvodina region indicated that the loess horizons formed during glacial periods, and each paleosol developed during an interglacial phase (Marković, 2000, 2001). Based on these data, Marković and Kukla (1999) designated the units by names that follow the Chinese loess stratigraphic system (Kukla, 1987), beginning with the prefix "SL" referring to the standard section at the Stari Slankamen site.

The Ruma profile is the first Serbian loess sequence


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DIVERSA TERRARUM ALVEI CONSTITUTIO.

A. Ripa. Terræ Fructifera. Pinguis. Nigra. et Cretacea.
B. Terra Nigra. Pinguis. Fructifera.
C. Terra Lutosa.
D. Ripa Arenosa,

Fundus Danubii.

DE
STRUCTURA
ALVEI.

PARTES, quæ materialiter Alveum continent, vel quæ ſive ad latera, ſive in fundo eum circumſtant, in hæc duo mihi diſtingui poſſe videntur, & quæ Aquas ſuperſtant, & quæ Aquis premuntur.

Quæ ſupra Horizontem aquæ eminent, & ſub conſiderationem noſtram veniunt, ſunt, diverſâ cum conſideratione Solum: Terra, (eademque vel pinguis nigra, vel Arenoſa, Cretacea, vel ex Topho cum nitro:) Ripæ, quali elevatione hoc vel illo intuitu ſint: viva ad aquas Saxa, ſeu Rupes.

De hoc priori præcedentis Tabulæ membro, jam nunc agemus. Reliqua, quæ tam ad latera, quàm in fundo, eundem, uti diximus, Alveum circumſtant, ut ſunt, Lutum, Arena, Sabulum, Glarea, in Tom. III. de Foſſilibus, ſeu Mineralibus reſervantes.

Tom. I. Ii DE

Figure 1. Description of loess-palesol bank of Danube river (Marsigli, 1726). Marsigli described modern soil (marked with A in Figure 1) as *Terra fructifera pinguis nigra et creatacea* (black fertile carbonate soil), paleosol (B) as *Terra nigra fructifera pinguis* (black fertile soil) and between them loess layer (C) as *Terra lutosa cinerive et in fragmento creatacea priabilis* [yellow-cinerary with carbonate fragments (concretions)].

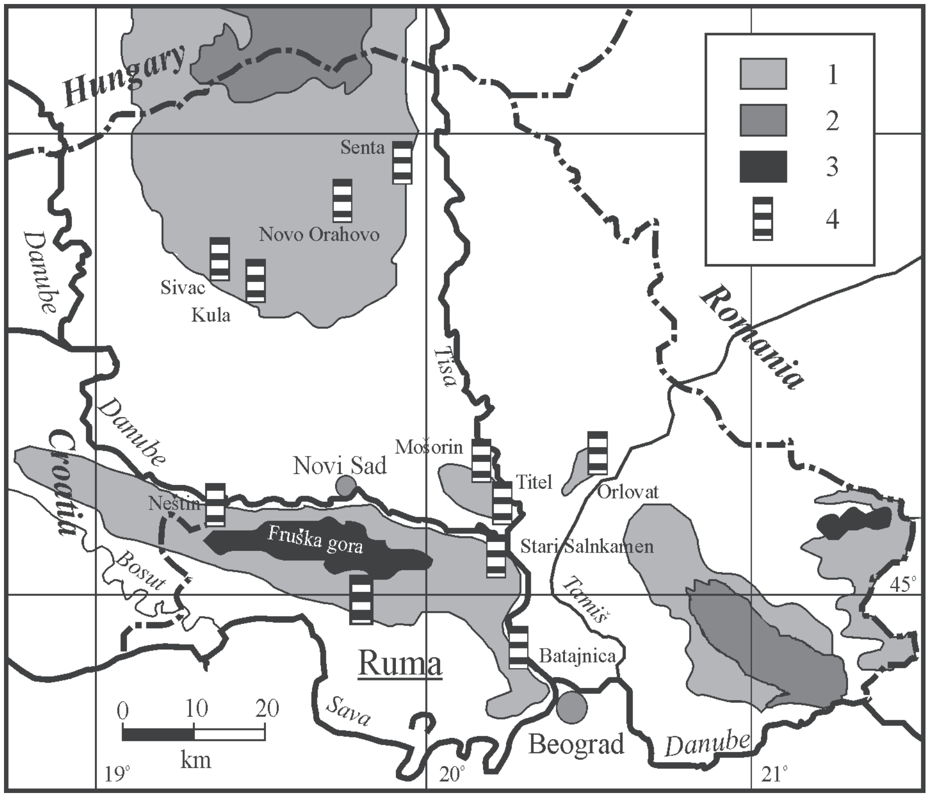

Figure 2. Location of Ruma and some other sites in Yugoslav loess area. 1: Loess plateau; 2: sandy area; 3: mountain; 4: main loess sections.

in which AAR analyses have been carried out. Data and initial interpretations are presented in Marković *et al.* (in press). AAR geochronology results from the Ruma sections suggest a reinterpretation of the previous chronostratigraphic scheme of Marković (2000). Eight different genera of therrestrial gastropod shells have been analyzed, including samples from eight levels within the sequence of loess and paleosols at Ruma. Sampled genera include *Bradybaena, Chondrula, Clausilia, Granaria, Helicopsis, Pupilla, Trichia* and *Vallonia*. Alloisoleucine/Isoleucine total acid hydrolystase (A/I-HYD) measurements on representative samples are shown in Figure 3. These data show a consistent increase in A/I values for individual genera from successively older stratigraphic units. *Chondrula* A/I-HYD values increase from 0.08±0.02 (n=5) in SL L1 to 0.19±0.02 (n=4) in SL L2 to 0.24±0.04 (n=2) in SL L3 (Table 1).

According to the present chronostratigraphic model, loess-paleosol sequences SL L1 LL1, SL L1 SS1, SL LL2 and SL S1 formed during glacial cycle B (Kukla, 1975), corresponding with marine oxygen-isotope stages (MIS) 2, 3, 4 and 5. Horizons SL L2 and SL S2 SS1 correspond with glacial cycle C and MIS 6 plus the later phase of MIS 7. The next thin loess and paleosol, SL S2 LL1 and SL S2 SS2, also formed during glacial cycle C and the earlier part of MIS 7. SLS2 SS1 and SLS2 SS2 are a double paleosol, comparable to the Basaharc Double (BD1 and BD2) in Hungary (Pécsi and Hahn, 1987), and are correlated with the BD pair on the basis of AAR data. Loess and paleosol units SL L3 and SL S3 correlate with glacial cycle D and MIS 8 and 9 (Table 2) (Marković *et al.*, in press). Following this chronology, a indicative correlation is observed between the clay content of the Ruma loess-paleosol sequence and the SPECMAP (Imbrie *et al.*, 1984) marine delta-^{18}O record (Figure 3).

PALEOSOL MORPHOLOGY

Five paleosol and six loess layers are distinguished at the Ruma quarry (Figure 4). Younger paleosol sequences show variable morphological characteristics. These soils were formed partly in paleo-depressions that are mirrored on the surface as modern depressions in the loess plateau. Paleosol horizons developed in these paleo-depressions have greater thickness and darker color. These paleo-depressions are not noticeable in older fossil soil sequences in the Carpathian Basin (Marković *et al.*, in press). Table 3 shows morphological description and paleopedological interpretation of paleosol horizons.

The oldest exposed paleosol, SL S3, is a strongly developed reddish forest soil. This paleopedological layer consists of a 105 cm thick Ck horizon with many carbonate concretions (2–4 cm diameter) and strongly developed humus infiltrations in fossil root channels. Above is a 25

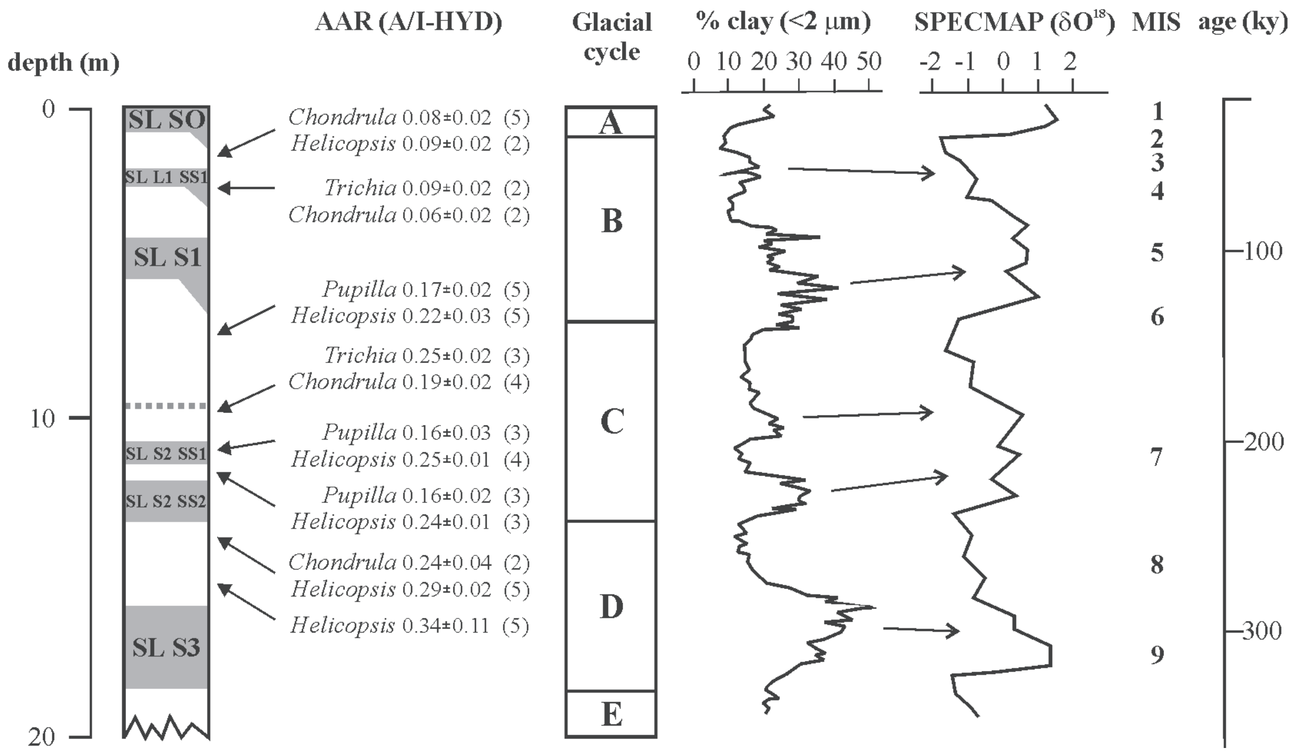

Figure 3. Results of AAR geochronology (A/I-HYD), clay record of Ruma loess-paleosol and correlation to Glacial cycles A, B, C, D and SPECMAP delta ^{18}O series.

cm thick BC horizon with small and soft spherical carbonate nodules, followed by a 75 cm thick reddish Bt horizon with a 15 cm thick weakly expressed eluvial layer at the top of the paleosol.

Paleosol SL S2 SS2 is a 115 cm thick Cambisol-Chernozem. The lower Ck horizon with carbonate concretions and humic infiltrations is 25 cm thick. Above is a 50 cm thick Bw horizon, which is a typical cambic paleopedological layer. Krotovinas are scattered throughout the upper lighter colored 40 cm thick AB horizon.

Paleosol SL S2 SS1 is a 45 cm thick weakly developed Chernozem with a few krotovinas filled with C horizon sediment from the overlying unit. At 100 cm above the base of loess unit SL L2, a 5 cm thick, darker (10 YR 6/3–5/4) humic marker horizon is developed .

Table 1. Aminostratigraphy of the Ruma section compared with Hungarian Mende site for glacial cycles B,C and D, that correspond to marine oxygene-isotope stages 2-5, 6-7 and 8-9 for the *Chondrula* genus.

Ruma		Mende	
Loess Unit	**A/I-HYD** mean ± s.d. (#)	**Glacial cycle**	**A/I-HYD** mean ± s.d. (#)
SL L1 LL1	0.08 ± 0.02 (5)	B	0.09 ± 0.01 (5)
SL L2	0.19 ± 0.02 (4)	C	–
SL L3	0.24 ± 0.02 (2)	D	0.27 (1)

Many carbonate concretions (1–2 cm in diameter) and humus infiltrations are formed within the Ck horizon of the SL S1 soil complex. The average thickness of fossil soil SL S1 is 75 cm, although in paleo-depressions it reaches approximatly 350 cm. The Ah horizon shows very similar morphological characteristics to the SL S2 fossil soil. However, profiles in paleo-depressions show much more complex structure. Profiles of SL S1 paleosol in paleo-depresions include different colored superimposed Chernozem soil horizons: the basal Ah4 darker layer with Mn mottles at the base is about 85 cm thick; a lighter orchic Ah3 is 35 cm thick; the 75 cm thick Ah2 subhorizon is slightly darker in color with mostly prismatic structure, and the uppermost Chernozem subhorizon Ah1 has numerous small carbonate concretions. At the top of this paleosol complex, a lighter yellowish brown A(h) horizon of loess Syrozem is developed. The youngest fossil soil SL L1 SS1 is a weakly developed Chernozem. Its thickness averages 45 cm, but increases to 105 cm in paleo-depressions.

The Holocene soil developed in the loess plateau surface, in the area surrounding Ruma, is a calcareous Chernozem (Živković *et al.*, 1972). At the top of the investigated section, the modern soil is 65 cm thick, although in recent depressions it reaches a thickness of about 135 cm. The lower Ck horizon contains many $CaCO_3$ nodules of 1–3 cm in diameter and numerous krotovinas filled with humic material. A transitional AC horizon (10YR 5/1–3/3)

Table 2. Chronostratigraphic models of Serbian loess-paleosol sequences.

Bronger (1976)		Singhvi *et al.* (1989)	Bronger (2003)	Our model	
Paleosol Name	Alpine stratigraphy	MIS	MIS	Stratigraphic unit	MIS
				SL L1 SS1	3
F2	würm	5a	5a	SL S1	5
F3	fossil	5e	5e	SL S2 SS1+SL S2 SS2	7
F4	soils		7	SL S3	9

is 20 cm thick silt loam with fine blocky structure and abundant pseudomycelia. The Ah horizon (10YR 6/3–4/4) is a 25 cm thick silt loam with granular structure and some carbonate pseudomycelia.

PARTICICLE SIZE DISTRIBUTION

Particle size distribution of Ruma's paleosol horizons is presented in Table 4. Variations of fine silt (20–2μm) and clay (<2μm) fractions illustrate the intensity of pedogenetic process, we believe weathering, in different paleosol horizons. Silt content increases overall from older to younger paleosols. In contrast, the clay record of the Ruma profile shows a generally decreasing trend in clay from older to younger fossil soils (Figure 4). The oldest ones strongly developed forest soil, SL S3, with a clay content ranging from 31 to 46%, indicates warm and humid paleoclimatic conditions. Paleosol SL S2 SS2 is a transitional steppe-forest soil with clay content of 29–33%. SL S2 SS1 has 23% clay. In the absence of paleodepressions, SL S1 has 25% clay, and the clay fraction of SL L1 SS1 is only 19%. This trend clearly suggests a paleoclimatic transition during the earlier part of the middle and upper Pleistocene. Similar results of particicle-size distribution in other Serbian loess sections are presented in Protić *et al.* (1995), Maković and Kukla (1999), and Kostić and Protić (2000).

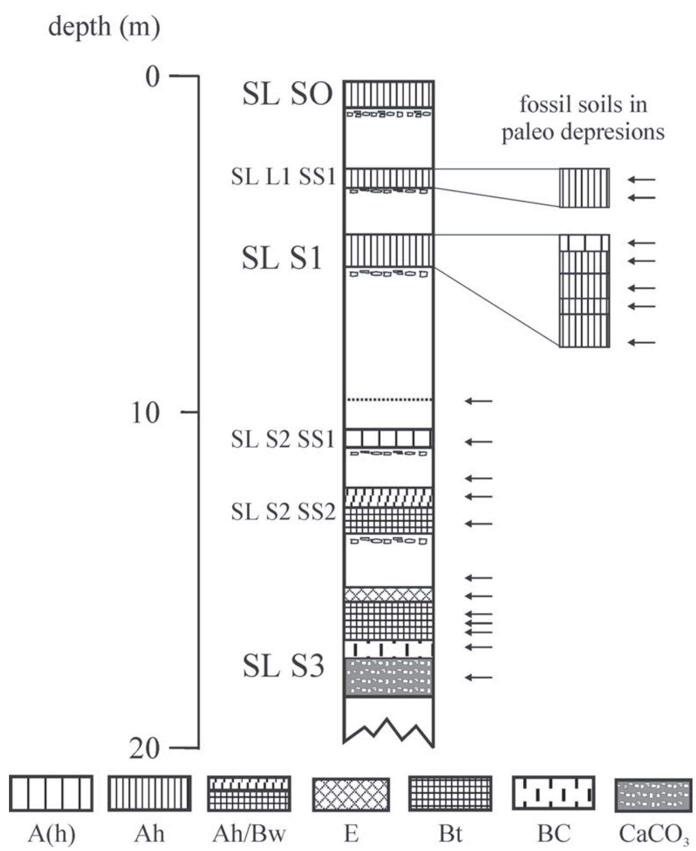

Figure 4. Paleopedological interpretation of Ruma loess exposure. Arrows show position of samples.

Table 3. Morphological description and paleopedological interpretation of paleosol horizons.

Horizon	Thickness (cm)	Depth (cm)	Description and color
SL S3			
C_k	105	1,855–1,740	Many carbonate concretions, humic infiltrations, 10 YR 7/3-5/4
BC	25	1,740–1,715	Soft carbonate spherical grains, 10 YR 7/3-5/6
Bt	75	1,715–1,650	Luvisol horizon, rubified, prismatic structure, 10 YR 4/3- 7.5 YR 3/2
E	15	1,650–1,635	Eluvial horizon, 10 YR 7/3-5/4
SL S2 SS2			
C_k	25	1,470–1,445	Carbonate concretions, weakly humic infiltrations
Bw	50	1,445–1,395	Cambic horizon, weakly rubified, 10 YR 7/3-4/4
AB	40	1,395–1,355	Transitional Chernozem/cambic horizon, 10 YR 5/4-4/3
SL S2 SS1			
Ah	45	1,305–1,260	Weakly developed mollic Chernozem, 10 YR 6/3-4/3
SL S1			
Ah4	85	745–680	4th Chernozem layer in base, 10 YR 5/1-3/2
Ah3	35	660–625	3rd Chernozem layer, ochric , 10 YR 5/2-3/3
Ah2	75	625–550	2nd Chernozem layer with small carbonate spherical grains, 10 YR 4/1-3/1
Ah1	70	550–490	1st Chernozem layer, granular structure, 10 YR 5/1-3/3
A(h)	35	490–455	Loess Syrozem layer, 10 YR 6/2-3/3
SL L1 SS1			
Ah	45–105	325–220	Weakly developed mollic Chernozem , 10 YR 6/3-4/3

Table 4. Particle size distribution of soil horizons in Ruma section.

Horizon	Depth from the top (cm)	Thickness (cm)	Fractions (%)			
			> 200 µm	200–20 µm	20–2 µm	< 2 µm
SL S3						
C_k	1,855–1,740	215–110	3.2	30.1	35.3	31.4
BC	1,740–1,715	110–85	0.6	31.6	26.7	41.1
Bt_3	1,715–1,680	85–50	0.1	30.0	26.2	43.7
Bt_2	1,680–1,660	50–30	0.1	22.4	31.3	46.2
Bt_1	1,660–1,645	30–15	0.2	29.4	24.7	45.7
E	1,645–1,630	15–0	0.1	32.8	33.3	33.8
SL S2 SS2						
C	1,470–1,445	115–90	1.6	40.5	31.3	26.6
B	1,455–1,395	90–40	0.2	34.0	32.4	33.4
AB_2	1,395–1,370	40–15	0.4	36.8	30.6	32.2
AB_1	1,370–1,355	15–0	0.5	37.4	33.2	28.9
SL S2 SS1						
Ah	1,305–1,280	25–0	1.0	38.3	37.3	23.4
SL L2						
marker	1,180–1,175	5–0	0.6	40.0	40.2	19.2
SL S1						
Ah4base	745–740	290–285	0.3	25.8	35.1	38.8
Ah4	740–680	285–205	0.6	24.6	36.8	38.0
Ah3	680–625	205–180	0.6	24.5	38.6	36.3
Ah2	625–550	180–105	0.2	24.1	35.4	40.3
Ah1	550–490	105–35	1.9	32.0	36.1	30.0
A(h)	490–455	35–0	1.2	31.0	39.3	28.5
SL L1 SS1						
Ah	265–250	45–30	3.9	45.1	36.9	14.1
Ah	250–235	30–15	1.4	38.0	41.4	19.2

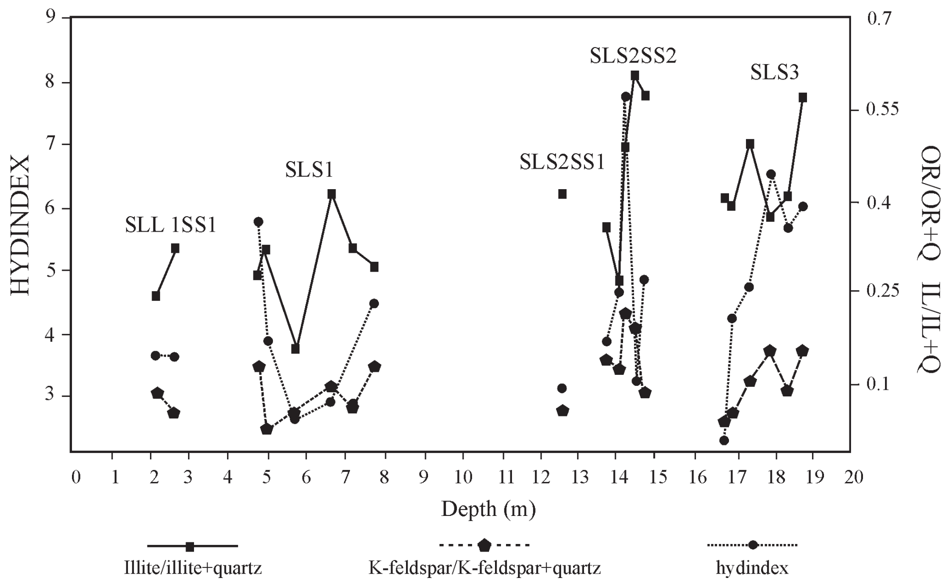

Figure 5. Hydrolitic index and mineral ratios for Ruma loess-paleosol sequences.

CARBONATE CONTENT

The carbonate content ranges from approximately 25.0–30.0 % in loess units (maximum of 33.0 % in SL L3) to very low values of carbonate in A, AB and B horizons (0.0–4.2 %). As a consequence of migration and accumulation processes, the higher concentrations occur in BC and C horizons immediately beneath the paleosol.

MINERALOGICAL COMPOSITION

The bulk mineral composition of all the samples is typical of loess-paleosol sequences. Quartz is dominant, with 22–78 %; followed by micas: 6–34 %; calcite: 1–16 %; feldspars 3–28 %; clay minerals: 5–26 %; chlorite: 5–18 %; dolomite: 0–8 %; and minor heavy minerals, such as amphibole, garnet, epidote, tourmaline, zircon, rutile, sphene, apatite and iron oxides. The clay fractions are composed mainly of illite (38–75%), smaller amounts of chlorite (7–28%), with variable amounts of smectite (2–14%), kaolinite (7–15%) and vermiculite (2–5%), and minor interstratified illite–smectite and chlorite-vermiculite.

Hydrolysis index values, following Thorez (1985), suggest a warm and humid paleoclimatic period during the formation of paleosols SL S3 and SL S2 SS2. A gradual decrease in weathering can be followed from SL S2 SS1 through SL S1 and SL L1 SS1 soil and loess sequences (Figure 5).

The orthoclase / (orthoclase + quartz) and illite / (illite + quartz) ratios (Figure 5) in the Ruma loess sequence support the climatic changes inferred from the hydrolysis index. Both illite and orthoclase are sensitive to hydrolysis by rainwater, whereas quartz is much more stable in a temperate climate, so larger values for both ratios indicate stronger weathering. The hydrolysis index curve for the Ruma sequence correlates well with both orthoclase / (orthoclase + quartz) and illite / (illite + quartz) ratios (Figure 5).

The changes in the hydrolysis index of Thorez (1985) and in the orthoclase / (orthoclase + quartz) and illite / (illite + quartz) ratios indicate a steady overall decreases in weathering rates after formation of the SLS3 and SLS2 SS2 paleosols, which also suggests a progressive decrease in precipitation during the later parts of the Quaternary, perhaps with some overall cooling and precipitation decrease (Figure 5). A tree diagram of depth, mineral ratio indexes (illite to quartz and orthoclase to quartz ratios) and hydrolitic index was obtained by means of cluster analysis by using weighted pair-group averages and the Pearson correlation coefficient (Figure 6). A significant correlation of these parameters for the Ruma paleosol sequence is observed. Illite to quartz plus illite mineral ratio reveals a positive correlation with

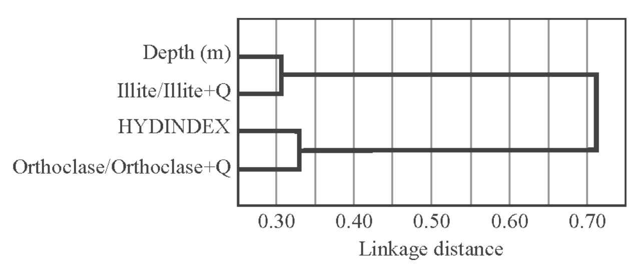

Figure 6. Tree diagram of relation between depth and mineral ratios for Ruma loess-paleosol sequences.

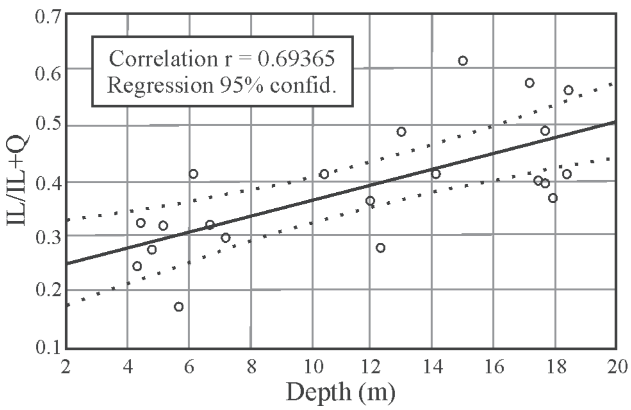

Figure 7. Relation between depth of profile and Illite/Q+Illite ratio values.

soil depth (r = 0.694), while hydrolitic index also shows significant positive correlation with feldspar to quartz plus orthoclase ratio (r = 0.671) in the paleosols investigated (Figures 7 and 8). Correlation between these two groups remains positive, but with a low non-significant (r = 0.211) correlation coefficient.

CONCLUSIONS

Paleopedological investigation of Ruma loess and fossil soils offers an understanding of natural processes of paleosol development during the second half of middle and late Pleistocene. Reconstruction of pedogenesis combined with other paleoclimatic proxies from Ruma's loess-paleosol sequences confirm previous interpretations of a paleoclimatic transition in the Carpathian (Pannoian) Basin region. Five fossil soils represent an environmental transition from humid forest to relative dry steppe during the last about 350 ka. Especially interesting are thick pedogenetic layers formed in paleo-depressions, which were created during the last glacial cycle.

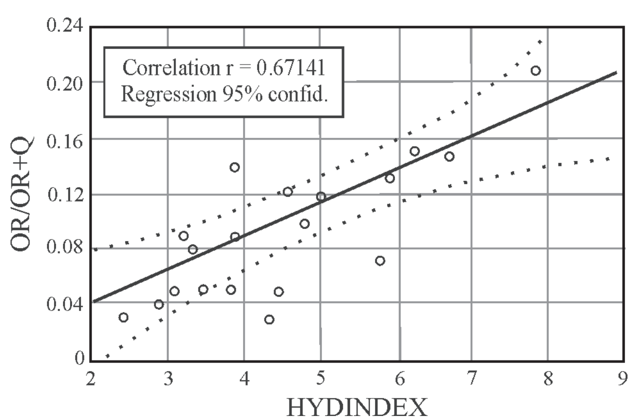

Figure 8. Relation between hydrolitic index and Orthoclase /Q+Orthoclase ratio values.

From statistical correlation analyses it is evident that the changes in hydrolytic index and feldspar to quartz plus feldspar ratio could suggest a progressive decrease in precipitation during the later parts of the Quaternary, with reduced formation of clay minerals in paleosols as well as lesser amounts of feldspar weathering, perhaps also due to a precipitation decrease. In addition, illite /(illite + quartz) ratios indicate steady overall decreases in weathering rates and clay mineral formation in paleosols after formation of the SLS3 and SLS2 SS2 paleosols.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. Arnt Bronger and Dr. Peter Jacobs for stimulating and critical comments. We would sincerely like to thank Dr. Sergey Sedov and Dr. Elizabeth Solleiro-Rebolledo and other organizers of VI International Paleopedology Symposium for their hard work in bringing the international paleopedological research community together again. A PAGES travel grant supported Marković's participation. Amino acid geochronology was supported by NSF Grant ATM0081754 to Oches.

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Manuscript received: April 22, 2002
Corrected manuscript received: September 30, 2002
Manuscript accepted: June 9, 2003