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Stratigraphical and Paleogeographical Interpretation of the Results of Heavy Minerals Analyses in Loesses of Voivodina*

Stratygraficzna i paleogeograficzna interpretacja wyników analiz składu minerałów ciężkich w lessach Wojwodiny

Abstract. Composition of heavy minerals assemblage was analysed in the fraction 0.06-0.01 mm of loesses to about 0.5 Ma old from the Mošorin-Dukatar, St. Slankamen and Batajnica-Kapela profiles. The age of these loesses was previously determined by different authors on the basis of geologic and paleopedologic criteria and TL datings. The interpretation of the analysis results is presented comparatively, with a special regard to periglacial loesses occurring in Poland. Distinctly different features of heavy minerals assemblages indicate that the loesses occurring in Voivodina are of the perimediterranean type.

Key words: periglacial loesses, perimediterranean loesses, heavy minerals, middle and upper Pleistocene, Pannonian Basin, Poland.

INTRODUCTION

Comparative analyses of the distribution and lithologic features of loesses indicate a distinct zonal differentiation of their accumulation conditions in Central Europe. Such a differentiation has also been confirmed, among other things, by the results of heavy minerals analyses in the loesses from the last glaciation (H. Maruszczak and R. Racinowski 1968). Loesses occurring in the northern part of Central Europe were accumulated in periglacial environment and are characterized by a high content of heavy minerals resistant to weathering/destruction. For example, in the Polish loesses (mean data for 56 samples) the following heavy minerals predominate: 1) zircon (39.0%), 2) garnets (20.1%), 3) rutile (14.2%), 4) tourmaline (8.9%), 5) amphiboles (5.7%). On the other hand, in loesses

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accumulated in the southern part of Central Europe, that is beyond the range of the Pleistocene periglacial zone, medium resistant and non-resistant heavy minerals play a more important part. It is documented by the analysis results (mean data for 40 samples) of loesses in the lower Danube basin, in which the following heavy minerals prevail: 1) garnets (32,4%), 2) zircon (15.8%), 3) biotite (12.7%), 4) rutile (9.5%), 5) amphiboles (7.7%).

Voivodina is one of the southern regions of the middle Danube basin (Pannonian Basin). Loesses were accumulated here in conditions similar to those on the lower Danube and form extensive covers, even over 45 m thick. On the steep, right Danube bank they are well exposed and easily accessible for investigations. In some loess profiles many paleosols were found, which were the basis for the stratigraphic scheme of the Yugoslavian loesses (J. Marković-Marjanović 1964). In the most known of these profiles, at Slankamen, eleven paleosols were found, i.e. three more than at Paks in the middle part of the Pannonian Basin (A. Bronger 1975). For three of the most known loess profiles of the southern Voivodina chronostratigraphic investigations were realized in the last years (J. Butrym, H. Maruszczak and M. Zeremski 1991, M. Zeremski, H. Maruszczak and J. Butrym 1991). For 46 samples collected for these chronostratigraphic studies the composition of heavy minerals assemblage was also determined.

Analysed samples were collected from loesses and intra-loessy paleosols distinctly differentiated with regard to typology. Thermoluminescence (TL) age of the samples was determined within the range from about 30 to 600 ka. Therefore, the results af analyses were the basis not only for the definition of a mean mineralogical composition of the examined loesses but also for estimation of changes occurring with the time and due to pedogenesis development.

STRATIGRAPHY OF LOESSES IN THE EXAMINED PROFILES

For chronostratigraphic studies three loess profiles were selected in the second part of the 80's. Two of them — at Slankamen and Mošorin — were known for a long time due to the papers published by J. Marković-Marjanović (1967, 1969) and J. Butrym (1974). The third of them, i.e. Batajnica-Kapela, was less known; its short description, worked up by H. Maruszczak, was published in 1991 y. (J. Butrym et al. 1991, M. Zeremski et al. 1991). In these papers a short characterization of the geologic-morphologic situation of the mentioned profiles was presented. The main differentiation features of the loesses and the intra-loessy paleosols are shown in Fig. 1.

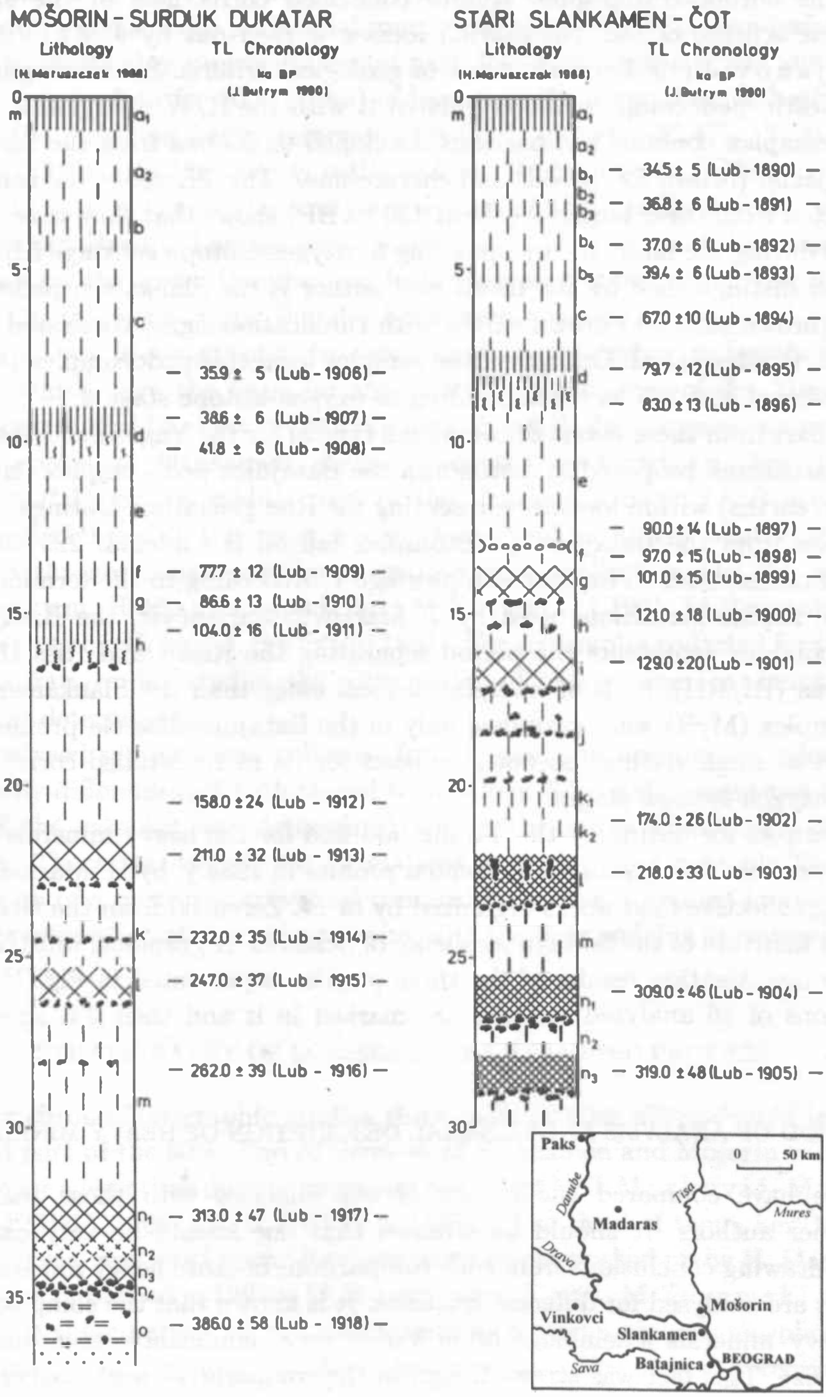
The chronostratigraphic studies confirmed correctness of the stratigraphic scheme of the Yugoslavian loesses worked out by J. Marković-Marjanović (1964) on the basis of geological criteria. She distinguished the Neštin pedocomplex and correlated it with the R/W interglacial. This pedocomplex contains soil horizons developed on loesses from the last but one glacial (brown forest soils and chernozems). The TL age of the samples collected from these horizons (about 130 ka BP) shows that they were developed during the interval corresponding to oxygen-isotope substage 5.5. The second distinguished by the mentioned author is the Slankamen pedocomplex (brown soils and brown earths with rubification signs) correlated with the M/R interglacial. Datings of the samples from this pedocomplex fall on the interval 330–305 ka corresponding to oxygen-isotope stage 9.

Apart from these two pedocomplexes typical for the Yugoslavian loesses, H. Maruszczak proposed to distinguish the Batajnica pedocomplex (largely brown earths) within loesses representing the Riss glaciation. Datings of the samples from the Batajnica pedocomplex fall on the interval 225–205 ka which corresponds to oxygen-isotope stage 7. According to the terminology of the Alpine glaciations used by J. Marković-Marjanović, the Batajnica pedocomplex represents the period separating the Riss I and Riss II glaciations (RI/RII). Soils of interglacial rank older than the Slankamen pedocomplex (M/R) were examined only in the Batajnica-Kapela profile; the results of single datings do not give basis for its more detailed correlation with oxygen-isotope stages.

Samples for dating by the TL method and for the heavy minerals analyses were collected from the presented profiles in 1988 y. by H. Maruszczak during collective field works organized by dr M. Zeremski from the Geographical Institute of the Serbian Academy of Sciences. A graphical illustration of the investigation results of the three profiles is presented in Fig. 1. The locations of 46 analysed samples are marked in it and their TL ages are given.

METHOD OF ANALYSIS AND GENERAL DESCRIPTION OF HEAVY MINERALS

We have compared the results of our analyses with those realized by other authors. It should be stressed that one should be very careful when drawing conclusions from such comparison, because heavy minerals in loesses are analysed for different fractions. It is known that the composition of heavy minerals assemblage often varies very significantly according to grain size. This fact was stressed, e.g., in the comparative work concerning loesses of Central Europe (H. Maruszczak and R. Racinowski 1968).


MOŠORIN - SURDUK DUKATAR
Lithology
(H. Maruszczak 1988)
TL Chronology
ka BP
(J. Butrym 1990)
0 m
5
10
15
20
25
30
35
a1
a2
b
c
d
e
f
g
h
k
m
n1
n2
n3
n4
o
35.9 ± 5 (Lub - 1906)
38.6 ± 6 (Lub - 1907)
41.8 ± 6 (Lub - 1908)
77.7 ± 12 (Lub - 1909)
86.6 ± 13 (Lub - 1910)
104.0 ± 16 (Lub - 1911)
158.0 ± 24 (Lub - 1912)
211.0 ± 32 (Lub - 1913)
232.0 ± 35 (Lub - 1914)
247.0 ± 37 (Lub - 1915)
262.0 ± 39 (Lub - 1916)
313.0 ± 47 (Lub - 1917)
386.0 ± 58 (Lub - 1918)
STARI SLANKAMEN - ČOT
Lithology
(H. Maruszczak 1988)
TL Chronology
ka BP
(J. Butrym 1990)
0 m
5
10
15
20
25
30
a1
a2
b1
b2
b3
b4
b5
c
d
e
f
g
h
j
k1
k2
m
n1
n2
n3
34.5 ± 5 (Lub - 1890)
36.8 ± 6 (Lub - 1891)
37.0 ± 6 (Lub - 1892)
39.4 ± 6 (Lub - 1893)
67.0 ± 10 (Lub - 1894)
79.7 ± 12 (Lub - 1895)
83.0 ± 13 (Lub - 1896)
90.0 ± 14 (Lub - 1897)
97.0 ± 15 (Lub - 1898)
101.0 ± 15 (Lub - 1899)
121.0 ± 18 (Lub - 1900)
129.0 ± 20 (Lub - 1901)
174.0 ± 26 (Lub - 1902)
218.0 ± 33 (Lub - 1903)
309.0 ± 46 (Lub - 1904)
319.0 ± 48 (Lub - 1905)
Paks
0 50 km
Danube
Tisa
Mures
Madaras
Drava
Vinkovci
Mošorin
Slankamen
Sava
Batajnica
BEOGRAD

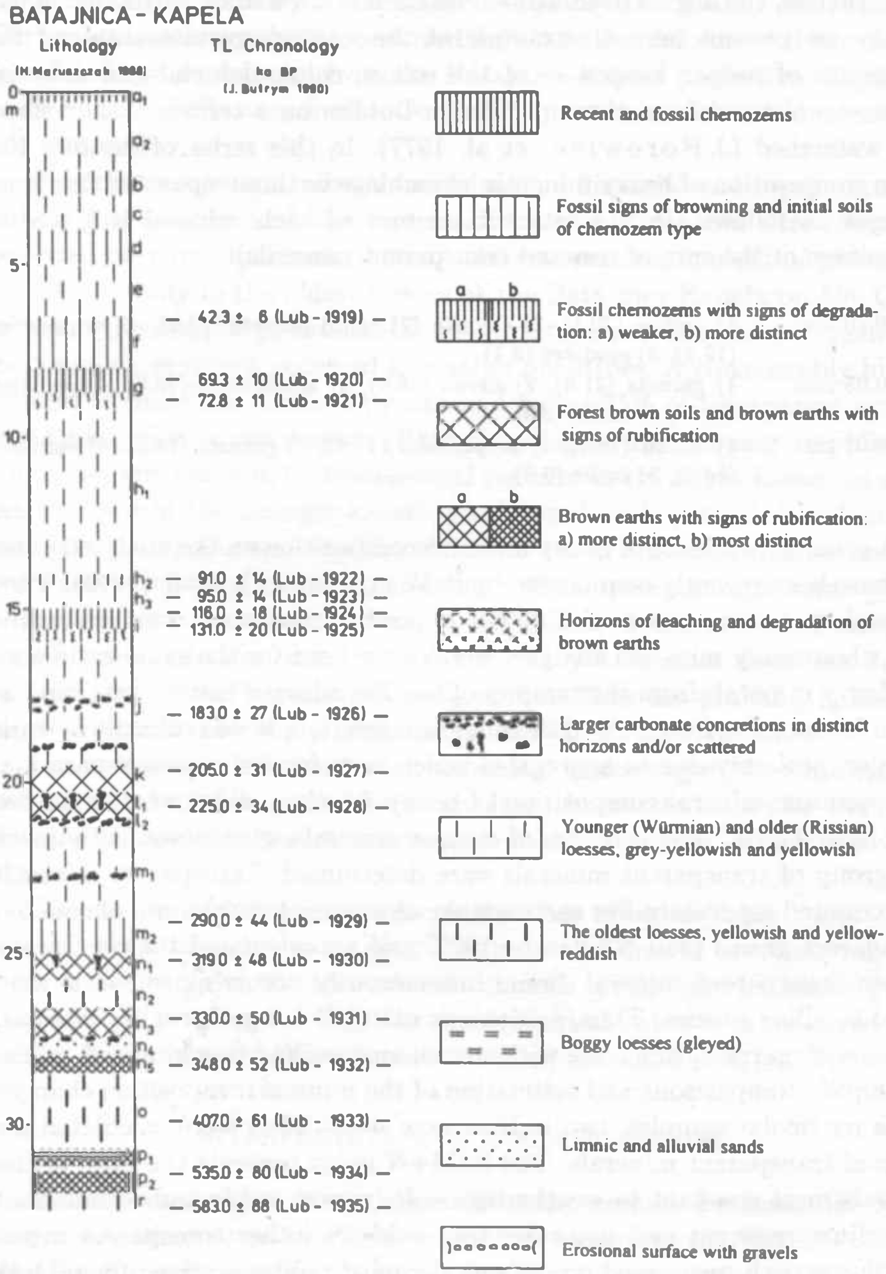


Fig. 1. Lithostratigraphic schemes of the examined profiles of the Voivodina loesses, with the results of TL datings of samples collected for heavy minerals analysis (after Butrym et al. 1991, Zeremski et al. 1991). At the bottom — a situation sketch of the sites of the loesses discussed in the text

Nevertheless, the degree of this differentiation is often underestimated. That is why we present here an example of the analysis results obtained for 7 samples of proper loesses — of the eolian, eolian-deluvial and deluvial facies — collected from three profiles in Lublin: on a terrace, valley slope and watershed (J. Borowiec et al. 1977). In this series of samples the mean composition of heavy minerals assemblage in three separated fractions changes as follows (in brackets the content of each mineral is given as percentage of the sum of counted transparent minerals):

1.00–0.10 mm	1) biotite (30.1), 2) chlorite (21.8), 3) garnets (12.9), 4) amphiboles (10.4), 5) epidotes (8.1)
0.10–0.05 mm	1) garnets (21.8), 2) zircon (16.6), 3) amphiboles (13.5), 4) epidotes (12.7), 5) rutile (9.9)
0.05–0.02 mm	1) zircon (18.4), 2) amphiboles (17.4), 3) garnets (14.5), 4) epidotes (14.2), 5) rutile (9.8)

A great dependence of heavy minerals composition on the analysed grain size have been recently emphasised by B. Wypyrsczyk et al. (1992). They stressed that comparison of different deposits (exposures) was reasonable only when heavy minerals analyses were carried out for the same grain size.

Heavy minerals from the samples of the Yugoslavian loesses were separated in bromoform from 0.06–0.01 mm grain fraction; it was difficult in some samples, probably due to aggregates which were formed during separation. To determine mineral composition of heavy fraction, slides were examined in polarized light. The contents of opaque minerals, glauconite, carbonates and group of transparent minerals were determined. Transparent minerals were counted separately. For each sample we assumed the amount of counted transparent grains (350–600) to be 100% and we calculated the percentage of each transparent mineral. Some innumerously occurring minerals were added to allied species. Thus, zoisite was calculated together with epidotes, spinels with garnets, monazite with zircon, anatase and brookite with rutile. To simplify comparisons and estimation of the mineral composition changes in the particular samples, two indices were used. They were calculated for group of transparent minerals. The R/M+N index presents the ratio of the minerals most resistant to weathering — R (zircon, rutile and tourmaline) to medium resistant and non-resistant — M+N (other transparent minerals). From each mentioned group, one the most representative mineral was chosen for calculating the second index: Z/G+A. This index presents the ratio of zircon grains to the sum of garnet and amphibole grains.

In the group of opaque minerals the particular mineral phases were not distinguished. Glauconite was almost absent in all examined samples. Carbonates occurred mainly as colourless, single crystals usually not rounded. Carbonate microaggregates occurred in a smaller amount and not in all samples. In some samples from the Batajnica-Kapela profile few fragments of carbonate shells were found. Coatings of iron oxides on carbonates were not recorded.

Among transparent minerals andalusite, sillimanite and topaz occurred only in few samples and in a very small amount. Pyroxenes were absent or occurred only in a minimum amount. Several per cent content of pyroxenes were found only in the oldest loesses at the Batajnica-Kapela profile. Colourless, orthorhombic pyroxenes of enstatite type prevailed here. Colourless, monoclinic pyroxenes occurred in smaller quantities. A considerably higher content of these two kinds of pyroxenes (almost 25% of transparent grains) was found only in one sample (Batajnica-Kapela 13). Among amphiboles, which content was usually from several per cent in the oldest loesses to a dozen per cent in the younger loesses, green hornblende prevailed. Colourless, monoclinic amphiboles from the actinolite group and blue alkaline amphiboles also occurred. The main component of the transparent minerals group — garnets were usually colourless. In all profiles, though not in all samples, dark-brown, isotropic grains were found. They were most abundant in the bottom part of the Batajnica-Kapela profile. They are probably spinels of picotite type, but strongly titanous garnets can be also similar.

For estimation of weathering intensity, percentages of non-corroded and corroded garnet grains were calculated in selected samples from the Batajnica-Kapela profile. Garnets with coatings of iron oxides were also counted.

The results of heavy minerals analyses are given in Table 1 and 2. To simplify their interpretation, diagrams were also drawn, in which only the main components of the transparent minerals group were included. These diagrams are presented in Fig. 2 in stratigraphical order, with the division of loesses for younger (= Würm), older (= Riss) and the oldest (= Mindel...).

INTERPRETATION OF ANALYSES RESULTS

Among transparent heavy minerals in the examined loesses, the following minerals occurred in a greater amount: 1) garnets (33.5%), 2) epidotes (15.4%), 3) rutile (11.0%), 4) zircon (10.0%), 5) amphiboles (9.0%). Thus, medium resistant and non-resistant minerals prevailed. Most resistant minerals (zircon, rutile, tourmaline) constituted together a little over 20%. Therefore, this mineral association can be recorded as follows: GR/EP+RU+AM (in the numerator — the main component making a third of all assemblage

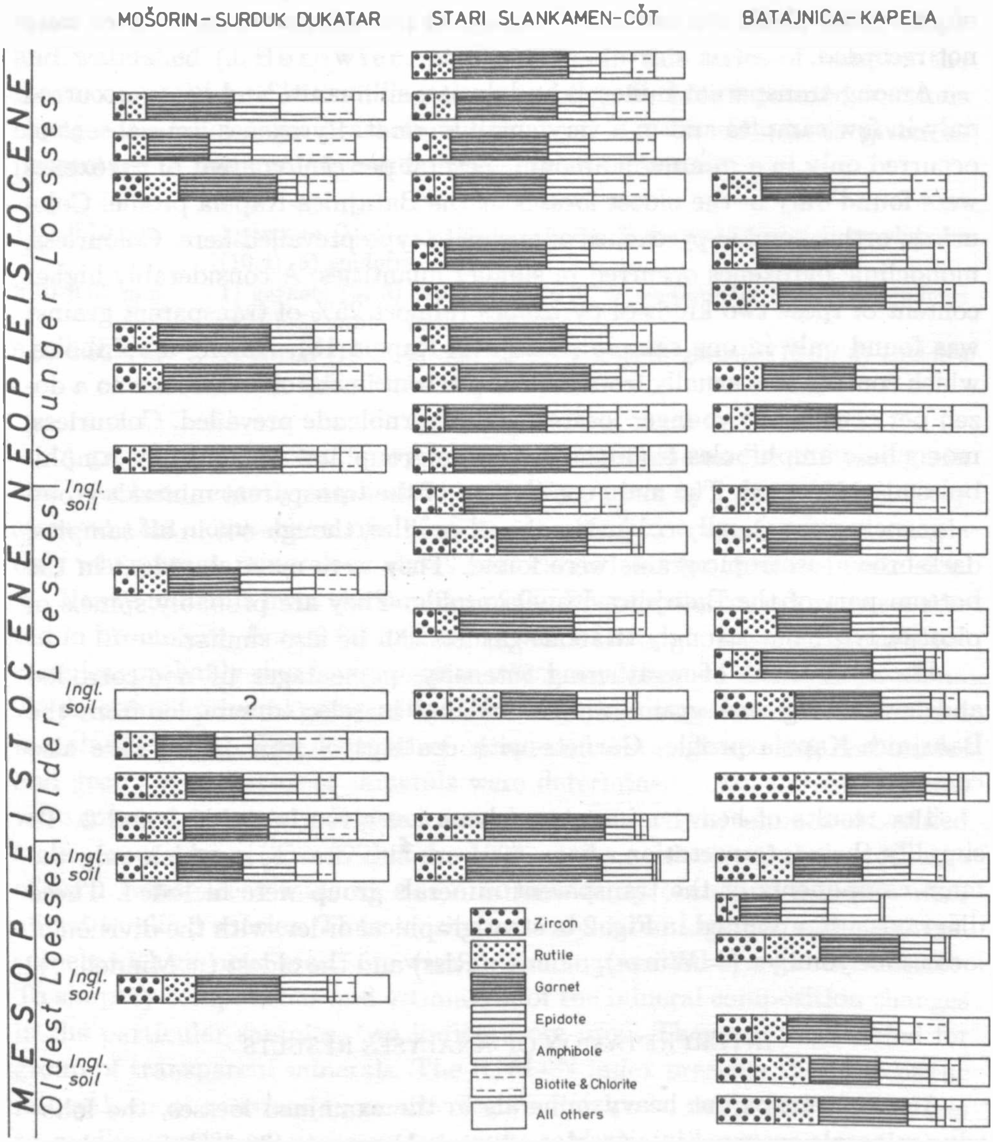


Fig. 2. Assemblage composition diagrams of the main heavy minerals in the loesses of three examined profiles in Voivodina — presented in a stratigraphic arrangement. On the left side — stratigraphic scheme with marked positions of samples collected from interglacial soils

of transparent minerals, in the denominator — three successive which constitute also about the third part). Establishing this index we took amphiboles as the fourth component in order to expose subordinate role of the most resistant minerals.

In loesses of the Hungarian part of the Voivodina, the composition of heavy minerals assemblage is probably very similar. It is confirmed, among other things, by information about the loess profile at Madaras (Fig. 1), where among transparent minerals garnet considerably prevails, and the second is amphibole (B. Molnár and E. Krolopp 1978).

A similar assemblage of heavy minerals was found in the loesses from the well known profile at Paks on the Danube (Fig. 1). It was examined by V. Codarcea (1977) and E. Szebényi (1970). The first mentioned author published results of quantitative analyses, so we could calculate the relations between the transparent components according to our principles. Mean values for 11 samples from the Paks profile are as follows: 1) garnets (35.4%), 2) epidotes and zoisite (16.1%), 3) amphiboles (12.8%), 4) rutile (11.1%), 5) disthene (6.2%). It is thus an association: GR/EP+AM+RU. Therefore, the predominance of medium resistant and non-resistant minerals is here even more evident than in the Voivodina loesses. Small differences existing between these two associations are difficult to interpret because analyses for the Paks profile were carried out for grains 0.3–0.06 mm, i.e. considerably coarser than those we analysed.

Loesses of the eastern Slavonia, which is SW part of the Pannonian Basin, are also characterized by a similar composition of the heavy minerals assemblage (R. Mutić 1975a, b). To demonstrate this fact, the analysis results of 15 samples from two profiles of the young Pleistocene proper loesses from the Vinkovci vicinity can be presented (Fig. 1). The mean content of five main components in the group of transparent minerals is as follows: 1) epidotes and zoisite (32.0%), 2) garnets (31.0%), 3) amphiboles (13.9%), 4) zircon (4.3%), 5) apatite (4.0%) (vide R. Mutić 1975b).

Therefore, a distinct predominance of medium resistant and non-resistant minerals, and the association of GR/EP+RU+AM or GR/EP+AM+RU type are typical for loesses of the southern and central part of the Pannonian Basin. This association is somewhat different than in the loesses of the lower Danube basin presented here in the introduction: GR/ZI+BI+RU. Differences between sets of minerals put in the denominator are perhaps important. However, they are difficult to interpret because analyses of loesses from the lower Danube basin were carried out for fractions smaller than 0.25 mm (H. Maruszczak and R. Racinowski 1968).

A similar composition of heavy minerals assemblage in loesses of the

Table 1. Results of composition analysis of heavy minerals assemblage in the

Profile	Sample No	Depth (m)	Content of main mineral groups (in %)($\sum$=100%)				Amount of analysed transp. grains				
			Opague minerals	Carbonates	Glauconite	Transparent minerals		Zircon	Rutile	Tourmaline	Disthene
Mošorin	1	8.0	15.8	42.1	–	42.1	616	4.4	7.8	1.1	0.5
	2	9.3	11.8	38.4	–	49.9	530	6.0	6.6	2.5	0.6
	3	10.2	43.4	9.5	–	47.1	423	11.1	12.8	0.7	0.9
	4	13.8	35.0	10.6	–	54.4	619	8.1	8.4	2.3	0.5
	5	14.7	24.9	32.4	–	42.7	426	10.1	8.2	1.2	0.2
	6	15.5	30.2	13.2	–	56.6	544	6.1	7.0	0.2	0.2
	7	20.5	34.1	5.4	–	60.4	379	9.0	11.1	0.8	0.5
	8	22.0	30.6	1.2	0.3	68.0	458	2.8	3.7	1.5	0.2
	9	24.4	6.7	69.7	0.2	23.4	414	6.0	9.2	1.9	–
	10	25.7	34.9	5.3	–	59.8	430	11.6	14.4	3.5	1.2
	11	28.3	10.0	76.8	–	13.2	421	11.2	14.5	1.0	0.5
	12	32.6	34.6	7.1	–	58.4	401	9.5	13.0	1.0	0.5
	13	35.8	19.9	51.6	0.2	28.3	484	17.1	12.2	1.9	0.6
Slankamen	1	2.1	14.1	44.4	–	41.5	386	6.7	8.3	1.6	1.0
	2	3.1	15.9	52.7	–	31.4	414	7.7	8.2	2.7	0.5
	3	4.3	17.4	32.6	–	50.0	472	6.6	7.2	1.1	1.1
	4	5.1	19.2	18.5	–	62.2	523	7.8	7.3	1.1	0.8
	5	6.4	15.2	42.9	–	42.0	434	5.5	6.2	0.2	0.7
	6	7.9	24.2	17.0	–	58.8	573	7.3	6.5	1.2	1.4
	7	8.9	25.6	13.0	–	61.4	504	5.8	7.9	0.8	0.6
	8	12.5	17.6	43.0	–	39.4	549	5.8	11.3	0,9	1.3
	9	13.3	20.3	33.5	–	46.2	435	4.6	7.6	0.9	1.6
	10	13.9	30.5	13.2	–	56.3	519	6.2	8.9	0.8	1.0
	11	15.1	17.5	36.1	–	46.4	370	8.6	10.3	1.9	1.4
	12	16.4	41.3	3.1	–	55.6	583	13.6	17.2	0.5	1.4
	13	21.0	35.2	14.1	–	50.7	487	8.4	8.6	0.2	1.0
	14	22.5	47.8	–	–	52.2	427	12.6	19.4	0.5	2.8
	15	26.0	41.8	1.2	–	57.0	455	14.1	11.6	0.9	2.0
	16	28.4	42.1	4.4	–	53.5	394	7.9	11.2	0.5	1.0
Batajnica – Kapela	1	6.6	16.2	48.8	–	35.0	372	6.2	12.1	2.2	1.6
	2	8.3	32.1	5.9	–	62.0	411	6.8	9.5	1.0	1.2
	3	8.9	33.7	4.0	–	62.3	403	11.7	11.9	1.5	0.5
	4	14.2	33.7	10.0	–	56.3	380	10.5	7.4	0.8	1.0
	5	14.7	30.2	13.8	–	56.0	431	6.5	9.3	0.9	1.2
	6	15.2	30.1	4.3	–	65.6	454	9.0	10.8	0.7	0.9
	7	15.5	41.4	2.7	–	55.8	428	11.0	8.6	1.6	0.5
	8	18.1	33.2	30.9	–	35.9	413	10.2	12.8	1.9	0.7
	9	19.7	41.1	0.4	–	58.5	374	6.4	11.2	1.3	1.1
	10	20.7	41.1	0.2	–	58.6	394	15.2	14.2	1.0	0.5
	11	24.1	57.6	2.5	–	39.9	398	29.4	19.1	0.5	0.3
	12	25.2	42.8	0.2	–	56.9	427	16.2	12.4	1.4	1.1
	13	27.0	33.9	–	–	66.1	448	4.0	4.5	2.0	0.5
	14	28.3	60.7	0.3	–	39.0	348	17.8	20.1	1.1	0.3
	15	29.9	42.9	23.6	–	33.4	397	12.8	13.4	1.5	1.5
	16	31.5	50.0	0.6	–	49.4	407	14.0	20.4	2.7	0.5
	17	32.4	38.8	35.7	–	25.5	432	21.5	16.0	1.9	0.2

fraction 0.06–0.01 mm of the loesses from three examined profiles in Voivodina

Transparent minerals (in %) ($\sum = 100\%$)										Indices of mineral composition	
Staurolite	Titanite	Garnet	Epidote	Amphibole	Pyroxene	Biotite	Chlorite	Apatite	Others	$\frac{R}{M+N}$	$\frac{Z}{G+A}$
2.8	2.3	31.7	17.0	15.4	–	5.8	6.0	1.8	3.4	0.15	0.09
1.3	1.3	22.5	15.8	14.2	–	14.2	9.6	2.3	3.2	0.18	0.16
2.1	2.1	36.2	11.6	7.6	–	5.4	4.0	2.4	3.1	0.33	0.25
3.7	1.3	40.1	16.0	8.2	–	3.7	2.9	2.1	2.7	0.23	0.17
1.6	1.4	40.6	14.1	9.4	–	4.7	4.9	1.6	1.9	0.24	0.20
2.0	2.0	48.7	13.6	8.1	–	6.1	2.2	1.8	2.0	0.15	0.11
1.8	1.1	25.3	19.3	8.7	–	6.6	8.7	2.4	4.8	0.26	0.26
0.4	0.4	7.9	7.6	8.1	–	50.7	12.0	1.3	3.3	0.09	0.18
3.4	2.2	21.3	14.0	15.7	–	11.6	7.5	2.7	4.6	0.21	0.16
1.6	1.4	21.4	19.8	7.9	–	2.6	3.5	4.9	6.3	0.42	0.40
2.1	1.4	29.7	15.4	4.0	–	3.3	10.2	2.6	4.0	0.36	0.33
2.7	1.7	24.4	20.9	8.0	–	2.7	3.7	5.7	6.0	0.31	0.29
1.4	3.3	30.8	17.4	2.1	–	3.9	3.7	2.5	3.1	0.45	0.52
3.4	1.6	42.2	11.9	11.9	–	4.9	3.1	1.0	2.3	0.20	0.12
1.9	2.4	37.4	11.6	9.9	–	7.0	5.1	2.2	3.4	0.23	0.16
2.1	1.9	35.4	15.3	16.9	–	3.6	4.2	2.3	2.3	0.17	0.13
3.6	2.1	33.8	17.2	11.9	–	4.6	3.8	2.1	3.8	0.19	0.17
3.2	1.4	36.9	15.9	14.1	–	4.8	4.6	2.1	4.4	0.14	0.11
3.5	3.1	33.0	16.8	13.3	–	4.0	3.3	2.8	3.9	0.18	0.16
1.4	4.0	42.7	15.5	10.5	–	3.4	2.0	1.8	3.8	0.17	0.11
2.7	2.7	47.7	11.5	6.6	–	1.3	2.7	2.6	2.9	0.22	0.11
1.1	2.8	37.0	15.2	11.0	0.7	3.9	7.6	3.0	3.0	0.15	0.10
2.5	2.9	42.8	14.8	10.4	–	2.9	1.7	1.9	3.3	0.19	0.12
4.0	4.3	28.4	14.0	8.1	–	4.9	2.7	6.5	4.9	0.26	0.24
3.6	3.2	33.1	16.1	2.6	–	0.9	0.7	3.2	4.0	0.45	0.38
3.3	2.5	41.9	14.6	7.8	0.2	2.0	1.8	4.1	3.5	0.21	0.17
3.0	3.7	28.8	18.0	2.6	–	0.2	0.7	2.1	5.4	0.48	0.40
4.4	2.4	44.2	10.5	2.2	–	0.7	1.8	1.8	3.5	0.36	0.30
2.0	2.8	49.0	18.5	1.3	–	0.2	0.5	2.3	2.8	0.24	0.16
1.9	1.1	25.0	14.2	15.9	–	7.0	6.7	1.6	4.6	0.26	0.15
2.2	2.2	36.7	18.2	10.2	0.5	2.4	3.2	1.5	4.4	0.21	0.14
1.7	2.5	38.7	12.9	8.7	0.5	1.7	2.5	1.0	4.2	0.33	0.25
1.6	3.4	33.4	15.5	13.4	0.3	3.4	2.4	1.3	5.5	0.23	0.22
2.6	1.6	29.7	16.5	15.5	0.2	6.5	4.2	1.8	3.5	0.20	0.14
1.8	3.5	38.1	14.5	9.9	–	2.9	1.3	1.8	4.8	0.26	0.19
1.4	1.6	34.1	18.0	10.5	–	6.8	1.6	1.6	2.6	0.27	0.25
1.4	2.9	26.9	18.4	7.5	–	6.8	4.8	1.7	3.9	0.33	0.30
4.3	2.9	40.4	19.0	4.0	0.3	1.1	1.3	2.1	4.5	0.23	0.14
1.0	3.8	31.2	18.8	5.1	–	3.0	2.0	0.5	3.6	0.44	0.42
1.3	1.0	29.1	9.0	3.8	1.5	1.0	0.5	0.5	3.0	0.96	0.89
4.0	1.1	24.8	17.8	9.6	3.3	2.8	0.5	0.5	4.4	0.43	0.47
3.8	0.7	15.0	17.2	18.8	24.6	0.5	0.7	–	8.0	0.12	0.12
1.1	1.4	29.3	11.8	5.7	6.3	0.6	0.6	0.9	2.9	0.64	0.51
1.5	1.8	31.0	10.1	5.5	3.5	8.1	4.0	1.8	3.5	0.38	0.35
2.0	–	25.1	18.7	6.9	1.5	3.2	1.0	1.5	2.7	0.59	0.44
1.6	0.9	32.9	10.9	3.0	0.7	3.2	3.0	1.2	3.0	0.65	0.60

southern part of the Pannonian Basin and of the lower Danube basin can be explained largely by geological (petrographic) conditions. In both these regions the parent material for loesses came from deposits transported by the Danube tributaries from the adjacent mountains. Therefore, this material was rather juvenile, because it was transported for relatively short distances. Freshness of this material is documented by the character of grain surfaces of heavy minerals. It is illustrated by the example of garnets (Table 2) among which grains without corrosion distinctly prevail (over 50–60%).

Table 2. Results of analysis of garnet surfaces in samples selected from three main stratigraphic units of loesses in the Batajnica-Kapela profile

Loesses	Younger			Older						Oldest		
Sample No	1	2	5	6	7	8	9	10	11	14	15	17
Non-corroded grains (in %)	68.8	63.2	59.7	65.6	49.7	69.6	63.5	66.9	50.0	58.3	55.4	51.7
Corroded grains (in %)	31.2	36.8	40.3	34.4	50.3	30.4	36.5	33.1	50.0	41.7	44.6	48.3
Grains with coatings of iron oxides (in %)	13.8	16.0	16.5	12.7	10.6	8.8	11.1	4.9	12.7	9.7	17.8	12.9

The character of parent material for loesses in Poland was different. Though fresh fluvial deposits also occur here their origin was various. Besides the material transported from the mountains, glacial deposits of different age were very important, too. The material of this second group was degraded and exposed for intensive weathering many times due to repeated advances of the Scandinavian ice-sheets. Therefore, the assemblage of heavy minerals in Polish loesses is characterized by a quite different association, in which the components most resistant to weathering prevail: ZI/GR+RU+TU. Most advanced degradation processes are documented by the character of grain surfaces of garnets among which grains without corrosion usually constitute 20–50% (H. Maruszczak and J. Morawski 1976).

Great differences in the composition of the heavy minerals assemblage between the loesses in Voivodina and Poland resulted not only from different geologic (petrographic) conditions. They should be also connected with climatic conditions. The parent material of Voivodina loesses was formed in warmer and drier climate than in Poland. It is distinctly indicated at least by the fact that the loesses in the first of these areas contain about two times more carbonates than in the second one. In Voivodina the parent material in the protogenic stage largely underwent weathering processes typical for temperate climate. Also during the syngenetic stage, i.e. in the period of loess accumulation, the southern part of the Pannonian Basin was largely beyond the periglacial zone. Even during the maximum stadial of the last glaciation, permafrost occurred in this area only in places (I.P. Gerasimov and A.A. Velichko 1982). Proper loesses were then accumulated mainly in drier sites, thus beyond local patches of permafrost (H. Maruszczak 1987). On the other hand, in Poland the parent material of loess in the protogenic stage was formed by different weathering processes typical not only for temperate but also periglacial and glacial environment.

In both compared areas the weathering processes developed with a different intensity also in the epigenetic stage. In this stage the climate in Voivodina was, as it is also nowadays, considerably drier than in Poland. These differences can be illustrated most simply by specific discharge of river waters. In Voivodina it is usually below 1.0 $l/sec/km^2$, and in the loess uplands of southern Poland — 3.0–4.0 $l/sec/km^2$. Therefore, carbonates in south-pannonian loesses are preserved even in layers older than 0.5 Ma. However, layers of the Polish loesses older than 0.2–0.3 Ma are usually decalcified (H. Maruszczak 1985, 1991).

Changes connected with weathering development in the epigenetic stage are documented, among other things, by composition indices of transparent heavy minerals assemblage. We use the most simple index which shows the relation between the most resistant minerals — R (zircon, rutile, tourmaline) and the sum of medium resistant and non-resistant minerals — M+N (all other). The mean value of this index for all 45 analysed samples from Voivodina is 0.30; the mean value for 21 samples of the young Pleistocene loesses is 0.21, and for the remaining samples, which represent the middle Pleistocene loesses and paleosols developed on them, it is 0.38. Such index value increase (from 0.21 to 0.38) should be probably connected mainly with weathering development during the epigenetic stage*. The qualitative composition of the heavy minerals assemblage has not been essentially changed during the last 0.5 Ma. Not only R/M+N but also Z/G+A index can be used to show the characteristics of heavy minerals assemblage in the Voivodina loesses, because the values of both indices behave similarly; they are listed in Table 3, and there is no need to comment them here separately.

Weathering processes developing inside a loess layer, i.e. during the epigenetic stage, caused also distinct changes in the content of opaque

* Epigenetic transformations connected with pedogenesis development are documented, among other things, by the data published by A. Bronger (1975). It can be concluded that in the humus horizons of the Holocene soil and of paleosols in the Voivodina loesses, the content of heavy minerals in the fraction 0.063–0.020 mm is somewhat smaller than in the horizons with carbonate illuviation.

Table 3. Mean content of main heavy minerals and mean indices of transparent mineral composition in three main stratigraphic units of the examined Voivodina loesses

	Opaque minerals (in %)	Carbonates (in %)	Main transparent minerals (in %)					Indices of mineral composition	
			Garnet	Epidote	Rutile	Zircon	Amphibole	$\frac{R}{M+N}$	$\frac{Z}{G+A}$
Younger loesses (from the last glacial cycle) .... 21 samples	24.1	25.7	36.8	14,8	8.6	7.2	11.6	0.21	0.15
Older and the oldest loesses (from preceding glacial cycles) .... 24 samples*	36,6	15.7	30.7	16.0	13.2	12.4	6.7	0.39	0.35
The oldest loesses (over 300 ka old) .... 10 samples	40.8	12.5	30.6	15.4	13.5	13.5	6.3	0.42	0.38
In all 45 samples	30.8	20.3	33.5	15.4	11.0	10.0	9.0	0.30	0.25

* Sample No 8 from the Mošorin profile was not included in the calculations.

minerals. The mean content of opaque minerals for 45 analysed samples is 30.8%; for 21 samples of the young Pleistocene loesses — 24.1%, for 24 samples of the middle Pleistocene — 36.6%, and for 10 samples of the oldest loesses — 40.8%. The content of carbonates changes inversely; it is 20.3% for all samples, for the young Pleistocene loesses — 25.7%, for the middle Pleistocene — 15.7%, for the oldest of the middle Pleistocene — 12.5%. Thus, with the loess age the content of carbonates in the heavy fraction decreases — as the total content of carbonates in loesses. These changes could be connected with developing aridity of the climate in the middle and younger Pleistocene (S.A. Hovan et al. 1989, A.A. Velichko 1990). Thus, the primary content of carbonates in the young Pleistocene loesses was probably greater than in the middle Pleistocene ones because the climate became more dry then. However, it seems that differences in the content of carbonates were, at least partially, the result of leaching during the epigenetic stage. This is indicated by the fact that in layers of older and the oldest loesses the content of secondary carbonates (pseudomycelia, concretions) increases (Fig. 1).

For comparison, suitable data for the Polish loesses can be given. They were obtained from analyses of heavy minerals composition of the same grain size, i.e. 0.06–0.01 mm (H. Maruszczak and J. Morawski 1976). The index of transparent minerals composition R/M+N for 59 samples from layers of different age is 0.87. For 10 samples of carbonate, young Pleistocene loesses the index is 0.52, and 1.36 for 19 samples of weathered (i.e. carbonate-free) middle Pleistocene loesses and paleosols connected with them. Thus, the difference between two extreme indices (0.52 and 1.36) is still bigger than in the Voivodina loesses. Therefore, it seems that weathering of loess layers during the epigenetic stage was developing better and faster in Poland than in Voivodina. Thus, the occurrence of carbonates in older loess layers points to limited weathering development in the epigenetic stage. So, the intraloessy paleosols in Voivodina usually containing carbonates, at least in the secondary forms, are not distinguished by increasing composition index of heavy minerals assemblage. On the contrary, the interglacial intraloessy soils in Poland and carbonate-free (decalcified) loesses are characterized by a distinct increase of this index.

FINAL REMARKS

1. The composition of heavy minerals assemblage was analysed in the typical loess fraction 0.06–0.01 mm, in layers to about 0.5 Ma old. In some samples separation of the heavy fraction was difficult probably due to aggregation of the finest grains. It seems that in the case of loesses it would be better to analyse grains of the fraction 0.06–0.03 mm.

2. The mineral composition of the examined loesses points to regional autochthony of their components (source material). In the assemblage of heavy minerals, medium-resistant and non-resistant components prevail. Their abundance points to a rather little intensity of weathering which affected grains in the protogenic stage. It could be connected with rather dry climate which varied here during the middle and young Pleistocene in the range typical for temperate zone.

3. A comparison of layers of different age indicates that in the epigenetic stage small changes of mineral composition occurred. With ageing of deposited layers the content of the most resistant components increased only slightly. It also could be connected with aridity of the climate which is documented by the fact that easily leachable carbonates are preserved even in the layers about 0.5 Ma old.

4. From the mineralogical point of view the Voivodina loesses distinctly differ from the Polish loesses. Though the Polish loess has also features of regional authchthony but: a) it is less loamy, so heavy minerals are easier to separate from the fraction 0.06–0.01 mm; b) in heavy minerals

assemblage the most resistant components distinctly prevail, which is the result of stronger weathering of grains in the protogenic stage. During this stage generally more humid climate was changed many times from temperate through periglacial to glacial type; c) in the epigenetic stage it underwent stronger weathering, so carbonates were leached and the content of the most resistant components increased with maturing of the deposit.

5. The analysed features of mineral composition indicate that the Voivodina loesses represent another geochemical and geographical type than the Polish loesses. Loesses occurring in Poland are typical for the periglacial environment. Those which occur in Voivodina should be included to the loesses of perimediterranean type (sensu H. Maruszczak 1990).

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STRESZCZENIE

Analizowano skład minerałów ciężkich w 46 próbkach, pobranych z trzech profili lessów wojwodinskich liczących do około 0,5 Ma; chronostratygrafię tych lessów przedstawiono w odrębnych opracowaniach (J. Butrym et al. 1991, M. Zeremski et al. 1991). Zróżnicowanie litostratygraficzne badanych profili oraz lokalizację próbek pobranych do datowania metodą TL i analizowanych w niniejszej pracy przedstawia ryc. 1 (do ryciny dołączony jest szkic położenia badanych profili w Wojwodinie oraz innych, omawianych dla porównania, z sąsiednich regionów).

Wyniki ilościowe analiz minerałów ciężkich, wyseparowanych z frakcji ziarna 0,06–0,01 mm, przedstawione są w tab. 1. Dla ułatwienia ich interpretacji opracowano diagramy udziału głównych składników, w grupie minerałów przezroczystych, uporządkowane zgodnie z układem stratygraficznym (ryc. 2). Analizowano także charakter powierzchni ziarn granatów dla wybranych próbek z profilu obejmującego lessy do najstarszych włącznie (tab. 2). Obliczono przeciętny udział wybranych minerałów oraz syntezujące wskaźniki składu zespołu minerałów przezroczystych dla trzech grup wiekowych lessów: młodszych, starszych i najstarszych (tab. 3).

Skład mineralny badanych lessów z Wojwodiny świadczy o regionalnym autochtonizmie ich tworzywa (materiału źródłowego). W zespole minerałów ciężkich przeważają składniki średnio i mało odporne. Świadczy to o stosunkowo małym natężeniu wietrzenia, kształtującego ziarno w stadium protogenetycznym. Można to wiązać ze względną suchością klimatu, który w środkowym i młodszym plejstocenie zmieniał się tutaj w przedziałach właściwych dla dziedziny umiarkowanej.

Porównanie warstw różnowiekowych wskazuje, że w stadium epigenetycznym następowały stosunkowo niewielkie zmiany składu mineralnego. Z postępującym wiekiem warstw

zdeponowanych wzrastał tylko nieznacznie udział składników bardziej odpornych. Można to wiązać także z suchością klimatu, na którą wskazuje fakt, że łatwo podlegające ługowaniu węglany zachowały się nawet w warstwach liczących około 0,5 Ma.

Lessy Wojwodiny składem mineralnym różnią się wyraźnie od występujących w Polsce. Wprawdzie less polski także wykazuje cechy regionalnego autochtonizmu, ale charakteryzuje się następującymi cechami: a) jest mniej gliniasty, dzięki czemu minerały ciężkie można łatwiej wyseparować z frakcji 0,06–0,01 mm; b) wśród minerałów ciężkich wyraźnie przeważają składniki odporne, co jest konsekwencją silniejszego zwietrzenia ziarna w stadium protogenetycznym, w którym klimat generalnie wilgotniejszy niż w Wojwodinie zmieniał się znacznie i wielokrotnie, od umiarkowanego przez peryglacjalny do glacjalnego; c) w stadium epigenetycznym efektywniej podlegał wietrzeniu, w związku z czym z wiekiem osadu szybciej następowało ługowanie węglanów oraz wzbogacanie udziału składników najodporniejszych.

Analizowane cechy składu mineralnego wskazują, że lessy Wojwodiny reprezentują inny typ geochemiczny i geograficzny niż lessy polskie. W Polsce występują lessy reprezentatywne dla środowiska peryglacjalnego. Te, które występują w Wojwodinie należy zaliczać już do lessów typu perymedyterańskiego (sensu H. Maruszczak 1990).