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MAR COMPARISONS BETWEEN DIFFERENT CHRONOMETRIC METHODS FOR TWO PROFILES IN THE BODROGKERESZTÚR AREA

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Abstract:
The deepening and exploration of the loess-palaeosol section at the foot of the Kopasz Hill at Bodrogkeresztúr have been carried out to expand the existing knowledge of the Carpathian foothill palaeoenvironmental factors and their impact. The study deals with particle size analysis, organic matter and carbonate content. For the presentation of age-depth models, the OSL dates of Bodrogkeresztúr (BKT) and the ^{14}C dates of Bodrogkeresztúr, brickyard 1 were used-, and the diagrams of the Accumulation Rates (AR) derived from them. These were compared with Mass Accumulation Rate (MAR) calculations based on OSL and ^{14}C data from BKT and ^{14}C data from Bodrogkeresztúr, brickyard 1. It became evident that there is a significant difference between the two sections, which may be due to the upland position, the overlap, or the wind tunnel effect. Sedimentological studies revealed coarser grain composition, however, the nearly complete absence of coarser sand fraction is also noticeable in the case of BKT. Also, the entire section is characterized by increased carbonate content due to post-sedimentation processes, recarbonization and leaching. The AR and MAR results show the difference between the suitability of different chronometric methods, indicating that the top of both sections may have been redeposited or eroded.

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Key words: loess, sedimentology, MAR, age-depth models, Bodrogkeresztúr

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INTRODUCTION

The loess-palaeosol profile of Bodrogkeresztúr (BKT; Bösken *et al*., 2019) (Fig. 1), located near Bodrogkeresztúr in the north-eastern part of Hungary at 48°8'50" N and 21°21'49" E, was modelled in 2014 by a German-Hungarian research team (University of Aachen and University of Szeged). The primary purpose of sampling and analysis was to supplement the previously surveyed area with data from a new section (Sümegi and Hertelendi, 1998; Sümegi and Rudner, 2001; Sümegi and Krolopp, 2002; Sümegi, 2005; Schatz *et al*., 2011, 2012, 2015; Sümegi *et al*., 2016). The previously investigated Bodrogkeresztúr, brickyard 1 profile – radiocarbon data of which are also used to create an age-depth model and MAR for the comparison, is located 100 m away from this new site. With the use of these two sections we aimed to compare the AR, MAR and the usage of age-depth models with different chronometric methods in these two profiles.

As a result, a summary article was published (Bösken *et al*., 2019), in which the authors discuss chronological, sedimentological and geochemical parameters and features of the section. To complement these assays, new assays such as organic and carbonate contents (LOI – loss on ignition; Dean, 1974), particle composition analysis, age-depth model and accumulation rate diagrams were made. The samples were taken in 4 cm resolution, from the 592 cm high wall, resulting 148 samples, but the uppermost 8 cm was not sampled.

For the study, the research team obtained three OSL dates, which can be used to produce today's depth models which show only a low degree of accuracy. Thus, we used the radiocarbon dating of the Bodrogkeresztúr, brickyard 1, similar to BKT, which was previously explored in its structure and composition to make the model. Neither the Bodrogkeresztúr, brickyard 2 would have been suitable because of its diverse composition, nor the Henye Hill section – which is a typical locality of Gravettian culture where mi-

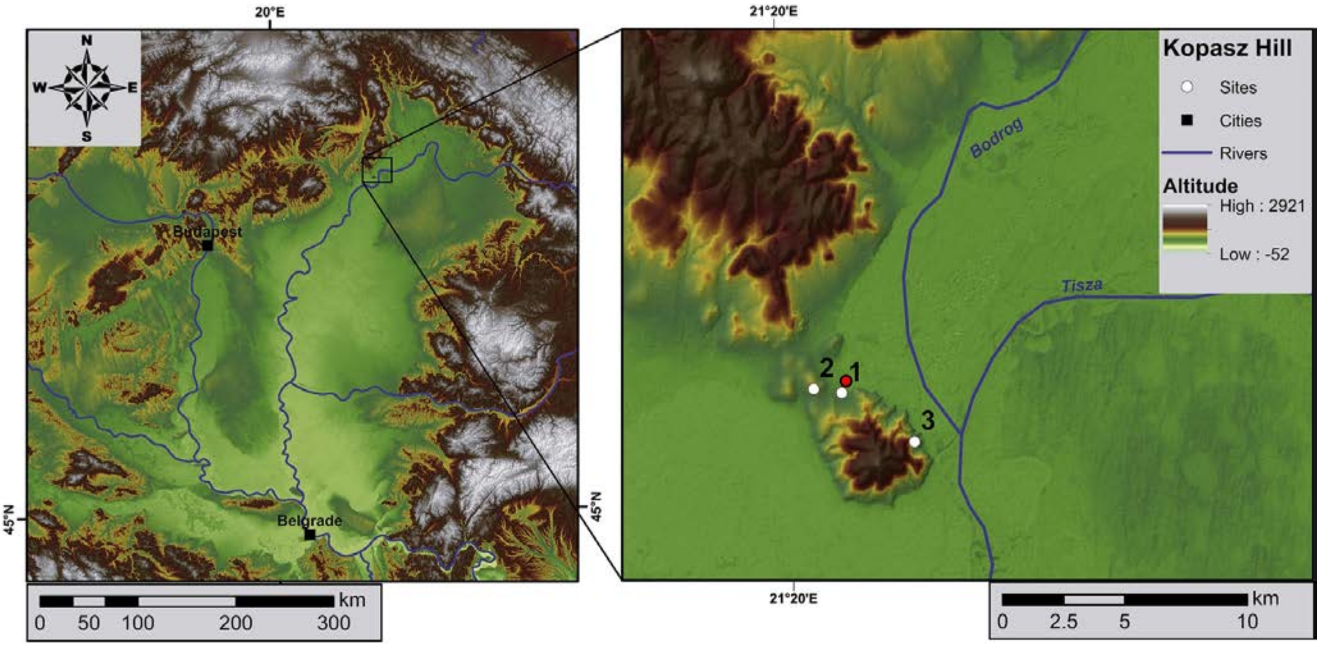

Fig. 1. The position of the Kopasz Hill in the Carpathian Basin (1. BKT, 2. Bodrogkeresztúr-Henye, 3. Tokaj, Patkó quarry, red dot: Bodrogkeresztúr, brickyard 1; modified after Bösken *et al.* (2019).

nor scattered bone and silica fragments were found (Sümegi *et al.*, 2016), with its single radiocarbon dating only.

METHODS

The particle size analysis of the samples collected from the BKT section was carried out based on the method of Bokhorst *et al.* (2011). Organic and carbonate matter values were obtained by using the Dean weight loss method (LOI; Dean, 1974). Measurements were made with the Omec Easysizer 20 Laser Sedigraph and with a furnace at the Department of Geology and Palaeontology (University of Szeged). The values of the laser sedigraph are plotted on a 100% stacked graph divided by the particle size ranges of the Wentworth scale (Wentworth, 1922). By analyzing the particle fractions in the diagram, the positions of loess and palaeosol horizons can be observed. In loess-palaeosol profiles, increased organic matter content may represent palaeosol horizons, as the result of the organic matter enrichment processes of pedogenesis. At the same time the weathering results in a decreased carbonate content. Therefore, carbonate accumulation zones appear due to the development of advanced palaeosols (Dokuchaev, 1879; Ding *et al.*, 2001).

Absolute dating

Knowledge of the ages is essential for the timely placement of the section and thus for correlation with each other (Sümegi, 2005). Two age determination methods were used in the examined segment, including OSL (optically stimulated luminescence; Huntley *et al.*, 1985) at three depths and radiocarbon dating at one (Bösken *et al.*, 2019). For the BKT OSL measurement methodology see Bösken *et al.* (2019). The radiocarbon ages from the two sections were calibrated using IntCal13 calibration curve with OxCal (Bronk Ramsey and Lee, 2013) and Calib 7.10 (Stuiver *et al.*, 1998) softwares. OSL measurements are reliable for up to 350,000 years and can vary by up to 5–10% (Rhodes, 2011).

Age-depth models

There are many age-depth models, from simpler (linear interpolation) to more complex ones. The essence of each model is to plot the values between the measurement points according to the given calculation method (Bennett, 1994). In the simplest approaches, sediment formation is uniform between the measured points, but this is not the actual case either since the rate of sediment accumulation is fluctuating. Therefore, models that rely on historical error values also consider previous data. The models were constructed with Bacon (Blaauw and Christen, 2011) program, used Bayesian MCMC (Markov Chain Monte Carlo) calculations. Both models were calculated in 4 cm sections, as the samples were taken and 100% of the results were fit in the 9% confidence interval (CI) ranges. In the BKT case, only the OSL ages were used, because the upward aging was distorted the result. In 592 cm, 149 sections were calculated by 33.22 mln iterations. At the Bodrogkeresztúr, brickyard 1 profile, the 700 cm resulted 176 sections by 39.16 mln iterations. The OSL and IRSL dates do not require calibra-

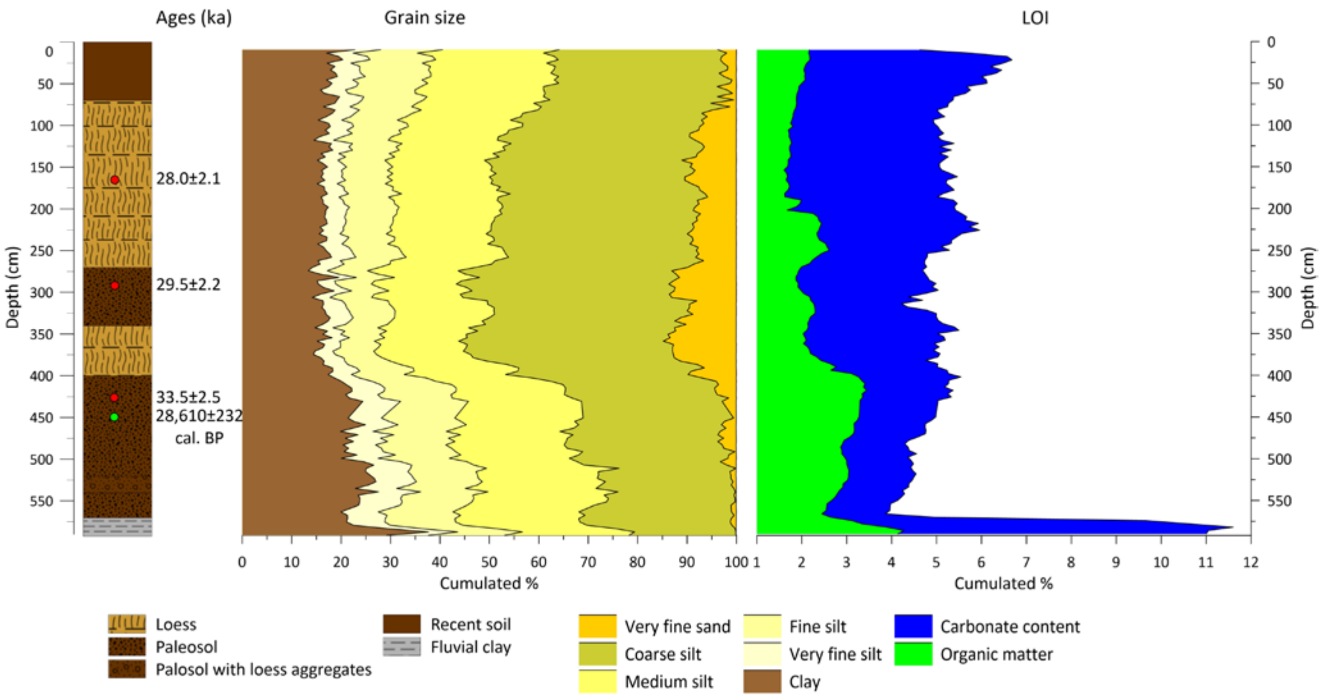

Fig. 2. Sedimentological (left) and LOI (right) results of the BKT section.

tion, but the uncertainty of the absolute dates obtained from them greatly influences the accuracy of the model. From this point of view, both OSL and IRSL (post-IR IRSL) measurements are unsuitable for making this type of model.

MAR calculation

By calculating the MAR (Mass Accumulation Rate), it shows the extent of sedimentation between two ages, considering the height of the section, sample density, and fraction size. Method of calculation:

$$MAR = LSR \cdot \rho_{dry} \cdot f_{eol} \left[\frac{gramm}{m^2 \cdot age} \right]$$

The LSR (Linear Sedimentation Rate) in the formula gives the thickness of the sediment formed over time (m a-1). The is the dry bulk density (g m-3), which for loess sediment is 1.5 g cm-3 according to Újvári *et al.* (2010). The parameter is the mass concentration of aeolian materials (Kohfeld and Harrison, 2001), which in case of loess is 1. The final result is obtained with the dimension g m-2 a-1 (Újvári *et al*., 2010; Sümegi *et al*., 2016, 2019).

RESULTS

Since the predominant particle size range of loess is medium and coarse silt (Pécsi, 1993), these fractions are present in the graph in increased amounts, whereas the increased content of clay is due to postgenetic processes. The presence of smaller grain fractions than sand may indicate weathering, but higher sand content may be a signal of a change in the energy of the transportation material (Pye, 1995).

Particle composition

In the publication of Bösken *et al.* (2019), based on grain composition results, the BKT profile was divided into 4 parts, which, can be further subdivided into a minimum of 7 (Fig. 2). The lowest of it, between 570–592 cm is a lower clayey fluvial sediment with high organic matter content (4%) and carbonate (7–8%) values. The part between 400 and 570 cm is an advanced palaeosol with upwardly increasing organic matter content (from 2.5 to 3.5%) and a significant proportion of coarse grain size (between 23–32%). Besides, loess aggregates appear between 520 and 540 cm. The next part (340–400 cm), which is a loess body, is marked by a coarser grain size upwards, with the highest fraction of sand (~15% very fine sand and ~0.5% fine and medium sand) in this section. Based on the increasing carbonate and decreasing organic matter values, this horizon may have been the carbonate accumulation zone of the poorly developed palaeosol above it.

Between 270 and 340 cm in the loess body, a poorly developed palaeosol can be defined according to the granular refinement, the increasing of organic matter and the decreasing of carbonate content. Above, between 240–270 cm a peak of organic matter with almost 3%, can be found. Between 70–200 cm a homogeneous loess body

Table 1 – OSL and radiocarbon data from BKT and Bodrogkeresztúr, brickyard 1 sections

Profile	Depth (cm)	OSL ages (ka)	Uncal age (years)	Cal BP age (years)	Lab code
BKT (Bösken *et al.*, 2019)	169	28000±2.1	–	–	C–L3799
BKT (Bösken *et al.*, 2019)	290	29500±2.2	–	–	C–L3797
BKT (Bösken *et al.*, 2019)	427	33500±2.5	–	–	C–L3795
BKT (Bösken *et al.*, 2019)	451	–	24580±90	28610±232	Beta–454081
Bodrogkeresztúr, brickyard 1 (Sümegi, 2005)	125–150	–	15388±147	18633±305	Deb–4358
Bodrogkeresztúr, brickyard 1 (Sümegi, 2005)	325–350	–	19813±170	23885±421	Deb–4335
Bodrogkeresztúr, brickyard 1 (Sümegi, 2005)	500–525	–	26851±398	30895±647	Deb–3049

with low sand content (5–10%), 2% organic matter and 3–4% carbonate content can be defined. The upper 70 cm is loose soil, where both organic matter, grain size increase upwards and carbonate also increases till the top 16 cm, when it decreases due to leaching.

Age-depth models

For the profiles, shown in Figs 3 and 4, age models were constructed using Bacon program (Blaauw and Christen, 2011) to obtain minimum, average, and maximum accumulation values per cm, and the charts were created with Grapher. Fig. 3 shows the section of BKT, including the OSL and the radiocarbon ages (Table 1), but the model was generated only by the OSL data which cause the homogeneity, because of its high (approx. 10%) error values. The mean accumulation is 0.49 mm/year, but the CI in one point reaches the 2 mm/year maximum value. In contrast, on Fig. 4 (Bodrogkeresztúr, brickyard 1) a more differentiated accumulation diagram can be observed. Its mean value is 0.28 mm/year which is almost half of the BKT's result. Usable information about the accumulation cannot be obtained from the lower loess body, because of the absence of any age data. The accumulation of the upper loess body is a little higher than the mean (~0.29 mm/year) but between

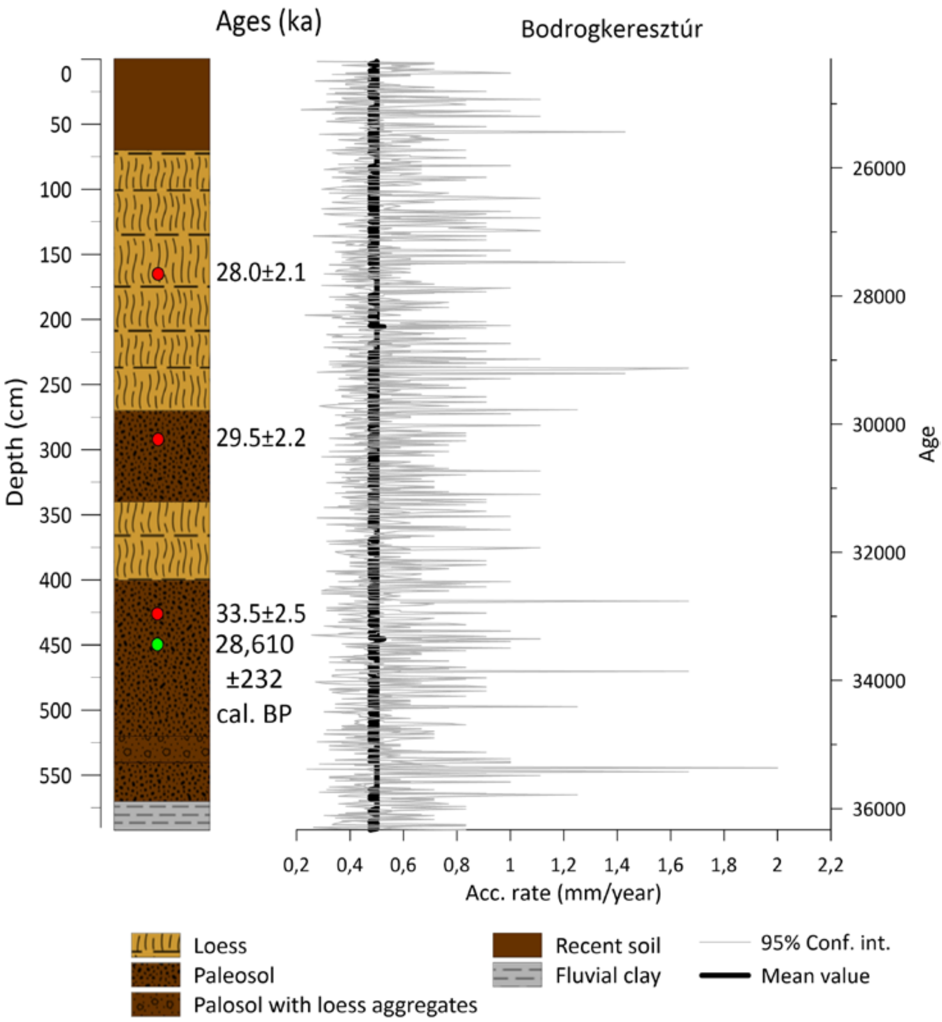

Fig. 3. BKT section with its OSL and radiocarbon dates and accumulation rate diagram.

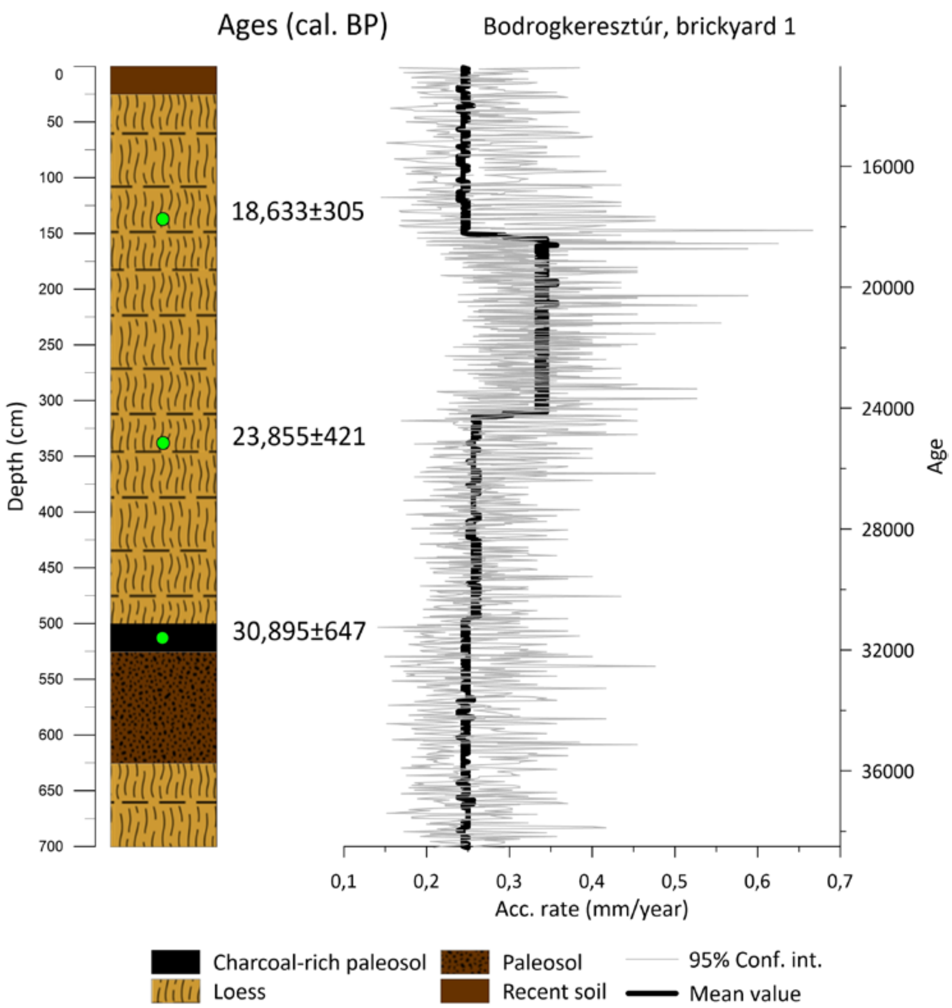

Fig. 4. Bodrogkeresztúr, brickyard 1 section with its radiocarbon dates and accumulation rate diagram.

18,000–24,000 cal. BP yr. a more dominant, 0.34–0.36 mm/year rate appears. Above that, the accumulation falls back to 0.23–0.24 mm/year.

MAR values

The MAR values nuances the AR values because, based on the models, we can separate the loess bodies, and we will be able to examine them separately. The MAR table of BKT (Table 2) was compiled from the OSL data, where we can see the same high accumulation results as in Fig. 3. In the upper loess body, we can see a similarity between the AR and MAR values, but there is still a difference. The AR rates here between 0.45–0.56 mm/year, which means 671–843 g m-2 a-1 dust accumulation. In the lower part a 0.49 mm/year accumulation can be seen, which means 738 g m-2 a-1 dust.

Table 3 shows the MAR of the Bodrogkeresztúr, brickyard 1, the ages for which were obtained from radiocarbon measurement. Here we have two ages from the upper loess body and one from the charcoal rich palaeosol (Fig. 4.), in absence of any age data, there is no information about the lower loess body. From the bottom to the top, we can see an increase in the middle of the loess body, but here the maximum AR is reaching the 0.38 mm/year, which means 571 g m-2 a-1 what is still lower than the lowest amount of dust in BKT (Table 2). The lower values similar or a little smaller to the AR, between 0.23–0.246 mm/year, which means 345–370 g m-2 a-1 dust accumulation.

DISCUSSION

The zones, delimited by the grain composition and the LOI examination show a high degree of coincidence, with unusually high clay content and low carbonate content in the entire section compared to loess. The difference between these two factors suggests that the material of the section is slightly weathered, since the fine effect of weathering and the decarbonisation caused by the lower pH increases the proportion of fine particles and decreases the carbonate

Table 2 – MAR results of the BKT section

Age (yr BP)	Depth (cm)	SR (cm/year)	ρ (g/cm3)	ƒeol	MAR (g/m2*age)
25744	70 (bottom of recent soil)	–	–	–	–
28000	169	0.045	1.5	1	671
29797	270 (bottom of the upper loess)	0.056	1.5	1	843
29500	290	–	–	–	–
31219	340 (top of the lower loess)	–	1.5	1	–
32439	400 (bottom of the lower loess)	0.049	1.5	1	738
33500	427	–	–	–	–

Table 3 – MAR results of the Bodrogkeresztúr, brickyard 1 section

Age (cal. BP)	Depth (cm)	SR (cm/year)	ρ (g/cm3)	ƒeol	MAR (g/m2*age)
13717	25 (bottom of recent soil)	–	–	–	–
18633	138	0.023	1.5	1	345
23885	338	0.0381	1.5	1	571
30461	500 (bottom of the upper loess)	0.0246	1.5	1	370
30895	513	–	–	–	–

content (Bohn *et al*., 1985; Ding *et al*., 2001; Molnár, 2015). Furthermore, the two studies support the hypothesis that the dark, clayey sediment on the underside of the section may have been of fluvial origin (Bösken *et al*., 2019), since high clay accumulation and high organic and carbonate content presuppose a fluvial sediment formation environment (Molnár, 2015; Molnár and Sümegi, 2016). The grain composition of this fluvial sediment is also distinct from that of the recurrent soil and the palaeosol layers.

The large difference between AR and MAR values is also partly explained by the upland position of the BKT section, which may result in higher accumulation values. Besides, the wind tunnel phenomenon assumed by the research team, may also increase the accumulation. It is also indicated that the Upper Tokaj Fossil Soil Horizon, which is a charcoal rich palaeosol containing Gravettian artefacts (Sümegi *et al*., 2016), does not appear in the surveyed section. Furthermore, 5,000 years of rejuvenation can be observed between the lowest OSL and the deeper radiocarbon values.

Comparing the AR values from the models and the MAR values derived from the ages and the models also, nuances of difference can be seen in both sites. As long as the AR values (Fig. 3.) totally uniform, the MAR values show changes in the accumulation inside the upper loess body (0.45–0.56 mm/year instead of 0.49), in the case of BKT. In the lower loess body, there are no further differences in accumulation. In contrast, in the case of Bodrogkeresztúr, brickyard 1, the AR and the MAR values almost the same, an increase in the accumulation can be observed from the bottom to the top. Based on the MAR, higher maximum accumulation value (0.38 mm/year instead of 0.34–0.36) can be seen. In absence of any age data, there is no information about the lower loess body. From the first MAR values of Table 2 and 3 and the ages it can be assumed that the top of the upper loess site is eroded or redeposited.

More accurate conclusions could be obtained by measuring and examining the radiocarbon dates of the profile since OSL / IRSL dates can only be examined with near-linear accumulation due to their high uncertainty. Therefore, the finding that younger sediments are older in OSL age determination than in radiocarbon age (Újvári *et al*., 2014; Bösken *et al*., 2019) should be treated with caution, so it is advisable to use ^{14}C for younger sedimentary contexts and use OSL or other luminescence age determination method on older sediments.

CONCLUSION

The loess-palaeosol profile, developed at Bodrogkeresztúr (Bösken *et al*., 2019), is the result of the changes in the palaeoenvironment at the foot of the Carpathians and allows us a better and more accurate understanding of the setting of the local Gravettian culture in the area. It deals with the analysis of the particle composition of the section, presents and compares the age models based on the OSL and radiocarbon derived from the radiocarbon results and accumulation rates of the section and the nearby Bodrogkeresztúr, brickyard 1. The Upper Tokaj Fossil Horizon appears both at Bodrogkeresztúr, brickyard 1 (30895±647 cal. BP), previously examined by Sümegi (2005) and at Henye Hill (30376±715; Sümegi *et al*., 2016) section – it contains Gravettian finds, but not in the BKT profile. This deficiency, as well as the significant accumulation, the smaller average particle size, the almost complete absence of the sand fraction and the increased carbonate content of the whole segment, are the results of sedimentation processes, recarbonization and leaching. The proximity of the sections, the consistency of their composition, and the differences in dating make it possible to study the accuracy and efficiency of dating methods through age-depth models. The accumulation rate diagrams from the data of our models show that the OSL/ IRSL correction methods are not suitable for constructing accurate Bayesian-type age-depth models because of their high uncertainty values. To get a better understanding of sediment accumulation, carbon isotopic data would be needed to clarify issues arising from accumulation differences. As radiocarbon analyses are no longer available at levels above 65,000 years (Stuiver *et al*., 1998a, b), it is necessary to use OSL assays at these levels for more accurate age determination (Újvári *et al*., 2014). However, our section is still at a chronological level measured by the radiocarbon dating method.

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