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DATING THE HOLOCENE INCISION OF THE DANUBE IN SOUTHERN HUNGARY

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Abstract

The alluvial development of the Great Hungarian Plain has greatly been determined by the subsidence of different areas in the Pannonian Basin. The temporal variation of subsidence rates significantly contributed to the avulsion and shifting of main rivers. This was the case in terms of the Hungarian Lower Danube when occupying its present day N-S directional course. The considerable role of tectonic forcing is also supported by the presence of different floodplain levels. Although, several channel forms are identifiable on these the timing of floodplain development has been reconstructed up till now mostly by the means of geomorphological analysis, and hardly any numerical dates were available. The main aim of this study is to provide the first OSL dates for palaeo-channels located on the high floodplain surface of the Hungarian Lower Danube, and to determine the maximum age of low and high floodplain separation on the Kalocsa Plain. For the analysis two meanders were sampled close to the edge of the step slope between the two levels. According to the results, the development of the investigated palaeo-meanders could be rapid. The formation of the older meander was dated to the Late Atlantic, while the possible separation of the high and low floodplain surfaces could start in the beginning of the Subboreal Phase.

Keywords: Hungarian Lower Danube, floodplain development, Holocene, OSL dating

INTRODUCTION

The alluvial development of the Great Hungarian Plain (GHP) has greatly been determined by the selective subsidence of different areas in the Pannonian Basin. The significance of tectonic control on fluvial processes has been indicated by several earlier research (e.g. Somogyi, 1961; Borsy, 1992; Gábris and Nádor, 2007; Kiss et al., 2015). The temporal variation of subsidence rates at different areas lead to the time-to-time avulsion and shifting of the main rivers and related tributaries. Major shifts however were also influenced by geomorphological processes, namely alluvial fan building and subsequent sliding off the rivers from these elevated surfaces.

Concerning the Danube a significant, but presumably gradual diversion occurred during the Late Würm Period (Pécsi, 1959; Pécsi, 1991; Mezősi, 2011) on its GHP section, when the river had shifted from its earlier NW-SE course to a N-S direction by sliding off its alluvial fan, the Danube-Tisza Interfluve (Mezősi, 2011). The process can also be explained by the activation of the Kalocsa and Baja Depressions, located near the Hungarian-Serbian border. According to Jaskó and Krolopp (1991), this subsidence zone attracted the Danube to its present direction at around 30-40 ka, and fault lines related to the zone are still active, though only moderately (Mezősi, 2011).

Obviously, in case a river shifts to a depression, let it be of geomorphic or tectonic origin, incision is generated, which propagates upstream and leads to the development of alluvial fan terraces indicating the major phases of changes (Bridge, 2003; Schumm, 1979). The age of fluvial forms on the abandoned floodplain (now terrace level) corresponds to the maximum, while that of active floodplain forms to the minimum age of incision. The numerical dating of fluvial forms therefore is crucial to reconstruct the timing of terrace formation and consequently the phases and sometimes even the rate of subsidence (Knighton, 1998).

The strath terraces of the Danube on its Hungarian upland section had been intensively studied with classical and more modern dating methods to assess the uplift rate of the adjacent members of the Transdanubian Mountains (Pécsi, 1991; Ruszkiczay-Rüdiger et al., 2005; Gábris, 2013).

Concerning the downstream GHP section of the river Pécsi (1959, 1967) investigated the geomorphological units, terrace materials and development of the floodplain and its levels. He concluded that the Northern part of the present GHP floodplain (Csepel-Solt Plain) is older than the Southern (Kalocsa Plain), and that the upper 10-20 m of sediments is almost completely reworked by the lateral movement of the Danube. Nevertheless, in both areas a low and a high floodplain surface (terrace) can be identified. The term high floodplain refers to the fact that although this surface lies 1-2 m higher it is still inundated by extreme floods. Consequently, Pécsi (1967) claims that fluvial deposits on the low and high floodplain cannot be separated in age, though the development of the high floodplain can clearly be related to the Late Pleistocene activation of the Baja and Kalocsa Depressions.

So far the timing of floodplain development in the area has been reconstructed mostly by the means of geomorphological analysis, hardly any numerical dates are available concerning the sediments and forms of the high floodplain surface. Two radiocarbon dates from subfossil drift woods placed the age of the right bank side high floodplain surface of the Danube, just opposite to the Kalocsa Plain, to cca. 40 000 and 11 000 BP (Hertelendi et al., 1991). In terms of Late Pleistocene and Holocen terrace surfaces, where the fluvial forms are still identifiable a straightforward method of dating is using optically stimulated luminescence (OSL), which determines the last exposure of sediments to sunlight, i.e. the time of sediment deposition. The method has been extensively applied in studies related to the dating of floodplain surfaces along several rivers (e.g. Kiss et al., 2013; Olszak et al., 2016; Ruszkiczay-Rüdiger et al., 2016; Meng et al., 2015).

By considering the above, the main aim of the present study is to provide the first OSL dates for palaeochannels located on the high floodplain surface of the Hungarian Lower Danube, and this way to provide a maximum age to the separation of the low and high floodplain levels on the Kalocsa Plain.

STUDY AREA AND SAMPLING

The study area is located on the Kalocsa Plain, which is situated at the middle section of the Hungarian Lower Danube (Fig. 1). The floodplain area is characterised by two floodplain levels: the elevation of the lower floodplain surface (A-level) is between 90 and 92 m asl, while that of the higher floodplain surface (B-level) is between

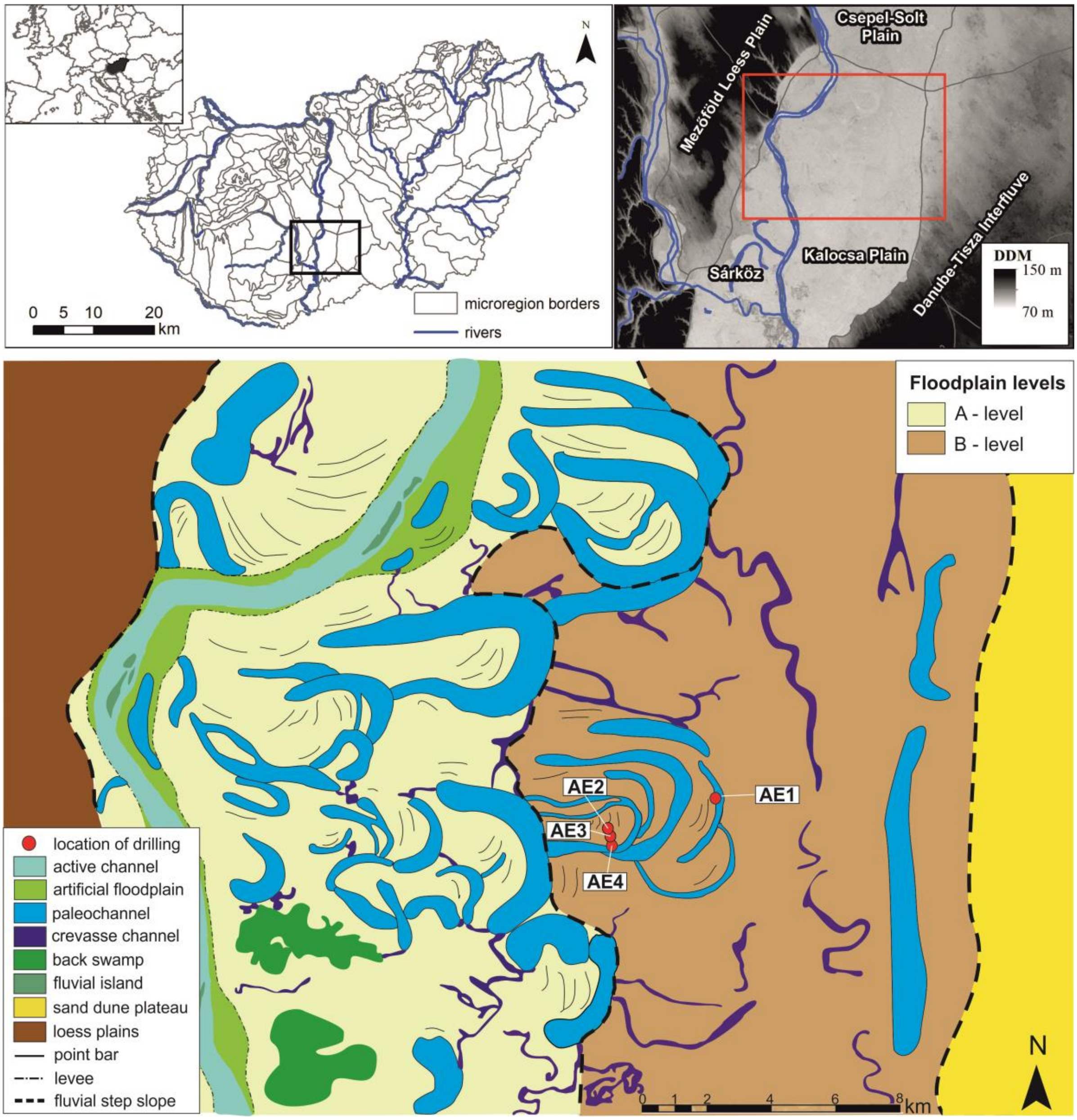

Fig. 1 Location of the study area, geomorphological setting, and sampling points

92 and 94 m asl. Eastwards the study area is adjacent to the Danube-Tisza Interfluve covered by sand dunes and characterised by a relief between 96 and 105 m asl. Westwards loess plains border the Danube plains, with an elevation reaching even 150 m asl (Fig. 1).

Sediment samples were collected from two palaeo-meanders located on the B-level to determine the maximum age of floodplain surface differentiation, and the time of active B-level floodplain development. The two selected palaeo-channels belong to two separate meander systems. Based on the geomorphological map (Fig. 1), both systems developed through chute cut-offs and consequent meander growth, being characteristic in case of meanders on the lower floodplain as well.

In case of the eastern meander (width=170 m, R=1,7 km) one drilling was made (AE1) to sample channel sediments, as point bars were hardly recognisable on the field (Fig. 1). At the AE1 drilling point 3 OSL samples were collected from 60, 130 and 190 cm (AE1/1, AE1/2, AE1/3). In terms of the western meander (width: 370 m, R=720 m), right on the edge of the B-level, point bars were sampled at three locations (AE2, AE3, AE4), from depths 70, 70 and 110 cm, respectively.

OSL samples were mostly taken from layers of pure sand, however in terms of AE1 upper two samples were categorised on the field as sandy silt. Undisturbed sampling was made with steel cylinders applicable to an Eijkelkamp hand drill system. Samples weighed approximately 200 g. Background samples were also collected from above and from below each OSL sample.

METHODS

The geomorphological map of the study area was compiled on the basis of 1:10 000 scale topographical maps, with 1 m contour line interval, occasionally supplemented by 0.5 m contour lines,

The age of sediment samples was determined by optically stimulated luminescence. Samples were either composed of medium sand, or the mixture of fine sand and silt, though containing an adequate amount of medium sand in the latter case as well, thus the so called coarse grain quartz dating procedure was applied.

In terms of fluvial samples usually the sand sized quartz fraction is investigated anyway, assuming that it usually has more chance for complete bleaching during sediment transport. The preparation of the samples followed usual laboratory techniques (Aitken, 1998; Mauz et al., 2002). After removing the samples from the cylinders they were dried and the 90-150 μm fractions was separated by sieving. The carbonate and organic material content was removed by repeated treatment in 10% HCl and 10% H_2O_2. A Na-polytungstanate (LST Fastfloat) heavy liquid flotation was applied for the separation of the quartz fraction. This step was followed by a 50 min etching in 40% HF, aiming at removing any remaining feldspar contaminations and the outer layer of quartz. Purified quartz grains were adhered to stainless steel discs of 10 mm diameter by silicone spray. For OSL a Ø6 mm mask for the final measurements Ø2 mm mask was applied to control the number of grains on a disc. A number of aliquots were prepared for luminescence tests and for equivalent dose (D_e) determination. Measurements were made using a RISOE DA-15 TL/OSL luminescence reader by applying the single aliquot regeneration (SAR) protocol (Wintle and Murray 2006).

A preheat test was used for determining optimal heating parameters during the SAR measurements. Preheat temperatures were varied between 180 ºC and 300 ºC. During the tests 1) SAR recycling ratios (ratio of two sensitivity corrected luminescence signals generated by identical regeneration doses); 2) recuperation (thermal and photo transfer of electrons to OSL traps); and 3) dose recovery (ratios recycling ratio being within 1.00 ± 0.05, De error being lower than 10%, recuperation being lower than 5%) were monitored to determine the best thermal treatment. A combined preheat and dose recovery test was performed. Preheat temperature was increased 200 °C SAR measurements were performed on 48–144 aliquots, depending on the proportion of acceptable measuremets. Acceptability was assessed using the standard rejection criteria for each aliquot. Thresholds of rejection were the following: recycling ratio being within 1.00 ± 0.05, De error being lower than 10%, recuperation being lower than 5%. Possible feldspar contamination was also monitored by measuring IRSL/OSL depletion ratio at the end of the SAR procedure. The first 0.5 s of OSL curves was taken as the signal, the last 10 s as the background of measurements. Sample De was calculated from aliquot D_e using either the minimum age model (MAM) (AE1/1, AE1/2), or the central age model (CAM) (AE1/3, AE2, AE3, AE4) depending on the dispersion D_e values (Galbraight et. al 1999). Environmental dose rate (D*) was determined by using high-resolution, extended range gamma spectrometry (Canberra XtRa Coaxial Ge detector), using 500 cm^3 marinelli beakers. Dry dose rates were calculated using the conversion factors of Adamiec and Aitken (1998). Wet dose rates were assessed on the basis of in situ water contents. The rate of cosmic radiation was determined by considering burial depth following the method of Prescott and Hutton (1994).

RESULTS AND DISCUSSION

During the evaluation, a major problem was the low luminescence signal intensity and the low sensitivity of the samples (Fig. 2). Consequently, numerous aliquots did not pass the necessary criteria and were finally rejected from D_e calculation. Therefore, a high number of aliquots were measured finally to get an adequate amount of results for the statistical analysis

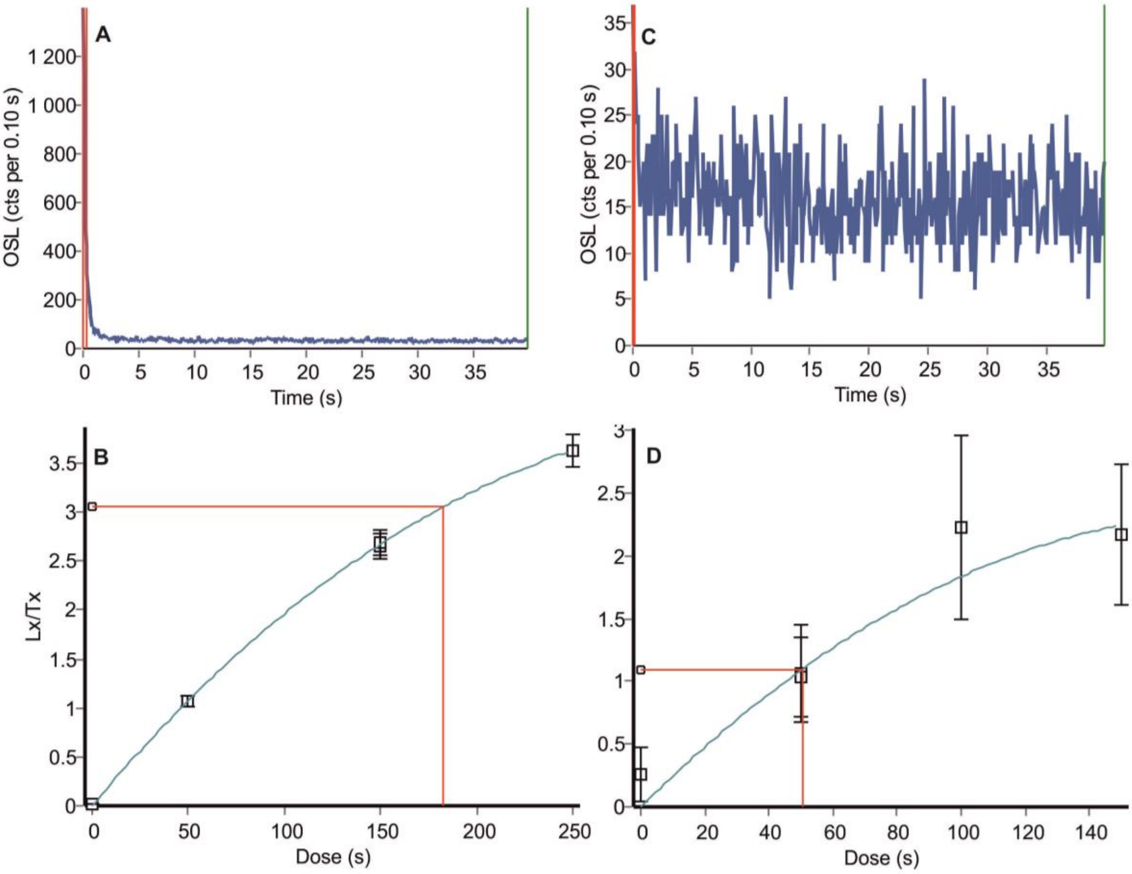

Fig. 2 Figures A and B show an appropriate shine-down curve (A) and dose response curve (B), meanwhile C and D figures represent the low intensity

of equivalent doses. In average 30-40% of the aliquots turned to be acceptable for sample D_e assessment (Table 1).

In case of preheat tests the problem of low sensitivity was a less significant issue, as due to the higher number of grains (Ø6 mm mask) on the measurement discs luminescence response was considerably higher. The most appropriate preheat temperature for all samples was 200 °C for the SAR measurements (Fig. 3), since the dose recovery ratio at this temperature was well within the limits of acceptability. Nevertheless, the spread of the recycling ratios was wider in some cases and recuperation was over 5 % in case of samples AE1/2 and AE4. Consequently, the final SAR measurements were carried out with using a hot bleach treatment, i.e. inserting a high temperature (280°C) optical bleaching at the end of each measurement cycle. By the application of the right temperature treatment the samples performed adequately to retrieve reliable results and ages.

Regarding drilling point AE1 the sampled sand layers at 70, 130 and 190 cm depth were dated to 6.7±0.6 ka, 7.2±0.4 ka and 6.1±0.5 ka, respectively. The lowermost sand layer (AE1/3) was characterised almost exclusively by medium sand, and the distribution of individual D_e results showed a central tendency (Fig. 4), consequently, it is suggested that this sample had undergone the most complete resetting process during transportation and sedimentation. Therefore, both from a sedimentological, and

Table 1 Dose rate, equivalent dose and age data of the investigated samples

Sample	Aliquots (used/measured)	Depth (m)	Moisture content (%)	U (ppm)	Th (ppm)	K (%)	D* (Gy/ka)	D_e (Gy)	Age (ka)
AE1/1	30/72	0.6	13±1.3	2.95±0.02	5.05±0.06	1.38±0.04	2.80±0.08	20.27±0.82	6.7±0.6
AE1/2	27/48	1.3	21±2.1	2.86±0.04	5.59±0.07	1.36±0.04	2.46±0.07	24.79±0.86	7.2±0.4
AE1/3	25/96	1.9	33±2	2.76±0.03	6.13±0.07	1.34±0.04	2.37±0.07	18.49±1.61	6.1±0. 5
AE2	26/72	0.7	16±2	2.87±0.02	4.53±0.06	1.22±0.04	2.49±0.07	11.76±0.65	4.7±0.3
AE3	35/64	0.7	7±2	1.80±0.02	3.63±0.04	1.13±0.03	2.27±0.07	11.05±0.5	4.9±0.3
AE4	58/144	1.1	7±2	2.22±0.02	3.68±0.04	1.18±0.03	2.55±0.08	12.87±1.07	5.0±0.5

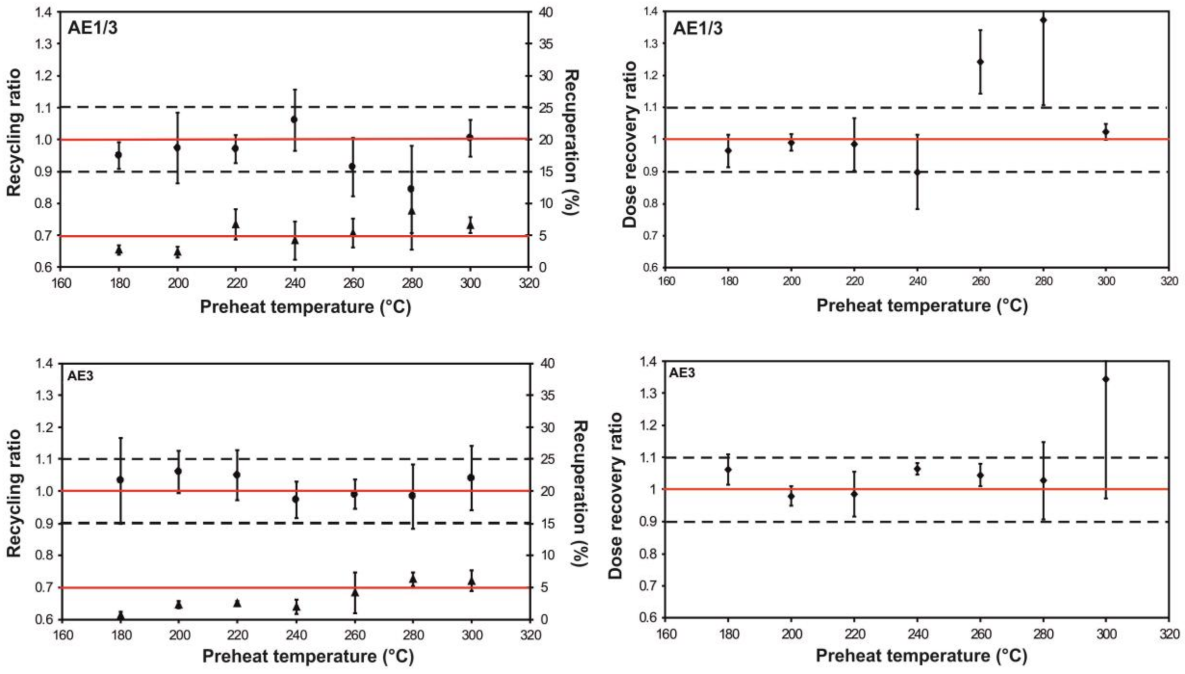

Fig. 3 Preheat and dose recovery tests of the samples. The red line and the dashed line mark the three criteria and the errors of the criteria

from an OSL point of view this sample can represent the time of major fluvial activity. This is in correspondence with the major findings of Tóth et al. (in press), who measured almost complete resetting in terms of modern coarse grain sediments along the present day Danube.

In the meantime the upper two samples yielded somewhat higher ages than AE1/3, which can be explained by their different sedimentology, i.e. the high proportion of fines, which refers to a post formational, lower energy deposition, being less favourable in terms of OSL signal resetting and leading to possible age overestimation. Based on the results, in case of sample AE1/2, characterised by the finest grain size, the age could be overestimated by more than 1 ka, while in case of the coarser AE1/1 by more than 0.6 ka (Fig. 5).

The ages of samples AE2, AE3 and AE4 were very similar and stayed within error, AE4: 4.7±0.3 ka, AE6: 4.9±0.3 ka, AE7: 5.0±0.5 ka (Table 1). As the formation age of point bars cannot be separated, results refer to a relatively fast meander development between 4.7 and 5.0 ka, reflecting the dynamic nature of Danube fluvial activity.

Based on the first age results from the area, the Danube was actively forming its present day high floodplain up till 5 ka. Consequently, the maximum age of incision and the development of the present day floodplain can be placed to the beginning of the Subboreal Phase. However, in order to question or reinforce the morphological interpretation of Pécsi (1967), i.e. the formation time of the higher and lower floodplain levels are hard to separate, needs further investigation in the area, especially focusing on lower floodplain palaeochannels. Nevertheless, the OSL dates presented here give a framework for further studies, and also imply that if there is a separation time between the two levels, it must be in the second half of the Holocene.

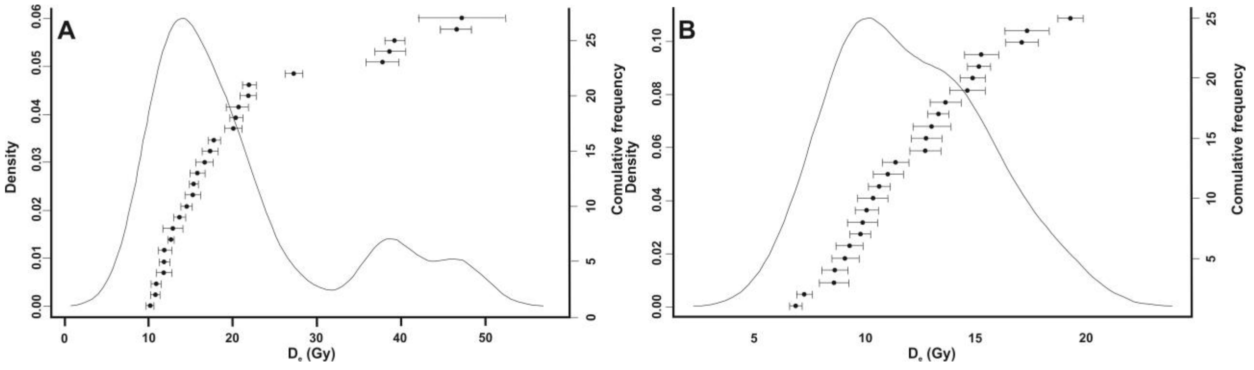

Fig. 4 Dose distribution of individual De of AE1/2 (A) and AE1/3 (B). In case of AE1/2 MAM, meanwhile in case of AE1/3 CAM was used for the calculations

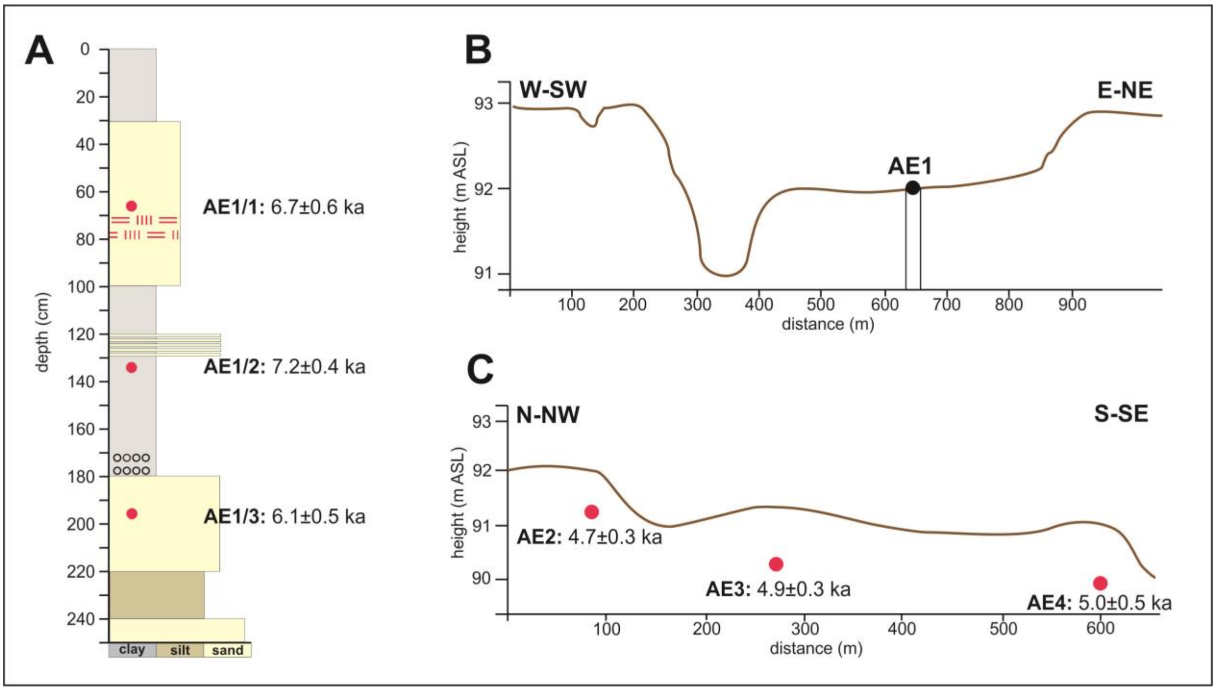

Fig. 5 The results of the two sample site. A: The AE1 drilling point, B: The ages of AE1 drilling point, C: The ages of the second site point bars

CONCLUSIONS

Floodplain development along the Hungarian Lower Danube has previously been reconstructed mainly on the basis of geomorphological evidence. The present study has provided the first OSL dates concerning the fluvial forms of the high floodplain surface on the Kalocsa Plain and therefore on the entire GHP section of the river.

The OSL sensitivity of the sampled sediments is low, therefore a high number of measurements is needed to get the necessary amount of results for the reliable statistical analysis of equivalent doses. However, by the application of the right temperature treatment the samples performed adequately to retrieve reliable results and ages.

The development of the investigated palaeomeanders could be rapid. In case of the older meander the age of channel forming fluvial activity can be inferred from the lowermost sample, yielding a 6.1±0.5 ka age placing the development of the meander to the Late Atlantic Phase. In terms of the younger meander, on the edge of the high floodplain the ages of consecutive pointbars were in the range of 4.7±0.3 ka and 5.0±0.5 ka, meaning, that the separation of the high and low surfaces could start in the beginning of the Subboreal Phase or later.

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