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INVESTIGATION OF FLUVIAL PROCESS BY OSL DATING ALONG THE HUNGARIAN SECTION OF THE DANUBE

Theses of Dissertation

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1. Introduction and aims

The evolution of the fluvial network in the Carpathian Basin is one of the key topics of the Hungarian geomorphological research, because a significant part of this territory is situated on floodplains and alluvial fans, which were actively formed and developed not only in the past, but also in more recent ages. Nevertheless, setting up the numerical timeframe of the fluvial processes are vital to reveal and understand the dynamics of the fluvial evolution of the area. To achieve this goal, several aging technics are available nowadays, but probably the optically stimulated luminescence (OSL) method is one of the most appropriate, which allows the age determination of the deposition time of sand and silt sized mineral grains available almost everywhere. Consequently, nearly any geomorphological process and its dynamics can be reconstructed by this method.

However, a basic prerequisite for luminescence dating is the sufficient light exposure of sediments during the transportation, because the complete resetting of the sediments can be ensured only this way. In term of fluvial sediments, the insufficient exposure of sediments can cause incomplete resetting and thus the preservation of residual signals in the sample, resulting in significant age overestimation. The incomplete resetting depends on several factors e.g. the duration of sunlight exposure, the length, distance, mode and recurrence of the transportation process, or the mineralogical composition and size of grains (Alexanderson 2007, Rittenour 2008). These effect can be hardly assessed and corrected during the OSL dating of older sediments. The degree of resetting in a river system can be estimated by the assessment of modern, or known-age sediments (Rittenour 2008).

In addition, in case of young sediments, another factor, the thermal transfer can further increase the age overestimation (Truelsen és Wallinga 2003). The results of these tests on young sediments can also be used effectively for older samples to enhance the accuracy of the age determination.

The Danube is the main river of the Carpathian Basin and it dominates its hydrography. Several research investigated its channel changes and morphology (Pécsi 1967, Somogyi 1974, Frisnyák 1977, Ruszkiczai-Rüdiger et al. 2006, Gábris 2007), however only a few numerical age data is available for the lowland section of the Danube, therefore several questions remained open related to the changes of flow directions on the alluvial area. Earlier studies not distinguished between terraces and floodplain levels on the section of the Danube (Cholnoky 1941, Bulla 1941, Pécsi 1959, Pécsi 1968). Hitherto the evolution of floodplains was investigated mainly by the means of geomorphological analysis, hardly any numerical dates are available concerning the sediments and forms of larger floodplain areas Sümegi et al. 2011, Sipos et al. 2014). According to Pécsi (1967, 1991) the terrace II/a can be observed between south of Budapest and the southern end of the Kalocsai-Sárköz and its development can be estimated to the Late Pleistocene. These estimations were proved also by later studies. The floodplain can be divided to two floodplain levels, the upper (terrace I.) and lower floodplains (Pécsi 1967, 1968), the development of the upper floodplain was estimated to new Holocene, but it is also stated that the chronological separation of the two floodplain levels is not obvious (Pécsi 1991).

Since the river regulation and flood protection works in Hungary, the importance of floodplain aggradation was increased. The Hungarian investigations in this topic are mainly applying granulometry, maps and digital elevation models (Károlyi 1960, Braun et al. 2003, Sándor és Kiss 2006). For the Danube, only a few investigations were implemented and they mainly focus on the aggradation processes of palaeo-channels and oxbows (Somogyi 1974, Tamás és Kalocsa 2003, Szabó 2007).

Considering the above described questions and problems, two main aims with several objectives were defined in this research:

(1) Complex assessment of the OSL characteristics of fine and coarse grain Danube sediments to achieve a more precise age determination and identification of spatial trends and patterns

The OSL dating of fluvial sediment may have significant age uncertainties. Therefore, the systematic assessment of coarse (sand) and fine (silt) grained modern fluvial sediments, deposited during the flood in 2013 was aimed along the whole Hungarian reach of the Danube, which can help to improve the accuracy of the dating results. These results can support future assessments of Danube sediments on the Hungarian section from the Kisalföld to Mohács. The spatial extension (~400 km) of these measurement is unique in this research field.

The following objectives were set up:

- Assessment of the influence of thermal transfer on the dating results of younger sediments
    - Determination of residual doses and thus the correction factor necessary for the measurement of older sediments.
    - Comparison of the results of thermal transfer and residual doses in terms of fine and coarse grain samples.

- Identification of any spatial trends or patterns in the results and the affecting geomorphological processes.

(2) Reconstruction of the floodplain evolution on the Kalocsai-Sárköz area

The second main of this research was to delineate the different floodplain levels and provide timeframe of the fluvial activity of the Danube in the region. The following objectives were set up to realise this aim:

- Delineation of the floodplain level on the basis of the available geomorphological maps, cross-sections of the floodplain based on 1:10 000 topographic map and SRTM DEM.
- Determination of the age of the floodplain levels. Dating of Lake Kolon sediments, a probable paleo-channel of the Danube.
- OSL dating of paleo-channels and point-bars on the Kalocsai-Sárköz
- Determination of meander migration rate based on OSL ages
- Assessment of the recent floodplain aggradation rate on a study site

2. Study area

Danube river with its 2860 km length is the second largest river in Europe, flowing from the Black forest to the Black-sea. The catchment of the river is 800 000 km2, and it is flow through 10 countries. The Danube can be divided into 3 main reaches: (1) the Upper Danube from the source to the Morava river, (2) the middle reach from the Morava to the Iron Gate, including the Carpathian Basin and (3) the Lower Danube from the Iron Gate to the estuary (Pécsi 1967, Frisnyák 1977). The Danube is the main river of the Carpathian Basin and it dominates its hydrography (Frisnyák 1977). The length of the Hungarian section is 417 km. On the Hungarian section, the river enters the lowland area and turns to North to South direction, where it lefts the Visegrád Gorge. Between Vác and Budapest and also between Budapest and Fajsz the river shows anabranching channel form, forming islands and bars in the channel e.g. Szentendei-, Csepel-, and Mohácsi-island, and several former islands were disappeared or joined to the floodplain by closing the side-channels.

One of the key questions in Hungarian geomorphological research is the reconstruction of the past channels shifts of the Danube on the Great Hungarian Plain. According to Somogyi (1961) the channel shifting of the Danube to the Visegrád Gorge was related to the Late Pliocene tectonic movements, caused by the intensive subsidence of the Gödöllő-Szolnok-Titel area. However, Mezősi (2011) highlighted that there may be other reasons of the channel shifting, e.g. sliding off the river from its alluvial fan, or the basaltic volcanism on the edge of the Little

Hungarian Plain (Kisalföld). More recent studies suggest that the Danube appeared on the area only in late Pleistocene (Ruszkiczai-Rüdiger et al. 2006).

Pécsi (1953) pointed out that two flood-free floodplain levels could be separated in the Danube floodplain. Among them, he identified the higher level as a terrace I and considered the time of its formation as early Holocene (Pécsi 1959). The lower level was identified as upper floodplain and this dual division was extended to the low floodplain level. In a later study he found that no significant age difference could be recognised between the floodplain levels (Pécsi 1968).

The modern samples for the analyses were collected on the floodplain along the whole Hungarian section of the Danube. Altogether 30 samples were collected on the right side of the river, where the sediment deposited by the flood in 2013 was sampled. To assess the upper floodplain samples were collected at the Lake Kolon, from the are of the Tókás (Izsák) and the Közös-forest (Páhi). The Lake Kolon is situated on the border of the Danube floodplain area dominated by fluvial forms and the blown sand area. The surrounding area of the study site is dominated by blown sand, however the reworked sediments of the paleo-Danube can also be found (Dövényi 2010).

The lower floodplain level was sampled at 6 sampling site on the Kalocsai-Sárköz (Nagykékes, Alsóerek, Kalocsa, Öregcsertő, Bogyiszló, Fajsz), where the sediment of palaeo-channels and point-bars was analysed. Furthermore the lower floodplain level was also sampled on the Solti-sík, where a sampling site was allocated on the active floodplain at Dunavecse. At this site, beside the period of floodplain evolution, the rate of floodplain aggradation could also be analysed.

3. Methods

The delineation of the floodplain levels was carried out on the basis of the 1:500 000 geomorphological map of Hungary (Pécsi 1975, Gábris 2017), the National Atlas of Hungary, however for the delineation of the floodplain levels on the lower floodplain with different elevation, 1:10 000 topographic maps and a DEM made of it were used. On the Kalocsai-Sárköz area, cross-sections were drawn and the floodplain levels were identified by elevation data, afterward the geomorphological forms on the different floodplain levels were also identified.

In of modern samples, collected for detailed methodological assessment, bot sandy (90-150 μm) and silty (4-11 μm) samples were collected, wherever it was possible. After the delineation of the upper and lower floodplains, both floodplain levels were sampled. The upper floodplain level was sampled at the Lake Kolon, on the oldest part of the lower floodplain, samples were taken from a borehole in a backswamp, while on the younger part of the lower floodplain point-bars and backswamps between the bars were sampled.

During the assessment of the OSL characteristics, tests were performed to define the factors that influence the equivalent dose. These tests were implemented on the quartz content of both sandy (coarse grain) and silty (fine grain) modern sediments. Firstly, the proportion of the OSL quartz components (fast, medium and slow) was defined, which was important for further assessment, because the higher the ratio of fast components, the more suitable the sample for OSL measurements. In the next step, the preheat test was used for determining the optimal heating parameters during the SAR measurements to enhance the accuracy of the measurements. After that, tests were conducted to determine the reproducibility of the measurements in laboratory conditions. Furthermore, the factors that may cause age overestimation during the calculations were assessed, e.g. the thermal transfer (TT) causing the electrons during subsequent heating back into the fast OSL component traps. Thus the measured equivalent doses are higher and consequently the resulting ages are also higher. The thermal transfer occurs mainly during the hot bleach (HB) included at the end of SAR cycles. Age overestimation could also be arisen because of the residual doses (D_{res}) remaining in the samples due to several factors in sediment formation. Using these results, correction was applied during the measurement of the older samples in any case where it was necessary for a more precise age determination.

4. Results

4.1. Characteristics of the floodplain levels

On the Danubian Plain, four floodplain levels were delineated on the basis topography and geomorphological forms, mainly fluvial forms were identified on the different floodplain levels. The loess covered area west of the Danube and the sand land east of the Danube descend to the floodplain levels of the Danube plain with 15-25 meter bluffs. The alluvial plain was earlier divided to two floodplain levels: the upper and lower floodplains by Pécsi (1967, 1991), however this research revealed that latter can be further divided into three levels: the oldest level (level I/3) that is situated in the western front of the II level east of the Danube, the younger level I/2., can be observed in smaller patches on both east and west of the Danube, and the youngest level I/1 was identified on both the right and left bank of the Danube, but also not uninterrupted. The level II has an elevation of 95-97 m a.s.l., and the level I/3 is situated on a 3 m lower elevation. The floodplain level I/2 is situated on a higher elevations compared to the floodplains level I/3 and level I/1 generally, except for the southernmost part of the study area.

The elevation change of the floodplain levels along the longitudinal section of the Danube is mostly divergent, indicating that these floodplain levels formed by cut back that was induced by the subsidence of the southern part of the Danube. The floodplain level I/2 is considerably different from level I/1 ad I/3, because this level has higher elevation than the older level (I/3) and a large number of palaeo-channels could be preserved on this level. This floodplain level – unlike the others – was formed by aggradation, indicated by its convergent surface and OSL characteristics of the samples. On the younger floodplain levels (I/1-2) the palaeo-channels are clearly observable, which indicate moderate floodplain aggradation processes.

4.2. Assessment of factors influencing the equivalent dose and the OSL characteristics

Along the Hungarian section of the Danube, modern samples were collected and tested to assess the applicability of the Danube sediments for OSL dating. The longitudinal trends and pattern of the OSL characteristics that can significantly influence the equivalent dose and the result of the OSL dating were analysed. The following OSL characteristics were assessed in details:

1) The OSL components, because it highly determines the applicability of the sample for OSL dating;

2) The appropriateness of SAR protocol (preheat and cutheat tests, dose recovery test) to determine the rate of reproducibility of the measurements. Detailed tests were performed to define the differences between the coarse grain and fine grain sediments;

3) Determining the thermal transfer value of the samples, which may cause age overestimation;

4) Measuring residual dose (D_{res}) in modern samples, which may result older ages than the actual deposition time.

Generally, the coarse grain samples had more OSL components than fine grain samples. For the former, detection of even 4-5 components was possible, which can be split into 'fast, medium and slow components and three slow components ('S1', 'S2' and 'S3'). Beside fast and medium components, mostly type 2 slow component could be detected in coarse grain samples. From fine grain samples generally only 2-3 component could be detected and the proportion of fast components was mostly very low compared to the proportion of medium component, or completely missed. In coarse grain samples, the proportion of fast components was sufficient for further measurement, while in fine grain samples fast components could also be detected, but their proportion was very low. Consequently, for Danube sediments coarse grain samples are more suitable for OSL measurements. Coarse grain samples are optimal for OSL dating, but samples dominated by medium components can also be suitable for OSL dating

with appropriate tests, considering the potential residual signals owing to the lower effectiveness of trap emptying.
Tests were made to define the preheat temperature for SAR measurement on all samples. On modern samples, combined tests were applied analysing not only the preheat, but also the cutheat temperatures. Based on the applied 3 criteria (recuperation: <5 %, recycling ratio: 1.0±0.1, dose recovery rate: 1.0±0.1) the 200°C/160°C preheat-cutheat combination proved to be the best option for further measurements. At this temperature combination the average recycling ratio, recuperation, and dose recovery ratio of samples were 1.02 ± 0.04, 2.58 % and 0.98 ± 0.05 for the coarse grain and 1.03 ± 0.05, 0.17 % and 0.99 ± 0.11 for the fine grain fraction, respectively. All of these results proved the appropriateness of the measurements, because the measurements were reproducible. Based on the results, the preheat temperature generally applied for Hungarian fluvial sediments (mainly 200-240 °C) can be considered appropriate.
In terms of coarse grain samples, the artificially irradiated doses correlated with the recovered doses to a much greater degree than in case of fine grain samples. The results of fine grain samples showed high scatter and only a small proportion of the aliquots were considered as applicable for the measurements. The reason for this is probably the low proportion of fast components in the samples. Consequently, it can be declared that the measurements can be reproduced with a slightly larger error in case of fine grains, but the values were within the error limits. For coarse grain samples the average value of the samples and their standard error was 1.01±0.02 Gy. Therefore, it seems sensible to collect both coarse and fine grain for the assessment of fluvial sediments, and if only fine grain samples could be collected, the test and measurements should be performed carefully.

4.3. Factors influencing the quartz equivalent dose and their spatial trends and patterns

The thermal transfer (TT) may cause significant overestimation during age calculation. On both fine and coarse grain modern samples from 5 study sites, detailed measurements were performed. Based on the analysis, two main questions were outlined: (1) is there any difference between the results of the two grain sizes in the equivalent doses based on thermal transfer; (2) how the hot bleach (HB) applied during SAR measurement influence the results? The tests were performed on modern coarse and fine grain samples collected from 5 study sites. The results emphasize the importance of 200 °C preheat temperature, because a gradual increase of TT value was observed above this temperature. In case of coarse grain samples, the mean value of TT at 200°C is 0.06 ± 0.05 Gy with a maximum value of 0.25 ± 14 Gy, while at 300°C it was

0.88 ± 0.33 Gy, when measurements were made without HB. When HB was applied, the mean value of TT at 200°C and 300°C was 0.65 ± 0.22 Gy (maximum value: 1.17 ± 0.19 Gy) and 0.68 ± 0.20 Gy, respectively. The tests shows that until 200 °C the TT is negligible without HB, however if temperature was set above 200 °C, not inevitably, but much higher values may occur, which can significantly influence the equivalent dose of young sediments. In terms of fine grain samples, the values of TT without HB showed a similar pattern than in case of coarse grain samples, however the difference between lower and higher temperature values was smaller. The mean TT at 200°C was –0.07 ± 0.03 (maximum value: 0.00 ± 0.01 Gy), while TT at 300°C was 0.18 ± 0.03 Gy, meaning that TT can be considered negligible. When measurements were made with HB the TT values were remarkably higher. With HB, the mean TT at 200°C was 0.94 ± 0.02 Gy with a maximum value of 0.99 ± 0.04 Gy, while at 300°C TT was 0.94 ± 0.02 Gy. Thus, insignificant difference of the TT can be observed at the two temperatures, but the values are relatively high comparing to measurements without HB.

Based on the above, it became obvious that the HB increases the value of TT, resulting in a potential overestimation of the ages. Following the tests, thermal transfer was measured on all modern samples, but only at one temperature value (200°C) and without HB. In general, the results of fine grain samples were lower (average: –0.02 ± 0.00 Gy; max: 0.04 ± 0.01 Gy) than those of coarse grains (average: 0.04 ± 0.00 Gy; max: 0.25 ± 0.14 Gy).

Consequently, measurements on both coarse and fine grain sediments proved that as a matter of TT, the equivalent dose of Danube sediments increases considerably if preheat temperature is set above 200°C. Although the use of a HB decreases the scatter of recovered doses, it also introduces a considerable degree of TT, which can differs from sample to sample. Therefore, the SAR protocol without HB is advised for analysing Hungarian Danube sediments. In general, the TT of samples was not considerable, however in case of modern and few centuries old sediments, correction seems to be necessary. Based on the assessments, 0.04 ± 0.00 Gy TT correction value is suggested for coarse grain young sediments. In TT values, no spatial trend or pattern was observed along the longitudinal section of the river.

Finally, the residual dose of the modern samples was determined. The coarse grain and fine grain samples were analysed separately and the result were compared to reveal whether any trend or pattern of residual doses can be detected along the Hungarian section of the Danube. In general, the D_{res} values of coarse grain samples were lower regarding both the average (0,10±0,01 Gy), and maximum values (maximum: 0.56 ± 0.17 Gy) than in case of fine grain samples (average: 2.34 ± 0.72 Gy, maximum: 14.50 ± 0.52 Gy). This means a 60–120 y age overestimation if 1.0–2.0 Gy/ky dose rates are considered in case of coarse grain samples. This overestimation is not remarkable for older samples, however for younger samples this can lead to a significant overestimation.

Concerning fine grain samples, these D_{res} values can lead to 1.1-2.3 ka overestimation, which is remarkable also for older samples. Consequently, the bleaching of coarse grain samples was fairly complete on the studied river reach, the standard error of D_{res} was 0.10 ± 0.01 Gy. It is suggested that in case of younger sediment deposits from the investigated area the equivalent dose should be corrected by this value until 1 ka. Besides, in case of older Danubian sediments the effect of incomplete bleaching on the measured equivalent dose seems to be of low significance if a proper statistical treatment is applied, however the depositional environment might cause some differences which should be investigated further in the future. However, concerning fine grain sediments the incomplete bleaching caused a major difficulty. On the lower section of the studied river reach this fraction can not be used safely for OSL dating of older sediments, because the residual dose was the most significant here. On the upper section of the Danube, fine grains can be an alternative, however an average (0.85 ± 0.12 Gy) D_{res} must be considered and the equivalent dose must be corrected with this value. The longitudinal pattern of the D_{res} shows that it is significantly higher at some sections, where the Danube is passing loess bluffs. Based on these, the D_{res} values of fine grains can be an indicator of modern day erosional activity.

The results of the above tests were applied also for older samples. Wherever it was possible, coarse grain samples were selected to avoid the effect incomplete bleaching. The OSL dating of samples collected from the previously delineated floodplains was also performed. During the measurements, the results of the preheat tests were applied and as many aliquots as possible were measured to achieve statistically relevant data. Most of the samples were older than 1 ka, only the age of samples collected from the active floodplain were proved to be younger, thus on these samples the necessary correction identified during residual dose tests was applied.

4.4. Evolution of the Danubian Plain from the Late-Pleistocene to the present age

Based on the OSL dating results and the performed geomorphological mapping, the evolution of the alluvial areas on the Danubian Plain could be reconstructed. In terms of samples from the oldest floodplain – the upper floodplain according to Pécsi (167) defined by this research as floodplain level II – collected at Lake Kolon, significant scatter of equivalent doses was observed. The Abanico plot indicated multiple modes, proving the existence of fluvial sediments in the area. At two sampling points the defined ages of the samples were around 10 ka (10.83 ± 0.66 ka, 10.92± 0.41 ka and 10.43 ± 0.71 ka, respectively), while at the other two sampling points older samples were identified (23.60 ± 1.18 ka and 17.38 ± 0.60 ka, respectively). Thus, it was proved that the Danube formed its II. upper floodplain level even at 17-23 ka ago during the Last Glacial Maximum, later the Danube incised into this floodplain level, but the exact date of this event could not be defined.

This 3-meter incision induced the formation of the lower floodplain level, which was separated to three levels based on their elevations and ages. The floodplain level I/3 could be preserved in the western front of the II level. The western edge of this level was sampled at Öregcsertő, where the borehole was drilled in a backswamp. The age of the samples was diverse, moreover the youngest samples were found at the bottom (475 cm: 15.67±0.75 ka, 620-670 cm: 8.90±0.35 ka, 770-780 cm: 9.84±0.58 ka and 920-980 cm: 7.55±0.28 ka). In terms of the fine grains sample from Öregcsertő (depth: 475 cm), age overestimation was especially emphasized, meaning even 2-3 ka overestimation. The youngest sample of this study site suggests that the floodplain level I/3 could be formed even until 7.5 ka ago, but after that time thick layer of floodplain sediment deposited on the area, which undergone only a very slight bleaching.

Consequently, the Danube created the floodplain level I/2 at about 7.5 ka ago, which level has higher elevation, indicating that it was formed by intensive aggradation processes. The rate of this aggradation however continuously decreased in downstream direction, as the elevation of two floodplain levels are close to each other on the downstream end of the study area, moreover in the southernmost area, the I / 2 level shows even the signs of incision. On this floodplain level, large palaeo-channels and their point-bars could be preserved. Some of these were sampled at Dunavecse, Nagykékes and Alsóerek. Based these drillings, the aggradation, the formation of the level was occurred at 6-7.5 ka ago. The rate of the aggradation could be relatively fast, because in the boreholes at Alsóerek and Nagykékes the 6-7.5 ka old sediments at the bottom (e.g. AE1/3: 6.95±0.71 ka, AE2: 6.30±0.37 ka, AE+: 6.61±0. 34 ka and AE4: 7.16±0.62 ka) was covered by sediments showing significantly older OSL ages (e.g. AE1/2: 9.19±0.53 ka and AE1/1 9.73±0.42 ka). These layers are fine grain (silty-sand) dominated layers, thus it is possible that (1) the suspended sediment in the river prevented the water from penetrating the solar rays, thus the sediment may not be exposed sufficiently to sunlight, resulting in incomplete bleaching; and/or (2) the loess bluff eroded intensively and the short transportation route caused the incomplete bleaching. This sediment was deposited not only on the level I/2, but also in the deeper geomorphological form of lower lying level I/3, as they were situated on the distal area of the floodplain, where only a smaller amount of suspended sediment could be transported. This could be the cause for the deep burial of the Öregcsertő sample on the border of the two layers, and for the occurrence of only a few geomorphological forms on the level I/3.

The1-1.5 m incision of the Danube into the I/2 level created the I/1 level, on which also a large number of meanders could be preserved. The sediments from the boreholes at the Kalocsa, Fajsz and Bogyiszló sites indicate that these sediments were deposited at 5.3-5.5 ka ago by the Danube. The intensity of fluvial formation was slowed down, the meanders developed slowly, as the development of the sampled palaeo-meander at Kalocsa was active for several thousand years. The sediments could hardly reach the level I/2, therefore their geomorphologic forms could be preserved. This fluvial activity was disrupted by the river regulation and flood protection works, and after that time only the artificial floodplain could be formed by the deposition of floods.

5. Theses

1. The sensitivity of the quartz components in the Danube sediments is quite low. The proportion of fast components in the coarse grain samples is generally higher than in fine grain samples. Consequently, the coarse (sand) grains are more applicable for OSL dating, but fine grain samples may also be suitable for OSL dating with appropriate tests, considering the potential residual signals, which may cause age overestimation.

2. Generally, the thermal transfer of quartz samples was not considerable in both coarse and fine grain samples, however in case of modern and few centuries old sediments, correction may be necessary depending on the value of equivalent doses. Based on the assessments, 0.04 ± 0.00 Gy TT correction value is suggested for coarse grain young Danube sediments. Furthermore, the SAR protocol without hot bleach is advised for analysing Hungarian Danube sediments, because this process significantly increases the thermal transfer.

3. In general, the residual dose value of coarse grain samples was lower than in case of fine grain samples. This means a 60–120 y age overestimation if 1.0–2.0 Gy/ka dose rate was considered in case of coarse grain samples. Concerning fine grain samples, the residual dose value can lead to 1.1-2.3 ka overestimation, which is remarkable also for older samples. Because of the significant residual dose of fine grain samples on the lower section of the Danube, it seems sensible to collect coarse grain samples for OSL dating wherever it is possible. On the upper section of the Danube, fine grains can be an alternative, however an average (0.85 ± 0.12 Gy) D_{res} must be considered and the equivalent dose must be corrected with this value.

The bleaching of coarse grain samples was fairly complete on the studied river reach, the standard error of D_{res} was 0.10 ± 0.01 Gy. It is suggested that in case of younger sediment deposits from the investigated area the equivalent dose should be corrected by this value until 1 ka age.

4. The analysis of the sediments at Lake Kolon proved the existence of fluvial sediments in the area, suggesting the presence of the Danube. Thus, it was proved that the Danube formed its II. upper floodplain level even at 17-23 ka ago during the Last Glacial Maximum, later the Danube incised into this floodplain level. This 3-meter incision induced the formation of the lower floodplain level I/3, which could be preserved in the western front of the II level. The floodplain level I/3 could be formed even until 7.5 ka ago.

5. The Danube created the floodplain level I/2 at about 7.5 ka ago, which level has higher elevation than the level I/3, indicating that it was formed by intensive aggradation processes. The rate of this aggradation however continuously decreased in downstream direction, as the elevation of two floodplain levels are close to each other on the downstream end of the study area, moreover in the southernmost area, the I / 2 level shows even the signs of incision. The1-1.5 m incision of the Danube into the I/2 level created the I/1 level, where sediments were deposited at 5.3-5.5 ka ago by the Danube. The sediments could hardly reach the elevated I/2 level, therefore their geomorphologic forms could be preserved.

6. It is not obvious that the climate or the tectonic processes had larger effect on the floodplain evolution. Probably tectonic movements played more significant role in the development of the floodplain levels, but climate changes might enhance these processes.

7. The floodplain aggradation rate of the artificial, active floodplain on the northern part of the Danubian Plain was also calculated based on the age data of a sampling site situated on the floodplain level I/2 within the artificial floodplain. The calculation indicates 0.1-0.2 cm/y floodplain aggradation rate, which is very low, not triggering significant increase of the flood risk.