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LATE PLEISTOCENE AND HOLOCENE FLOODPLAIN DEVELOPMENT ALONG THE LOWER TISZA RIVER

Thesis of Dissertation

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1 INTRODUCTION, AIMS

Natural floodplains formed along rivers are usually the result of a long development so their form reflects the changes having occurred during the time of their formation. Changes in the energy conditions, erosive capacity, and the runoff conditions of a river also cause the floodplain development to change. Most of the older forms situated near the active channel are destroyed either by lateral erosion or fresh sediment deposition in the new river development phase. However, the forms situated farther along the floodplain may be preserved, therefore these older forms can prove information about the changes in river dynamics (Nanson and Croke, 1992, Vandenberghe, 2003). Due to this fact, analysing wide floodplains are highly suitable for reconstructing fluvial surface development.

Even though the present-day modern technology would make it possible, the geomorphological analysis and evaluation of both the floodplain levels and their forms in the Lower Tisza Region have not been carried out yet, as opposed to the floodplains of the upper section of the Tisza (Bereg Plain, Middle Tisza) and the drainage-system of its tributaries (Sajó-Hernád, Zagyva-Tarna, Körös, Maros). Most of the studies concerning this particular river section were published decades ago, and they are mainly characterised by logical deductions rather than exact measurements. In addition, there are not only numerous differences in the research results, but the researchers themselves have completely opposing views on the same subject. At the same time, this region may gain great importance in understanding the various river processes of the Great Hungarian Plain since the more important rivers of the Great Hungarian Plain have run in that direction. It is due to the almost continuous sinking of the area since the Pliocene which means that there have not been any major changes in the river courses. The river processes may have been influenced by the fact, though, that the floodplain was enclosed by the huge alluvial fans of the Danube and the Maros, and, as a result, the younger processes occurring on their surface may have buried the older Tisza forms.

There are several unexplained aspects of the floodplain development in the Lower Tisza Region. It has not been clarified how many morphological levels can be distinguished on the floodplain, when they were formed, and what kind of factors influenced the river processes. It has not been explained whether the changes characterising the lower section of the Tisza may be related to the changes occurring on the Danube, and if yes, how far their influence spread.

The main aim of my dissertation is the geomorphological analysis of the floodplain of the Lower Tisza, stretching from Csongrád to the river mouth, and, based on this analysis, a more detailed and thorough reconstruction of the Late Pleistocene and Holocene evolution of the fluvial system. I compiled an investigation consisting of several stages in order to answer the following questions:

Analysing floodplain forms

- How many floodplain levels can be distinguished in the Lower Tisza Region on the basis of the erosional edges? What are the spatial characteristics of these floodplains?
- Is it possible to distinguish morphological units in the study area on the basis of the spatial characteristics of each floodplain level?
- What kind of morphometrical features characterise the paleo-channels of the different floodplain levels?
- Is it possible to classify them into various meander generations? How big could their bankfull discharge be?
- What types of erosional floodplain islands can be distinguished? What morphometrical features do they have (e.g. area, width, length)? How can the spatial development of their height and morphological features be characterised?
- What spatial characteristics do the other elements of the floodplain forms possess on each individual level? Are there any differences between the forms of the morphological units of the floodplains?

Investigating the height features of the floodplains

- What was the extent of erosion caused by the incisions separating the individual floodplain levels on the basis of the prepared cross-sections?
- Did the extent of the incisions change between the morphological units of the study area?
- How can the slope of the individual levels be characterised on the basis of the cross-sections?

Analysing the grain composition of the floodplain forms

- Concerning the grain composition of the sediment, is it possible to detect any kind of change between the individual floodplain development phases?
- What characterises the sediment deposited during the incision episodes?
- What bankfull depth characterised the meanders?

Reconstructing fluvial evolution

- When did the floodplain development phases of the Lower Tisza Region occur? What kind of hydrological and morphological processes characterised these phases?
- When did the incisions start? What could cause the bigger erosion? Did the incisions occur simultaneously in the morphological units of the study area?
- How the size, discharge and the sediment composition of the Tisza meanders change in the study period? How can these changes be related to the climatic changes having characterised the Great Hungarian Plain?
- What was the probable extent of the sedimentary deposition in the individual floodplain development phases?
- How can the floodplain development of the Lower Tisza Region be harmonised with the Late Pleistocene and Holocene evolution of the Carpathian Basin?

2 METHODS

In order to answer the questions relating to the fluvial evolution, I applied different methods. It was my intention to use identical methods for sampling and analysing the entire study area but, due to the varying scale of the maps available, it was not always possible to do so. For this reason, I had to use other data sources when identifying the different groups of forms on the Serbian side of the floodplain during the course of the geomorphological mapping. However, I was able to carry out the discharge calculations as well as the grain composition analysis and the OSL dating of the alluvium by applying a uniform methodology, of which results provided a comprehensive survey of the floodplain development of the Lower Tisza Region.

2.1 Mapping geomorphological forms

The first step of the investigation was to identify the forms of the study area, which I carried out by employing the ArcGIS 10. software on topographical maps as well as by specifying them in field trips. The area limits of the various forms found on the Hungarian floodplains were marked by using EOTR maps (scale 1:10,000) and digital terrain models, and I used topographical maps (scale 1:25,000), 90-m resolution SRTM images, and satellite images.

The bankfull discharge of the paleo-meanders was calculated by applying regional equations (Gábris, 1995; Timár and Gábris, 2008;

Sümeghy, 2014), which were based on morphometric parameters. In some cases, data refining was necessary, so I prepared cross-sections employing high-precision GPS measurements, while the depth of the paleo-meanders was determined by drilling.

2.2 Identifying the height features of the floodplains

In order to identify the floodplain levels and islands located at different heights, I drew cross-sections at an average of 5-8 km in a west-east direction on the basis of topographical maps. The downstream development of the floodplain height was examined on the basis of length-sections; data were taken per kilometer, but where the floodplain levels appeared only in small patches, I increased the data sampling density to 0.5 km. There was a 15-km-long data hiatus south to the Hungarian border, but, fortunately, it did not affect the tendency of the changes.

After digitising, I created a terrain model of the floodplain islands, which helped to identify their edge and forms. Then I determined the morphometric parameters (area, maximum width and length) and the height features (absolute height and relative height compared to the floodplain levels) of the islands.

2.3 Analysing the grain composition of the sediments

By analysing the grain composition of the samples coming from the point-bars and the meander beds identified in the study area as well as in the outer banks of the active channel of the Tisza and the Maros, my goal was the spatial determination of sediment quality. The forms were drilled at a total of 22 points, and 21 profiles were deepened into the river walls of the active channels. Sampling occurred every 10 cm. Grain size classes were determined by using the Udden scale. The evaluation of the results was based on the grain distribution of the d_{50} and d_{90} values of the samples.

2.4 OSL dating

The OSL sediment samples were taken from the point-bars of the paleo-channels and from the river walls of the present-day channel of the Tisza and that of the Maros in the study area, which provided information about the chronological order of the fluvial surface development processes. I intended to sample the oldest as well as the youngest point-bars of the individual meanders so that the activity period of the given meander could be determined too. My main aim concerning the river walls was to determine the age of their layers (e.g. paleo-soils, zone boundaries) in order to deduce the conditions of sediment accumulation.

3 RESULTS

3.1 Floodplain forms in the Lower Tisza Region

3.1.1 Based on my research, there are sharp erosional edges of north-south direction in the ***floodplain levels*** of the Lower Tisza Region, and these edges separate floodplain levels of significantly different morphological characteristics. The lowest floodplain level of these is *Level A* which is directly adjacent to the present-day rivers and was regularly flooded until the beginning of river engineering, and it became the present-day low-floodplain. It covers an area of 2,160 km^2, which is one-third of the whole study area. Almost the entire length of this area is bordered by a sharp edge (3-6 m), especially on the western side, where it is usually connected directly to the highest levels. *Level B* is not to be found as a whole area, only patches of different size remained, so it makes up only 17.8% of the total area (1,160 km^2). While the edges separating Level B from Level A are well-defined (3-5 m), the edges separating Level B from *Level C, the highest of the floodplain levels*, are not so well-defined (1.5-2 m). The highest floodplain level (C) makes up almost half of the Lower Tisza floodplain areas (47.4%, 3,070 km^2). This floodplain level remained only in the north-eastern boundary area in the northern part of the study area, while it was buried by the Maros Alluvial Fan in the south and the aeolian forms of the Danube-Tisza Interfluve (Kiss et al., 2013).

3.1.2 The study area can be divided into ***three units*** on the basis of the width features of the floodplain levels, the run and definition of the erosional edges, and the forms of the different levels (Hernesz et al., 2015). The smallest area (984 km^2) is the *northern* unit which stretches to the Dóc-Hódmezővásárhely line. The joint width of all three floodplain levels gradually narrows to the south (24,3 km on average). Level C constitutes about two-third of the study area. The southern border of the unit was drawn where the biggest and intertwined part of Level C ends. The *central* unit (1,424 km^2) of the study area stretches from the Dóc-Hódmezővásárhely line to the Horgos-Nagykikinda line. The average width of the floodplain is 21.2 km, but it is slightly narrower in the north. Most of its area belongs to the lowest floodplain level (Level A: 59,7%), the run of which is not uniform as it splits into two to the south of Szeged. The floodplain widens (36,5 km on average) in the *southern* unit (3,941 km^2), and a large proportion of its surface belongs to Level C again (60.2%). The floodplain area of the Danube and that of the Tisza are connected in the lower third part of the southern unit, however, the erosional edges running from the north to the south indicate that the last period of the floodplain development was influenced by the Tisza (Hernesz et al., 2015).

3.1.3 ***Paleo-meanders*** (281 pieces) were divided into four groups on the basis of the distribution curves of their horizontal meander parameters (Rc, L, H, Wm). The members of the group with *the smallest meanders* (Group I) are those which have smaller dimensions than the present-day Tisza, they mostly appear in the foreground of the Maros Alluvial Fan and along smaller streams running from the alluvial fan of the Danube(on Levels A and C). Paleo-meanders belonging to *Group II* are characterised by dimensions similar to the present-day parameters (before river engineering) of the Tisza. They are found mainly in a narrow range (3-10 km) adjacent to the present-day line of the Tisza (Level A). Paleo-meanders belonging to *Group III* are 1.5-2 times larger than the current channel of the Tisza, and they are adjacent to the zone of the meanders belonging to the Group II, or they are very near the largest channels (Levels A and B). *The largest meanders* (Group IV) exceed the parameters of the present-day Tisza at least four to five times. These meanders are characteristics to the east of the river, on the surface of Level C in particular.

3.1.4 In order to estimate the ***bankfull discharge*** of the paleo-meanders, I applied Sümeghy's formulas (2014). The mean bankfull discharge of the smallest meanders (Group I) was around 565 m^3/s. It is similar to the current discharge values of the Maros and those of the Körös. The bankfull discharge of the medium-sized meanders (Group II) corresponds to the mean present-day values of the Tisza (2,007 m^3/s), while the large meanders (Group III) could take 4,087 m^3/s of water on average at bankfull water-level. The bankfull discharge (10,907 m^3/s) of the largest paleo-channels (Group IV) exceeded the current values of the Tisza from five to six times (Hernesz et al., 2015).

3.1.5 Altogether 39 ***floodplain islands*** were distinguished in the study area, which I divided into two morphological groups (Kiss et al., 2012a). The *real floodplain islands* are the remnants of an earlier floodplain development phase, they are usually underwashed by either the paleo-meanders or the active channels, their edges are sharp. Surface forms are usually not recognizable. Another group of forms is the *meander core floodplain islands* (*umlaufberg*) created by the incision of the paleo-meanders. Their formation is connected to those of the ingrown-type meanders, their edges are less sharp. Height differences on their surface reach 1-2 m indicating the location of older point-bars and scroll-bars. Since they were formed during the time of incisions, their further investigation was appropriate.

3.1.6 The *downstream size of the meanders* which were formed at the incision on Levels C/B, when the ***umlaufbergs*** were formed, does not change significantly, which is due to two things: (1) at the time of their formation, only the upper part of the drainage basin provided the fluvial system with significant amounts of water, (2) the brooks and tributaries on the Lower Tisza did not have such a big discharge that would have affected the size of the meanders significantly. The umlaufbergs located on Levels B/A were formed by meanders with gradually increasing downstream size (Hernesz et al., 2015).

3.1.7 The *number of the point-bars* on the surface of the ***umlaufbergs*** may indicate the pace of incision, as slow incision causes the development of point-bar lines, while quick erosion causes the development of less point-bar lines. There are less point-bars on the umlaufbergs formed at the incision of Levels C/B (an average of 3.5 pieces), they are not defined and are hardly recognizable. In contrast, point-bars formed at the time of the separation of Levels B/A were preserved in great numbers (an average of 8.8). It suggests that the former incision happened faster than the erosional phase between Levels B/A.

3.1.8 ***Other forms*** (point bars, scroll bars, natural levees, crevasse channels, backswamps) located on the floodplain areas were best preserved on the lower (younger) and widening floodplain areas. There is no significant difference between the individual morphological units regarding the frequency of their forms (Kiss and Hernesz, 2011).

3.2 HEIGHT FEATURES OF THE FLOODPLAINS IN THE LOWER TISZA REGION

3.2.1 The erosional edges separating the floodplain levels are clearly visible on the cross-sections. Surfaces belonging to the individual levels can be identified on the basis of elevation data both on the western and eastern sides of the floodplain. The aeolian sand forms obviously raised the height of Level C on the north-western part of the northern unit and buried the fluvial forms. On the eastern part of the central and the southern units, the forms of the Maros Alluvial Fan moved onto the floodplain of the Tisza from east (Kiss et al., 2013).

3.2.2 Based on the cross-sections, it can be established that meanders from Level C were silted up as high as Level B, while meanders of Level B were silted up as high as Level A. It all shows that after the first incision the deeper meanders of Level C functioned as a low floodplain; a bigger part of its area, meanwhile, functioned as the high floodplain of Level B. During the second incision, Level B functioned as the high floodplain of Level A, however, its channels were silted up in the regular floods of

Level A. By this time, Level C became totally flood-free (Hernesz et al. 2015).

3.2.3 The ***slope*** of all three units is the biggest in the northern unit, but the height difference of the levels is not significantly different (they are parallel to each other). The slope in the central unit is a bit smaller, their height difference, however, remains similar. As opposed to this, the slope characterising the southern unit increases significantly for all three levels, but their height changes differently; the difference between Levels A and B increase slightly, while Levels B and C relatively converge to each other. The slope of Levels A and B continues increasing on the southernmost part of the study area, but the slope of Level C virtually disappears. Consequently, the individual levels take on a strongly divergent run compared to each other (Hernesz et al. 2015).

3.2.4 Changes in the slope and relative height may indicate the tectonic movements of the area as well as the incision of the erosion base (the Danube). Based on these data, there could have been a sinking area in the central unit (near the present-day mouth of the Maros), which caused a decrease in the slope of the floodplain levels. The sinking must have characterised the area for a long time as all three levels were exposed to a gradual back-cut in the northern unit. The increased slope in Levels A and B in the southern unit may have been formed the same way. Yet, the sinking that caused the previously mentioned phenomena may have started to the south from the mouth of the Tisza, perhaps somewhere adjacent to the Danube. The back-cut gradually moved upstream, as evidenced by the divergent run of the two lower levels.

3.3 Analysing the grain composition of the floodplain forms

3.3.1 Regarding grain composition, the analysis of point-bars coming from *Level C* shows significant differences within a relatively short distance, the grain size of the transported sediments varies greatly (e.g. Kis-rév: d_{90}: 0.042 to 0.059 mm; Téglás Brook: d_{90}: 0.170 mm). It may indicate significant (climatic) changes in the active phase of Level C which determined the energy conditions of rivers as well as the size range of the sediment (Kiss et al., 2014). The impact of the tributaries cannot be excluded either as the Maros, which had more and coarser sediment than the Tisza, often changed its flow direction (Sümeghy, 2014), and, as a result, also affected the sediment conditions of the Tisza.

3.3.2 The diameter of the transported fluvial sediment significantly decreased in the active phase of Level B, which is explained by low energy conditions (Hernesz and Kiss, 2013). The Tisza started to transport coarser sediment again as a result of the *incision separating*

Levels B and A, although there were not such big changes in the development of grain composition as in the previous erosional period.

3.3.3 Four of the sampled meanders belong to the largest channels (Group IV), Group III consists of three, and Group II consists of two meanders. It is remarkable that the finest sediment (d_{90}: 0.081 mm on average) was transported by the largest channels, and the coarsest sediment (d_{90}: 0.203 mm on average) was transported by the channels of Group III. The meander generation of Group II transported finer sediment again (d_{90}: 0.097 mm on average). I concluded that sediment composition did not change parallel to the decreasing discharge, which is due to other impacts occurring in the drainage basin (e.g. vegetation, changes of slope, erosion of loess sediments) (Hernesz et al., 2015). Channels formed during incisions can be characterised by coarser sediment, since the sampled third-generation channels were active mainly at that period.

3.3.4 Drillings in the meanders reveal that the channels were silted up with very fine alluvial sediment at all three levels once the active development ceased. After becoming inactive, they did not carry flood flows, and they became the lowest parts of the floodplain, where only the finest grain-sized suspended sediment could travel. It may indicate avulsion, the abandonment of the active channel.

3.4 OSL dating of the material of floodplain forms

3.4.1 Based on OSL dating, the oldest sample is 25.6 ± 1.4 thousand years old, while the youngest was deposited only 0.25 ± 0.03 thousand years ago. Thus, the fluvial processes taking place in the Lower Tisza Region can be reconstructed from the beginning of the Upper Pleistocene to the end of the Holocene (Hernesz et al., 2015).

3.4.2 It can be stated that since the beginning of the Upper Pleniglacial there can two longer floodplain development phases be detected in the Lower Tisza Region (Levels C and A). The activity of Level B and the beginning of the incisions that separate the levels took place at the end of the Pleistocene and in the early Holocene, about 4-6 thousand years ago. These floodplain development phases did not occur at the same time, nor did the incisions have the same degree in the units of study area, which indicates that factors influencing floodplain development had different intensity in the studied period (Kiss et al., 2014b).

3.5 The evolution of the Lower Tisza floodplain

3.5.1 The Nagybecskerek-channel, located on Level C, was active in the ***first half of the Upper Pleniglacial***, its oldest point-bars are 25.6 ± 1.4 thousand years old. Its estimated bankfull discharge was around 10,800

m^3/s, which is almost the same as the mean discharge (10,907 m^3/s) of the largest meander generation found on Level C. The meander development was accompanied by much colder and drier climatic conditions compared to today's climate (Kiss et al., 2014). Sediment grain size (d_{90}: 0.125 mm) indicates relatively high stream power, but it was not powerful enough to form braided patterns (due to the small slope and the small proportion of bedload sediment), similarly to many Western and Central European rivers (Kasse et al., 2003, Starkel et al., 2015).

3.5.2 The sample from the Szegvár erosional island core originates from the ***maximum of the last glacial period*** (20.1 ± 2.4 thousand years). The oldest point-bar of the Téglás Brook meander was formed at the same time (19.2 ± 2.7 thousand years). The eight point-bars of the Téglás Brook meander indicate an increased river activity. The greater erosional capacity is also indicated by coarser sediment (d_{90}-value: 0.242 mm and 0.152 mm). Based on the meander dimensions, discharge did not change significantly. All this shows that the morphological influence of the sharp cooling of the climate and that of the sparse vegetation was less significant in the Lower Tisza Region, it only caused the sediment to be coarser (Hernesz et al., 2015).

3.5.3 The floodplain development phase when the Tisza built the Szegvár floodplain island stretched into the ***Ságvár-Lascaux interstadial*** 18.1±2.4 thousand years ago (Kiss et al., 2012), similarly to the oldest point-bar (18.0±1.3 thousand years) located along the Kórógy Brook and the aeolian sand layer of 2-2.5 m (17.1±1.4 thousand years) covering the older point-bar along the Téglás Brook. The youngest point-bar of the meander was formed almost at the same time (16.9±1.1 thousand years) as the aeolian activity occurred. Although the horizontal parameters (Group IV), the discharge values and the number of the point-bars, of the channels being active in the interstadial do not show any major changes compared to the last glacial maximum, the sediment became considerably finer. Due to the increasingly denser and more closed vegetation (Gábris and Nador 2007), less sediment was washed into the channel, by which time the 3,000-4,000-year-long process of loess formation (Sümegi et al., 2014) was already indicated by the presence of the finer and finer alluvial sediment (Kiss et al., 2014; Hernesz et al., 2015).

3.5.5 The incision located between Levels C and B in the northern unit of the study area had not started in the ***Bölling-Alleröd interstadial*** either, because the youngest point-bar (13.2±0.9 thousand years) of the meander along the Kórógy Brook on Level C was being formed then, similarly to the lower zone of the Kisrév meander containing point-bar systems/layers (13.1±1.2 thousand years; Hernesz and Kiss, 2013). Meanwhile, a new incision started in the southern unit (between levels B/A) which is indicated by the age of the point-bar (13.4±0.7 thousand years), with the same height as Level B, located on the surface of the Törökbecse umlaufberg (Hernesz et al., 2015). An incision occurred on the Danube too, since, according to Gábris (2007), the formation of the Danube II/a terrace, having started in the Ságvár-Lascaux interstadial, continued due to the warming up that occurred at the beginning of the late-glacial.

3.5.6 The incision between Levels C and B started in the northern and central units ***at the end of the Bölling-Alleröd interstadial*** and ***at the beginning of Dryas III***. It is indicated by the Dóc umlaufberg, the youngest point-bar of which is 12.8±0.8 thousand years old. The discharge of the Tisza had already decreased significantly by then, the meander belonging to the erosional island can also be classified into Group III (7,480 m^3/s).

3.5.7 The incision between Levels C/B in the northern unit continued at the beginning of the ***Preboreal Phase***, which is indicated by the age of the younger point-bar (11.4±2.0 thousand years) of the Batida erosional island. The discharge was similar to that of the Dóc meander (8,240 m$_{90}$/s). The second half of the phase, however, witnessed the formation of Level B in the northern and central units, which is proved by the age of the Deszk meander (11.0±0.7, 9.9±0.7 thousand years; Sipos et al., 2009). The formation of Level A was already going on in the southern unit by then (Hernesz et al., 2015).

3.5.8 The incision between Levels B and A in the central and northern units took place in the ***Boreal Phase***. It is proven by the fact that the samples originating from the ***first half of the Atlantic Phase*** belong to the floodplain development cycle of Level A. An example of it is the age (8.0±0.8 thousand years) of the upper zone of the river wall along the Kisrév meander, which is similar to the lowest layer of the Árnyás meander (7.4±0.5 thousand years) too (Kiss et al., 2012b, Hernesz and Kiss, 2013).

3.5.9 The size of the Tisza meanders was considerably reduced in the ***Subboreal Phase***. It is evidenced in the Csúrog meander of the southern unit which was active 3.2±1.1 thousand years ago. This meander belongs to the second meander generation already, its estimated bankfull discharge (2,220 m$_{90}$/s) was only slightly bigger than that of the present-day values of the Tisza. On the basis of the morphological position of the meanders, discharge decreased gradually and not suddenly, and, by the end of the Subboreal Phase, the Tisza was characterised by the present-day values, just like during the ***Subatlantic Phase*** (Hernesz and Kiss, 2013), when the Kis-Tisza meanders were being formed (2.0±0.2 and 1.1±0.1 thousand years).

3.5.10 During my research it was proved that, unlike several previous researches (e.g. Miháltz, 1967, Mátyus, 1968, Popov et al., 2008, 2012), three morphological levels can be distinguished in the Lower Tisza Region, and not two as previously argued. These levels are separated by two strongly defined incisions. The OSL dating and the data of the morphological analyses also support Somogyi's theory (1962, 1967) that the flood-free level along the Tisza can be related to the Danube II/a terrace, and the beginning of its formation is associated with the erosional phases of the Danube.

3.5.11 Based on the results of my research, it can be stated that the development of the three floodplain areas in the Lower Tisza Region was determined by the following factors the most: 1) the proximity to the Danube mouth, 2) the great distance from the upper part of the drainage basin, 3) climatic factors, and 4) a combination of local tectonic movements (Hernesz et al., 2015). Thus, the phases of incision and alluvial deposition are the result of an extremely complex development, and they cannot be connected to the direct effect of individual factors.

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