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THE EVOLUTION HISTORY OF THE MAROS RIVER ALLUVIAL FAN

Theses of Dissertation

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Szeged, 2014

1. Introduction, aim

The Maros River drains the water of the Eastern and Southern Carpathians. As it reached the Great Hungarian Plain it built an extensive alluvial fan (ca. 8300 km^2) with a radius of 80–100 km. The present-day Maros River is located in the east-west axis of the alluvial fan. North of the axis, the alluvial fan is more elongated than on the southern part. The alluvial fan is shared by Hungary (45%), Romania (35%) and Serbia (15%).

Tectonic activity has always played an important role in the evolution of the alluvial fan as the surrounding floodplain areas are sinking areas (Szeged and Körös Grabens), and the alluvial fan itself is also dissected by fault lines. It is reflected by the dissected base-rock, which consists of uplifting blocks (Battonya and Battonya–Pusztaföldvár High) and sinking basins (Békés Basin and Makó–Hódmezővásárhely Graben) characterized by continuous sedimentation during the Quaternary.

The surface of the Maros alluvial fan is characterized by paleo-channels, secondary channels, ox-bows, and fluvio–aeolian dunes. However, according to *Sümegi et al.* (1999), aeolian activity was not present on the alluvial fan (in contrast with the other alluvial fans of Hungary), thus its original fluvial structure is still preserved.

There were some previous scientific investigations about the evolution of the Maros Alluvial Fan, but the resolution of the data or the lack of the appropriate dating methods resulted in gaps in the evolution history.

The main goal of the dissertation was to reconstruct the evolution history of the Maros Alluvial Fan using morphometric analysis and identifying the fluvial forms. As on the alluvial fan's surface there were no or limited aeolian activity, the remnants of the paleo-channels could be identified and the paleo-directions of the Maros could be reconstructed. During the last 20 thousand years the Maros had a very dynamic fluvial system, which always tried to reach an equilibrium. Therefore, my aim was to identify the elements of this system and to determine the responses on internal or external disturbing factors.

In order to the reconstruct the development of the alluvial fan, five main goals were appointed:

To analyze the forms on the alluvial fan and create a geomorphological map of the fan

- Is there any connection between channel patterns and the location of the channels on the alluvial fan?
- What kind of morphometric characteristics do the paleo-channels have?
- Is there any connection between the slope of the channels discribed by previous studies and channel patterns?
- Which factor effects on the avulsions and confluences typical of the anastomosing rivers?

To calculate the bankfull discharge of the meandering paleo-channels, using their morphometric parameters

- What kind of relationship exists between horizontal channel parameters and bankfull discharges of the channels?
- Which horizontal channel parameter shows the closest connection with bankfull discharges of the channels?

To analyze the main sedimentological characteristics of the paleo-channels

- Did the sediment composition change with the age of channels?
- Are there any tendency between the sediment composition and the channel location on the alluvial fan?
- How did the sediment composition change in the channel point bar system?

To define the paleo-direction changes on the alluvial fan's surface

- When were the different paleo-directions active channels of Maros?
- Is there any channel which was active on the alluvial fan at the same time?
- Which factors may have influenced the paleo-direction changes and the rapid avulsions on the alluvial fan?
- Which factors may have influenced the channel pattern changes?

To reconstruct the evolution history of the Maros River alluvial fan

- How did the vegetation affect the channel pattern in the given period of time?
- How do bankfull discharges of the paleo-channels reflect climatic conditions?
- Is there any temporal and spatial sequence connection between water and sediment discharges of the paleo-channels and channel patterns?

2. Methods

During the study a comprehensive research was carried out. As a first step the geomorphological setting of the alluvial fan was analyzed, then the age of the paleo-channels was determined. Finally, based on my results and of previous works, the evolution history of the alluvial fan was reconstructed.

The detailed geomorphological analysis was made just on the Hungarian part of the alluvial fan, as in the neighboring countries the maps with the available best resolution (1:25,000) are not suitable for the identification of fluvial forms. On the Hungarian part, topographic maps (1:10,000) were used under ArcGIS 10 for the analysis. The paleo-discharge calculation, the age determination and the sedimentological analysis were made on both Romanian and Hungarian territories.

2.1. Geomorphology of the alluvial fan's surface

To determine the slope of the alluvial fan longitudinal and transversal height profiles were drawn. Along the profiles the altitude was determined at every kilometer. Based on the longitudinal profiles the different parts of the alluvial fan (i.e. fanhead, midfan, distal part and foreground) were identified. The transversal profiles gave information on the fluvial forms of the fan (e.g. channel width, depth, relative age of avulsions).

To identify the paleo-channel on the surface of the alluvial fan, their bank-lines and center-lines were outlined. The mid-channel bars, islands, point-bars, point-bar systems, swales, scour channels, and natural levees were also identified. The slopes of the paleo-channels and their floodplains were also measured.

2.2. Paleo-discharge calculation

During the geomorphological analysis, the horizontal channel parameters (e.g. width, radius of curvature, meander length, chord length) of the meandering paleo-channels were determined. The bankfull paleo-discharge of the meandering and misfit channels were calculated using regional equations created for the fluvial system of the Tisza River.

2.3. Analysis of the bedload sediment

To determine the age and sedimentological settings of the paleo-channels samples were collected from the sandy bars of the paleo-channel fragments. Altogether drillings were made at 29 sites on the point-bars of meandering, misfit and anastomosing channels, and on the mid-channel bars of braided paleo-channels. Where the meanders had well-developed point-bar systems, the oldest and the youngest point-bars were also sampled to determine the period of channel activity.

During the sedimentological analysis the grain-size distribution (d_{90}) of the samples were also measured. The 150–220 μm and 90–150 μm particles were selected for OSL measurements in order to determine the age of paleo-channels.

2.4. Paleo-direction changes of the Maros River

One of the aims was to define the temporal and spatial sequence of the alluvial fan constructions. The OSL ages of the channels and the identified paleo-directions on the alluvial fan's surface were combined to fulfill this aim.

2.5. Evolution history of the Maros River alluvial fan

To reconstruct the evolution history of the alluvial fan my results (slope of the alluvial fan, channel pattern, slope of the channels and of the adjacent floodplains, paleo-discharge values, sedimentary characteristics of the studied bars) were combined with previous studies on the most important factors which could influence the fluvial system (e.g. precipitation, temperature, vegetation and tectonic activity). Those factors were selected, which significantly could alter the sediment- and water discharge, and generate alterations in the alluvial fan system.

3. Results

3.1. Geomorphological analysis of the alluvial fan

3.1.1. To determine the slope of the alluvial fan longitudinal and transversal height profiles were drawn. Based on the longitudinal profiles the different parts of the alluvial fan were identified. The fanhead of the alluvial fan is located in Romania, therefore its slope (46-52 cm/km) could be determined just approximately. The midfan is located in the Hungarian part, its mean slope is 27-28 cm/km. The steepest (37-65 cm/km) part of the fan is the distal part. The gentle sloping (7-9 cm/km) foreground of the alluvial fan connects the distal part of the Maros alluvial fan with the former floodplain of the Tisza River.

The transversal profiles reflect the height conditions of the paleo-channel zones, referring to incision, avulsion and overbank accumulation processes on the fan. Based on the height conditions of channels with similar age it could be reconstructed, whether they co-existed (same bottom-level) or one is older than the other (their bottom is at different level).

3.1.2. The channel pattern significantly depends on the slope of the alluvial fan. On the midfan, where the slope is moderate, the development of anastomosing channels are typical, while on the steeper distal part meandering channels are characteristic. Braided channel pattern developed from the midfan to the foreground part of the alluvial fan (*Sümeghy és Kiss* 2012).

3.1.3. The paleo-channels and their floodplains were grouped into paleo-channel zones (18) based on their channel pattern, course and morphometry. The area, length and width of the zones were defined. The length, mean width and pattern of the channels were identified in each zone. These data constitute the basis of the geomorphological map of the alluvial fan.

3.1.4. The most complex point-bar systems developed on the distal part of the alluvial fan where the slope is steeper. In the longer paleo-channel zones the complexity of point-bar systems increases downstream (*Sümeghy et al.* 2013), also in relation to the increased size and development stage of the meanders. For example, in paleo-channel zone XIII, the complexity of point-bar systems simultaneously increases downstream, with the increasing meander parameters and the increasing development stage (β) of the meanders (e.g., the radius of curvature increases from 458 to 854 m and β increases from 1.21 to 1.37). In the most complex point-bar systems the distance between the point-bars is 155–775 m. In case of only three- or four-member point-bar systems, the space between the forms is only 136–318 m. Consequently, the complexity of point-bar systems and the slope increase downstream on the fan. Similar phenomenon was described by some authors (*Schumm and Khan* 1972, *Blanka and Kiss* 2011).

3.1.5. The avulsions of the anastomosing channels driven by slope changes of the floodplain. At the avulsion-points the slope is moderate, while between them the slope decreases and islands were formed (*Sümeghy et al.* 2013).

3.1.6. The mean slope of the meandering paleo-channels is 13.2 cm/km. The slope of the braided paleo-channels a little bit greater (16.3 cm/km), while the anastomosing paleo-channels mean slope is the greatest, 20.7 cm/km.

3.1.7. The sinuosity of the misfit channels is the greatest (>2), the meandering channels sinuosity is 1.4-2.0, while the anastomosing channels has a sinuosity 1.1-1.3. The sinuosity of the braided channels could be 1. This results fit with previous works (*Brice* 1964).

3.1.8. On the surface of the alluvial fan three different types of incision were determined. (1) Incision on the distal part of the fan, which could developed due to headcut erosion, (2) incision of the misfit channels due to the decreased discharge, and (3) the fanhead incision on the apex of the alluvial fan.

3.2. Bankfull discharge of the paleo-channels

3.2.1. During my work my aim was to create regional equations based on the present hydro-morphological parameters of the Tisza and its tributaries (*Sümeghy and Kiss* 2011, *Sümeghy et al.* 2012). The horizontal channel parameters (meander length, chord length and radius of curvature) of the paleo-channels were used to calculate the bankfull paleo-discharge of the meandering and misfit channels. The correlation coefficients of the equations are between 0.70-0.82. The chord length (R^2=0.82) and the meander length (R^2=0.81) shown the closest connection with the bankfull discharge.

3.2.2. During filed works we had noticed that the width/depth ratio of the paleo-channels is different than of the present-day channels. This was the reason why correction was made on the calculated paleo-discharges. Based on sediment and the cross-section profiles (made with RTK GPS) the difference between the paleo- and present-day channel's width/depth ratios was calculated. Nowadays the channels are narrower (35%) and deeper (2.3 times). Thus, based on my calculations the paleo-channels could transport 65.5% of the calculated paleo-discharges.

3.2.3. The greatest paleo-channels on the alluvial fan had considerable bankfull discharge (1004-1231 m^3/s), which is within the range of the Tisza's mean (800 m^3/s) and the Maros's peak (1600-2500 m^3/s) discharge. Most of the channels had lower discharge (374-769 m^3/s), which is between the Tisza's discharge belong to mid-stage (550 m^3/s) and the present-day Maros's bankfull discharge (680 m^3/s). There are some channels which have very low discharge (208-250 m^3/s), which is within the range of the Maros's and the Tisza's discharge at low and middle stages (161 m^3/s and 550 m^3/s). The misfit channels had a discharge (77-110 m^3/s), which is within the range of the Maros's discharge at low and middle stages (21-161 m^3/s).

3.2.4. Former equations (*Leopold and Wolman* 1957, *Dury* 1976, *Timár and Gábris* 2008) were used to check the applicability of the created, regional equations. Applying the equation created by *Timár and Gábris* (2008) to calculate mean discharge, the resulted discharge was 30% less than the bankfull discharges calculated by my new equations. Applying the equations of *Leopold and Wolman* (1957), and *Dury* (1976) the resulted discharge was 3.3-5.7 times greater. One reason of this difference could be the regionality, as they were created for rivers of Great Britain and the United States, which are under different climate conditions. The other reason of the difference could be the methods of the calculation (see *Gábris* 1995).

3.3. Sedimentological analysis and OSL age of the bar sediments

3.3.1. Based on the depth of dated bar material, I could calculate the floodplain aggradation rate. During the last 20,000 years the mean aggradation rate on the Maros River alluvial fan was 1.88 cm/100 years. During the Holocene the floodplain aggradation rate was greater (2.83 cm/100 years), than during the Pleistocene (1.45 cm/100 years). These results fit to the previous works (*Borsy and Lóki* 1982, *Borsy et al.* 1989, *Félegyházi et al.* 2004), which gave similar aggradation rates in the Bodrogköz, in the Upper Tisza Region and in the Nyírség. At the same time the Holocene aggradation rate is just 1.2% of the recent aggradation rate (2.3±0.3 cm/year) measured on the regulated floodplain of the Maros River (*Kiss et al.* 2011).

3.3.2. The intensive floodplain aggradation rate during the Holocene also reflected by the sediment size of the sandy bar material. The Holocene sediment is coarser (mean d_{90}=221.9 μm), than the Pleistocene one (mean d_{90}=70.8 μm). In means that during the Holocene sandy point-bars and mid-channel bars were formed in an environment with higher energy.

3.3.3. In the next step the connection between the grain-size distribution and the location of the samples was evaluated. The percentage of the sandy material on the steeper alluvial fan parts (proximal and distal) is between 71.5-72%, while the mean d_{90} of the samples is between 185-190 μm. On the gentle alluvial fan parts (central and foreground) the percentage of the sandy material is similar (60-70%), but the mean d_{90} of the samples is just 59-70 μm.

3.3.4. During the analyses it became obvious, that the grain-size distribution could be very different on the same part of the alluvial fan, partly because the depth and age of the samples differed, but also because of their channel pattern. At the same part of the alluvial fan the coarsest sediment size was deposited in the braided channels (d_{90}=106.7 μm). The grain-size within the anastomosing channels is smaller (d_{90}=78.5 μm), while the meandering channels have the finest sediment (d_{90}=55.3 μm). It fits to the opinion of *Schumm* (1985), who declared that the braided and anastomosing rivers transport the coarsest sediment.

3.3.5. The sedimentological analyses of the point-bar systems reflect that within the same meander the younger point-bars have finer sediment. This is in good agreement with the contemporary point-bar system's grain-size distribution (*Magilligan* 1992). However, the misfit channels show different tendency. In their case the oldest point-bar has the finest sediment, while the point-bars of the misfit channels are coarser. This could be reasoned by the incision of the misfit channel into the coarse thalweg bottom.

3.3.6. Altogether 29 samples were collected for OSL dating to determine the age of the paleo-channels. The oldest paleo-channels were active 18.7±2.3 ka ago. On the alluvial fan's surface no older channels were identifiable, because the youngest channels reworked these forms. The youngest channels located on the southern, Romanian part of the alluvial fan. The age of the youngest channel is 1.6±1.3 ka. Thus the development of the alluvial fan could be reconstructed since the Late Pleniglacial (*Sümeghy et al.* 2013).

3.4. Paleo-direction changes of the Maros River

3.4.1. Eight paleo-directions (a-h) were separated based on the pattern, direction and OSL age of the paleo-channels. Altogether five paleo-directions (a-e) were active during the Pleistocene, all formed the Hungarian part of the alluvial fan. There was a considerable avulsion 9.6±1.3 – 8.5±0.9 ka ago, when the Maros River started to build the southern lobe of the alluvial fan (*Kiss et al.* 2014). At this time there was an extensive sinking which resulted the incision of the Tisza River and the base-level drop of the Maros River (*Kiss et al.* under review). After this, the Maros started to build the southern, Romanian part of the alluvial fan (f-h paleo-direction).

3.4.2. Some of the paleo-directions are corresponding with previous works. The a, b, c and e-paleo-directions are similar with directions defined by *Mike* (1975a) and *Somogyi* (1961), while the f and h-paleo-directions were also identified by *Mike* (1975b). The c-paleo-direction is very similar with the paleo-channel defined by *Borsy* (1989).

3.4.3. There were some examinations (*Borsy* 1989) to determine the ages of the channels. The direction and age of the c-paleo-direction fit with *Borsy* (1989) results. *Mike* (1991) defined the paleo-directions and the ages of the channels by the sedimentation of the channels. But the ages of the channels determined by *Mike* (1991) were younger like the OSL ages defined by my research.

3.5. Evolution history of the Maros River alluvial fan

3.5.1. Generally, when the climate was warm and wet denser vegetation developed, while when the climate was cool and dry sparse vegetation was typical (*Járainé Komlódi* 2000, *Murray and Paola* 2003). When dense vegetation formed, usually meandering channel pattern developed, because the denser vegetation could decrease the run-off and effectively control the lateral migration of the channels (*Brooks et al.* 2003, *Nádor et al.* 2007b, *Tooth et al.* 2009). In contrary, when the climate was cool and dry the vegetation became sparse, which resulted in increased surface runoff, which caused the formation of braided channel pattern. This pattern could develop because the banks were not stabilized by vegetation, thus lateral erosion could be active.

3.5.2. However, the connection between climate and channel pattern is not so clear, as sometimes the meandering, anastomosing and braided patterns co-existed. It means that the climatic conditions and the vegetation were not the only factors which affected the channel pattern. For example when the water and sediment discharge decreased the infiltration could increase (*Nádor et al.* 2007b). Besides, the slope of the alluvial fan also influenced the channel patterns.

3.5.3. In general, on the Maros River alluvial fan meandering channels developed during periods when the water and sediment discharge decreased. On the other, hand greater discharge was typical when the climate became cold and dry, which could form the development of the braided channels.

3.5.4. During the Holocene (Subboreal and Subatlantic Phases) the river transported coarser sediment than during the Pleistocene. This coarser sediment appeared in the bedload sediment of the meandering channels too. Thus, probably the Maros River had greater energy during the Holocene, which was also reflected by the intensive aggradation rate of the floodplain, though the discharge of the channels decreased.

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