The past of the river

Tímea Kiss, Petru Urdea, György Sipos, Borbála Sümeghy, Orsolya Katona, Orsolya Tóth, Alexandru Onaca, Florina Ardelean, Fabian Timofte, Cristian Ardelean, Árpád Kovács

The clues for deciphering the past evolution of River Maros/Mureş are hidden in its vast alluvial fan, located in Békés, Csongrád, Arad and Timiş counties (Fig. 1). A great number of abandoned channels are recording the history of a very active river, the evolution of which was greatly influenced by the climatic and morphological conditions of the time. When was the river the most dynamic? How much water did flow in the abandoned channels from Sannicolau Mare to Orosháza? When did the most abrupt changes occur in its evolution? A large set of questions for which we sought answers in the first phase of our research.

Fig. 1. – page 34

By finding the answers for the questions above it will be possible to reconstruct the dynamics of the alluvial fan development in the past several thousands of years, and to reveal further relationships concerning the evolution of ancient river channels and the prevailing climatic conditions on the catchment. Why are these investigations important from the aspect of the present and the future of River Maros/Mureş? The answer is rather complex: with the help of these data the long term behaviour of the river system can be understood, the magnitude of extremities that occurred and might occur in the future can be estimated, and the capacity of the river for adjustment can be assessed.

Methods

For the mapping of the ancient Maros/Mureş channels the best available data sources were applied on both sides of the border. The investigation was based on 1:10 000 scale Hungarian and 1:25 000 scale Romanian topographical maps. As the resolution of Romanian maps and contour lines were inadequate for detailed mapping at certain locations, satellite images and aerial photographs were also applied for the investigation. Although Hungarian territories could occasionally be mapped in more detail, characteristic channel types and related morphology could be detected and mapped quite precisely on the entire alluvial fan. This meant that both meandering sections with related point bars, and braided channels with their complex in-channel bar systems were quite well identifiable (Fig. 2).

Fig. 2. – page 35

During the mapping of abandoned river channels, sections with meandering, braided and anastomosed pattern were differentiated (Fig. 2) (Rust 1978, Rosgen 1984, Schumm 1985). The planform view of the channel usually reflects the hydrogeographical, hydrological and environmental parameters, determining both fluvial forms and processes in a river system. These so-called controlling parameters are closely related to the climate, geology, geomorphology and vegetation of the catchment, and rivers thus will always develop their unique morphology by adjusting themselves to the conditions above.

Meandering rivers are usually characterised by medium channel slope and discharge, mixed sediment composition, medium or strong vegetation control on the banks. These will result the development of well developed meanders and point bar systems. On the other hand, braided rivers are usually characterised by high channel slope and discharge, increased bed-load transport and weak vegetation control on the banks. These conditions are usually met at dry and cold climate and at high energy rivers leaving the mountains and entering the lowlands. Rivers of this type are characterised by wide and shallow anabranching channels, levees running along the branches and midchannel bars and islands. Anastomosing rivers usually have a low channel slope, they transport mainly suspended sediment, and vegetation control is considerable in their case. Close to their estuaries rivers will usually have this pattern. Anastomosing rivers are also anabranching, but islands which separate branches are much larger, and they are usually dissected from earlier floodplain surfaces.

In case of ancient meandering rivers the calculation of past discharge is usually based on channel parameters such as meander radius, amplitude or channel width (Gábris 1986, Timár and Gábris 2008). The idea behind these calculations is that the change in discharge values will naturally be resembled in the size of meanders, namely the greater the discharge is, the larger, wider and higher radius bends will develop. By utilising the meander parameters and discharge data of numerous present day rivers it is possible to determine a regionally valid functional relationship, based on which past, so called palaeo-discharges can be calculated from the size of abandoned channels (Gábris 1986). As the first step of our research we aimed to develop regionally valid equations, which in the given geographical setting and at given channel size define the relationship between channel parameters and the bankfull or channel forming discharge as precise as possible (Williams 1984). For determining the functions above the earliest possible discharge data (from the 1930s) was plotted against the natural pre-regulation meander parameters (radius, arc length, chord length) of different rivers on the Tisza catchment (Sümeghy and Kiss 2011). As a result, we were able to determine what discharge and consequently what climatic conditions were responsible for the development of the different meandering channels on the alluvial fan (Fig. 3).

Fig 3. – page 37

For creating the equations, the values of bankfull discharge (Q_b) were taken from the Hydrological Yearbooks of the 1930's. This ensured that the investigations were made on only slightly deformed, close to natural state cross-sections where bankfull discharges could resemble the original values. Only the data of those gauging stations were applied where cross-sectional measurements were regular during the 1930s, thus first bankfull water level then the related bankfull discharge could be determined. Altogether 18 stations met this criteria, 7 on the Tisza and 11 on its tributaries.

Meander parameters – radius of curvature (Rc), bend length (L) and chord length (H) – were determined on 5 meanders in the direct vicinity of gauging stations by digitizing river banks from the maps of the 3rd Military Survey (1882–1884). The reason for using this map series was that planform deformation due to river regulation and management was not significant at this time. The radius of curvature was determined based on a circle being tangential at least in 3 points to the centre line of the channel. Bend length was taken as the distance along the centre line between the midpoints of two neighbouring straight sections separating bends (inflection sections). Chord length was taken as the straight distance between inflection mid points. Measurements were made by ArcGIS 9.2.

After plotting the collected discharge data against measured meander parameters second order polinomial functions were formulated. The correlation coefficients (R^2) of these were in all case 0.7 or higher, which refers to a relatively strong statistical relationship between the parameters. It is very important to note, however, that the calculated equations are valid only in the domain of the investigated discharge values and meander parameters (Table 1).

The palaeo-discharge of rivers, leaving behind numerous channels on the Maros/Mureș alluvial fan, was calculated by the equations determined above. For the calculations only the data of well developed, mature bends (Laczay 1982) were used (Fig. 3), since Gábris (1986) has proved before that these are the most suitable for discharge calculations.

Table 1. – page 39.

The method above is only applicable for meandering river channels. In case of straight and braided sections a different approach is needed. In their case we calculated the bankfull, and thus channel forming discharge using the Manning equation, based on the cross-sectional area and the slope of channels (Baker et al. 1988). The area and other parameters of palaeochannel cross-sections were determined by sedimentological and geoelectrical (ERT) investigations. Slope was determined from digital terrain models made from topographic maps and SRTM data.

Sedimentological and geoelectrical profiles were acquired at 6 study sites, representing both meandering and braided river sections. The primary aim of the measurements was to identify the level of the original riverbed usually marked by coarser sediments. This way the average depth of chanels could be determined. In all, around 2 000 m of geophysical sections were measured (Fig. 4) and 38 drillings were made (maximum depth: 5.40 m, mean depth 2–3 m). Cores were sampled at every 10 cm, this way approximately 1 600 samples were collected (Fig. 5). These were then analysed by an automated laser grain size analyser (Fritsch Analysette 22 MicroTec plus) purchased in the framework of the present project. During the investigations, besides determining discharge values, we also explored the relationship between grain size and geoelectrical data, we determined site specific electric resistance values, and we made estimations for the energy conditions of past riverflows.

Fig. 4. – page 40
Fig. 5. – page 41

Two dimensional geoelectric profiling (ERT) was made by a PASI system, equipped with 32 electrodes (Fig. 4). Profiles were acquired by using the Wenner alpa (Wα) electrode array, having the advantage that compared to other arrays it enables faster profiling and it is less sensitive to horizontal inhomogeneity (Milsom 2003). To achieve the necessary resolution, electrode spacing was set to 2 m. The evaluation of profiles was made by software RES2DINV.

Sediment samples for granulometric measurements were treated by HCl and H_2O_2 to remove their carbonate and organic content, then after drying they were gently crushed. Prior to the measurements samples were homogenised for 3 min in the ultrasonic chamber of the measurement apparatus (36 kHz, 60 W) (Fig. 5). Measurements were made by two linearly polarised He–Ne lasers in the green (532 nm, 7 mW) and infrared (940 nm, 9 mW) domain. The grain-size range measured by the device is 0.08–2000 μm, analyses are made on 108 channels, thus a quasi continuous grain-size spectrum is received. Measurements were repeated three times in case of each sample, and results of the third measurement were used for further analysis (Kun et al. 2012). During the evaluation different statistical parameters were determined (mode, median, standard deviation, skewness, kurtosis, and te values of D10, D50 and D90) to describe the coditions of sedimentation and flow energy.

The bankfull discharge of palaeochannels was determined by using the Manning equation, which requires cross-sectional parameters and channel slope as input data ($Q_b = A * R^{2/3} * S^{1/2} * 1{,}49/n$, i.e. $Q_b = w * d^{5/6} * S^{1/2} * 1{,}49/n$, where A – cross-sectional area, R – wetted perimeter of the cross-section, S – channel slope, w – channel width, d – channel depth, n – Manning roughness coefficient). The equation has only one restriction, namely the width of the river must be greater than its depth by at least one order of magnitude (Baker et al. 1988). The value of the roughness coefficient in the equation is usually between 0.03 and 0.08 in case of natural waterflows. The roughness value used for the calculations (n=0.056) was determined on the basis of discharge measurements at the Makó gauging station. Beside the palaeo bankfull discharge the velocity ($v = R^{2/3} * S^{1/2} * 1{,}49/n$, where v: the mean velocity of the waterflow) and the specific streampower ($\omega = \phi * g * Q * S/w$, where ω: specific streampower, ϕ: density of the liquid, g: gravitational acceleration) of plaeo-rivers were also determined. Cross-sectional parameters were determined at several points on each channel, values were averaged and their standard deviation was built in the error of the final results (Taylor 1983).

The age of abandoned channels was determined by OSL (optically stimulated luminescence) measurements. With the help of this method it is possible to determine the time when the sandy-silty sediments, building up the investigated channels, were last exposed to sunlight. This also tells the depositional or burial age of sediments and thus the age of different channel forms. Consequently, sediments must not be exposed to light during sampling, and all laboratory work must be done in a dark room. Measurements are preceded by several chemical and physical procedures which aim at the separation of the quartz content of the samples (Fig. 6).

In all 27 samples were collected from the sediments of those palaeo-channels which are characteristic representatives of different channel generations, i.e. the main courses of ancient riverflows. Sampling was made on those forms (primarily point bars and islands) which could be clearly related to the last active phase of channel formation and sediment deposition.

Fig. 6. – page 44
Fig. 7. – page 46

For the OSL dating the sandy 90–150 μm and 150–220 μm quartz fraction of sediments were used (Fig. 6). The main steps of laboratory pretreatment were the following: removal of carbonate and organic matter content with acids (HCl, H_2O_2), separation of the quartz grains by heavy liquid density separation (LST), purifying the sample with hydrogen-fluoride (HF) etching and gluing the pure quartz sample onto stainless steel discs with silicone. The exact aim of the measurements is to determine the amount of radioactive dose (palaeodose) absorbed by the sample since its burial, which can be done through complex tests and measurements (Novothny and Ujházy 2000, Onac 2004, Sipos et al. 2009).

The amount of absorbed palaedose was determined with a RISØ TL/OSL DA-15 automated luminescence reader equipped with a radioactive beta source. Samples were stimulated with 470 nm blue light. For the measurements the widely used single aliquot regeneration protocol (SAR) was used with all its test for determining adequate measurement parameters (Wintle and Murray 2006). Each sample was divided into numerous subsamples (48–72 pcs), measurement results were analysed statistically (Galbraith et al. 1999) and the most probable value of absorbed dose was identified (Fig. 7).

Age calculation needs one further parameter, the amount of absorbed dose per unit time in other words dose rate, which is determined by the amount of naturally occurring radioactive elements (uranium, thorium, potassium) in the sediment. The concentration of these was measured by using a Canberra type low background Ge gamma spectrometer.

Results

Geomorphology

Based on the mapping and geomorphological evaluation, the total area of the alluvial fan is nearly 10 000 km^2 (Fig. 1). It is located mainly in Békés and Arad counties, but significant territories are situated in Csongrád and Timiș, and smaller parts extend even to Serbia. In the north the fan is bordered by the Körös/Criș River. However, the abandoned channels of the Maros/Mureș reach as north as Békéscsaba. West and southwest of the fan the floodplain of the Tisza, in the south the channels of the Béga/Bega are situated (Fig. 8). There is more than 30 m difference between the lowest and highest points of the alluvial fan. Although the entire alluvial fan is subsiding, some areas sink at a lower pace and form relative uplifts. As a consequence the river developed a spectacular valley with terraces in between the Battonya High and the Vinga Plateau (Fig. 9).

Based on the abandoned river channels, several generations were identified (Fig. 8). Discharge calculation and dating was focused on these major paths of fluvial activity. The pattern of channel generations was different, and the size of channels also showed a great variety. These facts already indicated that fluvial forms developed at very different discharges, meaning that the climate on the catchment was oscillating from time to time. The pattern and size of channels, however, is also influenced by their situation on the alluvial fan, the composition of the transported sediment and the slope of the area. In this sense the alluvial fan can be separated into three zones (Fig. 8). The first, upper zone extends to the Orosháza–Battonya–Lovrin line, has a slope of 20–25 cm/km and characterised mostly by braided channels. The second, middle zone is a narrow stripe with 25–30 cm/km where most of the past riverflows – even those being braided – developed large meanders. In the third, lower zone slope decreases to 22–27 cm/km, certain channels return to their upper zone pattern, but in most of the cases meandering becomes dominant. The steep middle zone can be regarded as the border of intensive sediment accumulation. Upstream of this area the anabranching braided rivers deposited large amounts of bedload on the alluvial fan, downstream the role of finer sediments is greater (Fig. 8).

The largest, at some locations 2 km wide, braided channels are related to three major channel generations situated on the Nagykamarás–Pusztaottlaka–Csanádapáca–Orosháza line, the Kunágota–Pitvaros–Kövegy–Apátfalva line and in Romania the Periam–Lovrin–Comloşu Mare line (Fig. 8). These channels are characterised by enormous islands and natural levees, which rise over the plane of the alluvial fan by 1.5–2 m, providing thus safe sites for the settlement of people and cultures living in the region in the past.

Most of the channels, detectable on the surface, however, were left behind by the meandering ancestors of the river. The largest bends are located northeast of Makó and near Mezőkovácsháza, Csabacsűd and Zimandu Nou (Fig. 8). Sometimes, e.g. in the vicinity of Periam or Tótkomlós it is clearly visible how younger generations can overwrite older ones, and practically wash away and rearrange previous channel forms. Another interesting geomorphological phenomenon is when the discharge of a river decreases and as a result the original large meanders are frilled by smaller, secondary bends (misfit phenomenon). Probably the best examples for this process can be found near Csanádalberti and Királyhegyes (Fig. 8).

Fig. 8. – page 49
Fig. 9. – page 50

Discharge and hydrology

Based on the geometric parameters of meanders and the area of cross-sections, the calculated discharge values varied in a wide range in the past. The largest cross-sections were found at the braided channels of Orosháza and Kövegy (Fig. 10). We suppose that when the river just filled these channels it could transport 2000–2500 m^3 water per second (Table 2. and 3.), however, during floods much higher amounts of water could be drained thhrough the channels of the ancient Maros/Mureş. Just for comparison, the present day bankfull discharge of the river at Makó is 600–700 m^3/s, while during the record flood of 1970 its discharge was 2420 m^3/s. It can be imagined what power the river could have in the past when it flowed in the direction of Orosháza, Kövegy or Pesac. This enormous amount of water was drained in relatively shallow (mean depth: 2–3 m, maximum depth: 4–5 m) but 1–2 km wide channels, in which huge bars and islands, still detectable on the surface, could develop (Fig. 10).

Fig. 10. – page 51

In periods when the Maros/Mureş drained the water of the catchment through meandering channels the amount of transported water was presumably lower. Although meander parameters at some channel generations occasionally imply 1500–2000 m^3/s discharges. However, on the basis of their cross-sectional area the same channels indicate significantly lower discharges (Table 2. and 3.). The possible reason of disambiguity is that although the Maros/Mureş developed large meanders, the channels were shallow due to the large sediment load. Thus, depth was not as much as it could be expected on the basis of other meandering rivers, such as the present-day Tisza/Tisa. As a consequence, these channels transported less water, than it was assumed on the basis of planform channel parameters. All these point to the necessity to use both methods for discharge reconstruction in the future.

Table. 2. – page 53
Table. 3. – page 53

Based on the comparison of geophysical and sedimentological data, coarse bed-load sediments can be clearly recognised on the geoelectrical profiles (Fig. 11). Therefore, geophysical measurements can be applied more widely in the future for determining past channel cross-sections and discharges.

On the basis of discharge and slope data, the mean velocity of the river could be as much as 1 m/s in case of certain braided channels. This means that the Maros/Mureş could have a considerable stream power. However, the so-called specific stream power, exerted on a unit surface of the channel, was close to the values of the present day Maros/Mureş at Makó (Table 3).

By investigating the grain size distribution of sandy, silty, sometimes fine gravel sized channel sediments the conditions of sediment transport were also reconstructed. At sites close to the proximal part of the alluvial fan, such as Horia and Pesac, bed load transport was dominant and highly turbulent flows were characteristic. Towards the west the turbulent character of the flow decreased and thus channel sediments became more and more sorted. Parallel to this the electric resistance of sediments decreases significantly towards the edge of the alluvial fan. Resistance, as it was mentioned before is in a strong relationship with mean grain size (Fig. 12).

Fig. 11. – page 54
Fig. 12. – page 55

The development of the alluvial fan the key information for the reconstruction of alluvial fan development was provided by the OSL dating of sediments. By the means of the measured ages the variation in morphology and discharge could be evaluated from a historical perspective, and the development of the alluvial fan could be interpreted in the context of past climatic changes. The results of the OSL measurements can be seen in Table 4, however, Fig. 13 showing not just OSL ages but the palaeochannels of the alluvial fan is more informative.

Table 4. – page 56

In the past nearly 20 thousand years the Maros/Mureş frequently changed its course on its vast alluvial fan. From the investigated channel generations the Battonya–Mezőkovácsháza–Makó palaeochannel proved to be the oldest, its meanders started to develop ca. 17–18 thousand years ago (Table 4 and Fig. 13). At this time, in the grasp of the last Ice Age the climate was very cold and dry in Europe and in the region as well, and the vegetation was also scarce. During this period (Older Dryas) glaciers were advancing in the elevated regions of the Southern and Eastern Carpathians. They reached their maximum extension 16–17 thousand years ago (Urdea et al. 2011). Consequently, discharge data of meandering channels dated for this period on the alluvial fan are reflecting lower water supply compared to present day values (Table 2 and 3).

The water of the Maros/Mureş found its way into this direction for 2–3 thousand years. Then, around 15–16 thousand years ago a braided channel arriving from the direction of Tótkomlós cleared away the meandering forms (Fig. 13). From time to time however the river revisited the abandoned Mezőkovácsháza meanders, and as a consequence 11 thousand years ago the Száraz Ér/Er developed some much smaller bends within the original meanders (misfit phenomenon) (Fig. 13).

The Kunágota–Kövegy braided channel generation, erasing the meandering forms of the Mezőkovácskáza palaeochannels signed the beginning of a new period (Bölling Interstadial) around 15–16 thousand years ago (Nádor et al. 2005, Gábris és Nádor 2007, Mezősi 2011). Climate became milder and lead to the intensive melting of glaciers on the upland catchment, while the amount of precipitation also increased considerably. Floods arriving in consecutive pulses lead to the development of several braided and meandering palaeochannels of similar age being around 14–15 thousand years old (Table 4). These were draining the water of the Maros/Mureş towards the Tisza through the Medgyesegyháza–Pusztaföldvár–Békéssámson, Kétegyháza–Nagyszénás and Kétegyháza–Csabacsűd corridors (Fig. 13). These channel generations on their upper sections were braided, while near the edge of the alluvial fan they left behind meandering channels. The development of the seemingly older braided sections was probably facilitated by the fact that during the transition from the cold and dry Older Dryas, vegetation was probably scarce and could not stabilise entirely the channel banks. Large meanders, such as those near Csabacsűd might have appeared a little later by the expansion of a denser vegetation regime (Sümegi et al. 2002). Based on the age data, it is not obvious whether this period was characterised by quick channel changes or the identified channel generations were functioning simultaneously. Anyhow, the bankfull discharge of the Kunágota-Kövegy channel was nearly 2000 m^3/s, while those going northwards from the direction of Kétegyháza drained 1000 m^3/s water individually (Table 2 and 3). This way the river could presumably have two or three main channels in this period.

Fig. 13. – page 59

The Medgyesegyháza–Orosháza braided channel generation, having the largest channels on the alluvial fan, can be clearly separated in time from the above systems (Table 4 and Fig. 13). It could be the main channel of the Maros/Mureş around 10–12 thousand years ago. The development of this system, draining 2500–2800 m^3/s water easily, can also be related to a cooling event and subsequent warming. Based on earlier research, around 12–13 thousand years ago ice was advancing again on the upland catchment (Reuther et al. 2007, Urdea et al. 2011). Following the so called Younger Dryas period intensive warming occurred which was dissected by several short term cooling phases. These conditions were highly favourable for the development of the enormous braided channels near Orosháza. Nevertheless, water was presumably drained through older channels as well, which resulted e.g. the development of the already mentioned Mezőkovácsháza misfit meanders (Fig. 13).

Although in the past 10–11 thousand years the Holocene period brought a relatively stable climate in Europe (Járainé Komlódi 1969), temperature and precipitation could still fluctuate from time to time. The next chapter in the development of the alluvial fan started 7–8 thousand years ago. After entering the lowlands the Maros/Mureş first flowed in a north-west direction, but then suddenly shifted towards south-southwest and passed south of the Battonya High (Fig. 13). The sudden channel shift, termed as avulsion might have been caused by intensive sediment accumulation on the northern half of the alluvial fan. The translation of the direction of flow is indicated by meandering channels near Horia–Zimandcuz–Arad and a more significant braided channel situated on the Periam–Lovrin line (Fig. 13). These channel generations had a similar age, however, their pattern and morphology was very different. In this period (Holocene, Atlantic Phase) the formation of braided channels could be explained by increased precipitation and discharge (2000 m^3/s at Lovrin). However, by this time the area is assumed to be covered by forests, making river banks more stable, which is unfavourable from the aspect of the development of braided forms. Further research is necessary to resolve the discrepancy above.

The Periam–Lovrin channel was active for only a short time. 6 thousand years ago the Maros/Mureş found its present course from East to West along the axis of the alluvial fan (Cornea et al. 1979), occupying several smaller meandering channels on the Sanpetru German–Sannicolau Mare line. The discharge of the fluvial system decreased by this time, however, based on certain meanders, bankfull discharges could be over 1000 m^3/s (Table 2).

The Maros/Mureş occupied finally its present channel 4–5 thousand years ago. Although the river had a natural outlet to the Aranka system towards the south until the river regulations of the 19^{th} c., most of the water has been drained since then (Fig. 13).

Conclusions

In this section we have investigated the past dynamics of the Maros/Mureş River. By the help of the above presented complex research the key events of the evolution of River Maros/Mureş could be reconstructed for the past 18–20 thousand years. Our general conclusions are the following:

- Numerous abandoned channel generations could be identified on the surface of the alluvial fan, resembling a considerable fluvial activity.
- In case of meandering channels past discharge values could be determined using planimetric parameters, however, in case of braided channels geophysical and sedimentological methods were necessary to reconstruct cross-sections and discharges. The two approaches need to be applied together in the future.
- Channel generations near Orosháza, Kövegy and Pesac could transfer bankfull discharges between 2000–2500 m^3/s. However during floods significantly higher amount of water could arrive from the catchment.
- The formation period of the different channel generations could be successfully resolved using optically stimulated luminescence (OSL). Results have shown that the river was developing much dynamically than it was previously expected.
- Major changes in fluvial processes occurred 15-16, 11-12 and 7–8 thousand years ago. These events occurred when the climate started to warm up after cold periods. Severe floods developed as a matter of increasing rainfall and intensive melting of glaciers on the upland catchment.

All this highlights how dynamically the river responded to ever changing geomorphological and environmental conditions. It could also be seen how significant changes could occur in the climate of the region in a few thousand years, leading to great differences in the amount of water drained, the power and destructive force of floods. The revealed relationships may serve as a sound starting point for future research and planning.

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