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RECONSTRUCTION OF PALAEO-HYDROLOGY AND FLUVIAL ARCHITECTURE AT THE OROSHÁZA PALAEO-CHANNEL OF RIVER MAROS, HUNGARY

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Abstract

Several studies have addressed the impact of climate change and tectonic activity on fluvial systems. When investigating these systems palaeo-hydrological and geomorphological data on abandoned channels can yield valuable results. The main aim of our work was to reconstruct morphological conditions at the Orosháza palaeo-channel and to estimate the bankfull discharge which characterized the channel during its formation. There are several equations predicting bankfull discharge on the basis of planform parameters, but these only work for meandering rivers. In case of braided channels flow reconstruction can only be made by using cross-sectional parameters. The Orosháza palaeo-channel provided the means of a comparative analysis in this respect. By a sudden pattern change both meandering and braided reaches, supposedly having a very similar bankfull discharge, could be simultaneously studied. Planform parameters and present cross-sections were determined on the basis of a high resolution DEM, while original cross-section parameters were assessed using sedimentological and geophysical methods. Based on sedimentological data, channel pattern transition was mainly driven by intensive bedload accumulation at the edge of the Maros Alluvial Fan (MAF). Slope differences could not be evened out due to an avulsion close to the apex of the fan. Concerning discharge calculations a good agreement was found between a region-specific planform based equation and the cross-section based Grauckler-Manning equation. Values determined for the braided and meandering reach were also in a good correspondence. Consequently, the presented approach is suitable to determine the discharge of other braided palaeo-channels on the MAF and elsewhere.

Keywords: morphological reconstruction, hydrological reconstruction, sedimentology, geophysics, discharge equations

INTRODUCTION

The reconstruction of fluvial systems is of key importance if the climatic variations or tectonic development of an area is investigated. Therefore in the past decades numerous studies have been made to investigate past fluvial architecture, morphology and sedimentology at various locations (e.g. Dury, 1976; Sridhar, 2007; Timár and Gábris, 2008). When studying ancient fluvial systems one of the basic approaches is to allocate and investigate abandoned channels still detectable on the surface. These provide information primarily on Late Pleistocene and Holocene changes in the environment (Carlston, 1965; Bridge, 2003). Based on the morphometry and sedimentary structure of these channels various conclusions can be made on the discharge of the forming river and the quality and quantity of its sediment. These in turn might provide information to the development of contemporary topography and palaeo-climatic conditions. The interpretation of surficial and shallow deposits is either based on in situ observations, laboratory experiments or geophysical methods (Bridge, 2003; Sridhar, 2007).

The fluvial network of the Pannonian Basin has been affected in the past by climate variations and different rate of tectonic subsidence and uplift processes, the effect of base level change can be regarded negligible (Bridge, 2003; Timár et al., 2005; Gábris and Nádor 2007; Nádor et al. 2007). Tectonic processes are primarily important in determining the gradient and the direction of the flow of rivers (Bridge, 2003; Laure, 2008). As the tectonic development of the Pannonian Basin has been very complex, the reconstruction of the changes in the fluvial network since the regression of the Pannonian Lake still poses some questions (Gábris et al., 1986) in case of the Maros River system as well (Mike, 1991).

Climatic factors, such as mean annual temperature and annual precipitation have an influence on channel pattern by determining runoff the type of weathering and vegetation cover (Schumm, 1985; Mackey, 1993; Bridge, 2003). In the temperate zone the dimensions of a fluvial system is usually adjusted to annually or biannually returning floods, however under changing climatic conditions the role of single, extreme events may be much more significant (Schumm, 1985; Bridge, 2003). Nevertheless, in terms of alluvial rivers the role of bankfull discharge is stressed as channel forming processes are related mostly to these in various works (Leopold and Wolman, 1957; Richards, 1982; Schumm, 1985; Bridge, 2003). In the Pannonian Basin, located in a climatic transition zone, variations could be significant in the past and could result tremendous changes in the dimensions and capacity of lowland rivers (Gabris, 1986). However, climate change and tectonic activity can be equally apparent and it is particularly difficult to know if a sedimentological and morphological change is due to which of the above controlling factors. (Krzyszkowski, 1996; Bridge, 2003; Vanderberghe, 2003).

Recent activity in data collection on present day rivers has allowed on many parts of the world to develop equations which can be applied to reconstruct past discharge values (Bridge, 2003). The relationship between discharge and planform parameters is well demonstrated in case of meandering rivers (Williams, 1984; Bridge, 2003). Parameters mostly used for the reconstruction are chord length, radius of meander and wavelength of meandering (Williams, 1984). These parameters are sometimes not easy to assess, due to the low number of detectable palaeo-channels, or blurred morphology. Discharge calculations of this type obviously will not work on straight or braided rivers.

Another approach for determining discharge is the application of hydraulic parameters, such as area of cross-section, slope, grain size and roughness. Relationships of this type are more or less based on the classical equation determined by Gauckler and Manning (1890s). The Gauckler-Manning equation has been reworked by several authors to fit to different channel patterns and different sets of empirical data (Lane, 1957; Leopold and Wolman, 1957; Osterkamp, 1978; Begin, 1981), however the original equation is still widely used in the literature (Bridge, 2003). When applying hydraulic parameters for the discharge calculations of palaeo-channels it is of major concern to determine values of original slope and cross-sectional area. In these investigations the role of topographical and sedimentological measurements is inevitable, however shallow geophysical methods, such as ground penetrating radar (GPR), or electrical resistance tomography (ERT) can be also efficient if environmental conditions are suitable (Gourrya et al., 2003; Carreon-Freyer et al., 2003; Bersezio et al., 2007; Van Dam, 2010; Yadav et al., 2010; Rucker et al., 2011)

Considering the above, the first aim of our study was to test morphological and hydraulical equations on a braided and meandering palaeo-channel section located on the alluvial fan of the Maros River in Hungary. For the calculations planimetric, topographic, sedimentological and geophysical data were applied. Henceforth the potential of different geophysical methods could be assessed. Finally, we aimed to calculate an average bankfull, or channel forming discharge, characterising the investigated palaeo-channel reach.

STUDY AREA

The study area is located on the interfluve area bordered by the Tisza, Maros and Körös rivers. Geomorphologically, the territory is primarily dominated by the alluvial fan of the Maros River (Pécsi, 1959). The Maros Alluvial Fan (MAF) with a total area of 10 000 km^2 hosts numerous palaeo-channels, representing Late Glacial, Holocene river generations of the Maros (Borsy, 1989; Molnár, 2007; Sipos et al., 2012). From these, one of the largest palaeo-channel is located in the axis of the alluvial fan, near its western edge at the town of Orosháza (*Fig. 1*).

The present day catchment of the river is 30 000 km^2, most of which is located in the Transylvanian Basin, the Eastern and Southern Carpathians (Molnár, 2007). There are no signs for significant changes in the size of the upland catchment during the Quaternary (Mike, 1991). On its lowland reach the Maros has built a large alluvial fan during the Late Pliocene and Pleistocene with a radius of 80-100 km starting from the Lipova gorge. Changes in the direction of its flow on the fan were caused partly by tectonic (local uplifts and subsidences) and geomorphological (avulsion) factors (Borsy, 1989). The apex of the fan is at 130 m asl while its rim is between 80-85 m asl. The slope of the fan is not uniform, usually it is between 20 and 30 cm/km however near the edge there is a belt where it can reach occasionally 50 cm/km (Sümeghy and Kiss, 2011).

Thanked to the above, the river has a relatively high energy which is also resembled by the high sediment transport capacity of the present-day Maros, which is similar to that of the Tisza or the Danube. Horizontally, the sediment of the MAF changes from primarily gravel near the apex to sand and silt towards the edges (Borsy, 1989). Vertical variations in the granulometry of the fan sediment are related to Pleistocene climatic changes in general, namely coarser and finer strata referring to glacial and interglacial phases, respectively (Mike, 1991; Molnár, 2007).

The Hungarian part of the MAF can be divided into four geomorphological subunits based on surface forms and sediments (Pécsi, 1959). The central part is covered by sandy loess and dominated by meandering palaeo-channels (*Fig. 1*). The NE wing is mainly composed of alluvial loess and silt deposits and hosts both meandering and braided palaeo-channels. The northern edge just south of the Körös Basin is covered with sandy loess and primarily braided channel forms are characteristic. Finally the western wing has alluvial loess on the surface and meandering channels.

The site of the investigation at Orosháza is right at the edge of the alluvial fan. East of the town the almost 1 km wide channel has a braided pattern with several sub channels and huge bar forms. Downstream the same channel after leaving the edge of the fan becomes meandering, its width decreases at certain sections to only a few 100 m. According to results of OSL dating the Orosháza channel was active during the Pleistocene-Holocene shift, between 14 and 8 ka (Sipos et al., 2012). As a consequence, post formational loess deposition could not be significant. Partly because of this and due to supposedly fast avulsion processes (Sümeghy and Kiss, 2011) forms are still sharp and well detectable. For the present research two study sites were investigated, one on the braided, the other on the meandering section of the palaeo-channel (*Fig. 1*).

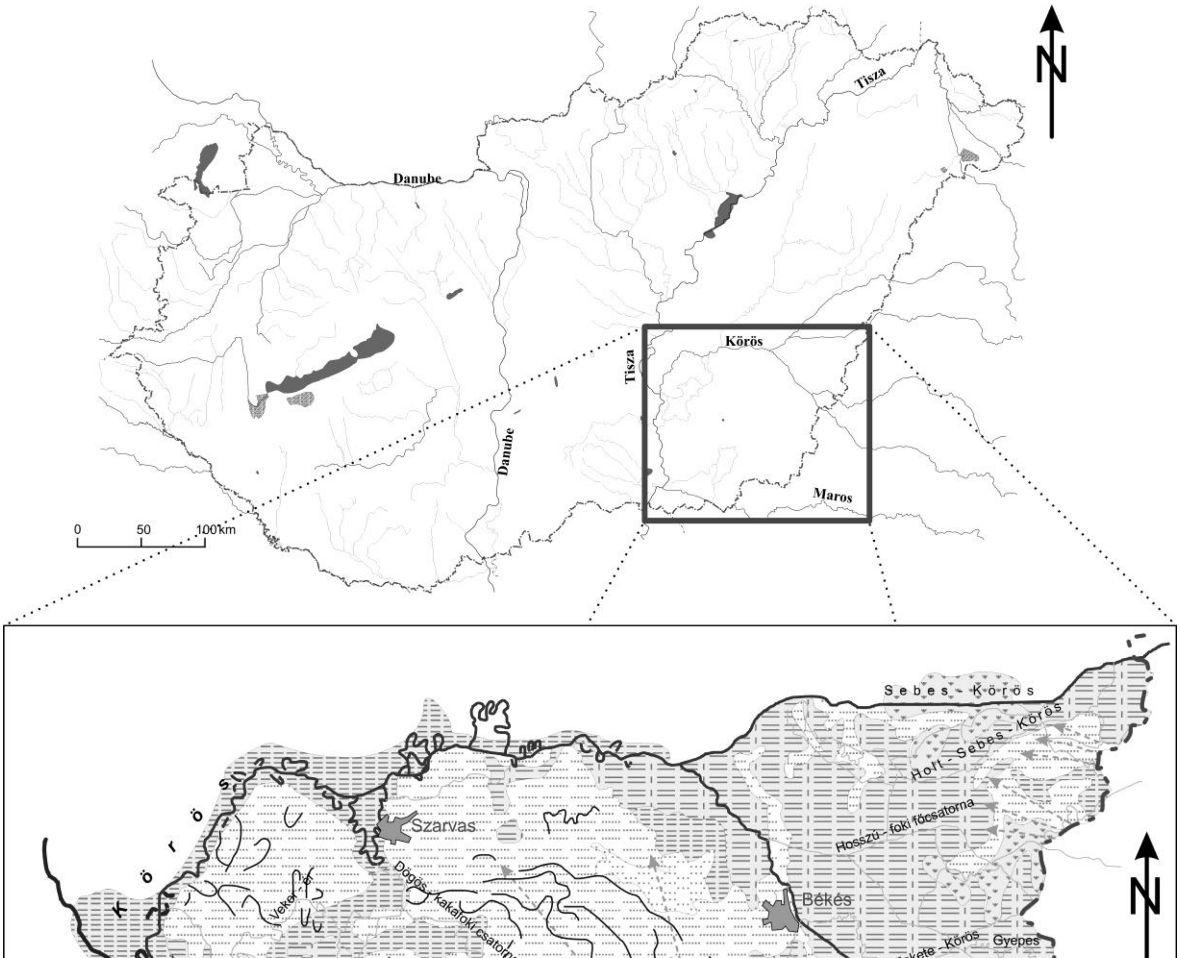

Fig. 1 Location of the study area and the Geomorphological Map of the region (based on Pécsi, 2000)

METHODS

As a first step a digital elevation model (DEM) was produced from 1:10000 scale topographic maps with 1 m interval primary contour lines, supplemented by 0.5 m interval secondary contour lines on flat areas. The DEM was made with the ArcGIS Topo to Raster interpolation tool. Vertical resolution was better than 1 m, while horizontal raster resolution was 10 m (*Fig. 2*). The DEM was used to determine channel planimetric parameters (meander wavelength, meander radius), present day silted up cross-sectional parameters (width, deth, area), and channel slope conditions on the investigated palaeo-reach. Cross-sectional indicators were measured at various points in order to get average parameters. The area's general slope was calculated on the basis of SRTM data.

Since the DEM enabled only the calculation of modified, silted up cross-sectional parameters other methods also had to be applied and compared to determine the original dimensions of the river. The primary aim was to determine the depth of channel sediments and calculate the true depth of the river. In all 16 drillings were made in two cross-sections representing both the braided and the meandering reaches (*Fig. 2*). Drillings were representing characteristic topographic features, such as the natural levee, river bed, bar crests, point bars and chutes. Bore holes were deepened till the level of the groundwater. The depth of the drillings in the channel was 1.5-2 m, on point bars and levees 5-6 m. Samples were taken at every 10 cm. Sedimentological analysis included grainsize analysis. The grainsize-distribution of the samples was determined by a Fritsch Analysette 22 laser equipment with a measurement range of 0.08-2000 μm. Samples underwent ultrasonic homogenisation and all measurements were repeated three times to check if there is further disintegration. For the geomorphological interpretation sample D50 values were determined.

In order to test the applicability of geophysical methods in determining sedimentary shifts GPR and ERT were applied in the drilling sections (*Fig. 3*). GPR measurements were made with a GSSI type instrument, using 200 and 270 MHz shielded antennae. Unfortunately right during the first field work it turned out that sedimentary conditions (high clay and silt content in the upper strata) disable the successful use of GPR technology on these sites. Therefore, ERT profiling was favoured during later measurements. For these measurements a PASI type 32 electrode system was used. ERT sections were measured using a Wenner electrode array. Electrode spacing was 5 m, one section

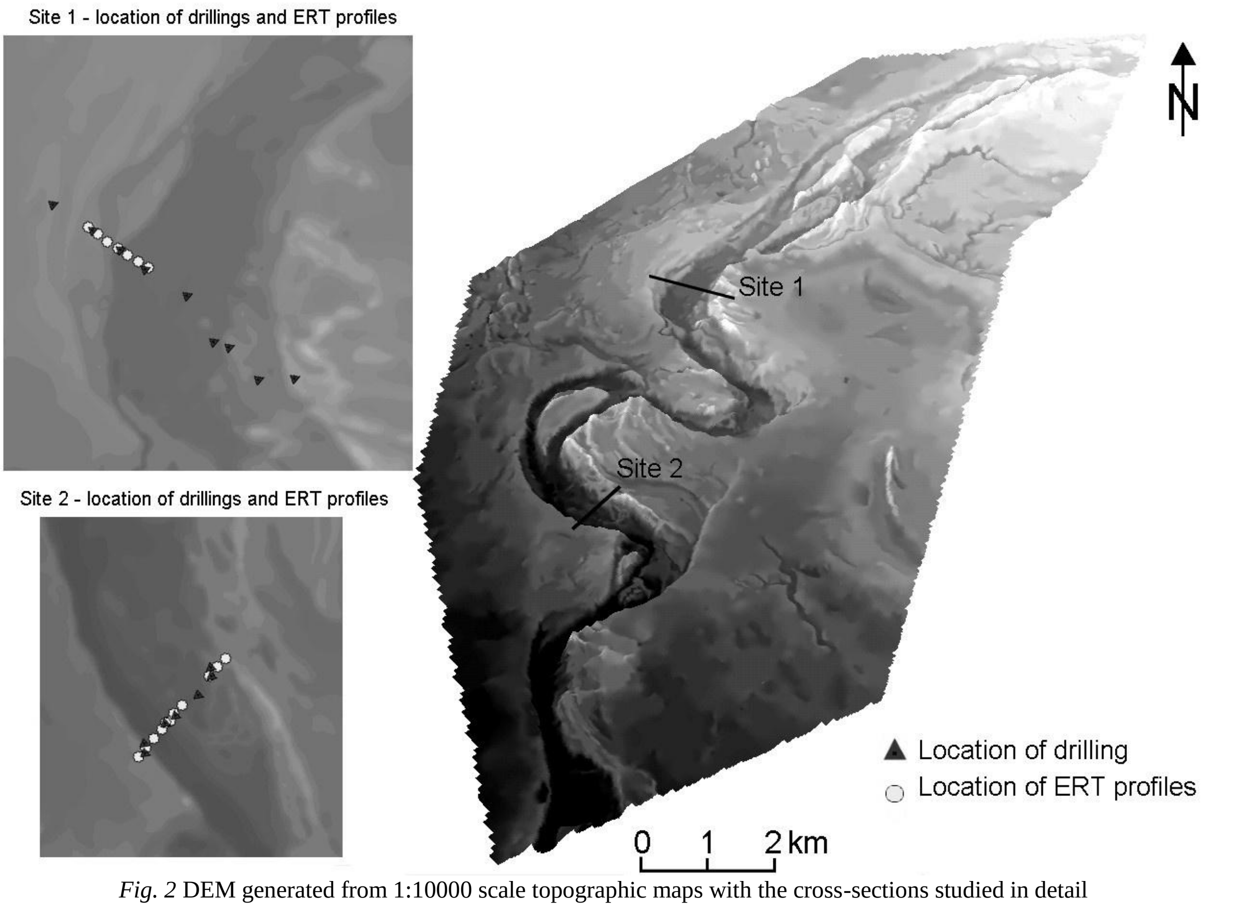

Fig. 2 DEM generated from 1:10000 scale topographic maps with the cross-sections studied in detail

Fig. 3 Geophysical field investigations. The bank of the braided section on the left, and bank of meandering on the right.

was therefore 160 m, from these 5 were measured on both sites. Neighbouring sections had a 50 % overlap. Maximum penetration was 20-30 m, data were collected from 10 levels.

From a geomorphological aspect bankfull discharge is one of the most important parameter of river flows, as it is highly responsible for the geometry of the cross-sections and the channel pattern as well (Schumm, 1985). Bankfull discharge was assessed by selecting and using equations from the literature, with special attention to the range of applicability of the published formulae.

In terms of planimetric parameters the equations of Leopold and Wolman (1957) and Mackey (1993) were selected (*Table 1*). These formulae can be applied only for meandering channels, and they use meander wavelength as the base parameter. The relevance and significance of meander wavelength was also reinforced by Timár and Gábris (2008) when studying the channels of the Great Hungarian Plain. The selected formulae operate up till the 1000 m^3/s discharge range, thus proved to be adequate as a first approximation.

Discharge calculations were also made from cross-sectional parameters. At the two measurement sites these were derived from DEM (present) and sedimentological (original) analyses, results were compared and coefficients were calculated. These coefficients were used to calculate average original cross-section parameters from representative present-day values calculated by taking the mean and standard deviation of several measurements on the DEM.

In case of the meandering section the relationships determined by Dury (1976) and Williams (1978) were tested. The range of the applicability of the Williams (1978) formula ($0.5<Q_b<28320 m^3/s$; $0.7<A_b<8510 m^2$; $0{,}000041<s<0{,}081$) is well over the expected discharge of the investigated system (*Table 1*). In terms of the braided reach the modified Gauckler-Manning equation was applied. The basic equation ($Q=AR^{2/3}S^{1/2}/n$) was modified and reduced by Rotnicki (1983) based on more than 1000 observations on rivers with highly variable geometry ($Q=(1{,}49/n)wd^{5/3}s_c^{1/2}$). Parameter "n" was determined after Goodwill and Sleigh (2002), and calculations made on the basis of present-day measurements on River Maros (Katona et al., 2012). The average value used for calculations was 0.056.

RESULTS

Sedimentological and geomorphological interpretation

The original channel cross-sections were reconstructed on the basis of sedimentological data and geophysical measurements. Channel sediments can be clearly identified in the sedimentary columns, thus the amount of silting up in the thalweg zone can be estimated to be approximately 2-3 m (*Fig. 4*). Silting up is suggested to be the result of post-formational fluvial activity as from time to time the channel could be partially reactivated during the extreme floods of the

Table 1 Equations applied for the calculation of bankfull discharge

meandering	author	equation
planform	Leopold and Wolman (1957)	$L=65.2Q_b^{0,5}$
	Mackey (1993)	$L=72.16Q_b^{0,49}$
	Sümeghy and Kiss (2011)	$Q = 0.0003*L^2+0.3440*L-81.329$
cross-section	Dury (1976)	$Q_b=9.93\ A_b^{0,85}$
	Williams (1978)	$Q_b=4.0A_b^{1,21}s_c^{0,28}$
braided	author	equation
cross-section	Grauckler-Manning	$Q=wd^{5/3}s_c^{1/2}*1.49/n$

Maros system. Natural levees, point bars and mid channel bars are still sharply detectable. We took the present level of these as the minimum heights of banks as subsequent erosion and agricultural activity could lower their level. The D50 value of overbank, or suspended sediments is similar at the two study sites, being 25-30 and 20-25 µm in the braided and the meandering corss-section, respectively (*Fig. 4*). Nevertheless, there is an abrupt change in the grainsize of the bedload. On the braided section the D50 value of channel sediments is 200-300 µm, representing the range of coarse grain sand. Meanwhile, less than 15 km downstream on the meandering section, mean grainsize decrease to 50-150 µm. The degree of sorting however also decreases, but this is due to the appearance of clayey fractions in channel sediments.

In terms of channel slope and general slope it turns obvious that the upstream braided section has a 15-20 % lower slope than the downstream meandering one (*Table 2*). The knick point signs the transition between channel patterns. Such change in slope is unusual in terms of normal gradient alluvial rivers (e.g. Schumm, 1985; Richards, 1996). In this case a possible cause could be tectonic activity, however, this does not explain the significant change in the composition of channel sediments. Pattern and slope change is rather caused by the geomorphological background, i.e. the knick point marks the edge of the alluvial fan.

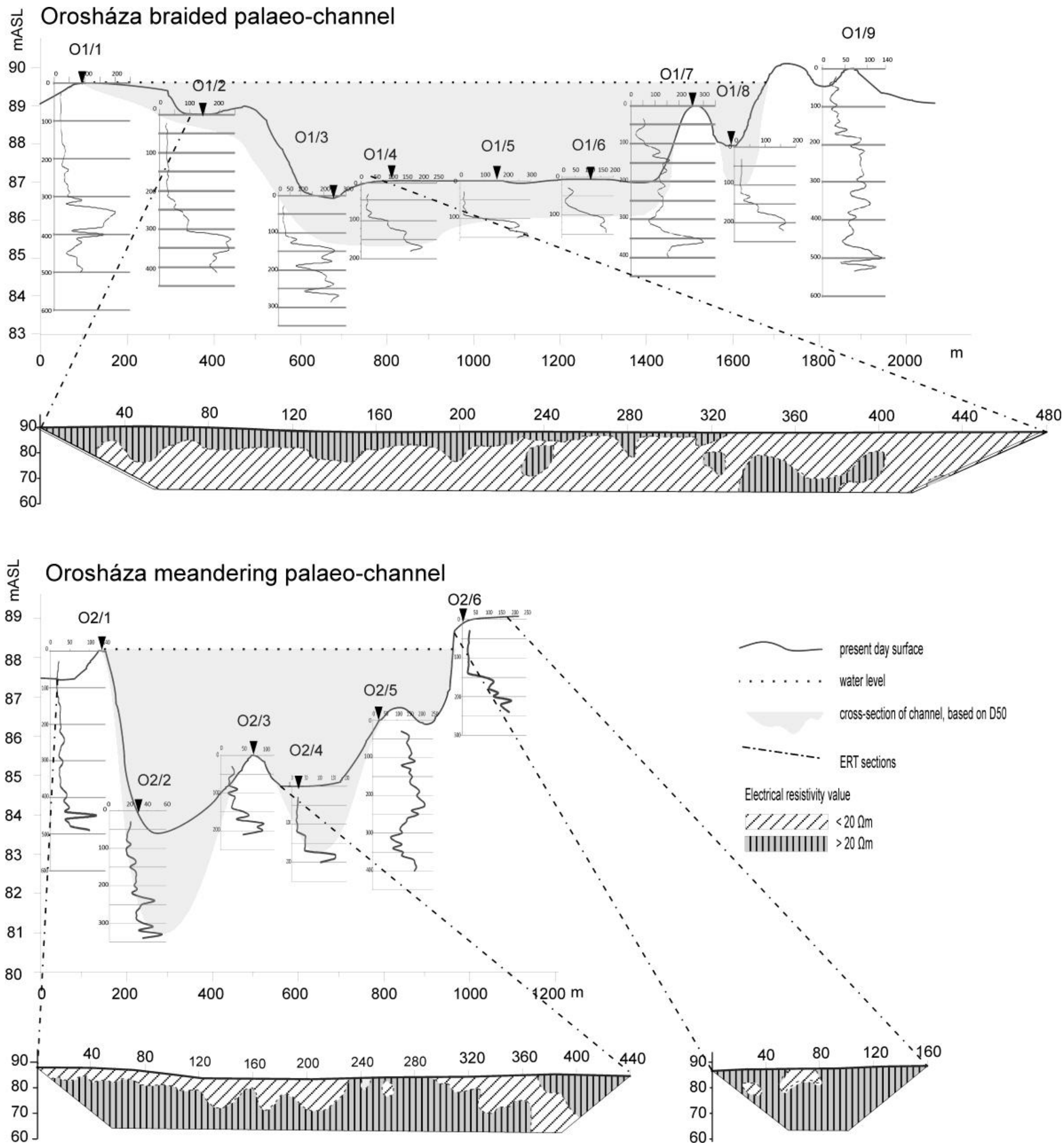

Fig. 4 Cross-section of the sites with sedimentary sequences of drillings and generalised ERT profiles

By reaching the distal parts of the fan the competence and capacity of the river, having a very high bed load of coarse sand, decreased considerably, leading to the development of an aggradation zone (braided section). Downstream of this zone slope and energy increased, and as the river already deposited its coarse sediment upstream, meandering was favoured. Meandering could be further facilitated by sedimentological differences, i.e. in front of the coarser alluvial fan sediments finer more cohesive floodplain deposits are located, confining the banks of the channel (*Fig. 1 and 4*).

Difference in slope suggests a difference in cross-sections as well, namely, larger slope means smaller cross-section at similar discharge on the same river. Data have reinforced this relationship (*Table 2*). The average cross-section of the braided and meandering reaches could be around 3000 and 3800 m^2, respectively. Width/depth ratios also show a remarkable difference between the two sections, being around 400 on the braided and 130 on the meandering section.

Geophysical interpretation

In an alluvial setting the electric resistance threshold between sedimentary units is hard to determine, as different sediments can have very similar resistance (Reynolds, 1997). In general however, the coarser and drier the sediment the higher resistance is received. The study area is primarily characterised by mixed silt, fine and medium sand, which made the interpretation of ERT profiles complicated.

The ERT measurements were made in autumn among dry conditions, thus precipitation could not influence resistivity parameters near the surface (Reynolds, 1997). The received values were between 0 and 300 Ωm. As a first approximation the threshold between silt and sandy sediments was based on the values reported by Nádor et al. (2005) and Yadav et al. 2010, and was taken 20 Ωm. Resistivity profiles however could not entirely be compared to the drilling profiles, due to the resolution provided by the 5m electrode spacing. Nevertheless, in case of Site 1 (*Fig. 5*) the top layers, especially near the bank of the channel, were dominated by sediments with high resistance down till 10-15 m (75-80 m asl). Note that ground water appeared at around 85 m asl, therefore the change experienced in this case is primarily due to changes in grainsize, meaning that coarser sandy sediments are deposited on finer clayey deposits. High resistivity strata wedge out towards the centre of the channel.

At Site 2 resistivity values were a little higher in general (*Fig. 6*), which seems to contradict the hypothesis that sedimentary deposits are finer in front of the alluvial fan. Contradiction can only be relieved if we suggest that the mineral composition of sediments at the two sites is slightly different. This hypotheses however needs further testing. Nevertheless, relative differences of the Site 2 profile show an opposite pattern than that of Site 1 profile. Lower than 20 Ωm values appear on the top left, while higher resistivity values characterise sediments 5-10 m below the surface. As the boundary is again beneath the ground water table it is obvious that palaeo-channel sediments were laid on coarser deposits. Lateral bar surfaces in the middle of the cross section have higher resistivity similar to point bar sediments on the right (*Fig. 6*). Based on these data, the boundary surface might represent the base of the palaeo-channel, although the 20 Ωm threshold needs to be revised in light of higher resolution ERT results. In all, further calculations were based on the results yielded by sedimentological analysis, at present resistivity profiles are not precise enough to draw unambiguous sedimentary boundaries.

Palaeo-discharge calculations

Bankfull discharges calculated by different approaches showed considerable variance (*Table 3*). In terms of the meandering reach discharges calculated on the basis of

Table 2 Cross-sectional parameters of the investigated sites

	Site 1 (braided)			**Site 2 (meandering)**		
L (m)	-			2500 ± 600		
s (cm/km)	25.6 ±1.3			29.7 ± 1.0		
s_c (cm/km)	20.3 ± 0.3			22.5 ± 1.0		
	Parameters of the investigated cross-sections					
	DEM	drilling	coeff.	DEM	drilling	coeff.
w (m)	1125	1125	1,00	685	685	1.00
d (m)	2,3	2,8	1,21	3,15	4,20	1.33
A_b (m^2)	2345	3150	1,34	2076	2870	1.38
	Average values based on several measurements on the DEM					
	DEM	original		DEM	original	
average w (m)	1120 ± 140	1120 ± 140		595±80	595±80	
average d (m)	2,2±0,32	2,7 ± 0,7		3,05±0,7	4,05±0,9	
average A_b (m^2)	2465±470	3025 ± 870		1815±480	2410±625	

L: meander wavelength, s: general slope, s_c: channel slope, w: width, d: deep, A_b: area of bankfull cross section

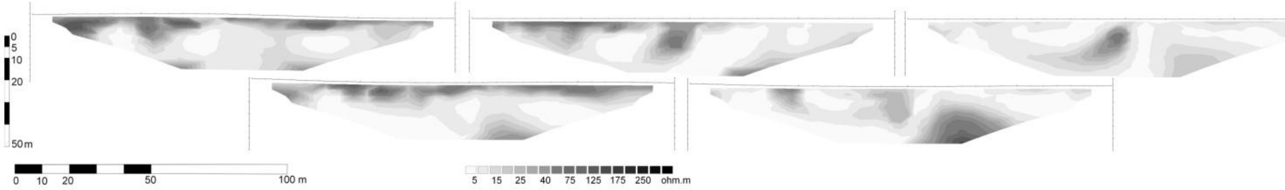

Fig. 5. ERT profiles at Site 1

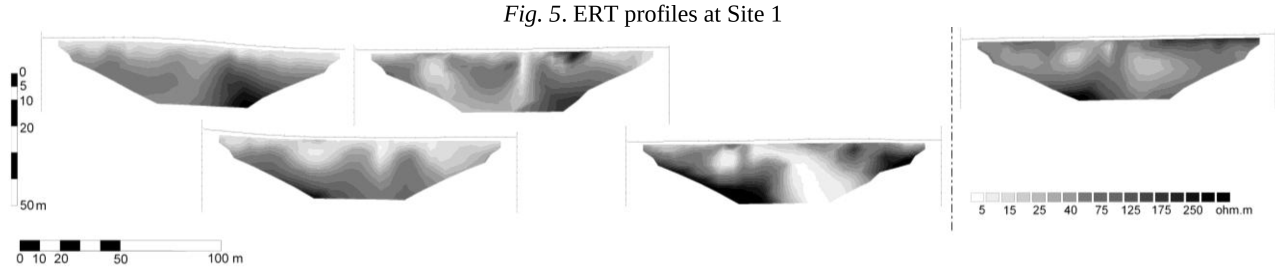

Fig. 6. ERT profiles at Site 2

the classical planform equations (Leopold and Wolman, 1957; Mackey 1978) were considerably, almost 50 % lower than the value received using the region-specific formula of Sümeghy and Kiss (2011). By using the equation of Dury (1976), setting up a relationship between discharge and cross-sectional area in case of meandering rivers, the received result was clearly and significantly overshooting the previous values. When slope was introduced to the relationship (Williams, 1978) the estimated discharge decreased, but it was still significantly higher than the values derived from planform parameters. By applying the modified Gauckler-Manning equation the calculated discharge was very close to the results yielded by the Sümeghy and Kiss formula. Based on this, we assume that the two approaches reinforce each other and the bankfull discharge of the river on the meandering section was approximately 2500 m^3/s.

In case of the braided section the only way to determine bankfull discharge was to use the Gauckler-Manning equation. In theory the result received for this section should be similar to that calculated for the meandering reach. As a matter of fact, results were fairly well corresponding, fell within the error limits and there was only a 9 % difference between the mean values. Consequently, the Gauckler-Manning equation seems to be suitable to determine bankfull discharge values on braided channel section on the MAF. It has been proved however that classical planform formulae significantly underestimate, while cross-section based formulae overestimate the discharges in this environment. One reason can be, that based on width/depth ratios the channels – even those meandering – of the MAF are transitional.

If we compare the received values to the present-day bankfull discharge (850 m^3/s) of the Maros River (Fiala et al., 2007), there is a considerable difference, referring to a much different flow regime during the onset of the Holocene.

Table 3 Bankfull discharge values calculated from planform and original cross-sectional parameters.

Equation	Site 1	Site 2
Leopold and Wolman (1957)		1470 ± 350 m^3/s
Mackey (1993)		1390 ± 330 m^3/s
Sümeghy and Kiss (2011)		**2650 ± 630 m^3/s**
Dury (1976)		7280 ± 1980 m^3/s
Williams (1978)		4570 ± 1240 m^3/s
Gauckler - Manning	**2220 ± 640 m^3/s**	**2445 ± 645 m^3/s**

CONCLUSIONS

The Orosháza palaeo-channel system provided a good opportunity to test different field and computational methods for determining the bankfull discharge of meandering and braided channel sections. The complex analysis included geomorphological, geophysical and sedimentological methods, and emphasizes the necessity of comparing these results.

Based on the investigations some important geomorphological results could be drawn. First, a discrepancy between slope and channel pattern was experienced on the area, which is probably due to inherited slope conditions and high bed load deposition near the edge of the MAF. This suggests that as a matter of an avulsion event the studied channel was not operating as a main flow path for a long time, i.e. channel slopes could not be adjusted to different general slope values. Since their formation the channel silted up 2-3 m, meaning that the forms studied are fairly young, thus the effect of post formational tectonic changes might be also of secondary importance.

At the present phase of research sedimentological and geophysical profiles could not entirely be overlapped, as a matter of their different vertical extent and resolution. However, ERT profiling seems to have a great potential in the fast detection of sedimentary structures on the study area if electrode spacing is decreased. GPR measurements failed due to the high clay and silt content of the sediments.

Discharge calculations on the meandering and braided reaches showed an acceptable agreement. In case of the meandering reach the results based on the meander wavelength/bankfull discharge formula of Sümeghy and Kiss (2011) and those derived from the Gauckler-Manning equation reinforced each other. Moreover, the value received for the braided reach was also in a good correspondence, meaning that cross-sectional parameters determined from sedimentological results can have an important role in estimating the bankfull discharge of braided channels on the MAF.

In all, the calculated bankfull discharges suggest much higher energy fluvial processes than today. Considering the age and the dimensions of the Orosháza palaeo-channel, and also taking into account that the area of the Maros catchment has not changed in the past 10-15 ka, we can suggest that high discharges were mainly related to the melting of glaciers in the upland drainage basin.

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