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DISCHARGE CALCULATION OF PALEOCHANNELS ON THE ALLUVIAL FAN OF THE MAROS RIVER, HUNGARY

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Abstract

The aim of the study was to identify the abandoned channels on the alluvial fan of the Maros River and to calculate their paleodischarge. As the first step of the investigation regional equations had to be made for discharge calculations based on the earliest available discharge data for the rivers of the Tisza catchment in Hungary. Equations between discharge and channel parameters were created with high correlation coefficient. Then the paleochannels were identified on the Hungarian part of the alluvial fan. The paleochannel generations are located in continuous zones with well defined boundaries. The density of the abandoned channels varies on the alluvial fan, as some areas densely covered by channels and on other areas almost free of paleochannels. Braided, meandering and misfit channels were separated, but only the morphometry of the meandering and misfit channels were measured (width, ratio of curvature, half-wavelength and cord-length). Based on these morphometric parameters and the discharge equations the mean discharge of the channels was calculated. The greatest discharge was around 6300 m^3/s while the smallest was 31 m^3/s. However, several abandoned meandering channels had slightly greater bankfull discharge (700-900 m^3/s) as the present-day Maros River.

INTRODUCTION

The paleoclimate reconstructions have an important role in the analyses of the paleoenvironmental events. There are several methods to complete it; most of them aim to determine the precipitation and the temperature. For example the former precipitation and runoff conditions could be reconstructed by calculating paleodischarge data (Stein et al. 2004, Scheurle et al. 2005, Carson – Munroe 2005, Saenger et al. 2006). Besides, these data could be used to reconstruct the magnitude and frequency of floods in the past and to evaluate the amplitude of the present-day floods (Thorndycraft et al. 2005, Benito – Thorndycraft 2005). The paleohydrological data can give useful contribution to study climate change tendencies (Carson – Munroe 2005).

There are several methods to examine and reconstruct the hydrological conditions of the past. Some studies use proxy data, for example the ratio of stable oxygen isotope or the rate of the high-resolution magnetic susceptibility. For example Scheurle et al. (2005) used paleo-oceanographic proxy data of stable oxygen isotopes to determine paleodischarge of the rivers. They analysed the rate of isotopes in calcareous shells of marine animals, because the rate of isotopes correlates with salinity, thus the ratio of salty- and freshwater (paleodischarge) were estimated using the known sea-level changes. Saenger et al. (2006) applied the same method, but they have also modelled the precipitation conditions of the drainage area.

Sedimentological, geochemical and micro-paleontological proxy data of surface sediments also allow to characterise the climate. High-resolution magnetic susceptibility record was used to estimate sediment fluxes and their relationship to paleo-environmental changes. The variability of sediment fluxes during the Holocene can be related to the changes in river discharge and coastal erosion input (Stein et al. 2004). Slack-water deposits were also analysed (Thorndycraft et al. 2005, Benito and Thorndycraft 2005) to study the floods of the last century and to reconstruct the main flood events. The growing amount of flood deposits was in connection with rising flood-level, which is was dated by radiocarbon measurements.

Carson and Munroe (2005) applied dendrohydrology to reconstruct mean annual discharge and precipitation data. The width of an annual tree ring reflects the yearly hydrological conditions and refers to the near-surface temperature, evapo-transpiration and precipitation (Werritty and Leys 2001).

Sidorchuk and Borisova (2000) used paleogeographical analogues to determine paleohydrological and paleoclimatic parameters. The paleogeographical analogue is based on two assumptions: (1) similar hydrological regimes were characteristic for the paleorivers in similar paleolandscapes; (2) the hydrological regime of a paleoriver within some paleolandscape would be similar to that of a present-day river in the same type of landscape. Thus, to determine hydrological parameters of paleorivers and the simultaneous climatic conditions a present-day river must be found which is very similar – every parameters and locations – to the paleoriver.

Lauriol et al. (2002) used fluvial morphology and deposits to conclude paleoclimatic conditions, because the changes in climatic conditions will be reflected by the discharge and they can affect channel parameters (in this case cross-sections were used to determine paleodischarge).

Since there is a close relation between discharge and different channel parameters, a wide range of paleodischarge calculations exist. For example Sylvia and Galloway (2006) reconstructed Late Pleistocene discharge, their calculation was based on radius of curvature, wavelength and some other channel dimensions.

In the Carpathian Basin Gábris (1986, 1995), Timár and Gábris (2008) made paleodischarge calculations to study Holocene climate change and the discharge of scour-channels. The relationship between meander wavelength and the characteristic discharge values was defined. Williams (1984) emphasized the regional validity of the equations, thus the equations can be used just in the same geographical environment and for the same river size as the equations based on.

According to Ward et al. (2007) the climate is a driving force in the hydrological system, therefore the smallest climate change can have significant effect on hydrological processes, including changes in the volume and temporal pattern of discharge. Ward et al. (2007) made climatic- and hydrological models to simulate paleodischarge of Holocene rivers using recent discharge data. The estimated paleodischarge data were close to the data created by the climate- and hydrological model, and the discharge change closely followed the latitudinal and seasonal variations in insolation.

The aim of the present study is to identify the abandoned channels on the Hungarian part of the alluvial fan of the Maros River and to determine their paleodischarge. Our secondary aims are to determine the river course changes based on the morphometry and spatial distribution of the channels and to create regional equations between the discharge values and morphometric parameters. The paleodischarge data could be important to forecast the maximum flood discharge, as increasing magnitude and frequency of floods are very important environmental hazards in Hungary.

STUDY AREA

Our study area is the alluvial fan of the Maros River, which located in the south-east part of the Great Hungarian Plain. The radius of the alluvial fan is 80-100 km (*Fig. 1*). The alluvial fan is shared by Hungary, Romania and Serbia. In this study only the Hungarian part of the alluvial fan (3640 km^2) is studied because of the limited availability the maps from the surrounding countries.

According to Mike (1991) the evolution of the alluvial fan started in the Late Pliocene, however, according to Molnár (2007) it started in the Early Pleistocene based on the sedimentary sequences of the deposits of the alluvial fan. According to Andó (1976) and Borsy (1989) the formation of the youngest part of alluvial fan started in the Late Pleistocene or in the Early Holocene. Nádor et al. (2007) found that the Maros River turned to its present direction during the Middle or Late Holocene, as it is reflected by the middle gravel layer in the three layers which can be found in the Maros River alluvial fan's sedimentary structure.

During the Late Pleistocene and Holocene the Maros River changed its flow direction on the alluvial fan frequently driven by the rising or sinking of the sur-

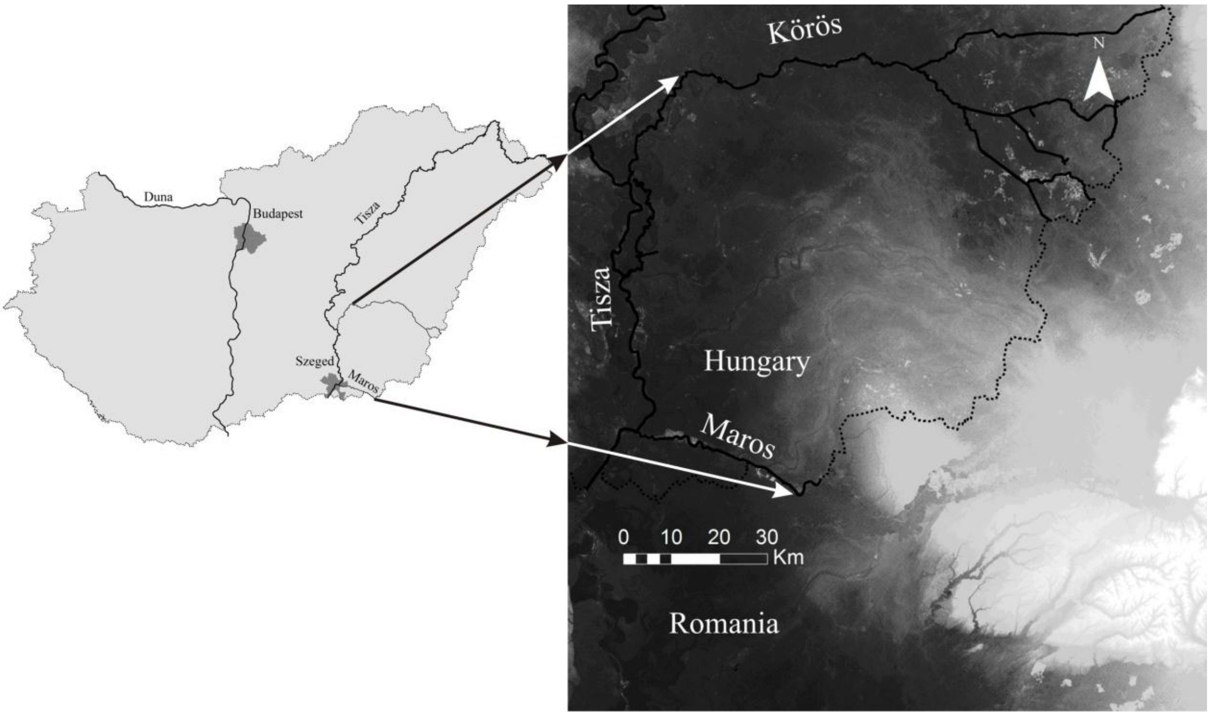

Fig. 1 Location of the alluvial fan of the Maros River (source: SRTM, resolution 90 m)

rounding areas (Mike 1975, Andó 2002). According to Márton (1914) the Maros had no well-defined channel until the Pleistocene, as it was split into several secondary channels. The frequent flow-direction changes were also described by Andó (2002), who mentioned four main course directions during the Pleistocene. According to Mike (1991) the Holocene Maros River changed channels on the alluvial fan frequently, but almost in each case at first it turned to north-east than towards south. However, none of these changes had real scientific evidences, as no precise age determination or sedimentary record exists.

METHODS

Creating paleodischarge equations

The paleodischarge equations are based on contemporary hydrological and morphometric data of the lowland rivers on the Great Hungarian Plain.

Determining bankfull discharge data

The first precise discharge data for the catchment of the Tisza are available from the 1930's, thus they were used because at that time the channel was has not been distorted yet by revetments (though cut-off were already made; Kiss et al. 2008).

The difficulties of the calculations were that (1) in the 1930's discharge measurements were not systematic, they were made mostly in extreme hydrological conditions like at floods or low water stages; and (2) several times the discharge were just calculated from the water level. The bankfull discharge was determined at 18 rivers gauging stations (7 gauging stations on the Tisza River and 11 on the tributaries: *Fig. 2*). In order to determine the bankfull discharge the contemporary cross-sections of the channel was also used.

According to Dury (1961) the bankfull discharge is the most hydrological parameter in connection which the morphometry of the channel. Therefore those horizontal morphometric parameters were measured which are in connection with the bankfull discharge.

Determining the morphometric parameters of the channel

The channel parameters were measured on the III. Military Survey maps (1882-1884), which were made at the time of the river regulations. For the measurements 5 km long river sections at each gauging stations were analysed. The bank-line and the centre-line of the sections were digitalised and the channel width (W), radius of curvature (Rc), half-wavelength (L) and cord-length (H) were measured.

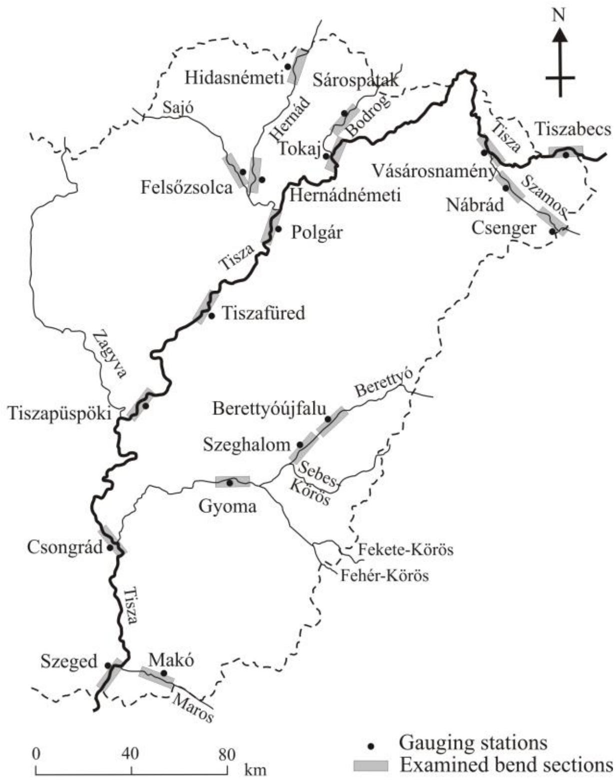

Fig. 2 The discharge data of 18 gauging stations were used and the meander parameters of the 5 km long river sections

According to Laczay (1982) the proportion of half-wavelength and cord-length (L/H) refers to the development phase of the meander, thus the bends can be classified as pseudo-bend, underdeveloped, developed, well-developed and close-to-cut-off meander. From these classes the developed and well-developed meanders are the best to calculate the relationship between morphometric parameters and discharge (Gábris 1986). Therefore, during the paleodischarge calculations only the developed and well-developed meanders were used, therefore 54 meanders were chosen from the 90 curves.

Creating equations between discharge and channel parameters

The equations were created using the water discharge bankfull data of the 1930's and the determined horizontal channel parameters of the Third Military Survey. The aim was to create equations with high correlation coefficient. Using these equations the paleodischarge of the paleochannels identified on the alluvial fan was determined.

Table 1 Relationships between discharge and channel parameters and their applicability range

Channel parameter	*Equation and correlation coefficient*		*Applicability range*
Width (W)	$Q = 0.0001*W^{3.2111}$	$R^2 = 0.7671$	55 – 185 m
Radius of curvature (Rc)	$Q = 0.0008*Rc^2+4.1692*Rc – 226.13$	$R^2 = 0.6983$	29 – 509 m
Half-wavelength (L)	$Q = 0.0003*L^2 + 0.344*L – 81.329$	$R^2 = 0.7235$	472 – 2538 m
Chord-length (H)	$Q = 0.0015*H^2 + 0.0647*H – 31.762$	$R^2 = 0.7888$	307 – 1197 m

The cord-length (H) and the width of the channel (W) show the highest correlation with bankfull discharge. However width characterizes only just one point of the meander and it depends on the channel material, just like the radius of curvature.

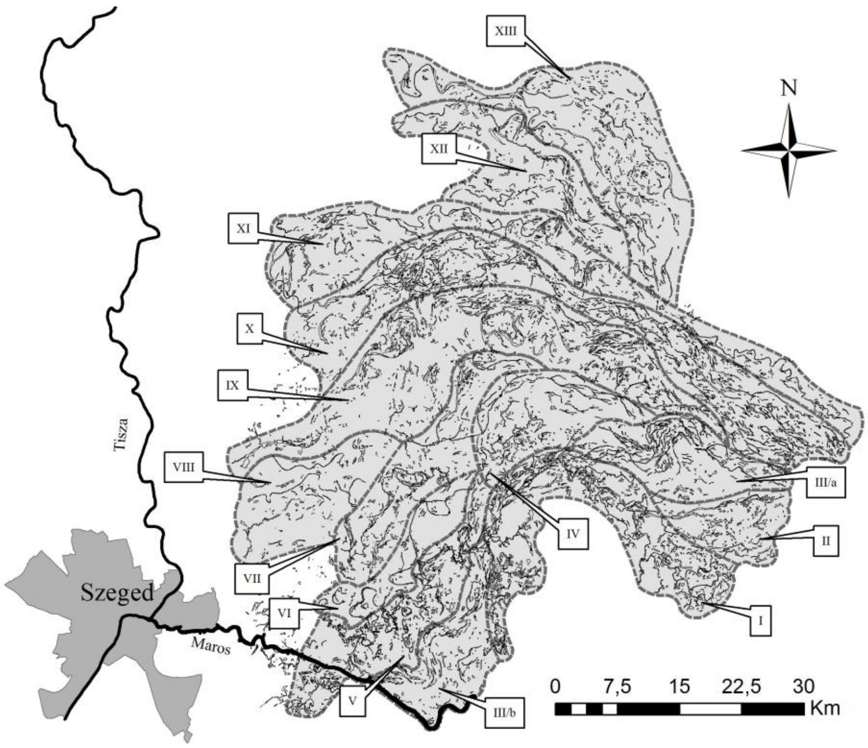

Fig. 3 Abandoned channels and their zones on the Maros River alluvial fan

3.2. Identification of paleochannels

To identify the abandoned channels on the alluvial fan 1:10.000 scale topographical maps and SRTM images (*Shuttle Radar Topography Mission* - with 90 m resolution) were used. Under ArcGIS 10 software the banklines of the paleochannels were digitalised. The different channel pattern types (braided, meandering and misfit) and channel generations were separated. On the identified meandering channels the horizontal morphometric parameters (W, Rc, L and H) were measured. The values of these parameters were substituted into the equations, thus the paleodischarge of the paleochannels was determined.

RESULTS AND DISCUSSION

Creating paleodischarge equations

Exponential and polynomial relationships were supposed between the bankfull discharge data from the 1930's and the horizontal channel parameters of the developed or well-developed type of meanders. Equations with the highest possible correlation coefficient were created (*Table 1*). The applicability range suggests the limits of the usage of the equations.

Distribution and morphology of paleochannels

The density of the paleochannels on the surface of the alluvial fan varies (*Fig. 3*). Some areas are densely covered by paleochannels (17.7%) and in some areas they rarely appear (2.4%). The abandoned channels show a

Table 2 Some typical parameters of the paleochannel zones on the Maros River alluvial fan surface

Zone						*Channel*			*Channel pattern*
No.	*area (km^2)*	*length (km)*	*Width (km)*			*Radius of curvature (m)*			
			min	max	mean	min	max	mean	
I (younger)	296	51	2.1	8.2	5.1	62	186	109	Misfit
I (older)						283	712	405	meandering
II	99	18	1.2	9.8	5.5	-	-	-	braided
III/a	164	27	1.8	10.6	6.2	-	-	-	braided
III/b	146	24	2.7	9.5	6.1	-	-	-	braided
IV	164	27	2.6	11.2	6.9	96	589	284	meandering
V	207	38	2.7	8.4	5.5	61	94	70	meandering/Misfit
VI	99	27	2.8	5.3	4.1	226	756	505	meandering
VII	200	39	2.0	7.6	4.8	-	-	-	braided
VIII	187	25	4.3	13.1	8.7	354	1182	656	meandering
IX	474	70	2.6	13.6	8.1	451	2299	1119	braided / meandering
X	452	77	2.5	8.6	5.5	-	-	-	braided
XI	348	80	1.5	10.2	5.8	256	542	384	meandering
XII	213	37	3.2	10.6	6.9	-	-	-	braided
XIII	375	51	2.0	12.3	7.1	437	532	485	meandering

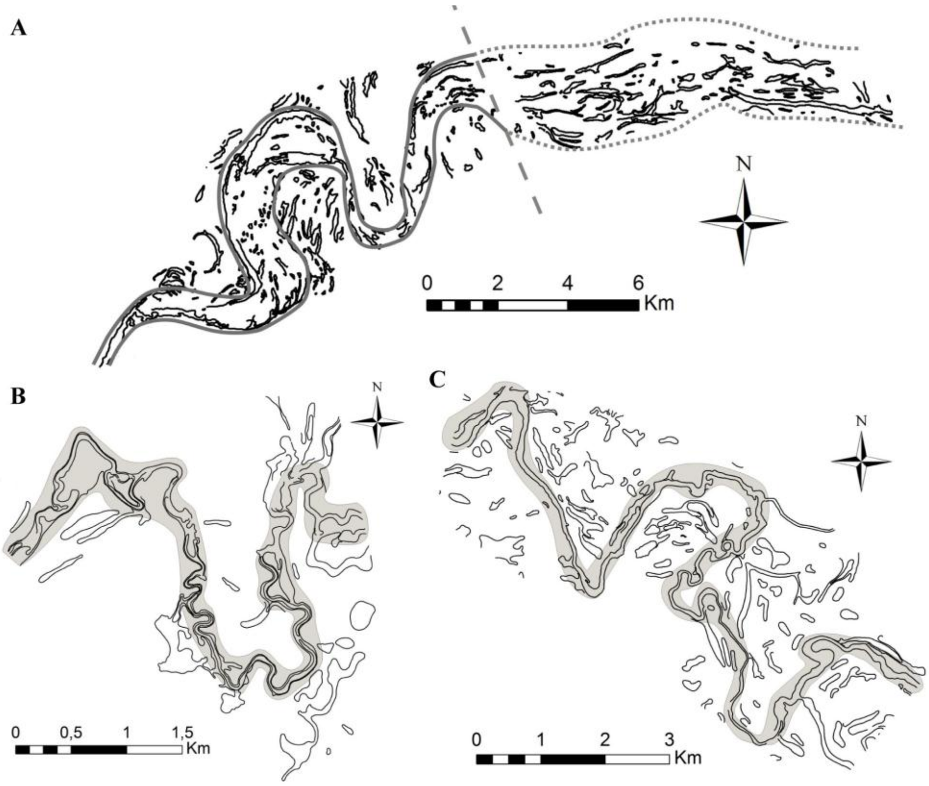

Fig. 4 (A) Transformation of a braided channel into meandering pattern (zone IX), and (B-C) misfit channels from zones V and I

typical pattern, as they appear in almost continuous zones with well-defined boundaries.

The channel pattern, the channel density and the ratio of curvature was the basis if the identification of the zones. These zones run from east to west in an anti-clockwise direction. The mean length of the zones is 42 km and their width changes between 4.1 and 8.7 km (*Table 2*).

Table 3 The calculated bankfull discharges of the paleochannel zones (grey numbers are beyond the application limit of the equations)

Zone	*Bankfull discharge*		
	minimum	*maximum*	*mean*
I (younger: misfit)	32	275	118
I (older: meandering)	656	3683	1338
IV	104	1870	637
V	13	76	31
VI	320	2833	1591
VIII	605	3414	637
IX	1682	12675	6300
XI	485	1429	840
XIII	1155	2515	1642

Determining paleodischarge for the meandering paleochannels of the alluvial fan

Applying the equations above, the paleodischarge of the abandoned meandering channels was calculated based on their horizontal morphometric parameters (*Table 3*). In the zones No. II-III, VII, X and XII the pattern of the paleochannel is braided, thus the equations can not be applied for them. There is also an applicability range limit for the equations (*Table 1*), though smaller and greater paleomeanders were also identified. However, the equations were used to calculate their paleodischarge, but it have to be noted that these data have the greatest error. To determine smaller and higher water discharges we have to extend the study on rivers with higher bankfull discharge, however it means that other rivers than of the Tisza's catchment have to be analysed from the Carpathian Basin.

On the surface of the Maros alluvial fan several channels were found which have slightly greater bankfull discharge like the present-day Maros River (680 m^3/s; Sipos 2004). The meandering channel in Zone IX had the greatest mean bankfull discharge (ca. 6300 m^3/s), which is much higher than the present-day bankfull discharge of the Tisza (3630 m^3/s; Fiala et al. 2006) or the Danube (6550 m^3/s, at Mohács, based on the data of Hydrographical Annals 1970-2000). However this data is beyond of the applicability range of the equations. The determination of the age of this paleochannel will be very important, as the environmental circumstances of such high discharges could be interesting in further research.

CONCLUSIONS

The aim of the present study was to indentify the abandoned channels on the alluvial fan of the Maros River and to calculate their paleodischarge based on newly developed equations between bankfull discharge and horizontal channel parameters.

The abandoned channels appear in zones. In the western part of the alluvial fan mostly meandering channels were identified, while on the eastern part the braided channels are typical. On the northern part of the alluvial fan the braided and the meandering patterns are varying. Other channels are misfit, suggesting radical discharge decrease.

The correlation coefficients (R^2=0.7-0.8) of the created equations are relatively high, but it could be increased by enlargement of the data base. The highest correlation was found in connection with chord-length, which value characterizes the whole curve.

The bankfull discharge of the braided paleochannels could not be calculated using the created equations, therefore it was calculated just for the meanders. Several abandoned meandering channels had slightly greater bankfull discharge (840 m^3/s) as the present-day Maros River, though some had very small (31 m^3/s) and other quite great values (6300 m^3/s), reflecting drastic environmental (i.e. precipitation and runoff) changes during their activity. In the middle part of the alluvial fan (Zone IX) the paleochannels had the highest discharge data, while the north and south direction from it, the value of the discharge is gradually decreasing.

The results could be used in future flood protection, because it pointed on the fact that extreme discharge conditions could appear in the system of the Maros River. Besides, the created regional equations could be used in river restoration projects, where the design of appropriate channels parameters is the key-point of each project.

Acknowledgement

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