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RESEARCH ARTICLE

First report on dendrochronological and radiocarbon studies of subfossil driftwood recovered across the Mureş/Maros Alluvial Fan

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ABSTRACT

Visiting three gravel pits and three natural outcrops across the Mureş/Maros Alluvial Fan, 58 samples were collected from subfossil driftwood recovered from coarse-grained fluvial sediment layers, while no subfossil wood was found at three additional gravel pits. Dendrochronological and radiocarbon analysis of these relict wood can support the temporal extension of the regional dendrochronological reference datasets and their dating can provide a useful contribution to the reconstruction of the landscape evolution of the Mureş/Maros Alluvial Fan. The tree-ring widths of the subfossil samples were measured. Dendrochronological synchronization resulted in two oak chronologies which encompassed five, and two reliably cross-dated series covering 191 years (MURchr1) and 127 years (MURchr2), respectively. Based on the ^{14}C ages the subfossil driftwood material represents Middle and Late Holocene ages. The occasionally up to 6 m-thick fluvial sediment covering relatively young, < 1000-yr-old wood, indicates intense accumulation at the apex of the Mureş/Maros Alluvial Fan, which explains the documented rapid and significant Holocene avulsions.

KEYWORDS

dendrochronology, fluvial process, Holocene, Hungary, oak, Romania, silver fir, ^{14}C ages

INTRODUCTION

Subfossil wood is non-petrified wood which has been preserved over hundreds or thousands of years in geologic environments (Kaennel and Schweingruber, 1995). Buried subfossil wooden remains were found in large quantities during the past decades in both natural and artificial excavations in the sediments laid by fluvial processes across East and Central Europe (Reinprecht et al., 1988; Becker, 1993; Krąpiec, 2001; Gębica and Krąpiec, 2009; Dzieduszyńska et al., 2011; Kolář and Rybníček, 2011; Nechita et al., 2014; Vitas et al., 2014; Pearson et al., 2014; Kern and Popa, 2016; Árvai et al., 2018). With rare exceptions (e.g., Kázmér, 2008) these are late Quaternary remains.

Studying these Holocene and Late Pleistocene remains helped the regional Quaternary dating efforts not only via the development of regional dendrochronological reference curves

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(e.g., Krąpiec, 2001; Kolář et al., 2012) but also greatly contributed to the radiocarbon (^{14}C) calibration database for the Northern Hemisphere (Kromer et al., 1986; Becker, 1993; Friedrich et al., 1999). Subfossil wood remains such as plant macrofossils are sources of information for the reconstruction of the age and species composition of floodplain forests (Árvai et al., 2017), and provide valuable geochronological evidence for the reconstruction of the fluvial activity and landscape development (Starkel et al., 2009; Gębica and Krąpiec, 2009; Rădoane et al., 2015, 2019; Gębica et al., 2013). Beside these scientific aspects, the interest of wood industry has also been aroused for the subfossil wood in the region (Beldean and Timar, 2021).

Subfossil driftwood material has been recovered from many places across the apex of the Mureş/Maros Alluvial Fan (Fig. 1). The river has been continuously shifting its course on the fan area throughout the Pleistocene and the Holocene (Kiss et al., 2012, 2014). The evolution of the area was greatly influenced by climatic and morphological factors. Results have shown that the river was developing much more dynamically than was previously expected. The major changes in fluvial processes were marked by „sudden" shifts

Fig. 1. Location of gravel pits and natural outcrops visited between December 2015 and September 2016 in searching for subfossil driftwood in Mureş/Maros alluvial sediments. Green circles show the collections sites along both sides of the river, among which crossed circles show sites where subfossil driftwood was not found. The location of the study area is indicated by the red rectangle in the inset map of Europe. Site photos showing typical subfossil driftwood collection sites from the Mureş/Maros Alluvial Fan. A: a dump of relic wood recovered during the exploitation of the gravel in Frumuşeni/Széplak Pit 1. B: a partially uncovered subfossil log close to the water table ~5 m below the ground level in Frumuşeni/Széplak Pit 2. C: the largest sampled subfossil trunk (sample code: MUR037) in Frumuşeni/Széplak Pit 2. The dimensions of the trunk are annotated in picture. D: a fragment of the bole of a conifer embedded in gravel (sample code: MUR075) and a closely-situated smaller oak remain (sample code: MUR076) in a natural outcrop at Zăbrani/Temeshidegkút

of flow direction and changes of channel pattern (Kiss et al., 2014). Based on geochronological evidence, major avulsion events took place at ~15 ka, ~12 ka, ~8 ka, and ~6 ka, and these can possibly be related to the intense deposition of coarse-grained sediments at the apex of the alluvial fan (Kiss et al., 2014). However, aggradation rates and fluvial dynamics have not been investigated in detail at the apex of the fan so far to support the hypothesis above.

This paper reports a brief summary of the field observations, species composition and dendrochronological studies of the subfossil driftwood collected across the Mureş/Maros Alluvial Fan from December 2015 to September 2016. In addition, the first set of ^{14}C ages from this relic wood is also presented for the first time, which can help to improve the picture of the Holocene fluvial landscape evolution of the Mureş/Maros Alluvial Fan.

METHODS

Study sites and sample collection

The Mureş River (Maros in Hungarian) springs from Hăşmaş/Hagymás Mts (Eastern Carpathians) and its outlet is in the River Tisa/Tisza near Szeged (Sipos et al., 2012). It is the largest tributary of the Tisa/Tisza to drain the waters of the Transylvanian Basin. The area of its catchment is 29,767 km^2 (Ujvari, 1972), bordered by the Apuseni Mts and the ranges of the Eastern and Southern Carpathians (Urdea et al., 2012). Its total length is 766 km and the lowland section from Lipova to Szeged is approximately 175 km in length, where the river built an extensive alluvial fan. The Mureş/Maros Alluvial Fan is one of the most extensive landforms in the western part of Romania, covering around 10,000 km^2, with a radius of 80–100 km. Nearby Lipova is located on the apex of the alluvial fan, where the slope of the Maros is ~30 cm km^{-1}; its mean discharge is 182 $m^3\ s^{-1}$, but during floods it can be as much as 2,200 $m^3\ s^{-1}$ (absolute maximum was on 18 May 1970: 2,320 $m^3\ s^{-1}$) (Urdea et al., 2012). Consequently, its sediment transport capacity is high, which leads to very active channel processes in the lowland section of the river.

The Mureş/Maros shifted its course within the fan area throughout the Pleistocene and the Holocene (Kiss et al., 2012, 2014). The surface of the Mureş/Maros Alluvial Fan is densely (0.78 km km^{-2}) covered by paleochannels (Sümeghy and Kiss, 2012). The present-day direction of the river probably exists since Roman times, around 2 ka ago (Sipos et al., 2012). The Mureş/Maros was regulated at Arad after 1815 CE in accordance with Johann Mihalik's plan (Sipos et al., 2012). The river could not yet reach equilibrium state, and channelization effects resulted in intensive lateral migration/erosion (Timofte et al., 2016). It is worth mentioning that exploitation of alluvial sediment, such as sand and gravel, intensified upstream of Arad because of the growing need for building materials (Timofte et al., 2016).

Six gravel pits and three natural outcrops were visited across the Mureş/Maros Alluvial Fan (Fig. 1) between December 2015 and September 2016. No subfossil wood remains were found at three gravel pits near Ghioroc/Gyorok, Horia/Újpanád, and Zimandu Nou/Zimándújfalu; however, relic wood was abundant at three closely situated gravel pits near Frumuşeni/Széplak and at the natural outcrops exposed by lateral erosion at Zădăreni/Zádorlak and Zăbrani/Temeshidegkút (Fig. 1).

A disk (~5–10 cm thick) was sliced from each trunk using a chainsaw and wrapped in plastic foil to protect the sample during transportation to the lab. Altogether 58 different subfossil trunks were sampled; however, the physical conditions of three samples turned out to be unsuitable for processing for dendrochronological analysis.

Xylotomical and dendrochronological analysis

Cross sections of the dried samples were mechanically sanded with successively finer wood abrasives to expose ring details to the cellular level (Stokes and Smiley, 1968). Genus or occasionally species could be identified based on basic xylem characteristics (Schoch et al., 2004; Wheeler, 2011). At the natural outcrop near Zăbrani/Temeshidegkút four coniferous samples were recovered from a gravel layer. Based on the basic xylotomical features, such as the texture of the tracheids and the earlywood-latewood boundary, these belonged to the same species. Since coniferous wood is quite exceptional in the subfossil driftwood material in this region (Árvai et al., 2017), a sample (MUR077) was selected for detailed wood anatomical analysis to clarify the wood species.

Thin sections (5–20 µm) were prepared using a sliding microtome (Thermo Scientific Microm HM 430) in the three main anatomical directions (tangential, longitudinal, and transversal) following standard protocol (Mihalik et al., 1999; Antalfi, 2015; Antalfi and Fehér, 2015). The preliminary analysis was carried out using a stereomicroscope (Nikon SMZ-2T) while a Zeiss optical microscope was used to obtain higher magnification to identify characteristic xylotomical features. Wood identification was performed based on the observed anatomical characteristics compared to reference databases (Hollendonner, 1913; Schweingruber, 1990; Butterfield et al., 1997).

A LINTAB digital-positioning table and TSAP Win 4.68 software (Rinn, 2005) were used to measure the annual increments to a precision of 0.01 mm. Annual growth widths were measured at least along two radii in each sample and the series were synchronized and averaged. Finally, the mean tree-ring series was determined for each disk and used in the analysis.

Visual and statistical methods were used to synchronize these individual mean curves. Standard dendrochronological statistics such as percentage of agreement (GLK%, Eckstein and Bauch, 1969; Buras and Wilmking, 2015) and modified t value (tBP, Baillie and Pilcher, 1973) were used to evaluate crossdating results.

Radiocarbon analysis and calibration

Small blocks, containing 10 to 16 annual increments, were detached from the outermost edge of four samples (Table 1). They were subjected to the standard AAA chemical treatment

Table 1. The results of the radiocarbon analysis of subfossil driftwood samples collected from the Mureş/Maros Alluvial Fan. Calibrated ages are reported in years as intervals corresponding to 95.4% probability range rounded to decadal precision. BP stands for "Before Present" where present refer to 1950 CE

Sample code	Lab code	Species	Conventional ^{14}C age (Year BP)	cal BP (yr)
MUR037 (F2/1)	CSZ103	*Quercus* sp.	623 ± 30	655–550 (95.4%)
MUR038 (F2/2)	CSZ104	*Ulmus* sp.	582 ± 30	650–580 (66.0%)
				570–630 (29.5%)
MUR015	CSZ111	*Quercus* sp.	5,193 ± 33	6,110–6,090 (2.6%)
				6,005–5,900 (92.8%)
MUR012	CSZ112	*Quercus* sp.	824 ± 28	780–680 (95.4%)

(Tans and Mook, 1980), then were converted to benzene using an Atomkomplex Prylad-type benzene synthesis line (Skripkin and Kovaliukh, 1998). Samples were pyrolyzed in vacuum in the presence of Li to produce Li_2C_2, which was converted first to acetylene by hydrolysis, then to benzene using a vanadium catalyst. Radiocarbon (^{14}C) activity was assessed by Liquid scintillation counting (LSC) using a Quantulus 1220™ ultra-low LSC instrument at the Geochronological Laboratory of the University of Szeged following the procedures detailed by Skripkin and Buzinnyi (2017).

Sample and background activities were calculated using quench curves generated from mixtures containing a different proportion of the standard and scintillation cocktail. Conventional ^{14}C ages were calculated using the Libby half-life (5,568 years) and the fundamental assumptions of the method according to Stuiver and Polach (1977). Calibration of conventional ^{14}C ages to calendar dates was performed using OxCal v.4.4.2 (Bronk Ramsey, 2009) in conjunction with the IntCal20 dataset (Reimer et al., 2020). Calibrated ages are reported with 95% probability in cal BP defined as years before present, where present is 1950 CE.

RESULTS AND DISCUSSION

Species and countable rings

The non-coniferous samples were assigned to four genera based on characteristic anatomical features as follows *Quercus* (n = 32), *Ulmus* (n = 15), *Populus* (n = 2), and *Fagus* (n = 1). The dominance of oak and elm in the subfossil driftwood (Fig. 2A) is usual in East and Central Europe and the occasional appearance of poplar and beech is also frequently documented (Kolář and Rybníček, 2011; Kern and Popa, 2016; Rădoane et al., 2015; Árvai et al., 2018).

In the coniferous sample the wood-anatomical analysis revealed distinct boundaries between earlywood and latewood (Fig. 3A). Resin ducts were observed neither between tracheids nor in the rays. Bordered pits were clearly visible in the walls of the longitudinal parenchyma cells (Fig. 3B, C). Rays were homogenous, built exclusively from parenchyma cells, occasionally with reddish-brown infilling. Taxodiod pits counted as 2 to 4 in the earlywood and 1 to 2 in the latewood. In tangential sections the height of the uniseriate rays was 1–40 cells, most often 8 to 10 (Fig. 3D). Based on these xylotomical features the wood of MUR 077, and very likely all the other coniferous samples found at the gully near Zăbrani/Temeshidegkút, is silver fir (*Abies alba*).

The occurrence of coniferous wood is rarely reported in a subfossil driftwood assemblage in this region. Scots pine (*Pinus sylvestris*) trunks were recovered after removing thick gravel layers during the construction of the Gabčíkovo dam and reservoir (Babos, 1987–88) and a chunk of European larch (*Larix decidua*) was reported recently from the Drava River (Árvai et al., 2018). According to our knowledge this is the first case of silver fir being found in a subfossil driftwood assemblage in East and Central Europe. However, the occurrence of this species is not surprising because silver fir

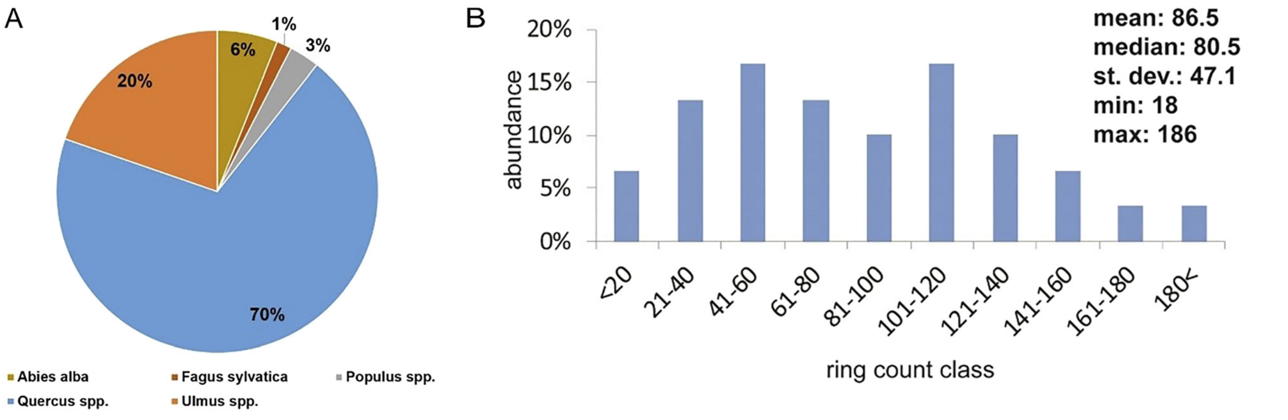

Fig. 2. Pie chart illustrating the species composition (A) and age distribution histogram (B) of subfossil driftwood collected from the Mureş/Maros Alluvial Fan between December 2015 and September 2016. Basic statistics are shown in the top right corner in panel B

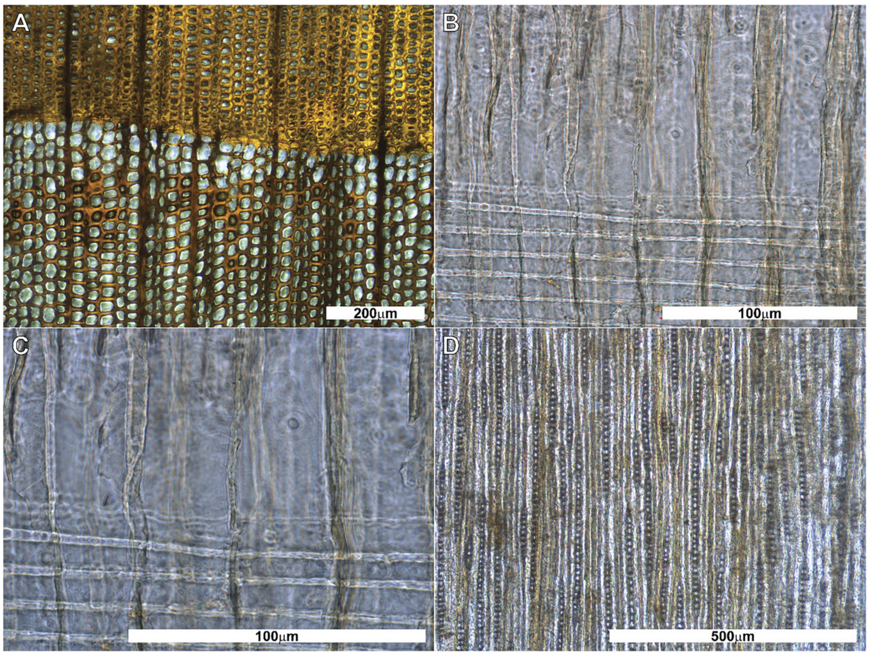

Fig. 3. Microscopic anatomical features of MUR077 sample. Cross (A) radial (B, C) and tangential (D) sections. White bars at the lower right corner of the images indicate the scale

is quite an abundant species in the current forests covering the mountainous part of the Mureş/Maros catchment (Popa and Sidor, 2010; Caudullo et al., 2017).

Counted tree rings ranged from 18 to 186 (Fig. 2B). The distribution of the counted rings shows a kind of concentration in the 21 to 80 range (~43%), while rather few samples preserved more than 120 measurable rings (~23%). The range and the observed skewness of the age distribution towards the younger specimens is again frequently observed in other subfossil driftwood assemblages (Kolář and Rybníček, 2011; Kern and Popa, 2016).

Results of the dendrochronological synchronization

Oaks yielded significantly more tree rings compared to the other species. Among the longer oak ring width series, we were able to find statistically and reliably synchronizable ring width series (Fig. 4). Five series were collected in a dataset (MURchr1) covering 191 years (Fig. 4A) and two very strongly correlated series were synchronized (MURchr2) covering 127 years (Fig. 4B). The current success rate of dendrochronological synchronization of the subfossil driftwood assemblage (7 out of 55 samples) collected from the Mureş/Maros Alluvial Fan is in agreement with the experience of subfossil driftwood analysis from the Suceava river (Kern and Popa, 2016) but far below the success rate reported from numerous Polish sites (Krąpiec, 2001) or a Belarusian site (Vitas et al., 2014), and from three Croatian sites located along the Sava river and its tributaries (Pearson et al., 2014). The explanation of this low success rate, as was addressed in other similar cases (Kolář and Rybníček, 2011; Kern and Popa, 2016), is very likely the adverse effect of the young bias of the collected samples (Fig. 2B). The low number of measurable rings is a well-known challenge in dendrochronological synchronization of subfossil material (Árvai, 2019).

The created mean oak ring width chronologies of MURchr1 and MURchr2 were compared with oak ring width chronologies available from various locations across Romania (Nechita et al., 2014; Chiroiu et al., 2018). However, no reliable synchronicity was found with these data (Constantin Nechita pers comm.; Patrick Chiroiu pers comm.).

Results of the radiocarbon analysis

The conventional ^{14}C ages ranged from 582 ± 30 to 5,193 ± 33 ^{14}C BP (Table 1). The calibration yielded 780–680 cal BP as the age range of MUR012 (median age: 720 cal BP), collected from a subfossil oak trunk partially embedded to the coarse fluvial sediment in the Frumuşeni/Széplak 1 pit. The calibrated age ranges of MUR038 and MUR037, collected from the Frumuşeni/Széplak 2 pit, largely overlap; moreover, their median age of the calibrated intervals pointed unequivocally to 600 cal BP. The lack of statistically significant synchronization between their ring width fluctuation, despite the radiometric evidence suggesting their close age and probably overlapping lifespan, can be due to the fact that they belonged to different species (Table 1), and that MUR037 had strongly asymmetric circumferential growth patterns, with indication of multiple changes of the direction of tilting of the trunk. MUR015 was also collected from dumped trunks in the Frumuşeni/Széplak 2 pit but yielded a much older age (Table 1).

Since two of the samples belonged to the created synchronized subsets, a ^{14}C-inferred age could be assigned to the developed floating mean ring width oak chronologies. Regarding the inferred median ages and the counted rings

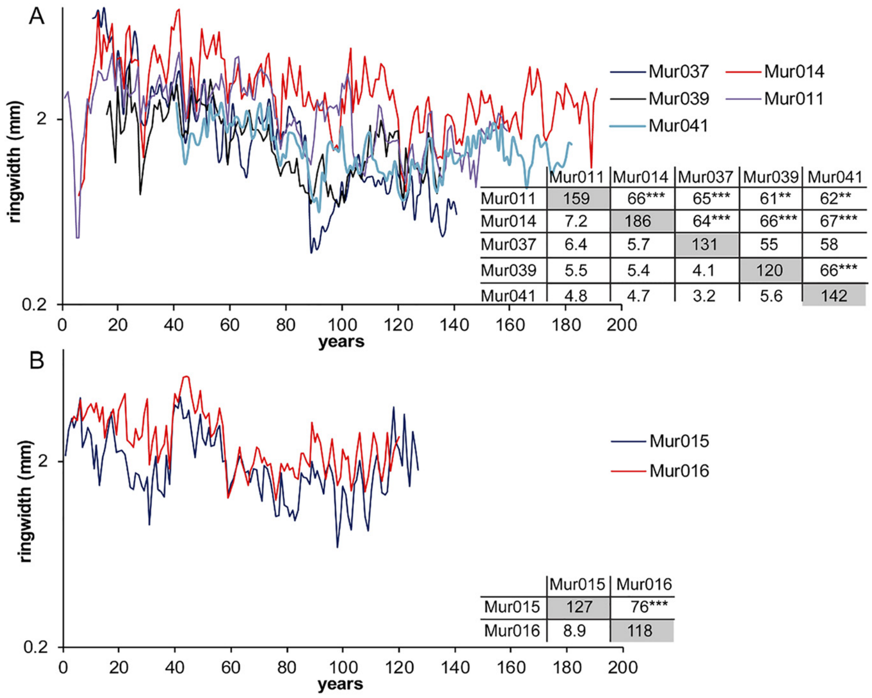

Fig. 4. Synchronized ring width series of subfossil oaks collected along the Mureş/Maros Alluvial Fan. Individual ring width series defining A) MURchr1 and B) MURchr2 are presented with different colors. Basic synchronization statistics are shown in the inset tables. The lengths of the series are given with a gray background along the diagonal, whereas percentage of agreement (GLK%, Eckstein and Bauch, 1969) and t_{BP} (Baille and Pilcher, 1973) are shown above and below the diagonal, respectively. The significance of the GLK% is marked as **: $P < 0.05$; ***: $P < 0.001$

from the ^{14}C segments to the terminal rings in the corresponding dataset, MURchr1 spans between c. 728 and 537 cal BP while MURchr2 spans between c. 6,077 and 5,950 cal BP.

Integrating the first results of dendrochronological and ^{14}C studies of subfossil driftwood with the knowledge about the quaternary landscape evolution of the apex area of the Mureş/Maros Alluvial Fan

The dynamic character of the river in the Late Pleistocene and the Holocene is clearly indicated by the significant changes of its flow direction at the apex of the alluvial fan (Fig. 5). The spatial contrast seen in the occurrence of subfossil wood south and north of the current Mureş/Maros river corresponds to a geochronological difference of the investigated sites. Driftwood samples were recovered either along the present course of the river, or in the vicinity of an avulsion node to the north (Fig. 5), where major shifts in flow direction took place in the Late Glacial and in the beginning of the Atlantic Phase, possibly in response to significant changes in the sediment regime during these periods (Bartyik et al., 2021). In terms of the sites along the present-day course of the river, no previous geochronological data are available. The occupation of this flow direction was previously assigned to the Subatlantic Phase (Sipos et al., 2012). However, the present ages prove that fluvial deposition can reach back as far as 6 ka, meaning that the river changed its course much earlier than was previously believed, or multiple channels were active during high flow periods, such as the Atlantic Phase. The examined sites lacking subfossil driftwood situated north of the current course of the Mureş/Maros represent channels developed before 13 ka BP on the basis of optically stimulated luminescence (OSL) ages of the fluvial sandy deposits (Kiss et al., 2014). Paleo-vegetation reconstructions pointed out that the major development of the temperate, deciduous forest overwhelmingly representing the subfossil driftwood assemblage in the Mureş/Maros Alluvial Fan, advanced mainly from 11 ka BP in the region also encompassing the Mureş/Maros catchment (Feurdean et al., 2011, 2014) and the surroundings of the alluvial fan (Magyari et al., 2019). Based on the above, it can be explained why the amount of large woody debris is considerably lower in sediments related mostly to Late Glacial fluvial activity. In fact, the existence of these oak forests is also supported by the presence of phaeozems, specific to the area, soils developed under oak forests, mixed with lime, hornbeam and maple (Ianoş and Puşcă, 1998). However, it must be noted that it cannot be ruled out that the lack of subfossil wood at certain gravel pits can be due to the different quarrying technology.

Unfortunately, the exact stratigraphic position of the oldest driftwood sample is not known; its presence, however, indicates a potential sediment pulse at around 6 ka BP which could have covered and trapped the trunk for a long time, surviving lateral movements of the river at the apex of the alluvial fan. While the clarification of this issue needs further investigation, the position of young, <1000-year-old wood

Fig. 5. Map of reconstructed paleochannel zones across the Mureş/Maros Alluvial Fan (based on Sipos et al., 2012) with the location of the visited gravel pits and natural outcrops with subfossil driftwood (full circle with indicated calibrated median age) and lacking subfossil driftwood occurrence (open circle)

remains clearly indicate a very intense aggradation in the past 1 ka, since the trunks were sometimes covered by 6 m of channel deposits, alternating with overbank fines. This finding underlines the significance of accumulation processes at the apex of the Mureş/Maros Alluvial Fan and provides a valuable piece of evidence for the trigger mechanisms of sudden avulsion events in the Holocene.

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