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Alluvial Ridge Development and Structure: Case study on the Upper Tisza, Hungary

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Abstract

The juxtaposition of natural levees results in alluvial ridges with a unique fluvial record. Our aims were to (1) identify the alluvial ridges of the Upper Tisza (Hungary); (2) determine their morphological characteristics; and (3) reconstruct the Late Quaternary fluvial history of the region. The oldest paleo-meander was abandoned ca. 29 ka ago; referring to early avulsion of the Tisza. Five alluvial ridges were identified with intensive fluvial activity at ca. 12-13 ka, 7.7-8.6 ka, 6.1-6.6 ka, 4.8 and 2.9 ka ago. Moderate fluvial activity was indicated by early Atlantic and Subboreal paleosols. The sedimentation rate in the paleo-channels (0.3-0.5 mm/y) and on the alluvial ridges (0.3-0.5 mm/y) was slow, influenced by the reactivation of a paleo-channel.

Keywords: natural levee; alluvial ridge; overbank sedimentation; crevasse channel; pollen analysis; OSL dating

Introduction

Natural levees develop along concave banks (Allen, 1965) or straight reaches (Gábris 2003) during floods, when the flow velocity entering the floodplain decreases (Piégay et al., 2003; Steiger et al., 2005). The sediments of the natural levees are coarser than floodplain deposits, but finer than the bed-load (Cazanacli & Smith, 1998). Their material gets finer downstream (Kiss et al., 2018) and laterally too (Wolfert et al., 2002). Farther from the banks their sediment layers become thinner (Gábris 2016), and their slope becomes gentler (Cazanacli & Smith, 1998). The size of the levees is related to channel and sediment transport characteristics (Hudson & Heitmuller, 2003; Kiss et al. 2018), slope (Fryirs & Brierley, 2012), channel-bed material (Ostrowski et al., 2021), flood height and frequency (Brown, 1983; Adams et al., 2004), floodplain characteristics (Pierik et al., 2017), and riparian vegetation (Adams et al., 2004; Steiger et al., 2005). They control the lateral connectivity (Fryirs & Brierley, 2012) by regulating the inundations (Makaske et al., 2009).

The natural levees are dissected by crevasses and crevasse channels, which convey water to the low-lying floodplain areas, and they regulate the sedimentation processes and avulsions (Hajek & Wolinsky, 2012; Nicholas et al., 2018). When the flood breaches the natural levee, a small crevasse channel develops (Fryirs & Brierley, 2012), and the eroded material creates a lobe-shaped crevasse splay (Smith et al., 1989).

The *juxtaposition* of natural levees creates high surfaces along the channel, with an increasing elevation over time due to aggradation during floods (Florsheim & Mount 2002). Their height depends on channel conditions, sediment transport and flood history (Florsheim & Mount, 2002; Kiss et al., 2018; Balogh et al., 2020). During thousands of years, several kilometers-wide and high forms can develop. This complex form was defined as a "mega-levee" (Gábris, 2016), or

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as an "alluvial ridge" (Pierik et al., 2017). Their height is controlled by channel bed aggradation rate and suspended load (Nicholas et al., 2018). Conversely, alluvial ridges control the water and sediment delivery to the floodplain and regulate avulsions (Nicholas et al., 2018).

The modern and Holocene aggradation rates on natural levees are different. For example, during a flood, 70 cm accumulation was measured along the banks on the natural levees (Florsheim & Mount, 2002; Oroszi et al., 2006). In contrary, the long-term fluvial levee aggradation rate is just 0.6-2.3 mm/y (Stevaux & Souza, 2004; Makaske et al., 2009), though back loading through crevasses can increase it to 3.2-4.3 mm/y (Ishii et al., 2021). The long-term (Holocene) natural levee evolution is driven by sediment supply changes (Pierik et al., 2017; Ishii et al., 2021). After a levee reaches a threshold height, lateral growth will be dominant related to overbank flows and activity of crevasse splays (Ishii et al., 2021).

The rivers of the Carpathian (Pannonian) Basin filled up the sinking areas and created large alluvial fans (Kiss et al., 2014b; Gábris, 2020). The last accumulation phase was terminated by increased run-off and tectonic-driven incision in the Late Glacial (Borsy, 1995, 1998). In this way, for example, the Upper Tisza River in NE Carpathian Basin incised into its alluvial fan, and by lateral erosion it created floodplain segments (e.g. Szatmár Plain, Bereg Plain, Rétköz and Bodrogköz).

There are two unclarified key points in the development history of Upper Tisza region. (1) Here some alluvial ridges evolved, but their morphology or evolution history is not known. (2) During the Pleistocene the Tisza ran to SW (Borsy, 1995, 1998; Gábris, 2020); however, nowadays, its active course is towards NW, however the exact time of the avulsion is not known. We hypothesize that the sedimentary structure of mega-forms is closely related to the prevailing hydrological and environmental conditions; thus, they are good archives of Late Quaternary fluvial activity. The goals of this study are (1) to identify and characterize alluvial ridges in NE Hungary; (2) to investigate the spatial characteristics of their sediments; and (3) to evaluate their role in the fluvial development history of the region.

Study area

The Bereg Plain is located in the NE Carpathian Basin (Fig. 1), gradually sloping from SE to NW. The subsiding area of the Bereg Plain was filled up by ca. 150 m deep fluvial sediments (Gábris, 2020), deposited by the Tisza and its tributaries, which built a large alluvial fan. The alluvial fan was dissected by tectonic activity ca. 25-30 ka ago: the area of the present-day plains (i.e. Szatmár Plain, Bereg Plain) subsided, while the Nyírség

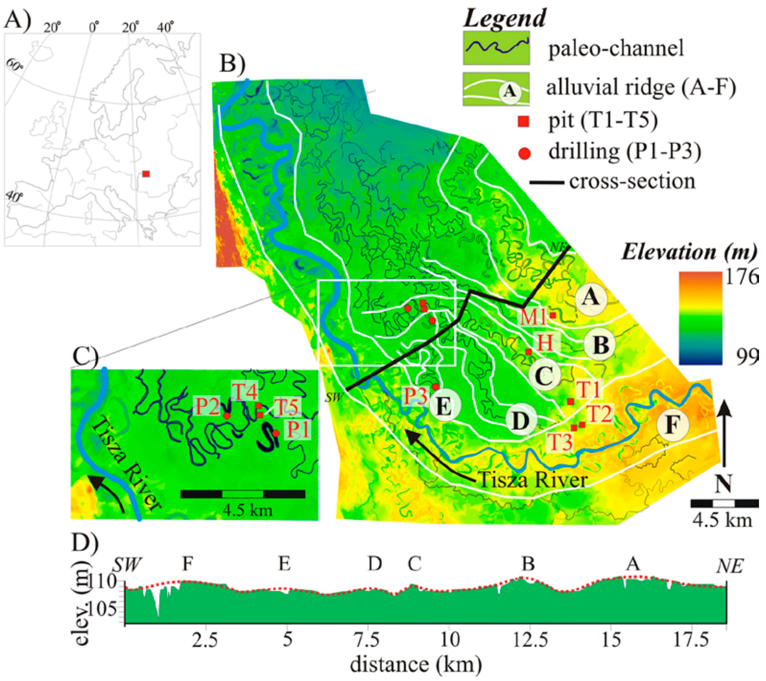

Figure 1. A) Bereg Plain is situated in NE Hungary. B-C) Its surface is densely covered by paleo-channels. Three of them (P1-P3) were sampled for pollen analysis. The alluvial ridges (A-F) were studied at mining pits (T1-T5). D) A cross-sectional elevation profile drawn along the black line on B.

elevated (Borsy, 1995). The Bereg Plain started to sink at the end of the Pleistocene (Borsy, 1998), forcing the avulsion of the Tisza River, which changed its course from SW to NE ca. 20-22 ka ago (Borsy et al., 1989). Subsequently, the Tisza eroded the alluvial fan, and later, it deposited clayey-silty materials along its courses and gradually reworked its floodplain (Sümegi, 1999; Magyari, 2002; Félegyházi et al., 2004; Vass, 2014).

Methods

To identify the forms a DEM (resolution 5 m) was created based on topographical maps (1:10,000). The paleo-meanders and alluvial ridges were identified, and their sizes were measured under ArcGIS 9.2.

Sediment samples were collected from the paleo-channels and their alluvial ridges (Fig. 1). The large clay and sand mine pits (T1-T5) provided a unique opportunity to study the fluvial sequence of alluvial ridges. At 25 points, we sampled the sediment layers for grain-size analysis. Paleosols were sampled for radiocarbon dating, and overbank deposits for OSL dating. Three paleo-channels (P1-P3) were sampled by drilling down to their coarse bed-load material (4.1-9.1 m) for grain-size and pollen analysis.

The preparation of samples for OSL dating followed Mauz et al. (2002), applying both the coarse- and fine-grain techniques. For the measurements a RISØ DA-20 TL/OSL luminescence reader and the single-aliquot regeneration (SAR) protocol was applied (Murray & Wintle, 2003). Environmental dose rate (D*) was determined by using Canberra XtRa Coaxial Ge detector, and applying the conversion factors of Liritzis et al. (2013).

On the organic-rich sediment samples radiocarbon dating was made. The standard AAA chemical treatment (Tans & Mook, 1980) was performed. The samples were converted to benzene using an Atomkomplex Prylad-type benzene synthesis line (Skripkin & Kovaliukh, 1998). Radiocarbon (^{14}C) activity was assessed by Liquid Scintillation Counting (LSC) using a Quantulus 1220 ultralow background LSC instrument (Skripkin & Buzinnyi, 2017). 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). The OSL and radiocarbon dating were made at the Geochronological Laboratory of the University of Szeged.

To provide data on the cut-off of the paleo-channels and environmental condition of the fluvial activity, pollen analysis was performed on 3 drilling cores. The pollen grains were extracted following the method of Zólyomi (1952). The identification was performed under 400-600x magnification on species, genus or family level. The visualization of the results was made under Tilia and TiliaGraph software.

The grain-size distribution of the dry, pulverized samples was determined by Fritsch Analysette 22.

Results

Geomorphology of the area

On the Bereg Plain, a dense paleo-channel network was identified (Figure 1B). In the eastern part of the study area, 6 paleo-channel courses were identified; however, in NW they create a net of paleo-channels, and it was impossible to classify them. The paleo-channels create 11-49 km long courses (Table 1), running north of the active channel belt of the Tisza (F course). Their mean channel width is 30-60 m; the widest channel (80-150 m) is the active channel of the Tisza. The sinuosity of most of the paleo-channels (D-F) is very similar (1.8-1.9); however, the B course has a very low sinuosity (1.2), whereas the A and C courses have a highly meandering pattern.

Table 1. Morphometric parameters of the paleo-channels and their alluvial ridges on the Bereg Plain

Channel course	Paleo-channel course				Alluvial ridge		
	length (km)	mean width (m)	sinuosity	mean slope (cm/km)	length (km)	relative height (m)	width (km)
A	47.2	30-60	2.3	12.7	21	1-2.5	2-3.5
B	19.5	30-60	1.2	10.3	17	0.5-2	0.5-1.6
C	22.2	30-50	2.2	6.6	17.4	1.5-2.5	0.8-2.0
D	23.6	25-60	1.8	8.5	13.1	0.5-1	0.8-2.5
E	11.1	20-40	1.8	9	6.1	0.3-0.5	0.3-0.7
F	49.5	80-150	1.9	14	26	2-3.5	2.5-4.0

The paleo-channels in the SE half of the study area are situated on elevated alluvial ridges (Figure 1D). The highest ridge (2-3.5 m) developed along the active Tisza (F course). Most of the ridges are 1-2.5 m high, but the E course has almost no alluvial ride. The width of these ridges is 2-3 km; however, the small E course is also very narrow (0.3-0.7 km). The ridges are the most elevated in their middle section, in the northwest they gradually lower to the floodplain level.

Results of the OSL and radiocarbon dating

Altogether 14 samples were collected for OSL dating from 6 sediment profiles, representing the sedimentary body of three alluvial ridges. Most of these samples were collected from the silty-clayey overbank deposits of alluvial ridges; however, two samples represent the first (T5/1) and the last member (T4/1) of a point-bar sequence. The paleosols between overbank sediments were dated by radiocarbon dating. The age of the sediments and the paleosols ranges between 2.9 and 24.7 ka, representing Late Pleistocene and Holocene fluvial activity (Table 2-3).

Description of sedimentary bodies

At four sites (T1-3, M1), the sedimentary sequence of ***alluvial ridges*** was revealed. The longest ***alluvial ridge sequence*** (300 m) was studied at site T1 (Fig. 1-2), which is ca. 1.5 km far from the paleo-channel C. The lowermost lacustrine sediments (≥1 m) were dated to 24.72±0.65 ka (T1/4). This layer is covered by fine-layered alluvial deposits (thickness: 200 cm), the topmost one is 13.23±0.35 ka old (T1/3). The fluvial activity repeatedly terminated, as it was reflected by paleosols. The lowermost paleosol (thickness: 30-40 cm) was represented all along the pit. It was covered by a silty-clayey layer (5-20 cm), which got thinner towards the distal edge of the alluvial ridge. The middle paleosol (thickness: 10-20 cm) was identifiable just along 260 m, as it was getting thinner towards the edge of the alluvial ridge, and finally, it terminated. This paleosol was covered by another silty-clayey layer (15-30 cm) dated to 8.17±0.20 ka (T1/2). The uppermost paleosol got thicker towards the distal part of the alluvial ridge (thickness: 20-60 cm) as it merged with the lowermost paleosol. The uppermost paleosol was dated to 6880-7620 cal BP (T1carb). This uppermost paleosol layer was buried by 90-120 cm thick silty-clayey deposits ca. 7.69±0.19 ka ago. The thickness of this sediment layer, just like the previous ones, got thinner towards the distal edge of the alluvial ridge.

A ***point-bar series*** buried by overbank fine-grained sediments were presented at the T4-5 sites (C paleo-

Table 2. Results of the OSL dating. W: water content, D*: environmental dose rate, De: equivalent dose.

Field ID	Course	Lab ID	Depth (cm)	W (%)	U (ppm)	Th (ppm)	K (%)	D* (Gy/ka)	De (Gy)	Age (ka)
T1/1	C	1129	60	23.9±2.4	3.05±0.02	11.39±0.08	2.62±0.06	3.95±0.09	30.33±0.28	7.69±0.19
T1/2	C	1120	100	29.9±3.0	2.56±0.02	9.80±0.07	3.00±0.09	3.79±0.09	30.94±0.28	8.17±0.20
T1/3	C	1126	125	23.4±2.3	1.59±0.02	6.86±0.06	1.57±0.04	2.38±0.06	31.52±0.27	13.23±0.35
T1/4	C	1132	345	25.5±2.6	3.24±0.02	11.03±0.08	2.49±0.06	3.81±0.09	94.2±1.04	24.72±0.65
T2/1	F	1334	135	10.4±2.1	3.32±0.02	12.72±0.08	2.73±0.06	4.80±0.11	15.88±0.34	3.31±0.10
T2/2	F	1128	245	17.3±3.4	3.30±0.02	12.30±0.09	2.82±0.06	4.48±0.11	21.46±0.20	4.80±0.12
T2/3	F	1331	300	12.8±2.6	3.33±0.02	11.83±0.08	2.63±0.06	4.50±0.11	28.34±0.29	6.30±0.16
T3/1	F	1121	150	10±2.0	2.02±0.02	6.62±0.05	1.67±0.04	2.51±0.04	9.94±0.79	3.96±0.33
T3/2	F	1127	215	16.6±3.3	1.80±0.01	5.51±0.04	1.67±0.04	2.24±0.05	9.29±0.66	4.14±0.31
T3/3	F	1124	315	30.0±5.0	2.30±0.02	9.04±0.06	1.68±0.04	2.67±0.08	32.46±0.29	12.15±0.40
T4/1	C	1130	250	16.4±3.3	1.77±0.01	5.54±0.04	1.39±0.03	2.01±0.05	5.89±0.69	2.93±0.35
T5/1	C	1123	225	17.2±3.4	2.17±0.02	7.15±0.06	1.59±0.04	2.34±0.05	9.88±0.38	4.23±0.19
M1/1	A	1125	65	20.1±2.0	3.23±0.02	11.66±0.08	2.60±0.06	4.15±0.09	25.37±0.41	6.11±0.17
M1/2	A	1122	130	14.0±2.8	2.78±0.02	10.34±0.08	2.34±0.05	3.93±0.10	33.98±0.42	8.65±0.23

Table 3. The radiocarbon age of the dated paleosols.

Field ID	Course	Lab ID	Depth (cm)	Conventional age (BP)	Calibrated age (cal BP) (2 sigma, 95.4 %)
T1carb	C	CSZ_45	80	6396±180	6880-7620
T2carb	F	CSZ_46	290	6837±140	7460-7950
T3carb	F	CSZ_47	280	4082±370	5492-3690
Hcarb	C	CSZ_39	190	5872±180	7158-6385
M1carb	A	CSZ_37	90	6171±200	6620-7470

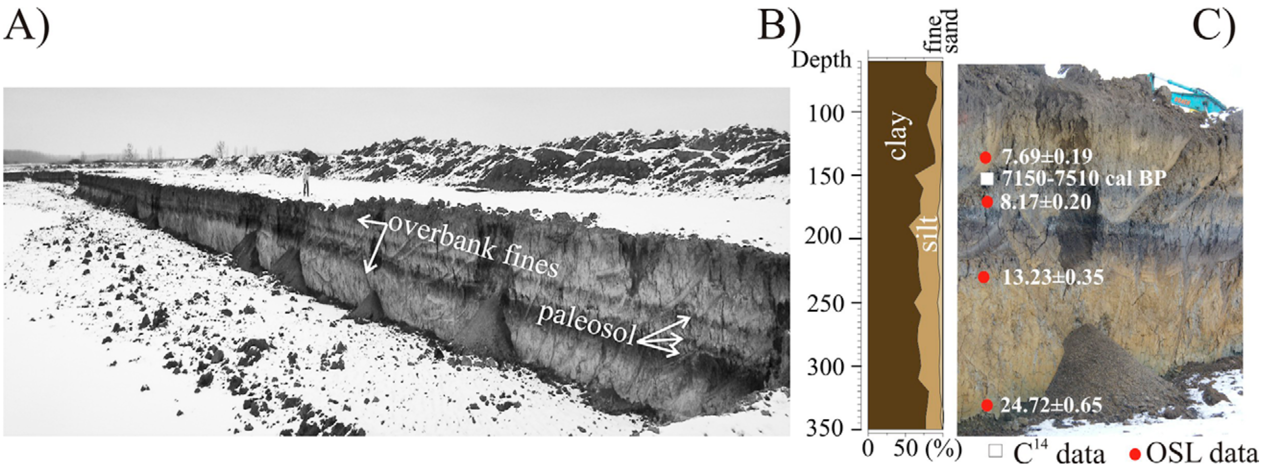

Figure 2. A) Typical alluvial ridge sequence at the T1 site. B) Grain-size distribution of the layers. C) OSL and radiocarbon age of the sediments.

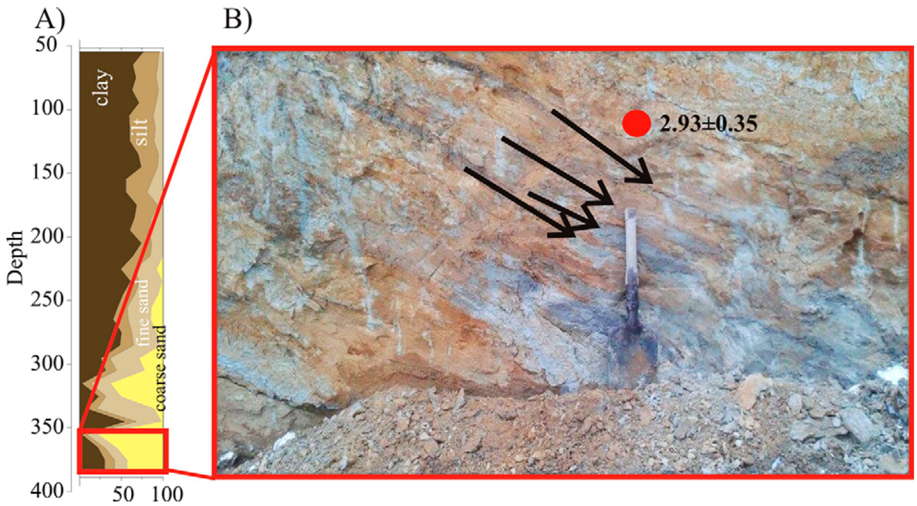

Figure 3. A) Point-bar sequence buried by fine-grained overbank material between the T4/1 and T5/1 sites. B) Within the point-bar sediments sandy and silty (indicated by arrows) alternate. The younger most point-bar layer was dated by OSL measurement.

channel course). The sandy material of the point-bar series (Fig. 3) was revealed along 340 m. The material of the oldest point-bar (T5) deposited 4.23±0.19 ka ago (T5/1), and the youngest point-bar was active 2.93±0.35 ka ago (T5/1). The point-bar series was covered by fine overbank deposits (200-220 cm), which got thinner towards the distal part of the alluvial ridge.

A ***crevasse channel*** was visible on alluvial ridge C. The crevasse started at the apex of the 105 m-wide paleo-channel. The cohesive material of the paleosol overhung the bank of the crevasse, referring to their co-existence at 7158-6385 cal BP (Hcarb) (Fig. 4). The crevasse was 31 m wide and ca. 4 m deep, and its bottom was filled with 1 m thick fine sand, referring to active bed-load movement. Later the crevasse channel and the paleosol were buried by silty-clayey material.

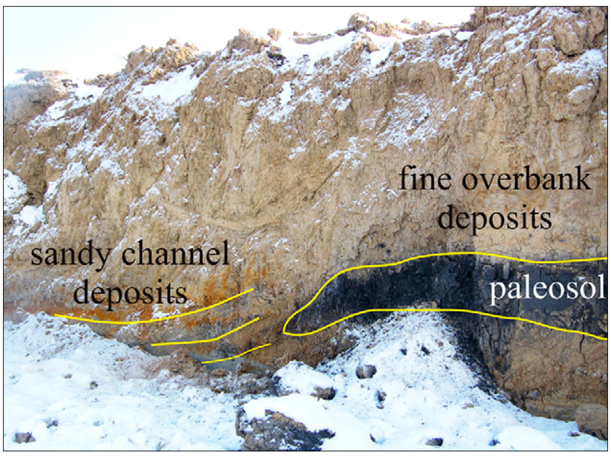

Figure 4. During the activity of the crevasse the overbank fluvial processes were limited, thus a thick paleosol developed.

Pollen analytical results

Not all the drillings contained enough pollen for statistical analysis; thus only 3 drill cores could be used. Here the deepest (910 cm) P1core is introduced in detail.

The lowermost samples (860-910 cm) contained medium sand (70-85%), representing the bedload (Fig.

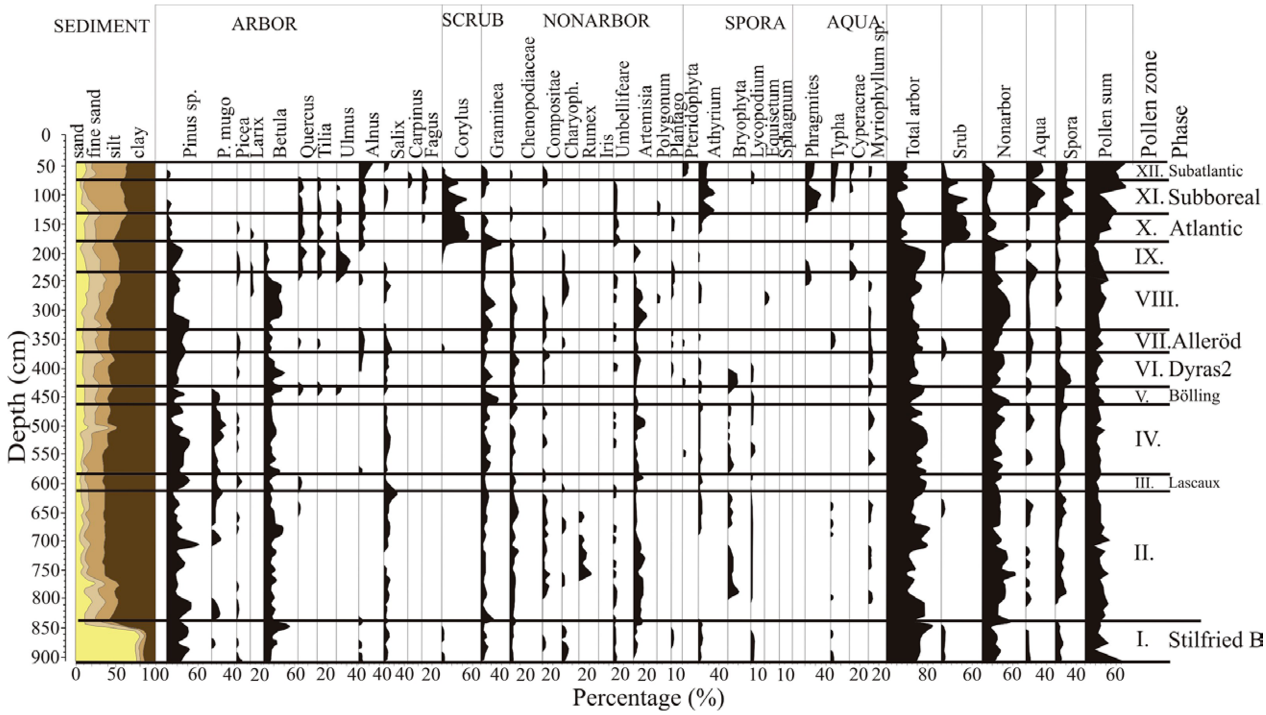

Figure 5. Sediment and pollen profile of the P1 paleo-channel, representing a paleo-channel in a back-swamp area between alluvial ridges

5). Upwards (860-780 cm) the proportion of sand decreased (15-30%), and the amount of silt (50-60%) and clay (10-20%) increased, reflecting a temporal connection to the main channel during floods. These sediments were covered by an almost homogenous silty-clayey layer (520-780 cm) deposited in an almost uniform sedimentary environment. In the next zone (0-520 cm), small sand peaks appeared, referring to sediment transport from a nearby active channel.

Altogether, 12 pollen zones were identified (Fig. 5). In the lowermost zones (I-VIII: 230-910 cm), *Pinus, Betula* and *Salix* dominated the arbor pollen, and the herbs were mainly represented by *Artemisia sp., Chenopodiaceae, Poaceae* and *Compositae*. In some samples (870-910 cm, 570-610 cm, 430-450 cm and 350-370 cm) deciduous tree pollen (e.g. *Quercus*, and *Alnus*) also appeared, referring to a milder climate. The *Sphagnum* indicates the existence of a peat (360-750 cm), and the algae refer to a cold lake (e.g. 440-450 cm: *Pediastrum kawrayskyi, Mallomonas teilingii*). These pollen refer to cold climate with taiga-like vegetation; however, the deciduous trees suggest short, warm periods. The channel was abandoned in the Stillfried B or Denekamp Interstadial. Similar pollen profile was found nearby, where the *Sphagnum* peat was dated to 29790±870 y BP (Félegyházi et al., 2004).

In the upper zones (IX-XII zones: 0-230 cm), the coniferous plant pollen disappeared, and deciduous trees became dominant (e.g. *Tilia, Quercus*, and *Corylus*). Based on the appearance of *Carpinus* and *Fagus* pollen, the material of the X zone (130-180 cm) deposited during the Atlantic Phase, while the XI zone (80-130 cm) represents the Subboreal, and the XII zone (0-80 cm) refers to the Subatlantic Phase. In these Holocene phases, the sedimentation rate was 0.2-0.3 mm/y, being the highest in the Atlantic and Subatlantic Phases, indicating that the nearby alluvial ridges were reactivated, and an extra amount of fine material was transported into this deep, back-swamp area.

Discussion

Formation of the Bereg Plain and the avulsion of the Tisza River

At the bottom of a back-swamp between alluvial ridges the oldest paleo-channel (P1) was identified, belonging to large river (ca. 9 m deep). It was already abandoned ca. 29 thousand years ago. The oldest OSL age of lacustrine sediments (24.72±0.65 ka) also supports the idea, that by this time the tectonic depression of the Bereg Plain already existed. The subsidence forced the rivers of the NE Carpathians to enter the area, so the avulsion of the Tisza was probably much earlier than it was expected (Somogyi, 1967; Borsy et al., 1989; Borsy, 1995; Tímár et al., 2005).

Temporal development of the alluvial ridges

According to our hypothesis, the paleosols reflect periods when the fluvial activity was moderate; thus, the overbank aggradation did not disturb the pedogenesis, just like in the case of loess profiles (Marković et al. 2007). On the other hand, the silty-clayey overbank deposits above paleosols refer to an increased fluvial activity when the aggradation impeded soil formation (Fig. 6). The identified paleosols refer to moderate fluvial activity in the first half of the Atlantic and in the Subboreal Phase. The beginning of the Atlantic was humid (Gábris, 1995), and the entire catchment was forested by closed oak and beech forests (Járainé-Komlódi, 1969, 2000; Sümegi et al., 2008); thus, the run-off and the sediment discharge decreased. These Atlantic paleosols were found in all dated alluvial ridges (A, C and F); thus, the declining fluvial activity was probably typical for the entire system. On most alluvial ridges, no younger paleosol was found above the Atlantic one, so the fluvial aggradation was still intensive; because the Subboreal Phase was more humid than the Atlantic Phase (Gábris, 1995, 2003). However, in the southernmost (F) alluvial ridge a Subboreal paleosol was identified, referring to a local sediment decline.

In the Late Glacial, ca. 12-13 ka ago, thick overbank fines deposited in C and F alluvial ridges (at the A ridge they were not revealed, probably because there the pit was not deep enough: its bottom sediments are 8.65 ka old). This increased fluvial activity could be related to the last deglaciation of the Carpathians (Bartyik et al., 2021), and the cool and dry climate during the Younger Dryas when the vegetation became sparse and the run-off intensified (Járainé-Komlódi, 1969).

During the next intensive fluvial period at the end of the Boreal Phase (ca. 7.7-8.6 ka) new overbank deposits were accumulated (A and C alluvial ridges), and one of the dated paleo-meanders (P2) was abandoned.

In the late Atlantic Phase (6.1-6.6 ka), overbank aggradation was detected on the A and F alluvial ridges. The sandy bedload of the excavated crevasse also suggests intensive sediment transport. In contrary, on ridge C the paleosol formation continued. The high flood magnitudes in the active channels were also supported by the palynological data of the P1 paleo-channel situated between two alluvial ridges, as its sedimentation rate increased in the Atlantic Phase.

The next period of intensive fluvial formation (2.9 and 4.8 ka) was verified on all dated alluvial ridges: in the Subboreal Phase thick overbank sediments were deposited. The lateral reworking of floodplain sediments was also intensive, as the dated meander of the C ridge intensively migrated. It is in accordance with the cooler and more humid climate of the Subboreal Phase (Gábris, 1995, 2003; Nádor et al., 2007).

In the Subatlantic Phase the former point-bar series (T4-T5) were covered by fine overbank sediments, referring to a high (0.5-0.8 mm/y) aggradation rate. The intensive, general aggradation is also supported by the high sedimentation rate of the back-swamp area (P1).

Thus, the paleo-channels on the alluvial ridges drained water almost during the entire Holocene, and they were active simultaneously. It is a different paleo-hydrological model than found on other rivers of the Great Hungarian Plain, as usually, the paleo-channel courses represent distinct channel generations (Borsy et al., 1989; Kiss et al., 2014ab; Gábris, 2020). The paleo-channel courses probably developed via avulsions. After the avulsion the channel had low-sinuosity and slightly developed alluvial ridge. This first development stage is represented by paleo-channel course B. Later the channel started to meandering, gradually increasing the size of the alluvial ridge (course E). As the activity of a paleo-channels was longer, its alluvial ridge progressively grew (course A and F).

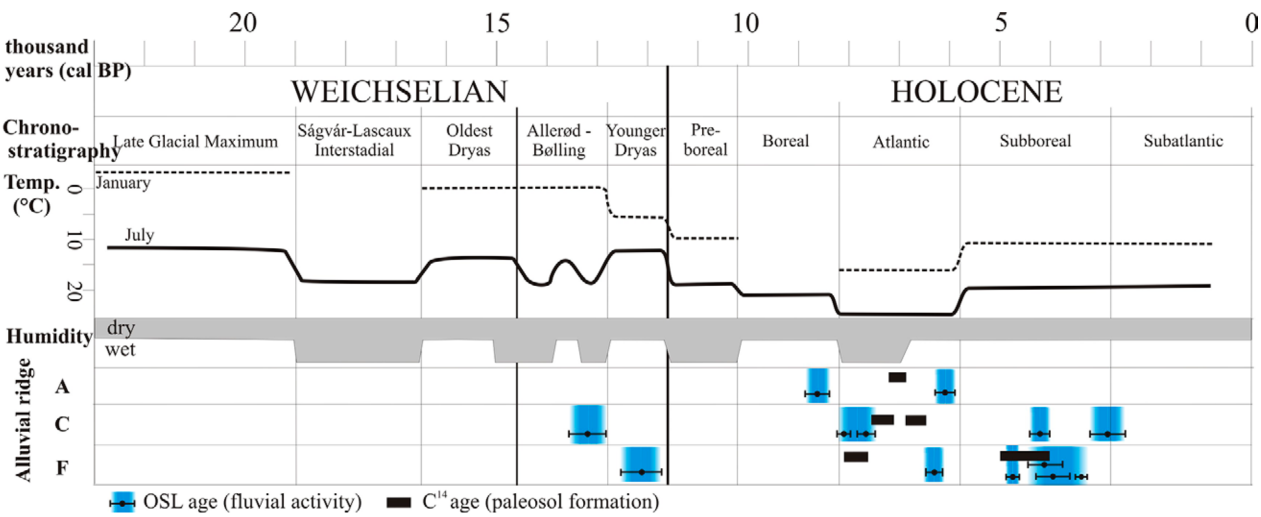

Figure 6. Formation of overbank deposits and paleosols compared to climate elements (source: Borsy et al., 1989; Gábris & Nádor, 2007, Hernesz & Kiss, 2013; Sümeghy et al., 2013; Kiss et al., 2014ab)

Architecture of the alluvial ridges and backswamps

The ridges are gently sloping towards the back-swamps: near the paleo-channel several overbank sediment layers were identified between the paleosols. However, the overbank layers wedge toward the distal areas, and the number of paleosols decreases as they merge into the back-swamp. The ridges are built of only fine-grained material, probably because sandy material was deposited just in a narrow strip along an active channel (Oroszi et al., 2006), and our sampling areas located further on.

The sedimentation rate in the paleo-channels and on the alluvial ridges was quite slow. Since the Late Pleistocene in the paleo-channels the mean aggradation rate was 0.3 mm/y. Usually, the paleo-channels had the highest sedimentation rate (0.5-1.2 mm/y) right after their cut off. During the Holocene the sedimentation rate was uneven, being the highest in the Atlantic Phase (0.3-0.5 mm/y), then it dropped in the Subboreal (0.2-0.3 mm/y), and slightly increased in the Subatlantic Phase (0.3-0.4 mm/y). Similar temporal pattern was revealed by Sümegi (1999), Magyari (2002) and Félegyházi et al. (2004).

The overbank accumulation rate (0.1-0.8 mm/y) on the alluvial ridges are dependent on the re-activation of a given paleo-channel and by the location of the sampling point relative to the channel. For example, in the case of the A alluvial ridge, until ca. 6 ka ago the aggradation rate was 0.27-0.28 mm/y, but then it decreased to 0.1 mm/y, referring to the Late Holocene abandonment or very low activity. Similar overbank accumulation (0.2-0.27 mm/y) was measured along the C paleo-channel in the first half of the Holocene; however, at the end of the Holocene, the aggradation rate increased (0.5-0.8 mm/y) referring to the re-activation of the paleo-channel and its alluvial ridge. Throughout the studied period, the highest aggradation rates (0.36-0.7 mm/y) were revealed from the F paleo-channel, suggesting that it served as the main channel of the Tisza continuously.

The aggradation rate alters laterally too: close to the former channel it was 0.8 mm/y, whereas 340 m further, it dropped to 0.5 mm/y, referring to rapidly declining sedimentation. The spatial pattern of the aggradation was also influenced by the distance from crevasses, which conveyed sediment to the distal floodplain areas. It is well-reflected by the P2 site, which had a higher sedimentation rate (0.5 mm/y) until the neighboring C paleo-channel actively conveyed floods. However, as this channel gradually lost its conveyance capacity due to its slow aggradation, the sedimentation rate also declined (0.3 mm/y).

Conclusions

The juxtaposition of natural levees results in large, convex forms, defined as alluvial ridges. In the Upper Tisza region, on the Bereg Plain, 5 alluvial ridges were identified (max width: 4.0 km, max. height: 3.5 m), providing detailed sedimentary archive on the fluvial history of the area. Based on the sedimentary profiles of the alluvial ridges, several periods with high fluvial activity were identified. According to the results the Tisza appeared in the region much earlier than it was expected, and the paleo-channels co-existed simultaneously conveying water. This paleo-channel network could be utilized in the future during large floods, as they could store and drain large quantities of water. In contrast, during droughts, they could provide water for irrigation.

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