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PALAEOMEANDER OF THE RUDAVA RIVER (SW SLOVAKIA) – AN INSIGHT INTO THE EVOLUTION OF LANDSCAPE AND VEGETATION

Peter Pišút*, Juraj Procházka*, Eva Uherčíková, Igor Matečný*, Adam Rusinko*, Tomáš Čejka*****

* Comenius University of Bratislava, Faculty of Natural Sciences, Department of Physical Geography and Geoinformatics, Ilkovičova 6, 842 15 Bratislava, Slovakia,

peter.pisut@uniba.sk, juraj.prochazka@uniba.sk, igor.matecny@uniba.sk, adam.rusinko@uniba.sk

** Slovak National Museum, Natural History Museum, Vajanského nábrežie 2, 810 06 Bratislava, Slovakia, eva.uhercikova@snm.sk

*** Plant Science and Biodiversity Center, Institute of Botany, Dúbravská cesta 9, 845 23 Bratislava, Slovakia, t.cejka@gmail.com

Palaeomeander of the Rudava River (SW Slovakia) – an insight into the evolution of landscape and vegetation

This study is focused on a cut-off palaeomeander of the Rudava River (SW Slovakia). Along its middle reach, Rudava passes through the extensive plain of Quaternary eolian sands covered with Scots Pine woodland. Specific landforms – semi-circled cut-bluffs (wagrams) are commonly found on either side of the river valley. They have been triggered by a meandering river in contact with both lower terraces and sand dune pseudoterrace and postgenously shaped by mass wasting. The left-bank palaeomeander and cut-bluff at river kilometre 13.2 is one of the most completely evolved and, until today, the best-preserved landforms of this kind. A palaeoecological study of the palaeomeander infill (two cores) combined with a digital elevation model, AMS radiocarbon dating, cartographic data analysis and a survey of present-day vegetation suggest the river meander was most probably cut-off in the 18th Century. Due to the flow hydrological regime, meandering dynamics at this reach is relatively slow. Numerous springs and seepage along the south edge of the river valley play an important role in the initiation and evolution of cut-bluffs. Also, at the site under study, such spring draining into the Rudava River has significantly contributed to the present-day variability of local soils, wood and marsh habitats. According to plant macrofossil records and ecogroups-based vegetative macrozones a riparian landscape in the time of meander abandonment and earlier was much more open and with a markedly human impact. Probably upon the pasture's decline, the Holocene floodplain's adjacent reach was completely reforested until the mid-19th Century. Current hardwood alluvial woodland (of the association *Ficario vernae-Ulmetum campestris*) originated in 1916 mainly from natural and perhaps artificial regeneration.

Key words: palaeomeander, alder carr, alluvial forest, palaeoecology, land use change, Rudava River, Slovakia

INTRODUCTION

River palaeomeanders (further on: PM) play an important role in the study of late Glacial and Holocene environmental history of valleys and evolution of floodplains (cf. Beneš and Pokorný 2001, Petr et al. 2014 and Procházka et al. 2021). Namely, terrestrialised fluvial lakes of former cut-off oxbows, which were gradually infilled with deposits (mineral, organic or combined), are suitable for multi-proxy analyses. Although fluvial lakes comprise only about 0.3% of the total world lake volume (Meybeck 1995, in Cohen 2003), they are widespread elements of alluvial plains. However, individual lakes are relatively short-lived features of fluvial systems (a few hundred to a few thousand years). They have provided important

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palaeolimnological records of past landscape development and hydro-climatic changes.

Water depth and area of lakes in PMs are directly related to rivers' original channel geometry and hydrological parameters. Therefore, morphometry and dimensions of abandoned PMs are geomorphological and sedimentary archives of longer-term hydrological variations of fluvial systems from the Late Pleistocene to the Holocene (Plotzki et al. 2013). Fluvial lakes are almost invariably quite shallow (Herdendorf 1990 in Cohen 2003), and none are deeper than 20 m. For instance, in Slovakia, the cut-off Danube meander downstream of Bratislava have reached a maximum depth of ~ 10 m (Pišút 2008) and the meanders of the lower Váh River – the second largest river of Slovakia – have been up to 2.69 m deep (Pišút et al. 2016) which may correspond to about 4 – 5 m of the resulting sedimentary infill.

Plant macrofossils have become an important part of palaeoecological analyses in analysing Central-Europe PM's sedimentary archives. They are often coupled with other biological proxies, most commonly with pollen analysis (Pokorný et al. 2000, Kozáková et al. 2014 and Petr et al. 2014), but also with microscopic charcoal examination (cf. Souza et al. 2021) and analysis of Cladocera, Ostracods or Chironomid assemblages (Galbarczyk-Gąsiorowska et al. 2009, Pišút et al. 2010, Pawłowski et al. 2012, Korponai et al. 2016 and Giaime et al. 2019). Chronostratigraphy of PMs is mostly based on radiocarbon dating (Late Glacial to Late Holocene), optical luminescence dating (Plotzki et al. 2013 and Sipos et al. 2016) or dating by pollen analysis (Gębica and Jacyšyn 2021). Last millennium PMs and the most recent deposits can also be dated with the aid of written records, historical maps (cf. Pepe et al. 2016) or radiometric dating using 210Pb or 137Cs (Wren et al. 2008). Both pollen and macrofossil evidence of PMs located in the vicinity of historical fortified sites or river ports coupled with archaeological data may reflect neolithic to medieval colonisation and changes in alluvial landscapes due to human activity (Kozáková et al. 2014, Látková and Hajnalová 2014, Giaime et al. 2018, Gębica et al. 2019 and Rennwanz 2019). Besides basic sedimentological characteristics and organic matter content (based on LOI analysis), sediment cores of abandoned PMs may also include geochemical parameters, magnetic susceptibility and/ or petrophysical proxies (Oliva et al. 2016, Sedláček et al. 2019 and Gałka et al. 2020).

As for Slovak streams forming relatively small but well-developed PMs, a good example is provided by the Rudava River. It is a small lowland meandering river with low to medium flow energy. In particular its mid-course is still relatively intact with prevailing natural fluvial processes and well-developed fluvial landforms. A series of PM remnants can be found along the river in various stages of conversion of the water body into a land community. Despite their relatively shallow depth (< 1 m), their potential for paleolimnological analyses is indisputable.

Present-day coverage of the territory of Slovakia with LiDAR and the widely available digital elevation model (DEM) derived from it has also brought about new information on the Rudava alluvium. Evidently, the interaction of fluvial and slope geomorphological processes resulted in the creation of semi-circled bluffs (wagrams; cf. Lehotský et al. 2015) and cut both into low terraces and the edge of windblown sands area. Cut-bluffs are to be commonly found on either side of the river valley. These landforms have been primarily a result of fluvial erosion leading to mass wasting and slope retreat, but additional controls may have played a role, as shown next.

In this study, we focus on probably the most representative and best-preserved landform of this type to survive on the left bank of the Rudava in the location Poľovnícky les (river kilometre 13.2). Interestingly, an actively developing "living" river meander is also nearby. The objectives of this paper are twofold. Firstly, we use cartographic sources, knowledge of fluvial processes and radiocarbon dating to determine the possible time of palaeochannel activity and meander cut-off. Secondly, by analysing PM sedimentary infill focusing on plant macrofossils, we aim to shed light upon the evolution of local vegetation and past riverscape land use.

Our work hypothesis is as follows: a PM under study might have been cut off sometime in the 19th Century. According to the records of the Forestry Geographical Information System (Slovak: L-GIS, henceforth F-GIS) a floodplain forest overgrowing the core area of the meander and its former point bar is 107 years old (in 2023). As indicated by specimens of old coppiced alders (*Alnus glutinosa*) which are a part of it (Fig. 6A), the wood must have been at least logged earlier once. This allows us to shift the age of the forest stand and its parental landform at least several decades back into the past before 1916. The mid-19th Century as a possible date of meander abandonment also seems to correspond with the still well-preserved shape of the studied landform. On the other hand, we suggest the PM is probably not too young since no open waterbody exists any longer at the site and current vegetative succession also suggests this.

MATERIAL AND METHODS

Study area and characteristics of georelief, geology setting, hydrological and fluvial geomorphological conditions

The Rudava River is the 45 km long left-side tributary of the Morava River that flows through the middle part of the Záhorská Nížina Lowland in SW Slovakia (particularly through its core subunit, designated as Bor Lowland). Almost half of the whole river's course has been channelised in the past decades. The middle reach of the Rudava (about 12 km long) – from the Veľké Leváre municipality up to the junction with the Rudávka stream – passes through the continuous territory of windblown sands with extensive pine woods. The area has been a part of the Záhorie Military District (since the 1920s). This fact hampered humans' more intensive land use of the mid-Rudava riverscape in the 20th Century. Past anthropogenic interference focused mainly on using the flow of water energy by isolated watermills, established during the 18th Century. Over time, small settlements have evolved around mills nowadays used for both recreational and permanent living. The settlements were named after former mill landlords or tenants – Soják, Chvála, Holbička and Tančibok.

Close to the above settlements, parts of the Rudava valley were also used as farmland in the past. There were ploughlands on raised terraces along the river, whereas portions of the flat floodplain were used for meadows and pastures. Since the 17th Century, when "a French way" of stabilising drifted sands by planting Scots pine (*Pinus sylvestris*) were widely introduced into the Bor Lowland, forestry in the region has gained more and more momentum (cf. Budke 1981). Certain professions and activities helped shape the forested rural landscape in this period (hunting, making pine-derived wood tar). Today's leisure activities comprise mainly short-term recreation, sports fishing, mushroom picking, horse riding, dog walking etc.

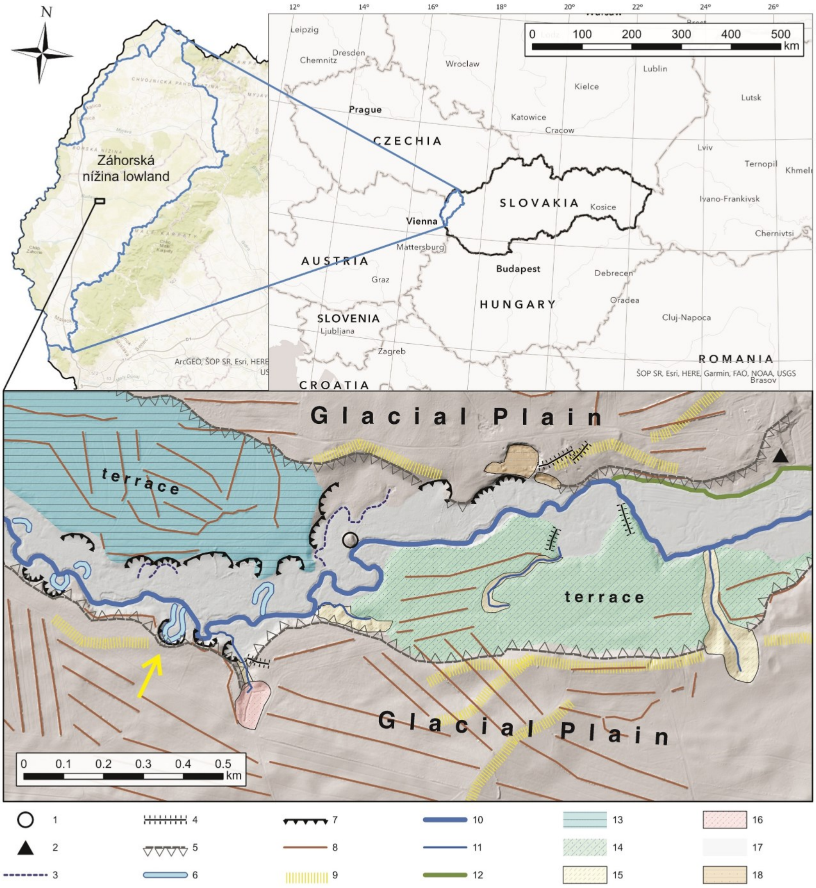

Fig. 1. Location of the study reach and simplified geomorphologic map representing an adjacent section of the Middle Rudava River

1 – leftover of the meander core, 2 – Tančibok settlement, 3 – palaeochannels, 4 – road cuts, 5 – edge / slope of the eolian-sands pseudoterrace, 6 – meander scars, isolated oxbows, 7 – cut-bluffs / wagrams, 8 – earthen lines with tree stumps related to Scots pine sylviculture, 9 – sand dune ridges, 10 – Rudava main channel, 11 – springwater-fed brooks, 12 – Rudava abandoned channel (former mill race), 13 – Upper Pleistocene sand terrace (Weichselian glaciation) locally overlain by the eolian sands, 14 – Middle Pleistocene sand terrace (from the Riss glaciation) locally overlain by the eolian sands, 15 – spring-fed valleys, 16 – artificially adjusted spring-fed area (water source Teplička), 17 – Rudava Holocene floodplain, 18 – disused clay outcrops and pit. Yellow arrow: studied site.

As for a *geological* classification, Rudava Valley forms part of the Vienna Basin. This subsiding basin was initially filled with lacustrine sediments, mainly clays (in the Miocene to Pliocene period). Later on, in the Quaternary, they were overlain by aeolian deposits – wind-blown sands.

The axis of the valley makes up the Rudava stream itself. Its alluvium is non-cohesive and sandy, only in places with the presence of pebbles. Due to the nutrient

-poor sandy substrate, a typical soil – vegetation zonation is disturbed here. Therefore, despite the lowland climate analogues with a mountain environment typical in Slovakia for elevations of 1,000 – 1,500 a. s. l., e. g., woodland plants *Asarum europaeum*, *Oxalis acetosella*, etc. can be found here.

In 1998 Rudava alluvium was enrolled on the list of Ramsar sites. Besides this, a large part of the Rudava Valley currently has a protected area status according to Slovak environmental legislation (effective since 2011). Sites and species of both national and EU interest have been the subject of protection.

Several palaeochannel remnants are along the river, mainly in the form of meander scarps and (avulsion) palaeochannels in different stages of infilling and plant succession. They are associated with wetlands and floodplain fens. From the conservation and biodiversity viewpoint, mainly original fen meadows and those with *Carex davalliana* are of unique value. Unfortunately, once the original land use was over, the status of nonforested wetland habitats has been unfavourable (Ondrášek 2000).

Besides the floodplain, the valley of Middle Rudava also consists of slightly elevated remnant Pleistocene terraces, Neogene bedrock outcrops and isolated meander cores. Rudava Valley mostly sharply borders the extensive areas of windblown sands it had cut into, although clayey Neogene deposits steps above the river water level at some places.

Regarding hydrological conditions, the Rudava covers a catchment area of 438.7 km^2 with a relatively high mean forest cover area (60%). The river rises in the Lakšár Hills at an elevation of 238 m a. s. l. and enters the Morava River by the Malé Leváre municipality (147 m a. s. l.) with a mean discharge of 1.924 $m^3.s^{-1}$. In the long term, the Rudava is characterised by balanced discharge. The highest flow occurs in spring months, with a maximum in March (2.708 $m^3.s^{-1}$) and minimum discharge in October (Qm = 1.360 $m^3.s^{-1}$; – SHMÚ 2011). In the Studienka gauging station (river kilometre 17.0) the highest flow on record (1971 – 2019) was measured on February 25, 2013 – 20.47 $m^3.s^{-1}$ (20-year flood; Hydrologická ročenka 2021). By these parameters, there are only a few historical mentions of flood-related damage possibly related to mills – e. g., to Fajtákovský Mill in Veľké Leváre (Urbar Mesteczka Welkich Leward ...1767) or Tančibok mill in 1930 and 1943 (Studienka. Tančiboky 2023).

Regarding neotectonic features, the current valley of the Rudava keeps track of a distinct fault running in the E-W direction. This fault separates two slightly elevated blocks – the northern (Lakšár) and southern (Malacky) blocks. Initially, the Paleo-Rudava River was only a short creek flowing into a closed sedimentary lake basin, which was extended into the surroundings of Sološnica and Plavecké Podhradie on the subsiding area. However, in the Quaternary, the river used a fault predisposed position and successively prolonged its course in a westward direction crossing an extensive plain of blown sands to finally enter a Paleo-Morava River near what is now the Veľké Leváre municipality. Ultimately, with the Morava retreating further westwards also the Rudava gradually prolonged its course up to the current position near the village of Malé Leváre (Škvarček 1975). Therefore, the middle reach of the Rudava currently represents a typical transfer zone (cf. Schumm 1977).

Evolution of the Rudava valley in the vicinity of the studied PM can be understood with the aid of DEM and basic geology of the territory derived from 1:

50 000 geologic map (Fordinál et al. 2012a – Fig. 1). The Rudava Pleistocene alluvium was around 3 – 4 times wider than present (Holocene) floodplain, as shown by remnants of two terraces of different age. Both are raised by 4 – 7 m above the current river. Next to the settlements of Tančibok and Holbičky, there is a strip of a Middle Pleistocene terrace, and the river abuts its right bank. This terrace possibly comes from the Riss Glaciation (cf. Škvarček 1975). Alongside a northern margin of the terrace, clayey bedrock steps out above the water level in the Rudava. This face is of Neogene, more precisely, of the Pontian age. This Čáry formation represents clays and sands with lignite intercalations (Fordinál et al. 2012a and 2012b).

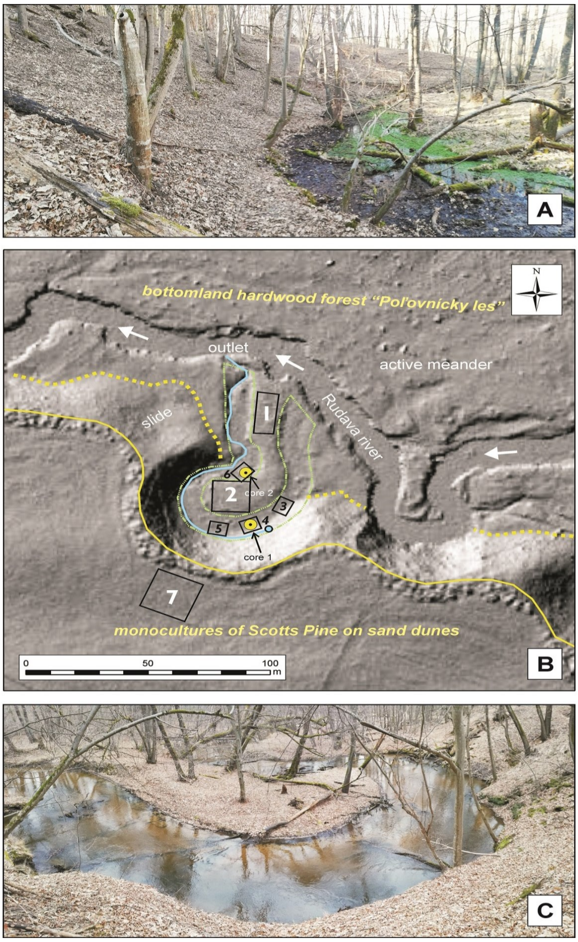

Fig. 2. A: View of the western part of the "amphitheatre" and Rudava palaeomeander, fed by spring waters. B: Twin meanders of Rudava River – studied abandoned PM and the active meander in its vicinity. Dotted line: supposed river edge at the moment of meander abandonment (which had been partially overlain by slope deposits). Coring sites and locations of 7 phytosociological relevées are also shown. C: The actively developing meander of Rudava River next to the studied PM gives an excellent idea of how once a studied meander may have looked like. An oblique view from the top margin of a Late Glacial wind-blown sands plain. 2022.

Photo P. Pišút, February 6 (A, C).

Closely upstream from the location of PM under study, the Rudava abruptly takes an S-turn, firstly to the south and again back westwards. From this point down river, the narrow Holocene floodplain abuts the left bank, whereas the rest of the valley covers a different Upper Pleistocene terrace from the Würm glaciation (Fig. 1). Here, the Neogene bedrock oscillates at the level of the current channel or below. Sheets of drifted sands had partially overlain both terraces.

The current Holocene floodplain along the study reach has only slight topographic variations. The single-thread meandering channel of the Rudava makes an axis of the floodplain. Mainly on the right side of alluvium, remnants of ancestral channels can be found in the form of *meander scars*, *meandering palaeochannels* and isolated oxbows (*neck cutoffs*) of different successional stages and ages. Channel geometry here is notably affected by *large woody debris* (LWD), almost exclusively coming from riparian trees which had been undercut *in situ* and fell into the stream. Here, dominant erosional features are minor *bank failures* and dozens of meters long *bank slips* and *slumps* (Fig. 2B). Forced mid-channel and bank-attached sand bars (cf. Friyrs and Brierley 2013) are prevailing fluvial in-channel forms. There is also an isolated *remnant of a rounded meander core* next to the double-headed meander with a height of around 5 m above the current alluvium.

In contact with the elevated valley margin the bank erosion in the past resulted in the retreat of slopes and the formation of distinctive cut-bluffs (*wagrams*). These concave landforms carved by the combined action of fluvial and slope processes are present on either side of the Holocene Valley, although slope processes and slides may have postgenously reshaped them. Typically, they are easily recognisable in DEM due to 1. an arcuate-shaped planform and 2. a markedly different elevation between the floodplain and their upper edge. Last but not least, more recent landforms used to have a still preserved original palaeomeander (gradually vanishing over centuries). The PM under study represents probably the best evolved and preserved landform of its kind.

Worthy of note are specific erosion landforms produced by *local spring outlets* in the study area. By coincidence, there are two such distinct and also historically important spring-fed areas – *Teplica* ("Warm water") and *Minor Teplica* that have already been depicted on the cadastral map in 1897 (Figs. 1, 4A and 8).

As for the *climate*, the Záhorská Nížina Lowland belongs to a warm and slightly dry region with a mild winter. The mean annual temperature is 9.5 ºC, and the mean annual precipitation is between 530 and 700 mm. The prevailing direction of winds is from the northeast (Fordinál et al. 2012b and Melo et al. 2022).

The studied bluff, and the Rudava River palaeomeander are located on the left edge of the river valley, 5 km east of the Veľké Leváre municipality, 1.5 km westward from the Tančibok settlement and 1.14 km from the former gamekeeper's lodge Mikohál (48.506351º 17.088380º)

Sediment sampling and palaeoecological analysis

Sediments of the PM infill were sampled using a Russian Peat Corer on May 4, 2022. Two cores (R-1 and R-2) 24 m away were located on opposite sites of palaeomeander. The lithology of the profiles was characterised in the field using a combination of the simplified Trøels-Smith system (Rybníček and Rybníčková 2013) and a German toolkit for field identification of organic deposits (Schulz et al. 2019). When wet, the sediment colour was determined with the aid of Munsell Soil

Colour Charts (2000). Sediment cores were subsequently subdivided into altogether 8 and 10 samples, respectively, with a regular interval at 5 cm (of respective weight between 32 and 80 g – Fig. 7).

Macrofossils and anthropogenic artefacts

Each sample of sediment was soaked in distilled water with 3% H_2O_2 and left covered for ~ 24 hours. Afterwards, the material was wet-sieved (mesh ø 0,25 mm). All eco- and artefacts were picked. Upon drying, plant diaspores were determined under a stereoscopic microscope with a magnification of 2 – 45 × and checked against a reference collection at the Faculty of Natural Sciences, Comenius University or compared to the seeds of plants growing *in situ*. We have also used atlases of plant seeds (Cappers et al. 2006 and Bojňanský and Fargašová 2007). The nomenclature of molluscs follows Horsák et al. (2022). Findings were evaluated and classified by numbers and species related to respective sample depth. Plant macrofossil diagrams for both cores were arbitrarily divided into zones according to changes in plant spectra and other macrofossils. For easy comparison, the determined seeds totals in the graphs have been recalculated to a common (standard) 100 g sample weight. Outputs of palaeoecological analysis are presented using Strater software.

Radiocarbon dating

In total 3 samples of biological material were radiocarbon dated at the Centre for Applied Isotope Studies, University of Georgia (Athens, USA) by the AMS method. We have only used survived waterlogged seeds from terrestrial trees and herbs. For calibration of ^{14}C dates the Excel 4.2 was used, using atmospheric data from Reimer et al. (2020) for 0 – 50 000 years cal BP.

Historical map analysis

We have scrutinised several maps to depict the Rudava Valley with a special focus on the floodplain situation and land use changes. The cadastral map of 1897 was resized to a common scale of an ordnance map 1:10 000 (georeferred into the S-JTSK system) within an ArcGis environment. With the aid of 8 points, the map shot was georeferenced with the RMS error = 1.85679 m. Geographical coordinates of various locations described in the text are given in WGS84 (ψ, λ).

Vegetation survey

Current vegetation was surveyed for two reasons. Firstly, to characterise the current successional status of PM alluvial habitats. Secondly, to provide an essential species database so that palaeoecological findings (plant macrofossils) could be more exactly determined and interpreted.

The site of palaeomeander was visited on several occasions during the 2022 season. Besides the repeated floristic surveys, altogether 7 phytosociological relevées were taken by standard field method (Braun-Blanquet 1964) on May 19, 2022. Plant nomenclature follows Marhold and Hindák (1998).

RESULTS

Anatomy of studied palaeomeander

The Rudava Valley at the study site has a width of 110 to 190 m. The stream itself is only 6 – 15 m wide. Correspondingly, the abandoned PM is quite small. It is 200 m long (= measured in channel centerline), and its core area covers an area of 0.128 hectare. The meander neck is extremely narrow, only reaching a width of 8 to 14 m. The radius of PM is some 19 – 20 m (Note: the active Rudava meander nearby has a radius ± 15 m).

During the meander evolution, the Rudava penetrated ~ 60 m into the margin of the pseudoterrace with eolian sands. This created a rounded "amphitheatre" with an upper edge 144 m long. The margin of the wind-blown sands area lies in an elevation of 174.3 – 177.0 m a. s. l. Since the PM has an elevation of 167.2 – 166.5 m a. s. l., an altitudinal difference between the Holocene floodplain and the highest elevation of the Pleistocene sand dunes ranges from 7.1 to 10.5 m.

As for a meander neck, it lies at around 167.1 – 167.2 m a. s. l. The PM's bottom itself lies in 166.5 – 166.7 a. s. l., whereas it is slightly sloping towards the former lower estuary and the Rudava (166.0 – 166.2 m a. s. l.) in its lower section.

Along the SE base of the slope action, slope processes are evident. The whole slope is overgrown by mature trees. However, there are almost no shrubs, and even the herb layer is poorly developed. Although the slope is protected by a tree canopy interception against the direct effect of raindrops, wild game here are a disturbing factor. Trails of big game (mainly wild boar and roe deer) leading to water promote the creeping of the slope material towards the base of the slope. Sand accumulations are evident at the SE part of the footslope (Fig. 2B). In the western half of cut -bluff the slope angle is steeper. This is associated with a spring by the south toe of the bluff. From this point towards the Rudava springwater discharge and velocity gradually increases, so much so, that at some places its bed is even sandy, free of plant detritus. Ultimately, springwaters flow through a narrow outlet into the Rudava River (Fig. 6B).

A local gradient of groundwaters has also determined a hydrosequence of local soils within the PM core area. They have been derived from fluvial sands or organic hydromorphic material. Whereas the former convex bank of the PM (relevée no. 2) with a soil type *Gleyic Fluvisol* (IUSS Working Group 2022) has a groundwater 68 cm deep, *Haplic Fluvisol* amidst the palaeomeander neck (hardwood floodplain forest, relevée no. 1) has a groundwater already much deeper, 157 cm deep. This moisture gradient – gradually decreasing groundwater from the toe of the bluff towards the active river channel – is mainly caused by the presence of springwaters, controlled by a surface of Neogene clays. However, the face of the clayey bedrock itself is not visible at the site since it probably lies ± at the level of the floodplain surface. Eventually, the former river channel's wetland soils vary from *Histic Gleysol*, *Arenic* to *Histic*, *Limnic Fluvisol Arenic* (IUSS Working Group 2022).

The Rudava palaeomeander on historical maps

Since the studied site lies in a secluded area amidst the extensive woodlands, a proximal floodplain can be first recognised as late as on the 1st Military survey map from the early 1780s (No. 1 in the map list). By then, almost the whole eolian

Glacial plain beyond the floodplain edge had been continuously forested with pine woodland. As to the relief, both the valley edge and the elongated sand dunes above the river are depicted with linear hatching. The most relevant fact visible on the map is that almost the whole river alluvium along either bank is shown as open grasslands in places with light patches that can be interpreted as places with disturbed sandy soil. On the river's right bank, close to the inscription "*Rudava Fluv* (ius)" a narrow incipient belt of the alluvial forest is recognisable, roughly in a place of the later Poľovnícky Les (Poľovnícky forest – Fig. 3A).

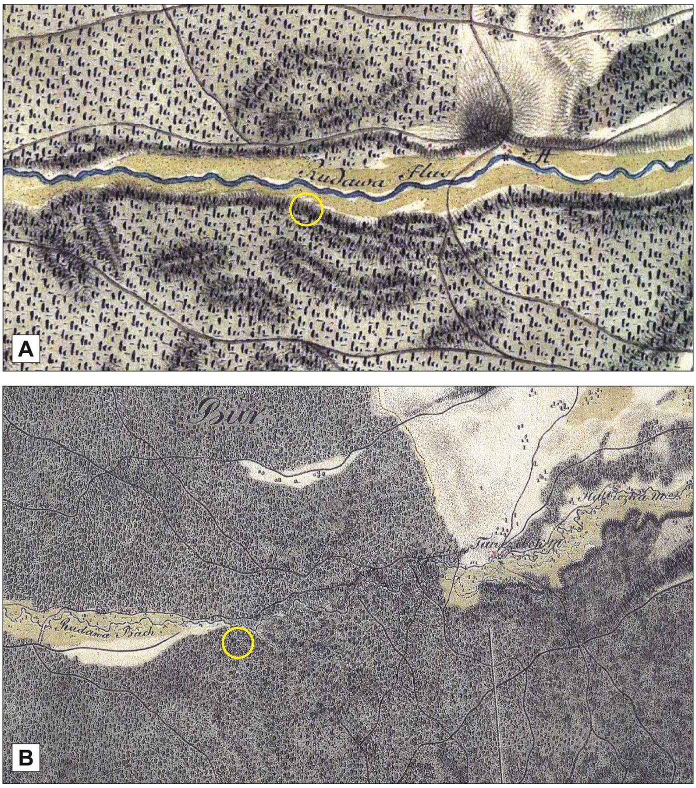

Fig. 3. A: Alluvium of the Rudava River in the 1780s. B: Middle section of the Rudava River channel in the mid-19th Century. Circle = location of study site

The map sheet of the 2nd military survey captures a forested countryside around the mid-19th Century (no. 2 in the checklist). Unlike the previous situation, a floodplain section around and upstream of the studied PM is seen as being completely forested, starting downstream from the Tančibok mill and settlement (*Tanczibok M.*). A formerly continuous belt of grasslands was then already disrupted, and it only proceeded again some distance away downstream of the PM.

Undoubtedly, the most relevant for knowledge of the past Rudava River meandering behaviour is the cadastral map of 1897 (no. 3). Here, both riverbanks of the stream (*Rudava patak*, "Rudava creek") along with the position of meander loops had been accurately depicted (Fig. 4A). Back then, the PM under study must have been already cut off for some time. Surveyors completely omitted the area of the then palaeomeander, perhaps as irrelevant to them (Fig. 8). However, they precisely captured the forest plot's semi-circled margin, representing the upper edge of the cut-bluff. We may hypothesise that most probably an open waterbody no longer existed at the site then; only a vegetated swamp was left behind. Also, two important spring-fed areas with related toponyms were thoroughly depicted on this map upstream of the studied PM (*Teplica, Kis Teplicza*).

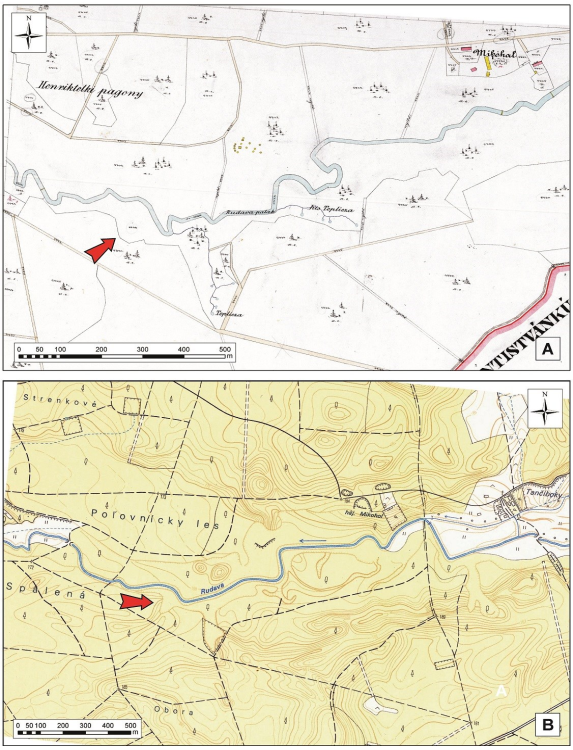

Fig. 4. A: Rudava River channel and adjacent spring-fed areas (*Teplicza*, *Kis Teplicza)* according to a cadastral map of 1897. Top right – game's keeper lodge and premises of a brickyard *Mikóhal.* B: Stretch of Rudava River downstream of Tančibok settlement according to the 1969 ordnance map. Red arrow = location of PM.

Interestingly, the precise and detailed representation of the very channel of the Rudava River on the 1897 map has not been outcompeted since then, neither by more recent maps of the 20th Century. The whole area was intensively mapped in the period after WWII. These cartographic works provided a more accurate and updated representation of the blown-sand relief (terrain contour lines). However, the representation of the meandering Rudava channel can be ascertained as a step backwards compared to the 1897 situation. As the combined civilian-military map of 1963 shows (n. 5 in the checklist), the flow is more generalised, and its course evidently simplified. The same depiction was later used in more recent maps, e.g. the ordnance map of 1969 (Fig. 4B; no. 6 in the list). These drawbacks can be explained by the mapping method – field measurements coupled with photogrammetry. Similarly, as on a 1950 historical orthophoto map (no. 4), the position of the Rudava channel was possibly obscured by the tree canopy. However, it was, for some reason, inadequately revisited directly in the field.

Meander abandonment based on radiocarbon dating (chronology)

Plant material from the base of the coring R-1 and R-2 provided the relatively young age of seeds, dated from the Modern age period. A wide range of calibrated dates spans from 1652 to 1918 calAD. In general, analysed plant seeds should be coeval with the sediments. Calibrated data are relatively consistent and do not contain distinctly older, possible residual material. However, as the results show, it can not be excluded that some of them may represent slightly younger intrusions (with regard to the shallowness of the studied profile and possible bioturbation, e. g. by wild game).

Tab. 1. Radiocarbon ages of biological samples (waterlogged plant seeds)

UGAMS#	Sample ID	Depth (cm)	$\partial^{13}C$, ‰	^{14}C age, years BP	Calibrated yr. AD (95,4 %)	Median
59655	RDV-1	36.0	-28,55	110	1689 – 1730 calAD (24.7 %) 1807 – 1924 calAD (70.7 %)	1843
59656	RDV-2	32.5	-27,15	140	1672 – 1778 calAD (36.1 %) 1797 – 1944 calAD (59.4)	1830
59657	RDV-3	47.5	-28,75	190	1652 – 1694 calAD (22.4 %) 1726 – 1811 calAD (56.6 %) 1918 calAD (16.5 %)	1766

In the sample RDV-1 from the base of the core 1 (depth of 36 cm) two seeds have been dated – of *Alnus glutinosa* and *Sambucus ebulus*. Due to a plateau on the calibration curve, there is a 70.7% probability of dating them into the 19th century, more specifically into its first half (median 1843 calAD). However, there is also a 24.7 % probability that at least one of the seeds might date back to the turn of the 18th Century (1689 – 1730 calAD – Fig. 5 and Tab. 1).

A sample RDV-2 represents plant material from the same core (depth 32.5 cm). Here again, due to a plateau, two seeds of *Ajuga reptans* and *Sambucus ebulus* provided calibrated ages between 1672 – 1944 calAD (Fig. 5). Dated material from this layer, which should be expectedly a little younger than a previous sample, provided quite consistent, though somewhat older date (median value 1830 calAD). Compared to RDV-1, there is an even higher probability (36.1%) that at least one seed comes from the period 1672 – 1778 calAD (Tab. 1).

Finally, the third sample RDV-3 from the base of core 2 (depth 47.5 cm) gives a median 1766 calAD (1726 – 1811 calAD, 56.6% probability). Nevertheless, there is also a 22.4% probability of its dating into the period 1652 – 1694 calAD (Fig. 5). In this case, in total 3 seeds of *Persicaria lapathifolia*, *Polygonum aviculare* and *Polycnemum arvense* were dated.

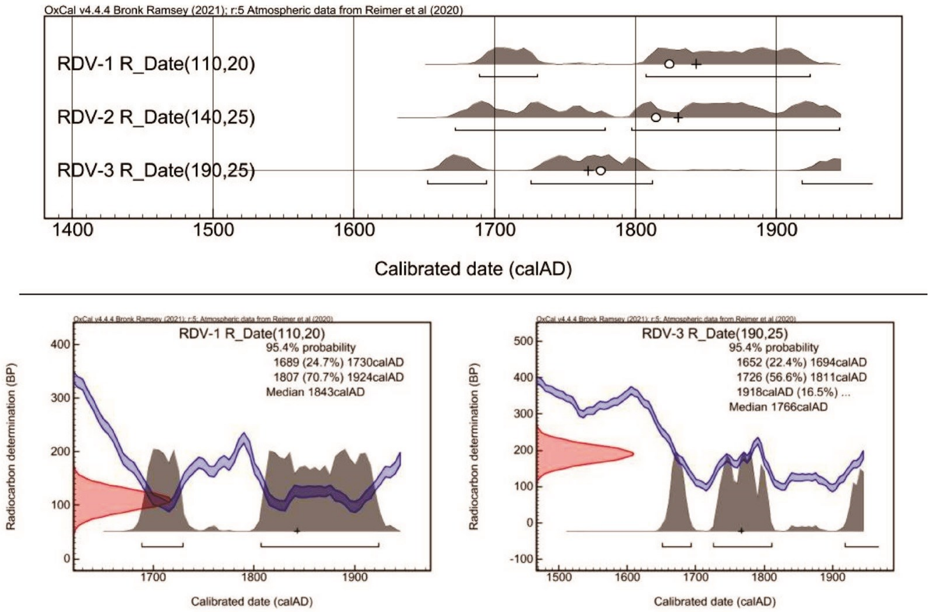

Fig. 5. Calibrated dates of analysed samples – multiple diagram (up), calibrated samples RDV-1 and RDV-3 (below)

Note: Empty circle – mean, + median value.

Current vegetation and habitats

According to F-GIS, woodland vegetation within a PM neck is part of a 107-year-aged forest (management unit code 541 d). As for nature conservation, it is classified within the category of Protected forest (= prevailing function is defined as soil protection). Scots Pines stand on nearby sand dunes is a typical economic woodland aged 42 years. All local woods are being managed by the Military Woods and Estates, State Enterprises.

In the area of the studied fluvial landform and in its close vicinity, altogether 82 taxa of both lower and higher plants were found, representing 13.9% of all species that had been reported earlier from the whole Rudava alluvium (Stanová 1993). The variability of microhabitats is closely related to the evolution of the fluvial-slope landform and local vegetation succession, but also current hydro-pedological and microtopographical conditions. A detailed checklist of species will be published elsewhere. Basic data of vegetation taken at relevées are listed in Tab. 2.

Relevée no. 1: Narrow neck of the former meander is overgrown by alluvial forest with alder, maple, lime, common hornbeam and elm. The shrub layer is rare. The ground layer is dominated in a spring aspect by *Allium ursinum* (values 4.5 of Braun – Blanquet combined scale) and with subordinate *Asarum europaeum* (3.2 Br. – Bl.). Worthy of note is also the presence of *Carex brizoides*, *Urtica dioica* and *Oxalis acetosella*. Seedlings of 7 tree species are present, as well. Soil type: Haplic Fluvisol, groundwater layer in 158 cm.

Relevée no. 2: Initially dominated by alder (*Alnus glutinosa*, old coppiced trees along the convex bank and point bar of former meander). Hardwood floodplain trees – common ash, hornbeam, maple and lime – gradually penetrate into the understorey and partly even into the main canopy. The field layer is composed of alluvial woody species and mainly by wet-tolerant species dominated by different sedge taxa with the highest cover area of *Carex brizoides* (3.4 Br. – Bl.). Soil type: Gleyic Fluvisol, groundwater in 68 cm.

Tab. 2. Phytosociological survey, basic data on relevées

No	Plot area	Number of species	Cover area (%)					Coordinates (WGS-84)	
	(m)		E3-1	E3-2	E2	E1	E0	N	E
1	30×10	35 (6-1-34)	80	30	1	95		48.50208°	17.07586°
2	30×15	36 (5-3-34)	75	45	5	90		48.50174°	17.07574°
3	10×5	(1-0-18)	80	0	0	80	5	48.50170°	17.07600°
4	7×8	(0-0-20)	0	0	0	98		48.50159°	17.07580°
5	5×6	(0-0-19)	0	0	0	98		48.50158°	17.07559°
6	5×6	(2-4-15)	70	40	30	65		48.50187°	17.07578°
7	20×20	21 (1-0-16)	75	0	0	5	100	48.50131°	17.07542°

Note. Number of species: total number of taxa; the number of trees in a tree-, shrub- and herb layer, respectively.
Cover area: E3-1 – main canopy, E3-2 – tree understorey, E2 – shrub layer, E1 – field layer, E0 – moss layer, respectively.

Relevée no. 3: swampy ground partially with shallow open water (to 10 – 15 cm) and alder trees in E3. No shrubs, field layer is dominated by *Carex acutiformis* and *C. remota*.

Relevée no. 4: open waterlogged swamp (in places with patches of shallow water) with no tree canopy. Vegetation is dominated by sedge species (*Carex acutiformis*, *C. brizoides*, *C. elongata*), *Iris pseudacorus* and fern *Dryopteris carthusiana* (Fig. 4C). Along with additional indicative swamp species low shrub *Ribes nigra* is also present in E1. Coring site no. 1.

Relevée no. 5: marsh vegetation, associated with the exit of spring water with shallow (= slowly flowing) open water (up to 10 – 15 cm) and no tree/shrub layer. The field layer is dominated by *Berula erecta* and subdominant *Cardamine amara* (Fig. 4D).

Relevée no. 6: Mixed wood with alder and additional tree species in the understorey and shrub layer (hornbeam, lime, elm, maple). Here, the field layer is dominated by *Carex remota*, and with sub-dominant *Dryopteris carthusiana* and *Oxalis acetosella* (the latter growing at the trunk-toes and microelevations). Worthy of note is the presence of *Staphyllea pinnata* in the shrub layer. Coring site no. 2 (Fig. 4E).

Relevée no. 7: Planted Scots pine (*Pinus sylvestris*) monoculture. The homogenous even-aged stand has no shrub layer and only scarce herbs (e. g. *Calamagrostis epigejos*, *Festuca ovina* agg.); however, a moss layer (E0) covers 100% of the plot area (3 moss species).

Regarding a syntaxonomical classification, relevées no.1 and 2 represent the woody vegetation of the alliance *Fraxino-Quercetum roboris* (*Oak-Elm-Ash hardwood floodplain forest*) and belong to the specific association *Ficario vernae – Ulmetum campestris*. Differential taxa also recorded in our sites are *Carpinus betulus*, *Asarum europaeum*, *Oxalis acetosella*, *Stellaria holostea*, *Aegopodium podagraria*, *Millium effusum*, *Moehringia trinervia*, *Cardamine impatiens* and *Ficaria bulbifera*. Dense tree canopy is variable. However, *Alnus glutinosa*, *Carpinus betulus* and *Tilia cordata* play a decisive role and the absence of *Fraxinus danubialis* differentiate this association from the more common hardwood forest of lowlands in Slovakia (*Fraxino pannonicae-Ulmetum campestris*). Geophytes (*Allium ursinum, Ficaria bulbifera*) are typically present in the herb layer in the spring phenophase. Stands of the association have been reported from the territory of Slovakia, exclusively from the Rudava alluvium. This location probably represents the SE margin of the distribution range of this subatlantic unit which is commonplace e. g. in Poland where it represents actually the only hardwood floodplain forest on sandy parent material (Hrivnák et al. 2021b).

By contrast, the marshy vegetation of the palaeochannel bed itself (relevées no. 3, 4 and 6) belongs to the different alliance – *Alnion glutinosae – Alder carr*, in particular into the association *Carici acutiformis-Alnetum glutinosae*. The tree layer is dominated by Black Alder (*Alnus glutinosa*). In the herb layer, typical marshy species prevail, dominated by *Carex acutiformis*. With a high presence occur *Galium palustre*, *Lycopus europaeus*, *Scirpus sylvaticus* and *Solanum dulcamara* (the last two taxa absent on our site). Also, the species of spring-fed areas (*Carex remota*, *Cardamine amara*), nitrophilous and nutrient-demanding species are present (*Impatiens noli-tangere*, *Lamium maculatum*, fern *Dryopteris carthusiana* agg.). Our relevées represent a moister variant of the association, as indicated by swamp plants *Iris pseudacorus*, *Mentha aquatica* or *Peucedanum palustre* (the latter less endangered LR species). In low-lying places, water ponds at or above the surface and the microrelief are composed of patches of drier microelevations (with tussocks of *Carex remota*, *C. elongata*, decomposing tree trunks) and open water (with *Lemna minor*). Relatively high amounts of total nitrogen and carbon accumulate in the soil. However, due to permanent waterlogging, it is present in forms unavailable for plants (Hrivnák et al. 2021a). This association's habitat is mapped as habitats of national importance (code Ls 7.4).

A special variant of marsh vegetation is represented by relevée no. 5. This is classified into the class *Phragmito-Magnocaricetea*, alliance *Sparganio-Glycerion* and into the association *Cardamino-Beruletum erecti* (Turoňová 1985). Besides characteristic and dominant *Berula erecta, Cardamine amara* and *Mentha aquatica* are also present. *B. erecta* belongs to a vulnerable species of the Slovak flora (VU category, Marhold and Hindák 1998). It forms lively emergent stands in streams, spring-fed areas and alternatively in artificial canals with slowly flowing or stagnant water, 10 – 20 cm deep, where raw and partly decomposed plant material accumulates. The number of species in our site (19) is relatively higher, typical for stands in tranquil sites overgrowing with vegetation (Turoňová 1985). Following the changed ecological conditions (no more flowing water, infilling waterbody) *B. erecta* as a weak competitor declines, and the community develops towards vegetation of tall sedges (alliance *Magnocaricion elatae*). This community has been reported from several locations in the Borská nížina Lowland at the closest around the village of Studienka (Hegedüšová et al. 2009).

Relevée no. 7 represents a the woody vegetation of the extensive areas just beyond either side of the Rudava alluvium. The Scots Pine forest community belongs to the *Dicrano-Pinion* alliance – *acid tolerant pine forests on sands* (Valachovič 2021) and is a typical representative of the Borská nížina Lowland pine woodlands. These economic forests are traditionally established using heavy machinery and by subsequent artificial planting. Following a clear-cutting of the mature stands, tree stumps from the whole cleared area are mechanically removed by a bulldozer. In doing so, trunks and a whole humic layer are housed onto lines so that the development of soil and herb vegetation repeatedly starts from a zero point. In our case, such an accumulated line stretches along the upper edge of the cut-bluff (Fig. 2B).

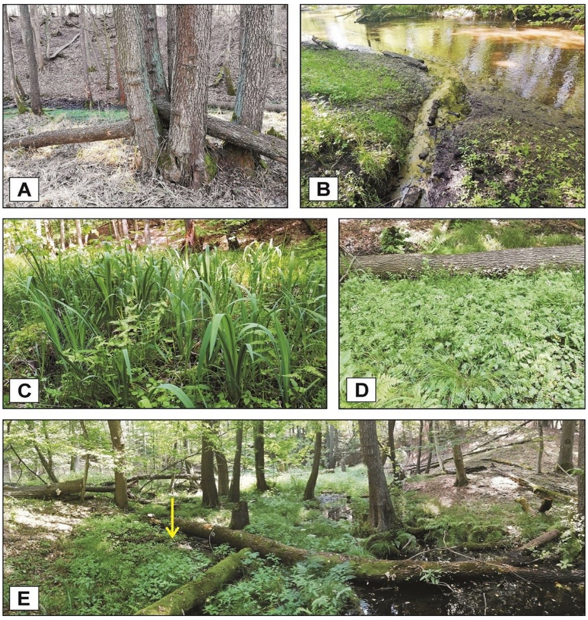

Fig. 6. Marshy habitats of the lower half of the paleomeander

A: Old coppiced alders along the inner bank of the paleomeander. B: The outlet of spring waters into the Rudava is located in the former lower outlet of the PM. C: Coring site R-1, phytosociological relevée no. 4. D: shallow water environment with leaves of dominant *Berula erecta*, the zone already influenced by a spring at the footslope (relevée no. 5). D: Skyline view of the Rudava palaeochannel seen from the north, coring site R-2 (arrow). Photo P. Pišút, February 6 (A), May 14 (B, C), June 19 (D) and July 31 (E), 2022, respectively.

Rudava palaeomeander wetland site – lithological characteristics of the profiles

The first core (R-1) was 37.5 cm deep, and the second one (R-2) reached up to 50 cm. Below these depths, there was a hardened (muddy) sand impenetrable by a Russian peat corer, which we considered to represent the material of the former palaeochannel bottom. In general, the composition of both cores was similar: partly decomposed black (*Alnus*) peat on the top pass downwards into fine organic sediment with a different share of organic mud, plant detritus, remnants of herbaceous plants, wood fragments and minor admixture of sand particles (Tab. 3). There was a distinct smell of H_2S (= reduction conditions, cf. IUSS Working Group 2022). In both cases, the soil was saturated with water which is at the surface. Within this classification, the soils can be classified as a *Histic*, *Limnic Fluvisol*, *Arenic*.

Tab. 3. Lithological characteristics of studied profile

Core no.	Depth (cm)	Troels-Smith code	Description (Schulz et al. 2019)	Munsell colour
1	0 – 10	Th4	black (Alder) peat	10 YR 2/1
	10 – 15	Th2 Dg1 Ld1	highly decomposed peat	7,5 YR 3/1
	15 – 20	Th1 Dh1 Ld2	detritus gyttja	
	20 - 25	Ld2 Dg2	- // -	
	25 – 37.5	Ld2 Dg1 Gmin 1	sand gyttja	7,5 YR 3/2
2	0 – 5	Th4	black (Alder) peat	
	5 – 10	Th2 Dg2	highly decomposed peat	7,5 YR 2,5/1
	10 – 20	Th1 Dg2 Dh1	detritus gyttja	
	20 – 30	Th1 Dg1 Dh1 Ld1	- // -	
	30 – 35	Ld2 Dg1 Dh1	- // -	7,5 YR 1,5/3
	35 – 40	Tl1 Dg1 Dh1 Ld1	- // -	
	40 – 45	Dg2 Dh1 Ld1	- // -	
	45 – 50	Tl1 Ld1 Dh1 Gmin1	sand gyttja with wood fragments	7,5 YR 3/2

Explanation: Th – herbaceous peat, Tl – parts of tree trunks and branches, Dg – plant detritus (< 2 mm), Dh – plant detritus (> 2 mm), Ld – remnants of water plants (< 0.1 mm), Gmin – mineral particles of sand (0.06 – 2 mm).

Local vegetation succession based on plant macrofossils

Within ecofacts, a total of 1 443 seeds of plants have been retrieved from both studied cores R-1 and R-2 (370 and 1 073 pieces, respectively). Furthermore, it contained remnants of plant tissues, bark, rootlets, twigs, leaves, wood and charcoal fragments. At least 72 plant taxa were determined either into the family, genus or down to a species level (Tab. 4). As for life forms, besides numerous hemicryptophytes, terophytes and some geophytes we have identified in total 7 tree species (= phanerophytes) along with 2 shrub nanophanerophytes / woody chamaephytes (*Rubus caesius, R. idaeus*) and even some hydrophytes (*Myriophyllum verticillatum, Oenanthe aquatica*). Identified plant species of a ground layer belonged mainly to the family of Cyperaceae, Polygonaceae, Caryophyllaceae, Poaceae, Ranunculaceae, Chenopodiaceae, Lamiaceae and some others. Plants are mainly represented by the wet tolerant marsh species of the plant association *Carici elongatae – Alnetum glutinosae* and *Carici acutiformis – Alnetum glutinosae*, but also species of meadows/grasslands and ruderal taxa of anthropogenically disturbed grounds were present, mainly in the earlier stages of succession. Based on seed abundance and diversity in individual sediment layers, both examined profiles can be subdivided into two macrofossil zones (MZ – 1 and 2) and 4 subzones.

As to a faunistic record, besides cocoons of Annelids and numerous fragments of insects (Fig. 7), subfossil shells of Mollusca were also retrieved from either core. However, due to the acidity of the soil substrate, shells were only present only in its uppermost layers (MZ – 2 zones, 0-20 cm). Cocoons of Annelids were much more numerous in core R-1, indicating a more stable depositional environment.

In contrast, charcoal fragments retrieved from both profiles were almost exclusively found in profile lower sections within macrofossil zones MZ – 1 (beneath 15 or 20 cm). Their presence is not only associated with the then-human activities but also with the fact the abandoned palaeochannel may have been still periodically affected by running water during earlier stages of succession carrying these artefacts.

Macrofossil ecogroups. To better cover successional changes in local vegetation over time, determined plant macrofossils were subdivided into 8 groups according to their present-day ecological requirements (Tab. 4). In contrast, mainly in some synanthropic species, their source habitats are easily recognisable as human-affected areas (e. g. *Chenopodium album*, *Portulaca oleracea* and *Solanum nigrum*), while others may occur in several habitat types. For instance, Moehringia trinervia is typically found in the alluvial forest, but as a shade-tolerant species it also commonly grows on the undercut slopes, even in pine monocultures. Therefore, besides information from the vegetation of the whole Rudava alluvium (cf. Stanová 1993) we have also considered the distribution of single plant species in current communities at the studied site and on the alluvium nearby. The last (leftover) group comprise of taxa which were only classified into the genus/family, so they may have grown in different habitats (*Carduus* / *Cirsium*, *Poaceae*).

Tab. 4. Identified taxa in plant-macrofossil record and their typical present-day habitats (with a focus on the studied segment of the Rudava River)

Species	1	2	3	4	5	6	7	8
Ajuga reptans				x		+		
Alisma lanceolatum	x					+		
Alisma sp.	x					+		
Alnus glutinosa	+	+	x					
Alliaria petiolata				x			+	
Aphanes arvensis / Alchemilla						+	x	
Betula cf. *pendula*				+	x	+	+	
Bidens cf. *cernuus*	x							
Cannabis sativa	+						x	
Carduus / Cirsium		+		+		+	+	x
Carex acutiformis	+	+	x			+		
Carex brizoides	+	+	x			+		
Carex elongata	+	+	x					
Carex diandra	+					x		
Carex paniculata	x	+	+					
Carex pseudocyperus	x	+	+					
Carex remota	+	x	+					
Carex riparia	x		+			+		
Carpinus betulus				x				
Circaea x *intermedia*	+	x	+					
Cornus sanguinea			+	x				
Cyperus fuscus	x	+						
Eupatorium cannabinum		+	x	+		+		
Fragaria vesca / moschata								
Galeopsis speciosa / tetrahit	+			x			+	
Glechoma hederacea				x				
Glyceria declinata / notata	x	+						
Hypericum cf. *maculatum*						x		
Hypericum tetrapterum	+	+				x		
Chenopodium cf. *album*							x	
Chenopodium hybridum							x	
Impatiens noli-tangere		+	x					

Continuation of Tab. 4.

Juncus sp.	+	+	x					
Juncus cf. *conglomeratus*	+	x	+			+		
Lamium album / purpureum							x	
Lamium sp.				+		+	+	
Linum catharticum						x		
Lycopus europaeus	+	+	x					
Lychnis flos-cuculi						x		
Lysimachia nummularia	x	+	+			+		
Lythrum salicaria	+	+	x					
Mentha longifolia	+					x		
Mentha aquatica	x					+		
Moehringia trinervia				x	+		+	
Myosoton aquaticum	+					+	x	
Myriophyllum verticillatum	x							
Oenanthe aquatica	x							
Oxalis acetosella			+	x				
Panicum miliaceum							x	
Persicaria lapathifolia	+						x	
Pinus cf. *sylvestris*					x			
Poaceae sp. div.	+		+	+	+	+	+	x
Polycnemum arvense					+		x	
Polygonum aviculare							x	
Polygonum cf. *hydropiper*	x						+	
Portulaca oleracea							x	
Prunus padus				x				
Quercus cf. *petraea*				x	+			
Ranunculus acer / repens				+		x		
Ranunculus sceleratus								
Rubus caesius	+	+	+	x		+		
Rubus idaeus					+		x	
Rumex conglomeratus	x					+		
Rumex obtusifolius	+						x	
Sambucus ebulus							x	
Scirpus sylvaticus	+	+	x					
Silene dioica				x				
Solanum nigrum							x	
Stellaria media							x	
Urtica dioica				x			+	
Verbascum cf. *blattaria*						x		
Viola sp.				x			+	

Explanation notes: x – dominant habitat, + alternative subordinate habitats. Ecological groups of species: 1 – shallow stagnant / slowly flowing waters and their littoral zones, temporarily exposed/flooded banks; 2 – forest wetlands and spring-fed areas; 3 – Alder carr (Carici elongatae – Alnetum glutinosae, Carici acutiformis – Alnetum glutinosae); 4 – alluvial forest (of the Rudava – type) Ficario vernae – Ulmetum campestris; 5 – Scots Pine economic woodlands on eolian sands (Dicrano – Pinion); 6 – wet to mesic meadows (grasslands); 7 – roadsides and forest edges, ruderal sites, fallow lands, moist fields; 8 – ecologically indifferent species.

Core R-1 (0 – 37.5 cm) contained altogether 370 pcs of determined plant seeds. As a whole, the profile was quite species-poor – the mean number of species in samples was < 10. The lower half of the profile (MZ – 1, 15 – 37.5 cm) also contained a comparatively minute number of seeds per sample (9 – 34 pcs). More seed -rich was only the MZ – 2 zone (0 – 15 cm). In the profile, typical species of Alder carr community prevailed (216 seeds = 58.4 %), mainly represented by seeds of alder itself (*Alnus glutinosa*, 38.9%) and by *Carex elongata* (61 pcs – 16.5%), the latter only missing from the lowermost MZ – 1a zone. Besides these, mainly in samples from the core upper part (MZ – 2), also species of forest wetlands and spring-fed areas were more notably present (*Carex remota* and *Circaea* × *intermedia* with a total of 23.22%). Taxa of alluvial forest altogether counted for 9.7% (*Moehringia trinervia*, *Oxalis acetosella*, *Silene dioica*, *Glechoma hederacea*).

Although representing only 3.0% of all seeds, there were also diaspores of plants of wet to mesic meadows (grasslands) found in the lower part of the profile, along with scarce anthropogenic indicators (*Hypericum tetrapterum*, *Verbascum* cf. *blattaria*, *Sambucus ebulus*, *Chenopodium hybridum*, Chenopodiaceae sp., *Solanum nigrum, Rubus idaeus*).

Core R-2 (0 – 50 cm) was much more diverse regarding the number of species identified and the total number of seeds (1 073). In this case, particularly the lower half of the profile was extraordinarily species-rich (MZ – 1b), with seed numbers reaching 108 – 223 (maximum in 25 – 30 cm). In a profile as a whole, the largest proportion of taxa fell into the typical community of Alder carr, which was even higher here (62.7%) than in core R-1. Both alder and *Carex elongata*, as indicator species of this community, were constantly present from top to bottom (with a share of 31.5% and 5.3%, respectively). Interestingly, some other Cyperaceae family members must have played an important role in local succession – particularly *Scirpus sylvaticus* (190 seeds = 17.7%). Wood clubrush was present from a depth of 40 – 45 cm almost until the topmost layer with a closed curve. However, the species is entirely absent from the site today though it is commonplace elsewhere along the river banks.

In contrast, species of shallow stagnant / slowly flowing water and their littoral zones reached up to 15.1 % here (whereas those of forest wetlands and spring-fed area only counted for 1.2 %). Among these taxa, Juncus sp., *Alisma*, *Polygonum* cf. *hydropiper*, and *Cyperus fuscus* (7.4%) were important during earlier plant succession (MZ – 1b, 20 – 45 cm). Although the proportion of these species over time has been positively affected by a presence of a permanent rivulet with water flowing alongside coring site R-2, it is also probable that an open shallow waterbody must have persisted in this area for a more extended period than in the case of coring site R-1. A relative proportion of alluvial hardwood taxa was slightly lower here (6.5%) compared to a core R-1; however, a nitrophilous *Urtica dioica* was constantly found in almost all samples.

As noted above, macrofossil zone MZ – 1 of this profile had relatively diverse marsh flora with a maximum of 35 – 40 cm (33 species). In addition, this zone also exhibited relatively high proportion of both meadow / grassland taxa and synanthropic taxa (6.8% and 2.8%, respectively), pointing towards still at least a partially open and human-affected environment in the vicinity of the studied area during an earlier stage of palaeochannel terrestrialisation. In this case, several species unequivocally indicate wet to mesic meadows/pasture grasslands (*Myosoton aquaticum*, *Hypericum tetrapterum*, *H. maculatum*, *Lychnis flos-cuculi*, *Mentha longifo-*

lia, Ranunculus acer / repens, Linum catharticum etc.). Similarly, we have recovered seeds of several ruderal taxa, either species growing alongside roads/forest edges, plants indicating trampling or those directly associated with farmland activities and ruderal sites rich in nitrogen and phosphorus (*Cannabis sativa*, *Panicum miliaceum*, *Polycnemum arvense*, *Aphanes arvensis*, *Chenopodium* sp., *Stellaria media*, *Portulaca oleracea*, *Solanum nigrum*, *Sambucus ebulus*, *Polygonum aviculare*). Besides, the then possible human action in the alluvial landscape may also be (indirectly) indicated by some additional species, which are largely nitrophilous and able to grow on sites disturbed by humans or cattle (*Ranunculus sceleratus*, *Cyperus fuscus*, *Persicaria lapathifolia*, *Glyceria notata / declinata*, some *Rumex* etc.).

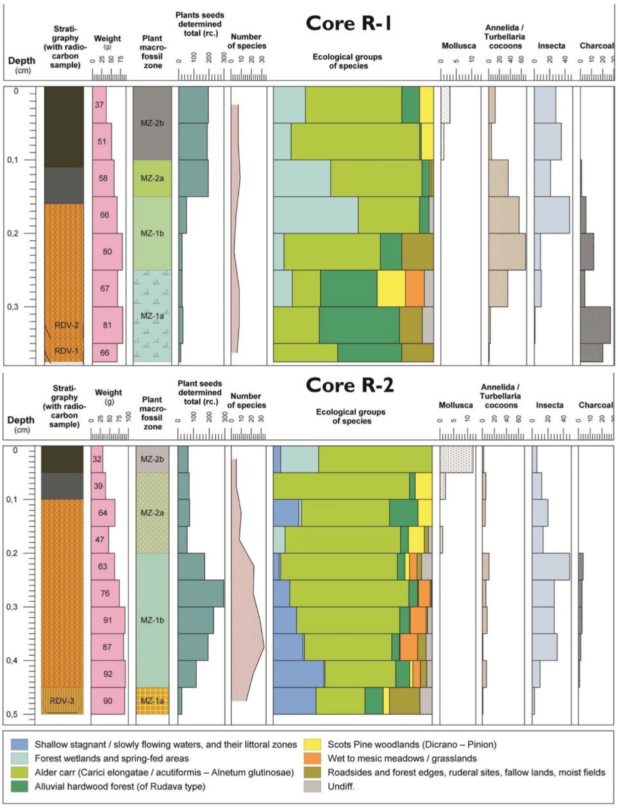

Fig. 7. Lithological characteristics, basic morphological parameters, sampling intervals and sample weight, plant macrofossil zones and ecogroups, the content of different eco- and artefacts in the cores R-1 and R-2

Analysis of Mollusca

Among identified molluscan taxa, the dominant terrestrial species was the distinctly hygrophilous species *Zonitoides nitidus*. There were also shells of two additional wet-loving species (*Carychium minimum*, *Succinella oblonga*, and partly *Nesovitrea hammonis*). One shell of the snail *Vertigo pygmaea* was recorded in the surface soil layer (0 – 5 cm). Although this snail prefers open mesic habitats, it can also live in open wetlands.

Among aquatic species, the bivalve *Pisidium casertanum* predominated. We have also recovered one eurytopic bivalve *Sphaerium corneum* shell from a depth of 15 – 20 cm.

In general, fossil and subfossil molluscan shells indicate the presence of unspecified waterbodies and more or less open wetland.

DISCUSSION

Dating of the Rudava meander abandonment

The thickness of PM infill, captured in either core 37.5 vs. 50 cm, respectively, corresponds to the natural morphological variability of the river channel depth associated with channel morphology and in-channel forms. It is comparable to the Rudava channel variability reported next to the Studienka municipality (Derka et al. 2001). There, at a reach some 5 km upstream away from our site, the mean depth of the Rudava channel was 34 cm, the maximum 75 cm. Prevailing types of the bottom substrate were sand (55%) and plant detritus (25.5%), followed by wood (14.5%), roots of riparian trees (3.9%) and hard mud (2.1%).

In the case of both cores R-1 and R-2 the channel bed facies were represented by a mineral material, most probably (coarse) hardened sand, which a Russian peat corer could not have further penetrated. Admixture of sand was palpable in the lowermost samples of both cores. Therefore we suggest the radiocarbon-dated samples from the bottom of profiles are as closest as possible to the exact date of palaeochannel abandonment. Radiocarbon datings show the meander could have been cut-off naturally between 1766 and 1843. This corresponds to the suggestion that local floodplain forest might had already been felled once before the establishment of a current forest (in 1916). On the other hand, its possible dating back to the late 17th Century (sometime after 1672) cannot be wholly ruled out. However, if also the results of the palaeoecological analysis – vegetative succession and land use changes are taken into account, we are inclined to date meander abandonment in the 18th Century, anyway in the first half of the 19th Century at the latest.

Past meandering of the Rudava river, fluvial landform evolution and abandonment

Historical maps overlay illustrate the relatively slow development of the Rudava meanders at this stretch over the past 126 years. Hypothetically, this is mainly due to a quite balanced river discharge. The prevailing trend of channel evolution has been unilateral bend rotation (translation) downstream (Fig. 8). The current active Rudava meander already existed back in 1897, and since then, its outer bank has only shifted a few meters. Based on this, it is assumed even the very evolution of PM preceding its abandonment may have lasted a relatively long period, at least dozens of years, even with the contribution of springwaters. By cutting off the meander loop channel of Rudava, it became shortened from 200 to 25 m.

Interaction of fluvial and slope processes and impact of springwaters

One of the most important controlling factors of cut-bluff development along the Middle Rudava stretch is the presence of local springwaters.

Despite their relatively small thickness, a large extent of eolian sands in the central part of the Bor Lowland allows a larger accumulation of groundwater to be produced. In eolian sediments, groundwater moves towards a relative erosion base, and its flow is comparatively rapid. This hydrogeological structure is exclusively supplemented by rainwater. The groundwater level is free and moves at a certain depth below the surface (from 1.0 – 14.5 m, – Fordinál et al. 2012b). Since the erosional base in this region is the Rudava, passing through the territory of Quaternary windblown sands, rainfall waters drain into this stream either by a system of springs or by obscured inputs and direct seepage of the groundwater.

Fig. 8. Rudava River position in 1897, georeferred map projected into the underlying present-day DEM

A number of springs do exist alongside a river stretch between municipalities of Veľké Leváre and Studienka where a study site is located. Some of them have a discharge of up to 12 $l.s^{-1}$. There are in total 4 important spring-fed spots on the 1.5 km long stretch between the study site and the Tančibok settlement. Exits of springs have also resulted in the creation of marked landforms – isolated valleys that partly cut across Rudava terraces. Such a valley opposite to Tančibok settlement (river km 14.6) is distinctly carved and 340 m long (Fig. 1). Spring-fed areas *Teplica* and *Minor Teplica* had been thoroughly delineated as early as in 1897 (Figs. 4A and 8). The first of the two was collected in the 1960s and its surroundings has been technically adjusted. The mean discharge of this spring (today referred to as *Teplička*) was 4.64 l.s-1 between 1985 – 1999, according to Slovak Hydrometeorological Institute records. The original shape of this spring area can be judged by the Minor Teplica spring-fed area. Nowadays, it represents an interesting landform, creating principal and slowly expanding secondary incipient valleys. Also, direct seepage into the Rudava is relatively large. For instance, ~ a kilometre-long stretch next to a Tančibok has a total increment of 50 $l.s^{-1}$ (Fordinál et al. 2012b). A transversal fault to cross the main Rudava fault in this region (Fig. 1) may have determined this concentration of local springs.

The presence of springwaters may have had essential importance in both the triggering and continuation of slope erosion. Pre-wetting is the most essential weakening mechanism before grains entrainment at a higher flow stage (cf. Fryirs, Brierley 2013). The influence of springs is possibly one of the controls of both meander evolution and preservation of marshy habitats and is also evident in additional PMs along the Rudava river.

Taphonomy of the macrofossil spectra

It is assumed that in the case of river floodplains where periods of erosion and accumulation may alternate in both time and space, there is a pertinent question of to what extent the studied profiles may have been disturbed and influenced by the accumulation of flood material. Therefore, the deposition of both pollen and macrofossils may complicate the interpretation of the palaeoecological record. However, there are already numerous examples of coherent floodplain diagrams to suggest that this is not an insurmountable problem in most cases (cf. Pokorný et al. 2000). As to macrofossils, even the oxbow profiles in the vicinity of archaeological sites (e. g. medieval strongholds) are usually dominated by autochthonous water and littoral plants thus reflecting predominantly local conditions and plant succession. Nevertheless, some plant macrofossils are typically present in respective macrofossil zones related to the periods of foundation and existence of strongholds/settlements recorded by archaeological methods. They represent a component reflecting local ruderalisation or direct human impact in the vicinity of oxbows; some of them may have been brought in by running water and have an extra-local origin (Kozáková et al. 2014, Látková and Hajnalová 2014).

This is also a case of our studied profiles R-1 and R-2. Both were probably early on periodically influenced by overbank floods (charcoal record), although the admixture of sand grains was only visible in the lowermost part of detritus gyttja (Tab. 3). Therefore, human impact clearly seen in the macrofossil zones MZ-1 and partially MZ-2, as well also in our case, reflects the original conditions of the valley floor next to the PM over a specific time period (at the time of its abandonment and some decades later) and can be directly confronted with the depictions from historical maps. Even though macrofossil analysis is time-consuming, two cores for macrofossil evidence proved to be extremely useful. Despite small thickness and possible bioturbation, either core provided a coherent palaeorecord showing not only variability in local conditions and a different pace of succession, but they also complement each other well. Multiple cores are essential in plant-macrofossil ana-lysis for the reconstruction of lake-level changes (Hannon and Gaillard 1997).

As for species composition, it can be optimally compared to an unpublished report of A. Potůčková (Databáze rostlinných makrozbytků ...2023) from the location "Holbičky" which is only 2.7 km away from our study site. There, a palaeorecord from a swamp possibly at the former Rudava palaeochannel from the Subatlantic period (based on 6 radiocarbon data) contained in total 253 plant macrofossils belonging to 43 species of mostly wet-tolerant and littoral species, similar in composition to our findings. The set contained some isolated seeds, indirectly indicating the possible presence of humans in the floodplain (*Fallopia convolvulus*, *Ajuga reptans*, *Carex panicea*, *Solanum nigrum*). However, in our case, macrofossil assemblage – similar as in Kozáková et al. (2014) – already reflects a direct human action and even the presence of cultivated fields (seeds of *Panicum miliaceum*, *Cannabis sativa*, *Polycnemum arvense*, *Portulaca oleracea* etc.). There are also additional pollen and macrofossil data representing past dune and wetland vegetation available from the upper Rudava basin. However, they come from two dune slacks dated to the Late Glacial (Hájková et al. 2015).

For this study, we have not submitted a "classical" macrofossil diagram (which will be published elsewhere). Instead, for a more illustrative interpretation of plant macrofossil data, we have mainly used ecogroups based on modern vegetation or habitat types (cf. Birks 2014) of the Rudava River valley. It optimally corresponds to a geographical viewpoint, particularly for direct visual comparison of reconstructed habitats with information from historical maps.

Reconstruction of local vegetation and alluvial landuse in the 17th – 20th century

Synthesis of hydropedologic, palaecological data and knowledge of present-day vegetation allows us to present a hypothetical evolution of local alluvial vegetation within a landform under study, partially of the proximal floodplain. There were two different successional pathways of vegetation: 1. in an abandoned palaeochannel itself (hydroseral succession) and 2. in the core area of PM (terrestrial pathway).

1. According to palaeodata from the macrofossil zone MZ – 1 (either core) representing a base of sedimentary profiles (late 17th Century – first half of the 18th Century), the alluvial plain of the Rudava in contact with a palaeochannel in the time of its abandonment was markedly open and anthropogenically affected (Fig. 9A). The river floodplain then was most probably grazed by cattle and/or parts may have also been used for damp hay meadows. Isolated single ancient trees (oak, elm, alder) were possibly scattered across these grasslands. The channel of the Rudava was flanked on either side by Black Alder trees. This situation is in good accord with a map depiction of the first Military survey (1782 – 1784), and also, in turn, it supports a dating of PM into the 18th Century at the latest. Back then, ~ 1 km away upstream of the site already existed a brick house and a mill (perhaps along with some additional outhouses), possibly with patches of arable lands nearby. Seeds of plants coming from these ruderal sites and/or paddies located on alluvium or toeslopes were delivered into a palaeorecord even sometime after meander cutoff (carried by running water or via zoochory etc.).

2. Upon abandonment of the meander loop, the area under study became separated on the left bank from the still grazed "mainland", or at least grazing pressure and trampling dropped significantly, allowing for a secondary plant succession (Fig. 9B). This was combined with ongoing geomorphic changes. Local georelief was reworked by two antagonistic factors: on one side, post-abandonment slope processes (sheetwash, sand sliding into the palaeochannel) and on the other side – action of a spring outlet in mid-paleochannel (retarding of both deposition and succession by entrainment and erosion of sand particles). Thus, both natural succession and depositional processes were unevenly distributed across the studied landform.

2. A. When a new Rudava channel originated from a meander cutoff, we suggest sand deposits relatively quickly infilled the 60 – 70 m section of the former channel close to its upper inlet (*sand plugs*). Despite the slopes of a still active cutbluff possibly already being partially vegetated, a sandy material may have still easily moved to the toeslope and into a palaeochannel, thus contributing to palaeochannel obliteration (as it can be seen elsewhere in the Rudava). These postgenous accumulations are clearly visible on DEM. This is why along this section an open waterbody quickly disappeared, and a shallow channel was probably intensively overgrown by marsh vegetation (including *Scirpus sylvaticus*, *Carex elongata*, *Juncus* sp., *Cyperus fuscus*, *Polygonum* cf. *hydropiper*, *Carex brizoides* etc.) and tree seedlings, mainly of alder (*Alnus glutinosa*), due to the low-lying groundwater.

2. B. Along the western section of palaeomeander, the terrestrialisation proceeded at a relatively slower pace, thanks the presence of a local spring. Here, a permanent water flow (with a discharge of several litres per second) could at least partly remove sliding material. In this section of the palaeochannel, the open waterbody persisted for a longer time, reaching a depth of up to 50 cm (core R-2). Better conditions favoured the survival of a wider range of marsh species (mainly *Carex acutiformis*, *C. elongata*, *C. pseudocyperus* and other sedges), but even some water and littoral species (*Myriophyllum verticillatum*, *Alisma* sp., *Oenanthe aquatica*, *Bidens* cf. *cernuus*). However, also this lake was infilled with detritus from dead plants over time. With a presence of spring-fed there areas is unequivocally an associated occurrence of *Carex remota*, and hemicryptophyte *Cardamine amara*, but also vulnerable *Berula erecta* with its characteristic community (relevée no. 5, Fig. 6D).

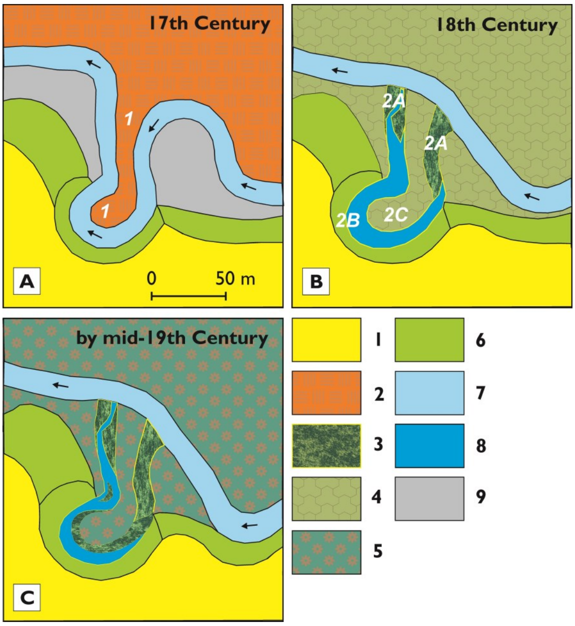

Fig. 9. Schematic stage evolution model of habitats in and around PM

Explanation notes: 1 – closed Scots Pine planted woodlands; 2 – open grasslands, in places ruderalised, with scattered solitary trees; 3 – swamp and incipient woodland (mainly Black Alder), 4 – former grassland, being colonised by trees (birch, pine, lime, elm, maple, hornbeam); 5 – full-blown hardwood floodplain forest; 6 – slopes of eolian pseudoterrace, partially forested; 7 – Rudava active channel; 8 – oxbow lake, fed by springwaters; 9 – vegetation cover unclear.

2. C. Succession within the interior of the former point bar and meander neck. This area was gradually reforested, as well. The first tree to occupy a former grassland was Black Alder, but it was certainly followed by additional taxa, possibly including a birch. Pioneer birch trees may have originated from wind-dispersed seeds of trees which had been growing on adjacent slopes or pine woods edges. Birch seeds have been documented in both cores (second most common tree species after alder). Mature birch trees later produced seeds until they reached a physical age or had been overshadowed by a "climax" trees of alluvial hardwood (elm, lime, hornbeam etc.).

As to a succession of the *ground layer in a former pasture* within a PM, *Carex brizoides* may have played an important role. This is evidenced by its until today relatively high proportion in both forest relevées (1 and 2). *C. brizoides* is originally a forest sedge of less dense alder woods and oak woods. In past decades, this species has been reported to massively expand into wet meadows after mowing / pasture being over, e. g., in the Czech Republic. In a relatively short time of a few years, thanks to rhizomes' vegetative reproduction, it can form a dominant community and become a resilient and competitive plant edificator able to affect even the edaphic environment (Blažková 2010). The species was also evidenced by our palaeorecord (profile 2), even though only by a single achene (sample from core R-2, 40 – 45 cm). This is easy to understand since *C. brizoides* remains sterile under shade, and it mainly reproduces itself vegetatively.

By the mid-19th century, not only at the cutoff area but also over the whole right -bank floodplain, a closed woodland arose with lime, sycamore maple, hornbeam and elm (Fig. 9C). Forested alluvium is clearly seen on the map sheet of IInd military mapping (n. 2 in the checklist). The succession of hardwood alluvial forest of Rudava type still goes on within the former meander point bar (relevée no. 2).

3. The third – ultimate – stage in the studied area's evolution comprises the latter half of the 19th and 20th centuries until the present. Over this period even a shallow lake in the lower part of a palaeochannel underwent complete terrestrial conversion and the status of marsh phytocoenoses became close to the current one. In the 1910s, floodplain forest in PM was logged, and a new one mostly originated from natural regeneration, and partially was planted. A mature forest existing prior to WWI is still evidenced by thick coppiced alders (Fig. 6A). According to F-GIS data, the current forest stand was established in 1916, and its rotation age is scheduled for 150 years, which would represent – concerning interests of the Nature Conservation – the longest physical age in its history. Presently it is evaluated as a well preserved "old-growth forest" with unique heterogeneity of habitats. With time, several typical ground-layer species – *Allium ursinum*, *Ficaria bulbifera*, *Moehringia trinervia*, *Stachys sylvatica*, *Pulmonaria officinalis*, *Galeobdolon luteum*, *Aegopodium podagraria*, *Alliaria officinalis*, *Festuca gigantea*, *Melica* sp., *Geum urbanum* gradually became a part of hardwood vegetation. Ultimately, some neophytic species have penetrated this woodland, which are currently considered to be naturalised – *Impatiens parviflora*, *Parietaria officinalis*. In the near future yet additional taxa are anticipated to occur here, which are presently invading adjacent Scots Pine monocultures (e. g. *Phytolacca americana*, *Prunus serotina*).

CONCLUSION

In this paper, we have used complex analyses of historical maps, lidar data, geomorphological mapping, vegetation survey and palaeoecological reconstruction coupled with dating methods for understanding channel and floodplain development. We have focused on the abandoned palaeomeander and related cut-bluff of the Rudava River to identify morphological and vegetation changes of a floodplain landscape in the long-term.

Semi-circled cut-bluffs (wagrams) are commonly found on either side of the river valley along its middle reach. They have been triggered by the meandering river when in contact with both lower terraces and the Late Glacial aeolian pseudoterrace. The studied left-bank PM and cut-bluff at river kilometre 13.2 is one of the best evolved and, until today, well-preserved landforms of this kind. According to our findings, the PM was probably cut off naturally in the 18th Century (or perhaps back in the late 17th Century).

Palaeobotanical record of two cores from palaeomeander sedimentary infill has been coupled with a survey of a current vegetation. They provided us with a detailed picture of a hydroseral succession at the former channel and a knowledge of the evolution of a wider adjacent river reach. In this study, plant-macrofossil diagrams based on ecological groups (analogues of modern vegetation) allowed reconstructed habitats to be directly compared with information retrieved from historical maps. Besides prevailing marsh species typical of a local alder carr we have also evidenced seeds of grassland plants and synanthropic species (up to almost 10 % out of the total number; particularly in core R-2). This allochthonous component in palaeorecord comes from a proximal floodplain which, in the time of meander cutoff and for some time later, must have been covered in open grasslands. They were grazed or used as alluvial hay meadows. Some of the seeds belonging to species typical of human-affected and ruderal sites may have even come directly from alluvial / slope paddies (including *Cannabis sativa*, *Panicum miliaceum*), located near the premises of a brickyard and game's keeper lodge short distance upstream. Palaeobotanical data are in good accord with depictions of the earliest 18th and 19th-century maps. They also show a current hardwood floodplain forest of high conservation value resembling an "old-growth forest" (Poľovnícky les) that has only originated upon the decline of pasture along this reach (by the mid-19th Century). Once this early wood had been first logged (around 1916), a present-day forest stand was established mainly by natural and partially also by artificial regeneration.

In the Rudava river, large woody debris appears to play an important role in the variability of in-channel forms and new meander initiation. However, further evolution of wagrams is also possibly controlled by numerous springs and seepage. This is also a case of a PM under study where a local spring still affects the gradient of groundwater, and heterogeneity of local soils, forest and marshy habitats, respectively. Concurrently, it also contributes to the conservation of the original landform. The studied PM and wagram may also provide relevant benchmarks for comparison, study and dating of additional fluvial landforms of this kind along the Rudava river.

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Peter P i š ú t, Juraj P r o c h á z k a, Eva U h e r č í k o v á, Igor M a t e č n ý, Adam R u s i n k o, Tomáš Č e j k a

PALEOMEANDER RIEKY RUDAVY (JZ SLOVENSKO) Z 18. STOROČIA – KĽÚČ K POZNANIU VÝVOJA ALUVIÁLNEJ KRAJINY A VEGETÁCIE

V príspevku predstavujeme inovatívny interdisciplinárny prístup k rekonštrukcii zaniknutých mokradných biotopov a historického využívania riečnej krajiny Záhoria. Predmetom štúdie je odstavený palaeomeander (ďalej PM) rieky Rudavy (Borská nížina, JZ Slovensko). Táto na svojom strednom toku prechádza územím kvartérnych eolických pieskov so súvislými hospodárskymi porastami borovice lesnej (*Pinus sylvestris*). Na okraji oboch strán riečnej doliny sa nachádza celý rad špecifických krajinných foriem – polkruhovitých zárezov (wagramy). Sú výsledkom interakcie meandrujúcej rieky nielen s nízkymi pleistocénnymi terasami, ale aj vyššími pseudoterasami pieskových dún, formovaných tiež synchrónnymi a postgénnymi svahovými procesmi. Najlepšie vyvinutou a podnes zachovanou krajinnou formou tohto typu je ľavobrežný PM a wagram neďaleko vodného zdroja Tepličkа (riečny kilometer 13,2). Paleoekologická štúdia výplne tohto odstaveného riečneho PM (dva profily R-1 a R-2) v kombinácii s využitím DTM na báze LiDARu, AMS rádiouhlíkovým datovaním prírodnín z bázy profilov (3 vzorky), analýzou údajov historických máp, ako aj detailným prieskumom súčasnej vegetácie odstaveného fragmentu alúvia (7 fytocenologických zápisov) ukázala, že meander bol s najväčšou pravdepodobnosťou odrezaný prirodzenou cestou niekedy v 18. storočí (prípadne ešte koncom 17. storočia). Zodpovedá tomu aj súčasný stav klimaxových geobiocenóz a zotretia pôvodnej krajinnej formy. Vďaka hydrologickým parametrom je dynamika zmien koryta Rudavy na jej strednom toku pomerne malá.

Na základe celkove 1 443 determinovaných semien a ďalších eko- aj artefaktov (schránky Mollusca, fragmenty hmyzu, kokóny *Annelida/Turbellaria*, uhlíky a i.) získaných výplavom vzoriek sedimentárnej výplne bývalého koryta (2 vrty) bolo možné rekonštruovať sukcesiu hydrosérie na dne bývalého meandra. Celkove najmenej 72 identifikovaných druhov rastlín (z toho napr. 7 druhov drevín a 2 nanofanerofyty) bolo zatriedených podľa svojich ekologických nárokov do niektorej z 8 ekologických skupín. Hoci v profiloch prevládali močiarne druhy asociácie *Carici elongatae – Alnetum glutinosae* a *Carici acutiformis – Alnetum glutinosae*), zazemňovanie prebiehalo s miestnymi odlišnosťami. Druhovo i početne bol bohatší profil R-2 (hĺbka 50 cm), najmä jeho spodná časť. V tejto časti PM sa aj historicky najdlhšie udržala plytká vodná plocha, dokonca s doloženými hydrofytmi (napr. *Myriophyllum verticillatum*, *Oenanthe aquatica*), početnými litorálnymi druhmi najmä z čelade šachorovitých (Cyperaceae) a ďalších rastlín, ktoré sa dnes v študovanom fragmente alúvia už vôbec nevyskytujú.

V spodnej časti oboch profilov, najmä R-2, hoci v menšej miere, boli navyše doložené aj semená rastlín lúk, pasienkov (6,8 %) a ruderálnych stanovíšť (2,8 % celkového počtu). Tieto jednoznačne dokumentujú, že v čase odstavenia meandra ešte priľahlé alúvium nepokrýval lužný les, ale trvalé trávne porasty otvorenej krajiny, azda so solitérmi starých stromov, prepásané dobytkom (kravy, ovce a kone), prípadne využívané aj ako lúky na seno (druhy *Hypericum tetrapterum*, *H. maculatum*, *Lychnis flos-cuculi*, *Mentha longifolia*, *Linum catharticum* atď.). Doložili sme aj celý rad semien druhov pochádzajúcich z antropicky ovplyvňovaných a ruderálnych biotopov, prípadne priamo políčok na alúviu alebo svahoch (vrátane *Cannabis sativa*, *Panicum miliaceum*), zrejme z okolia tehelne a neskoršej horárne Tančibok. Paleobotanické údaje sú v dobrej zhode so zákresmi najstarších máp z 18. a 19. storočia. Ukazujú taktiež, že súčasný, ochranársky veľmi cenný lužný les pralesovitého charakteru (Poľovnícky les; spoločenstvo asociácie *Ficario vernae-Ulmetum campestris*) je sekundárneho pôvodu. Sformoval sa až po ukončení pastvy na tomto úseku (najneskôr v prvej polovici 19. storočia). Dnešný porast vznikol najmä prirodzenou, sčasti zrejme aj jeho umelou obnovou v roku 1916.

Dôležitú úlohu pri variabilite vnútrokorytových foriem a iniciácií nových zákrut rieky zohrávajú veľké kusy dreva (LWD) pochádzajúce výlučne z brehových porastov *in situ*. Vývoj polkruhovitých wagramov pozdĺž južného okraja riečnej doliny Rudavy však ovplyvňujú aj početné pramene a priesaky podzemných vôd. Dokladá to práve aj študovaná lokalita, kde takýto miestny prameň, odtekajúci dnes dolnou polovicou PM do Rudavy, mohol významne ovplyvniť už nielen samotné zarezávanie sa meandra do pseudoterasy, ale podnes determinuje aj gradient podzemných vôd, variabilitu pôdnej pokrývky i lesných a močiarnych biotopov (napr. prítomnosť asoc. *Cardamino – Beruletum erecti*). Zároveň prispieva ku konzervovaniu pôvodnej riečnej formy, keďže vodný prúd s prietokom niekoľkých litrov vody za sekundu strháva aj častice piesku, ktoré sa za prispenia lesnej zveri zosúvajú po svahu do bývalého koryta. Výskum PM a wagramu Teplička taktiež poskytuje dôležité porovnávacie a východiskové údaje pre štúdium a datovanie ďalších riečnych foriem tohto typu.

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