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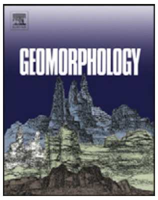

Late Holocene fluvial activity and correlations with dendrochronology of subfossil trunks: Case studies of northeastern Romania

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ABSTRACT

The main objective of this paper is to describe the late Holocene behaviour of rivers using an interdisciplinary approach combining fluvial geomorphology and subfossil trunk dendrochronology. The subfossil wood material collected along the rivers was investigated for dendrometric and dendrochronologic parameters. The research methods in these fields helped us to understand the effect of the fluvial environment on riparian trees and their records and helped in reconstructing the riparian palaeoenvironment.

The study area consists of two rivers with different typologies but comparable sizes: the Moldova River, which features a braided to wandering channel in its lower reach, and the Siret River, which features a sinuous-meandering channel. Along the 100-km-long floodplain of the former and the 144-km-long floodplain of the latter, we found and sampled 77 subfossil trunks, of which 26 were subjected to ^{14}C dating. The resulting data consist of floodplain facies mapping data, electric resistivity measurements, absolute dates, and dendrometric and dendrochronologic data. The results indicate that during a 100-year period, the two rivers were sensitive to climate change and anthropogenic effects, particularly a narrowing of the active channel by 76% in the braided channel and 38% in the sinuous-meandering channel. During the past 3300–3000 YBP, the Moldova River maintained its braided style, whereas the sinuous-meandering style has been characteristic of the Siret River for the previous 6800–4600 YBP. The two distinct fluvial environments are recorded in the dendrometric structure of the trunks buried in the channel-fill sediments. The braided fluvial environment was more effective in uprooting riparian trees and incorporating them in the floodplain deposits, whereas the sinuous-meandering style of stream effectively buried tree trunks in lateral accretion lobes. Absolute and dendrochronologic dating allowed for the reconstruction of timelines of the felling of the trees and estimates of the magnitude of the responsible hydrological event. The flood events on the Siret River with a recurrence interval of 200 years (Q_{max} ~ 2500–2800 m^3/s) were those most effective in destroying riparian forests, and the events on the Moldova floods with a 100-year recurrence interval (Q_{max} ~ 1200–1400 m^3/s) were the most effective. Dendrochronology allowed for identification of wet phases (i.e., 3500–2900 YBP, 2200–2075 YBP, and 1000–800 YBP) and dry phases (e.g., 3200–3150 or 2775–2700 YBP, 1400 YBP). Finally, we draw attention to the potential for creating a highly replicable dendrochronological series spanning at least 7000 YBP.

1. Introduction

The rivers of eastern Romanian came to the attention of geomorphological researchers owing to the palaeogeomorphological significance of their longitudinal profiles (Rădoane et al., 2003; Dumitriu, 2007; Cristea, 2011; Molin et al., 2012) and the adjustments of their contemporary channels (Ichim and Rădoane, 1990; Rădoane et al., 2008a,b; Chiriloaei, 2012; Rădoane et al., 2013). However, the study of river behaviour during the Holocene has received relatively little attention in this part of Europe. Nonetheless, some data regarding the type and structure of fluvial deposits and palaeochannel detection and dating have been gathered (Ichim et al., 1989; Ghenea and Mihailescu, 1991; Necea et al., 2013; Kiss et al., 2014), and several attempts were made to determine the streamflow discharge through palaeochannels to understand the behaviour of these rivers during the late Holocene (Howard et al., 2004; Feier, 2010; Nádor et al., 2011). The recent undercutting of river channel banks because of elevated rates of channel incision (Rădoane et al., 2013) and the presence of subfossil tree trunks in various fluvial sedimentary deposits (Chiriloaei et al., 2012) raised interest in deciphering the past fluvial activity of these rivers. The use of so-called black oaks buried in alluvium to date sedimentary sequences has caused controversy. The

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method, which has been used to date alluvium based exclusively on single trunks or single generations thereof has usually led to erroneous results because the majority of such trunks were redeposited (Kalicki and Krąpiec, 1995, 1996). However, certain shortcomings can now be eliminated during the sampling; for example, trunks with bark, sapwood, and branches can be selected.

The majority of investigations based on subfossil trunks in fluvial geomorphology were conducted in Poland. Radiocarbon dating and tree-ring chronologies of subfossil trunks in alluvial sediments enabled the dating of alluvial fills and the correlation of phases of heightened river activity with stages of intense human impact in valley systems of the Upper Vistula and Upper Dniester River catchments (Krąpiec, 1996). Similar cases have been investigated in detail in the Upper Vistula River catchment, Czarna Nida River valleys in the Eastern Carpathian Foreland, and the tributaries of the Siret and Prut rivers in the Bukovyna Carpathian Foreland (Starkel, 1981; Kalicki, 1991; Gębica and Krąpiec, 2009; Dzieduszyńska et al., 2011; Gębica, 2011, 2013; Krupa, 2013). The channel and overbank alluvium containing numerous tree trunks indicated aggradation in the Roman Period and the early Middle Ages (Starkel et al., 2009; Gębica et al., 2013). A total of 400 absolutely dated dendrochronological sequences from the previous 3800 years permitted the identification of periods with prevailing seeding and felling of trees on the floodplains, which were interpreted, respectively, as drier periods and more-humid periods characterised by frequent floods (Krąpiec, 1998, 2001). Other regions in Central Europe where subfossil trunks have been used to reconstruct late Holocene floodplain evolution include the Bečva River floodplain (outer Western Carpathians) (Stacke et al., 2014) and several rivers in the Morava drainage basin (Czech Republic) (Kolář and Rybníček, 2011). In Romania, studies on the floodplain evolution and fluvial activity reconstruction have been elaborated for six rivers located in the NW, NE, and S of Romania on the basis of interpretation (among others) of more than 55 subfossil trunks (Lupu and Roman, 1987; Howard et al., 2004; Feier, 2010; Chiriloaei et al., 2012).

The main objective of this study was to conduct an analysis of the behaviour of distinct eastern Romanian rivers during certain periods of the late Holocene and to correlate the data with trends observed on a regional scale in Central and Eastern Europe. Secondary objectives were as follows: (i) characterising recent (i.e., the previous 100 years) fluvial morphology to reconstruct the evolution of channel styles during the late Holocene; (ii) attempting to reconstruct palaeodischarge values of the rivers and their relations with those of neighbouring geographic areas; (iii) performing dendrometric and dendrochronological analyses of subfossil trunks to determine their environment of origin and the fluvial-sedimentologic context in which they were deposited; (iv) identifying dry and wet periods based on the average growth of dated subfossil trunks; and (v) identifying major river pattern changes.

2. Study area and methods

We selected two representative reaches along two major rivers of eastern Romania: the Siret River and its right-bank tributary, the Moldova River (Table 1). Both rivers originate in the Eastern Carpathian Mountains, which are underlain by quasi-parallel, southward-trending exposures of crystalline rocks and Mesozoic limestone and flysch, where the majority of the river tributaries flow. The rivers cross the eastern part of the mountain range through transverse valleys. After exiting the mountains, they flow SSE and join near the city of Roman (Fig. 1).

The two rivers are similar in terms of streamflow discharge and suspended sediment load (although the Siret River drainage basin is more than 1600 km^2 larger than the Moldova River basin). The channel types of the two selected reaches differ. The Siret River channel is meandering-sinuous, whereas the Moldova River channel is braided. Both channels are semiconfined within the study reaches, confinement (cf. Brierley and Fryirs, 2005) ranges from 35 to 40% higher on the Siret caused by the contact with the Moldavian Plateau and high terrace scarps. Moreover, the Siret Valley is a NW–SE-oriented corridor, in which the floodplain allows for only limited lateral migration of the channel.

The dynamic nature of these two river channels during the previous decades and the extensive gravel mining resulted in the exposure of numerous tree trunks. Table 2 lists the locations and ages of subfossil trunks and the depositional context in which they were located. The specimens for dating and dendrochronological investigations were carefully selected to ensure that trunk redeposition was minimal in these cases (Fig. 2). The contraindications of redeposition included the presence of bark and/or sapwood, the presence of branch and root fragments, and position in the deposit (Kalicki and Krąpiec, 1995).

The two rivers were investigated in several field campaigns between 2011 and 2013, during which multiple elements were mapped: river banks, current and palaeochannel paths, width of the channel migration belt, types of riparian vegetation, and the effects of damming and other construction works, such as bridges and water intakes. The sedimentary structure of the banks was mapped, terrain profiles were surveyed, and samples were collected for grain size analyses. In instances where the continuity of sedimentation was uncertain, we also collected samples for OSL dating (i.e., Liteni site). At certain sampling sites (such as Timisesti and Tupilati on the Moldova River and Liteni on the Siret River; cf. Fig. 1), our interpretations of subfossil trunk data were supported by resistivity measurements (electrical ground imaging, ERGI), which helped provide a better understanding of the lithology and geometry of buried sedimentary structures. The electrical resistivity tomography (ERT) interpretations were supported by boreholes ($n = 200$, cf. Chiriloaei et al., 2012), analysis of recent bank exposures and absolute dating of subfossil trunks (LSC) or fluvial sediments (OSL). The ERT profiles presented in this paper consist of a modelled cross-sectional (two-dimensional) plot of resistivity ($\Omega \cdot \text{m}$) versus depth (Fig. 11).

Thus, we obtained a general overview of the positions and ages of subfossil trunks along the rivers (Table 2). The ages of the subfossil trunks do not exceed 6900 YBP, but they mostly exceed 3000 YBP. The wood samples were dated using the liquid scintillation counting (LSC) method (http://www.carbon14.pl/c14lab/index.htm) at the Radiocarbon Laboratory at the Institute of Physics of the Silesian University of Technology in Gliwice, Poland (Laboratory Report No. 49/2013). Radiocarbon dates were calibrated using the OxCal 4.2.3 calibration program (Bronk Ramsey et al., 2013) and the IntCal13 calibration curve (Reimer et al., 2013). One modern sample, DH2, was calibrated using the post-bomb atmospheric NH1 calibration curve (Hua et al., 2013). The samples of fluvial sediments (sand/quartz) were dated using optically stimulated luminescence (OSL) by the Luminescence Dating Laboratory (http://www.carbon14.pl/lumdatlab/) Institute of Physics of the Silesian University of Technology in Gliwice, Poland. The samples for

Table 1
Main characteristics of river reaches.

River	Drainage basin area upstream of the study area, A (km^2)	Reach length, L_s (km)	Average channel slope, S (m/km)	Discharge, mean annual, Q (m^3/s)	Discharge, annual maximum, Q_{max} (m^3/s)	Suspended load, mean annual, Q_s (kg/s)	Bed material median diameter, D^{50} (mm)
Siret (between Suceava to Moldova confluence) a left tributary of Danube River	5921	144	0.41	36.8	503	52.9	11.2
Moldova (between Molid to Siret confluence)	4316	110	0.82	32.8	546	35.3	17.0