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Lost in dating – Problems with the absolute chronologies and sedimentation rates of Late Glacial and Early Holocene oxbow lake deposits in Central Europe

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A R T I C L E I N F O

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A B S T R A C T

This article presents potential errors related to the construction of absolute chronologies for Late Glacial and Early Holocene sediments accumulated in oxbow lakes in Central Europe and their influence on palaeoecological reconstruction. Our study is based on two sediment cores: (i) from the San River (Stubno-Nakło site in south-eastern Poland; S-N) and (ii) from the Dniester River (Luka site in western Ukraine) valleys. Accelerator mass spectrometry (AMS) ^{14}C dating was performed on terrestrial plant macrofossils from each site to produce Bayesian age–depth models and to calculate sedimentation rates (SRs). The SR in both sites was characterised by high variability reflecting the developmental stage of oxbow lake. The highest SR values (1.18–1.23 cm yr^{-1}) were identified at the S-N site at the beginning of the Holocene (ca. 11,550–11,470 cal. BP) and related to enhanced overbank deposition. The lowest SR values (0.01–0.02 cm yr^{-1}) were identified in the transitional layer between the Younger Dryas and the Preboreal chronozone (ca. 11,810–11,160 cal. BP) in the Luka profile; this may have been related to the sedimentary gap(s) caused by falls in the water table and/or temporary desiccation of the water body. Moreover, our study revealed the presence of three distinctly aged AMS ^{14}C dates in the Younger Dryas section of the Luka profile. These radiocarbon inversions were completely undetected by pollen analysis, which indicated the domination of *Pinus* and *Betula* without any significant fluctuations throughout the entire subsection. The presence of such 'cryptic' insertions of older material could lead to erroneous palaeoenvironmental reconstruction. Similarly the S-N site revealed anomalously 'aged' dates which were also difficult to detect by pollen analysis.

1. Introduction

Palaeoecology is a scientific branch of ecology concerned with the reconstruction of past ecosystems (Birks and Birks, 1980)

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providing an understanding of the functioning of ecosystems over longer time scales. It can facilitate the study of ongoing as well as future environmental changes more precisely (Seddon et al., 2014). However, to obtain a reliable reconstruction of past environments, an absolute chronology is vital as it provides information on the timing of processes and therefore their dynamics.

Lacustrine sediments and different kinds of peat can provide valuable palaeoecological archives that preserve information regarding environmental changes in several biotic and abiotic proxies (e.g., Birks and Birks, 1980). The most widespread method of the establishing the age of this type of deposits, if the last 50,000 years is considered, is ^{14}C dating (Jull, 2013a). However, radiocarbon dating is strongly dependent on the provenance of organic carbon incorporated in deposits. Hence, dating bulk deposits is encumbered by a risk of obtaining a false age signature due to the presence of different types of contaminations. The most common contaminants include: (i) old carbonates dissolved in water from older beds/sediments, which may be redeposited in younger layers or incorporated as ions by aquatic plants, thereby contributing to the ageing of the ^{14}C signatures of sediment layers; (ii) plant rootlets that overgrow deposits and cause age rejuvenation and (iii) redeposition generated by different types of organisms or surface run-off (Hatté and Jull, 2013). The solution, at least partial, to these problems was the development of accelerated mass spectrometry (AMS), which enables dating of very small samples (Jull, 2013b). Since then, the dating of particular plant macrofossils has become possible which significantly reduce the probability of dating contaminated material (Hatté and Jull, 2013). However, even after carefully selecting a material for dating, there is no guarantee that a good correspondence between the date and the sediment layer can be obtained (e.g., Turney et al., 2000; Kołaczek et al., 2015a, b). Hence, to detect inconsistencies within the age–depth relationship, a series of dates is necessary. In practice, the dense radiocarbon dating of the entire sedimentary sequences is very difficult (or even impossible). Therefore, to obtain a reliable chronology for samples devoid of ^{14}C dates, methods of statistical interpolation are applied (e.g., Bronk Ramsey, 2008; 2009; Blaauw and Christen, 2011). In the case of sediments deposited in an environment characterised by a relatively stable sedimentation rate (SR), such interpolations are not problematic (e.g., Pędziszewska et al., 2015); however, many types of sediments are deposited in a dynamically changing environment, in which sedimentation progressed at different rates with time. Examples of such an environment include oxbow lakes and peatlands found in river valleys where sedimentation is highly influenced by the fluvial activity of the river. Moreover, fluctuations of the water table, often in a decadal scale, can lead to the discontinuities in sedimentation in such ecosystems. Nevertheless this kind of archive is the only source of information regarding long-term changes in the ecosystem in vast areas of sub-Carpathian basins and the lowlands of Central and Eastern (CE) Europe due to the paucity of other natural lakes or ombrotrophic peatlands (e.g., Kołaczek et al., 2016).

In CE European rivers, the Younger Dryas (ca. 12,846–11,653 cal. BP according to Lowe et al., 2008) and the beginning of the Preboreal chronozone were the periods of intense fluvial activity manifested by the cutting of large palaeomeanders and avulsions (Andres et al., 2001; Starkel, 2003, 2011; Starkel et al., 2013; Gębica et al., 2015; Panin and Matlakhova, 2015; Pawłowski et al., 2015; Petera-Zganiacz et al., 2015). These processes may have contributed to a number of phases of the redeposition of older material, from river banks, on younger layers of sediments accumulating in these types of lakes. Hence, dense ^{14}C dating performed by AMS technique may be a better tool to detect such redeposition, thereby validating the quality of such sequences for further palaeoecological reconstructions.

This article discusses limitations associated with the construction of absolute chronologies for deposits spanning the Younger Dryas and Preboreal chronozones that are based on Bayesian age–depth models calculated from multiple ^{14}C dates (7–8 dates for each meter of the profile). Furthermore, it presents the potential influence of some unexpected errors on palaeoecological inferences. The investigated deposits accumulated in two oxbow lakes located in two different broad river valleys in Central Europe (i) the Dniester River and (ii) the San River. The research question addressed in this article is how does the presence of insertions of redeposited material and dating bulk sediments contribute to inaccuracies in the reconstruction of past environmental changes and the dynamics of sediment accumulation?

2. Material and methods

2.1. Geographical setting and criteria of selection of sites

Two terrestrialised oxbow lakes were selected for this study: one is located in the village of Luka (ukr. Лука) on the right bank of the Dniester River (western Ukraine) and the other is located between villages of Stubno and Nakło (abbreviated S-N) on the right bank of the San River valley (south-eastern Poland) (Fig. 1).

The Luka site (core site: 49°11′48.50″N, 24°30′46″E; 226 m a.s.l.) is a rich fen that developed in a former oxbow lake (meander radius: 600 m, channel width: 200 m) on a Late Glacial terrace of the Dniester River (Gębica and Jacyšyn, 2013). This part of the valley, covered by sands, silts and clays (overbank facies), is situated in the Halyč-Bukačivci Basin lying between the Zaliska Plateau (to the south) and the Opillje Upland (to the north), both predominantly covered by loess (Gębica and Jacyšyn, 2013). The S-N site (core site: 49°51′47″N 22°58′08″E; 186.5 m a.s.l.) is the palaeomeander (meander radius: 300 m and channel width: 100 m) located in the San River valley within the Late Glacial flood basin limited to the west by wide natural levees cut by a system of younger palaeomeanders of the San River. The Holocene flood plain of the San River valley in the S-N palaeomeander area reaches a width of 10 km and rises 6–8 m above the river channel (Klimek et al., 1997). The S-N site is located in the eastern part of the Sandomierz Basin, a vast depression that adjoins the Carpathian Mountains to the south.

Both sites were selected as a focus for palaeoecological research to examine the Late Glacial and Early Holocene spread of elm (*Ulmus*) forests in the area north of the Carpathian region. The Luka site is unique in terms of the quality of its pollen preservation for both the period of interest and for the area. The S-N site was preliminarily examined by Klimek et al. (1997), who dated the bottom sediments at 15,200 ± 500 ^{14}C BP, making this palaeomeander the oldest in this part of the San River valley. The detailed results of the palaeoecological studies at these sites are not the subject of this article, but will be discussed elsewhere.

2.2. Field methods and lithology of profiles

Core retrieval at the Luka site was conducted in July 2010 (Harmata et al., 2013), whereas at the S-N site, it was undertaken in September 2014. In both cases, the selection of the core site was preceded by survey coring to identify the maximum thickness of the sediments. At Luka site, the profile (345 cm long) was collected using a Russian-type sampler (chamber dimension: 50 × 7 cm). The sampler failed to reach the bottom of the palaeochannel which was assessed at ca. 4 m after the survey coring using a Hiller sampler (chamber dimension: 50 × 2 cm). From the S-N site two profiles were collected: the first (S-N 1a) was retrieved using a petrol percussion hammer (Ejikelkamp™; gauge in various diameters: range

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