DENDROCHRONOLOGICAL STUDY OF WOODEN CONSTRUCTIONS UNEARTHED FROM A SUBALPINE PEAT BOG FROM MARAMUREŞ MTS., ROMANIA

DENDROKRONOLÓGIAI VIZSGÁLATOK A MÁRAMAROSI-HAVASOK (ROMÁNIA) TERÜLETÉN ELHELYEZKEDŐ SZUBALPESI TŐZEGLÁPBÓL ELŐKERÜLT ÁCSOLT FASZERKEZETEKEN •

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Abstract

Two simple wooden constructions were found in a peat bog, called 'Vinderel 3', located in the Maramureş Mts. (Romania). They were constructed from spruce timber and a 67-year-long floating chronology, called MM8, was developed using the cross-dated tree-ring width series of six samples. An AMS ^{14}C age dates the wood and provides target intervals for dendrochronological cross-dating to the late-18th century and the mid-17th century. Running statistics with the nearby reference chronologies peaked at 1664 CE, suggesting the possible felling date of the timber contributing to MM8. The wooden constructions were likely built soon after the felling date in the early second half of the 17th century CE. We think that the timbered constructions can be installed at the edge of the former lake, on the one hand, to protect the lakeshore from trampling, on the other hand, to protect the drinking livestock from slipping to the swampy peat bog. These wooden constructions, with their inferred likely date to the mid-17th century CE provided the earliest material evidence for the agropastoral activity in the subalpine zone of the Maramureş Mts.

Kivonat

Két egyszerű, lucfenyőből készített faszerkezet került elő a Máramarosi-havasokban (Románia) található "Vinderel 3" nevű tőzeglápból. Az évgyűrűszélesség mintázatok szinkronizálásával hat adatsorból egy 69 évet lefedő átlagos évgyűrűszélesség kronológiát (kódjele: MM8) lehetett létrehozni. Egy AMS ^{14}C adat faanyagot a 18. század végére és a 17. század közepére keltezi, és célintervallumokat biztosít a környező területekről rendelkezésre álló luc referencia-kronológiákkal végrehajtott dendrokronológiai keltezéshez. A közeli referencia-kronológiákkal futóablakban számított t-statisztika a csúcsot Kr. u. 1664-ben érte el, ami a faszerkezetekhez kivágott faanyag lehetséges kivágási időpontját sugallja. A faépítményeket valószínűleg nem sokkal a fák kivágása után, a 17. század második felében készíthették. Úgy gondoljuk, hogy az ácsolt

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faszerkezeteket az egykori tó szélén állíthatták fel, egyrészt a tópart védelmére a taposástól, másrészt annak érdekében, hogy megelőzzék, hogy az ivó állatok a mocsaras tőzeglápba csússzanak. Ezek az ácsolt faszerkezetek, amelyek valószínűsíthetően a Kr. u. 17. század közepére datálhatók, a Máramarosi-havasok szubalpin zónájában folytatott legeltető állattartás legkorábbi tárgyi bizonyítékai.

KEYWORDS: TREE RING, RADIOCARBON, ARCHAEOLOGY, CARPATHIANS, EARLY MODERN AGE

KULCSSZAVAK: ÉVGYŰRŰ, RADIOKARBON, RÉGÉSZET, KÁRPÁTOK, KORA ÚJKOR

Introduction

Wood is an essential raw material used for artefacts and construction for almost half a million years (Barham et al. 2023). Wooden tools for foraging and hunting appeared since ~400 ka in Europe (Aranguren et al. 2018, Thieme 1997). Owing to the environmental conditions, wood is widely used in the material culture of subalpine pastoralism in Europe. Mountain people used wood in the construction of both buildings and tools for everyday usage.

Archaeological research of the alpine/subalpine belt of the Carpathians provided evidence for long-lasting human activity at the high-elevation lands (Andronic & Niculică 2012, Bobînă 2015, Dragoman et al. 2018). The history of alpine/subalpine grazing and its impact on mountain vegetation has been reconstructed in recent decades in the Romanian Carpathians based on information mainly derived from documentary, ethnoarchaeological, and palaeoecological data but direct archaeological material evidence is rare. The documentary evidence of pastoralism in the Romanian Carpathians dates to the 13th century (Idu 1999). However, palaeoecological data (e.g., Feurdean & Willis 2008, Tanţău et al. 2003, Jakab et al. 2023) indicated the appearance of seasonal grazing at high elevation much earlier than the written sources indicate. For instance, alpine grazing on naturally open meadows in the Retezat Mts. (South Carpathians) was very likely as early as 4200 years ago (Vincze et al. 2017). Based on the sedimentary records of two subalpine lakes, (Lake Gropile in the Rodna Mts. and Lake Vinderelu in the Maramureș Mts.) anthropogenic impact became evident 2800 years ago the Eastern Carpathians, when landscape openness, pasturing, and disturbance of soil cover increased and intensified over the last four centuries (Florescu et al. 2024).

One of the last European colonization that affected a nearly intact landscape was the Wallachian colonization of the mountainous parts of the Carpathians by shepherds starting in the 12th to 13th century in the Southern Carpathians (contemporary Romania) and reaching the Western Carpathians during the 16th to 17th century (Štika 2007, Kłapyta 2013, Wistuba et al. 2018).

Ethnoarchaeological (Maxim 1988-1991) sources support the multi-centennial tradition of alpine grazing in the Romanian Carpathians. However, accurate dating of sporadic settlement remains, exploring the historical dimensions of population movements (e.g., the presence or absence of shepherding in pre-medieval and early modern times) suggested by the finds (Bartosiewicz & Greenfield 1999) is necessary.

Dendrochronological analysis of the wooden constructions proved to be an effective tool for evaluating the settlement and building history in many European mountain regions (Büntgen et al. 2006, Opala & Kaczka 2007, Shindo & Giraud 2021). Dendrochronological analysis of abandoned shepherds' buildings in the Polish High Tatras showed that the oldest preserved constructions date back to the 18th century providing direct evidence for the ~250-yr-long tradition of pastoral activity in that particular region (Opala & Kaczka 2007).

This paper presents wooden constructions providing direct material evidence (pastoral wooden structure) of subalpine agropastoral activity in the early modern times in the Maramureș Mts. (Eastern Carpathians). Dendrochronological and radiocarbon data are evaluated to date the timber, estimate the construction period, and infer implications about the agropastoral activity in the subalpine zone of the Maramureș Mts.

Material and methods

Site description and the stratigraphic context of the wooden construction

The study site (1530 m a.s.l., N47°54'11", E24°26'37") was a peat bog, called 'Vinderel 3', located in the Farcău Massif, Maramureș Mts. (Romania). Peat deposits were formed in a landslide concavity ('slope pocket') on the western slope of the Farcău Massif (**Fig. 1**). Currently, the peat bog is surrounded by entirely treeless subalpine pastures (**Fig. 1**) and based on cartographic evidence (Jankó 2007) the study site had been deforested at least since 1859 CE (Árvai et al. 2016).

Subfossil logs were found in large quantities in the peat deposit (Árvai et al. 2016) and seven floating synchronized sets of tree-ring width series, coded from MM1 to MM7, were created from the collect-

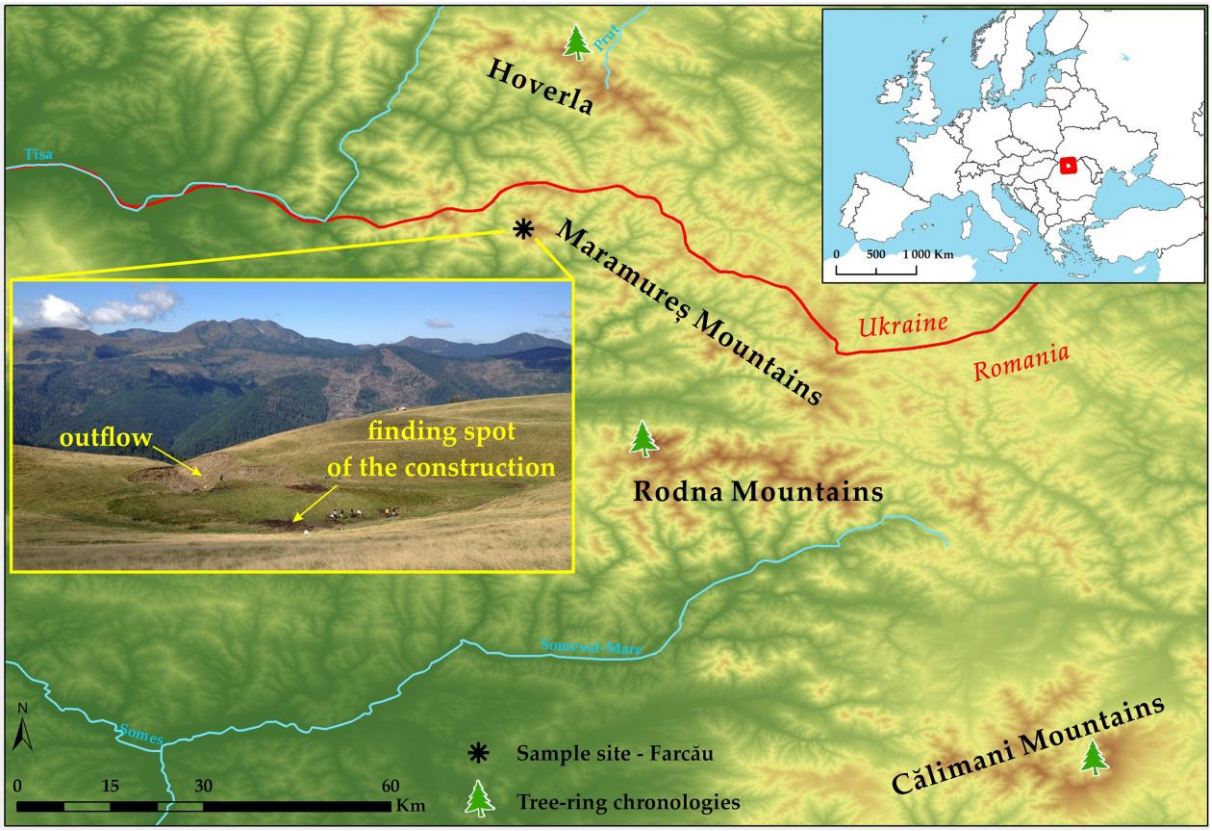

Fig. 1.: Location of the study area. The location of 'Vinderel 3' peat bog is indicated by asterisk on the digital terrain model, while red rectangle in the inset map shows the area zoomed in the main map within Europe. The location of the spruce chronologies available from nearby ranges and used as reference in crossdating trials are marked by the tree symbols. The site photo illustrates the currently treeless surroundings of the peatbog and the position of the outflow of the peatbog and the finding spot of the timbered constructions.

1. ábra: A kutatási terület elhelyezkedése. A "Vinderel 3" tőzegláp helyét csillag jelzi a digitális terepmodellben, míg a kinagyított területet Európán belüli elhelyezkedését a piros téglalap jelöli. A szomszédos hegységekből rendelkezésre álló és a dendrokronológiai szinkronizálási kísérletek során referenciaként használt lucfenyő kronológiák helyét a fenyő szimbólumok jelölik. A helyszíni fotó a tőzegláp jelenleg fátlan környezetét, valamint a tőzegláp kifolyójának és a vizsgált faépítmények lelőhelyét szemlélteti.

ed samples spanning from 47 to 259 years and dated between the 3rd and 11th centuries AD by the aid of ^{14}C analysis (Árvai 2019).

Beside the subfossil logs, two wooden constructions were also excavated from the peat bog between the 3rd and 8th of September 2013. The wooden structures are situated at a relatively shallower depth in the peat deposit compared to the usual occurrence of the subfossil logs. Their finding spot was situated principally opposite the outflow point of the peat bog (**Fig. 1**). Traces of human wood processing were clearly recognizable on the timber structures (**Fig. 2**). The smaller elements were longitudinally halved stakes which were fixed without the use of nails or stables in axe-carved grooves. Cross sections were sawn from three larger logs and three smaller stakes (**Fig. 2**, **Table 1**). Important to note that bark remains were observed on one of the larger elements (MUR032).

The archaeological value of the wooden structures could not be determined, and as their transportation was logistically unsolvable, we placed them back to their original location after sampling. They can be found based on the accurate coordinates above, if further inspection is needed or interesting. This approach agrees with international calls for in situ preservation of dendroarchaeological samples (Creasman 2012).

Xylological and dendrochronological analysis

Cross sections of the dried samples were mechanically sanded with successively finer wood abrasives to expose ring details to the cellular level (Stokes and Smiley 1968) following the sample preparation protocol of the Budapest Tree-Ring Laboratory (Kern et al. 2024). Based on the basic macroscopic xylological features, such as the texture of the tracheids and the earlywood-latewood transition, the samples belonged to the same

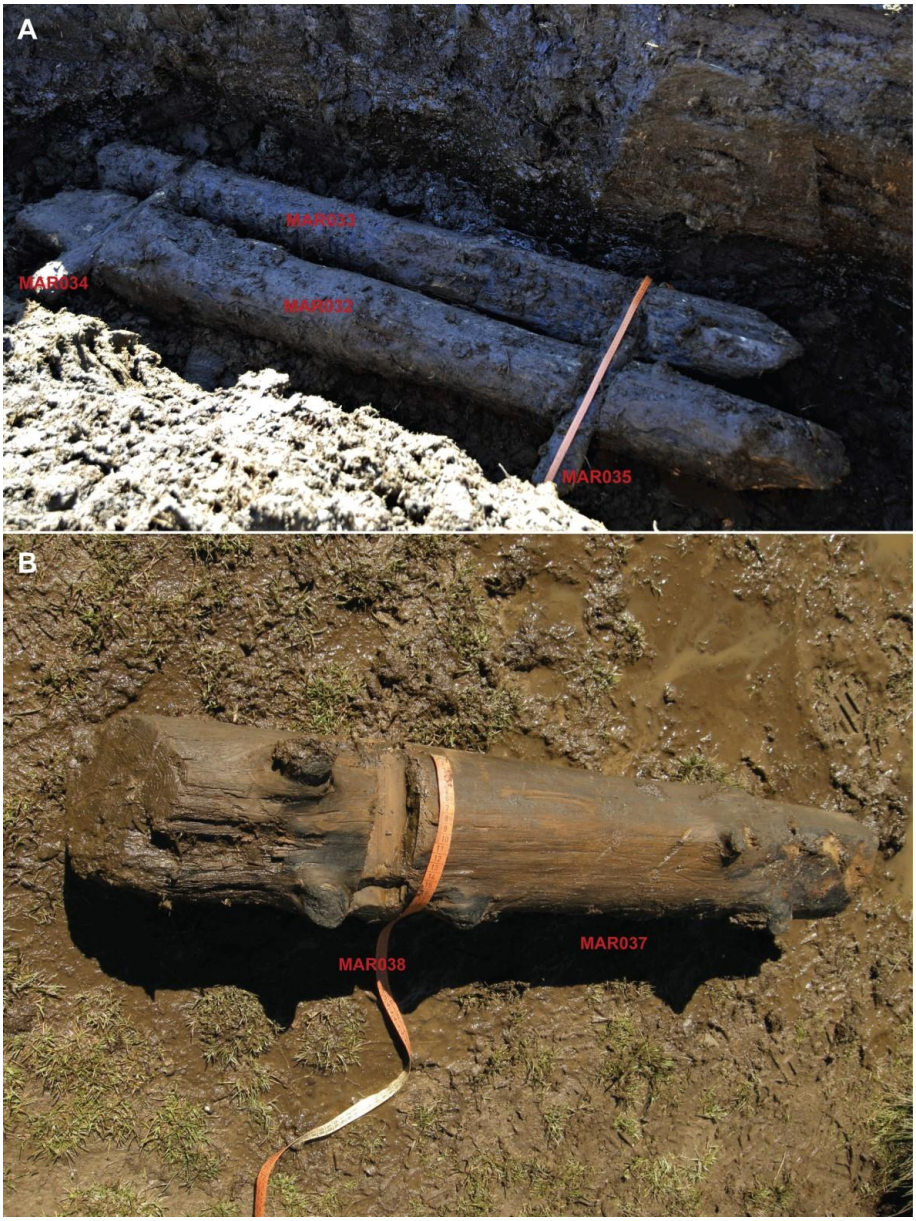

Fig. 2.: Timbered constructions excavated from 'Vinderel 3' peat bog (Maramures Mts., Romania). A: two larger logs fixed parallel along their longitudinal axes with halved stakes. B: A single log with a similarly inserted halved stake fragment.

2. ábra: A 'Vinderel 3' tőzeglápból (Várkő, Máramarosi-havasok, Románia) 2013 szeptemberében kiemelt faszerkezetek. A: két nagyobb rönk, amelyeket hossztengelyük mentén párhuzamosan rögzítettek felezett karókkal. B: egyedi rönk, hasonlóan behelyezett felezett karó töredékével.

Table 1: Synchronized positions and corresponding dendrochronological statistics of the mean annual ring-width chronology of the samples collected from two timbered structures found in the Maramures Mts. and calculated using.

1. táblázat: A Máramarosi-havasokban talált ácsolt faszerkezetekből gyűjtött minták szinkronizált pozíciója és az átlagos évgyűrűszélesség-kronológiával számított dendrokronológiai statisztikák.

Sample code	Position in the synchronized dataset	Crossdating to the mean ring-width chronology	
	First ring / last ring	GLK%	t_{BP}
MAR032	23/67	66 *	4.4
MAR033	1/66	81 ***	12.4
MAR034	37/67	68 *	4.3
MAR035	37/63	75 **	3.4
MAR037	29/67	80 ***	7.2
MAR038	40/67	80 ***	3.8

Probability level accompanied with GLK% is indicated by asterisks as follows: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

species, so MAR032 was selected for detailed wood anatomical analysis to clarify the wood species (Tuzson 2016). Thin sections (5–20 µm) were prepared using a sliding microtome (Thermo Scientific Microm HM 430) in the three main anatomical directions (tangential, longitudinal, and transversal) following standard protocol (Mihalik et al. 1999, Antalfi 2015, Antalfi & Fehér 2015). The preliminary anal-ysis was carried out using a stereomicroscope (Nikon SMZ-2T), while a Zeiss optical microscope was used to get higher magnification to identify characteristic xylological features. Wood identify-cation was performed based on the observed anato-mical characteristics compared to reference data-bases (Hollendonner 1913, Schweingruber 1990, Butterfield et al. 1997).

A LINTAB digital-positioning table and TSAP Win 4.68 software (Rinn 2005) were used to measure the tree-ring width with a precision of 0.01 mm using the facilities of the Budapest Tree-Ring Laboratory (Kern et al. 2024). Tree-ring widths were measured at least along two radii in each sample and the series were synchronized. Finally, the mean tree-ring series was determined for each disk and used in the analysis. Visual and statistical methods were used to synchronize these individual mean curves.

The longest reference chronologies with fixed calendar dates (so-called master chronologies) for the same species are available from 1698 CE (Hoverla, Charnagora Mts.; Kaczka & Büntgen, 2007) ~30 km northward, from 1635 CE (Pietrosul Rodnei, Rodna Mts.) ~35 km southward and from 1551 CE (Călimani Mts.) ~100 km southeastward (Popa & Sidor 2010, Sidor et al. 2015) in the sur-rounding region (**Fig. 1**). Standard dendrochrono-logical statistics such as percentage of agreement (GLK%, Eckstein & Bauch 1969, Buras & Wilmking 2015) and modified t value (t_{BP}, Baillie & Pilcher 1973) were used to evaluate crossdating results.

Radiocarbon analysis

Two rings were removed from MAR033 represent-ing cambial ages 58th and 59th of growth. Samples were pretreated by the conventional acid-alkali-acid (AAA) treatment. Measured targets were prepared using sealed-tube graphitization method (Molnár et al. 2013a, Rinyu et al. 2013). The $^{14}C/^{12}C$ ratio and the necessary $^{13}C/^{12}C$ correction were measured by accelerator mass spectrometry (AMS) on the EnvironMICADAS ^{14}C facility in the Hertelendi Laboratory of Environmental Studies in Debrecen, Hungary (Molnár et al. 2013b). The radiocarbon ages were calculated according to Stuiver & Polach (1977). Calibration of ^{14}C dates to calendar years was performed by the OxCal v.4.4.4 (Bronk Ramsey 2009) program in conjunction with the IntCal20 (Reimer et al. 2020) dataset. Calibrated ages are reported with 95% probability with interval boundaries given in the cal AD timescale.

Results and discussion

Xylological and dendrochronological assessment

The wood anatomical analysis revealed distinct boundaries between earlywood and latewood (**Fig. 3a**). Resin ducts were observed both between tracheids and in the rays. Bordered pits were visible in the walls of the longitudinal parenchyma cells in the radial section (**Fi. 3b**). Rays are heterogeneous built from parenchyma and tracheid cells. The wall of ray tracheids is smooth with small, bordered pits at the thicker sectors. Piceoid pits counted as 1 to 5. The height of the uniseriate rays in the tangential section ranges from 1 to 26 cells (**Fig. 3c**). Biseriate rays can be observed at the resin ducts. Based on these xylological features, the wood of MAR032, and very likely all the other samples in the studied constructions is Norway spruce (*Picea abies* (L.) Karst.).

Fig. 3.: Microscopic anatomical features of MAR032 sample. Cross (A) radial (B) and tangential (C) sections. Red bars at the lower right corner of the images indicate the 100 µm scale.

3. ábra: A MAR032-es minta mikroszkópos felvételei. Keresztmetszeti (A) sugárirányú (B) és érintőirányú (C) metszet. A 100 µm-es méretskálát a fotók jobb alsó részén látható vörös sávok jelölik.

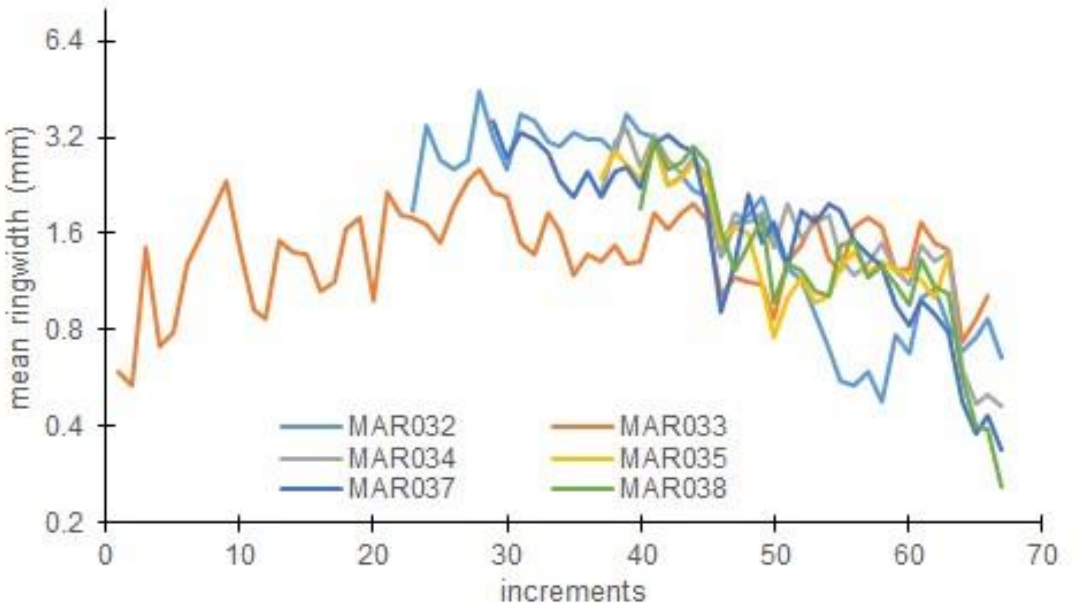

Fig. 4.: Synchronized dataset of ringwidth curves of the wooden construction found in peat bog 'Vinderel 3' locating in the Farcău Massif, Maramureș Mts. (Romania).

4. ábra: A 'Vinderel 3' tőzeglápból (Várkő, Máramarosi-havasok, Románia) 2013 szeptemberében kiemelt, ácsolt szerkezetek évgyűrűszélesség-idősorainak szinkronizált halmaza.

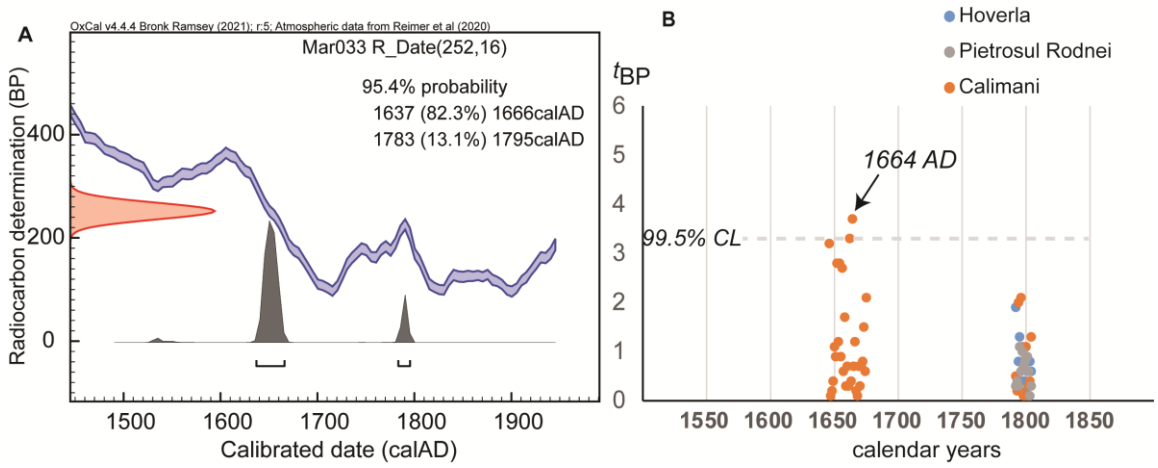

Fig. 5.: Radiocarbon calibration and running crossdating statistics calculated in running windows between mean ringwidth of MM8 and nearby spruce reference chronologies. (A) The blue band shows the distribution of the IntCal20 data and the red curve on the left indicates the ^{14}C age of the 58th and 59th growth rings of MAR033. The probability distribution of the calibrated ages is shown in grey. (B) Modified t value (t_{BP}, Baillie & Pilcher 1973) calculated for each year over the range indicated by the calibrated 95% probability intervals between MM8 and nearby spruce references: Hoverla (Kaczka & Büntgen 2007), Pietrosul Rodnei and Calimani Mts. (Popa & Sidor 2010, Sidor et al. 2015). Dashed horizontal line shows t_{BP}=3.2 approximating the empirically-determined 99.5% confidence level (Fowler & Bridge 2017) regarding the overlapping series length (n = 67).

5. ábra: Radiokarbon kalibráció és az MM8 és a közeli lucfenyő referencia-kronológiák átlagos gyűrűszélessége között számított szikronizálási statisztikák. (A) A kék sáv az IntCal20 adatok eloszlását mutatja, a bal oldali piros görbe pedig a MAR033 58. és 59. évgyűrűjének ^{14}C korát jelzi. A kalibrált korok valószínűségi eloszlása szürkével látható. (B) Az MM8 és a közeli lucfenyő-referenciák (ú.m. Hoverla (Kaczka &Büntgen 2007), Pietrosul Rodnei és Kelemen-havasok (Popa & Sidor 2010, Sidor et al. 2015)) között a kalibrált 95%-os valószínűségi intervallumok által jelzett tartományba eső évekre számított módosított t-érték (t_{BP}, Baillie & Pilcher 1973). A szaggatott vízszintes vonal a t_{BP} =3,2 értéket mutatja, amely megközelíti az empirikusan meghatározott 99,5%-os megbízhatósági szintet (Fowler & Bridge 2017) az átfedő sorozatok hosszára vonatkozóan (n = 67).

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The number of counted complete rings in the disks ranged between 27 and 66 (**Table 1**, **Fig. 4**). Crossdating statistics ranged from 66 to 81 and from 3.4 to 12.4 for GLK and t_{BP}, respectively (**Table 1**) supporting the visual impression of strong synchronicity between the variability of tree-ring width series of the samples (**Fig. 4**). The last extant ring in MAR032, MAR034, MAR037, and MAR038 coincides and defining the last ring of the tree-ring dataset and suggesting that the separately found objects were produced at the same time using the same timber source. The synchronized set of tree ring series and the mean tree-ring width chronology spans 67 years and is coded as MM8.

Dating the timber, estimating the construction date

Radiocarbon age (**Fig. 5a**) obtained from the construction timber of MAR033 points to a much younger age compared to the ages obtained from the subfossil material (Árvai et al. 2016), agreeing with the relative stratigraphical position of the wooden constructions. Due to the fluctuations of the atmospheric ^{14}C activity during the past centuries, calibrated ages are split up into separate intervals pointing to the late 18th century and the mid-17th century (**Fig. 5a**). These calibrated intervals can effectively delimit the timeframe over which the dendrochronological synchronization against potentially available master chronologies can be examined (e.g., Reinig et al. 2018, Helama et al. 2023).

Target intervals for the dendrochronological crossdating tests were inferred after shifting the calibrated intervals by +9yr, considering the 9 rings from the ^{14}C dated segment to the last ring of the synchronized dataset. The shifted target intervals are 1646–1675 CE and 1792–1804 CE. Each nearby spruce master chronologies are available in the recent target interval, however the Hoverla reference chronology (Kaczka & Büntgen 2007) does not reach back to the previous one. In addition, only a single series represent the Piertrosul Rodnei chronology before 1756 CE and even the overlapping years are vanishing from 41 (in 1675) to 11 (in 1645) so only the Călimani reference chronology (Popa & Sidor 2010, Sidor et al. 2015) was used in the earlier target interval. The 67-yr-long mean tree-ring width chronology (MM8) was compared to these regional reference chronologies using the t_{BP} statistics calculated for each position within the target intervals.

Crossdating against the nearby master chronologies suggested a lack of synchrony for the late 18th century (**Fig. 5b**). However, few positions displayed considerably stronger crossdating in the former target interval. The peak value at 1664 CE (t_{BP}: 3.7) exceeds the empirically determined 99.5% confidence level (Fowler & Bridge 2017). Crossdating tests were run with the Transylvanian spruce datasets from the Medieval and Early Modern ages (Tóth & Botár 2021), but no reliable synchronicity was found further arguing for the local (i.e., Eastern- or Northeastern Carpathian) origin of the timber. Taking into consideration that the probability of the calibrated ages also heavily weighted to the mid-17th century interval, we tend to accept that the possible felling date of the timber contributing to MM8 is 1664 CE and the wooden constructions were assembled soon after the felling date in the early second half of the 17th century CE.

Implications for the agropastoral activity of the subalpine zone of the Maramureş Mts.

Considering the potential utilization of the construction one can assume that it was sort of dam construction to retain water since these plateaus, far up above the water-rich valleys, are water-scarce places, and only in hollows animal watering is possible. However, we tend to exclude this explanation considering that the constructions were located just opposite to the potential run-off, tapping side of the peat bog.

But the hollows turn into swampy lakes, and those can be dangerous for the livestock, because they cannot get out of the swamp/peat bog. Trapped animals can be exposed to attack of the predators (e.g., wolves) and have no chance to escape (especially horses which were very valuable). Worth mentioning that a horseshoe and an oxenshoe (**Fig. 6a**) were found near the wooden construction, supporting the notion that domesticated animals visited the site. The imagined appearance of the wooden construction during utilization was reconstructed in a drawing form (**Fig. 6b**).

In other words, it is a mixed structure that acts as both a low boundary fence and a retaining wall. By this way the constructors could allow the livestock close to the water, but prevent them from slipping into the swamp, so they stabilized the bank but kept the water available for drinking, i.e. they did not erect a higher fence-wall construction.

The presented wooden construction and its inferred likely date to the mid-17th century CE provided material evidence for the agropastoral activity in the subalpine zone of the Maramureş Mts. Interestingly, the inferred construction date of the wooden structures points shortly after the onset of intensification of increased and intensified landscape openness, pasturing, and disturbance of soil cover c. 400 years ago (Florescu et al., 2024), as reconstructed partly from the sedimentological changes of Lake Vinderel situated only ~1200 m from 'Vinderel-3' peat bog. The inferred construction date of this wooden construction corresponds with the Wallachian (shepherd) colonization in the

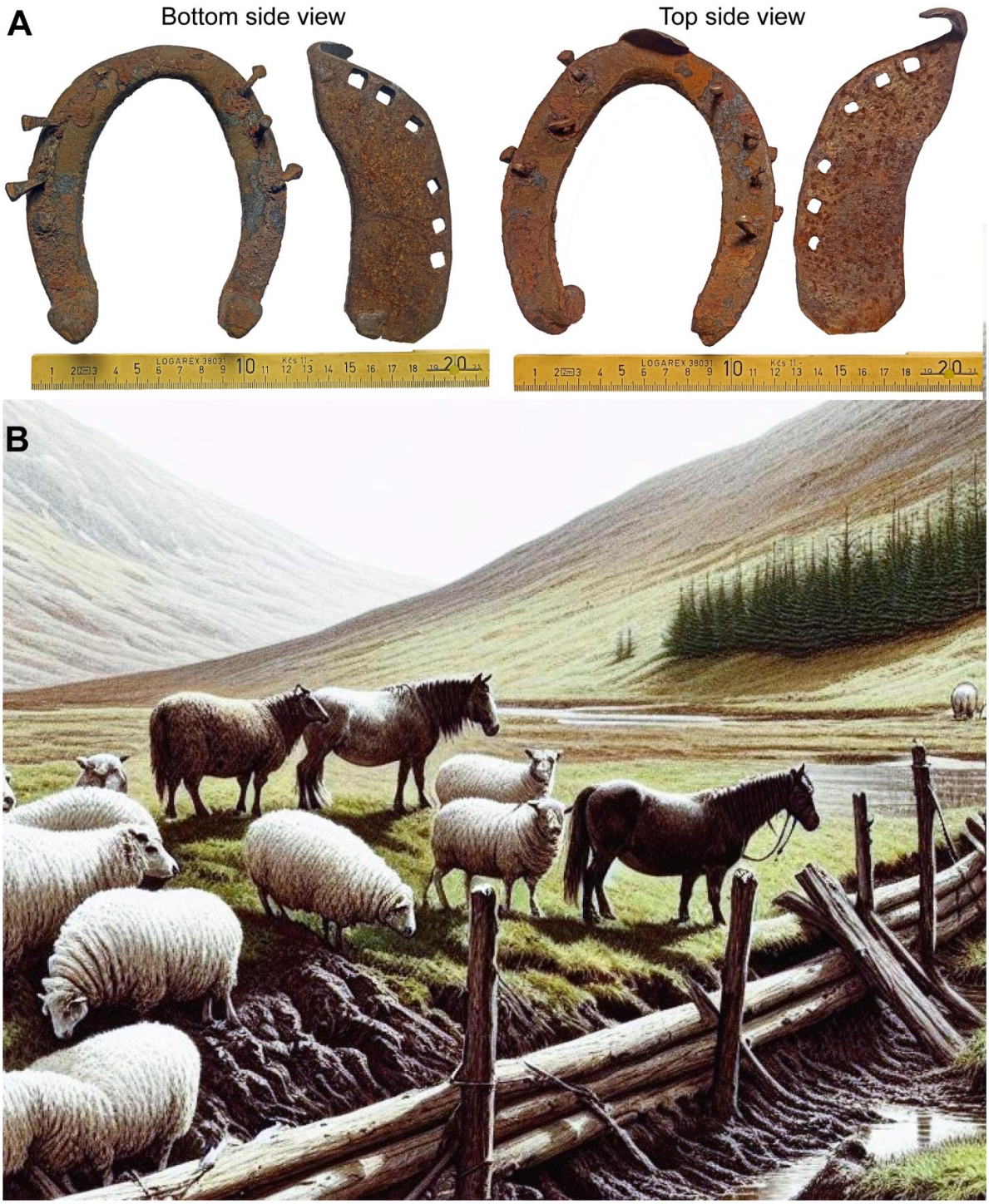

Fig. 6.: A horseshoe and an oxenshoe (A) found near the timbered structures. A visual reconstruction of a stake-fixed beam structure at the edge of the peat-bog (B). The digital visual reconstruction was created using Bing Image Creator.

6. ábra: Az ácsolt szerkezetek közelében talált lópatkó és marhapatkó (A). A vizenyős terület szélén karókkal rögzített gerendaszerkezet látványrekonstrukciója (B). A digitális látványrekonstrukció a Bing Image Creator segítségével készült.

Western Carpathians (Kłapyta 2013, Kapustová et al. 2018) so probably belongs to an established stage of pastoral activity of the subalpine zone of the Maramureș Mts. since based on the historical data Wallachian expansion has reached this region already in the 14th century (Bélay 1943, Popa 1969, Kłapyta 2013, Wistuba et al. 2018). In the 16th century, under Ottoman financial pressure, Transylvanian nobles sought to exploit the potential of mountain farming (Tóth 2024).

Dendrochronological and radiocarbon evidence from these wooden constructions provided the currently earliest material evidence for the agropastoral activity in the subalpine zone of the Maramures Mts. It argued at least 350-years old tradition of subalpine grazing in this sector of the Eastern Carpathians.

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Contribution of authors

Árvai Mátyás Conceptualization, Methodology, Formal analysis, Interpretation, Writing – Original Draft, Visualization. **Ionel Popa** Interpretation, Writing – Review & Editing. **Marcel Mindrescu** Interpretation, Writing – Review & Editing. **Antalfi Eszter** Methodology, Interpretation, Writing – Review & Editing. **Fehér Sándor** Methodology, Interpretation, Writing – Review & Editing. **Nagy Balázs** Interpretation, Writing – Review & Editing. **Kern Zoltán** Conceptualization, Methodology, Formal analysis, Interpretation, Writing – Original Draft, Visualization.

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