

COMBINED TECHNIQUES TO DATE THE FIRST TURKISH BRIDGE OVER THE TISZA RIVER, HUNGARY

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ABSTRACT. Given the fluctuating nature of the radiocarbon calibration curve, the precision of single ^{14}C dates on the calendar timescale is limited. However, ^{14}C dating combined with dendrochronology enabled us to date timbers found in the Tisza River, Hungary, during the dry period of summer 2003. Routine preparation of wood samples gave ^{14}C results spread over 4 centuries. By extracting alpha-cellulose from the samples, 2 distinct and relatively narrow historical time periods were obtained: the first period (AD 1505–1595 and 1612–1673, respectively) coincided with the Turkish occupation period, while the second interval (1733–1813) obtained in the case of 2 samples did not exclude the existence of another bridge constructed later. The dendrochronological data confirmed that the bridge was constructed from oak timbers felled between 1558 and 1565. The ^{14}C and dendrochronological dates correspond with the date of a letter written in 1562 by Antal Verancsics, Bishop of Eger, mentioning the construction of the first bridge. In conclusion, the archaeological excavation revealed proof of the first historically attested wooden bridge over the Tisza River.

INTRODUCTION

Situated at the junction of the Tisza and Zagyva rivers, the territory of present-day Szolnok, Hungary, has been nearly continuously inhabited since the beginning of the Early Neolithic, as evidenced by archaeological finds (Stanczik 1975). The importance of Szolnok increased significantly in the middle of the 16th century AD. As a consequence of the threatening Ottoman Turkish invasion in 1550–1551, King Ferdinand I decided to strengthen the town of Szolnok by constructing a surrounding palisade along with a palisade fort (with a trapezoidal ground plan and 4 ancient-style Italian bastions at the corners) at the confluence of the Tisza and Zagyva rivers. Despite the newly commissioned defense works, the Turkish forces succeeded in occupying the fortress defended by Captain Lőrinc Nyáry during the 1552 campaign. As part of the Buda *vilayet* (province), Szolnok played an important role in the Turkish administration during the later 16th century and was given the seat of the *sanjak* (first level subdivision within the Ottoman empire) probably the same year as it was occupied. The town was governed by the *sanjak bey*, appointed by the Sultan, who administered military and civilian affairs. It was also during this period that historical sources make reference to temporary pontoon bridges over large rivers (e.g. Danube, Drava) in Hungary (Gáll 1970).

Due to extremely low water levels (–279 cm relative to the null point of the Szolnok watermark), the remains of an old bridge were discovered in the summer of 2003 in excavations of the Tisza riverbank in Szolnok, Hungary. In fact, the possible remains of 2 bridges were discovered: one aligned towards the fortress, used in the beginning mainly for military purposes, and the other aligned towards the town and presumably used mostly for trade (Kertész et al. 2004).

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Engravings (see Figure 1) and written documents attest to the presence of a bridge over the River Tisza; therefore, it was believed that the remains found were probably part of the bridge constructed by pasha Gueselde Ruestem in 1562, the first wooden bridge over the Tisza River mentioned in the letter of Bishop of Eger (Verancsics 1868).

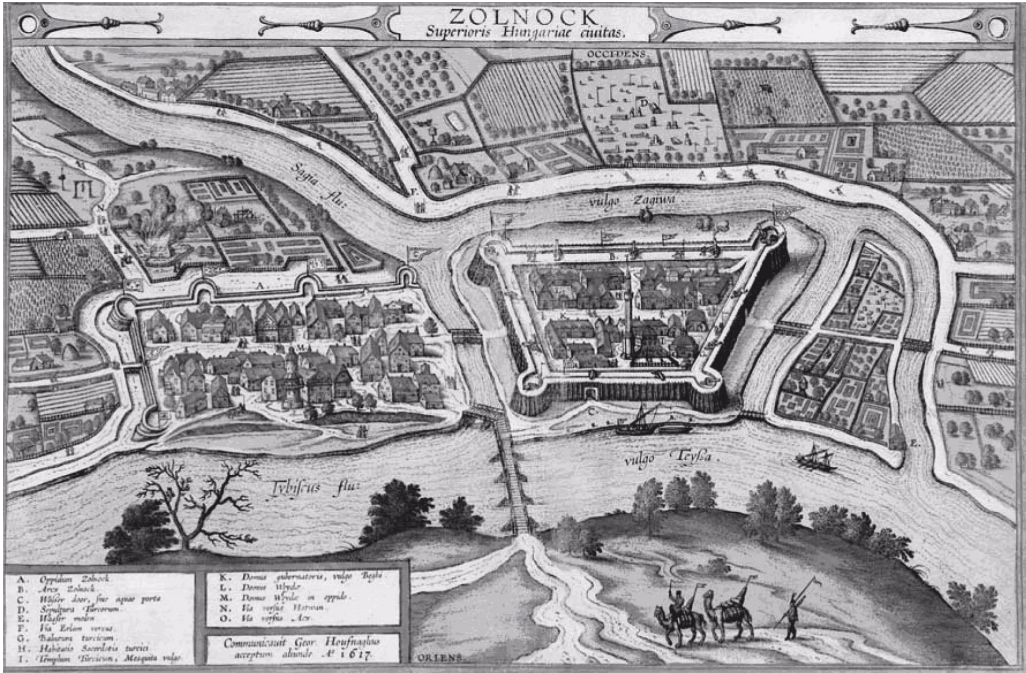


Figure 1 Engraving by Georgius Houfnaglius, published in 1617, representing the town of Szolnok with a bridge over the Tisza and Zagyva rivers, connecting both the town and the fortress.

A topographic survey undertaken at the site provided data supporting the idea that the timber remains might correspond to the bridge drawn by Philippo Fernandeo Georgius Houfnaglius⁷ (based on the direction and position of the pylons). The size and position of each of the timbers was documented and the location recorded. Two groups of pylons were identified 70 m from the present-day Tisza bridge (Figure 2): group I situated in the shallow water of the left bank of the river opposite the mouth of Zagyva River and group II further on in the deeper part of the river (Kertész et al. 2005, 2007).

Some of the wooden logs (5 in total, identified as being of pedunculate oak, *Quercus robur* L.) were partly deposited into the sand and silt, lying horizontally on the surface of the riverbed (see Figure 3), while most remained standing firmly in their original configurations (standing either vertically or angled slightly inwards). There were also quite a few closely set double posts and some additional posts under the water, which could not be seen from the surface. The posts were, without exception, cylindrical, conforming to the natural form of unhewn oak logs. Most had a round cross-section and a diameter of 20–25 cm (except a few with a diameter >30 cm and some with a diameter

⁷Engraved by Georg Braun and Franz Hogenberg after Georg Houfnagel from *Civitates Orbis Terrarum* (1572–1617), Liber Sextus, Köln, 1617.



Figure 2 Photo of the archaeological site



Figure 3 Horizontal timber deposited in the riverbed

<20 cm). The standing pilasters were mostly vertical, up to 0.6 m in length and up to 0.3 m in diameter. Two of the horizontal logs were 1 to 1.5 m in length (Kertész et al. 2004).

The topographic survey suggested that the pile bents (for term definitions, see Table 1) of the bridge were arranged into 2 or 3 rows. A determination of the intervals at which the posts were driven into

Table 1 Definitions of terms used in this paper.

Term	Definition
Bent	A substructure unit supporting each end of a bridge span; also called a pier; made up of 2 or more columns or column-like members connected at their topmost ends by a cap, strut, or other member holding them in their correct positions.
Log	A long, thick section of trimmed, unhewn timber; wood from trees used for construction.
Pilaster (inner post)	Structural vertical element that undertakes the weight of the structure above.
Pile	Structural element of the bridge foundation; a vertical shaft driven into the ground that carries loads through weak layers of soil to those capable of supporting such loads.
Pile bent	A row of driven or placed piles with a pile cap to hold them in their correct positions; structure that has round posts, which are driven directly into the ground; there are 6 posts in a bent (4 inner and 2 outer posts). The inner posts were vertical and outer posts were angled. (See bent.)
Timber	Wood either standing or that has been processed for use; wood used as building material; a dressed piece of wood, especially a beam in a structure.
Walkway	Deck of the bridge; a passage or path for walking.

the riverbed was based on the greatest possible size of the timbers: the greatest distance between individual pile bents was no more than 10–12 m, meaning that at least 9 or 10 pile bents arranged in 2 rows had to be constructed between the 2 bridgeheads (Kertész et al. 2005, 2007).

After a careful examination of the position, length, and distance of the timbers from each other, a graphical reconstruction of the structure of the bridge is shown in Figure 4.

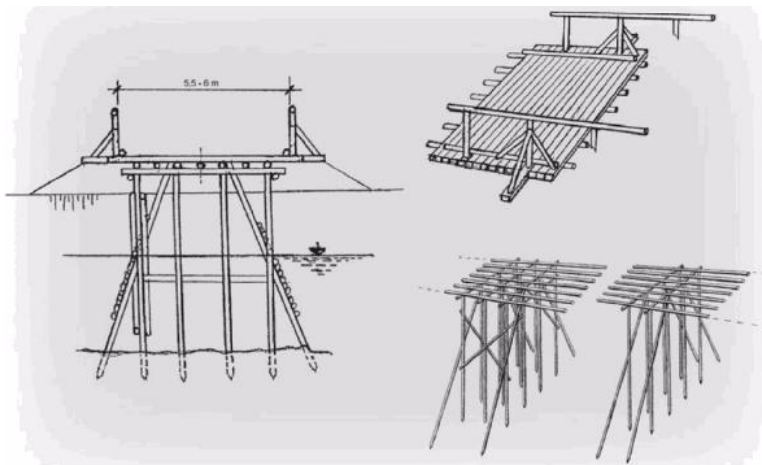


Figure 4 Schematic reconstruction of the bridge over the Tisza River, Hungary

The reconstruction suggests that the platform was 5.5 to 6 m wide, allowing 2 carts to pass one another comfortably. This agrees with the available historical documentation. The overall length of the structure (110 m) allows us to suppose that a bridge of this proportion required a large amount

of timbers (~367 m³ of wood), which had probably been felled and partially worked prior to the process of construction (Kertész et al. 2005, 2007).

The post sections found underwater were extremely well preserved and quite hard; in contrast, the sections rising above the water were poorly preserved and fragmentary, most likely because this was not the first time that the upper part of these posts had been exposed.

The higher water level of the Tisza had kept the timbers waterlogged for hundreds of years, preventing them from drying out. The top of the piles had either rotted away or washed downstream long ago and the rest of the piles had been hardened and covered by silt and sand. The vertical stakes were incomplete; the tops had been exposed and weathered away. In total, 6 wood logs (2 vertical and 4 horizontal pylons) were excavated from the riverbed (Kertész et al. 2005, 2007).

In order to determine the absolute age of the discovery, radiocarbon dating was used in combination with dendrochronology. Dendrochronology provided a level of accuracy unsurpassed by other scientific dating methods and aided the accurate determination of the chronology of the dated samples. Tree-ring chronologies have the advantage of being continuous, well-replicated, and exactly dated to the calendar year; therefore, they are easily comparable to instrumental records (Baillie 1982; Stokes and Smiley 1968).

MATERIALS AND METHODS

Radiocarbon Dating

Although the mineral water and sodium silicate have penetrated the wood logs, resulting in tough, blackish-brown timbers, the sapwood rings were readily distinguishable from the inner heartwood. Six sections of timber off-cuts (7 samples) have been ¹⁴C dated. Samples were physically and chemically pretreated to remove contamination before they were converted to CO₂. In order to avoid the “old wood” effect, in which the inner tree rings may be tens of years older than the outer ring of sapwood deposited just before the tree died, the exterior (the bark, terminal ring, and sapwood) was separated from the heartwood using a hammer and chisel and further processed.

Physical treatments consisted of cleaning, sorting, grinding, and sieving. Chemical treatment included the standard acid-alkali-acid (AAA) method. Following routine laboratory procedures, the sample was treated first with hot dilute hydrochloric acid to remove any carbonates, and then with hot dilute sodium hydroxide solution to remove any younger humic acids or other organic contaminants. The samples were heated at 80 °C for 24 hr in 0.5M HCl, filtered, rinsed, heated in 0.1M NaOH, filtered, rinsed, and finally heated in 0.5M HCl, filtered, rinsed with distilled water until pH 3 was reached, and then dried.

The chemically pretreated samples were combusted to CO₂ in a controlled oxygen stream. Gaseous impurities (like traces of NO_x) and excess O₂ unused during combustion were removed by passing the produced CO₂ through a hot copper furnace. The purified CO₂ was trapped into a stainless steel vessel using liquid nitrogen and measured by gas proportional counting (Hertelendi et al. 1989). The multicounter ¹⁴C dating system consists of 9 electrolytic copper proportional counters filled with CO₂. The overall precision of the system for modern carbon samples is better than 4‰ after a counting period of 7 days (not including random errors in the process of chemical pretreatment and preparation). Correction for fractionation was achieved by measuring the δ¹³C_{PDB} value using a stable isotope ratio mass spectrometer in dual-inlet mode (Thermo Finnigan Delta^{plus} XP). Calibration of ¹⁴C dates to calendar years was performed using the CALIB 4.4.2 program used in conjunction with CALIB 4.0 (Stuiver and Reimer 1993).

Since the preliminary results obtained on the whole wood sample showed ^{14}C ages spread over 4 different time periods, it was believed that the sample processed was heterogeneous, possibly containing contaminants of more recent carbon material. Humic acids (the degradation products of plant material) are very mobile and may exchange carbon with or adhere to samples with large surface areas, yielding erroneous ^{14}C results (biased towards younger ages). In order to avoid humic acids (as well as lignin), α -cellulose was extracted from the wood samples by bleaching with NaClO_2 solution under acidic conditions. Although preparation of α -cellulose is a time-consuming procedure due to its singular composition and its immobility in wood, it is useful for woods that are either very old or highly contaminated. Two main reasons for the extraction of α -cellulose were as follows: 1) the cellulose can be unambiguously linked to a specific growth period since it is the cellulose that forms the cellular framework of the tree ring; 2) a greater level of homogeneity can be attained during the purification process, yielding an improvement in the counting statistics, which in turn facilitates the achievement of a better resolution.

Alpha-cellulose was extracted from 20–40 g of each wood sample by the following procedure. The samples were washed in distilled water with an ultrasonic cleaner. Next, each sample was treated with 1.2M HCl and 1.2M NaOH solutions alternately on a hot plate (60–70 °C). The above treatments were repeated several times. The samples were bleached with 0.07M NaClO_2 solution under acidic conditions adjusted with HCl (70–80 °C). This 1-hr bleaching treatment was repeated 4 times. Alpha-cellulose was separated finally by washing the residue with 17.5% NaOH solution for 30 min at room temperature, rinsed with distilled water, and dried.

Dendrochronology

Dendrochronology enables dating of wooden artifacts and objects to the year or even to the quarter year in optimal cases. This discipline takes the relatively straightforward process of annual tree-ring growth to produce precise, exact calendar determinations (Becker 1993). Each year, trees grow an additional ring, with the size of each depending to a large extent on weather conditions (e.g. precipitation, temperature). The ring patterns can then be matched against others from the same tree species to produce environmental records of regional warming and cooling events. These patterns can then be fitted onto a master dendrochronology and correlated with similar records in widely different geographical locations to show the limits of an environmental event. The environmental information provided by dendrochronology can therefore be expressed in terms of historical time.

The dendrochronological study conducted in the Hungarian National Museum was used to refine the ^{14}C dates obtained in the Institute of Nuclear Research of the Hungarian Academy of Sciences. In order to achieve accurate results and avoid the high uncertainty of the interpretation, only sample 6, which had enough tree rings (a pedunculate oak post slice having 102 tree rings), was analyzed.

The sample was pared with a special blade (Apollo-Herkenrath, Solingen) and rubbed in chalk dust to make the tree rings visible for the dendrochronological measurements. The width of the tree rings was measured under a binocular microscope to a precision of 0.01 mm. The measurement table was connected to a computer and the tree-ring width curves were displayed and printed in a logarithmic graph for visual comparison.

The measurement results obtained were used for dendrochronological dating, and the tree-ring curves were then synchronized with various chronologies using the DenScan v 3.4 program (written by György Hovánszky, Hungary), which calculates the t value, the trend coefficient, and the dating index (Eckstein and Bauch 1969). The values thus obtained enabled cross-correlations to be made.

RESULTS AND DISCUSSION

In routine analysis, 1 wooden sample and 6 cellulose samples have been ^{14}C dated (Table 2).

Table 2 Results of ^{14}C dating of remains of a wooden bridge over the Tisza River, Hungary.

Lab code	Sample name	Sample type	$\delta^{13}\text{C}$ (PDB) ± 0.2 (‰)	Conventional ^{14}C age (BP)	Calendar age (cal AD 1σ)
Deb-11094	Tisza bridge 1/b	Cellulose	-22.5	275 ± 60	1505–1595 1612–1665
Deb-11018	Tisza bridge 2/b	Cellulose	-23.8	220 ± 45	1641–1677 1747–1803 1941–1947
Deb-11084	Tisza bridge 3	Cellulose	-24.6	295 ± 45	1510–1585 1621–1652
Deb-10850	Tisza bridge 5	Wood	-26.1	250 ± 50	1519–1565 1626–1673 1771–1794 1943–1946
Deb-11004	Tisza bridge 5	Cellulose	-23.7	270 ± 35	1522–1561 1628–1662
Deb-11012	Tisza bridge 6	Cellulose	-23.7	290 ± 40	1513–1581 1622–1651
Deb-10924	Tisza bridge 7	Cellulose	-23.7	180 ± 45	1659–1687 1733–1813 1926–1948

The cellulose samples Deb-11094, -11018, and -11084 were prepared from timbers forming group I. Deb-11004 was a stray find, while samples Deb-11012 and Deb-10924 were prepared from a spliced pile (made of 2 different timbers connected by joints) found in front of group I and near group II.

The preliminary results (Deb-10850) showed the wood sample prepared by AAA gave results spread over 4 centuries (AD 1519–1565, 1626–1673, 1771–1794, 1943–1946). Although the expected period of the 16th century presented the highest relative area under the probability distribution (56%); additional calibrated ages with lower relative area under the probability distribution were also found. This may be due to the presence of different contaminants of more recent carbon material and/or to the inhomogeneity of the material processed. Wood is a complex material comprising a range of chemical components, including cellulose, lignin, hemicelluloses, resins, tannins, etc. Since the biochemical processes used in the formation of each component are different, the isolation of a single component (in this case, α -cellulose) reduced problems associated with variability in the lignin-cellulose ratio that could occur through time and resulted in a homogeneous (also humic acid-free) material. Moreover, using α -cellulose for dating, the estimation of the extent to which the formation of the wood predated the archaeological event of interest became more precise due to the fact that the exchange with the atmosphere “reservoir” ceases at cellulose formation, preserving more evident ^{14}C fingerprints.

Dating the extracted α -cellulose, 2 different historical time periods were obtained that coincide with the Turkish occupation period in Hungary: AD 1505–1595 and 1612–1673, respectively. Two samples have also shown a third interval (AD 1733–1813) with a relative area under a probability distribution of 64%, allowing us to postulate the timbers were parts of a bridge constructed later.

After careful analysis of the position of the timbers found at the site, it seems that the piles of groups I and II were actually parts of 2 bridges built on different alignments, probably one a replacement for the other, the reconstruction serving military as well as commercial purposes and providing easier access to the town. There are no historical data on the events that lead to the destruction of the first bridge directed to the fortress (group I of piles). However, contemporary sources kept record of extremely severe ice runs, which frequently damaged the pile bents and necessitated maintenance and/or partial reconstruction of the bridge over the Tisza River (Kertész et al. 2007). According to the engravings of that period, it seems probable that at the end of the 16th century another pile bridge was built aligned towards the town (group II). After the Turks conquered Eger in 1596, Szolnok lost its importance as a border fortress and grew as a trade center with dynamic commercial activity; therefore, a direct connection to the town was needed. This structure was presumably burnt when the Turkish army left the town in 1685, as attested by documents of that period (Kertész et al. 2005, 2007).

The close time span obtained in this study cannot exclude the possibility for reuse of timbers that remained a valuable commodity throughout the centuries, the reuse being obvious from the context (the metallic joints and nails found were used to connect the old unburnt wood timbers with freshly cut ones). Another explanation could be that the timber had been stockpiled in advance of construction; although the normal procedure with oak was to use it green (soon after felling), since it was easier to work before the timbers dried, shrank, warped, or hardened (Kertész et al. 2004).

If we assume that one of the structures was built in the 16th century and the second at the end of the 16th century or in the first half of 17th century, some questions remain as to the cause of the existence of the third interval (AD 1733–1813). Is it possible that the dated timbers were actually part of 3 bridges, two (with different alignments) built during the Ottoman Turkish occupation and a third built in the 18th century on the same alignment as one of the Turkish bridges?

Written records for the 18th century are more detailed and precise than for the 16th or 17th centuries: military maps and administrative reports of the town of Szolnok document the fact that after 1721, all wooden bridges over the Tisza River were built west of the archaeological site, close to the present-day Tisza bridge (located approximately 70 m from the present remains; Kaposvári 1983). A devastating ice-run flood destroyed the last wooden bridge in 1909 and no other wooden bridges were built. Although ^{14}C data did not exclude the discovery of remnants of 3 different bridges, historical documentation seemed to contradict this possibility.

Given the importance of present findings in order to cross-check historical evidence and increase the credibility of ^{14}C results, the tree-ring measuring technique was also applied in this study. Dendrochronology as an absolute dating tool is often used to refine the time span given by ^{14}C dating, as it can provide the exact date of an individual tree ring, while the historical documentation can further attest the correctness of data.

If the timber sample has its outer sapwood intact to the bark or underneath of bark, then a precise date can be ascribed for the felling of the tree. By identifying the completeness of the last ring under the bark, the dendrochronologist can determine if the tree was felled in early, mid, or late spring; early or late summer/early autumn; or in the dormant period (late autumn and winter) of a particular year.

If some or all of the sapwood is missing from a timber due to conversion or decay, then it is impossible to determine precisely how many rings have been lost to the bark edge. Attempts have been made to determine a most likely date within this range, but these have seen varying degrees of suc-

cess (Miles 1997). Although sample 6 did not contain all the tree rings to the bark, the boundary between the heartwood and the sapwood could be determined on the basis of color (Fritts 1976). As a clear heartwood/sapwood transition was observed, the heartwood/sapwood boundary date was easily determined and the missing outer sapwood rings were estimated. In this way, determination of an estimated felling date range was possible. The results of the cross-dating of sample 6 are summarized in Table 3.

Table 3 Results of the cross-dating of sample 6 taken from the oak post recovered from the Tisza River, Hungary, with the east Austrian and south German oak chronologies.

	Tree-ring nr of sample	Nr of over- lapping years in the match	t value ^a	Trend co- efficient (GL)	Dating index (D)	Date of last tree ring
East Austrian oak chronology	102	102	5.58	59.80	54.75	1546
South German oak chronology	102	102	4.21	64.22	59.90	1546

^aResults given at 95% confidence level. t values (Baillie and Pilcher 1973):

$$ybp_i = \ln\left(\frac{y_i x^5}{y_{i-2} + y_{i-1} + y_i + y_{i+1} + y_{i+2}}\right).$$

Calculation of the t value:

$$t = \frac{c_{coeff} x \sqrt{n-2}}{(1 - c_{coeff}^2)} \text{ where } c_{coeff} = \frac{\sum_{i=x \dots y} (s_i - \bar{s})x(r_i - \bar{r})}{\sqrt{\sum_{i=x \dots y} (s_i - \bar{s})^2 x \sum_{i=x \dots y} (r_i - \bar{r})^2}}$$

and n = the number of overlapping years.

The 2 independent oak chronologies presented in Table 3 indicated that the last tree ring of sample 6 can be dated to 1546. According to Baillie and Pilcher (1973), for English oak trees, the correlation between 2 tree-ring curves is acceptable in the case of t values over 3.5 if the visual correlation between the curves is good (Baillie and Pilcher 1973). Comparing the curve obtained for sample 6 with the curves of the east Austrian (Figure 5) and south German oak chronologies (Figure 6), a good correlation of data is observed.

As a rule, the dating index (D score) based on the GL (trend coefficient) and t test value is low in the case of accidental matches and high for genuine matches (with higher t test and GL values). The most reliable indication of a correct dating is if all 3 values are high. In the present study, the statistical data analysis resulted in t values of 5.58 and 4.21 and dating index values of 54.75 and 59.90, respectively. As shown in Table 3, the obtained statistical values are all high ($t > 3.5$, $GL \approx 60-70$, $D > 50$); moreover, the correlation graphs indicated a good match (at the 95% confidence level). Since the influence of climate on oak growth determines the cross-dating process, the tree-ring chronologies are constructed according to areas of climatic influence. The fact that the statistical data analysis showed a better match with the south German oak chronology rather than the east Austrian oak chronology can be explained by similarities and differences in climatic conditions. Hungary has a continental climate, distinctly warm and dry in summer and cold in winter, unlike the Atlantic-type climate of western Europe. Surrounded by the arc of the Carpathians, exposed to Atlantic, Mediterranean, and Siberian influences, the regional climate displays steep gradients. As the connection of

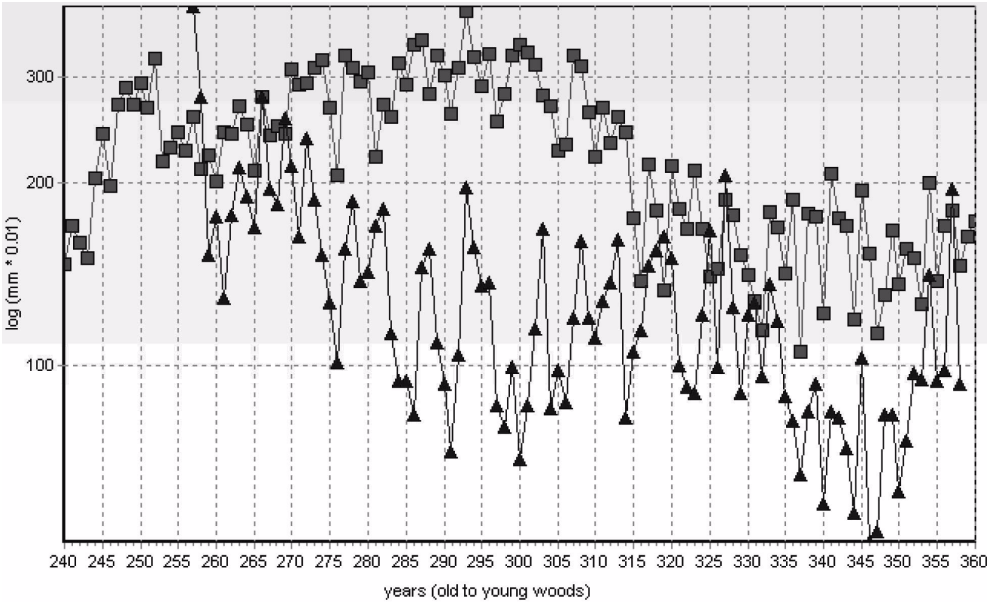


Figure 5 Comparison of the curves of the east Austrian oak chronology (squares) and sample 6 taken from the oak post recovered from the Tisza River, Hungary (triangles).

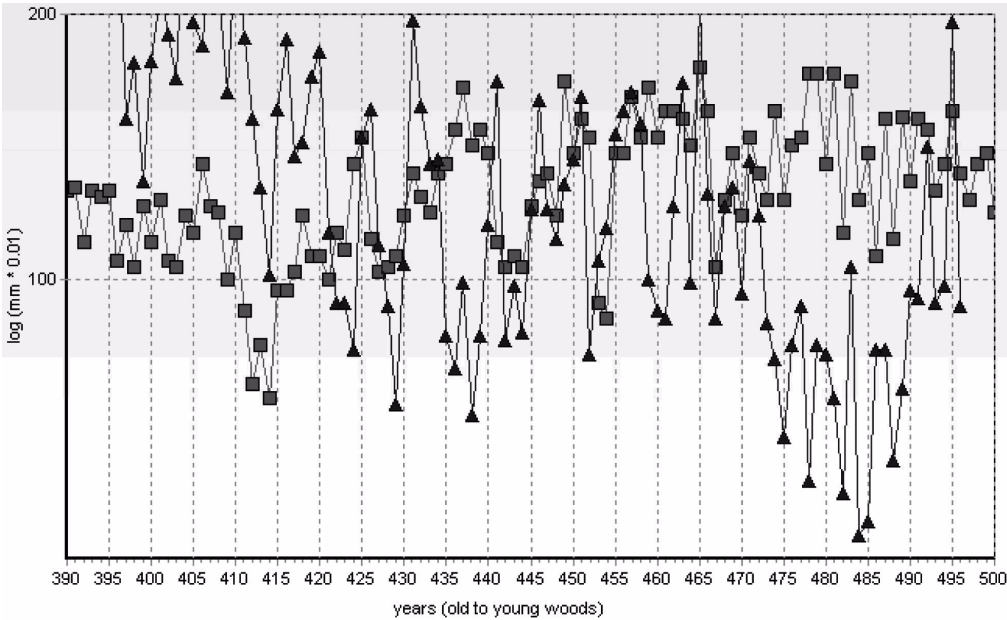


Figure 6 Comparison of the curves of the south German oak chronology (squares) and sample 6 taken from the oak post recovered from the Tisza River, Hungary (triangles).

the chronologies in and around Hungary is not yet studied in detail, further investigations are needed to understand the nature and causes of local effects.

Following dating of the last tree ring of sample 6, the next step was the correct estimation of the felling year of the tree. Given the fact that only a section of the first ring of the sapwood survived, a time bracket for the felling of the tree could be given based on the average sapwood tree-ring number (minimum – maximum) for the studied region. In Hungary, the formation of an average sapwood tree ring in the case of oak trees is $17 \pm 2/-5$ yr (i.e. a minimum of 12 and a maximum of 19 yr) (Grynaeus 2004). As the growth date of the last heartwood tree ring was 1546, considering the minimum and maximum age of the growth of a sapwood tree ring, the tree was most probably felled sometime between 1558 and 1565.

While it may be possible to date a single timber, the chance of achieving a reliable date is far higher if multiple timbers are used. On the other hand, the date for a single timber may not be really meaningful as one cannot determine if the timber has been reused, stored before use, or used as an undetected repair. If several timbers give dates within a few years, one can have far more confidence that the whole structure has been securely dated (principle of replication).

However, in the present study, the dendrochronological data confirmed the assumed calendar time span. The archaeological excavation revealed convincing proof of the first historically attested wooden bridge over the Tisza River.

CONCLUSIONS

^{14}C dating enabled us to date the timbers found in the Tisza River during the dry period of summer 2003, when the water level decreased dramatically. In order to provide more reliable dates, ^{14}C results were augmented using additional information derived from archaeology and dendrochronology. The ^{14}C date obtained for sample 6 (cal AD 1513–1581, 1622–1651) was further refined by the dendrochronological analysis of the same timber. In all likelihood, the oaks were cut between 1558 and 1565, with the construction being completed sometime in 1562 according to historical documentation. The investigations have demonstrated that the archaeological wood finds are a highly revealing source of information, and also that further investigations are needed to take full advantage of it.

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