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Tree-ring analysis and absolute dating of a wooden water-drain installation from the Late Bronze Age underground spring chamber of Oymaağaç Höyük/Nerik, Türkiye

Y. Özarslan [a,*], D.P. Mielke [b], A. Christopoulou [c], R.M. Czichon [d], T. Ważny [e]

[a] Department of Archaeology and History of Art, Koç University, Istanbul, Türkiye
[b] Department of Pre- and Protohistoric Archaeology, University of Münster, Germany
[c] Biodiversity Conservation Lab, Department of Environment, University of the Aegean, Mytilene, Greece
[d] Department of Archaeology, Uşak University, Uşak, Türkiye
[e] Institute for the Study, Conservation and Restoration of Cultural Heritage, Faculty of Fine Arts, Nicolaus Copernicus University, Toruń, Poland

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ABSTRACT

At the archaeological site of Oymaağaç Höyük, located in the Turkish province of Samsun and home to the ruins of the Hittite cult city of Nerik, an exceptional underground construction complex was excavated between 2009 and 2019. The building complex, dating back to the Late Bronze Age/Hittite period, consists of a long staircase leading into a chamber with an artificial spring. In the chamber, which lies around nine metres below the present surface level and in the groundwater horizon, a large number of ancient wood finds have come to light that have been preserved in a low-oxygen environment. A particular highlight was the discovery of a wooden structure installed into the chamber and likewise dating back to the Late Bronze Age/Hittite period, which can be interpreted as a water-drain installation. The meticulously preserved wooden structure consisted of two massive blocks encasing a holed trunk, likely serving as a controlled water outlet. Along with the spring chamber, this unique installation provided crucial insights into ancient wood use, water management, and cultic practices. This article presents the results of the first dendroarchaeological analysis of the wooden installation conducted by the Balkan-Aegean Dendrochronology Project (BAD Project). The analysis aimed to identify the wood type used for the installation and establish an absolute date for its construction. Wood anatomical analysis identified the species as *Pinus brutia*, indicating local timber usage. Radiocarbon dating and wiggle-matching modelling placed the installation's construction between 1525 and 1426 BCE, corroborating an earlier 14C dating. Despite challenges in cross-dating, these findings offer a crucial anchor for understanding the Late Bronze Age settlement of Nerik and its broader historical context, shedding light on socio-historical dynamics and cultural practices in the Central Black Sea Region. The absence of overlapping reference chronologies from the region underscores the need for further regional dendrochronological research for which our study lays the first foundations.

1. Introduction

During excavations at Oymaağaç Höyük (Figs. 1 and 2) situated in the Central Black Sea Region of Türkiye, which is most likely the site of the Hittite cult city of Nerik, an exceptional underground construction complex representing an artificial spring was uncovered (Fig. 3). From the top of the höyük (settlement mound), an underground staircase leads to a spring chamber around nine metres below the present-day surface level. After ten years of arduous and difficult work, this building structure has been excavated completely. Since the chamber is lying entirely below the underground water level, the conditions for the survival of organic remains in its context were quite ideal. Nevertheless, the discovery of several hundreds of perfectly preserved wooden pieces and a unique drain installation (Figs. 4 and 5) in the same spring chamber in 2018 and 2019 was a great surprise for the excavation team (Czichon et al., 2019: 147–160, Czichon and Mielke, 2020: 157–187). The great bulk of these wooden pieces were intentionally deposited in the basin sometime during the Iron Age to create a great fire in order to destroy the chamber. In contrast, the water-drain installation was placed and fixed in the chamber during the Late Bronze Age (LBA). To answer

* Corresponding author.
E-mail address: yozarslan@gmail.com (Y. Özarslan).

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fundamental questions about the function and construction as well as the specific and broader historical context of this unparalleled installation, wood anatomical, dendrochronological, and 14C wiggle-matching analyses were carried out. This work was undertaken by the international team of the "Balkan-Aegean Dendrochronology Project (BAD Project)" whose main goals were to identify the type and origin of the wood utilized for this installation and to contribute to the absolute dating of its construction and use.

2. The Hittite spring chamber and the wooden installation

The existence of an underground construction complex at the archaeological site of Oymaağaç Höyük has been known since a survey in the 1970s (Czichon et al., 2011: 238–243). However, the site had not been excavated until the launch of a long-term archaeological research program in 2005 under the direction of Rainer M. Czichon and Jörg Klinger (Free University Berlin) when the administrative, logistical, and technical prerequisites for investigating such a construction complex were met. These long-term excavations at the site have revealed a complex settlement history from the Chalcolithic period to the end of the Iron Age (Czichon et al., 2011, Czichon et al., 2016, Czichon et al., 2019, Czichon and Mielke, 2020). Based on cuneiform clay tablet finds from the site, Oymaağaç Höyük could be identified as the Hittite cult city of Nerik and represents the northernmost settlement with substantial material remains of the Hittite culture.

Recording, documentation, and excavation of the underground complex were initiated in 2009 (Fig. 2) and completed in 2019 despite many physical difficulties that may arise when excavating under the ground and below groundwater level (Czichon and Mielke, 2020: 157–178). This exceptional building complex consists of an underground staircase, approx. 29 m long, which is constructed using the corbelled vault technique (Fig. 3). Leading through a natural cavity, the staircase ends in front of a 3.70 m-long, 1.80 m-wide and 1.60 m-deep rectangular basin made of large stones (Fig. 4), which, as with the staircase, is closed off at the ceiling by a corbelled vault. The entrance (Figs. 2 and 3) to the underground complex lies directly on the hilltop and was originally situated at the foot of the fortification wall of the city. The basin, on the other hand, lies about nine metres below the present surface at the foot of the höyük, whose base is formed by a natural

Fig. 2. Entrance to the LBA underground construction complex of Oymaağaç Höyük/Nerik during the initial stages of its excavation in 2010 (Photo: Oymaağaç Project, H. Marquardt).

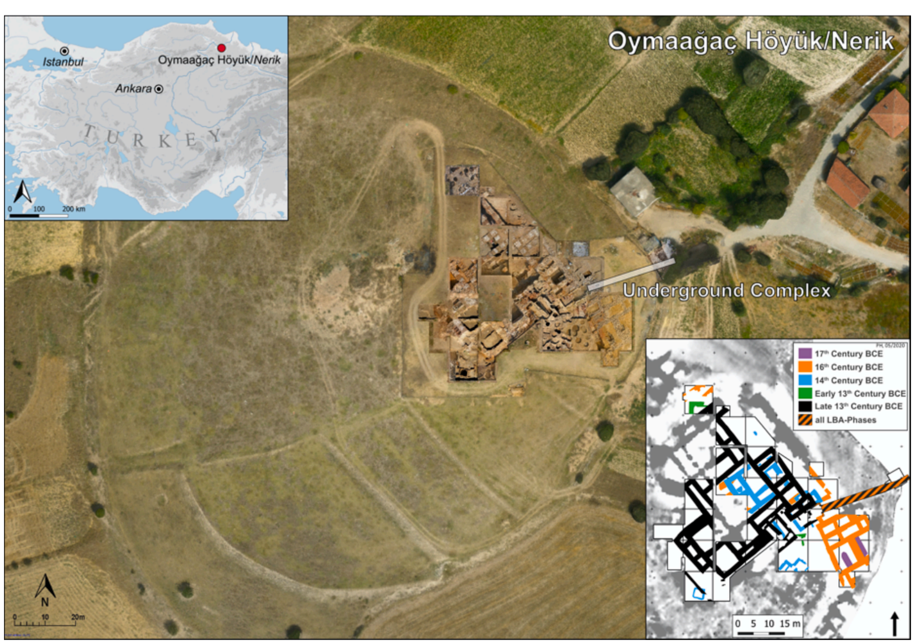

Fig. 1. Oymaağaç Höyük/Nerik. Site location, excavation results from 2007 to 2020, and location of the Late Bronze Age (LBA) underground construction complex (Graphic: Oymaağaç Project, D.P. Mielke (map), M. Lehmann (orthophoto), and P. Hnila (excavation plan)).

travertine rock. Here, the geological conditions supply mineral-rich water sources, which is highly likely the reason for the construction of the underground complex. The building complex thus provides secure access to the water resources outside the former city fortification. The water basin at the bottom of the building complex functioned as an artificial spring with an inlet in the form of a triangular gutter stone installed on the rear vertical wall (Fig. 4). The wooden installation under the focus of this study, on the other hand, allowed for a controlled outlet. Erected in the 17th century BCE, the artificial underground spring complex had been used far beyond the Hittite period or LBA, respectively (ca. 1700–1180 BCE) and remained active for almost 1000 years before it was intentionally rendered unusable during the Iron Age around 800 BCE. The construction of such an underground complex demonstrates not only distinctive skills of controlled water management but also highly developed engineering knowledge above all. As an important element of the urban infrastructure, the spring also had a cultic function because it is highly likely that this structure represents the "spring of *Nerik*" known from Hittite texts (Czichon and Mielke, 2020: 178).

The wooden installation[1] was found in its original position firmly attached to the rear right (southern) corner of the spring chamber (Figs. 4 and 5). Thanks to anaerobic conditions in the ground water zone for many centuries, the wood was impressively preserved. The installation consists of two massive rectangular blocks that are fitted tightly into the chamber wall, one on top of the other (Fig. 5). The upper wooden block has a slightly rounded surface – the original outer surface of the beam – and is 94 cm long, 20 cm wide, and 33 cm high. The lower block, fully rectangular, is about 100 cm long, 24 cm wide, and 28 cm high. The two blocks form an edging or enclosure for a massive wooden trunk. The underside of the upper wooden block and the top of the lower block were worked into a semi-circular shape for this purpose. The outermost part of the trunk, which lies at right angles to these two wooden blocks, was hardly worked, but merely stripped of its bark. The trunk protrudes about 30 cm from the edge of the two rectangular wooden blocks and is about 15 cm above the ground. In cross-section, the trunk has a height of nearly 31 cm and a width of 42 cm. Close to the centre of its cross-section, the trunk has an opening with a diameter of 11 cm at the beginning, which then becomes narrower but obviously passes completely through the beam. As tool marks demonstrate, this hollow was not drilled but chiselled out. The cavity of the trunk could be traced for more than 2.60 m and is slightly inclined upward towards the other end. The fact that this long trunk leads out of the chamber makes us think that we are dealing here with an installation functioning as a

Fig. 4. The LBA underground spring chamber of Oymaağaç Höyük/Nerik with the water inlet stone on the rear chamber wall and the wooden water-drain installation in the right rear corner after completion of the excavation in 2019 (Photo: Oymaağaç Project, D.P. Mielke).

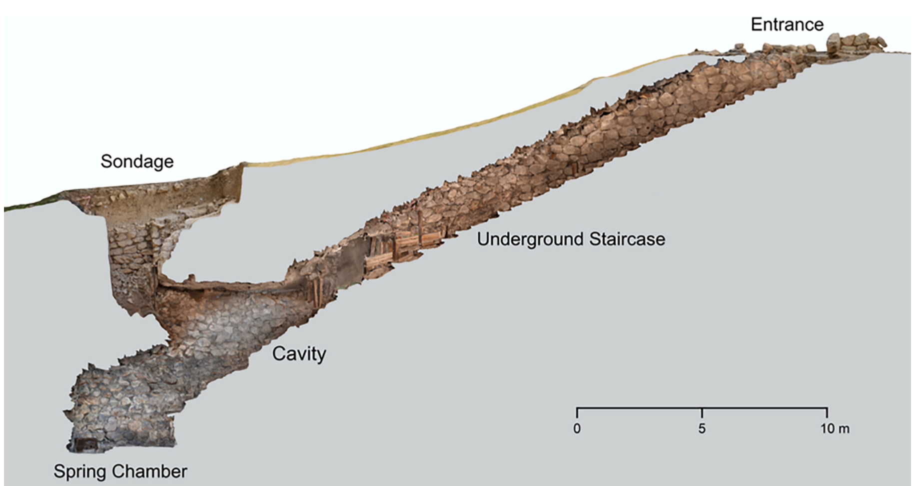

Fig. 3. Section of the photogrammetric documentation of the LBA underground construction complex of Oymaağaç Höyük/Nerik with its entrance, staircase and spring chamber representing the state of research at the end of the excavation season in 2019 (Graphic: Oymaağaç Project, M. Lehmann).

[1] Find Complex Number 8080:17:5. See the detailed description of the installation in Czichon and Mielke 2020: 169–177.

water outlet or a wooden water pipe. On the top of this wooden water pipe, another opening runs vertically or at right angles to the horizontal cavity and is connected to the latter. The opening has a lead insert, which is shaped like the rim of a vessel, with a total diameter of 13 cm, while its opening is only 6 cm in diameter. The function of the vertical opening was presumably to close or control the water outlet.

The LBA construction of the Hittite spring chamber and the wooden installation is strongly supported by the stratigraphy, the presence of corresponding pottery, and absolute dating evidence from a 14C sample collected by the excavators from the outermost part of the upper squared beam, dated to 3202 ± 28 BP (Tübitak-0825) which is 1510–1420 BCE with a 95.4% probability (2σ) in calendar years (Czichon and Mielke, 2020: 172–174).[2] Due to structural changes or modifications observed around the immediate context of the wooden installation, the excavators assume that it was probably installed during a repair or renewal work of an already existing water outlet in the LBA (Czichon and Mielke, 2020: 175). However, the circumstances in which such a huge wooden water pipe was placed in the stone walls of the spring chamber, and whether it was part of a more complex water pipe system remain to be explored.

3. Wood samples and analytical procedures

The BAD Project team was informed by the Oymaağaç Höyük excavation team in May 2018 about the discovery of an extraordinary archaeological context and associated waterlogged wood remains at the site. The team visited the site in July 2018 to inspect its potential and arrange a more formal visit in 2019. During the excavation campaign of 2019 the BAD-team climbed together with the excavators down into the underground spring complex to closely examine this wooden installation situated in the corner of the spring chamber and to take samples from it in its original position (Figs. 6 and 7). The collected samples (Figs. 7 and 8) included one slice from the lower beam cut from a non-visible part (Sample NER01), one core from the upper beam (Sample NER02), and another core from the perforated trunk in the middle (Sample NER03). The cores were collected using a 5 mm increment borer while the slice was cut with a Japanese handsaw.

The initial examination of the cores and the slice were carried out in the Oymaağaç Höyük excavation house using a DELTA stereomicroscope at 10x-70x to identify their species, at least to the genus level, and then to assess their potential for further dendrochronological analysis. These three samples were then carefully packed and transported to the Laboratory for Dendrochronology at Nicolaus Copernicus University in Toruń (Poland) for further examination and dendrochronological analysis after the issue of the required official permission from the Ministry of Culture and Tourism of Türkiye.

In the laboratory the three samples (Fig. 8) were prepared with the use of razor blades to make ring boundaries and xylem cells clearly visible under magnification in reflected light. This was followed by a four-step analytical procedure, including wood identification, dendrochronological analysis, radiocarbon dating, and wiggle-matching modelling, respectively.

Wood identification for tree species is an initial step before any kind of absolute dating activity with archaeological and historical wood. During this step we took transverse, radial, and tangential sections (Fig. 9) of each of the three Oymaağaç Höyük samples and observed them under a biological microscope, OLYMPUS BX-53 (50x-400x), to identify their species based on their micro-anatomical structures and reference material from known tree species across the Mediterranean region (Schweingruber, 1990; Akkemik and Yaman, 2012). Besides identification, we also examined the growth ring patterns and their properties, such as the number of preserved rings, presence of pith and/or bark, ring curvature, as well as the presence of characteristic rings (e.g., wedging, false, and/or extremely narrow rings), scars, woodworm boreholes, fungal strains, and evidence for ancient woodworking (Marguerie and Hunot, 2007; Crivellaro and Schweingruber, 2013; Rowell, 2013). Examination of such characteristics are crucial for a full understanding of dendrochronological samples to avoid potential measuring errors and other complications that might emerge during further tree-ring analysis and cross-dating.

The second step was dendrochronological analysis following standard dendrochronological practices (Baillie, 1982; Schweingruber, 1988). Firstly, we measured the tree-ring widths preserved in each of the three samples to 0.01 mm using the Time Series Analysis and Presentation Software (TSAP-Win) (Rinn, 2011) and a LINTAB measuring table

Fig. 5. The LBA wooden water-drain installation in the right rear corner of the spring chamber of Oymaağaç Höyük/Nerik (Photo: Oymaağaç Project, D.P. Mielke).

[2] 14C dates were calibrated with OxCal 4.4.4 (Bronk Ramsey, 2009) and IntCal20 Curve (Reimer et al., 2020).

Fig. 6. Dendrochronologist Tomasz Ważny sampling the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik with a 5 mm increment borer in 2019 (Photo: Oymaağaç Project, D.P. Mielke).

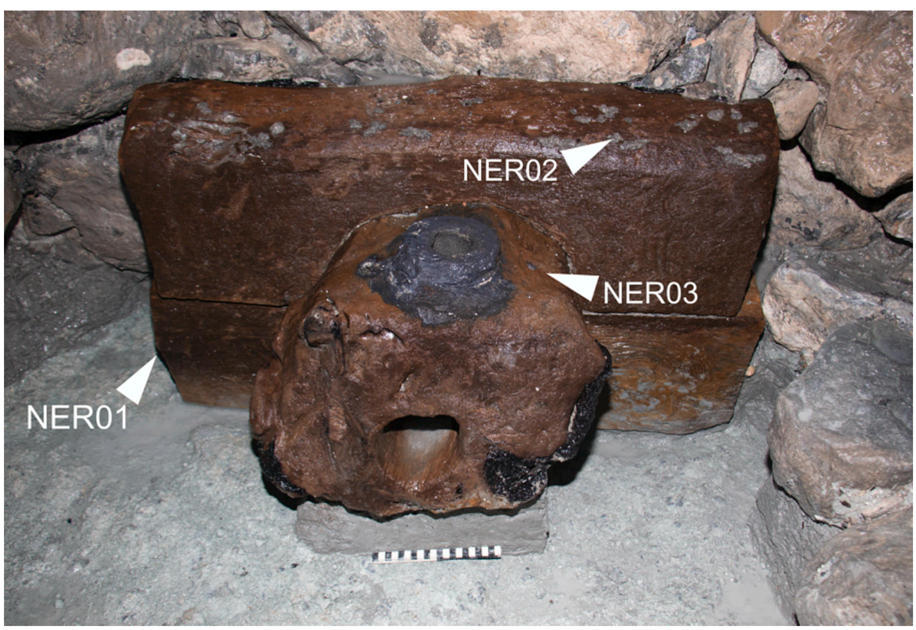

Fig. 7. Dendroarchaeological sampling spots on the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik (Photo/Graphic: Oymaağaç Project, D.P. Mielke).

(Rinntech Inc. Heidelberg, Germany). We then compared our ring-width measurements from each sample to one another to build a mean "floating" chronology, a tree-ring chronology whose beginning- and end-dates are not known. Finally, we synchronised and cross-dated our newly built "floating" chronology against available reference chronologies covering the LBA period in Anatolia. We carried out both visual and statistical cross-dating using TSAPWin and evaluated our results based on the following parameters: 1) the concordance coefficient Gleichläufigkeit (Glk) (Eckstein and Bauch, 1969); 2) t-values after Baillie and Pilcher (TVBP) (Baillie and Pilcher, 1973) and Hollstein (TVH) (Hollstein, 1980); and 3) Cross-Dating Index (CDI), which combines 1 and 2 (Rinn, 2011). The common interval expressed by the number of overlapping years (OVL) was also considered as an influencing statistical parameter. For the visualization of our results, we used TSAP and DENDRO for Windows 10 (Tyers, 2004).

Following the dendrochronological analysis and the development of a floating chronology, we extracted three small samples from selected individual tree-rings of Sample NER01 and sent them for radiocarbon dating to the Laboratory of Absolute Dating in Cracow, Poland. The 14C dates obtained via Accelerator Mass Spectrometry (AMS) (Mook and

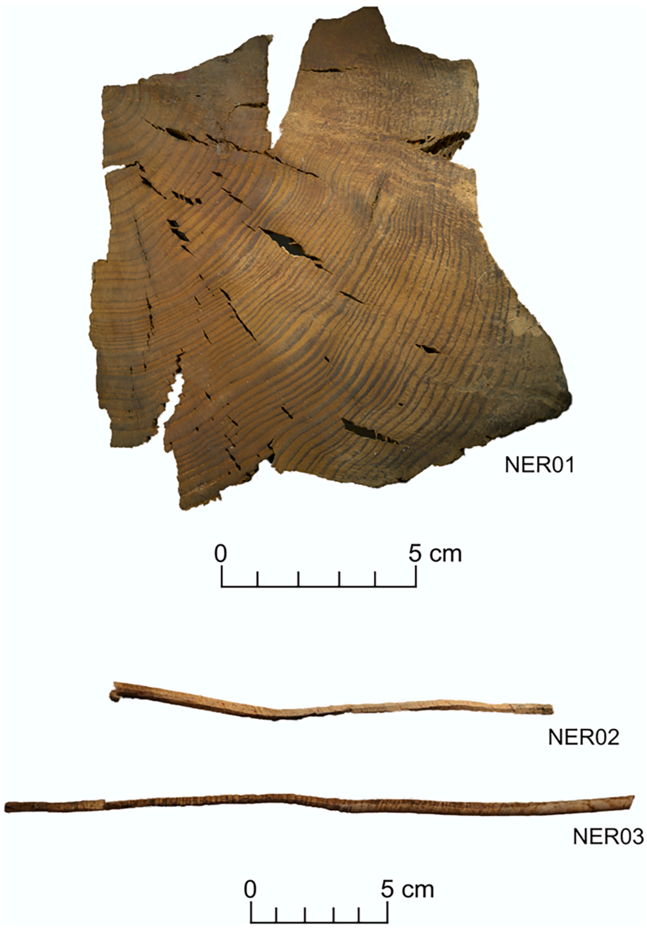

Fig. 8. Slice sample cut from the lower trunk, NER01, after preparation of its surface for tree-ring analysis in the laboratory and the two drilling cores, NER02, collected from the upper trunk, and NER03, collected from the middle trunk of the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik (Photos: BAD Project, A. Christopoulou and P. Matulewski).

Waterbolk, 1985) in this laboratory were calibrated against the IntCal20 (Reimer et al., 2020) calibration curve using OxCal v 4.4.4 program (Bronk Ramsey, 2009; Bronk Ramsey, 2001). Lastly, we applied wiggle-matching modelling (Bronk Ramsey, 2001)[3] on the calibrated dates, a method which provides the age determination of a sequence/chronology with higher precision than 14C dates alone (Pearson, 1986; Bronk Ramsey et al., 2001). The same methodology has been successfully applied in previous studies within Eastern Mediterranean archaeology (e.g., Gmińska-Nowak et al., 2021).

4. Results and Discussion

4.1. Wood identification and general characteristics of the samples

Wood anatomical characteristics of the examined samples clearly show that all the three wooden elements of the installation were made of *Pinus brutia* Ten., also known as Turkish or Calabrian pine (Fig. 9). The characteristic features of *Pinus brutia* are resin canals, cross-fields with one to four pinoid pits, and ray tracheid with clearly visible dentate walls, as observed in the radial section (Fig. 9a). The number of rays per 1 mm^2 observed in the tangential section was less than 70 while the height of the rays varied from 1 to 15 cells (Fig. 9b) (Akkemik and Yaman, 2012: 40-43).

Generally, it is hard to distinguish *Pinus brutia* from *Pinus halepensis* Miller (Aleppo pine) on the basis of their wood anatomy (Akkemik and Yaman, 2012). Nevertheless, the presence of *Pinus brutia* is much more likely in the case of Oymaağaç Höyük, given its current natural distribution, covering mainly Türkiye, Crete, Cyprus, Syria, Lebanon, with some patches in Iraq and Iran, whereas *Pinus halepensis* is concentrated in the western part of the Mediterranean basin (Mauri et al., 2016), with small populations in Türkiye, southern Lebanon, Israel/Palestine, and northern Jordan (Liphschitz and Biger, 2001). *Pinus brutia* is commonly found along the Black Sea coast, expanding from the sea level up to 600 m (Kurt et al., 2012), sometimes forming old stands, reaching the age of almost 300 years (Kukarskih et al., 2020). Therefore, we can assume that similar old stands of *Pinus brutia* were also available in the area surrounding Oymaağaç Höyük and its timber could have been obtained locally in the past. Small *Pinus brutia* stand growing around the höyük additionally supports this assumption.

To date, there are no vegetation-historical analyses from the region around Oymaağaç Höyük that would provide information about the climate and vegetation in the LBA. Today, the region is characterised by a sub-humid, Mediterranean climate with summer-green sub-Mediterranean mixed oak forests (*Carpino-Quercetum cerridis*). It is assumed that this was also the natural vegetation of the last 4000 years (Kürschner, 2006). Anthracological studies of charcoal remains from the excavations at Oymaağaç Höyük have shown that *Pinus* sp. (pine) is the most common tree species among the wood types used in the Late Bronze and Iron Ages, accounting for nearly 40% of the total (Riehl and Marinova-Wolff, 2011: 209–210; Hahn, 2013: 70, Fig. 7; Rössner et al., in press). In the presumed natural vegetation, however, pines would only account for a small proportion. Therefore, the anthracological studies would indicate a deliberate preference for pinewood by the LBA settlers of Oymaağaç Höyük. Nevertheless, no statement can be made from the charcoal remains about the former utilisation of the wood. Regarding the wood used for the water-drain installation, the current available information indicates that *Pinus brutia* was probably not one of the dominating species during the LBA in the not yet deforested neighbourhood of the settlement. Instead, its use likely reflects a deliberate selection based on its specific characteristics.

The fairly durable wood of *Pinus brutia* is currently used as sawn wood in carpentry and to produce structural elements for house building and infrastructure, such as telephone posts and railway sleepers (Farjon, 2010). Thanks to its mechanical properties and broad availability, it has also been widely used in shipbuilding since the Bronze Ages until recent times (Liphschitz and Pulak, 2007; Akkemik, 2015; Ingram, 2018). Both Turkish and Aleppo pine are considered to have lower quality timber than some pine species growing in higher altitudes, and therefore also used as firewood and charcoal (Meiggs, 1982; Lorentzen, 2015; Mauri et al., 2016). The use of pine logs as piping or sewer in water supply systems has also been common across the world until recently (Cembrzyński, 2011; Broda et al., 2021). *Pinus brutia* was used for the spring chamber in Oymaağaç Höyük most probably because of its local availability, straight growth, and durability in a continuously wet environment. The close proximity of the höyük to densely wooded Pontic Mountains where *Pinus brutia* supposedly grew in the Bronze Ages makes a local origin highly likely.

4.2. Dendrochronological analysis and radiocarbon dating

The number of rings in the three samples collected from the installation ranged from 138 to 182 (Table 1). This shows that the trees were rather old when they were cut. Both statistical and visual cross-matching of Samples NER01 and NER02 representing the lower and upper blocks of the installation indicate that they were cut from the same tree (Fig. 10). Besides this, in the case of Samples NER02 and NER03 the bark edge was present.

[3] See Bronk Ramsey (2001) for further description of this technique and its mathematical background.

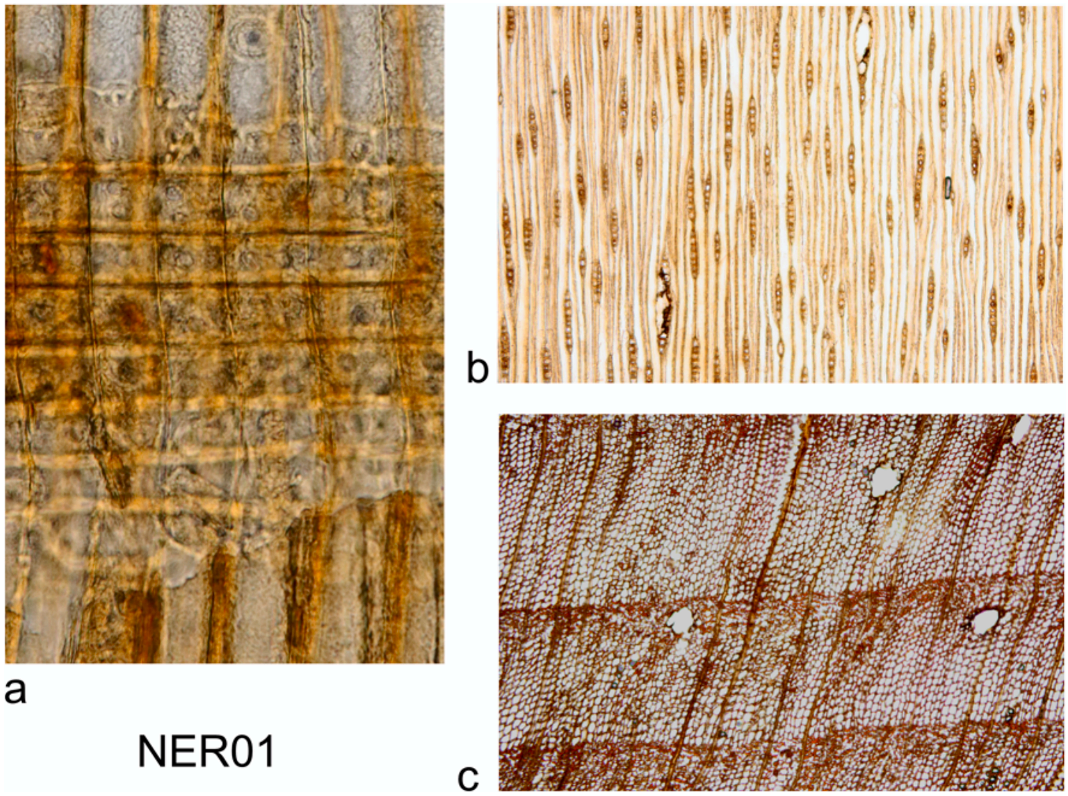

Fig. 9. Microscopic wood anatomy of Sample NER01 from the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik. Radial (a), tangential (b) and cross-section (c). Ray with visible pinoid pits in the cross-fields (a). The species of this sample is *Pinus brutia* (Turkish pine) (Photos: BAD Project, T. Ważny).

Table 1
General characteristics of the wood samples from the Late Bronze Age (LBA) installation found in the spring chamber of Oymaağaç Höyük/Nerik.

Sample ID	Excavation Code	Wood Type	Ring Series	Number of Rings	Bark Edge	Relative Begin Year / Innermost Ring	Relative End Year / Outermost Ring
NER01 (slice from lower block)	8086:17:4	Pine	NER0001	138	No	21	158
NER02 (core from upper block)	8086:17:2	Pine	NER0002	147	Yes	36	182
NER03 (core from trunk)	8086:17:3	Pine	NER0003	182	Yes	1	182

The high number of tree-rings in each of the three samples permitted us to cross-date their ring series and build a mean chronology with a total length of 182 rings (Fig. 11). This 182-yearlong floating chronology was coded as NER-Pine-05 in continuation of previously built sequences (see below). The three samples, or the three elements of the LBA wooden installation, from the spring chamber were contemporary. Nevertheless, NER-Pine-05 could not be absolutely dated because there are no available *Pinus brutia* reference chronologies for Anatolian Bronze Age and the broader area. For Anatolia, the only available long-term tree-ring chronologies covering the second millennium BCE have been built from juniper species (*Juniperus* spp.) since the late 1990s (Kuniholm et al., 2011: 79–122). Our Oymaağaç Höyük *Pinus brutia* sequence shows no similarity with this, nor with any of the existing dendro-chronologies from Anatolia (Kuniholm et al., 1996; Kuniholm et al., 2011). The wood structure of the installation indicates that the analysed trees grew steadily and slowly in a fairly dense forest. The average tree-ring width of our samples is only 1.06 mm, which is relatively small for *Pinus brutia* as we know it today.

Prior to our dendroarchaeological study at Oymaağaç Höyük, the Cornell Tree-Ring Laboratory under the direction of Sturt Manning had also analysed several wood samples from the site. In one of the initial examinations, the Cornell team was able to create a combined pine sequence, the Oym sequence, comprising 88 annual rings using two charred wood remains from the younger temple at Oymaağaç Höyük (Manning et al., 2016: 98–103). One sample was identified as *Pinus brutia* (Cornell sample Oym-3), the other as *Pinus nigra* (Cornell sample Oym-4). The calculated placement via radiocarbon dating and wiggle-matching of the last ring in this sequence was 1261–1229 BCE with 95.4% (2σ) probability (calibrated with OxCal 4.2.4 (Bronk Ramsey, 2009) and IntCal13 curve (Reimer et al., 2013)). Later, another sample of *Pinus nigra/sylvestris* with 90 preserved rings (Cornell sample Oym-22) was dated via radiocarbon dating and wiggle-matching, providing the time span of 1612–1542 BCE with 95.4% (2σ) probability for the last ring (Manning et al., 2019: 174–175). Intensive and detailed analyses resulted in the Cornell sample Oym-50, a round and almost complete cross-section with 77 annual rings of a *Pinus brutia* trunk from the deposited wood in the spring chamber (Manning et al., 2019: 161–178). The calculated timespan for the last growth ring beneath the bark via

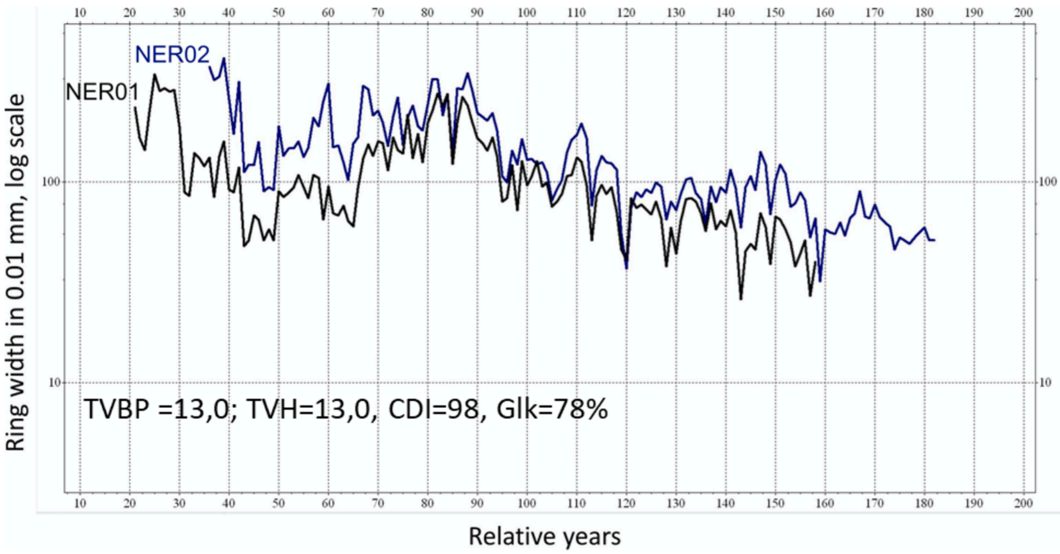

Fig. 10. High visual similarity and statistical agreement of cross-dating of the tree-ring curves of Samples NER01 (black) and NER02 (blue) from the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik indicate that the two timbers most probably originate from the same tree (Graphic: BAD Project, A. Christopoulou).

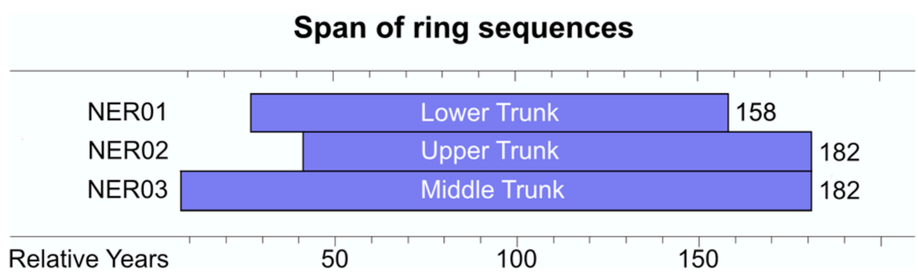

Fig. 11. Relative dating of the three wood samples, NER01–03, collected from the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik (Graphic: BAD Project, Y. Özarslan and A. Elzanowska).

radiocarbon dating and wiggle-matching was 879–814 BCE with 95.4% (2σ) probability. Close to this date range is another *Pinus nigra/sylvestris* sample with 46 annual rings from the Iron Age settlement at Oymaağaç Höyük (Cornell sample Oym-21) (Manning et al., 2019: 175). The last ring from this sample was dated between 885 and 813 BCE with 95.4% (2σ) probability. All samples were calibrated with OxCal 4.3.2 (Bronk Ramsey, 2009) and IntCal13 curve (Reimer et al., 2013).

Unfortunately, our NER-Pine-05 sequence from Oymaağaç Höyük/Nerik could not be cross-dated with any of these four disconnected pine sequences. Therefore, we used radiocarbon dating and wiggle-matching analysis. For this purpose, we extracted three small samples from selected individual growth rings representing specified rings/years of our NER-Pine-05 sequence and sent them out for radiocarbon dating (Table 2). The three 14C samples, coded as NERIK.28.1, NERIK.89.1, and NERIK.150.1, were extracted from Sample NER01, the slice cut from the lower block (Figs. 7 and 8). We then prepared an exact protocol of the position of the extracted rings and the distances in years between them. The samples and associated rings selected for wiggle-matching analysis are given in Table 2.

Table 2
Radiocarbon samples extracted from Sample NER01 for wiggle-matching analysis.

14C Sample No	Ring code on the NER-Pine-05 sequence	Ring code on the NER01 sample sequence	Years BP	Lab No
NERIK.28.1	28th	7th	3329 ± 22 BP	MKL-A4999
NERIK.89.1	89th	68th	3310 ± 24 BP	MKL-A5031
NERIK.150.1	149th, 150th, 151st	128th, 129th, 130th	3273 ± 22 BP	MKL-A5000

The individual radiocarbon ages for each ring are also given in Table 2. Wiggle-matching analysis revealed that the calibrated age of the youngest/outermost ring (182) of our mean sequence, NER-Pine-05, falls between the years 1511–1466 BCE (45 years) with a 68,3% (1σ) probability and the years 1525–1426 BCE (99 years) with a 95,4% (2σ) probability (Fig. 12). These results agree with the previously published absolute dating results from the upper block, dated to 1521–1420 BCE with a 95.4% (2σ) probability (Czichon and Mielke, 2020: 172–174). All these results confirm that the three wooden elements of the installation from the spring chamber of Oymaağaç Höyük were felled during the LBA sometime between 1525 and 1426 BCE, or roughly in the last quarter of the 16th or the first three quarters of the 15th century BCE.

4.3. Archaeological and historical implications

Based on the above dendroarchaeological results, the specific and also the broader historical background to the construction of the wooden installation at Oymaağaç Höyük/Nerik can now be further explored. The current state of research at the site shows that the construction of the entire underground complex took place at the same time as other larger buildings within the settlement, approximately at the beginning of the Hittite period during the 17th century BCE. This is clearly earlier than the determined dendrochronological date of the installation.

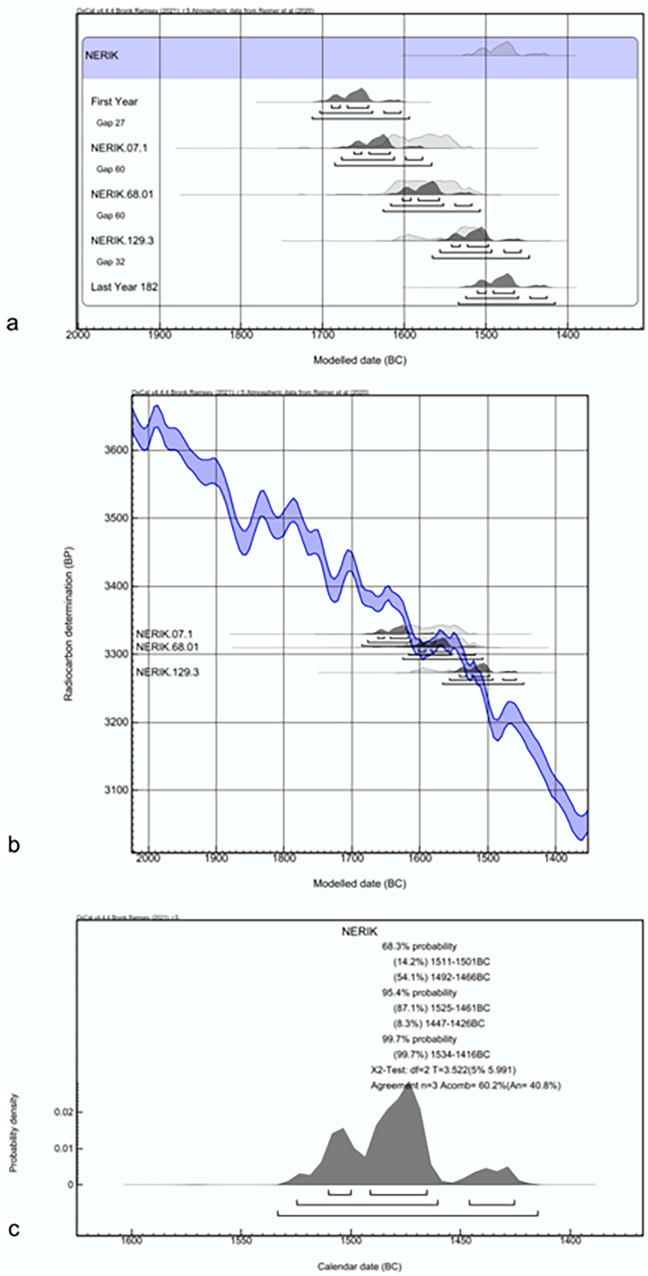

Fig. 12. Wiggle-matching results for the NER-Pine-05 sequence from the LBA wooden water-drain installation of the spring chamber of Oymaağaç Höyük/Nerik. All results are based on OxCal v 4.4.4 (Bronk Ramsey, 2009) and IntCal20 calibration curve (Reimer et al., 2020). a) multiple plot for the sequence analysis with the calibration of the first year of the radiocarbon samples from the rings NERIK.28.1, NERIK.89.1, NERIK.150.1 of Sample NER01 and the last outermost ring of the NER-Pine-05 sequence; b) multiple plot for the wiggle-matching placement of the radiocarbon samples from the rings NERIK.28.1, NERIK.89.1, NERIK.150.1 of Sample NER01; c) single plot showing the calibration of the outermost ring of the NER-Pine-05 sequence (Graphics: BAD Project, Y. Özarslan and A. Elzanowska).

Stratigraphically, the wooden installation is a renewal phase, as the floor stones of the basin in the rear area were removed to create space for the installation. The resulting absolute dating, 1525–1426 BCE, not only confirms this, but also falls into a period in which hardly any other major construction activities took place at Oymaağaç Höyük/Nerik. Historically, it is a phase in which the Hittites had major problems asserting themselves in the northern areas against the so-called Kaškaens (Mielke, 2022). Whether these people also had anything to do with the erection of the wooden installation must now be investigated in a broader context and with additional information. Regardless of this, the results presented here provide an important anchor for the diverse history of the LBA settlement of Nerik and the Central Black Sea Region.

5. Conclusion

The dendroarchaeological analyses presented here have yielded important insights for the dating and interpretation of the unique wooden installation from the underground spring chamber of Oymaağaç Höyük/Nerik. Wood anatomical and dendrochronological examination of the individual wooden elements of the installation show that the two blocks of the edging or enclosure come from one single tree trunk that was felled at the same time as the trunk that acted as a drainage pipe. Mature pine trees of considerable size were used as construction material. The identification of the tree species of all the elements of the construction as *Pinus brutia* shows that the locally available resources of the Central Black Sea Region were most likely utilised. The absence of false rings or intra-annual density fluctuations in the examined material likely indicates that the timber originates from a higher altitudinal zone. However, a more systematic study of *Pinus brutia* across the broader region would be necessary to make a more definitive conclusion.

The resulting absolute dates using dendrochronology in tandem with wiggle-matching analysis yielded a time span of 1525–1426 BCE with 95.4% (2σ) probability for the year the trees were felled. This not only confirms a previously established 14C date, but also provides a high degree of certainty in the absolute dating of this exceptional installation that single dating can ever yield. More precise chronological investigation faces the problem that no single dendrochronological reference chronologies are available for northern Central Anatolia. Therefore, our analysis can be seen as a step towards a regional reference chronology for pine, which, hopefully, can be extended by further research with new samples from Oymaağaç Höyük and other sites in the Central Black Sea Region, and could be absolutely dated via the available millennia-long juniper chronology from Central Anatolia.

CRediT authorship contribution statement

Y. Özarslan: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **D.P. Mielke:** Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Investigation, Conceptualization. **A. Christopoulou:** Writing – review & editing, Visualization, Validation, Formal analysis. **R.M. Czichon:** Writing – review & editing, Validation, Resources. **T. Ważny:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Funding acquisition, Formal analysis.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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