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Dendrochronological analysis and radiocarbon dating of charcoal remains from the multi-period site of Uşaklı Höyük, Yozgat, Turkey

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ABSTRACT

In the current study we use methods in dendrochronological dating, radiocarbon dating and wiggle-matching analysis to accurately date charcoal samples collected from the archaeological site of Uşaklı Höyük, Yozgat, Turkey. These data contribute to the understanding of the stratigraphical relationships in three different contexts of this multi-period mound. The examined charcoal materials were identified as cedar (*Cedrus* sp.) and oak (*Quercus* sp.). The analysis of the cedar samples resulted in establishing a floating chronology with a length of 49 rings. Further analysis of the material revealed that secure dendrochronological dating against the existing reference chronologies cannot be achieved for any of the Uşaklı Höyük samples selected for dendrochronology. This is due to the insufficient length of the developed mean chronology (49 rings), the shortness of single tree-ring sequences (max. 34 rings for cedar and 23 for oak) and the scarcity of reference chronologies that can be used for cross-dating. Therefore, we use radiocarbon tests and wiggle-matching analysis as the main dating method. Radiocarbon testing and further analysis of absolute dating of the charcoal pieces point to three different archaeological periods: the wooden post found in Room 433 of Building III is dated to the range of 1415 – 1363 BCE (2σ), confirming the assumption that it was an architectural element of the original construction of this Late Bronze Age/Hittite building. Radiocarbon dating results of charcoal pieces from the filling of Pit 330, 1008 – 905 BCE (2σ), can only be used tentatively and require cross-checking against additional samples and other organic material from the same context. The results of radiocarbon dating of charcoal samples associated with the Iron Age stone glacis built on top of Building III (763 – 486 BCE, 2σ) confirm that they are associated with the Iron Age occupation at Uşaklı Höyük.

1. Introduction

Central Anatolia and neighboring areas witnessed the rise and fall of major administrative centers and complex societal events during the course of the second millennium BCE due to reasons not fully understood. Recent archaeological survey and excavation work in the region, however, have been reshaping our knowledge about this dynamic time period by providing fresh new chronological evidence from a number of Bronze and Iron Age sites. Uşaklı Höyük is one such project that has been playing a key role in casting light upon the political and social context, particularly, of the territories once controlled by the Hittite rulers. In this paper we present new absolute dating evidence from Uşaklı Höyük that would shed further light on the chronology of the site and beyond.

The archaeological site of Uşaklı Höyük is a multi-period settlement located in the province of Yozgat in central Turkey, about 50 km from the Hittite capital, Ḫattuša (Fig. 1, Fig. 2). The site, composed of a high mound and a lower terrace covering an area of nearly 10 ha, was first identified by the 20th century archaeologists as a potential Hittite

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settlement (Gurney, 1995; Mazzoni and Pecchioli, 2015). Since 2008 an international team of researchers led by Prof. Stefania Mazzoni has been exploring different sections of the mound using systematic survey and excavation methods. This work has revealed that the site was occupied from the end of the third millennium BCE to the Common Era, experiencing multiple construction and destruction events at different scales (Mazzoni and Pecchioli, 2015; Mazzoni et al., 2019). Current evidence from its Late Bronze Age layers increasingly suggests that it may have been the sacred city of Zippalanda, mentioned in Hittite cuneiform texts (Mazzoni and Pecchioli, 2015).

During the 2015–2019 seasons a monumental building, Building III, in addition to domestic structures and a stone glacis built over the ruins of Building III were uncovered in Area D of Uşaklı Höyük (Fig. 3, Fig. 4). Although architecture and pottery strongly indicate a major Late Bronze Age settlement destroyed by intensive fire and a following Iron Age occupation built over its ruins (D'Agostino, 2020), further high-precision dating evidence was required to refine and consolidate our ideas about the periodization and chronology of these structures and associated contexts to better understand how they relate to each other and other contemporary sites in the region.

The primary aim of this study is to determine the age of a group of charcoal remains found in three different contexts in Area D, using dendrochronological dating method and radiocarbon analysis, in order to explore the stratigraphical and chronological relationships within these contexts. These data will test hypotheses about the foundation and use dates of the associated structures. Our secondary aim is to identify tree species chosen by the Bronze and Iron Age settlers of Uşaklı Höyük, specifically as construction material.

2. Material and methods

The material under study are charcoal remains collected from Area D

Fig. 2. Uşaklı Höyük and the location of Area D on the southern slope of the high mound (2015). View from the south-east. (Photo by A. D'Agostino).

of Uşaklı Höyük, where a monumental Late Bronze Age/Hittite building in addition to domestic structures and a stone glacis hypothetically of Iron Age date were uncovered (Fig. 3, Fig. 4).

We examined sixteen samples – single pieces and fragmented charcoals. Fourteen samples come from the Late Bronze Age/Hittite building. Single samples were found in two other contexts (Table 1).

Thirteen samples (including Sample 66 and Sample 68 – ten charcoals with common number, Sample 69 and Sample 71 – all related to Sample 66) come from a burned post excavated at the center of Room 433 in Building III (Area D, Square 015A4, US 425: Fig. 4). All of these samples come from the lower part of the burned post inserted in a posthole (Fig. 5). The original function of the element was to support the roof.

Sample 54 is a small fragment of charcoal from the layer of yellowish sand above the main layer filling of Building III (Area D, Square 015A4, US 411: Fig. 3).

Fig. 1. Location of the study area, Uşaklı Höyük (blue dot) and neighboring archaeological sites discussed in the paper (white dots). (Prepared by Y. Özarslan using an ArcGIS Online basemap). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 3. View of Area D from the south and the walls of Building III. (Photo by A. D'Agostino).

Sample 6 comes from the stone glacis dated to the Iron Age found in Area D, Square NI5-D3, US 87 (Fig. 6a and 6b).

Sample 36 is a fragment of charcoal from the filling of Pit 330. The pit cuts the remains of Building III; Area D, Square 014A4, US 331 (Fig. 7).

The study of the charcoals was a four-stage procedure. First, the samples were analyzed for tree species identification by observing characteristic features of the wood-anatomical structure. The second step was to perform a dendrochronological analysis for qualified samples. Then the material was selected and sent for radiocarbon dating. The last stage was the calibration of C14 age and the modelling of the results of radiocarbon dating using a wiggle-matching method.

The identification of wood species is based on the microscopic observation of the anatomical features of wood. Examined charcoals were hand-fractured in order to achieve radial, tangential, and cross sections, clear enough to observe anatomical features. Sections were observed under a biological microscope, OLYMPUS BX-43, under magnifications of x40, x100 and x200, in reflected light. As a reference material, we used the anatomy atlas of Schweingruber (1990) and the anatomy atlas of eastern Mediterranean species of Akkemik and Yaman (2012).

In addition to wood identification, the following features were observed: number of preserved rings, presence of pith and/or bark, ring curvature, presence of characteristic rings: wedging, false, and/or extremely narrow rings, scars, woodworm boreholes, fungal strains, and evidence of woodworking (Marguerie and Hunot, 2007; Crivellaro and Schweingruber, 2013; Rowell, 2013).

For the dendrochronological study we divided the samples into groups based on their archaeological provenance and the results of tree species identification. Then we examined the samples to determine the number of preserved rings and potential for dendrochronological research (Baillie, 1982; Eckstein et al., 1984). The width of tree rings was measured using LINTAB-TSAP Tree-ring measurement system. The tree-ring series representing different radii of the same sample were compared to verify the quality of the measurements and to assess possible growth anomalies. Then the datasets from each sample were compared with other samples from the same group to develop a mean chronology, representative for the group. Subsequently, we made attempts to cross-date the developed floating chronology against reference chronologies for the study area. The data analysis was carried out using TSAP-Win software (Rinn, 2011).

After dendrochronological analysis, we performed radiocarbon tests on three selected charcoal pieces. Four samples representing single rings were extracted and sent to the Laboratory of Absolute Dating in Cracow (Poland). The principle of radiocarbon dating is based on the calculation of the proportion of radioactive isotope 14C to stable carbon 12C in a sample of organic material. Calendar age is calculated from the radiocarbon date using the calibration curve. The accuracy of the method depends on the age of the tested organic matter and the type and quality of the material itself. In the case of wood, it is possible to achieve dating results with a precision of $\pm$ 20 years (Walanus and Goslar, 2009).

In the samples selected for radiocarbon dating the Accelerator Mass Spectrometry method (AMS) was applied (Mook and Waterbolk, 1985). Received radiocarbon dates were calibrated. For further analysis we applied wiggle-matching modelling. For both procedures we used OxCal v 4.4.2 program (Bronk Ramsey, 2009; Bronk Ramsey et al., 2001) and the calibration curve IntCal20 (Reimer et al., 2020). The wiggle-matching method can be used when there are at least two samples of an ascertained age difference. It provides higher precision than calibration of the C14 age of a single sample. While modelling, 14C dates of

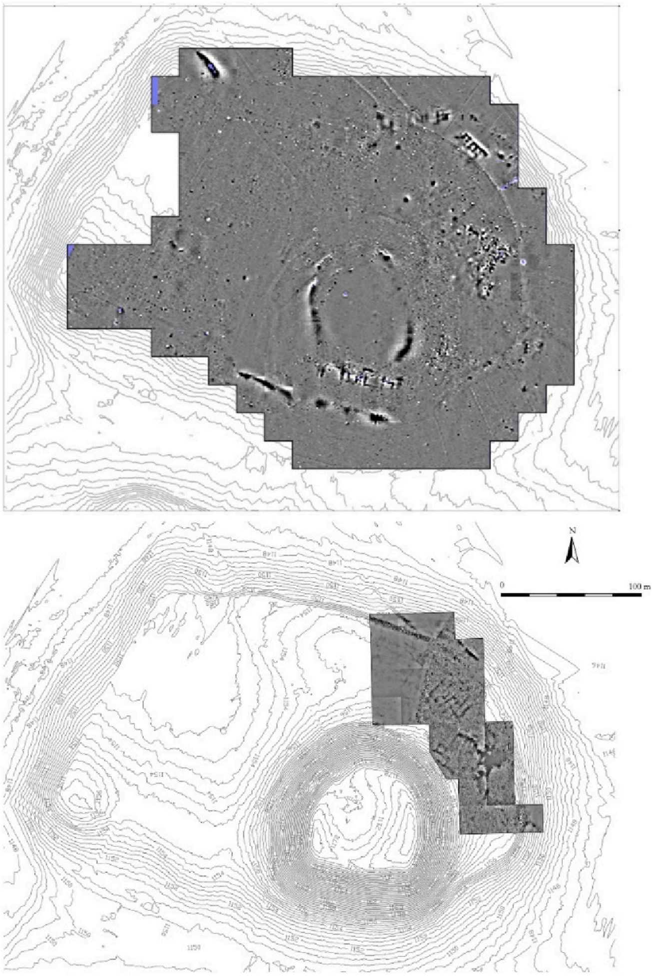

Fig. 4. Results of the 2008–2010 geophysical survey at Uşaklı Höyük with geomagnetic (top) and geoelectric anomalies (bottom). Building III is visible on the southern slope of the main mound. (Map by G. Carpentiero).

selected rings with specified positions in the sequence are fitted simultaneously to the shape of the calibration curve (Bronk Ramsey et al., 2001; Pearson, 1986). The wiggle-matching technique, together with its mathematical background, is described exhaustively by Bronk Ramsey (2001).

Table 1
Basic information about the received and selected samples under study.

Sample no.	Excavation description/ collecting date	Structure of the sample	Sample lab code
66	Area D, Square 015A4, US 425/ 18.06.2017 Fragment of the burned post	1 piece, full circumference of a trunk	USHO01
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO02
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO03
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO04
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO05
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO06
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO07
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO08
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO09
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO10
68	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	1 piece	USHO11
69	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	12 fragments	USHO12A USHO12B USHO12C USHO12D
71	Area D, Square 015A4, US 425/ 18.06.2017 Related to Sample 66	7 fragments	USHO13A USHO13B
54	Area D, Square 015A4, US 411/ 14.06.2017 Fragment from the layer above the main layer filling of Building III	1 piece	USHO15
6	Area D, Square NI5-D3, US 87/ 06.06.2016 Fragment from the stone glacis	1 piece	USHO17
36	Area D, Square 014A4, US 331/ 28.05.2017Fragment from the filling of Pit 330	1 piece	USHO14

3. Vestiges of a Major Fire Event in the Late Bronze Age

Uşaklı Höyük was intensively occupied in the course of the entire second millennium BCE, reaching its maximum extent and becoming an important settlement with urban characteristics (Mazzoni et al., 2019). This settlement shows clear evidence of monumental public architecture that can be attributed to the Hittite period, qualifying it as an important centre with administrative, political and economic functions. Quality of findings, size of settled area and sequence of occupation are of key reference for the region, placing Uşaklı Höyük among the major sites east of the Hittite capital, Ḫattuša at this time period. Remains of this period, belonging to large public buildings, have been exposed on the lower terrace and on the high mound that probably housed the citadel. Excavations on the southern slope of the mound (Fig. 3) revealed the external portion of an associated building, Building III.

Located at the ancient top of the mound, Building III is an imposing feature of the urban landscape and of reference for the countryside and paths crossing the valley. The sector exposed so far is constituted by two rows of rooms delimited by a perimetral southern wall made of granite boulders. The building masonry is in Hittite tradition. The walls – preserved for a few centimeters - are in mudbricks reinforced with a timber structure of which indirect evidence remains in some discontinuity at the base of the wall, directly on top of the stone foundation and by the effects of its combustion on the walls and floors at the time of the final fire that destroyed Building III.

Portions of a layer of whitish thick plaster that have been found on some walls and other fragments within the debris belonging probably to Building III bear traces of painted decoration. Floors are in clay or cobbled, but no material in situ have been uncovered. All this portion of Building III ended in a major fire event that burned the mudbricks of the walls and melted the clay floors (D'Agostino, 2020).

A large portion of the burned base of a wooden post (Sample 66, Fig. 5) was found in a post-hole in the middle of the clay floor of Room 433 that became vitrified due to this fire, in addition to other pieces partially lying in close proximity (Samples 68, 69 and 71). The architectural features excavated so far do not permit us to definitely consider the remains of Building III as a temple or a palace, but location, dimension, quality of construction and the use of granite boulders for the

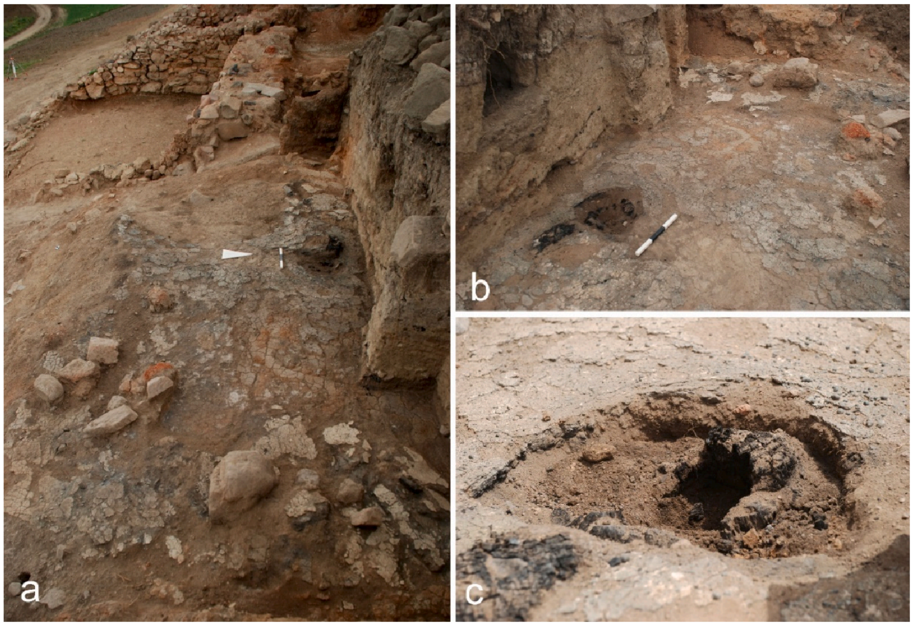

Fig. 5. Burned post excavated at the center of Room 433 of Building III (Area D): a – the location of the post-hole nearby the section of the excavation area in 2017 and some debris above the melted floor (from east); b, c – the element in situ. (Photo by A. D'Agostino).

Fig. 6. Stone glacis found in Area D. Sample 6 in situ: a – the corner of the wall partially dismantled and reused as glacis, b – Sample 6 between the stones of the inner portion of the glacis. (Photo by A. D'Agostino).

Fig. 7. Pit 330. The pit cuts the red burned filling of Building III and is covered by a layer with stone walls and open-air installations containing Alişar IV style potsherds. (Photo by A. D'Agostino). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

southern wall highlight its great importance. In addition, five fragments of clay tablets with cuneiform script found in secondary contexts, probably originated from the collapse of Building III (Orsi, 2020). This was a building of the Hittite settlement whose construction was probably planned by the central administration following a detailed project, including the procurement of appropriate beams.

The ruins of Building III collapse were partially removed while a new settlement was expanding on top of the mound. A sequence of layers documents a different type of use of this part of the site. Ordinary houses with open workspaces and pits, where Sample 36 was found in Pit 330, identify an Iron Age occupation lying directly on top of the erased walls of Building III (Fig. 7). This solid ground represented by its remains was used as a base for a large structure made of rough middle-sized stones (US 87) that encompasses the southern slope. The structure, having the shape of an escarpment of dry-stones partially fallen down, could have been constituted by the remains of a large wall – to which pertain a corner with some more regularly cut stones – reused as a rampart at a later time and intended to strengthen and fortify the citadel of the first millennium BCE. Fragments of charcoal have been found among the stones of this wall (Sample 6). These fragments belong to the timber originally used to reinforce or stabilize the structure.

4. Results

4.1. Tree species identification and characteristics of wood structure

Microscopic observation and analysis of anatomical features of charcoals resulted in the identification of two genera: cedar (*Cedrus* sp.; most likely *Cedrus libani* A.Rich.) – 14 samples and oak (*Quercus* sp.) – 2 samples.

Charcoals identified as cedar are: Sample 66 (lab code USHO01), Sample 68 (lab codes from USHO02 to USHO11), Sample 69 (USHO12) and Sample 71 (USHO13), which are all related to the burned post found at the center of Room 433 of Building III. Sample 54 (USHO15), which is not related to the post, is also cedar.

Since in Sample 66 (USHO01) the vast majority of the circumference of the trunk, the outermost rings, was considerably preserved (Fig. 8), it can be used to estimate the minimum original diameter of the post which is 31 cm. There is no bark nor clear bark edge preserved in the sample, so it can be assumed that the original diameter of the post could have been slightly larger.

Tree ring curvature observed in all of the charcoal pieces related to Sample 66 (USHO02 – USHO13) is similar and corresponds to the curvature of Sample USHO01. Tree ring curvature observed in Sample 54 (USHO15) suggests that the piece comes from the outermost part of the trunk.

In all cedar samples slight cracks in wood structure in radial direction can be observed. No woodworm boreholes, fungal strains, or any evidence for woodworking can be found. The growth pattern observed in all cedar samples can be qualified as regular. The charcoals contain some narrow and wider rings, but we did not observe extremely narrow rings, which would suggest disturbances or extremely difficult environmental conditions. At the same time in the studied cedar group, we observed one very characteristic feature: tangential rows of traumatic axial resin canals known to be caused by some injury of a tree or extremely low temperatures. In such cases the tree reacts to stress by producing traumatic resin canals from the cambium, usually of irregular size and shape, arranged in transition zone to latewood (Rowell, 2013; Krokene et al., 2008; Desch and Dinwoodie, 1996). Stoffel (2008) explained such wounding effect as a potential consequence of geomorphic events, such as debris flow, snow avalanches, or rockfall activity. Cedar is one of the species of conifers that normally do not produce axial and radial resin canal complexes, but can produce traumatic resin canals similarly to *Abies* species (Akkemik and Yaman, 2012).

Traumatic resin canals are present in the charcoal pieces, USHO05 (Fig. 9), USHO07, USHO08 (Fig. 10), USHO10, USHO12, and USHO13. Since there is no signal for extremely low temperatures in the growth pattern of the studied cedar samples, the presence of traumatic resin canals seems to be the effect of injury caused by debris flow, snow avalanches, or rockfall, which suggests that the wood must have come from a mountain area.

Samples 36 (USHO14) and Sample 6 (USHO17) represent *Quercus* sp. The characteristic of rays, as well as the arrangements of vessels of latewood suggest that both samples belong to the white oak group (Fig. 11, Fig. 12) and they could belong to *Quercus infectoria* Oliv., *Quercus pubescens* Willd., *Quercus robur* L. or *Quercus petraea* (Matt.) Liebl., which are all native in this region.

Sample 36 (USHO14) comes from the inner part of the trunk. The radius of this charcoal piece is 11 mm (14 tree rings). Yet, the analysis of tree ring curvature allows us to estimate the distance of the piece from the pith as 51 mm. Regular growth can be observed (Fig. 11). There are no scars, woodworm boreholes, or fungal strains.

Sample 6 (USHO17) has a radius of 12 mm (23 tree rings). The position of the piece in the trunk is very close to the pith – tree ring curvature suggests that the distance to the pith is around 13 mm. Inner rings are narrow and suggest disturbed growth during the first years of life of the tree (Fig. 12). There are no scars, woodworm boreholes, or fungal strains.

4.2. Determination of the age: dendrochronological analysis and radiocarbon dating

Dendrochronological analysis and radiocarbon dating were carried out separately for the following four groups/objects (based on the archaeological context and the results of tree species identification):

- Sample 66 and related pieces: burned post excavated at the center of Room 433 of Building III (USHO01-USHO13);
- Samples 54: fragment of charcoal from the layer above the main layer filling of Building III (USHO15);
- Sample 6: stone glacis (USHO17);
- Sample 36: filling of Pit 330 (USHO14).

4.2.1. Sample 66 and related charcoal pieces

The number of rings preserved in all charcoal pieces representing the

Fig. 8. USHO01: main part of the trunk registered as Sample 66. (Photo by B. Gmińska-Nowak).

Fig. 9. USHO05: tangential rows of traumatic axial canals. (Photo by B. Gmińska-Nowak).

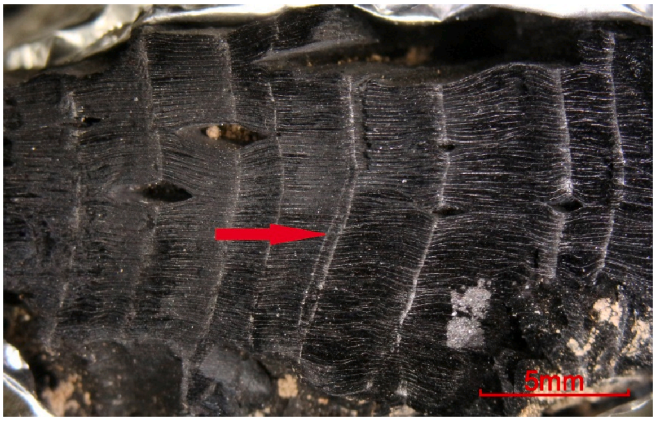

Fig. 10. USHO08: tangential rows of traumatic axial canals. (Photo by B. Gmińska-Nowak).

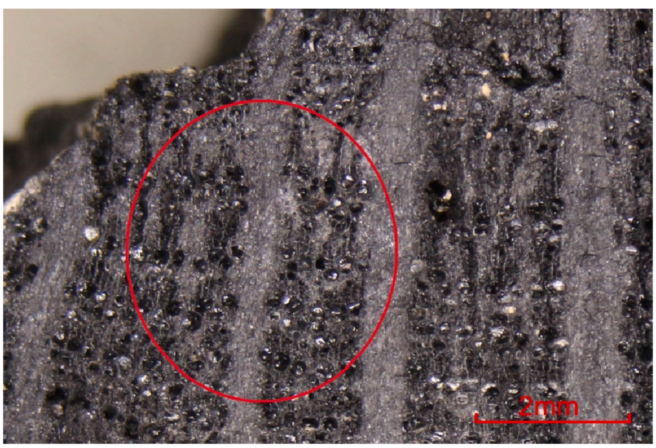

Fig. 11. Samples 36 (USHO14): white oak group. The arrangement of vessels of latewood is characteristic for this group. (Photo by B. Gmińska-Nowak).

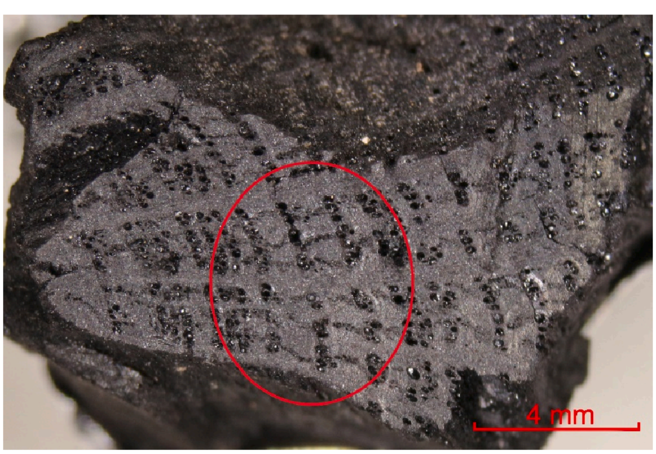

Fig. 12. Sample 6 (USHO17): white oak group; the flame-like arrangements of vessels of latewood. (Photo by B. Gmińska-Nowak).

burned post excavated at the center of Room 433 of Building III varied from 7 to 34 (see Table 2). It means that all series are too short to carry out a secure dendrochronological analysis using statistical evaluation (Baillie, 1982; Eckstein et al., 1984). Therefore, only a visual synchronization of graphs illustrating tree ring widths was possible. The simultaneous observation of graphs and charcoal pieces was very helpful

Table 2
Dendrochronological analysis and results of visual synchronization of cedar charcoal pieces representing the burned post excavated at the center of Room 433 of Building III.

Sample lab code	Measurement code	Number of measured rings	Included in average curve: Y/N	Position in chronology(49 rings)
USHO01	USHO01A	34	Y	10–43
	USHO01B	30	Y	10–47
USHO02	USHO02A	24	Y	17–40
	USHO02B	25	N	–
USHO03	USHO03A	17	Y	11–27
	USHO03B	17	Y	11–27
USHO04	USHO04A	25	Y	9–33
	USHO04B	25	Y	9–33
USHO05	USHO05A	17	Y	9–25
	USHO05B	17	Y	9–25
	USHO05C	18	N	–
	USHO05D	19	N	–
USHO06	USHO06A	19	Y	13–31
	USHO06B	19	Y	13–31
USHO07	USHO07A	12	Y	0–11
	USHO07B	12	Y	0–11
USHO08	USHO08A	10	Y	4–13
	USHO08B	10	Y	4–13
USHO09	USHO09A	16	Y	33–49
USHO10	USHO10A	14	N	–
	USHO10B	15	N	–
	USHO10C	13	Y	24–36
USHO11	USHO11A	7	Y	27–33
USHO12A	USHO12A1	15	Y	16–30
	USHO12A2	15	Y	16–30
USHO12B	USHO12B1	14	Y	29–42
	USHO12B2	15	Y	29–43
USHO12C	USHO12C1	15	Y	28–42
USHO12D	USHO12D	17	N	–
USHO13A	USHO13A	11	Y	5–15
USHO13B	USHO13B	10	Y	27–36

in the process of fitting all pieces in the right position in the trunk. All pieces belonging to Sample 66 were compared with the sequence USHO01, representing the sample that preserved about 50% of full radii trunk – its outermost part (Fig. 8). The analysis resulted in establishing a floating cedar chronology, USHO66_m, with a length of 49 rings (Fig. 13) developed from 16 charcoal pieces and 25 measured sequences (Table 2).

Attempts were made to cross-date the developed cedar floating chronology, USHO66_m, against existing reference chronologies shown in Table 3. Nevertheless, we did not obtain any significant results. The limitation is not only the low number of reference chronologies, but also the length of the Uşaklı cedar chronology, which is not sufficient for reliable synchronization.

From the group of charcoal pieces representing the burned post, two annual radiocarbon samples were selected for C14 tests: the first and the last (49th) ring of the chronology USHO66_m (Fig. 14).

The results of the absolute dating for the first ring are 3165 $\pm$ 20 BP while the 49th ring's age was determined as 3085 $\pm$ 21 BP. Calibration of the radiocarbon age of the last ring of the chronology, USHO66_m, results in a range of 98 years: between 1406 and 1303 BCE, with a probability of 68.3% (1σ), and 1417 – 1284 BCE, with a probability of 95.4% (2σ). Therefore, the span of possible dating is either 104 years (1σ), or 134 years (2σ).

To reduce the calibrated time range, wiggle-matching analysis was carried out using information on the order of the measured tree rings as statistical constraints. Analysis was done in a Bayesian statistical framework through the *D_Sequence* function in OxCal. The result of the analysis is provided in Fig. 14. The model showed agreement index (A_{comb}) of 118.3% - above the minimum acceptable threshold of 50% (corresponding to $1/\sqrt{2n}$, n being the number of measurements) (Bronk Ramsey, 1995).

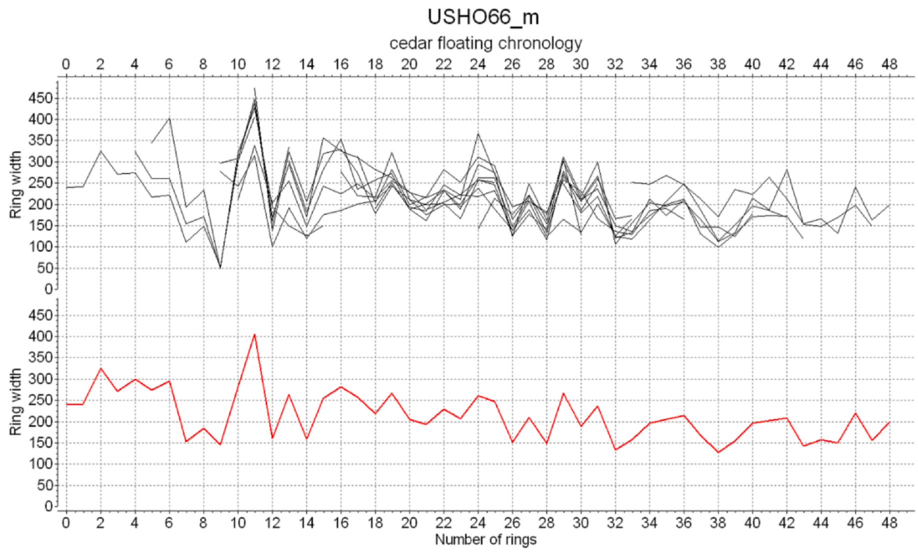

Fig. 13. Development of the floating Uşaklı cedar chronology, USHO66_m. Series worked out from the charcoal pieces belonging to Sample 66 (upper graph) and the mean chronology (red curve) (TSAP-Win; Rinn, 2011). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Reference chronologies used for dendrochronological dating of the Uşaklı cedar chronology, USHO66_m.

Code	Area	Authors	Tree species	Length	Time span
IronBronzeJun	Anatolia – multiple sites including: Gordion (main component), Kültepe, Acemhöyük, Ayanis, Kuşaklı, Karahüyük, Porsuk/Zeyve Höyük, Ankara (pines), plus Agora (Athens)	Kuniholm and Newton, unpubl.	*Juniperus* spp. (main component), *Cedrus libani* A.Rich, *Pinus nigra, Pinus brutia* Ten.	1979	2651–673 BCE
JunBronz	Anatolia - multiple sites including: Kültepe, Acemhöyük, Ayanis, Kuşaklı, Karahüyük, Porsuk/Zeyve Höyük, Kaman Höyük and Tille Höyük, Ankara (pines), plus Agora (Athens)	Kuniholm and Newton, unpubl.	*Juniperus* spp. (main component), *Cedrus libani* A.Rich, *Pinus nigra, Pinus brutia* Ten.	1575	2247–673 BCE
Gordion1	Gordion	Kuniholm et al. 2011	*Juniperus* spp.	1028	1767–781 BCE

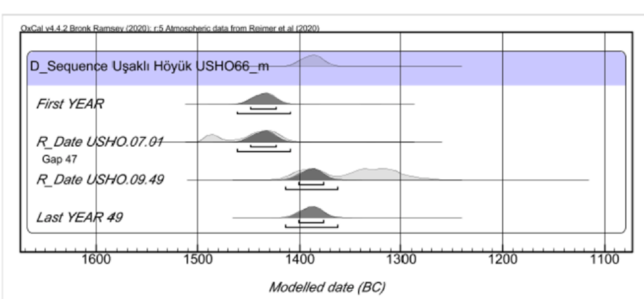

Fig. 14. Calibration of the age of the USHO66_m chronology. Wiggle-matching modelling – multiple plot: OxCall v 4.4.2 (Bronk Ramsey, 2001), calibration curve IntCal 20 (Reimer et al., 2020).

The wiggle-matching analysis significantly reduced the span of the calibrated age of the chronology. The final result of dating of the youngest (most recent) ring in the USHO66_m chronology is in the range of 25 years: **1401 – 1377 BCE**, with a probability of 68.3% (1σ), and in the range of 53 years: **1415 – 1363 BCE**, with a probability of 95.4% (2σ) (Fig. 14, Fig. 15).

Since there is no bark preserved in Sample 66, the obtained dating result of its outermost ring need to be considered as a minimum date for when the tree was cut and a *terminus post quem* for the timber's use as a post.

4.2.2. Sample 54

Two series were measured for Sample 54 (USHO15). The series have

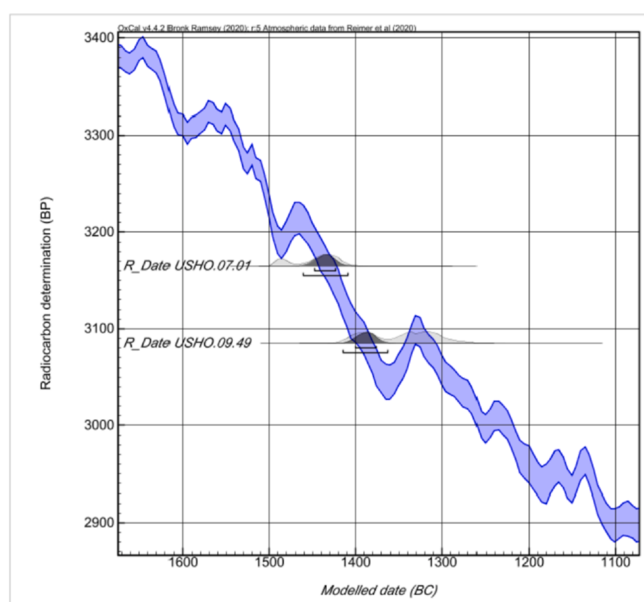

Fig. 15. Calibration of the age of the USHO66_m chronology. Wiggle-matching modelling – curve plot: OxCall v 4.4.2 (Bronk Ramsey, 2001), calibration curve IntCal 20 (Reimer et al., 2020).

a length of 19 and 20 rings. They could be visually synchronized with the USHO66_m mean chronology. However, since the sample does not belong to Sample 66 in the excavation records, it was not included in the newly developed chronology – the length of the series is not sufficient for secure interpretation of the origin of this charcoal piece and/or its relation to the post (Sample 66).

4.2.3. Sample 36

The number of preserved tree rings in Sample 36 (USHO14), the oak piece from the filling of Pit 330, is 14, which makes it sufficient neither for dendrochronological analysis nor for wiggle-matching. The only dating method that could be applied to this charcoal piece is radiocarbon testing with further calibration.

The result of the absolute dating of the outermost ring preserved in this charcoal piece is 2802 ± 19 BP. The calibrated age is in the range of 64 years: **984–921 BCE**, with a probability of 68.3% (1σ), and in the range of 104 years: **1008 – 905 BCE**, with a probability of 95.4% (2σ) (Fig. 16). Since Sample 36 comes from the inner part of the trunk, the obtained dating result of its outermost ring gives only a *terminus post quem* for the timber's use at the site.

4.2.4. Sample 6

The number of preserved tree rings in Sample 6 (USHO17), the oak piece associated with the Iron Age stone glacis built on top of the Late Bronze Age Building, is 23, which is not sufficient for cross-dating against the existing reference chronologies. Moreover, concerning the dendrochronological analysis of the two oak samples, the limited number of rings preserved does not allow for synchronizing them with each other either by statistical evaluation, or by visual cross-matching.

Since the sample is suitable for neither dendrochronology nor wiggle-matching, we performed radiocarbon testing with further calibration. The results of the absolute dating for the youngest ring preserved in this charcoal piece is 2474 ± 20 BP. Due to the fact that the sample falls on the Hallstatt plateau, covering **800–400 BCE** (Becker and Kromer, 1993), its calibrated age is in wide ranges: **763–543 BCE**, with a probability of 68.3% (1σ), and **763 – 486 BCE**, with a probability of 95.4% (2σ) (Fig. 17). Moreover, since Sample 6 comes from the inner part of the trunk, close to the pith, the obtained dating result of its outermost ring gives only a *terminus post quem* for the timber's use at the site.

5. Dating of tree-rings and Uşaklı Höyük Stratigraphy

The examination of charcoal samples collected from the archaeological site of Uşaklı Höyük has provided important information about the nature and age of a group of wooden remains from Area D and stratigraphical relationships in three different excavation contexts.

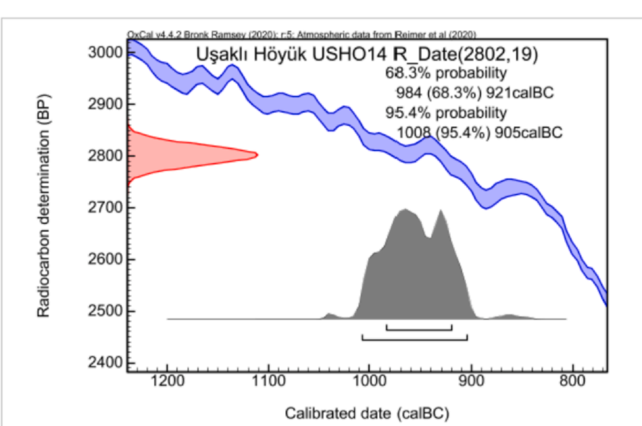

Fig. 16. Calibration of the age of the last ring of the USHO14 sample. OxCall v 4.4.2 (Bronk Ramsey, 2001), calibration curve IntCal 20 (Reimer et al., 2020).

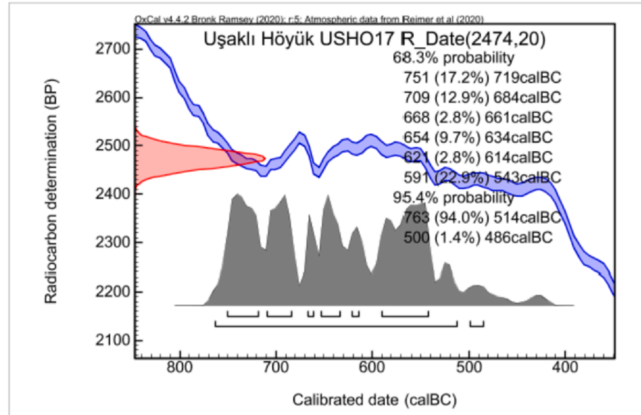

Fig. 17. Calibration of the age of the last ring of the USHO17 sample. OxCall v 4.4.2 (Bronk Ramsey, 2001), calibration curve IntCal 20 (Reimer et al., 2020).

The analysis of the material revealed that secure dendrochronological dating against the existing reference chronologies cannot be achieved for any of the samples selected for dendrochronology. This is due to the very short tree-ring sequences (max. 34 rings for cedar, and 23 for oak) and the few reference materials that can be used for cross-dating. Therefore, the developed floating cedar chronology needs to be extended to increase the possibility of secure cross-dating against the existing reference chronologies. *Cedrus* species are suitable for dendrochronology: they are generally long-lived species; their ring boundaries are rather distinct, and the transition from early wood to latewood is usually continuous (Schweingruber, 1993).

Radiocarbon testing and further analysis of absolute dating of the selected charcoal pieces provided significant information, especially about the wooden post found in Room 433 of Building III, represented by the USHO66_m chronology. The results (**1415 – 1363 BCE**, 2σ) indicate that the post could be securely dated to the Late Bronze Age/Hittite Period. They also confirm that the post was an element of the original construction of the building. In terms of the archaeological sequence, the inventory of artefacts lying on the building floors is too limited to offer a sound reference for the Building III phase of use, but the ceramic inventory from the foundation levels supplies a reference *post quem* for the building's construction. The assemblage, which includes samples ranging from the Early Bronze to Late Bronze Age, testifies to post-depositional events already occurring in ancient times, but the most recent set of materials, most closely related to the building's construction, has been hypothesised to be settled between the 15th and 14th centuries BCE, or slightly earlier (Orsi, 2020). Considering the degree of continuity recorded in the Hittite ceramic sequence, the use of pottery is remarkably challenging for investigating chronological issues (Mielke, 2010; Schoop, 2006). The dating of Sample 66, which falls between the middle and late phase of the Hittite ceramic sequence (for which see Schoop 2011: 242-243), confirms and refines our preliminary suggestions: it implies that the presence of materials from the first half of the 14th century BCE in the building's foundations is possible while the presence of materials from the second half of the 14th century and the 13th century BCE should be definitely excluded. Moreover, the dating offers a reference for the chronology of residual Late Bronze Age materials found in Area D and C Iron Age contexts (Orsi, 2020).

The interpretation of the results of radiocarbon dating for Sample 36 (USHO14) requires special attention. Given the size of the samples and due to the fact that it is not possible to determine the original size of the trunk and the number of missing outermost rings, the results (**1008 – 905 BCE**, 2σ) can only be used tentatively and require cross-checking against additional samples and other organic material from the same context. In terms of the sequence of occupation at the site, the dating of Sample 36 between the end of the 11th and 10th centuries BCE would confirm an Early Iron Age occupation at the site, a period scarcely attested in North Central Anatolia and until now hypothesised at Uşaklı on the sole basis of pottery comparison (Orsi 2020). The presence of a typical red painted potsherd in the same context (U17.319) would further confirm the association of this peculiar ceramic typology with this chronological phase. Moreover, although post-depositional events seem to have deeply affected the depositional sequence of the area, Sample 36 may represent *a terminus post quem* for the appearance of typical Alişar IV style pottery at Uşaklı Area D, whose earliest examples appear within the layers above Pit 330 (Fig. 7). Although mainly considered a marker of the Middle Iron Age period, in fact, the dating of this peculiar ceramic production in North Central Anatolia is largely debated (Orsi, 2019).

The results of radiocarbon dating for Sample 6 (USHO17) associated with the Iron Age stone glacis built on top of the Late Bronze Age building are not precise due to the Hallstatt Plateau (**763 – 486 BCE**, 2σ), but its dating between the 8th and the first half of the 5th centuries BCE finally confirms the attribution of the stone glacis and associated activities to the Late Iron Age period or to the very late phase of the Middle Iron Age.

The absolute dating results obtained through Uşaklı Höyük charcoals are significant in two aspects: First of all, the presence of a precisely dated burned post found in situ inside a Hittite public building allows us to fit our stratigraphic sequence and associated findings within an absolute chronological framework. Secondly, the identification of cedar used as construction material provides a rare evidence for the use of this type of wood in Bronze Age architecture. The absolute dates also help us accurately document a building project carried out between the end of the 15th and the beginning of the 14th centuries, a period characterised also by increased political crisis and military difficulties in Central Anatolia according to written sources (Bryce, 2005; Klengel, 1999). Furthermore, the analysis of Uşaklı charcoals provides us with fresh and potentially contrasting evidence from the south-east of the Hittite capital, Ḫattuša, where authorities were still organised and equipped enough to conduct new monumental projects.

6. Use of Cedar and its Archaeological Implications

Wood identification informed us about the types of wood used at Uşaklı Höyük, its possible resources, quality of building materials and thus indirectly – about the status of the buildings. It revealed that cedar was used by the Late Bronze Age settlers of the site. The large use of wood is typical of the building technique of the Anatolian uplands (Naumann, 1971) and cedar was among the different species chosen for architectural purposes although there is a rarity of remains. This is probably because it was not locally available and easily accessible in most cases (Miller, 1999). Although rare, cedar remains are known from several Anatolian Bronze and Iron Age settlements, and usually from élite contexts (Kayacık and Aytuğ, 1968; Simpson, 2010). In Hittite architecture, large beams were demanded for roofs, their support, and wall frames. A particular use of construction wood is known from Ortaköy (Fig. 1), ancient Šapinuwa, one of the main Hittite centers, where cedar logs of about one meter in diameter – probably of local origin – were used in relation to the floors of the monumental Building A where royal seals were discovered (Süel, 2002, 1998). From an archaeological perspective such cases show us that cedar was deliberately chosen and used in architecture and furniture manufacture by élite members of ancient Anatolian societies despite the difficulties in its acquisition.

Cedar as construction material in public buildings could have also had an underlying and evocative meaning. Hittites appreciated cedar as aromatic substance and for medical purposes and believed that cedar tree was sacred and its use with the intend to purify and sacralize a place is documented in various rituals (Christiansen, 2006; Mouton, 2008; Turgut, 2019). Written sources indicate that such rituals were performed in connection with the construction of the building; they also mention that the wood was granted from gods to the king (Beckman, 2010; Torri, 2012). In the context of Uşaklı Höyük, we can speculate that the fragrance emanating from the cedar posts of a newly built structure may tell us about a 'scentscape' perceived as ritual, an environment that could assume religious significance and where the divine presence was imminent. The presence of a cedar post in Building III of Uşaklı Höyük can offer more evidence for the use of this wood in situ and in relation to an important public building of Hittite date.

The growth pattern analysis and the detection of traumatic resin canals in the studied charcoal pieces suggest that the cedar wood used at Uşaklı Höyük must have come from a mountain area. Uşaklı Höyük is located about 200 km north of the Taurus mountain range in southern Anatolia, an area of natural distribution of *Cedrus libani* (Aytar et al., 2011). Patches of cedar forests are also present in the cities of Erbaa and Niksar of the province of Tokat in just north of Yozgat (Akkemik, 2020), also which could be their possible origin. The distribution of the species in the past, however, could be completely different from the current one (Rogers and Kaya, 2006, Akkemik et al., 2012). Today the landscape around Uşaklı Höyük is characterised by extended agricultural fields and small orchards only in proximity to sparsely delineated small villages, lines of trees mainly along small creeks, and large spaces without signs of intense activity, or human presence, partly with some paths crossing them. In ancient times, this area, as well as wide portions of the Central Anatolian plateau would have been covered by large woodlands (van Zeist and Bottema, 1991; Wright et al., 2015; Woodbridge et al., 2019) that underwent intense deforestation over the course of the following centuries for obtaining grazing lands, fields for agriculture and construction timber. In any case, the presence of cedar, whether local or imported, at Uşaklı Höyük indicates that its Late Bronze Age settlers must have had enough economic resources and social motives to acquire and transport cedar during a time of changing fortunes.

7. Conclusion

The analysis of charcoal samples from Uşaklı Höyük, despite the seemingly limited research potential of the material, provides substantial information. Firstly, the results of wood identification, especially the cedar case, have important implications for discussions about the archaeological, social and economic context of the site. Secondly, the newly developed floating cedar chronology, consisting of 49 rings, is the first step in the cedar chronology puzzle and an important basis for further dendrochronological analysis of new materials from this area. Thirdly, the results of radiocarbon dating can be used to support and strengthen hypotheses about the wooden remains of Uşaklı Höyük.

Additional charcoal samples from Area D and other contexts at Uşaklı Höyük are required to continue work on dendrochronological dating and to obtain more precise dating results for a better understanding of the depositional processes at this multi-period site. They will also help us reveal the origin of cedar and other species used in this region in the past. By providing a record of environmental conditions and events, annual tree-rings from such archaeological wood samples may also provide insights into the past climatic conditions of the region.

CRediT authorship contribution statement

Barbara Gmińska-Nowak: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **Anacleto D'Agostino:** Resources, Visualization, Writing - original draft, Writing - review & editing. **Yasemin Özarslan:** Conceptualization, Resources, Visualization, Writing - review & editing. **Valentina Orsi:** Resources, Writing - original draft, Writing - review & editing. **Anastasia Christopoulou:** Writing - review & editing. **Stefania Mazzoni:** Resources, Supervision, Writing - review & editing. **Ünal Akkemik:** Validation, Writing - review & editing. **Tomasz Ważny:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing - review & editing.

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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References:

Akkemik, Ü., 2020. Pinaceae, in: Akkemik, Ü. (Ed.), Türkiye'nin Bütün Ağaç ve Çalıları [All trees and shrubs of Turkey], IsKültür Publications, pp. 161-213.

Akkemik, Ü., Yaman, B., 2012. Wood Anatomy of Eastern Mediterranean Species. Verlag Kessel Publishing House, Germany, p. 312.

Akkemik, Ü., Caner, H., Conyers, G.A., Dillon, M.J., Karlıoğlu, N., Rauh, N.K., Theller, L. O., 2012. The archaeology of deforestation in south coastal Turkey. International Journal of Sustainable Development & World Ecology 19 (5), 395–405.

Aytar, F., Dağdaş, S., Duran, C., 2011. Biology and Control of Calomicrus apicalis Demaison, 1891 (Col.: Chrysomelidae), a New Pest of Cedrus libani A. Rich. in Turkey, Silva Lusitana. Special issue, pp. 33-40.

Baillie, M.G.L., 1982. Tree-Ring Dating and Archaeology. Croom Helm, London and Canberra, p. 274.

Beckman, G., 2010. The Building among the Hittites, in: Boda, M.J., Novotny, J. (Eds.), From the Foundations to the Crenellations. Essay on the Temple Building in the Ancient Near East and Hebrew Bible. Alter Orient und Altes Testament, Band 366, Ugarit-Verlag, Münster, pp. 71-89.

Becker, B., Kromer, B., 1993. The continental tree-ring record – absolute chronology, 14C calibration and climate change at 11 ka. Paleogeography, Paleoclimatology, Paleoecology. 103, 67–71.

Bronk Ramsey, C., 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. Radiocarbon. 37 (2), 425–430.

Bronk Ramsey, C., 2001. Development of the radiocarbon calibration program. Radiocarbon. 43 (2A), 355–363.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon. 51 (1), 337–360.

Bronk Ramsey, C., van der Plicht, J., Weninger, B., 2001. 'Wiggle matching' radiocarbon dates. Radiocarbon. 43 (2A), 381–389.

Bryce, T., 2005. The Kingdom of Hittites. Oxford University Press, p. 576 pp..

Christiansen, B., 2006. *Die Ritualtradition der Ambazzi. Eine philologische Bearbeitung und entstehungsgeschichtliche Analyse der Ritualtexte CTH 391, CTH 429 und CTH 463.* Studien zu den Bogazköy-Texten 48. Harrassowitz. Wiesbaden. 449.

Crivellaro, A., Schweingruber, F.H., 2013. Atlas of wood, bark and pith anatomy of eastern Mediterranean trees and shrubs: with a special focus of Cyprus. Springer Sience and Buisness Maedia 583 pp.

D'Agostino, A., 2020. Tracing fire events and destructions of Late Bronze Age date: the end of the Hittite Building on the citadel of Uşaklı Höyük. In: de Martino, S., Devecchi, E. (Eds.), Anatolia between the 13th and the 12th century BCE, (Eothen 23). Firenze, LoGisma Editore, pp. 69–93.

Desch, H.E., Dinwoodie, J.M., 1996. Timber: structure, properties, conversion and use, Seventh ed. Macmillan Press LTD., London, p. 305.

Eckstein, D., Baillie, M.G.L., Egger, H., 1984. Dendrochronological Dating: Handbooks for Archaeologists No. 2, Strasbourg, European Science Foundation: 56 pp.

Gurney, O.R., 1995. The Hittite Names of Kerkenes Dağ and Kuşaklı Höyük. Anatolian Studies. 45, 69–71.

Kayacık, H., Aytuğ, B., 1968. A study on the wooden materials of the Gordian royal tomb with special reference to forestry. Review of the Faculty of Forestry, University of Istanbul. 18, 37–54.

Klengel, H., 1999. *Geschichte des Hethitischen Reiches* (Handbuch der Orientalistik, 1, 034). Brill, Leiden, p. 429.

Krokene, P., Nagy, N.E., Krekling, T., 2008. Traumatic Resin Ducts and Polyphenolic Parenchyma Cells in Conifers. In: Schaller (Ed.), Induced Plant Resistance to Herbivory, pp. 147–169.

Kuniholm, P.I., Newton, M.W., Liebhart, R.F., 2011. Dendrochronology at Gordion, in: Rose, C.B., Darbyshire, G. (Eds.), Gordion Special Studies IV. The New Chronology of Iron Age Gordion, pp. 79 -123.

Marguerie, D., Hunot, J.-Y., 2007. Charcoal analysis and dendrology: data from archaeological sites in north-western France. Journal of Archaeological Science. 34 (9), 1417–1433.

Mazzoni, S., D'Agostino, A., Orsi, V., 2019. Exploring a site in the North Central Anatolian Plateau: Archaeological Research at Uşaklı Höyük (2013–2015), *Asia Anteriore Antica*. Journal of Ancient Near Eastern Cultures. 1, 57–142.

Mazzoni, S., Pecchioli, F., (Eds.), 2015. The Uşaklı Höyük Survey Project (2008–2012). Firenze University Press, A final report, Firenze, p. 423.

Mielke, D.P., 2010. Kuşaklı und Boğazköy (Türkei) - Zwei Ansätze zur Bearbeitung großer Keramikmengen aus hethitischen Kontexten, in: Horejs, B., Jung, R., Pavúk, P. (Eds.), Analysing Pottery. Processing - Classification - Publication, Bratislava, pp. 187-208.

Miller, N.F., 1999. Seeds, Charcoal and Archaeological Context: Interpreting ancient environment and patterns of land use. TÜBA-AR Türkiye Bilimler Akademisi Arkeoloji Dergisi.

Mook, W.G., Waterbolk, H.T., 1985. Radiocarbon dating. European Science Foundation Standing Committee for the Humanities Sub-Committee for Archaeology, Strasbourg, p. 65.

Naumann, R., 1971. Architektur Kleinasiens von ihren Anfängen bis zum Ende der hethitischen Zeit. E. Wasmuth, Tübingen, p. 508.

Mouton, A., 2008. Les rituels de naissance kizzuwatniens: un exemple de rites de passage en Anatolie hittite. Études d'archéologie et d'histoire ancienne, De Boccard, Paris, p. 148.

Orsi, V., 2019. Ceramics and materials, in: Mazzoni, S., D'Agostino, A., Orsi, V., Exploring a site in the North Central Anatolian Plateau: Archaeological Research at Uşaklı Höyük (2013-2015). Asia Anteriore Antica 1, Firenze, pp. 92-142.

Orsi, V., 2020. In: The Transition from the Bronze to the Iron Age at Uşaklı Höyük: The Ceramic Sequence, pp. 271–316.

Pearson, G.W., 1986. Precise calendrical dating of know growth-period samples using a "curve fitting" technique. Radiocarbon. 28, 292–299.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 CAL kBP). Radiocarbon. 62 (4), 725–757. https://doi.org/10.1017/RDC.2020.41.

F. Rinn TSAP - Time Series Analysis and Presentation for Dendrochronology and related applications. Version 4.64 for Microsoft Windows - User Reference 2011 Heidelberg, Germany.

Rogers, S.O., Kaya, Z., 2006. DNA From Ancient Cedar Wood From King Midas' Tomb, Turkey, and Al-Aksa Mosque. Israel. *Silvae Genetica*. 55 (2), 54–62.

Rowell, M. (Ed.), 2013. Handbook of wood chemistry and wood composites. Second edition, CRC PRESS, p. 703.

Schoop, U.D., 2006. Dating the Hittites with Statistics: Ten Pottery Assemblages from Boğazköy-Ḫattuša. In: Mielke, D.P., Schoop, U.D., Seeher, J. (Eds.), Strukturierung und Datierung in der hethitischen Archäologie. Byzas 4, Istanbul, pp. 215–239.

Schoop, U.D., 2011. Hittite pottery: a summary. In: Genz, H., Mielke, D.P. (Eds.), *Insights into Hittite history and archaeology*, Colloquia Antiqua 2. Leuven, Paris, Walpole, pp. 241–274.

Schweingruber, F.H., 1990. Microscopic wood anatomy. WSL FNP. 226, pp.

Schweingruber, F.H., 1993. Trees and wood in dendrochronology: Morphological, anatomical, and tree-ring analytical characteristics of trees frequently used in dendrochronology. Springer-Verlag, New York, p. 402.

Simpson, E., 2010. The Furniture from Tumulus MM. The Gordion Wooden Objects. Brill, Leiden and Boston, p. 274 pp..

Stoffel, M., 2008. Dating past geomorphic processes with tangential rows of traumatic resin ducts. Dendrochronologia. 26 (1), 53–60.

Süel, A., 1998. Ortaköy-Şapinuwa: BirHitit Merkezi. TÜBA-AR Türkiye Bilimler Akademisi Arkeoloji Dergisi. (1), 37–61.

Süel, A., 2002. Ortaköy-Sapinuwa. In: Yener, K.A., Hoffner Jr., H.A., Dhesi, S. (Eds.), Recent Developments in Hittite Archaeology and History, Papers in memory of Hans Gustav Güterbock. Eisenbrauns, Winona Lake, Indiana, pp. 157–165.

Torri, G., 2012. Rituale di costruzione di un tempio (CTH 415), hethiter.net/: CTH 415 (INTR 2012-07-30), https://www.hethport.uni-wuerzburg.de/txhet_besrit/intro.php?xst=CTH%20415&prgr=&lg=IT&ed=G.%20Torri#fnunt1. Accessed January 2020.

Turgut, M., 2019. The using of trees in Hittite rituals. International Journal of Agriculture, Forestry and Life Science. 3 (1), 22–30.

Walanus, A., Goslar, T., 2009. *Datowanie radiowęglowe* [Radiocarbon dating]. AGH, Cracow, p. 147.

Woodbridge, J., Roberts, C.N., Palmisano, A., Bevan, A., Shennan, S., Fyfe, R., Eastwood, W.J., Izdebski, A., Çakırlar, C., Woldring, H., Broothaerts, N., Kaniewski, D., Finné, M., Labuhn, I., 2019. Pollen-inferred regional vegetation

patterns and demographic change in Southern Anatolia through the Holocene. The Holocene. 29 (5), 728–741.
Wright, N.J., Fairbairn, A.S., Faith, J.T., Matsumura, K., 2015. Woodland modification in Bronze and Iron Age central Anatolia: An anthracological signature for the Hittite state? Journal of Archaeological Science. 55, 219–230.
van Zeist, W., Bottema, S., 1991. Late Quaternary Vegetation of the Near East. Reichert, Wiesbaden, p. 156.