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Conservation of Waterlogged Wooden Structures from the Late Bronze Age at İnönü Cave (Türkiye)

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ABSTRACT

During the excavations carried out in the İnönü Cave, located within the Western Black Sea region of Türkiye, four separate floor structures made of wood, dating back to the Late Bronze Age (1436–1123 Cal BCE), were unearthed. The way the corners of the structures are connected shows that the structures were built with the *çanti* or bell technique, a traditional nail-less wooden architectural form of the Black Sea region. Thanks to the wet and stable environmental conditions within the cave, the wooden floors have survived and are well preserved from the Late Bronze Age to the present day. This study presents the details of the conservation practices developed and deployed in order to ensure that the wooden floors are well protected and remain available for study in the short and medium term.

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KEYWORDS

İnönü Cave; wood preservation; waterlogged wood; Late Bronze Age; *çanti* technique

Introduction

Excavations conducted 2017–2023 in İnönü Cave (Figure 1), have provided important information about the protohistoric cultures of the Western Black Sea region, one of the least archaeologically explored regions of Türkiye (Efe, Ekmen, and Ekmen 2022). One of the most surprising results generated by this work was the discovery of well preserved *in situ* wooden architectural remains. Wood preservation is rare in ancient Anatolia with the new finds from İnönü Cave representing some of the earliest wooden structures in Anatolia. Discovery of these unique remains also poses significant problems in terms of conservation. In this paper, we describe the Bronze Age wooden structure recently uncovered in the cave, and present the details of the conservation practices developed and deployed in order to ensure that these unique ancient wooden structures are well protected and remain available for study in the short and medium term.

İnönü Cave is located within the boundaries of Karadeniz Ereğli district of Zonguldak province on the coast of the Western Black Sea region of Türkiye, a densely forested region¹, approximately 25 km inland from the coast (H. Ekmen et al. 2021, 25). The cave has easy access to the coast and inland areas through the Gülüş Valley. The cave's internal properties and environmental conditions offer significant advantages as a settlement. The cave's wide mouth ensured that the interior remains illuminated

throughout the day (H. Ekmen et al. 2020, 35, Figure 5) creating an attractive living space. Spring water which flows out of the interior of the cave (Figure 2), must have provided a significant proportion of the settlers' freshwater needs (F. G. Ekmen 2021, 402).

The cave consists of three chambers, A, B, and C, the latter two of which were found to contain rich archaeological deposits. Based on excavations that have been carried out within the cave, mainly in chamber C, since 2017, evidence suggests use of the cave extending back to the early Late Chalcolithic Age and extending intermittently to the Middle Ages representing more than 5000 years of occupation (F. G. Ekmen 2020, 50) was found (Table 1).²

The waterlogged wooden structures

The research at İnönü Cave has produced important new evidence for the archaeology of the Western Black Sea region of Anatolia. One of the most exciting discoveries has been the remains of ancient *in situ* wooden floors (Ekmen, Ekmen, and Seçer-Fidan 2021, 64–65). Parallels between the artefacts found on these wooden floors and those found in other settlements as well as C14 assays on samples taken from the wood itself indicate that the wooden floors date to the Late Bronze Age (Table 1). Although the preservation of unburned wood in Anatolia from the Bronze Age is extremely rare, these wooden structures were preserved through the process of spring water

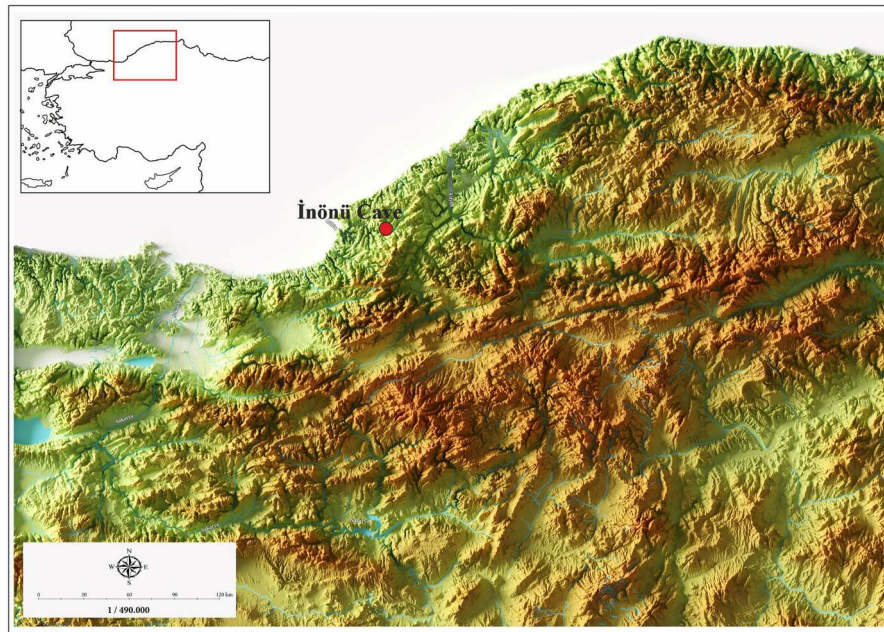


Figure 1. Location of İnönü Cave.

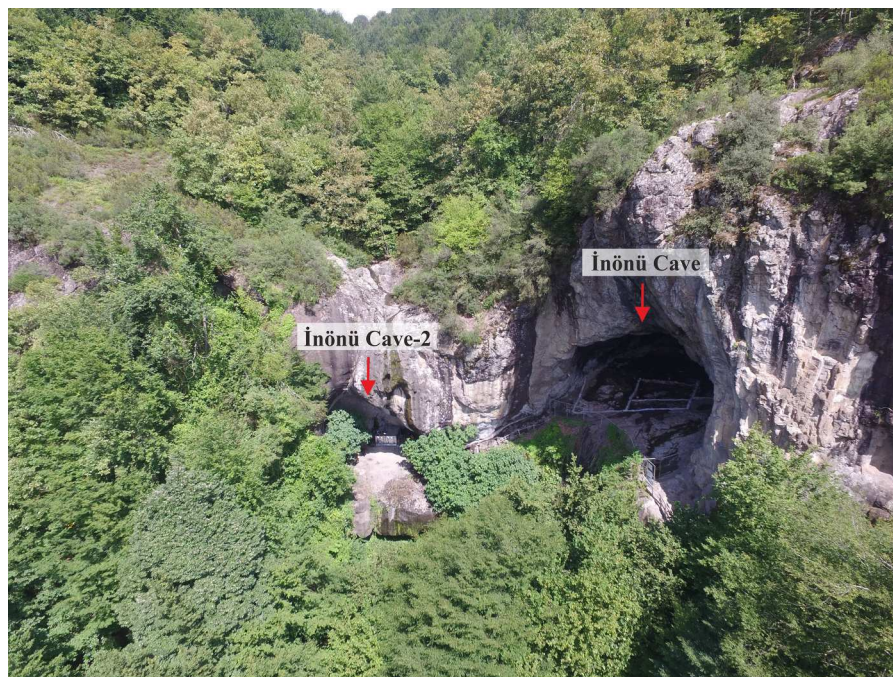


Figure 2. İnönü Cave and its natural surroundings are covered with dense forests.

Table 1. Stratigraphy of İnönü Cave (H. Ekmen et al. 2021, Table 1).

Levels	Periods	Typical find	Approximate dates
I	Medieval	Glazed ceramics (<i>Sgraffito</i>)	10th-12th centuries CE
II	Early Iron Age	Coarse ware/Barbarian ware	1200-980 BCE
III	Late Bronze Age	Bronze weapons and tools	1400-1200 BCE
IV	Early Bronze Age	<i>Yassıkaya</i> type ceramics	3100-2130 BCE
V	Chalcolithic Age	Similar findings from Varna Cemetery	4300-3950 BCE

continuously seeping from the cave floor creating a waterlogged environment, thus promoting the presence of anoxic conditions (Yaman and Ekmen 2023).

Yaman and Ekmen (2023) argue that archaeological levels II and I, which lie on top of the wooden floors, as well as the 20–30 cm thick animal dung deposits that accumulated on the surface of the cave in later periods, further facilitated the protection of the levels below.

Excavations in level III, the stratigraphic unit to which the wooden architecture belongs, revealed a total of four wooden floor structures, two of which

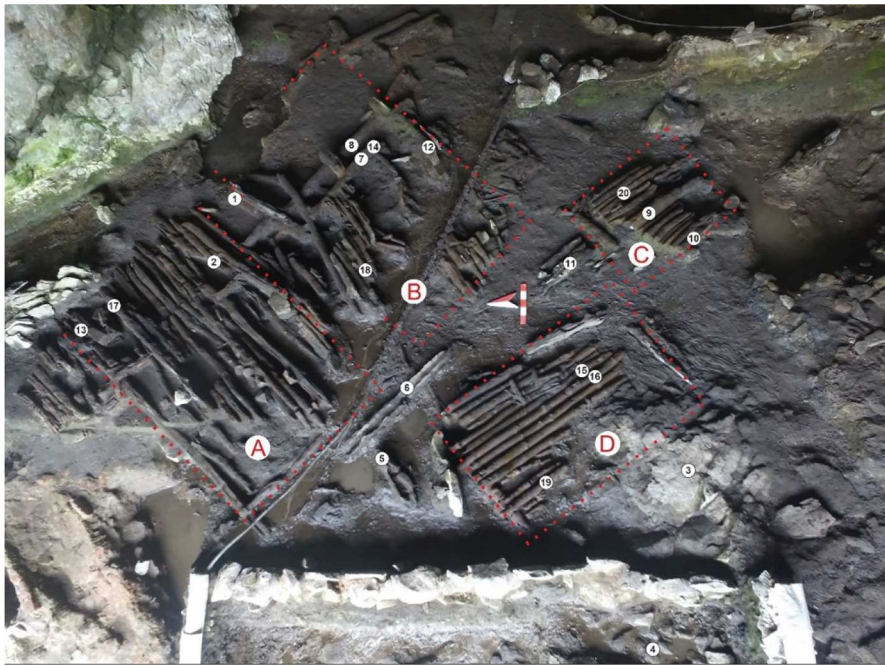


Figure 3. General view of the wooden floors of the level III.

were larger (structures A and B) and the other two smaller (structures C and D) (Figure 3). It is thought that these floors were constructed in the Bronze Age and excellent preservation allows a reconstruction of the construction techniques. The straightened, thick logs were interlocked with a technique known as the *çantı* or bell to create the outlines of the rectangular bases. Then, the floors of the structures were covered with thinner woods (H. Ekmen et al. 2022, 351–352). Small piles were driven into these woods here and there as a precaution against the risk of slippage (Figure 4). Finally, a smooth floor was obtained by covering the wooden platforms with a thin clay plaster (H. Ekmen et al. 2021, 29).

This represents the best preserved example of the *çantı* woodworking technique in Anatolia. This technique is a well-known wood joinery technique using complementary notches to join perpendicular stacked beams without the use of nails and has a long history in the Black Sea region. Moreover, it is visible in the vernacular architecture of the villages



Figure 4. Piles driven between wooden bases.

located near İnönü Cave³ thus reflecting a tangible aspect of the architectural heritage of this lumber rich region (Figure 5).

In addition to the wooden structures themselves, a large quantity of artifacts characteristic of the Late Bronze Age was recovered directly associated with their floor surfaces. These include a rich assemblage of tools, weapons, and ornaments made of copper alloy. These remains provide a unique window into the lifestyle, social structure, beliefs, and practices of the Late Bronze Age communities of İnönü Cave (Ekmen, Ekmen, and Seçer-Fidan 2021, 64–65).

Wooden materials rarely survive in the archaeological record due to their susceptibility to decay. The preservation of wooden floors at İnönü Cave is significant in this respect, representing one of the rare wooden structures that survived the Late Bronze Age and providing a tantalising glimpse into rich traditions of woodworking and lumber construction rarely represented in the archaeological record.

Evidence indicating the utilisation of wood, the principal construction material in the Black Sea region's architectural heritage, can be traced back to the Late Chalcolithic Age, where archaeological excavations at Samsun İviztepe (Dönmez and Dönmez 2007, 219; Tuna 2008), Düdartepe⁴, and Sinop-Kocagöz Höyük (Erzen 1956, 71) have produced direct and indirect evidence for the use of wood as a building material.

In addition to examples from the Black Sea region, where lumber has always been the primary building material, numerous wooden remains have been discovered in archaeological research conducted

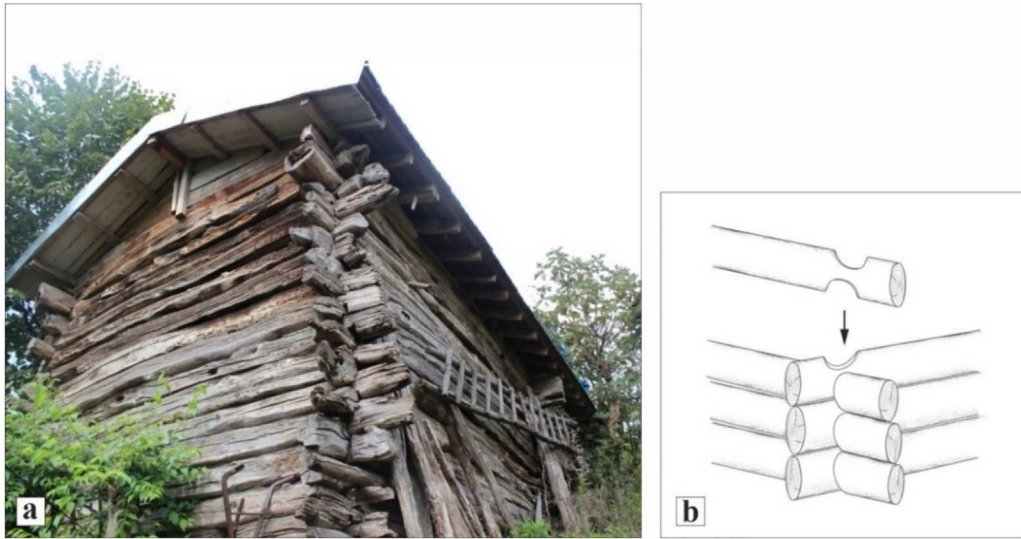


Figure 5. a: An example of a traditional wooden building built with the *çantı* technique in Çaylıoğlu Village, located near the cave; b: Schematic drawing of the *çantı* technique.

throughout Türkiye. The earliest findings are related to the use of wood for fuel rather than architecture; these derive from Öküzini and Karain B (Epipaleolithic) caves near Antalya on the Mediterranean coast (Martinoli 2009). These dense wooden remains were found in a carbonised state (Yaman and Ekmen 2023). Moreover, wood remains recovered from graves dating to the Neolithic period were unearthed during the excavations at Yenikapı, within modern İstanbul has survived to the present day, exhibiting remarkable preservation in the swampy local environment (Yılmaz 2011). The Uluburun and Gelidonya shipwrecks discovered on the Mediterranean coast of Türkiye represent unique examples from the Bronze Age (Liphshitz and Pulak 2008) and the wood of the sunken trade and warships in the Theodosius Harbor in Yenikapı, İstanbul, also show waterlogged wood characteristics (Akkemik 2015). Perhaps the most famous example of wood preservation in Anatolia, and representing the oldest intact wooden building in the world, is the juniper and pine tomb chamber at the heart of tumulus MM near the ancient city of Gordion, dating to the Iron Age (Young 1981).

Waterlogged wooden samples used as building materials and tools have been unearthed within an underground spring/pool at the site of Samsun-Oymağaç (Czichon and Yılmaz 2023, 87). Some of the wooden objects, discovered in a mixed assemblage in Oymağaç, are dated to the Late Bronze and early Iron Ages (Czichon and Mielke 2020). It is notable that some of the Oymağaç samples also show evidence for the *çantı* technique. The waterlogged woods found in the Late Bronze Age cultural level in İnönü Cave are therefore part of a small but important corpus of ancient wooden remains and represent the oldest wooden structures found in a cave environment in Anatolia (H. Ekmen 2020).

Taxonomic identification

To determine the types of wood used in the construction of the structures at İnönü cave, samples were taken from the logs forming the outer perimeters of the building platforms and from the smaller wooden rods that formed the flooring inside. Twenty samples were taken (Figure 3) and examined at the Wood Anatomy and Dendrochronology Laboratory at Bartın University, Türkiye. The taxonomic identification of the wood samples was carried out using a light microscope (Olympus CX21), based on the list of microscopic features determined by the International Association of Wood Anatomists (IAWA) for Gymnosperm and Angiosperm woods (IAWA Committee 1989; IAWA Committee 2004) and anatomy atlases used in wood identification (Benkova and Schweingruber 2004; Akkemik and Yaman 2012).

Examination of the samples showed that the wood of the floor structures is over 60% saturated with water due to spring water seeping from the cave floor. As a result of the light microscope examinations on thin sections of waterlogged wood samples, it was concluded that oak (*Quercus* L.) (Figure 6) was generally used in the construction of wooden bases (Table 2). Moreover, it has been determined that pine (*Pinus* L.), alder (*Alnus* Mill.), and maple (*Acer* L.) were also used, albeit to a lesser extent (Yaman and Ekmen 2023, 9, Figures 11 and 12).

Materials and methods

The excavation of the wooden floors of level III, dating back to the Late Bronze Age, was completed between 2018–2020 (Figure 7). Given the uniqueness of this feature, it was decided to take the necessary precautions to protect the structures and preserve them as

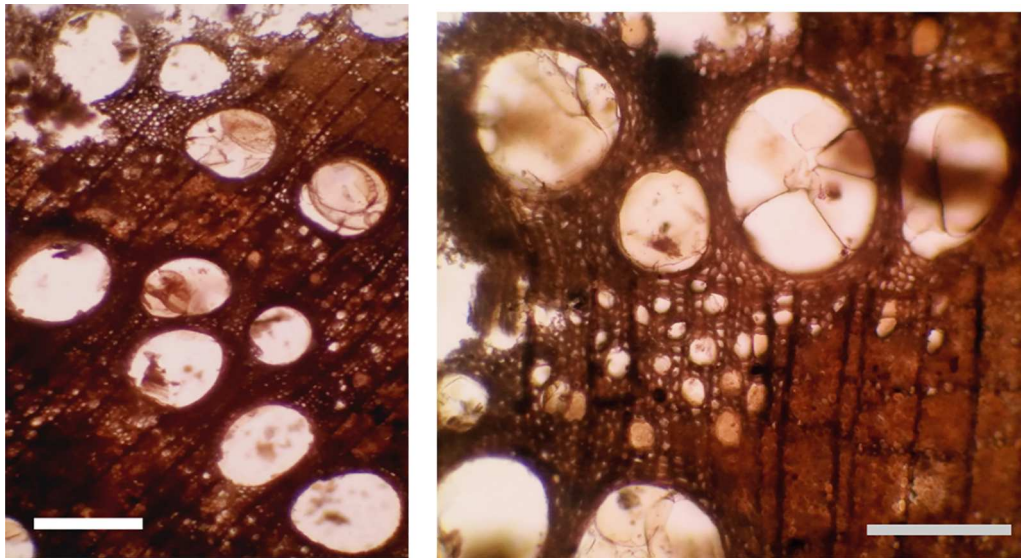


Figure 6. Transverse section of waterlogged *Quercus* sp. from White Oak Group, Scale: ~ 120 µm.

Table 2. Descriptions of waterlogged wood residues at family, group, genus, or species level.

No. (Wood Numbers on Figure 3)	Structure and Wood Sample Number	Family	Genus	Group or Species
1	A-1	Fagaceae	<i>Quercus</i> sp.	Section <i>Quercus</i> (White Oak)
2	A-7			
3	D-DK-1			
4	X-DK-1			
5	O.L.-1*			
6	O.L.-2*			
7	B-2b (big)			
8	B-1			
9	C-8			
10	C-14			
11	C-17			
12	B-19			
13	A-24			
14	B-2a (small)			
15	D-6			
16	D-7	Betulaceae	<i>Alnus</i> sp.	<i>Alnus glutinosa</i>
17	A-20			
18	B-8			
19	D-13			
20	C-3	Sapindaceae	<i>Cf Acer</i> sp.	-

a data source for archaeology and other branches of science.

Once the excavation of the wooden floors was completed, the state of preservation of the wood was determined and studies were carried out, including measures to protect the wooden remains. Despite exposure through the removal of surrounding soil in the process of excavation, thanks to the constant flow of fresh water on the cave floor, the drying of the wet wood was significantly prevented. Spring water seeping from the bottom of the walls and various cave parts created natural preservation conditions for the wooden remains in the damp, moist soil. On the surfaces of the wooden remains situated above the water level and in some of the samples taken for species/genus determination (Figure 8), partial colour change due to drying and slight signs

of decay and fungal growth were detected. This situation is associated with changes in environmental conditions (microclimate) related to the location, orientation, and shape of the wood.

During the examination of the wood, six samples were assessed and the wet-dry weight difference was calculated using the protocol described below. The aim of this assessment carried out on broken pieces (four wood, two soil + crumbled wood) (Figure 9) was to detect damage relating to the amount of water in the wood. Examining the amount of water in wood samples also provides information about the structural state of the wood and is important for decision-making related to conservation methods (Rodgers 2004).

According to Rodgers (2004, 41), the classification of the amount of water contained in archaeological wood is given below:

Class 1: In wood containing more than 400% water, the wood tissue has been extensively damaged. It has become very soft, and the amount of cellulose has decreased. Only a minimal amount of wood tissue remains in the innermost part.

Class 2: In wood containing 185–400% water, the amount of cellulose in the thin upper level has decreased, and there is a vast, hard, and solid wood texture under advanced rot.

Class 3: Wood with a water content of less than 185% has a broad, solid wood texture under a thin surface level that has been slightly degraded and whose permeability has not increased.

In order to apply this test, firstly, the wet weights of the samples taken were obtained on a precision scale. They were placed in an oven at a constant temperature (103°C) for 24 hours. Their exact dry weight was recorded using a precision scale.

Water contents were successfully evaluated for four of the six wooden samples and it was determined that the samples had water contents between the 'Class 3'



Figure 7. Carefully carried out excavation revealing the wooden floors.

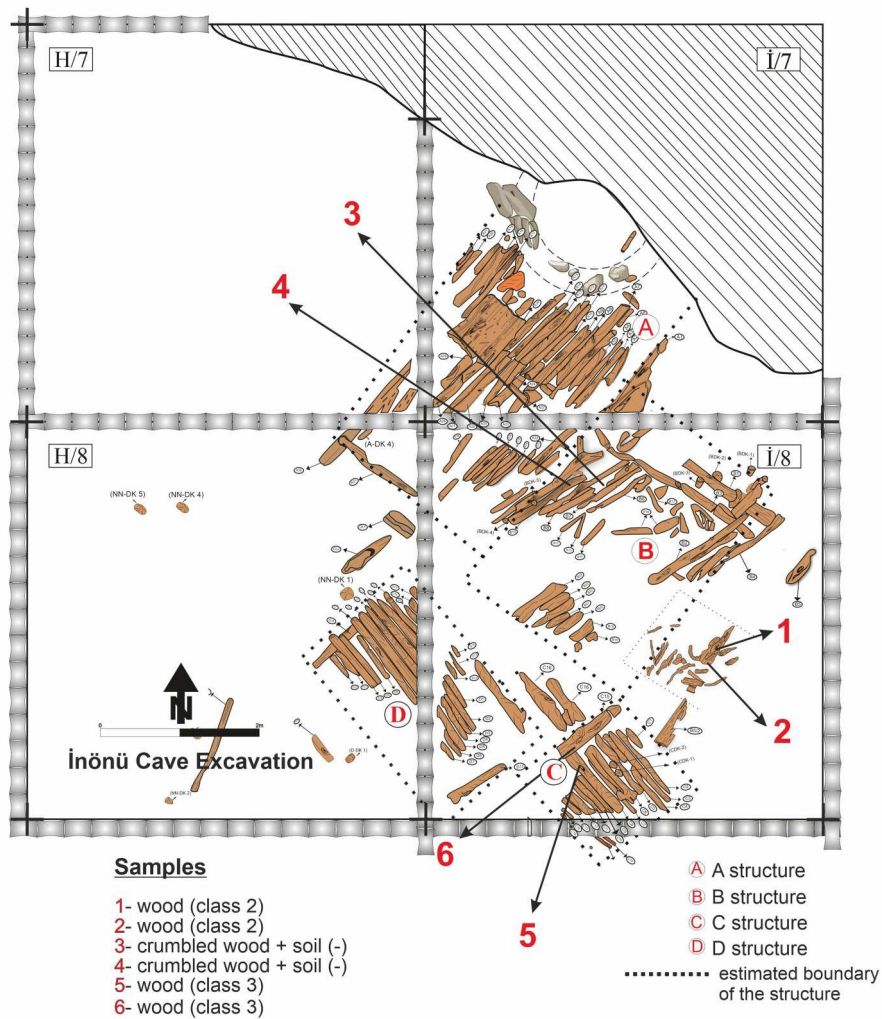


Figure 8. Samples were taken for examination from wooden structures.

and 'Class 2' limit values. This shows that the wooden finds were water-saturated wood. At the same time, it was determined that they were not in the excessively

deteriorated wood class. In this case, it was observed that the inner wood structure of the wooden finds was structurally sound (Table 3).



Figure 9. Wood samples whose textural structures were examined by looking at the wet-dry weight difference.

Table 3. Textural classification based on water saturation rates of wood samples.

	The amount of water (%): $\frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$					
Sample No:	1	2	3	4	5	6
Material type	Wood	Wood	Sawdust + Soil	Sawdust + Soil	Wood	Wood
Wet weight (g)	8,768.8	7,936.3	15,858.4	12,522.4	35,676.2	35,407.5
Dry weight (g)	2,431.6	2,541.5	7,842.4	6,365.4	26,775.7	25,030.6
Water content (%)	260.62	212.26	102.21	96.72	33.24	41.45
Structural class	2	2	-	-	3	3

As a result of these findings showing the structural integrity of the wood remains, it was concluded that the timbers could be protected by temporarily transferring them to an on-site protection pool and monitoring them there. In this regard, it was decided to build a reservoir pool in İnönü Cave-2 (Figure 2), a small cave chamber located adjacent to the main İnönü Cave lacking in cultural deposits, and systematically transfer the wood to this pool.

It was decided to remove the timbers from structures A and B and leave the timbers in structures C and D in place, as structures C and D were built directly on the bedrock. Structures A and B were removed in order to facilitate conservation and also to investigate the underlying 70–80 cm of archaeological deposits corresponding to stratigraphic level IV, representing the Early Bronze Age and level V which dates to the Chalcolithic Age. Structures C and D, located just above the cave floor and containing no cultural deposits from earlier periods, were well preserved and did not need to be removed.

Protection pool and its features

A protection pool was constructed in İnönü Cave-2, a convenient and appropriate location protected

against external factors (weather, etc.) and is where the spring water inside the cave could be easily transferred. In this way, the wood could be transported without affecting its dimensions, and the water will always be kept fresh by constantly entering and exiting the pool. Considering these needs, a galvanised sheet metal, anti-bacterial, portable, and modular pool with dimensions of 2.15 × 2.15 × 1.10 m and a 5-ton water capacity was chosen. In addition, the water intake and outlet was designed to ensure that the pool constantly contains fresh water. In this way, the water circulation will be ensured, thus preventing the formation of algae or harmful organisms in the pool.

Choosing İnönü Cave-2 as the location of the protection pool also facilitated the process of collecting the spring water inside the cave, which the wood is accustomed to, and transporting it with a discharge pipe at a slope that will create a natural pressure. In addition, the fact that İnönü Cave-2 is covered and protected against changing weather conditions throughout the year and that it receives daylight in a similar way to the location and environment of the archaeological wood's original depositional environment are among the factors that positively affected the



Figure 10. Construction of the flood basin on which the protection pool was positioned.

construction of the protection pool in this location (Figure 2).

Inside İnönü Cave-2, the water leaking from the cave was transferred to the pool positioned on a thin carefully prepared platform (Figure 10). The discharge valve under the pool was left partially open, ensuring that the water remains fresh at all times. The interior of the pool is divided into two levels. The second level is constructed of water – and moisture-resistant marine plywood (Figure 11).

Work done before transporting the wood to the protection pool

Detailed photographs and drawings were made after the pool was prepared and the timbers were ready

to be removed. Photogrammetry and orthophoto (Figure 12) studies were carried out with the use of a drone. In addition, the wood was scanned with a laser scanner and a 3D model of the structures was created (Figure 13). Following this detailed documentation, pre-prepared plastic cards with coded context information on them were attached to each piece of wood from Structure A with plastic clamps, ensuring that the wood was removed sequentially and systematically (Figure 14).

The wood from structures A and B was successfully transported to the protection pool by applying different methods depending on each specimen's preservation status and dimensions. The large logs that form the outline of the structures were not removed at this stage but were left in place



Figure 11. Construction of the platform where the wooden bases were placed in the pool.



Figure 12. The orthophoto image was created after all the wooden bases were opened.



Figure 13. Scanning of wooden floors with a laser scanner.

temporarily to enable the stratigraphic order to be seen during the lower-level excavations. Most timbers from Structures A and B could be removed in one piece because they were well-preserved. Wood that could not be lifted in one piece and/or whose condition was deteriorated was placed on marine plywood or wooden boards, then wrapped

with soft, finely porous textile to the board and attached with tacks.

In this way, 26 timbers from Structure A were transported to the conservation pool in one piece, five timbers in two pieces, nine timbers in three pieces, one timber in four pieces and one timber in five pieces. From structure B, 12 timbers were



Figure 14. Connecting plastic cards with coded information to the wood with plastic clamps.

transported to the protection pool in one piece, six timbers in two pieces, two timbers in three pieces, and one timber in four pieces. The timbers recorded and prepared in this way were successfully placed into the pool, taking into account the spaces reserved for the structures and their dimensions (Figure 15). In subsequent examinations of the wood in the pool, carried out approximately every three-four months throughout the year, it was observed that the timbers were well protected with no deterioration of preservation condition. There were no algae in the water indicating that the water was circulating adequately.



Figure 15. Placing the timbers in the protection pool.

Evaluation and conclusion

Wood has been used for various purposes since the earliest periods of human history, but it is rarely preserved in the archaeological record. Despite this, a limited number of examples unearthed during archaeological research provide evidence of the use of wood in early periods. Traces of the use of wood during the Epipaleolithic Period were detected in the Öküzini and Karain B caves near Antalya in Türkiye (Martinoli 2009). In addition, the Yenikapı excavations found many unique wooden objects dating to the Neolithic period. (Kızıltan 2014). Information on the use of wood as a building material in Türkiye dates back to the Late Chalcolithic Period, thanks to excavations carried out in the Black Sea and Marmara regions (Roodenberg 1995; Dönmez and Dönmez 2007). Due to the environmental and climatic conditions of these regions, it is expected that wood was widely used in the construction of buildings even if they are poorly recorded in the archaeological record. The use of wood together with other building materials is common in the colder and more arid regions of Türkiye as well. In these regions, wood is used together with stone and/or adobe, depending on availability, especially in constructing supporting posts and roof beams (Tuna 2008).

The wooden floor structures identified in İnönü Cave represent one of the earliest examples of preserved wooden architectural structures in Anatolia. The Late Bronze Age residents of İnönü Cave constructed these wooden floors in order to protect themselves from the damp ground, transforming the interior of the cave into a dry residential space. In addition, these communities took advantage of the rich forest cover around the cave using oak, pine, elm, and alder in their construction.

Because of the unique nature and age of the wooden structures discovered in İnönü Cave, it is crucial to take conservation measures in order to avoid deteriorating the structural and chemical properties of wood, which constitutes a data source for many fields of study such as archaeobotany, paleoclimatology, and dendrochronology. Careful and meticulous work was carried out to document and remove wooden structures A and B; the timbers of which were successfully transferred to the protection pool built in the adjacent cave chamber. This allowed us both to conserve these unique wooden remains, making them available for further study, but also to continue to investigate the underlying Early Bronze Age and Chalcolithic deposits within the cave. Regular inspections throughout the year have shown that the protection pool is working well and that the timbers of structures A and B are well protected. Two additional large wooden floors, Structures C and D, were left in place because they were built directly on the bedrock and were well preserved in their location.

Notes

1. The region in which İnönü Cave is situated is characterised by the presence of several tree species, including *Alnus glutinosa* (L.) Gaertn. (Common alder), *Salix alba* L. (White willow), *Platanus orientalis* L. (Oriental plane), *Quercus robur* L. (Pedunculate oak), *Quercus cerris* L. (Türkiye oak), and *Populus nigra* L. (Black poplar). The following species were observed in the region: in slightly higher areas, the species *Quercus petraea* (Matt.) Liebl. can be found (Sessile oak), *Fagus orientalis* Lipsky (Eastern beech), *Pinus nigra* Arnold (Black pine), *Acer campestre* L. (Field maple), *Castanea sativa* Mill. (Sweet chestnut) (*Castanea sativa* Mill.), *Tilia tomentosa* Moench (Silver lime), and *Corylus avellana* L. (Common hazel) become increasingly common. In areas with higher altitudes, *Populus tremula* L. (Common aspen) and *Taxus baccata* L. (European yew) species are rarely encountered. (Koday 2002, 99–100).
2. Before the İnönü Cave excavations began, the only findings from the Early Bronze Age were obtained in Yassıkaya Cave, which is the only settlement in the Western Black Sea region that has been systematically excavated. T. Efe, who was the scientific consultant of the excavation, defined this material, which has a very local character, as Filyos Culture, taking into account its unique characteristics and the distribution of similar findings obtained in surface surveys (Efe and Mercan 2002; Efe 2004).
3. This technique, known as ‘wooden masonry system’ (the Turkish name is *Çanti* or *Çandi*) in wooden architecture, is also defined as ‘nailless’ among the public and is defined as ‘setting long unhewn or lumbered timbers on top of each other by means of dowels (as stacking)’ (Arseven 1983, 368; Tuna 2008). The technique, which has been used for many years in the construction of wooden structures in the Black Sea region, where trees are abundant, is called by different names depending on the shape of the logs or timbers or the way they are connected. For example, the system created by connecting rectangular sectioned timbers together is called *kurt boğazi*, while the system created by connecting round sectioned logs together is called *kara boğaz*. Another technique, *çalma boğaz*, is created by placing timbers in pre-opened channels inside wooden carriers called *armoz* (Furtuna and Ulusoy-Binan 2021, 21–22).
4. It has been stated that wood was used in architecture since no foundation stone was found in the levels from the Chalcolithic Age to the Hittite Period and clay pieces bearing traces of wooden walls were found (Kökten, Özgüç, and Özgüç 1945, 368–370).

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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