

**Реставрация, консервация и музеефикация
археологического дерева и органических материалов**

УДК 902 /904

<https://doi.org/10.24852/2587-6112.2023.4.8.19>**CONSERVATION OF WATERLOGGED WOOD OF THE YENIKAPI
SHIPWRECKS, ISTANBUL-TÜRKIYE¹**©2023 **Ufuk Kocabaş, Işıl Özsait-Kocabaş**

Theodosian Harbour was one of the principal harbors of Byzantine Constantinople, actively serving trading ships from the 4th to the early 11th centuries AD at the Sea of Marmara shore of the imperial center. Almost ten years of rescue excavations by Istanbul Archaeology Museums in the silted harbor site revealed considerable archaeological evidence dating from the Ottoman and Byzantine periods to the Neolithic age. The artifacts uncovered within the Byzantine harbor context constitute the majority of archaeological finds yielding much information on the trading network of the imperial center. Upon the invitation of the Istanbul Archaeological Museums, Istanbul University undertook the removal, documentation, and construction technology studies of twenty-seven shipwrecks and the conservation work of 31 shipwrecks. For conserving the waterlogged timbers, mainly PEG (polyethylene glycol), preimpregnation+vacume freeze drying, or melamine-formaldehyde (Kauramin®) resin for the highly-degraded timbers is used. The present paper discusses the conservation processes of the shipwrecks excavated under the responsibility of the Istanbul University's Department of Conservation of Marine Archaeological Objects.

Keywords: archaeology, Yenikapı shipwrecks, conservation of waterlogged wood, PEG, freeze-drying, melamine formaldehyde, Kauramin®.

**КОНСЕРВАЦИЯ МОКРОЙ ДРЕВЕСИНЫ ЗАТОНУВШИХ КОРАБЛЕЙ
В ЕНИКАПЫ, СТАМБУЛ-ТУРЦИЯ²****Уфук Коджабаш, Ышыл Озсайт-Коджабаш**

Гавань Феодосия была одним из главных портов византийского Константинополя, регулярно принимавшим торговые суда с IV по начало XI вв. н.э. на побережье Мраморного моря. В результате почти десятилетних спасательных работ, проведенных Археологическим музеем Стамбула на месте затонувшей части гавани, были обнаружены значительные археологические находки, относящиеся к османскому и византийскому периодам вплоть до эпохи неолита. Обнаруженные при раскопках предметы, имеющие отношение к гавани, составляют большинство археологических находок, которые позволяют пролить свет на торговые связи столицы империи. Стамбульский университет по приглашению Археологического музея Стамбула провел работы по извлечению, документированию и изучению технологии строительства двадцати семи затонувших кораблей и консервации 31 судна. Для консервации мокрого дерева используется, в основном, ПЭГ (полиэтиленгликоль), предварительная пропитка + вакуумная лиофилизация или меламинаформальдегидная смола (каурамин®) для древесины с высокой степенью разложения. В данной статье рассматриваются процессы консервации затонувших кораблей, раскопки которых проводились под руководством отдела консервации подводных археологических объектов Стамбульского университета.

Ключевые слова: археология, затонувшие корабли Еникапы, консервация мокрой древесины, ПЭГ, лиофилизация, меламинаформальдегид, каурамин®.

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Fig. 1. Yenikapi excavation area.

Рис. 1. Раскопки в Еникапы.

Rescue Excavations at Yenikapi

Rescue excavations at the Yenikapi quarter of Istanbul, where the Marmaray railway and the subway stations were about to be built, were initiated by the Directorate of Istanbul Archaeological Museums in 2004 (Fig. 1) (Karamut 2007; Kızıltan 2007). The excavations were conducted in an area of 58.000 m² in five adjacent sections (Karamut 2007; Kızıltan 2007). The first remains unearthed under today's buildings that were expropriated during the excavations in the area, where the Marmaray railway station was going to be built, and approximately 3 m above the sea level yielded cultural strata from the early Republican Period and Ottoman Period. Archaeologists decided to proceed with extensive excavations in the area upon recovery of a substantial amount of processed wood and rope fragments. The salvage excavations unearthed a large portion of the Harbor of Theodosius, named after the founder of the harbor in Byzantine Constantinople, that was the largest trade center during the 4th and 11th centuries. A cultural stratum that belongs to the

Prehistoric Period was identified at about 6.30 m below sea level, inside the deposit beneath the harbor floor. Finds from the Neolithic Period were particularly important for the history of the city as well as for research on prehistoric periods in the region. The 13 m deep cultural deposit where excavations took place contained cultural layers from the Ottoman, Byzantine, and Neolithic Periods, respectively, as well as finds from the Archaic, Classical, and Hellenistic Periods. The excavations continued below the sea level, and hence in an area called “wetland,” consisting of sand, sediment, mud, and wetland deposits at the very bottom layers. Despite the challenges of performing excavations in such an area, the environmental conditions were particularly helpful for preserving organic remains, ensuring that they have survived to the present day.

Theodosian Harbor

The Harbor of Theodosius was built in a deep bay on the coast of Propontis (the Sea of Marmara). The presence of granaries such as horrea Theodosiana and horrea Alexandrina on the east-

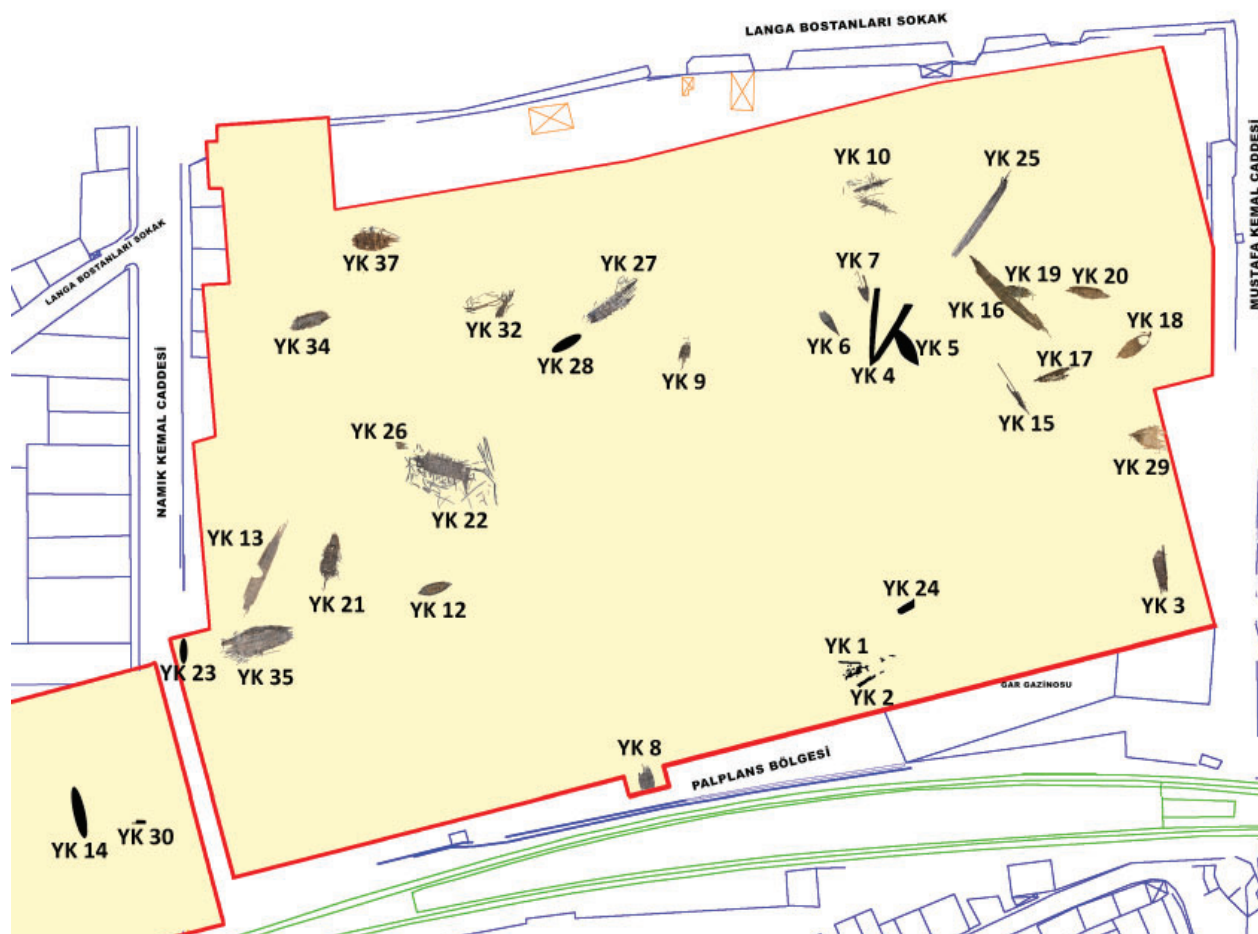


Fig. 2. Distribution of shipwrecks in the excavation area.

Рис. 2. Местонахождения затонувших кораблей на территории раскопок.

ern end of the harbor suggests that it was an extensive commercial harbor where ships from Alexandria unloaded cereals and other materials. The deep bay at the mouth of the Lykos (Bayrampaşa) Stream was improved probably during the reign of Emperor Theodosius I (379–395) by building a breakwater (Fig. 2). The eastern part of the harbor, which began to have silted up from the west by silt and debris brought by the Lykos stream from the north, was used for a while, and it continued to be used by small vessels and fishing boats until the 11th century. Starting in the late 12th century, almost the entire harbor was filled with debris, and it became a shelter for fishing and coastal traders.

Excavation of the Ships

The 37 shipwrecks uncovered during the excavations are considered the largest medieval shipwreck assemblage in the world by scientific circles. A team of ship experts and conservation specialists continue the conservation work of 31 shipwrecks, with full-scale drawings, analyses,

evaluations, and construction technology work on a total of 27 shipwrecks, under the direction of Prof. Ufuk Kocabaş on behalf of the Department of Conservation of Marine Archaeological Objects at Istanbul University.

Shipwrecks yielded on land due to silting up of the harbor were identifiable by their forms and in situ conditions. The original hull forms, floor timbers, and futtock curves can be observed. The hull bottoms of many shipwrecks survived to the present day in their entirety and are well-preserved. The shipwrecks that were identified and excavated by the İstanbul Archaeological Museums have been temporarily protected under a tent, incorporating a water-spray system to keep them wet (Fig. 3). Upon creation of a suitable working environment, It was started detailed cleaning and documentation procedures by the IU team During all these stages, direct physical contact with severely deteriorated timbers was avoided, and thus a scaffold system was installed over the shipwrecks to proceed with studies.



Fig. 3. Excavation and cleaning of the shipwrecks.

Рис. 3. Раскопки и очистка останков затонувших кораблей.

The shipwrecks were documented *in situ* with 2D and 3D measurements, full-scale hand drawings, photography, and photo-mosaics (Özsait-Kocabaş 2008; Özsait-Kocabaş 2010).

Lifting the Wooden Elements of the Shipwrecks

Various lifting solutions have been applied to the Yenikapı shipwrecks with different preserved rates. However, the general principle is to remove the wooden elements by dismantling them in molds that maintain their existing form. These molds act as carriers for the hull timbers in the tanks until the studies on the wrecks begin. Dismantling is started with ceilings, stringers, and frames and ended with planking. The lifting by the dismantling of the shipwrecks is facilitated detailed documentation and reconstruction works, as well as conservation and drying works (Fig. 4) (Kocabaş, Özsait-Kocabaş, Kılıç 2012; Kocabaş, Özsait-Kocabaş 2013).

Post-Excavation Documentation

Post-excavation documentation and ship-building technology studies of the shipwrecks are continued in the IU Yenikapı Shipwrecks Project Application and Research Laboratory. The timbers with invisible joints under *in situ* conditions are documented in detail after disman-

tlng in order to proceed with the reconstruction project in the laboratory. Each wooden element of all shipwrecks, like floor timber, keel, and ceiling plank, is photographed, 3D drawn, and cataloged. The most significant phase of the laboratory documentation is the digitalization of data for each part by means of a 3D digitizer measurement system (*FaroArm*[®]), which was used for the first time in archaeology in Türkiye by our team (Fig. 5).

Conservation

Due to a thick layer of muddy sediment, Yenikapı shipwrecks were found in a relatively better condition than the other shipwrecks found underwater in the Mediterranean. However, regardless of their fair condition, it is unlikely to store or display any waterlogged ship timber in the museum without conservation and restoration procedures. The biological activity inevitably has caused different levels of degradation on the cell structure of timbers for centuries, even preserved by the heavy mud on them. The conservation procedure was begun immediately as the shipwrecks were brought to daylight (Kocabaş 2015b, 9). The primary works focused on preventive conservation in the excavation site to avoid cracks and shrinkage on waterlogged timbers



Fig. 4. Removal of findings after in situ drawing.

Рис. 4. Извлечение находок после составления ситуационного плана



Fig. 5. 1:1 scale digital drawings with the digitizer (FaroArm) device.

Рис. 5. Цифровые чертежи в масштабе 1:1, сделанные цифровым устройством (FaroArm).

due to drying out. The excavations started with constructing a temporary tent to shield the shipwreck from external ambient conditions such as sunlight and winds. An atomized spraying system was installed inside the tent to create an environment of 100% relative humidity and keep the timbers wet for 24 hours. During the work on the wrecks, the irrigation system was operated

regularly to prevent the wood from drying out. After the excavation, the timbers were preserved in freshwater tanks at the Istanbul University Yenikapı Shipwrecks Project Application and Research Laboratory (Fig. 6). Desalination and impregnation carried out within the scope of conservation are carried out in these tanks, which are usually built of stainless steel due to their high



Fig. 6. Storage tanks where the preservation of waterlogged wood is carried out. (Yenikapi Shipwrecks Application and Research Laboratory).

Рис. 6. Резервуары для хранения мокрой древесины. (Прикладная исследовательская лаборатория затонувших кораблей Еникапы).

corrosion resistance. One of the biggest problems encountered in the desalination and impregnation of organic artifacts in countries with a temperate climate, such as Türkiye, is the activation of fungi and bacteria in shipwreck tanks. Against biological activation during desalination, Acticide SPX (5-chloro-2-methyl-4-iso-thiazolin-3-one and 2-methyl-2H-isothiazol-3-one) liquid biocide is added into the tank at a ratio of 1/1000 (Kılıç, Kılıç 2019a).

The most crucial stage of the conservation procedure is the impregnation of chemicals into the cell structure of the wood. By this technique, chemical material penetrates into the cells, replaces water in the cell structure, and provides mechanical strength. After the process, the wood is dried in a controlled manner and taken under protection in a suitable environment. It was preferred two conservation methods in the Yenikapi shipwrecks project. Polyethylene glycol (PEG) impregnation and vacuum freeze-drying are the main methods. This method uses PEG, with different molecular weights of 400, 2000, 3350, and 4000, determined according to the density and maximum water content values of the wood. For example, Impregnation begins at a 5% concentration to minimize the occurrence of osmotic collapse in wood using PEG 2000. Although the application in which PEG of a single molecular weight is impregnated is mainly preferred, applications in which PEG of different molecular weights are mixed and impregnated are also carried out on woods with varying density values. Scanning Electron Microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) analyses are performed by taking

samples from the wood during the impregnation process to detect the distribution of the chemical and its presence in the wood (Kocabaş, Kılıç, Asal 2020, 38-42). After PEG pre-impregnation, wood is subjected to vacuum freeze-drying. The procedure that takes place according to the sublimation principle; consists of freezing, freeze-drying, and returning the wood to ambient conditions. Istanbul University Yenikapi Shipwrecks Project Application and Research Laboratory has two devices for the vacuum freeze-drying procedure. Thanks to these devices, which are 2.50 m in length, 90 cm in diameter, and 9 m in length, 2.10 m in diameter product chamber, the conservation of wooden elements of various sizes can be done as a whole (Fig. 7a, b). The other method is melamine formaldehyde (Kauramin® 800). Based on the polymerization principle of the melamine formaldehyde method, the wood is impregnated by dipping and dried by heating in the oven. Low molecular weight (400-700 g/mol) melamine-formaldehyde prepolymer is dissolved in 25% concentration in deionized water. 0.5% triethanolamine based on melamine-formaldehyde is added to increase the solution's pH and extend the solution's curing time (12-14 months). In addition, 10% triethylene glycol is added to the solution to give flexibility to the wood, and 5% urea is added to support absorption by obtaining a more fluid solution. Polycondensation of melamine formaldehyde is carried out at a temperature of 50-55°C, and a 10 m long furnace is used for this process in Yenikapi. Following conservation procedures, which take a considerable time, re-assemble ship timbers for future public exhibitions will be possible (Fig. 8a, b).



a



b

Fig. 7a, b. D 21/85 model vacuum freeze dryer used in the Yenikapı Shipwrecks Project.

The diameter of the product chamber of the device is 2.10 m; length is 9 m.

Рис. 7а, б. Устройство D 21/85 для вакуумной лиофилизации, используемое в проекте "Затонувшие корабли Еникапы". Диаметр камеры составляет 2,10 м, длина - 9 м.

Conclusions

The Yenikapı Shipwrecks studied by Istanbul University works were removed from the field with appropriate methods and stored in the stainless steel and concrete tanks at IU Yenikapı Shipwrecks Project Application and Research Laboratory. The preservation status of the Yenikapı shipwrecks, the number of existing hull elements, their structural features, chemical and biological

deterioration of their wood, and how they were removed from the site vary. These parameters play a decisive role in the decisions and methods followed in the post-excavation works. In the general workflow, the conservation process begins after the documentation and technology studies on the wrecks are completed. However, as in the YK12 example, the only drawing time of small-sized wrecks may take more than one year



Fig. 8a. Placing the small timbers of the shipwrecks in the drying oven (Yenikapı Site Lab.)

Рис. 8а. Помещение небольших обломков в сушильную камеру (лаборатория объекта Еникапы).

Fig. 8b. A 10 m long drying oven for large-scale timbers at Yenikapı Site Lab.

Рис. 8б. Камера длиной 10 м для сушки крупной древесины в лаборатории объекта Еникапы.



(Fig. 9) (Özsait-Kocabaş 2018; Özsait-Kocabaş 2022). The high number of wrecks prolongs the waiting time for the timbers in the tanks. It has increased the risk of deterioration in the right proportion with time elapsed in the waterlogged wood waiting for treatment. For this reason, it was decided to take conservation of the shipwreck timbers, which have a high risk of deterioration, by drawing the outlines and then carrying out detailed documentation. PEG (polyethylene glycol) pre-impregnation followed by vacuum

freeze-drying is applied in most Yenikapı shipwrecks. On the other hand, the melamine formaldehyde (Kauramin®) method is used in conserving ship timbers with high water content and low density, woods that need immediate intervention (Fig. 10). Depending on the deterioration of wood, as a single method is used on all woods of a shipwreck, two different ways can be applied. For example, melamine formaldehyde was used in the highly deteriorated floor timbers from the plane tree of the YK3 and YK16 shipwrecks. In



Fig. 9. Yenikapı 12 is a small merchantman found with its cargo.

Рис. 9. Yenikapı 12 - небольшое торговое судно, найденное с грузом.

contrast, the other elements of these shipwrecks in better condition were conserved using the PEG method. Both ways successfully provided dimensional stabilization (Fig. 11). However, using two different chemicals in the elements of the same shipwreck causes different colors, mechanical strength, fragility, flexibility, and weight in the woods. Similarly, their resistance to biological activation, environmental impact values, and reaction to the support materials used vary by impregnation chemicals. Cracks, excessive lightening of the natural color, and whitening are observed in the woods that have been applied melamine formaldehyde method. In addition, wooden elements become lighter than necessary (Hoffmann, Wittköpper 1999; Kocabaş 2023). These disadvantages are not seen in the use of PEG. However, using iron in the supports that will carry the body or in the storage construction has not become a problem for timbers impregnated melamine formaldehyde, but it has created a

corrosive effect on PEG (Kılıç, Kılıç, Akgün, 2021). When iron is combined with sulfate in the wood structure and high relative humidity in the environment, reactions that cause acidity, salt precipitates, and risk of deterioration develop in waterlogged woods. Also, PEG is a hygroscopic chemical and undergoes degradation at high illuminance. High ambient temperature can cause softening of treated woods, separation of bonded surfaces, and deterioration of PEG. This issue should be considered in the re-installation of shipwrecks hull for exhibition purposes, in the exhibition environment, and in the creation of storage conditions. Melamine has more flexible conditions than PEG in formaldehyde, relative humidity, temperature, and light values. However, direct sunlight is a negative factor for both materials. For all these reasons, the temperature, relative humidity, and light intensity should be kept at values suitable for the wood, an organic material, and the conservation chemical used to preserve



Fig. 10. Image of a group of timbers belonging to the Yenikapı 36 shipwreck after conservation with Kauramin 800.
Рис. 10. Рисунок древесины, принадлежащей затонувшему судну Yenikapı 36, после консервации с применением Kauramin 800.



Fig. 11. Image of a floor timber from the Yenikapı shipwrecks before and after the Kauramin conservation.
Рис. 11. Изображение деревянного настила с затонувших кораблей Еникапы до и после консервации Каурамина.

the archaeological ship woods' current condition and prevent further deterioration during display and storage. Temperature, relative humidity, and pH controls regularly occur in the IU Yenikapı Shipwrecks Project storage area.

The laboratory studies of the IU team started with the YK6 wreck in 2006. In the sixteen years since this date, the difficulties brought by the process and the results of the first practices have emerged. Studies are performed continuously for the drawing, photographing, analysis, desalination, cleaning, impregnation, and drying processes of numerous wooden elements of 31 shipwrecks in various sizes ranging from 2 m to 23 m in existing length. The studies are blended with struggles for the area's safety, financing the

works, and the sustainability of the current opportunities, beyond the intensive labor and workforce. The most significant handicap has been the time factor, which works against the preservation of the timbers. Conservations of 70% of Yenikapı shipwrecks are finished or continued, and 30% have not yet started. The conservation of the shipwrecks is foreseen to continue for about the next 15 years. Therefore, measures to be taken and solutions to be developed in this direction will positively affect the success of the studies. Today, the extraordinary construction story of the stations in Yenikapı, where everybody hastily passes by, will always be remembered in many aspects. The Yenikapı Excavation, which has already claimed its place among the archaeologi-

cal discoveries of the century, will be immortalized with a must-have museum.

Contributions

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