

# WOOD IDENTIFICATION OF WOODEN MARINE PILES FROM THE ANCIENT BYZANTINE PORT OF ELEUTHERIUS/THEODOSIUS

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The purpose of this study was to identify the wood species of the marine and filling piles obtained from the ancient Byzantine port of Eleutherius/Theodosius, Istanbul, Turkey. Anatomical descriptions and identifications of 12 marine and 4 filling piles were performed by microscopic evaluations. In the study, *Castanea sativa* Mill., *Quercus ithaburensis* Decne., *Quercus pontica* C. Koch., and *Cupressus sempervirens* L. species were identified. No precise identifications were completed for only six samples at the species level; however, those samples showed significant similarity to *Quercus* spp. and *Fagus* spp. It was concluded that the economically viable supply of wood was more appropriate than obtaining it from nearby regions. The people living in ancient times had solid knowledge and experience on the utilization of wood species.

*Keywords:* Marmaray Project; Archaeological wood, Wood identification; Port of Eleutherius/Theodosius

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## INTRODUCTION

Throughout its long history Istanbul has served as the capital city of four great empires, namely the Roman Empire, the Byzantine Empire, the Latin Empire, and the Ottoman Empire, for more than 1,600 years. Istanbul has been a crucial trade center for various goods as well as a 'metropolitan' city for more than 2,800 years since the city was not only an administrative, but also a religious center (Keskin and Diren 1992).

In 2004, an enormous project called Marmaray was given a start to construct an underwater tunnel between the Asian and European sides of Istanbul, and thus to ease the city's traffic problem. The tunnel under the Bosphorus will be the deepest built ever with its deepest point being about 58 m under the water surface. The deep stations and tunnels are being constructed in the area where civilization can be traced more than 7,000 years back in time (Lykke and Belkaya 2005). The ancient Byzantine port of the fourth-century has been recently uncovered under the slums of Yenikapi as the focal point of \$4 billion tunnel project, in the European side of Istanbul, (Fig. 1) (Marine Cultural and Historic Newsletter 2006).

The port is a trove of relics dating back as far as the time of Constantine the Great. The Roman emperor Constantine moved his capital from Rome to Byzantium in 330 AD and renamed the city Constantinople, which became Istanbul later (Journal of Indian Ocean Archeology 2006). It finally grew into the busiest trading center in the



**Fig. 1.** The Marmaray Project along the coast line of the Marmara Sea and Yenikapi excavation area

eastern Mediterranean. The ships from here carried the wine in jars and amphorae from the Sea of Marmara and the cargoes of grain came in from Alexandria. The ancient Byzantine port called Port of Eleutherius / Theodosius, which was built by The Roman Emperor Theodosius I (A.C. 379–395), was an important one until the 7th century; however, it was abandoned since then because grain trade came to end. Afterwards, this ancient port area became filled by alluvium of the River Bayrampasha, was merged with the mainland during the first years of the Ottoman Empire, and was used for vegetable farming at a site called Vlanga (Langa) Bostani (ARIT Newsletter 2006, 2007).

This paper aims to identify the wood species of wooden marine and filling piles from the biggest port of the Byzantine Era (Günsenin 2007). For this purpose, wooden objects excavated from the port were subjected to anatomical examination by using light microscopy analysis.

## EXPERIMENTAL

### Materials

In 2007, 16 wood samples (12 marine and 4 filling piles) in varying sizes and characteristics were obtained from the Yenikapi Marmaray site (Table 1), where

excavations continue, led by the Istanbul Archaeological Museum (Fig. 2). The site showed barren sandy sediment characteristics; however, no soil analyses were done to determine site characteristics. Since wood may shrink, fragment, and collapse into small pieces, all samples were stored in water at 4°C, and the water was renewed at two- or three-week intervals (Blanchette 2000).



**Fig. 2.** General view of the excavation site and wooden marines (marine and filling piles)

## Methods

Anatomical descriptions and identifications of each sample were performed based on the microscopic studies of cross (CS), radial (RS), and tangential sections (TS). For these purposes, approximately 10 by 10 by 20 mm blocks were cut from the samples. Well-preserved samples were cut to thin sections (about 20 to 30  $\mu\text{m}$ ) using a Reichert sliding microtome; however, heavily decomposed samples were not suitable for cutting with a microtome. Such samples were hand-cut with a razor blade.

**Table 1.** Information on Wood Samples Obtained From the Ancient Port of Eleutherius / Theodosius

Sample No	Sample Code	Depth (m)	Pile Description
1	4Ab2	-1.54	Marine
2	1Bd3	-2.55	Marine
3	YKM'07 2Ea2	-3.62/-4.52	Marine
4	YKM'07 2Ec4	-1.90/-2.10	Marine
5	2Gc3	-1.25	Filling
6	2Hb3	-2.30	Marine
7–8	2Hd1	-2.30	Marine
9	MRY'07 I 10	-2.30	Marine
10	MRY'07 I 140	-1.70	Marine
11	I L 124–125	-1.16	Marine
12	MRY'07 J 142	-0.80	Filling
13	MRY'07 J 144	-0.80	Filling
14	MRY'07 J 145	-0.50	Filling
15	MRY'07 K 140	-1.70	Marine
16	MRY'07 L 140	-2.69	Marine

Sections from the blocks were stained with safranin and safranin–picro–aniline blue and were then observed by means of an Olympus BX51 Light Microscope. Images were taken by using analySIS FIVE software and a DP71 Digital Camera installed and adapted on the microscope. The terminology for the wood descriptions generally conforms to the format by the International Association of Wood Anatomist (IAWA Committee 1989, 2004).

Wood identification was done considering not only quantitative features but also qualitative anatomical characteristics of the samples observed under the microscope. Tangential vessel diameters, vessel frequencies (only in diffuse porous wood), ray heights/widths, and intervessel pits size were measured for hardwood identification. Tangential tracheid diameters, ray heights, and cross-field pits number per field were determined for identification of softwood samples. On the other hand, the presence of growth ring boundaries, porosity, vessel arrangements, shape of the solitary vessel outline, type of axial parenchyma patterns, cellular composition of rays, intervessel pits arrangement, and types of perforation plates were used as qualitative anatomical characteristics for hardwood identification. Presence of growth ring boundaries, transition from earlywood to latewood, presence of axial parenchyma, arrangement of earlywood tracheid pitting in radial walls, ray composition, horizontal and end walls of ray parenchyma cells, cross-field pitting, and end walls of axial parenchyma cells were also used for softwood identification. Quantitative and qualitative features of the wood samples were then compared with microscopic slides in the Xylarium of Forestry Faculty, Istanbul University, Turkey. Atlases, websites and publications were also used as references for comparisons.

## RESULTS AND DISCUSSION

### Restrictions in Examinations

There were some restrictive factors in the study. One was the selection of the areas to measure anatomical characteristics of wood samples and number of measurements due to distortions and decompositions of wood during burial. Despite the negative structural features of the wood samples, measurements were carried out on the cells without decomposition. Another restrictive factor was unknown tree age and growing conditions of the wood samples used in the construction of the port. Since changes in wood structure depend on age, growing conditions, and location height that the specimen is taken from the tree, even the same wood species can show more or less variations in anatomical properties such as growth ring width, cell size, and cell wall thickness (Bozkurt and Erdin 2000).

Uncertainties in anatomical features of the samples for wood identification depending on the restrictive factors mentioned above can be explained as follows.

There was obvious distortion in the shape of the some vessels because the wood was compressed during burial in samples of MRY'07 J 142, MRY'07 L 140, and YKM'07 2Ea2.

Since there was obvious distortion in sample of MRY'07 J 144, the number of earlywood vessels in radial multiples; tangential diameter of vessels was not determined. The shapes of latewood vessels and scanty paratracheal parenchyma were indistinguishable.

Since there was obvious distortion in the structures of the growth ring in the sample of YKM'07 2Ec4 the shape of the vessels, types of the axial parenchyma, appearance of flames in latewood were indistinguishable, and the diameters of the vessels were not measured. Only apotracheal diffuse type axial parenchyma was observed in this sample.

Sample MRY'07 I 10 showed distinct distortion and decomposition in the structure of the growth rings. Therefore, types of the axial parenchyma were not distinguished and only apotracheal diffuse type axial parenchyma was observed.

### Anatomical Descriptions and Identification of Wood Samples

The qualitative results of the samples and comparisons to literature are summarized below, and the quantitative results are given in Tables 2 and 3, respectively.

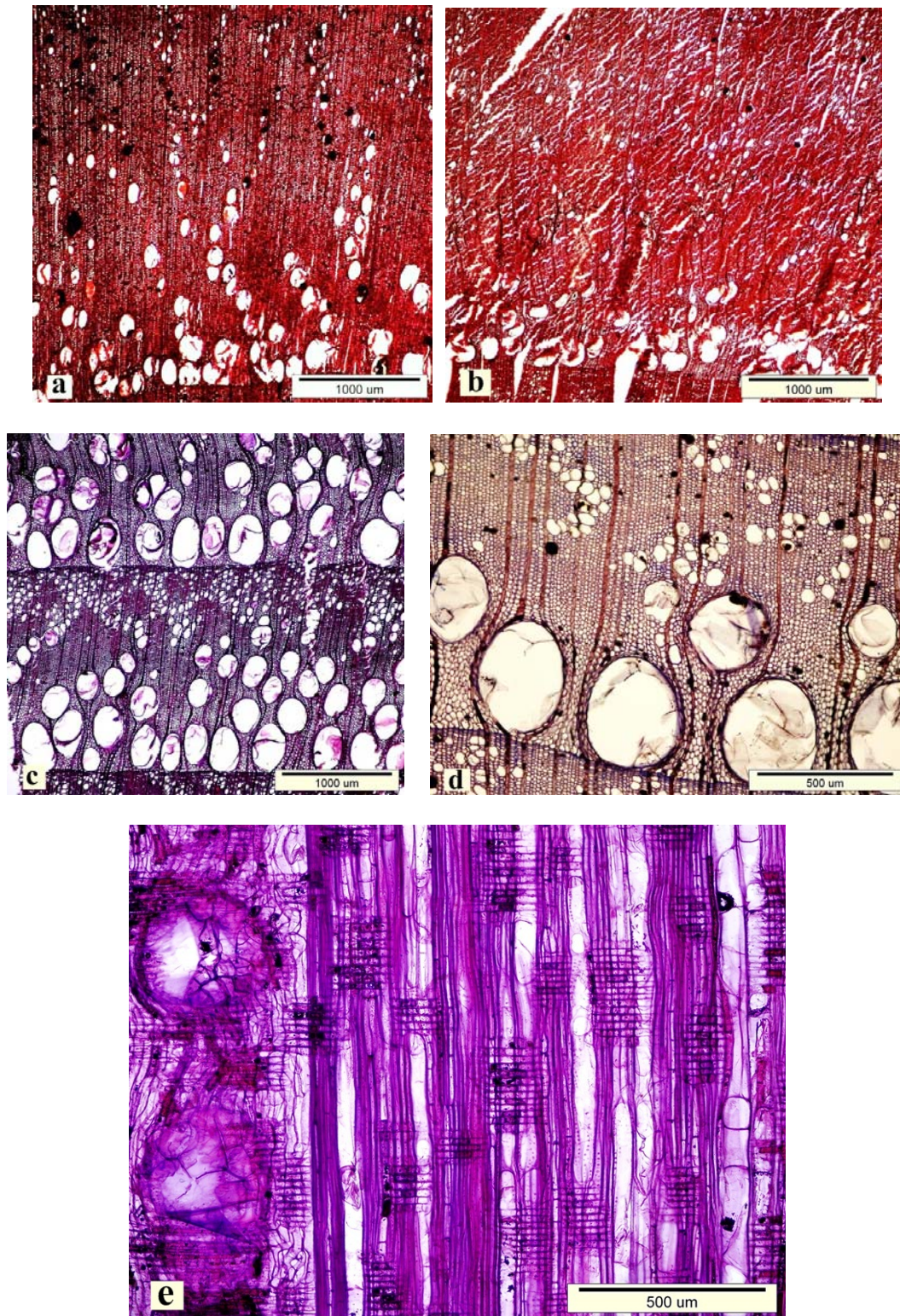
#### Hardwoods

Family: *Fagaceae*

***Castanea sativa* Mill.** (Sample code: 2Hb3, 2Hd1, MRY'07 J 144, MRY'07 J 145)

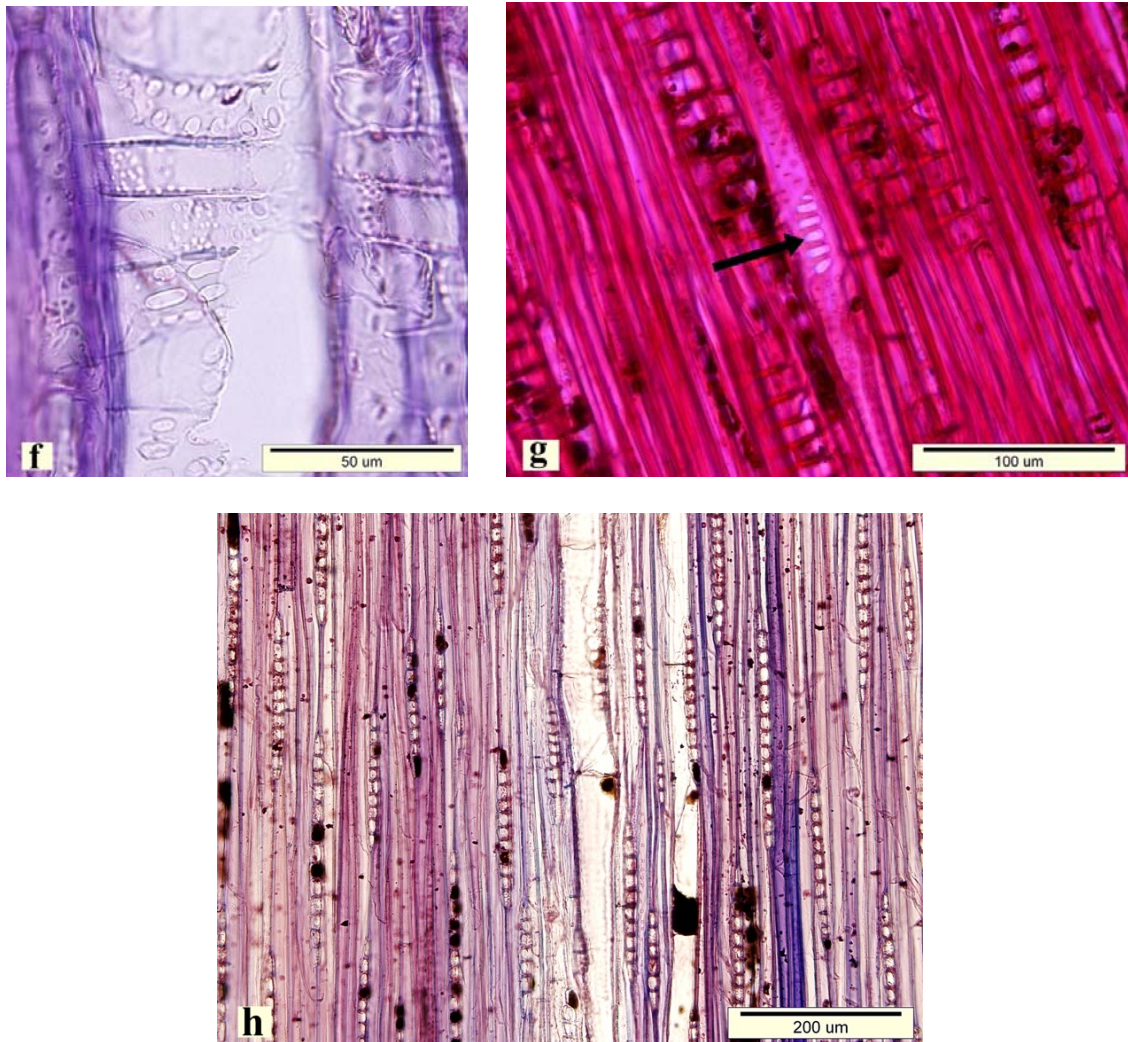
CS—Growth ring boundaries distinct. Wood ring-porous. Earlywood vessels mostly solitary and in radial multiples of 2–5 (in 2Hb3) and 2–6 (in 2Hd1 and MRY'07 J 145). Tyloses common. Latewood vessels in radial and / or diagonal pattern (in MRY'07 J 144, MRY'07 J 145) and almost in dendritic pattern (in 2Hb3, 2Hd1), angular in outline. Axial parenchyma scanty paratracheal and apotracheal diffuse, diffuse-in-aggregates (Figs. 3a–d).





**Fig. 3.** *Castanea sativa* samples obtained from the ancient Port of Eleutherius/Theodosius  
a) Cross section of MRY' 07 J 145, b) Cross section of MRY' 07 J 144, c) Cross section of 2Hd1,  
d) Cross section of 2Hb3, e) Radial section (2Hd1)





**Fig. 3** (continued). f) Vessel-ray pits (2Hb3), g) Scalariform perforation plate in latewood (MR'07 J 145), h) Tangential section (2Hb3)

*RS*—Perforation plates simple, rarely scalariform in latewood. Rays composed predominantly of procumbent cells, sometimes with one row of upright and / or square marginal cells. Vessel-ray pits with much reduced borders to apparently simple: (i) pits rounded or angular, (ii) pits horizontal (scalariform) (Figs. 3e—g).

*TS*—Rays exclusively uniseriate. Intervessel pits alternate (Fig. 3h).

*Comparison to literature*—Earlywood vessels mostly solitary (Schoch et al. 2004) and in radial multiples of 2–6 (Merev 1998a; Bozkurt and Erdin 2000). Latewood vessels in radial and / or diagonal and sometimes in dendritic pattern (Merev 1998a; Bozkurt and Erdin 2000). Tangential diameter of earlywood vessels 240–400  $\mu\text{m}$  (Bozkurt 1967), 120–394  $\mu\text{m}$  (Merev 1998a),  $\leq 300$   $\mu\text{m}$  (Bozkurt and Erdin 2000), 100–200  $\mu\text{m}$  (The Xylem Data Base). Tangential diameter of latewood vessels 19–99  $\mu\text{m}$  (Merev 1998a), 30–40  $\mu\text{m}$  (Bozkurt and Erdin 2000). Axial parenchyma paratracheal, apotracheal diffuse, diffuse-in-aggregates (Merev 1998a; Bozkurt and Erdin 2000; Schoch et al.

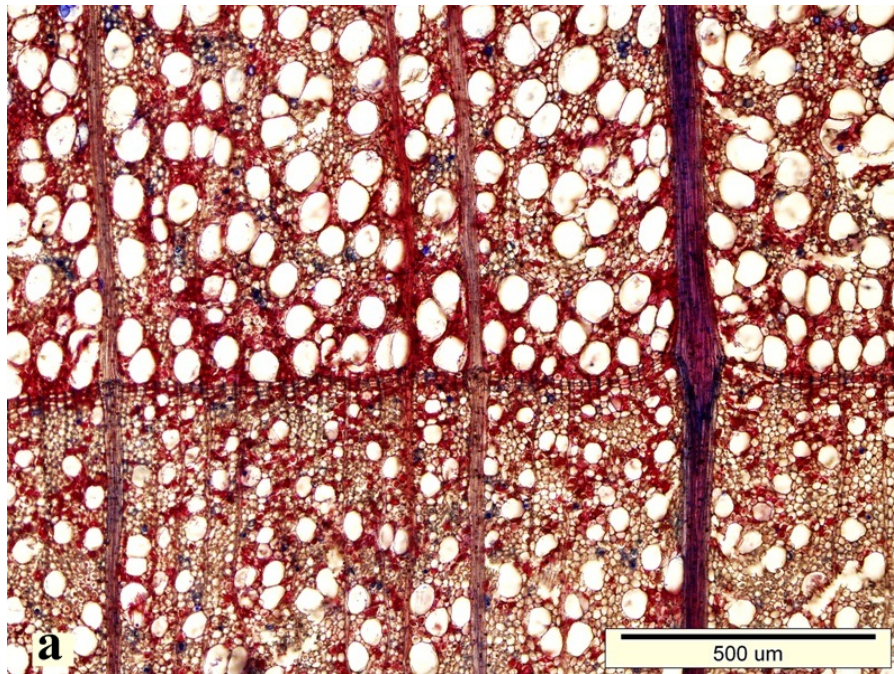
2004; The Xylem Data Base) and in marginal (The Xylem Data Base). Perforation plates simple (Bozkurt and Erdin 2000; Akkemik et al. 2004; Schoch et al. 2004; The Xylem Data Base) and scalariform in latewood (Merev 1998a). Rays composed exclusively of procumbent cells (Merev 1998a; The Xylem Data Base), uniseriate (Merev 1998a; Bozkurt and Erdin 2000; The Xylem Data Base) and rarely biseriate (Bozkurt 1967; Akkemik et al. 2004; Schoch et al. 2004), 1-20 (9) cells high (Merev 1998a),  $\leq 30$  cells high (Akkemik et al. 2004) and 10–30 cells high (Schoch et al. 2004). Intervessel pits alternate (Merev 1998a; The Xylem Data Base).

***Fagus* spp.** (Sample code: 1Bd3)

**CS**—Growth ring boundaries distinct. Wood diffuse-porous. Although there is a gradual change to narrower vessels in the latewood, vessel diameter is uniform throughout most of the growth ring. Vessels mostly solitary, angular in outline, 108–145 per square mm. Larger rays distended at the growth ring boundary. Axial parenchyma apotracheal diffuse, diffuse-in-aggregates (Fig. 4a).

**RS**—Perforation plates simple in large vessels and scalariform in narrow vessels. Rays composed predominantly of procumbent cells, sometimes with one row of upright and / or square marginal cells. Vessel-ray pits with much reduced borders to apparently simple: (i) pits rounded, (ii) pits horizontal (scalariform) (Fig. 4b and Fig. 4c).

**TS**—Rays of two distinct sizes, smaller rays 1–6 seriate, larger rays > 10-seriate. Intervessel pits opposite and scalariform (Fig. 4d).



**Fig. 4.** *Fagus* spp. sample obtained from the ancient Port of Eleutherius/Theodosius  
a) Cross section



**Table 2.** Some Quantitative Anatomical Features of Hardwood Samples

Sample Code	Species	Tangential Vessel Diameter ( $\mu\text{m}$ )			Ray Height				Intervessel Pits Size	
		Earlywood	Latewood	Growth Ring	Uniseriate		Multiseriate		( $\mu\text{m}$ )	Category
					$\mu\text{m}$	Number of Cells	$\mu\text{m}$	Number of Cells		
2Hb3	<i>Castanea sativa</i> Mill.	(257) <sup>a</sup> (131-364) <sup>b</sup> 40 <sup>c</sup>	(62) (30-114) 30	—	(215) (58-384) 81	(10) (2-20) 43	—	—	(8.37) (5.32-11.23) 100	M <sup>d</sup>
2Hd1	<i>C. sativa</i> Mill.	(289) (111-467) 42	(63) (33-122) 68	—	(252) (67-580) 115	(10) (1-21) 60	—	—	(9.39) (5.01-13.93) 130	M
MRY'07 J 144	<i>C. sativa</i> Mill.	*	—	—	(196) (44-571) 100	(11) (2-31) 38	—	—	(8.02)(3.91-16.87) 33	M
MRY'07 J 145	<i>C. sativa</i> Mill.	(112) (59-186) 51	(27) (11-55) 50	—	(211) (53-615) 82	(12) (2-31) 41	—	—	(6.78) (4.60-10.16) 73	S <sup>e</sup>
1Bd3	<i>Fagus</i> spp.	—	—	(76) (33-108) 50	(193) (67-286) 33	(9) (3-23) 36	—	(26)(9-50) (2-6 seriate) 36	(7.03) (4.33-11) 73	M
4Ab2	<i>Quercus ithaburensis</i> Decne.	(147) (75-233) 39	(37) (20-78) 34	—	(161) (37-452) 60	(11) (1-28) 51	—	—	(6.81) (5.10-8.99) 45	S
2Gc3	<i>Q. ithaburensis</i> Decne.	(230) (128-341) 44	(54) (17-141) 51	—	(201) (43-645) 203	(10) (2-26) 42	—	—	(7.86) (4.51-12.29) 50	M
MRY'07 J 142	<i>Quercus</i> spp.	(205) (83-305) 49	(31) (19-60) 62	—	(175) (44-586) 141	(12) (3-32) 50	—	—	(6.28) (4.42-7.92) 69	S
I L 124-125	<i>Q. pontica</i> C. Koch.	(205) (94-296) 30	(55) (22-109) 34	—	(184) (47-494) 93	(13) (2-29) 50	—	—	(6.67) (4.77-9.70) 67	S
YKM'07 2Ea2	<i>Quercus</i> spp.	(284) (156-392) 31	(50) (15-147) 34	—	(241) (46-557) 120	(10) (1-24) 47	—	—	(8.69) (6.43-12.16) 62	M
MRY'07 L 140	<i>Quercus</i> spp.	(296) (154-442) 43	(54) (25-156) 33	—	(269) (68-564) 70	(11) (2-26) 40	—	—	(6.72) (4.77-9.75) 67	S
YKM'07 2Ec4	<i>Quercus</i> spp.	*	—	—	(179) (47-454) 85	(12) (3-26) 48	—	—	(5.94) (4.05-8.29) 55	S
MRY'07 I 10	<i>Quercus</i> spp.	(283) (193-352) 31	(84) (45-136) 37	—	(173) (47-397) 84	(10) (2-22) 34	—	—	(8.85) (5.99-12.16) 51	M

<sup>a</sup> Mean values are given in the first parenthesis in italics

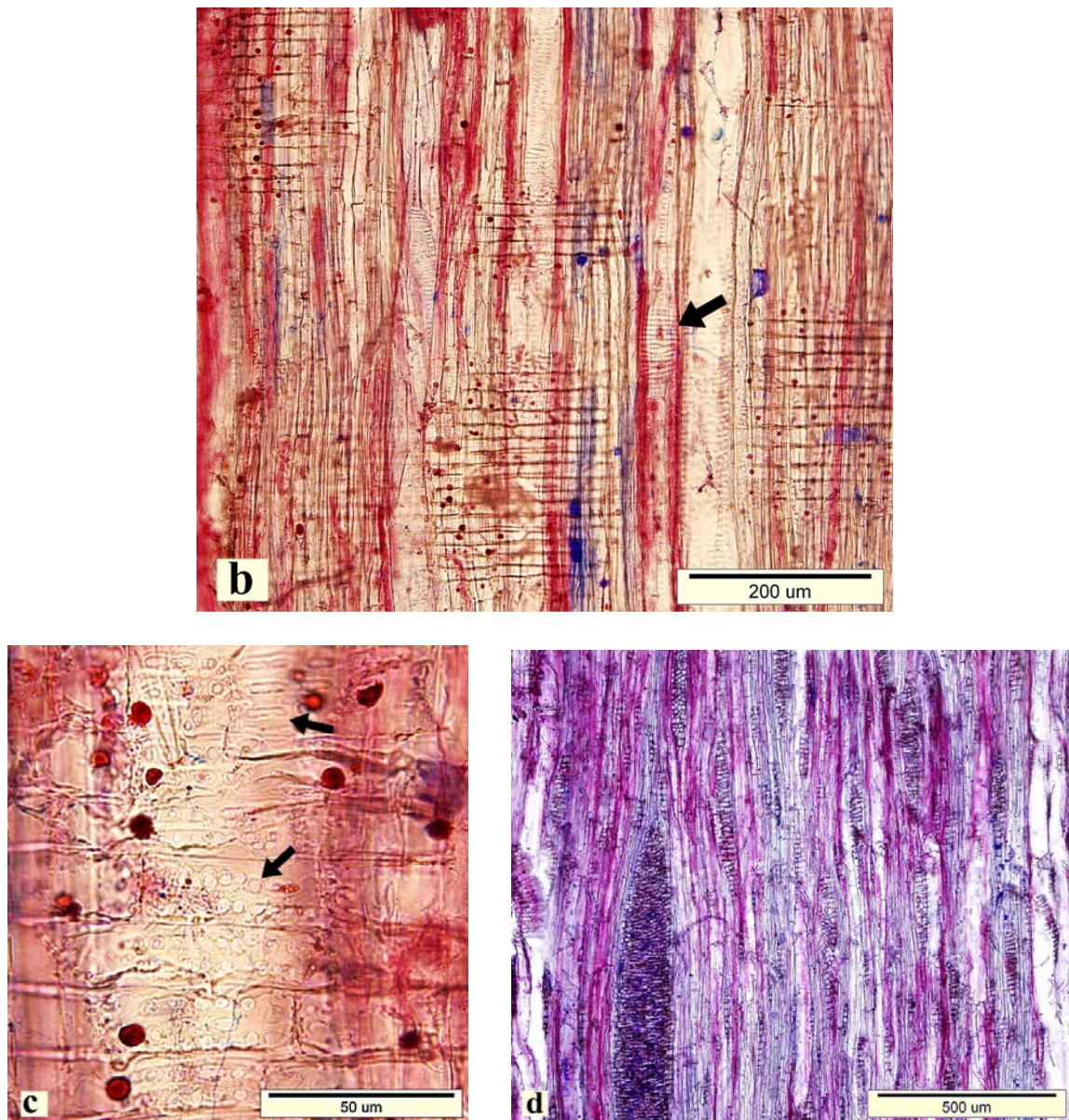
<sup>b</sup> Min. and max. values are given in the second parenthesis

<sup>c</sup> Values outside parenthesis indicate the numbers of observation

<sup>d</sup> Medium

<sup>e</sup> Small

\* Could not be measured



**Fig. 4** (continued). b) Radial section and view of scalariform perforation plate (arrow) c) Vessel-ray pits, d) Tangential section

*Comparison to literature*—Wood diffuse-porous (Bozkurt 1967; Sanli 1978; Merv 1998a; Bozkurt and Erdin 2000). Wood semi-ring-porous (Sanli 1978; The Xylem Data Base). Vessels predominantly solitary and sometimes in clusters (Merv 1998a; The Xylem Data Base), vessel number in per sq mm of 120–180 (Bozkurt 1967), 81–170 (116) (Merv 1998a). Tangential diameter of vessels 60–80 µm (100 µm) (Bozkurt and Erdin 2000), often > 50–90 µm (The Xylem Data Base). Axial parenchyma apotracheal diffuse and diffuse-in-aggregates (Merv 1998a; Bozkurt and Erdin 2000; The Xylem Data Base). Perforation plates simple and scalariform (Bozkurt 1967; Sanli 1978; Merv 1998a; Bozkurt and Erdin 2000; The Xylem Data Base). Rays composed predominantly

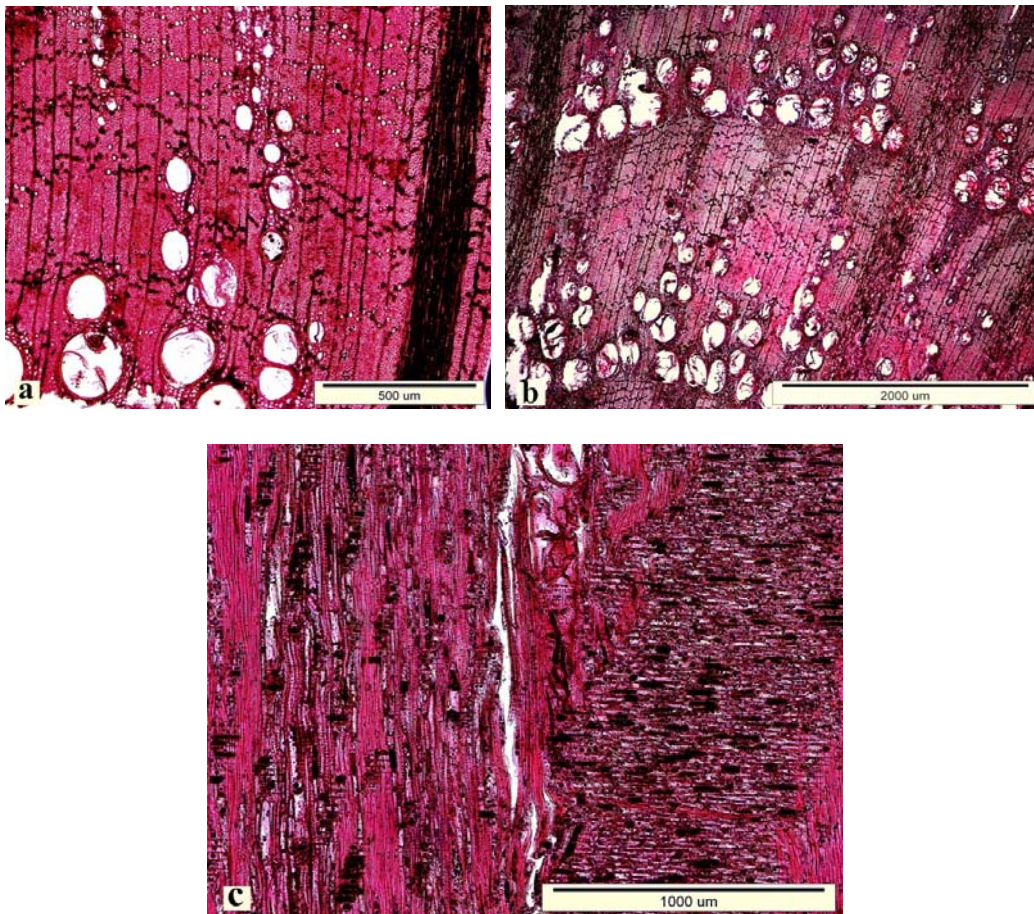


of procumbent cells (The Xylem Data Base), sometimes with one row of upright and / or square marginal cells (Sanli 1978; Merev 1998a), commonly 1–6 seriate and > 10 seriate (Sanli 1978), 3–10 seriate and > 10 seriate (The Xylem Data Base), multiseriate ray height > 1mm (Sanli 1978; Merev 1998a; Bozkurt and Erdin 2000; The Xylem Data Base). Intervessel pits opposite (Bozkurt and Erdin 2000; The Xylem Data Base), alternate in earlywood, opposite and scalariform in latewood (Merev 1998a).

*Wood identification*—Considering quantitative/qualitative features of the wood samples and literature information, those samples are notably similar to *F. orientalis* Lipsky. or *F. sylvestris* L.

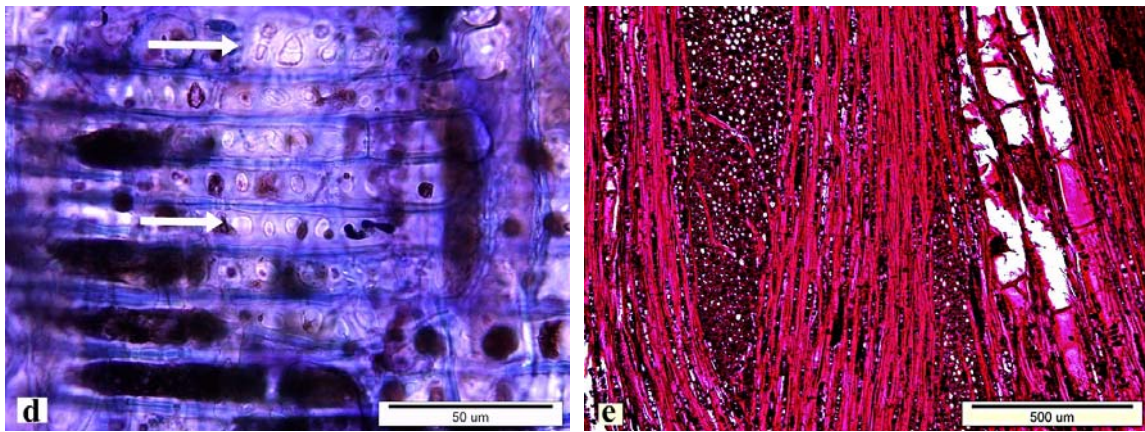
***Quercus ithaburensis* Decne.** (Sample code: 4ab2, 2Gc3)

*CS*—Growth ring boundaries distinct. Wood ring-porous. Earlywood vessels mostly solitary, occasionally in pairs and in radial multiples of 2–5 (in 4ab2) and 2–6 (in 2Gc3). Tyloses common. Latewood vessels in radial and / or diagonal pattern, rounded to oval in outline. Transition from early- to latewood usually gradual. Axial parenchyma scanty paratracheal and apotracheal diffuse, diffuse-in-aggregates (Fig. 5a and Fig. 5b).



**Fig. 5.** *Quercus ithaburensis* samples obtained from the ancient Port of Eleutherius/Theodosius a) Cross section of 4ab2, b) Cross section of 2Gc3, c) Radial section (2Gc3)





**Fig. 5** (continued). d) Vessel-ray pits (2Gc3), e) Tangential section (2Gc3)

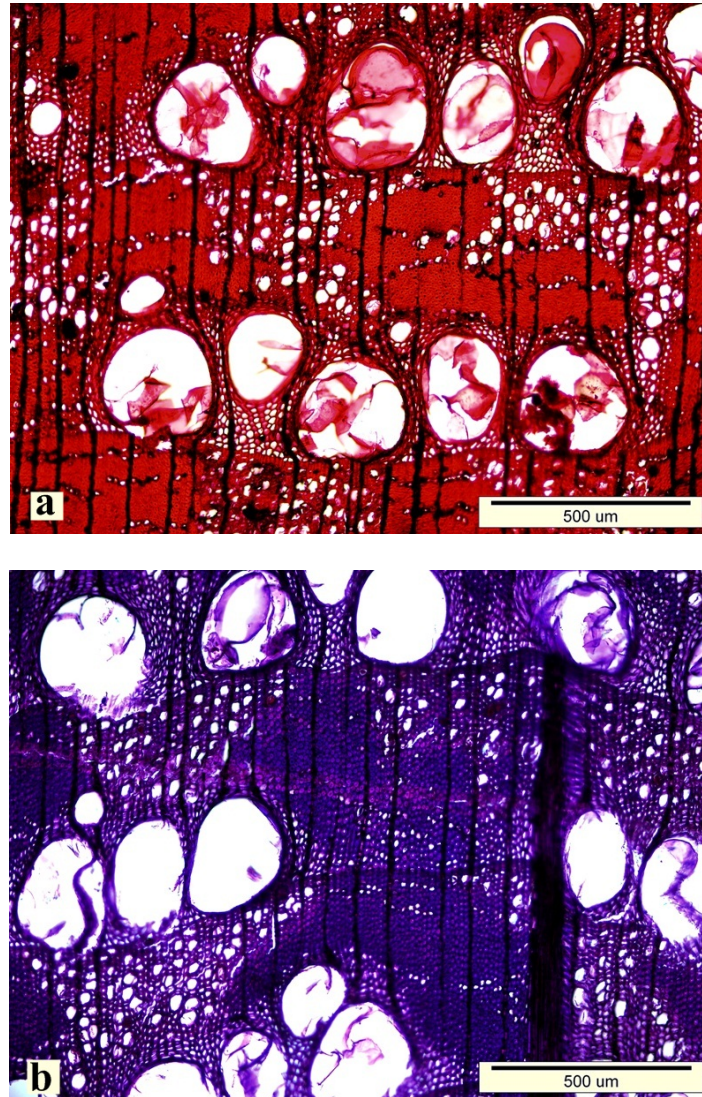
*RS*—Perforation plates simple. All rays composed of procumbent cells. Vessel-ray pits with much reduced borders to apparently simple: (i) pits rounded or angular, (ii) pits vertical. Prismatic crystals present in chambered ray and axial parenchyma cells, many of the crystalliferous cells enlarged and sclerified (Fig. 5c and Fig. 5d).

*TS*—Rays uniseriate and multiseriate, the latter often aggregate. Intervessel pits alternate (Fig. 5e).

*Comparison to literature*—Wood ring-porous (Merev 1998b; Lev-Yadun and Weinstein-Evron 1994). Wood ring- to semi-ring-porous, vessels almost exclusively solitary, occasionally in pairs, forming a radial, sometimes oblique or dendritic pattern, rounded in cross-section, 50–200  $\mu\text{m}$  in tangential diameter (Fahn et al. 1986). Mean tangential diameter of vessels 260  $\mu\text{m}$  in earlywood and 70  $\mu\text{m}$  in latewood (Merev 1998b). Axial parenchyma apotracheal diffuse-in-aggregates (Merev 1998b) and diffuse, scanty paratracheal (Fahn et al. 1986). Perforation plates simple, rays homocellular (Fahn et al. 1986; Merev 1998b), with two distinct sizes, 1(2) –seriate rays 2–10(20) cells high and multiseriates up to 30 cells or more in width and up to 11 mm high, multiseriates often compound or aggregate (Fahn et al. 1986), uniseriate and multiseriate (Lev-Yadun and Weinstein-Evron 1994) and mean height of multiseriates 3.65 mm (Merev 1998b). Intervessel pits large and simple, round to elongate in various directions (Fahn et al. 1986).

***Quercus* spp.** (Sample code: MRY'07 J 142, YKM'07 2Ec4)

*CS*—Growth ring boundaries distinct. Wood ring-porous. Earlywood vessels mostly solitary, in radial multiples of 1–2. Transition from early- to latewood abrupt. Tyloses common. Earlywood vessels rounded in outline in MRY'07 J 142. Latewood vessels almost begin from the central part of the growth rings. Vessels relatively in uniform diameter in latewood (identified only as visually in YKM'07 2Ec4), in oblique to dendritic (flame – like) pattern, appearance of flames strap-like or stream-like and bifurcation, if present, weak in MRY'07 J 142. Latewood vessels in dendritic (flame – like) pattern in YKM'07 2Ec4. Solitary latewood vessels angular in outline. Axial parenchyma apotracheal diffuse (in MRY'07 J 142 and YKM'07 2Ec4), scanty paratracheal and diffuse-in-aggregates (in MRY'07 J 142) (Figs. 6a–c).



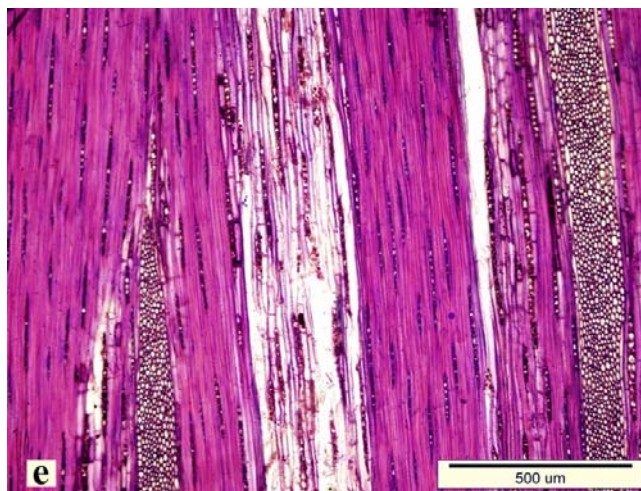
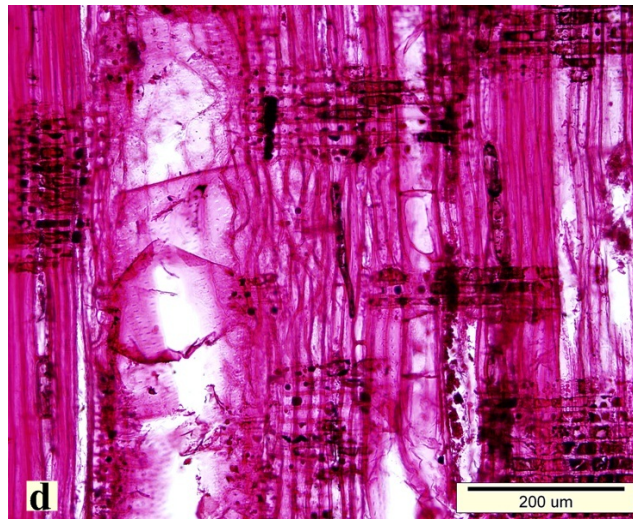
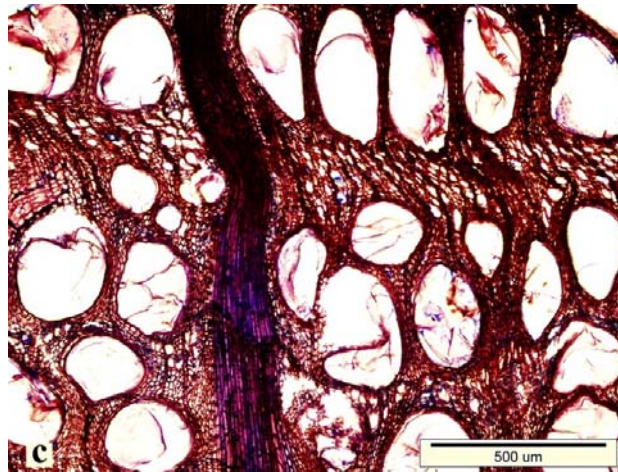
**Fig. 6.** *Quercus* spp. samples obtained from the ancient Port of Eleutherius/Theodosius (similar to *Q. petraea* Liebl.) a-b) Cross sections of MRY'07 J 142

*RS*—Perforation plates simple. All rays composed of procumbent cells. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular (Fig. 6d).

*TS*— Rays uniseriate and multiseriate. Intervessel pits alternate (Fig. 6e).

*Comparison to literature*—Number of earlywood vessel rows 1–2 and rarely 3 (Huber et al. 1941; Fletcher 1978; Walker 1978; Feuillat et al. 1997; Bozkurt and Erdin 2000), one to many (Schoch et al. 2004). Vessel shapes in earlywood almost circular (Huber et al. 1941; Fletcher 1978; Walker 1978; Bozkurt and Erdin 2000). Mean tangential diameter of vessels >200 µm (Merev 1998b; Bozkurt and Erdin 2000; The Xylem Data Base). Transition from early- to latewood abrupt (Huber et al. 1941; Fletcher 1978; Walker 1978; Merev 1998b; Bozkurt and Erdin 2000).





**Fig. 6** (continued). c) Cross section of YKM'07 2Ec4, d) Radial section (MRY'07 J 142), e) Tangential section (MRY'07 J 142)



Latewood vessels almost begin from the central part of the growth rings (Merev 1998b). Individual cross-sectional area of latewood vessels predominantly relatively uniform (Huber 1941). Vessels solitary or in radially orientated to dendritic groups in latewood (Schoch et al. 2004; The Xylem Data Base). Appearance of latewood vessels groups (flames) narrow and clear (Huber 1941), strap-like or stream-like and bifurcation, if present, weak: small and clear (Fletcher 1978), narrow and strap-like; bifurcation, if present, weak (Walker 1978), narrow and strap-like (Feuillat et al. 1997). Axial parenchyma either diffuse or in uniseriate diagonal and tangential bands (Bozkurt and Erdin 2000; Schoch et al. 2004) and paratracheal (The Xylem Data Base). Perforation plates simple (Merev 1998b; Bozkurt and Erdin 2000; Schoch et al. 2004; The Xylem Data Base). All rays composed of procumbent cells (The Xylem Data Base) and sometimes with square cells in uniseriate rays (Schoch et al. 2004). Rays uniseriate and multiseriate, the latter up to 1 mm wide (up to 30 cells) and up to 5 cm high (Bozkurt and Erdin 2000; Schoch et al. 2004). Intervessel pits alternate (The Xylem Data Base).

*Wood identification* —Despite the negative structural features, this sample showed significant properties of oak wood. Based on quantitative/qualitative features of the wood samples and literature information, those samples are notably similar to *Q. petraea* Liebl.

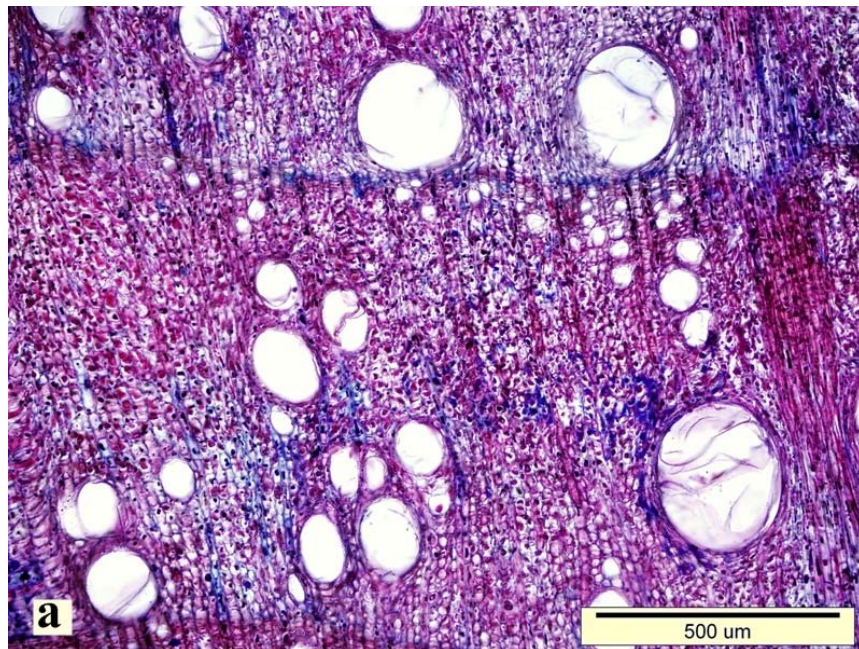
***Q. pontica* C. Koch.** (Sample code: I L 124-125)

*CS*—Growth ring boundaries distinct. Wood ring-porous. Earlywood vessels not constitute continuous rings, mostly solitary, in radial multiples of 1–2, sometimes 2–3, oval, oval to rounded in outline. Transition from early- to latewood gradual. Latewood vessels in radial and / or diagonal pattern, mostly not reach to end of the growth rings, begin next to or just above earlywood vessels. Axial parenchyma apotracheal diffuse, diffuse-in-aggregates (Fig. 7a).

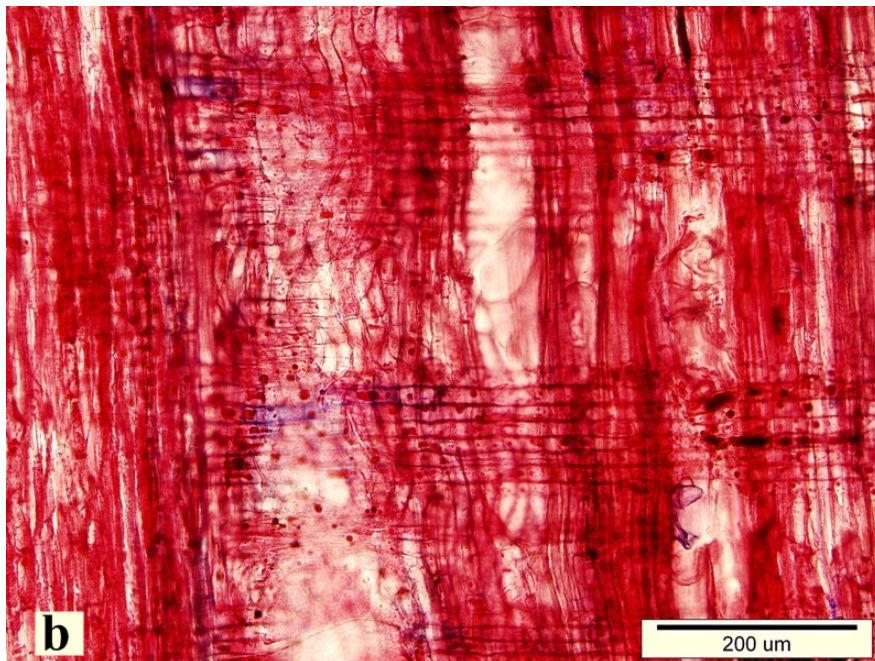
*RS*—Perforation plates simple. All rays composed of procumbent cells. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular (Fig. 7b).

*TS*—Rays uniseriate and multiseriate, the latter sometimes aggregate. Intervessel pits alternate (Fig. 7c).

*Comparison to literature*—Merev (1998a), Yilmaz et al. (2008) and Kutbay et al. (2009) obtained similar results about growth ring structure and vessel shapes and arrangements as we found. Tangential diameter of vessels 100.80 – 216.00  $\mu\text{m}$  (158.43  $\mu\text{m}$ ) in earlywood and 9.60 – 134.40  $\mu\text{m}$  (63.94  $\mu\text{m}$ ) in latewood (Merev 1998a), often > 200  $\mu\text{m}$  in diameter (The Xylem Data Base). Axial parenchyma apotracheal diffuse-in-aggregates (Merev 1998a) and paratracheal (The Xylem Data Base, Yilmaz et al. 2008). Perforation plates simple (The Xylem Data Base). All rays composed of procumbent cells, uniseriate and multiseriate (The Xylem Data Base) and uniseriate rays abundant (Kutbay et al. 2009), and maximum 40 cells high, multiseriate rays often aggregate (Merev 1998). Intervessel pits alternate (Merev 1998; Kutbay et al. 2009; The Xylem Data Base).

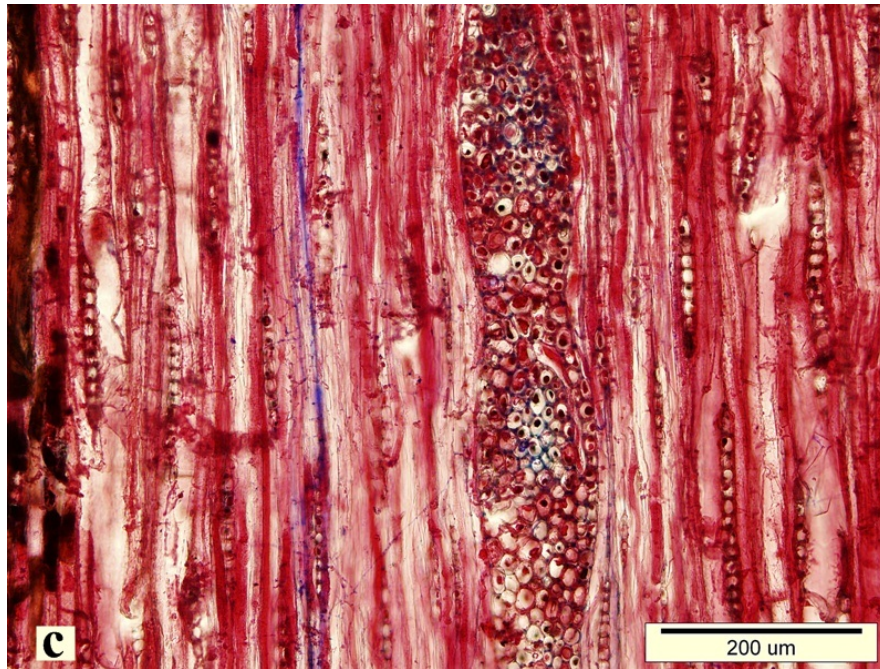


**Fig. 7.** *Quercus pontica* sample obtained from the ancient Port of Eleutherius/Theodosius  
a) Cross section



**Fig. 7 (continued).** b) Radial section





**Fig. 7** (continued). c) Tangential section

***Quercus* spp.** (Sample code: YKM'07 2Ea2, MRY'07 L 140)

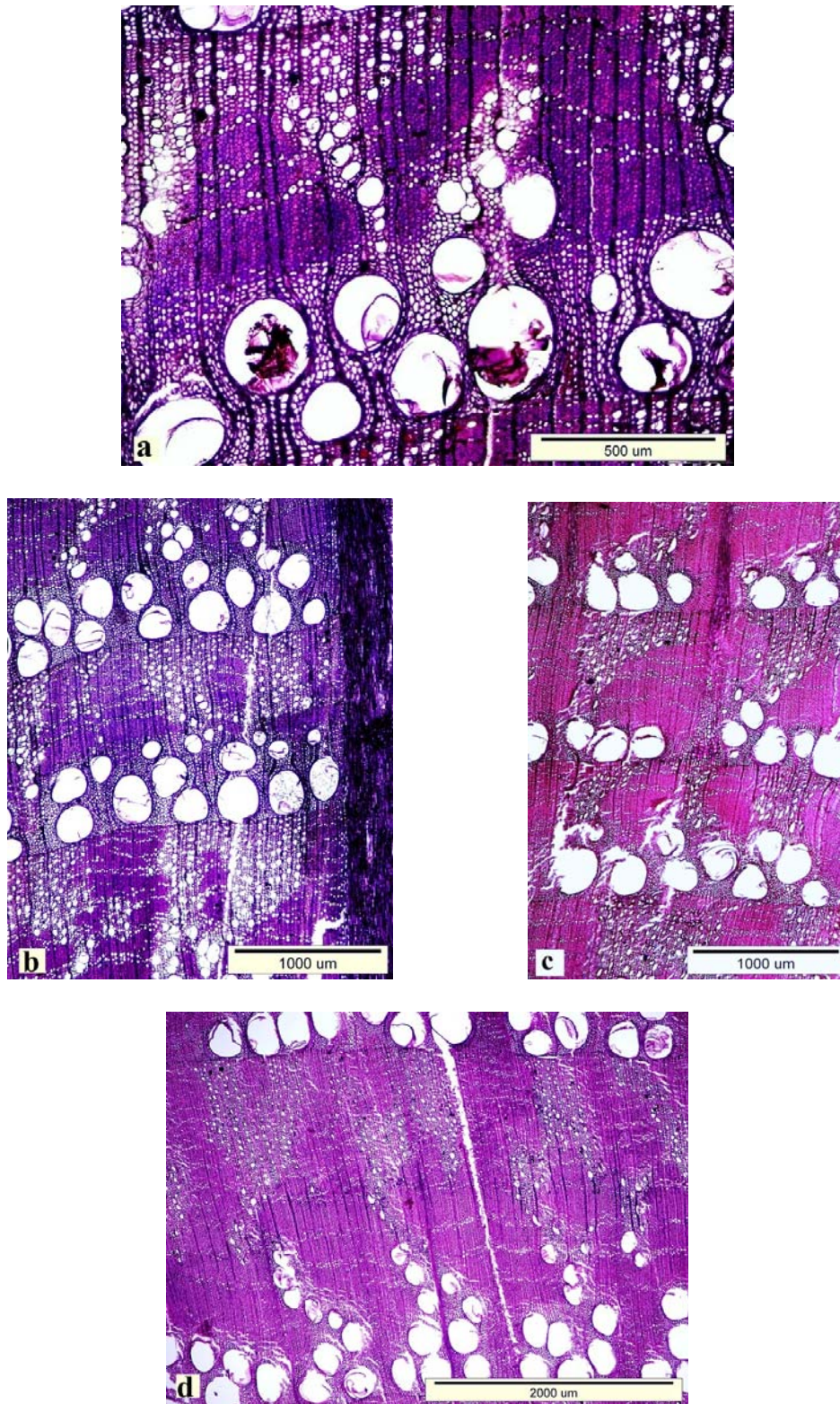
*CS*—Growth ring boundaries distinct. Wood ring-porous. Earlywood vessels mostly solitary, in radial multiples of 2-4 (in YKM'07 2Ea2) and 2-7 (in MRY'07 L 140), generally oval, some of them oval to rounded in outline. Tyloses common. Transition from early- to latewood gradual. Diameter of latewood vessels decreases toward the end of the rings. Latewood vessels almost in dendritic (flame-like) pattern, appearance of flames wide and broadened towards the end of the ring, if not, bifurcation frequent. Solitary latewood vessels angular in outline. Axial parenchyma scanty paratracheal and apotracheal diffuse, diffuse-in-aggregates (Figs. 8a—d).

*RS*—Perforation plates simple. All rays composed of procumbent cells. Vessel-ray pits with much reduced borders to apparently simple: (i) pits rounded or angular, (ii) pits vertical (Fig. 8e).

*TS*—Rays uniseriate and multiseriate. Intervessel pits alternate (Fig. 8f).

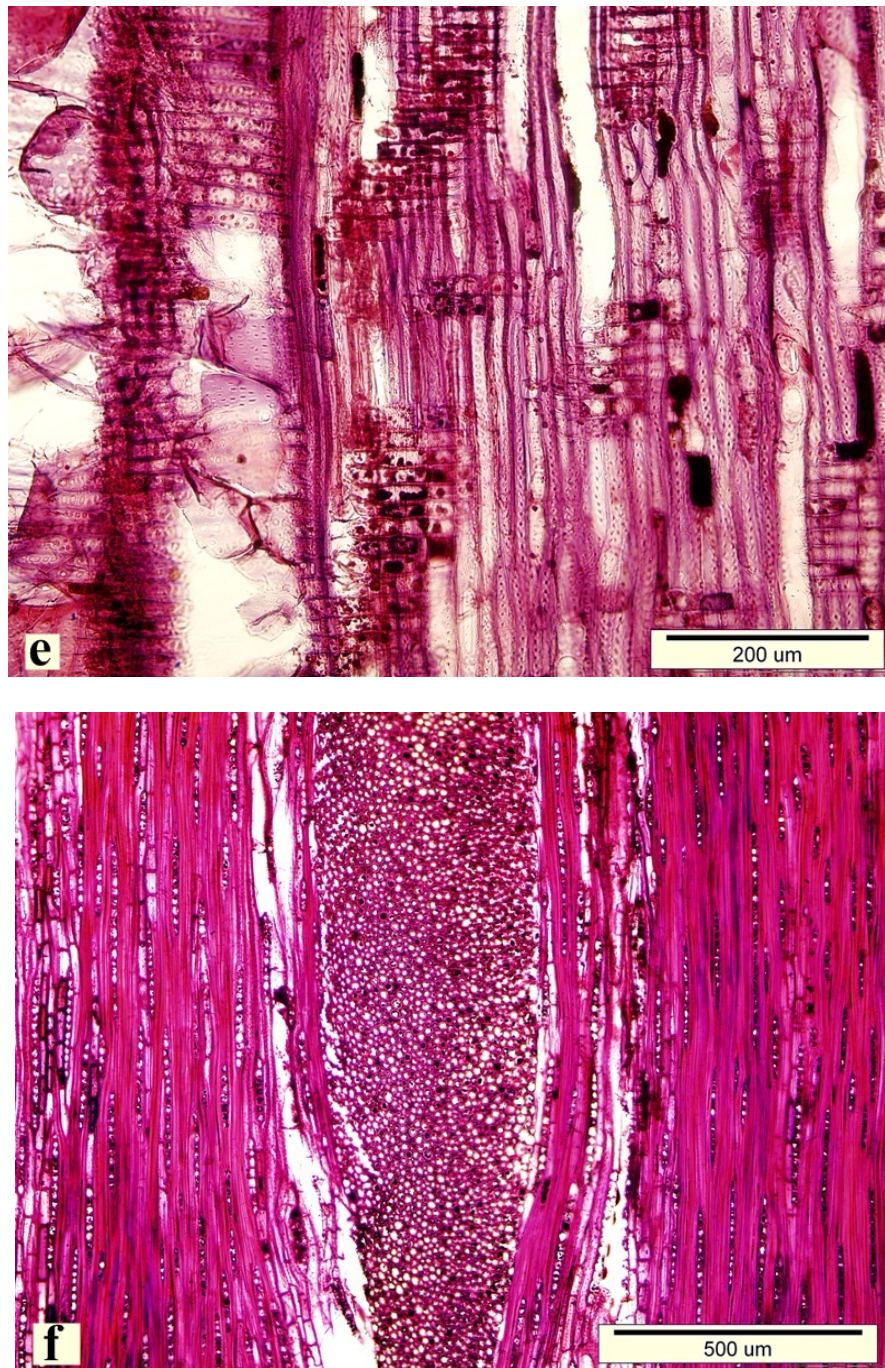
*Comparison to literature*—Number of earlywood vessel rows 3–4 or more (Huber et al. 1941; Fletcher 1978; Walker 1978; Feuillat et al. 1997; Bozkurt and Erdin 2000), one to many (Schoch et al. 2004). Vessel shapes in earlywood almost oval (Huber et al. 1941; Fletcher 1978; Walker 1978), mean tangential diameters >200 μm (Merev 1998b; Bozkurt and Erdin 2000; The Xylem Data Base). Transition from early- to latewood gradual (Huber et al. 1941; Fletcher 1978; Walker 1978; Feuillat et al. 1997; Bozkurt and Erdin 2000). Individual cross-sectional area of latewood vessels predominantly decreasing towards the end of the growth ring (Huber 1941). Vessels solitary or in radially orientated to dendritic groups in latewood (Schoch et al. 2004; The Xylem Data Base). Appearance of latewood vessels groups (flames) clear and wide, particularly in young stems (Huber 1941), club-like; broad towards end of the year; if not, bifurcation frequent (Fletcher 1978).





**Fig. 8.** *Quercus* spp. samples obtained from the ancient Port of Eleutherius/Theodosius (similar to *Q. robur*) a-b) Cross sections of YKM'07 2Ea2, c-d) Cross sections of MRY'07 L 140





**Fig. 8** (continued). e) Radial section (YKM'07 2Ea2), f) Tangential section (YKM'07 2Ea2)

Latewood vessels groups wide and broadened towards the end of the year; if not, bifurcation frequent (Walker 1978), wide and broadened towards the end of the growth ring (Feuillat et al. 1997). Axial parenchyma scanty paratracheal in earlywood, apotracheal diffuse-in-aggregates in latewood occasionally lines up to 5 cells wide (Gasson 1987). Perforation plates simple (Merev 1998b; Bozkurt and Erdin 2000; The Xylem Data Base). All rays composed of procumbent cells, only occasional with square

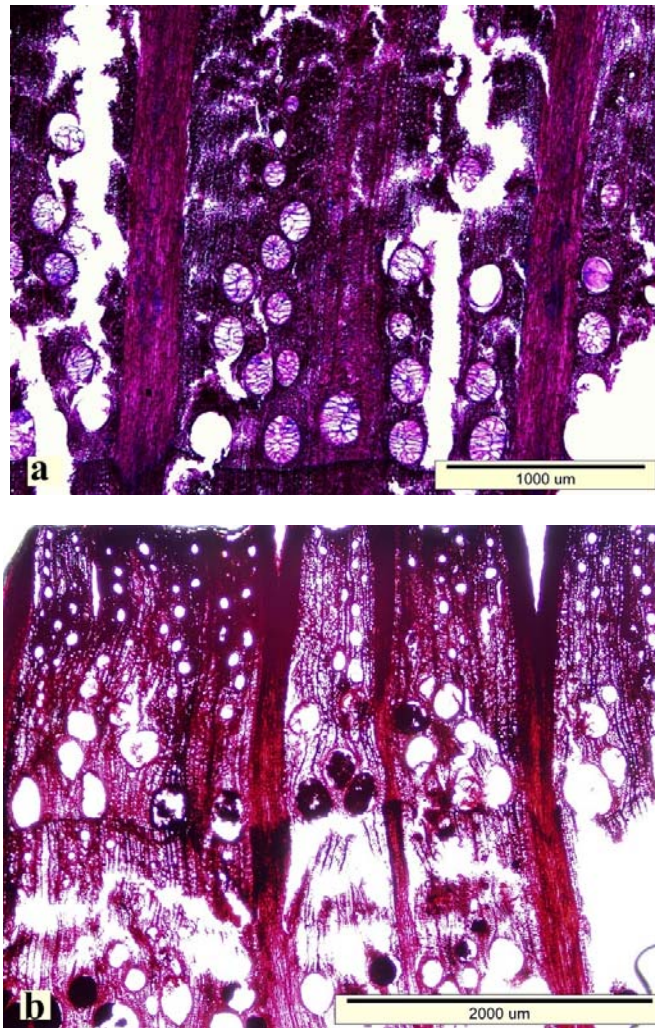


cells, uniseriate and multiseriate (Schoch et al. 2004) and many uniseriate rays and fewer wide multiseriate rays, the latter may be aggregate (i.e., composed of several narrow multiseriate rays in close proximity, separated by one or more axial cells) or they may be entire and unseparated, uniseriate rays usually less than 35 cell high, multiseriate rays 1 cm or more high (Gasson 1987). Intervessel pits alternate (The Xylem Data Base).

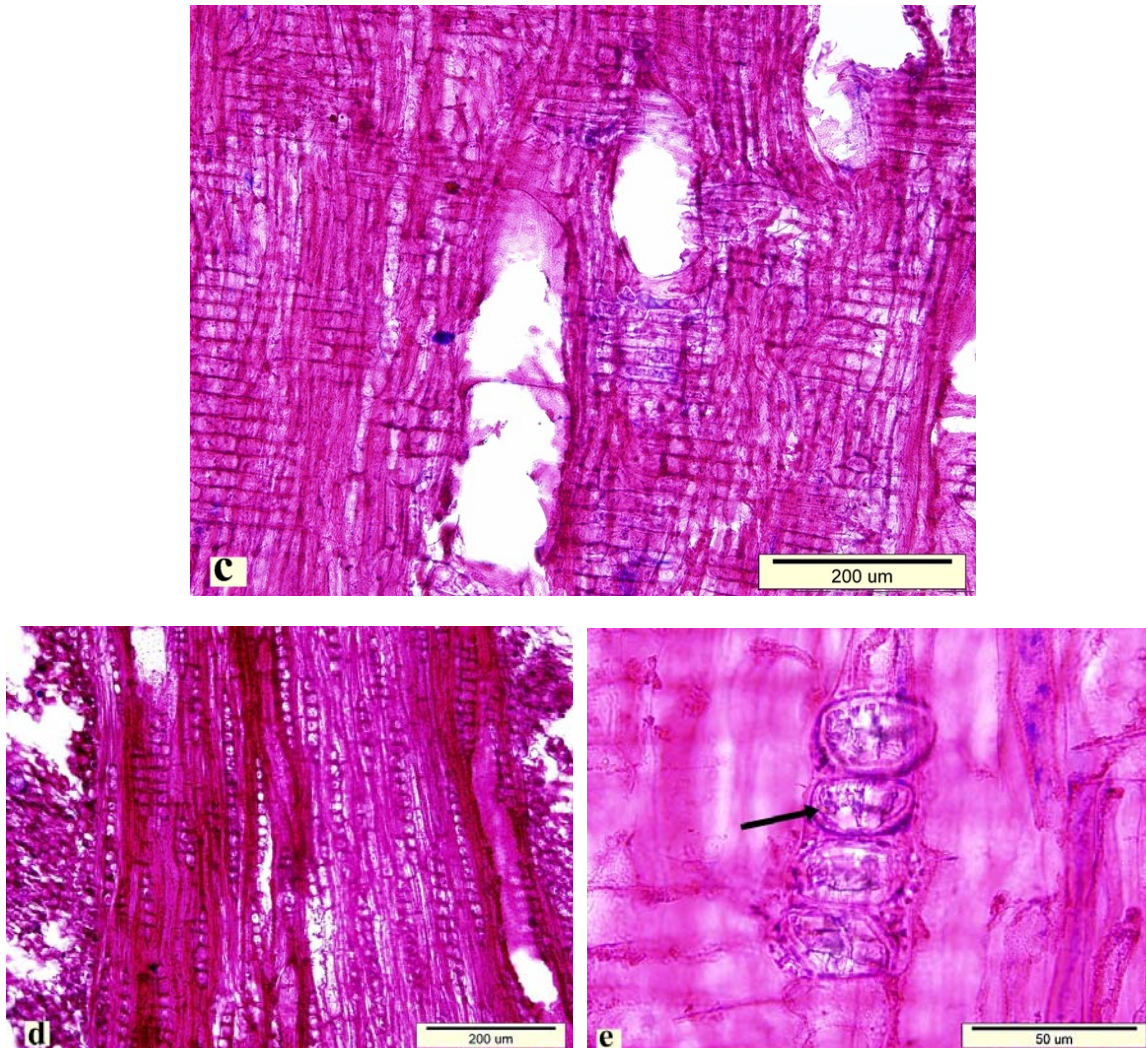
*Wood identification* —Based on quantitative/qualitative features of the wood samples and literature information, those samples are notably similar to *Q. robur* L.

***Quercus* spp.** (Sample code: MRY'07 I 10)

CS—Growth ring boundaries distinct. Wood ring-porous. Earlywood vessels mostly solitary, and in radial multiples of 1–6 (1–3 rows of earlywood vessels in narrow growth rings and more than 3 rows in wider rings). Tyloses common. Latewood vessels in radial and / or diagonal pattern, rounded to oval in outline. Transition from early- to latewood usually gradual (Fig. 9a and Fig. 9b).



**Fig. 9.** *Quercus* spp. samples obtained from the ancient Port of Eleutherius/Theodosius (similar to *Q. ithaburensis*) a-b) Cross sections



**Fig. 9** (continued). c) Radial section, d) Tangential section, e) Prismatic crystals in chambered axial parenchyma cells

*RS*—Perforation plates simple. All rays composed of procumbent cells. Vessel-ray pits with much reduced borders to apparently simple: (i) pits rounded or angular, (ii) pits vertical. Prismatic crystals present in chambered ray and axial parenchyma cells, many of the crystalliferous cells enlarged and sclerified (Fig. 9c and Fig. 9e).

*TS*—Rays uniseriate and multiseriate, the latter often aggregate. Intervessel pits alternate (Fig. 9d).

*Wood identification*—Despite the distortion and decomposition of wood, significant properties of oak wood were observed. Considering quantitative/qualitative features of the wood samples and literature information, those samples are notably similar to *Q. ithaburensis* Decne.



**Softwoods**Family: *Cupressaceae****Cupressus sempervirens* L.** (Sample code: MRY'07 I 140, MRY'07 K 140)

*CS*—Growth ring boundaries distinct. Transition from early- to latewood gradual. Axial parenchyma diffuse in the transition zone from early- to latewood and in latewood, in short tangential lines more or less parallel to growth ring boundaries (Fig. 10a and Fig. 10b).

*RS*—Rays composed of parenchyma cells only. Horizontal walls of ray parenchyma cells distinctly pitted and end wall pitted with slightly different appearance. Cross-field pits 1–4 (2) per field, cupressoid type (Fig. 10c). Tracheid pitting in radial walls uniseriate, rarely biseriate, pit apertures essentially circular in earlywood.

*TS*—Rays mostly uniseriate, rarely biseriate. Axial parenchyma with nodular end walls (Fig. 10d and Fig. 10e).

*Comparison to literature*—Jacquot (1955) and Fahn et al. (1986) obtained similar results for growth ring structure, axial parenchyma arrangements, ray compositions and pitting in radial walls of tracheids and in cross-fields as we found. Fahn et al. (1986) mentioned that pit apertures in earlywood mainly circular in *C. var. horizontalis*, elliptic to spindle-shaped in *C. var. pyramidalis*. Rays 1(3) – 20(40) cells high (Fahn et al. 1986), max 20 cells high (Jacquot 1955).

**Table 3.** Some Quantitative Anatomical Features of Softwood Samples

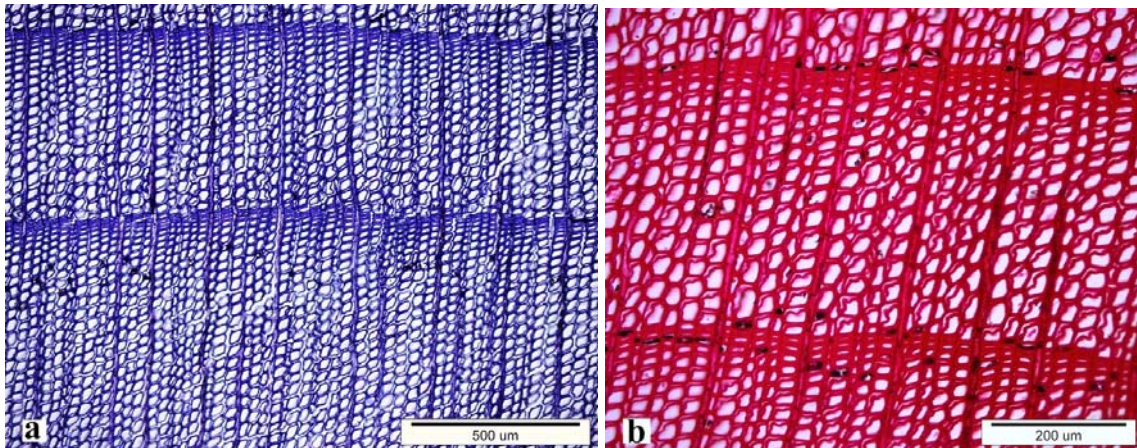
Sample Code	Specimens	Tangential Diameter of Tracheid (µm)		Ray Height		
		Earlywood	Latewood	µm	Number of Cells	Category
MRY'07 I 140	<i>Cupressus sempervirens</i> L.	(29) <sup>a</sup> (17-40) <sup>b</sup> 76 <sup>c</sup>	(21) (12-35) 69	(156) (28-547) 94	(8)(1-26) 59	M <sup>d</sup>
MRY'07 K 140	<i>C. sempervirens</i> L.	(32) (19-52) 55	(25)(13-37) 58	(243) (60-838) 104	(10) (1-31) 66	M

<sup>a</sup> Mean values are given in the first parenthesis in italics

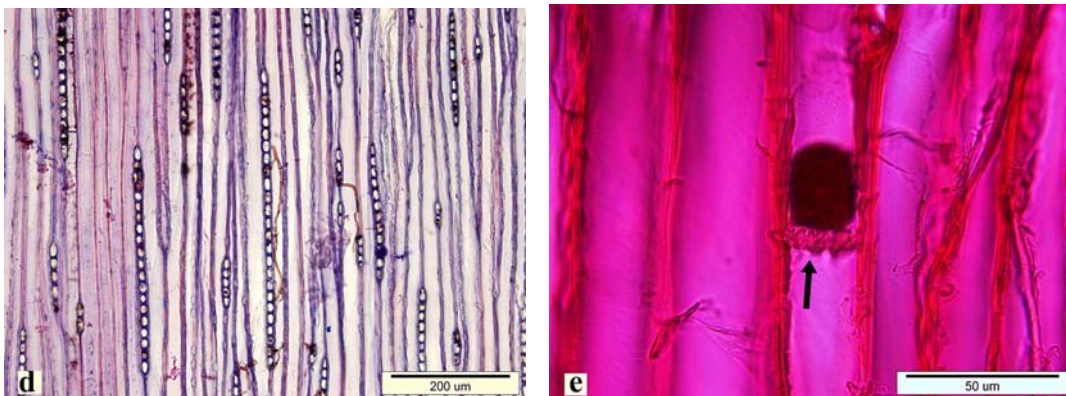
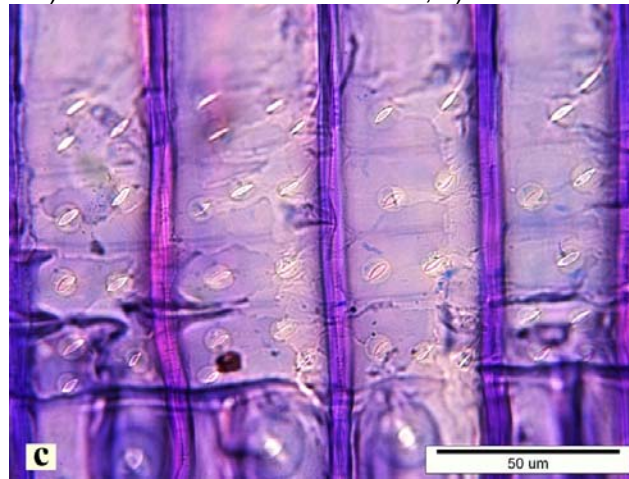
<sup>b</sup> Min. and max. values are given in the second parenthesis

<sup>c</sup> Values outside parenthesis indicate the numbers of observation

<sup>d</sup> Medium



**Fig. 10.** *Cupressus sempervirens* samples obtained from the ancient Port of Eleutherius/Theodosius a) Cross section of MRY'07 I 140, b) Cross section of MRY'07 K 10



**Fig. 10 (continued).** c) Cupressoid type cross-field pits (MRY'07 I 140), d) Tangential section (MRY'07 I 140, e) Axial parenchyma cell with nodular end wall



## Regional Distribution of the Wood Species and Their Uses in the Past and Present

### *Castanea sativa* Mill. (sweet chestnut)

The region of western Turkey is considered to be the centre of sweet chestnut domestication (Haltofová and Jankovský 2003). It was introduced to the whole Mediterranean and across France to Western Europe by Romans (Villani et al. 1994; Oosterbaan 1998; Seemann et al. 2001). Today sweet chestnut grows in Marmara region and north Anatolia in Turkey (Yaltırık and Efe 1994).

The wood of sweet chestnut is considered as moderate shrinking and not easy to dry. Natural durability of chestnut heartwood is very high to microbial deterioration. The physical and mechanical properties of the wood are very good (Militz et al. 2003).

Over many centuries, chestnut wood was used for local purposes such as wine barrels, vineyard pegs, tools handles, carpentry (Arnaud and Bouchet 1995) and shipbuilding (Giachi et al. 2003). Today, chestnut wood has a wide variety of uses from manufacture of furniture, panels, boxes and crates, veneer, flooring to structural purposes including fence posts, poles, and traverse (Bozkurt and Erdin 2000).

### *Fagus spp.* (beech)

*F. sylvatica* L. (European beech) became abundant and dominant on almost all the suitable sites of Europe between 500 and 1000 AC (Giesecke et al. 2007). Today, *F. sylvatica* L. is distributed in southern, central and western Europe, whereas *F. orientalis* Lipsky (Oriental beech) grows only in a restricted area of south-eastern Europe, e.g. Bulgaria, Greece, Romania, and Turkey (Jalas and Suominen 1972–1999). Contact zone between the natural ranges of both species runs in northern Greece and Bulgaria (Paule 1995).

The wood of beech is classed as heavy, hard, strong, high in resistance to shock, and highly suitable for steam bending. Beech shrinks substantially and therefore requires careful drying. It machines smoothly, is an excellent wood for turning and wears well (Wiemann 2010). Beech wood is easily attacked by fungi and not resistant to insects (Gambetta and Orlandi 1982 (4)). On the other hand, it is rather easily treated with preservatives (Wiemann 2010).

Beech wood has always been important economically both a structural wood and for its use in the manufacture in domestic and industrial artifacts (Hather 2000). Although beech has a non-durable wood, it was used for the keel of small ships due to its density and hardness in the past (Giachi et al. 2003). Today beech wood is used for flooring, furniture, brush blocks, handles, veneer, woodenware, containers, and cooperage. When treated with preservative, beech is suitable for railway ties.

### *Quercus spp.* (oak)

*Q. petraea* Liebl., *Q. pontica* C. Koch., and *Q. robur* L. are within white oak group, whilst *Q. ithaburensis* Decne. is within red oak group. Due to low temperatures and aridity during the ice-age, many trees could only survive in limited areas in the Mediterranean region, so-called refugia, where a favorable climate existed. Oaks, in particular, were confined to three main refugia in the Iberian Peninsula, the Apenine Peninsula and the Balkan Peninsula, from where re-colonisation took place (Huntley and

Birks 1983; Brewer et al. 2002). Today *Q.petraea* Liebl. and *Q. robur* L. have a native distribution in Europe (Hather 2000). They also grow in different regions of Turkey.

*Quercus pontica* C. Koch. is found in northeast Anatolia and the Caucasus (Ansin and Ozkan 1993).

The distribution area of *Q. ithaburensis* Decne. extends from Turkey (the coastal plain bounded by Mersin-Adana-Iskenderun) via Syria, Lebanon and Jordan to Israel (the coastal plain North of Tel Aviv) (Avishai 1967). It is known that it has been planted in the lands of the eastern shores of the Mediterranean Sea as a supplementary food source since ancient times (Eliav 1985).

The woods of white oak group have good mechanical and physical properties and are very heavy (Giordano 1981). Durability of heartwood within white oak group is very high, thanks to the tannins content that act as fungicide and insecticide (Gambetta and Orlandi 1982). Wood is not easy to work in white oak group, but it is easy to cleave both radially and tangentially. The wood of white oak group was one of the most important building materials since prehistoric time (Gale and Cutler 2000). White oak group was also widely employed in the Roman shipbuilding industry, mostly for transversal and axial longitudinal carpentry (Rival 1991; Guibal and Pomey 2003).

Today white oaks are usually used for lumber, railroad crossties, cooperage, mine timbers, fence posts, veneer, fuelwood, and many other products. High-quality white oak is especially sought for tight cooperage. An important use of white oak is for planking and bent parts of ships and boats; heartwood is often specified because of its decay resistance. White oak is also used for furniture, flooring, pallets, agricultural implements, railroad cars, truck floors, furniture, doors, and millwork (Wiemann 2010).

The technological and physical properties of red oaks are similar to white oaks. On the other hand, heartwood of red oak group is less durable and subject to fungi and insect attack unless treated with preservatives. Red oaks typically suffer from considerable shrinkage when being dried. Major uses include furniture, flooring, caskets, and cabinets. With preservative treatment, uses include railroad ties, mine timbers and fence posts (Flynn and Holder 2001).

### ***Cupressus sempervirens* L. (cypress)**

Cypress covers a large part of Europe, especially in Mediterranean Basin. It has been introduced with these regions on a large scale since the time of the ancient Greeks (Baumann 1982). Nowadays, the natural resources of this species are very limited but quite large areas over most of the country are covered by this species in the form of plantations (Paraskevopoulou 1991). Cypress has been cultivated in plantations from ancient times onwards on sites which are unsuitable for agricultural cultivation, and produces wood in very good quality (Uzielli and Berti 1979; Tischler 1981; Papamichael and Paraskevopoulou 1982), which has been used extensively in building constructions (chiefly as roofing poles), furniture, joinery, vine props, shipbuilding etc. (Panetsos 1967).

Cypress has differentiated wood, extremely fine texture and frequently irregular grain. Its mechanical properties, such as surface hardness and bending strength are rather good and its heartwood durable. Wood processing is always difficult, but finishing, even



if not easy, leads to a very high surface quality. Shrinkage values and hardness are moderate (Giordano 1981).

Today cypress is used for furniture, fence posts, poles, carpentry and marine construction. It is also used to make clothes chests due to its nice smell (Yaltrık and Efe 1994).

## CONCLUSIONS

Among the 12 marine pile samples two of *Cupressus sempervirens* L., three of *Castanea sativa* Mill., one of *Quercus ithaburensis* Decne., and one of *Quercus pontica* C. Koch. species were identified. No exact identification in five samples was possible at species level; however, among those samples one of was significantly similar to *Fagus* spp. and four of were significantly similar to *Quercus* spp. On the other hand, one *Quercus ithaburensis* Decne. and two *Castanea sativa* Mill. species were identified from totally four filling piles. Wood species could not be identified definitively for only one sample; however, it was significantly similar to *Quercus* spp.

Ever since earliest antiquity, the Mediterranean has served as a channel for trade both between the countries bordering upon it and later, with the refinement of navigation techniques, with the other regions of the world (Quéguiner 2003). The Mediterranean trade route has been the reason for the development of important ports like Puteoli, Naples, Ostia, Cosa, Pisa, Portus, Alexandria, Carthage, Sebastos, Cadiz or Marseille (Oleson et al. 2004; Kampbell 2007; Votruba 2007).

Yet, due to sea level rise and sedimentation, most ancient ports are found submerged (Fleming 1969; 1978) or silted up, and their study is extremely difficult (Schlaeger 1971; Oleson 1988; Lamprecht 1985; Hesnard 1994). Therefore, there is not enough information about wood species that used in the port constructions. On the other hand, the Sebastos is a well-preserved 1<sup>st</sup> century-BC port which is reached today from the ancient times. Archaeological research of the remains of the port has identified wooden building materials at the genus and species level. *Abies* spp., *Cedrus libani* A. Rich., *Cupressus sempervirens* L., *Fagus sylvatica* L., *Picea* spp., *Pinus brutia* Ten., *Pinus nigra* Arnold., *Populus* spp., *Quercus* spp., *Quercus cerris* L. and *Quercus coccifera* L. were identified. In addition, a portion of a pier was determined as *Abies alba* Mill. from the excavations of the Etruscan-Roman port of Pisa (Macchioni 2003). It is clear that *Cupressus sempervirens* L., *Fagus* spp. and *Quercus* spp. are common to the port of Sebastos and Eleutherius / Theodosius when we compare the results of the studies. It could be concluded that the wood choice of people living in the past was similar to each other.

In the current study, the majority of wood samples evaluated were hardwood and two samples only were found as softwoods. Among the hardwoods, *Castanea* and *Quercus* were the most seen genus. The wood species with the exception of *Q.pontica* C. Koch. grew in the some parts of Europe and/or coastal regions of eastern Mediterranean in the past. All wood species have also grown in the different regions of Turkey from past to present, in the Marmara region as well (Yaltrık and Efe 1994). *Q.pontica* C. Koch. has grown only in northeast Anatolia up to now. In the light of this information, it may be

considered that wood species used in the construction of the port had been obtained from Turkey, especially in the Marmara region. On the other hand, water transport was considerably more economical than land transport in ancient times (Votruba 2007). It was estimated a general ratio of prices of 1 (sea) to 5 (river) to 28 (land) using ancient economic data (Meijer and Nijf 1992). It may therefore have been more economical for the construction of Eleutherius / Theodosius Port, being located on the coast, to ship woods from across the Mediterranean and the Black Sea than bring them from a nearby inland location. This phenomenon is in well accordance with the preliminary results of the Aegean Dendrochronology Project (Aegean Dendrochronology Project 2010). In this report, it seems possible that a portion of the timbers used as pilings in the port construction were imported from as far west as the North Adriatic, and as far east as the Black Sea, and perhaps even a significant distance up the Danube River. It is clear that the economically viable supply of wood was more appropriate than obtaining it from nearby regions in the past.

The majority of the species especially *Quercus* spp. and *Castanea* spp. has wide heartwood portions. Durability of heartwood within white oak group (*Quercus petraea* Liebl., *Quercus robur* L., *Q. pontica* C. Koch.) and *Castanea sativa* Mill. is very high due to tannin content which improves resistance to microbial deterioration. On the other hand, heartwood of the red oak group (*Quercus ithaburensis* Decne.) is less durable. Between the last two wood species, *Cupressus sempervirens* L. has durable heartwood whilst *Fagus* spp. is non-durable (Bozkurt et al. 1993).

It is clear that the wood species used in the construction of the ancient Byzantine Port reflect a sensible choice, and people living in that time period had solid knowledge and experience on the utilization of wood. Among the wood species identified *Fagus* spp. only seems to be not suitable for the construction because of its non-durable heartwood.

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