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MEDITERRANEAN SEAFARING IN THE 1ST MILLENNIUM, A STATISTICAL APPROACH

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The aim of this paper is to test the current narrative models on shipbuilding construction in the Mediterranean through a series of statistical analyses, in order to see if the evolution from lashed to pegged mortice-and-tenon really fits the evolutionary model that dominates the field today. Based on a traditional view that technology gets more complex through time,[1] and that the transition from lashed to pegged mortice-and-tenon happened in the eighth century BCE,[2] [3]current research on the topic has been more centred in creating a timeline of this technological evolution than in explaining the non-technological reasons that could have motivated this change.

The results of this study propose a revision of the traditional chronology of the transition from lashed to pegged mortice-and-tenon, as well as well as some theoretical, non-technological scenarios that explain better the correlation and development of these techniques. The statistical results indicate that the development of warfare in the Eastern Mediterranean was the main driving force in the adoption of the pegged mortice-and-tenon as the main shipbuilding technique of the period.

1.-Shipbuilding in the Mediterranean before 300 BCE:

Cargo ships of this period were built in the Eastern Mediterranean tradition of shell-first construction. The planks are fastened edge to edge from the keel to the gunwale using lashed or pegged mortice-and-tenon joints, reinforced with internal transverse timbers.

1 See Oleson 2008 for a general approach of technology in antiquity; for the evolution of seafaring technology, see Casson 1994; Gardiner 1996; Greenhill 1995 and McGrail 2001.
2 As illustrated in the debates around 'Homeric' seafaring; See Casson 1964; Mark 2005: 28-31.
3 As illustrated in the debates around 'Homeric' seafaring; See Casson 1964; Mark 2005: 28-31.

With this method, mortices were carved in the planks of the hull, which are fastened together using tenons *(gomphoi*), pieces of wood inserted in the mortices and designed to avoid the horizontal displacement of the planks. The use of lashes or pegs *(tuloi*), cylindrical pieces of wood transversally inserted through the planks and mortices, controls the vertical displacement.
This horizontal and vertical control of the mortices, which act as an internal frame for the hull, is one of the main advantages of this fastening.[4] In regards to this, Ulrich observed 'In addition to factors of stress, the craftsman must consider the nature of the wooden piece to be joined. A tenon, for example can only be cut so that the fibres of the wood (generally referred to as the grain) run parallel to its long axis, otherwise the tenon itself will quickly break in half.'[5]

Both techniques are present in the archaeological record (see section three) as early as the thirteenth century BCE, although it seems pegged mortice-and-tenon disappears from the archaeological record during the disturbances in the Eastern Mediterranean during the eleventh century BCE. Casson considers that this technique reappeared in the Archaic period, using as evidence the passage of the *Odyssey* in which Odysseus builds the boat to leave the island of Calypso.[6] Mark,[7] however, interprets this passage as literary evidence of the use of lashing joinery as late as the eighth century BCE, not as an archaism of Homer's writing style but contemporary evidence of the shipbuilding techniques of the time. The use of pegged mortice-and-tenon is known in Egypt as early as the NaqadaIIIa period (c. 3200 BCE for the fabrication of furniture and coffins, although it was never used in Egyptian shipbuilding due to the impossibility of disassembling the ship and transport them overland.[8]

The material of construction also conditioned the structural capabilities of the cargoes. Our main source of information for timber in naval construction is Theophrastus, an author of the late fourth - early third century BCE who recorded the use of several kinds of wood for the construction of the hulls. Thus, keels and internal frames would be made of hard

4 Steffy 1985: 90; McGrail 2001: 148.
5 Ulrich 2008: 451.
6 Casson 1964; Homer *Odyssey* 329-345; Stein 2008.
7 Mark 2005: 28-31.
8 Ward 2000: 32, 48; Ward 2006: 124; Creasman and Doyle 2010: 14.

woods, mainly oak, or *drun (quercus cerris*). To lighten the ship, acacia, or *akantha* (*Acacia decurrens*) was used sometimes instead of the oak for the internal framing; it also has the advantage of the natural curvature of the trunk, that matches that of the frames and increases their strength.[9]

The hull of the merchant-ships is made in pine, or *peukē,* (*pinaciae*) preferred to other woods because it does not decay. Masts and spars were made of *elatē* since they have straight trunks; pegs of oak, since their structural importance requires a hard-wood. Finally, hulls were needed to be watertight. In order to achieve this, a coat of pitch was applied. It seems that the shipbuilders relied on this and not in caulking*,* the process by which fibrous material were driven between the planks to make the hull watertight. The controversy arises because of the contradictory evidence, both direct and indirect, that has been preserved. It is generally considered that the vessels were not caulked, since no traces of this have been found in the archaeological record or in the literature, although Morrison *et al.* suggested[10] that flax was used to this purpose. Although the fibre was available at this time in Greece, the only evidence the authors present is an statement by Herodotus that assess Egyptians make everything just opposed to the Greeks.[11] For them, since Egyptians caulked their ships, Greeks did not do the same. However, we have indirect evidence for the pitching of the ships. In two comedies of Aristophanes,[12] pitch is mentioned alongside the ships. The best evidence comes from an inscription of 330 BC, in which a substance, *hypaloiphē*, classified as white and black, is listed. For Morrison *et al.*[13] these substances for the application to a ship's bottom would be resin mixed with lime or wax.

2.-Nature of the evidence:

The sample of this study consists of fifteen shipwrecks located in the Mediterranean sea, and dated between 1300 BCE and 300 BCE. These include all the sites in which at least part of the hull was recovered during the excavations, which is unfortunately not always

9 *Enquiry into Plants 4.2.8,* 5.7.1-3 Hort 1916.
10 Morrison *et al.* 2000: 184.
11 Herodotus *Histories* 2.96.2; Godley 1920.
12 Aristophanes *Acharnians* 190; *Frogs* 364.
13 Morrison *et al.* 2000: 187.

possible.

With regards to the acquisition of data, the original interest was centred on three parameters: general data (date, origin, construction technique), size of the hull, and dimensions of the tenons. As was indicated in the previous section, the most important element of the shell-first construction is the use of tenons as internal frames of the hull, as opposed to the frame-first construction, in which the planks are nailed to a pre-existent skeleton instead of being carved. This conditions not only the integrity of the hull, but also the range of repairs available.

*Figure SEQ ""Figure"" *Arabic***Error! No sequence specified.***: Map of the distribution of sites used in this research*

Unfortunately, the available data on tenons is, at best, poor. Despite the number of references on shipwrecks listed in this paper, the information on the characteristics of the ship is uneven, and varies greatly from one reference to another. There are several reasons for this state of the discipline. When the field was defined by Bass in the 1960's after the excavation of the Gelydonia wreck, the interest was centred in the study of the cargo, as a new way to study the evolution of trade routes in the Mediterranean.[14] Although further research has emphasized the study of shipbuilding techniques, the poor preservation of hull remains at most sites and, mainly, the absence of final reports, has caused biased literature. To illustrate this point it will be only necessary to point out that of all the vessels recorded in this work, only one vessel, the Ma'agan Michael, had its final results published in three extensive volumes which are now re-edited in one final report.[15] Other important sites such as Uluburun, Jules Verne and Kyrenia, do not have a final report with the relevant measurements for this study, despite the excavations that took place more than three decades ago.

3.-Shipwrecks in the Mediterranean (c. 1300 BCE- 300 BCE)

1. Chios A:

This site, dated to the fourth century BCE, was found off-shore of Chios by using remote sensing, due to the depth of the site. The size of the ship was estimated in 21x8 metres, and its method of construction pegged mortice-and-tenon, although no excavation has been carried out since the initial survey in 2009.[16]

2. El Sec:

This wreck was excavated in the 1980's offshore of the island of Mallorca, in Spain. Although some information is provided about the size of the ship (13.6x4.40 m), most of the study on the wreck was devoted to the cargo of the wreck, considered to be Eastern Mediterranean. These finds allowed the dating of the site around 375 BCE.[17]

3. Kyrenia:

The wreck was located on the north shore of Cyprus, near the city of Kyrenia. Excavated by Katzev between 1969-1972,[18] the ship presents the same shape as the Ma'agan Michael wreck, although the method of construction was pegged mortice-and-tenon.[19]

[14] Bass 1967.
[15] Linder and Kahanov 2003.
[16] Foley 2009.
[17] Arribas 1989.
[18] Parker 1992: 231.
[19] McGrail 2001: 149.

Large sections of the hull made in Aleppo pine have been preserved, including sections of the keel, the keelson, the planking and the internal frames with their cooper nails. The preservation of most of the hull has also allowed an intensive study of the different components of the ship and its further use as a paradigm of the pegged mortice-and tenon technique as well as the blueprint for the construction of the Kyrenia 2.[20] The vessel measured 13.6x4.4 m, with tenons of Anatolian oak measuring c.15-20 cm in length with rounded borders. The structure was so tight that McGrail considered caulking was not necessary,[21] but Steffy assumed the existence of some form of caulking that, due to the conditions of the site, was not preserved.[22] Several lead sheets were used to make the hull watertight under the waterline, as well as protecting the wood from the effects of the *teredo* worm.[23] The number and distribution of these sheets were interpreted as repairs in the hull, since they were found associated to planks that in most cases showed a structural problem. The goods were transported in *amphorai* that were traced back to Rhodes, Samos, Paros, Crete and Palestine, and seem to indicate a Greek origin for the ship. The ship was dated, using the C14 method, to 389 BCE.[24]

4. Porticello:

This site, located in the Calabrian coast, was badly looted before archaeological excavation was carried out by Owens and Eiseman in the 1970's. Most of the spoiled goods of the cargo, recovered from the looters, date the vessel between 415-385 BCE, and quite plausibly of Greek origin. With regard to the hull, the few remains recovered indicate and estimated length of c. 17 m, with a solid construction of pegged mortice-and-tenon joints. Patches of lead, the earliest example of this technology, were used to prevent leaking.[25]

5. Ma'agan-Michael:

The wreck was located very close to the shores of Haifa in 1985, and was excavated and raised by Linder, Raban and Rosloff between 1988 and 1989.[26] The structure of the hull

[20] Steffy 1985.
[21] McGrail 2001: 151.
[22] Steffy 1985: 887.
[23] Kahanov 1994.
[24] Delgado 1997: 228; Parker 1992: 232.
[25] Delgado 1997: 213, 415.
[26] Delgado 1997: 212.

was very light. It was constructed with pegged mortice-and-tenon, although some sections not related to repairs are lashed and resemble the technique used in the Gela vessel.[27] It measured c. 13 m with oak tenons spaced c. 8.7 cm (McGrail 2001: 136). No cargo was found, but the pollen preserved and the nature of the wood points out to a Levantine, probably Phoenician, origin for the ship.

6. Tektas Burnu:

Found in the Aegean coast of Turkey in 1996, the wreck was excavated between 1999 and 2001. Although there is no final report of the excavation, a synthesis of the work was published by Carlson.[28] The ship was left exposed in the seabed for a long time, allowing the biological agents to destroy the hull remains; the original size of the hull could not be determined, although bits of wood recovered seem to indicate that the ship was constructed with the pegged mortice-and-tenon technique. Two *ophthalmoi* [apotropaic eyes in the prow of the ship], the first ever recovered in direct association to a shipwreck, ascribe the vessel to the Greeks, quite possibly Athens, due to the resemblance between this and other examples recovered in the Peiraeus.[29]

7. Gela:

This wreck, located in the south coast of Sicily, was excavated by Freschi and dated between 500-490 BCE.[30] Although McGrail indicates that research is in progress, no further publications of original data of the site have been published.[31] The planks of the hull are fixed using the sewn mortice-and-tenon technique, similar to the finds of Jules Verne 9. Parker estimates an overall length of the hull of 20 m.[32]

8. Jules Verne:

This site, located of the coast of Marseilles, was excavated between 1992-1993 by Patrice Pomey.[33] Two wrecks, known as wreck 7 and wreck 9, were recovered during the excavation, a cargo ship and a fishing boat. Wreck 9, a fishing boat of 5x1.5 m, is an

27 Kahanov 1998: 159.
28 Carlson 2003.
29 Carlson 2003: 594, 596.
30 Freschi 1991.
31 McGrail 2001: 135.
32 Parker 1992: 189.
33 Pomey 1995, 1998.

example of sewn mortice-and-tenon, while the wreck 7 is a cargo ship of 14x4 m.[34] The main characteristic of this ship is that it is the first time since the end of the second millennium BCE that the hull is constructed with the pegged mortice-and-tenon technique, although repairs in the ship were made by using sewn planking.[35] The measurement of the tenons are 14-15x3.0 - 3.5x0.5 cm. The excavator believed both vessels were of Greek origin, around 500 BCE.[36]

9. Bon Porté:

Located near St-Tropez, in the south of France, this vessel, excavated in 1973-1974, was interpreted by the excavators as a pegged mortice-and tenon ship,[37] but re-examination by Basch[38] and Pomey[39] demonstrated that it is a sewn-plank vessel. The planks were 2 cm thick, locked with treenails of 0.9 cm of diameter and separated 14-16 cm.[40] Pomey considered it to be an Etruscan vessel, of no more than 10-12 m.[41] Re-examination of the hull and the cargo, now consider it an essential example of the emergence of Massalian archaic trade, and has led to the conclusion that the vessel was Greek, and of no more than 10 m.[42]

10. Pabuç Burnu

This site, located close to the shores of ancient Halicarnassus, was excavated in the summers of 2002-2003. The only preliminary report was published by the excavators in 2008. Planks were badly preserved and affected by the *teredo navalis* [a common type of shipworm], although in enough condition to reveal remains of lashing techniques. The size of the ship was estimated around 17.00-18.00 metres, and dated between 575-525 BCE.[43]

11. Giglio:

This wreck was located on the Campese bay, in the western coast of Italy, with a cargo of

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34 Pomey 1997: 92.
35 McGrail 2001: 134.
36 Pomey 1995: 459.
37 Jestin and Cazarré 1980.
38 Basch 1981.
39 Pomey 1981, 1997.
40 McGrail 2001: 134.
41 Pomey 1981.
42 Delgado 1997: 69.
43 Greene *et alii* 2008: 701-706.

copper and lead ingots, as well as Etruscan, Samian, Punic and Ionian pottery.[44] Found in 1961, it was excavated by Bound in 1983-1985. Only three planks and part of the keel have been recovered, with treenails to fix them in place before being lashed. No information about measurements of these elements has been published, with the exception of the treenails (referred to as dowels by the excavator). Although some shrinkage is expected due to the conditions of preservation in the site, they measured an average of 2.7 cm long by 0.75 of diameter, and the separation between two of these treenails would be 0.56 cm. The excavator, based on the nature of the cargo recovered, considered that the origin of the ship is Etruscan rather than Greek.[45]

12. Cape Gelydonia:

The excavation of this wreck on the southern coast of Turkey during 1960 is considered the foundation of underwater archaeology as a discipline.[46] Works continued between 1987 and 1989.[47] Although only some fragment of the hull were recovered under the remains of copper and tin ingots and ballast stones, the size of the hull was estimated between 9-11 m, constructed with pegged mortice-and-tenon, although smaller than those of the Uluburun wreck.[48] The vessel was dated using radiocarbon around 1200±50 BCE, probably constructed in the Syro-Cananite area, although Parker locates its origin in Cyprus.[49]

13. Carmel

The ship, located on the Levantine coast, has been considered a ‘shell-first’ hull, using mortice-and-tenon and sewing, assuming that no nails were found on the site and the extension of the sewing technique in the period.[50] The size of the ship was determined by the size of the anchors, comparing them to those found in the Uluburun shipwreck;[51] the total weight of 3470 kg seems to point out to a medium sized (15–18 m) vessel.[52]

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[44] Parker 1992: 134.
[45] Bound 1985: 49, 55.
[46] Bass 1967.
[47] Lambrou-Phillipson 1995.
[48] Pulak 1998: 210.
[49] Delgado 1997: 86; McGrail 2001; Parker 1992: 109.
[50] Casson 1971: 14-16, 201-214.
[51] Pulak 2011: 15.
[52] Galili *et alii* 2012: 15.

14. Uluburun:

Located on the southwest coast of Turkey, this wreck has become the paradigm of Late Bronze Age since its first season of excavation in 1984, mainly because of the amount of metal (10 tons of cooper and 1 ton of tin) that it carried.[53] Although only a section of 2 m of the hull has been recovered, Steffy estimated an overall length of 15-16 m.[54] The cedar planks of the hull presented a thickness of c. 60 mm, and they are fastened together with mortice and tenon joints of oak at a space of space 21 cm (Bass 1986: 275). Pulak dated the construction of the vessel to 1305 BCE using dendrochronology, probably in the Levantine coast due to the artefacts recovered and not specifically associated to the cargo of the ship.[55]

Statistical Analysis:

The aim of this section is to test the narrative models on ship construction with the data collected from the archaeological evidence (see table 1).

Table 1: Data collected from the published wrecks (14th to 3th century BCE). All measurements in cm.

This collection of data shows the problems mentioned in previous paragraphs. Most of the information comes from preliminary reports of the sites, usually after the first or the second season only; although the hull, in the case it is preserved, is always analysed, more

[53] Frey 1984; Bass 1986, 1988; Bass *et al.* 1984, 1989; Pulak 1988, 1998.
[54] Steffy 1994.
[55] Pulak 1998: 214.

attention is paid to the goods. These finds help greatly trying to estimate the origin and date of the ship, but leave us with almost no parametric information on thickness, size or distance between tenons, or the nature of the repairs; not even the width of the hull in order to establish a ratio of the proportions of the vessel.

Only three of the recorded parameters proportioned an *n* value high enough to perform statistical analysis (see figure 2). The nature of the data also conditioned the range of available analysis. Since date is an ordinal scale and length a ratio scale, only non-parametric analysis are available. In consequence, the study is going to be divided in two sections. The first one will present the results of descriptive statistics based on the relationship of different parameters and the type of construction of the hull. The second section will present the results of analytical statistics, trying to assess the consistency of the data across the different categories.

Table 2: Data selected for analysis (14th to 3th century BCE). Length measurements in cm.

A) Descriptive statistics:

In this section I will explore the relationship between the construction technique on one side, and the date and length of the ship on the other. It is traditionally assumed that the lashing technique is characterized by a) a previous development of the pegged technique, and thus earlier in time, and b) a weaker method of construction that would affect negatively the integrity of the hull and the capability of the shipbuilders in making large vessels. In order to explore these two theories the relevant data from table 2 were plotted in two boxplots, with the percentiles defined by standard deviation (2σ). The selection of a median-based graphic instead of a mean-based was motivated by the preference of a method that does not analyse the range of data based on an arithmetic centre (the mean value) but in an absolute value.[56] This is especially important for the dates included in the first boxplot, since they are an ordinal scale.

In the first figure we can see how both techniques have a similar origin in time, with a stronger presence of lashed shipwrecks in the transition of the first millennium and disappearing by the beginning of the fifth century BCE period. This overlap in the techniques is now new, and widely attested in the literature. However, it is the length of the parallel overlap and not the overlap itself, which must be considered. Both techniques are known at the end of the second millennium BCE, but the pegged mortice-and-tenon, traditionally considered a more solid construction, does not have a real presence in the record before 850 BCE and does not become the dominant technique until the Classical period.

[56] Shennan 1997.

In figure 2 we can appreciate how the consideration of lashing as a weaker technique cannot be sustained if we consider the size of the ships. Although the absolute values of lashed and pegged mortice-and-tenon are very similar, the latter shows a lower median and shorter percentiles if compared to the former. This means that lashing does not constrain the size of the cargo vessels, and some other reasons must be found to explain this disparity. The next paragraphs offer some possible explanations.

Figure 3: Boxplot Construction Technique/Length of the hull

B) Analytical Statistics:

The second step in this study is to test the hypotheses that the exploration of descriptive statistics has generated. Since the relation between construction technique and time/length cannot explain the general model for the evolution of shipbuilding in the Mediterranean, the next step is to explore a more direct relationship between dates and sizes of the ship. The combined analysis of ratio (length) and ordinal (date) values, non-parametric tests (based on the median instead of the mean) must be carried out.

The correlation between two variables, length and date, can be analysed using the Spearman-Rho test, the non-parametric version of the Pearson's correlation test. This test can measure the intensity of the relation between two non-parametric sets of data, in this case it can test how strong the relationship between the date of the ship and the length of the hull. The results show a low negative correlation between both parametres.[57]

Figure 4: Plot data from the Spearman-Rho test.

The generated value for $r = -0.146$ indicates a low negative correlation between date and length. With $-1 < r^2 = 0.021316 < 1$ it is clear that the size of the hull is not related to its date, invalidating the traditional evolutive perspective in hull construction that postulates an increase in vessel size with the imposition of the pegged mortice-and-tenon technology during the Classical period, mainly influenced by the development of the "super fleets" during the Hellenistic period.[58] The implications of these results for the study of naval

57 Drennan 2004: 227-228.
58 Casson 1994: 78.

technology are explored in the next section.

The evolution of the shell-first construction, the economic limitations:

The statistical analyses have revealed that the size of the vessels was not conditioned by the type of construction or the date of the ship. If the structural design of the ships did not influence its construction, and there is not a diachronic constraint to the methods of shipbuilding, since they are both present around c. 1300 BCE, we have to find the reason for their evolution and development.

The great difference between the lashed and pegged technique lays not in the construction of the vessel, but its repairs. Lashed planks are easily dismantled and replaced by new ones, while in pegged hulls planks cannot be replaced without dismantling large sections of the vessel. This technological constrain has deep implications in the expenses required to extend the life-use of the ship, but the research on this specific topic is still limited.[59]

But if we carefully observe the data, we can perceive how the disappearance of the pegged tradition is synchronic with the struggles in the Eastern Mediterranean at the end of the 2nd millennium BCE. The high costs of repairs in the pegged system encouraged the adoption of the lashed mortice-and-tenon construction in a period characterised by economic stress. This model confronts the evolutive perspective of several scholars who consider that it was the lack of technological capability the cause of the late development of pegged mortice-and-tenon ships.[60] Paradoxically, this is not the only period in which economic stress caused a change in shipbuilding; recent works link the appearance of the frame-first construction to the economic stress of the Late Roman Empire, since this model is a more efficient way of building and repairing the vessels.[61]

But if we agree with this model we have to provide a reason for the recovery of the pegged mortice-and-tenon technology. I believe that the answer lies in the development of naval

[59] Pomey pers. Comm.; Rodríguez-Álvarez in press.
[60] e.g. Casson 1994; McGrail 2001; Parker 1992.
[61] Rodríguez-Álvarez in press; Pomey *et alii* 2012.

warfare in the Eastern Mediterranean. The earliest examples of pegged technology after the crisis of the second millennium BCE are synchronic to the development of the first ramming warships in the Mediterranean, the *pentekonteroi*. These galleys of 50 rowers were small scale *triremes*. Unfortunately, no warship has been ever found, but the indirect evidence has allowed us to study, and even reconstruct, one of these vessels.[62] What we know about them is that its elongated design caused too much stress in the hull, due to the differential tension between the centre of the ship and the bow and the stern, which made necessary the use of huge ropes called *hypothomata* to compensate the tension of the hull. The pegged mortice-and-tenon technique is able to resist more differential tension in the hulls of the warships, and it is feasible that the imposition of this technology in the military construction during the sixth and fifth centuries BCE was the cause of the disappearance of the lashed technique in the fifth and the fourth centuries BCE.

Whatever the reason for this disappearance is, two steps are necessary to develop this theory. First, better access to the measurements of every element of the hull, and not just its general dimensions. The second, more emphasis on the study of repairs as a way of addressing the use-life and the structural defects of the hulls. The traditional approach has defined a non-linear model in the development of the lashed and pegged techniques; from the more simple to the more complex. These results show a parallel model in which the construction style becomes a technological decision based on the expected use and performance of the ship, something that goes far beyond the moment the vessel left the shipyard.

[62] Coates *et al.* 1990; Coates 1993; Morrison and Coates 1989; Morrison *et al.* 2000.

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