The structures of Atlantic shipbuilding in the 16th century. An archaeological perspective.[1]

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The 16th century has long been regarded as a period of accelerated change in Atlantic shipbuilding, characterized by a general increase in ship's tonnage, the opening of new routes and the birth of state shipbuilding programmes. It is also sometimes thought, based on the appearance of theoretical texts on hull design, that the rise of modern naval architecture dates to this century. It was a time when the transition from clinker to carvel planking, begun a century earlier, was consummated, when whole-moulding became widespread and when ships were no longer assembled "planking-first" but rather "frame-first". These perceptions of 16th-century shipbuilding have been inherited from historians, and only recently have archaeologists begun to shape their own debates, drawing upon a growing body of evidence. Work on formal shipwreck typologies has pursued since the 1980s and recently, research on hull design and on wood as a primary material has opened new perspectives on the subject of Renaissance shipbuilding.[2]

In this paper, we shall address the structures of Atlantic shipbuilding, using an archaeological approach that is at once comparative and historical. Our main sources are a classic example of Biscayan construction, the Red Bay whaler of 200 to 250 tons presumed to be the *San Juan* that sank in 1565, and an example of the English art, the warship *Mary Rose* of about 700 tons launched in 1511 and lost in 1545. Firstly, we will address those structures that were durable over time and occurred throughout the Atlantic space. For example, the predominance of oak may be contrasted to the Mediterranean where a wide variety of species was used. In addition, the Atlantic method of hull design contains contrasts with Mediterranean at this time. We shall sketch the broad outlines of how forestry and hull design were bound into a common technology.

Secondly, we will address those structures that varied geographically within the Atlantic realm, but appear nonetheless to have been quite long-lived. Since many features fall into this category, the range of possible subjects is quite large, and so we will concentrate on a few commonly recorded features that can be explained by referring to archival sources. In treating the 16th century as one "horizon", we do not wish to contest the historians' view that this was a time of rapid transition in shipbuilding, but rather hope to set a benchmark from which shipwrecks from earlier or later periods can also be better understood.

The Mary Rose and the Red Bay vessel

Found in the Solent where she capsized while sailing out to confront an approaching French fleet, the *Mary Rose* was excavated by a combined team of volunteers and full-time archaeologists under the direction of Margaret Rule. The intact remains of the hull were raised and placed in a converted dry dock at Portsmouth in 1982-1983. Here, the study and the conservation of the wooden structure are carried out before the eyes of visitors to the museum that has been created around the ship and its material culture. Much of the framing structure is covered by ceiling timbers, and work on developing a plan of the frame timbers has often relied on the use of wire probes that were slipped through the seams of interior planks. The hull has been surveyed at 11 stations at intervals of approximately 10 English feet (3,05 m), corresponding to the positions of the riders and major deck beams, by triangulating from reference lines using standard survey techniques. From these sections, the lines of the hull were compiled. Dendrochronological research has been conducted to ascertain the origin of the timbers and to determine what pieces were added to the hull during one of the vessel's major refits (Rule, 1982; Dobbs, 1995; Rule and Dobbs, 1995; Bridge and Dobbs, 1996.).[3]

Across the Atlantic on the south coast of Labrador, references to the wreck of the Basque whaler *San Juan* led archaeologists to the discovery of a wreck buried under several layers of collapsed whale-oil casks. Excavation was carried out from 1979 to 1985 under the supervision of Robert Grenier, following a research design that called for the underwater dismantling of the ship's structure and the recording, on the surface, of about 3,000 timbers by 1:10 drawings, photographs and visual observations on the tool marks. The timbers duly reburied, the data was then used to build a model of the hull remains, to develop a lines plan and to study the sequence of the vessel's grounding and break-up. A study of the ship, including its reconstruction, its hull design and its method of construction has been carried out. Tree-ring research in view of establishing a chronological parallel with the *San Juan* has been inconclusive, although it has been learnt that the felling date for the cask material was no later than 1562 (Grenier, 1988; articles by Proulx, Izaguirre, Rieth, Loewen and Chrestien, in Bourgoin, 1995).[4] The Red Bay vessel is part of a significant group of Biscayan and Iberian wrecks that is quite coherent from a typological perspective, although the Labrador example remains the best preserved and, to date, the most studied (Oertling, 1989; Rieth, 1998).

Timber supply

Both the English and the Biscayan ships were built of European oak, *Quercus robur*, and in order to learn something about the forest that produced the frame timbers and planks, we have compared data on the age of the trees and the dimensions of the timbers. Recalling that timber contracts from the 16th century often divided the pieces into three large categories – frames, planking and knees, which sometimes appear to have been taken from different forests – we have divided our analysis of the archaeological remains into similar groups. The Red Bay futtocks were generally taken from trees aged between 36 and 40 years. In contrast, two frame timbers in the *Mary Rose* respectively contained 95 and 97 growth rings, without any sapwood, and a third sample contained 88 rings including 13 sapwood rings. While these ages show an interesting contrast, it must be considered that the data from Red Bay was a preliminary count that served only to eliminate these timbers from subsequent dendrochronological study, while the examples from the *Mary Rose* represents the identification of some very-old trees during a broader tree-ring analysis.[5] (Bridge and Dobbs, 1996; Waddell, pers. comm.) (Bridge and Dobbs, 1996, p. 491-496; Waddell, pers. comm.)

As for the planking, one piece from the *Mary Rose* contained 127 rings, while the Red Bay planking yielded a chronology of 152 years based on 11 timbers (Guibal, 1995, p. 2). The ages of the trees used to make the planking thus seem to be comparable. Finally, the majority of the 76 timbers cored for tree-ring study on the *Mary Rose* were knees, riders and other internal braces. Of this total, 20 had more than 100 rings and "many" had less than 50. For the Red Bay wreck, the number of rings contained in the knees was estimated, during the selection of timbers for coring, at 80 to 100. Based on these somewhat disparate data, the age of the trees used in the two wrecks does not show any significant contrast except for the futtocks that, in the Red Bay vessel, appear to have been harvested at a uniform and exceptionally young age.

In order to gain a better understanding of the production of frame timbers, we compared the maximum dimensions of the frame timbers in the two vessels, excluding the floor timbers.

First of all, the lengths fall into neat groups. For the *Mary Rose*, 75% of the frame timbers fall into three lengths of 8-10, 12-14 and 16-18 English feet (0.305 m), in roughly equal percentages (Table 1). For the Red Bay vessel, 90% of the timbers fall into two categories of $4^{1}/_{2}$-$5^{1}/_{2}$ and 6-7 *codos de ribera* (0,575 m), with a third of the timbers being in the longer group. The two length categories from Red Bay are similar to the two shorter categories from the *Mary Rose*. All the Red Bay futtocks were taken from the entire sections of trees and the length used for the frames contained no branches.

TABLE 1

Comparison of frame-timber lengths

Mary Rose			**Red Bay**		
% of timbers	feet	meters	% of timbers	*codos*	meters
27%	8 to 10	2,4 to 3,0	62%	$4^{1/2}$ to $5^{1/2}$	2,6 to 3,2
24%	12 to 14	3,7 to 4,3	28%	6 to 7	3,5 to 4,1
24%	14 to 16	4,9 to 5,5			

An important contrast between the two ships occurs in the diameter of the trees, based on the moulded dimensions of the frames. At the bilge, the *Mary Rose* futtocks measure 32 cm in thickness, while the Red Bay frames measure only 20 cm. At the height of the upper deck, the *Mary Rose* frames have a moulded thickness of 20 cm, where the Red Bay frames have diminished to 14 cm. The Red Bay frames often include the naturally rounded periphery of the tree, indicating that the diameter of the trees was less than 30 cm. The *Mary Rose* frames contain little sapwood, and the parent trees had a diameter as great as 40 to 45 cm. These differences in size may well be related to the difference in ages noted above.

The timber supply for the two vessels also contains some parallels, especially in the ages of the trees that furnished the internal braces and the planks. As well, practices of cutting frame timbers into certain length categories were similar between the two regions. These parallels however serve to highlight the contrast in the age and the size at which the frame-timber trees were harvested, for the young and uniform age of the Red Bay frame timbers and the great age of at least some of the *Mary Rose* futtocks point to different naval forestry practices.

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Hull design

Both the *Mary Rose* and the Red Bay vessel were designed according to the method known as "whole moulding", in which a master mould was used to give shape to the frame timbers and, ultimately, to the hull. However, the earliest shipbuilding treatises, from the period 1570-1620, describe two slightly different methods of whole-moulding, one of which occurs only in English manuscripts and the other only in Mediterranean and Iberian texts. The design of both ships corresponds to the method found in the English manuscripts, which may thus indicate a distinctively "Atlantic" method of whole-moulding.

In both the Atlantic and the Mediterranean methods, a shipwright followed three basic steps in designing a hull. Supposing that a ship owner placed an order for a vessel of 400 tons, the shipwright's first step was to work out the overall dimensions of the hull, using a standard formula that equated hull dimensions with ship's tonnage and was predicated on fairly standard proportions among the breadth, keel, overall length and depth of hold. Secondly, having set the overall dimensions, the shipwright designed a "master frame", using a combination of arcs and straight lines. This became the mould. Thirdly, the shipwright systematically modified the arcs and straight lines of the mould in order to generate the remaining frames of the hull, forward and aft of the master frame. However, the geometry available to the 16th-century shipwright being limited, these modifications could be calculated only as far as the "quarter frames" or "tail frames", and the remaining frames in the bow and stern quarters were projected empirically according to the carpenter's guise, using ribbands. It is in this third step, the modification of the master section, where the Atlantic and the Mediterranean texts differ. After the "rising and the narrowing of the floor", the English manuscripts prescribe a method called "hauling down the futtock" while the Iberian and Mediterranean texts prescribe one called, in Portuguese, *espalhamento*.[6] The Atlantic method, analyzed by Richard Barker, modified the shape of the futtocks by varying ("hauling") the chords of the tangent arcs that composed the master mould. The Mediterranean method, as studied by Cruz Apestegui and Eric Rieth, did not modify the futtock's arcs but tilted the entire futtock outward from a fulcrum at the turn of the bilge (Fig. 1).

"HAULING DOWN"
after R. A. Barker, *Design in the Dockyards, about 1600* (1991)

"JOBA" ou "ESPALHAMENTO"
after M. Fernandez (1616) fo. 71 r-v.

FIG. 1 – The Atlantic and Mediterranean moulding methods.

Our interest here is to describe the second and third steps as they appear in the two wrecks, and to compare them with the respective steps in the English and Iberian treatises. Turning first to the conception of the master frame, that of the *Mary Rose* was designed to a width of 38 English feet and an upper-deck height of 22 feet. From the top-centre of the keel to the upper deck, the following geometrical components are found in the master frame (Fig. 2):

- from the keel, a straight "floor" of $3^{1}/_{2}$ feet (there is some dead rising to the master frame);
- from the floor, a tangent "bilge arc" with a 14-foot radius;
- from the bilge arc, a tangent "futtock arc" with a 21-foot radius;
- from the futtock arc, a tangent "breadth arc" with a 14-foot radius;
- from the breadth arc, a tangent "tumblehome" with, possibly, a reverse curve.

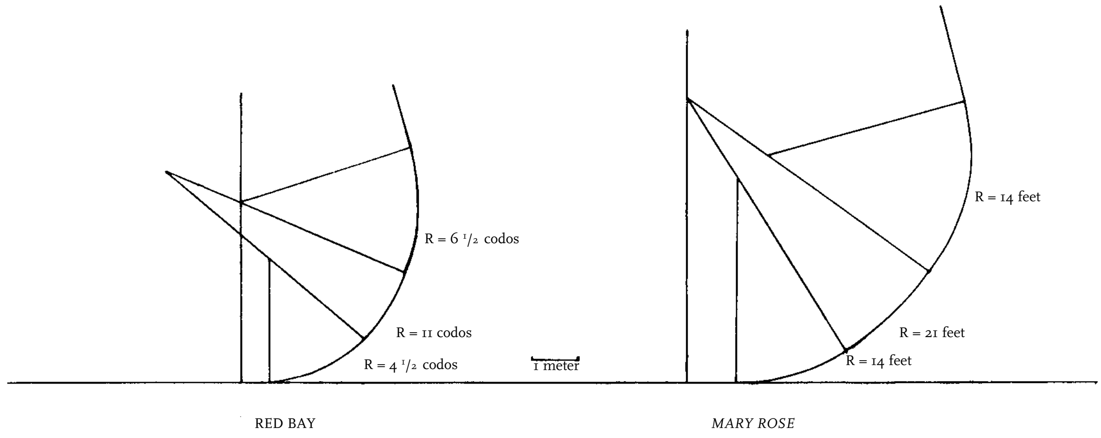


FIG. 2 – The conception of the Red Bay and *Mary Rose* master frames.

While the measures are unique to the *Mary Rose*, the components themselves are identical to those making up the master frame of the Red Bay vessel, designed to a breadth of 13 *codos de ribera* and an upper-deck height of 10 *codos*. The Red Bay master frame contains the following elements:

- from the keel, a straight horizontal "floor" of 1 *codo* (there is no dead rising);
- from the floor, a tangent "bilge arc" with a $4^1/_2$-*codo* radius;
- from the bilge arc, a tangent "futtock arc" with a 11-*codo* radius;
- from the futtock arc, a tangent "breadth arc" with a $6^1/_2$-*codo* radius;
- from the breadth arc, a straight "tumblehome", apparently not quite tangent(?).

The only naval treatises of the day to give comparable details of the master frame's conception are those of Mathew Baker, Manoel Fernandes and João Baptista Lavanha. The first two authors employed a sequence of tangent circular arcs as observed in the two archaeological examples.[7] Lavanha's master frame, however, was conceived differently. Here, the shipwright plotted a series of offset points and then found a fair curve which passed through the points. The resulting master frame formed an oval, not a sequence of tangent circular arcs.[8]

Turning now to the frames forward and aft of the master frame, the builders of the *Mary Rose* modified the shape of the master frame in three ways:

- the "rising of the floor", in which the outboard end of the "floor" was incrementally raised from one frame to the next;
- the "narrowing of the floor", in which the $3^1/_2$-foot breadth of the "floor" was incrementally reduced from one frame to the next;
- the "hauling down of the futtock", in which the chord of the "bilge arc" was incrementally reduced from one frame to the next, while that of the "futtock arc" was increased.

While the linear measures for each modification are, naturally, unique to the *Mary Rose*, all three methods are also found in the Red Bay ship. In the "rising and the narrowing of the floor", the two archaeological examples echo all the treatises, but in the "hauling down of the futtock", both shipwrecks faithfully reproduce the method described in the English manuscripts but diverge from Iberian and Mediterranean texts. The archaeological distinction lies in the bilge area: in the Mediterranean method, a kink develops at the fulcrum point (Apestegui, 1992) while in the Atlantic method, the bilge remains a circular arc which varies only in the length of its chord *vis-à-vis* that of the "futtock arc". While the difference in the final hull shape can be minimal, the Mediterranean method is capable of producing a flatter floor and a more vertical futtock, joined at the bilge by an "elbow" whose form, from frame to frame, does not obey a geometric rule.

This difference may have been crucial in the history of naval architecture. Because the Atlantic method was entirely geometric and could thus be calculated using the trigonometry and the logarithms of the day, English shipwrights were able to stun their continental colleagues with their ability to design a hull using only calculations. In their theory, these geometric principles of course were known to the ancient Greeks, but their first use in shipbuilding remains undated.[9] In practical terms, by using the same arcs in each frame along the hull, the Atlantic method of hull design minimized the number of compass-timber shapes needed to build a hull, and thus the method was tied into the Atlantic oak economy.

The relation between oak forestry and hull design

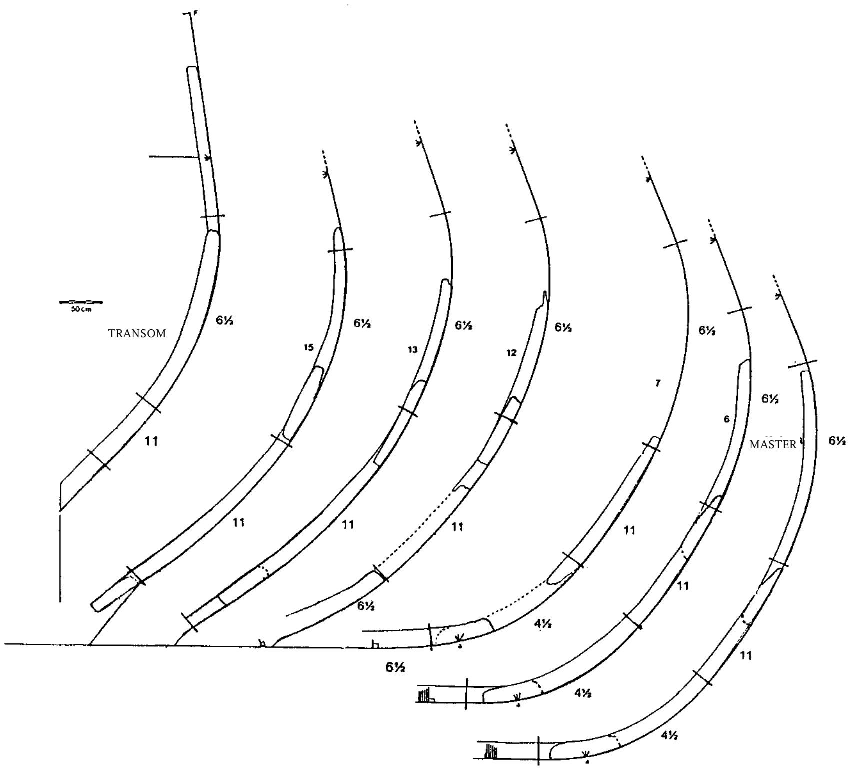
The *Mary Rose*, an unusually large vessel for its time, also had unusual timber requirements and its carpenters' approach can be better understood through a comparison with the Red Bay vessel whose size and timber needs were closer to being "typical". However, both vessels were framed using principles that linked the method of hull design to a "typical" timber supply. Here, it is useful to begin with the Red Bay vessel, which provides a clear example of the relation between oak forestry and hull design (Fig. 3).

The frames of the Basque vessel have clearly distinct components, namely floor timbers and first, second and third futtocks. The components overlap at three specific heights along the frame, namely, at the turn of the bilge, at the lower deck, at the main and so on. However, each frame timber also stands alone between the overlap zones. The overlapping ends of successive timbers are "sandwiched" in place by the bilge stringers and the deck clamps and thus, the frame-timber lengths are irrevocably tied to the deck heights. In the Red Bay vessel, each timber is also related to precise elements in the frame's design, as follows:

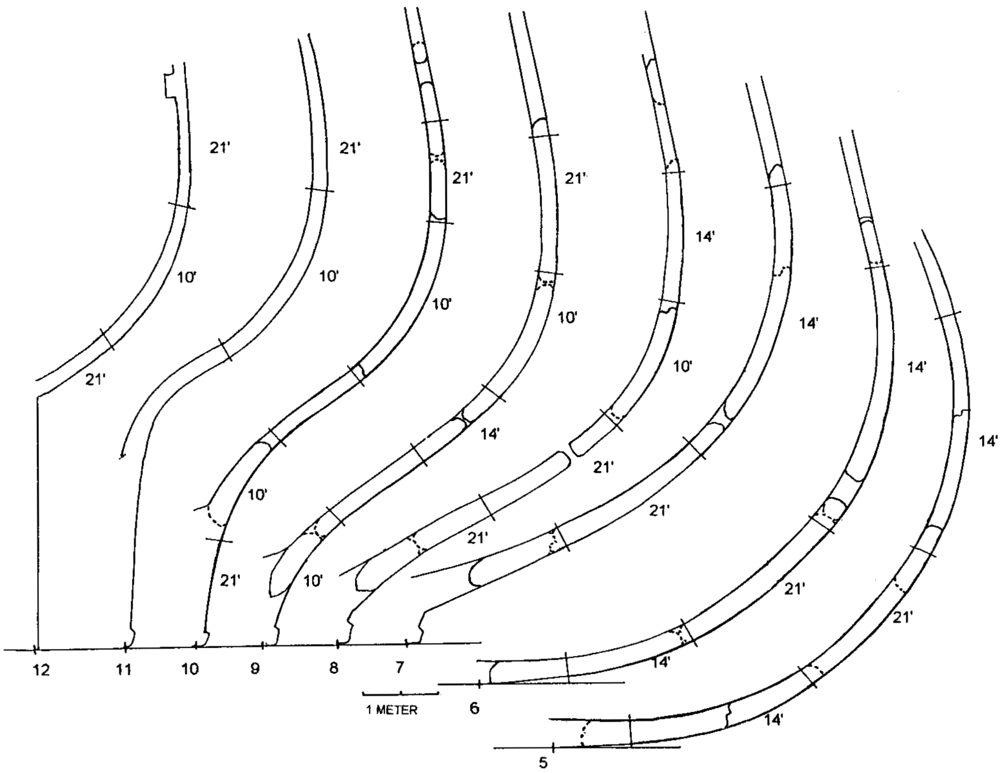
- Floor timber — floor + lower half of bilge arc
- First futtock — entire bilge arc + futtock arc + lower deck
- Second futtock — lower deck + breadth arc
- Third futtock — "tumblehome"

This regular form and distinctive assembly forms a contrast with the later style of "double-sawn" frames in which the overlap of component timbers was continuous along the length of the frame. In this style, component timbers did not necessarily overlap at the same height in each frame, as available lengths of wood were pieced together in combinations that might vary from one frame to the next. "Double-sawn" frames allowed a wide variety of timber shapes and lengths to be exploited, for the shape and length of the component pieces were not predetermined as in the 16th-century Biscayan framing style.

In the case of the *Mary Rose*, the concept of tying each frame timber to a specific element in the frame's design had become impracticable because the arcs were too long for the available timber supply. In particular, long enough first futtocks could not be found to cover the "bilge arc", the "futtock arc" and overlap with the clamps at the first deck. The solution adopted by the



Red Bay. Radii of arcs used from the master frame to the transom (in *codos de ribera*)



Mary Rose. Radii of arcs from the master frame to the transom (in English feet)

FIG. 3 – The relation of the moulding method and frame-timber shapes in the *Mary Rose* and the Red Bay ship.

builders was in some ways a precursor to the "double-sawn frame". Instead of overlapping the floor timber and the first futtock, these pieces were laid end-to-end, and a second timber was laid between frames in order to reinforce the area of the end-to-end joint. The same principle was used at the joints between first and second futtocks higher up in the hull. With its end-to-end scarfs and its between-frame reinforcement timbers, the *Mary Rose* framing structure contains none of the gaps that characterize the Biscayan style, even though the frames are not yet, technically speaking, "double-sawn".

Although destined to disappear, the way in which the Basques related hull design to timber supply had a great advantage in that the shape and length of each timber could be exactly predicted. The arc of the second (and third) futtocks was invariable (the "breadth arc" and the tumblehome), and all the first futtocks had the same arc in their upper half (the "futtock arc"). The lower half of the first futtock, which partly overlapped the floor timber, formed one of three general shapes, depending on the fore-and-aft position of the frame in the hull. Firstly, in the midship area, the lower half of the futtock corresponded to the "bilge arc". Secondly, at the quarters of the ship where the futtock has been "hauled down", the lower half of the futtock continued the same "futtock arc" found in the upper half. Thirdly, in the bow and stern of the vessel, in the area of the gripe and the run, the lower half of the futtock formed a reverse curve.

The predictable relationships between specific frame timbers and hull-design elements gave rise to a precise technical vocabulary that was shared by ship carpenters and timber growers. The 16th-century Basques named the three futtock shapes, respectively, *genolbeazes* ("toed futtocks"), *genoles burbulus* ("bowed futtocks") and *genoles rebeses* ("reversed futtocks") (Grenier, Loewen and Proulx, 1994, p. 137-141). The Red Bay vessel allows us to see each of these pieces, all of which fall in the range of 6 to 7 *codos de ribera* in length. The floor timbers that corresponded to the three futtock groups were respectively called *varengas caladas* (floor wrongheads), *hurculus* (rising floors) and *picas a terçias* (crutches in the "thirds", that is, the bow and stern "thirds"). In the Red Bay vessel, the central *varengas coladas* were taken from the curved trunks of trees, the *hurculus* from L-shaped embranchments, and the *picas a terçias* from Y-shaped embranchments. Tree shapes, ship's timbers and vocabulary were inseparable elements of a common technology.

As it turns out, the rigid and elaborate Biscayan system resulted in simpler and more predictable timber needs. The Red Bay vessel contains only five different shapes of futtock timbers, excluding the floor timbers, while the comparable timbers of the *Mary Rose*, designed according to the same geometric principles, contains at least eight different combinations of three arcs having radii of 7, 14 and 21 English feet (Fig. 4). Five of the shapes found on the *Mary Rose* occur along the turn of the bilge, including three kinds of reverse futtocks. In the same area, the Biscayan vessel needs three shapes of timbers, only one of which has a reverse curve. When the two approaches to timber use are compared at the level of a regional shipbuilding industry, the rigidly invariable Basque method represented a more efficient use of forests than the "pragmatic" choice of timbers observed in the *Mary Rose*.

When exploring the relation between oak forestry and hull design, it becomes clear that the notion of a shipwright going to a natural forest to collect suitable shapes of timber, visualizing the ship's shape in the trees, does not explain what we observe in the archaeology. When the Red Bay framing pattern is seen in its 16th-century Biscayan context of intensive oak forestry and shipbuilding in a limited coastal space, it is unthinkable that a ship carpenter would be allowed to pick only certain shapes and lengths to suit his ship design, leaving all other trunks and branches to go to waste. Instead, we may hypothesize that the invariable Basque framing pattern and its relation to the hull's geometry were an adaptation by ship carpenters to the specific timber shapes that were produced by the oak growers. The Red Bay vessel contains evidence that this was in fact the case. All the futtocks were made from trees that were uniformly about 40 years old, and all had

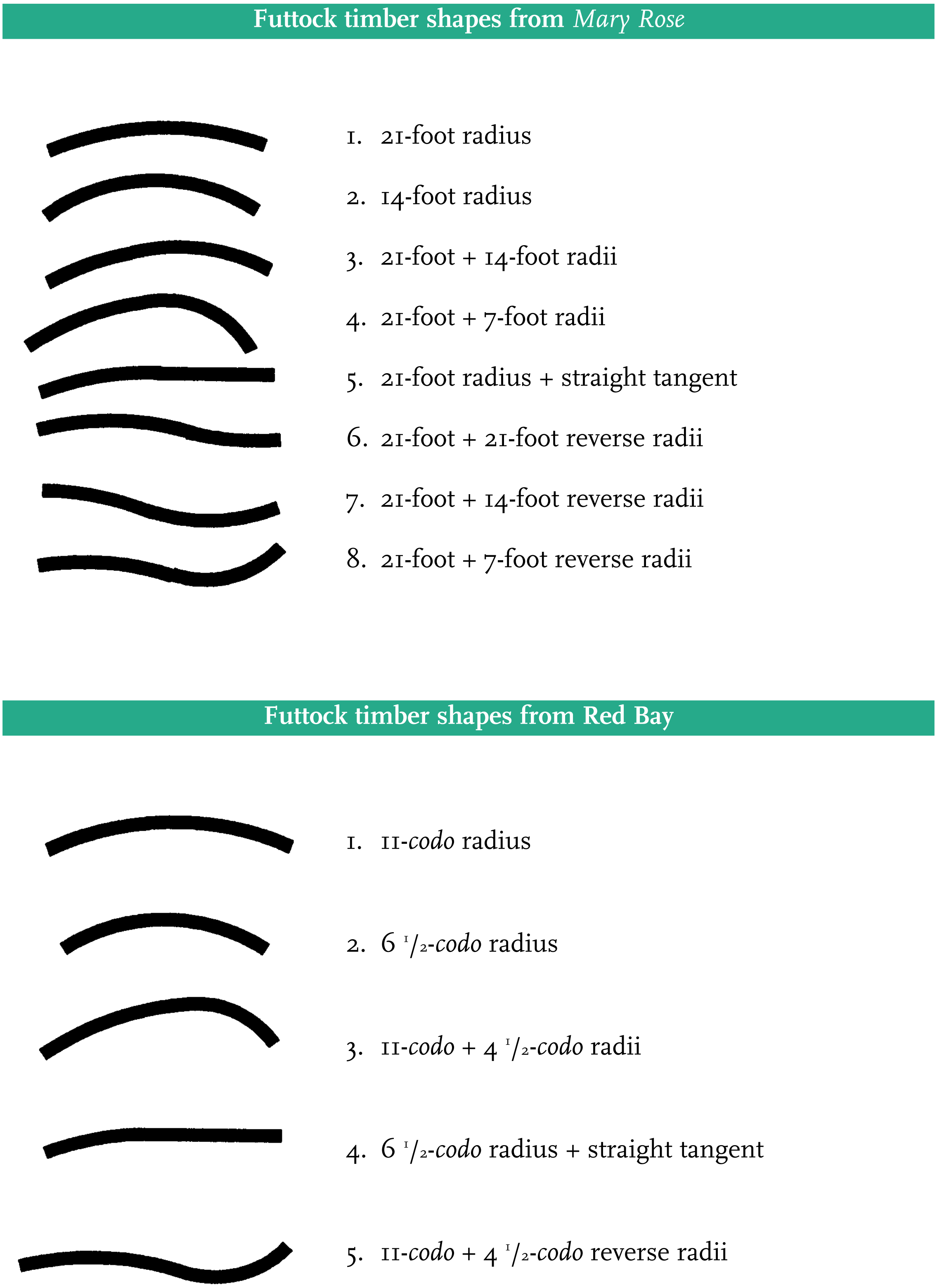


FIG. 4 – The shapes of futtock timbers from the *Mary Rose* and the Red Bay ship.

just the right diameter, curvature and branchless length to be converted into futtocks. Such perfection in timber production formally excludes the possibility that the trees were harvested in a "wild" forest. Indeed, the history of 16th-century Basque naval oak production reveals that two or three small plantations, located less than ten kilometers from a river mouth shipbuilding site, typically provided all the framing and planking for a given ship (Barkham, 1988). The archaeology of ships reveals that these planters practiced highly refined methods of producing ship's timbers.

Forestry operations were not limited to growing specific shapes, and could include the moulding of a ship's framing. This is revealed from a 1547 shipbuilding project in San Sebastian, which resulted in a lawsuit when the ship, ordered at 450 tons, was erroneously built to 600 tons. The ship owner sued the timber merchant for cost overruns encurred by the monumental error, while explicitly exonerating the carpenter from blame. The "moulds, plans and *graminhos*" (*la forma y traça y hechura*) had been lent by the ship owner to the timber grower and carried into the forest, where the moulding took place without the carpenter. The timber grower moreover failed to return the instruments.[10] Confirmation that framing timbers were shaped on the oak plantations comes from the 1583 sale of timber for an Usurbil building project, in which the timber grower agreed to deliver the frame timbers fully finished in accordance with the "moulds and scales" (*moldes y gruas*) that the ship owner supplied.[11]

The design of these moulding instruments, jealously guarded by the ship owners, was a rare skill. In 1577, an Orio carpenter was hired by the state to build a large vessel "as drawn by master carpenter Calatras of Renteria who knows how to build ships for the Indies route." [12] No doubt, new designs were not welcomed by oak growers whose trees were pruned and trained a generation earlier. However, carpenters fully understood the use of moulds, plans and scales. In a 1579 construction project at Zumaia, the oak grower delivered framing timber to the shipbuilding site where the carpenters then inscribed marks (*scrivir*) on the pieces in preparation for their assembly.[13] And in a 1585 contract, a Zumaia ship owner hired a carpenter to build a ship according to the "measures and drawings" (*medidas y traçadas*) furnished by the ship owner at the time the contract was draughted.[14] Ship owners and timber growers controlled hull design, and construction was left to the carpenters.

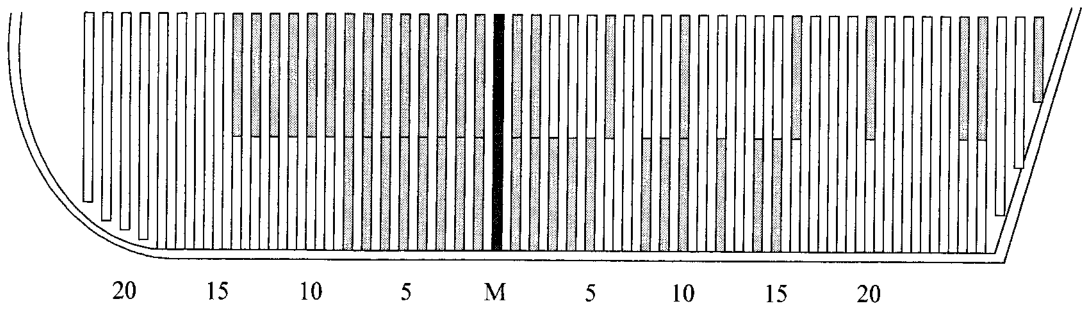
Frame assembly

Sixteenth-century Atlantic shipwrecks are characterized by a mixed pattern of frame construction, in which most frame timbers are not joined in any way and are held in place only by the ship's longitudinal structures while the timbers of a few frames are joined by a mortice-and-tenon assembly. These morticed frames occur in a group near midship and include the master frame. In most cases, only the floor timber and the first futtock are linked, although some wrecks also contain frames where upper timbers are also linked. Research on the Red Bay vessel has shown that the "floating" futtocks were held in place, during construction, by three temporary ribbands that were placed at levels corresponding to the "touches" of the tangent arcs used to design the hull. This finding, made possible by the dismantling of the hull and the discovery of nail holes where the ribbands had been attached, is similar to that illustrated by Lavanha and presumably explains all archaeological instances in which a mixed pattern of frame construction is found.

Both the *Mary Rose* and the Red Bay vessel contain this mixed pattern of frame assembly. On the English ship, where starboard evidence of mortices is obscured at the bilge by the ceiling, the evidence comes from the exposed port side. Here, 24 morticed frames are found in a fairly coherent group extending from the 8th frame forward to the 15th frame aft (Fig. 5). Forward, the sequence may have been even longer, but the evidence is lost, while the gaps aft of the master

Mary Rose morticed frames

Upper level: morticed first and second futtocks
Lower level: morticed floor timber and futtock



Red Bay morticed frames

Lower level: morticed floor timber and futtock

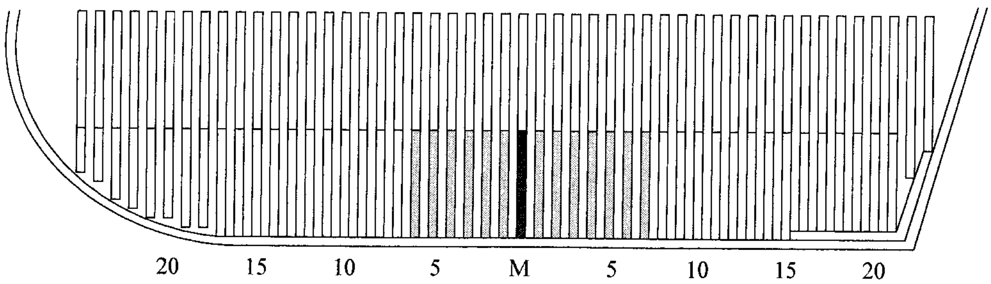


FIG. 5 – The positions of mortices frames in the *Mary Rose* and the Red Bay ship.

floor timber may also be due to the loss of evidence. In the frames forward of the master frame, the tenon part of the futtock is let into the aft side of the floor timber. In the frames aft of the master, the futtock tenon is morticed into the forward side of the floor timber, with two exceptions where the relation is inversed (the 3rd and 11th frames aft).

In addition, mortice assemblies also link some 24 first and second futtocks on the starboard side, at a level between the first and second decks. In 14 cases, the upper futtock is forward of the adjoined lower futtock, but there is no apparent pattern to the distribution of this characteristic, as might be expected since the mortice forms, in most cases, an end-to-end scarf. Assuming that the *Mary Rose* had 60 frames in all, nearly half the frames contained a mortice assembly on the starboard side, but it is worth emphasizing that upper mortices are found in numerous frames that lack this feature at the bilge.

On the Red Bay vessel, the pattern is much simpler. Out of a total of 48 frames, the floor timbers and first futtocks of 14 frames are assembled, including the master frame, which has two futtocks on either side of the floor timber. In the 6 morticed frames forward of the master frame, the futtock is attached to the forward face of the floor timber and in the 7 examples aft, the futtock is aft of the floor timber.

Different hypotheses have been advanced concerning the significance of the morticed frames. M. Redknap suggested that the function of assembling the frames was to bring strength to the hull (Redknap, 1984). R. Barker saw a potential parallel between the series of morticed frames at midship and the series of *madeiras do conta*, or calculated frames, described in early Iberian shipbuilding treatises, and thus saw the presence of these frames as early evidence of whole-moulding (Barker, 1991). Several archaeologists have noticed that the frames were assembled prior to being set in place on the keel, and thus see them as evidence of partial frame-first construction. Finally, T. Oertling included dovetail-shaped mortices in a typology of Ibero-Atlantic wrecks, although this morphology has also been observed in a Genoese context (Oertling, 1989; Guérout, Rieth and Gassend, 1989). Morticed frames can be viewed in numerous ways, but it is clear that they were a structural aspect of Atlantic shipbuilding, and possibly Mediterranean as well, in the 16th century.

Mortice morphology

We shall now turn to some of the regional variants that appear within the Atlantic space, based on our comparison of Biscayan and English examples. In a comparison between the *Mary Rose* and the Biscayan tradition, it is necessary to treat the style of the mortice assembly as a separate characteristic and as a potential way of distinguishing between different regional traditions. In Basque wrecks, the floor timber and first futtocks are linked by a characteristic "dovetail" mortice, reinforced by two iron nails and two treenails. The presence of these fasteners may be a key in distinguishing Ibero-Atlantic examples from others having a similar dovetail form (Fig. 6). The futtocks are attached to the face of the floor timber that is turned away from the master frame, while the master floor timber usually, but not necessarily, has two futtocks attached at each end.

In the *Mary Rose,* three forms of joint occur in roughly equal numbers, but in a random distribution. The dovetail form is notably absent (Fig. 7). The first style of mortice is a square lap joint, such as is also found on the Studland Bay wreck in which the two timbers are scarfed end-to-end. The second style, also creating an end-to-end joint, is a diagonal butt scarf. The last style is a hooked diagonal scarf is similar to the "knuckle" found in eastern Mediterranean ships (Steffy, 1994, p. 134, 137). In contrast to the first two morphologies, the "knuckle" is not a true end-to-end scarf. All three styles are represented in roughly equal numbers at both levels

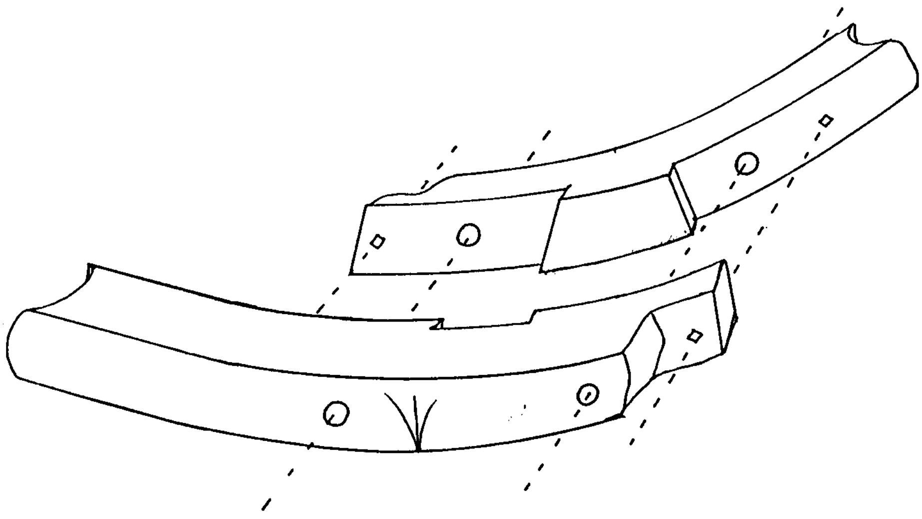


FIG. 6 – The “dovetail mortice” feature linking the floor timber and the first futtock, showing the round treenails and the square nails typically found in Biscayan wrecks.

Mortice styles in the *Mary Rose*

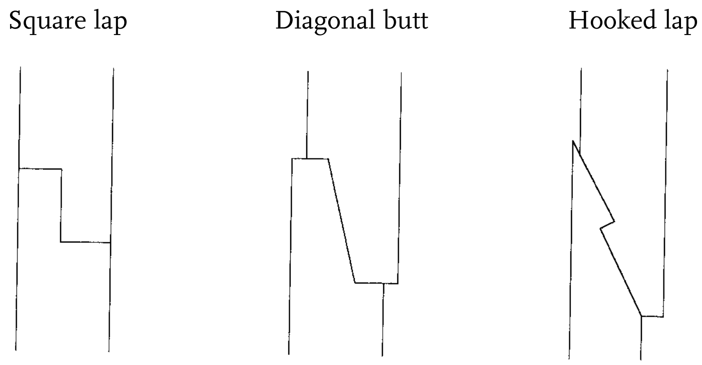


FIG. 7 – Three styles of mortice as found in the *Mary Rose*.

Biscayan timber *codos*

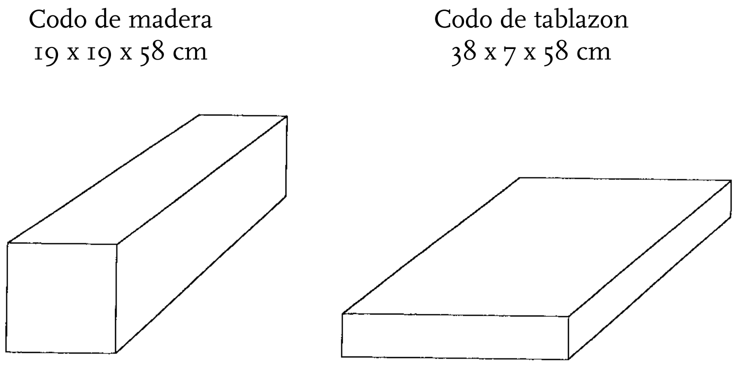


FIG. 8 – The Biscayan timber *codos* which are reflected in the scantlings of Basque wrecks.

where they occur, sometimes appearing in clusters of two or three of the same style, but otherwise, no distribution pattern emerges. The different styles of mortices suggest that at least three carpenters were allocated the work of joining frame timbers, and may well relate to the vessel's 1536 refit.

In contrast to the Biscayan examples, the end-to-end composition of *Mary Rose*'s morticed frames means that these frames were not necessarily pre-assembled or installed as a group. There was sufficient space between frames — provided the adjacent filler was still absent — for the frames to be assembled in place, and no fore-and-aft fasteners have been detected in association with the joints. A great deal of ambiguity remains in the interpretation of the morticed frames and the morphology of the mortices themselves, with only the "Biscayan" style appearing to have a regional association. The use of mortices may have been universal, but their style varied in ways that often defy any generalization.

Naval metrology

Perhaps the most frequently overlooked element of shipwreck archaeology is metrology, yet the regional association of specific units of measure is a well-documented fact. The *Mary Rose* was built using the English foot of 0,305 meter, while the Red Bay vessel's constructors used the Biscayan naval measure called a *codo de ribera* of 0,575 meter. More than a regional "signature", the historical role of a standard metrology was to create norms among related but different trades such as forestry, shipbuilding and marine transport. The application of a given metrology to each trade helps understand the degree to which these trades were integrated as a common maritime industry.

As mentioned, the overall dimensions of both ships correspond to even feet and *codos*.[15] These measures were also used to calculate ship's tonnage, and their application to both construction and transport points to the integration of regional shipbuilding trades with international shipping standards. Tonnage thus was a fundamental element of Atlantic shipbuilding, and regional systems of measure had methods of integrating with the international tonnage standard. A different picture emerges from a comparison of how shipbuilding and forestry measures were integrated in Biscay and in England.

The scantlings, or dimensions, of individual timbers in Biscayan shipwrecks conform to the volumetric *codo* used in Biscayan naval forestry, where three different *codos* were used, depending on the type of timber that was being prepared (Fig. 8). Invariably one *codo* in length, the framing timber *codo* (*codo de madera*) measured one third *codo* square (19 cm) while the planking *codo* (*codo de tablazon*) had a width of two thirds *codo* (38 cm) and a thickness of an eighth of a *codo* (Villareal de Berriz, 1736). These units correspond to the maximum timber scantlings found on Basque wrecks, which are highly regular within a given ship, and from one ship to the other. The third *codo*, expressed as *dos por uno* or "two for one", applied to smaller planks for the castles and lesser frames, such as ledges and top timbers, which had to be sawn once more and thus, the sawyers were paid at a rate of two *codos* for one. Again, the lesser planks on Biscayan ships often measure 19 cm wide — half that of hull planks — and lesser frame pieces measure up to 14 cm square - half the cubic volume of a *codo de madera*.

English volumetric measures of planks and frames were given in *feet*, that is cubic feet, but unlike the Biscayan system there was no standard for the outside measures of a cubic foot. The lack of a dimensional standard for a *foot* of timber is reflected in the scantlings of the *Mary Rose*. The sided dimension (room) of the floor timbers, which in the Red Bay example is constant at 19 cm, varies in the *Mary Rose* from 22 to 50 cm (Fig. 9). Faced with the choice of where to place

Room of the *Mary Rose* floor timbers (cm)

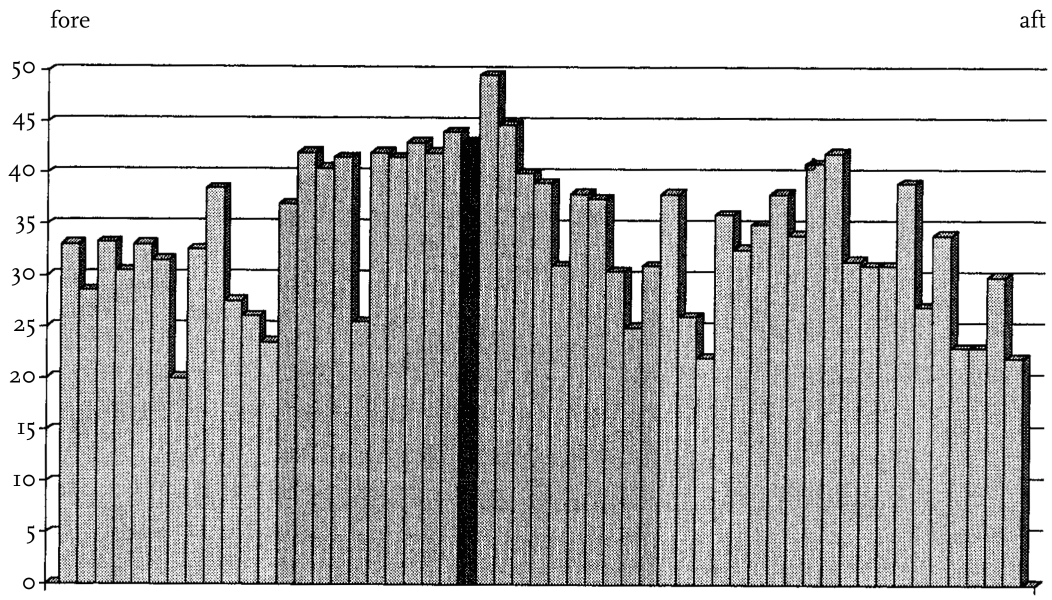


FIG. 9 – The sided dimension, or room, of the *Mary Rose* floor timbers at the keel (cm).

Fastening patterns

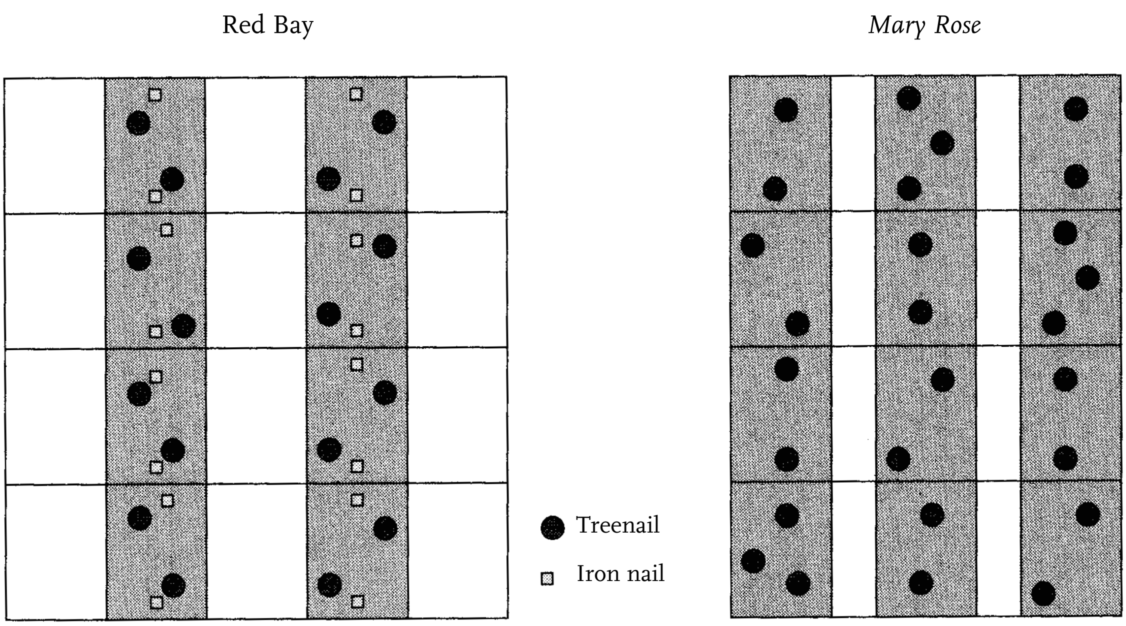


FIG. 10 – The typical arrangement of treenails and iron nails holding the hull planks.

the timbers of different widths, the *Mary Rose* builders grouped the widest floor timbers around midship, and placed the narrowest timbers around the 12th frames fore and aft of the master frame, and again, toward the stern of the ship. English forest metrology gave timber producers a great flexibility in their choice of trees but, by the same token, the builders of the *Mary Rose* were obliged to construct their ship with frames of irregular width. In contrast, the more restrictive Biscayan metrology resulted in a more regular, and generally more efficient, construction.

Fasteners

The idea that the style of hull fasteners may be a regional characteristic can be traced to J.B. Lavanha who, in the early 17th century, stated that northern ships had wooden nails while ships sailing into warmer seas needed to have iron nails that could not be tunnelled by teredos. Other studies have confirmed the occasionally local character of fastening styles (Lavanha, c. 1600-1620; Barata, 1965; Adams, Holk and Maarleveld, 1990, p. 83-91, 117), and our two examples form a clear contrast (Fig. 10). On the *Mary Rose*, at each joint of a plank and a frame, two treenails are found, measuring 25 to 30 mm round and centred on the frames (Fig. 10).

In Biscayan ships, the fastening pattern is considerably more complex (Loewen, 1995, p. 145--158). At each joint of a plank and a frame, two iron nails and two treenails are found. All are countersunk with an adze, apparently to assist in positioning and drilling the fastener hole. The iron nails measure 10 to 12 mm square, and are inserted along the centre line of the frame timber. The treenails are 25 to 28 mm round and tapered at the inboard end, and are fabricated from split oak. These are offset to alternate sides of the frame timber, but in regular patterns. Along one frame, the upper treenail on each plank may be near the forward edge of the timber, while along another frame, the upper treenail may be near the aft edge.

Analysis of the Red Bay fasteners has revealed that the iron nails were used to tack the planks and frames in place during their installation, and that the treenails were added later to ensure a more solid structure. Variations in the pattern, particularly in offsetting the treenails, have shown that the treenailing was carried out in several phases as different components of the hull were assembled. The use of iron nails thus allowed the carpenters to assemble the hull rapidly and independently of the treenailers, who arrived at the shipyard at different moments and thus were able to work on more than one ship at once. Such a division of labour was possible given the intensity of shipbuilding activity along the Basque coast, and given the proximity of an important iron-producing region immediately inland.

The economic development of Biscay around 1565 appears to have been based on an intensive coordination of different maritime trades and industries, which resulted in complex and, occasionally, rigid norms. The *Mary Rose*, built in the first decade of the century, does not tell a similar story of a refined maritime industry, but rather one that had considerable flexibility and an abundance of material. In both cases, the fundamental aspects of Atlantic shipbuilding, an oak economy and a geometric hull design, were certainly present.

Conclusion

While the natural range of *Quercus robur* provides the simplest geographical definition of the Atlantic space, the finding of a distinctive Atlantic method of hull design is more difficult to explain. We have tried to understand these structures, and others that are common to the Atlantic realm, through a comparative approach that operates on two levels. Firstly, we have identified common Atlantic features that form a contrast with parallel Mediterranean features and, secondly, we have identified regional structures within the Atlantic space by comparing equivalent forms from two shipbuilding regions, Biscay and England. These comparisons suggest that oak supply, geometric hull design and the morticed assembly of selected frame timbers had an Atlantic association that, except for the latter feature, contrasted with the Mediterranean space. On the other hand, systems of measure, nailing patterns and certain frame-mortice styles had regional associations within the Atlantic space. However, there is no reason to think that these features were specific to the 16th century and, in fact, some can be traced to a much earlier date. The structures of Atlantic shipbuilding were thus already in place before the launching of the *Mary Rose* and underlay the construction of new, larger ship's hulls that were produced throughout the century.

NOTES

1 This paper was prepared at the invitation of Robert Grenier, Parks Canada, Ottawa, and Chris Dobbs, The Mary RoseTrust, Portsmouth, to whom the author wishes to express his gratitude, as well as to Richard Barker who collaborated on parts of the Mary Rose analysis.

2 We have discussed these research tendencies in Loewen, 1998.

3 In addition to the guidance and generosity of Chris Dobbs of The Mary Rose Trust, the contributions of Andrew Fielding and Alexander McKee are gratefully acknowledged.

4 This paper owes much to the many hours of collaboration with the staff at Parcs Canada in Ottawa, of whom Robert Grenier, Charles Bradley, Peter Waddell, Carol Pillar, Marc-André Bernier and Fred Werthman have my special gratitude.

5 The tree-ring research on both shipwrecks is ongoing and C. Dobbs and R. Grenier are thanked here for communicating up-to-date information.

6 In Italian texts, this is called legno in ramo, a concept described by M. Baker as being unfamiliar to English builders. The Spanish equivalent is joba, and the French, trébuchement. Cf. Bellabarba, 1993; Apestegui, 1992: commentary; Rieth, 1996.

7 Baker, 1580, Ms 2820; Fernandes, 1616, facsimile 1989, fo. 83r: the radius of the "bilge arc" is 21 palmos, that of the "futtock arc" is 63 palmos, and that of the "breadth arc" is again 21 palmos.

8 Lavanha, c. 1600-1620: Ms 63. Our analysis of the master frame follows Barata, 1965.

9 The lost work of Hipparchus On the Chords in a Circle contained a table of chord lengths, as does Ptolemy's Mathematical Syntaxis. Clagett, 1955, p. 238-244.

10 ARC (Valladolid), pleitos civiles, Taboada fenecidos, 75-5 (1547-1551), fos. 1r-31r, and AGDG (Tolosa), civiles Mandiola, leg. 157, escribano Perez (1552), fos. 1r-60v (especially fo. 3v); cf. R. Grenier et al., op. cit.

11 AHPG (Oñati), III, 2710, fo. 58v (San Sebastian, 1583): "...todo lo demas que abra menester ser acabada en toda perfeçion y de tal manera que los genoles y fieles e barengas y corbotones y todos los otros materiales que en la dicha nao se pusiere sean de mui buen escarpe ligadura y sean gruesos, a contento de el dicho Sebastian de Valerd y conforme a los moldes y gruas que él le diere para la fabricaçion de la dicha nao..."

12 AHPG (Oñati), III, 1803, fo. 46r (San Sebastian, 1577): "...como lo traçare el maestre Calatras, vecino de la Renteria, que save como se an de faser las naos para la Carrera de las Yndias..."

13 AHPG (Oñati), II, 3299, XI, fo. 47r (Zumaia, 1579): "...el dicho Pero Fernandez a de dar en la rribera desta billa donde la dicha nao se a de hazer el maderamiento y tabla a donde se fuere menester de donde los dichos carpinteros sean de scrivir..."

14 AHPG (Oñati), II, 3313, fo. 32r (Zumaia, 1585).

15 The confirmed dimensions of the Mary Rose the greatest breadth (38 feet) and the deck heights, from the ceiling to the tops of the deck beams at midship ($8^1/_2$, $15^1/_2$ and 22 feet). The riders are placed at intervals of 10 feet along the keel. Those of the Red Bay vessel are the breadth (13.15 codos), the deck heights (4,7 and 10 codos), and the overall length ($38^1/_2$ codos).

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