CAULKING TECHNIQUES IN NORTHERN AND CENTRAL EUROPEAN SHIPS AND BOATS:
1500 B.C. - A.D. 1940

A Thesis
by
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CAULKING TECHNIQUES IN NORTHERN AND CENTRAL EUROPEAN SHIPS AND BOATS: 1500 B.C. - A.D. 1940

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ABSTRACT

Caulking Techniques in Northern and Central European Ships and Boats:
1500 B.C. - A.D. 1940. (December 1985)
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Caulking, the essential process of stopping up the seams of wooden ships and boats to prevent leakage, is a severely neglected aspect of ship and boat archaeology.

This study of caulking techniques attempts to rectify this situation through an examination of caulking methods and materials throughout Northern and Central Europe from about 1500 B.C. to A.D. 1940, being the period from the earliest known boat finds in this area to the advent of the Second World War.

The study includes an examination of caulking techniques employed in all types of ships and boats, from the smallest riverine craft to the massive oceangoing vessels of the 18th century.

The examination is divided into three main sections. The caulking techniques of early watercraft are studied first, evidence for which is largely based on limited archaeological information. The study then moves onto an examination of larger seagoing and oceangoing vessels and the subsequent regularisation of caulking techniques. The final section concerns the caulking techniques of smaller native craft confined to riverine, estuarine and coastal areas until their virtual obsolescence in the early 20th century.
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INTRODUCTION

"Caulk, Calk: to stop up the seams of (a ship etc) by driving in oakum, or the like, melted pitch or resin being afterwards poured on, so as to prevent leaking" (O.E.D., 1933).

Caulking is very much an underrated task in the process of building ships and boats. Indeed, little documentation exists concerning this necessary process, although archaeological evidence indicates that the seams of even the earliest boats were caulked.

The aim of this thesis is to study caulking techniques throughout Central and Northern Europe from about 1500 B.C., being the period of the earliest-known boat finds in this geographical area to the advent of the Second World War, which stimulated the experimentation in and development of synthetic caulking compounds.

This study will cover all of Northern and most of Central Europe, comprising Great Britain and Ireland, Northern and Central France, Belgium, the Netherlands, East and West Germany, Denmark, the Swiss Plateau region, the Upper Danube valley, Western Czechoslovakia, Western and Northern Poland, the Eastern Baltic coast of U.S.S.R. and Finland, Norway and Sweden (figure 1). The region covered is thus designed to include the area of so-called Celtic influence, the coastal plains and major river valleys.

The study falls into three main sections. The first section covers the caulking techniques of watercraft in general before the development of larger, seagoing vessels

The journal used as a pattern for the format and style of the thesis is the International Journal of Nautical Archaeology, Academic Press, London.
capable of extensive voyages over large areas of open water, covering watercraft from about 1500 B.C. to the rise of sea power in the 13th century. This section also includes the caulking techniques of Scandinavian lapstrake-hulled vessels which were capable of sea voyages, but which cannot be categorised along with the larger seagoing vessels of the later Medieval period onwards. The evidence for these early vessels is almost entirely based upon archaeology, and is therefore somewhat limited and cannot be considered totally conclusive.

Figure 1. Map to define area covered by this study.
The second section of the study covers the caulking techniques and development of larger seagoing vessels of the later Medieval period onwards, until the advent of the Second World War (about 1940) and the subsequent experimentation with synthetic caulking materials brought about by the need for speed and simplicity in the ship-building industry to supply the demand of warfare.

The final section investigates the caulking techniques of smaller, native craft confined to coastal, estuarine and riverine areas, techniques which often reveal little development from the earliest known methods and which persisted in remote areas into the 20th century.
EARLY WATERCRAFT

The earliest watercraft, used for short journeys across or down rivers, would have been small, primitive craft such as dugouts (monoxylons) or rafts. Such vessels would only have required caulking during repairwork, holes and cracks stopped up as they formed with materials closest to hand in order to keep the craft watertight. Riverine muds and silts were probably first tried and found ineffective, whilst mosses and grasses were found to be more successful, simply wedged tightly into hole or crack.

The development of more sophisticated watercraft constructed with separate planks rather than a single hollowed trunk resulted in the appearance of caulked seams as a feature of construction as well as repair.

Clear evidence for developed moss-caulked seams can be seen in the three sewn, plank-built boats found at North Ferriby, Yorkshire, England, dated around 1500 B.C. (Wright, 1976: 16). Each boat was caulked with moss of a common woodland variety (Neckera complanata, species), in the form of a worked moss rope covered with moss wads. The seams were then capped by neatly cambered oak slats and tied together with cords (figure 2). In one area of Boat 3 the caulking rope consisted of worked common hair moss fibres (Polytrictium commune, species).

The three Ferriby Boats indicate that the major problem of how to prevent the moss caulking from falling out of the seams had already been resolved by the Early Bronze Age: this technique of fastening wooden battens over the caulk-filled seams was to continue, with little modification, in small, native craft, right up to and beyond the 1940's.
Figure 2. Ferriby Boat caulking technique.

Little other evidence for the caulking techniques practiced in the Bronze Age in Northern and Central Europe has either survived or been discovered, although at least two Bronze Age dugouts found in England had evidence for the use of moss caulking (McGrail, 1978: 167)(1). The Brigg Raft, dated to around 700 B.C. likewise has evidence for moss caulking (McGrail, 1975: 9). The two Bronze Age dugouts from Lake Bienne, Switzerland, however, were made watertight simply through the swelling of the wood of the end planks when immersed in water, thus negating the need for any additional caulking material (Arnold, 1977: 293)(2).

The use of moss as a common caulking material is further witnessed by Strabo. In his Geography (Book 4, 195), Strabo makes the following comments about the Veneti tribe of northwest France: "They do not close up the seams of the planks but leave gaps and these they caulk with moss so that on beaching the unwetted wood does not dry out, the moss being naturally moister and the wood dry and un-absorbent." (Wright, 1976: 48)(3).
The proportionately high number of boat remains datable to the Iron Age and Roman Period in Northern and Central Europe yields substantial evidence for at least some of the caulking techniques of the period.

The evidence from Continental Europe reveals a general technique for caulking boats (with a few minor variations), consisting of moss wads and ropes laid in seams and capped by wooden slats, held in place by thousands of small bent nails, small metal staples or metal clamps. Perhaps the best examples for the technique of slats held by bent nails can be seen in the boats found at Bevaix and Yverdon, Lake Neuchatel, Switzerland. Both these vessels, of the so-called Celtic Type, were found to have identical caulking, consisting of strings of Gramineae stalks overlapped by several layers of moss (Neckera crispa species), held by a willow slat, itself fixed by thousands of small, curved iron nails approximately four centimetres apart (Arnold, 1974: 136; 1975: 125) (figure 3).

![Figure 3. Caulking technique of the Bevaix and Yverdon Boats.](image-url)
Similarities between the caulking of the boats from Bevaix and Yverdon (dated to the 1st century A.D.) can instantly be seen with that of the North Ferriby boats, and appear to demonstrate a direct development of this type of caulking. It should, however, perhaps be described as a logical progression of ideas rather than a direct development in view of the wide time span and geographical location of these examples. This same general technique of caulking can be seen time and time again with minor differences right into the 20th century.

The author contends that the evidence for caulking techniques in early watercraft is demonstrative of localised development using easily available materials. She would further contend that the common occurrence of battedened-moss caulking is not demonstrative of a common influence, that the common occurrence is suggestive of coincidental development following the restrictive parameters of availability of materials and hull design (i.e., the prevention of caulking falling out of the seams). The evidence for battedened-moss caulking, which was to become more widespread, is also perhaps indicative of a successful technique.

From the evidence available, the various species of mosses used for caulking boats is suggestive more of local availability rather than specific selection, although the hairier *Polytrictium commune* moss rope from Ferriby Boat 3 was probably more easily spun or woven into ropes than the more compact *Neckera* species otherwise found. Ferriby Boats 1 and 2 have no evidence of the former species of moss, yet still have moss rope caulking: perhaps these vessels were constructed at a different location than Boat 3, where none of the hairier moss was available.
Moss, however, was not universal in its use as a caulking material: there is a striking distinction between the Lake Neuchatel boats and boats found in London, which were caulked with crushed hazel twigs (*Corylus*, species, probably *Corylus avellana*, a species which grows in England).

The distinctive material of the London boats found at Blackfriars (Boat 1) and New Guys House, both dated to the late 2nd century, is interesting in terms of its uniqueness but probably represents a local technique arising from the ready availability of hazel twigs in the home region of the two vessels. Since it is unlikely that the New Guys House vessel would have been utilised in a seagoing capacity (Marsden, 1966: 31; 1976: 51), the use of hazel twigs should be considered a phenomenon so far confined to the lower reaches of the river Thames and its environs, rather than indicative of a widespread technique.

In contrast to the methods used in the moss-caulked vessels, the method of application of the caulking of the London boats was such that no supporting battens were required to hold the hazel twigs in position, although it is likely that they would have been used during the caulking process itself (Marsden, 1966: 14-15). A detailed study of the nature and condition of the hazel twigs from the Blackfriars 1 vessel indicated that the twigs were hammered into the seams from the outside inwards, while a flat piece of wood was held over the inside, until the seams were tightly filled with crushed twigs (4). The effect of this method of caulking was to create a more permanent infilling of the seams of the boat than could be provided by the less stable moss, which would be affected by immersion in water to a greater extent than the less-absorbent hazel twig matting. There would, therefore, have been little need to protect the seams with wooden battens to prevent possible loss of the hazel twig caulking.
It should be noted, however, that the apparent lack of evidence for batted, moss-caulked boats in Great Britain at this time is probably not demonstrative of general adoption of alternative caulking techniques, but rather derives from a lack of archaeological evidence for moss caulking, especially since evidence exists for moss-caulked vessels in Great Britain both before and after the Iron Age and Roman period (5).

Scandinavian lapstrake vessels

The Scandinavian practice of building ships and boats with overlapping planked hulls necessitated a different approach to the problem of stopping the seams and preventing water ingress. Whereas the problem was relatively easily resolved regarding water ingress in carvel-built hulls by means of the insertion of caulking material after the hull had been constructed, the overlapping of the planks in lapstrake or clinker-built hulls prevented the use of such a technique. Lapstrake hulls had to be caulked during construction, while the planks were being laid.

Whereas the caulking process is essential in edge-aligned or carvel construction to prevent water seepage through open seams, the tight overlap of the lapstrake hull planking often served the same purpose: if the strakes are a good fit, caulking should not be necessary (McGrail, 1974: 13). It would appear that many of the known examples of caulking in lapstrake construction, however, were caulked simply as an added precaution against seepage, with caulking material placed in specially-cut channels or "coves" in the overlapping planks the entire length of a vessel (Fenwick, 1978: 96) (figure 4).

The different approach to the problem of caulking in lapstrake hull construction brought with it the use of different caulking materials. Whereas moss was the most common material used for caulking early carvel-built hulls,
the use of animal hair or wool with resin or tar predominates in lapstrake hull caulking.

Figure 4. Luting technique of the Svollen Boat.

The term "luting" has generally been adopted in place of the term "caulking" with regard to lapstrake hull construction, describing the practice of inserting material between two members before, rather than after they have been constructed, thus making a watertight joint (McGrail, 1974: 53-54).

The use of this term, however, is perhaps problematic, inasmuch as it is simply an artificial tidying-up of terminology, and it would not, therefore, have been recognised by the boatbuilders of antiquity (Hutchinson, 1981: Pers Comm). Furthermore, the original definition of the word as "Chemists' Clay, a plastic form of stopping" would
suggest that the difference between "caulking" and "luting" lies more in the nature of the material used than in its place in the building sequence.

The term "luting" will, however, be used in this study following the general adoption of the term to describe "lapstrake hull caulking". Although the apparent confusion in terminology should not be ignored, the clear distinction brought about by the archaeological definition renders it very useful with regard to the caulking of ships and boats.

Materials used for luting have changed but little since the earliest known lapstrake vessels: the pine fragments of an Early Bronze Age vessel found at Valderøy, Norway, are luted with wool impregnated with "some matter that might be birch bark oil, tar or resin" (Brogger & Shetelig, 1971: 25). Similar material is found associated with the early hull remains from Fjørtoft, Norway, although the boat from Hjortspring appears to have been luted with a form of resin glue (Brogger & Shetelig, 1971: 33).

Evidence for the use of wool and/or animal hair mixed with pitch or wood tar in lapstrake hull construction continues to amass throughout antiquity, and it is perhaps fair to say that these freely-available materials form a luting material characteristic of Scandinavian ship finds from an early period (Fenwick, 1978: 277).

There is evidence, however, for the use of alternative materials such as cloth or moss for luting purposes rather than the wool/hair and pitch luting, which remains a specifically Scandinavian compound. The 1st century boat find from Halsnøy, Norway, was luted with strips of red woven cloth soaked in tar (Brogger & Shetelig, 1971: 34), a material known as "sr", for which evidence was to re-appear in English dockyard records of the later 13th and 15th centuries (Sandahl, 1951: 176-177), and which name also persists today in the dialects of Orkney and Shetland.

The boat found at New Fresh Wharf, London, was caulked with moss (Marsden, 1982: Pers Comm). Dated to the 8th or 9th century, this lapstrake hulled vessel is the earliest known example for the use of this material in this type of caulking. Moss luting was to become more common: evidence for its use has been found in several medieval lapstrake-hulled vessels in the southern Baltic States (Rudolph, 1983: Pers Comm) and in the 16th or 17th century vessels from Pwll Fanog and Llyn Peris, Wales (Roberts, 1982: Pers Comm).
SEAGOING CRAFT

The later Medieval period can be seen as a period of expanding maritime enterprise, with the development of more widespread trading connections and the establishment of powerful associations of merchant venturers (9).

The expansion of maritime commerce created a need for the development of larger vessels capable of carrying large cargoes over open water. This, in turn created a need for the re-thinking of basic ship design. Literary sources indicate the names of numerous types of new vessels, although a certain amount of confusion over type name prevails: around 1400 a ship would often be called a "hulk" in one harbour and a "cog" in the next, although in the previous centuries these two types were kept quite distinct (Crumlin-Pedersen, in Bass, 1972: 186).

The remains of two cog-type vessels, both dated to around 1380, have been found at Bremen in Germany and at Vejby in Denmark, both with evidence for the caulking techniques employed in their construction.

The caulking of the Bremen Cog has been examined in some considerable detail (Borsig, 1978: 87-97) and reveals the continued practice of a well-established caulking technique employed in a new design concept. Werner Lahn, of the Stiftung Deutsches Schiffahrtsmuseum, Bremerhaven, offers the following description of the caulking of the Bremen Cog: "The clinker planks of the cog were caulked from the inside. The caulking rope consisted of moss, animal hair and tar. After the caulking the caulking material was fixed by means of a thin ridge (splitted willow twigs) and clamps into the upper edging of the plank underneath and into the inner edge of the upper plank", and further, "Ends of planks, keel seams and cracks were caulked. Caulking material in the form of a flat layer was
between all grooves." (Lahn, 1981: Pers Comm) (figure 5). The Bremen Cog demonstrates continuity in caulking techniques at least with the preceding boat-building schools of Central, and, to a lesser extent, northwest Europe. Although the same caulking technique is employed for both the overlapped plank and the edge-aligned plank sections of the Cog's hull, the clamps used to hold the caulking and associated battens in position in and over the seams are, none the less, identical to those found in the Gallo-Roman vessels of Lake Neuchatel\textsuperscript{10} (Arnold, 1976: 114, Photo 16).

![Diagram of caulking technique of the Bremen Cog]

Figure 5. Caulking technique of the Bremen Cog.

The Danish Vejby Cog was, however, caulked with sheep wool (Weeks, 1978: 237) and consequently reflects its ancestry in the lapstrake-hulled luting techniques of Scandinavia rather than the battened-moss caulking of Central and Northwest Europe.
The evidence for the caulking materials of the two cogs perhaps indicates the necessary development of this specialised hull form within the context of the well-established boat building industries of the two areas, with the use of labour skilled in well-established techniques to build new vessel types.

The increase in size and number of vessels constructed as a result of the massive increase in demand for merchant vessels would have created many problems within the boat- and ship-building industries of Northern and Central Europe. Not least of these problems would have been the concern over the quantities of caulking materials required for these vessels: caulkers must have been forced to look for alternative materials capable of fulfilling the same function as the moss or hair generally in use.

An examination of British dockyard records of the 13th to 15th centuries reveals the introduction of new types of materials for caulking purposes, although there is little or no indication of the method of application of these materials within the context of caulking the vessels concerned.

The Exchequor's Pipe Roll Accounts of Edward I reveal detailed records of the construction of twenty galleys following the declaration of war with France in 1294 (PRO, 1294-95: E/101/5). The records include entries concerning the caulking of the vessels throughout the building process, suggesting that the hulls were luted rather than caulked. Furthermore, references to materials known variously as "burr", "blare", "wiveling" and "wyldyng" generally thought to mean hair, wool or hay, often in association with pitch or tar (Whitwell & Johnson, 1926: 153) reflect the Scandinavian luting techniques, with the inference that these galleys were based on lapstrake shell hulls.
The appearance of new terms, "tow", "hards" and "okam" in the British dockyard records of the late 14th and 15th centuries are perhaps indicative of a change in ship design. No longer are the luting terms associated with lapstrake hull construction widely documented: tow, hards and okam, terms associated with the flax or hemp industry, are more suggestive of edge-aligned or carvel-hull construction.

Flax and hemp cultivation were long-established industries throughout most of Europe, the Baltic States and parts of U.S.S.R. Wild flax (*Linum angustifolium*, species) had been used by Swiss Lake dwellers as early as 8000 B.C. (Wilson, 1979: 11), although there is no evidence for its use as a caulking material at that time. The flax and hemp trades had flourished in the Roman Period, only to fall into decline following the collapse of the Roman Empire: between the 6th and 9th centuries flax cultivation was a small community occupation only. Following the restoration of the industry by Charlemagne in the 8th century, cultivation again became widespread, creating large quantities of discarded coarse fibres known as "tow" or "hards", materials found to be suitable replacements for moss in the caulking process (see Appendix I).

The earliest-known appearance of the term "okam", in dockyard records for 1416 (Carpenter-Turner, 1954: 66), reveals the use of this material, itself a waste product of the flax industry, in conjunction with the use of moss and pitch. Whether the okam (oakum) was used separately or mixed with the moss or pitch is uncertain; the entry suitably demonstrates the application of the new material alongside the old (11).

It must be emphasised, however, that the early references to the term "okam" in the dockyard records of the 15th and 16th centuries should not be taken with the
modern meaning of "tarred hemp or manilla fibres made from old and condemned ropes which have been unpicked" (Kemp, 1976: 610). The word "okam" or "oakum" stems originally from the Anglo-Saxon word "aecumbe" or "aecuma", literally meaning "off-comblings" or "the coarse part of the flax separated in heckling" (O.E.D., 1933). Oakum was, therefore, simply another word for "tow" or "hards", terms already documented as caulking materials in the late 14th century.

Thus by the early 15th century we have the appearance of that material commonly associated with caulking today, although in its original sense as a by-product of flax or hemp.

The definition of the term "oakum" was to change within the following two hundred years, although the earliest use of this word in its modern sense is problematic. The association of "oakum" with unpicked rope junk rather than as flax or hemp waste probably came about as a result of the increased demand for caulking material to supply the ever increasing tonnage of ships constructed. It is proposed that the demand for this material rapidly outweighed the amount of available waste material, creating the necessity for an alternative source, which was to be found in the huge stocks of scrap rope condemned from the Navy and available for reprocessing. The Elizabethan Poor Law of 1601 (the "43rd of Elizabeth") reveals that the "picking" of oakum had become a recognised occupation within the poor houses and prisons of Britain by the beginning of the 17th century (H.M.S.O., 1950: 346-7), a practice which was to persist extensively as a prison employment until the end of the 19th century (Ruggles-Brise, 1921: 136). The Netherlands is reported to have also practiced oakum picking until recently (Bijl, 1983: Pers Comm); the widespread use of oakum as a caulking material amongst the maritime nations of Europe would suggest that
the occupation of oakum picking was to become standard practice.

The use of oakum for caulking ships seems to have been practiced widely by the 16th century, although the older techniques and materials continued in use. The continuing evidence for old, well-established caulking techniques such as seam battening in large merchant and naval vessels suggests a partial lack of understanding of design, or rather a too rapid development of hull construction; the remains of an early 16th century ship discovered at Woolwich, London\(^{(12)}\), reveals the continuing use of wooden battens or ribbands over the seams to hold the pitch and oakum caulking in place (Salisbury, 1961: 87). The use of ribbands infers that the shipwrights had not yet mastered the caulking spacing between the planks, presenting novel difficulties to the caulkers in preventing the material from falling out. Similarly, the Swedish Elefanten, constructed in 1554, has battens between the frames, which would have acted as stoppers for the caulking (Salisbury, 1961: 87).

The 16th and early 17th centuries can be seen as a period of mixed ideas and change associated with the large scale and rapid development of ship design and construction, a period in which well-established caulking techniques continued to exist side by side with new materials and methods, culminating in the general adoption of pitched-oakum caulking.

Clamped battens and moss caulking in larger ship construction is known to have eventually died out in the Netherlands in the 16th century in favour of pitched-oakum caulking (Reinders, in McGrail, 1979: 35, 43), although moss continued to be utilised elsewhere as a caulking material on a large scale at least into the 17th century. There was a long tradition of moss collection from the

There is evidence for the use of hair or wool mixed with tar as a caulking material on large seagoing vessels of this period: the Mary Rose, sunk off Portsmouth, England in 1545, appears to have been caulked with cattle hair and wood resin (13), and the Swedish early 17th century ship Wasa was similarly caulked with cowhair (Cederlund, 1982: Pers Comm).

The geographical explorations of the 16th century resulted in the development of maritime enterprise, both commercial and naval, on a world-wide scale, creating further demands for large seaworthy vessels capable of carrying large cargoes and withstanding severe sea conditions. The free flow of ships throughout the known world brought with it a general assimilation of ideas in ship design and construction. The transmission of techniques, methods and skills throughout Europe and beyond came about as a result of the interchange of knowledge and expertise between the ship-building industries of Europe, as well as through the copying of designs of naval prizes, etc.. The practice of studying ship-building techniques and working in foreign shipyards is well documented. For example, Peter the Great of Russia travelled extensively in Holland and England studying their ship-building techniques in an extraordinary effort towards raising a naval power in Russia (Fincham, 1851: 69)(14).

The free flow of ship-building knowledge included the general acceptance of pitched-oakum caulking in large ships throughout the maritime powers of Central and Northern Europe in the 17th century. By 1644, the term "caulking" had assumed the definition by which it is known today, that of "driving of ockham, spun haire and the like, into
all the seames, rends and treenels throughout the ship, without the which it is impossible for a ship to be made tight to swimme and keepe out water" and oakum "is nothing but old roapes or others untwisted, and so pulled out as it were into loose flax againe" (Manwayring, 1644: 23, 71).

It is proposed that there developed a gradual change in the primary function of the caulking process. Whereas the initial purpose of caulking was to keep a hull waterproof through the blocking of the seams with material often held rigidly in place by a clamped or nailed wooden batten, the function became more to stop up the seams with a flexible, compressible material such as oakum with a waterproof covering of tar or pitch. Shipwrights finally learned to work alongside the caulkers; the outer plank edges were deliberately bevelled one-sixth of an inch per inch of plank thickness before a hull was constructed, to allow for the insertion of caulking material without the necessity for battens or internal ribbanding (Abell, 1962: 81). The caulking material in turn allowed the timbers to work freely without causing structural damage to the hull which might otherwise have occurred in a rigid vessel of large dimensions. Seams were finally tarred or pitched to prevent the oakum becoming wet and rotting. Oakum is more susceptible to decay than moss, wool or hay. Whereas tar or pitch was not essential to the preservation of these old caulking materials (although it was often used in conjunction with them), tar or pitch, itself a flexible compound, had to become the final protective layer in the caulking process. For the same reason, large hulls were not simply planked and pitched without benefit of any additional caulking material; the flexible qualities of the tar or pitch would have been insufficient to allow the considerable movement of the ship's timbers to occur without resultant leakage.
In British naval shipyards the science of naval architecture brought about the appearance and establishment of specific rules and regulations for many aspects of ship construction, including caulking. Rules were laid down stipulating the size of bevel to be cut on the plank edges calculated in the manner shown in figure 6 (Macquorn-Rankine, 1866: 198) (15), and lists drawn up indicating the number and types of oakum threads to be caulked per plank size and seam location for wales, planks, gun decks, weather decks and so on, as in table 1 (Fincham, 1852: IV, 48). It is presumed that similar rules and regulations were established in the shipyards of other European navies.

Example: plank 5" thick

\[ \frac{1}{4}" \text{ bevel} \]
\[ 10" \]
\[ \frac{1}{2}" \]

(Not to scale)

Figure 6. Working diagram for plank-edge bevel calculation.

These conventions have continued in use with little change, although today the bevels are largely cut by eye on the smaller wooden craft still under construction in the many wooden boatyards of Europe.

The mid to late 18th century was a period in which much experimentation in various concepts of ship design was
Table 1. The number of threads of oakum used in caulking the seams of planking of different thicknesses: British Naval practice, mid 18th century

<table>
<thead>
<tr>
<th>Thickness of Plank</th>
<th>Double threads of oakum</th>
<th>Single threads of spun yarn</th>
</tr>
</thead>
<tbody>
<tr>
<td>10&quot;</td>
<td>13 in number</td>
<td>2 in number</td>
</tr>
<tr>
<td>9&quot;</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>8&quot;</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>7&quot;</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>6&quot;</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>5&quot;</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>4&quot;</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>3&quot;</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>2½&quot;</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>2&quot;</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>1&quot;</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness of Plank</th>
<th>Double threads of black oakum</th>
<th>Double threads of white oakum</th>
</tr>
</thead>
<tbody>
<tr>
<td>9&quot;</td>
<td>11 in number</td>
<td>-</td>
</tr>
<tr>
<td>8&quot;</td>
<td>10</td>
<td>-</td>
</tr>
<tr>
<td>7&quot;</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td>6&quot;</td>
<td>7</td>
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<td>5</td>
<td>1 in number</td>
</tr>
<tr>
<td>4&quot;</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>3&quot;</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2½&quot;</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness of Plank</th>
<th>Double threads of black oakum</th>
<th>Double threads of white oakum</th>
</tr>
</thead>
<tbody>
<tr>
<td>4&quot;</td>
<td>3 in number</td>
<td>1 in number</td>
</tr>
<tr>
<td>3&quot;</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Thickness of Plank</th>
<th>Single threads of black oakum</th>
<th>Single threads of white oakum</th>
</tr>
</thead>
<tbody>
<tr>
<td>3&quot;</td>
<td>2 in number</td>
<td>1 in number</td>
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<tr>
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<td>2</td>
<td>1</td>
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<tr>
<td>2&quot;</td>
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</tbody>
</table>

(after Fincham, 1852: IV, 48)
carried out within British Royal Naval Dockyards. The maintenance of a dry, sound ship was largely the concern of the caulkers, who were having to face the interminable problem of re-caulking hulls rotten from the action of teredo and gribble infestation. Experiments had already been carried out with various substances "payed" (applied) over ships' hulls in attempts to prevent worm infestation and severe marine growth. Falconer's Marine Dictionary of 1780 states that "the bottom of a ship is paid with a composition of tallow, sulphur, resin & c." (Falconer, 1780: 213). Known as "boot-topping", the substance did in fact partly inhibit the growth of weed and barnacles (Kemp, 1976: 97, 107). The use of tallow, alone or mixed with soap, had also been practiced but, as Manwayring had pointed out over a century before, these substances "will quickly grow foule" (Manwayring, 1644: 74).

The age-old application of an extra layer of planking over a thickness of material such as hair soaked in tallow or pitch was often carried out in an attempt to protect the hull from degradation, but simply had the effect of slowing down the rate of decay. The hull of the Royal Naval frigate Dartmouth (wrecked off Mull, Scotland in 1690) was found to have been sheathed with a half-inch layer of fir deals over a layer of hair and tar payed over the main hull planks (Martin, 1978: 49-50). Although the felting and sheathing had been placed so as to enhance the caulking of the hull by overlapping the main plank joints, the Dartmouth had been much afflicted with shipworm.

It was not until the development and introduction of metal sheathing around ships' hulls that the problem of rotten hulls was finally resolved. The introduction of metal sheathing itself brought new problems. Initial re-experimentation into the use of lead plates was found to be unsatisfactory (17) as a result of the electrolytic
reaction between the lead and the iron bolts of the planking, as well as the easy detachment of the plates from the hull.

In 1761 the British Navy successfully experimented with the use of copper sheathing on the hull of the 32-gun frigate *Alarm* (Davis, 1955: 205), and had adopted it for general use by 1783. Initially, hulls were simply caulked with pitch and oakum in the usual manner before the overlapping copper plates were fastened to the hull with iron nails. It was soon found necessary, however, to use some means to protect the iron fastenings from the combined action of the salt water and the copper (Fincham, 1851: 134-135). In January, 1779, it was therefore ordered that a layer of tarred paper should be applied by the caulkers between the bottoms of hulls and the copper plates. In 1796 this practice was discontinued following the replacement of the iron fastenings by copper, although the use of tarred paper was re-introduced in 1799 following the discovery that leakage through an open treenail hole had been prevented by the presence of tarred paper under the copper sheathing of the frigate *Caroline* (Fincham, 1851: 135)(18). Alternative substances such as layers of pitched felt (stuff made of wool and hair [Smythe, 1867: 291]) or canvas were also used between the sheathing and the hull, with the same effect.

The appointment of Sir Robert Seppings (1767-1840) as Master Shipwright at the Royal Naval Dockyard at Chatham and his subsequent appointment as Surveyor of the Navy in 1813 brought about great improvements in the science of ship construction. Among his many achievements, most notable of which was the introduction and use of internal diagonal bracing of ships' hulls, was an experimental method for the preparation of oakum for caulking (P.R.O., 1820: CHA/E/140/1104). The method involved the passing of
properly spun oakum through a kettle of mineral tar, followed by the repicking of the oakum and its application to the seams of the hull below the waterline and any other places susceptible to decay. The purpose of this experiment was presumably to determine whether oakum specifically impregnated with tar lasted longer than oakum made simply from unpicked tarred rope. The caulkers carrying out this experiment were instructed to call upon the assistance of the Master Ropemaker of Chatham, indicating that the experiment was not undertaken within the Chatham Ropeyard (19).

Seppings was further involved in the introduction of caulked wooden "fillings" inserted between the frames of ships from the floorheads downwards in 1810 for the purpose of strengthening the hull and preventing water ingress in cases of structural damage to the keel (Fincham, 1851: 200). Initial experimentation on the part of the caulkers into the use of Roman Cement mixed with water was found to cause decay, but in all cases where the Cement had been mixed with vegetable or coal tar the timbers were preserved. The great quantities of mineral tar involved in this process became very offensive by its odour, however, and was considered by some to be injurious to the health of the crew. The use of the tar was, therefore, discounted in favour of a mixture of oil and whiting which was introduced into the seams and crevices of the internal members of ships' hulls, and which "doubtless contributed much to their durability" (Fincham, 1851: 202).

Pitched-oakum caulking: Techniques and tools

Techniques

The amount of oakum driven into each seam or joint of a vessel was determined by the thickness of the planks and parts to be caulked, following the guidelines laid down in the 18th century (Fincham, 1852: IV, 48).
Shipwrights deliberately bevelled the edges of the planks so that the seams and joints were made close at the inner part and open at the outer, at a ratio of one inch in twenty inches, or more recently, to a depth that they felt was satisfactory (figure 7).

Figure 7. Bevelled deck seams awaiting insertion of oakum caulking.

Known as "allowing" the seam, final adjustments to the seam space were made after the planks had been laid by a process known as "reaming". Sharp iron wedges called "reaming irons" were driven into the seams with a heavy mallet or beetle to open the seams to their correct width prior to the insertion of the oakum (figure 8). The process of reaming tended to close up the seams near that being opened, to the extent that even those adjacent seams which may have previously been the correct width or wider would still require to be reamed (Macquorn-Rankine, 1866: 198). The opening of the seams in this manner was
considered a test of the sufficiency of the fastenings of the planking; should the reaming cause the planks to start, new fastenings were at once put in.

![Seam before "reaming"
Seam after "reaming"

Figure 8. Schematic diagram demonstrating effect of "reaming" or "allowing" a seam.

There were two types of oakum used in the caulking of the large naval vessels. The first type to be inserted into the seam consisted of an oakum made from the spun fibres of unpicked and untarred ropes. Known as "white" oakum, this type was more susceptible to decay than oakum made from unpicked tarred ropes, and had to be protected from becoming wet. The "white" oakum would be covered by threads of "black" oakum, that is, oakum made from the spun fibres of unpicked and tarred ropes, or oakum which had undergone the Seppings mineral tar impregnation process, and as such was less susceptible to decay.

Oakum was brought to the shipyards by the hundred-weight from the local prisons and workhouses where it had
been spun (Hamblin-Smith, 1934: 43; Watson, 1983: Pers Comm).

The process of pitched-oakum caulking of the prepared (reamed) seams or joints was as follows: *(20)*

Each oakum thread was individually driven into the seam to ensure that the seam was well caulked. The white oakum threads (if used) were inserted first, followed by the black oakum threads, the seam finally being covered with a layer of pitch to prevent the oakum becoming wet and rotting.

Each caulker would have been assigned his own section of hull to caulk, the size and location of which depended upon his speed, experience and efficiency. Left-handed caulkers were preferred to caulk certain parts of the hull.

The method of insertion of each thread of oakum involved the driving in of the end of a length of spun oakum, after which some three or four centimetres of oakum would be scooped up with a narrower version of that caulking iron used for reaming and tapped into the seam, leaving a small loop of oakum protruding (figures 9, 10 and 11). The process would be repeated along a short length of seam giving the effect of a piece of twisted hemp rope lying neatly along the edge of that seam (figure 12). This process was often known as "making" the seam, and the iron used was known as a "making" iron.

The caulker would then proceed to "finish" the seam, driving the loops of oakum right back into the seam with a special "finishing" iron, which was either blunt or grooved along its work edge, in order to prevent the oakum threads being cut by the iron during the driving process (figure 13).
Figure 9. Caulker "making" seam: first stage.

Figure 10. Caulker "making" seam: second stage.
Figure 11. Caulker "making" seam: third stage.

Figure 12. "Made" seam awaiting "finishing".
Figure 13. Caulker "finishing" seam.

The same process would be repeated over the other seams in the caulker's immediate area or "berth", with the result that the seams would all contain a single strand or thread of oakum before the successive threads were inserted. Special attention was paid to the caulking of butt-joints; so that no corners would be left for possible water seepage, each oakum thread was caulked in different directions across the joint, as indicated in figure 14.

The caulked seams of the larger vessels had to be hardened or "horsed up", which was done by one man holding a caulking iron fixed in a long handle (a "horsing iron") within the seam, while a second man drove the iron with a heavy beetle, to make the oakum as firm as possible and lie within the outer surface of the plank (figure 15).
Figure 14. Diagram to show direction in which oakum is laid around butt joints.

Figure 15. "Finished" seam awaiting pitching
It was necessary for the oakum threads to be driven as far back as possible into the seam to give firmness and prevent decay, with the effect that the driven oakum formed a wedge as far in as the thickness of the plank. This was known as being "well-bottomed" (Fincham, 1852: IV, 48) (figure 16). Oakum which was merely wedged in a mass near the surface of the seam, leaving the bottom empty, created what was described as a "choked" seam, with the result that the oakum would easily become dislodged and allow water ingress with the working of the timbers of the hull.

![Diagram of a well-bottomed seam]

Figure 16. A "well-bottomed" seam.

In the caulking of fir decks, however, the operations of reaming and horsing up were generally omitted because of the softness of the wood of the deck planking (Macquorn-Rankine, 1866: 198).

After the oakum had been driven into all the seams, joints and treenails of the hull, the seams had to be payed
with melted pitch to prevent the oakum from getting wet. On the sides of the ship, the pitch was applied with a pitch "mop", which consisted of a round, stiff-bristled brush on a long handle (Horsley, 1978: 125). On the decks a pitch ladle was used (figures 17 and 18). Weather decks, however, were often payed with "marine glue", a solution of caoutchouc and shellac in naptha (Macquorn-Rankine, 1866: 198).

Figure 17. Caulker pitching deck seams.

Caulking Tools

The caulking trade involved the use of a wide selection of curiously similar iron tools. The origin and evolution of these caulking irons or chisels is uncertain (21); a late 17th century Swedish book on shipbuilding illustrates caulking irons which are identical to those in existence today (Rålamb, 1690: Plate K) (figure 19), the only possible difference being that the early
irons would have been of wrought iron with steel face whilst later irons would have been all-steel (Hawley, 1983: Pers Comm).

Figure 18. The end product: a well-caulked, pitched seam.

Figure 19. Caulking mallets after Rålamb, 1690. 
a, English caulking mallet. 
b, Swedish caulking mallet.
No archaeological evidence for early caulking irons is available to the author, although the remains of two 17th century caulking mallets were discovered during the excavations of the Wasa (Cederlund, 1983: Pers Comm).

Figure 20 illustrates a selection of modern caulking irons of various types, all used in the caulking of a carvel-hulled fishing vessel.

![Figure 20. Types of caulking irons.](image)

The following descriptions can be offered for the range of irons used in the caulking trade and illustrated in figure 21:

1. Treenail iron, used for splitting the ends of treenails for caulking. This iron usually has a blunt edge about two and a half centimetres wide.

2. Spike, Sharp or Butt iron, used for caulking
in narrow spaces. Blade is tapering, usually about two centimetres wide.

3. Sharp iron, used in repairwork for chiselling out old oakum. Blade is sharpened in the manner of a chisel.

4. Caulking, Setting or Making iron, used for caulking-in or making the seam. Fan shape blade varies in width and is either sharp or blunt.

5. Bent iron, used in the same context as the Caulking iron, but narrow and bent for caulking difficult areas. Blade is usually flat across the edge.

6. Making or Finishing iron, used for finishing the seam. Various types: narrow or wide blade, with blunt, flat or creased edge. Creased edge type is also known as a Crease iron, and has one, two or even three creases in the edge.

7. Bent iron, with wide blade used for caulking-in making seams in inaccessible areas.

8. Jerry irons, used in repairwork for clearing out old seams. Blades are usually about thirty centimetres in length and are tapered from front to back to prevent jamming in the seam.

9. Horse or Hawse iron, with or without iron bridle or handle, used by two men on thick planking.

Figure 21. Various types of caulking irons.
Each caulker was known to have taken a particular interest and pride in his caulking mallet (Salaman, 1975: 116), a large, long-headed wooden mallet made of a hard wood such as beech, boxwood or lignum vitae. The faces of the head of each mallet were usually bound with tapering irons rings which were themselves caulked in place (Horsley, 1978: 127), and which could be moved back towards the centre of the head as the faces were worn down from use. The design of the mallet seems to have altered but little at least since the early 17th century; the two caulking mallets found in the carpenter's tool chest on board the Wasa had their faces bound with rings, although they have long since vanished (Cederlund, 1983: Pers Comm) (figures 22 and 23), and iron-ringed mallets are likewise illustrated in Rålamb's treatise of 1690 (Rålamb, 1690: Plate K).

Figure 22. Caulking mallet found on the Wasa.
Figure 23. Second caulking mallet found on the Wasa.

Some distinction can, however, be seen between the straight-headed caulking mallets of English design (figures 24 and 25) and the caulking mallets of Northern Europe and Scandinavia with their slightly curved heads (figure 26). The sketch of the two mallets illustrated in Rålamn's treatise (figure 19[p. 35]) shows the clear distinction between the straight-headed caulking mallet, his "Drif hammar på Angelstt Maneer" (English caulking mallet) and the curved Swedish caulking mallet, his "Swänst Dref hammar" (Rålamn, 1690: Plate K, 45).

The English type of mallet head has an enlarged central area, often reinforced by two horizontal rivets, which are also sometimes found in the curved-head mallet type. The central portion of the mallet is bored centrally
for a round handle, one end of which, either straight or
tapered, is caulked in place and often left protruding. An
example of a 19th century straight-headed caulkling mallet
in the National Scheepvaartmuseum Steen in Antwerp, Belgium
has a small peg through the protruding section of handle
above the head presumably to secure the handle in position
(figure 26).

Figure 24. English-type caulkling mallet (1).

A unique feature of these caulkling mallets is the
presence of a longitudinal slot cut on each side of the
shaft hole and extending towards the faces, often with a
round hole through its centre. The horizontal rivet or
rivets through the central portion of the head prevented
the head from splitting as a result of these slots.
Figure 25. English-type caulking mallet (2).

Figure 26. Northern European caulking mallet replica in the National Scheepvaartmuseum Steen, Antwerp.
Several explanations for these longitudinal slots have been made, although their real function is perhaps to give the mallet a degree of springiness, thus preventing the constant jarring of the caulker's arm which would otherwise have occurred on striking the iron. Often known as "whistle slots" (Hogg, 1983: Pers Comm), they are said to give the mallet a musical note, the pitch of which was arrived at and tuned by the length of the slot and the size and number of holes therein. A team of caulkers might tune their mallets through the adjustment of the slots and holes to sound like a peal of bells, and working in rhythm could help them keep up a fast rate of work. It is also said that the Master Shipwright in many yards could tell which of the caulkers was slacking if his mallet did not fall at the right time (Horsley, 1978: 127).

The ringing sound made by a caulking mallet on striking an iron cannot be denied, particularly when compared with the dull sound of the striking of a caulking iron by an ordinary mallet. The long existence of these slots, however, from the early 17th century at least, both in the straight- and curved-headed mallets is itself suggestive of a more practical function.

With time, the heads of the caulking mallets wore down on their faces too far to be of any further use for caulking. When this occurred, they were seldom discarded but converted into small chiselling mallets and used by shipwrights for light work (Horsley, 1978: 127).

The large caulking hammer or "beetle" used to drive the reaming and horse irons was quite distinct from the caulking mallet, consisting of a heavy, long-headed mallet with the faces bound with iron in the same manner as the caulking mallet, to prevent splitting.

Other tools used in the caulking trade included a small, carved wooden box used to contain a small quantity
of linseed oil, into which the irons were dipped periodically to prevent them sticking in the seams. Linseed oil and pitch are compatible: the oil did not prevent the pitch sticking when the seams were payed (Horsley, 1978: 127).

Paying the seams was undertaken by one of two methods, depending on the area of hull to be covered. The seams of the ships' sides and bottom were payed with a stiff-bristled brush or mop on a long handle (Salaman, 1975: 119), in what must have been an extremely messy task, whilst the seams of the decks were payed with pitch or "glue" poured from a pitch ladle, which had a long spout to aid and control the flow and to prevent as much overspill as possible (figure 27).

![Pitch ladle](image.png)

**Figure 27.** Pitch ladle.

When not in use, the tools were kept in a wooden box which also served as a seat for the caulker while he worked. Boxes varied considerably in design, an example of which
can be seen in figure 28. There is often a ring on one end of the box for carrying over the shoulder with the handle of the caulking mallet (Salaman, 1975: 118).

![Image of typical caulking tool box]

Figure 28. Typical caulking tool box.

Caulking repair and ship cleaning operations

A ship's compliment invariably included a caulker, or at least a carpenter capable of repairing and renewing caulking as and when it proved necessary. Not only was this the privilege of the naval vessel: the East Indiaman Colchester (450 tons) carried both a caulker and his mate amongst her 89 man crew when she sailed at the end of 1703 (Davis, 1962: 110-111).

The evidence for the caulking mallets amongst the carpentry tools in the box found on board the Wasa (Cederlund, 1963: 7) indicates that the shipboard caulker carried sufficient materials to undertake any repairwork.
Supplies of oakum would have been replenished while at sea: not only was the picking of oakum an occupation of workhouses and penal establishments ashore, but also an old naval punishment, in which every man condemned to cells on board ship was required to unpick a pound of rope junk daily (Kemp, 1976: 610).

Caulking repairwork can be divided into two categories, temporary or small caulking repairs following hull damage or degradation, where the vessel cannot be docked; and the major task of careening, breaming and recaulking a deliberately grounded vessel.

It was the responsibility of the caulker to devise whatever means possible of stopping up the leaks in the vessel as they occurred, through the patching of holes with metal sheets, canvas or any other suitable material, or the temporary caulking of small cracks or seams or holes, in a process known as "chinsing" (Smythe, 1867: 184).

A number of small sheet lead patches or "tingles" were found amongst the wreckage of the frigate Dartmouth (1690). Although none were observed fixed to the hull (Martin, 1978: 49), the presence of small holes around the perimeter of the tingles indicated the sheets would have been attached by means of numerous small nails. The use of such patches was recommended by Manwayring (1644: 61) for stopping leaks inboard and out. Holes below the waterline were made accessible by a process known as a "parliamentary heel", by which the guns of the side known to have been holed were run across to the opposite side of the vessel in order to give the ship a degree of list, thus (hopefully) exposing the cause of the leak (Kemp, 1976: 632)(22).

Shot holes could be plugged with wooden bungs and canvas, but larger holes were more problematical:
Manwayring further suggests the use of sailcloth or netting and oakum drawn under the hull in the area of the leak, a method which was to be developed as the "collision mat" by Rear Admiral Cochrane of the British Royal Navy in the mid 19th century (Kemp, 1976: 187). An alternative method, known as "fothering", was to fill a basket with ashes and chopped rope yarns or oakum and cover it loosely with canvas. The basket was then fixed to the end of a long pole and plunged repeatedly into the sea as near as possible to the leak. As the oakum was gradually shaken from the basket, it was drawn into the leak with the water entering it, eventually choking the hole (Kemp, 1976: 322).

Major caulking and hull cleaning operations involved the process of careening or laying the ships aground to facilitate access to the bottom. The initial task was the "breezing" or "graving" of the vessel, which involved the holding of "kindled furze, faggots or reeds to the bottom, which, by melting the pitch which formerly covered it, loosens whatever filth may have adhered to the planks" (Smythe, 1867: 131). The seams could then be examined and recaulked after the old and rotten caulking had been picked out, after which the vessel could be refloated and returned to duty. It was not unusual for operations of this magnitude to be carried out during voyages, particularly those involving tropical waters which encouraged rapid worm infestation and marine growth on a large scale. Numerous stations were established throughout the colonies for the purpose of careening the vessels, evidence for many of which can still be found in the many geographical references incorporating the term.

Caulking techniques: the last hundred years

The mid 19th century could be said to be the beginning of the end of the caulking trade on a large scale, with the introduction of iron and steel as the major building medium
in ship construction.

The development of composite hull construction for many clipper ships in the 1850's and 1860's (Kemp, 1976: 790) ensured the continued existence of pitched-oakum caulking as an important aspect of shipwrightry, but the abandonment of this type of hull led to its gradual demise in all but the smaller, wooden-hulled vessels which continued to be built.

The substitution of iron and steel for wood in the ship construction industry led to the collapse of the institution of oakum picking as an occupation within poorhouses, mental institutions (Watson, 1983: Pers Comm) and prisons, although it did not lead to the collapse of the oakum trade itself as has been suggested (Ruggles-Brise, 1921: 136). Oakum was still required in large quantities for repairwork and small ship construction, and it also found an important place as a caulking or stopping material in alternative industries such as plumbing, where it was employed in the tightening of pipe connections (Bijl, 1982: Pers Comm).

Methods for the mechanisation of oakum preparation were investigated in the latter half of the 19th century. Machines for both the preliminary operation of unpicking hemp rope and finishing the product had been constructed and were in use in factories throughout Europe at the beginning of the 20th century (Bijl, 1983: Pers Comm). Two such machines, still in use at the Dutch Oakum Works in Schiedam, Netherlands, can be seen in figures 29 and 30.

The oakum trade rapidly became an offshoot of the waste material industry, which had easy access to large quantities of old tarred hemp ropes, although the practice of making oakum from fresh hemp fibres was quickly adopted, simplifying the operation in as much as the fibres did not require to be unpicked but simply impregnated with tar and spun (Bijl, 1983: Pers Comm).
Figure 29. Oakum machine, circa 1920, Dutch Oakum Works, Schiedam, Netherlands.

Figure 30. Second oakum machine, circa 1920, Dutch Oakum Works.
The ever-increasing percentage of vessels built of iron and steel, however, resulted in the inevitable decline in demand for oakum, although it is unlikely that demand for superior, naval quality oakum will collapse altogether as long as wooden ships and boats continue to be built. The decline in demand can easily be seen in the decline in numbers of establishments manufacturing oakum: before the Second World War there were oakum factories in practically every country in Europe, whilst today only one such factory exists. The Dutch Oakum Works, in Schiedam, Netherlands, still exports oakum in small quantities all over the world, although it should be stated that the superior, naval quality oakum used in the caulking of wooden ships and boats is now only secondary, the main product of the factory being oakum and waste materials for industrial purposes (industrial cleaning rags and the like) which are manufactured on those same machines previously used for naval quality oakum.

The introduction of ships constructed of separate iron or steel plates rivetted together brought about a change in the role of the shipyard caulkers, with the result that the caulker ultimately became one of the steelworking tradesmen in his own right (Horsley, 1978: 98).

Before the advent of welded steel hulls, the rivetted seams of plated vessels still required to be caulked, although not with the standard method using pitched oakum. Rivetted joints were "fullered", grooves parallel to and near the edges of the joint were made by means of a hammer and blunt cold chisel, which had the effect of upsetting and spreading the metal towards the joint in order forcibly to close up any crevices (Salaman, 1975: 119). The ends of the chisels were ground at a blunt angle for the butt-joints and at a less-blunt angle for the lapped seams (Macquorn-Rankine, 1866: 198). Watertight iron bulkheads
and platforms within the hulls were caulked in the same manner, although the decks, constructed of wooden planks, were still caulked with oakum in the usual manner.
COASTAL, ESTUARINE AND RIVERINE CRAFT

Smaller craft for use on coastal waters, estuaries and rivers continued to play an essential role in national and international commercial activity throughout Northern and Central Europe from the Medieval period onwards. The development in design of these vessels, however, was along completely different lines to that of the larger cargo vessels designed for sea voyages. The nature of the craft and their geographical locations led to localised development and the persistence of well-established methods of construction, including caulking techniques.

It was not until the 18th century at least that coastal craft were designed with specialised features to fulfill specific functions, such as the large, flat-bottomed spritsail barges of the River Thames and Medway of England, which had to be able to settle on uneven fore-shores while loading and unloading cargoes, pleasure yachts and lifeboats, all of which required methods of caulking peculiar to that function.

The institution of moss caulking was to continue in inland areas of Northern and Central Europe even into the early 20th century: the relatively small sizes of the vessels did not create the same problems as the large sea-going vessels in terms of quantities of caulking required, and thus would not have created such a need to look elsewhere for alternative caulking materials.

Evidence for the continued use of moss caulking has been recorded in Poland, the Upper Danube valley, Switzerland and the Saône region of eastern France, often involving the use of nails or clamps and wooden battens, in a technique virtually unchanged from the earliest-known examples.
Przemyslaw Smolarek, Director of the Polish Maritime Museum, Gdansk (1982: Pers Comm), reports that moss caulking continued to predominate in inland craft and small coastal vessels of Poland into the 20th century. Despite the gradual introduction and use of both oakum and animal hair caulking in the larger vessels constructed in the Polish ports and coastal belt (areas more susceptible to outside influence), indigenous Polish watercraft were caulked with moss until their disappearance in about the 1950's. The use of animal hair was similarly superceded by oakum, which became the predominant caulking material for Polish vessels for sea going, coastal and riverine use.

The caulking techniques of the indigenous, flat-bottomed craft of the Upper Danube Valley have been studied by Siegfried Richter (1980: 47-48). Seams of the boats were caulked with dried moss held in place by wooden battens, which in turn were secured by rectangular metal clamps or staples laid diagonally across the seams, both inside and out. The seam at the chine was further sealed with moss on the inner side, held in place by wooden battens and wire staples laid diagonally across the seam in the opposite direction to the metal clamps, giving a crossed effect and ensuring maximum tightness to the seam.

The metal clamps of the Upper Danube boats appear to have the dual function of both securing the caulking in place and fastening the hull planking together, with the result that the clamps themselves are perhaps somewhat more substantial than those caulking clamps found in other areas, being some three to four centimetres in length. A boat of about eight metres in length would require some thousand to twelve hundred and fifty of these clamps for its construction and caulking.

The diagonal placing of the rectangular metal clamps or staples of the Upper Danube boats is interesting,
inasmuch as the clamping technique differs slightly from those found elsewhere in Northern and Central Europe. Whilst the caulking method of the Upper Danube boats reflects that of the so-called Celtic technique of ship and boat construction, with its nailed or clamped and battened moss-filled seams, the positioning of the clamps is more reminiscent of sewn seam construction, the lashings simply having been replaced by metal staples (figure 31). The overall construction of these craft, however, is clearly of so-called Celtic origin: the singular method of seam fastening merely suggests that sewn or lashed seams persisted longer in this region than elsewhere, eventually to be replaced by stitch-like metal fastenings.

Figure 31. Caulking technique of the Upper Danube craft.

The caulking technique in so-called Celtic boat construction has been examined extensively by Béat Arnold (1977: 293-97), who considers that the complex method of caulking using moss "has allowed us to pinpoint one of the important traits of Celtic naval construction which has
survived until the present day in a strip north of the Alpine arc" (Arnold, 1977: 297).

The complex moss-caulking technique of the boats from Lake Neuchatel persisted with little change until the early 20th century in the Swiss Plateau region. The geographical location of the region created natural barriers in the form of major rapids along the Rivers Rhone, Rhine and Aar to all but specially-adapted local craft, resulting in its isolation from the exterior influence of commercial riverine transport after the fall of the Roman Empire. The commercial isolation of the region was further enhanced by the introduction and imposition of excessive tolls and transshipment stations during the Medieval period.

State intervention in the 13th and 14th centuries with the importation of Genoese naval engineers and carpenters to build a small war fleet on Lake Léman resulted in the adoption of new ideas and techniques. The Genoese-style war vessels were slowly adapted for mercantile use by the end of the 17th century, reaching a climax in the later 19th century in the form of a lateen-rigged, two-masted vessel with keeled hull, alongside the smaller, so-called Celtic type flat-bottomed fishing craft (Arnold, 1977: 296-7).

This outside influence is perhaps further evidenced in the caulking techniques of these merchant vessels. Whereas the smaller, flat-bottomed native craft retained the clamped and battened moss caulking techniques, the Leman vessels were caulked with numerous overlapping strings composed of spun limetree bark held together by many small wrought iron nails (Arnold, 1977: 297). Whilst the method of application retained its so-called Celtic origins, the material used was quite different, perhaps reflecting the Genoese influence in the design of the vessels (figure 32).
Figure 32. Caulking technique of the Lake Léman Boats.

Elsewhere in the Swiss Plateau region, historic evidence for naval construction and caulking techniques is scarce until the 19th and 20th century, when few native craft remained in use. It is only through the few archaeological finds and the extensive recording of the obsolescent craft in recent years that the continued existence of clamped and battened moss caulking has been studied.

The "Weidling", a boat still in use on the Rivers Aar and Upper Rhine in Switzerland, possesses extremely complex caulking techniques: a string of reed fibre (Phragmites, species), or, more recently, cotton, covered by a trapezoidal batten is secured by clamps of circular section, whilst cracks are stopped both during and after construction of the hull by chiselling a semi-circular groove along their length, into which trimmed reed mace leaves (Typha, species) are placed, covered by semi-circular battens and secured by clamps (figure 33). This method of caulking can be paralleled with the more primitive boats of Lake Bourget, where moss is used instead
of string (Arnold, 1977: 296), and the general technique involving clamped battens has clear Celtic origins.

Figure 33. Caulking technique of the "Weidlings" of the rivers Aar and Upper Rhine: a, original seam; b, repaired crack.

The appearance of materials other than moss in the so-called Celtic caulking tradition is problematical, since they appear in areas where moss would have been readily available, as can be seen from the numerous examples of moss-caulked native craft throughout the Swiss Plateau region. The use of the spun lime tree bark caulking in the boats of Léman has possibly been attributed to the Genoese influence in their design. Perhaps the use of the reed fibre and reed mace leaves in the caulking of the "Weidling" boats is likewise indicative of some outside influence. The more recent use of cotton as a replacement for the reed fibres in the "Weidling" caulking is not uncommon; cotton string was to become a common caulking material in modern craft with thin hull walls requiring fine strands of caulking material(23).
The 19th century barge discovered at Cudrefin, Lake Neuchatel was found to be caulked with moss (Phuidium, species) overlapped by an oak (Quercus, species) batten held in place by a continuous row of spade-shaped clamps. The clamps found on this barge are absolutely identical to metal objects found in the excavation of La Tène, unfortunately out of any positive stratigraphical context and therefore of uncertain date (Arnold, 1976: 112). Similarly, identical clamps are used in the caulking of boats in the Saône region of eastern France, indicating a clear relationship between construction techniques of Lake Neuchatel and the Saône Valley (figures 34 and 35). The Celtic origins of the Cudrefin Barge can further be seen in the presence of moss-caulked nails hammered in from the outside of the hull, identical to those found in the Gallo-Roman Bevaix Boat.

Figure 34. Caulking technique of the Cudrefin Barge. a, clamped and battened, moss-caulked seam; b, composition of the caulking: 1, moss; 2, oak batten; 3, metal clamp
Figure 35. Clamped and battened, moss-caulked seam, Chalon, Granges Forestier (Saône region).

The Cudrefin Barge can thus clearly be seen as a direct descendent from the so-called Celtic type boats of Lake Neuchatel, particularly in terms of its caulking techniques, revealing little change for more than seventeen centuries. These techniques however, were to have become virtually obsolete by the early 20th century throughout the entire region of Celtic influence.

The Saône region of eastern France yields substantial information concerning the caulking techniques of the native riverine craft of the area, techniques which strongly reflect their Celtic origins and which can be paralleled directly with techniques found in other areas of Celtic influence, in other words in those areas lying immediately north and west of the Alpine arc.

Studies carried out by the Musée Denon at Chalon-sur-Saône, France, indicate that moss was used for caulking
purposes in the Saône region in antiquity: a boat find dated 1240 ± 60 A.D. from Saint-Marcel (Saône et Loire) was found to have been caulked with moss in a manner identical to that found in the Bevaix Boat from Lake Neuchatel (Bonnamour, 1984: Pers Comm). Figure 36 illustrates a further example of caulsing from the Saône region identical to that found in the Bevaix Boat. Moss caulking is known to have been used extensively during the 19th century in Saône boat construction, but this practice fell into decline in the early 20th century. Native river craft were no longer constructed after 1936 and the practice of moss caulking was to survive only in repairwork (Benoît, in Bonnetoi, 1979: 50)(24).

Figure 36. Nailed and battened, moss-caulked seam, Chalon, Granges Forestier (Saône region).
The practice of clamped, battened moss caulking in the Saône region survived long enough to enable a detailed study of the method of application to be made by the Musée Denon. The direct parallels between the caulking techniques of the Saône region with its spade-shaped metal clamps and those of the Lake Neuchatel region would suggest strong similarities in the method of application. The Saône caulking study could thus be applied to other regions of Celtic influence and is therefore of considerable importance. It should also be compared with the method of application of pitched-oakum caulking in the construction of larger seagoing craft to emphasise and highlight the major differences in function and technique of the two caulking types.

Large quantities of moss would have been collected from the nearby regions and then cleaned and sieved to remove any twigs and other impurities before being soaked, pressed and spun into strands of varying thicknesses. Figure 37 demonstrates the stages in the process of caulking with moss in the boats of the Saône region.

No preparatory work was done to the plank edges before the hull was constructed, planks simply being laid edge to edge (figure 37 a). V-shaped channels were cut along the length of the seams with an axe after planking up, with the result that only the outer portion of the seam would be caulked (figure 37 b)\(^{(25)}\).

The tools employed in moss caulking were all wooden, unlike those used in pitched-oakum caulking, in order to prevent the possibility of cutting the moss when driving it into the seams. The moss was initially pressed into the grooves with a curved wooden tool known as an "empognou", before being forced back into the seam (finished) by means of a wooden chisel-like tool known as a "calfat" ("caulker") and a wooden mallet. Such tools are known to have been
made by the caulkers themselves (Bonnamour, 1984: Pers Comm) from wood found when collecting the moss for caulking.

Planks were simply laid edge to edge

V-shaped channels cut with an axe after planking up

Moss wads required to be held in place

Notches were cut either side to locate clamps

Wrought iron, spade-shaped clamps

Tips of clamps located in uppermost notches, battens laid over moss

Clamps located in lower notches & hammered home

Figure 37. Stages in the process of moss caulking in the boats of the Saône region of France.
In much the same manner as in pitched-oakum caulking, several strands of moss were driven into the seams one after another to ensure that the seam grooves were tightly packed with moss, the size and quantity of the strands depending upon the thickness of the planking. The method of application of the moss caulking into the seams was such that, in order to prevent the moss being cut even by the wooden tools, no two strokes of the tool should fall on the same spot. Any moss accidentally cut during the caulking process had to be replaced to prevent possible leakage.

The final application of moss into the seams was such that the moss tended to form wads rather than actual spun strands, situated as it was at the top of the V-groove and thus compressed to a slighter extent. The nature of this final layer or strand of moss resulted in the necessity for additional means of security in the form of wooden battens and metal clamps (figure 37 c).

After the required quantity of moss caulking had been driven into the seams, small notches were cut on the planks on either side of the caulked grooves with a metal chisel in order to locate the ends of the spade-shaped metal clamps or "appes" (figure 37 d). The clamps, identical to those found on the Cudrefin Barge of Lake Neuchatel, were wrought-iron pieces of metal in the shape of a spade or leaf some thirty five to sixty millimetres in length (figure 37 e), which would have been placed close together along the length of the battened, moss-caulked seams to prevent the loss of any of the caulking material. The tips of the clamps were located in the uppermost notches, and irregularly-lengthed battens of willow or juniper laid directly over the moss-filled seams under the clamps, effectively obscuring the moss (figure 37 f). The clamps were bent down over the battens with the aid of a special
hammer, and the base located in the appropriate notch on the lower plank before being hammered down hard, thus securing the moss and wooden battens in place (figure 37 g).

The persistence of native craft with clamped and battened seams into the early 20th century at least would suggest that the age-old problem of how to keep the moss caulking in the seams had never been properly resolved, suggesting that the comparatively short moss fibres could not be spun into coherent ropes for caulking as easily as the longer oakum fibres. This method of caulking, however, is considered by some to be more satisfactory in terms of watertightness than pitched-oakum caulking: a bevelled seam badly caulked with oakum would certainly leak, whereas a seam grooved after construction and badly caulked with moss would be less likely to leak as a result of the tightness of the butted section of the seam (Benoît, in Bonnetoi, 1979: 51), despite the absence of an outer pitch covering as part of the pitched-oakum caulking technique.

Furthermore, the evidence for the continued use of clamped and battened moss-caulked seams in the area north and west of the Alpine arc indicates that this method of caulking was both well-established and well-proven, despite the possible contention that the necessity for battens and clamps is itself indicative of a less-advanced process than that of pitched-oakum caulking. There would, therefore, have been little need to change or try other methods or materials for caulking purposes, since the geographical isolation of the region created little need for the development and expansion of its commercial water activities. The result of this geographical isolation can easily be seen in the lack of major development in boat design since the Iron Age and period of Celtic influence.

The existence of a well-established hemp and flax growing industry in much of Europe and the U.S.S.R. (Wilson, 1979: 15) appears to have had little or no effect on the
caulking techniques of native craft until recent years. The presence of moss caulking as a well-proven technique in such areas and the lack of evidence of the use of oakum caulking is perhaps problematical. One explanation is that the moss caulking was such a well-proven and successful technique. The possibility of restrictions in the use of flax and hemp products in terms of political restraints must not be forgotten, although the author considers that the lack of evidence for the use of oakum caulking on native craft was simply a result of a lack of necessity to experiment with alternative materials. Native craft remained sufficiently small in size to prevent the need to look elsewhere for large quantities of other materials such as oakum for caulking purposes, and the continued use of rigid clamped and battened seams did not create the problems of timber-flexing found in the larger seagoing vessels. Furthermore, the landlocked nature of this region north and west of the Alpine arc did not create the parallel existence of a seagoing shipbuilding industry which could have itself influenced the design, construction and method of caulking of the purely native craft(26).

The late 19th and early 20th centuries can be seen as an age of widening political and economic horizons. Large-scale commercial activity spread to areas previously isolated, resulting in the spread of foreign techniques and ideas, including ship- and boatbuilding. This spread of foreign influence can be seen in the gradual decline in the use of clamped and battened moss caulking in this period, together with the decline in the very existence of localised boatbuilding techniques in favour of "standardised" hull forms caulked with pitched oakum. Native boatbuilding continued on a very small scale up to the advent of the Second World War, ultimately in terms of repairwork only.
Native lapstrake craft

The use of moss for caulking purposes was not, however, confined to native craft with edge-aligned or carvel construction. Evidence for the use of moss as a luting material in lapstrake hull construction has been found in the southern Baltic regions of Germany, Poland and the U.S.S.R., and also in England and Wales. The vessel found near Stettin, Poland (Rudolph, 1983: Pers Comm) and that from New Fresh Wharf, London (Marsden, 1982: Pers Comm), both dated to the 8th or 9th century, represent the earliest known examples of moss-luted lapstrake construction, although it is extremely unlikely that these two vessels are in any way connected in terms of boat-building skills and techniques.

The technique of moss luting appears to have been practiced widely in the southern Baltic States, evidence for which can be seen in the number of boat finds demonstrating moss luting in this area from the 9th century onwards (Rudolph, 1982, 1983: Pers Comms)(27). It would thus appear that moss was the preferred material for stopping up the seams of all types of southern Baltic native craft, despite the adoption of the technique of pitched-oakum caulking for the larger merchant vessels of the Baltic. Large supplies of moss would have been locally available to the boatbuilders, and the use of this material for both edge-aligned and lapstrake hull-caulking purposes is perhaps indicative of an interplay of ideas between local builders, rather than the strict maintenance of two separate building techniques. The lack of evidence for the use of animal hair, wool or oakum luting in the southern Baltic States would suggest that this interplay of ideas extended no further: the existence of well-established boatbuilding techniques using readily available, local materials would not create a necessity to look for
alternative materials and methods.

Evidence for moss luting has been discovered in two vessels possibly dated to the 16th century from Pwll Fanog and Llyn Peris, North Wales. The keel scarph of the Pwll Fanog vessel was found to have been luted with moss (*Sphagnum*, species), although the rapid discoloration of the moss following excavation does not exclude the possibility that this material was inserted shortly before the sinking of the vessel, thus representing fresh caulking rather than original luting material (Roberts, 1982: Pers Comm). The Llyn Peris Boat, a vessel roughly constructed with numerous short planks of varying widths requiring extensive infilling was, however, luted with a mixture of clay and twisted moss strands. Luting coves were found on at least a few of the planks, and it is conjectured that more clay of the same type was either deliberately added to the gaps sometime after construction or accidentally washed into the gaps from passengers' feet (Roberts, 1982: Pers Comm). The exterior of the hull below the waterline was coated in yellow tallow as a further precaution against water ingress (Roberts, 1980: 344), and a patch on the bottom of the Llyn Peris Boat had been made watertight by a wad of moss (*Sphagnum*, species).

The existence of moss-luted, lapstrake vessels in areas apparently confined to the southern Baltic and North Wales is perhaps problematical, in terms of the somewhat unusual distribution pattern of this luting technique throughout Northern and Central Europe. The lack of evidence for moss luting in other regions and the substantial distance between the two areas would immediately suggest that the similar techniques developed independently as a result of local influence such as availability of material. The absence of evidence for moss-luted lapstrake craft in other regions of Northern and Central Europe, however, is not conclusive, particularly when the meagre
amount of archaeological evidence for boat remains is taken into account. The dominance of animal hair or wool luting in Scandinavia, on the other hand, would infer that moss luting was almost certainly not undertaken: out of eight examples of moss caulking or luting found within Scandinavia, evidence points to an eastern, non-Scandinavian origin for at least seven (Cederlund, 1978: 78).

The 17th or 18th century sewn and battened lapstrake vessel "4" found at Skeppargaten, Stockholm, Sweden, was caulked with moss (*Sphagnum magellanicum* and *Sphagnum angustifolium*, species), analyses of which would indicate a probable middle Baltic origin, which is further indicated by the heavy construction and clamped, battened seams foreign to Scandinavian ship types (Cederlund, 1978: 79).

Whilst following the middle Baltic technique of moss-luted lapstrake construction, the Skeppargaten 4 vessel incorporated the edge-aligned technique of clamped, battened seam construction, in a manner remarkably similar to that found in the 14th century Bremen Cog (Lahn, 1981: Pers Comm) (figure 38, see also figure 5[p. 14]). The presence of clamped battens would suggest that this vessel was caulked after, rather than luted during planking up, and the sewn construction of the vessel itself reflects an ancient technique known to have been practiced in northwestern Russia and the Baltic States. The Skeppargaten 4 ship find could thus be said to represent the survival, into the late 17th century at least, of ancient building and caulking techniques as yet little defined or understood, clearly of non-Scandinavian, middle Baltic origin, and apparently incorporating aspects of carvel and cog caulking techniques within a sewn lapstrake hull design.

The avoidance of the use of oakum or flax/hemp waste as a luting material in lapstrake construction appears to be universal throughout Northern and Central Europe: no single
example of its use has been found, even in regions in which native lapstrake craft have been built along side carvel-built seagoing vessels caulked with pitched oakum. The reasons for this avoidance are uncertain, although the fibrous structure of the oakum may be less effective as a stopper in overlapped planked seams than the less-fibrous moss, wool or animal hair, all of which would mat down more successfully between the planks. Furthermore, it should not be forgotten that oakum or flax/hemp waste is more prone to decay and degradation through water contact, and thus would not be particularly suitable for luting purposes. Edge-aligned vessels can be recaulked as necessary without undue difficulty. Not so with the lapstrake hull luted during, rather than after, construction, which would require major rebuilding to rectify leakage through rotten caulking. The author would, therefore, contend that the establishment of a satisfactory luting technique involving the use of easily-available local materials, be they moss, animal hair or wool, would have occurred early in the various native boatbuilding industries throughout Northern and Central Europe, and that native boatbuilders would have had no necessity or even desire to change or adapt such techniques, once well-established, in favour of novel materials and methods used by foreign boatbuilders.

The universal decline of native boatbuilding techniques for coastal, estuarine and riverine craft through expanding commercial activity resulted in a rapid decline in the use of moss luting in lapstrake hull construction during the late 17th and early 18th centuries, parallel to the slower decline in the construction of clamped and battened moss-caulked carvel craft. No evidence for the use of moss luting is currently available later than the mid 18th century\(^{(28)}\), although there could have been some persistence beyond this date, particularly in more isolated
Figure 38. Caulking technique of the Skeppargaten 4 Ship.

Specialised craft of the late 18th century onwards

The expansion and development of large-scale commercial maritime enterprise in the 18th century onwards in coastal and inland waterways was to create a demand for more specialised craft designed to fulfill specific functions. This period can be seen as one of radical change in terms of small ship and boat design, in which were to appear new and very specialised caulking techniques.

The flat-bottomed barges of the River Thames and Medway of England are an excellent example of interplay between development in caulking technique and hull form. Sailing vessels capable of carrying heavy cargoes in both coastal and riverine conditions had to be able to settle on uneven foreshores to load and unload various cargoes where necessary without the risk of damage to the hull. Hull
timbers consequently had to be able to move or work to such an alarming extent during these activities that conventional pitched-oakum or moss caulking would have quickly fallen out of the seams (Sattin, 1982: Pers Comm). Specialised building techniques had to be devised to allow for such movement and twisting within the hull, resulting in the development and use of a singular caulking technique known as "set-work" (March, 1970: 58).

The spritsail barges were built in numerous yards throughout southern and southeastern England(29) and were either constructed with a single layer of oak or double layer of pine or larch planking, often at the option of the intending purchaser. Seams were invariably filled with tar and hair "set-work", regardless of the number of layers of planking, although each yard is known to have had its own method of building (Sattin, 1982: Pers Comm). The seam between the outwale and the covering board (figure 39) was exceptional, however, in that this was the only seam to be caulked in the standard method using pitched oakum: less strain would have been put on this joint, and the degree of flexibility required for the sides and bottom of the hull would not have been required.

Figure 40 demonstrates the methods of construction of the barge hulls, which were flat-bottomed with sharp chine and heavy oak wales. Planks had rabatted joints cut along their length, although only the outer layer of a double-planked pine or larch hull was usually rabotted, the inner plank being edge-aligned (Sattin, 1982: Pers Comm). A mixture of hair and tar, the last commonly known as "hot-stuff", was laid along the seams and joints during construction, resulting in a very flexible joint. The "set-work" therefore should perhaps more correctly be described as a specialised form of luting rather than caulking, undertaken as it was during rather than after the planking
process. The hair used for the "set-work" was usually elk hair, but the unavailability of this type of hair in the early 20th century led to the use of cow hair in its place, which itself was finally superceded by the use of felt. If double planking was used, the joints and all the inner surfaces of the outside layer of planks would have felt and "hot-stuff" applied before their attachment to the inner planking.

Figure 39. Spritsail Barge "set-work": location of seam caulked with oakum.

The combined use of this type of rabbeded seam construction and singular luting technique resulted in a hull form that was sufficiently flexible to enable a vessel to be set aground in almost any berth, and to suffer the resultant stresses without harm.

The lack of sufficient flexibility in pitched-oakum caulking and edge-aligned hull construction is beyond doubt. The single-planked barge Goldfinch, which sprang a leak during a voyage from Kings Lynn, England to Scheldt, Holland
in 1912, was found to have been previously repaired by caulkers in Hull, England, who were ignorant of the appropriate method of hair and tar "set-work" following the holing of the hull in a bad berth. The oakum caulking inserted during this repair work had finally worked out and the vessel ultimately was required to be repaired once more and double-bottomed on her return to Whitstable, England (March, 1970: 59).

Figure 40. Spritsail Barge "set-work": methods of construction.
A, Single planked; B, Double planked.

The widening of maritime enterprise and accompanying rise in interest in purely social maritime activity brought about the development of an increasingly wide range of small wooden-planked pleasure craft for use on both inland and coastal waters. Interest was originally confined to the more affluent sector of society able to afford such luxuries, with the result that the boats or yachts required a high standard of construction and finish hitherto unseen
in vessels of this size in order to reflect the high social status of their owners.

The standard practice of pitched-oakum caulking would have been unsuitable and perhaps inappropriate in the construction of these high quality, lightly-timbered vessels. The use of waste cotton yarns applied in a technique very similar to that of pitched-oakum caulking found rapid acceptance and became used extensively for the caulking of this type of craft (Kemp, 1976: 796).

The development of the technique of caulking the seams of yachts and similar craft with cotton created a demand for spun cotton yarns of various thicknesses. A source for this new material was soon found in the waste short fibres extracted from the imported raw cotton prior to spinning, which fibres in turn were spun into poor quality yarns unsuitable for the cloth or woollen trade and supplied to boat yards for caulking purposes (Kershaw, 1982: Pers Comm).

Cotton yarn caulking also had to be protected from water contact to prevent rotting in much the same manner as oakum, but the emphasis placed on visual quality of the finished vessel created the necessity for greater care to be taken on paying the seams with hot pitch.

Planked yachts with pitched-cotton caulking continued to be constructed until the mid 1940's. The experimentation into, and general introduction of, water-resistant marine plywoods for boatbuilding purposes during the Second World War brought about a totally new concept in the design of dinghies and small pleasure craft of up to twelve metres or thereby (Kemp, 1976: 797), requiring new caulking techniques in the form of synthetic resins.

The end of the 18th century saw the appearance of the first lifeboats, designed purely for the purpose of saving the lives of shipwrecked mariners. The vessels used for
this purpose had to be, by necessity, extremely stable, buoyant, fast, and robust in construction, to carry out successful rescues in the worst conditions. Experimentation in an attempt to design the ideal lifeboat resulted in the development of highly-specialised craft with hulls similar to those used in high-speed racing boats. High-speed craft had already been developed with double-skinned hulls, with planking laid diagonally rather than along the length of the hull, the outer layer being laid on the opposite diagonal to minimise timber movement and water penetration as a result of the severe stresses brought about by high speed movement through rough water. The design of the life boats differed from that of the high-speed boats in one major aspect: whereas the high-speed craft would perhaps only have been caulked (with cotton) along the garboard seam (Turner, 1983: Pers Comm), the hulls of the life boats were caulked in a technique peculiar to these craft. The inner skin of the hull was fitted using a "pitch and shutter" method, in other words alternate boards fastened blind onto the frames with the remaining boards spiled to give a very close fit, no caulking being inserted at this stage (Hatch, 1982: Pers Comm). The timbers, wales and stringers were then caulked with cotton and a layer of white lead and calico laid over the outer surface of the planking. The outer skin of planking would then have been fastened in similar fashion along the opposing diagonal to that of the inner skin. Seams of the outer skin were then reamed and caulked with three strands of "normal weight" boat-caulking cotton. Interestingly, the inner skin of planking was then caulked with cotton from the inside, apparently defeating the original objective of creating a tightly-fitted, virtually seamless inner skin. That this method of caulking was effective is beyond question, since most lifeboats remained trouble-free after at least twenty five years of service (Hatch, 1982: Pers Comm).
Lifeboats began to be caulked with synthetic resins following their development in the 1930's and 1940's, and were ultimately constructed of glass-reinforced plastic (G.R.P.), requiring caulking only in the seams of their wooden decks.

The advent of the Second World War brought about many changes in ship and boat construction, and thus in caulking techniques. World-wide war conditions resulted in the necessity to be able to construct vessels in as short a time period as possible. The war years marked the appearance of synthetic resin compounds originally developed in the U.S.A. (Boatlife (UK) Limited Brochure, no date) for marine use, as well as the appearance of water-resistant marine plywood, which in turn led to the appearance of a whole new construction technique, particularly for smaller vessels.

The established techniques of wooden-planked hull construction were not completely swept aside in the new developments in ship and boat design: pitched-oakum caulking did continue on a smaller scale, particularly in the construction of wooden-hulled fishing vessels, a hull form which is unlikely ever to vanish completely.
SUMMARY AND CONCLUSIONS

It can clearly be seen that the caulking of early water craft can be divided into two parallel techniques, the moss caulking of most of Central and Western Europe and the animal hair/wool and pitch luting of Scandinavia.

The earliest boats of Western and Central Europe, caulked with mosses of various species, reveal a technique which was to survive in small native watercraft at least until the late 19th century in many areas of Central Europe. Mosses of numerous species would have been easily found in suitable quantities within reach of the boat-building communities, its compressible nature and resistance to rot making it well suited for caulking the seams of boats. The design and construction of the craft themselves was partly dependent upon this use of moss caulking since the nature of the material and method of application was such that the caulked seams had to be covered by wooden battens held securely in place by stitching, small bent iron nails, metal staples or clamps, resulting in a rigid construction. The type of moss used in the caulking process did not seem to matter. Evidence reveals the use of numerous species of mosses, both of the shorter and longer fibred varieties, for caulking purposes throughout Central and Western Europe.

The Scandinavian technique of lapstrake hull construction required a vastly different approach to the problem of prevention of water ingress. Additional material had to be placed within the seams of lapstrake hulls during rather than after construction, in contrast to the post-assembly caulking of carvel hulls. Different methods require different materials, the Scandinavian luting technique ideally called for a coherent string of material capable of sticking to the one plank while the other was laid in position above, whereas carvel caulking techniques
simply required material to be compressed between two planks already located. It can therefore be seen that the use of two distinct types of caulking materials is far from surprising, although the appearance of lapstrake hulls caulked with moss could perhaps be said to dispute this view. Evidence for moss-luted lapstrake hulls, however, falls almost exclusively outside the area of direct Scandinavian influence\(^{30}\), and well within the moss-caulked schools of boat construction, perhaps suggesting these craft were constructed by boatbuilders who used moss for caulking as a matter of course, to whom the thought of using alternative materials would not have occurred simply because the boats under construction were of a different design.

The demand for large seagoing vessels brought about by the rapid expansion of international commercial maritime enterprise from the Medieval period onwards was itself an important factor in the development of caulking techniques. Supplies of the locally-available mosses normally used for caulking purposes must have proved totally inadequate in terms of the huge quantities involved in the caulking of these larger craft: suitable alternative materials capable of fulfilling the same functions were to be found in the waste products of the hemp and flax industries widespread throughout Europe, the use of which being documented in dockyard records of the early 15th century onwards. The recorded use of oakum in conjunction with moss and pitch clearly indicates that this material was initially introduced to augment supplies of moss, and it can be presumed that the success of this material led to its general adoption as a caulking material in the construction of large seagoing vessels.

The use of pitched oakum for caulking purposes saw a rapid development in method of application, accompanied by
equally rapid development in ship construction techniques. The deliberate bevelling of plank edges for caulking purposes before construction resulted in the obsolescence of the age-old seam batten technique, which in turn allowed the degree of flexibility required in wooden hulls of large dimensions.

The development of pitched-oakum caulking paralleled the continued existence of both moss caulking and animal hair/wool and pitch luting in small native craft, but was eventually to supersede these ancient caulking techniques in the late 19th and early 20th centuries. Pitched-oakum caulking was itself to suffer a major decline in favour of modern synthetic compounds following the Second World War.

As assessment of the available evidence for caulking techniques in ships and boats in Northern and Central Europe indicates that the possibility of regional similarities in materials and techniques is not wholly conclusive, with the possible exception of lapstrake luting. It has been demonstrated that lapstrake luting appears to fall into two main areas, the animal hair/wool and pitch luting tradition of Scandinavia, Great Britain and parts of the southern Baltic, and the moss luting technique of the southern Baltic and Wales, although even this is not particularly demonstrative since there is considerable overlap in materials and a marked lack of any caulking evidence from many areas. Pitched-oakum caulking can also be excepted since this later method became universal, particularly in seagoing craft.

The practice of caulking seams with moss covered with clamped wooden battens is found throughout Western and Central Europe, but not Scandinavia (with the exception of the Skeppargaten 4 Ship, which is itself probably of middle Baltic origin [Cederlund, 1978: 79]), a technique which, it can be argued, developed out of necessity (to secure the
moss in position) rather than as a result of inter-cultural transmission of ideas.

The widespread distribution of the technique of clamped, battened moss caulking should be regarded as a widespread adoption of the most satisfactory method of application of a material found extensively throughout Central and Northern Europe, a material not restricted by problems of cultivation or politics of any kind. The author considers the extensive use of moss for caulking purposes to be nothing more than localised use of easily-available materials for which there could only be a limited number of suitable methods of application. It is therefore not very surprising that a more or less identical technique was generally adopted throughout the distribution area. The author does not consider the widespread adoption of moss caulking to be indicative of external influences.

Divergence in caulking materials and techniques came about as a result of divergences in size, function and design of vessels with the expansion of international commercial maritime interest. It could be argued that the introduction and general adoption of oakum as a caulking material came about solely as a result of excessive demand, and the disuse of those wooden battens previously essential to the moss caulking process created the opportunity for large hulls to be designed with that degree of flexibility essential to withstand those stresses unencountered by smaller vessels in more sheltered waters.

"Tradition: that which is handed down; a statement, belief or practice transmitted (especially orally) from generation to generation" (O.E.D.,1933). To what extent can this problematical word be applied as a factor in the development of caulking techniques in Northern and Central Europe?

The author has deliberately avoided the use of the
word "tradition" throughout this study because of the vagueness and implications of the term. To offer explanations simply in terms of "tradition" would be too easy, merely assuming that a particular caulking technique was carried out in a particular area because it had been for generations, and for no other reason.

The term "tradition" can not be offered as a satisfactory explanation for the distribution and development of caulking techniques in Northern and Central Europe, which could perhaps be explained as coincidental adoption and use of similar materials, although it must be admitted that "tradition" would have played a considerable role in the continuity of caulking techniques, creating a tendency towards a lack of advancement of technique as a result of a lack of desire for innovation, whether through necessity or otherwise.

"Tradition" did little to save the ancient methods of caulking. Both moss caulking and animal hair/wool and pitch luting were obsolete by the early 20th century, preserved only in museums and memories; the introduction and widespread adoption of steel-hulled ships in the mid 19th century and the experimentation in and development of synthetic caulking compounds for use in wooden ships during the Second World War led to the collapse of the oakum industry and a major decline in pitched-oakum caulking in wooden ships and boats throughout Northern and Central Europe and beyond.

Whilst it can be argued that the "traditionalists", those followers of "tradition", could have played a part in slowing the development of caulking techniques through a lack of desire to try something completely new, it can, on the other hand, also be argued that they could prevent the total extinction of the old method of pitched-oakum caulking through the preservation of the old techniques of
ship and boat construction. A prime example of this phenomenon can be seen in the parallel construction of wooden-hulled and steel-hulled fishing boats for use in the same waters for the same purpose.

Tables 2 and 3 represent the stages in the development and decline in the caulking techniques of the two major categories of ship and boat construction as described in the text, namely seagoing craft and non-seagoing craft. As such they should be regarded as independent summaries of the development of caulking techniques in Northern and Central European ships and boats between 1500 B.C. and A.D. 1940.
Table 2. Flow diagram showing development of caulking techniques in seagoing craft

SEAGOING CRAFT

Development of larger vessels capable of crossing large tracts of open water

Development of oceangoing craft

Development of construction techniques: 16th and 17th centuries

Ground rules, including caulking, adopted by navies in naval shipyards

Further European assimilation: general standardisation following superior methods

Driven oakum becomes standard practice

Continuation of tradition in smaller wooden vessels

Persistance of driven oakum in planked vessels

Development of steel-hulled vessels requiring different caulking techniques: later no caulking required at all

Decline in old method

Development of synthetic caulking compounds

Maintenance of tradition: wooden-planked fishing boats

Development of marine plywood

Development of glass-reinforced plastic hulls

caulking for wooden decks only
Table 3. Flow diagram showing development of caulking techniques in non-seagoing craft

NON-SEAGOING CRAFT

Localised development due to geographical restraints

Persistance of old caulking methods

Political restraints

Unavailability of alternative material

Tradition

Unwillingness to change

Lack of outside knowledge

Lessening political restraint

Increase in commercial maritime trading

Introduction of outside skills

Widening of local horizons

Decline in old methods

Repairwork only

? Museums only?
NOTES

(1) McGrail (1978: 148, 167) notes the following Bronze Age dugouts in England with evidence for moss caulking:

i. Dugout remains from Appleby, Lincolnshire, dated to about 1100 B.C., in which repair work appears to have been caulked with moss and sealed with a batten and sewn.

ii. Dugout found at Brigg, Yorkshire, dated to about 800 B.C., which was reputed to have been caulked with a total of twenty three species of mosses and liverworts (Heptera, species). This was evident around the stern transom and in subsequent repair work. The dugout is no longer in existence and evidence cannot be verified.

(2) The dugouts in question are the Vingelz II Boat (discovered in 1874, dated by ceramics) and Twann Boat (discovered in 1976; B-2750: 1300 ± B.C.). These dugouts illustrate an early solution to the problem of sealing two joined boards in the development from a dugout to a plank boat, relying entirely upon the expansion of the wood when wet to seal the seams (Arnold, 1977: 293).

(3) The translation of the word "βρύοις" as "seaweed" (Casson, 1971: 209 n. 38) is both misleading and incorrect.

(4) The hazel twigs from the caulked seams of the Blackfriars I Ship were found to be wedged cross-wise in each seam. In the outer half of each seam they tended to be crushed, but were otherwise intact, whereas in the inner half they were broken and matted together. No pitch or any other substance was mixed with the caulking. This difference in the condition
of the ends of the twigs on the outside and inside of each seam indicated the method probably used to insert the caulking. It seems likely that a flat surface was held over the opening of the seam inside the ship, while hazel twigs were hammered into the seam from outside. As a result of being knocked against the flat surface they would tend to break, crumple and mat together inside the seam. The flat surface would then have been removed, leaving the seams tightly filled with crushed and broken twigs.

It is interesting to note that a wooden mallet was found within the hull, which may have been used in the caulking process.

Unfortunately no evidence for caulking was found in the similar boat find from Bruges, Belgium, but the New Guys House vessel was identical to that of the Blackfriars I Ship (Marsden, 1966: 14-15).

(5) Moss-caulked vessels in Great Britain to date comprise the following:

North Ferriby Boats 1, 2 & 3 (battened)  1500 B.C.
Appleby Dugout (battened repair)  1100 B.C.
Brigg Dugout  800 B.C.
New Fresh Wharf Boat (lapstrake)  8th/9th century
Welsh Slate Boats (lapstrake)  16th century
River Rother Boat (lapstrake)  16th century

(6) Vessels luted with animal hair/wool and pitch to date comprise the following:

Valderøy Boat (Norway)  Early Bronze Age
Fjørtoft Boat (Norway)  Bronze Age
Nydam Boat (Denmark)  A.D. 350
Sutton Hoo Boat (England)  A.D. 625
Gokstadt Ship & Faering (Norway)  A.D. 850
Graveney Boat (England)  10th century
There is, however, a degree of ambiguity in the meaning of the term. Whilst the word "sie" refers to tar-soaked cloth for caulking purposes in the Orkney and Shetland dialects, Sandahl (1951: 177) comments that "the word survives in modern Icelandic as si, sy 'oakum' and in Norwegian as si 'oakum, 'cow's hair' etc." It cannot, therefore, be taken for granted that the writers of the medieval English dockyard records had tar-soaked cloth in mind whenever they listed "sie" or "sy".

Medieval moss-luted vessels found in the Southern Baltic States to date comprise the following:

- Stettin Boat 8th century
- Danzig-Ohra Boat 10th century
- Mechlinken Boat 11th century
- Charbrow Boat 11th/12th century

Most notable would have been the establishment of the great Hanseatic League of merchants in northern Germany in the 13th century.

Identical clamps were also found in the Cudrefin Barge and the boats from the Saone region of France (See p. 58).

Official records for the construction of Henry V's great ship Gracedieu in Southampton, England in 1416 - 1420, together with her retinue of two balingers Valentine and Falconer and three cok boats indicate that materials supplied to the yard included the following: Moss and Okam, thirteen lasts, ten barrels Pitch, fourteen lasts, eleven barrels Bitumen, seven thousand, six hundred and one quarters, nine pounds
Resin.

While not specifically stating which of these were used to caulk these vessels, it can be assumed that both the moss and okam were destined for this purpose, probably also some of the pitch.

It should be noted, however, that this huge, 1400 ton vessel was unusual, constructed as it was with triple lapstrake planking on the lower hull, and as such would not have been representative of ship construction at that time.

(12) Salisbury (1961: 81-90) suggested that this vessel was possibly the Sovereign, dated to around 1521. An 800 ton ship of this name was constructed in 1496/7, accounts for which indicate the use of oakum caulking. No evidence was found within the accounts to indicate the presence of absence of wooden ribbands (Oppenheim, 1896: 175-8).

(13) Whilst it is understood that some analyses of the caulking and weather-proofing materials found on the Mary Rose have been carried out, the author was unable to obtain official confirmation on the types of materials found from the Director of the Mary Rose Trust, Mrs Margaret Rule. The cattle hair and wood tar mentioned within the text appears to have been found in association with repairwork.

(14) Tsar Peter the Great also engaged the Englishman, John Deane, for the purpose of constructing a naval fleet and advancing Russian naval construction. For further information on John Deane's work in Russia, see his letters to the Earl of Carmarthen, 1699.

(15) The seams of the planks required to be opened to the extent of about one-twentieth of the thickness of the plank, or about one-half inch per ten inches of
plank thickness.

(16) Fincham (1851: 95) details experiments carried out by the British Royal Navy in the early 18th century to counter the shipworm infestation and adhesion of marine growth on ship's hulls, the results of which led to the general adoption for use of a composition of tar, pitch and brimstone originally prepared for the purpose by the Master Caulker of Portsmouth Dockyard in 1737. Falconer's definition (1780: 48) indicates that a similar sulphur-based composition was still in use some fifty years later.

(17) There is clear evidence that the practice of sheathing wooden hulls with lead plates was carried out in the Mediterranean at least from the 5th century B.C. (Katzev, in Bass, 1972: 52) and continued in use through much of the Roman period. The disappearance of lead-sheathed hulls probably came about as a result of a general decline of metallurgy and mining throughout the Roman Empire from the 3rd century onwards (Forbes, in Singer, 1956: 61).

(18) It is interesting to note that the use of tarred paper has not been forgotten: the old fishermen on the Isles of Scilly, England, have been known to repair leaky seams of their boats with brown paper stuck on with tar, coated with a further layer of tar and covered with sheet lead (Jenkins, 1982: Pers Comm), in a manner identical to that used in the 18th century.

(19) No documentation was available to the author concerning the results of Sepping's experiments, although the current practice of impregnating oakum with wood-or mineral-tar would suggest that impregnated (black) oakum did last longer that unimpregnated (white) oakum. Presumably, unpicked rope of high tar content would also have been beneficial over untaared rope
junk.

(20) The following description of the stages in the caulking process and the accompanying figures are based on visits by the author to a modern shipyard in North east Scotland (Messrs. Herd & McKenzie of Buckie, Banffshire) during the construction of a wooden-planked fishing boat. The process of caulking a carvel-built hull has remained unchanged for at least three or four hundred years, and as such, the author feels justified in offering this description, which could not otherwise have been as detailed, based as it would have been upon the scanty historic and archaeological evidence available.

(21) While outside the scope of this study, it is interesting to note that the representation of caulkers at work on a 13th century marble relief carved above the central portal of Saint Mark's Basilica in Venice portrays caulking tools more or less identical to those still in use today (Thubrou, 1980).

(22) The potential risks involved in the practice were sadly revealed when H.M.S. Royal George sank at Spithead, England in 1782 as a result of a parliamentary heel carried out to repair hull damage below the waterline. The angle of heel achieved was such that the sea was able to enter her lower gunports causing the ship to capsize and sink with great loss of life (Kemp, 1976: 632).

(23) Examples in which caulking is carried out with cotton strands rather than the coarser oakum can be seen in the high quality yachts of the late 18th century onwards, multi-skinned lifeboats and other high speed craft involving thin planking and high quality finish.

(24) Moss-caulking repair work survived in the Saône region until as recently as 1981, when the last known work
was carried out at Seurre (Côte d'Or). This repair work was recorded and documented by the Musée Denon (Bonnamour, 1984: Pers Comm).

(25) The overall effect would have created a tight and rigid hull structure which would be less vulnerable to leakage, provided that the vessels were comparatively small in size. Benoît (in Bonnetoi, 1979: 51) considers that a badly-oakumed seam would be more likely to leak than a seam cut in this manner and badly caulked with moss. Such a seam would partly depend upon the close fit of the two planks one upon the other, the effect of which would have been negated in the bevelling of the entire plank edge in the oakum caulking process. The seam would, of course, be protected further by the clamped wooden batten.

(26) The existance of the Genoese-influenced Lake Léman vessels are perhaps an exception to this view.

(27) Evidence for vessels luted with moss from the south Baltic States area to date comprises the following:

Stettin Boat 8th century
Danzig-Ohra Boat 10th century
Lebafelde Boat 11th century
Mechlinken Boat 11th century
Charbrow Boat 11th/12th century

(28) Evidence for the most recent moss-luted vessel can be found in the remains of the lapstrake vessel found at Prora (south Baltic States), which has been dated from coin evidence to +1764 (Rudolph, 1983: Pers Comm).

(29) March (1970: 223) lists the following centres for wooden spritsail barge construction:

River Thames, as far upstream as Reading 38 areas
Medway 18 areas
Sittingbourne, Faversham and Whitstable, Kent 11 areas
Essex 7 areas
Suffolk 2 areas

Occasional construction work has also been recorded at Cowes, Isle of Wight; Portsmouth, Hampshire; Appledore and Ramsgate, Kent; Shoreham, Sussex; Aldeburgh, Suffolk; Ware, Bishop's Stortford and Berkhamsted, Hertfordshire; Topsham, Devon; Guernsey, Channel Islands.

(30) An exception is the Skeppargaten 4 Ship found at Stockholm, although this vessel is itself thought to have non-Scandinavian origins (Cederlund, 1978: 79), which would thus fall outside the area of Scandinavian luting techniques.
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Non-literary references

The nature of this study of caulking techniques and the lack of published documentation has resulted in the inclusion of a considerable number of unpublished references within the text. These have been obtained through correspondence and interview with the persons concerned. There follows a catalogue of these non-literary sources, together with information identifying the person of origin.

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Bijl, M., 1983, Interview, August
M. Bijl has recently retired from the position of Managing Director of the Dutch Oakum Works, Schiedam, Netherlands.
Bonnamour, L., 1984, Letter, 6th April
L. Bonnamour is the Conservator at the Musée Denon at Chalon sur Saône, France, and is involved in the study of native Saône river craft.

Cederlund, C. O., 1982, Letter, 9th March
Cederlund, C. O., 1983, Letter, 19th October
C. O. Cederlund is the Head Keeper of the Statens Sjöhistoriska Museum, Stockholm, Sweden.

Hatch, J. H., 1982, Letter, 23rd September
J. H. Hatch is the Course Tutor for Yacht and Boatbuilding at the Isle of Wight College of Arts and Technology.

Hawley, K. W., 1983, Letter 23rd September
K. W. Hawley is a Director of Messrs. K. W. Hawley (Tools) Limited of Sheffield, England.

Hogg, J. C., 1983, Interview, 24th August
J. C. Hogg is a member of the Society of Nautical Research. Based near Southampton, England, his research has covered many aspects of ship and boat construction, including caulking.

Hutchinson, G., 1981, Letter, 28th July
G. Hutchinson is the Medieval Archaeologist at the National Maritime Museum, Greenwich, London.

Jenkins, A., 1982, Letter, 27th May
A. Jenkins is a researcher from the Isles of Scilly, England.

Kershaw, K., 1982, Letter, 4th October
K. Kershaw is the Technical Director of British Twines Limited of Wakefield, England.

Lahn, W., 1981, Letter, 16th October
W. Lahn is on the museum staff at the Stiftund Deutsches Schiffahrtsmuseum in Bremerhaven, and is involved in the study of the Bremen Cog.
Marsden, P., 1982, Letter, 1st February
P. Marsden is the Urban Archaeologist for the Museum of London.

Roberts, O., 1982, Letter, 28th June
O. Roberts is the Director of the Welsh slate boats project and a member of staff of the History Department of the University College of North Wales.

Rudolph, W., 1982, Letter, 25th May
Rudolph, W., 1983, Letter, 23rd October
Based in Berlin, W. Rudolph is an authority on the ship and boat archaeology of the Baltic States.

D. L. Sattin is a shipwright skilled in the art of building spritsail barges, and is also a Trustee of the Dolphin Sailing Barge Museum Trust, based at Sittingbourne, Kent, England.

P. Smolarek is the Director of the Polish Maritime Museum, the Centralne Muzeum Morskie, in Gdansk.

Turner, R. E., 1983, Letter, 9th October
R. E. Turner is the Maintenance Surveyor for the Royal National Lifeboat Institution.

Watson, F. R., 1983, Letter, 14th April
F. R. Watson is the Archivist for Grampian Health Board, Aberdeen, Scotland.

Williamson, A., 1981, Letter, 29th June
A. Williamson is the Curator of the Shetland Museum, in Lerwick, Shetland Islands.
APPENDIX I

CULTIVATION OF FLAX AND HEMP IN NORTHERN AND CENTRAL EUROPE:
ITS ROLE IN THE DEVELOPMENT OF NEW CAULKING MATERIALS

Flax: The plant Linum usitatissimum, cultivated for its textile fibres and for its linseed oil-bearing seeds, may well have been the first plant used for fibre (Wilson, 1979: 11).

The flax plant is cultivated in the following manner: about a hundred days after planting, flax is pulled up by the roots, gathered into bundles and left in the field to dry. The seeds are removed by threshing or by a process known as "rippling", in which the heads of the plants are drawn through a special comb, after which the flax is stored in bundles in a dry place.

In order to extract the textile fibres from the plant, the flax has to be "retted" to decompose the pectins and gums that hold the bast fibres together and free them from the straw. The process of "retting" has been done in various ways: by spreading the flax on dewy fields over several weeks, by immersing in special ponds or slow-running streams, or, more recently, by using tanks of water under controlled conditions.

The woody stems then have to be pounded or "broken" using a device known as a "brake", and stem particles removed in a process known as "scutching" or "swingling", in which the flax is laid over the edge of an upright board and tapped with a wooden knife.

The broken flax is finally "heckled" ("hackled" or "hatchelled") to separate the "line" or long fibres from the waste short fibres of "tow" or "hards". It is this process of "heckling" or combing the flax with an instrument (a "hackle") set with parallel steel pins which yields the
waste material which was to be used for caulking, the "oakum" or "aecumba", the "off-combings" of flax. The long fibres are then ready to be spun in preparation for their use in the textile industry.

**Hemp:** The plant *Cannabis sativa*, a relative of the common stinging nettle is really a native of India and Persia, but has long been cultivated primarily for rope-working in Europe.

There are, however, a number of other plants often grouped together under the name of hemp (Horsley, 1978: 290), none of which are true hems, but all of which are used in varying degrees in the making of rope. These include sisal, manilla and henequen.

In England, ropemaking was a thriving industry from the Medieval period onwards. The production of marine ropes was concentrated at an early date in those areas where the best hemp could be grown, around Bridport in Dorset and in parts of Somerset (Horsley, 1978: 192), although ropemaking itself was widespread throughout the country. The Royal Navy had its own ropewalks incorporated into the Royal Dockyards.

The hemp was harvested twice a year, in July and in September, since the male (seedless) plants mature in July and the seeded female plants in September. The English crop had a staple of between three and four feet. On harvesting, the hemp was tied in bundles and left to dry for about twenty four hours and then threshed. The bundles of hemp were then "retted" in much the same way as the flax to reduce the fibres and "hackled" to ensure that the fibres were clean, straight and parallel. Any waste short fibres were similarly known as "tow" or "hards" and destined for use in the caulking industry.

The large quantities of waste flax or hemp "tow" or "hards" were an ideal source of material suitable for
caulking purposes, comprising short fibrous matter readily spun and compressed into the seams of vessels, and the persistence in use of this material and of oakum made from old rope junk is itself witness to this.
## APPENDIX II

### CAULKING MATERIALS: THE EVIDENCE

<table>
<thead>
<tr>
<th>DATE</th>
<th>NAME</th>
<th>LOCATION</th>
<th>CAULKING MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>c. 1500 B.C.</td>
<td>Ferriby Boat 1</td>
<td>Yorkshire, England</td>
<td>Moss rope &amp; moss wads <em>(Neckera complanata)</em>; sewn battens</td>
</tr>
<tr>
<td>c. 1500 B.C.</td>
<td>Ferriby Boat 2</td>
<td>Yorkshire, England</td>
<td>Moss rope &amp; moss wads <em>(Neckera complanata)</em>; sewn battens</td>
</tr>
<tr>
<td>c. 1500 B.C.</td>
<td>Ferriby Boat 3</td>
<td>Yorkshire, England</td>
<td>Moss rope &amp; moss wads <em>(Neckera complanata and Polytrictium commune)</em>; sewn battens</td>
</tr>
<tr>
<td>c. 1100 B.C.</td>
<td>Appleby Dugout</td>
<td>Lincolnshire, England</td>
<td>Moss and sewn batten as repair work</td>
</tr>
<tr>
<td>c. 800 B.C.</td>
<td>Brigg Dugout</td>
<td>Yorkshire, England</td>
<td>Reputedly 23 species of moses and liverworts. No longer in existence</td>
</tr>
<tr>
<td>c. 700 B.C.</td>
<td>Brigg &quot;Raft&quot;</td>
<td>Yorkshire, England</td>
<td>Moss</td>
</tr>
<tr>
<td>c. 295 B.C.</td>
<td>Poole Dugout</td>
<td>Dorset, England</td>
<td>Animal Hide</td>
</tr>
<tr>
<td>1st century B.C.</td>
<td>Veneti Boats</td>
<td>Bay of Biscay, France</td>
<td>Moss: literary reference</td>
</tr>
<tr>
<td>1st century A.D.</td>
<td>Zwammerdam Barges</td>
<td>Netherlands</td>
<td>Moss</td>
</tr>
<tr>
<td>1st century A.D.</td>
<td>Pommeroeul Boat</td>
<td>Belgium</td>
<td>Nailed cord</td>
</tr>
<tr>
<td>1st/2nd century</td>
<td>Bevaix Boat</td>
<td>Lake Neuchatel, Switzerland</td>
<td>Moss rope <em>(Gramineae)</em> &amp; moss wads <em>(Neckera crispa)</em>; nailed battens</td>
</tr>
<tr>
<td>DATE</td>
<td>NAME</td>
<td>LOCATION</td>
<td>CAULKING MATERIALS</td>
</tr>
<tr>
<td>-----------</td>
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<td>---------------------------</td>
<td>---------------------------------------------------------</td>
</tr>
<tr>
<td>1st/2nd century</td>
<td>Yverdon Boat</td>
<td>Lake Neuchatel, Switzerland</td>
<td>Moss rope (Gramineae) &amp; moss wads (Neckera crispa); nailed battens</td>
</tr>
<tr>
<td>2nd century</td>
<td>Blackfriars Boat 1</td>
<td>London, England</td>
<td>Hazel twigs (Corylus avellana)</td>
</tr>
<tr>
<td>2nd century</td>
<td>New Guys House Boat</td>
<td>London, England</td>
<td>Hazel twigs (Corylus avellana)</td>
</tr>
<tr>
<td>8th/9th century</td>
<td>Utrecht Boat 1</td>
<td>Utrecht, Netherlands</td>
<td>Moss</td>
</tr>
<tr>
<td>12th century</td>
<td>Utrecht Barge</td>
<td>Utrecht, Netherlands</td>
<td>Moss</td>
</tr>
<tr>
<td>12th century</td>
<td>Utrecht Boat 3</td>
<td>Utrecht, Netherlands</td>
<td>Moss</td>
</tr>
<tr>
<td>1380</td>
<td>Bremen Cog</td>
<td>Bremen, West Germany</td>
<td>Moss; clamped battens</td>
</tr>
<tr>
<td>&quot;Medieval&quot;</td>
<td>Meinerswijk Boat</td>
<td>Netherlands</td>
<td>Moss</td>
</tr>
<tr>
<td>1416 - 1420</td>
<td>Gracedieu</td>
<td>Southampton, England</td>
<td>Moss &amp; okam; pitch</td>
</tr>
<tr>
<td>1416 - 1420</td>
<td>Valentine</td>
<td>Southampton, England</td>
<td>Moss &amp; okam; pitch</td>
</tr>
<tr>
<td>1416 - 1420</td>
<td>Falconer</td>
<td>Southampton, England</td>
<td>Moss &amp; okam; pitch</td>
</tr>
<tr>
<td>1495 - 1497</td>
<td>Sovereign</td>
<td>Portsmouth, England</td>
<td>Oakum, tallow, pitch and rosin for repairwork</td>
</tr>
<tr>
<td>1495 - 1497</td>
<td>Regent</td>
<td>Portsmouth, England</td>
<td>Oakum, tallow, pitch and rosin for repairwork</td>
</tr>
<tr>
<td>1495 - 1497</td>
<td>Sweepstake</td>
<td>Portsmouth, England</td>
<td>Oakum, tallow, pitch and rosin</td>
</tr>
<tr>
<td>1495 - 1497</td>
<td>Mary Fortune</td>
<td>Portsmouth, England</td>
<td>Oakum, tallow, pitch and rosin</td>
</tr>
<tr>
<td>1514</td>
<td>Henry Grace a Dieu</td>
<td>England</td>
<td>Ox hair, lime and rosin</td>
</tr>
<tr>
<td>DATE</td>
<td>NAME</td>
<td>LOCATION</td>
<td>CAULKING MATERIALS</td>
</tr>
<tr>
<td>-------------------</td>
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<td>---------------------------</td>
<td>---------------------------------------------------------</td>
</tr>
<tr>
<td>1545</td>
<td>Mary Rose</td>
<td>Portsmouth, England</td>
<td>Probably cattle hair and wood resin</td>
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<tr>
<td>16th century</td>
<td>Zuiderzee Boats</td>
<td>Zuiderzee, Netherlands</td>
<td>Moss; clamped battens</td>
</tr>
<tr>
<td>16th century</td>
<td>Halwil Boat</td>
<td>Switzerland</td>
<td>String; clamped battens</td>
</tr>
<tr>
<td>1628</td>
<td>Wasa</td>
<td>Stockholm, Sweden</td>
<td>Cow hair</td>
</tr>
<tr>
<td>17th century</td>
<td>Léman Boats</td>
<td>Lake Léman, Switzerland</td>
<td>Spun limetree bark string; nails</td>
</tr>
<tr>
<td>17th century</td>
<td>Large seagoing craft</td>
<td>universal</td>
<td>Pitched oakum</td>
</tr>
<tr>
<td>onwards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1690</td>
<td>H.M.S. Dartmouth</td>
<td>Mull, Scotland</td>
<td>Oakum, tar and resin; layer of hair and tar paid between main planks and fir sheathing</td>
</tr>
<tr>
<td>Late 18th century</td>
<td>Pleasure yachts</td>
<td>universal</td>
<td>Cotton string covered with pitch/marine glue</td>
</tr>
<tr>
<td>onwards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Late 18th century</td>
<td>Life Boats</td>
<td>United Kingdom</td>
<td>Cotton string; layer of white lead and calico paid between planking skins</td>
</tr>
<tr>
<td>onwards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before early</td>
<td>Saône Boats</td>
<td>River Saône, France</td>
<td>Moss; clamped battens</td>
</tr>
<tr>
<td>20th century</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before early</td>
<td>Danube Boats</td>
<td>Upper Danube, Germany</td>
<td>Moss; stapled battens</td>
</tr>
<tr>
<td>20th century</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before early</td>
<td>Senne Boats</td>
<td>Switzerland</td>
<td>Moss; clamped battens</td>
</tr>
<tr>
<td>20th century</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATE</td>
<td>NAME</td>
<td>LOCATION</td>
<td>CAULKING MATERIALS</td>
</tr>
<tr>
<td>--------------</td>
<td>------------------</td>
<td>-----------------------------</td>
<td>------------------------------------------------------------------</td>
</tr>
<tr>
<td>19th century</td>
<td>Cudrefin Barge</td>
<td>Lake Neuchatel, Switzerland</td>
<td>Moss <em>(Phuidium)</em>; clamped oak battens</td>
</tr>
<tr>
<td>Modern - early</td>
<td>Weidling Boats</td>
<td>Switzerland</td>
<td>Reed fibre string <em>(Phragmites)</em>; clamped battens. Repair work with trimmed mace leaves <em>(Typha)</em>; clamped battens</td>
</tr>
<tr>
<td>Modern - later</td>
<td>Weidling Boats</td>
<td>Switzerland</td>
<td>Cotton string; clamped battens</td>
</tr>
</tbody>
</table>
APPENDIX III

LUTING MATERIALS: THE EVIDENCE

<table>
<thead>
<tr>
<th>DATE</th>
<th>NAME</th>
<th>LOCATION</th>
<th>LUTING MATERIALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Bronze Age</td>
<td>Valderøy Boat</td>
<td>Norway</td>
<td>Wool and birch bark oil/ tar/resin</td>
</tr>
<tr>
<td>Bronze Age</td>
<td>Fjørtoft Boat</td>
<td>Norway</td>
<td>Wool and cattle hair</td>
</tr>
<tr>
<td>1st century A.D.</td>
<td>Halsnøy Boat</td>
<td>Norway</td>
<td>Red woven material</td>
</tr>
<tr>
<td>c. 350</td>
<td>Nydam Boat</td>
<td>Denmark</td>
<td>Wool and pitch</td>
</tr>
<tr>
<td>c. 625</td>
<td>Sutton Hoo Ship</td>
<td>East Anglia, England</td>
<td>Animal hair and Stockholm tar</td>
</tr>
<tr>
<td>8th/9th century</td>
<td>New Fresh Wharf Boat</td>
<td>London, England</td>
<td>Moss</td>
</tr>
<tr>
<td>c. 850</td>
<td>Gokstad Ship</td>
<td>Norway</td>
<td>Animal hair and pitch</td>
</tr>
<tr>
<td>c. 850</td>
<td>Gokstad Faering</td>
<td>Norway</td>
<td>Animal hair and pitch</td>
</tr>
<tr>
<td>8th/9th century</td>
<td>Stettin Boat</td>
<td>Stettin, Poland</td>
<td>Moss</td>
</tr>
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<td>9th century</td>
<td>Baumgarth Boat</td>
<td>Baltic States</td>
<td>Animal hair</td>
</tr>
<tr>
<td>10th century</td>
<td>Graveney Boat</td>
<td>England</td>
<td>Wool and tar/pitch</td>
</tr>
<tr>
<td>10th century</td>
<td>Danzig-Ohra Boat</td>
<td>Baltic States</td>
<td>Moss</td>
</tr>
<tr>
<td>10th century</td>
<td>Ralsweik Boat</td>
<td>Baltic States</td>
<td>Animal hair</td>
</tr>
<tr>
<td>10th/11th century</td>
<td>Frauenburg Boat</td>
<td>Baltic States</td>
<td>Animal hair</td>
</tr>
<tr>
<td>c. 1000</td>
<td>Skuldelev Ship 1</td>
<td>Denmark</td>
<td>Animal hair and pitch</td>
</tr>
<tr>
<td>c. 1000</td>
<td>Skuldelev Ship 2</td>
<td>Denmark</td>
<td>Animal hair and pitch</td>
</tr>
<tr>
<td>c. 1000</td>
<td>Skuldelev Ship 5</td>
<td>Denmark</td>
<td>Animal hair and pitch</td>
</tr>
<tr>
<td>Date</td>
<td>Name</td>
<td>Location</td>
<td>Luting Materials</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------</td>
<td>-------------------------</td>
<td>-----------------------------------</td>
</tr>
<tr>
<td>11th century</td>
<td>Mechlinken Boat</td>
<td>Baltic States</td>
<td>Moss</td>
</tr>
<tr>
<td>11th century</td>
<td>Lebafelde Boat</td>
<td>Baltic States</td>
<td>Moss</td>
</tr>
<tr>
<td>11th/12th century</td>
<td>Charbrow</td>
<td>Baltic States</td>
<td>Moss</td>
</tr>
<tr>
<td>13th century</td>
<td>Svollen Boat</td>
<td>Norway</td>
<td>Animal hair and pitch</td>
</tr>
<tr>
<td>13th century</td>
<td>Custom House Boat</td>
<td>London, England</td>
<td>Animal hair</td>
</tr>
<tr>
<td>1294 – 1295</td>
<td>Newcastle Galley</td>
<td>Newcastle, England</td>
<td>&quot;Blare&quot;, &quot;burr&quot;, &quot;wilding&quot;</td>
</tr>
<tr>
<td>1294 – 1295</td>
<td>York Galley</td>
<td>York, England</td>
<td>&quot;Blare&quot;, &quot;sye&quot;</td>
</tr>
<tr>
<td>1380</td>
<td>Vejby Cog</td>
<td>Denmark</td>
<td>Wool and pitch</td>
</tr>
<tr>
<td>14th/15th century</td>
<td>Elbing Boats</td>
<td>Holstein, Germany</td>
<td>Moss, cow hair and pitch</td>
</tr>
<tr>
<td>15th century</td>
<td>Blackfriars Ship 3</td>
<td>London, England</td>
<td>Animal hair</td>
</tr>
<tr>
<td>16th century</td>
<td>Pwll Fanog Boat</td>
<td>Wales</td>
<td>Moss (Sphagnum)</td>
</tr>
<tr>
<td>16th century</td>
<td>Llyn Peris Boat</td>
<td>Wales</td>
<td>Moss (Sphagnum) and clay</td>
</tr>
<tr>
<td>17th century</td>
<td>Blackfriars Ship 2</td>
<td>London, England</td>
<td>Animal hair</td>
</tr>
<tr>
<td>17th century</td>
<td>River Rother Boat</td>
<td>England</td>
<td>Moss and/or hair, paid with pitch</td>
</tr>
<tr>
<td>17th century</td>
<td>&quot;7 finds&quot;</td>
<td>Swedish East coast</td>
<td>Animal hair</td>
</tr>
<tr>
<td>17th/18th century</td>
<td>Skeppargaten 4</td>
<td>Stockholm, Sweden</td>
<td>Moss; clamped battens</td>
</tr>
<tr>
<td>+ 1764</td>
<td>Prora Boat</td>
<td>Baltic States</td>
<td>Moss</td>
</tr>
</tbody>
</table>
VITA

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