# A preliminary assessment of the state of preservation of the wreck of the *Belgica*

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## Introduction

The raising of a wooden shipwreck is a large undertaking, both the practicalities of excavating and lifting, and the requisite long term commitment of funding and personnel to its subsequent conservation, exhibition and curation. In reality, although technically challenging, the actual raising of a wreck takes the shortest time in the whole process. The subsequent conservation can take many years, followed by continual curation. However, as attested by the finds of the *Vasa*[6], *Skuldelev ships*[7] and *Mary Rose*[8], which were discovered and excavated between the 1950s and 1980s, shipwrecks provide an important insight into maritime history both academically and through their public presentation.

Prior to attempting to raise a wreck it is important to carry out a pre-disturbance survey *in situ,* in order to obtain a better understanding of its state of preservation. This is useful both in terms of designing a lifting strategy and in terms of advance planning of the conservation process. For example, the integral strength of the remaining wood determines if it is responsible to raise the wreck as a complete unit, or if it requires disassembly and lifting in separate sections/pieces. Furthermore, knowledge of the state of preservation of the wood can help in construction of holding tanks for impregnation and designing the optimal processes in terms of impregnation materials and drying regimes.

Such a pre-disturbance survey of the state of preservation of the wreck of the *Belgica* was carried out in connection with proposals to raise her. The aims of the assessment were fourfold:

- To get an overall impression of the strength of the wood from the *Belgica*, through *in situ* measurements and on samples of wood taken from the site.
- To assess the presence and on going activity of macro wood boring organisms (molluscs such as *Teredo navalis* (shipworm) and crustaceans, such as *Limnoria tripunctata* (gribble)).
- To analyse the wood to see if inorganic compounds were present, these may affect the subsequent conservation of the wreck should it be raised.
- To test the developed assessment methodology on a large wooden shipwreck lying out at sea and by doing so contributing to conservation issues in maritime archaeology.

## 1 The *Belgica*[9]

The *Belgica* was a Norwegian whaler built in Svelvik in 1884 (fig. 1). She was designed and built by Johan Christian Jakobsen and her dimensions were 36 x 8 x 4 metres. She was built from pine and pitch pine on oak ribs. Her stern and bow being protected by four inch planks of greenheart (*Chlorocardium rodiei*), with the mid ship ice sheathing being made of oak. Her bow and stern were also strengthened above and below the water line with solid iron ribs. The bent shape of the bow below the water line enabled the ship to slide on the ice and to break it with its weight and movements. She was originally three masted and barque rigged weighing 263 tons and fitted with a 35 hp steam engine.

In 1897 she was sold to Adrien de Gerlache from Belgium and sailed to the Antarctic on a purely scientific expedition. Between 1905 and 1909 she made three more arctic expeditions and was thereafter sold back to Norway and used for transporting coal and other goods from and to Spitsbergen. She ended her working days as a fish processing plant in Harstad, Norway and was finally used as an ammunition depot by the British army during the beginning of World War II. She sank in 1940 and presently rests in 20 metres of water 200 metres off the coast in an inlet of Brurvik at the Gangsasen peninsula, which is located about two kilometres from the city of Harstad (fig. 2-4). However, this may not be her final resting place. In 2006 the *Belgica Society*[10] was

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5 Vlaams Instituut voor het Onroerend Erfgoed, Koning Albert II-laan 19 bus 5, 1210 Brussel, marnix.pieters@rwo.vlaanderen.be.
6 Cederlund & Hocker 2006.
7 Crumlin-Pedersen & Olsen 2002.
8 Marsden 2003.
9 Based on Kjaer 2005.
10 www.belgica-genootschap.be, 14.12.2009.


FIG. 1 The *Belgica* lying in the harbour of Ostend, 1905 (photo courtesy Archives of the city of Ostend).
*De* Belgica *in de haven van Oostende in 1905 (foto stadsarchief Oostende).*

FIG. 2 Location map with indication of the wreck-site of the *Belgica*.
*Lokalisatiekaart met aanduiding van de wraksite van de* Belgica.

created in Ostend, with the aim of trying to salvage the wreck, or at least significant parts of it, for display in an exhibition.

In 2007-2008 the Flemish Heritage Institute (VIOE) set up a collaborative project with the Conservation Department of the National Museum of Denmark (Brede) who had previous experience with the assessment of waterlogged archaeological wood in situ underwater. By participating in this joint venture the Flemish Heritage Institute had the opportunity to gain extra expertise in conservation issues related to waterlogged wood which would be very useful for future conservation and research projects such as the study of the remains from the Cog from Doel[11] which started in the spring of 2010.

Besides conservation aspects and related exhibition and outreach potential[12], the wreck of the *Belgica* presents an interesting case-study in (industrial) archaeology. These aspects, resulting from the correlation of the written and other sources with the physical remains of the wreck itself, will be the matter of a future contribution to this journal.

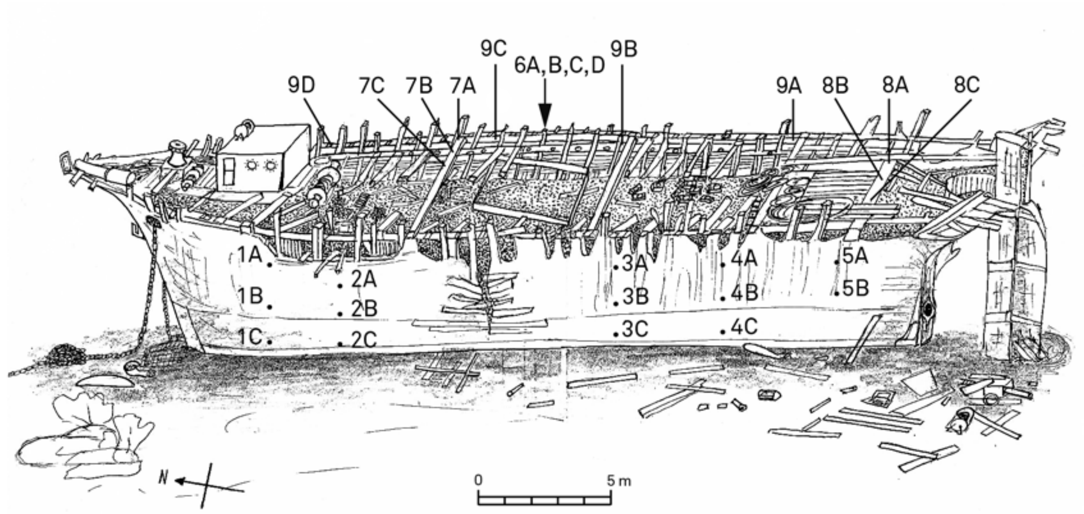



**FIG. 3 Sketch of the *Belgica* as she presently lies on the seabed (Courtesy Drawing: Tomas Termote) with localisation of the samples.**
***Schets van de* Belgica *zoals ze nu op de zeebodem ligt (Tekening Tomas Termote) met aanduiding van de genomen stalen.***

**FIG. 4 The wreck of the *Belgica* lying on the seabed, view on starboard side (Courtesy Tom Leys).**
***Het wrak van de* Belgica *op de zeebodem, zicht op stuurboord (Foto Tom Leys).***

11 Terfve 2001; Van Hove 2005.

12 Pieters *et al.* 2008.

## 2 Deterioration of wood in the marine environment

When wood is exposed to seawater, it is gradually colonised by many different macro- and micro-biological organisms[13]. Some of these organisms use the wood simply as a substrate to colonise and others are active degraders of the wood. By far the most damaging of these degraders are the wood boring mollusca and crustacea, such as shipworm (fig. 5) and gribble (fig. 6)[14]. Given the right conditions, these can both attack wood and can cause destruction and loss of archaeological information in a relatively short period of time; within months or years rather than centuries. Furthermore, fungi and bacteria (micro organisms) cause degradation of the wood, albeit it at a much slower rate, but their activity can drastically reduce the inherent strength of wood, even though from the surface it may appear well preserved[15]. This is because wood is effectively a complex mixture of various sugars (cellulose) and lignin which serve as a rich source of nutrients for these micro organisms. In the marine environment, bacteria and fungi degrade the sugars in the wood cells and water replaces them (fig. 7). The wood becomes 'waterlogged' and, to all intents and purposes, retains its

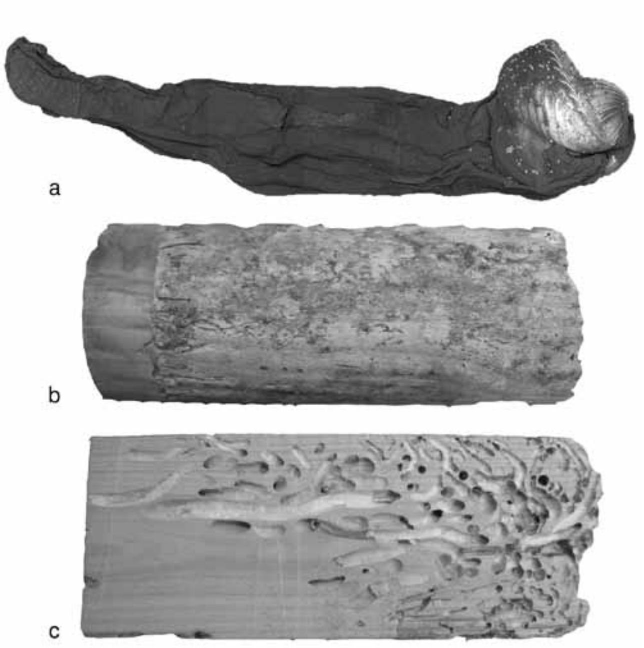



**FIG. 5 Shipworm (*Teredo spp.*) and its effects on wood. a) Shipworm ca. 3 months old (2.5 cm long). The two calcareous valves, which bore into the wood, are to the right, b) Outside of a piece of fresh pine submerged in seawater showing how difficult it can be to see the evidence of shipworm attack, c) Inside of wood section showing calcium carbonate lined tunnels created by shipworm.**
***Paalworm (Teredo spp.) en de effecten ervan op hout. a) paalworm van ongeveer 3 maand oud (2,5 cm lang). De twee kalkhoudende kleppen die in het hout boorden, zijn rechts zichtbaar, b) buitenkant van een vers stuk naaldhout ondergedompeld in zeewater dat toont hoe moeilijk het kan zijn om aantasting door paalworm vast te stellen, c) binnenkant van een stuk hout met door paalworm gemaakte gangen die gecoat zijn met kalk.***

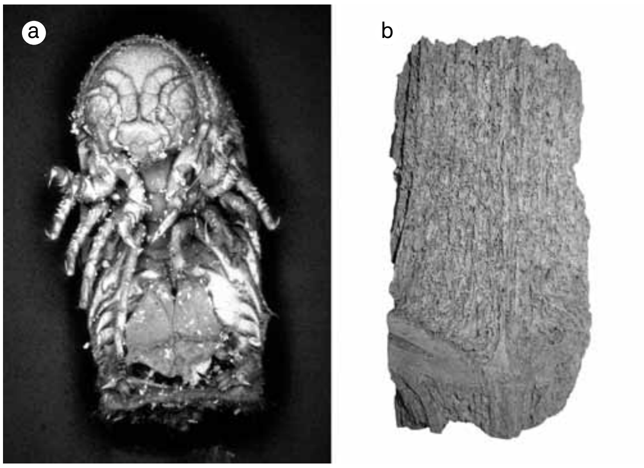



**FIG. 6 Gribble (*Limnoria spp.*) and its effect on wood. a) Adult gribble, less than a grain of rice in size, b) Section of modern pine wood attacked by gribble. Unlike the shipworm the gribble create tiny galleries on the surface of the wood.**
***Paalpissebed (Limnoria spp.) en de effecten ervan op hout. a) volwassen paalpissebed, kleiner dan een rijstkorrel, b) doorsnede door een stuk vers naaldhout aangevreten door de paalpissebed. In tegenstelling tot de paalworm maakt de paalpissebed gangen aan de oppervlakte van het hout.***

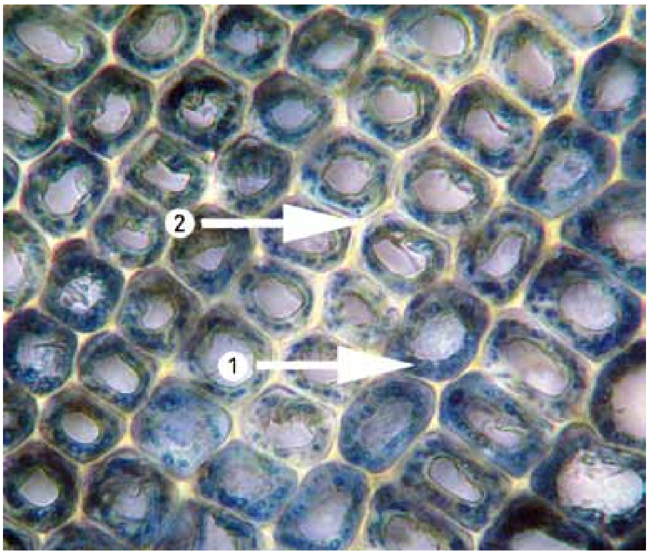



**FIG. 7 Cross section of section of modern pine wood which has been degraded by *soft rot fungi* in seawater. Arrow 1 shows the cellulose rich secondary wall, with characteristic holes formed by the hyphae of these fungi. Arrow 2 indicates the well preserved compound middle lamella of the wood cell wall, which these fungi cannot fortunately totally degrade.**
***Doorsnede door een stuk modern naaldhout dat is aangetast door schimmels in zeewater. Pijl 1 duidt de celluloserijke secundaire celwand aan met de kenmerkende gaten gemaakt door de hyfen van deze schimmels. Pijl 2 duidt de goed bewaarde samengestelde, middelste lamel van de houtcelwand aan. Deze schimmels kunnen dit soort lamellen gelukkig niet volledig aantasten.***

13 Cundell & Mitchell 1977; Floodgate 1971; Gareth Jones *et al.* 1976; Zabel & Morell 1992.

14 Eaton & Hale 1993.

15 Blanchette *et al.* 1990.

shape and surface details. This is fortunate for archaeologists and conservators yet, if the wood is allowed to dry uncontrollably, it can both shrink and collapse – hence the need for conservation[16].

The net effect of deterioration is that the structure of the wood is weakened as wood cell wall material is degraded and replaced by water. The overall strength of the wood can be estimated by assessing the density of the remaining wood – the more degraded the wood the lower the density. Density is a good parameter as it serves as a proxy indicator for many of the structural properties of the wood, such as compression, tensile and bending strength and its modulus of rupture[17]. In these investigations determination of density was the main parameter used for assessing the wood, as will be discussed.

## 3 The fieldwork

In order to obtain the necessary field data for the assessment of the state of the preservation of the *Belgica* two successive field campaigns were organised in the first half of 2008. The aim of the first campaign was to make a comprehensive photographic record of the wreck. This was carried out in February to ensure maximum underwater visibility due to limited algae in the water during winter months. In order to facilitate this documentation, a large fishing net that had been colonised with seaweed and was covering the central and lower parts of the wreck, was removed. A photomosaic of the wreck was taken (fig. 8) with overlapping pictures for the mosaic being taken along the longitudinal axis of the wreck, more or less at the same level above the wreck. This photomosaic allowed for the first time a visual overview of the entire wreck and was subsequently used to locate the samples taken for assessing the structural strength of the wood. The mosaic will also be used for the further archaeological analysis of the wreck. During this campaign, details as well as overviews, such as fig. 4, showing the starboard side of the wreck were also taken.

The objective of the second fieldtrip of 2008 was extensive sampling of the wood from the wreck[18]. The field campaign started with the placing of tags to mark where samples would be taken and *in situ* measurements made.

Some of the diving of these field campaigns was done from the beach; as the wreck only lies 200 meters off shore. However, in most cases a boat was available for the fieldwork, which made the fieldwork much more efficient.

## 4 Methods

### 4.1 Sampling strategy

Density was determined at the locations shown in figures 3 and 8 by two methods; in the laboratory using small samples of wood taken using an increment corer, or non-destructively *in situ* using a Pilodyn wood tester. The selection of these locations was based on knowledge of the wreck from previous diving expeditions and advice from a naval architect from the Viking Ship Museum in Roskilde, (Morten Gøthche pers. com.), and could point out where typical 'weak' points may be, in connection with the possibility of raising the wreck. The areas were selected in order to give as much information as possible about the structural strength of the ship within the time limits of the fieldwork.

From earlier dives on the site[19], the port side was considered to be the most poorly preserved and 15 locations were assessed. A further 3 areas on the starboard side and 10 areas on beams and other structural parts inside the wreck were also selected giving a total of 28 areas. Sampling areas were labelled with colour-coded labels denoting port, starboard and structural timbers – it was important that the same areas for *in situ* measurements and wood core sampling were used in order to compare and contrast the results.

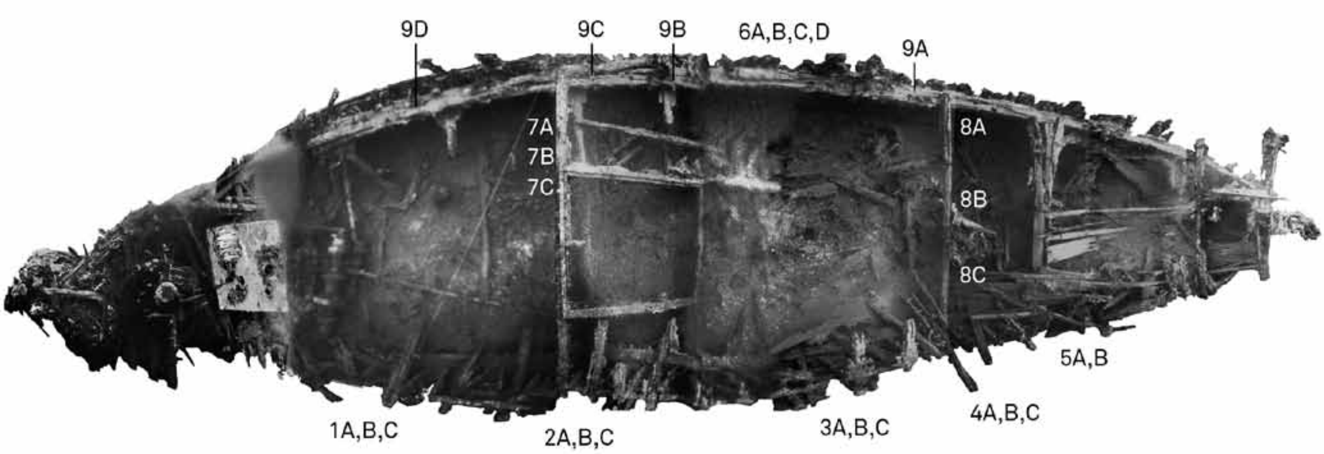



**FIG. 8 Locations where density samples and Pilodyn measurements were taken indicated on the photomosaic (Courtesy photo Nicolas Mouchart).**
***Aanduiding op de samengestelde overzichtsfoto van de plaatsen op het wrak waar de stalen voor het bepalen van de dichtheid zijn genomen en waar de Pilodyn-metingen zijn uitgevoerd (foto Nicolas Mouchart).***

16 Grattan 1987.
17 Jensen *et al.* 2005; Jensen & Gregory 2006.
18 Gregory *et al.* 2008.
19 Termote & Cattrijsse 2006.

## 4.2 Core sampling

Samples were taken using an increment borer (fig. 9), which yielded samples ca. 5 mm in diameter with lengths up to 100 mm. Generally, the corer was screwed ca. 7 cm into the wood. The corer with the sample was brought to the surface, and the sample was removed, labelled and packed into small plastic vials held in place with wetted paper towels to prevent destruction during transport. All samples and measurements were collected within a radius of 20 cm from the identification label and generally one core sample was taken per area. However, the quality of the wood varied; some samples had to be retaken and a few areas were abandoned after several unsuccessful trials[20]. Density of the samples was determined at the laboratories of the National Museum.

## 4.3 Density determination

Waterlogged archaeological wood often shows a gradient of degradation; from a poorly preserved outer zone to a better preserved inner zone[21], as can also be seen in a typical core sample taken from the wreck (fig. 10). To account for this gradient, the cores were sectioned into smaller pieces and their bulk density determined. The distance from the surface of the outer end of the sample (surface of the wood) to the centre of the sectioned sub samples was measured in order to establish a density gradient.

Bulk density ($\rho_{wood}$) of the wood (dry weight per wet volume) was determined according to the method described by Jensen and Gregory[22]. To summarize the method: the dry weight was determined after drying the samples to constant weight at 105°C and the wet volume was determined by the Archimedes principle.

## 4.4 Pilodyn measurements

The Pilodyn wood tester, figure 11, works by firing a spring-loaded blunt pin into the wood, to a maximum depth of 40 mm. The depth of penetration of the pin is indicated on a scale on the side of the instrument; the more degraded the wood, the further the pin will penetrate. The average of three measurements taken at each location was used for subsequent calculations. The penetration reflects the shock resistance of wood, that is to say, the resistance of wood to a suddenly applied load. The energy required to overcome this resistance in non-archaeological wood is a complex interaction of the various properties of wood. Research[23] has shown that the correlation between the density of waterlogged archaeological wood and the depth of penetration of the Pilodyn pin (fig. 12) makes it possible to compare the Pilodyn results with the densities determined from the core samples. Although the standard curve refers to measurements taken in air, the curve can also be used for measurements taken in water by means of a correction factor[24].

The Pilodyn is also useful in the event of shipworm being present in timbers. The presence of these organisms can be difficult to see from the surface of the wood, especially if there are other colonising organisms or seaweed present, as they only make a very small hole in the surface of the wood before growing inside the wood. In this event, the density of the wood cannot be determined using a Pilodyn, as one effectively 'shoots' through the tunnels of the shipworm (see figure 5). Nevertheless, one is left in no doubt that the wood has been attacked by shipworm as the needle effortlessly penetrates to the maximum depth of 40 mm and so in this instance a qualitative assessment of the wood is at least possible with the instrument.

## 4.5 Ash and iron content of wood samples

After determination of the density of the wood core samples, it was noticed that the dried wood was very red in colour. The change to red indicates an oxidation of the iron compounds in the sample during the oven-drying at 105°C. Therefore it was suspected that there were considerable amounts of iron corrosion products and other inorganic matter in the samples, presumably resulting from the corrosion of iron bolts and fastenings

**FIG. 9 Increment corer used for taking samples.**
***Een aanwasboor om houtstalen te nemen.***


**FIG. 10 Typical core sample showing a darker degraded outer area to the left and a lighter better preserved inner area to the right.**
***Typisch boorstaal met een donker, gedegradeerd buitenste deel links en een beter bewaard en lichter binnenste deel rechts.***

20 At some places it was impossible to get the increment corer into the wood, at other places the increment corer didn't deliver a useful sample.

21 Brorson-Christensen 1970.

22 Jensen & Gregory 2006.

23 Gregory *et al.* 2007.

24 Gregory *et al.* 2007.

from the ship. Admittedly not statistically representative of all the core samples, an XRF-analysis of one sample with a high inorganic content indicated an iron content of more than 90% of the analyzable atoms. The oxidation of the iron has probably resulted in the formation of Fe3O4 or Fe2O3. The formation of oxidized iron also indicates that there have probably been sub oxic to anoxic conditions inside the wood, which has lead to the migration of soluble iron (in the reduced state) into the wood.

The dried samples were placed in a muffle oven at 600°C for 12 hours and the %w/w[25] inorganic content (ash, iron oxides) calculated. The amount of iron oxides can be calculated from the dry weight of the wood in order to obtain a corrected density for the wood without any inorganic material. The method of subtracting the ash content from the dry weight is subject to some errors as the oxidation at 105°C might not be complete and because more anions are lost during the heating to 600°C in the muffle oven than by just drying at 105°C.

## 4.6 Assessment of wood boring organisms

Two large samples of oak wood, which were lying loose and adjacent to the wreck, were taken from the site and assessed both visually and with X-Ray. It was immediately apparent that the outer surfaces of the wood had been extensively attacked by wood boring crustacea. In order to check whether there were living organisms present on the wood, the samples were covered in a damp cloth and left overnight. As the crustaceans responsible for this type of attack require oxygen, the presence of the wet cloth restricts the passage of oxygen to the wood and any living crustacean will come to the surface of the wood to gain more oxygen.

The presence of shipworm is very difficult to see on the surface of the wood with the naked eye. However, as they bore into the wood, they secrete a layer of calcium carbonate, which lines the holes of the tunnels they create. Under X-ray this lining is visible due to it being denser than the surrounding wood and this method can be a way of non destructively assessing their presence.

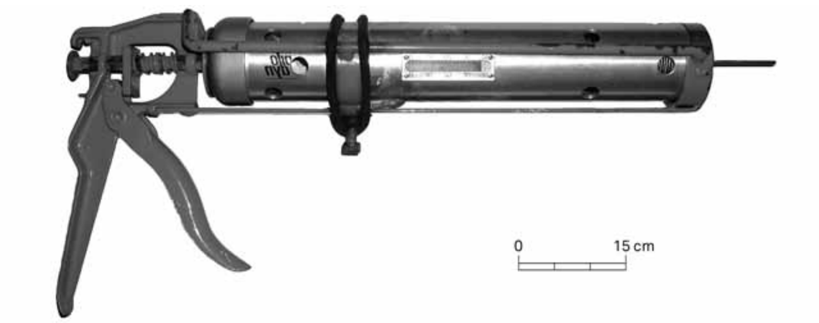



**FIG. 11 The Pilodyn wood tester.**
***De Pilodyn houttester.***

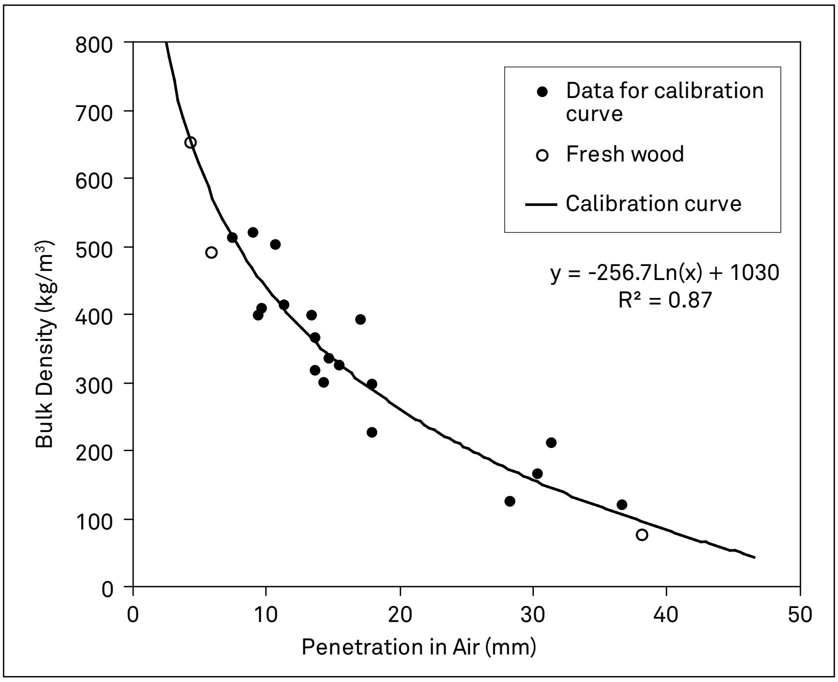



**FIG. 12 Correlation between the depth of pin penetration and bulk density of waterlogged archaeological wood.**
***Correlatie tussen de penetratiediepte van de pin en de schijnbare dichtheid van het waterverzadigde archeologische hout.***

25 This is the weight of the resulting ash divided by the weight of the dry sample multiplied by 100.

## 5 Results

### 5.1 Density and inorganic content (ash) of core samples

The samples were treated in two discrete populations. Table 1 shows a summary of all results from the planking (Samples 1-6) and table 2 shows a summary of results from structural timbers (Samples 7-9).

### 5.2 Presence and activity of wood boring organisms

Figure 13 shows the two samples of oak wood taken to assess the activity of wood boring organisms. There were definite signs of colonisation by fouling organisms. These organisms tend to live on the surface of the wood rather than bore in to the wood (figures 14 and 15).

**TABLE 1**
**Summary of results from planking. Samples 1-6.**
*Samenvatting van de resultaten van de planken. Stalen 1-6.*

| Sample | Comments | Depth in core (mm) | Density ($kg/m^3$) | Average Pilodyn penetration (mm) | Density from Pilodyn ($kg/m^3$) | Ash Content (%) | Density corrected for Ash content ($kg/m^3$) |
|---|---|---|---|---|---|---|---|
| 1A | Good sample | Total length 62 mm | | | | | |
| | | 18 | 309 | 3 | 646 | 16,8 | 257 |
| | | 47 | 341 | | | 18,8 | 277 |
| 1B | | Total length 56 mm | | | | | |
| | | 2 | 643 | 9 | 382 | 46,2 | 346 |
| | | 25 | 489 | | | 30,3 | 341 |
| | | 47 | 469 | | | 25,7 | 349 |
| 1C | | Total length 60 mm | | | | | |
| | | 5 | 425 | 3 | 703 | 6,2 | 398 |
| | | 17 | 426 | | | 7,5 | 394 |
| | | 35 | 466 | | | 6,0 | 438 |
| 2A | Very poor | Total length 50 mm | | | | | |
| | | 10 or 40 | 350 | 6 | 510 | 18,8 | 284 |
| 2B | Good sample | Total length 77 mm | | | | | |
| | | 9 | 353 | 7 | 455 | 9,4 | 320 |
| | | 39 | 419 | | | 5,2 | 398 |
| | | 62 | 469 | | | 11,2 | 417 |
| 2C | Good sample | Total length 63 mm | | | | | |
| | | 11 | 543 | 3 | 673 | 31,1 | 374 |
| | | 30 | 667 | | | 37,4 | 418 |
| | | 51 | 826 | | | 45,5 | 450 |
| 3A | Good sample | Total length 86 mm | | | | | |
| | | 8 | 417 | 8 | 416 | 16,3 | 349 |
| | | 24 | 400 | | | 11,0 | 356 |
| | | 45 | 494 | | | 9,0 | 449 |
| | | 67 | 486 | | | 9,9 | 437 |
| | | 80 | 532 | | | 12,3 | 466 |
| 3B | Poor sample | Total length 74 mm | | | | | |
| | | 13 | 325 | 8 | 434 | 13,4 | 281 |
| | | 37 | 388 | | | 11,5 | 343 |
| | | 52 | 408 | | | 9,0 | 372 |
| | | 69 | 450 | | | 7,9 | 414 |
| 3C | Good sample | Total length 81 mm | | | | | |
| | | 2 | 636 | 3 | 646 | 43,9 | 357 |
| | | 16 | 574 | | | 19,1 | 465 |
| | | 37 | 505 | | | 4,6 | 482 |
| | | 59 | 454 | | | 5,5 | 429 |
| | | 80 | 494 | | | 4,7 | 470 |

| Sample | Comments | Depth in core (mm) | Density (kg/m³) | Average Pilodyn penetration (mm) | Density from Pilodyn (kg/m³) | Ash Content (%) | Density corrected for Ash content (kg/m³) |
|---|---|---|---|---|---|---|---|
| 4A | Good sample | Total length 70 mm | | | | | |
| | | 2 | 450 | 9 | 382 | 27,0 | 328 |
| | | 9 | 392 | | | 8,0 | 361 |
| | | 23 | 416 | | | 6,4 | 389 |
| | | 39 | 376 | | | 6,6 | 351 |
| | | 58 | 367 | | | 8,4 | 336 |
| 4B | Good sample | Total length 73 mm | | | | | |
| | | 8 | 403 | 7 | 455 | 5,9 | 380 |
| | | 26 | 350 | | | 6,3 | 328 |
| | | 46 | 515 | | | 28,0 | 371 |
| | | 69 | 390 | | | 5,9 | 367 |
| 4C | Good sample | Total length 88 mm | | | | | |
| | | 17 | 453 | 9 | 391 | 20,8 | 359 |
| | | 36 | 385 | | | 11,8 | 339 |
| | | 56 | 476 | | | 22,9 | 367 |
| | | 85 | 533 | | | 25,0 | 400 |
| 5A | | Total length 59 mm | | | | | |
| | | 3 | 591 | 6 | 481 | 30,4 | 412 |
| | | 26 | 450 | | | 17,0 | 374 |
| | | 51 | 490 | | | 15,6 | 414 |
| 5B | Good sample | Total length 43 mm | | | | | |
| | | 2 | 447 | 5 | 525 | 15,1 | 380 |
| | | 18 | 455 | | | 7,7 | 420 |
| | | 33 | 421 | | | 5,3 | 399 |
| 6A | Good sample | Total length 73 mm | | | | | |
| | | 5 | 438 | 9 | 401 | 11,0 | 389 |
| | | 21 | 467 | | | 7,3 | 433 |
| | | 43 | 468 | | | 11,4 | 414 |
| | | 60 | 474 | | | 7,8 | 437 |
| 6B | Good sample but surface missing | Total length 63 mm | | | | | |
| | | 15 | 342 | 18 | 213 | 7,0 | 318 |
| | | 36 | 321 | | | 9,3 | 291 |
| | | 54 | 362 | | | 6,2 | 340 |
| 6C | Good sample but surface missing | Total length 32 mm | | | | | |
| | | 8 | 356 | 10 | 364 | 3,3 | 344 |
| | | 24 | 492 | | | 3,7 | 473 |
| 6D | Good sample but surface missing | Total length 98 mm | | | | | |
| | | 6 | 352 | No Pilodyn Measurements | No Pilodyn measurements | 6,6 | 329 |
| | | 24 | 394 | | | 7,7 | 364 |
| | | 40 | 378 | | | 7,8 | 349 |
| | | 55 | 349 | | | 8,0 | 321 |
| | | 74 | 295 | | | 8,2 | 271 |
| | | 90 | 366 | | | 6,5 | 342 |

**TABLE 2**

**Summary of results from structural timbers. Samples 7-9.**

*Samenvatting van de resultaten van de structurele stukken hout. Stalen 7-9.*

| Sample | Comments | Depth in core (mm) | Density (kg/m³) | Average Pilodyn penetration (mm) | Density from Pilodyn (kg/m³) | Ash Content (%) | Density corrected for Ash content (kg/m³) |
|---|---|---|---|---|---|---|---|
| 7A | Only Pilodyn measurement | | | 5 | 525 | | |
| 7B | Good sample | Total length 82 mm | | | | | |
| | | 9 | 397 | 7 | 443 | 6,2 | 372 |
| | | 28 | 402 | | | 5,9 | 379 |
| | | 50 | 386 | | | 6,0 | 363 |
| | | 68 | 418 | | | 5,1 | 397 |
| 7C | Good sample | Total length 83 mm | | | | | |
| | | 14 | 407 | 9 | 386 | 6,5 | 381 |
| | | 34 | 397 | | | 6,7 | 371 |
| | | 54 | 427 | | | 8,0 | 393 |
| | | 74 | 658 | | | 3,3 | 636 |
| 8A | Good sample | Total length 65 mm | | | | | |
| | | 10 | 527 | 5 | 525 | 3,1 | 511 |
| | | 34 | 585 | | | 2,2 | 572 |
| | | 53 | 516 | | | 2,5 | 503 |
| 8B | Only Pilodyn measurement | | | 7 | 468 | | |
| 8C | Good sample | Total length 107 mm | | | | | |
| | | 3 | 406 | 8 | 421 | 10,0 | 366 |
| | | 22 | 502 | | | 6,0 | 472 |
| | | 42 | 490 | | | 4,6 | 467 |
| | | 63 | 397 | | | 5,4 | 376 |
| | | 80 | 355 | | | 6,0 | 333 |
| | | 98 | 397 | | | 5,8 | 374 |
| 9A | Poor sample | Total 51 mm | | | | | |
| | | 3 | 453 | 8 | 411 | 14,9 | 385 |
| | | 22 | 648 | | | 34,9 | 422 |
| | | 45 | 648 | | | 26,7 | 475 |
| 9B | Good sample | Total length 68 mm | | | | | |
| | | 15 | 449 | 7 | 443 | 4,6 | 428 |
| | | 37 | 438 | | | 6,4 | 410 |
| | | 58 | 530 | | | 11,4 | 470 |
| 9C | Good sample | Total length 63 mm | | | | | |
| | | 8 | 366 | 9 | 391 | 5,7 | 345 |
| | | 27 | 382 | | | 5,5 | 361 |
| | | 46 | 408 | | | 5,2 | 387 |
| 9D | Only Pilodyn Measurement | | | 11 | 347 | | |


FIG. 13 **Two samples of wood taken from the wreck of the *Belgica*.**
***Twee houtstalen van het scheepswrak van de* Belgica.**

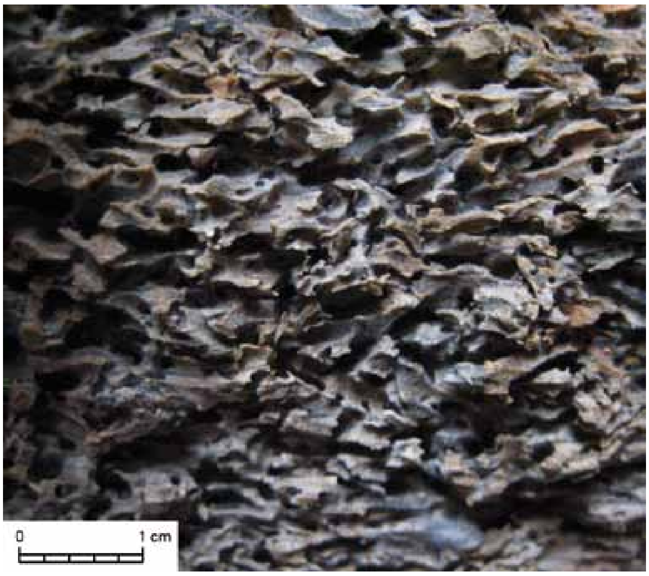



FIG. 14 **Surface of wood sample (figure 13a) extensively degraded by gribble.**
***Oppervlak van een houtstaal (figuur 13a) dat in sterke mate is aangetast door paalpissebed.***


FIG. 15 **Close up of biofouling organisms on the surface of wood (figure 13b), including calcareous tubeworms and barnacles.**
***Detailopname van biologische aangroei op het houtoppervlak (figuur 13b) met inbegrip van kalkhoudende buiswormen en zeepokken.***

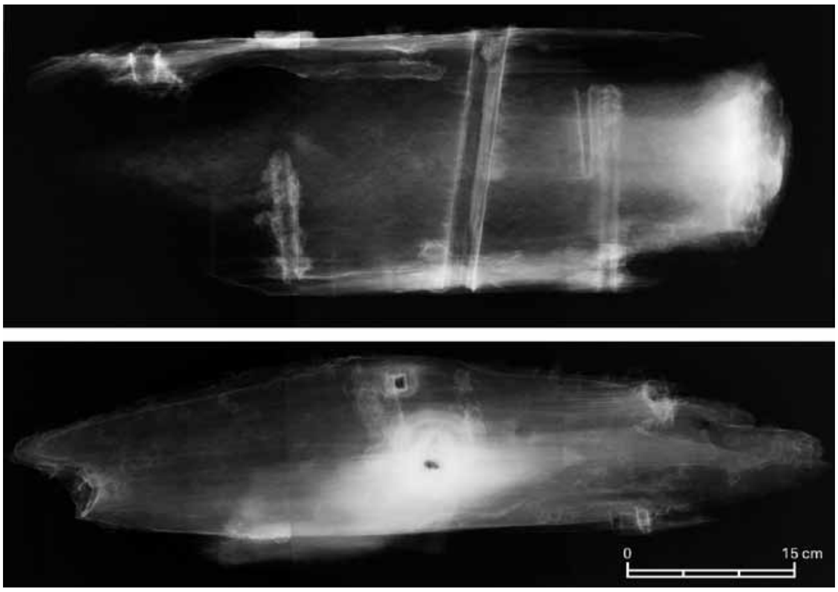



**FIG. 16** **X-Ray pictures of samples from the wreck site. No characteristic shipworm tunnels are present. The calcareous tubeworms on the surface of the wood samples in the lower picture are clearly visible (see figure 15)(Birthe Gottlieb, The National Museum of Denmark).** ***X-stralen-foto's van houtstalen van de wraksite. Er zijn geen kenmerkende paalwormtunnels aanwezig. De kalkhoudende buiswormen aan de oppervlakte van het hout op de onderste foto zijn duidelijk zichtbaar (zie figuur 15)(Birthe Gottlieb, Nationaal Museum van Denemarken).***

#### 5.2.1 Wood boring crustacea (Gribble)

The surfaces of both wood samples were heavily degraded by the activity of wood boring crustacea (figure 14). Although there were no signs of living organisms on the wood, it should not necessarily be concluded that they are not present and active on other parts of the wreck.

#### 5.2.2 Wood boring mollusca (Shipworm)

Figure 16 shows X-ray pictures of the two samples in figure 13. No shipworm tunnels were visible in the samples, yet as with the boring crustaceans, it does not mean that shipworm are not present on other parts of the wreck as the environmental conditions around the site (salinity, temperature, dissolved oxygen) are conducive to the growth of wood boring organisms.

## 6 Discussion

### 6.1 Density measurements on samples and with Pilodyn

According to diver reports many of the timbers on the wreck have been attacked by wood boring organisms. This has implications for the accuracy of the methods to assess the density of the remaining wood. If we consider the Pilodyn measurements on very degraded surfaces, it is very easy to remove the outer degraded surface layer of wood when positioning the instrument. This would lead to a low penetration of the needle, as the needle is penetrating well-preserved wood, resulting in an artificially high density (see table 1, samples 1A, 1C, 2C and 3C). If we consider the use of the increment borer, a similar problem can be encountered as underwater it is very easy to lose the outer degraded surface of the wood (see Figure 10) during collection. This leads to an incorrect determination of the depth of the core in the wood and will give artificially high densities nearer the surface of the wood (see table 1, samples 1B and 6B).

### 6.2 Correlation between density and depth in wood

The average density of fresh waterlogged oak wood (*Quercus robur L.*) is between 500 and 600 kg/m$^3$ (dry weight/wet volume). The densities of all samples taken from the wreck were plotted against the corresponding depths of the sample cores. As figure 17 shows there is a poor correlation between these parameters, indicating that the local environment and various properties of the different pieces of timber have all affected the rates and extent of deterioration.

Based on this, it was decided to split the wood samples into two discrete populations – those samples relating to the planking of the ship (samples 1-6) and those relating to the structural timbers, such as the beams (samples 7, 8 and 9), and analyse the results separately.

The planking, samples 1-5 on the port side and sample 6 on the starboard side, were from locations on the wreck which appear to have been continually above the seabed and therefore exposed predominantly to oxic conditions. The densities of the samples reflect the long-term deterioration caused by micro organisms (fungi and bacteria). The results show that there is no significant correlation between height on the wreck or location on the sides of the ship and average density, indicating that all planks are evenly degraded.

Figure 18 shows summaries of average density measurements on core samples corrected for ash content, in relation to depth in the core sample, arranged in depth groups.

Similarly there was little correlation between depth of sample core and corresponding density. However, the results demonstrate that the outer zone of the wood is the most degraded with average densities increasing towards the centre of the planks. The innermost parts of the planks, i.e. at depths deeper than 60 mm, have an average density, corrected for ash content, of 392 kg/m$^3$, giving a loss of mass of more than 28% (density of fresh oak taken as 550 kg/m$^3$). One must expect that the samples have had a loss in strength of more than 28%, due to cleavage of the wood polymers during the degradation processes in the wood[26].

26 Wood Handbook 1999, 13-5.

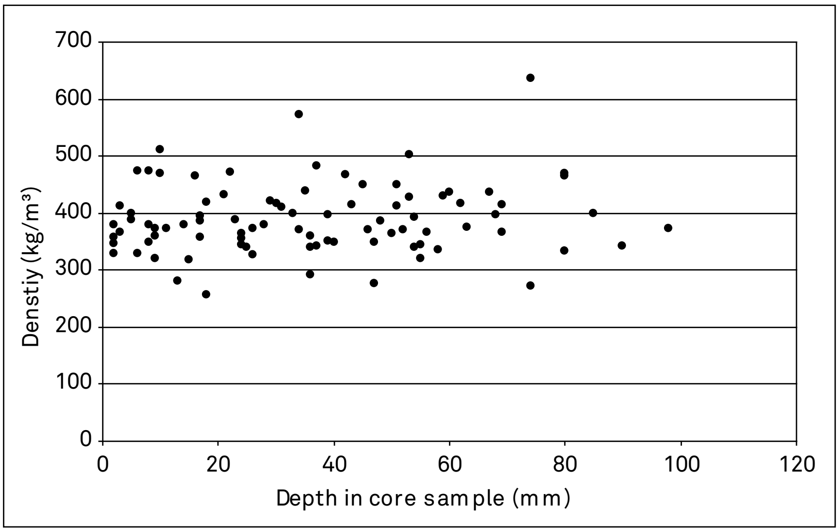



**FIG. 17 Depth in core sample versus density of sample taken with increment corer.**
***Diepte in het boorstaal versus de dichtheid van het staal genomen met de aanwasboor.***

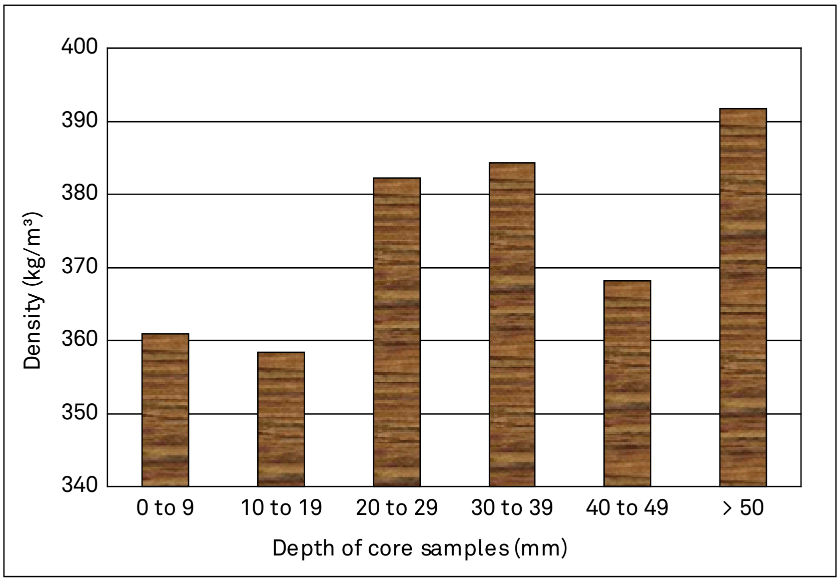



**FIG. 18 Depth in core samples versus average corrected densities of depth groups from measurements taken from planking core samples.**
***Diepte in de boorstalen versus gemiddelde gecorrigeerde dichtheid van dieptegroepen genomen van de stalen van de planken.***

The structural timbers (samples 7, 8 and 9) were all exposed and located on the upper part of the wreck. Considering the densities determined on the core samples (table 2), it is apparent that all timbers have been homogeneously degraded throughout the length of the cores. Densities from the Pilodyn give a good correlation with the densities determined from the core samples. However, the results show that there is no significant correlation between location of the structural timbers and their average density. As with the planks, there is not a high correlation between depth of core sample and the corresponding density. Nevertheless, the results demonstrate that the outer zone of the wood is more degraded than the centre of the timbers.

The innermost parts of the cores from the timbers, i.e. depths below 50 mm, have an average density corrected for ash content of 427 kg/m³, giving a loss of mass of more than 22% (density of fresh oak taken as 550 kg/m³). Again one must expect that the samples have had a loss in strength of more than 22%, due to cleavage of the wood polymers during the degradation processes in the wood[27].

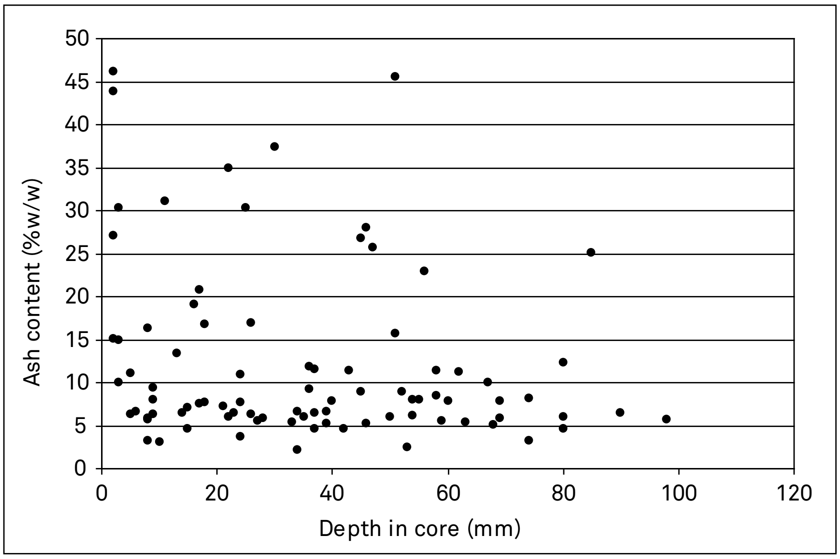
To put this into context, timbers from the wrecks of the *Kolding cog, Vasa and Mary Rose* had average densities of 450, 470 and 400-650 kg/m³ respectively[28]. The *Kolding cog* was dismantled prior to lifting, whereas the other two were lifted with supporting craddles.

## 6.3 Ash content measured on samples

The ash content, on all sub samples was between 5 and 45% w/w. Figure 19 is a plot of the ash contents versus the spatial position of the sub core samples (in the ship, depth of the sub sample in the sample) and shows the poor correlation between these parameters. This indicates that the ash content is dependent on local parameters, although there is a tendency for higher concentrations at the surface of samples.

27 Wood Handbook 1999, 13-5.
28 Jordan 2003; Almkvist 2008; McConnachie *et al.* 2008.

**FIG. 19 Depth in core sample versus ash content.**
***Diepte in het boorstaal versus asgehalte.***




## 6.4 Wood boring Organisms

From the two oak samples taken from the wreck site, it could be seen that the wreck has been exposed to predominantly oxic conditions since sinking. This is attested by the presence of wood boring organisms, which require dissolved oxygen from the surrounding seawater for their respiration. Even though there was no apparent sign of deterioration by large wood boring shipworm, the outer surfaces of the samples were heavily degraded by wood boring crustaceans. There was no sign of living organisms on the samples taken for this investigation.

## Conclusions

From these analyses the following can be concluded about the current state of preservation of the *Belgica:*

- The surface of the timbers is heavily degraded by wood boring crustacea but there is no apparent sign of wood boring molluscs. This was based on two samples taken from the site and wood borers may be active on other areas of the wreck.
- At a micro-structural level all wood has been homogeneously degraded by micro organisms. Structural timbers, such as the beams, show that the density at depths greater than 50 mm in the timbers has decreased from ca. 550 kg/$m^3$ (fresh oak) to 427 kg/$m^3$. In the planking, the density at depths greater than 60 mm, has decreased from 550 kg/$m^3$ to 392 kg/$m^3$.
- The developed methodology for assessing the structural strength of wooden shipwreck remains, has been applied successfully to the well known shipwreck of the *Belgica*.
- All timbers contain inorganic matter, as determined by ashing of the samples. The results range from 5 – 45%, with highest contents being seen at the surface of the wood. A preliminary analysis of the composition of the ash indicates that it is predominantly iron which should be taken into consideration if there are plans to raise and conserve the *Belgica*.

Even though this assessment has given an overview of the current state of preservation of the *Belgica*, it is based on relatively few samples from the site. Further research to supplement this work could be:

- A fuller assessment of the strength properties of timbers – in particular those timbers which would be subjected to the most stress and strain - should the wreck be raised either as a complete unit or as separate sections. This could be achieved by measuring the compression and tensile strength, modulus of elasticity and rupture on selected timbers.
- The iron content and sulphur content of the wood must be taken in to consideration. Although this may not be relevant to the actual raising of the wreck, it has a significant bearing on the future conservation and curation of the find. In the archaeological conservation world there is an ongoing debate about the need to remove iron and sulphur compounds, as they are believed to produce acid within the wood leading to its chemical degradation[29].
- Should the wreck be left *in situ* it is important to carry out a more systematic marine biological survey of the wreck focusing on the presence of living/active wood boring organisms.

## Acknowledgements

The authors would like to thank Stephen Wickler, from the Tromsø University Museum, for introducing the National Museum to the *Belgica* and particularly the members of the *Belgica Society*. The costs and logistics for the field work were generously supported by the following people and organisations:

- *Belgica Society* (http://www.belgica-genootschap.be/?lang=en) for transport and logistics. In particular the support of the Society's members Willy Versluys, Kjell Kjaer, Rudi Caeyers and Ragnar Klevaas.
- Dive vessels were provided by the *Anna Rogde* society and the harbour master of Harstad.

29 Fors 2008.

- Diver support by divers of the Harstad Diving Club and Karl Emil Rikardson.
- Participants to the 2008 fieldtrips: Cris Beerens, Jan Lettens, Tom Leys, Nicolas Mouchart, Tomas Termote, Mayke Van Hecke, Wim Vermeire.

Personal Communication: Morten Gøthche, Naval Architect, The Viking Ship Museum, Vindeboder 12, Roskilde, DK-4000.

Suppliers:
- Pilodyn wood tester (underwater model): Kai R. Spangenberg's EFTF. I/S, Hovedgaden 26, 2970 Hørsholm, Denmark, www.krsis.dk.
- Increment borer: Dansk Skovkontor A/S, Kalundborgvej 92, DK-4180 Sorø, www.dansk-skovkontor.dk.


## Samenvatting


**Een eerste beoordeling van de bewaringstoestand van het wrak van de *Belgica***

De *Belgica*, in Noorwegen gebouwd in 1884, heeft in de loop van haar leven verschillende functies gehad, zoals walvisvaarder, schip voor wetenschappelijke expedities, vrachtschip en munitieopslagplaats. Het meest bekend is ze uiteraard als het schip waarmee Adrien de Gerlache de eerste puur wetenschappelijke expeditie naar Antarctica uitvoerde in 1897-1899 en voor verschillende andere Arctische expedities tussen 1905 en 1909. Het schip zonk uiteindelijk in Noorwegen tijdens WO II en werd in 1990 herontdekt door sportduikers uit Harstad.

In het kader van een voorstel om het schip (of delen ervan) te bergen werd een voorafgaandelijk stabiliteitsonderzoek van het wrak uitgevoerd. Dit gebeurde om een beter inzicht te verwerven in de bewaringstoestand van het hout van de romp en om te zien of er actieve degradatie plaatsvond door houtborende organismen, zoals paalwormen en paalpissebedden. Daarnaast werden ook beperkte chemische analyses op het hout uitgevoerd als voorbereiding op een conservatieprogramma, in het geval het wrak of delen ervan zouden geborgen worden.

De resultaten gaven aan dat het schip sinds het zinken actief werd belaagd door de bovenvermelde houtborende organismen. Uit de stalen die voor onderzoek beschikbaar waren, bleek dat deze organismen op dit ogenblik niet actief waren. De houtdegradatie is vooral het gevolg van microbiële aantasting, zoals aangetoond door een daling van de dichtheid van zowel de structurele houten elementen als van de planken met respectievelijk 22% en 28%. Deze vaststellingen hebben implicaties voor een eventuele bergingsstrategie. Bij de *Kolding Kogge* was het hout minder aangetast (450 kg/m$^3$) en toch werd geoordeeld dat de aantasting niet toeliet de scheepsromp in één blok te bergen. Ook bij de *Vasa* en de *Mary Rose* met dichtheden van respectievelijk 470 en 400-650 kg/m$^3$ werd geoordeeld om voor de berging gebruik te maken van speciaal op maat gemaakte ondersteunende wiegen.

Het hout van de *Belgica* heeft ten slotte een hoog anorganisch gehalte (tussen 5% en 45%), hoofdzakelijk van ijzerhoudende zouten. Dit heeft grote implicaties op het voorgestelde conservatieproces indien het wrak of houten onderdelen ervan zouden geborgen worden.

Dit onderzoek ten slotte werd opgezet als een experiment. De methode die werd ontwikkeld in het Laboratorium voor Conservatie van de Deense nationale musea werd met succes toegepast op een volledig en groot houten scheepswrak in zee.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