HMS VANGUARD 100

Rowland, Chris; Hyttinen, Kari

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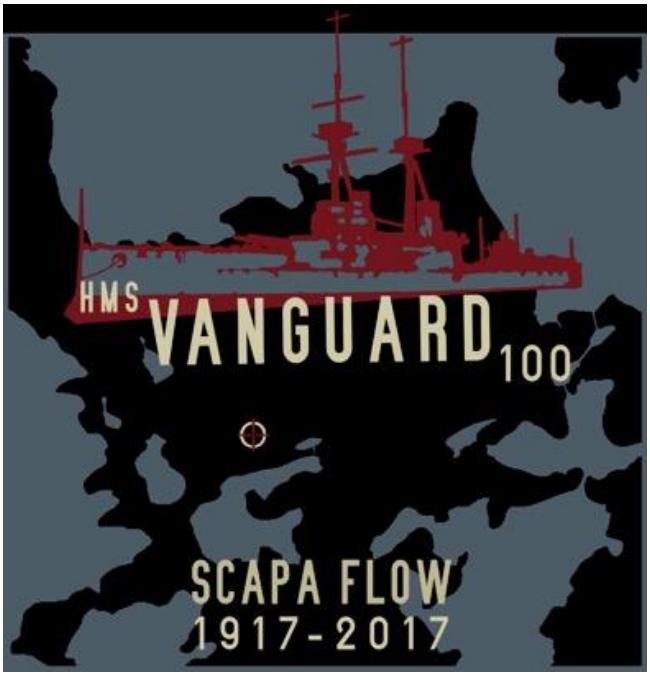

HMS VANGUARD 100

SURVEY 2016-2017

Survey Report

Emily Turton, David Crofts, Dr Clare Fitzsimmons, Prof Chris Rowland, Prof Kari Hyttinen, Simon Kay, Lt Jen Smith, Bob Anderson, Marjo Tynkkynen, Kieran Hatton, Dr Joanna Porter, Ben Wade

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1 Executive Summary

At approximately 2320 on the 9th July 1917 HMS VANGUARD suffered a series of catastrophic explosions. The ship and 843 of her crew were lost. The HMS VANGUARD 100 Survey was conducted between October 2016 and February 2017 under special licence from the Secretary of State for Defence. The survey was self-funded and conducted by volunteer professional divers. The purpose of the survey was to document this protected war grave after 100 years underwater.

HMS VANGUARD was a dreadnought battleship of the World War 1 (WWI) era. She was built by Vickers of Barrow-in-Furness, launched in 1909 and commissioned in 1910 into the First Battle Squadron. The wreck was legally salvaged between 1957 and 1975. In 1984 the ship was recognised as a war grave. Little recreational diving has taken place on the wreck of HMS VANGUARD prior to her becoming a controlled site in 2002, when all diving without permission was banned.

The VANGUARD 100 survey used remote survey techniques to identify the extent of the wreckage and debris field. Specialist divers conducted underwater surveys of the entire site using underwater mapping and forensic diving techniques. The wreck was documented using videography, stills photography and 3D photogrammetry.

The site is extensive and complicated. For the purposes of this survey, it was divided into three main sections: main wreck site, outer wreck site and the outer debris field. Further division was utilised to better manage survey activity, data recording and cataloguing. The bow and stern remain intact, severed during the explosion, they sank in situ and lie approximately 163m apart. All five twelve-inch gun turrets are present on the site, some displaced from their original position during the explosion. Substantial wreckage has been blown up, out and aft in the explosions. There is a notable "gap" in the main wreck at the location of the main, primary explosion consistent with the P and Q Turret magazine. Significant artefacts and architectural features have been discovered and documented. The marine life legacy of HMS VANGUARD as a relatively undisturbed site is substantial. The evidence of salvage is extensive.

Evidence from sinking is broadly consistent with the Royal Navy Court of Enquiry. A significant quantity of ordnance remains on the wreck site. Significant wreckage lies outside the current exclusion zone including some historically important and valuable artefacts. It is recommended that the exclusion zone be extended. VANGUARD should continue to be treated as a site of huge historical importance. Notwithstanding her war grave status, she also has a substantial relevance to current naval safety. She is a time capsule into WWI naval architecture, and mid-20th century ship wreck salvage techniques. Methods used by the VANGUARD 100 survey team have been shown to be highly effective and should be widely communicated to benefit future wreck site surveys and wreck site management.

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Acknowledgements

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Image Copyright

Purpose of Report

The purpose of this report is to disseminate the information gathered by the HMS VANGUARD 100 Survey. This Survey is the most comprehensive conducted to date on HMS

VANGUARD and the imagery gathered brings the ship to the surface for non-divers and future generations. The report describes HMS VANGUARD, her construction, service history and loss. A detailed description of the survey design and methodology are included. A complete and illustrated description of the wreck site is provided, complemented by description and photography of the marine life legacy of this relatively undisturbed wreck site. Munitions experts were part of the survey team and have provided a forensic explanation of how and why VANGUARD is where she is today.

1. Introduction

At 2320 in the late evening of the 9th July 1917, HMS VANGUARD, a dreadnought battleship of the Royal Navy Grand Fleet moored in Scapa Flow, Orkney, suffered a series of catastrophic explosions resulting in the loss of the ship and 843 of her crew. The resulting Royal Navy Court of Enquiry concluded an unintentional cordite explosion caused the loss of HMS VANGUARD, making it the largest accidental loss of life in the Royal Navy during the 20th century.

The HMS VANGUARD 100 Survey was conducted during October 2016 and February 2017 under special licence from the Secretary of State for Defence. The Survey used remote surveying techniques to identify the extent of the wreckage and debris field. Specialist divers conducted underwater surveys of the entire site using underwater mapping forensic techniques. The wreck was documented using videography, stills photography and 3D photogrammetry.

The survey was self-funded and conducted by volunteer professional divers. The purpose of the survey was to document this protected war grave at 100 years underwater. The purpose of this report is to disseminate the information gathered by the HMS VANGUARD 100 Survey for the historical record, non-divers and future generations, in memory of those lost in the sinking of this great ship.

1.1 The Vessel

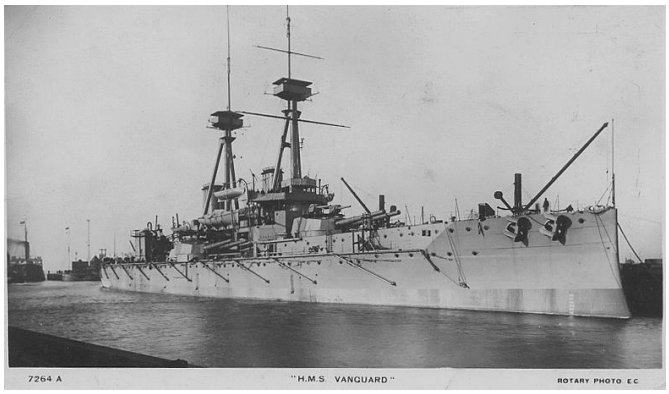


Figure 1: HMS VANGUARD 1910

VANGUARD – forefront of a movement or action, the foremost part of an advancing army or naval force.

1.1.1 Build

HMS VANGUARD was ordered as part of the 1907 build programme. This made her one of the third class of British 'Dreadnought Battleships' and the last built to the same basic design as the original HMS DREADNOUGHT.

Figure 2: HMS VANGUARD in drydock and on launch day - 22nd February 1909

Whilst the Admiralty would have liked a significant re-work of the design, parliament had planned to cancel the 1907 programme. Managing to force through approval there was no spare money for a redesign, so the ST VINCENT class was born. VANGUARD had two sister ships HMS ST VINCENT and HMS COLLINGWOOD. Visually significant differences as compared with HMS DREADNOUGHT were the repositioning of the foremast, similar to the BELLEROPHON class before, and the increase in length of the main guns by 61 inches from 45 to 50 calibres, resulting in the overall lengthening of the ST VINCENT class to accommodate them. Vickers of Barrow-in-Furness won the contract to build HMS VANGUARD, launching her in 1909. Incidentally the current HMS VANGUARD, a ballistic missile submarine, was also built at Barrow in Furness.

HMS VANGUARD was a steam powered ship. Eighteen Babcock and Wilcox boilers were arranged in 3 boiler rooms. The 18 boilers powered two sets of Parsons Steam Turbines which, in turn powered 4 propellers. The boilers also powered two large steering engines to turn VANGUARD's twin rudders.

1.1.2 Service

VANGUARD was commissioned in 1910 into the Royal Navy's 1st Battle Squadron at Devonport. This was a time of vast naval modernisation and the 'Dreadnought' concept was quickly evolving, the march of progress quickly leaving VANGUARD and her sisters looking dated. A numerical superiority in numbers of dreadnoughts was, however, essential and here VANGUARD played a key role.

VANGUARD had taken up station in Scapa Flow prior to the outbreak of WW1 and was already there when the British Fleet was reorganised to form the Grand Fleet.

In the early days of WW1 it became apparent that the defences of Scapa Flow were inadequate and fear of attack reigned supreme. On the 1st September 1914, VANGUARD

opened fire with her secondary armament at a suspected periscope sighting. As for most of the Grand Fleet during the early war years, time was spent at anchor, training and conducting gunnery exercises as well as occasional sweeps and sorties into the North Sea. It was not until the 31st May 1916 and the Battle of Jutland that VANGUARD was able to fire her big 12-inch guns in anger for the first and only time.

Captained by James D Dick, VANGUARD sailed in the 4th Division of the Fourth Battle Squadron, accompanied by IRON DUKE, ROYAL OAK, SUPERB, CANADA, BENBOW, BELLEROPHON, and TEMERAIRE. She took up position as the 16th ship in the battle line.

VANGUARD never engaged any capital ships but fired 57 heavy shells at light cruisers and destroyers, striking SMS WIESBADEN (later sunk) with her fourth salvo. She suffered no hits or casualties during the battle.

Post Jutland, VANGUARD resumed her role in the Grand Fleet exercises, sweeps in the North Sea and lots of time at anchor. She received a refit in Rosyth during December 1916 before returning to Scapa Flow.

1.1.3 Sinking

On the 9th July 1917, VANGUARD was conducting abandon ship drills. Concluding these, she returned to her anchorage between NEPTUNE and COLLINGWOOD, dropping anchor at approximately 1830. Most of the ship's boilers had been in use during the day, and these were now damped down, with the exception of those required for auxiliary power.

At 2320, VANGUARD was seen to suffer two or three explosions and disappeared beneath the surface of Scapa Flow in the time it took for the smoke to clear. As a result of the explosion, 843 sailors and officers were lost. Few bodies were recovered for burial.

The cause of the explosion was undoubtedly a cordite explosion. This was not the first such occurrence suffered by a naval vessel at anchor, and similar catastrophic explosions were suffered at Jutland by British Cruisers and Battle-Cruisers due to the effects of gunfire.

A Royal Navy Court of Enquiry into the loss of the ship began aboard the EMPEROR OF INDIA on the 10th July 1917. The report, dated 30th July 1917, included witness accounts stating that two (potentially three) explosions occurred near midships. The report cited potential catalysts as:

- Lack of ventilation causing a build-up of heat in the magazine. There was no statutory system for recording and controlling temperatures, and cordite MD such as that on-board VANGUARD at the time of her sinking could be very unstable under some conditions, such as elevated temperature.
- Storage of coal sacks adjacent to P and Q turret handling rooms.

- Poor maintenance of the ventilation systems.

Regardless of the root cause, the enquiry found that the most likely cause for the loss of the VANGUARD was a fire starting in the 4-inch magazine, quickly spreading to P and Q magazines, resulting in a massive internal explosion and the loss of the ship. VANGUARD's 4-inch armament had been reduced and embarked 12-inch ammunition increased, resulting in some 4-inch magazines being used to store 12-inch cordite and projectiles. Based on inspection of debris recovered after the explosion, it was felt unlikely at the time that A turret magazine was significantly involved.

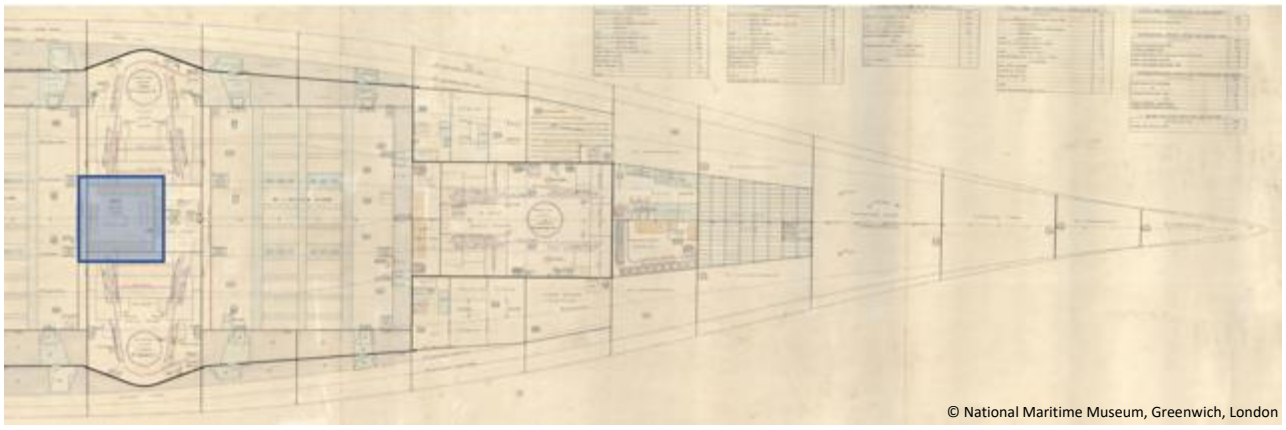


Figure 3: Ship's plan showing 4-inch magazine

Whilst the initial explosions were witnessed, there is no recorded evidence of anyone seeing VANGUARD sink.

1.2 The Wreck

Attitudes towards our underwater heritage and gravesites have changed considerably over the last 100 years. The wreck of the VANGUARD has been considered a war grave (in the official sense) since 1984 and designated a 'Controlled Site' since 2002, which means no visiting is permitted without Ministry of Defence (MOD) authorisation.

The MOD sold the salvage rights to the wreck of the VANGUARD, and there were two distinct periods of salvage.

1.2.1 Salvage by Nundy Marine Metals

In 1957 Nundy Marine Metals purchased the salvage-rights to the VANGUARD. Records[1] from the 1958/59 period report salvage of the 12-inch gun barrels, armour plate, propellers, general non-ferrous metals and the main ship's bell. This is consistent with evidence from

[1] http://www.gwpda.org/naval/vanfrank.htm

the wreck and suggests this was the most intense period of salvage undertaken on the VANGUARD.

1.2.2 Salvage by Dougall Campbell of Scapa Flow Salvage

By the 1970s Nundy Marine Metals had sold on their salvage interest to Dougall Campbell. Mr Campbell came on board MV HUSKYAN at various times during the survey of the VANGUARD and he was able to provide invaluable insight into some of the salvage activities.

Whilst in Scapa Flow, their main interest were the wrecks of the scuttled German High Seas Fleet and they only turned attention to VANGUARD if the weather dictated. The biggest item of recovered scrap was the inboard port propeller (no mean feat given the stern lays to port). Other small and general non-ferrous materials were also recovered.

Figure 4: Inboard port propeller salvaged in 1975

Increasing activity at the Flotta oil terminal and the later designation of the VANGUARD brought the era of salvage to an end.

1.2.3 Surveys to date

Finding accurate information regarding surveys conducted on VANGUARD is difficult. The report from the Court of Enquiry suggests divers were despatched to survey the wreck in the immediate aftermath of the sinking. Personal accounts of these divers are included in the book *Scapa Flow* by Malcolm Brown and Patricia Meehan.

Salvage divers will have conducted some form of survey as part of their work in the 1950s-70s.

The Royal Navy conducted a survey in 1975.

An ROV survey was conducted in the 1980s.

The vessel was dived during the 1970s, 1980s and 1990s by recreational divers, prior to designation as a 'Controlled Site'. There is an extensive online report written by Schleihaef, a diver[2], and some underwater photography exists from this period. Some artefacts were also recovered during this period by recreational divers.[3]

The Royal Navy placed an ensign in 2009, though it is unknown how much additional time was spent on the wreck site.

During the winter of 2016/17 the most extensive diver survey to-date was completed. This report covers the results and processes of this survey.

In January 2017, a multibeam survey of many of Scapa's wrecks, including VANGUARD was completed by the Danish Sea War Museum. Results of this have yet to be published.

1.3 Rationale for project

The underwater archaeology of Scapa Flow and beyond has long been of interest to divers. However, as many of these wrecks approach their 100th anniversary they are becoming of more interest to the wider population. Most people are familiar with major First World War land battles such as the Somme or Passchendaele, but are less familiar with our naval history.

Modern underwater stills and video cameras, together with associated software now allow us, as divers, to document wrecks in ways and at a level of detail not possible until very recently. Technology is allowing us to spend increased time underwater, meaning more survey time and more data to relay back.

The results of the HMS VANGUARD 100 Survey will paint the fullest picture yet in terms of data gathered, pictures taken and 3D visualisation accessible to those unable to dive on the wreck herself.

1.4 The Project

The aim of the diving survey is to tell the story of the ship at 100 years underwater, to document the ship using photography, videography and 3D photogrammetry and to conduct a full diver survey of the site. Due to the nature of the loss of the ship it was anticipated that the wider wreck site would be well dispersed. In order to identify all targets to be included in the survey a full sidescan sonar of the site was conducted before any diving took place.

The diving survey had two clear objectives: to gather as much information about the wreck today and to publish these results, and; to identify evidence from the wreck site that might

[2] William Schleihauf - http://www.cnrs-scrn.org/northern_mariner/vol10/tnm_10_3_57-89.pdf
[3] Artefacts were reported to the Receiver of Wreck in 1975

enhance the findings of the Royal Navy's Court of Enquiry towards determining the cause of the explosion that sank HMS VANGUARD.

2 Survey Methods

2.1 Overview

The VANGUARD 100 Survey utilised both in-water and remote survey techniques. Sidescan sonar survey techniques provided an overview of the site including the main wreck site and outer debris field. An in-water diver survey allowed detailed architectural features and artefacts to be located and documented. One focus was to conduct an explosive effects survey of the site to describe the layout of VANGUARD today, and to gain insight into the explosions that caused the loss of the ship and into the subsequent salvage techniques used. HD and 4K video were used for broad scale documentation of the site while underwater stills photography and 3D photogrammetry were employed for recording the site and her features.

The survey took place under special licence from the Secretary of State for Defence. The licence holders were Emily Turton and Benjamin Wade of Huskyan Charters, Stromness, Orkney. The licence period for the survey ran from 14th September 2016 – 28th February 2017. All diving took place from the dive charter vessel MV HUSKYAN, owned and operated by the licence holders

Twenty-two volunteer divers conducted over 500 survey hours on the ship. The survey was self-funded.

2.2 Sidescan

A remote survey was conducted prior to any diving by Kevin Heath of Sula Diving, using sidescan sonar. The purpose of this survey was to identify the extent of the main wreck site and outer debris field in order to plan the in-water diving activity. A digital scanning unit called a towfish is towed behind a boat in the water column above the seabed. The sidescan looks to both sides of the towfish over the seabed, producing easily interpreted images of the seabed and objects on it. This survey technique allows large areas to be covered quickly. A contact report detailing all the wreck, large pieces of wreckage and debris and smaller contacts was created. In total, 54 spearate targets were dived, identified and catalogued.

2.2.1 Technical Information

The sidescan used was a C-Max CM2 EDF. Two main surveys were conducted; a preliminary survey in order to gain a general layout of the site and a secondary survey, using High Frequency (HF) to provide more detailed imagery. In addition, a third survey was conducted in the vicinity of the steam pinnace, which had been obscured on the original surveys.

Details of the surveys were as follows:

Survey	Frequency (kHz)	Range (m)	Swath (m)	Ping Rate (per second)
Preliminary Survey	325	75	150	9.4
Secondary Survey	780	50	100	13.8
Pinnace Survey	780	37.5	75	17.8

2.2.2 Sidescan Data Processing and Analysis

All sidescan data was post processed using Sonarwiz 6 software, allowing mosaics and contact reports to be generated. Initial analysis of the sidescan data showed that the wreck site covers a large area and that the wreck is extensively broken. The scans revealed the vast majority of the wreckage lies within an area roughly consistent with the original dimensions of the ship and is orientated on an approximate bearing of 340˚T/160˚T. More detailed analysis of the scans identified likely candidates for the bow and stern, as well as numerous targets out with the main site, some of which were significantly large in size.

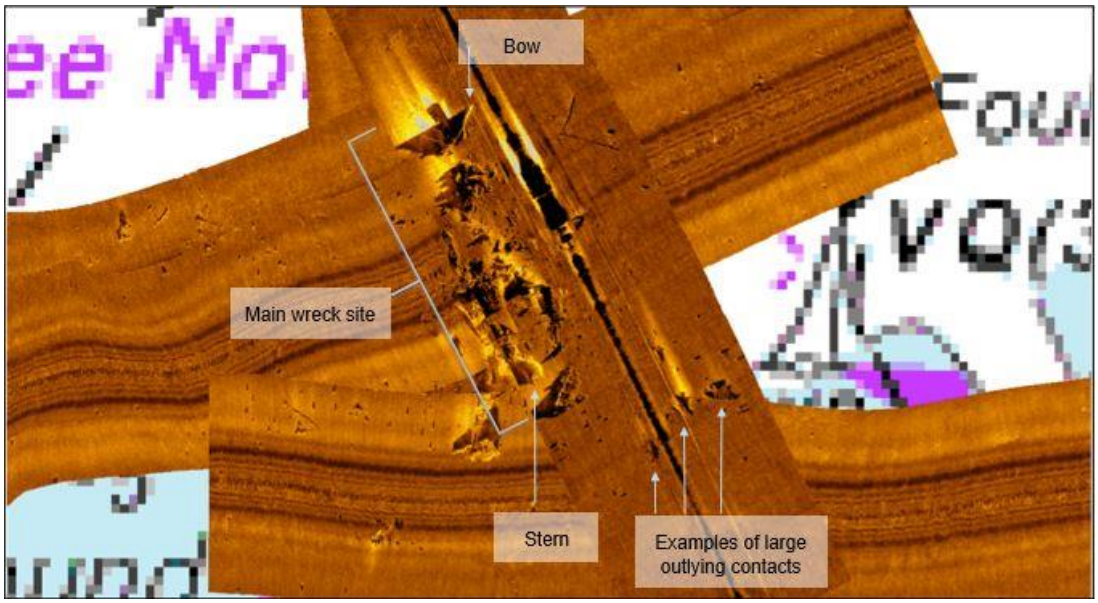


Figure 5: Sidescan mosaic of the wreck site, overlaid on a chart to aid orientation

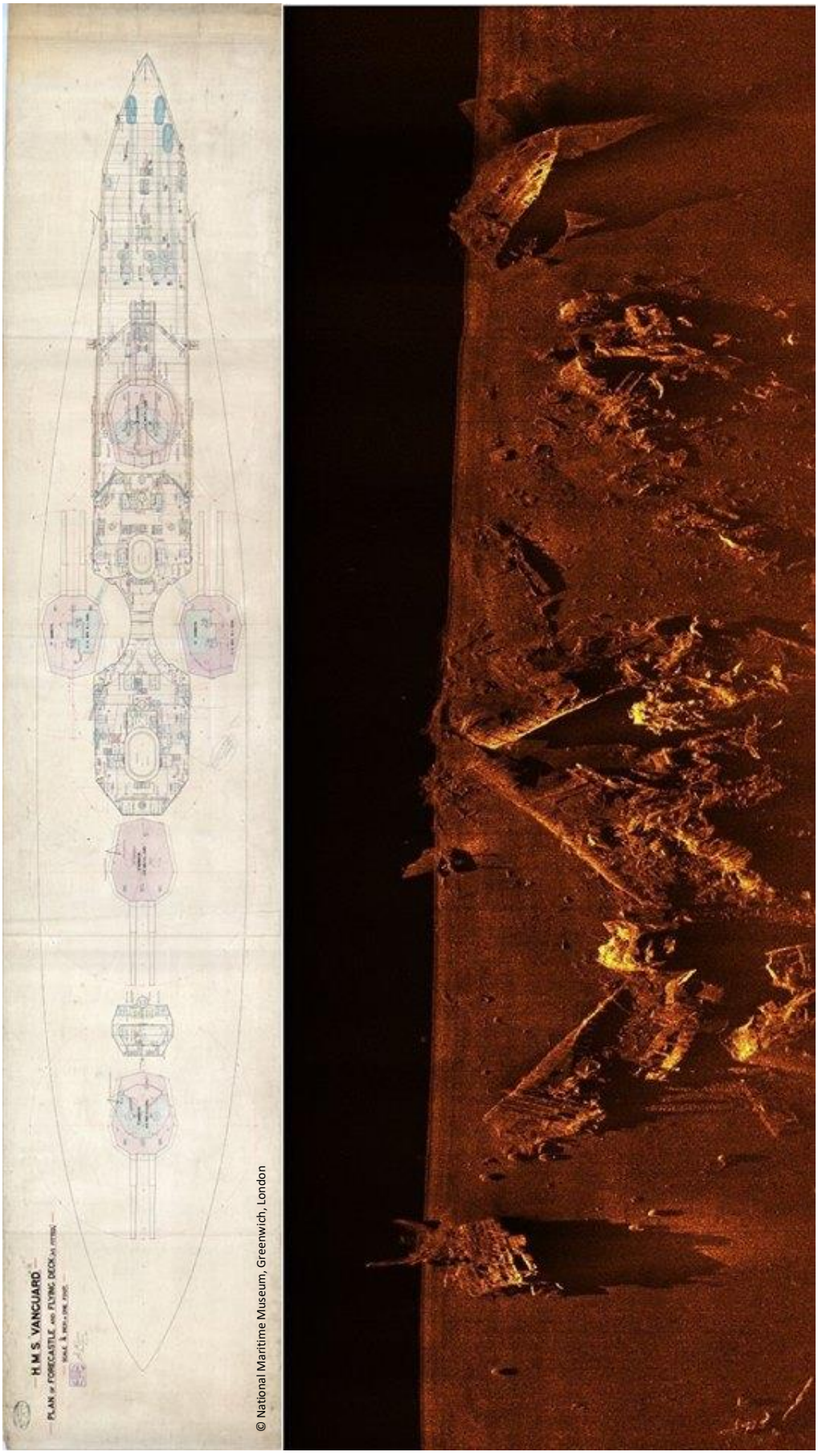


Figure 6: Sidescan sonar image of the main wreck adjacent to a plan overview

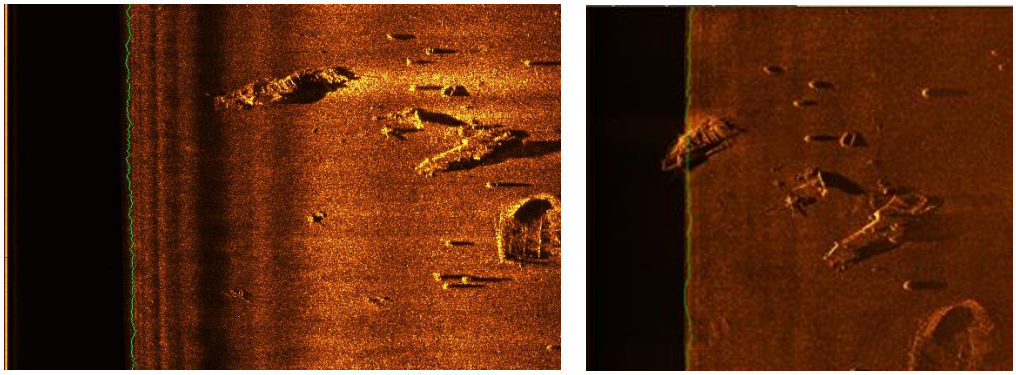


Figure 7: Sidescan imagery of the debris 1, 2 & 3 (325 kHz on left, 780 kHz on right)

As each target was identified on the sidescan imagery it was assigned a local number and name using the following convention:

Local name	Description
Debris xx	Large targets or isolated targets close to the main wreck site
Contact xx	Small targets located a significant distance from the main wreck site
Named targets	Specific targets that were easily identifiable from sidescan imagery (eg. 'BOW') or were part of the main wreck site and identified at a later date

There is no geographical order to the numbering, it is simply the order in which the targets were identified as analysis of the sidescans took place. For example, "38 – Contact 6" has the local number "38" and name "Contact 6," indicating it was the 38th target to be identified on the sidescans, and the 6th smaller target to be identified away from the main wreck site.

The diving team worked in close collaboration with Kevin Heath of Sula Diving to continually update the sidescan database and contact reports. This allowed for a flexible method of working and thus ensured all the data was collated and recorded as accurately as possible.

2.3 Diving Methods

The in-water diver surveys were conducted by a team of technical divers using closed-circuit rebreathers or open-circuit twinsets. The team consisted of professional underwater image makers, technical wreck divers, marine biologists and experts in munitions, weaponry and explosive effects.

The site has an average seabed depth of 32m and most dives were conducted with a 90-minute run-time, giving approximately 60 minutes of bottom-time. The use of technical diving equipment was key to enabling relatively long bottom-times, thus allowing large areas of the wreck site to be covered in a single dive.

2.3.1 Survey Design

2.3.1.1 Preliminary Diver Surveys

Working from the sidescan data, the initial dives concentrated on the larger targets of the main wreck site. The bow and stern were quickly identified and were allocated permanent shot lines to provide fixed datums. Working out from these datums, the divers undertook free swimming around the site and identified key features such as turrets, boilers, turbines etc. This allowed the divers to explore the site, identify navigational features and build a mental picture of the general site layout. After each dive the divers annotated their findings on a whiteboard, thus gradually building an overall picture of the site. Note, at this stage the features were annotated by their relative positions to each other, rather than a fixed measurement.

It became apparent during these initial dives that the site is very complex, with sections of wreckage a significant distance from where they should be located on the ship. In order to prevent diver disorientation and to aid navigation, a number of jackstay lines were laid. In addition, the boilers (which were scattered around the site and easily recognisable) had numbered markers attached to aid navigation and prevent duplicate identification. All survey material was removed at the end of the survey period.

2.3.1.2 Detailed Diver Survey

Once a basic understanding of the site had been achieved, work began to accurately record the site layout and document key features. In broad terms, the divers were split into two teams; a reconnaissance team to locate and identify parts of the wreckage, and a documentary team to photograph/video key features. For details of photography methods, see section 2.3.1.3.

The reconnaissance team's method of working was essentially to sketch or video (GoPro) parts of wreckage, then compare to the original ship's plans. Features such as side scuttles (portholes), hatches, vents, bilge keel, bollards, cleats, skylights etc. provided indicators to where certain sections of wreckage originated. For example, the arrangement of side-scuttles to square hatches varied throughout the ship, thus by counting the ratio of side-scuttles to square port hatches in a section of wreckage allowed the team to identify that particular section on the plans.

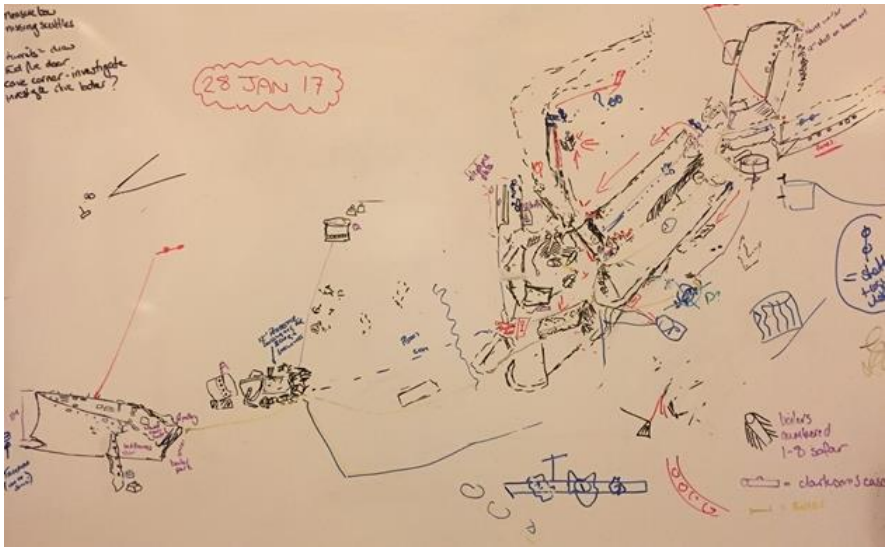


Figure 8: Initial sketch of wreck site from preliminary surveys

The site was divided into a grid to better manage survey activity and provide a logical means to catalogue and record data. The grid sections were defined as follows:

- Main Wreck Site: Main Forward, Main Centre, Main Aft, NE Wreck Site, SE Wreck Site, SW Wreck Site, NW Wreck Site

- Outer Wreck Site: NE Outer, SE Outer, SW Outer, NW Outer. (Note. the "Outer" sections are areas out with the Main Wreck Site sections, having the same centre point of origin, but extending indefinitely.)

In addition to the grid sections, certain areas of the main wreck site were allocated a specific designation. This was due to their relative size, location or composition. These were Bow, Stern, A-Turret & Bridge, Q-Turret, Debris 6, Debris 8.

A main datum line was laid on what was assessed to have been the approximate centreline of the ship; bow section to stern section, 340°T/160°T, 140m, marked at 10m intervals. The features that had been identified in the preliminary surveys were then measured with reference to this datum line, and the white board re-drawn to accurately reflect the site layout.

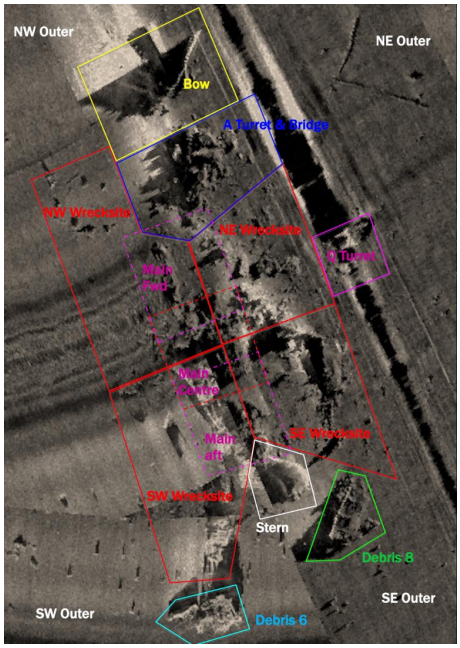


Figure 9: Wreck site sections

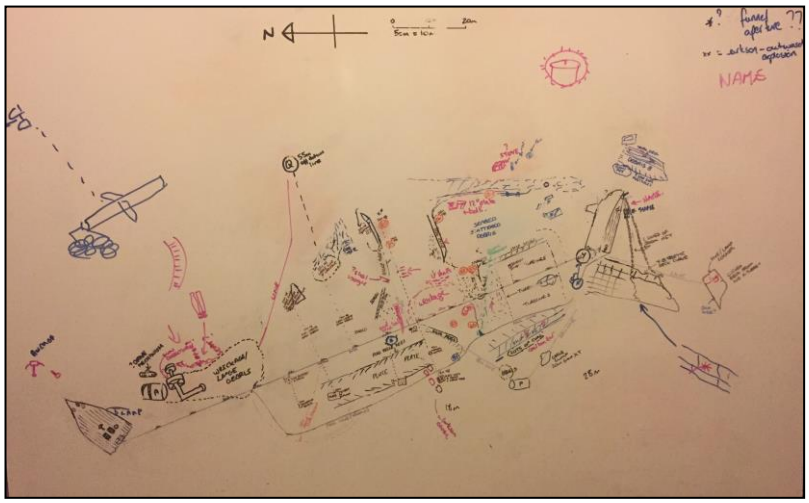


Figure 10: Updated site sketch, with features referenced to datum line

In addition to surveying the main wreck site, concurrent activity took place to identify contacts located in the outer wreck site. The majority of these contacts were located in isolation, thus navigating from the bow or stern shot lines would be challenging and time consuming. Instead, temporary shot lines were inserted on some of the outer contacts. Using the sidescan data, distance and bearings were obtained of the relative locations of nearby contacts, and vector diagrams generated. Divers could then cover a number of contacts on a single dive using underwater navigational techniques, without the need to dive every contact in isolation.

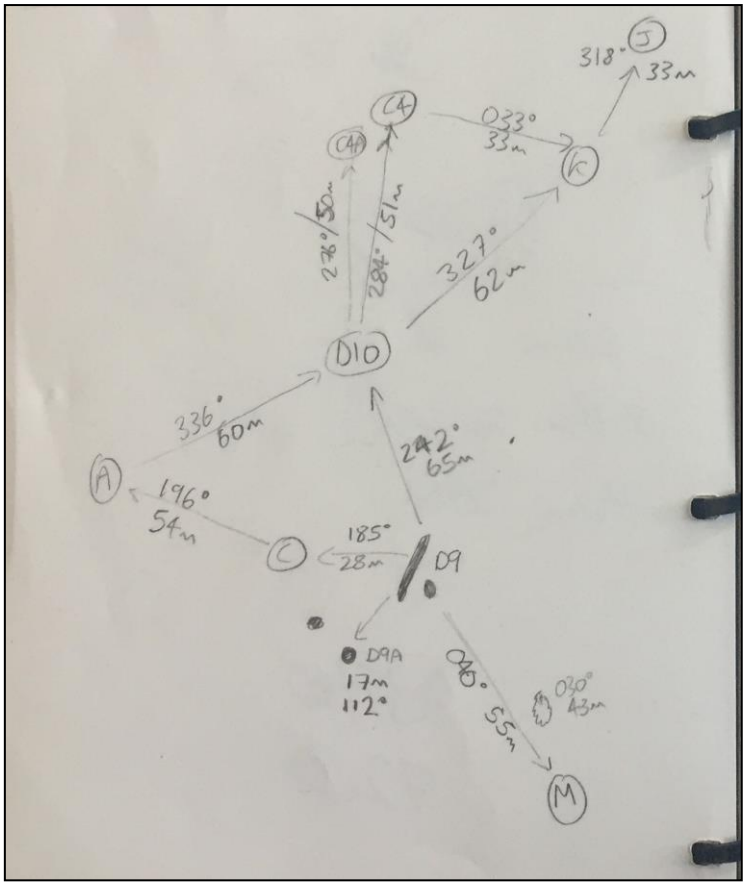


Figure 11: Example of vector diagram from diver's notes

Debriefs were held at the end of each day and the findings recorded in a working "ID Spreadsheet." This allowed data to be captured in a logical manner, as well as providing a platform to formulate future dive plans.

Local No.	Area	Area	Sidescan Run	Dived? Y/N	Identification and Notes	ID Confidence	Further Information or Investigation Required?
18	DEBRIS 1 (D1)	SE Outer	VANGUARD013 VANGUARD001 VANGUARD012	Y	Almost certainly one or both sides of the stern superstructure, 4-inch gun mount and associated cut out (BW has video), at least one Main Mast strut base (poss both).	Almost certainly	N
19	DEBRIS 2 (D2)	SE Outer	VANGUARD013 VANGUARD003 VANGUARD012	Y	Sick Bay skylight (this pinpoints this wreckage to aft stbd side), intact 4-inch gun (inc housing, barrel), large 'bathtub' type object. DEBRIS 2A: 4inch gun mount is on a plate with a scupper and square hole	Almost certainly	Y - where is the 4-inch gun from? Check video against plans.

Figure 12: Extract of working "VANGUARD ID" spreadsheet

Over the course of the survey the majority of targets identified in the original sidescans were dived, although some targets were omitted due to time constraints and prioritisation of other targets.

2.3.1.3 Photography and Videography

Both underwater stills photography and videography were used to document the wreck. The survey team included three professional stills photographers and one professional videographer. In addition, all survey divers carried small underwater video cameras to capture details during exploratory dives. This information was collated after each dive, enabling specific areas to be identified which were then documented by the professional image takers.

The photographers were chosen specifically for their different technical and artistic approaches to image taking in order to best capture the essence and detail of the VANGUARD at one hundred years underwater. It was important to gather large wide-angle images which gave a broad impression of the ship and to capture images which speak to a non-diving audience. Equally important was the documentation of small artefacts and specific details in the wreckage which help tell the story of life aboard. Other images were gathered to document the explosive effects of the loss.

The survey team included three photographers.

i. Marjo Tynkkynen

As a photojournalist, Marjo Tynkkynen records reality as it appears in front of her lens. Her images pursue the truth and penetrates through layers of time and history. This same approach was employed in photographing VANGUARD.

Photography equipment:

- Canon 5D mkIII body
- 16-35mm wide-angle lens & 15mm fisheye lens
- 2 x Canon Speedlite 580 EXII flashes
- Light & Motion Sola focus light
- Subal underwater housing for camera and flashes
- Diver lighting images with two Scubamafia, 300W, 150° beam (“The Beast”) floodlights

It was essential that each image captured enough information for it to be readily interpreted. Site familiarisation was key to this process. Consideration was also given to the direction and quality of light to create the desired ambiance and to identify which shapes and forms needed to be highlighted. Image composition also explored diver positioning in relation to the subject.

The method employed was as follows:

- The photographer used two powerful flashguns to light the image.
- A second diver operating two 300W floodlights, often from within the image.
- The second diver is often pictured within the image to provide scale and orientation.

All the lights used to capture the images help reveal the visible spectrum of light unaffected by the water. The colour was vital for the viewer to accurately interpret images, such as ageing wood, fresh rust, growth on different surfaces and marine life.

The interplay between the lighting diver and photographer was paramount, simple underwater verbal and hand signal communication allowed the photographer to fine tune the floodlight and diver positioning. However, pre-dive planning of each image was essential.

Camera and flashguns were operated on manual mode to find a suitable balance between ambient light and flash. Frequent rotation of the flash arm extensions both created top/bottom light and illuminated the diver in the image. Objects within the image were illuminated by the second diver's floodlights on full or half power depending on the distance to the camera lens, the degree of ambient light, and waterborne particulates.

ii. Bob Anderson

To provide a broad scale view of significant elements of the site, Bob Anderson photographed VANGUARD using a Nikon D500 in a NA-D500 Nauticam housing and a Tokina 10-17mm lens. Two Inon Z240s were occasionally used for close up images. Off camera lighting included Light and Motion Sola 500, 800 and 1200 lights and an Orca SeaWolf EX2260 Dive Light.

Due to low light conditions, images were almost all recorded using a camera supported on an underwater tripod with the intervalerometer set to trigger the shutter in a sequence of exposures at 6 second intervals. This allowed long exposures of up to 1/2sec at low ISO (typically ISO 200) and wide-open apertures (typically f3.5) to be recorded without incurring blur. Files were recorded in the proprietary Nikon NEF format then imported into Adobe Lightroom before being processed and exported.

Editing was largely restricted to colour balance changes, slight exposure changes, minor cropping, sharpening, and exporting in an appropriate jpeg image for wider dissemination. No major manipulation was undertaken, though some back scatter and other artefacts were removed from the image. The original files were retained for archiving.

The ambition was to record images that reflected as accurately as possible what the diver both saw and 'felt' while in the water. Long exposures allow ambient light to be recorded and give the images a green hue reflecting the conditions as seen by divers in the water. The wide angle aimed to give some indication of scale to this large wreck site. The subjects recorded were chosen to tell the story of the men and the machine lost from a personal perspective.

iii. Kieran Hatton

Working between these scales, Kieran Hatton's photography was broken down into two categories, identification and 'engaging' pictures, though these are not mutually exclusive. One of Kieran's aims was to integrate elements of the two previous approaches, capturing both foreground colour and ambient light: "*It is easy to create the perception that we are swimming around in the pitch black, which is often not the case. This was quite challenging, especially on some of the grey winter days*."

Equipment

- Sony A7rii, 10-18mm (fixed at 13mm) or 16-35mm; Nauticam housing
- Inon Z240 strobs x 2
- Kelden Luna 8 x 2
- Diver carried lights - Halcyon Focus, Light-for-Me Redstar Video, Light and Motion Sola x 2

In taking pictures for identification purposes the aim was to light the subject as well as possible, highlighting individual characteristics. Lamps, sighting binoculars, pottery are all excellent examples of this, the bigger picture is less important in this case. 'Engaging' pictures aim to show a part of the wreck that is of interest, but to also highlight that interest with the inclusion of a diver. The diver may be adding scale to the photo or enjoying the same focal point as the viewer. These are exemplified in the bow, stern, boiler and gun shots. Exceptions include challenging shots, such as the huge scale captured in Figure 28, which also clearly identifies the foremast bent at 90 degrees.

2.3.1.4 Photogrammetry

Creating 3D models of archaeological sites using structure from motion (SfM) photogrammetry is an established and well documented method (Green, Bevan & Shapland, 2014). The simplicity of the process and the availability of open source photogrammetry tools has facilitated the digital capture of heritage sites in and around Scapa Flow and other significant global sites above and below water. Commercially available tools (e.g. Agisoft Photoscan, Reality Capture and Remake) condense the processes involved into a single streamlined package that simplify the process further. Underwater sites present specific challenges for photogrammetry. They are often difficult to access, require specialist equipment (e.g. camera housings, lights) and diver training. When the site of interest is beyond the safe range of open-circuit scuba equipment or requires repeat diving, technical dive training, closed circuit rebreathers and mixed gas blends also become necessary.

Alternate remote sensing technology such as multibeam sonar and subsea laser are effective methods to survey shipwreck sites without diver involvement. However, these technologies do not capture colour information and the resolution and quality of the point cloud data produced can vary significantly. When good quality multi-beam sourced point cloud data is available, this can provide a base map to locate higher detailed and textured photogrammetry data. At the time of the site survey, this multibeam data of the site was not available.

Equipment

A range of camera and lighting equipment was used during the project. When possible, high-end mirrorless full frame digital cameras were employed with multiple light sources. This required the coordination of pairs of divers, one camera operator and one lighting operator in support. In sites with low visibility it is necessary to move the camera as close to the target object as possible. This reduces the volume of sediment in the water between the lens and the object. Therefore, high quality wide angle rectilinear lenses produce the best results, a wide field of view with minimal distortion.

The primary photogrammetry team was augmented by support teams operating action cameras (e.g. GoPro) with diving lights, who were tasked with investigating unidentified targets from the side scan images gathered at the start of the project.

- Sony A7SI full frame mirrorless camera with Vario-Tessar FE 4/16-35 ZA OSS rectilinear wide-angle lens (@16mm setting) In Nauticam NA-A7 underwater housing
- Lights: 2 x Keldan 8X Flux (13,000 lumens per light) supported with Norther Lights Scuba Supernova (30,000 Lumens)
- GoPro Hero 3 cameras in standard 40 metre housings with various dive lights

The SfM Process

SfM photogrammetry can be created from sequences of still images captured through time lapse or extracted from video footage. The method adopted for the project was to shoot HD video and sample images at 2-3 frames per second. This method allowed wider coverage and a greater selection of images to choose from. The process involves the identification of common features which are visible in an array of photographs. The photogrammetry algorithm identifies these common features and uses them to triangulate the position of the camera in 3D for each image. From these calculations the spatial position of features in the image can be calculated and a 3D model is produced.

There are a number of distinct steps in the process:

- Record an image sequence with overlapping images
- Photogrammetry algorithm calculates the relative spatial position of features and creates a sparse point cloud with camera positions
- Dense point cloud is calculated based on the camera positions
- A 3D mesh is created from the dense point cloud (optional)
- Images are projected from the camera positions to create a texture (optional)
- The combined mesh and texture can be exported for analysis, visualisation and animation.

There are two stages described are optional. It is possible to produce an accurate dense point cloud that accurately represents the topology and surface texture of the targeted object, features of VANGUARD in this case. The optional stages are necessary when the final output is designed for virtual reality experiences or game engine implantation. These technologies require point cloud data to be converted to polygon meshes.

Software and Post-Processing

SfM image processing was carried out using a combination of Agisoft Photoscan and Reality Capture software. Data was processed on site using an XMG U726 64GB, Intel core i7-6700K Notebook with two Nvidia GTX980M graphics cards, and followed up, post-survey, on HP workstations. The output from this is an extensive library of point cloud data visualising significant features from the wreck site. Data processed on the survey vessel was used to debrief the dive team and identify target areas for attention on the following day. Further processing was carried out overnight to inform the briefing sessions for the subsequent day's survey dives.

The SfM process: X Turret example

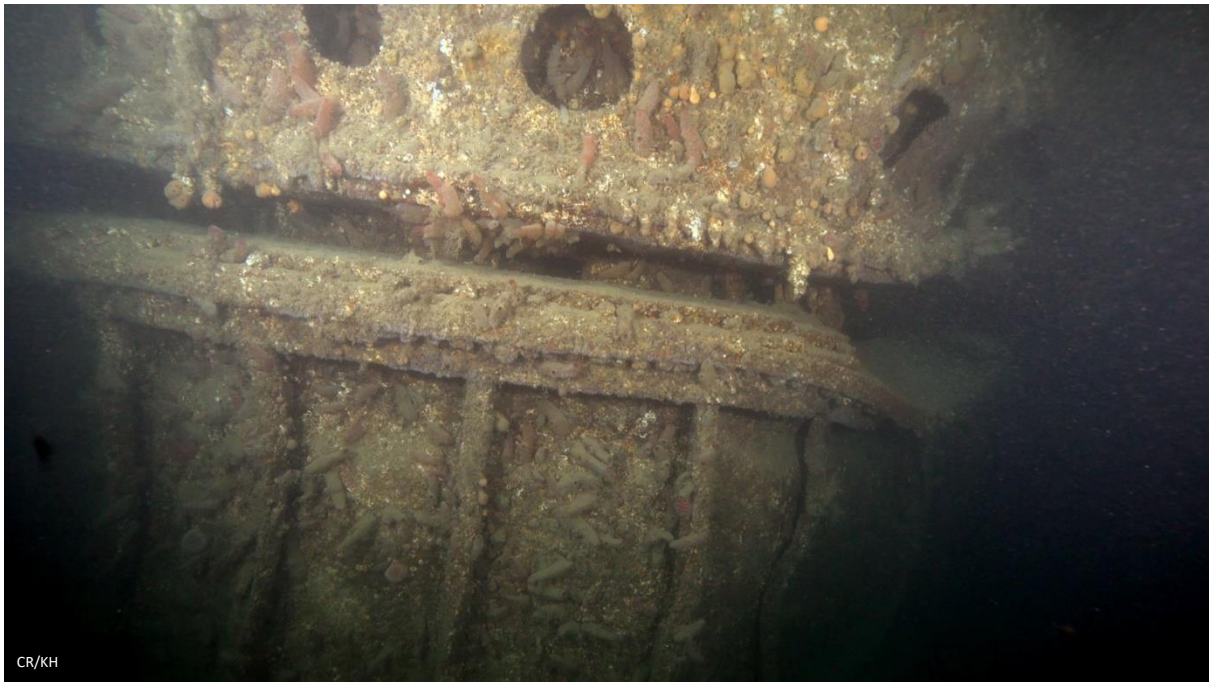


Figure 13: Image from diver recorded video sequence of X Turret

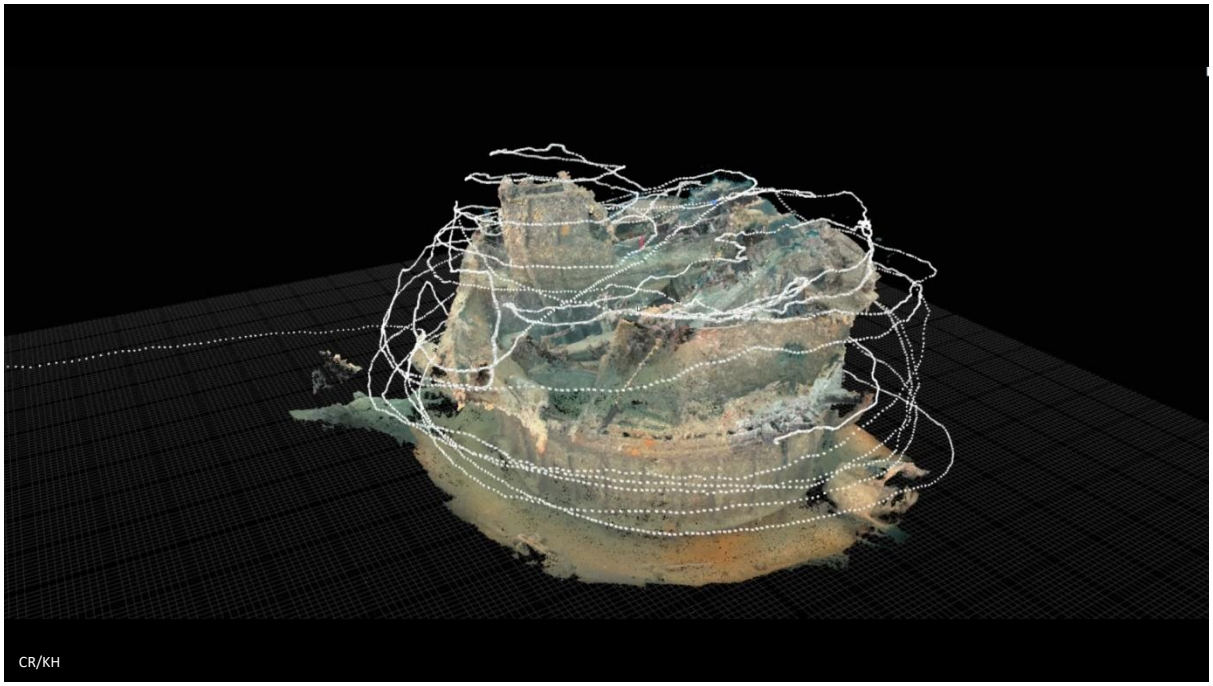


Figure 14: Point cloud of X Turret, each white dot represents the position of the camera as calculated from the image sequence

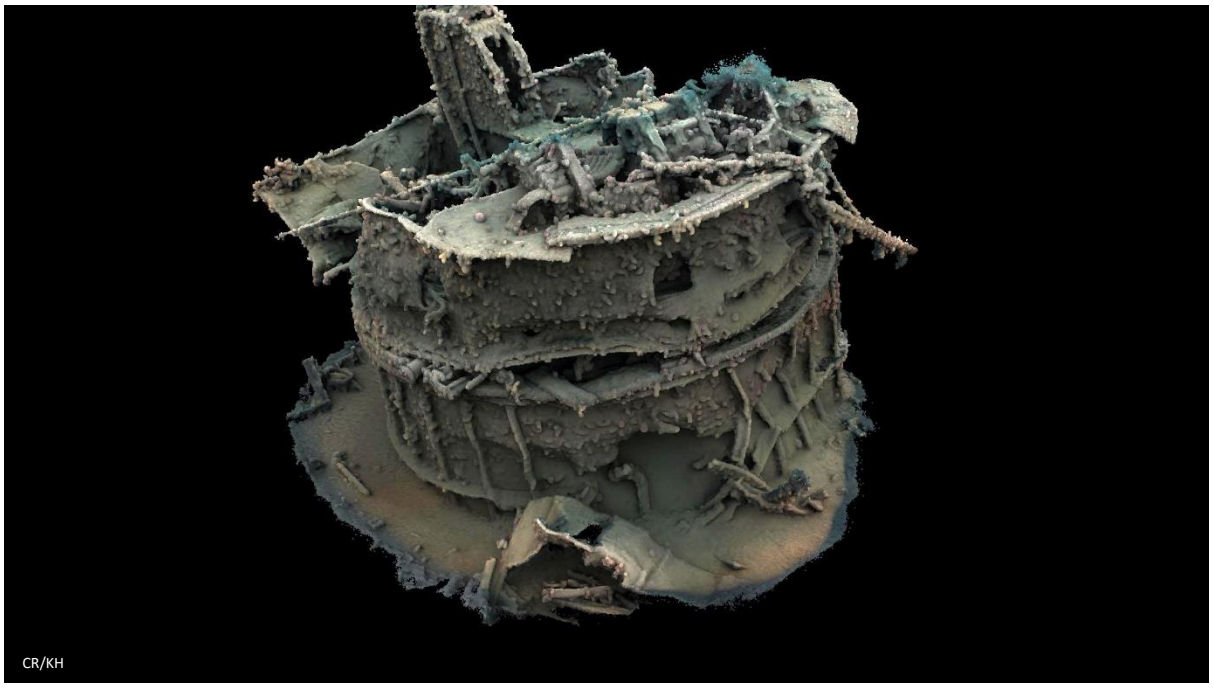


Figure 15: Dense Point cloud of X Turret rendered with lighting and visualisation techniques

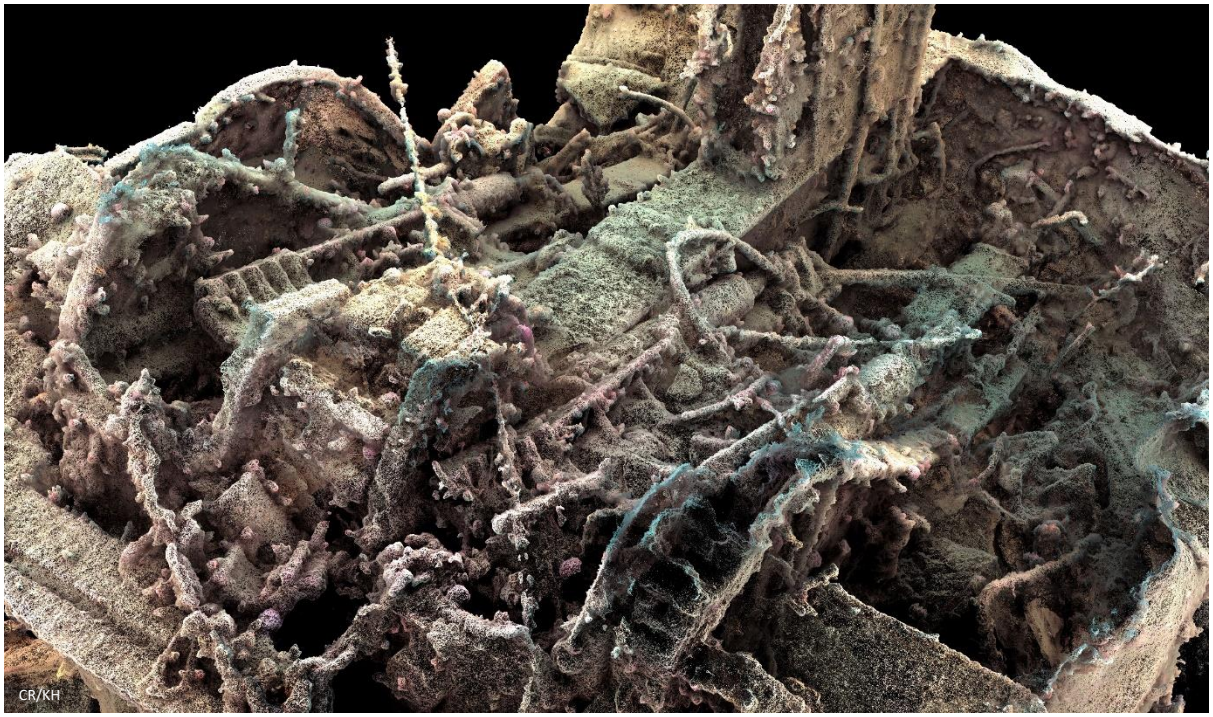


Figure 16: X Turret detail from dense point cloud

Data distortion

Data distortion can occur when aligning images over a large distance using a long image sequence. This is evident when the 3D model appears to bend when features observed in the original images show straight lines. The effect is caused by small incremental errors in the 3D calculation over distance. To counteract this problem, 1 metre rulers were weighted and placed on the seabed at key features of the wreck. These rulers can then be identified in the recorded image sequences and marked as straight edges with known length in the photogrammetry software. At smaller sites than VANGUARD it is possible to capture multiple rulers within the same image and thus avoid the data bending problem. Unfortunately in our case this was not practical.

To cover the full extent of the site would have required the placement (and recovery) of approximately two hundred rulers to cover all sections of the wreck. Therefore, the photogrammetry team focussed on capturing major features such as the bow and stern sections, remains of turrets and other auxiliary features and ensuring each section started or passed over at least one strategically placed ruler. The alignment of features over the full extent of the wreck site was ascertained through standard survey methods using rope lines and compass bearings, which were translated to a site drawing during de-briefing each day.

Target Features

Following initial mapping of the site to identify significant features, the photogrammetry team were initially directed to focus on the bow and stern sections, followed by larger sections of hull and the individual turret remains. For large features, multiple dives were required to allow full coverage. The image sequences were planned to include overlapping

sections which could be combined in the SfM process to give the best chance of matching scale and colour.

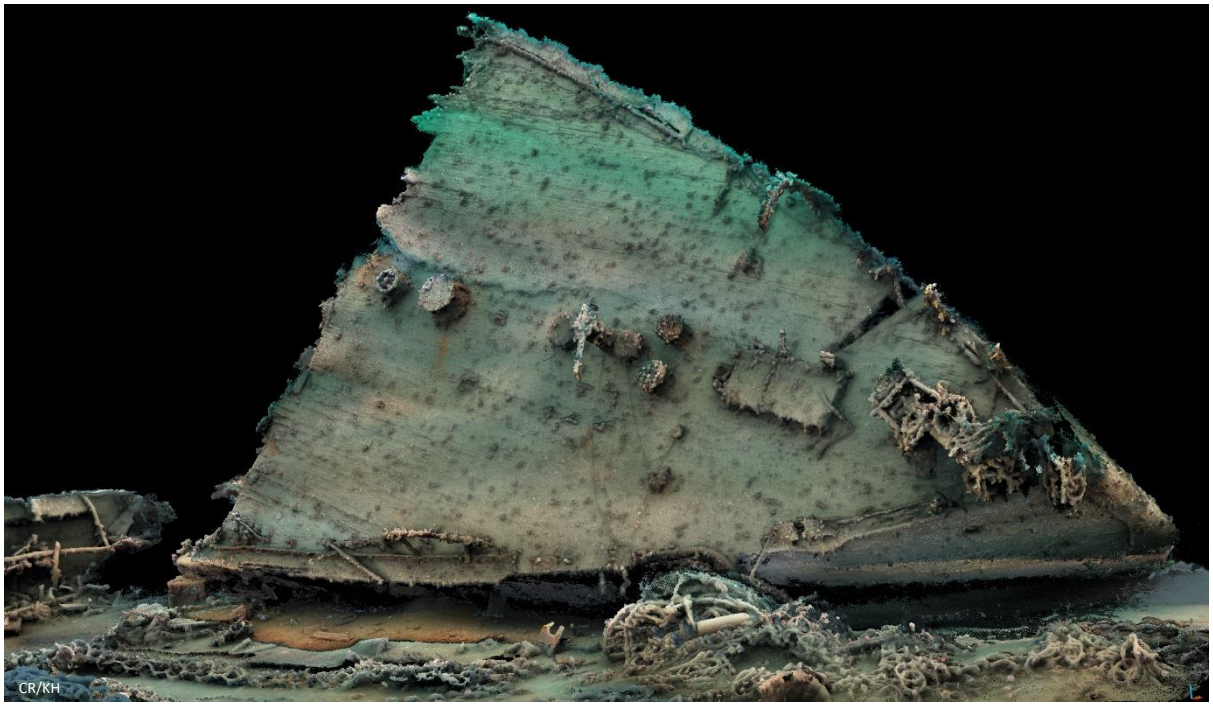


Figure 17: Dense point cloud showing the Stern section and torpedo nets on the seabed

Once the main features were captured, smaller targets were identified, including a ship's bell and an outlying anchor.

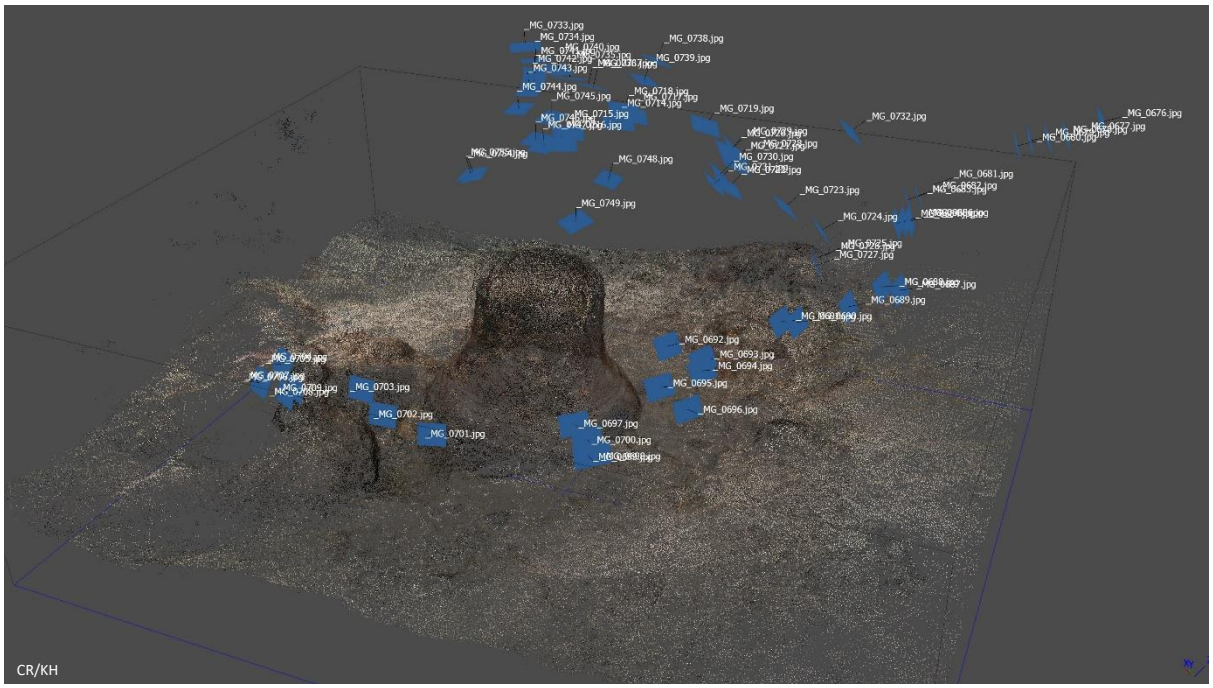


Figure 18: Dense point cloud showing a ship's bell with camera positions

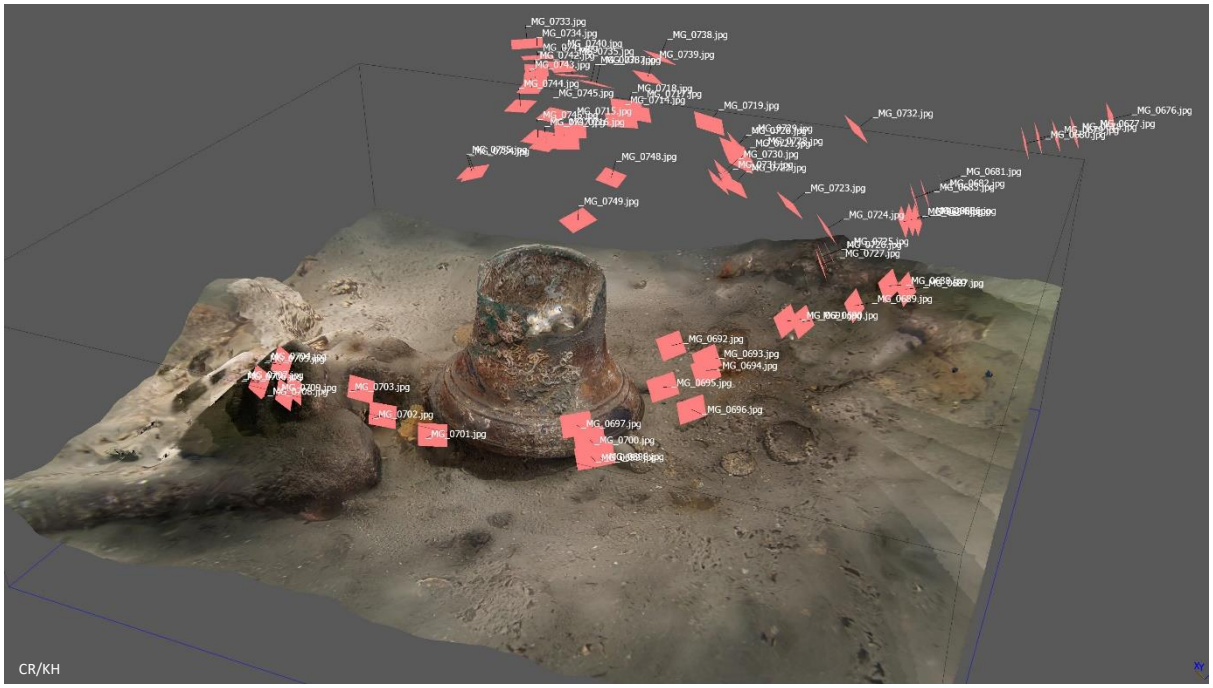


Figure 19: Textured Mesh showing a ship's bell with camera positions

Figure 20: Dense point cloud showing one of the ship's anchors

The 3D models produced through the structure from motion process can be viewed from any direction, allowing further analysis after completion of the survey. The process also removes any moving object from the image, so fish and detritus in the water column are not visible in the final 3D model. The critical element in the process is the initial image capture. When high resolution image sequences are captured with appropriate depth of focus (i.e. not blurred), they can be reused as photogrammetry algorithms improve in the future and computing power increases.

Data from future surveys could be combined with current data to extend coverage of the site and also show any changes occurring to the wreck over time.

3 Results and Discussion

3.1 Site Description - Overview

The wreck of HMS VANGUARD lies in approximately 34 metres of water 1.3 kilometres (0.72 nautical miles) off the north coast of the island of Flotta in Scapa Flow, Orkney. Examination of the site leaves no doubt that the ship suffered a catastrophic internal explosion. The ship's structure is very broken up and distributed over a wide area of seabed, far exceeding the size of the ship itself. The wreck site covers an area of approximately 132,300m². The wreckage positions have been identified and accurately chartered. It is noteworthy that some of the wreckage from VANGUARD lies out with the current exclusion zone.

For the purpose of the survey, the wreck site was divided into sections in order to best manage the survey activity, and thus provide for easier referencing of wreckage. To aid navigation on the wreck, a 140m datum line was laid (later removed) in a straight line from the Wardroom Skylight on the bow section, to Y Turret adjacent to the stern section, and divided the east and west wreck-sites. This datum-line is frequently referred to in the following descriptions of wreckage sections and key features.

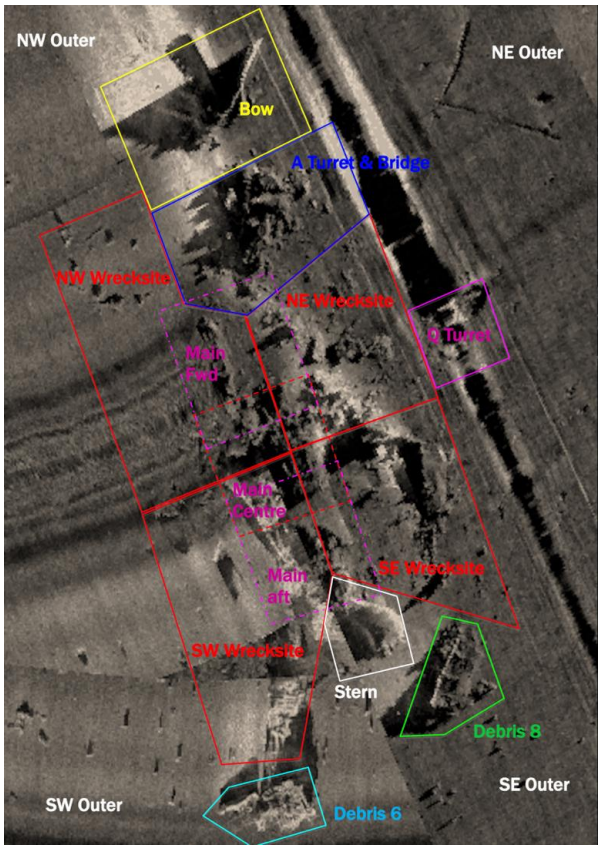


Figure 21: Wreck site sections

3.1.1 Anatomy of HMS VANGUARD

The main structure of HMS VANGUARD comprised eight decks within the hull and superstructure from the Hold at the bottom of the hull to the Shelter Deck at the top of the superstructure. Atop the Shelter Deck were the Bridge structures, funnels and masts. 228 keel frames are marked on the plans, equally spaced at approximately 2 feet 4 inches (0.7m) along the length of the ship and numbered from bow to stern. The deck level and frame numbers are used in the following table to identify the location of significant features in the ship.

Table: Significant Features located by Frame & Deck level

Significant Features	Frame	Distance from bow frame (m)	Deck level								
			Hold	Platform	Lower	Middle	Main	Upper	Forecastle & Flying Bridge	Shelter	Bridges
Officers' cabins	14 - 140	10 - 97					■				
Capstan Machinery	26 - 30	18 - 21		■							
Wardroom Skylight	36	25							■		
Underwater Torpedo Tubes	41 - 43	29 - 30		■							
A magazine	45 - 62	31 - 43		■							
Bilge Keels	46 - 184	32 - 128	■								
A Barbette	52	36					■	■			
Hydraulic Machinery Compartment	54 - 66	38 - 46			■						
Navyphone Exchange (Stbd)	56	39			■						
Conning Tower & Foremast	66	46								■	■
Boiler Room 1	72 - 88	50 - 61	■	■	■						
PQ Magazine	88 - 100	61 - 70		■							
PQ Barbette	94	65				■	■				
Boiler Room 2	100 - 120	70 - 84	■	■	■						
Boiler Room 3	120 - 140	84 - 97	■	■	■						
Crew Mess Space & WCs	140 - 214	97 - 149					■				
X Magazine	140 - 148	97 - 103		■							
X Barbette	144	100				■	■				
Engine Rooms	148 - 183	97 - 127	■	■	■						
Y Magazine	182 - 201	127 - 140		■							
Y Barbette	194	135				■	■				
Propellers Outer	210	146	■								
Propellers Inner	214	149	■								
Rudder Post	219	152		■							
Stern frame	228	162		■	■	■	■				

3.1.2 Main Wreck Site

The main wreck site incorporates the vast majority of the wreckage of HMS VANGUARD. The bow and stern are easily recognisable and located approximately 140m apart, the bow is north-northwest of the stern. The central area of the main wreck site comprises primarily of the structure and equipment from the Platform Deck and Hold Deck at the bottom of the hull, distributed on the seabed over an area consistent with the layout and size of the ship close to its mooring position. Details of the sections of the main wreck site are as follows:

3.1.2.1 The Bow

The bow of VANGUARD was ostensibly severed intact from the rest of the ship in the explosion. This is an exquisite surviving example of a dreadnought battleship bow – her iconic shape standing proud as a monument to a lost ship and the men who served on her.

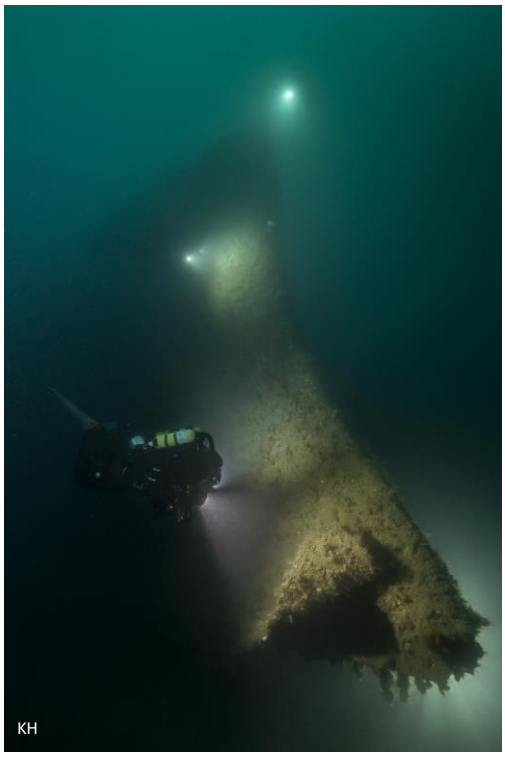


Figure 22: The Bow

Approximately 26m long and 11m proud of the seabed at its highest point, the Bow lies upright, pointing towards the north-northeast. It comprises of the hull structure above the Platform Deck up to the Forecastle Deck, and from the Wardroom skylight (frame 36 just forward of A Turret breakwater) to the bow post. The Forecastle Deck slopes downwards from the bow to the Wardroom skylight at an angle of approximately 25 degrees and is bent downwards at the hull break. The hull side plating is bent outwards on both sides at the hull break consistent with damage from an internal explosion and impact with the seabed. This has exposed the officers cabins on the port side of the main deck where white bed frames are visible.

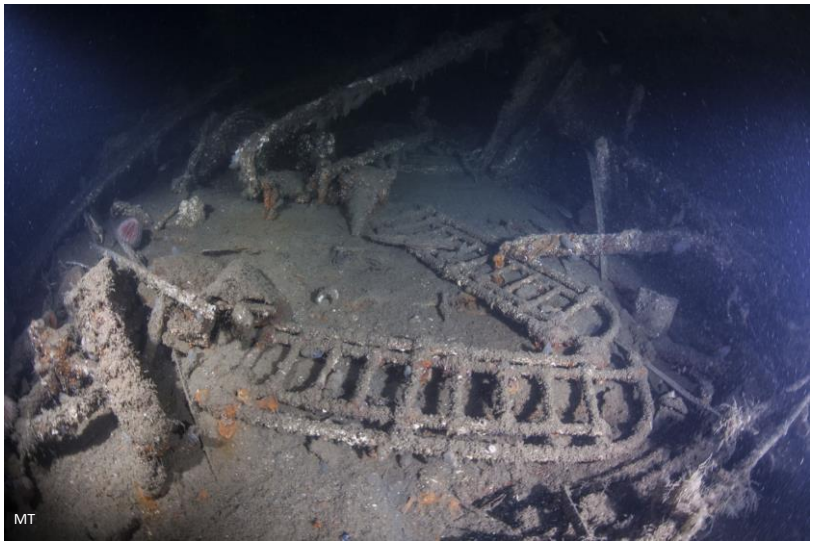


Figure 23: Officers bed frames

Other key features include teak planking on the Forecastle Deck, fairleads, side scuttles, the main capstan protruding from the deck, three cable holders (only 1 intact) and three hawsepipes.

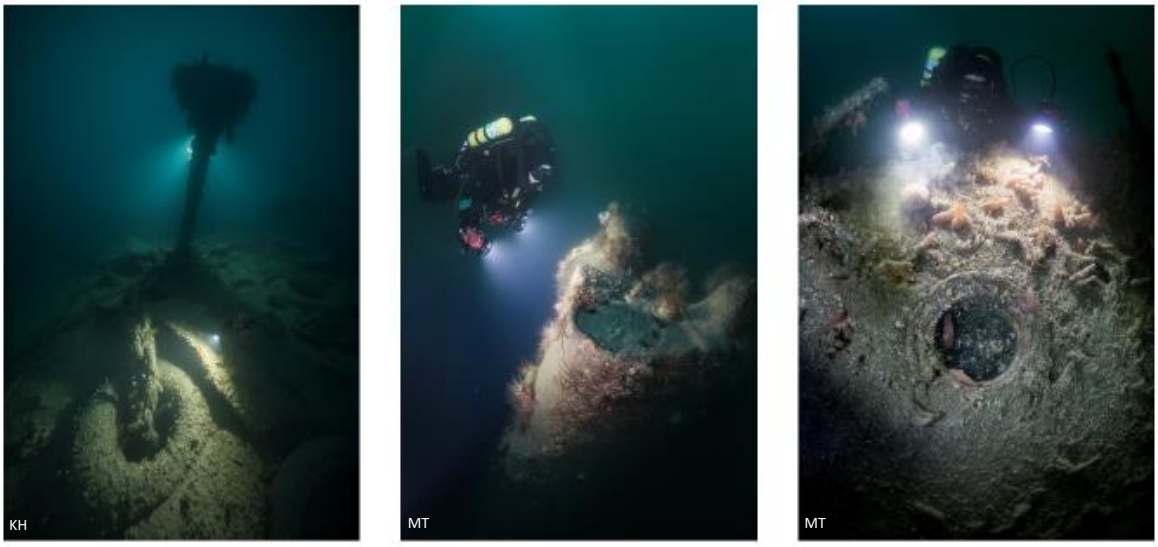


Figure 24: Main capstan protruding from the deck: the Bow; starboard side scuttle

Figure 25: Intact cable holder, forward skylight, teak decking and fairleads

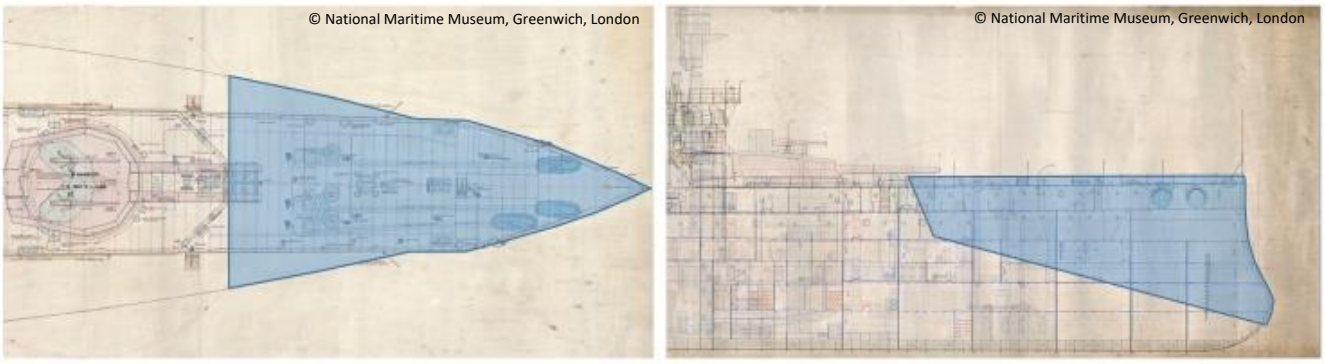


Figure 26: Bow section visible on the wreck site

3.1.2.2 A Turret & Bridge

This is a substantial collection of wreckage covering an area of approximately 40m by 15m. A 12-inch turret, almost certainly A Turret, rests on its side. Abaft of this is wreckage from the bridge area including the foremast, spotting top, fore bridge and compass platform, signal and conning tower. The wreckage also includes capstan machinery from the Platform Deck (frames 26-30) and the substantial double bottom hull plating on which it was mounted, and the submerged torpedo tube doors from the forward hull sides at Platform Deck level (frames 41-43).

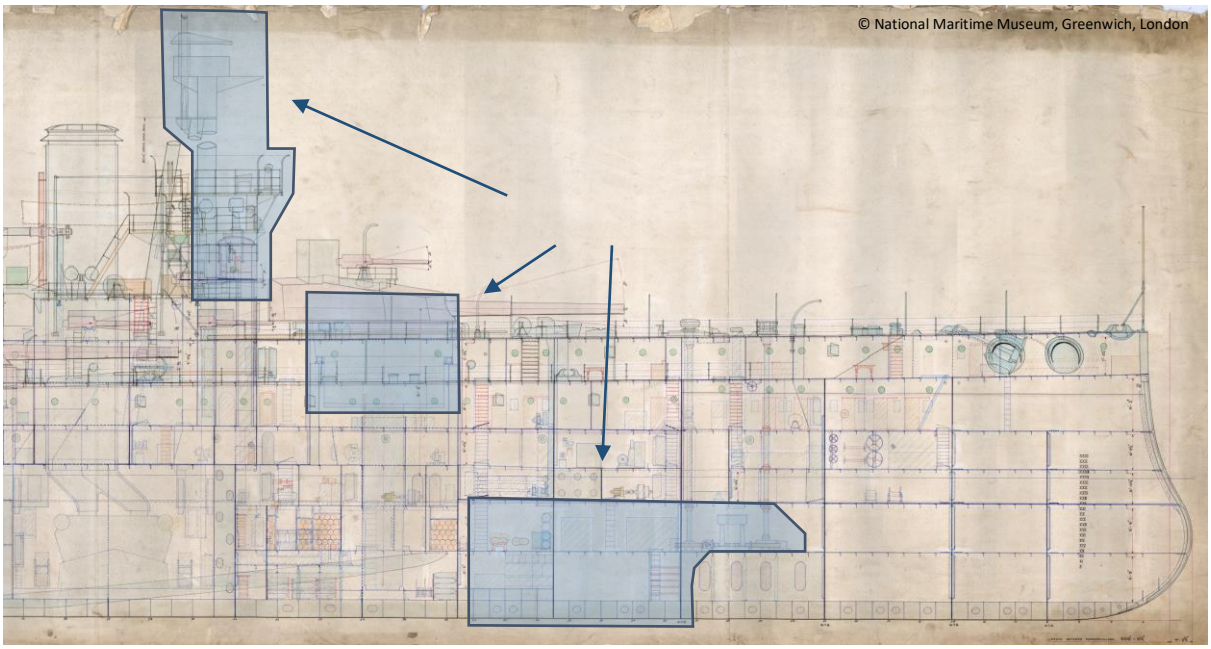


Figure 27: Extent of wreckage at A Turret and Bridge

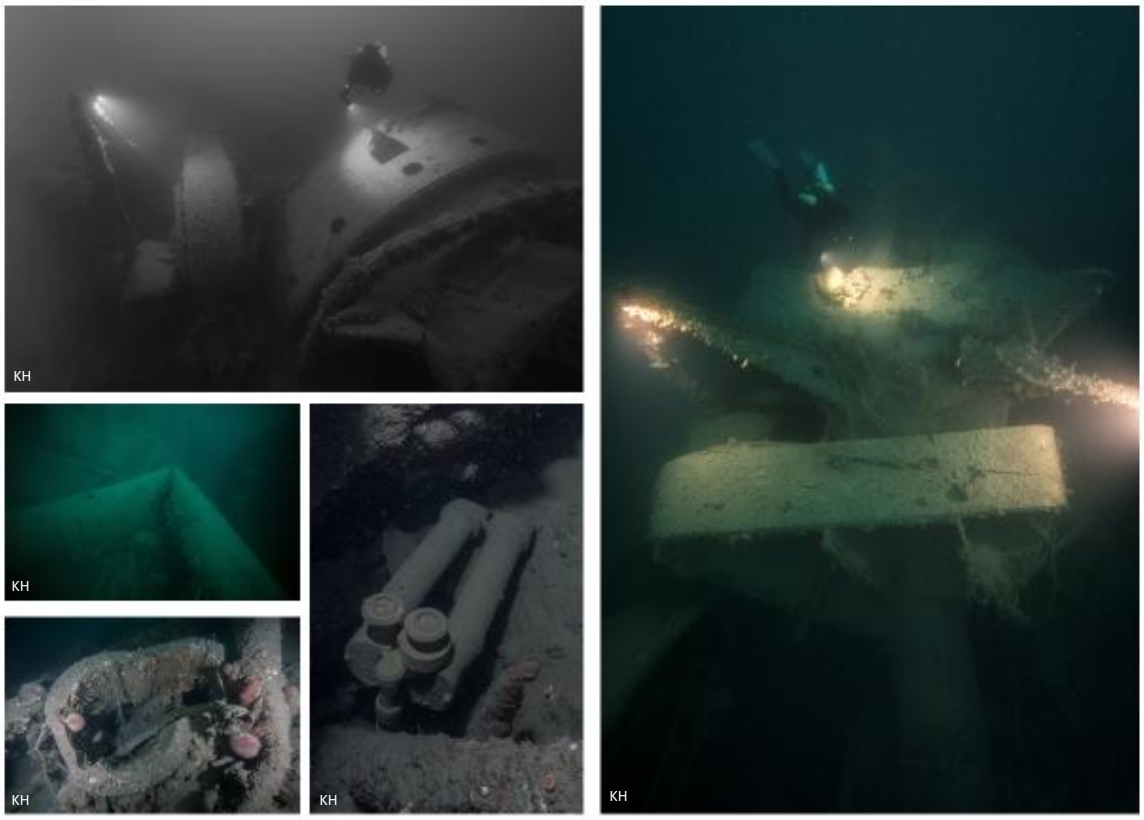


Figure 28: Clockwise from top left: A Turret and spotting top, foremast bent at 90 degrees, forward torpedo tube door, periscope binoculars, spotting top

3.1.2.3 Main Hull Wreckage

The main hull section extends from abaft the A Turret & Bridge section to the Stern and covers an area approximately 100m by 25m. Further divided into 3 sub-sections;

3.1.2.3.1 Main Hull Wreckage Forward

This area is dominated by a "gap" of approximately 35m where very little wreckage is present. This "gap" is characterised by:

- A slight depression in the seabed of depth ≅1m, absent of substantial pieces of wreckage.
- Randomly scattered sticks of cordite and small pieces of coal and shoe soles.
- 4-inch cordite cases heavily deformed and turned inside out by the effects of explosion, clearly identifiable by their corrugated case-form.
- 12-inch Clarkson cases empty of cordite, split open and with heat damage.

Figure 29: Explosively formed Clarkson Case; example section of the “gap" detailing shoe soles, coal and cordite; deformed 4-inch cordite case

This area corresponds to the position of A magazine, Boiler Room 1 and P/Q Magazine (frames 47 to 100).

The Main Forward area also contains a section of wreckage approximately 30m by 10m, which lies 5m to the west of the datum line. The underside has bilge keel visible, therefore this is likely hull section from the port side of the ship.

3.1.2.3.2 Main Hull Wreckage Centre and Aft

The centre section contains the wreckage of Boiler Rooms 2 and 3, and X Magazine. The aft section comprises port and starboard Engine Rooms on top of double bottom hull plating, and two 12-inch turrets (almost certainly X and Y Turrets).

The decks and hull from above the Boiler Rooms and Engine Rooms are absent. The hull bottom throughout these sections is heavily distorted. It is severed to the west side of the wreckage forward of X Magazine in the vicinity of Boiler Room 3. Ostensibly, the lower hull is lying on her port side. Ten metres to the east of the datum line the double bottom stands up to 5m proud and is bent upwards in the vicinity of X Magazine forming a sharp bend at the apex and a “tunnel” beneath the hull approximately 5m wide that extends, with reducing width and height, almost the full width of the hull, emerging to the severed west side of Boiler Room 3 adjacent to the port side bilge keel. The westerly edge of the wreckage at this point lies approximately 15m to the east of the datum line and is in the vicinity of Boiler 1. Sections of the main outer 10-inch belt armour lies horizontally just off the seabed.

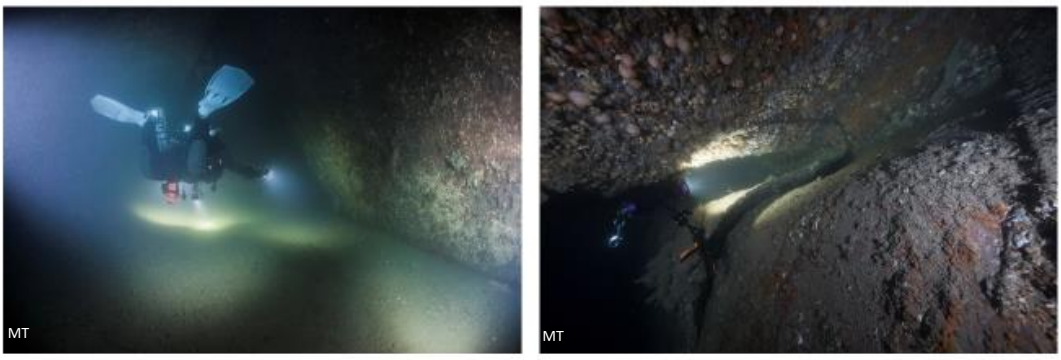


Figure 30: "Tunnel" beneath the hull and the sharp bend in the hull at the Apex

Figure 31: Sections of port side 10-inch armour belt and wooden lining

Eight boilers (survey numbers 1, 2, 3, 4, 5, 7, 8, 13) have been identified in this area, however, it is highly likely that more are buried beneath the visible boiler wreckage. Aft of the boilers and on the datum line is a circular ring structure likely to be deck structure for X Turret. X Turret is missing from this section and has been displaced towards the stern. To the west of the datum line is an area with a high concentration of 12-inch Clarkson cases. Four-inch propellant cases and 4-inch shells are also present. This is consistent with the X Turret Magazine and adjacent 4-inch Shell Room. To the east of the datum line is an area with multiple 12-inch shells, which appear to be 'stacked.' Based on location, this is highly likely to be the 12-inch Shell Room for X Turret (frames 139 to 148).

Figure 32: Babcock and Wilcox boilers

Figure 33: 4-inch shell & cordite; 12-inch Clarkson cases and 4-inch propellant cases; X Turret deck ring; X Turret 12-inch shell bin

To the west of the datum line is a large section of wreckage, measuring 18m long and standing 8m high. On one side of this section is a 13m section of bilge keel, on the other is a small compartment containing ladders. The layout of the ladders and dimensions of the space suggest this is highly likely a coal bunker. Therefore, this section of wreckage is highly likely port hull wreckage from the vicinity of the boiler rooms.

The forward Engine Room bulkhead (frame 148) is intact, along with associated machinery on the aft side. The longitudinal bulkhead between the port and starboard Engine Rooms is also partially present. The port Engine Room inner turbines, the cruising turbine and low pressure ahead & astern turbine are in place and almost intact. The two portside outer high pressure turbines were not located. These may be buried below the low pressure turbine or they may have been salvaged. The starboard Engine Room is much more broken, with only splintered turbine blades visible and no sign of intact turbines. Anecdotal evidence refers to salvaged condensers from VANGUARD having quantities of cutlery concreted to the condenser casings. Cutlery was also located in the Engine Room wreckage. This may have originated from the Main Deck above the Engine Rooms where the Petty Officers Mess and Seamen's Galley and Admirals Galley were located.

Figure 34: Starboard Turbine Room splintered turbine blades; port turbines; cutlery

3.1.2.4 Stern Section

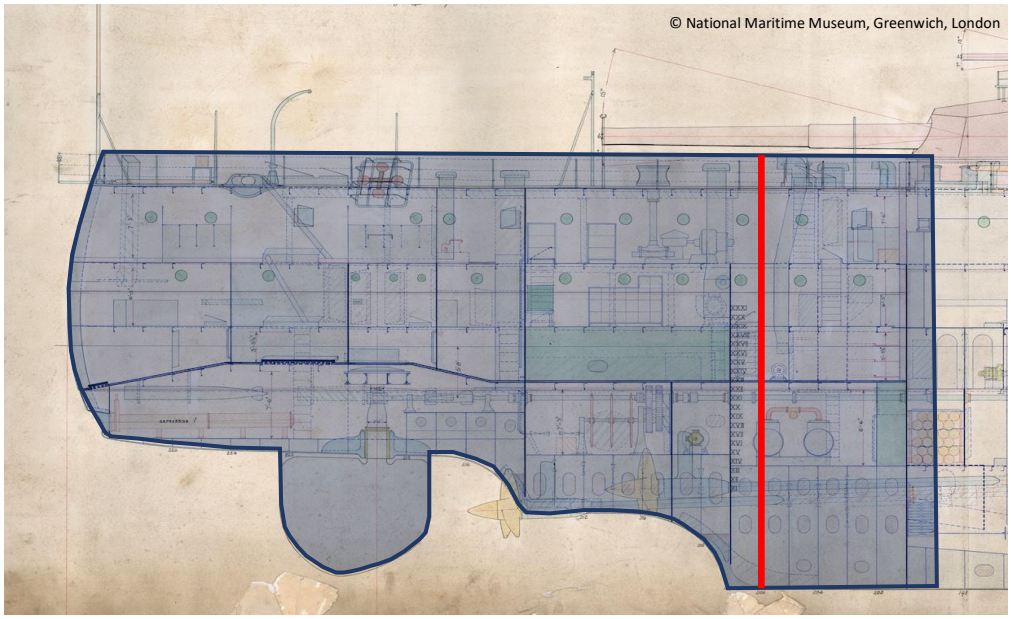


Figure 35: The extent of the intact stern section. The red line denotes the break in the deck

The stern section is located immediately south-east (aft) of the Engine Rooms and Y Turret. It remains ostensibly intact abaft frame 206 (aft of Y Turret) and resting on its port side. The name "VANGUARD" can still be read on the port side. The Stern is orientated approximately east/west, with the sternpost to the east. The teak on the Upper Deck is in remarkably good condition and is bent downwards at approximately 90 degrees just aft of the barbette

aperture at the “break” in the hull. This bent section of upper decking contains a distinctive curved edge, that is almost certainly the deck aperture for Y Turret barbette (frame 200). Adjacent to this, Y Turret sits upright on the seabed. The gun house and barrels are missing. On the seabed sits the only 12-inch barrel located during the survey. It shows signs of salvage – the barrel is broken and the base of the barrel is stuck in the seabed, but has salvage chains wrapped around it. X Turret sits 10m to the northwest from Y Turret. It is also upright with gun house and barrels missing. The turret has been displaced from its original position forward of the turbine rooms.

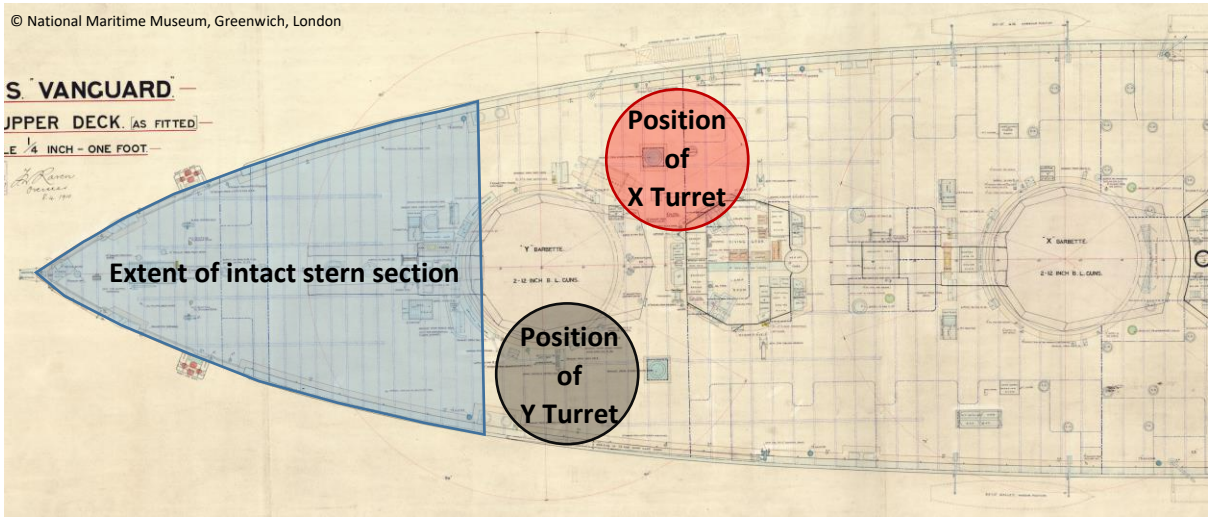


Figure 36: Position of X & Y Turrets in relation to the stern

Both rudders are visible, although the port rudder is partially buried in the seabed. None of the four propellers are visible. Severed A frame brackets for both starboard propellers and the port inner propeller are visible, attached to the hull and keel. The two inner propellers are known to have been salvaged by Nundy and Campbell, it is presumed that the third accessible (outer starboard) propeller was also salvaged by Nundy with the fourth propeller likely still buried under the stern section itself. Two guns are present on the Upper Deck of the stern section; a Hotchkiss gun located at frame 216 (not on the original plans, probably retrofitted for signalling and saluting) and a 3-inch 20 cwt Mk II quick firing high angle gun mounted on the very stern for engaging aircraft. The exit port for the rear torpedo tube is visible, with a large hole in the hull immediately below, which allows viewing into the Stern Torpedo Compartment. No torpedo tube or associated equipment is present. The larger hole is highly likely exploratory, made by the salvagers to locate the aft torpedo tube, but it would not have been large enough to remove the torpedo tube itself. It is therefore likely that the torpedo tube had already been removed from VANGUARD during a refit period. This is confirmed in the St Vincent Class Cover records held at Greenwich Maritime Museum.

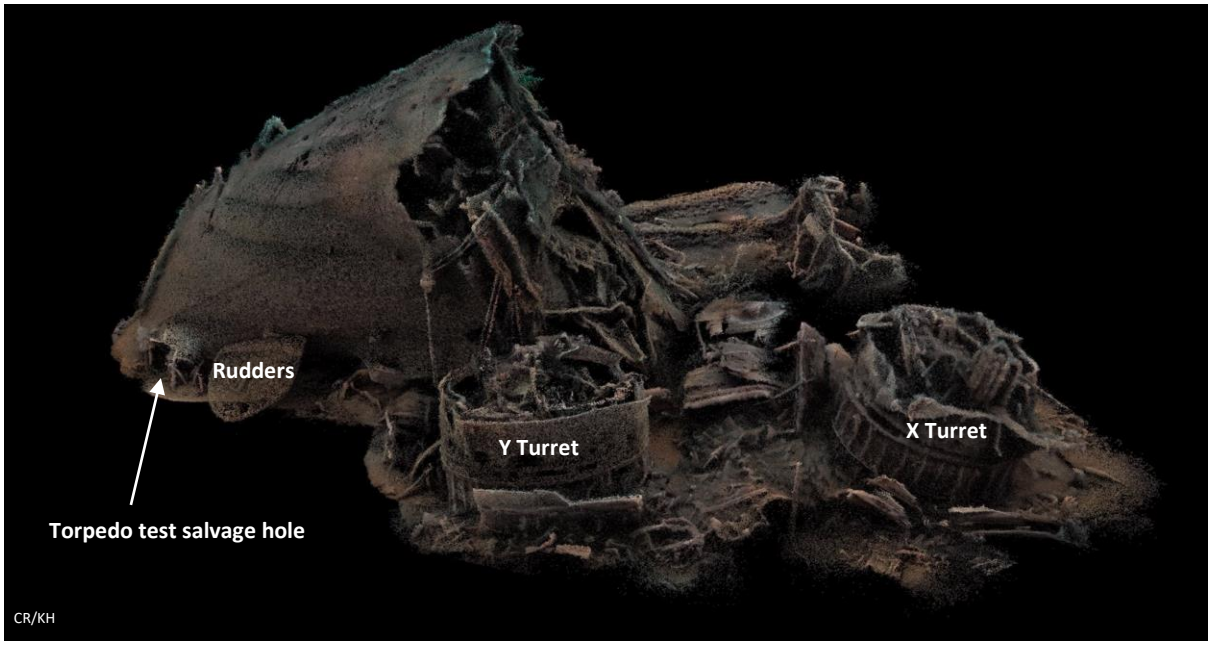


Figure 37: 3D photogrammetry stern image

Figure 38: Y Turret teak deck ring; 90 degree snapped deck; identifying capstan and vent at snapped stern section; torpedo salvage hole; stern name lettering; Hotchkiss gun

3.1.2.5 Turrets

All five 12-inch gun turrets are located on the wreck site. All turrets are absent their shield and barbette armour and gun barrels presumably salvaged. The remaining turret structures measure approximately 7m diameter by 5m tall, and comprise of cylindrical barbette with training rack and turntable roller bearing, cylindrical rotating platform with ammunition handling room beneath, equipment to support and operate each gun barrel including cradle, trunnion, slide, loading arm & chain ram, recoil cylinder, curved loading cage track, training and elevating machinery.

It has not been possible to identify distinguishing features of the turrets to positively identify their original location and identification in the ship. The turrets are therefore identified by their location on the wreck site relative to each other and nearby wreckage, taking into account the effects of the explosion.

3.1.2.5.1 A Turret

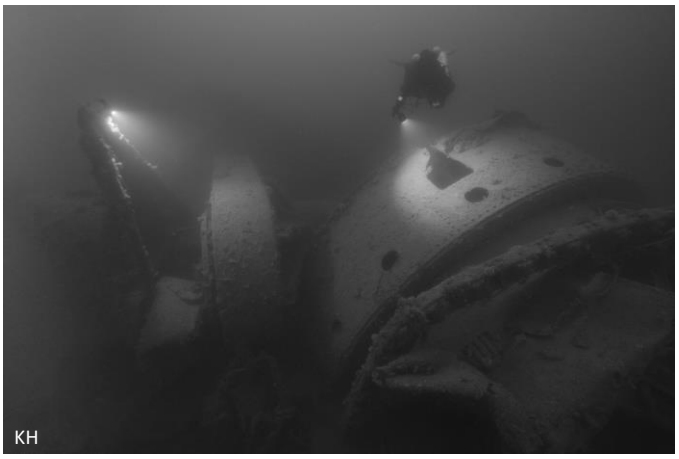


Figure 39: A Turret

A Turret is located in the A Turret & Bridge wreckage on its side on top of other wreckage. The barbette is broken open to reveal the training rack. A Turret lies approximately 15m due east of the current position of the bow.

3.1.2.5.2 P Turret

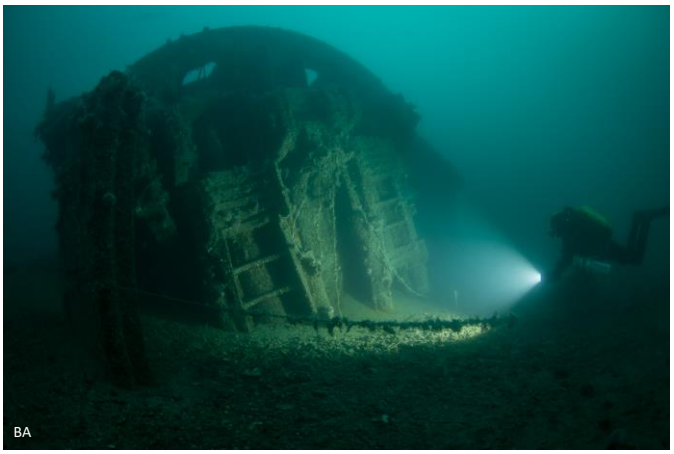


Figure 40: P Turret

P Turret is located on the seabed approximately 20m to the west of Boiler Room 3, approximately 35m south-southwest (aft-port) of its original position in the ship. P Turret lies on its side and some shield armour remains jutting out of the seabed.

3.1.2.5.3 Q Turret

Figure 41: Q Turret

Q Turret is located on the seabed approximately 55m to the east of the datum line. Q Turret is the only turret that is inverted, and lies approximately 45m east northeast (directly to starboard) of its original position in the ship. Approximately 25m west southwest of Q Turret is its ammunition hoist tube, which shows substantial crush damage typical of the effects from explosion.

3.1.2.5.4 X Turret

Figure 42: X Turret

X Turret is located in the Main Aft section and is in the best condition of the five turrets. It lies upright on the seabed approximately 10m to the west of Y Turret. X Turret lies approximately 25m south-southwest (port-aft) of its original position in the ship.

3.1.2.5.5 Y Turret

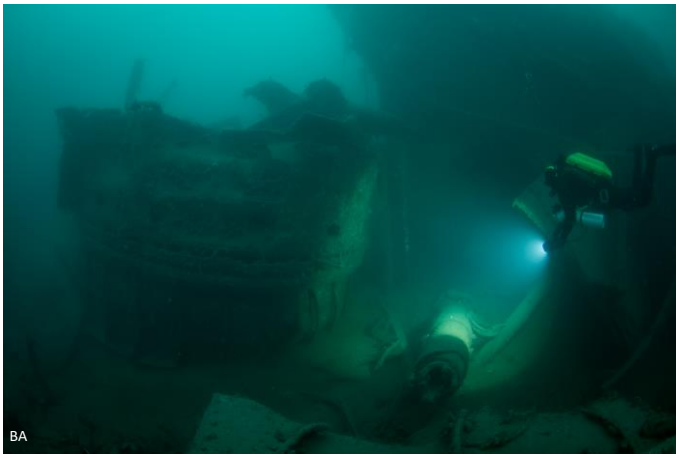


Figure 43: Y Turret & severed gun barrel

Y Turret is located in the Main Aft section. It is detached from the stern and lies upright immediately south of the Engine Rooms. It is in approximately the same position relative to surrounding wreckage as it was in the ship.

3.1.2.6 NW Wreck site

This area is relatively sparse of debris in comparison to other areas. Although there are some pieces of debris up to 3m in size, nothing was significantly identifiable. The area has numerous pieces of crockery, likely from the officers quarters.

3.1.2.7 NE Wreck site

This area is characterised by a large amount of scattered and broken debris, mainly consisting of twisted steel plating and pipes. Most of the debris is small in size, although there are two larger sections located 20-25m east of the datum line. One of these sections contains a magazine hoist trunk and revolving shell bogie, likely associated with Q Turret. To the east of the datum line there is a section of ship's hull, approximately 30m in length, orientated east/ west, with 22.3m of bilge keel including the tapered forward end. This is almost certainly from the starboard hull, between A Turret and Q Turret, having been thrown here by the force of the explosion. In addition, two boilers (survey numbers 9, 10) are located in this area. Both of these boilers show compression damage consistent with an explosion.

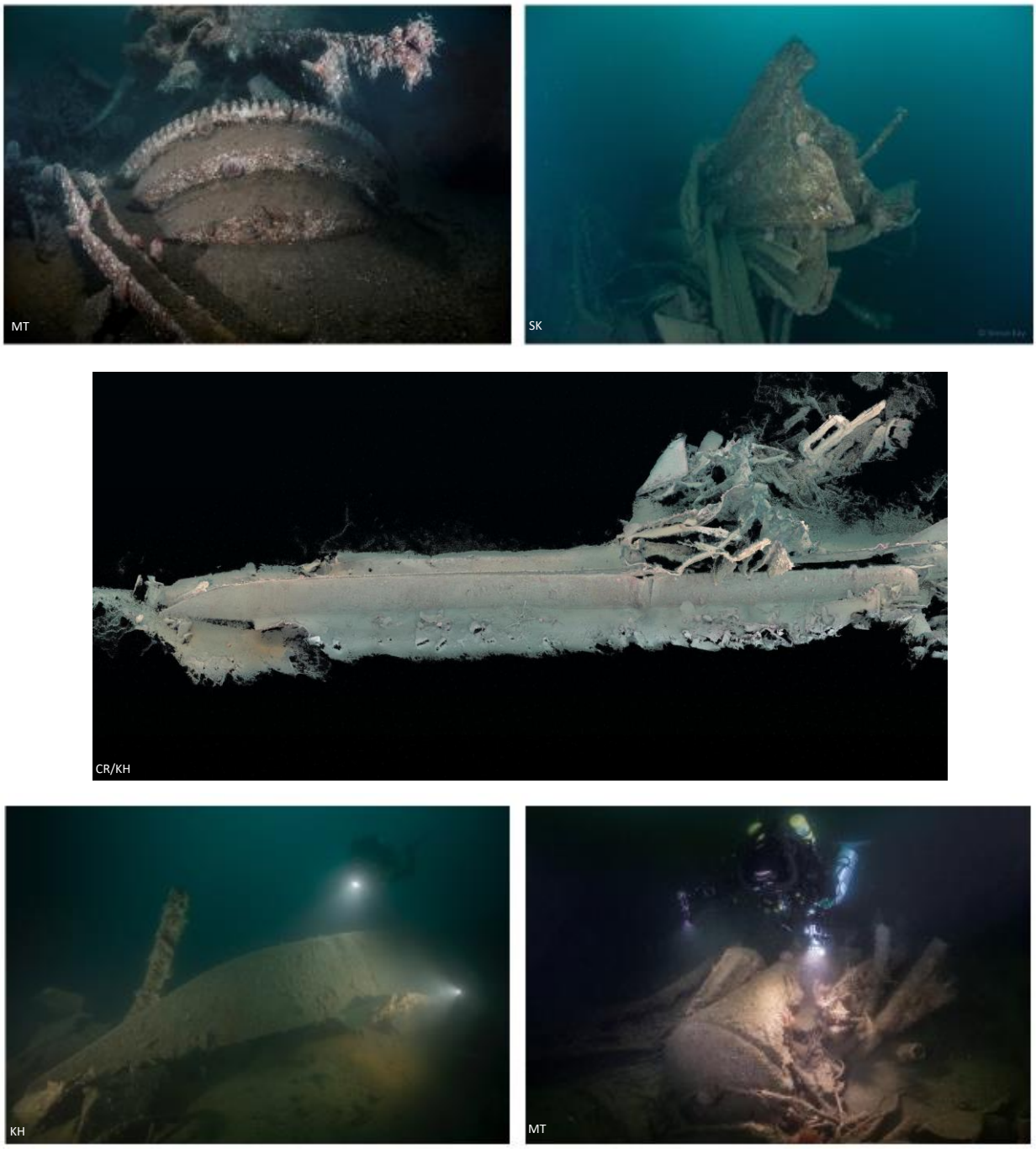


Figure 44: NE wreck site wreckage. Top: Q Turret shell bogie upper rack; Q Magazine hoist trunk. bottom: starboard side forward bilge keel; 3D image of bilge keel wreckage; Boiler 10 showing compression damage

3.1.2.8 SE Wreck site

This area contains a very large section of wreckage, likely associated with the starboard hull between Q and X Turrets. The wreckage begins approximately 10m east of the datum line and extends a further 20m before bending at 90 degrees to the south for a further 30m. At the corner a section of 10-inch armour plating protrudes from the seabed. Evidence of coal bunker structures are present, including large amounts of coal. There is a 30.4m continuous section of bilge keel visible, providing evidence for this wreckage being hull section. Two

boilers (survey numbers 6, 11) are located here. Other features in this area include a range finder and a lay shaft from one of the engineers workshops. The remains of musical instruments were located on the seabed, specifically the body of an oboe and clarinet and the remains of a brass instrument, probably a euphonium given the size of the valve block. A rifle lies in the vicinity of the musical instruments.

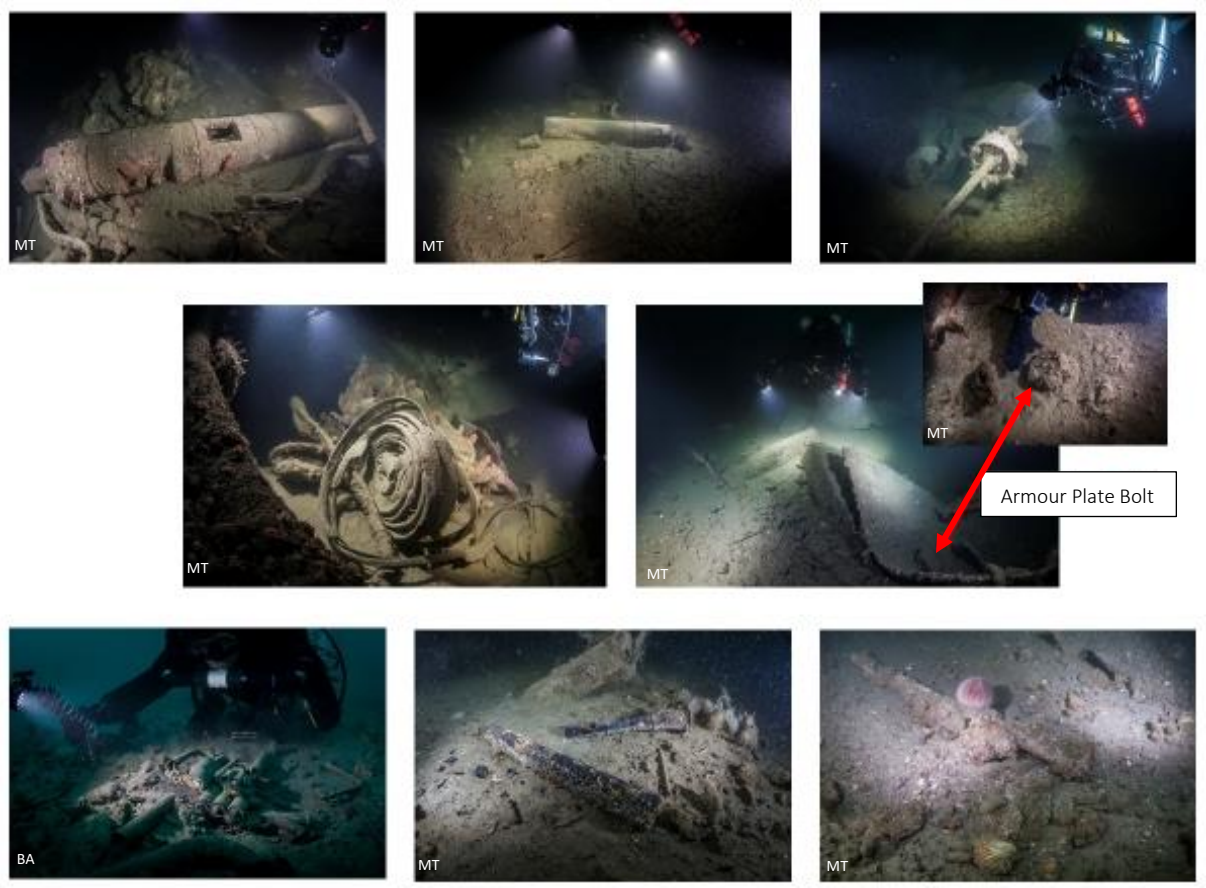


Figure 45: Top: two sections of range finder; lay shaft. Middle: coil of hose; armour plate with armour bolt inset. Bottom: brass instrument; woodwind instruments; rifle

3.1.2.9 SW Wreck site

This area contains a very large section of wreckage, almost certainly from the port side of the ship in the vicinity of X Turret. A curved section of main deck is present, probably a barbette aperture. This curved section is immediately next to two hatches, a door and a pump, which can easily be seen on the ship's plans and enabled identification of this section. A 12-inch turret is also located in this area, located 30m west of the datum line and 28m north of the port side wreckage. This is highly likely P Turret, and is lying on its side.

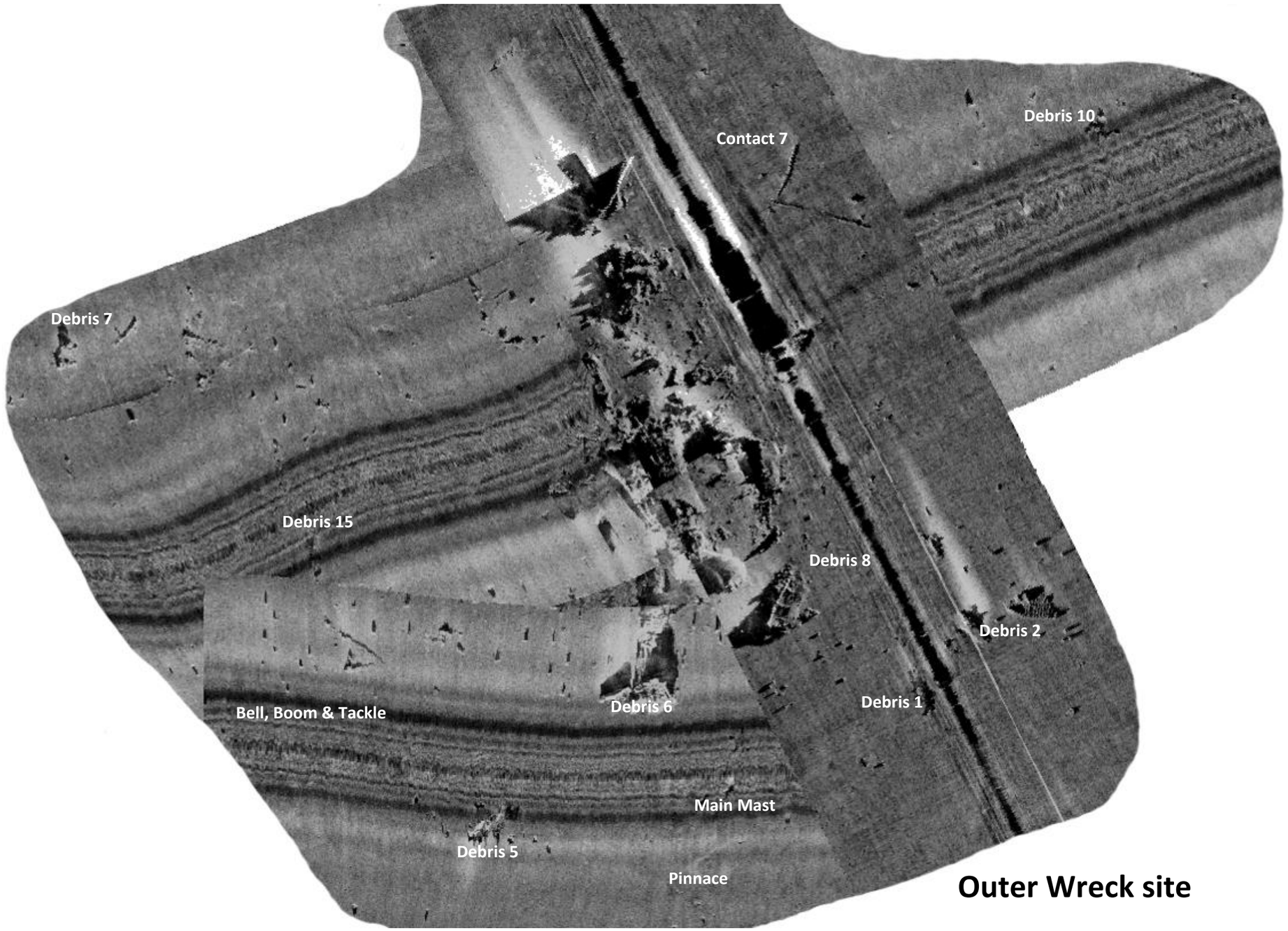


Figure 46: Sidescan sonar image of the outer wreck site

3.1.3 Outer Wreck Site

The most widely dispersed wreckage comes from the superstructure, upper deck and upper parts of the hull above the main deck, which have been projected substantial distances from the main wreck site. There are numerous examples including:

3.1.3.1 Debris 5, Aft Superstructure, SW Outer

A section of aft port side superstructure (Forecastle and Flying Deck) lying on its side on the seabed in the SW Outer area >50m beyond the stern section. One 4-inch gun sits mounted in its embrasure with splinter shield. Louvered vents for coal bunkers litter the wreckage and at the aft end a section of bunker vent pipes protrudes from the seabed. External domed bulkhead lights are present around the wreckage along with a bulkhead door with glass porthole. Lying off to the side off the main lump of wreckage is a section of plating containing a second 4-inch gun mount. An access ladder lies to the south of the wreckage.

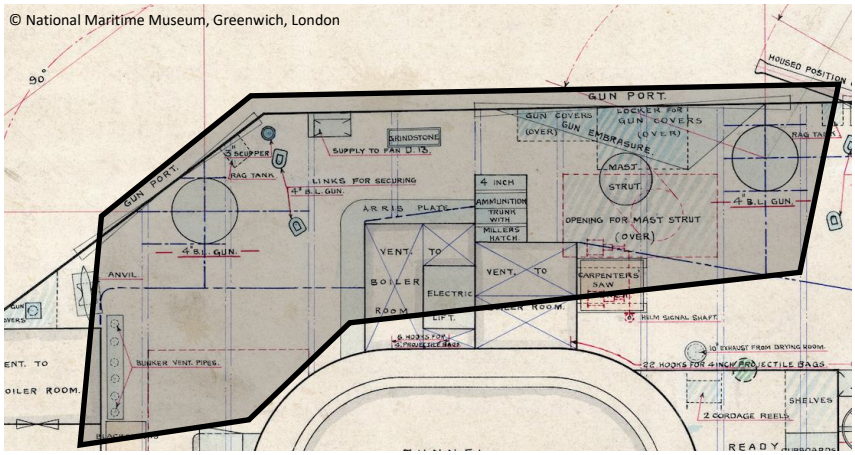


Figure 47: Extent of Debris 5 wreckage

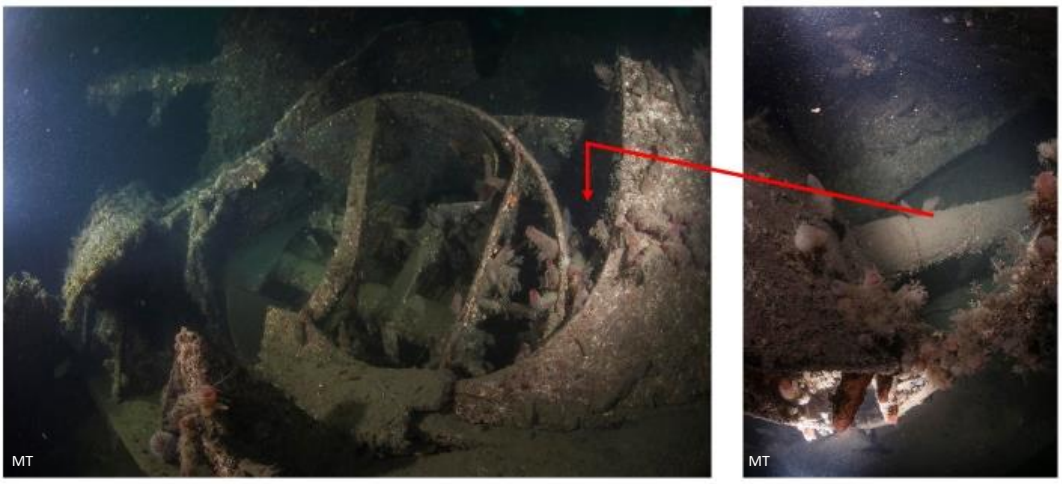


Figure 48: 4-inch gun with barrel visible

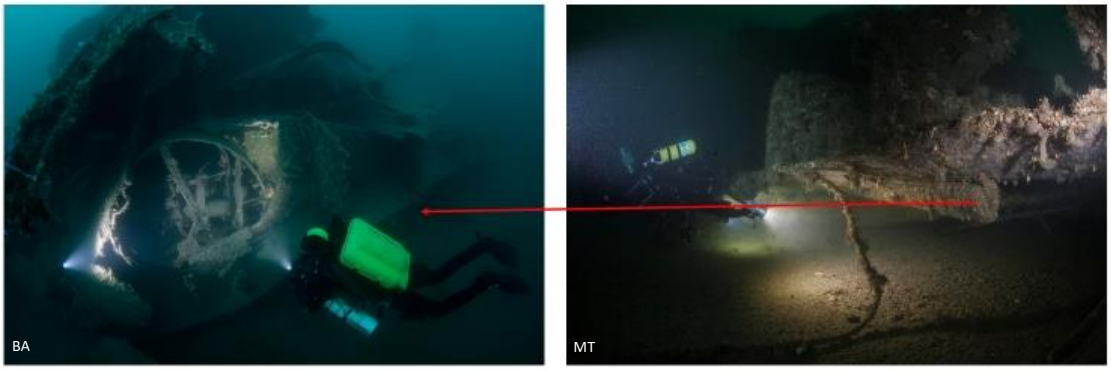


Figure 49: Debris 5: gun barrel visible under wreckage

Figure 50: Debris 5: gun mount; door with porthole; air vents; bulkhead lamp

3.1.3.2 Debris 1, Aft Superstructure, SE Outer

An isolated section of aft starboard side superstructure, including a 4-inch gun mount and embrasure and the base of the starboard main mast strut.

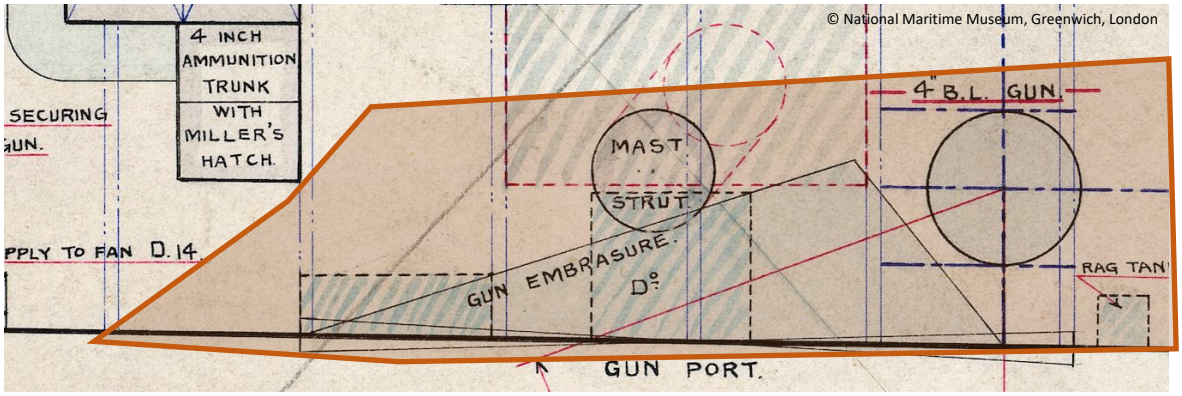


Figure 51: Debris 1

3.1.3.3 Main Mast, SW Outer

Three distinct pieces of the main mast lie on the seabed some 72 metres aft of the stern. The external ladder is visible on the north-most section. Spotting top platforms and part of a rangefinder were located on the other sections.

Visible are the remains of the uppermost platform and a short section of the main leg and approximately 10m of one of the mast struts, side unknown. The remainder of the main mast and struts are missing and were not located on the wreck site.

Figure 52: Main mast section and spotting top

3.1.3.4 Bell Boom and Tackle, SW Outer

Isolated and lying some 180 metres from the main wreck site and 60 metres from the aft superstructure is a ship's bell, presumed to be the aft bell from VANGUARD. No lettering was visible. There is damage to the top of the bell consistent with an explosion. The distinctive end of the ship's main boom with associated lifting tackle lies some 10m from the bell.

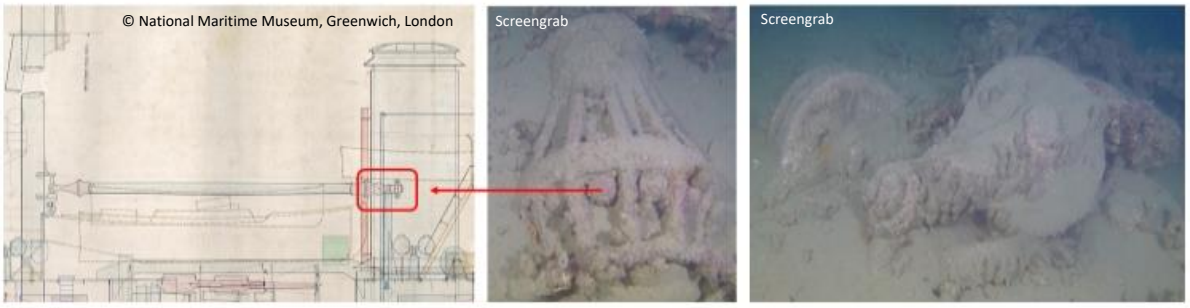


Figure 53: End of the main lifting boom and associated tackle

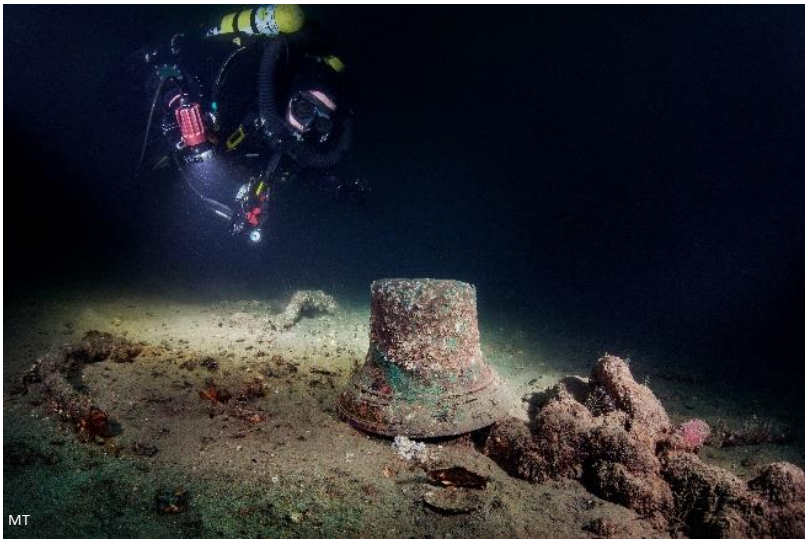


Figure 54: Ship's bell

3.1.3.5 Debris 2, Debris 3 and Contact 16, SE Outer

Debris 2 consists of a large piece of starboard side decking lying over the top of a smaller piece of decking. The larger piece contains a four-paned skylight adjacent to a small square vent which pinpoints this to the sick bay. Only two four-paned skylights are found on the ship's plans. The first is in the bow above the Gun Room, which is still in situ, and the second above the Sick Bay towards the stern on the starboard side. Also present is part of the curved deck aperture for X Turret. The smaller decking underneath is a piece of side decking with spurn water still intact. Brackets for stanchions, a small deck cleat and a scupper are all visible.

Figure 55: Debris 2: Sick Bay skylight and X Turret deck aperture

Approximately two metres to the north lies an intact section of bunker ventilation pipes and associated louvered covers. These lie adjacent to an intact 4-inch gun with splinter shield. The mount for this gun lies upturned attached to twisted decking just behind the gun.
Five metres to the east is a very heavily built trough-like structure similar to a bathtub, but double the size. The thickness of the steel is approximately two inches.

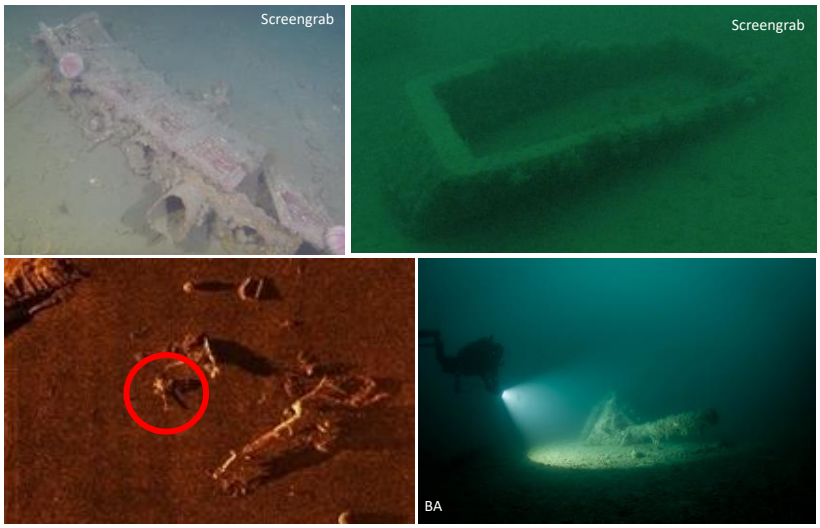


Figure 56: Debris 2: Bunker ventilation pipe; heavily built trough structure; sidescan image of 4-inch gun; 4-inch gun;

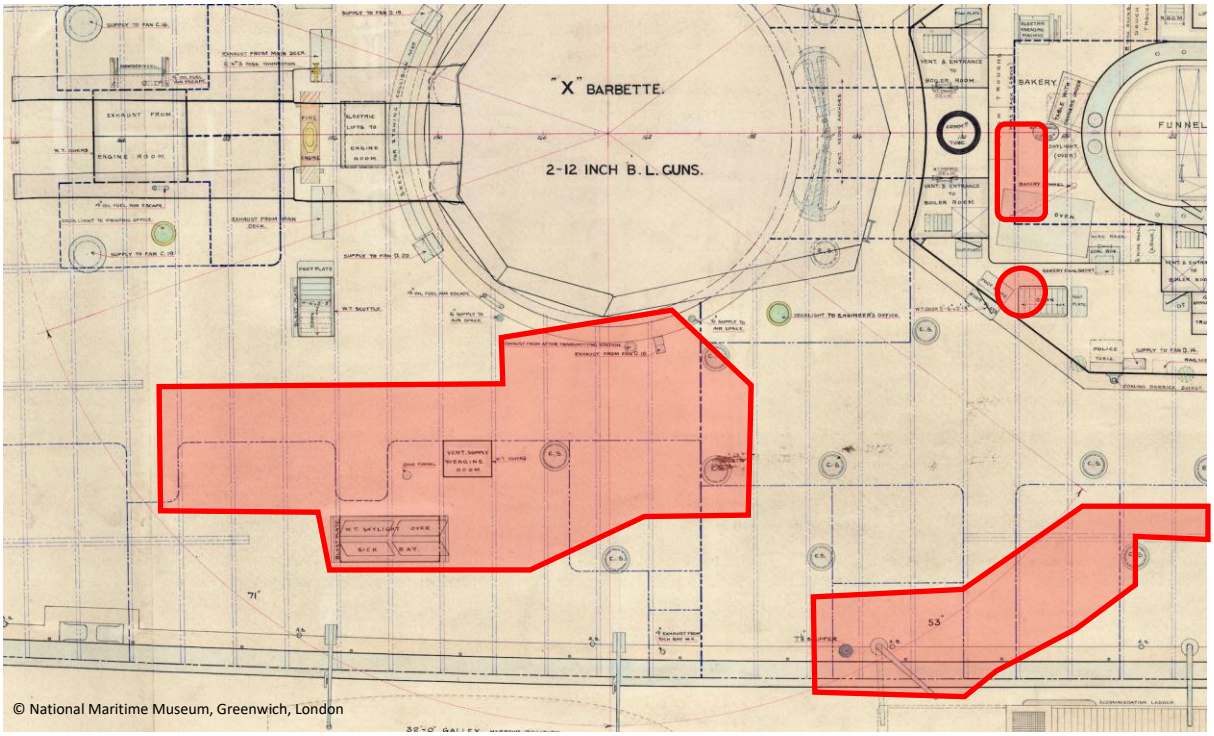


Figure 57: Debris 2 overview showing origins of wreckage

Debris 3 consists of a large flat piece of plate possibly internal deck. Also found in this location is a section of hull plating with a porthole in it. Sitting on top of this is a single cage lamp.

Contact 16 is an isolated 4-inch gun located some 40m from the SE corner of Debris 3.

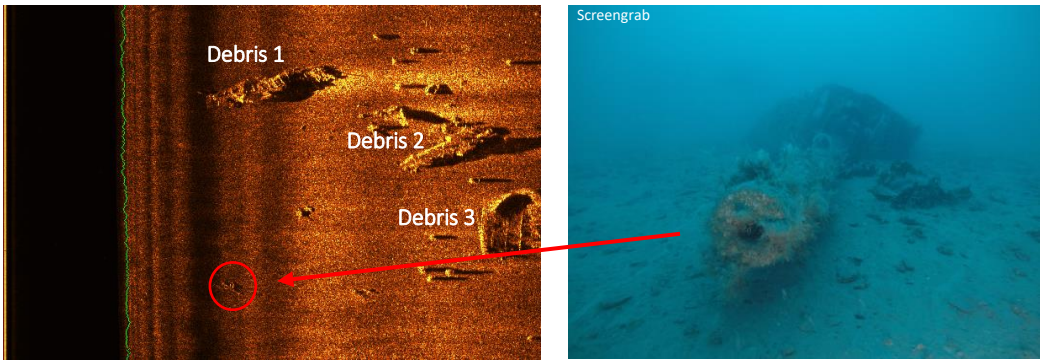


Figure 58: Contact 16 Four-inch Gun

3.1.3.6 Debris 8, SE Outer

A large section of wreckage (approx. 30m by 10m), located 15m SE of the stern, being a combination of ship's side identifiable by side scuttles and teak deck. This section comprises two distinct parts. The first is a large length of ship's side from the main deck sitting upright with internal decking still attached containing several deck hatches and vents. The combination of square and round scuttles in the side, along with the main deck hatches and vents and the remains of bulkheads, indicates that this section of wreckage is from frames 130–187. Lying on top of this is a smaller section of Upper Deck. A fairlead and swinging boom bracket pinpoints this section to the Upper Deck, starboard side between X and Y Turrets, approximately frames 156–182. The two sections originate from the same place on the ship. However, the section of decking has been separated and turned through 180 degrees before landing on top of the main deck wreckage.

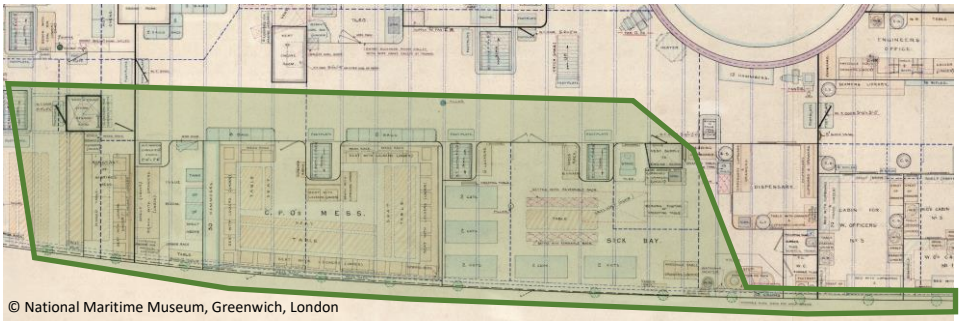


Figure 59: Debris 8 Main Deck wreckage showing visible hatches

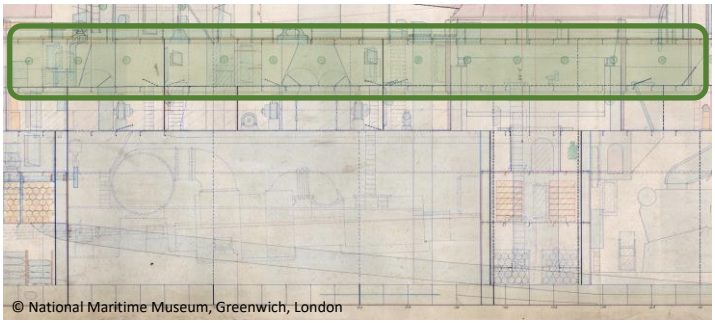


Figure 60: Debris 8 Main Deck wreckage profile of scuttles/portholes

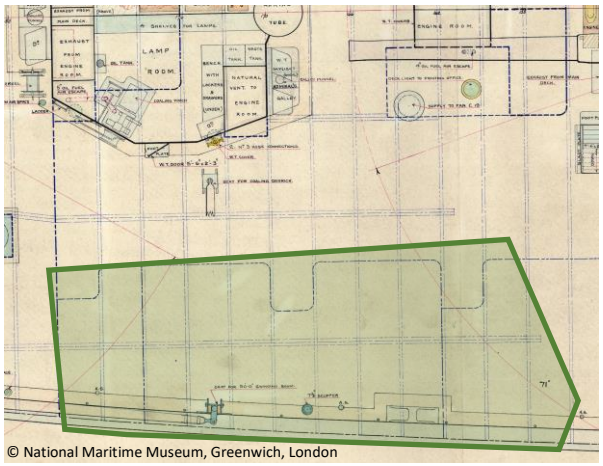


Figure 61: Debris 8 Upper Deck wreckage showing identifying fairlead and swinging boom bracket

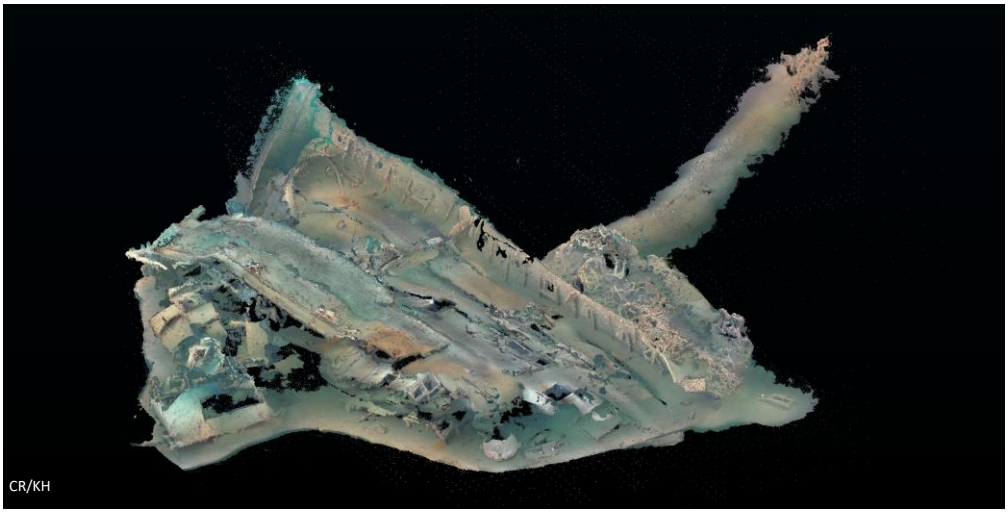


Figure 62: 3D photogrammetry image of Debris 8

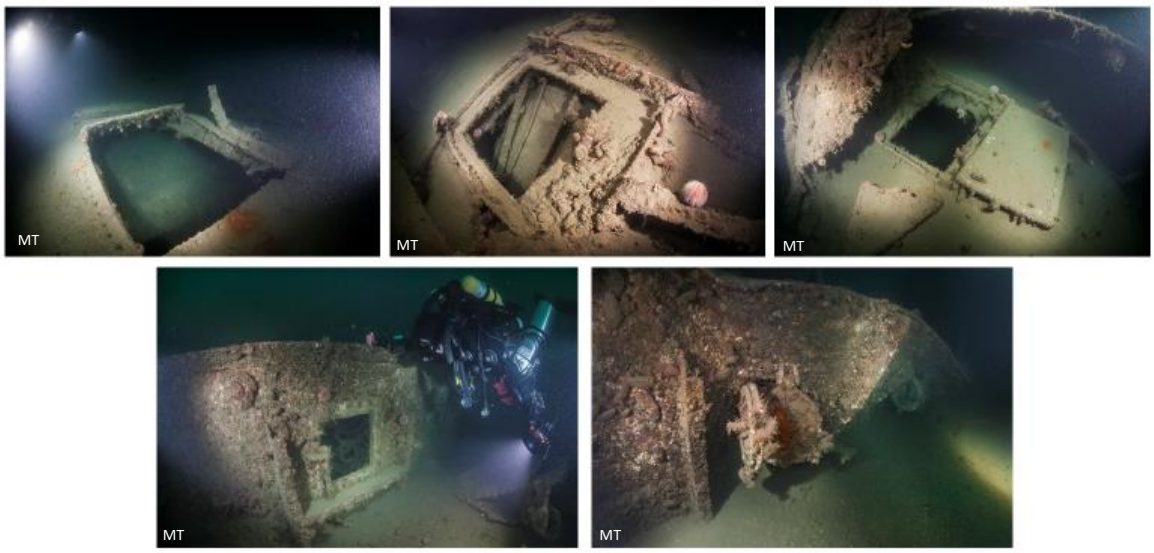


Figure 63: Debris 8: Top: Main Deck hatches. Bottom: square and round scuttles

Also present is structure from the Flying Deck, including shelter decking with searchlight director tower, a 4-inch gun mount and a 4-inch propellant charge case or Clarkson case. The rectangular corrugated cases for the 4-inch guns appear to be copper or brass and designed to hold four or six propellant charges. This one is adjacent to the remains of one of the 4-inch gun mounts, and so would have been for "ready ammunition" for the first firings of an engagement (somewhere nearby would have been 4-inch projectiles/shells). This example is the same as an exploded one located in the Main Hull wreckage forward (see Figure 29), which would have been in the 4-inch Magazine adjacent to P/Q Magazines.

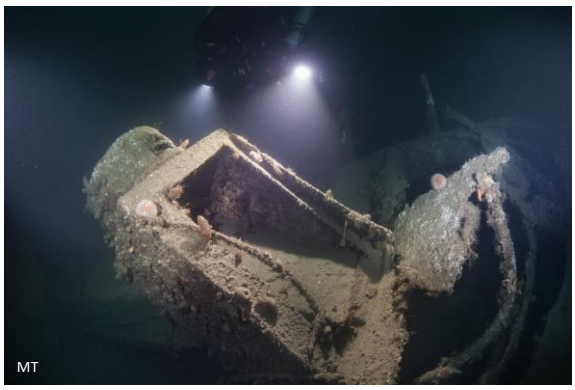


Figure 64: Debris 8 searchlight director tower

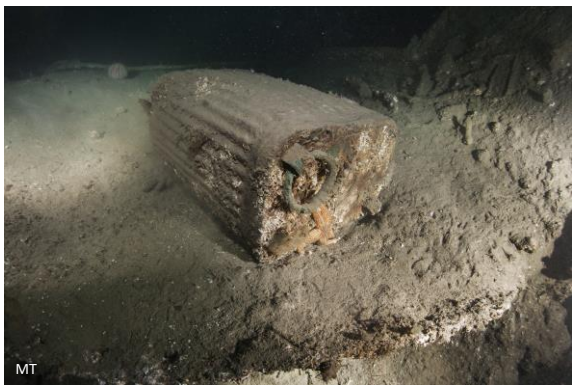


Figure 65: 4-Inch propellant charge case

3.1.3.7 Debris 6 – Diving Gear Store and Lamp Room, South West Outer

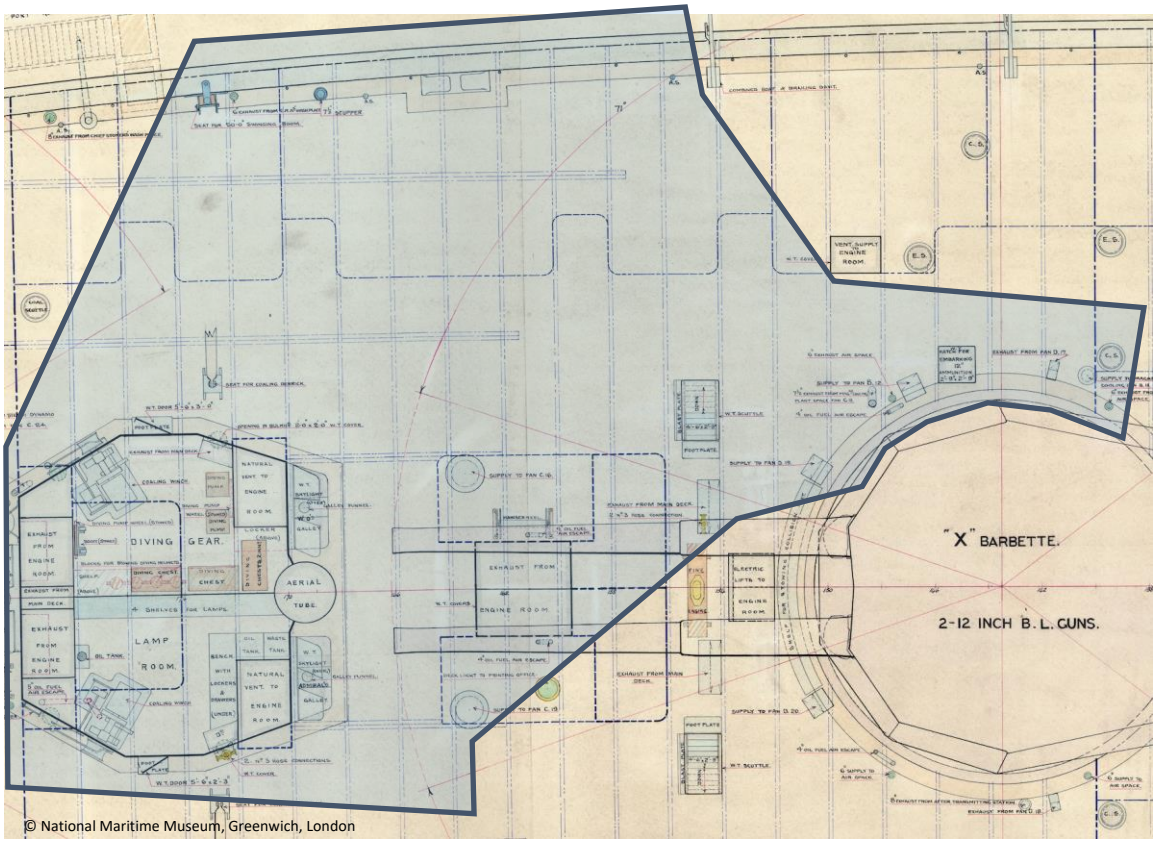


Figure 66: Debris 6

A large section of the Upper Deck from inbetween X and Y Turrets has been displaced to the south west. The wreckage lies upside down and extends from frame 140–180 (approx. 30 metres). At the east end visible under the structure are the Diving Gear Store and Lamp Room. Identifying features include two coaling winches. One is on the port side adjacent to the Diving Gear Store door, the other is on the opposite side adjacent to the Lamp Room door. The remains of the store appear largely empty but the remains of one diving pump and one wooden equipment chest are visible. The Lamp Room contains many different examples of ships lamps.

The room above the Diving Gear Store and Lamp Room labelled as the Painted Canvas Room on the ship's plans is still in-situ, but rests partially buried in the seabed. The compass platform that should sit on top of this lies upright on the seabed approximately two metres away from the door to the Diving Gear Store. There is some research evidence to suggest that the compass was removed between May and July of 1917[4] and replaced with a 3-inch gun. A mount is clearly visible, although we found no evidence to suggest it is for a gun. The survey found no evidence of the original compass.

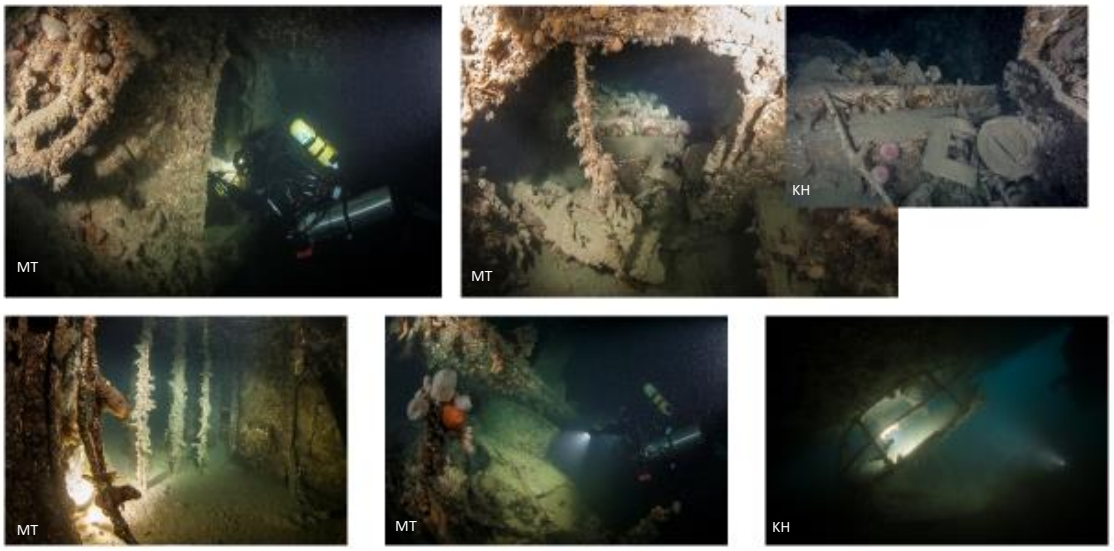


Figure 67: Debris 6: Top: Entrance to dive locker with coal winch; entrance to lamp room with lamps inset. Middle: Painted canvas room; 2 x different aspects of compass platform

The upturned deck contains several features consistent with the internal deck-head including several deck-head lamps, vent apertures and coal scuttle apertures identifiable on the ship's plans. This extends to the outer edge of the deck with the spurnwater, several deck cleats and the seat for the portside 50 feet swinging boom. This part of the ship housed the Petty Officers Mess, a Canteen, Hammock Storage and the ERA's Mess (Engine Room Artificer). Directly adjacent to this is the Band Instrument Room.

[4] British Warship Recognition, *The Perkins Identification Albums Volume 1*. Richard Perkins. Page 25 – 26. Unfortunately, Perkins had limited access to the ships during the war years and as such this is may not be accurate.

Throughout, the site artefacts directly linking the ship to the men who served are visible. At Debris 8 the most prominent of these was a set of brass coat hooks mounted on a wooden bracket. On the south west side is a nearly semi-circular curve, consistent with the deck aperture for a 12-inch barbette. This is most likely the X Barbette deck aperture. Several deck vents present in the structure are identifiable on the ship's plans.

Figure 68: Debris 6, brass coat hooks

3.1.3.8 Debris 15, South West Outer

Debris 15 consists of a corner section of outer deck with spurnwater and small section of hull. Also present are two anchors with chain that wraps around the whole structure. The main locating features are the centre accommodation ladder bracket and a small brass numbered plaque for frame 120, which is the centre frame of the ship. Coal hatches and numerous deck fittings are also present, and portholes stick out of the silt.

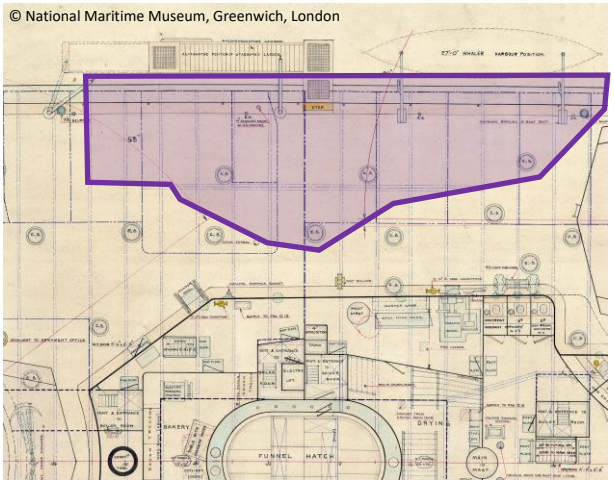


Figure 69: Debris 15

Figure 70: Debris 15 accommodation ladder step at frame 120

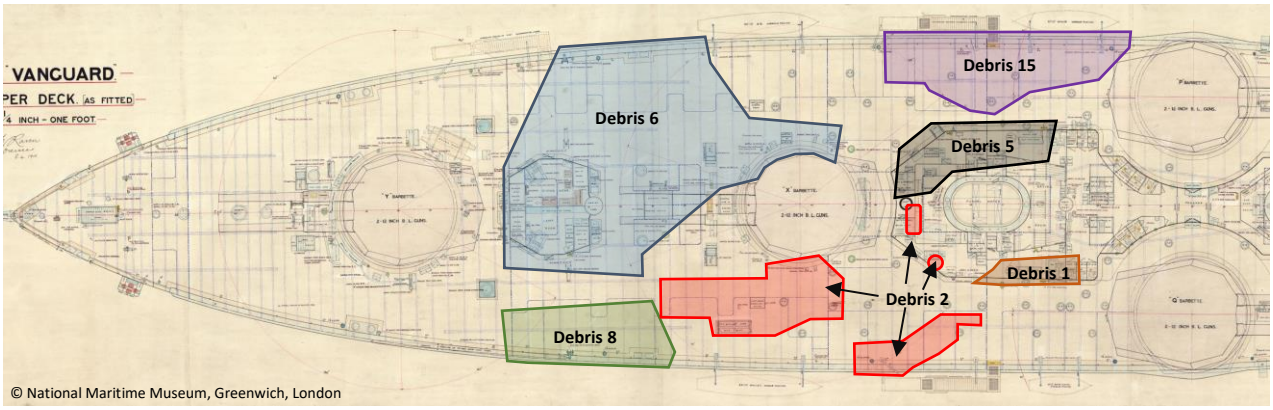


Figure 71: Overview Showing Origins of Outer Wreckage

3.1.3.9 Debris 7, NW Outer

Debris 7 consists of three distinct pieces of wreckage. The first is a flat piece of side hull plating containing several round and one square scuttles/portholes. The second piece contains a flattened splinter shield from a 4-inch gun and a 4-inch gun mount. Also present is a searchlight director tower containing two large voice pipes. This searchlight director tower was the second of three found across the entire site. One is also present at Debris 8 and one at Contact 13, although none appear on the ship's plans. The third piece of wreckage is part of the port strut of the foremast with visible external ladder and associated support brackets.

3.1.3.10 Contact 7, Foremast, NE Outer

Contact 7 is made up of almost the entire length of the starboard strut of the foremast with external ladder and relevant supporting bracket located part way up the leg. This lies adjacent to a large L-shaped length of WWII boom net which confuses the sidescan sonar image.

3.1.3.11 Debris 10, North East Outer

Three smaller lumps of wreckage consisting mostly deck and hull plating make up Debris 10. A section of deck plating reveals a barbette curve and 4-inch armour. It is likely that this deck plating is from Q Turret. Two important artefacts were located within the vicint of Debris 10. The first was a 12-inch tampion with leather and "horse hair" innards, the second a decorative bronze crest/ship badge of Nelson from the twelve-inch guns. The ship's badge for this HMS VANGUARD was of a bust of Nelson with the word *Nile* and date *1798*. The 1787 built HMS VANGUARD was Nelson's flagship at the battle of the Nile in 1798.

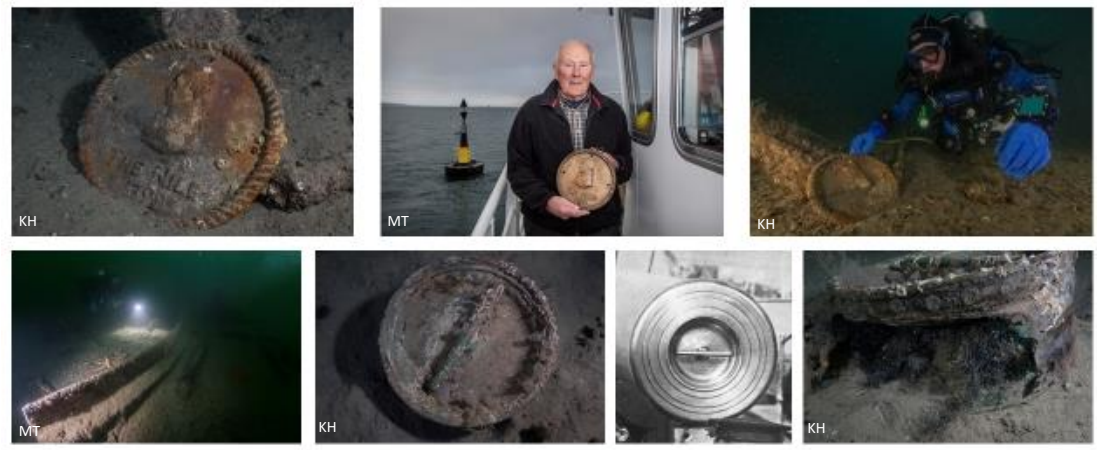


Figure 72: Debris 10: Top: HMS VANGUARD bronze ship's badge; Dougall Campbell holding a bronze ship badge legally salvaged in 1975; Diver with bronze badge. Bottom: 4-inch deck armour showing curve; tampion images.

3.1.3.12 Steam Pinnace, South West Outer

Steam pinnaces were central to the Royal Navy's ship-to-ship and -shore transport. Used as guard boats and for offensive use in shallow waters they were built in small shipyards countrywide. The Navy List of 1914 showed 634 such vessels in service. Most were armed with a 3-pdr gun, a Maxim gun and rifles plus 14 inch diameter torpedoes and were capable of 12 knots. Pinnaces were often used as picket boats patrolling capital ship anchorages, due to their ability to move and fire at moderate speeds.

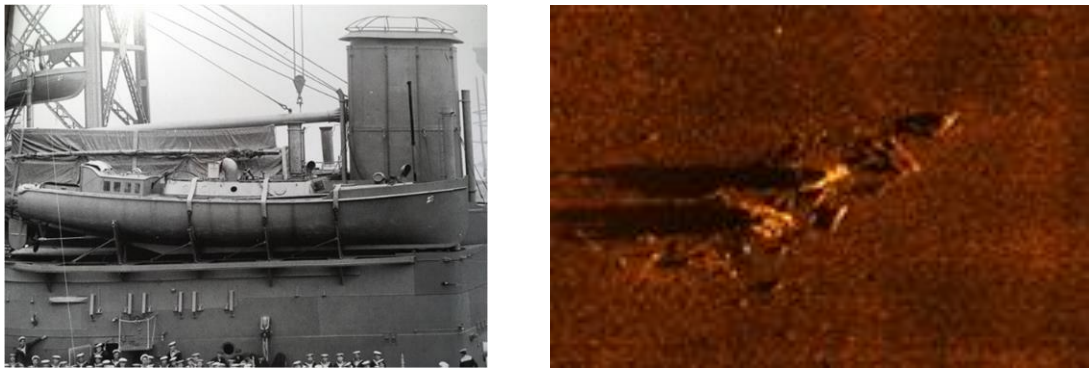


Figure 73: A Royal Navy Steam Pinnace

As with most capital ships, VANGUARD carried two 50' steam pinnaces (numbers 247 and 248). Their wooden carvel constructed hulls were built by Forrest and Co in Wivenhoe, Essex, in 1908. They were then fitted with a pinnace boiler and compound engine each by Mumford's of Colchester, before being delivered to Barrow in May 1909. While Pinnace number 247 is recorded as surviving to be unappropriated at Chatham in 1926 before its sale in 1928, Pinnace 248 was reported lost with the ship .

On the night of the explosion, 16 of the ship's officers had been on another vessel watching a concert, and Pinnace 247 manned by 8 ratings was dispatched to collect them. When she was just 120 yards off Vanguard's starboard quarter, they witnessed the vessel explode. It was assumed that Pinnace 248 went down with VANGUARD, and although Campbell salvors reported having found 'the admiral's pinnace' in the 1970s, evidence of its discovery did not reach the surface at that time.

While exploring scattered debris in the vicinity of the main mast (see Figure 52), hull sections of characteristic lattice wood construction were observed, and a small vessel located to the south of the main VANGUARD site. A nameplate later connected her directly with that vessel, and confirmed the find as Pinnace 248. A basic survey of the area was undertaken, and key measurements recorded. A photogrammetric map of the small site was produced, using a GoPro Hero 4 and two 3XML Light-For-Me Video Lights, 3600 lumens each.

Figure 74: Steam Pinnace 248 - HMS VANGUARD

Pinnace Survey Results

Divers found a site with low lying debris along most of the ~20m extent, but with areas of significant wreckage standing up to 2m proud of the seabed. From the basic sidescan available, remains appear to be oriented northwest (rudder) to southeast (bow).

Denser wreckage (helm, engine, boiler) indicate that the bulk of the vessel came to rest in near original configuration on an approximately even keel, in 26-32m of water on a sand and mud bottom. Water movement in the area is limited, and both the state of fragile elements of wreck and growth of marine life (limited coverage of short animal turf) are also indicative of a low energy site. Debris surrounds the main area of pinnace wreckage so, while this remains reasonably contained, the total footprint covers an area larger than the original vessel dimensions. Although the remains are well broken up, multiple artefacts were exposed. A name plate at the stern and maker's plate on the boiler permitted identification.

Swimming south from the main VANGUARD site the rudder is first encountered, its brass frame upside down on the seabed, all outer materials having been destroyed in the intervening years. The nameplate was found in this area. Barren seabed (possibly disturbed by fishing gear) is soon followed by sections of wooden hull, rib remains and planking, and frames of varying size scattered on the surrounding seabed. Some of the frames contain copper pins, and abundant large fragments of latticed wood provide evidence of the characteristic pinnace double hull design, diagonal inner sheets combined with fore and aft outer sheets.

The central section is the most intact with helm and bridge fittings (including Dent's boat compass) still in situ. Moving forward, the steel engine and boiler stand clearly proud of the seabed, details like pressure and sight gauges still intact and in their original positions. Pipes and valves are evident aft of the boiler. The brass funnel sits off the wreck to the starboard side between the two. Moving towards the bow small bullets can be found, but the guns were not in position.

Figure 75: Pinnace steering helm, Dent's boat compass and rudder

Further sections of latticed hull finally terminate in bow plating complete with cleats; chain locker and anchor; and the keel itself, original bronze bolts evident (Figure 76).

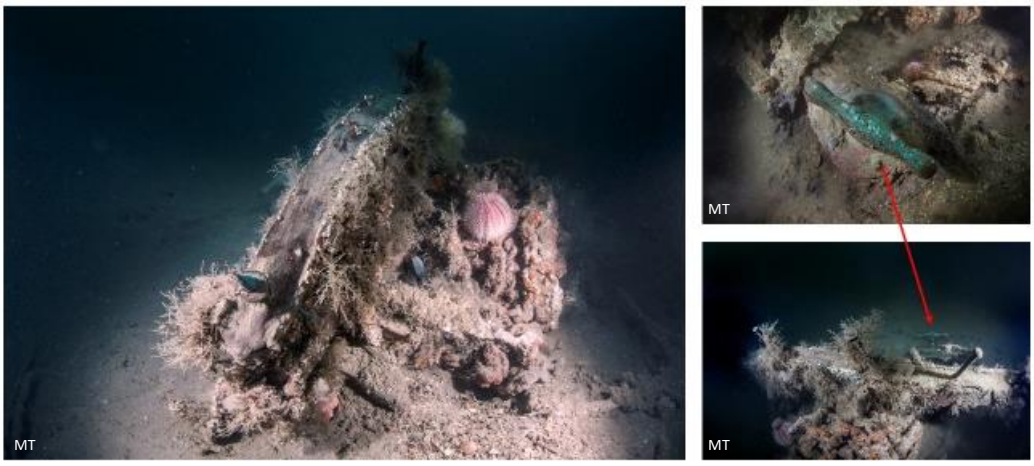


Figure 76: Wooden bow post with bronze bolts and a deck cleat

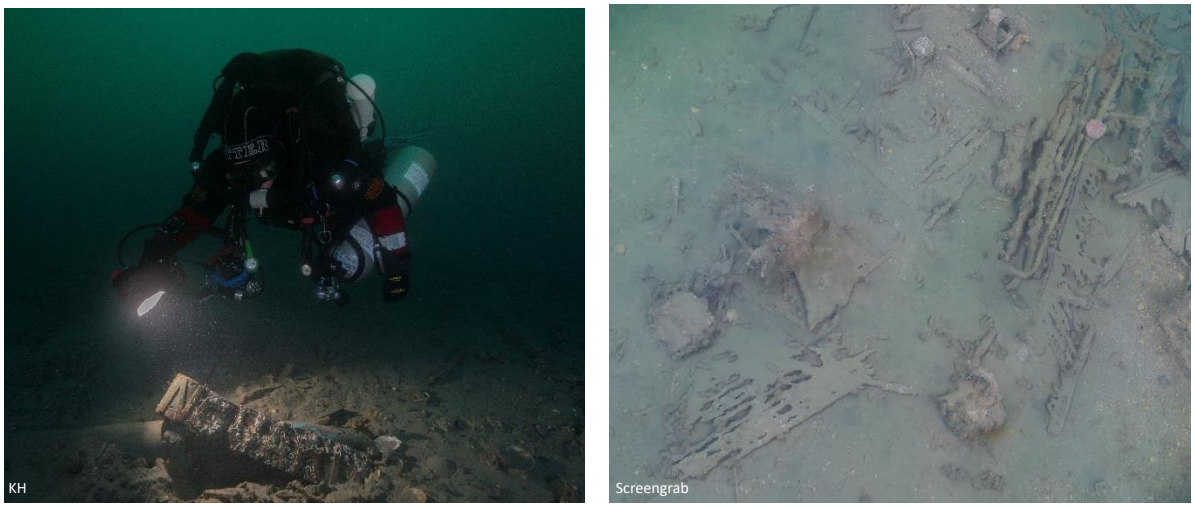


Figure 77: Nameplate and lattice frame hull

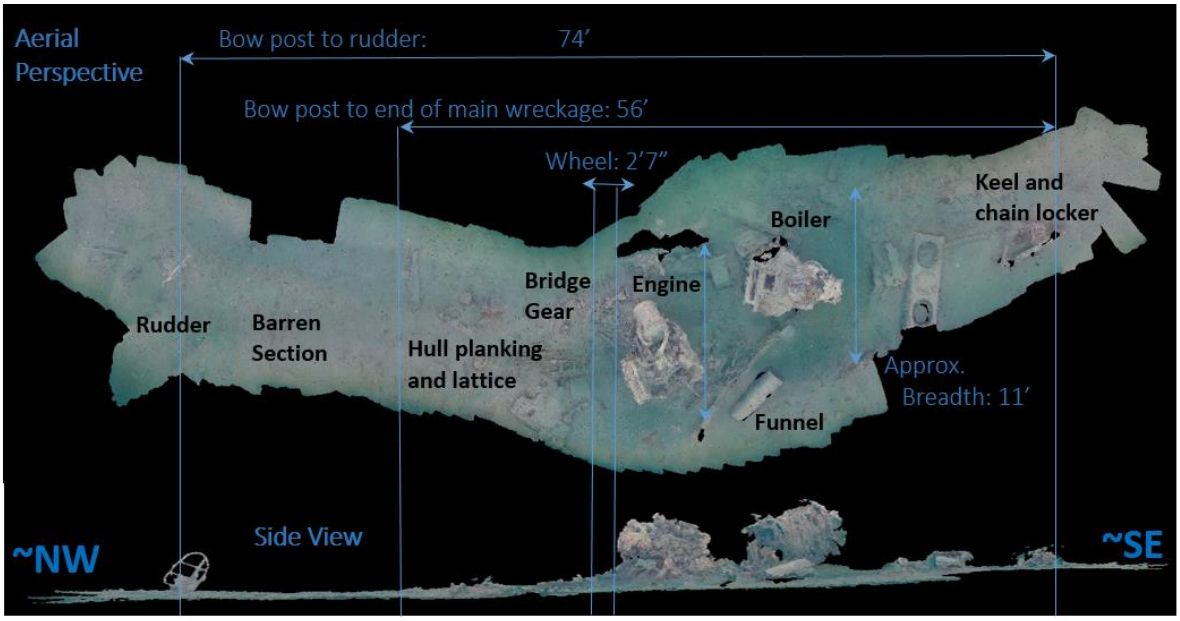


Figure 78: Basic survey measurements of Pinnace 248 site visualised over aerial and side views of the site, created using structure from motion photogrammetric techniques (Fitzsimmons/Wade).

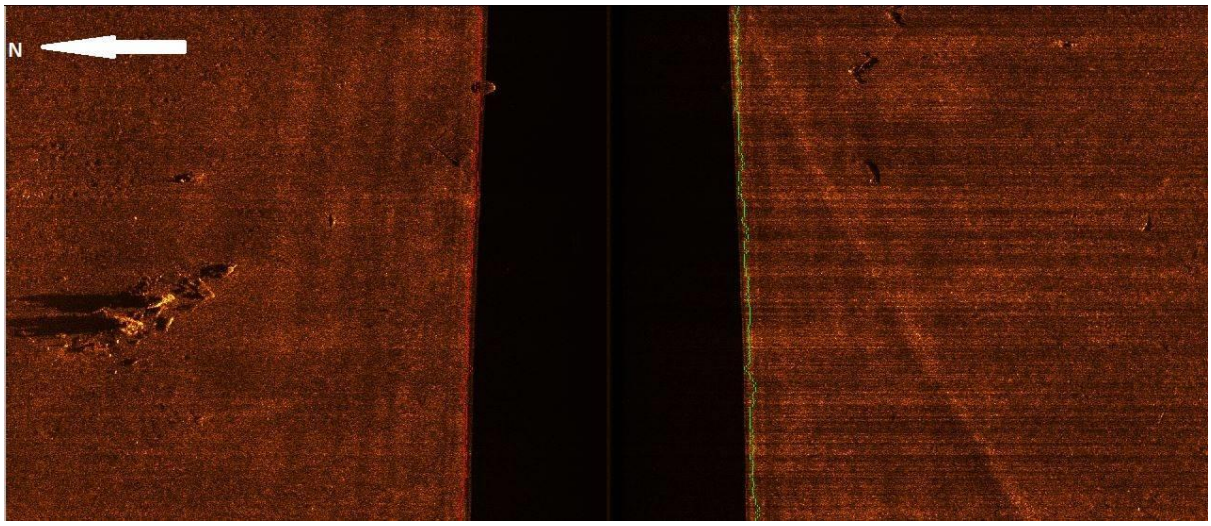


Figure 79: Sidescan sonar image of Pinnace 248

3.2 100 years on: the marine life legacy of HMS VANGUARD

A number of dives were conducted focusing specifically on the marine life of the bow and stern sections of the wreckage.

Bow section

The bow section lies on a coarse gravel and silt seabed, and so itself provides hard surfaces for encrusting animals to grow on in an area of the seabed which otherwise is devoid of hard surfaces. The gravel of the seabed is made up of the shells of bivalve molluscs, the shells of dead barnacles and overlain by a layer of silt. Lying on the sediment are sticks of cordite, which are encrusted with calcified worm tubes (*Spirobranchus triqueter*) and Saddle Oysters (*Anomiidae*).

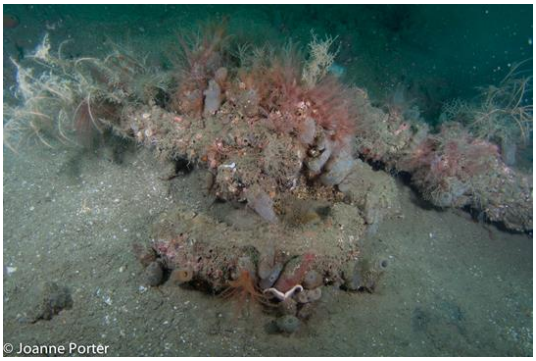
On the surface of the sediment, large predatory starfishes can be observed, including the sunstar (*Crossaster papossus*) and the seven armed starfish (*Luidia ciliaris*). Smaller starfishes that are known to live on the surface of sediment are also present, these include the common brittlestar (*Ophiura ophiura*).



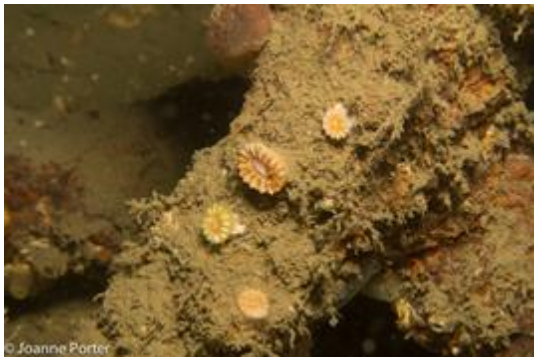

The remaining bow structure provides some extensive sloping and vertical surfaces, which are well colonised by a range of different animals. Particularly on the steeper sections where sediment does not gather, filter feeding animals such as encrusting tube worms are dominant, along with feather stars (*Antedon bifida*), cushion starfish (*Porania pulvillus*) and the occasional plumose anemone.

In sections which are more gently sloping, there is more sediment accrual, and sea squirts including *Ascidia mentula* are abundant, along with edible urchins and clumps of herringbone and antenna hydroids; all animals which will tolerate a certain amount of sedimentation.

On surfaces which are overhanging with lower levels of light reaching them, the dominant animals are sponges and large numbers of the sessile phase of the moon jellyfish (*Aurelia aurita*). These jellyfish polyps (Scyphistosomae) appear as a white fur-like coating on undersurfaces.

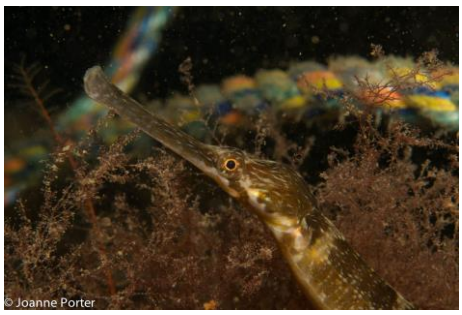


Also on the more horizontal surfaces are large numbers of the colourful solitary Devonshire cup coral (*Caryophyllia smithii*).



Stern section

Many of the animals observed at the bow are also present at the stern section. However, at the shallowest point of the stern sparse clumps of seaweed, including the brown algae *Dictyota dichotoma* and small clumps of red algae including *Brongniartella byssoides* were also present. Nestled amongst the algae a large individual specimen of the greater pipefish (*Syngnathus acus*) was observed.



Also present in this kind of mixed turf of algae and hydroids are scorpionfish (*Taurulus bubalis*), well camouflaged so as to be able to surprise the prey organisms.

At the seabed adjacent to the stern is a large overhanging section, rather cave-like, and here is the home of territorial cuckoo wrasses. A colourful male along with several females could be seen in this area. Moving away from the stern and out among wreckage and anti-submarine defence netting more sticks of cordite are found, some of these covered in pink encrusting coralline algae. Between the pieces of cordite are lumps of coal and pieces of crockery. These have been colonised by tube worms and barnacles.

In nooks and crannies there are many small crustaceans to be seen scuttling away from the torchlight, especially the long armed squat lobster (*Munida rugosa*).

Scuttling around on the seabed there are other crustaceans, including the common hermit crab, which uses a large whelk shell to protect its soft body.

Another type of hermit crab is present and distinguishable as it protects itself by associating with a sea anemone known as the cloak anemone. If the anemone is attacked it emits purple fibres from slits in the body wall, these fibres known as acontia are armed with arrays of stinging cells, and therefore act as a defence.

Pairs of mating swimming crabs can be seen huddled together. The male perched on top of the female, protecting his investment.

Edible crabs on the other hand, are buried in the sediment so that just the eyes and the pie crust shell can be seen.

Also out on the gravelly seabed, individuals of the bottom dwelling dragonet (*Callionymus lyra*) can be seen, darting about furtively, blending in well.

Among the mixed turf on the decking, the keen eyed will notice the presence of sea slugs, including *Coryphella lineata* feeding on the polyps of the hydroid colonies there.

Whilst out on the gravel an iridescent specimen of *Facelina bostoniensis* could be seen foraging.

Summary

The VANGUARD wreckage site now supports a wide variety of creatures, many of which are well known from elsewhere in Scapa Flow. There was no evidence from the surveys here of the presence of any Priority Marine Features of conservation importance, however, further investigation in the extensive wreckage zone between the bow and stern, or in the general surrounding environs of the wreck may yet reveal the presence of such species.

Perhaps what makes this site different from others in Scapa Flow is the sheer number of scallops (both *Pecten maximus* and *Aquepecten opercularis*) present at the site. In places, the density was as high as 5 per square metre, with individuals of various sizes occurring.

Amongst the seaweed turf on the stern deck, juvenile scallops were also observed.

This indicates that VANGUARD is now acting as a nursery site for these commercially important shellfish. The kind of habitat that the wreck site now provides may well be a significant contributing factor towards the future sustainability of Scapa Flow's inshore shellfish stocks.

3.3 Why and how VANGUARD is where she is now

The current condition of the wreck of the VANGUARD is the consequence of the internal explosion and sinking of the ship, deterioration over 100 years on the seabed, and a significant amount of salvage work. Consequently, much of the ship's internal structure and equipment now lies exposed on the seabed providing a level of access not possible on other dreadnought shipwrecks.

3.3.1 Salvage

There is much evidence of salvage work on the wreck of the VANGUARD including:

i. The absence of at least three of VANGUARD's four propellers.

ii. The absence of turbine engines and condensers from the starboard Engine Room, and the condensers from the port Engine Room.

iii. The almost complete absence of thick armour plate from the hull sides (main belt), turret shields (face, roof and sides) and barbettes.

iv. The absence of 12-inch gun barrels from the turrets. (Half a gun barrel remains partially buried beside Y Turret with a salvager's lifting strop wrapped around it.)

v. An exploratory blast hole in the stern at the location of the aft torpedo tube.

vi. The relatively small number of brass Clarkson (cordite) cases on the wreck. Up to 2,000 12-inch and 500 4-inch Clarkson cases were embarked, but only approximately 1% of this quantity has been observed on the wreck, particularly at X and Y Magazines where there is no evidence of magazine explosion, and where up to 40% of this quantity would have been stored. However, these magazines are close to the heavily salvaged Engine Rooms and propellers.

3.3.2 The Court of Enquiry

The Royal Navy's Court of Enquiry into VANGUARD's loss had little solid evidence on which to determine a definite cause, but was able to conclude that the ship's destruction was due to the ignition and explosion of cordite in a magazine from the deterioration of unstable cordite and/or an "avoidable cause" such as unsuitable storage conditions, unrecognized hazards and sabotage.

The consensus of eye witnesses reported flames and the initial explosion coming from between VANGUARD's foremast and forward funnel (witnesses aboard NEPTUNE, moored to port) and between VANGUARD's Q and X Turret (witnesses aboard COLLINGWOOD, moored to starboard). Many witnesses reported more than one explosion, however had witnesses been looking at the ship at that time they would have seen the explosion approximately one second (longer for more distant ships) before hearing it, due to the distance and the difference in speed of light and sound, so would have the impression of a second explosion. Nonetheless a second "sympathetic" magazine explosion remains a strong possibility.

A steel plate of wreckage from VANGUARD landed on BELLEROPHON, moored to the southeast, starboard aft of VANGUARD. The wreckage was considered by the Court of Enquiry to have come from the longitudinal bulkhead in No2 Hydraulic Room, which was on the starboard side of the Lower Deck, frames 54 to 66, one deck above and slightly aft of A Magazine on the Platform Deck, frame 45 to 62, some distance forward of P and Q magazines.

The plate was buckled but absent of heat damage, which led the Court of Enquiry to conclude that the primary explosion had not occurred in A Magazine.

3.3.3 Cordite

Gun propellants such as the cordite MD aboard VANGUARD are explosives that burn rapidly and at high-pressure ≈18.5 tons/in^2 (2.8 kilo bar) when confined inside the breech of a gun. This controlled explosion propels the projectile along the gun barrel and towards the target at high velocity ≈2825 ft/sec (861m/s).

Cordite is a double-base gun propellant made of nitroglycerine, nitrocellulose and petroleum jelly and introduced into Royal Navy service from 1893 to replace brown gunpowder, in order to provide more power and thermal efficiency. It was continuously developed and improved up to, during, and after WWI to improve performance, manufacture quality and stability, and to reduce wear of the gun barrels. The cordite aboard VANGUARD at the time of her sinking was of a type (MD, modified) and vintage (1909 and later) known to be potentially unstable and prone to spontaneous combustion and explosion under certain conditions of increased temperature and humidity. This remains the most likely root cause of the magazine explosion that destroyed VANGUARD.

Cordite was manufactured by (i) mixing the ingredients with acetone solvent into a paste, (ii) extruding the paste through a die into cords, and (iii) drying the cords to remove the solvent. The diameter of the cords was important to control the burn rate, with larger cord diameters providing longer burn times for larger calibre guns. The maximum diameter of the cord was effectively limited to a maximum of 0.45-inch by the drying process and cord shrinkage until the introduction of solvent-less cordite SC in 1927. Cordite cords are light brown in colour and have the physical appearance of uncooked pasta.

Bundles of cordite cords were packaged into silk bags for use in breech loading (BL) guns such as the 12-inch and 4-inch guns on HMS VANGUARD. Silk propellant bags for the Royal Navy's BL guns were transported and stored in brass Clarkson cases to protect them from damage and heat. The Clarkson cases were fitted with lid closures that could be partially unfastened as a safety measure to relieve pressure and reduce the risk of mass explosion should the cordite cases be exposed to heat in the magazine.

Cordite MD (modified) was introduced from 1901 to replace cordite Mk1 because it had lower burn temperature and caused less wear to the gun, potentially more than doubling the gun-barrel service life. The Royal Navy preferred cordite because it was found to give more regular ballistic performance than other propellants used by foreign navies.

Cordite MC (modified cracked) was introduced from April 1917 to replace cordite MD. Cordite MC had improved manufacturing quality and thermal stability by using cracked mineral jelly instead of petroleum jelly, and increased nitrocellulose nitration time during manufacture. Cordite MC was introduced into the Royal Navy following the loss of BULWARK (1915) and NATAL (1916) to accidental magazine explosions, and its introduction was accelerated following the loss of VANGUARD, completed by September 1918.

Unstable cordite has a darkened appearance associated with incomplete removal of volatile matter such as the solvent when drying during manufacture (particularly difficult for larger diameter cords), and the formation with time of fine particles of nitrocellulose and iron pyrites. This would decrease thermal stability and create the risk, if stored in hot conditions, of exothermic reaction, self-heating and spontaneous explosion. Consequently, ships' magazines were equipped with temperature monitoring, cooling and ventilation equipment, which the crew would monitor and manage according to strict drills and procedures.

Evolution of Royal Navy Cordite

Propellant type	Cordite MC	Cordite MD	Cordite Mk1
Nitroglycerine	30%	30%	58%
Nitrocellulose	65%	65%	37%
Stabilizer	5% cracked mineral jelly	5% petroleum jelly	5% petroleum jelly
Introduction	From April 1917	From 1901	From 1893
Improvement	NC nitration >2.5 hrs, improved stability & quality control	Reduced corrosion & increased gun barrel life by reducing burn temperature 3675 K to 3215 K	Improved power & thermal efficiency compared to brown powder

HMS VANGUARD, Main & Secondary Gun Propellant		
Gun Type	12-inch Mk XI BL 50cal	4-inch Mk VII BL 50cal
Propellant type	Cordite MD45	Cordite MD16
Propellant cord diameter	0.45-inch	0.16-inch
Propellant charge weight	307lb	9lb 5oz
Chamber volume	23031-inch^3	600-inch^3
Chamber pressure	18.5 tons/in^2	18 tons/in^2
Rounds / gun	80-100	120
Projectile weight	850lb	31lb
Projectile muzzle velocity	2825 ft/sec	2821 ft/sec

The Royal Navy's Court of Enquiry into the loss of VANGUARD found the drills and procedures for the monitoring and control of magazine temperature in the Grand Fleet's battleships to be inconsistent. The likely storage conditions in VANGUARD's magazines and the condition of the cordite were both considered by the Court of Enquiry to have contributed to the cause of the magazine explosion that sank the ship.

3.3.4 Cordite Explosions

When unconfined and at normal temperature, small quantities of unconfined cordite will burn without exploding. VANGUARD had aboard approximately 140 tons cordite MD45 for 12-inch guns and 13 tons cordite MD16 for 4-inch guns distributed around the ship, mainly inside magazine compartments on the Platform Deck just below the waterline. Such large quantities of cordite, if ignited, will burn to explosion by a process of self-heating and pressure increase. Gun propellants, unlike normal fuels, do not require oxygen to burn. Confinement inside a sealed container or a ship's magazine will not extinguish burning cordite, on the contrary, such confinement causes pressure, heat and burn rate to increase, leading to explosion.

A cordite explosion in one of VANGUARD's magazines would have caused blast overpressure (blast-wave) and fireball (flash) to propagate rapidly through the ship, initially following the path of least resistance along decks and passageways, through open doors and hatches, and rupturing bulkheads and doors. Such an explosion could have propagated between magazines, so more than one magazine could have exploded.

In warships the decks are stronger than bulkheads in order to withstand the weight of men and equipment placed on them. In battleships such as VANGUARD the lower and middle decks were strengthened and armoured to protect the magazines, engines and boilers from shellfire above. Consequently, the blast-wave and fireball flash from the magazine explosion

in VANGUARD would have initially spread horizontally along the Platform Deck and into the Boiler Rooms, coal bunkers and Engine Rooms, before heaving and lifting the decks and superstructure above, bending outwards and rupturing the side-plating of the hull.

3.3.5 The Wreck of HMS VANGUARD today.

Examination of the wreck of VANGUARD leaves no doubt that the ship suffered a catastrophic internal explosion. The ship's structure is very broken up and distributed over a wide area of seabed far exceeding the size of the ship itself.

3.3.5.1 The Main Wreck Site

The Main Wreck Site comprises primarily of the structure and equipment from the Platform Deck and Hold at the bottom of the hull, distributed on the seabed over an area consistent with the layout and size of the ship and its mooring position. The seawater would have limited the dispersion of this wreckage by the explosion. The main wreck site comprises of:

- The Bow Section, approximately 26m long and 11m high and comprising of the hull structure above the Platform Deck up to the Forecastle Deck, and from the Wardroom skylight (frame 36 just forward of A Turret breakwater) to the bow post. The Forecastle Deck slopes downwards from the bow to the Wardroom skylight at an angle of approximately 25 degrees and is bent downwards at the hull break. The hull side plating is bent outwards on both sides at the hull break consistent with damage from an internal explosion and impact with the seabed. The Bow lies pointing towards the northeast.

- The A Turret & Bridge wreckage includes capstan machinery from the Platform Deck (frames 26 to 30), submerged torpedo tube doors from the forward hull sides at Platform Deck level (frames 41 to 43). The bridge wreckage includes the foremast, spotting top, fore bridge and compass platform, signal and conning tower.

- The Main Hull Section comprises Boiler Rooms 2 and 3, X Magazine, Port and Starboard Engine Rooms on top of double bottom hull plating. The decks and hull from above these compartments are absent and the wreck lies with a noticeable list to port. The double bottom is bent upwards on the starboard side in the vicinity of X Magazine, forming a sharp apex approximately 5m proud of the seabed, and a "tunnel" beneath the hull approximately 5m wide that extends, with reducing width and height, almost the full width of the hull, emerging on the port side of Boiler Room 3.

Wreckage Adjacent the Main Hull Section to port and starboard comprises of substantial pieces of wreckage that have some significant features identifying them as coming mainly from the Lower, Middle, Main and Upper Decks above Boiler Rooms 2 & 3 and Engine Rooms. For example, lay shaft from the engineering workshop, musical instruments from the crew accommodation, and main turret aperture from the Upper Deck.

- The Stern section lies on its port side immediately south (aft) of the Engine Rooms and remains ostensibly intact abaft frame 206 (aft of Y Turret). The Upper Deck is bent downwards at the hull break, similar to the Forecastle Deck at the bow. The stern lies approximately east-west with the sternpost to the east.

3.3.5.2 Outer Wreck Site

The most widely dispersed wreckage comes from the superstructure and upper parts of the hull above the Platform Deck, which have been projected substantial distances from the main wreck site. There are numerous examples including:

- Two 4-inch guns, mounts and surrounding superstructure and casemate shield from the aft Flying Deck lying on the seabed in the southern outer wreck site, more than 50m beyond the stern section (Debris 5).
- The Diving Gear Store and Lamp Room section of the Upper Deck from between X Turret and Y Turret lying approximately 60m southwest of the stern section (Debris 6).
- Upper Deck with fairlead, Flying Deck and 4-inch gun mount, casemate shield and 4-inch cordite case, and shelter decking with searchlight spotting position, lying approximately 30m southeast of the stern section (Debris 8).
- Hull and deck plating from around Y Barbette on the seabed to the southwest of the stern section.

3.3.5.3 Forward Wreck Site "Gap"

There is a "gap" of approximately 35m in the main wreck site between the A Turret and Bridge wreckage and the Main Hull Section, characterised by:

- A slight depression in the seabed of depth approximately 1m, absent of substantial pieces of wreckage.
- Randomly scattered sticks of cordite and small pieces of coal.
- 4-inch cordite cases heavily deformed and turned inside out by the effects of explosion, clearly identifiable by their corrugated case-form.
- 12-inch Clarkson cases empty of cordite, split open and with heat damage.

This area corresponds to the position of A Magazine, Boiler Room 1 and P/Q Magazine (frames 47 to 100).

3.3.5.4 Turrets

All five turrets are absent their shield and barbette armour and gun barrels, presumably salvaged. The remaining turret structures measure approximately 7m diameter by 5m tall, and comprise of:

- Cylindrical barbette with training rack and turntable roller bearing.
- Cylindrical rotating platform with ammunition handling room beneath.
- Equipment to support and operate each gun barrel including cradle, trunnion, slide, loading arm & chain ram, recoil cylinder, curved loading cage track, training and elevating machinery.

A Turret lies in the A Turret & Bridge wreckage on its side on top of other wreckage. The barbette is broken open to reveal the training rack. A Turret lies approximately 15m due east of the current position of the bow.

P Turret lies on the seabed approximately 20m to the west of Boiler Room, 3 approximately 35m south-southwest (aft-port) of its original position in the ship. P Turret lies on its side and some shield armour remains part buried in the seabed.

Q Turret lies on the seabed approximately 55m to the east-northeast of the Forward Wreck Site "gap". Q Turret is the only turret that is inverted and lies approximately 45m east-northeast (directly to starboard) of its original position in the ship.

Approximately 30m west-southwest of Q Turret, on the south-east perimeter of the Forward Wreck Site "gap," is its ammunition hoist tube, which shows substantial crush damage typical of pressure damage from an explosion.

X Turret is in the best condition of the five turrets and lies upright on the seabed, approximately 10m to the west of Y Turret in the Main Wreck Site. X Turret lies approximately 25m south-southwest (port-aft) of its original position in the ship.

Y Turret is detached from the stern and lies upright immediately south of the Engine Rooms in the Main Wreck Site. It is in approximately the same position relative to other wreckage as it was in the ship.

Gun Turrets

The projectile or shell is the weapon, everything else, guns, turrets and the ship itself is the means of delivering that weapon to its target.

The gun turrets on the Upper and Foredeck of VANGUARD are the visible part of a large and complex mechanical system which extended down through several internal decks to transfer ammunition rapidly from storage in the lower decks to the guns, from which they are fired at the target. The turret system was capable of a firing rate of approximately 1 round every 45 seconds from each gun, and constantly training (turning) and elevating to track the target, and counter the ship's own motion and manoeuvring at sea.

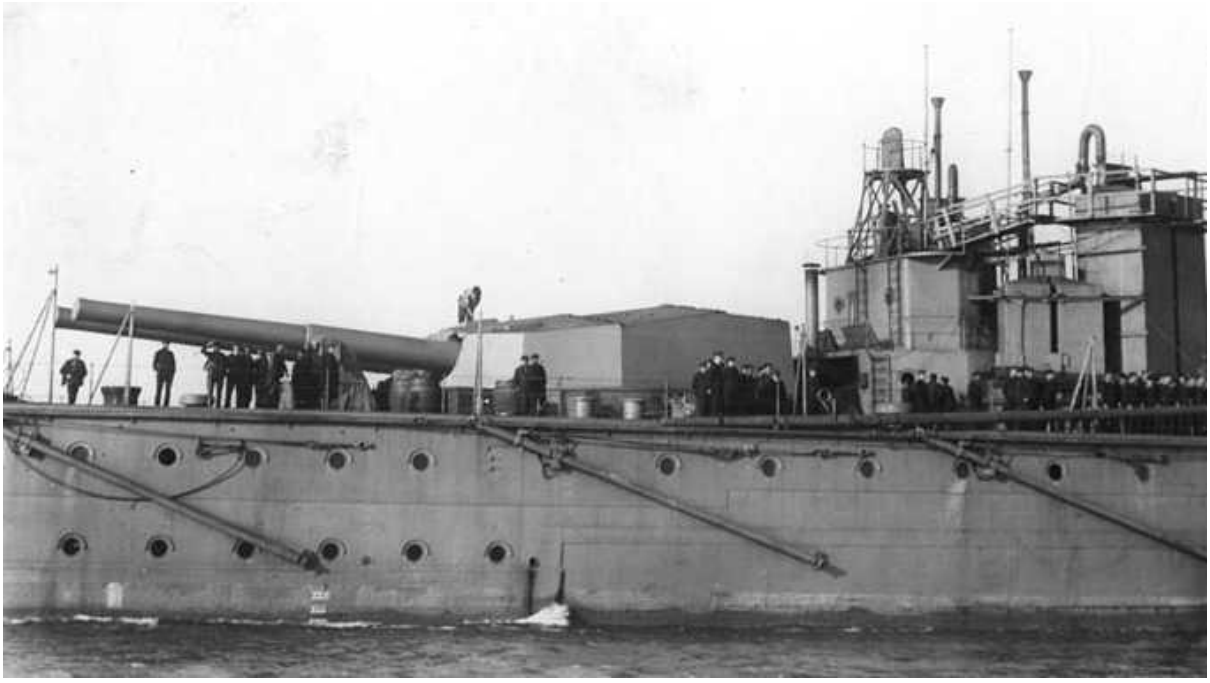


Figure 80: Y Turret (aft)

The turret system and ammunition were protected from enemy gunfire by armour, comprising of large thick and hard steel plates up to 11-inches thick, attached to the ship's decks, hull sides, turrets and barbettes. The barbette was the round structure within the hull that surrounded the turret system. The turret crew comprised of dozens of men who operated the mechanical, hydraulic, electrical and optical equipment to load the ammunition and to aim and fire the guns. All these men worked within the turret system.

The primary purpose of the battleship was to carry and operate the main gun turrets. VANGUARD had five similar main turrets, which had a large influence on her design. The turret systems were complex and cramped, having to accommodate equipment, ammunition and crew, and fit into the battleship within defined size and weight limits.

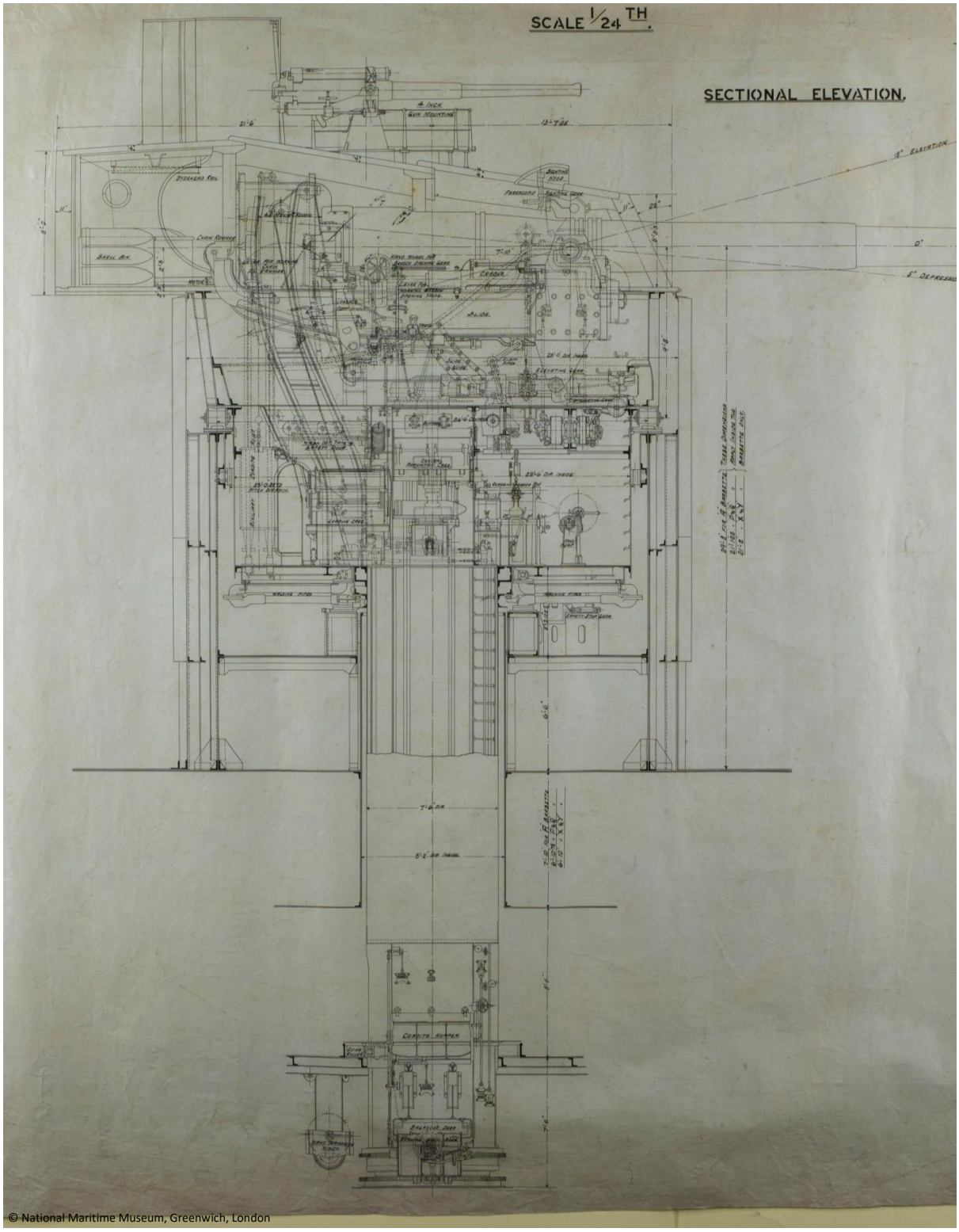


Figure 81: VANGUARD turret as built, the 4-inch gun on the turret roof was removed later

Ammunition Storage and Handling

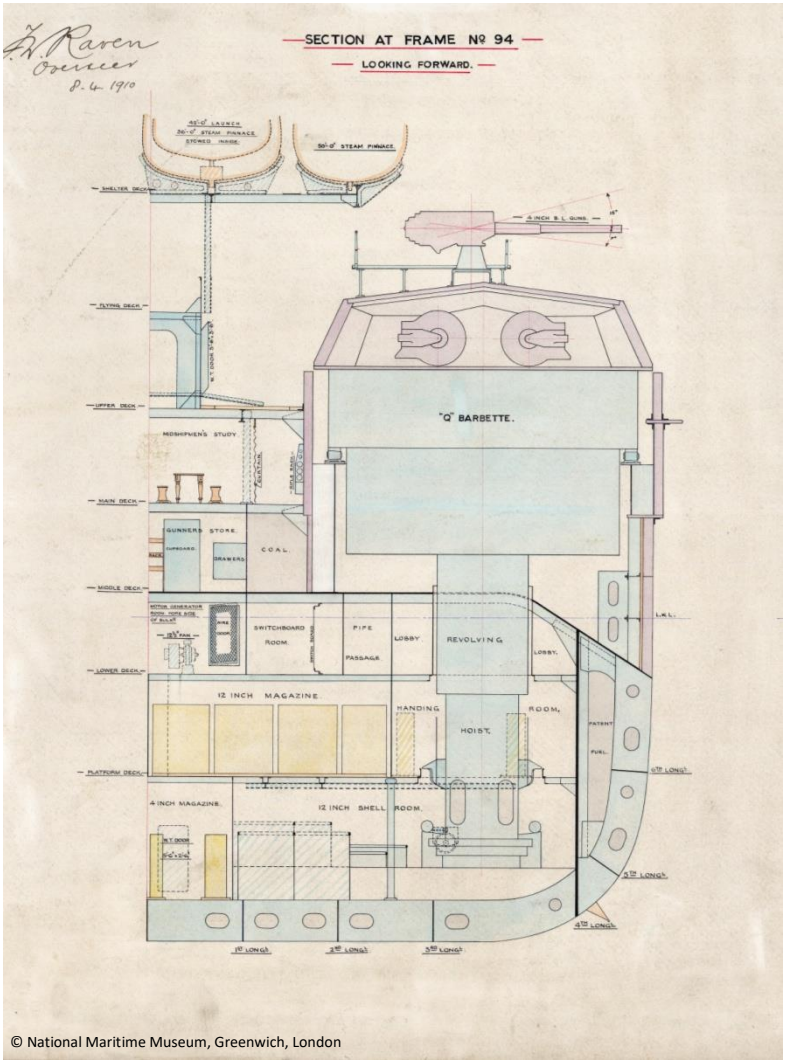


Figure 82: General arrangement of Q Turret and Magazine

Shells or projectiles were stored in shell rooms in the Hold, the lowest deck in the hull. The cordite propellant charges were stored in magazines on the Platform Deck just above. The shells and charges were lifted up to the turret in two cages, one per gun, running in a hoist tube that revolved with the turret and passed from the Hold and Platform Deck through the armoured Main Deck and into the turret's ammunition handling rooms below the guns.

The ship carried approximately 100 shells per gun, stacked five deep in bins inside the shell rooms. The shells were insensitive and robust, able to withstand launch from a gun and impact with the target before exploding. They weighed 850lb (386 kg) each, so a system of winches, rams, cables, grabs, hoists and traversing rails was necessary to move them inside the ship as it pitched, rolled and manoeuvred at sea. The shell handling equipment was operated by sailors winding handles and operating hydraulic valves.

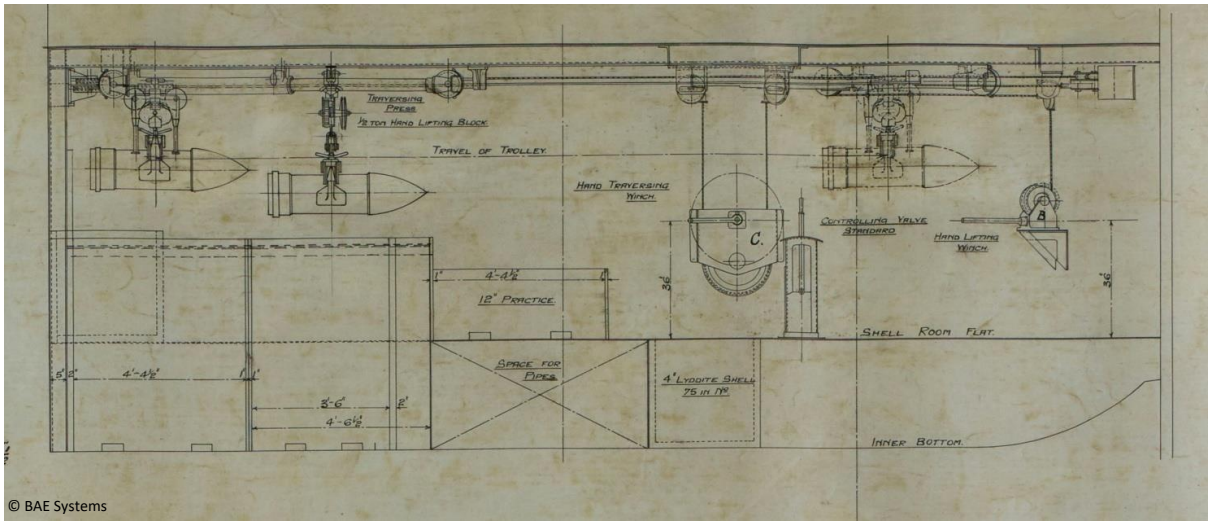


Figure 83: Q Turret shell room

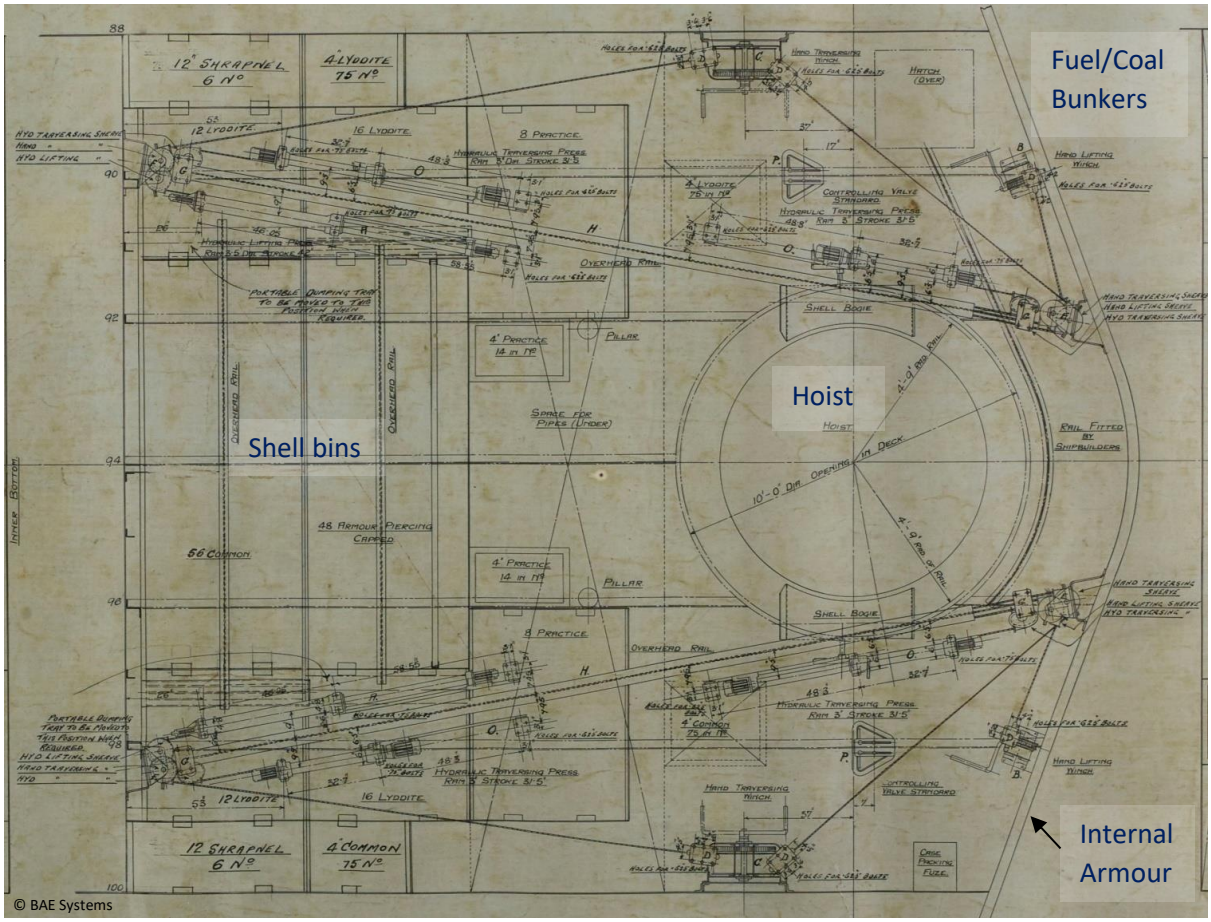


Figure 84: Q Turret shell room, plan view

The shells were transferred into the hoist cage using a ‘shell bogie’ that ran on racks around the base of the hoist tube so that the shell could be loaded into the hoist cage at any rotational position of the turret. The hoist cage would then be lifted to the Platform Deck level for the propellant charge to be loaded.

The cordite propellant charges were stored in the magazines on the Platform Deck above the Shell Room. In contrast to the shells, the propellant charges were sensitive and vulnerable to damage and accidental ignition by spark, impact or overheating. The cordite propellant stands were contained inside silk bags and protectively stored inside brass Clarkson cases until needed.

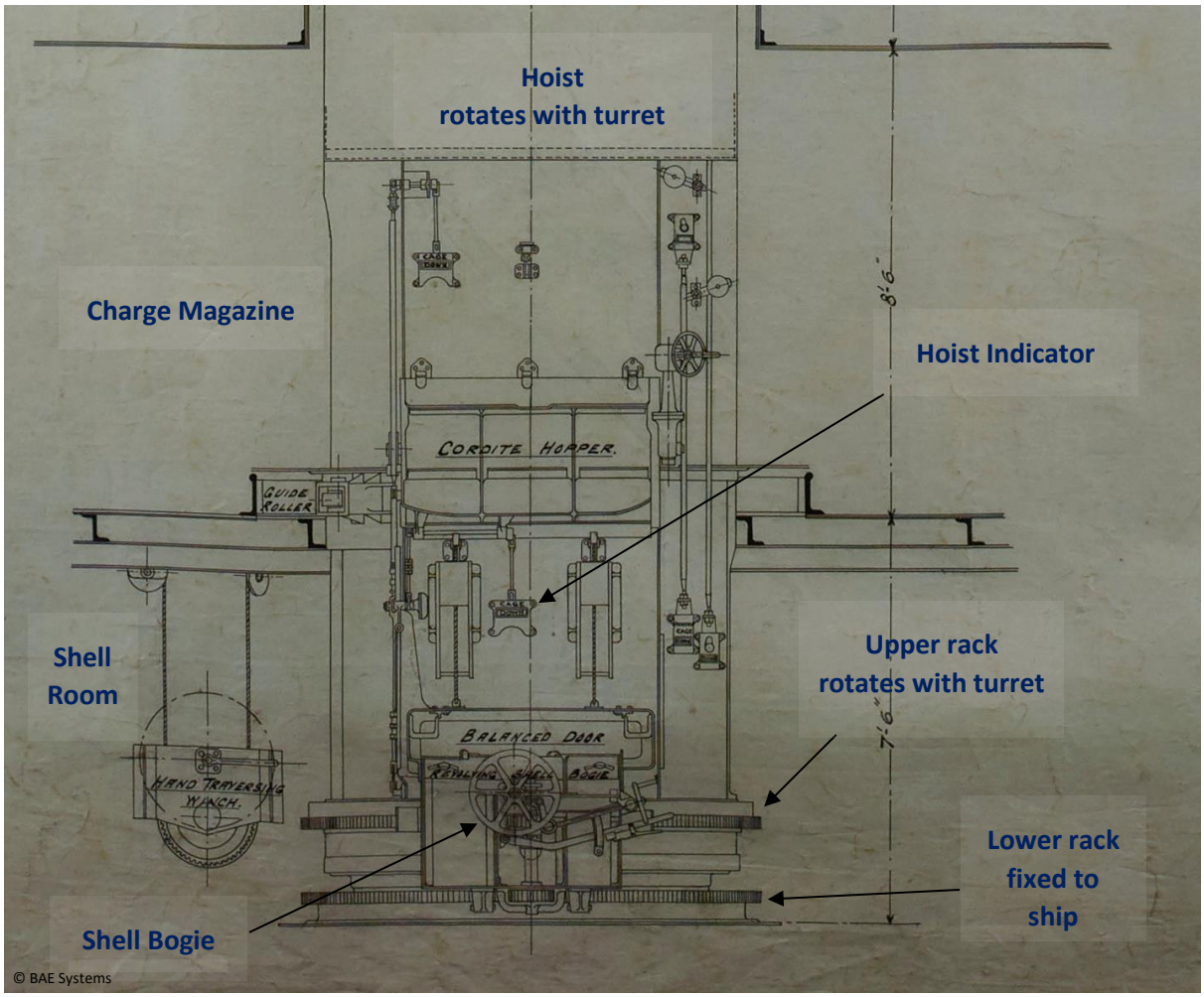


Figure 85: Bottom of hoist

Figure 86: Q Turret shell bogie upper rack

Figure 87: Hoist indicator

A complete propellant charge weighed 307lb (139 kg), made up of four quarter-charges to ease handling and enable reduced propellant weight in the gun for firing at shorter range. The quarter-charges were removed from the Clarkson cases and transferred into the hoist-cage via the cordite-hopper that, like the shell bogie below, was mounted on the outside of the hoist and enabled the ammunition to be loaded into the hoist cage at any rotational position of the turret. Flash doors to protect the magazine from accidental fire in the turret would be opened when the cordite-hopper and hoist-cage were aligned and ready to transfer the quarter charges into the hoist. Empty Clarkson cases were stored out of the way in the magazines and discarded at the earliest opportunity.

Figure 88: Crushed and torn hoist trunk from Q magazine

Turret

The main turret structure was the turntable which carried the elevating mass (gun and cradle) and contained the ammunition handling room and associated equipment to transfer the shells and charges from the hoist to the guns, rotate the turret, elevate, aim and fire the guns. The turntable rotated on roller bearings mounted on the ring bulkhead inside the barbette, which supported the turret's weight and firing loads within the ship's structure.

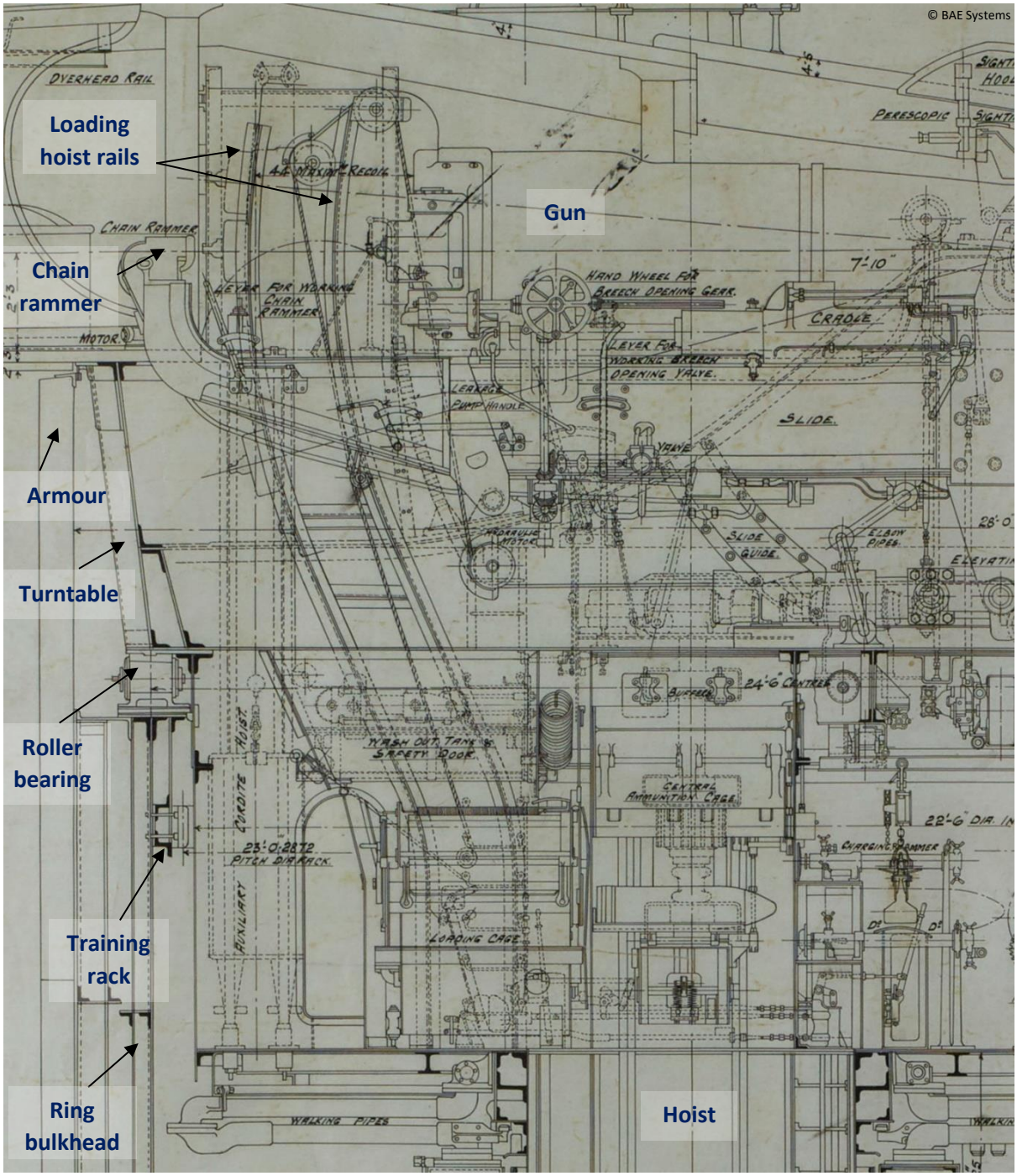


Figure 89: Details of the ammunition path through the turret

The top of the ammunition hoist was in the centre of the ammunition handling room beneath the guns. Two pairs of rams pushed the shells and charges into the loading cages which were then hoisted up behind the guns. Curved guide rails ensured the loading hoist were aligned behind the gun at any angle of elevation. Chain rammers pushed first the shell out of the loading cage into the gun-barrel until its copper driving band engaged with the rifling, and then the propellant charges into the gun chamber. The rammer would then retract, the gun breach close for firing, and the loading cage drop to the handling room ready to receive the next round of ammunition from the hoist.

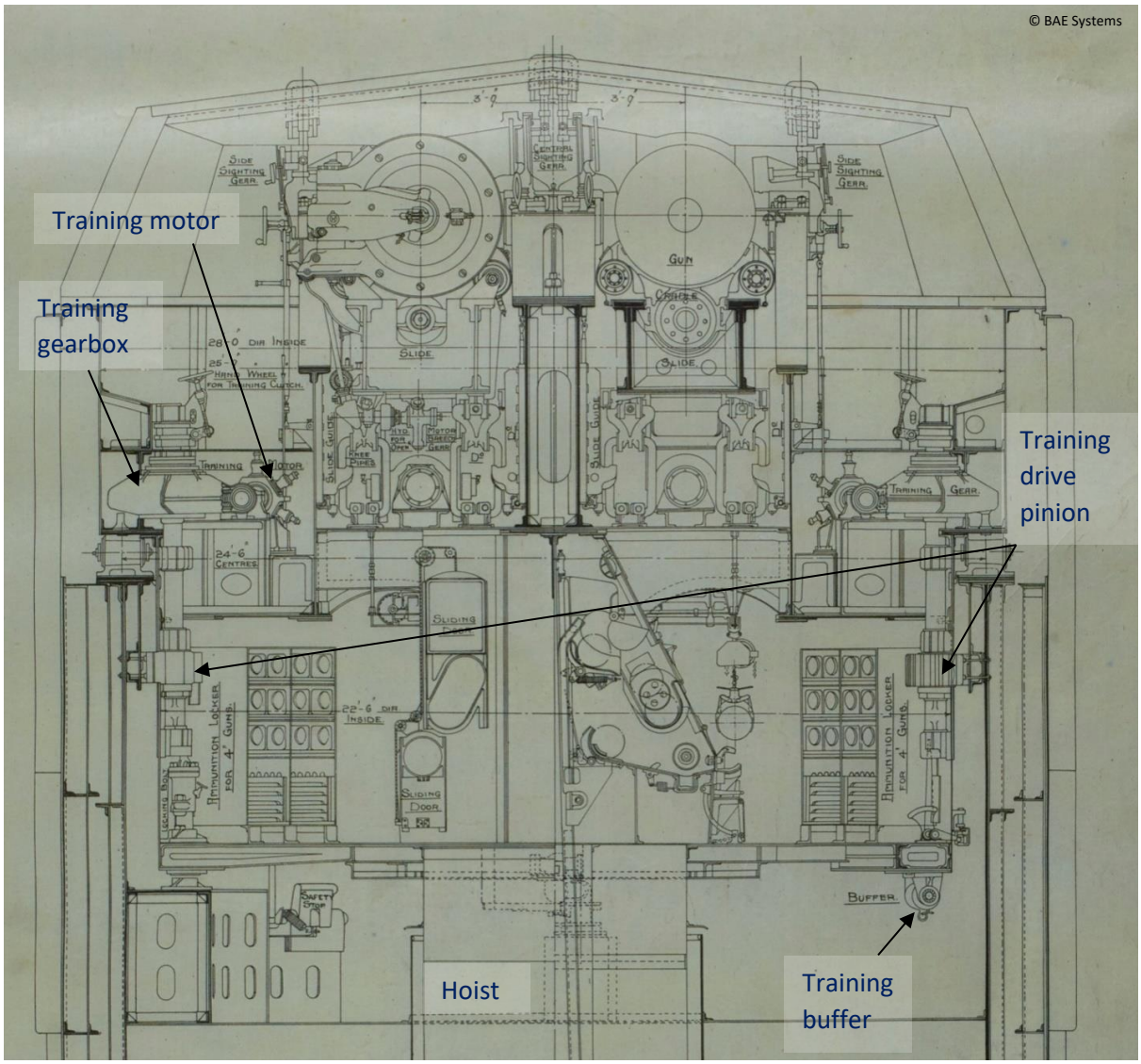


Figure 90: End elevation of turret

The turrets were each rotated by two hydraulic training motors driving geared pinions engaged in the training rack inside the ring bulkhead of the barbette. Turret rotation was limited by buffers on the turntable to prevent the gun barrels striking the ship's superstructure, and over-extension of the pipes and cables that provided power to the turret.

Figure 91: Q Turret training buffer

Figure 92: Chain rammer head

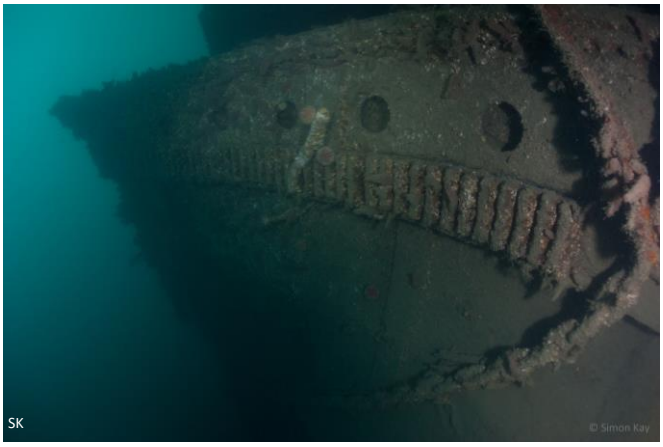


Figure 93: A Turret training rack in the broken open ring bulkhead

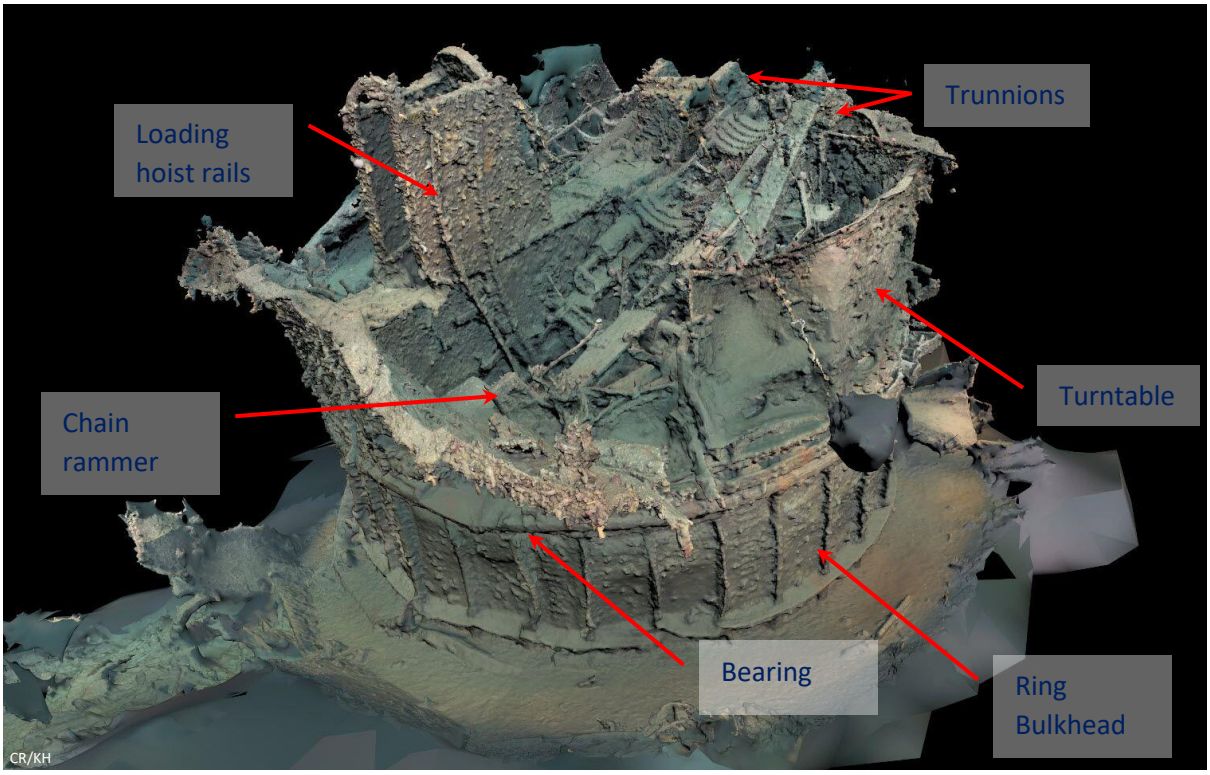


Figure 94: X Turret 3D photogrammetric model

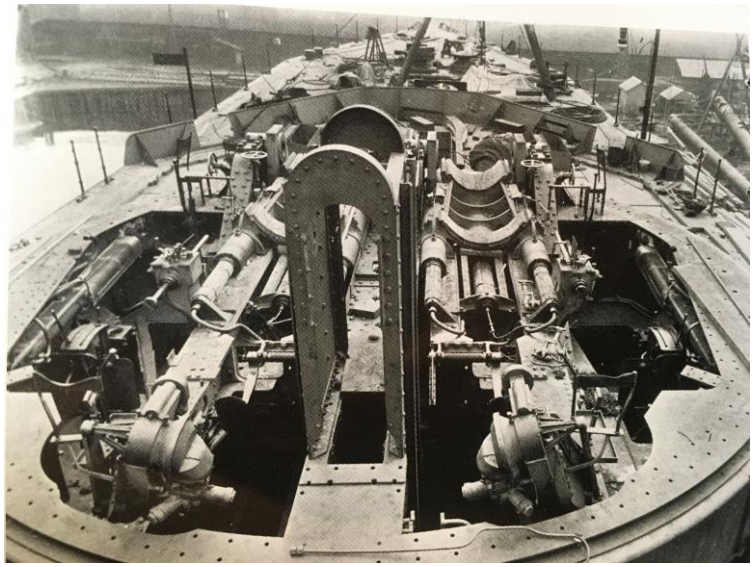


Figure 95: A turret under construction waiting for the guns to be lowered onto their cradles

Elevating mass

The elevating mass comprised of the gun barrel, cradle and slide. The gun barrel sat in a cradle with interlocking ridges locking them together and transferring firing loads. The cradle ran on a track in the slide and recoiled backwards about four feet when the gun fired. Buffers absorbed the rearwards motion before a recuperator spring pushed the gun forward again at the end of recoil for reloading.

Figure 95 shows the cradles and slides of A Turret during construction prior to fitting of the gun barrels. The interlocking grooves on the cradle have been covered to protect from damage. The buffers can be seen on each side of the right-hand gun slide, and the chain rammer mounted at the rear of the slide, behind where the barrel will be fitted.

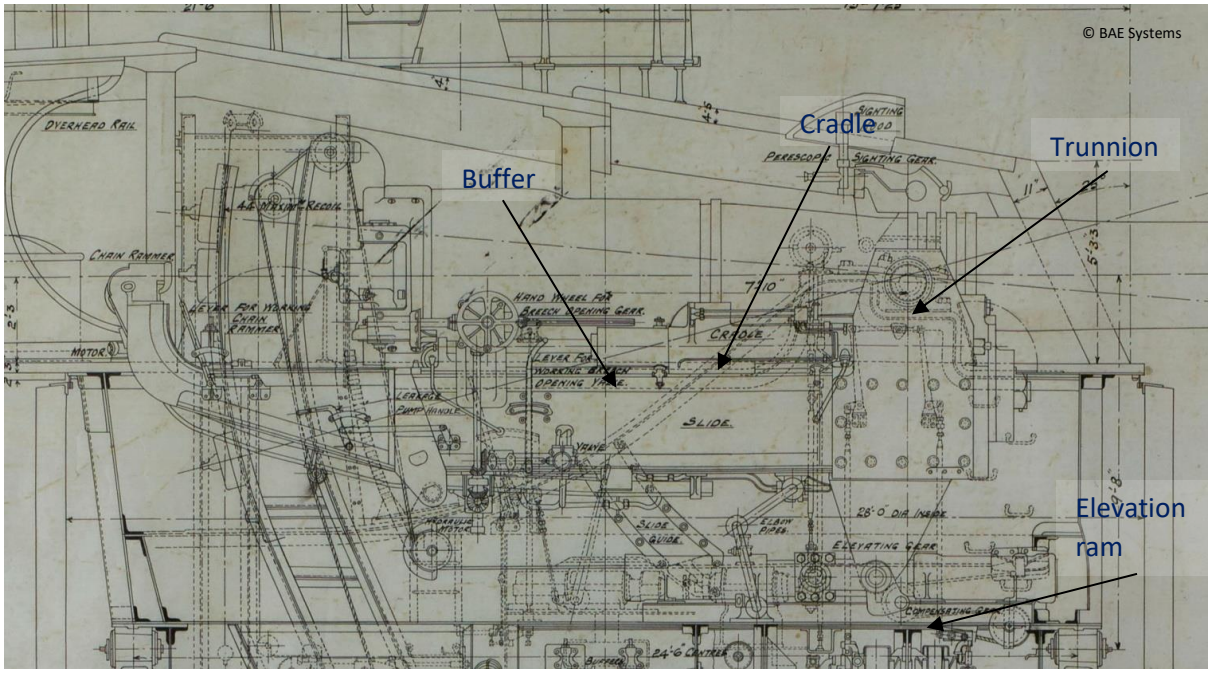


Figure 96: Section of plan image of gun, buffer, cradle, trunnion and elevation ram highlighted

Figure 97: Elevation ram for one of A Turrets guns

Figure 98: P Turret gun cradle

Fire control

Many of the naval engagements of WWI were fought at high speed and extreme range as the inferior force sought to escape destruction by the superior force. This resulted in long range gunnery from ships running at full power producing vast quantities of black funnel smoke and vibration, which made range estimation and gunnery control very difficult.

VANGUARD's gunnery fire control was located in the spotting top high on the foremast forward of the funnels to reduce the likelihood of obscuration by funnel smoke. Optical rangefinders and other optical equipment was used to accurately estimate the target's range, bearing and speed, and spot where the shells were landing (fall-of-shot). This information was relayed to the transmitting station deep inside the ship.

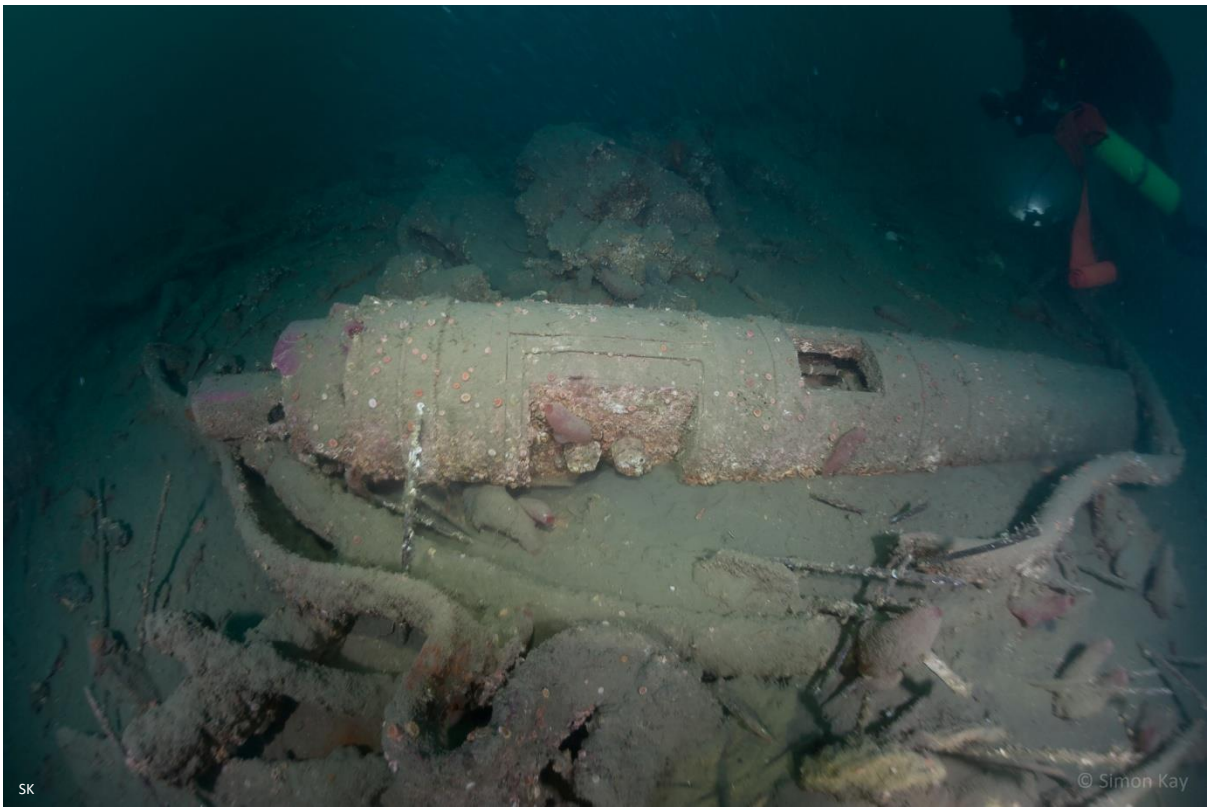


Figure 99: Part of an optical rangefinder

Inside the Fire Control Transmitting Station on the Lower Deck below the bridge and foremast, a mechanical computer was used to determine the firing data for the next salvo from the guns, taking into account the time of flight of the shell and the rate at which the range and bearing to the target was changing. Information from the spotting top was often intermittent and subject to error, therefore much depended on the skill and experience of the operators in the transmitting station.

The firing data was then passed to the turrets and to the Gunnery Director mounted on a platform just below the spotting top on the foremast to afford the best possible view of the target. The Gunnery Director had similar gun-laying (aiming and firing) equipment to that in the turrets and was used to confirm the firing data and gun readiness, and to centrally control the firing of the guns in each turret in order to achieve the best probability of hit on the target.

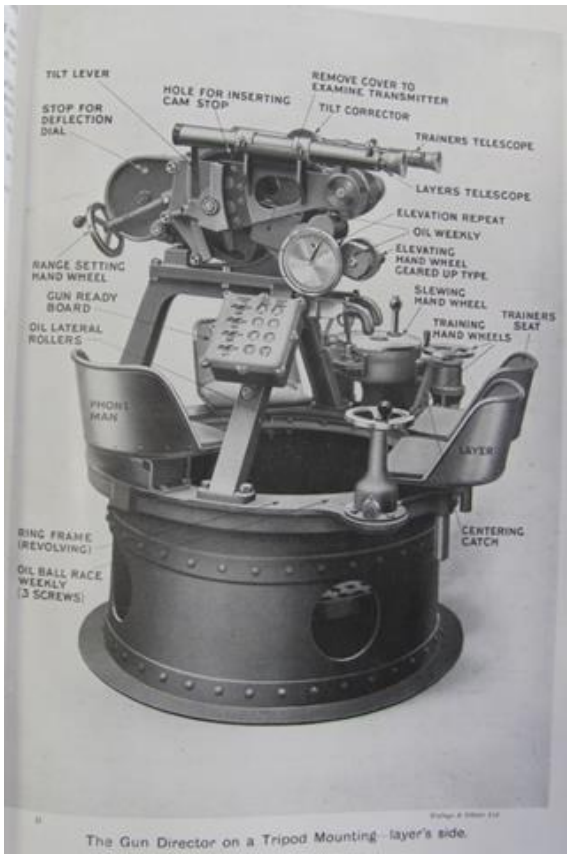


Figure 100: Gun director, note gun firing triggers below elevating hand wheel

Figure 101: Gun firing trigger

Figure 102: Lamp and push box in the fire control top, one light for each barrel in the five turrets

Should the fire control system fail due to breakdown or battle damage the turrets could revert to local control where the gun was aimed by sights in the individual turrets and fired locally.

Figure 103: A Turret periscope gun sights

3.3.5.5 Interesting Wreckage

There are a number of pieces of wreckage that provide insight into the explosion that sank VANGUARD.

3.3.5.6 Forward Bilge Keels

The fore and aft ends of the two bilge keels had a distinct tapering shape and were attached to the hull sides at Platform Deck level adjacent to A Magazine at the bow (frame 32) and Y Magazine at the stern (frame 128). All four bilge keel ends are now lying in the main wreck site with the two forward bilge keel ends lying at the northern (forward) end of the Main Hull Section, in the wreckage on the southern perimeter of the Forward Wreck site "gap." They are approximately 25m apart in an east-west direction, and approximately 35m south-southeast (aft) of their original position in the ship.

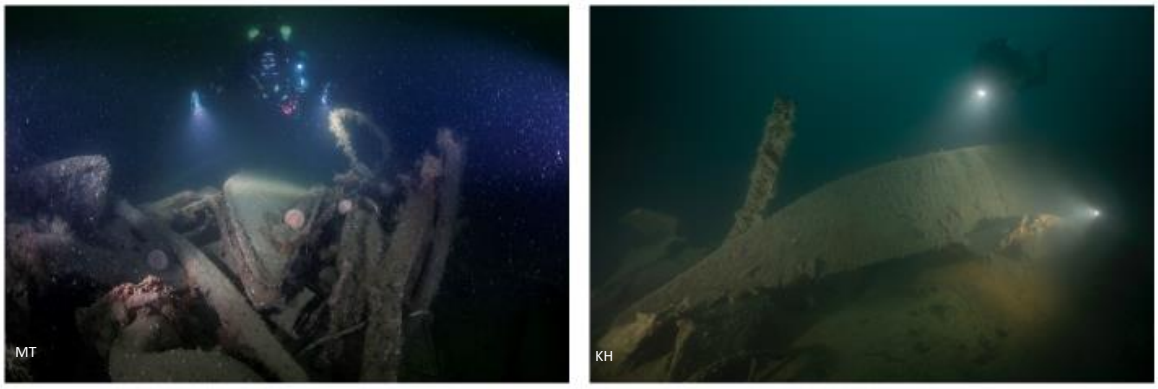


Figure 104: Port and starboard forward bilge keep ends

3.3.5.7 Coal Shutter Door

Adjacent to the forward port bilge keel end is a coal shutter door. These were fitted in internal longitudinal bulkheads between coal bunkers and Boiler Rooms. Noteworthy, this door is open. Two were located during the survey, the second is partially buried and is in the closed position.

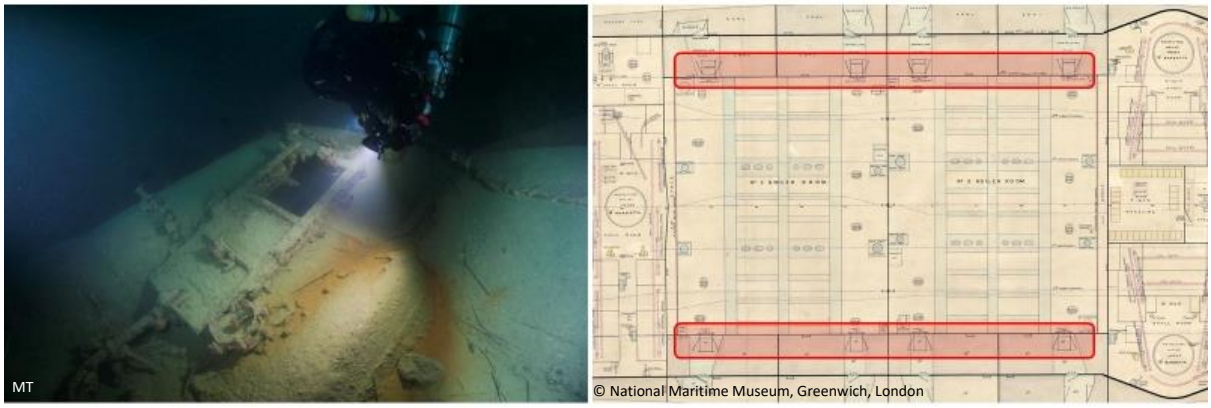


Figure 105: Coal Shutter Door and location on ship's plans

3.3.5.8 Navyphone Plate

There is a cast brass "Navyphone" cover-plate on wreckage to the northeast of the Main Hull section, close to one of the bilge keels and Q Turret ammunition hoist tube. In VANGUARD, the Navyphone switchboard was located in the telephone exchange on the Lower Deck starboard side, directly above A Magazine and adjacent to the Forward Fire Control Transmission Room and the Starboard Hydraulic Room. The plate is now approximately 50m to the southeast (aft-starboard) of its original position in the ship.

Figure 106: Navyphone Plate

3.3.5.9 X Magazine Clarkson Cases

In the area of X Magazine port side there is a small quantity of empty and open brass Clarkson cases for 12-inch cordite charges, closed brass Clarkson cases for 4-inch cordite charges, and sticks of cordite littering the wreckage.

Figure 107: Clarkson cases

3.3.5.10 12-inch Shells/Projectiles

12-inch shells/projectiles are present at many locations on the wreck of VANGUARD, particularly to the east of X Magazine, beneath the stern nameplate, and on the seabed in the Forward Wreck Site "gap." No evidence of shrapnel damage from detonation of shells has been observed.

Figure 108: 12-inch shells

3.3.5.11 Contact 17

A significant piece of wreckage exhibiting damage consistent with the effects of an explosion was located some 605m north of the main wreckage. It has not been possible to positively identify this wreckage as being from VANGUARD, however its damage and position are consistent with it having been projected from the forward part of the ship close to the exploding magazine(s). A positive identification of it would significantly add to the body of evidence relating to the location of the explosion in the ship.

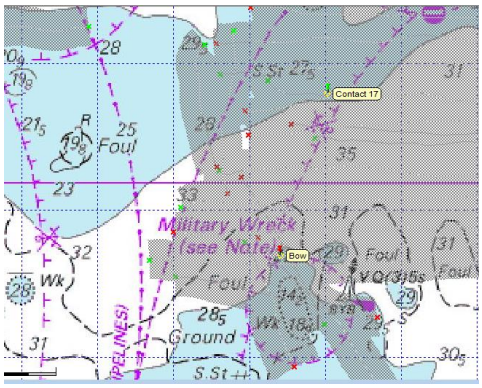


Figure 109: Chart extract showing Contact 17 in relation the the bow of HMS VANGUARD

3.3.5.12 Discussion

Evidence from the wreck of VANGUARD is broadly consistent with the findings of the Court of Enquiry, but adds some additional findings, insight and understanding.

i. The explosion appears to have split the hull horizontally at Platform Deck level along almost the entire length of the ship from the bow to just aft of Y Turret. The decks, hull structure and ships equipment above the Platform Deck have been lifted from the main wreck by the explosion and projected tens, and in some cases hundreds of meters. The bow and stern sections broke away and settled onto the seabed close to their original positions. The lower hull, split open below the waterline, rapidly filled with seawater and sank.

ii. The Forward Wreck site "gap" clearly indicates the probable location of the explosion in P, Q and/or A Magazines. The explosion of up to three main magazines containing up to 90 tons of cordite is consistent with the catastrophic damage observed on the wreck.

iii. The damage evident on the wreck around X Magazine and Y Turret is not consistent with a magazine explosion in those locations, more consistent with salvage of Clarkson cases, turbine machinery and condensers, and the breakup of the ship structure caused by the explosion of the forward magazine(s).

iv. The damage to Q Turret ammunition hoist tube is consistent with an explosion in Q Magazine.

v. Q Turret was projected approximately 45m directly to starboard of the ship in an easterly direction, and was turned upside down. The position of P and Q Magazines between the two turret ammunition hoists is consistent with the distance and direction of projection of Q Turret upwards and straight out from the side of the ship by an explosion in Q Magazine.

vi. P Turret was projected approximately 35m in a south-southwest direction, i.e. aft port of its position in the ship, and turned onto its side. This is significantly different to Q Turret and suggests that the projection of P Turret was affected by influences other than or additional to an explosion in P Magazine, such as an explosion in A Magazine and/or the heaving upwards of the middle deck beneath the barbette, caused by the explosion of Q Magazine.

- P and Q Magazines were adjacent compartments on the Platform Deck. It is probable that a fire and explosion in one of them would cause the other one to explode, however there may have been a short delay between these events.

vii. The location of the Navyphone plate and bilge keels, some tens of meters to the south and southeast (aft-starboard) of the Bow Section and A Turret & Bridge wreckage are

consistent with an explosion in A Magazine. If such an explosion had not occurred, the bilge keels and Navyphone plate would probably now lie in the A Turret & Bridge wreckage near the torpedo tube doors and capstan machinery.

viii. The projection of the Hydraulic Room plate hundreds of meters to the southeast onto BELLEROPHON, as reported to the Court of Enquiry, is consistent with an explosion in A Magazine. The absence of heat damage to this plate suggests that there wasn't a severe cordite fire in A Magazine prior to explosion. Nonetheless, the blast and fireball from an explosion in P and/or Q Magazine(s) through Boiler Room 1 and along the Platform Deck could have caused explosion of A Magazine without the fireball (flash) necessarily reaching the Hydraulic Room.

ix. Identifiable wreckage from Boiler Room 1 is absent from the Forward Wreck Site "gap," whereas some wreckage from Boiler Room 2 is evident at the northern (fore) end of the Main Hull Section, e.g. bulkhead, boiler tubes and a coal bunker shutter door. Consequently, it appears that Boiler Room 1 was more severely damaged and dispersed by the magazine explosions than Boiler Room 2, which is consistent with an explosion in A Magazine at the fore end of Boiler Room 1, as well as explosion(s) in P and/or Q Magazine(s) at the aft end.

- X Magazine would have been protected from explosion of P and/or Q Magazine(s) to a greater degree than A Magazine by Boiler Room 3, located aft of Boiler Room 2.

x. The presence of 4-inch cordite cases that have been heavily deformed and turned inside out by the effects of explosion, and split and heat damaged 12-inch Clarkson cases lying on the seabed in the Forward Wreck Site "gap," suggests that both MD45 (12in) and MD16 (4in) cordite exploded in the magazines.

xi. The general layout of the wreckage is consistent with the primary explosion occurring on the starboard side of VANGUARD, i.e. Q Magazine, particularly:

a. Orientation of bow section pointing northeast, and stern section pointing west. The ship was moored pointing approximately north when she sank, so the rotation of bow and stern is consistent with the central part of the hull being pushed a short distance to the westward, i.e. to port, by the explosion.

b. The bending and folding of the hull double bottom beneath X Magazine on the starboard side, consistent with greater explosive impulse on the starboard side of the ship.

c. The distribution of the turrets on the seabed, particularly P and Q, as described above.

3.3.5.13 Conclusions

i. Evidence gathered from the wreck is broadly consistent with the findings of the Royal Navy Court of Enquiry.

ii. The primary explosion that sank VANGUARD was probably in Q Magazine, followed within seconds by secondary explosions in A Magazine and P Magazine, the "gap."

iii. The hypothesis of an explosion in A Magazine is contrary to the findings of the Court of Enquiry, and is based on the position of wreckage on the seabed coming from positions in the ship close to A Magazine, and reinterpretation of evidence gathered by the Court of Enquiry.

iv. The primary explosion caused Q Turret to be projected from the ship directly to starboard in an easterly direction, and the ship to be pushed a few meters to port by the force of the explosion, causing the bow section to sink pointing towards the north-east, and the stern to lie east-west with the sternpost to the east.

v. The blast wave and fireball from the magazine explosions travelled along the Platform Deck breaching bulkheads and splitting the hull horizontally, heaving upwards the decks and superstructure above the Platform Deck, and projecting this wreckage tens, and in some cases hundreds, of meters as far as neighbouring ships.

vi. The bow and stern sections broke away as the central part of the ship heaved upwards, and sank onto the seabed close to their original position.

vii. The lower part of the hull below the Platform Deck, including Boiler Rooms and Engine Rooms, will have filled rapidly with seawater, and sunk.

4 Conclusions

The wreck of HMS VANGUARD is a complex site and difficult to interpret. Each diver dedicated many dives to orientate themselves, and therefore be best able to provide useful survey information from the wreck site. The use of remote survey techniques, specifically sidescan sonar, was invaluable in order to identify the extent of the wreck site and wider debris field and to inform the in-water activity. The wreck is very broken by effects of her sinking and subsequent salvage, making many historical artefacts plainly visible and accessible without wreck penetration (which was strictly prohibited by the diving licence). Significant wreckage lies outside the current exclusion zone, including some historically important and valuable artefacts.

The evidence of salvage is extensive. Most of this legal salvage was conducted by Arthur Nundy of Nundy Marine Metals during 1957 and in the early 1970s, including propellers, turbines, condensers, armour plate and gun barrels. Smaller items of nonferrous metal were also salvaged by Nundy Marine Metals. Some artefacts were donated to Stromness Museum. Dougall Campbell of Scapa Flow Salvage salvaged the inner portside propeller in 1975 along with two bronze tampion badges. Post 1975, a historical restriction to the site due to its proximity to the Flotta Oil Terminal and the current status as a controlled site has ensured a high level of preservation of the site and therefore its historical and ecological value. There is now evidence that the wreck site is acting as a wildlife haven, being undisturbed by diving and fishing, and is consequently of great benefit to the local fisheries.

The current layout of the wreck site and wider debris field informs our understanding of the effects of catastrophic cordite explosions. Evidence from her sinking is broadly consistent with the Royal Navy Court of Enquiry, although the conclusions made by the munitions experts better inform those findings and adds significant detail. A significant quantity of ordnance remains on the wreck site, ostensibly in locations not vulnerable to damage by further deterioration of the wreck. Consequently, they are not considered to present a significant ongoing safety risk in their current disposition, and their existence presents possibilities for future research under the guidance of subject matter experts.

Teamwork was key to the success of the survey. Building the right team was vital in both skill and attitude. The combination of in-water subject matter experts (explosives, guns, wildlife, navy personnel), wreck diving specialists and underwater photographers, videographers, and 3DPG experts proved highly successful. The diving methods employed during the survey worked very well and the results prove that a dedicated volunteer team can produce an extremely high standard of work. The use of technical diving equipment was imperative, enabling relatively long bottom-times and therefore efficient data capture. The use of forensic diving techniques and underwater mapping and navigation techniques allowed the site to be accurately described and catalogued. Digital underwater camera equipment allowed the site to be documented. The use of reconnaissance dive teams carrying small HD/4K video cameras for broadscale documentation and artefact location proved highly successful on such a disparate and complicated site, thus allowing the documentary team the

freedom to photograph/video key features. 3D photogrammetry allowed large sections of the site to be documented accurately and in full, and the models displayed to a wider audience. Survey logistics should be exact to maximise in-water survey efficiency. Such surveys should place safety as a priority. Careful consideration should be given to the dive platform in use, team ability, skillset and equipment requirements.

The survey has successfully brought to the surface a rich body of information and imagery, and made it available to the wider public for the centenary commemoration and historical record, to the relatives of the lost sailors in memory of their sacrifice, and to national and international audiences to raise awareness and promote learning from the loss of HMS VANGUARD.

4.1 Outputs

In addition to publication of this report, a number of different media have been prepared, including pop-up banners, photographs and PowerPoint presentations for both civic and professional events and museum display.

A series of talks and lectures to interested bodies is being undertaken as we finalise this report.

Media based dissemination of information has been undertaken, including newspaper and magazine articles.

Social media based dissemination of imagery has been undertaken and is available on the Scapa 100 Facebook page.

Additional web-based publication will be available in due course on the Scapa 100 website, www.scapa100.org.

The project has inspired additional Vanguard Social History Projects. *The HMS Vanguard 9th July 1917 Lost Crew* project was set up by a relative of one lost sailor to gather crew images, history and stories. It was directly inspired by our dive survey. More details can be found here: https://www.facebook.com/groups/285557418518769/.

5 Recommendations for Future Work

- Extend the exclusion zone. Considerable wreckage lies out with the current exclusion zone. It is strongly recommended that this zone be extended to cover all wreckage identified in the survey. This will include extending the area in which any fishing can take place. The findings of this survey recommends that the exclusion zone be altered, and increased to a radius of 350 metres from the chart position of 58°51.47N/003°06.54W.

- It is recommended that the survey be repeated every 2 – 5 years to monitor the site, record deterioration and provide opportunity to extend the 3D photogrammetry and photographic documentation. This information should be widely shared in an appropriate manner.

- Consideration should be given to recovery of small samples of cordite from the wreck site to be subjected to testing to provide information regarding its chemistry and deterioration underwater.

- VANGUARD should continue to be treated as a site of huge historical importance. Notwithstanding her war grave status, she also has a substantial relevance to current naval safety. She is a time capsule into WWI naval architecture, and mid-20th century ship wreck salvage techniques. Methods used by the VANGUARD 100 survey team have been shown to be highly effective and should be widely communicated to benefit future wreck site surveys and wreck site management.

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Admiralty, *St Vincent Class Cover (Director of Naval Construction's Design Files),* ©National Maritime Museum

Vickers Sons & Maxim Ltd, *HMS Vanguard Drawings, April 1910,* ©National Maritime Museum

Vickers Sons & Maxim Ltd, HMS Vanguard Gun Drawings, © BAE Systems

7 Annex

The original application to survey the wreck of HMS Vanguard can be found in the following location: www.huskyan.com/project-applications.

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