The Use of Multi-Image Photogrammetry to Record At-Risk Archaeological Material from the Wreck of *Invincible*

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PROJECT REPORT
2017

PASCOE ARCHAEOLOGY

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PROJECT REPORT

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Summary

In 2016 Pascoe Archaeology Services (PAS) was commissioned by Historic England to conduct a detailed photogrammetry survey of vulnerable and at-risk areas of the *Invincible* wreck site. This was due to the site experiencing significant losses in surrounding seabed sediments caused, in part, by high energy storm events during the winter months. The exposure and subsequent vulnerability of the *Invincible* wreck site has led to it being on Historic England's Heritage at Risk Register. It has therefore been necessary to use rapid but also accurate survey methods to record large areas of the site before they deteriorate through exposure to biological and physical erosion. For this reason, photogrammetry was used as the primary recording method for the 2016 fieldwork. The results of which will be used in the creation of a 3D web tour of the site.

For this project, PAS teamed up with the Nautical Archaeology Society, MSDS Marine and the University of Southampton. Diving investigations took place over five days from the 15th-17th May and the 1st-2nd June 2016. Despite poor underwater visibility caused by a plankton bloom the fieldwork was successful in recording a large section from the bow of the coherent portside (Area 1), which included parts of the gundeck, orlop, hold and even a group of disarticulated timbers lying directly outside the coherent structures. In addition, a 14m long section of starboard side structure (Area 3), consisting of riders, frames and planking were recorded in very high detail. The photogrammetry data was processed and the accuracy of the results were tested by Southampton Masters student, Ben Jones. The results of which went on to form the basis of Ben's Master's dissertation and are included in this report.

The results of the photogrammetry surveys produced accurate 3D models which were then passed onto Grant Cox of ArtasMedia. Grant has used the models alongside multi-beam bathymetry, 2D plans, photographs and videos to render a 3D animation of the *Invincible* wreck site. These animations along with other visual aids and narration have been exported into a html5 web framework by Stuart Graeme to create the *Invincible* virtual web tour. This project reports accompanies the *Invincible* wreck site web tour.

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Acknowledgements

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- John Bingeman, the previous Licensee for thirty years;
- Mark Beattie-Edwards, Nautical Archaeology Society (NAS);
- Dave Wendes, skipper of *Wight Spirit*;
- The Nautical Archaeology Sub-Aqua Club (NASAC) for use of the club facilities;
- All members of the NAS that took part in the fieldwork;
- The University of Southampton;
- Mark James, MSDS Marine;
- Grant Cox, ArtasMedia;
- Stuart Graeme, CyanSub

The fieldwork was carried out by Dan Pascoe, Mark Beattie Edwards, Mark James, Rodrigo Ortiz-Vasquez, Ben Jones and Felix Pedrotti, with assistance from members of the NAS, NASAC and the University of Southampton. This report has been written by Dan Pascoe, Ben Jones and Grant Cox. The illustrations have been prepared by Dan Pascoe and Grant Cox.

1. INTRODUCTION

1.1.1. This report has been prepared by Pascoe Archaeology Services (PAS) for Historic England (HE). It constitutes a Project Fieldwork Report on the site of the designated wreck of HMS *Invincible*, in the Eastern Solent. The fieldwork and post-fieldwork analysis have been undertaken with funding from HE.

1.1.2. The programme of work was conducted in accordance with the Project Design agreed by HE. Diving fieldwork took place over five days during the 15th-17th May and 1st-2nd June 2016.

2. BACKGROUND

2.1.1. The extremely stormy winter of 2013/2014 caused considerable exposure throughout the wreck site (PAS 2015, WA 2015 and Licensee Report 2014). This left exposed features at-risk from biological, chemical and physical processes (PAS 2015, WA 2015:9). This was confirmed by the results of diving fieldwork by PAS and by geophysical surveys by Wessex Archaeology (WA) in 2014. Unfortunately, sediment levels had not returned to a level significant enough to protect the site. Therefore, the site is susceptible to further exposure.

2.1.2. Fears of further exposure of the wreck were realised during inspection dives by the author in March and April 2015. These dives identified that the site was even more exposed than the previous year with many fragile artefacts also exposed. The main site, which consists of the coherent portside, was exposed from the bow to the stern (50m) along the remains of the gun deck and structures relating to the orlop. There were also a series of broken frames exposed relating to the bottom of the ship at the bow. Therefore, there were structural remains exposed relating to all remaining decks of the wreck. Exposure of the gundeck at the bow had revealed not only the deck and hull structure but also fragile organic and glass artefacts.

2.1.3. To the north and northeast of the main site lie the broken-off remains of the starboard side. Drastic loss of seabed sediments revealed that these remains, although broken, are extensive. Much of the exposed structures have fresh, clean timber surfaces. These newly exposed timbers have the potential to identify many constructional details and methods used in the building and later re-building of the ship.

2.1.4. This project focused on the detailed survey of these exposed areas of the wreck. To gain as much detail as possible photogrammetry was used as the primary recording method.

2.2. The Site

2.2.1. The site of the *Invincible* lies on Horse Tail in the Eastern Solent and is designated under Protection of Wrecks Act 1973 (Figure 1). The statutory Instrument is Order No. 1980/1307. The restricted area is a circle with a radius of 100m. The position of the Centre of the circle is as follows:

Lat.	

2.2.2. The remains of the wreck lie in shallow water on a sandy bottom in approximately seven to nine metres. The exposed wreck structure attracts an abundance of flora and fauna that thrive both on and within the many nooks and crevasses. The site is surrounded by an extremely mobile and slightly undulating sandy seabed.

2.2.3. The main site is over 50m long consisting of the intact portside, orientated NW/SE with the remains of the bow at the NW end. Exposed lines of timbers associated with the lower gun deck and orlop deck protrude from the sand. Most of the remains of the main site are buried beneath the sand.

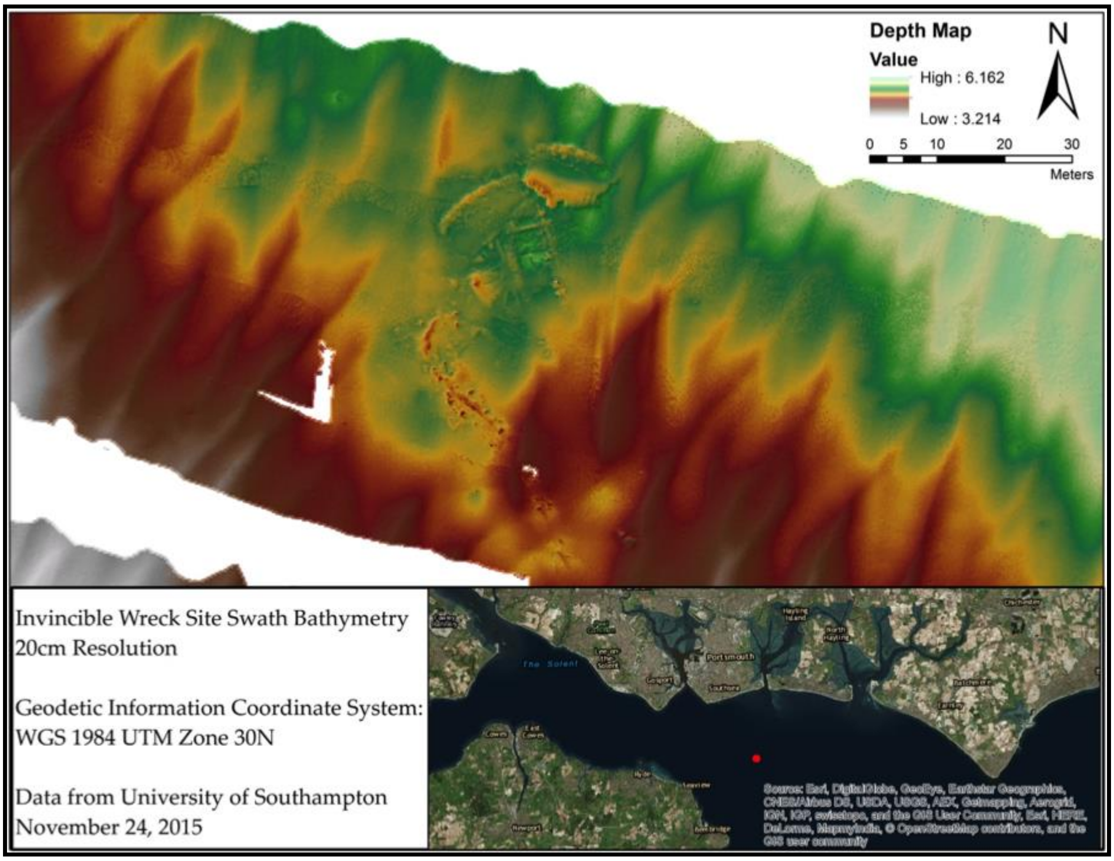

Figure 1: Site location and appearance on 2015 Swath Bathymetry.

3. PROJECT AIMS AND OBJECTIVES

3.1. PROJECT AIMS

3.1.1. To target specific archaeological features for detailed recording that are exposed and at risk, and to include the results in a virtual diver trail on the Designated Site of HMS *Invincible*.

3.2. PROJECT OBJECTIVES

3.2.1. The following were the Primary Objectives for the fieldwork:

- Undertake archaeological recording of areas most at risk using a variety of techniques, including photogrammetry. This will save constructional information from loss via preservation through record;
- Produce a structured record of field observations; including a photographic record, 3D photogrammetric models and site plans of targeted survey areas;
- Diver ground-truth magnetic and side scan sonar anomalies outside the protected area, which were identified by the WA 2015 geophysical report (WA 2015). This is extremely important because if the anomalies relate to *Invincible* then the current Statutory Instrument boundary will have to be extended to protect these new parts of the site;
- Measure the sediment levels on the monitoring poles. This will identify changes in the seabed over time and reveal which areas of the site are exposing or covering up. This will highlight which parts of the site are most at risk and are, as such, a priority for further work, thereby assisting future management strategies;
- Continue to identify and relate the remains of the starboard side structure to the original parts of the ship. This will also enhance the understanding of site formation and wrecking processes and help determine the extent of the survival of the ship;
- Training NAS members, University of Southampton students and creating experience for professionals. Previous projects on *Invincible* have demonstrated that NAS volunteers working alongside professional archaeologists have made a valuable contribution to the recording of the site. This project will also provide valuable fieldwork and post-fieldwork experience for students, which will assist them in their career development;
- Creation of a virtual diver trail to be displayed on the HE's website. This will provide public access and an increased understanding of the site to a wider audience, including the non-diving community; and
- Recovery of artefacts that have become exposed, are vulnerable and at risk of biological and physical degradation. Also, artefacts that, through exposure, have become loose on the seabed and are therefore in danger of being swept off-site.

4. METHODOLOGY

4.1. DIVING

4.1.1. PAS and the NAS staff operated as part of a four-person HSE scuba team. All diving involving PAS and NAS staff complied with the Diving at Work Regulations 1997 and associated Scientific and Archaeological Approved Code of Practice.

4.1.2. Operating alongside the HSE divers, but not forming part of the core HSE team, were volunteer divers from the NAS membership. The volunteers dived according to the rules and regulations of their certifying organisations and the NAS code of practice, but under the supervision of the diving supervisor.

4.1.3. Diving operations were carried out from the MCA accredited diving support vessel *Wight Spirit II*, an Evolution 38s and licensed to carry 12 divers.

4.1.4. At the beginning of each day the project team were briefed on the dive plan, survey and recording methods and health and safety. The team members were then divided into buddy pairs for diving and given survey tasks to carry out underwater.

4.1.5. A buoyed shot was deployed on the site which the divers descended. When at the bottom divers clipped onto the bottom of the shot and reeled-out to their chosen areas to survey. This method ensured that divers never got lost from the shot and could always return safely to the surface to be picked up by the dive vessel.

4.2. SURVEY AND RECORDING METHODS

4.2.1. The methodological approach to carrying out archaeological work underwater followed the procedures and guidelines set out in 'Underwater Archaeology: The NAS Guide to Principles and Practice' (Bowen 2008).

4.2.2. The recording of the site was carried out following procedures and guidelines set out in the 'Institute for Archaeologists Standards and Guidance for Nautical Recording and Reconstruction' (CIFA 2014).

4.2.3. Initial site assessment and recording involved observational survey and sketch plans of potential areas of recently exposed material. These were supplemented by digital photographs and HD video. The observations were recorded by the diver onto survey boards using digital cameras and GoPro HD cameras.

4.2.4. Selected features and areas were recorded using a number of underwater survey techniques using planning frames and tape measures for trilateration and baseline offset measurements.

4.2.5. Photographic and video surveys were taken to record key constructional features and exposed artefacts.

4.2.6. Plans, sections and elevations of archaeological features were drawn at a 1:10 or 1:20 scale. Drawings were made in pencil onto permatrace, transferred onto a master copy and then digitised in Site Recorder 4.

4.2.7. Following each dive, team members filled in an archaeological record sheet which provided details of specific work undertaken on each dive and referenced any numbers utilised e.g. context numbers and feature numbers.

4.3. PHOTOGRAMMETRY METHODS

Photogrammetric marker generation and attachment

4.3.1. A set of 161 12-bit Photoscan targets were generated and printed on a composite plastic and aluminium boards. During the first dives of the project, targets were taken down by the divers and either nailed to the structures of the wreck or attached to the seabed with tent pegs. Consistent spacing was aimed for across the site so that any given swath of photos would include at least two individual targets. More targets were added on subsequent dives to improve coverage in key areas.

4.3.2. The site had already been split into numbered survey areas during the 2013 survey (PAS 2014, 12). Numbered areas 1, 2 and 3 were chosen for photogrammetric survey during this project. Area 1 represented an area crossing the port bow extending from the main gundeck down to the floor of the ship. Areas 2 and 3 comprise large sections of the starboard side, which were scattered to the North of the intact portside.

Cameras

4.3.3. Two cameras were used during the photogrammetric survey, they were:

- Nikon D610 with attached 20mm wide angle lens, Ikelite underwater TTL housing, and modular 8” dome port with 4.125” lens extension;
- GoPro Hero4 Black, used both with the ‘flat port’ afforded by the GoPro standard dive housing, as well as with an Inon UFL-G140 semi-fisheye dome port.

4.3.4. The GoPro with the flat port was used entirely as an ancillary camera attached to the Nikon’s housing, and was not worked up into the models.

Dive teams and survey pattern

4.3.5. During diving operations, teams of two were sent down onto the wreck and tasked to survey specific areas. Areas were assigned during the dive briefings at the beginning of each day, and teams were shown on a site plan the area to be covered. Divers were equipped with the available cameras; typically dive teams were either assigned the Nikon with the attached GoPro with flat lens, or the standalone GoPro with the dome port. Divers covered their designated areas in a ‘lawnmower’ pattern with the intent to ensure overlap between photo rows and columns.

4.3.6. During dives, the cameras were set to automatic white balance settings and focus. This workflow was designed to eliminate user error and the need for a comprehensive understanding of camera theory among the team.

4.3.7. The Nikon was set to capture manually, while the two GoPros were set to automatic capture at one image per second. While some projects have had success extracting photogrammetric stills from GoPro video (Pacheco *et al* 2015, CA 2015 and Van Damme 2015), this approach was not selected due to the resolution loss inherent in the extraction process, and the sufficiently large data sets generated by the automatic still capture setting.

Target measurement

4.3.8. When photogrammetric survey was not being undertaken, measurements were collected between many of the Photoscan targets on the wreck. A pair of divers were equipped with a measuring tape and dive slate. The divers used the tape to take millimetric measurements of the distances between the marked centre-points of each target and those of its nearest neighbours. This process generated a set of 19 hand measurements from Area 1 and 14 measurements from Area 3.

Data processing

4.3.9. The raw images from Areas 1-3 (NEF from the Nikon and JPG from the GoPros) were brought into RawTherapee. In RawTherapee, the spot white balance tool was used to colour correct the photos based on the PhotoScan targets as white points. However, this was generally insufficient to provide a clear model. Further settings were changed, most frequently by selectively reducing the green channel to mitigate the effects of suspended biological material, and increasing contrast.

4.3.10. All files were output from RawTherapee as 16-bit PNG files with no compression. PNG files were chosen for producing smaller file sizes than TIFs, while still being a lossless format. The PNGs were then opened in Agisoft Photoscan for photogrammetric processing.

4.3.11. Once in PhotoScan, image sets were broken into chunks if necessary, to lower processing times on datasets with a large number of images, with chunk size typically staying in the 300-500 image range, with some outliers.

4.3.12. Images were then aligned using PhotoScan's medium accuracy setting. Medium was chosen due both to high processing times observed when attempting alignment of larger datasets on the 'high' and 'highest' settings, as well as occasional highly confused models generated due to the high sensitivity of the setting attempting to highlight water particles as features of interest.

4.3.13. After chunks of photos were aligned, dense point clouds were generated, using high or medium settings. If successful, interpolative meshes and textures were generated from the dense cloud. Textures were rendered as orthophotos. Marker detection was run on successful models, and modelled chunks were aligned using overlapping markers and PhotoScan's merge chunk feature to create full models.

4.3.14. Once full models were created, the models were scaled in PhotoScan, using the onsite hand measurements between photogrammetric targets as a guide; these measurements were applied to the distances between target markers detected by the software. The scaling accuracy of this method will be discussed below.

4.3.15. The mesh and texture stages were then exported into 3ds Max and other modelling applications with the surveys ultimate goal of creating a virtual dive trail for the *Invincible*.

Target baseline measurement

4.3.16. The photogrammetric targets used on the *Invincible* were machine cut and therefore uniform in size.

5. PROJECT RESULTS

5.1. INTRODUCTION

5.1.1. Five days of diving were conducted on site during two sessions, the 15-17th May and the 1-2nd June 2016. A total of 69 dives were undertaken by 14 divers, with a total bottom time of 3757 minutes.

5.1.2. In addition to the results from the specific project dives this report will also include observations made during diving visits by the current licensed team.

5.1.3. Prior to the start of the project the site was visited on the 1st and 3rd May by the author. During these visits the underwater visibility was excellent and survey areas were confirmed. Newly exposed archaeological features were also identified and images and descriptions of the chosen survey areas will be included below.

5.1.4. In general, underwater conditions during the project were not as anticipated for the time of year. Going from experience of diving on the site the period of May going into early June is the best time to dive the site and conduct a photogrammetry survey. Underwater visibility is generally around 5m. Uncharacteristically, the in-water visibility during the project was exceptionally poor due to a dense plankton bloom. Visibility ranged from 1-2m, depending on the density of biological matter (plankton) suspended in the water.

5.1.5. Although conditions were not ideal for underwater photogrammetry it did not hinder the results of the project. Methods had to be altered to ensure the collection of good data. This meant getting closer to the subject matter when capturing images. The disadvantage of this was that it took longer to survey targeted areas and not all targets were reached. The advantage, however, was that the archaeological features were captured in greater detail at a high resolution because the cameras were closer to the subject.

5.2. AREA 1

Description of Area 1

5.2.1. This area extends from the very point of the bow back to the third gunport and down to the floor of the hold. In this area, the entire remains of the gundeck are exposed. Below the remains of the gundeck are three upstanding iron knees, below which is the orlop. The space between the knees and deck beams of the orlop has been scoured exposing more of the ship's cable and a pine-clad deck. There is a 10m exposed section of the orlop consisting of the tops of deck beams, half beams and sections of deck planking clad with pine. Lying on top of much of the orlop are piles of cable (Figure 2-4).

Figure 2: View looking NW between gundeck and orlop © PAS.

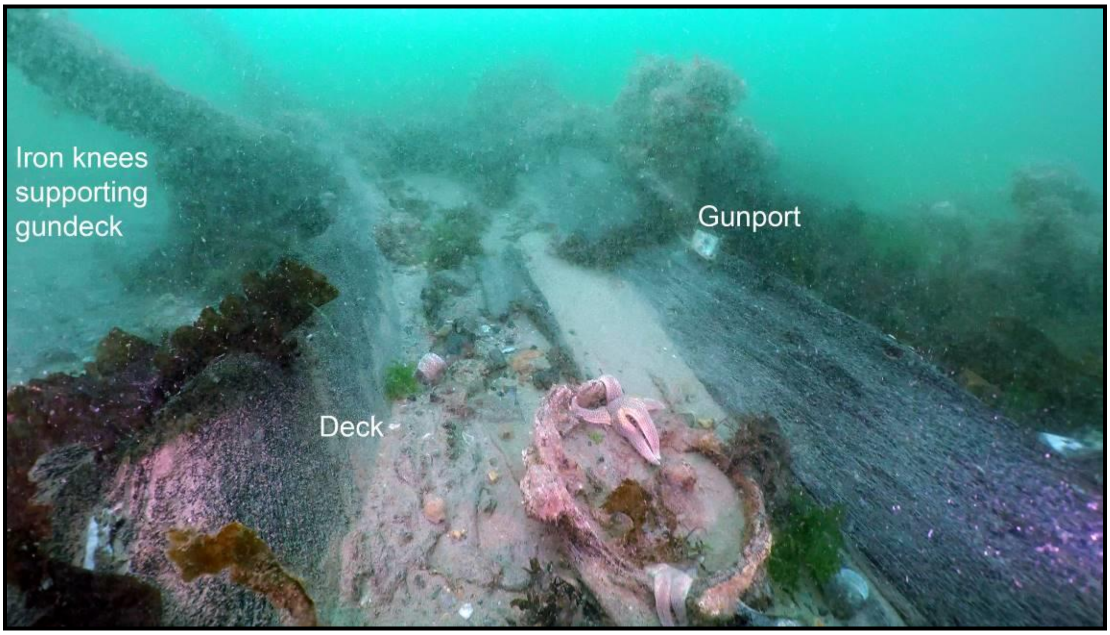

Figure 3: View looking SE along gundeck © PAS

Figure 4: View looking North with cable lying on the pine clad orlop © PAS

5.2.1. Towards the forward-most part of the bow, structural features of the orlop and internal structures and artefacts within the hold are exposed. Immediately below a section of exposed deck and half beams of the orlop are the remains of a compartment or shelving structure (Figures 5-6). Below this is an area of ship's cable and a partial barrel that have all been exposed since 2011. Although the cable and barrel have been observed for a number of years, the internal structures have only recently become clear. The height of exposure of the deck and half beams from the orlop has increased by 150mm. This would explain the recent exposure of the internal structures immediately below.

Figure 5: View looking NW towards the bow with the orlop deck and half beams aligned through the centre of the image © PAS

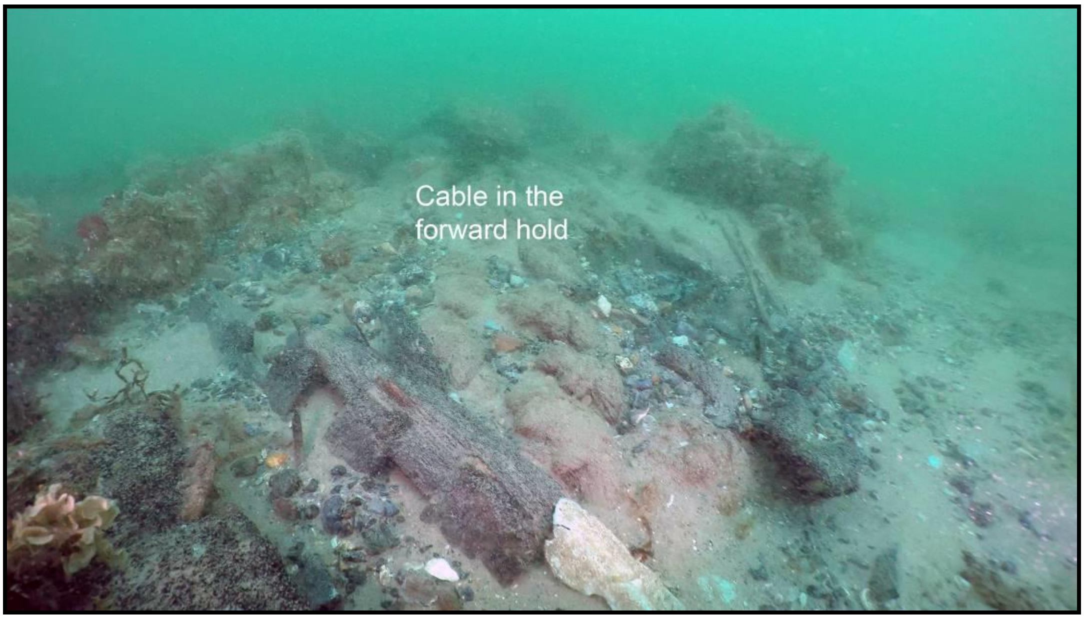

Figure 6: View looking North from orlop into the forward hold. Note the slighter constructed internal structures above a bundle of cable © PAS.

5.2.1. At the bottom of the forward hold are exposed floor timbers and futtocks and immediately above these large timbers are the remains of frames and planking of a slighter construction. These most likely represent the floor of a storeroom which was suspended above the ceiling of the hold (Figures 7-9).

5.2.2. From studying the internal forward plan of *Invincible* in Bingeman's 2010 publication following her major refit in 1752-56, this internal structure could be related to the light room or filling room (Figure 7). Above the light room and filling room was the gunner's store. On the seabed, scattered on the planks of this floor structure, are musket shot, probably originating from the gunner's store.

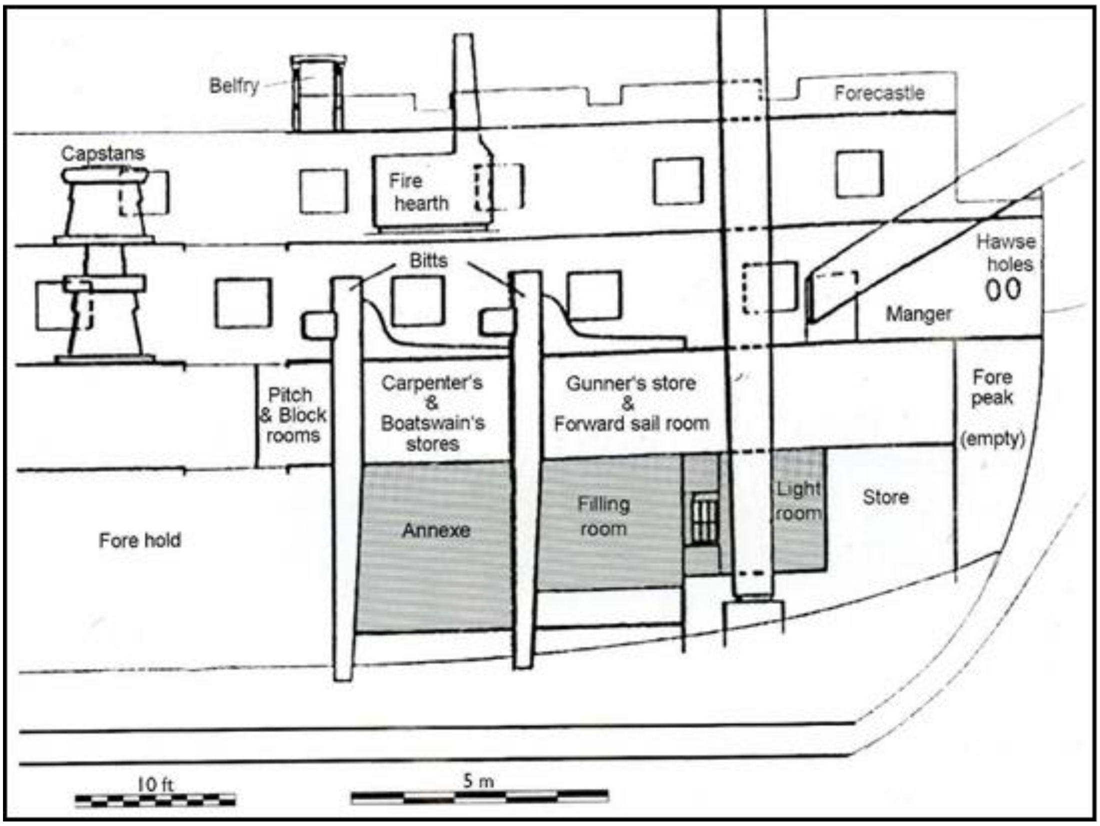

Figure 7: *Invincible's* forward arrangements. Drawing John Betwell

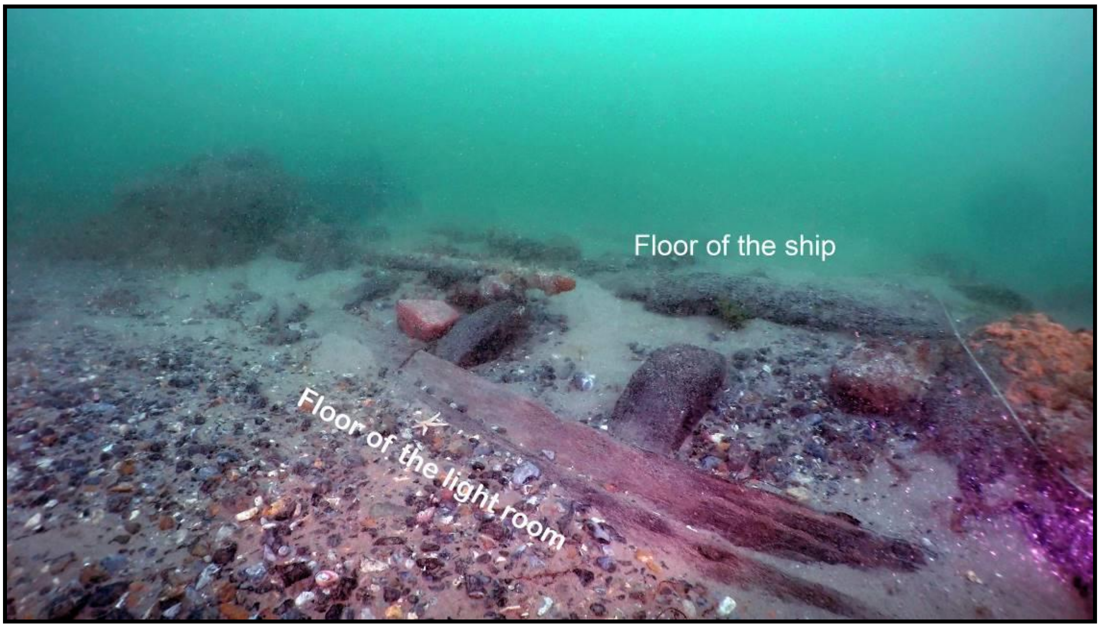

Figure 8: Internal floor of a compartment above the ceiling of the forward hold, possibly the light room © PAS

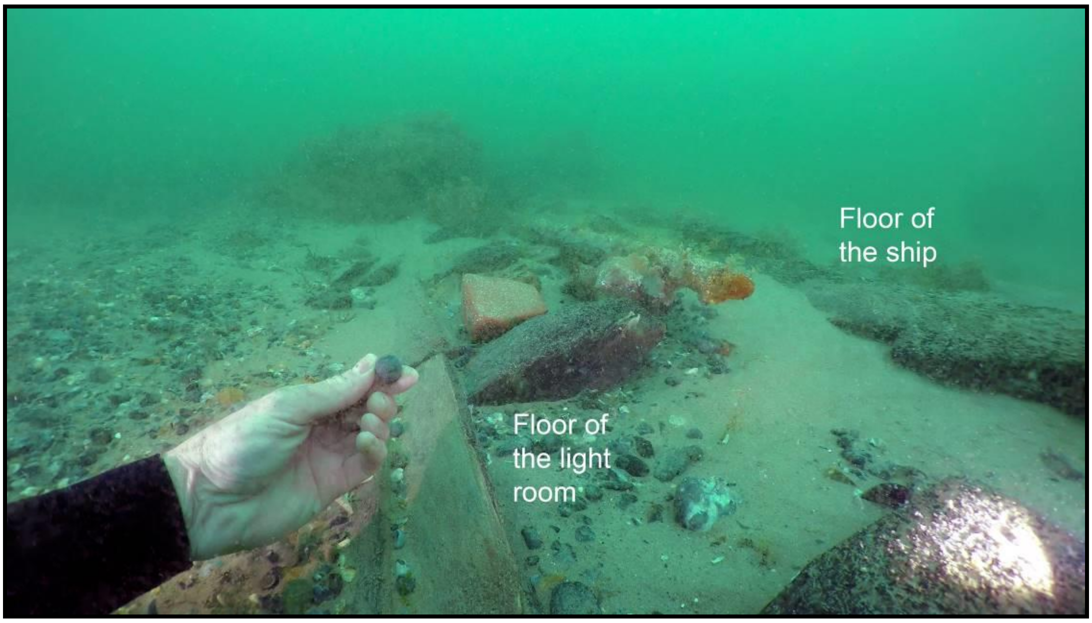

Figure 9: View looking NW, scattering of musket shot on the floor of a forward compartment, possibly the light room © PAS.

Photogrammetry results from Area 1

5.2.3. In the original project design it was only intended to record along the length of the gundeck forward from the third upstanding iron knee. Following the reconnaissance dives in early May and observations of greater exposure of features, it was decided to extended this to include the sections of exposed orlop, the floor of the ship, as well as the sweep of the bow (as described above), and an area of disarticulated timbers extending out from the coherent forward bow structure.

5.2.4. Unfortunately, not all of this area was completed. Instead the team manged to achieve the survey of the gundeck and orlop, forward from the point of the second upstanding iron knee. This also included the sweep of the bow, the forward most section of the hold and the area of disarticulated timbers outside the bow (Figures 10-15 and see larger images on plates in the Appendix). The survey of the floor timbers was not achieved.

5.2.5. The results from Area 1 derive from three data-sets, taken from three individual dives. The first data-set includes the gundeck and the sweep of the bow. The second data-set includes the orlop and a section of the forward hold. The third data-set includes an area of disarticulated timbers outside the coherent port structure. These individual data-sets can be clearly seen in Figure 11. Differences in colour have occurred in the data-sets due to changes in ambient light. Subtle changes in light occur depending on the height of the tide, angle of the sun, whether it is a cloudy or sunny day and the clarity of the water. Underwater conditions are constantly changing throughout the day and this influences the appearance of the data.

Figure 10: This is a reconstructed plan of the site, the purple shaded areas represent the areas which have been recorded photogrammetrically. Area 1 and 3 are sections recorded in 2016 © PAS.

Figure 11: Image showing the original photogrammetry model of Area 1 with Photoscan targets. This image also identifies the three separate data sets, which have been merged to form Area 1 © PAS.

Figure 12: Image showing the reworked and colour corrected model of Area 1 without Photoscan targets © PAS.

5.2.6. Figures 13 and 14 are close-up images from the photogrammetry model of Area 1, which focus on the exposed remains of the gundeck and orlop. Identified in these images are features that relate to the remains of the most forward gun station on the gundeck and a section of the orlop immediately below.

5.2.7. The gun station can be identified by the gap in the frames, which represents the location of the gunport. Immediately aft of the gunport are the remains of a hanging wooden knee. Below the gunport are the remains of the deck, which can be seen to be supported by ledges and deck beams. The deck only survives 0.5m out from the side of the hull. Forward of the gunport the frames are clear to see, which are constructed and fastened in pairs. There are two lead scuppers at the end of the gundeck. One can be clearly seen lying in the sand just outside the frames. The other is still in its original location between the frames.

5.2.8. Below the gundeck are the remains of the orlop. The line of the orlop deck can be seen emerging from the sand, parallel to the remains of the gun deck. On top of the deck is a coil of exposed anchor cable. The cable is lying directly on top of the deck which is clad with pine. At the forward end of the orlop, halfway between the decks, are the remains of a wooden breast hook fastened to the inside of the hull. Below the deck of the orlop there are the exposed ends of deck beams and ledges (Figure 12).

Figure 13: Close-up view of the forward gundeck and orlop © PAS.

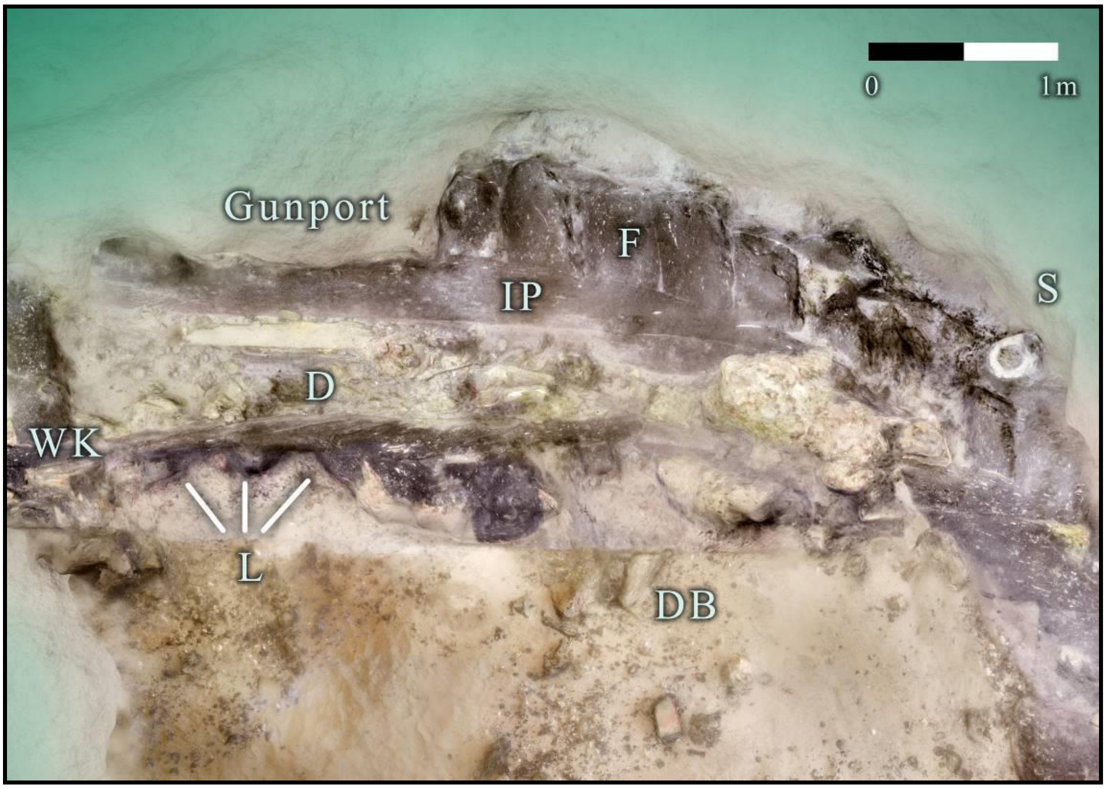

Figure 14: Close-up view of the forward most gun station (see annotations from Figure 11) © PAS.

5.2.9. Figure 15 is a close-up view of a section of the forward hold. Within it is a jumble of cable and the remains of a spirit barrel. It is also possible to identify a section of an internal structure just below the beams and ledges of the orlop, which can also be seen in Figures 5 and 6. Looking closely, it is also possible to see that some sections of cable are served. This means the cable has been wrapped with a smaller gauge of rope which acts as protection against wearing and chaffing.

5.2.10. Outside the remains of the coherent structure are numerous disarticulated timbers (Figures 10-12). These timbers appear to be a collection of broken deck beams, carlings and wooden knees. To the north are large sections of starboard side hull structure consisting of planking and framing. The disarticulated timbers are obviously associated with the decks of *Invincible* that have broken up as the starboard side broke away from the portside.

5.2.11. One of the timbers amongst the disarticulated timbers appears to be a deck beam because it has a slight curve, which would have followed the camber of the deck. The camber in the deck would have allowed unwanted water to run off to the sides and out through the scuppers.

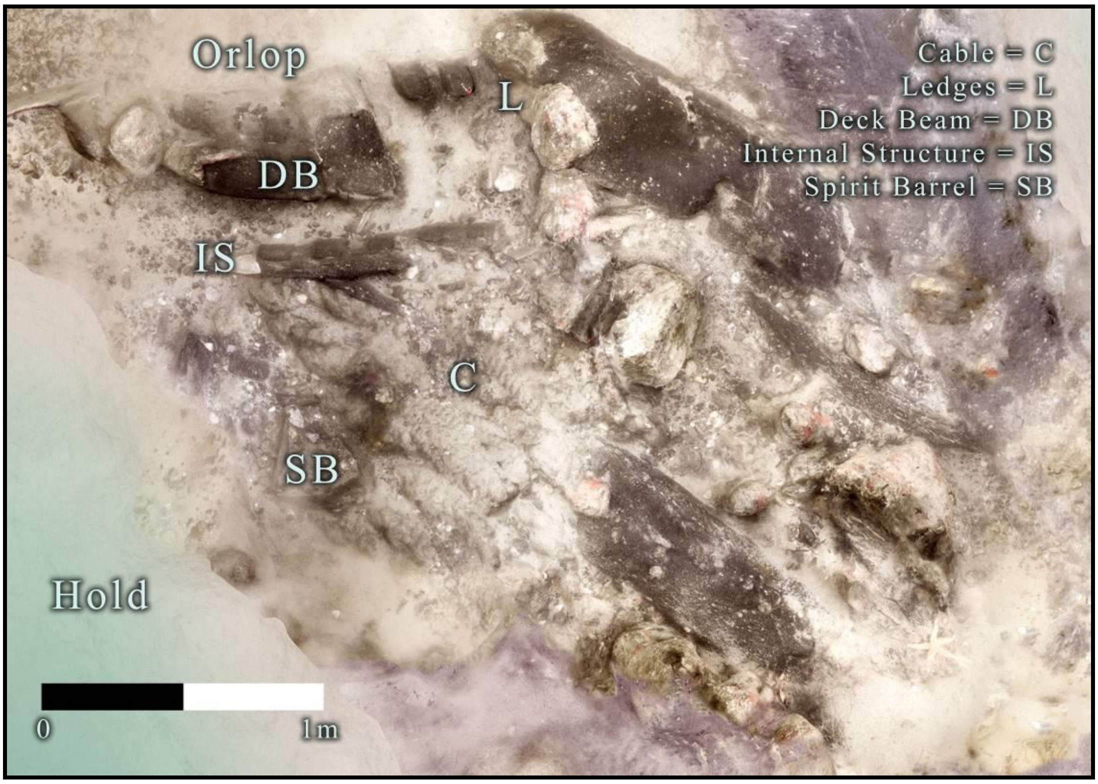

Figure 15: Close-up view of the forward hold immediately below the orlop © PAS.

5.3. AREA 3

Description of Area 3

5.3.1. **Area 3** is located 15m NE of the main site and roughly 2m south of **Area 2** (Figure 10). It is a large coherent section of starboard side structure relating to the hold and orlop. It consists of riders, inner and outer planking, frames and wooden and iron knees. This whole section is roughly 14m long by 5m wide.

5.3.2. Further exposure over the winter led to the identification of structural features relating to the support of the decks. An in-situ lodging knee marks the line between the hold and the orlop. Above each end of the lodging knee is a section of deadwood known as an oak pad piece. This is where the iron knees were counter sunk into the pad piece and then bolted through the hull (Figures 16-18). The iron knees are missing from this particular location but there are a number surviving in locations either side. Although some iron knees have survived they are no longer in the upright position as found in Area 1 of the coherent port bow.

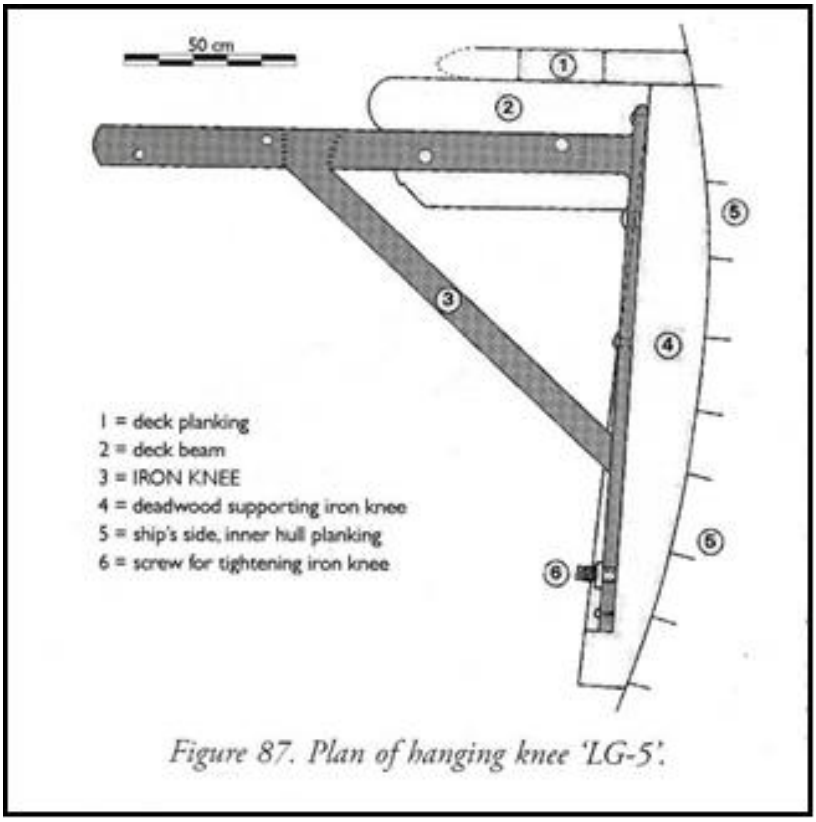

Figure 16: Plan of how the iron knees fitted to the inside of the hull (Bingeman 2009, 73).

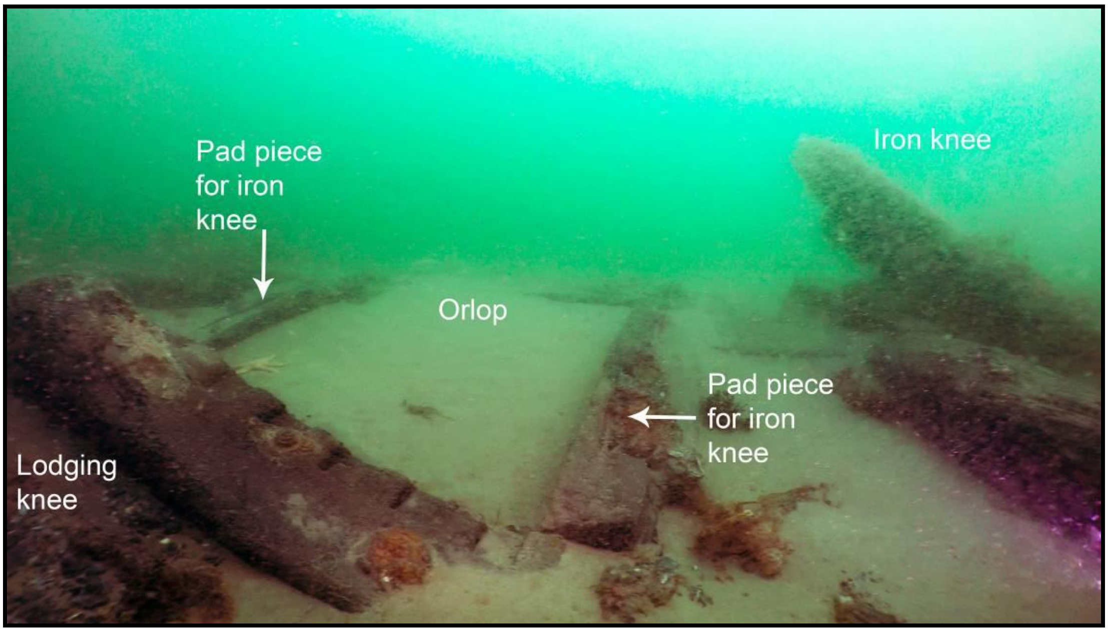

Figure 17: Exposed section of the orlop within Area 3, showing lodging knee and pad pieces © PAS.

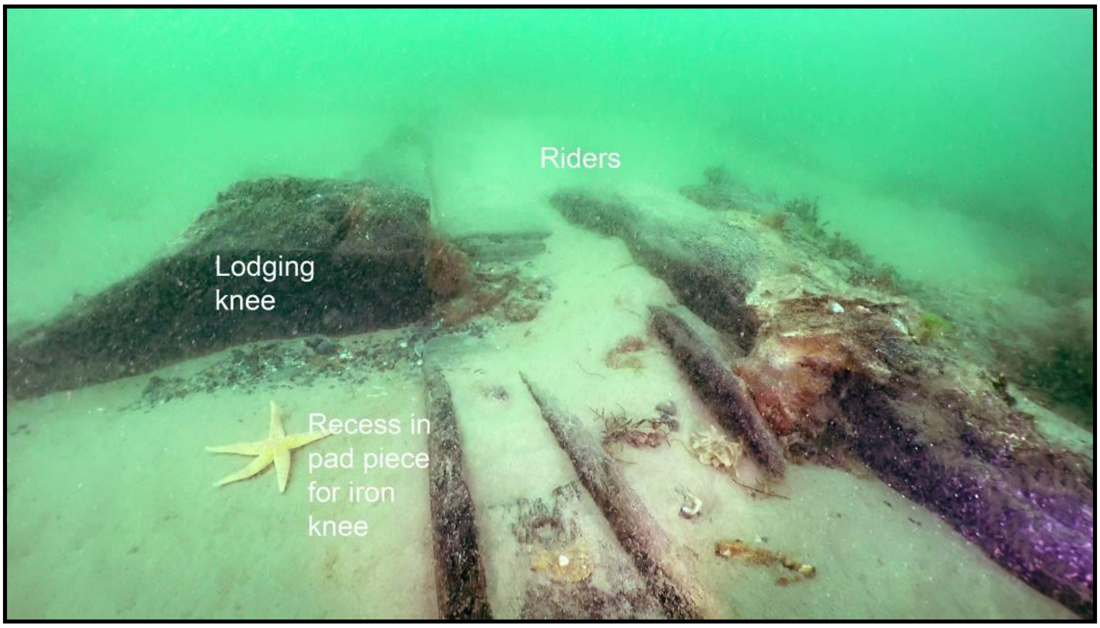

Figure 18: Close-up view of the recess in the pad piece for the iron knee © PAS.

Photogrammetry results from Area 3

5.3.3. As intended the west and central section of Area 3 were successfully photogrammetrically surveyed (Figure 10). The survey recorded the large pairs of riders fastened over the ceiling planking and frames of this section of starboard side lower hull structure. Although the survey of the eastern side of Area 3 was not originally in the project design, it was hoped this could have been carried out because of the exposure of new features. However, as previously mentioned, the underwater conditions slowed the progress of the survey and there was insufficient time to complete the whole of Area 3.

5.3.4. The results of the photogrammetry survey of Area 3 come from three individual data-sets which can be seen in Figure 19. The first data-set is at the south end and includes the first 6.5 pairs of frames or 13 individual frames. The second data-set is in the middle and includes six individual frames. The third data-set includes 6.5 pairs of frames or 13 individual frames from the north end. The three data-sets represent three individual dives that were made to complete the survey.

5.3.5. The three data-sets have been merged together to form one model representing the total area surveyed. Figure 20 represents the colour-corrected version of the same model. The two models represent the inside of a section of the starboard side hold.

5.3.6. The survey has recorded four stations of riders (3 pairs and 1 single) fastened over ceiling planking and frames beneath. The model shows circular concretions on top of the riders which represent the remains of iron bolts fastening them to the inside of the hull. The role of riders were to add additional strength to the hull, at amidships they reached from the keelson up to the deck beams of the main gundeck (Lavery 1991, 110).

Figure 19: Image showing original processed photogrammetry model of Area 3 with Photoscan targets. The image also shows Area 3 is made from three data sets © PAS.

Figure 20: Image showing the colour corrected model of Area 3 © PAS.

5.3.1. Immediately below the riders are the ceiling planks, which are exposed at the west end of the riders. The planks have been fastened to the frames below using wooden treenails. The high-resolution renders provide an immense amount of detail, allowing for the visibility of very small details like treenails, plank joints, biological damage and even wood grain (Figure 21).

5.3.2. In Figure 21 it is possible to identify the planks that had only recently become exposed against the planks that had been exposed for some time. The planks immediately to the west of the ends of the riders are heavily eroded by marine borers. This is clearly evident from the white calcareous tunnels left behind by the borer. The planks immediately below the riders are smooth with pristine surfaces.

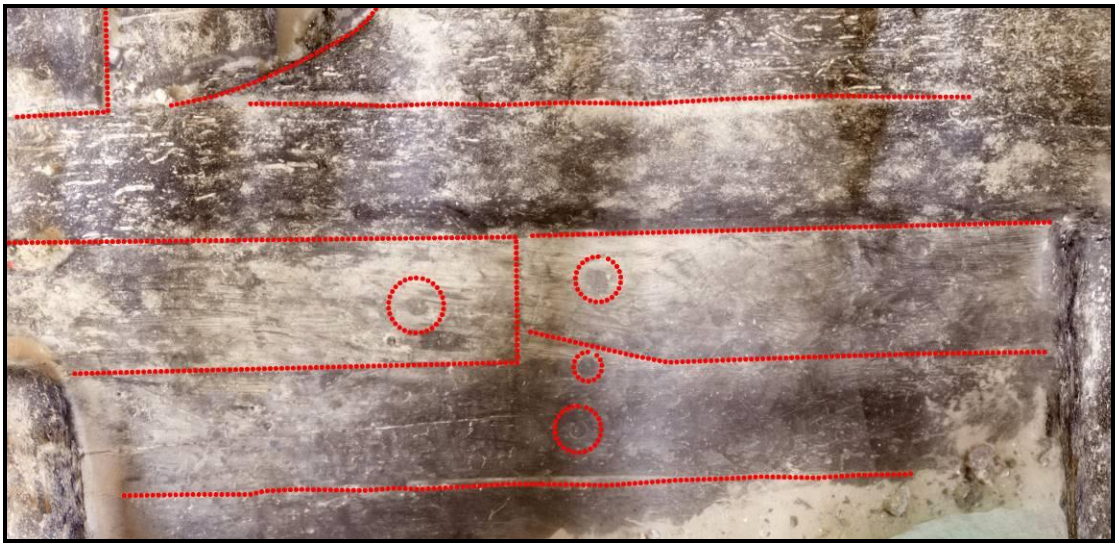

Figure 21: Close-up of a section of exposed planking in Area 3 © PAS.

5.3.3. The photogrammetry survey also clearly shows the framing pattern in the construction of *Invincible*. She has been constructed with frames fastened in pairs followed by a space before the next pair. The model identifies that the space between the frames is not always uniform (Figures 19, 20 and 22).

5.3.4. Where the frames join is also obvious and it is clear to see from the model that this section of the starboard side broke at the joins of the framing timbers (Figure 22), which was a clear weak point.

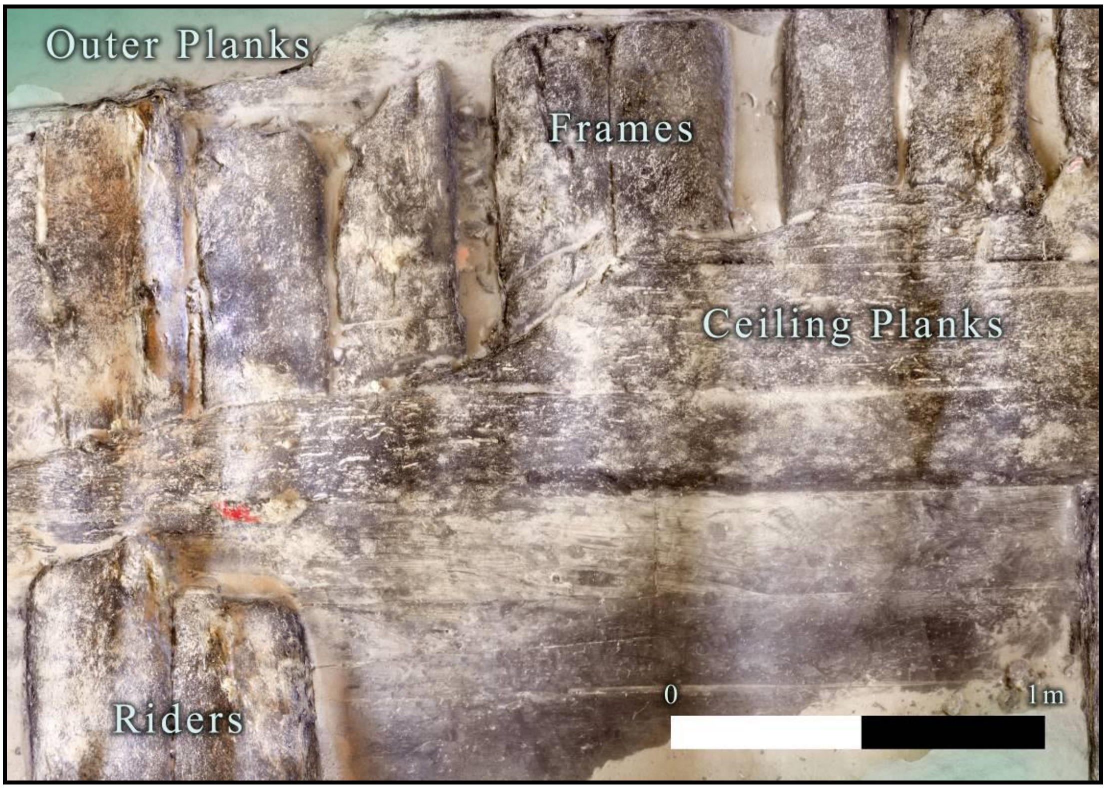

Figure 22: Close-up showing framing pattern and joint lines where frames are joined together © PAS.

5.4. Accuracy Analysis of Specific Areas

5.4.1. For the purposes of this report two dense point clouds were analysed for accuracy in the XY plane: one model covering Area 1 and one covering Area 3, both generated using footage from the Nikon D610. These models represent the best outputs of the *Invincible* photogrammetric surveys; meshes and textures of these areas are intended to form the basis of the wreck model in the eventual virtual dive tour. It is therefore these areas where an understanding of the error margins will be the most valuable.

5.4.2. As a check of the metric spatial accuracy of the final models, the final scaled point cloud models of areas 1 and 3 were exported into CloudCompare. Here, CloudCompare's point-to-point measurement feature was used to take length and width measurements of the PhotoScan target cards affixed to the wreck. The target cards were of a uniform size and were measured using calipers with a stated accuracy of ±0.254mm.

5.4.3. Three separate measurements were taken of each card in the software, averaged to mitigate human error in point selection, and compared against the caliper measurements of the real-world targets. These measurements were used to generate average error figures for the final models.

5.4.4. Ultimately, the comparisons showed an average error of 2.028mm in Area 1 and 1.416mm in Area 3. These measurements had standard deviations of 1.827 and 0.852, respectively. Two standard deviations on either side of the mean is accepted as an error margin within which 95% confidence is possible. In this case, the spatial error of the final model can be stated to be at or lower than 5.7mm in Area 1 and 3.1mm in Area 2 with a high degree of confidence.

5.5. 3D Animation Creation for Web tour

5.5.1. The creation of 3D content for this project can be organised into three parts: **1)** The editing of the Photogrammetry, **2)** the physical creation of an overall model and resource inside of 3DS Max and **3)** the outputs that have been created that constitute the various parts of the web tour content.

5.5.2. **1)** Creating and the model and reconstructing the photogrammetric content required a fairly hefty investment of time to match up each piece. A side effect of capturing data in the field is that it becomes progressively more complicated when layered variables are introduced, creating a vicious circle where the archaeology most in need of coverage is also frequently the trickiest to document and therefore the least likely to have good quality coverage. As mentioned earlier in this report, low visibility, changing lighting conditions and other marine factors produced a range of photogrammetry that differed in its appearance and required considerable knowledge of the CGI pipeline to fix, something that is not always available to every heritage project. An example of the kinds of processes used can be seen here: (https://vimeo.com/196040988). This video highlights how each piece needed to be reworked into a separate, lower polygon mesh, was patched to remove any holes and then heavily edited to match colour profiles and fix any problems with the diffuse textures.

5.5.3. The Photographs themselves, taken at a very close proximity to the archaeology, produced very high resolution images that drove the final 3D models. The side effect of this was a very large archive of data, with Photoshop files for the maps exceeding the 2gb limit and requiring .PSB file extensions to work with. Whilst this yielded an immense amount of detail, especially visible in close ups of Area 03, of which the final renders could still be revisited to create larger versions (which at this time due to computing power is somewhat unfeasible), it had a natural side effect of making the models very difficult to work with due to long saving and opening times as well as enacting great stress on workstations even with high RAM (24gb+).

5.5.4. **2)** Once worked together and placed into the model in respect to plans and other data (Multibeam surveys etc), an environment was created (Figure 23), including flora/fauna and visibility fog inside of Vray in 3DS Max. Forest Pack was used to create underwater plant life and textures were created for created assets like the iron knees and modelled timbers from existing Photogrammetry textures. These were plugged into PBR (physically based rendering) material nodes and built into a complex network of shaders (Figure 24).

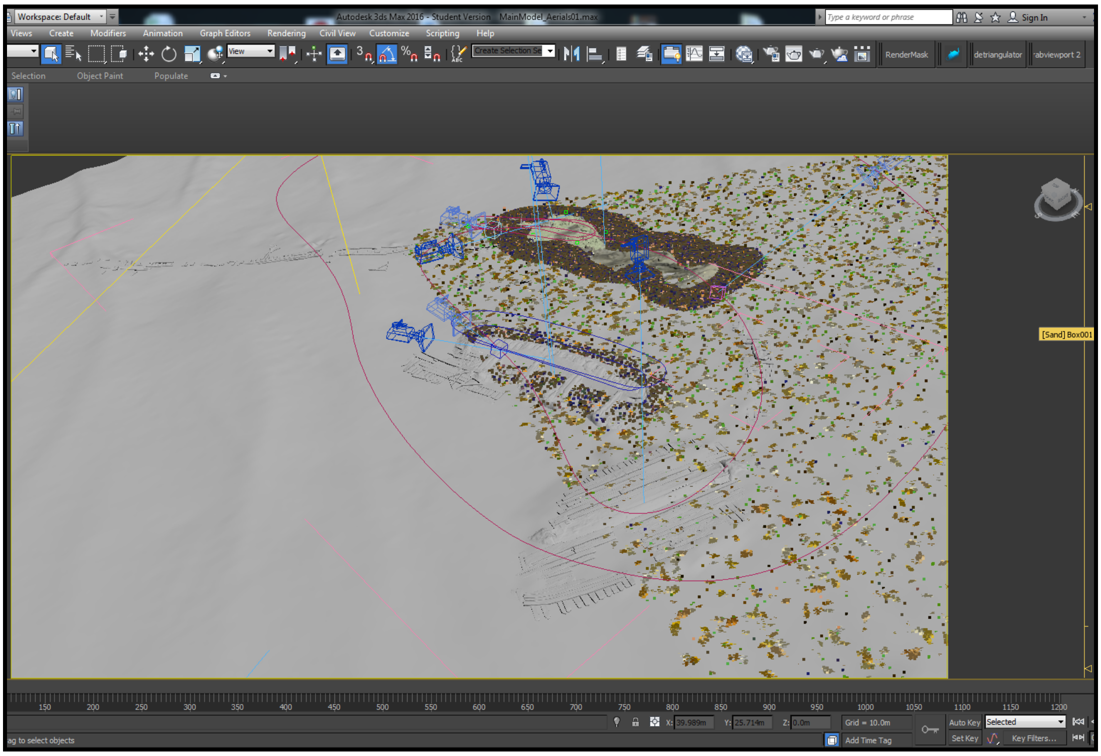

Figure 23: Creating an environment inside Vray in 3DS Max.

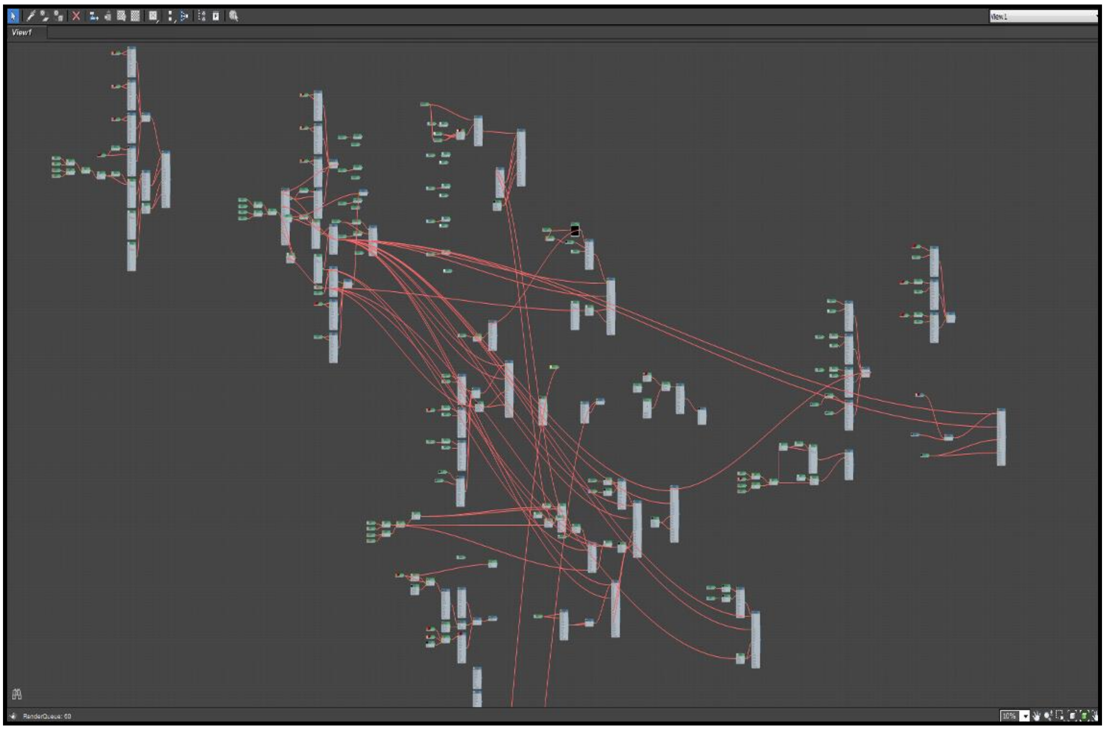

Figure 24: The complex network of shaders.

5.5.1. **3)** Cameras were created and routes established that would create a beneficial experience and then these were rendered through the Vray renderer using Brute Force raytracing into a series of OpenEXR files. Along with the animation sequences, cameras were set up for the map based shots and were rendered out at a very high resolution (10k), which in turn produced 45 megapixel images.

5.5.2. These were edited inside of after effects for post-production where levels, colours and camera effects were added (Depth of field, Chromatic Abberation etc). Once ready, the new versions were cut into PNG sequences and sent to Stuart to place into the final Web Tour. Figures 25-27 show some of the sequences of the web tour.

Figure 25: The beginning sequence showing the plan of the whole site © PAS.

Figure 26: Area 3 with hotspots for the viewer to follow and find information, video clips and 3D animation © PAS.

Figure 27: The 3D animation sequence of Area 3 © PAS.

6. THREATS AND VULNERABILITY

6.1. SITE MONITORING STRATEGY

6.1.1. Monitoring of the sand levels has revealed that the site has not recovered from the 2014 storms and further reductions in sediments are still occurring, most noticeably in the northern areas (Figure 27). On the western edge (out-board) of the main site from CP1 to CP6 there has been an average loss of sediment of 0.08m. However, the recording of the height above the seabed and the extent of newly exposed structures and artefacts within the hull of the main site (inboard) have revealed a much greater loss. The reduction of sediments within these inboard areas is the most significant, especially towards the bow where it is revealing fragile internal structures and organic artefacts (Figures 1-13). In the northern and eastern areas of the site between CP7 and CP15 there has been an average loss of 0.4m. The loss of 0.4m has exposed large areas of starboard side structure (Figure 27).

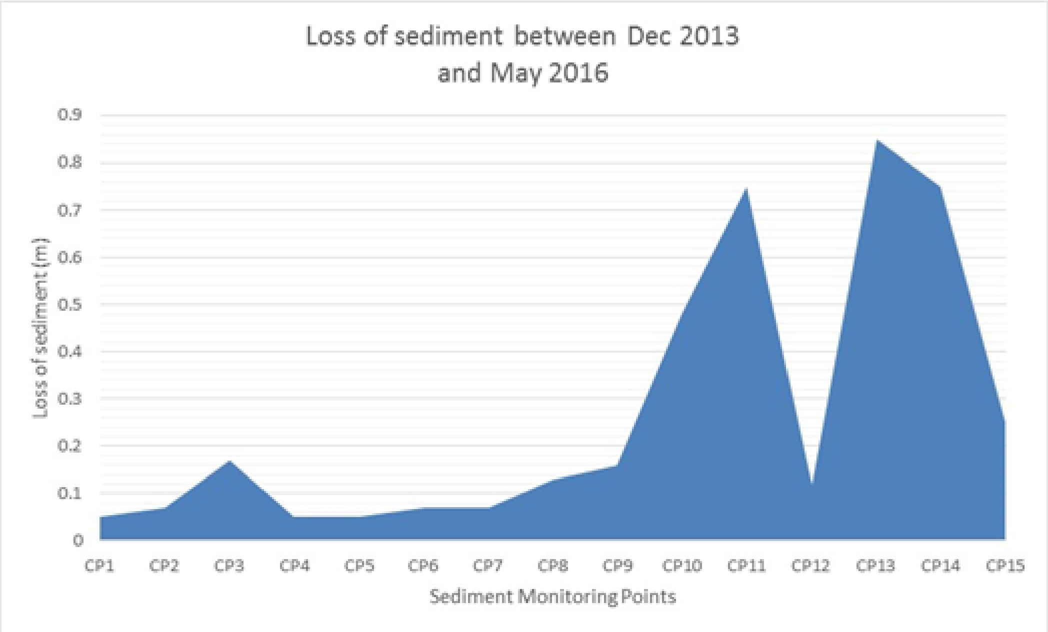

Figure 28: Sediment monitoring results

6.1.2. In May 2016, a large concretion consisting of strips of iron was noticed at the stern end of the main site. This feature had not been seen on the site by the current licensee and had only uncovered during the winter of 2015/2016. The concretion was upstanding by up to 1m from the seabed level (Figure 29). However, CPs 1 and 2 which lie on the outboard side of the stern only recorded slight reductions in the level of the seabed (Figure 28). This was another example of how the inboard side of the main site experiences a much greater loss of sediments than the surrounding seabed to the west of the site. This means the internal structures of the site are at a much greater risk.

Figure 29: Exposed strip iron at stern.

6.2. FINDS RECOVERED IN 2016

INV16A001 – Double block

6.2.1. The double block was recovered from outside the south end of **Area 3**. It is complete with some biological damage on one side. The block has a shell carved from a single piece of wood with two slots to house two wooden sheaves, which turn on a single wooden pin inserted through the centre of the block. There is scoring on the sides of the shell at either end to allow the rigging to fit snuggly to the block. The crown end is flat and the other /breech end is eroded.

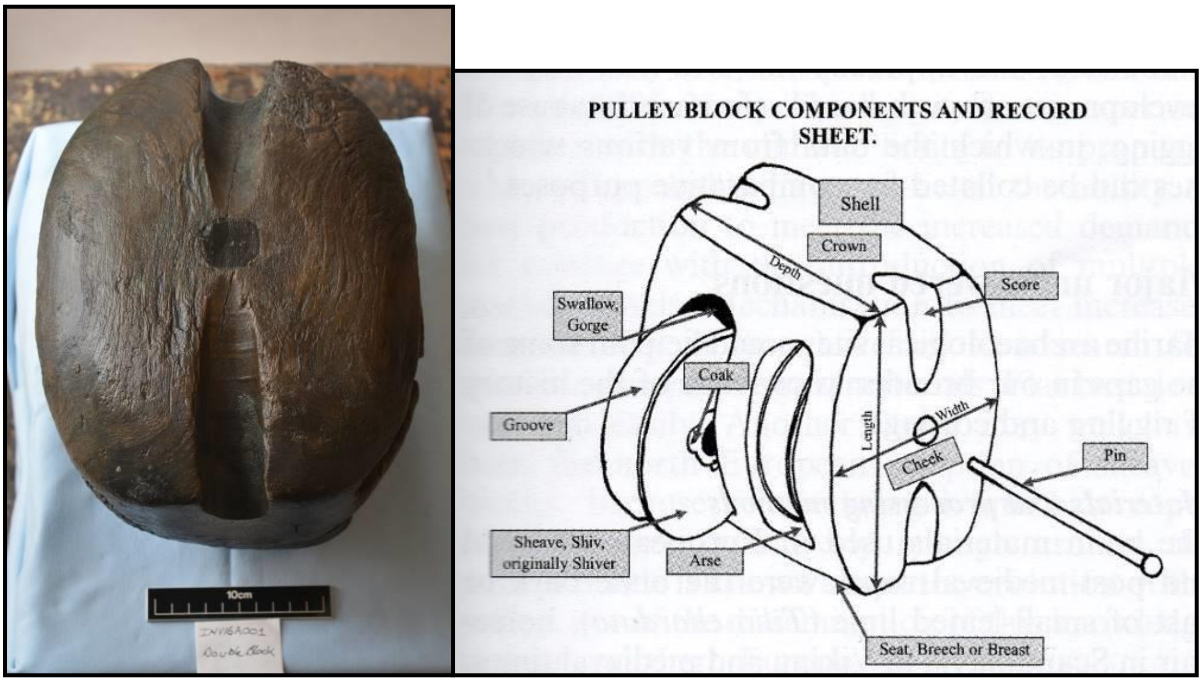

Figure 30: Photograph of the double block with diagram of pulley block components (Saunders 2010:17).

INV16A002 – Leather shoe

6.2.2. The leather shoe was found between a section of planking from an area of structure to the west of Area 3. It is complete but very fragile.

Figure 31: Leather shoe

INV16A003 – Unidentified bamboo object

6.2.3. This object was found outside Area 1 amongst the disarticulated timbers. It is tubular with a rectangular cut down one side. It is 300mm long with a diameter of 67mm. The slot is 285mm long and 35mm wide. It was possibly used as some sort of container or scoop.

Figure 32: Bamboo object

6.3. Conservation Management Statement

6.3.1. All finds that have been recovered have been treated following the guidelines set out in 'First Aid for Underwater Finds' (Robinson 1998) as stated in the Project Design.

6.3.2. Since recovery the finds have been kept in containers of fresh water, covered and kept away from direct sunlight. The water within the containers has been changed regularly. All finds have been photographed with details recorded in a finds record sheet.

6.3.3. The double block and shoe have been given to Angela Middleton for conservation. These finds will be deposited with The Chatham Historic Dockyard Trust (CHDT) who hold the existing site archive and house over 700 artefacts from previous excavations. To clarify, any finds recovered in the future as part of the agreed excavations will be deposited with the National Museum of the Royal Navy.

6.4. ARCHIVE

6.4.1. A copy of the project archive will be deposited with the Archaeological Data service (ADS). The cost of depositing with the ADS is yet to be determined.

7. DISCUSSION

7.1. ARCHAEOLOGICAL DISCUSSION

7.1.1. Although underwater conditions were not ideal during the fieldwork the results have demonstrated that it is still possible to collect high quality data. The poor visibility meant that the photographer had to get as close as 300mm to the subject, which led to an extremely high resolution of detail being captured. This is particularly evident in the survey of Area 3.

7.1.2. Had the visibility been better during the fieldwork a larger survey area could have been recorded, however the images collected may not have been as detailed due to the height of the photographer above the subject matter. Therefore, if there was a lesson to be learned from this project it would be that if time is not a constraint the photographer should aim to get as close to the subject as possible so as to collect the highest resolution of data. A natural side effect of this process, however, is a fractured final model, both physically and visually in terms of potential colour differences, missing information and general model noise. To edit these into a clean and useable asset for 3D packages (3DS Max/Maya etc) requires not only a large amount of work, but also considerable knowledge of the CGI pipeline; it is not something that an archaeologist new to the process would be able to pick up swiftly as many of the techniques used during this project span much of the professional CGI pipeline (UVWs mapping/Texture Baking/Rendering/Material Editing etc). This means that unlocking the true potential of Photogrammetry as a recording process at the highest level requires more than just a traditional archaeologist with a camera. Rather, it relies on a series of professionals that understand the varying shifting problems that can be created through this process, can deal with any of the issues that might arise and can voice these in advance and communicate efficiently with team members who are recording the primary data.

7.1.3. The method used in this process is also dependent on the archaeological feature being recorded and the detail that one requires. For instance, if recording concreted objects such as iron guns then perhaps the highest level of detail is not as beneficial as the object is hidden behind layers of concretion. In the case of ships timbers however, it is extremely beneficial to get as close to the subject matter as possible so to be able to record fine constructional details such as tool marks, joins and fastenings. Therefore, on sites such as *Invincible* where there are lots of exposed timber structures, photogrammetry is an extremely useful method for recording a high level of detail.

7.1.4. With the case of *Invincible* the benefits of recording the site photogrammetrically is three-fold. First, it produces highly detailed and accurate images for study, research and publications. Second, the high-resolution images can be used in underwater interpretation booklets to enable divers to instantly recognise parts of the wreck. Third, the high-resolution models can be transformed into 3D animations and utilised in a virtual tour of the wreck, which allows non-divers to see what the site actually looks like and also enables visiting divers the chance to familiarise themselves with the wreck before making the dive.

7.1.5. For the creation of the *Invincible* virtual tour the 3D models of Area 1 and 3 along with Area 2 from a previous survey have all been scaled and geo-rectified to fit alongside the multi-beam data and reconstructed plans of the site. The models have therefore been positioned accurately in relation to the actual topography of the site and are easily related and connected to other surveyed areas through the reconstructed survey plans.

7.1.6. The accuracy trials performed on the digital model suggest that the 2016 photogrammetric survey of the *Invincible* was able to generate data with a sub-centimetric accuracy over a large area. This demonstrates the value of photogrammetric survey not only as a means of illustration and publication of the *Invincible* wreck site, but of scientific data gathering and analysis. Given that the site is undergoing rapid change, making speed of recording essential, the demonstrated accuracy of photogrammetric survey justifies its ongoing use as a primary survey method (Jones 2016). More so, the photogrammetry models produced during this project have not fully reached their maximum possible quality. This is due to the natural restrictions in computational power at the time of this study. The 10000 resolution size was not enforced by the original resolution of the Photographs, but instead by the time and power requirements necessary to output such large images. It is highly probable that the true resolution of output achievable from this model is much higher, possibly even 20-30k resolution or more, depending on how many photographs were originally taken and what their initial resolution was (10 photographs to cover Area 3 laterally at 3k resolution each would create a 30k resolution image, for example). However, currently using these sizes as textures and rendering them out is unfeasible, but should it become possible it is something that could be revisited.

7.1.7. The results of the photogrammetry have demonstrated that the level of detail recorded far exceeds the level of detail that can ever be recorded by a diver on a regular 2D drawing. As seen in Figure 21 the use of a high resolution DSLR allows the capture of the finest details. This enables zooming close into the models to see the seams, joins, fastenings in the timbers and even the grain of the wood. The other major positive is that this level of detail can be recorded very quickly. In the case of Area 3 it took only three dives to record a 14m long section of structure that would normally take several divers many dives to complete.

7.1.8. The final rendered 3D models are ideal for the virtual dive tour because it enables the viewer to experience exactly what certain areas of the site look like. Not only are the models 3-dimensional but the textures on the models are real as they are created from actual images of the site. So the viewer is seeing the wreck through the eyes of the diver. This, however, requires a lot of time investment, especially as realism is strived for and has the natural effect of increasing the time required rendering out frames for the animation as more visual data is included. It also requires a large amount of storage and good means to transfer this information between parties. Indeed, aside from the rendering (which can take weeks), information transfer was one of the biggest bottlenecks to the Invincible Web Tour, with some large maps/image sequences taking days to transfer. Thus, content management and time organisation become very important in this process.

7.1.9. In addition to the advances in the use of photogrammetry on the site, the information recorded was used to help identify and relate the exposed remains with their original locations on the ship. The identification of the line of the orlop on Area 3, from the discovery of an in-situ lodging knee and counter sunk knee stations confirmed Area 3 is a section of the hull consisting of the hold and orlop.

7.1.10. The reduction in sand around the coherent bow structure revealed a group of disarticulated timbers associated with the decks of *Invincible*. This would suggest further potential for similar features to survive between the coherent portside and the remains of the starboard side to the north.

7.2. RECOMMENDATIONS

7.2.1. Due to the poor conditions experienced during fieldwork all available time was used to support the collection of good photogrammetry data. As a result, the magnetic anomalies outside the designated area were not investigated. It is therefore recommended that these are investigated when the author next plans to dive the site during the forthcoming spring. Should the author find and identify the anomalies he will inform HE immediately.

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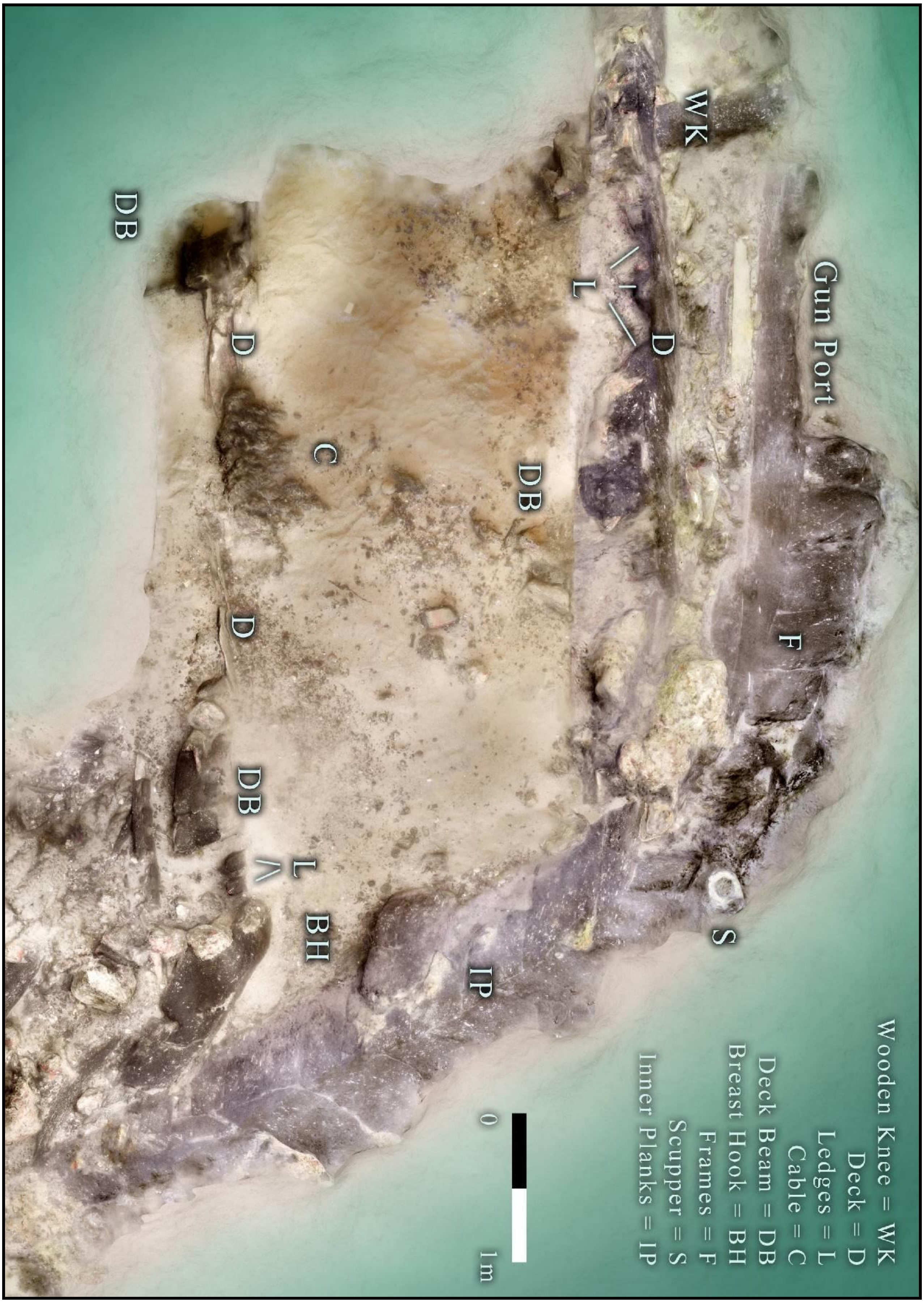
9. APPENDIX 1: AREA 1 PHOTOGRAMMETRY MODEL

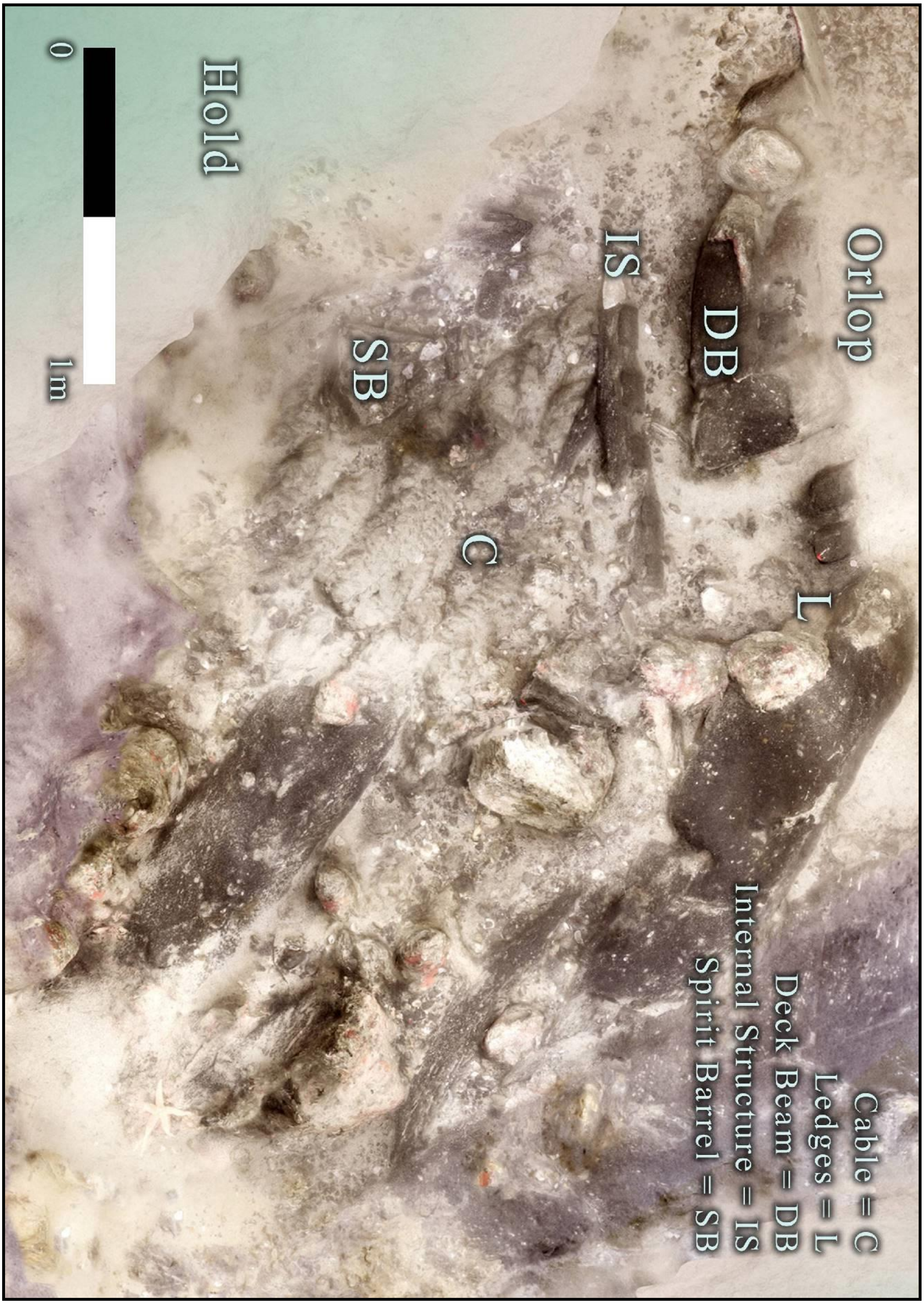
10. APPENDIX 2: AREA 1 COLOUR CORRECTED MODEL

11. APENDIX 3: MODEL OF GUNDECK AND ORLOP



12. APPENDIX 4: MODEL OF GUNDECK

13. APPENDIX 5: MODEL OF THE FORWARD HOLD



14. APPENDIX 6: PHOTOGRAMMETRY MODEL OF AREA 3

15. APPENDIX 7: COLOUR CORRECTED MODEL OF AREA 3

16. APPENDIX 8: SOUTH END OF AREA 3

17. APPENDIX 9: NORTH END OF AREA 3



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