

Survey Report

Kystverket - U-864 Wreck Investigation 2025 Campaign 1



KYSTVERKET

28 August 2025

Issued for Review

Revision 2



REVISIONS

Rev.	Date	Description	Origin	Checked	Approved
1	2025.07.16	Issued for Review	KT	ES	RW
2	2025.08.28	Issued for Review	KT	CS	RW

PROJECT DATA

Data Type	Description
Project title:	Kystverket - U-864 Wreck Investigation 2025 Campaign 1
Project code:	600057
Operation period:	24.05.2025-29.05.2025
Vessel(s):	M/V Go Electra

COMPANY DATA

Data Type	Description
Company	Kystverket
Company document number	-

CHANGE LOG

Revision	Change	Page/Section
1	N/A	N/A
2	Client comments implemented	All

ABBREVIATIONS

Abbreviation	Definition
CPT	Cone penetration test
CRS	Coordinate reference system
DTM	Digital terrain model
GNSS	Global navigation satellite system
GPS	Global positioning system
GVI	General visual inspection
HSE	Health, Safety and Environment
MAG	Magnetometer
MBES	Multibeam echo sounder
MV	Motor vessel
PPE	Personal protective equipment
PPS	Pulse per second
QC	Quality control
RGB	Red, green, blue
ROV	Remote operated vehicle
SBP	Sub-bottom profiler
SfM	Structure from motion
SIT	Surrogate item test
SVP	Sound velocity profile
TBT	Toolbox talk

Abbreviation	Definition
UHRS	Ultra-high resolution seismics
UT (probe)	Ultrasonic thickness
UTC	Coordinated universal time
UXO	Unexploded ordnance
WROV	Work-class remote operated vehicle
ZDA	Time and Date

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1 INTRODUCTION

The German submarine U-864 was torpedoed by a British submarine in 1945. U-864 broke in half and sank just outside of Fedje, Norway with the two pieces located between 135 m and 165 m water depth. The submarine is assumed to have contained 1857 mercury canisters, stored in the keel. At least six of these containers have been recovered in previous surveys. Campaigns in 2005, 2006, 2013, 2014 and 2016 have been conducted to best determine the conditions of the wreck and to best handle the mercury contaminated area.

Reach Subsea was contracted by Kystverket to perform visual and geophysical surveys of the submarine, U-864, off the coast of Fedje, northwest of Bergen. The survey area is approximately 70 m ×140 m in size and is located at approximately 4 km west of Fedje. The survey was carried out from the survey vessel M/V Go Electra between 24 May and 29 May 2025. The purpose of the survey was to obtain:

- Detailed external and internal visual inspection of the wreck parts;
- Detailed geophysical and electromagnetic data of the wreck site;
- Determination of the overall condition of the wreck parts;
- Identify mercury canisters;

This report covers the geophysical and visual results of the submarine wreck U-864 (Figure 1-1 and Figure 1-2) The coordinates for the corridor outline are listed in Table 1-1.

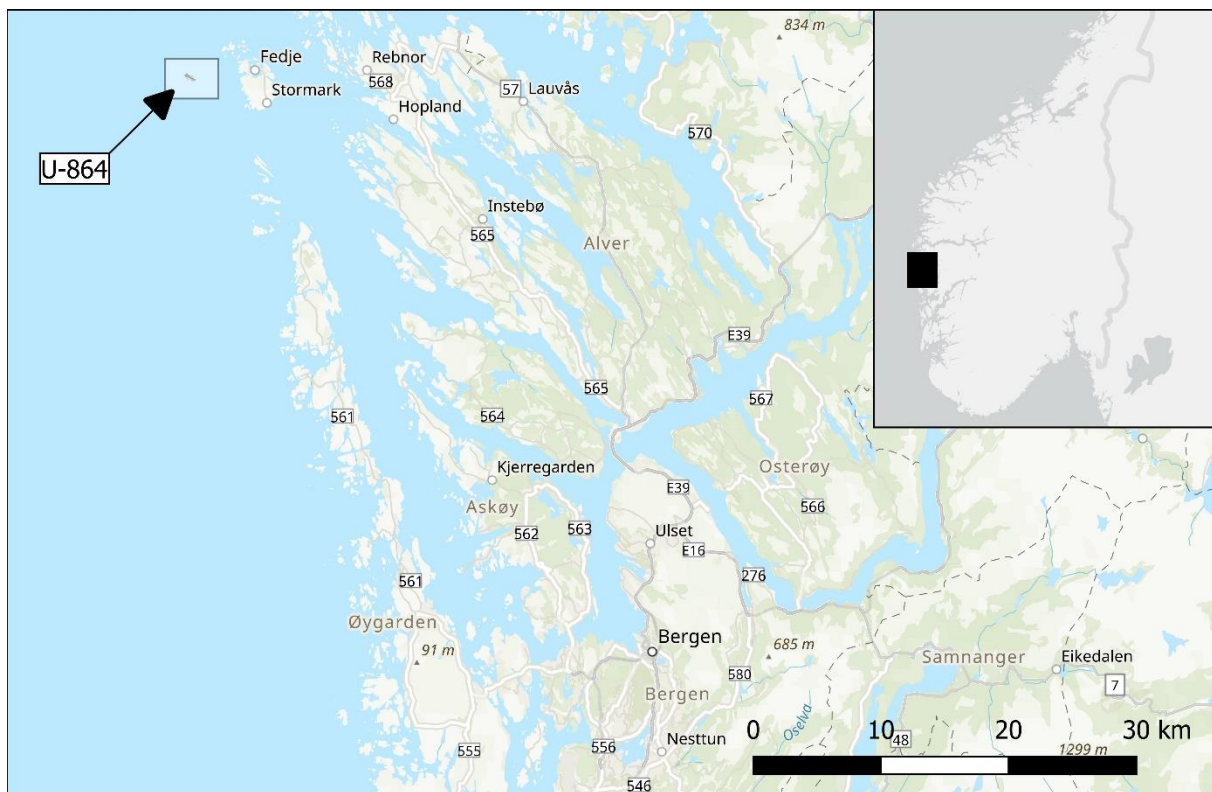


Figure 1-1 Wreck U-864 location

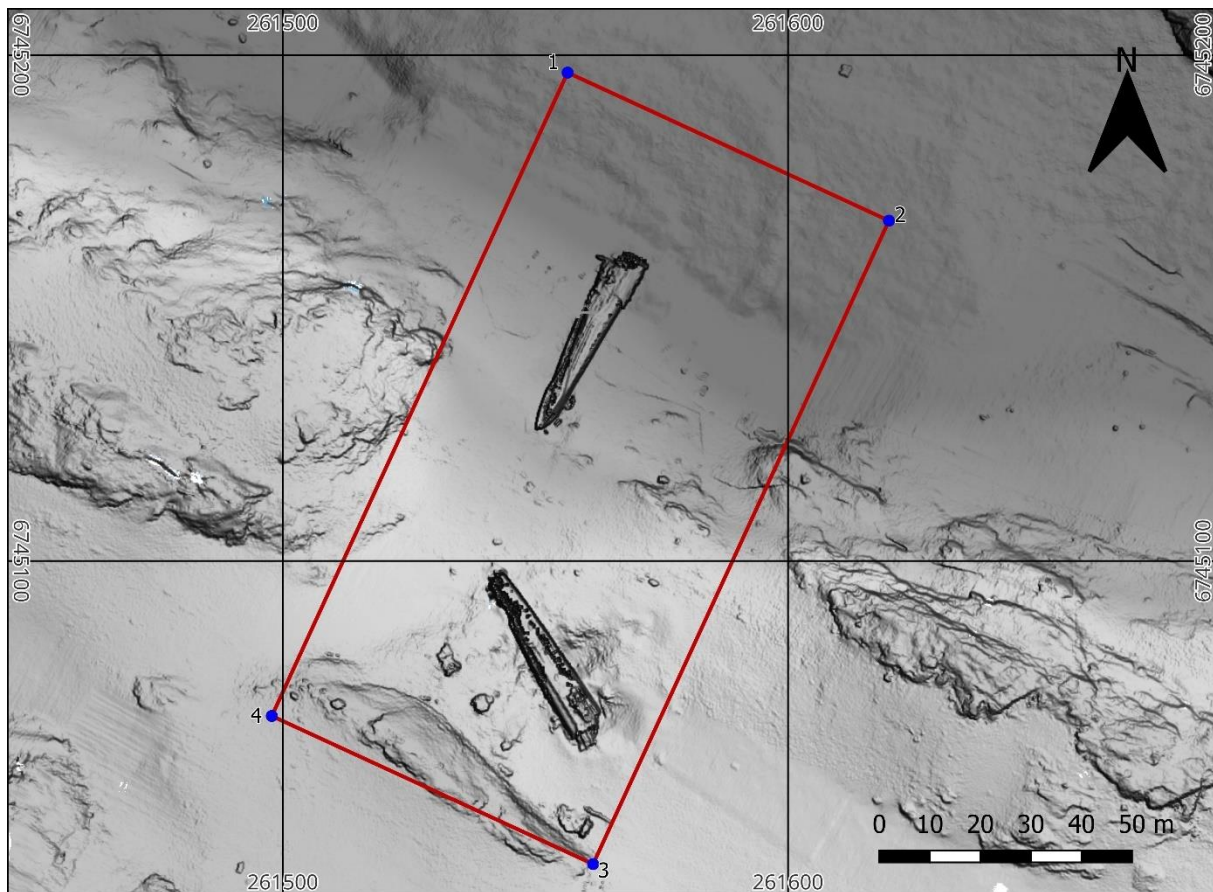


Figure 1-2 Wreck U-864 survey area

Table 1-1 Location Summary U-864 Bounding Box

Boundary Point	Easting (m)	Northing (m)
1	261556.37	6745196.52
2	261619.96	6745169.25
3	261561.42	6745040.08
4	261497.83	6745069.35

1.1 SCOPE OF WORK

The survey of the wreck site was conducted to collect high-quality bathymetric, sub-seabed and electromagnetic data to characterize the conditions within the survey area. The data acquisition was carried out by using multibeam echo sounder (MBES), sub-bottom profiler (SBP), TSS 440, Elwave Octopulse, Voyis monocramera and video. The purpose of the survey was to acquire as much information as possible about the external and internal conditions of the wreck and to determine if access to the keel was possible. The keel of the bow section is located beneath the sediment surface, and its condition is unknown. Determining whether the keel is currently in contact with the bedrock below the seabed surface was a key objective for any future work. In addition, an important objective of the survey was to attempt to locate mercury canisters within the sediments. Future work is planned to involve excavating sediments around the wreck to gain access to the keel.

The following tasks were considered the main priority during phase 1:

- General Visual Inspection (GVI) of wreck
- Measure heel and trim angles of wreck parts
- Detailed external visual and photogrammetric survey of wreck parts, including storage areas (steel containers) beneath the casing (deck). Access to these storage containers requires removal of wooden deck in relevant areas.
- Detailed external photogrammetric survey of sediment levels at wreck parts
- Detailed internal visual and photogrammetric survey of wreck parts and internal sediment levels, with special focus on determining whether the hatch to the torpedo room (forward wreck section) is open and, if accessible, entering the torpedo room to count and inspect the torpedoes.
- Visual detection and registration of possible UXO at the surface around the surveyed wreck parts
- Thickness measurements of pressure hull
- Determine keel position/fracture zones and geometry
- Identify mercury canister outside the wreck parts
- UXOs and debris survey
- Surface of seabed and surface of rock under soft soil
- Identify possible "ponds" of liquid mercury

1.2 CHANGES TO SCOPE OF WORK

Due to the limited operation window, two of the planned scopes were not completed. The following scopes were omitted to allow greater focus on other inspections tasks:

- Gradiometer survey -> was to be used to detect buried targets
- Depth measurement survey -> was to be used to calculate pitch and roll

The gradiometer survey was cancelled after it was determined that any potential results would not be able to provide additional information beyond the electromagnetic survey. Potential targets in close proximity to the bow and stern of the wreck would be masked by the magnetic signal of the larger wreck pieces. The decision to cancel was made onboard following discussions with the client representative.

It was also decided that the depth measurement survey, intended to calculate pitch and roll of the wreck, was redundant and was cancelled to allocate more time to the visual inspection. Pitch and roll of the two wreck pieces can be calculated from the multibeam echo sounder data and the photogrammetry data. The cancellation of the depth measurement scope was accepted by the client representative.

No official management of change was required for the changes to the scope, since it was decided prior to operations that the tasks could be reprioritised during operations.

1.3 DOCUMENT ARRANGEMENT

The reports for the Kystverket U-864 wreck survey are arranged in the following structure:

- REACH-600057-MAC-001 – Mobilisation and Calibration Report– details the mobilisation, verification checks and calibration results of MV Go Electra;
- REACH-600057-SR-001 – U-864 Investigation Report (**this report**) – details the survey and investigation results;

1.4 SURVEY PARAMETERS

1.4.1 HORIZONTAL DATUM

The coordinate reference system (CRS) was WGS84 UTM zone 32 N with parameters detailed in Table 1-2.

Table 1-2 Local Survey Datum

Survey Datum	
Spheroid	WGS84 UTM zone 32 N
Authority	EPSG: 32632
Ellipsoid Data	
Authority	WGS 84
Ellipsoid	EPSG: 7030
Semi major axis (a)	6 378 137.00
Inverse flattening (1/f)	298.257223563
Projection Data	
Authority	EPSG: 16032
Projection type	Universal Transverse Mercator (UTM)
Zone	32 North
Latitude of natural origin	0°
Longitude of natural origin	9 East
False northing	0
False easting	500 000
Scale factor at natural origin	0.9996

1.4.2 VERTICAL DATUM

Soundings were reduced to NN2000. Tidal heights shall be computed from GPS ellipsoidal height observations converted to NN2000 using the height reduction model HREF2018B.

Reach Subsea provided vertical offset between NN2000 and Nautical Chart Zero ("Sjøkartnull") in reports and maps to allow for depth conversion.

Table 1-3 Vertical Datum

Geoid Model	Reference
HREF2018B	NN2000

1.4.3 TIME REFERENCE

All survey computers, video and log keeping were synchronised to coordinated universal time (UTC) which is derived from the GNSS (global navigation satellite system) and supplied through a timeserver.

A GNSS receiver outputs one pulse per second (1PPS) with corresponding ZDA message and is distributed to all time critical systems.

2 OPERATIONAL SUMMARY

The survey of wreck U-864 consisted of six individual surveys, categorised as either visual, geophysical, electromagnetic or mechanical surveys. Together, these surveys were integral to assessing the overall condition of the wreck and for providing a better understanding of the surface and sub-surface conditions without disturbing the contaminated area. All sensors were mounted on the remote operated vehicle (ROV). Table 2-1 outlines a short summary of the performed surveys.

Table 2-1 Summary of Survey Operations

Survey Type	Sensor	Use	Reason for Use
Bathymetry (geophysical)	R2Sonic 2024	Used to map and provide 3D representation of the seabed. Acoustic waves emitted from the sensor are used to calculate accurate water depths.	The bathymetric survey was included to acquire a more detailed and updated 3D depth model of the wreck site
External GVI (visual)	Imenco Spinner Shark (HD camera)	Used to inspect the external conditions	The external visual survey was included to evaluate the conditions of the pressure hull and identify any potential dangers/targets on the surface close to the wreck
Target investigation (electromagnetic)	Teledyne TSS 440	Used to detect conductive surface/ sub-surface targets by creating a magnetic field. Potential targets cause disturbances in the magnetic field	The electromagnetic surveys were included to detect potential mercury canisters buried below the seabed surface. The Octopulse system was included as a supplementary system as the technology is previously untested
	Elwave Octopulse	Used to detect surface/sub-surface targets by measuring disturbances in a low-frequency electric field.	
External Photogrammetry (visual)	Voyis Discovery Stereo	Used to extract georeferenced datapoints from high resolution images and create detailed 3D models	The photogrammetry survey was included to provide an extremely detailed 3D model of the wreck and surrounding seabed
Internal GVI (visual)	Imenco Lizard Shark (lance camera with 4x3 W LED lights)	Used to inspect internal conditions where objects are too small or access with conventional subsurface cameras is limited	The internal visual survey was included to evaluate the conditions inside of the wreck and determine if the torpedo bay hatch was open
Sub-bottom (geophysical)	Edgetech 2-16 kHz chirp	Used to depict the geological setting below the surface. The sensor is able to identify different sedimentary layers due to the different acoustic properties.	The sub-bottom profiler survey was included to map the location and depth of the submarine keel and detect and map the bedrock depth
Thickness measurements (mechanical)	Cygnus UT probe	Used to determine the thickness of the remaining material of the pressure hull and estimate any reductions	The thickness measurements were included to determine if the external pressure hull is deteriorating

2.1 BATHYMETRIC SURVEY

A 70 m × 140 m area centred on the wreck of the U-864 was surveyed using multibeam echo sounder (MBES), with the ROV flying at an altitude of 15 m. A total of seven high-fly survey lines were completed, in addition to four lines close to the wreck sections to cover any gaps. The survey of the wreck was carried out to map the seabed and identify any potential obstacles or dangers. Multibeam was also acquired to obtain an updated depth model for the photogrammetry. Backscatter data was recorded to provide information on where to concentrate SBP profiles.

The multibeam as-found survey was conducted over the U-864 Wreck survey area between 06:23 and 09:17 (UTC) on 25.05.2025.

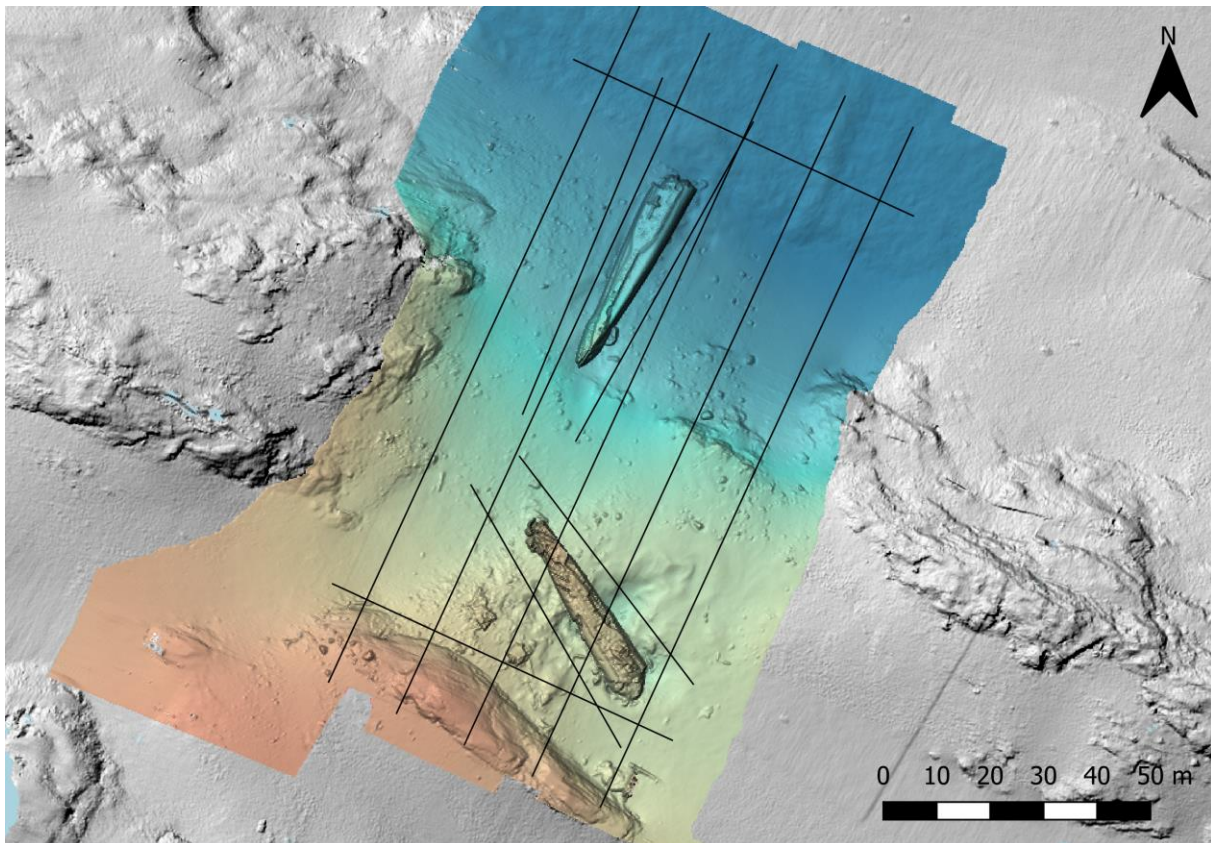


Figure 2-1 Overview of surveyed lines for multibeam echo sounder survey

2.2 EXTERNAL VISUAL INSPECTION

A general visual inspection was conducted externally on the bow and stern wreckage sections. However, access to the internal areas was limited due to obstructions resulting from the nature of the vessel's sinking. Three main objectives during the external visual inspection of the wreck:

- As-found video inspection of bow and stern sections
- Debris survey of bow and stern section
- Identification of wooden deck on bow and stern section

The as-found video surveys were primarily used to determine the overall conditions of the wreck sections and find locations suitable for internal inspection with the lance camera. The dedicated inspection of the removable wooden deck was based on information gathered during the 2013 survey. The 2013 survey stated that a number of external storage containers had been identified and located beneath the submarine's removeable deck. Before any removal, the deck needed to be properly inspected.

The wooden deck inspection was conducted by flying directly over the wreck with a downwards facing camera to determine if any storage compartments were open. The external video inspection was conducted between 14:28 and 18:51 (UTC) on 25.05.2025.

2.3 ELECTROMAGNETIC SURVEY - TSS 440

An electromagnetic survey, using a TSS 440 system, was conducted around the wreck sections to detect possible mercury canisters below the seabed. The TSS 440 system was run every 2 m to ensure adequate coverage (Figure 2-2). The TSS 440 was intended to be surveyed at an altitude of 1 m above the seabed; however, due to the rapid changes in the seabed gradient within the survey area, the ROV had to adjust its altitude during operations to avoid damage to the system.

The TSS 440 survey was conducted between 19:38 on 25.05.2025 and 06:13 (UTC) on 26.05.2025.

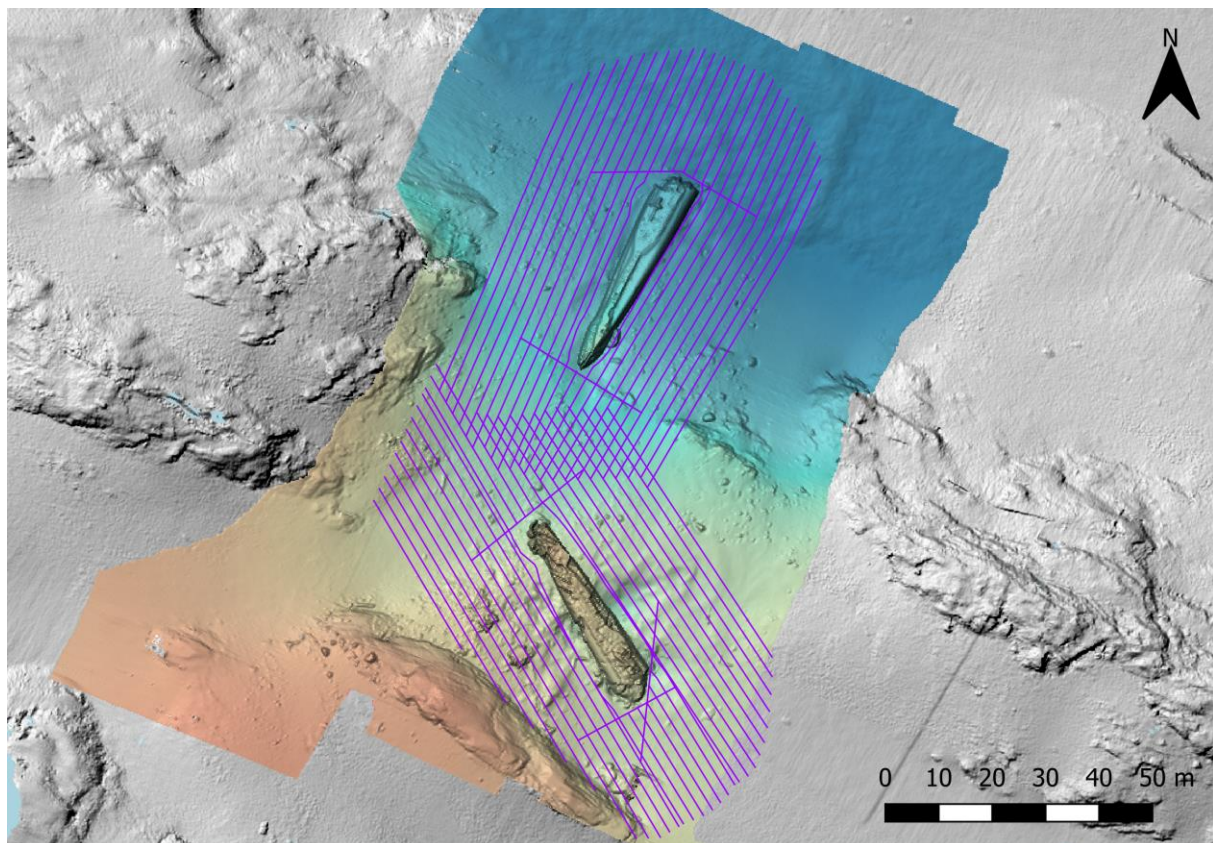


Figure 2-2 Overview of surveyed lines for the TSS 440 survey

2.4 ELECTROMAGNETIC SURVEY – OCTOPULSE

An additional electromagnetic survey using the Octopulse system was conducted around the wreck sections. It was only utilised on either side of the two wreck sections (Figure 2-3) to focus on the areas of interest. These areas were considered the most likely locations of any mercury canisters. The Octopulse system was surveyed every 1 m to ensure sufficient coverage. The sensors were mounted at the base of the ROV, resulting in a survey altitude 0.5 m above the seabed. The survey was conducted between 11:26 and 19:19 (UTC) on 27.05.25.

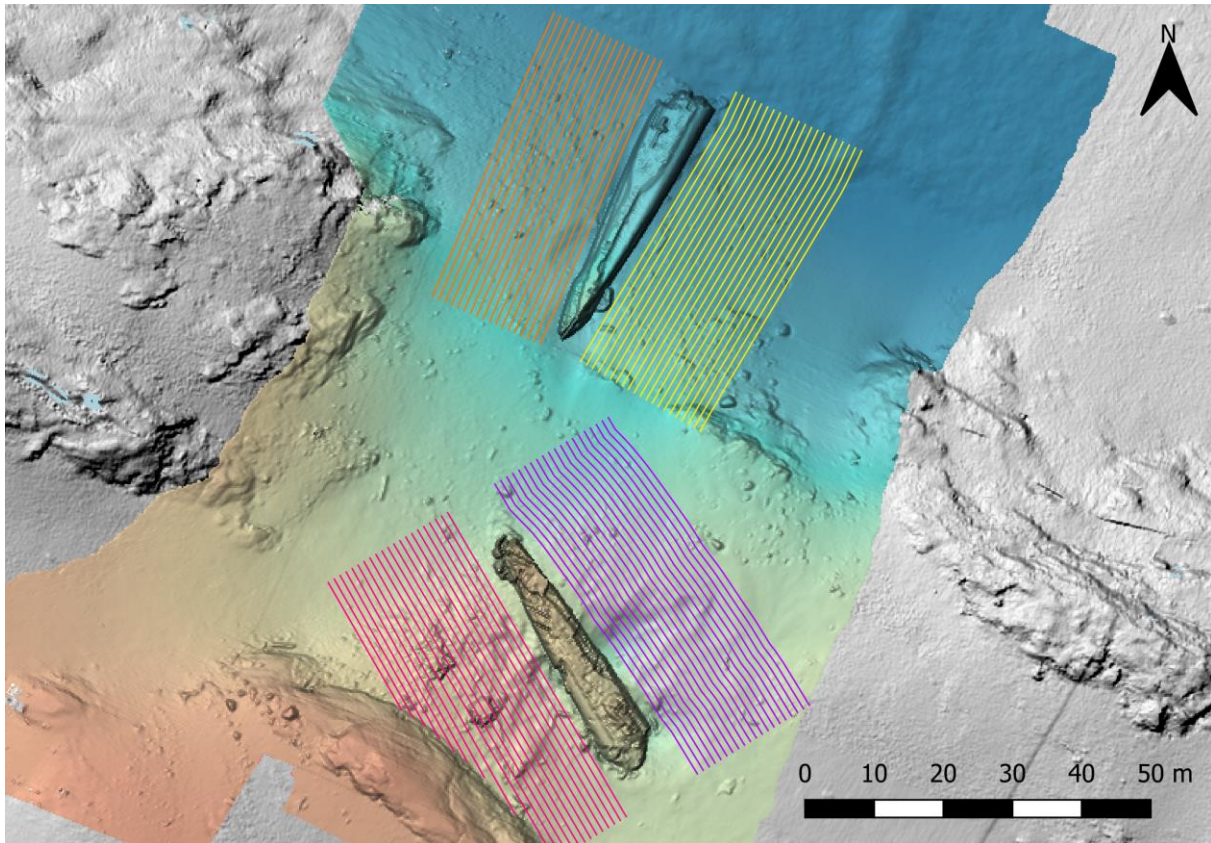


Figure 2-3 Overview of surveyed lines from the Octopulse survey

2.5 PHOTOGRAMMETRY SURVEY

Photogrammetry was carried out on the bow and stern section of the wreck to create a 3D model. The main photogrammetry survey was performed between the 26.05.2025 14:35 and the 27.05.2025 10:42 (UTC). An infill survey was also conducted on 29.05.2025 between 09:34 and 12:11 (UTC) to ensure sufficient overlap.

Before the survey commenced, the system was tested and adjusted to the local subsea conditions. Around 150.000 images were captured during the survey covering around 6000m². Figure 2-4 displays the survey track during the acquisition of the images.

The focus area consisted of the two main sections of U-864 and the parts scattered close to the stern section. The photogrammetry camera was also active during the Elwave survey to extend the seabed coverage to include the areas further out from the wreck.

The survey area had good visibility for most of the survey, which resulted in images well suited for photogrammetry.

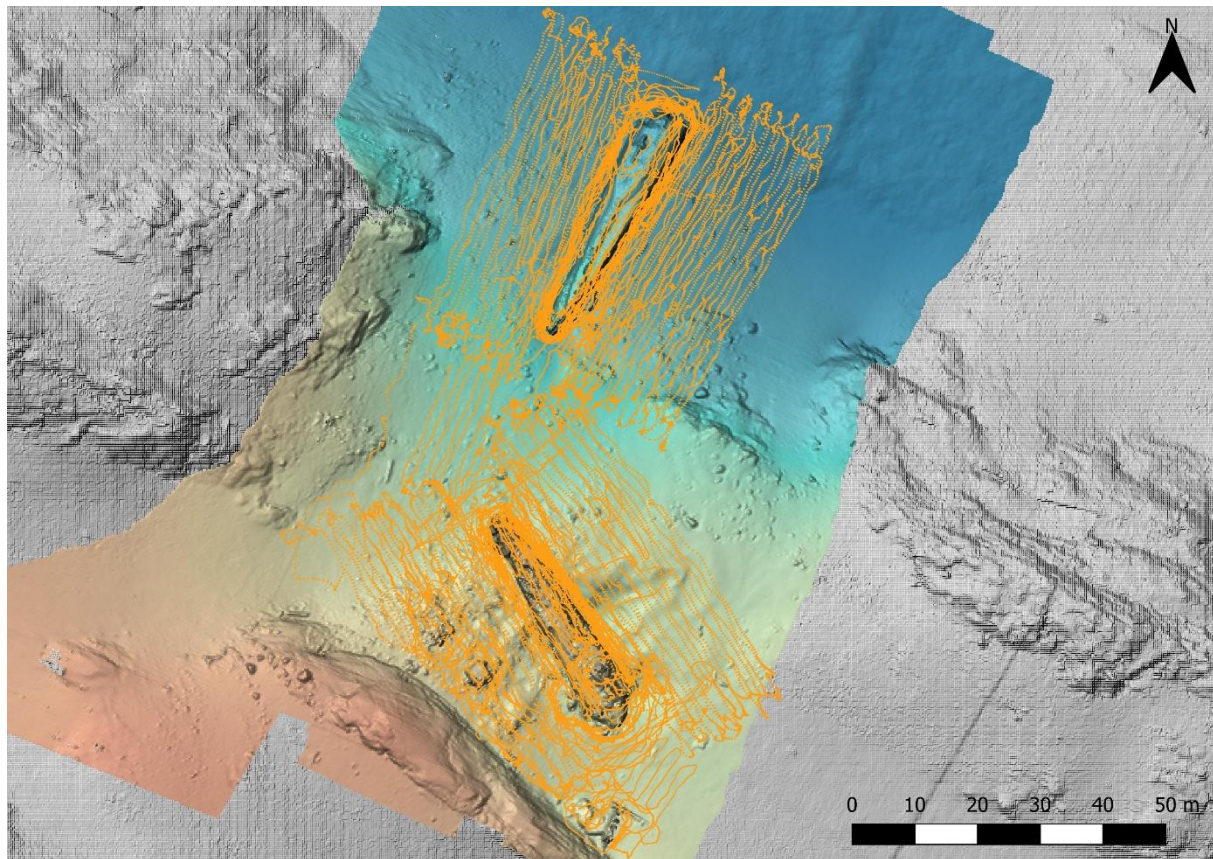


Figure 2-4 Photogrammetry track including the Elwave survey

2.6 INTERNAL VISUAL INSPECTION

During the external GVI, multiple potential points for internal inspection were identified. The three locations that were selected were the fracture point of each wreck piece and a previously cut-out opening on the stern wreck section. During the internal inspection, the ROV was equipped with a 2 m long lance, fitted with a camera, which was extended into the wreck. Figure 2-5 displays the 360° camera mounted on the lance, and Figure 2-6 displays the viewpoint from the lance camera.

Access inside the wreck was achieved, with limitations, through the bow and stern fracture points and via the pre-cut hatch on the starboard side of the aft wreck section. The locations of the internal inspection are presented in Table 2-2. The lance camera inspection was conducted in two phases due to a signal loss to the camera. The first phase was surveyed between 22:44 and 23:27 (UTC) on 27.05.2025 and the second phase was surveyed between 16:59 and 17:25 (UTC) on 28.05.2025.

Table 2-2 Internal Inspection Locations

Location	Approximate Easting (m)	Approximate Northing (m)
Bow fracture point	261570.31	6745162.44
Stern fracture point	261562.91	6745063.13
Stern torpedo bay	261542.69	6745090.10



Figure 2-5 A 360° camera mounted on a lance



Figure 2-6 Point of view from the lance camera

2.7 UT MEASUREMENTS

A Cygnus Manipulator-mounted ultrasonic thickness (UT) probe was utilised to measure the wall thickness of the pressure hull at specific points of interest. The selection of the points was based on historical data and previous inspection locations to support a proper monitoring of the thickness. The ROV was equipped with the UT probe and a rotary brush. Before the probe was placed on the pressure hull, the area was cleaned for marine growth to ensure accurate measurements. Figure 2-7 displays the rotary brush being used on the hull of the wreck, while Figure 2-8 displays the UT probe. The locations for the thickness measurements are presented in Table 2-3. The thickness measurements were conducted between 19:18 and 21:17 (UTC) on 28.05.20205.

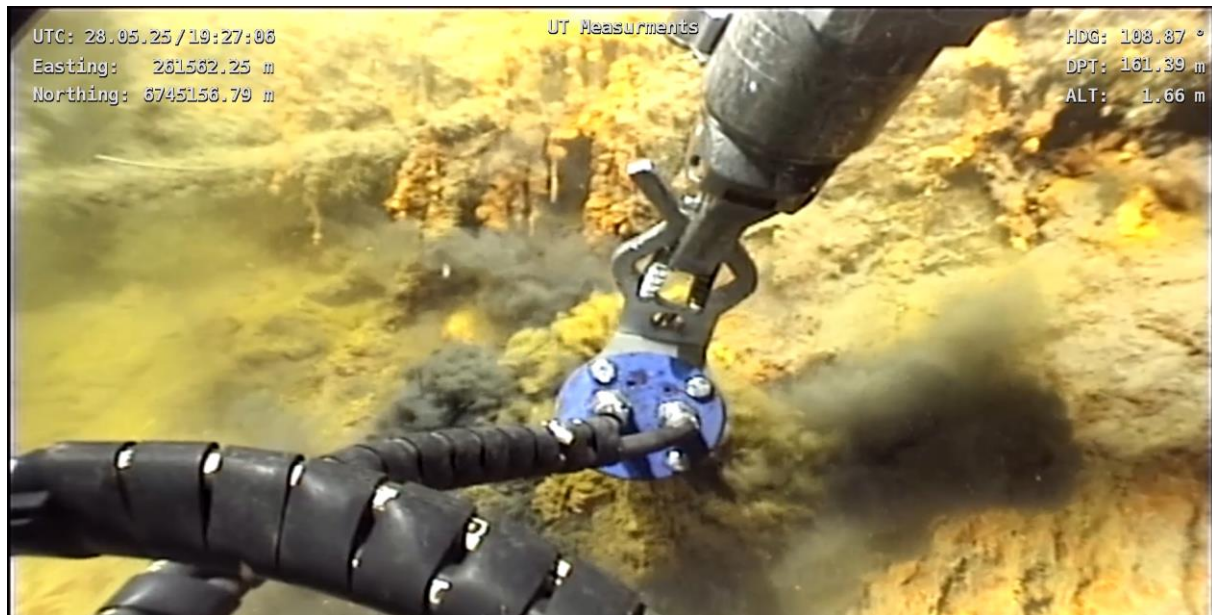


Figure 2-7 Removing marine growth from wreck hull

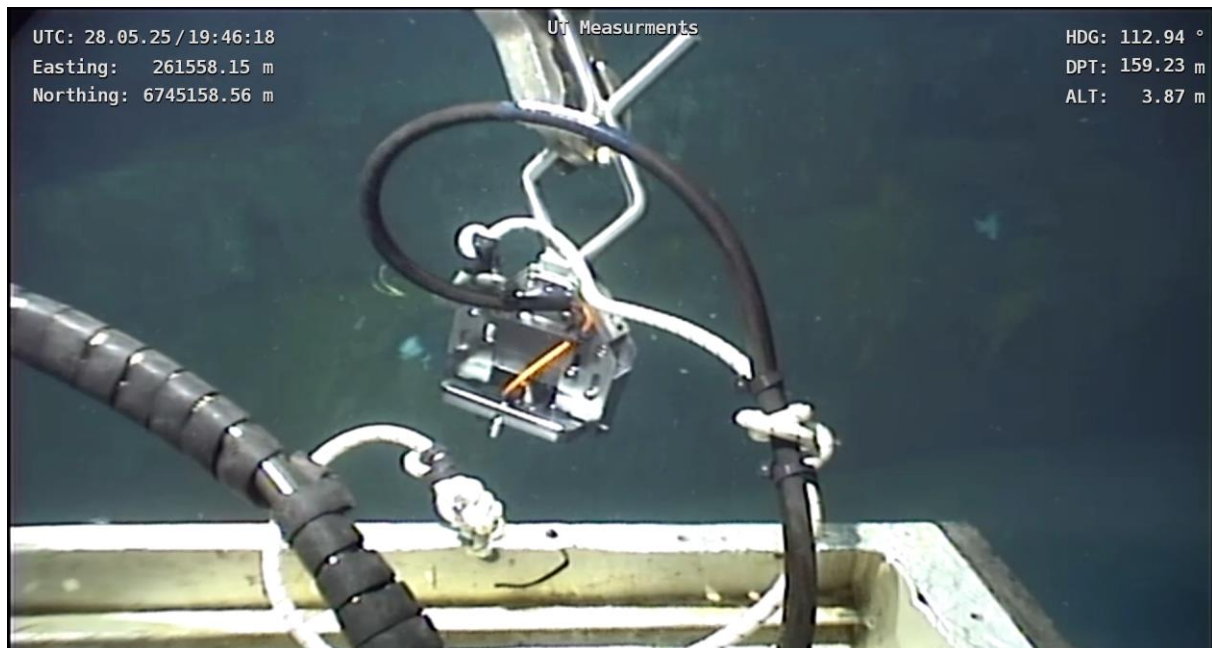


Figure 2-8 UT probe mounted from the ROV manipulator

Table 2-3 UT Probe Measurement Locations

Location	Easting (m)	Northing (m)
A – Bow Stbd Casing	264561	6745154
B – Bow Stbd Casing	261562	6745157
C – Stern Port Pressure Hull	261563	6745065
D – Conning Tower Pressure Hull	261562	6745047
E – Conning Tower Bunker Tank	261562	6745048

2.8 SUB-BOTTOM PROFILER SURVEY

The Sub-bottom survey consisted of 52 lines with 21 lines covering the stern section and 31 lines covering the bow section. The primary goal of the sub-bottom profiler survey was to provide sub-surface information of the seabed sediments down to the harder substrate. A secondary goal for the sub-bottom survey was to investigate targets from the TSS 440 and Octopulse surveys. The line spacing was set to 5 m for most of the survey, but was increased to 10 m in non-critical areas, as shown in Figure 2-9 and Figure 2-10.

After completion of the traditional geophysical survey, the sub-bottom profiler was tilted approximately 20° in an attempt to map the submarine keel under the wreck. Eight lines were surveyed on either side of the two sections with 5 m line spacing, as shown in Figure 2-11.

The sub-bottom survey was completed in two phases with the first phase surveyed between 10:49 and 13:28 (UTC) on 28.05.25 and the second phase was completed between 23:35 on 28.05.2028 and 07:44 (UTC) on 29.05.2025.

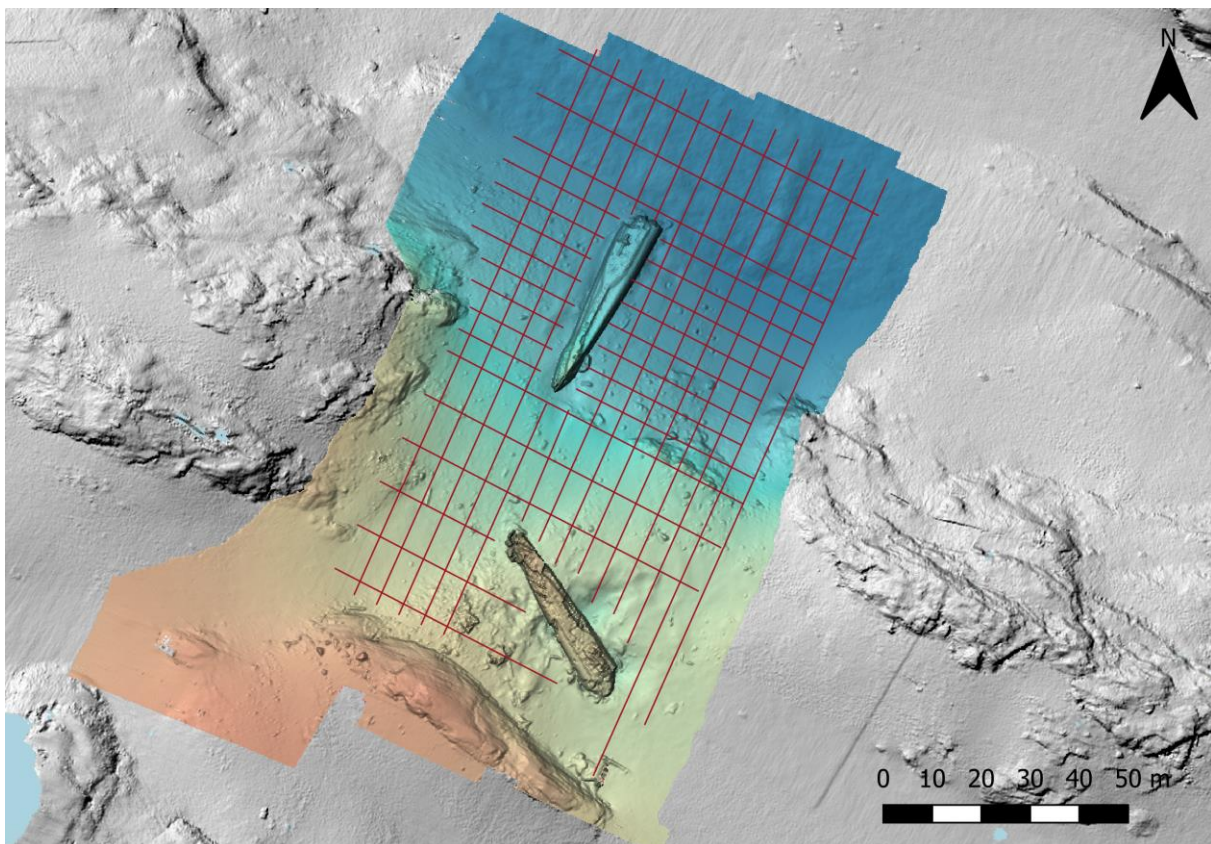


Figure 2-9 Overview of the surveyed lines over the bow section of U-864

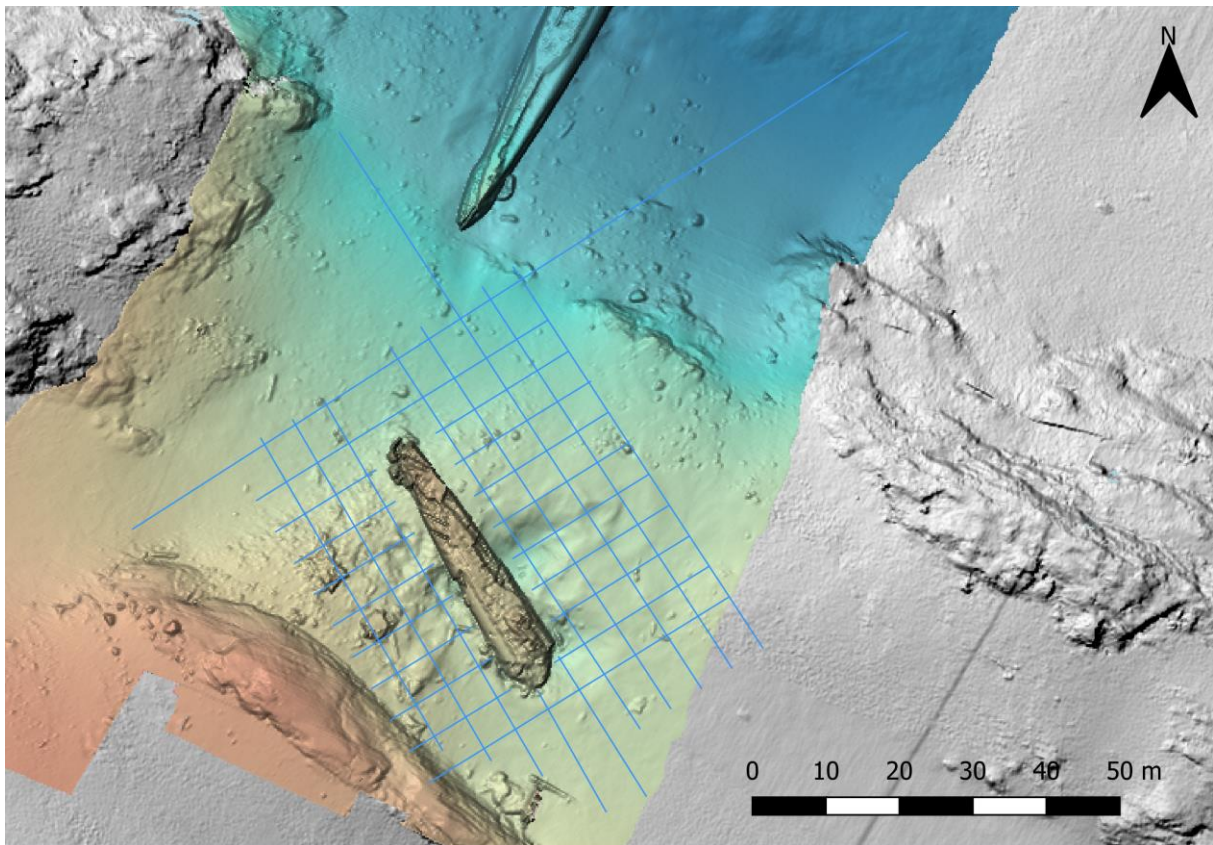


Figure 2-10 Overview of the surveyed lines over the stern section of U-864

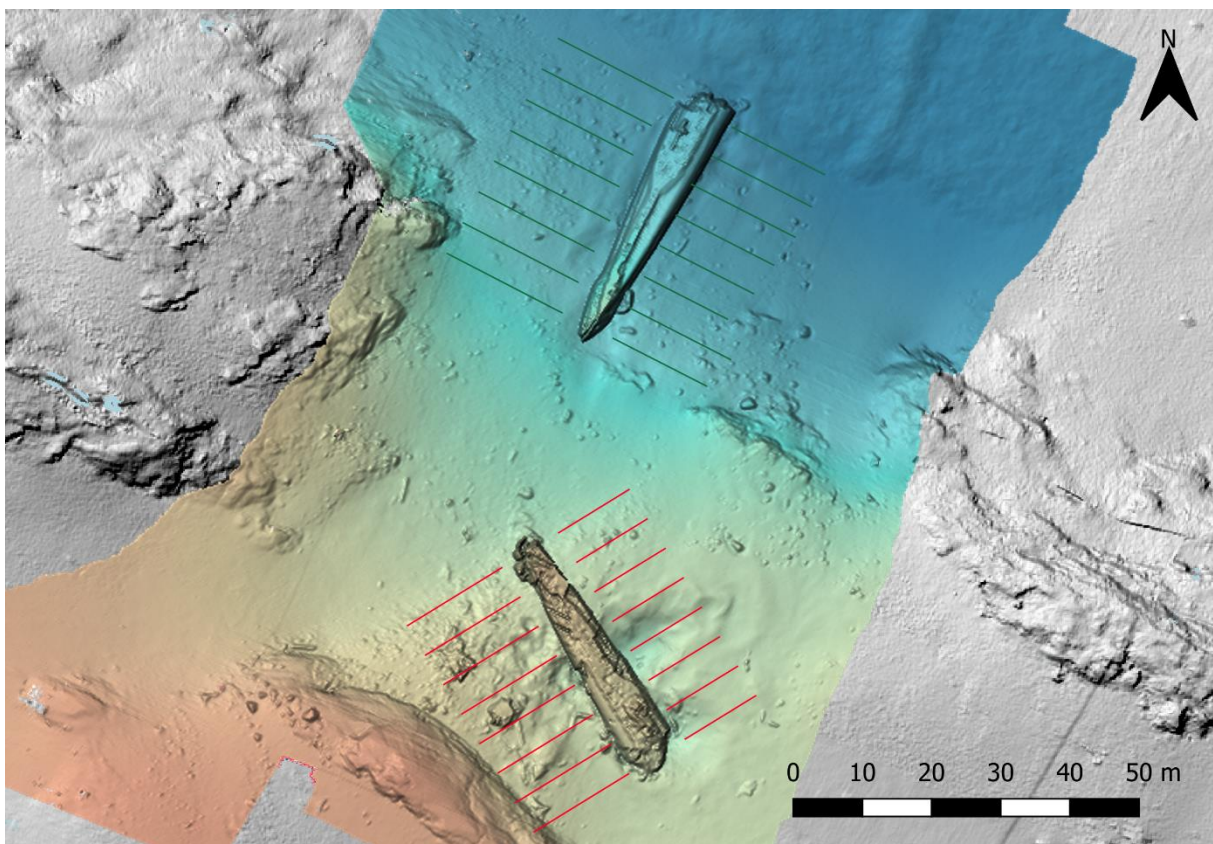


Figure 2-11 Overview of the surveyed lines for with the tilted transducer

3 DATA QUALITY AND INTERPRETATION ACCURACY

3.1 BATHYMETRY

The multibeam echo sounder data was of very good quality with very little noise or other interference. The bathymetric data was acquired using a R2Sonic 2024 dual-head system, attached to the work-class ROV (WROV). The system was operated in equidistant mode and frequencies of 360/400 kHz, resulting in a 100% coverage within the survey area. The collected data was loaded into the Eiva NaviEdit database for post processing and quality control by the offline survey department. The data had a sound velocity profile (SVP) taken from the area applied to it, together with the tide correction file. The navigational data was also post processed before being merged to the original data to give enhanced positional accuracies. The data was then loaded into the Eiva NaviModel software to clean the data and merge the individual data sets into a single DTM covering the required survey area. This surface was then used for reporting and all required MBES deliverables.

The bathymetry data was processed to a 0.2 m × 0.2 m grid cell size in accordance with procedures, and the data density requirement was generally achieved. Figure 3-1 displays the digital terrain model coloured by data density values. Areas coloured in yellow and green meet the project requirements, with green areas representing 10 or more points per cell. The red areas, where the requirements are not met, are located where slight shadowing occurred due to seabed features and beam angle effects.

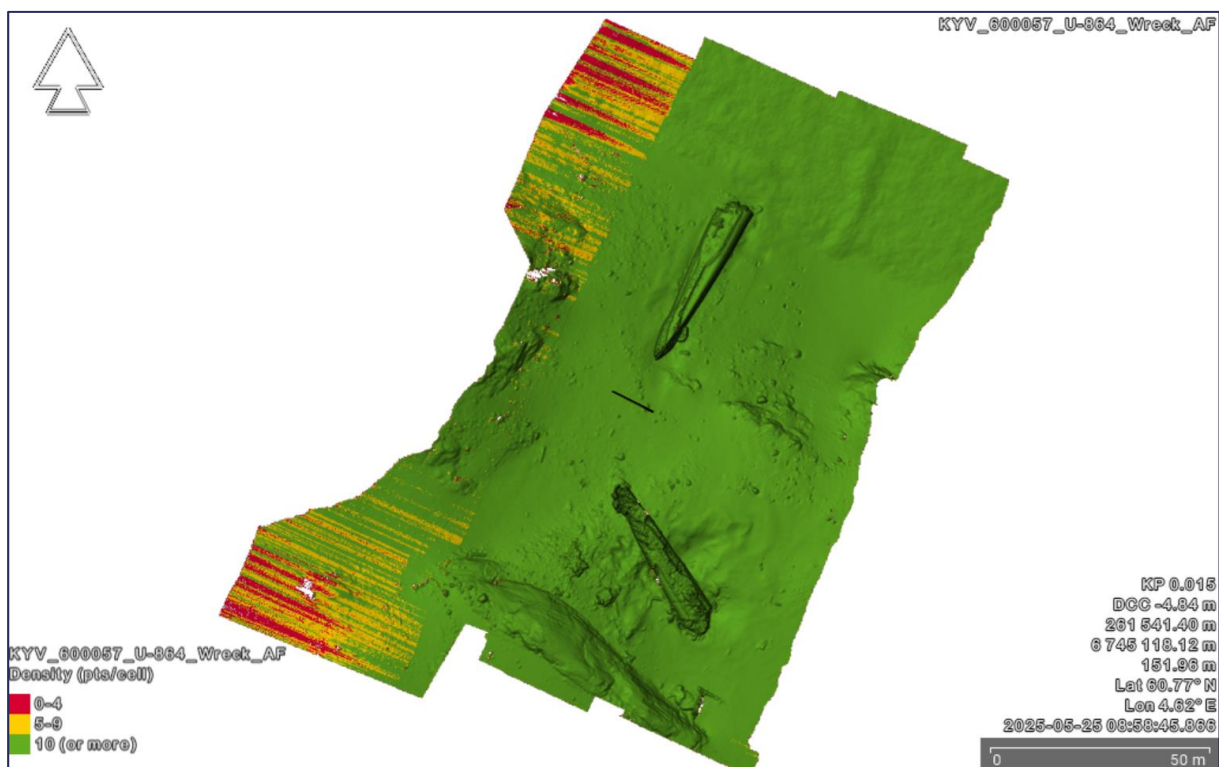


Figure 3-1 MBES data coloured by data density (Red = 0-4, Yellow = 5-9, Green = 10 or more)

3.2 SUB-BOTTOM PROFILER

The quality of the sub-bottom profiler data was overall sub-par, with multiple areas without any usable information below the seabed surface. There was minimal noise and interference in the dataset overall, and it was usually restricted to data close to the wreck pieces. The penetration of the system was relatively poor for most of the survey area and failing to provide clear images of the sub-surface. The data was acquired using an EdgeTech 2–16 kHz chirp sub-bottom profiler, with operational frequencies ranging from 2–8 kHz to 2–15 kHz and a 5 ms pulse length to achieve optimal vertical resolution for the geological setting. Different frequencies and pulse lengths were tested to improve the results. However, due to time constraints, it was not possible to fully optimize the settings for ideal penetration and resolution. During the short testing, no significant improvement of the sub-bottom data was observed with the different settings.

Sub-surface penetration was limited across much of the survey area due to the seabed characteristics, including bedrock areas, hard sediments on the seabed and previous work activity. Smearing effects and acoustic noise from the wreck and debris further compromised the data quality, making interpretation difficult. Penetration up to 5 m was occasionally achieved, however, it was usually less. Figure 3-2 - Figure 3-9 display data examples from the SBP profiler. The absence of distinct sub-seabed reflectors in the data examples illustrates the limited penetration achieved.

Profiles across areas with inclined seabed, particularly to the east and west of the stern section, show apparent vertical drops in the seabed (Figure 3-10). These are motion-induced artifacts caused by ROV heave and attitude movements. The actual seabed morphology in these areas is generally smooth and gradually sloping.

It is likely that the debris found scattered all over the survey area had a negative impact on the signal. Large and dense pieces of debris and boulders are known to cause acoustic shadows, reducing the signals penetration and visibility below the surface. Another SBP, such as the Innomar medium-100 or the Kraken SBI, could possibly have provided better resolution. However, this cannot be verified without testing the systems.

SBP results from a previous survey (Van Oord, 2016) using the same system showed equally poor resolution. This indicates that the poor resolution is not isolated to this year's survey.

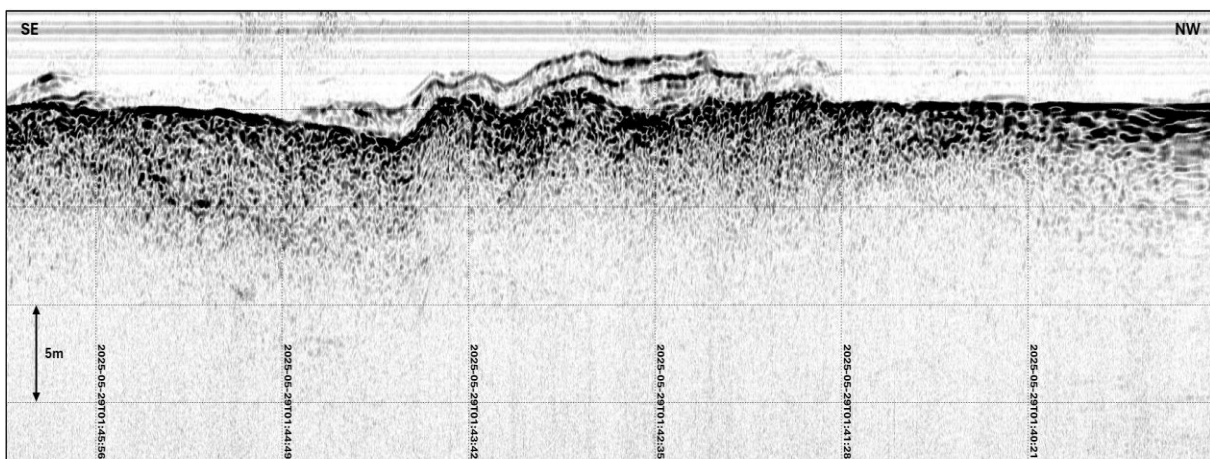


Figure 3-2 Line SBP_Geo_Stern_M_010 Data example with noise from the stern section of the wreck, in the middle of the profile

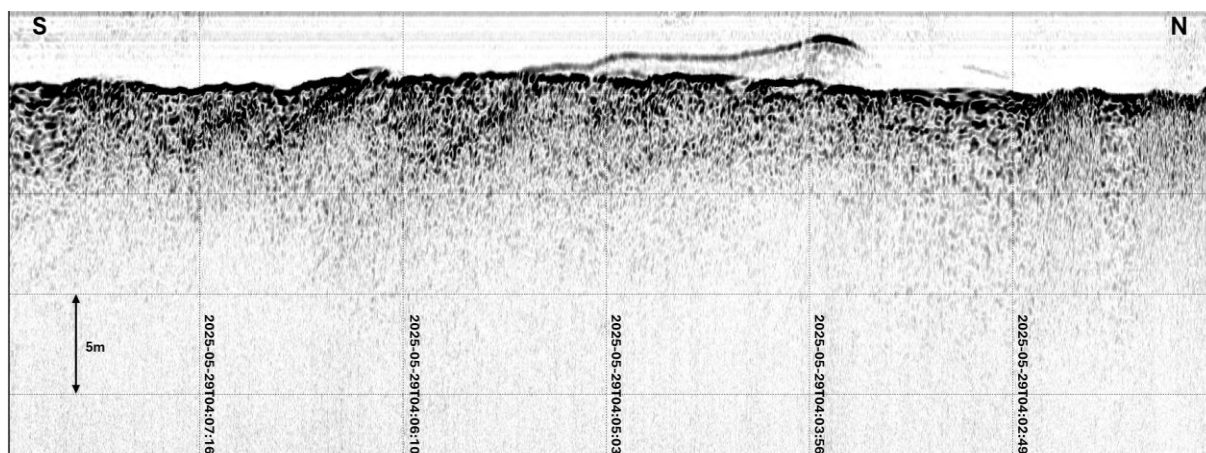


Figure 3-3 Line SBP_Geo_Bow_M_030 – Data example with noise from the bow section of the wreck, in the middle of the profile

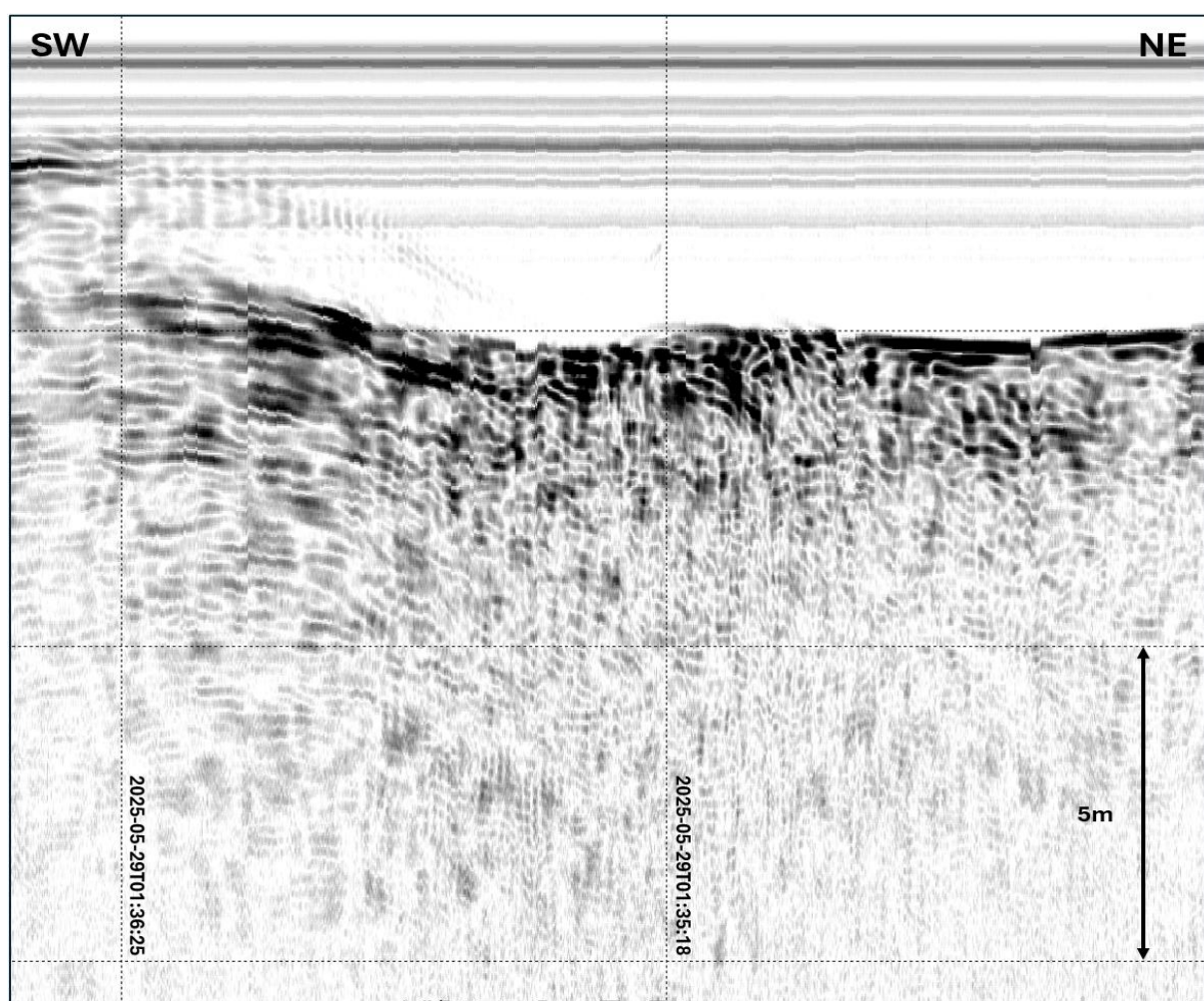


Figure 3-4 Line SBP_Tilt_Stern_S_06 - Data example of tilted sub-bottom data, with the wreck in the left side of the profile

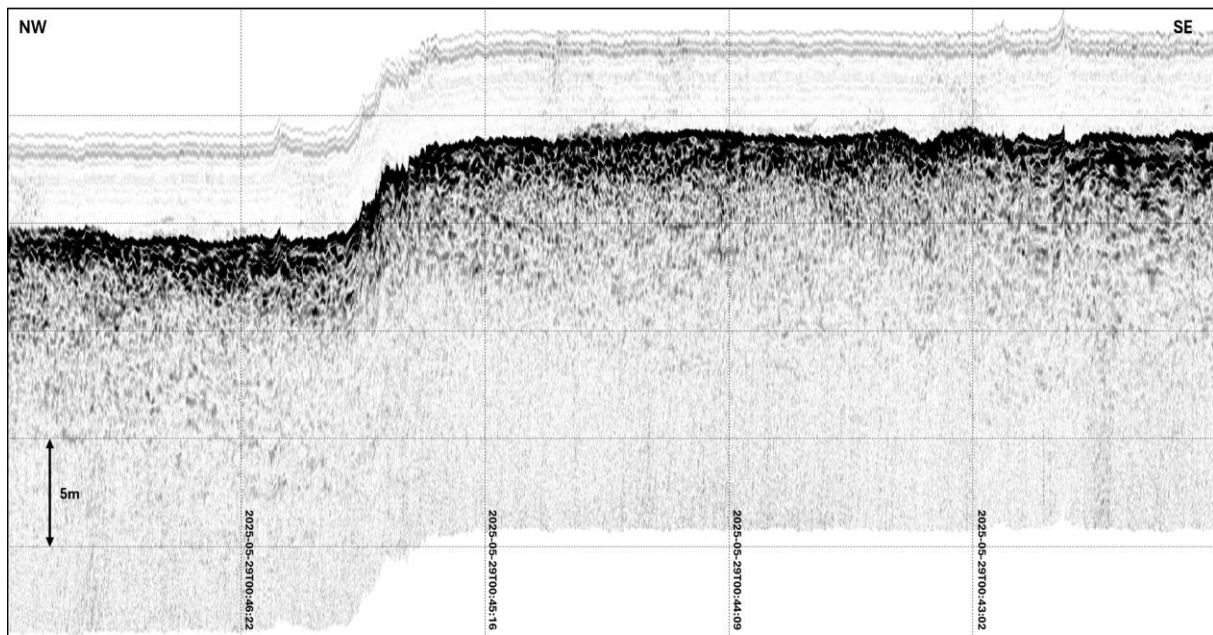


Figure 3-5 Line SBP_Geo_Stern_M_040 – Data example with no visible reflectors due to limited penetration

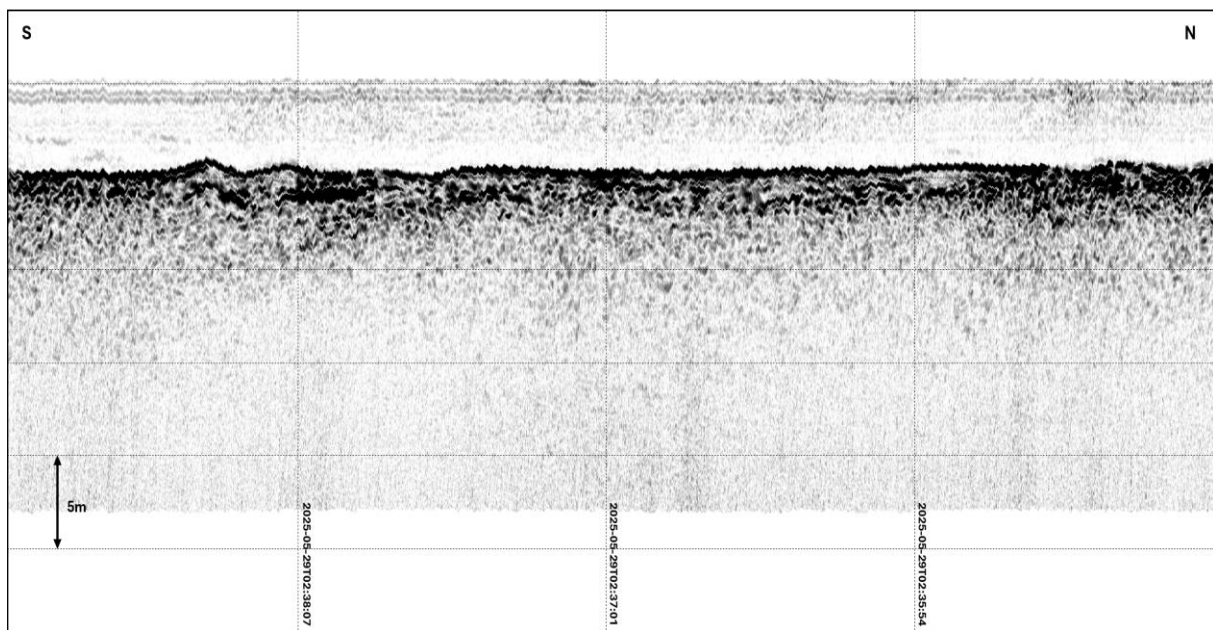


Figure 3-6 Line SBP_Geo_Bow_M_060 – Data example with a weak irregular reflector

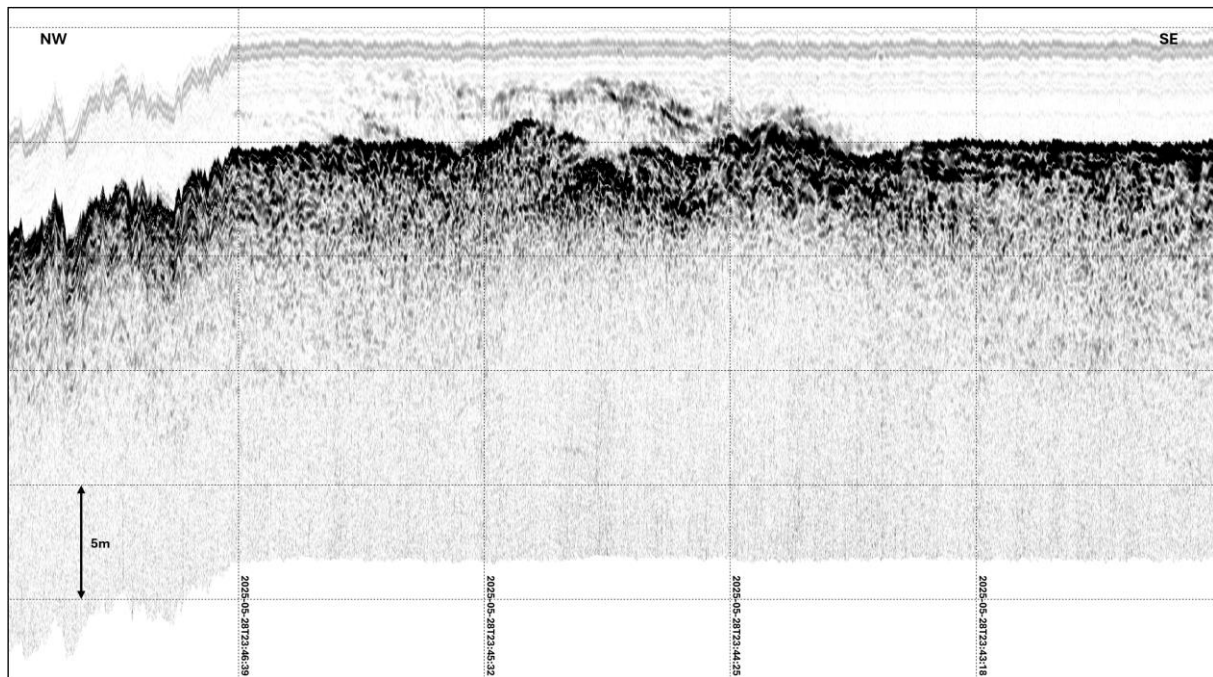


Figure 3-7 Line SBP_Geo_Stern_M_021 - Data example with a weak irregular reflector

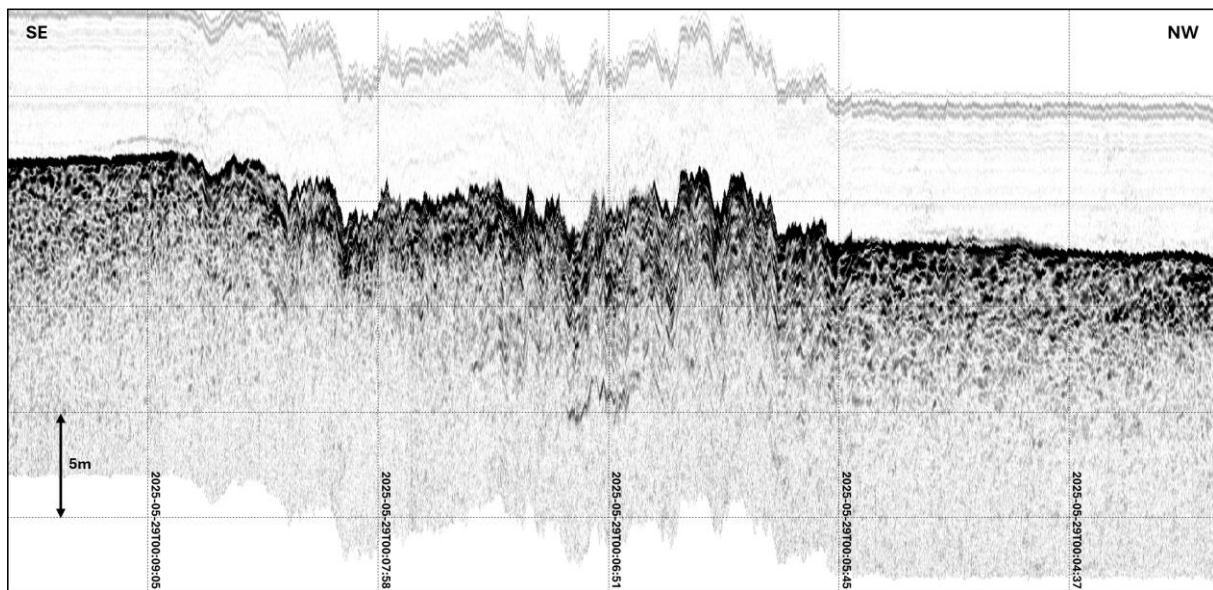


Figure 3-8 Line SBP_Geo_Stern_M_025 - Data example of noisy data

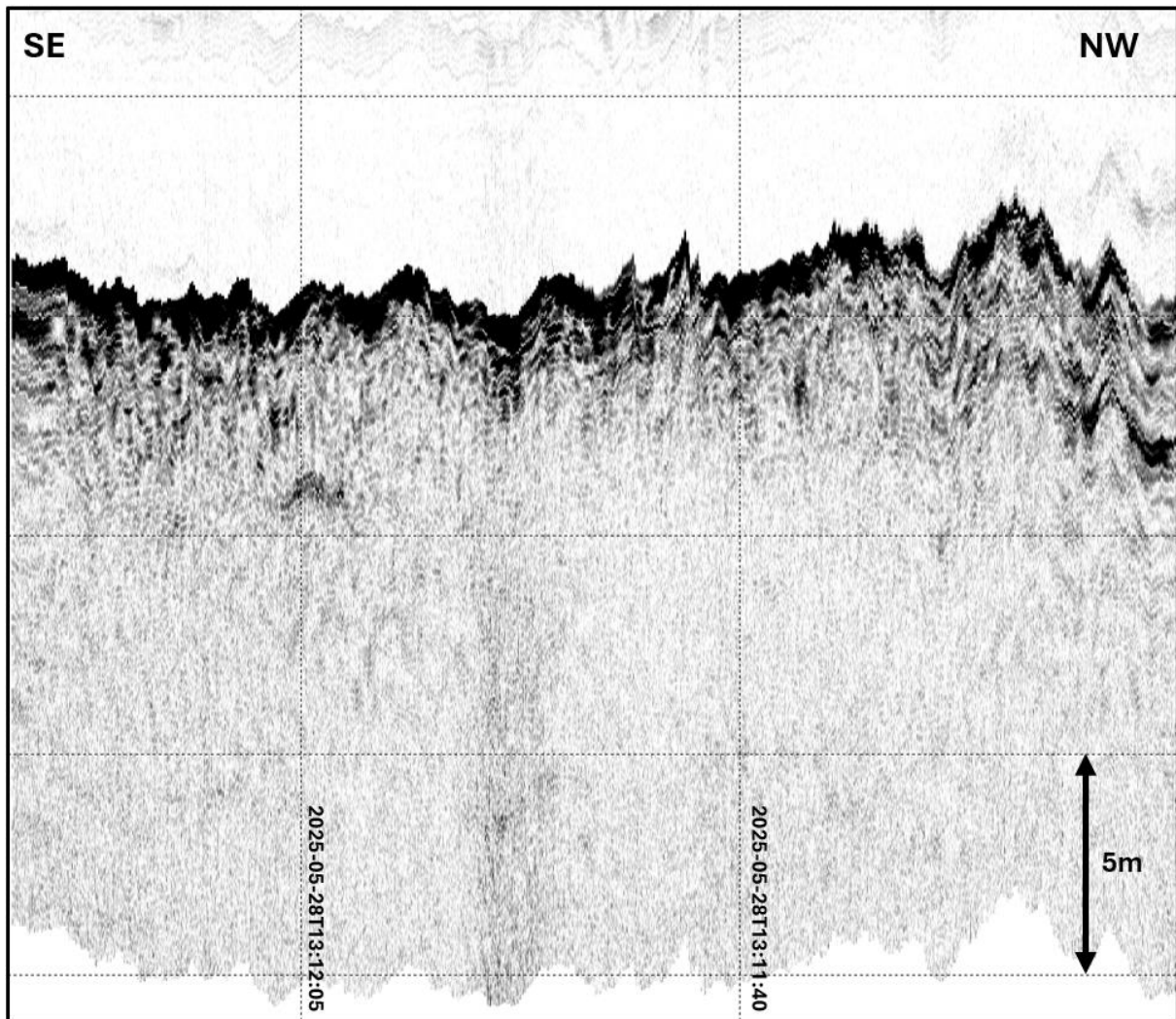


Figure 3-9 Line SBP_Geo_Stern_X_035b – Data example of noisy data

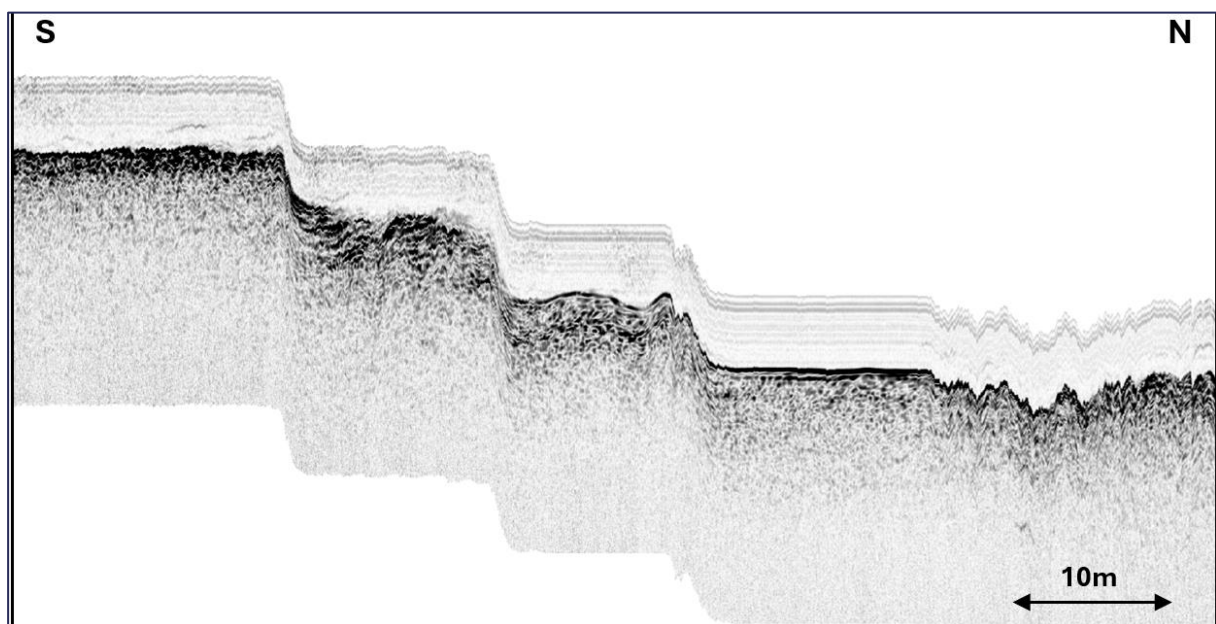


Figure 3-10 Line SBP_Geo_Bow_M_055 – Data example of motion-induced artifacts caused by ROV movements

3.3 ELECTROMAGNETICS - TSS 440

The quality of the TSS 440 system was overall good and was able to detect the magnetic field of a mercury canister on the seabed surface during the surrogate trials. Based on the different fly heights performed with the ROV (1 m-2 m), a detection range between -40 nT and 2500 nT for a single canister was established during the SIT. The main challenge with the TSS survey was the number of debris surrounding the wreck sections. As illustrated by Figure 3-11, there are multiple anomalies (red) identified by TSS signal that have values equal to or larger than 2500 nT. Due to the large range of detectability from the TSS 440, it is difficult to assess the usability of the data. On one hand, the system is detecting magnetic ranges corresponding to mercury canisters, however, the system cannot distinguish possible mercury canisters from other debris or determine if something is buried.

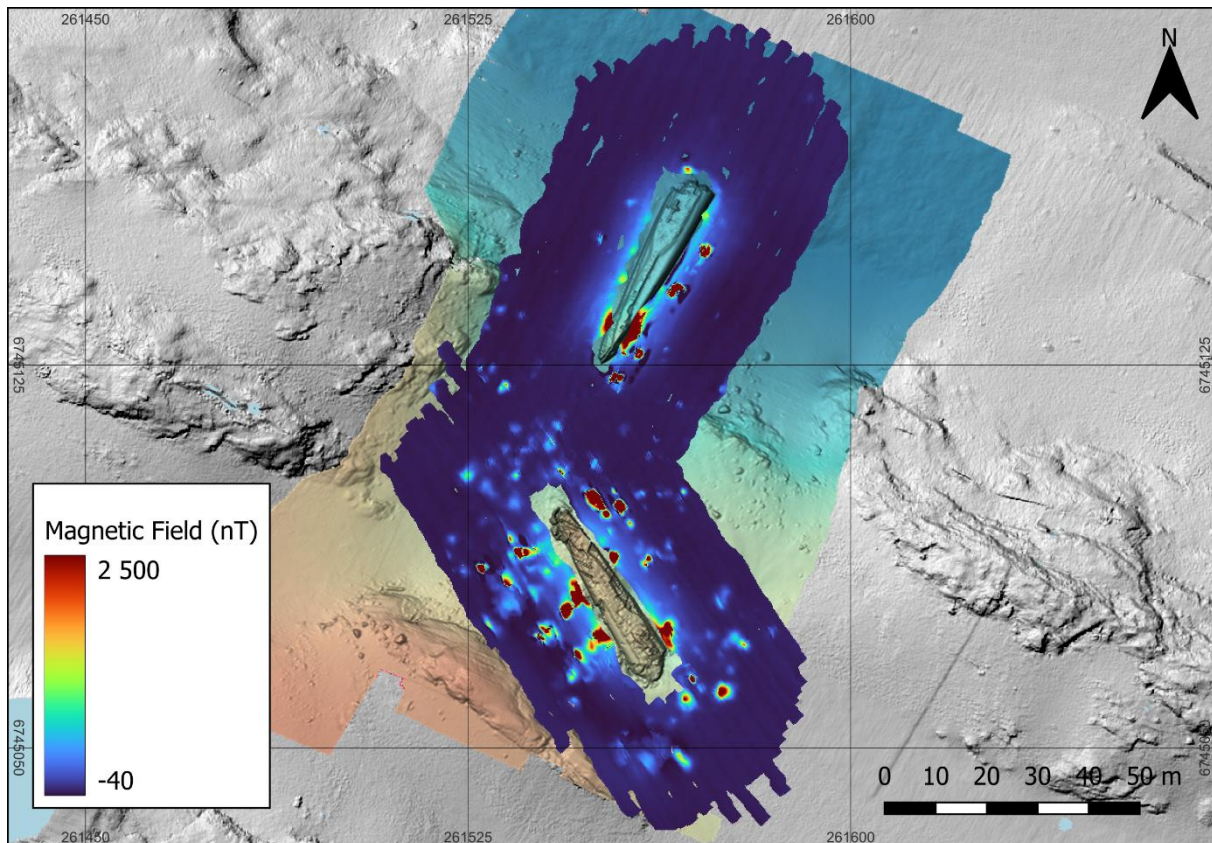


Figure 3-11 TSS 440 heatmap showing increase in the magnetic field (nT) where metallic debris is located

3.4 ELECTROMAGNETICS – OCTOPULSE

The quality of the Octopulse system was overall ok and was able to detect the surrogate canister on the normalized impedance module. Based on the data collected at three different survey heights (0.5 m-1.5 m), it was determined that the Normalized Impedance Module was positive for active dipoles (Figure 3-12). This meant that the object that was detected was less conductive than the surrounding environment. As it is unlikely that a metallic canister filled with mercury is less conductive than saltwater, it was determined that the system was responding to the rope attached to the canister.

The SIT was not able to determine the signature of the canister; however, it did prove that the system could detect changes in the overall environment. To determine a level of detection for the actual canisters, previous data matching the characteristics of the mercury canisters was used.

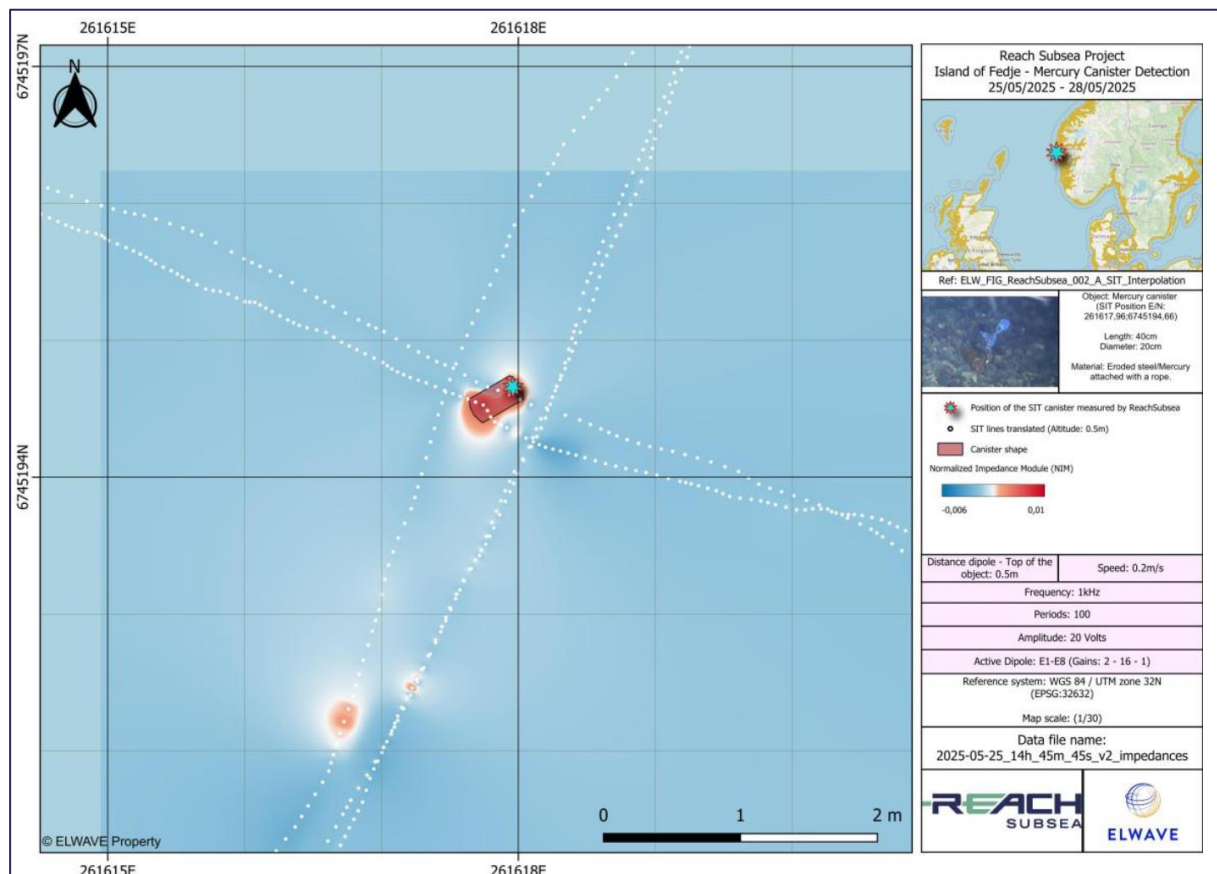


Figure 3-12 Interpolation of the Normalized Impedance Modulus at 0.5 m altitude showing the detection of the canister w/rope

From historic data, a detection range suitable for the mercury canisters was established (Table 3-1). The results from the Octopulse system were processed and interpreted by Elwaves's own inhouse team. The report is found in Appendix D.

Table 3-1 Canister Detection Limits

Level of Detection	Normalized Impedance Modulus of an Active Dipole
A01	1.10^{-3} & Detection on other sensors
A02	1.10^{-3}
A03	5.10^{-4}

3.5 PHOTOGRAMMETRY

The Voyis images and photogrammetry results were of excellent quality. The visibility during the photogrammetry work was good, resulting in high quality images and a detailed point cloud model of the wreck. Before the data acquisition started, the lights, camera and timing were tested on deck. A clock test was conducted to verify correct camera timing. After the ROV was launched, the system was tested again and the camera settings were tweaked to match the environmental conditions on site.

During the survey campaign, approximately 150.000 images were taken using the Voyis Discovery Stereo camera. Of these images, around 60.000 were selected to be used in the photogrammetry models. The selection was carried out to remove dark or unusable images, remove excessive overlap, and ensure a reliable reconstruction of the wreck. Initial processing was performed on board the vessel during acquisition to check the quality of the results as soon as data was available. More robust quality control and processing was performed onshore after the end of the survey campaign. The finished models achieved an accuracy down to 2 mm with nearly 100% coverage. The only areas where the coverage was incomplete were beneath the wreck and at the fracture points.

3D reconstruction was performed using structure from motion algorithms (SfM). The results of the 3D reconstruction were red, green and blue (RGB) coloured point clouds and meshes of both sections of the wreck. The camera baseline was used for obtaining scale during the photogrammetry processing. The results were verified using scale-bars placed on the wreck during the survey campaign to ensure proper scaling of the models, and no deviations were found. Figure 3-13 shows an example of the images taken with the Voyis camera, while Figure 3-14 and Figure 3-15 display the finished point clouds generated from the images.

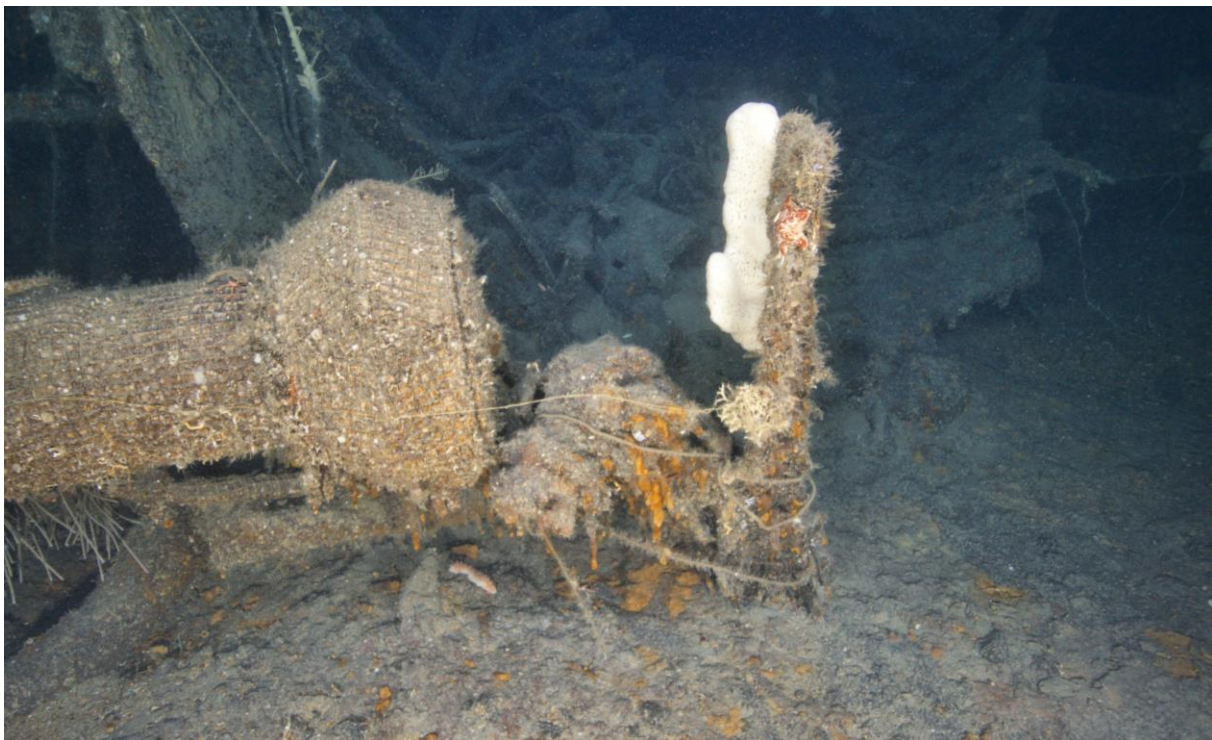


Figure 3-13 Voyis image example showing the snorkel with “tarnmatte”

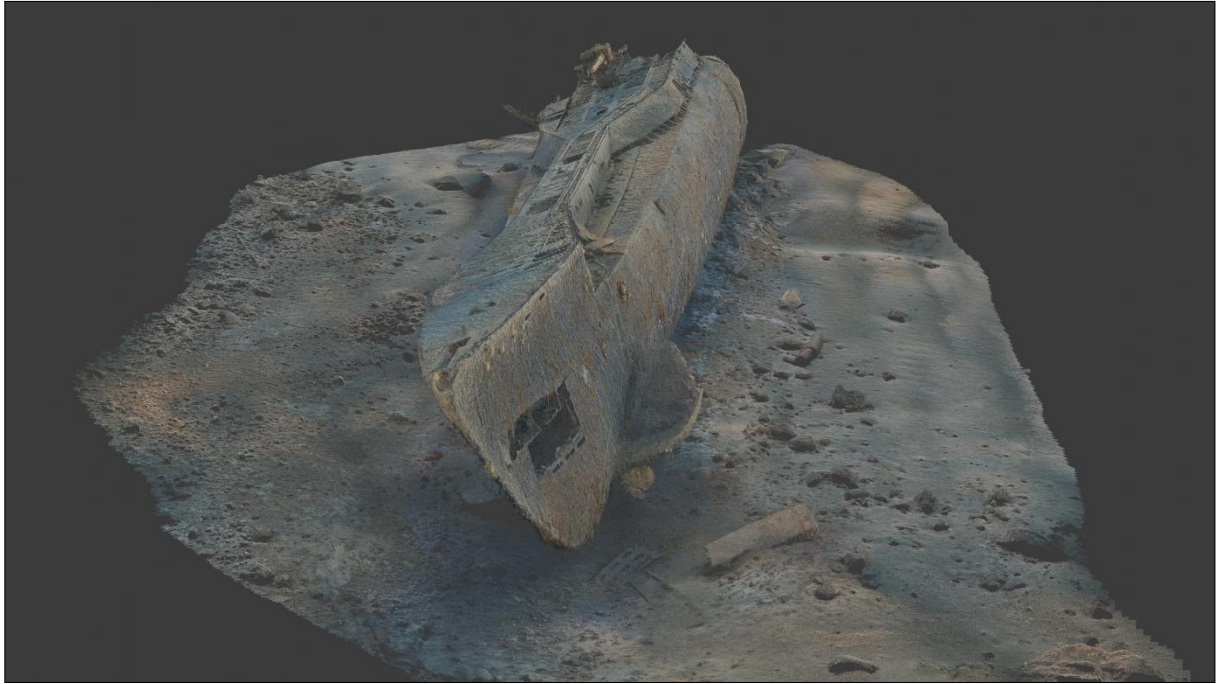


Figure 3-14 Point cloud of the bow section of U-864



Figure 3-15 Point cloud of the stern section of U-864

3.6 VISUAL INSPECTION

The overall quality of the video data was good. The conditions around the wreck site had minimal suspended sediments and other organic materials, resulting in good visibility during the video surveys. Figure 3-16, Figure 3-17 and Figure 3-18 display examples of video acquired during the as-found survey and external inspection survey. Both examples display good quality images without significant suspended sediments and/or organic material obstructing the view.



Figure 3-16 HD video example from the stern fracture point



Figure 3-17 HD video example from the bow fracture point



Figure 3-18 HD video example from the stern section showing debris

For the lance camera survey, the overall quality of the video was good; however, insufficient lighting and suspended material limited the visibility within the wreck. Examples of poor visual conditions are presented in Figure 3-19 and Figure 3-20. Figure 3-21 and Figure 3-22 show examples from both the ROV and the lance camera, displaying high video quality before entering the wreck.



Figure 3-19 Lance camera example showing suspended material obstructing the view



Figure 3-20 Lance camera example inside the wreck. Low visibility due to poor lighting



Figure 3-21 Lance camera example before entering the hull at the torpedo bay



Figure 3-22 ROV camera example showing the lance camera before entering the hull

3.7 THICKNESS MEASUREMENTS

The thickness measurements of the pressure hull were performed well within specifications, with an accuracy of ± 0.1 mm. The sensor was calibrated by Cygnus Instruments on 18.12.24. The sensor was calibrated using a range of thicknesses, all within the accepted tolerance of ± 1 mm. Calibration details from the supplier are presented in Appendix F. Pre- and post-dive calibrations of the sensor were performed on a 15 mm steel block. Both calibration checks were within the ± 0.1 mm acceptance tolerance. Details from the measurements are presented in Table 3-2.

Table 3-2 Deck Calibration Checks

Pre-Dive Measurement (mm)	Post-Dive Measurement (mm)
15.10	15.05
15.10	15.05

4 RESULTS – U-864 WRECK SITE

The survey results cover the visual, geophysical and electromagnetic survey of the U-864 wreck site off the coast of Fedje. The results focus on bathymetry, sub-seabed conditions and photogrammetry to create a comprehensive 3D model of the survey area. The survey area is approximately 70×140 m in size and covers both pieces of the submarine U-864 (Figure 4-1). The coordinates of the survey boundary are presented in Table 4-1.

Table 4-1 Wreck Site Boundary Coordinates

Boundary Point	Easting (m)	Northing (m)
1	261556.37	6745196.52
2	261619.96	6745169.25
3	261561.42	6745040.08
4	261497.83	6745069.35

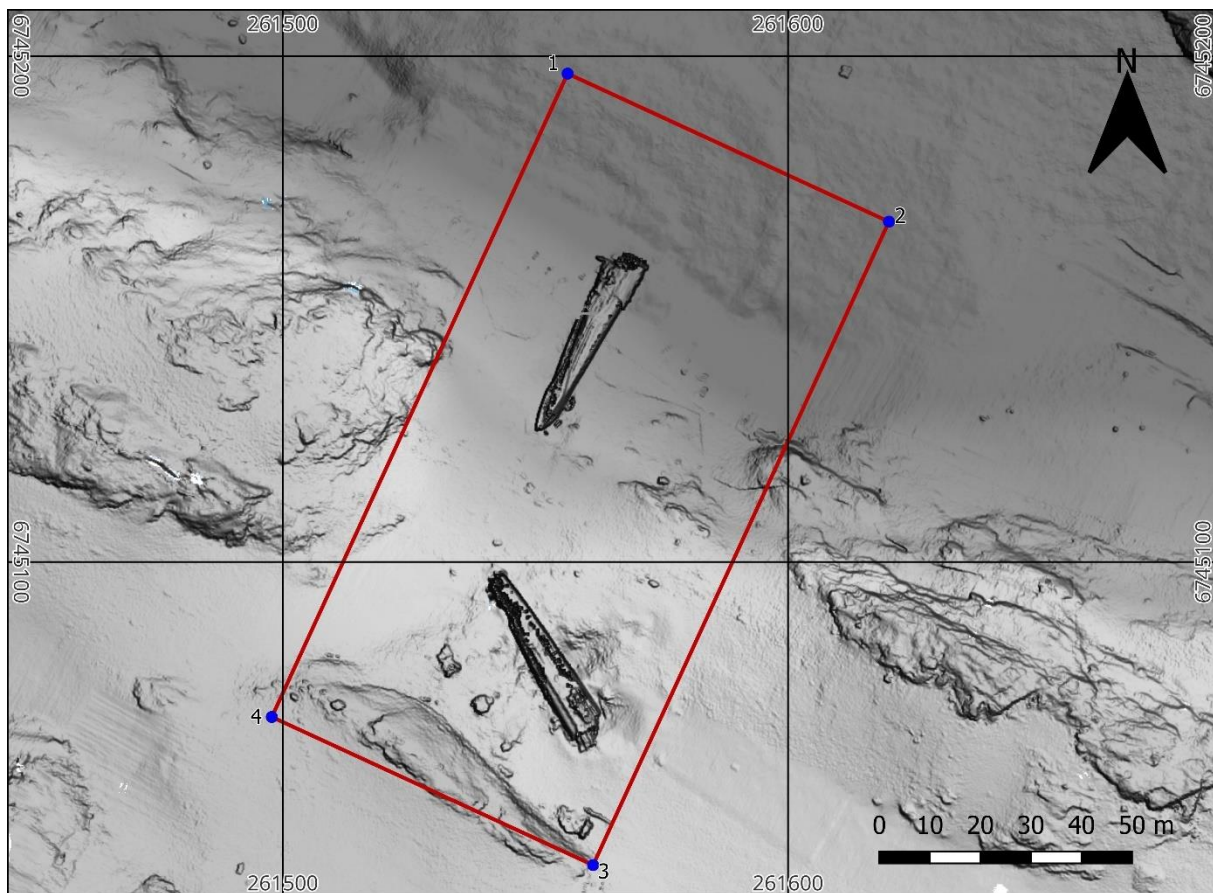


Figure 4-1 U-864 wreck survey area

4.1 GEOPHYSICAL SURVEY

4.1.1 BATHYMETRIC SURVEY

The description of the bathymetric results is derived from a 0.20×0.20 m resolution digital terrain model (DTM). Water depths within the survey corridor ranges from approximately 139 m to 167 m. The maximum and minimum water depths are presented in Table 4-2. The relatively large change in depth over such a small area is due to the wrecks position on a very steep slope. Apart from vertical, or near vertical slopes, the multibeam survey produced 100% coverage of the survey area around the wreck of the U-864 (Figure 4-2).

The survey area can be classified as very steep with an average gradient of 16.5°, sloping down from south-southwest to north-northeast. An overview of the gradients of the area is presented in Figure 4-3. The stern section is located in the southern part of the survey area, laying at an angle of approximately 2-4°. The bow section is in the northern part of the survey area, laying at an angle of approximately 14.3°. Scour marks in the sediments around the wreck are associated with tidal action and subsurface currents. A seabed profile, highlighting the rapid change in depth within the survey area, is presented in Figure 4-4.

The geological formations in the survey area are characterized by bedrock outcrops, poorly sorted gravel and interstitial finer sediments associated with the outcrops. There is a very shallow ridge running approximately east-southeast to west-northwest. The northeastern area is characterized by gravel from a dumping campaign to stabilize the wreck U-864.

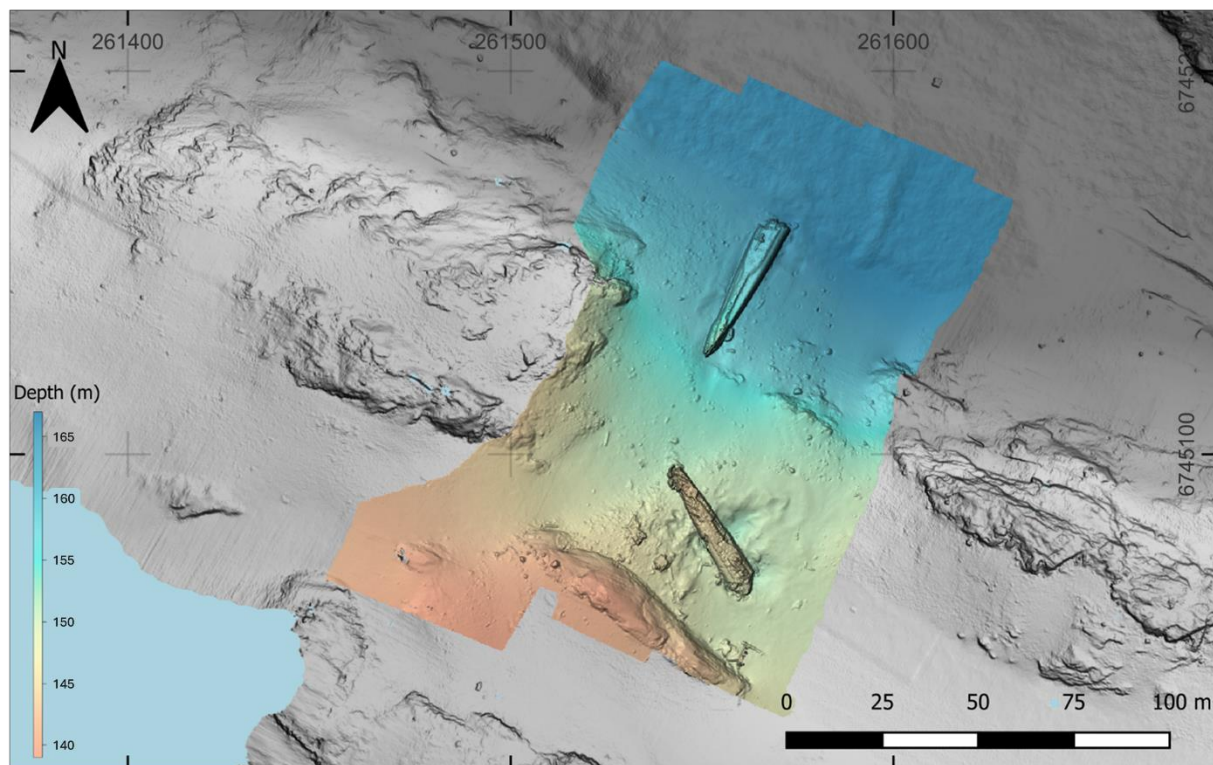


Figure 4-2 Bathymetric overview of the survey area with historic bathymetry as background

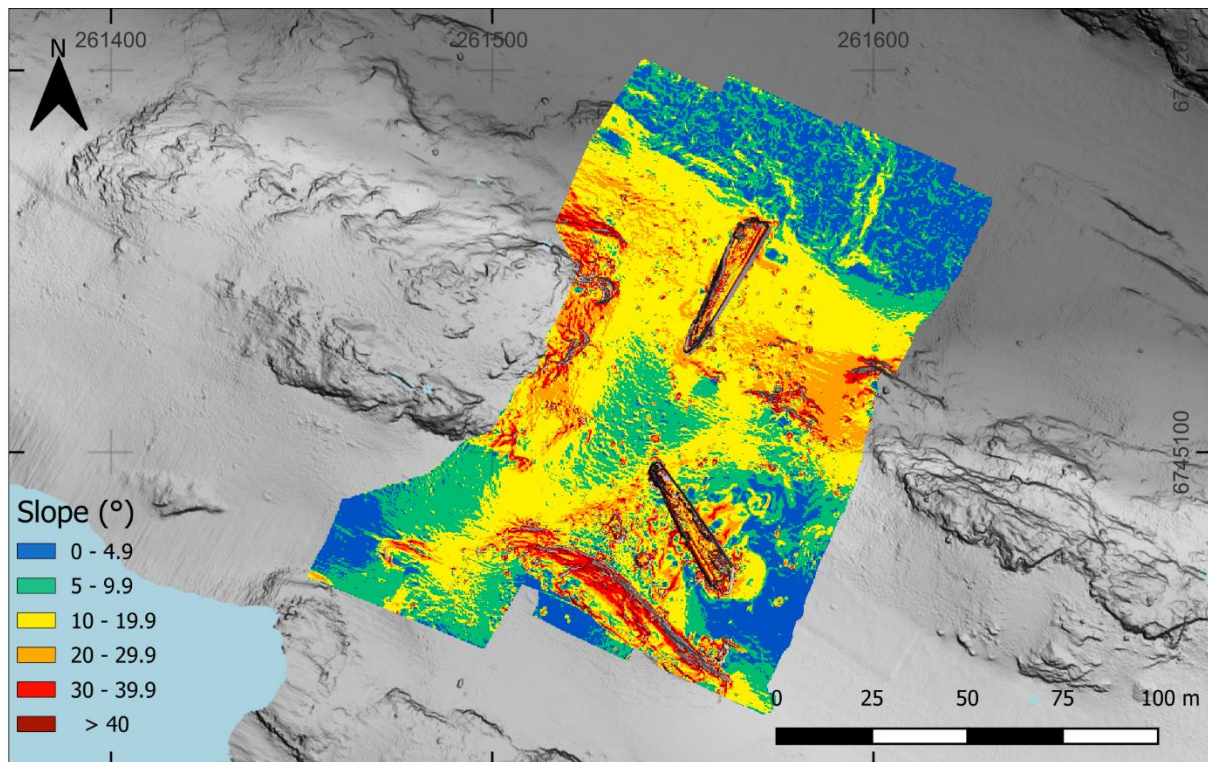


Figure 4-3 Seabed slope overview of the survey area with historic bathymetry as background

Table 4-2 Bathymetry Summary

Depth in m (MSL)	
Minimum depth	138.7
Maximum depth	166.8

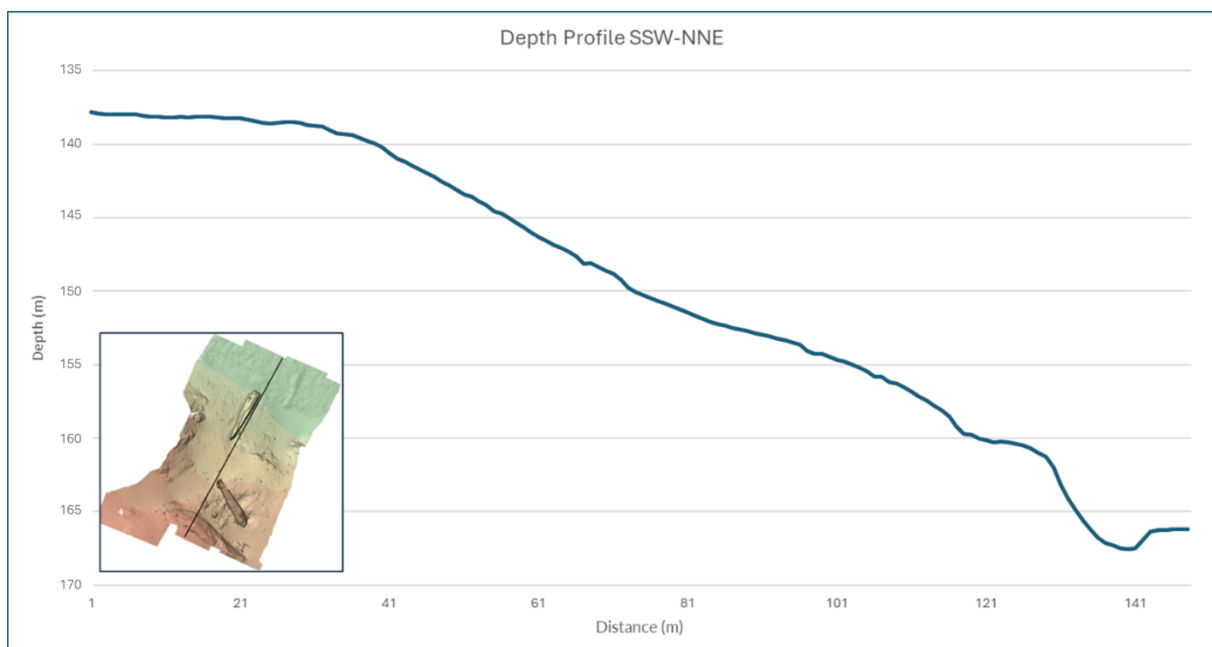


Figure 4-4 Depth profile along the survey area

Figure 4-5 and Figure 4-6 display the two pieces of the submarine U-864 as multibeam point clouds, presenting a detailed view of the wreck.

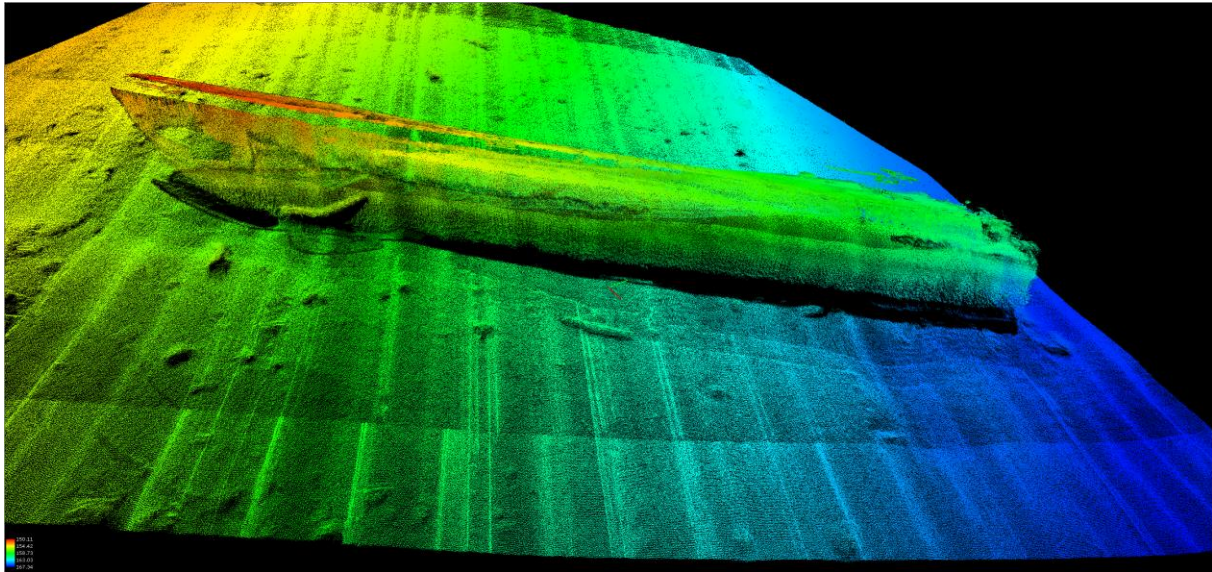


Figure 4-5 Point cloud data example showing the bow section of U-864

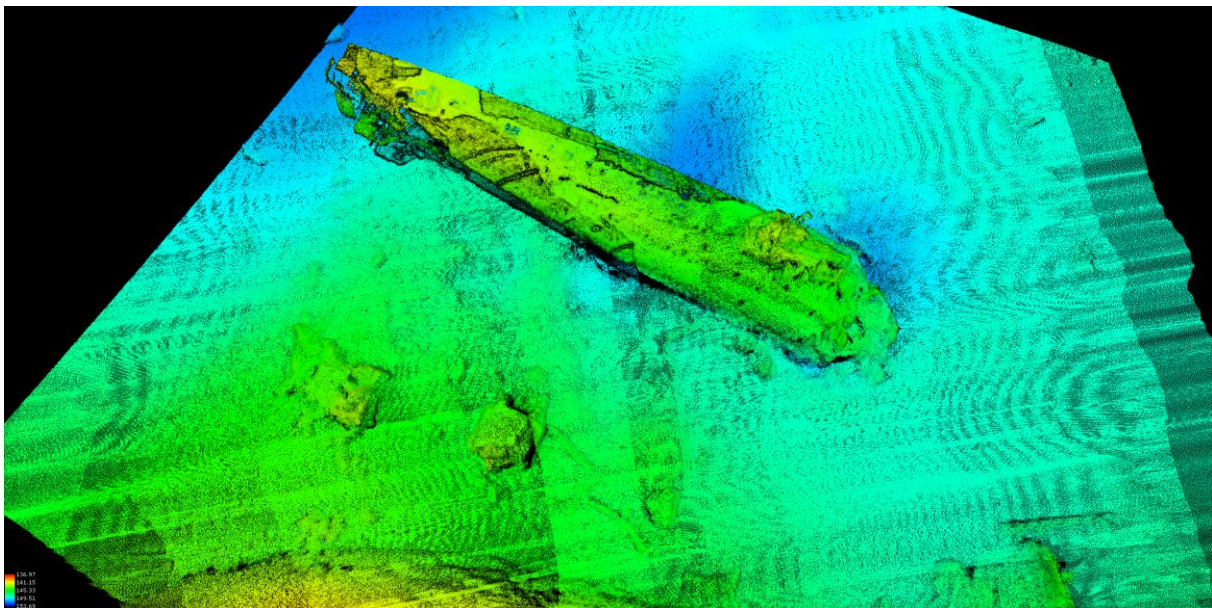


Figure 4-6 Point cloud data example showing the stern section of U-864

4.1.2 SUB-BOTTOM PROFILER SURVEY

The interpretation of the shallow geology was based on the seismic character of the sub-bottom profiler data, MBES data and geotechnical samples collected by NGI in 2006 (Reference 1). Due to the shallow penetration of the sub-bottom profiler, no stratigraphic units were identified.

The signal penetration was generally limited across the survey area. A few irregular and weak reflectors were visible, but no continuous reflectors were observed. Consequently, identification of clear sedimentary units was not possible, and only the top of bedrock partially interpreted (Figure 4-7). This interpretation was based on several data sources and could not have been completed by sub-bottom profiler data alone. The digital terrain model (DTM) derived from multibeam data shows multiple exposed outcrops, while cone penetration test (CPT) data, collected by NGI in 2006, provide point measurements of sediment thickness (Figure 4-8). In some areas where no reflectors were visible, the CPT results were used to interpret the position of the top of the bedrock. The top of bedrock was primarily found in the area between the two wreck sections and on the eastern side of the bow section.

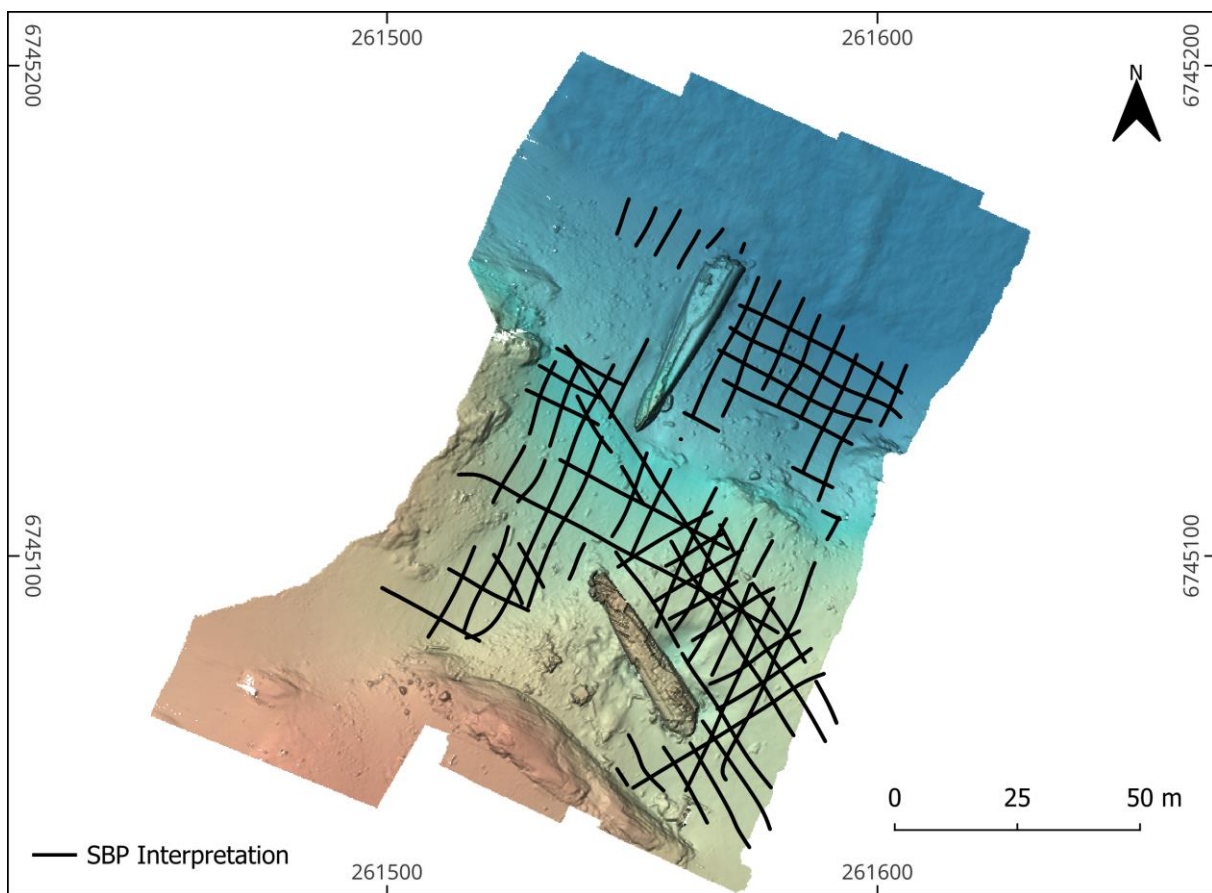


Figure 4-7 Overview of where the top of bedrock has been interpreted

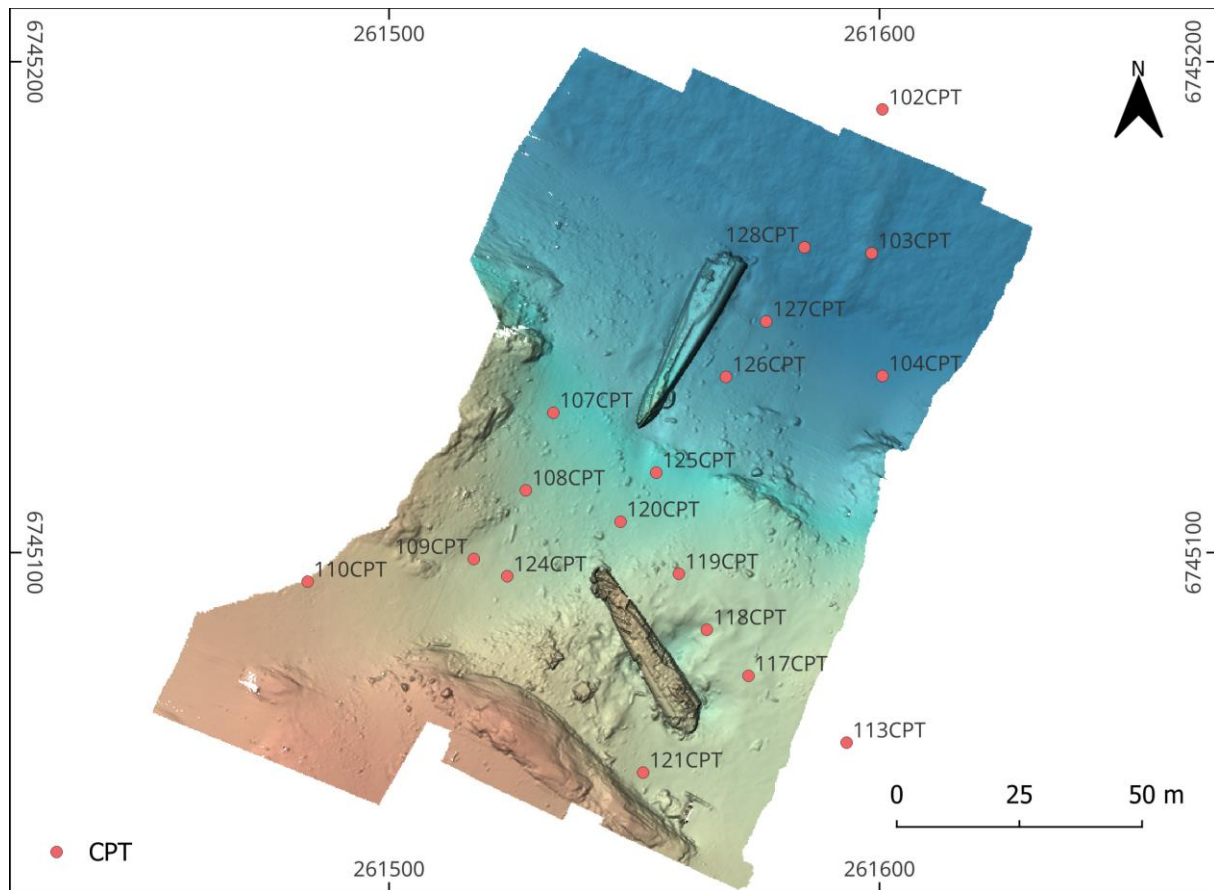


Figure 4-8 Overview of CPTs performed by NGI in 2006

Figure 4-9 and Figure 4-10 display depth below surface for the bedrock horizon derived from the CPT and SBP data. Note that the generation of isopach relies on interpolation and due to the limited interpretation in the area, the map may not be 100% accurate.

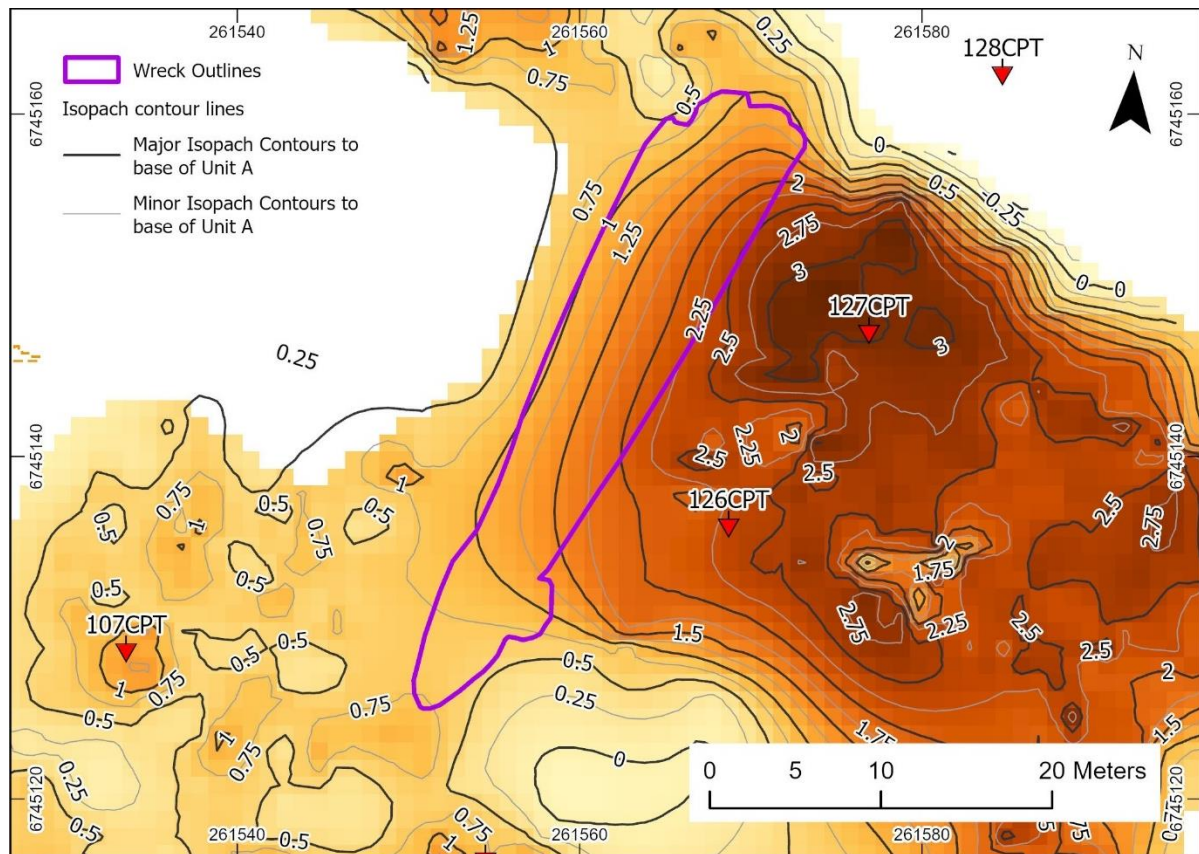


Figure 4-9 Isopach showing bedrock depth below surface at the bow section

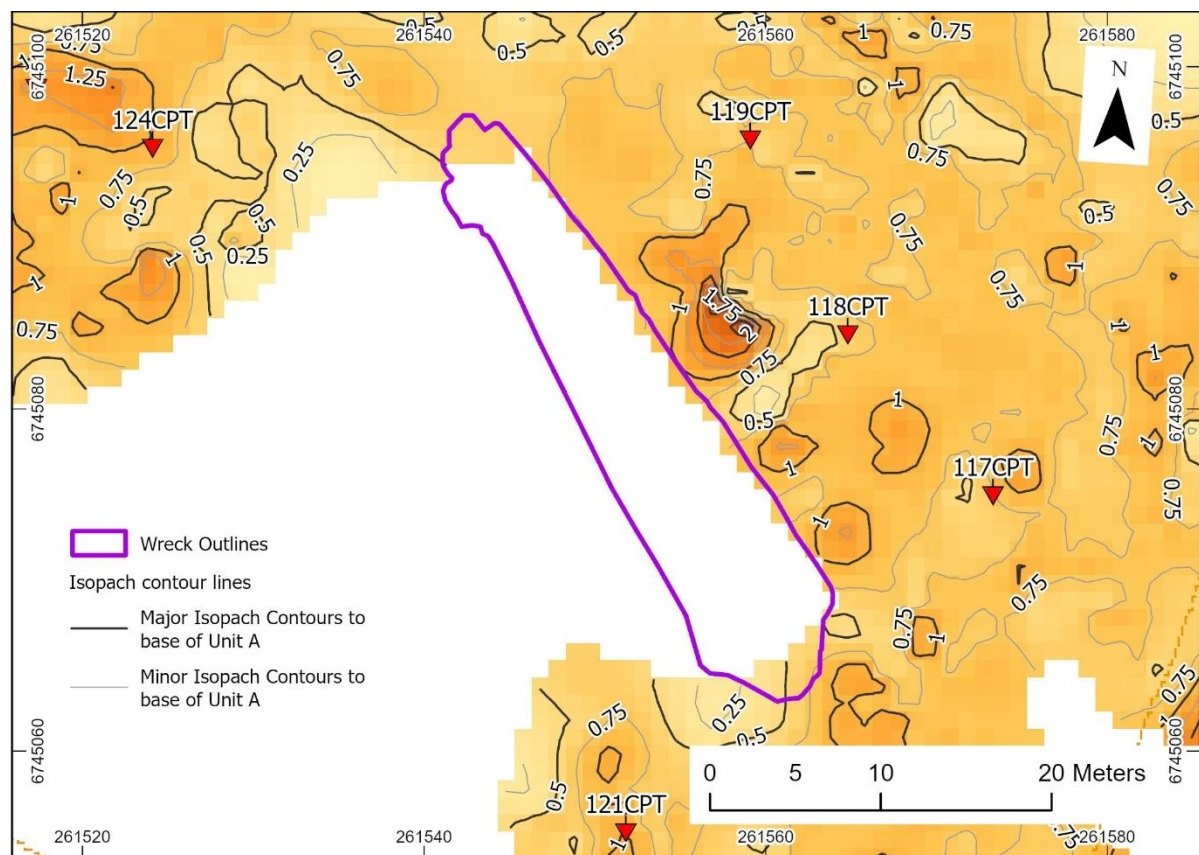


Figure 4-10 Isopach showing bedrock depth below surface at the stern section

On the eastern side of the bow section, acoustically transparent sediments were visible below the seabed. A weak irregular reflector underneath has been interpreted to be top of the bedrock. Sediment thickness in this area varies from less than 3 m up to 5 m (Figure 4-11 and Figure 4-12). To the west of the bow section, no sediments or bedrock reflectors were identified, and no CPT data was available in that area. Noisy data, in some of the survey lines, complicated the interpretation and may have affected the results.

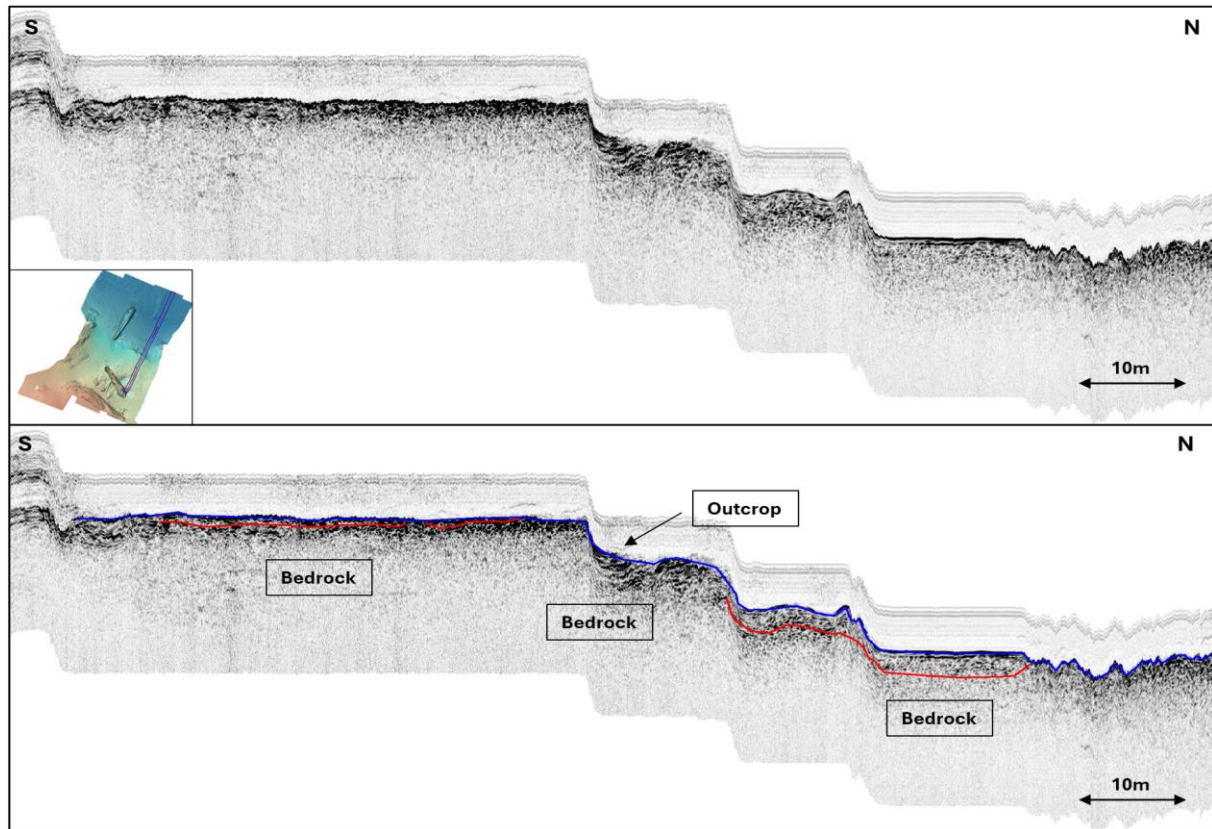


Figure 4-11 Sub-bottom profiler data example from Line SBP_Geo_Bow_M_055. The vertical drops in the seabed are motion-induced artifacts from ROV movements

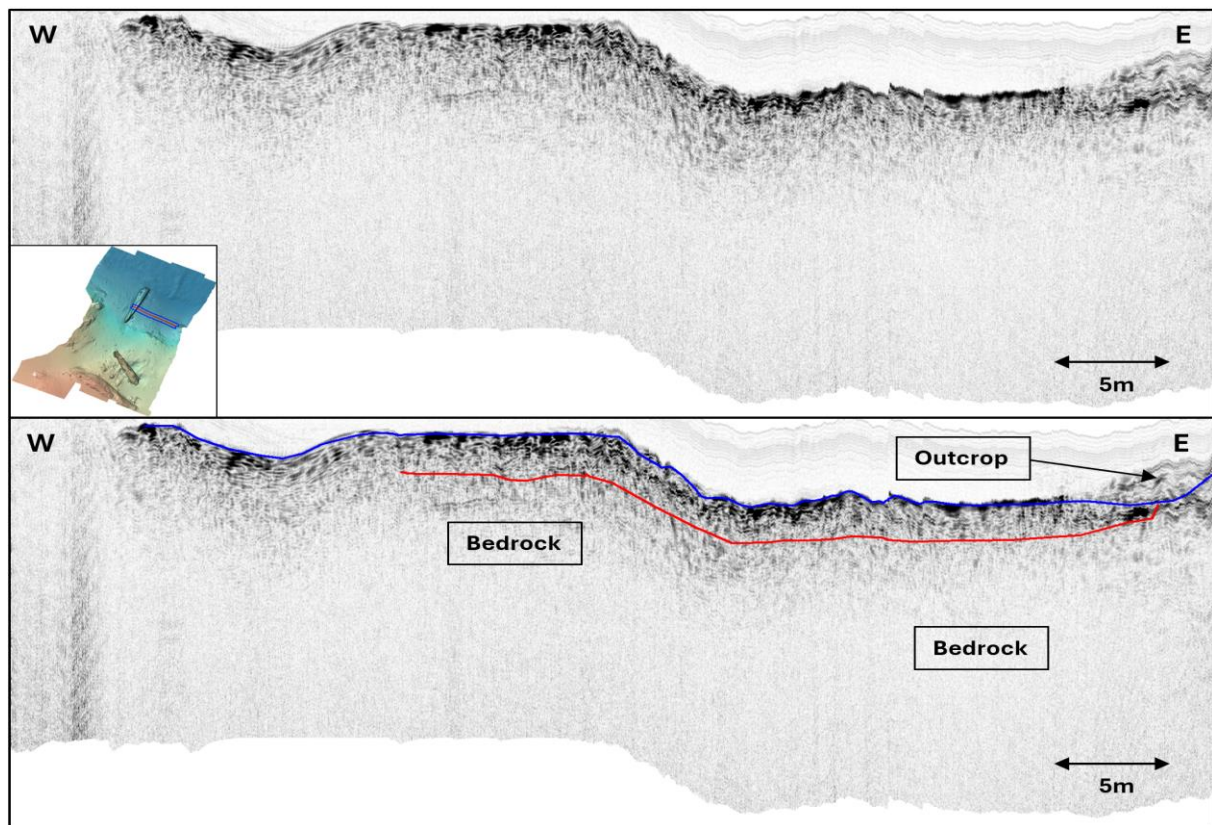


Figure 4-12 Sub-bottom profiler data example from Line SBP_Geo_Bow_X_045b

Several CPTs were taken in the area northeast of the stern wreck. Combined with irregular reflectors, the sediment thickness in this area was estimated between 1 m and 2 m (Figure 4-13 and Figure 4-14). A prominent bedrock slope is located 15 m southwest of the stern wreck. Acoustic interference from the wreck and debris between the outcrop and the wreck prevented any interpretation in this area.

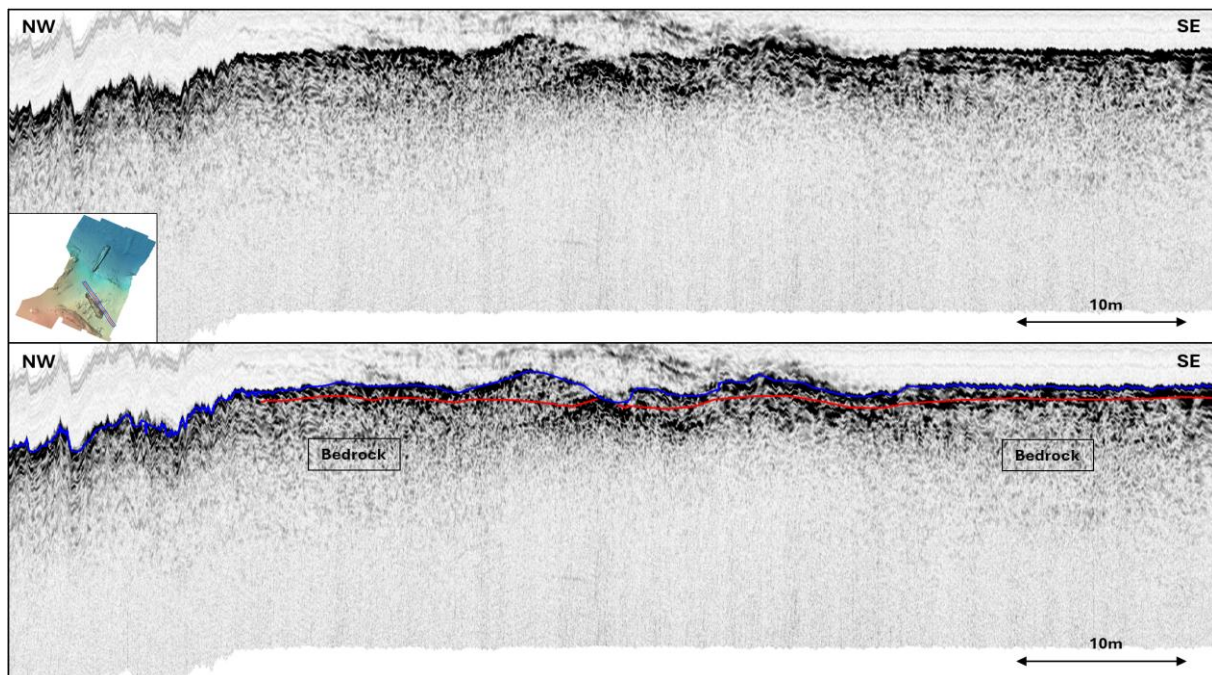


Figure 4-13 Sub-bottom profiler data example from Line SBP_Geo_Stern_M_021

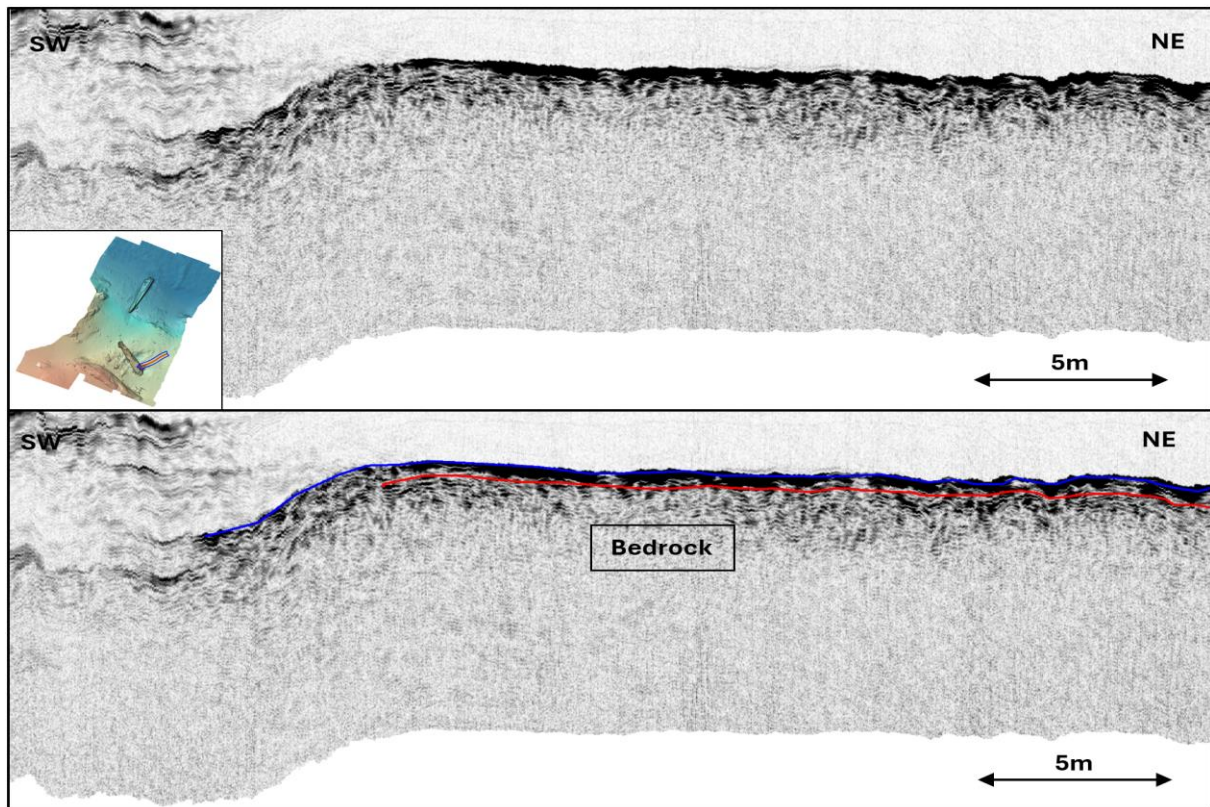


Figure 4-14 Sub-bottom profiler data example from Line SBP_Geo_Stern_X_040b

A tilted sub-bottom profiler survey was conducted to estimate the burial depth of the keel and the distance to bedrock directly under the wreck pieces. The tilted transducer increased the already wide opening angle, resulting in increased interference from surrounding objects. This was particularly noticeable close to the wreck, where interference from the hull distorted the data. The data acquired during the tilted SBP survey did not provide any results that could be further used to interpret the seabed nor the position of the keel. Figure 4-15 and Figure 4-16 display examples from the tilted SBP survey. Note how the images become more distorted on the western and northeastern sides due to the wreck.

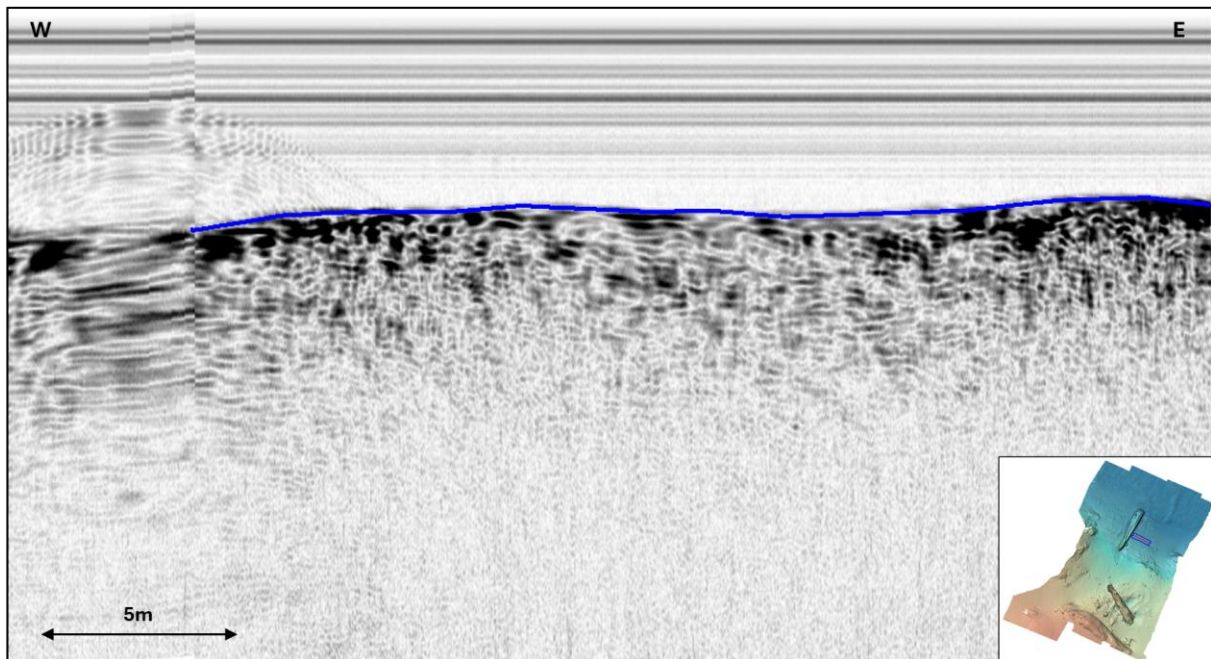


Figure 4-15 Sub-bottom profiler data example from Line SBP_Tilt_Bow_P_04 Note the hyperbolic shape on the western side, masking the seabed below

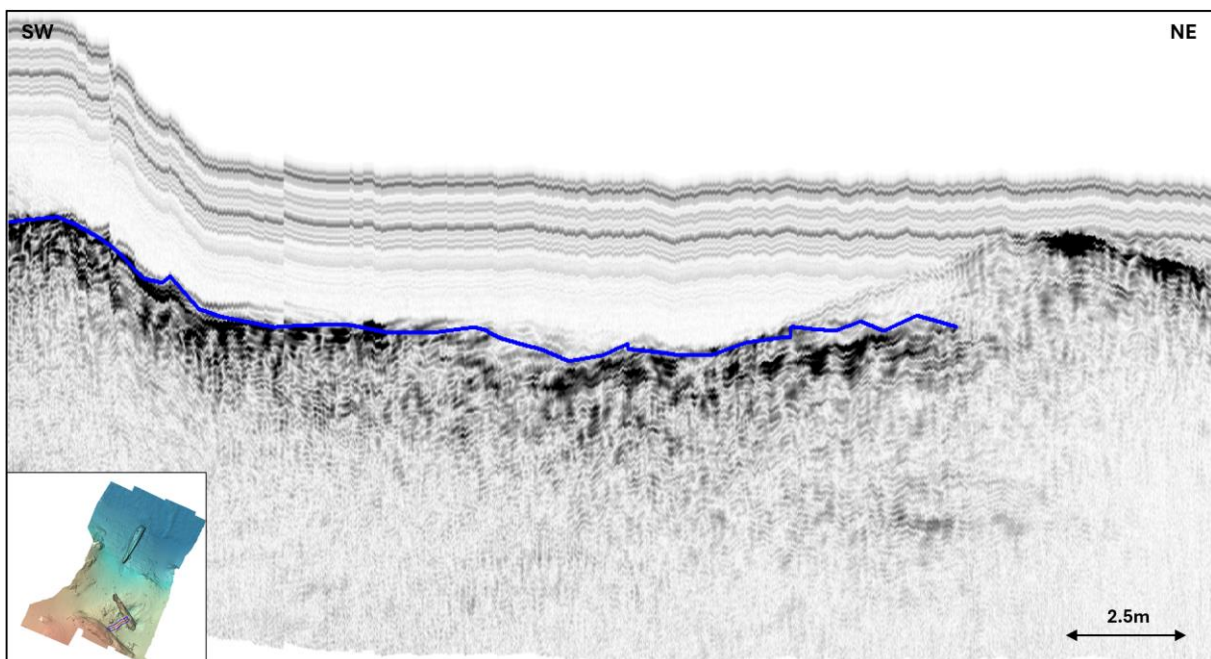


Figure 4-16 Sub-bottom profiler data example from Line SBP_Tilt_Stern_P_06

4.2 ELECTROMAGNETIC SURVEY

Two electromagnetic surveys were conducted to detect any potential buried mercury canisters within the survey area. The surveys consisted of a TSS 440 system and a Elwave Octopulse system. The TSS 440 system measures the magnetic field, and anomalous readings appear as spikes in the data. The Octopulse system measures the impedance of the seabed and will register significant changes in the signal as anomalous readings, which could correspond to mercury canisters.

4.2.1 TSS 440

During the surrogate item trial, it was established that the expected magnetic field from a mercury canister ranged between 40 nT and 2500 nT, depending on the height above the canister. Any buried canister would register a significantly lower magnetic field than a canister on the surface. The large range in magnetic field, found during the SIT, presented a challenge considering any signal between that range could represent a canister. Given that the area was cluttered with other debris on the surface and below, producing similar signatures, it was not possible to distinguish mercury canisters without visual confirmation.

Another challenge during the TSS 440 survey was the high magnetic interference from the wreck itself and its masking effects on the survey lines closest to the wreck. The magnetic signature from the wreck primarily impacted survey lines closest to the wreck (within 3 m) before being reduced further away. Readings up to 99999 nT were recorded during the survey, caused by the outer hull of the wreck. Examples from line TSS 440_EM_Bow_030 (Figure 4-17) and line TSS 440_EM_Stern_014 (Figure 4-18), display profile view of the magnetic field where the signal is responding to the wreck itself. It should be noted that the maximum recorded magnetic field may represent the upper limit of the system and not the actual reading from the hull.

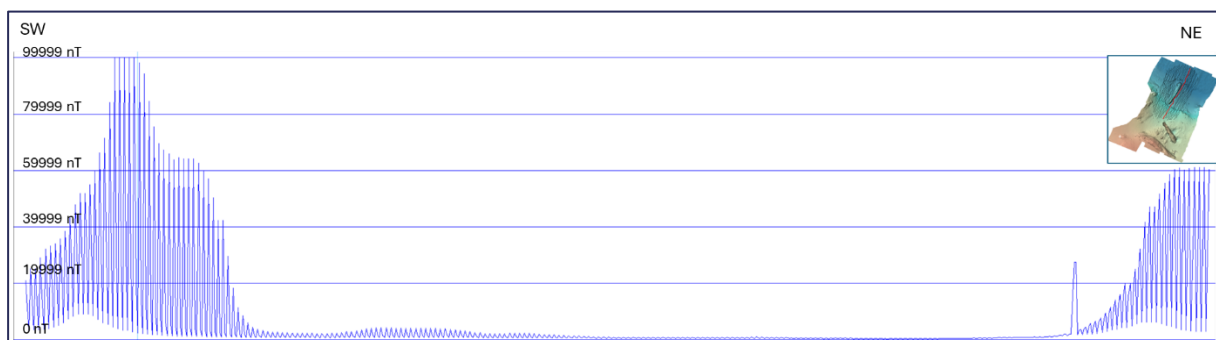


Figure 4-17 TSS 440 data example from line TSS 440_EM_Bow_030_20250226_0220 highlighting the maximum value recorded

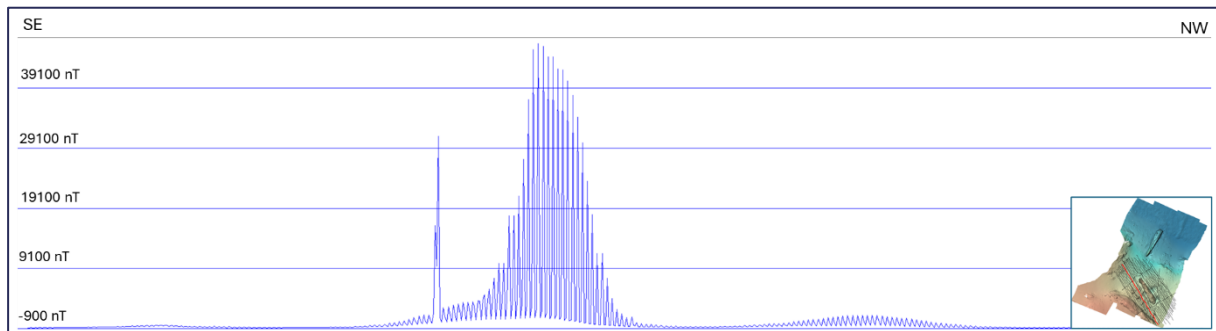


Figure 4-18 TSS 440 data example from line SS440_EM_Stern_014_20250225_2231

Figure 4-19 displays the magnetic field grid with approximate maximum and minimum values. Within this range, only a few anomalies are seen, and all can be correlated to large pieces of debris on the surface. In order to get a more realistic representation from the magnetic field grid, the data was limited to only include results between -40 nT and 2500 nT (Figure 4-20).

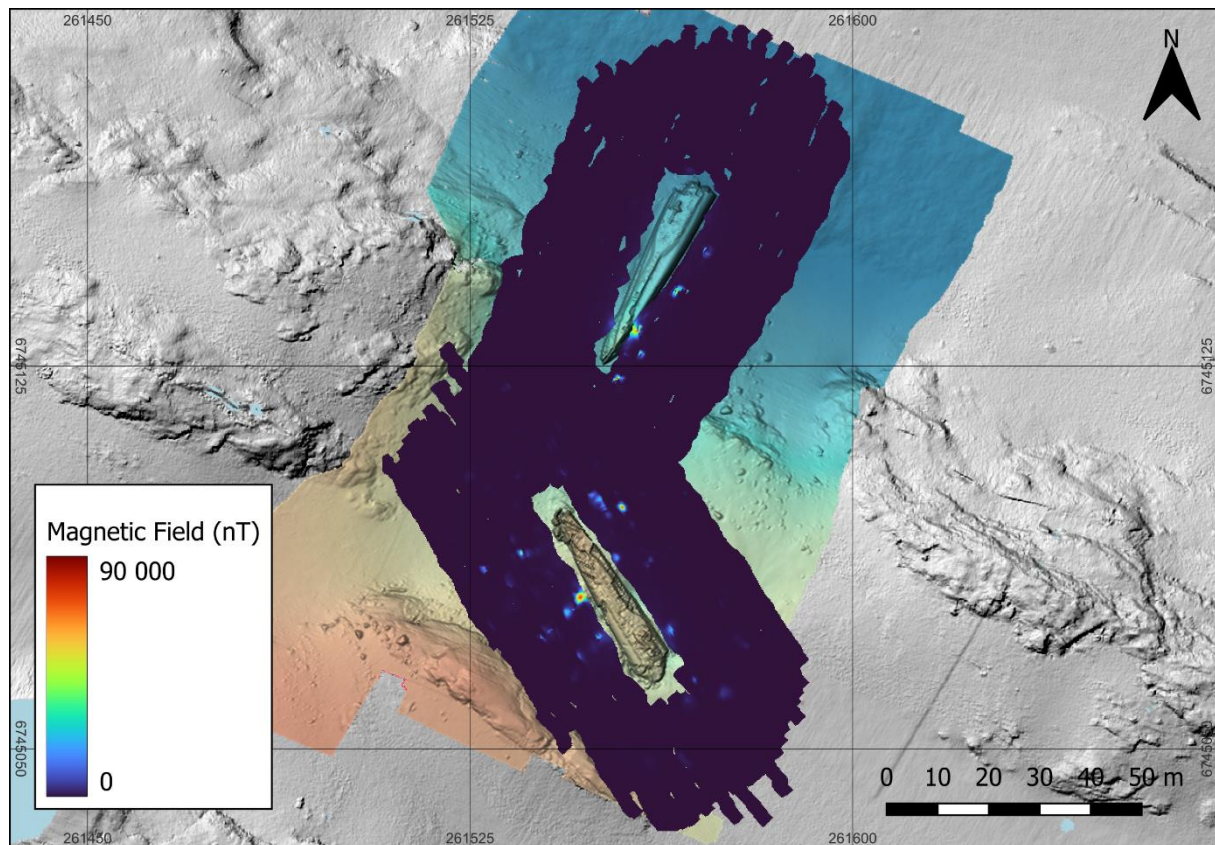


Figure 4-19 TSS 440 magnetic field grid showing approximate max and min values

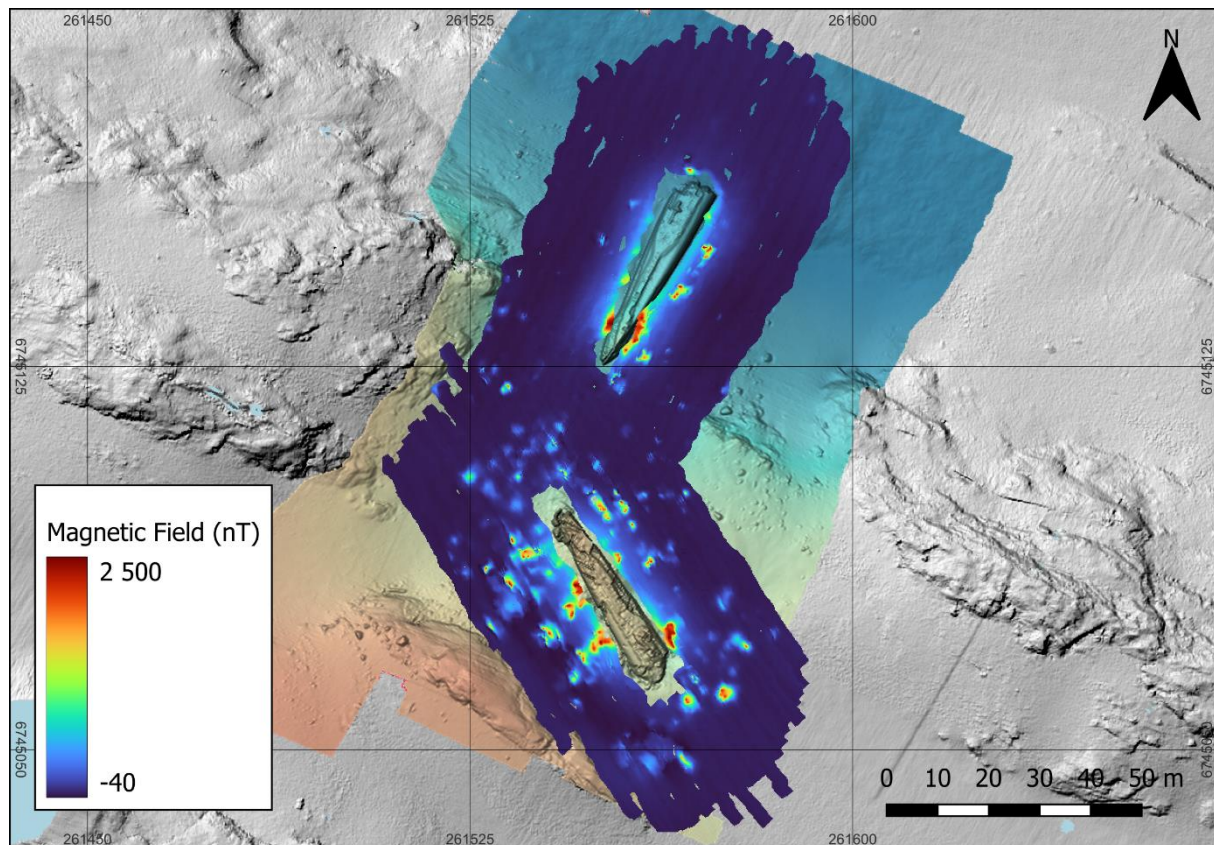


Figure 4-20 TSS 440 data clipped to only incorporate magnetic field signal between -40 nT and 2500 nT

However, even with the reduced signal range, magnetic masking caused by the larger pieces of debris and the hull of the wreck, still affected the data. Figure 4-21 shows an example where the range of the magnetic field interval is set between 0 nT and 300 nT. More anomalies are enhanced, however, the magnetic field surrounding the wreck masks any potential targets up to 4 m away from the hull.

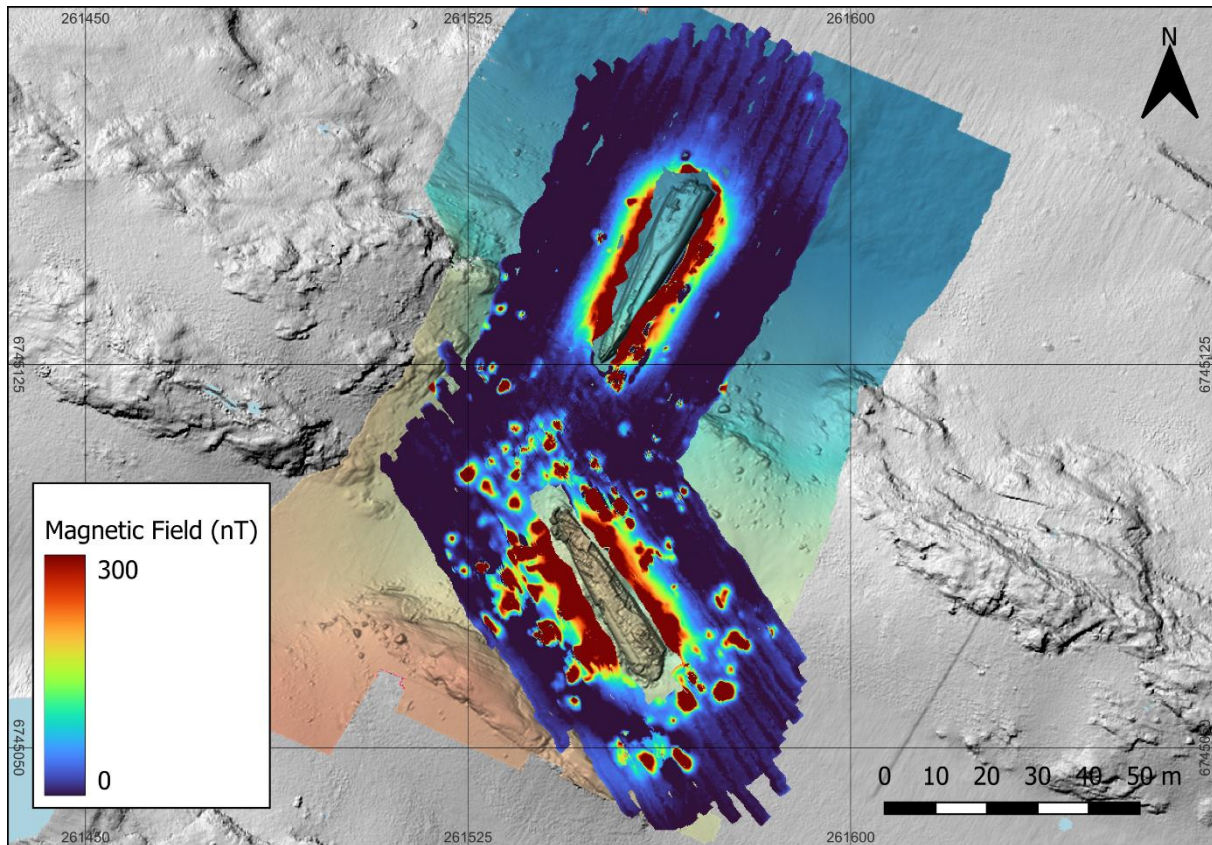


Figure 4-21 TSS 440 heatmap with reduced magnetic range showing large masking area from the bow wreck

Due to the high frequency of debris and the large magnetic range detected by the TSS, the resulting data could not identify any new targets with certainty. Almost all the anomalies detected by the TSS 440 could be correlated to previously identified targets and new anomalies could be identified as surface debris. Figure 4-22 displays an example where a magnetic anomaly was observed away from any previously identified targets. The magnetic signal was within the range of a mercury canister, however, the video confirmed that the target did not match the expected shape of a mercury canister (Figure 4-23).

It is important to understand that this does not exclude the existence of mercury canisters below the seabed. It is far more likely that their signal is either masked by a surface target or that the canister is buried deeper than 1 m. From the surrogate trial, it was established that the signal is greatly reduced as the distance from target to the sensor is increased. At the outer boundaries of the survey area, the magnetic field was found to be close to 0 nT. This indicates that there are no targets further away from the bow and stern sections. In addition, the seabed further away from the wreck pieces shows a more featureless seabed which indicates that debris and canisters are not present on the surface. It cannot be determined if there are any buried targets further away from the wreck without additional surveying.

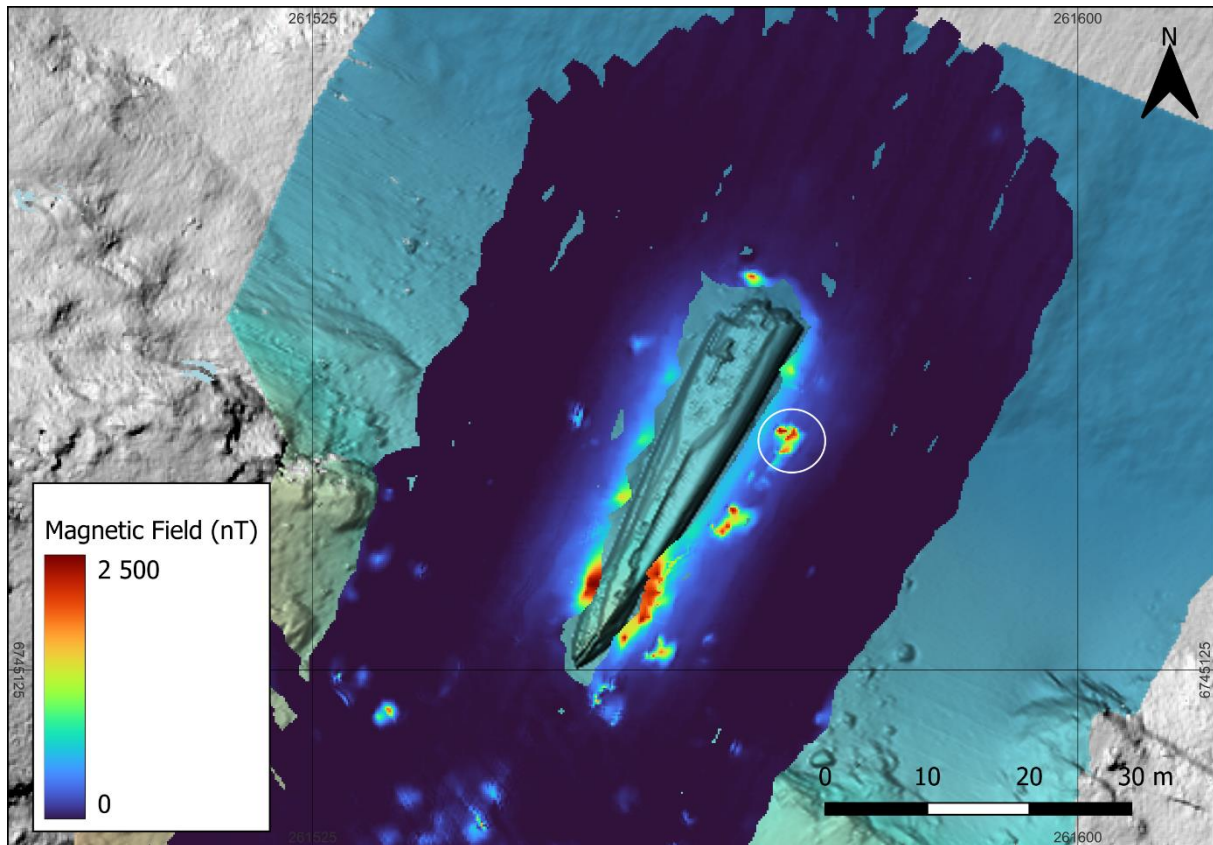


Figure 4-22 Possible new magnetic anomaly



Figure 4-23 Video image of the magnetic anomaly. It is most likely some debris

4.2.2 OCTOPULSE

Considering the SIT did not result in the direct detection of the mercury canister, a historic survey with a similar target signature was used for detection limitations. The target that was used to establish the detection range was a 155 mm steel artillery projectile with a length and diameter of 680 mm and 163 mm respectively. Based on the projectile, the following detection levels were established (Table 4-3).

Table 4-3 Canister Detection Levels

Level of Detection	Normalized Impedance Modulus of an Active Dipole	Target Type
A01	1.10^{-3} & Detection on other sensors	Probable canisters
A02	1.10^{-3}	Probable canisters
A03	5.10^{-4}	Possible target
A04	-	Isolated targets (not conductive)

Based on the derived detection levels and the calculated impedance grids (Figure 4-24 and Figure 4-25), a total of 149 electrical anomalies were revealed (Figure 4-26). 103 of the targets were also classified as conductive anomalies. 15 of these fall within A01 or A02, indicating that they have a similar signature as a mercury canister.

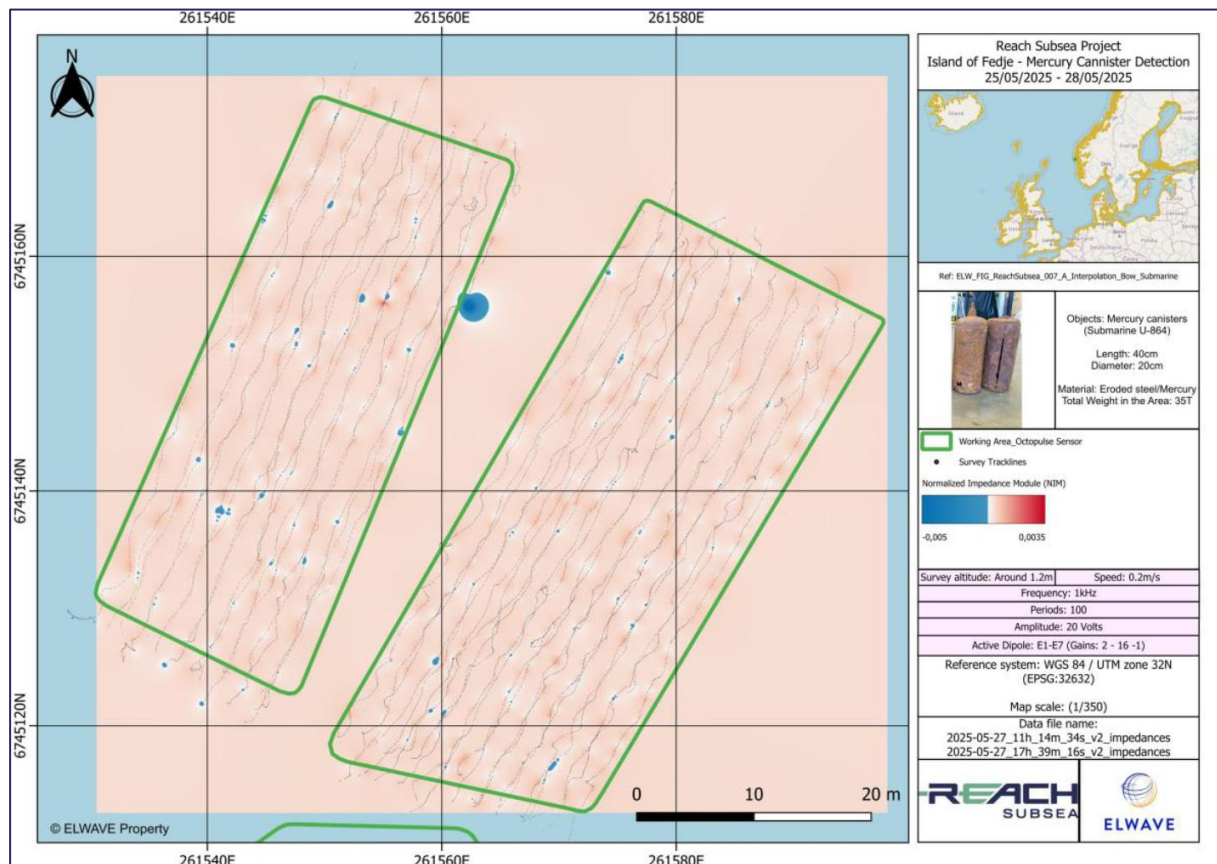


Figure 4-24 Normalized impedance module for the bow wreck

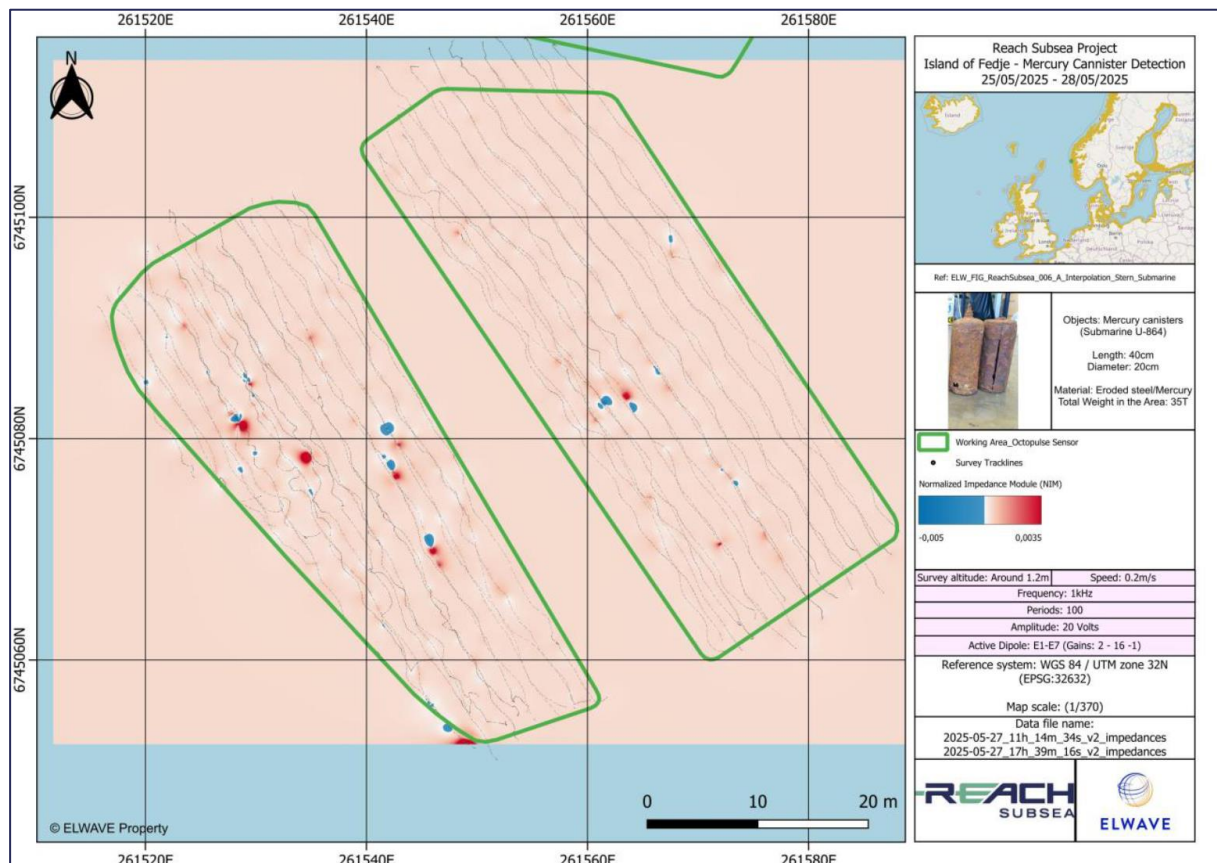


Figure 4-25 Normalized impedance modul for the stern wreck

For the stern section, the targets found by the Octopulse system match relatively well with the results from the TSS 440 survey. The results are consistent with the significant number of debris that is found around the wreck. However, potential targets are more likely a result of a piece of metal debris rather than a canister.

For the bow section, there is a bigger deviation from the TSS 400 survey. The Octopulse system was able to detect multiple individual targets, whereas the TSS could only differentiate a few from the magnetic signal of the wreck. It should be noted that most of the targets identified around the bow section of the wreck fell within the A03 category. Additionally, the area, particularly the starboard side, is characterized by large boulders, which may have impacted the performance of the Octopulse system.

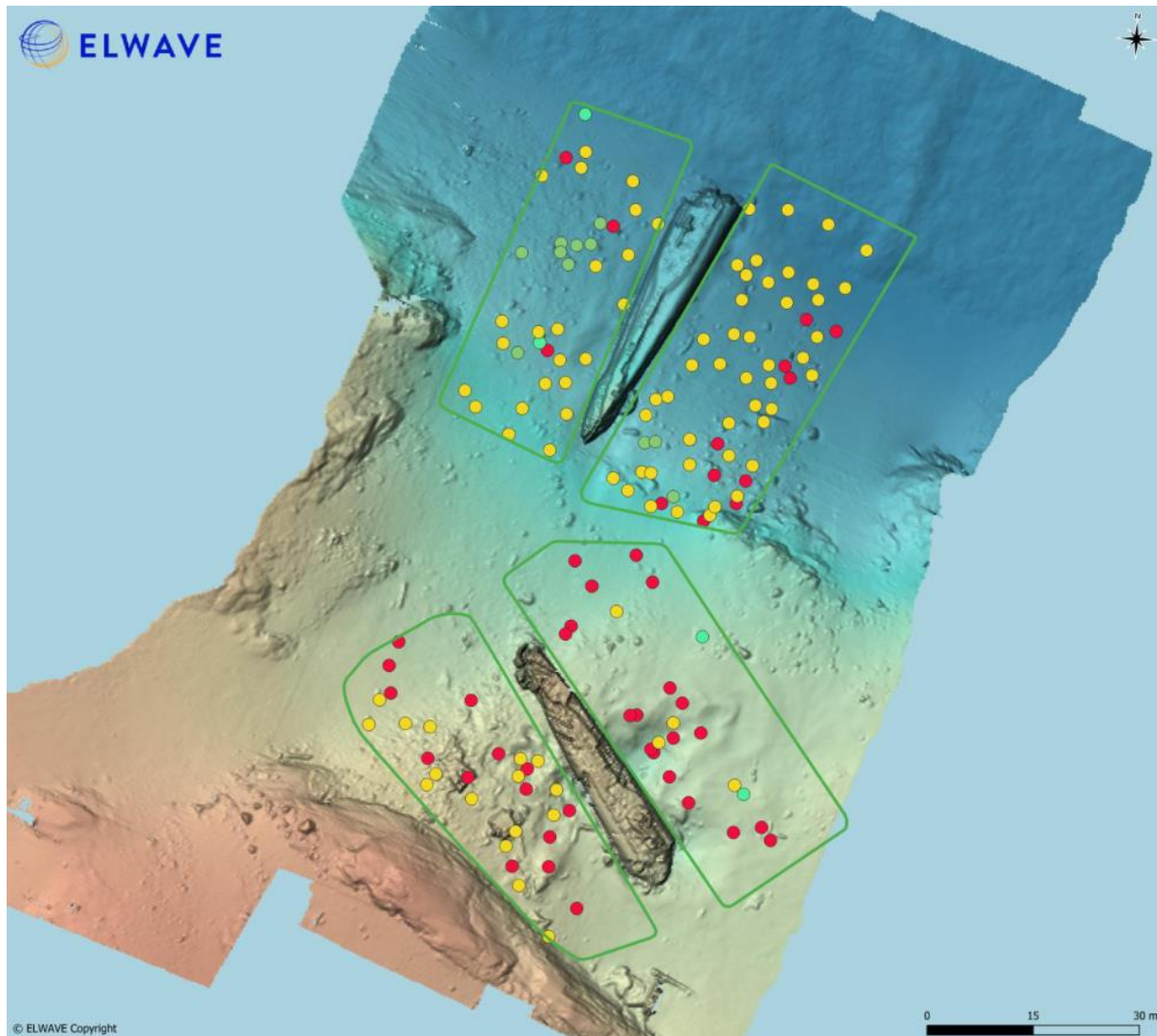


Figure 4-26 All targets detected by the Octopulse system. Bright green represents A01, green represents A02, yellow represents A03, and red represents A04 (not conductive)

The results from the Octopulse system were processed and interpreted by Elwaves's own inhouse team. Further details are found in their report (Appendix D).

4.3 VIDEO SURVEY

The visual survey of U-864 consisted of an external general visual inspection (GVI), internal lance camera survey and a debris survey. The aim of the external GVI survey was to confirm any dangers to the ROV for the geophysical and visual surveys. In addition, the external GVI was performed to identify any points of interest for the internal video survey with the lance cameras and the overall conditions of the wreck. The aim of the lance camera survey was to get an overview of the wreck's interior, and if possible, identify torpedoes in the torpedo bay and assess their condition. Another objective of the internal inspection was to obtain an overview of the overall conditions inside the wreck in case further investigations are needed for future inspections. Sedimentation levels within the wreck were of special interest. The visual inspection report is presented in Appendix E.

4.3.1 EXTERNAL VISUAL INSPECTION

During the external visual inspection, two passes were conducted across each accessible face of the wreck sections, providing complete coverage from the seabed to the top of the outer hull. The main objectives of the external video inspection were to determine the overall conditions of the hull, identify areas of interest for internal inspection and see if the bow section hatch to the torpedo bay was open.

As expected, the wreck was corroding freely with certain areas exhibiting more advanced degradation for reasons unknown. The corrosion and marine growth on the wreck made it very difficult to even identify the locations where the previous thickness measurements had been performed. Figure 4-27 and Figure 4-28 display examples of the corrosion and marine growth observed during the inspection of U-864.



Figure 4-27 Voyis image example showing the deck canon covered with marine growth

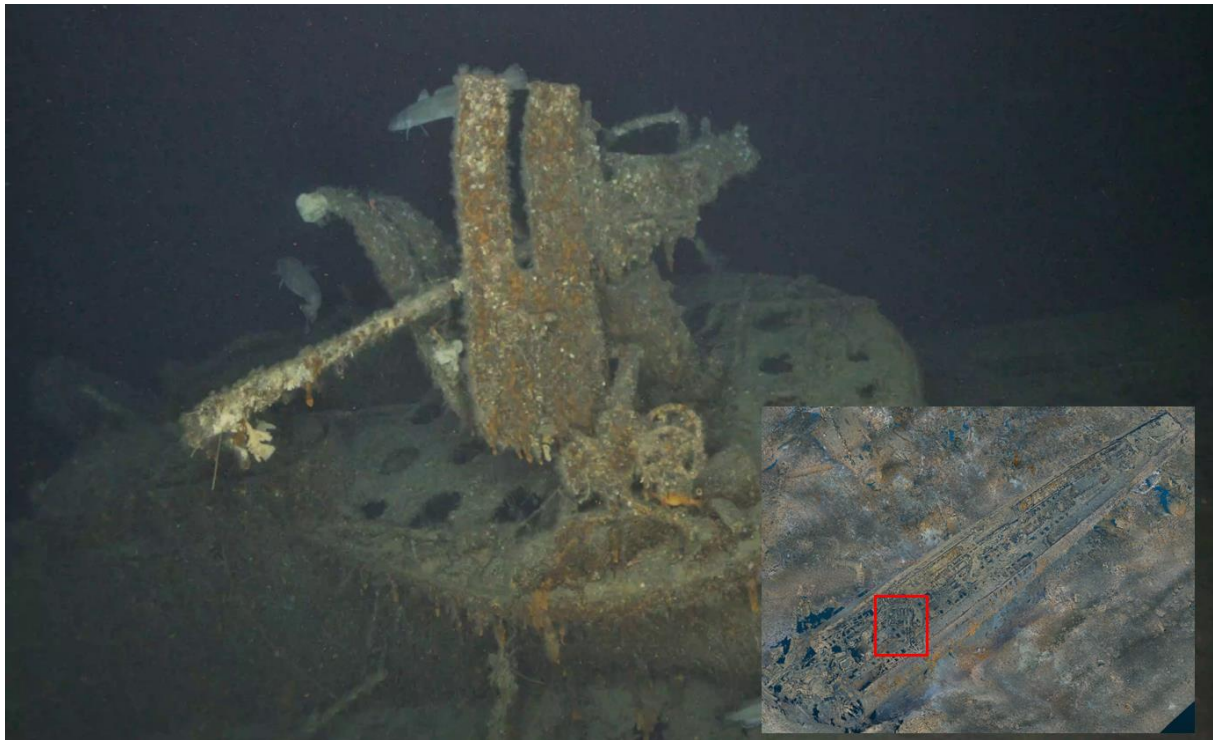


Figure 4-28 Voyis image example showing the 20 mm flank gun covered with marine growth

The visual inspection of the bow section revealed that the wreck has undergone significant corrosion. Several panels were missing from the hull on the port side, exposing compartments on the hull (Figure 4-29 and Figure 4-30). The starboard side was more or less intact with a few minor panels missing at the front of the wreck (Figure 4-31). The anchor can still be seen on the starboard front side (Figure 4-32).

The bow fracture point showed significant damage and was heavily littered with debris. Sediments could be seen on the inside of the wreck, covering a significant part of the submarine base. Access for internal inspection was difficult due to the debris and a possible gas cylinder on the top of the wreck. An example of the fracture point is seen in Figure 4-33.

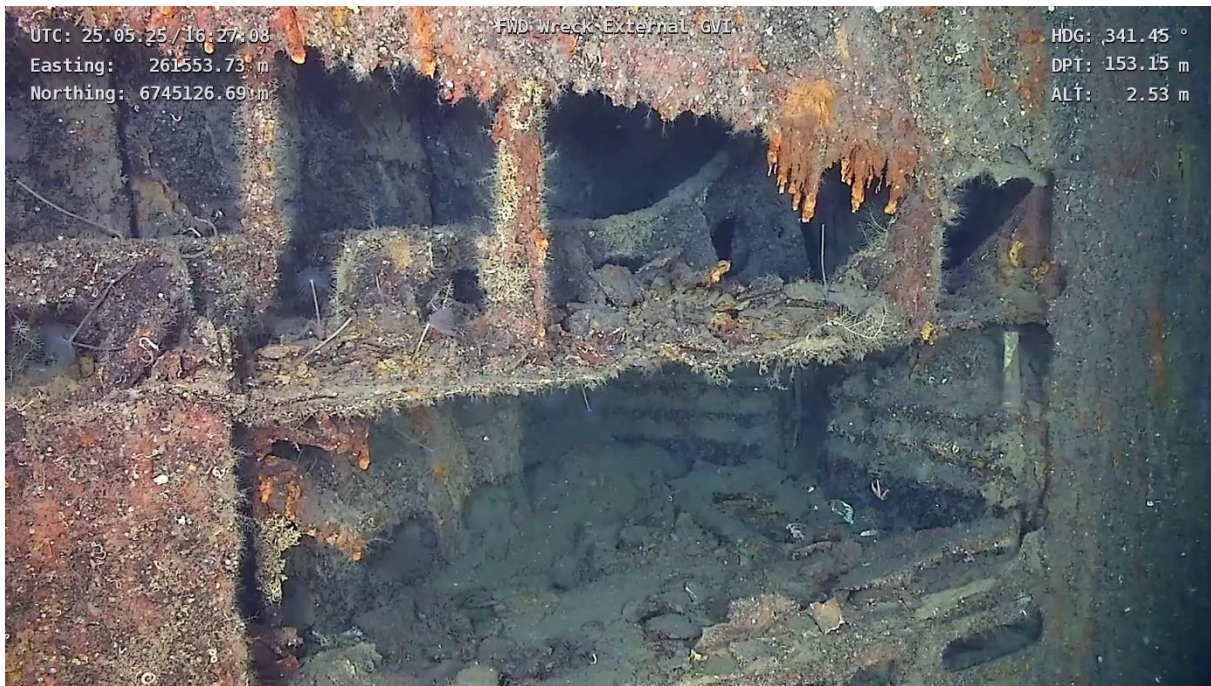


Figure 4-29 Missing panel on the front port side



Figure 4-30 Port side view of the bow section showing missing panels at the front



Figure 4-31 Starboard side view of the bow section showing that the side is mostly intact. Note the location of the anchor within the red square.

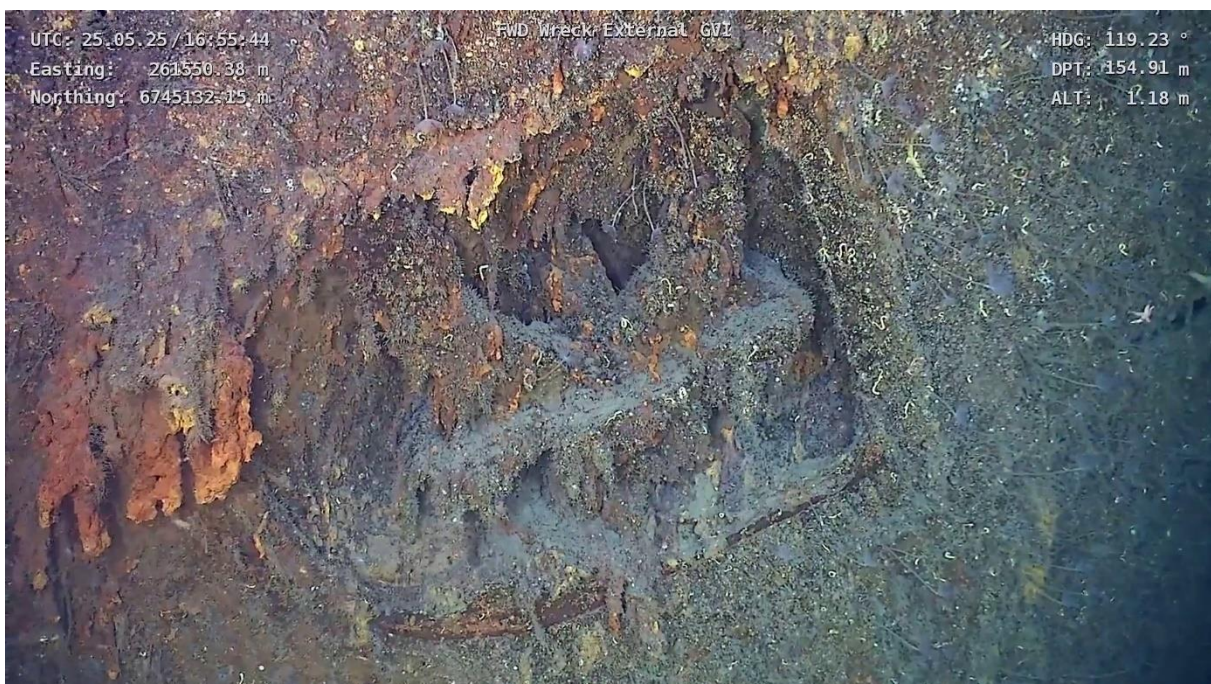


Figure 4-32 Starboard side anchor still intact



Figure 4-33 Bow section fracture point showing damages. Significant sedimentation is seen within the opening

Similar to the bow section, the stern was found to be heavily corroded and multiple steel panels from the outer hull were missing (Figure 4-34 and Figure 4-35). The most notable area was found on the starboard side, close to the propellers, where a large piece of the hull had detached. The cut-out location to the stern torpedo bay is located within that area (Figure 4-36).



Figure 4-34 Port side view of the stern section

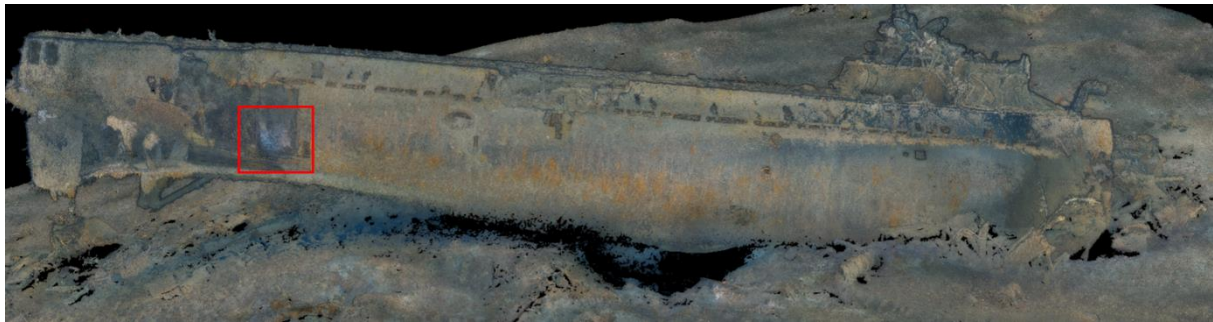


Figure 4-35 Starboard side view of the stern section. Note the small light-coloured area, within the red square, where the cut-out opening to the torpedo bay is located

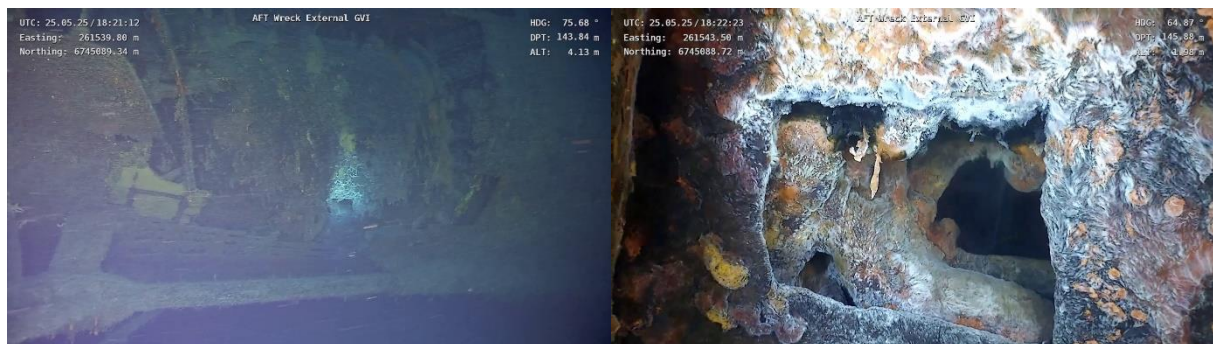


Figure 4-36 Location of the cut-out to the torpedo bay

The back of the stern wreck was mostly detached and fallen to the seabed, exposing the torpedo tubes. The tubes were obstructed by a significant amount of small metallic debris from the wreck itself. The propellers and rudders were found to still be in place and appearing to be relatively securely attached to the wreck (Figure 4-37). The fracture point at the stern section was difficult to access due to the inclination of the wreck. The entrance had significant damage and was riddled with debris. An example of the significant damage to the fracture point is the missing conning tower. Figure 4-38 shows that the security hatch, from the submarine to the conning tower, is exposed.



Figure 4-37 Back of the stern section showing the rear torpedo tubes



Figure 4-38 Securing hatch for the entrance of the missing conning tower close to the fracture point

4.3.2 DEBRIS SURVEY

As a part of the survey, video footage was thoroughly reviewed. The main objective was to identify any new debris on the seabed, with particular focus on detecting potential mercury canisters and other cylindrically shaped debris. As this was not a dedicated debris survey, the focus was not on identifying new pieces of debris, but rather on locating larger and more significant debris that could either be canisters or pose a potential hazard to future operations. The potential new targets observed during the video inspection were compared against target lists from surveys conducted in 2005 and 2013. The historic targets are presented in Appendix F.

During the video and photogrammetry review, nine previously unregistered targets were identified (Figure 4-41 - Figure 4-57). None of the new targets were identified as mercury canisters. Details are presented in Table 4-4 and an overview of their locations is displayed in Figure 4-39 and Figure 4-40.

Table 4-4 New Targets

Target ID	Easting (m)	Northing (m)	Length (m)	Width (m)	Height (m)	Comment
1	261553.454	6745087.356	0.62	0.32	0.32	Hollow cylinder object
2	261548.167	6745064.049	1.36	0.40	0.40	Canister with open lid
3	261541.983	6745068.199	3.50	0.50	0.50	Large cylindrical container
4	261564.163	6745089.290	0.67	0.20	0.20	Partially buried container
5	261570.618	6745147.429	0.25	0.26	0.10	Cylindric debris, mostly buried
6	261555.841	6745141.880	3.80	0.70	0.20	Metal sheet
7	261567.121	6745143.297	1.43	0.55	0.50	Debris part of the submarine
8	261555.024	6745127.535	1.45	0.65	0.20	Metal sheet

Target ID	Easting (m)	Northing (m)	Length (m)	Width (m)	Height (m)	Comment
9	261555.160	6745125.821	2.85	0.55	0.10	Metal sheet

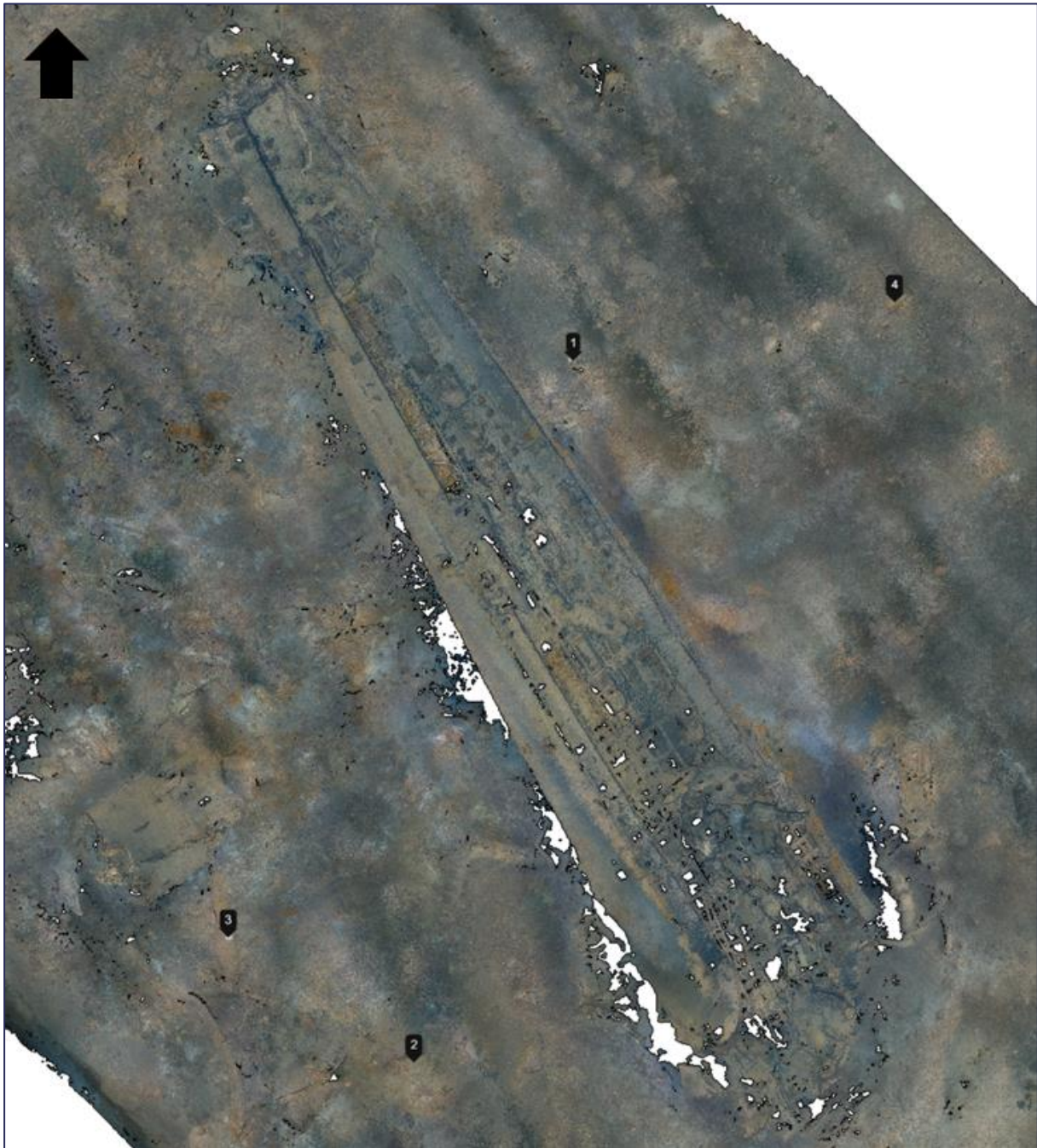


Figure 4-39 Overview of the locations for targets 1-4



Figure 4-40 Overview of the locations for targets 5-9



Figure 4-41 Target ID 1



Figure 4-42 Target ID 1 from photogrammetry model



Figure 4-43 Target ID 2

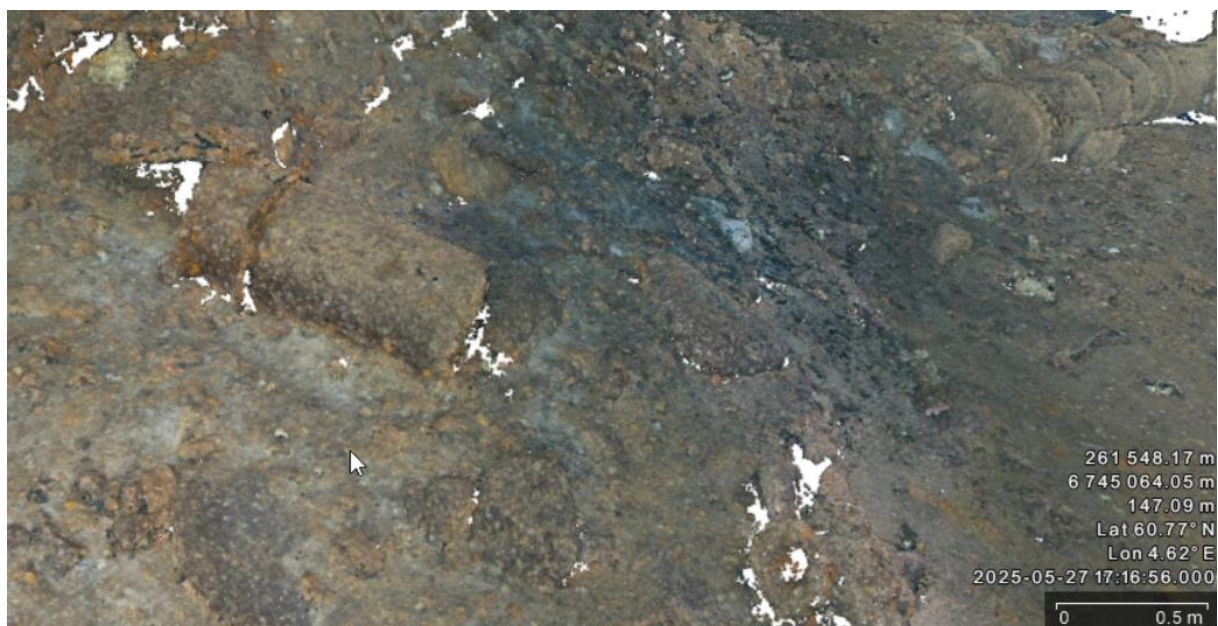


Figure 4-44 Target ID 2 from photogrammetry model



Figure 4-45 Target ID 3



Figure 4-46 Target ID 3 from photogrammetry model



Figure 4-47 Target ID 4 from photogrammetry model



Figure 4-48 Target ID 5



Figure 4-49 Target ID 5 from photogrammetry model



Figure 4-50 Target ID 6

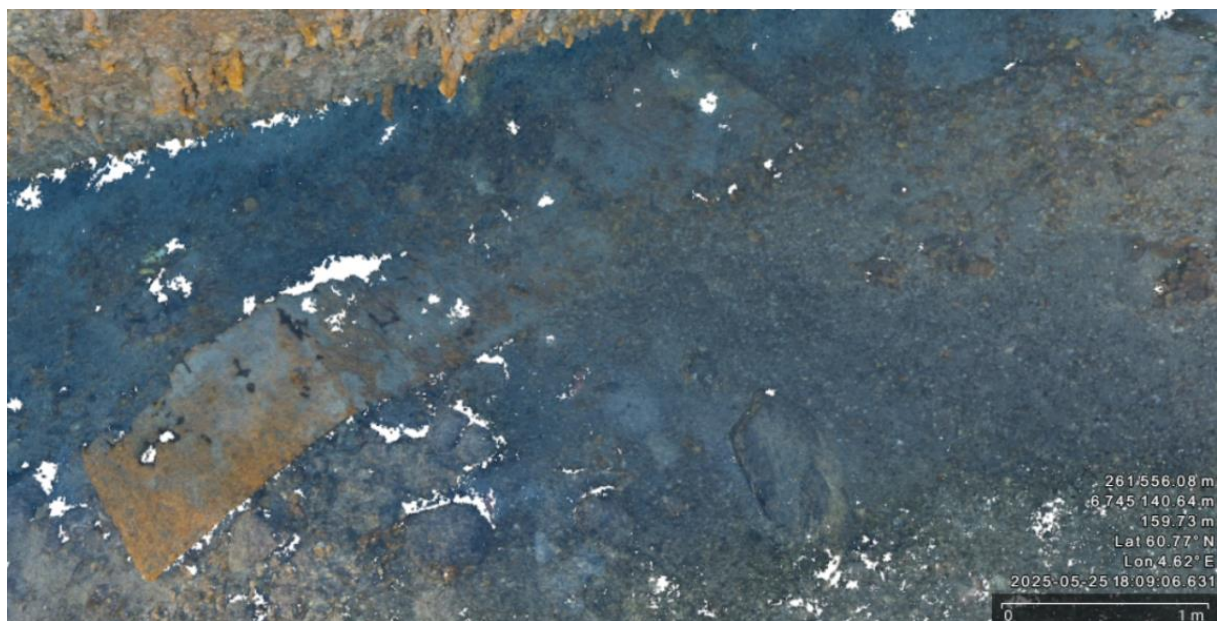


Figure 4-51 Target ID 6 from photogrammetry model



Figure 4-52 Target ID 7



Figure 4-53 Target ID 7 from photogrammetry model

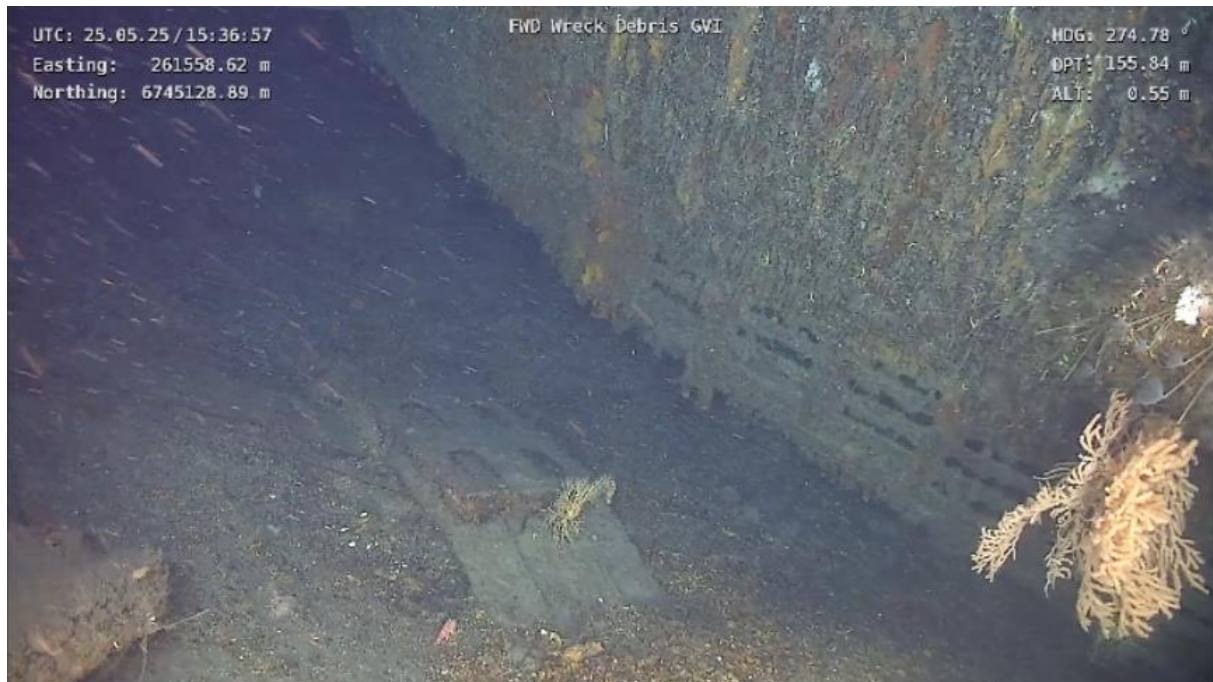


Figure 4-54 Target ID 8



Figure 4-55 Target ID 8 from photogrammetry model



Figure 4-56 Target ID 9



Figure 4-57 Target ID 9 from photogrammetry model

4.3.3 INTERNAL VISUAL INSPECTION

The main objective of the internal video inspection to get an overview of the internal structure of the wreck sections at two different locations. The main tasks included;

- Sediment build-up inside the wreck
- Potential debris/hazards;
- Hatch to torpedo bay on bow section
- Previous cut-out

During the external inspection, the hull was examined for any points of access for further internal inspection with a lance camera.

At the bow section, only the fracture point was selected for internal inspection, as no other points of interest were possible to investigate with the lance camera. The main purpose of the internal inspection of the fracture point was to determine if the hatch to the torpedo bay was open and potentially inspect any torpedoes remaining inside. Figure 4-58 displays the opening at the fracture point where the internal inspection took place.

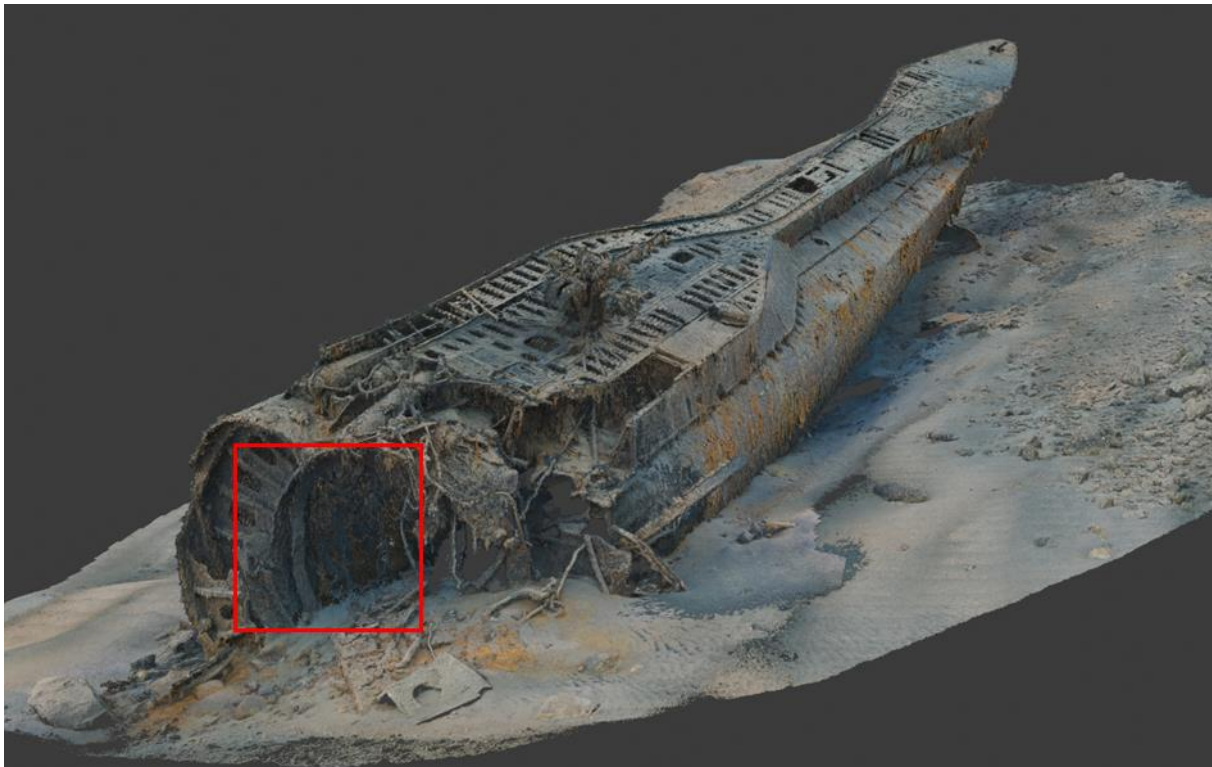


Figure 4-58 Photogrammetry data example showing the bow fracture point. The red square shows where the internal inspection was conducted

Internal access to perform the internal inspection was limited due to debris blocking the opening (Figure 4-59). This made it difficult for the ROV to get close enough to the opening to get a good view of the inside. The lance camera was extended 2 m into the fracture point from where the ROV stopped. Figure 4-60 shows how the lance camera is held by the ROV manipulator and then extended into the wreck.

The inside of the wreck showed significant damage and was covered by sediments. The sediments reduced the ability to identify any key points (Figure 4-61). The lack of proper lighting, in combination with the internal damage, made it difficult to get a clear image from the lance camera (Figure 4-62). Consequently, the inspection could not confirm if the hatch to the torpedo bay was open, nor was it possible to investigate the potential for torpedoes inside.

In order to get a better view of the insides of the fracture point a much smaller ROV would be required. However, debris blocking the path would make safe navigation difficult, with a high risk of damage or loss; therefore, it is not recommended.



Figure 4-59 Video image from the bow fracture point showing debris blocking the entrance



Figure 4-60 Video image showing the lance camera extended into the bow fracture point

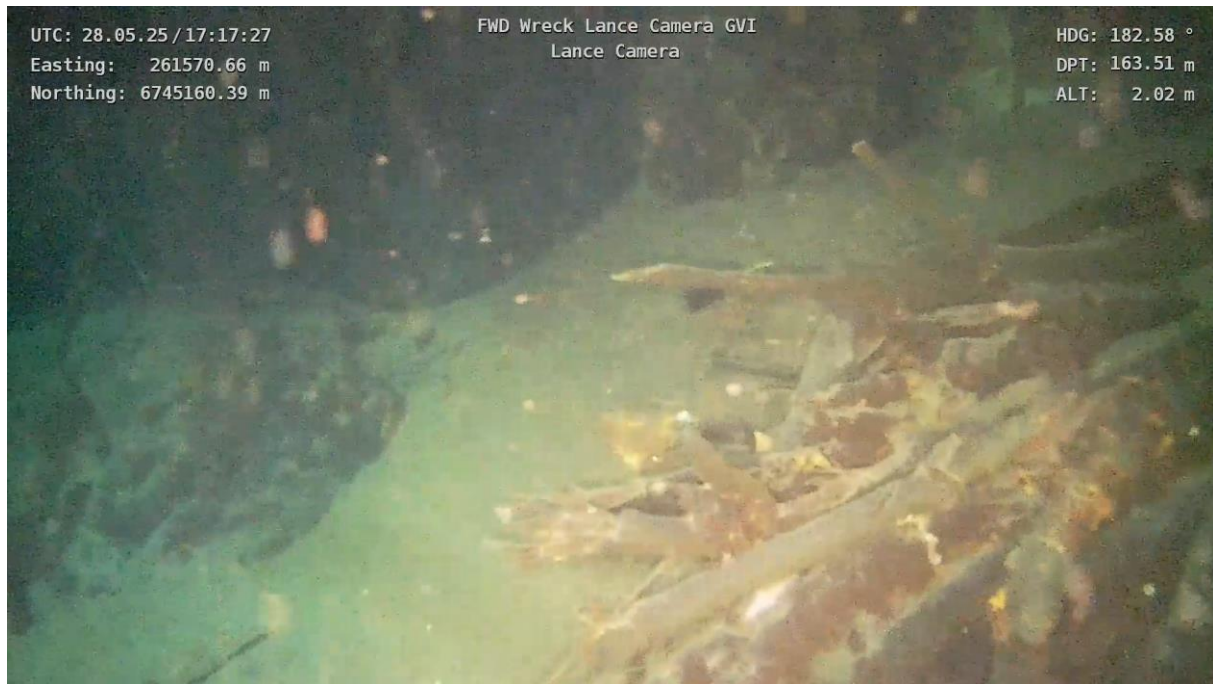


Figure 4-61 Lance camera example showing sediments within the wreck

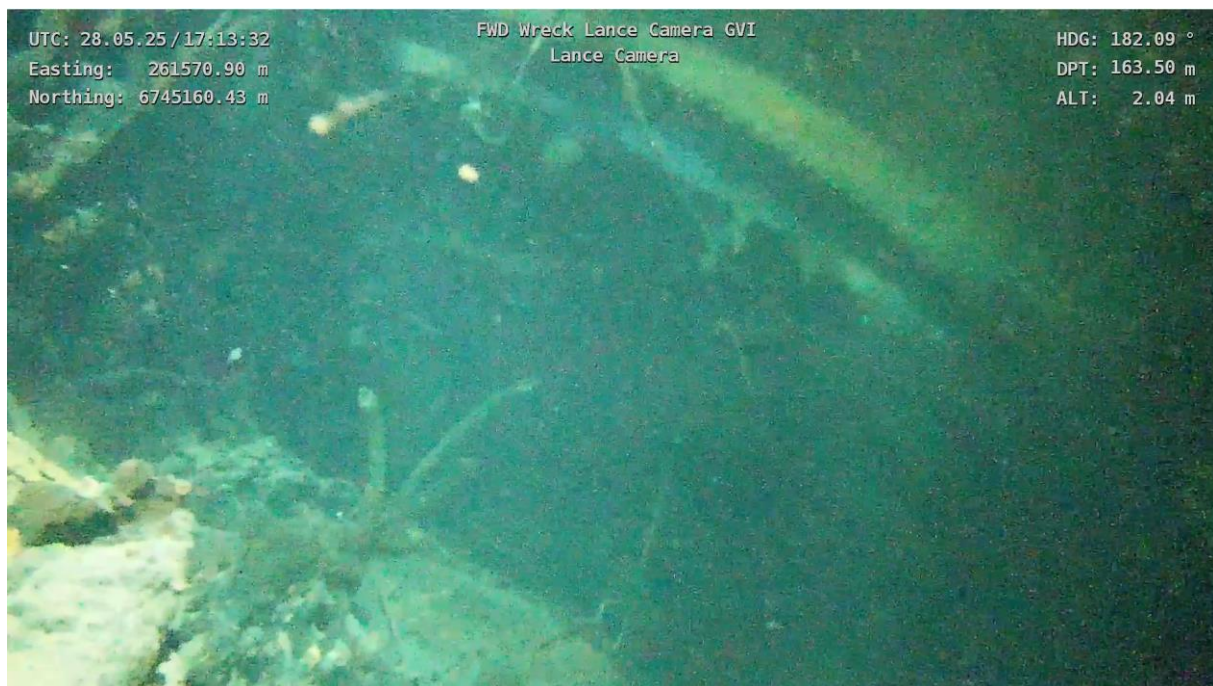


Figure 4-62 Lance camera example showing the inside of the fracture point

At the stern section, two locations were picked for the internal inspection. The two locations were the stern fracture point and the previously cut-out close to the stern torpedo bay. Figure 4-63 and Figure 4-64 display the locations where the lance camera was inserted into the wreck. The cut-out is located on the starboard side of the stern section.

Similar to the bow section, the fracture point at the stern was difficult to access due to debris blocking the entrance. The angle of the wreck also made it difficult to access the fracture point, as it was tilted down into the seabed surface. Consequently, the ROV was positioned slightly above the fracture point with no visibility into the wreck (Figure 4-65). The inside of the wreck showed significant damage, with debris and cables exposed (Figure 4-66 and Figure 4-67).

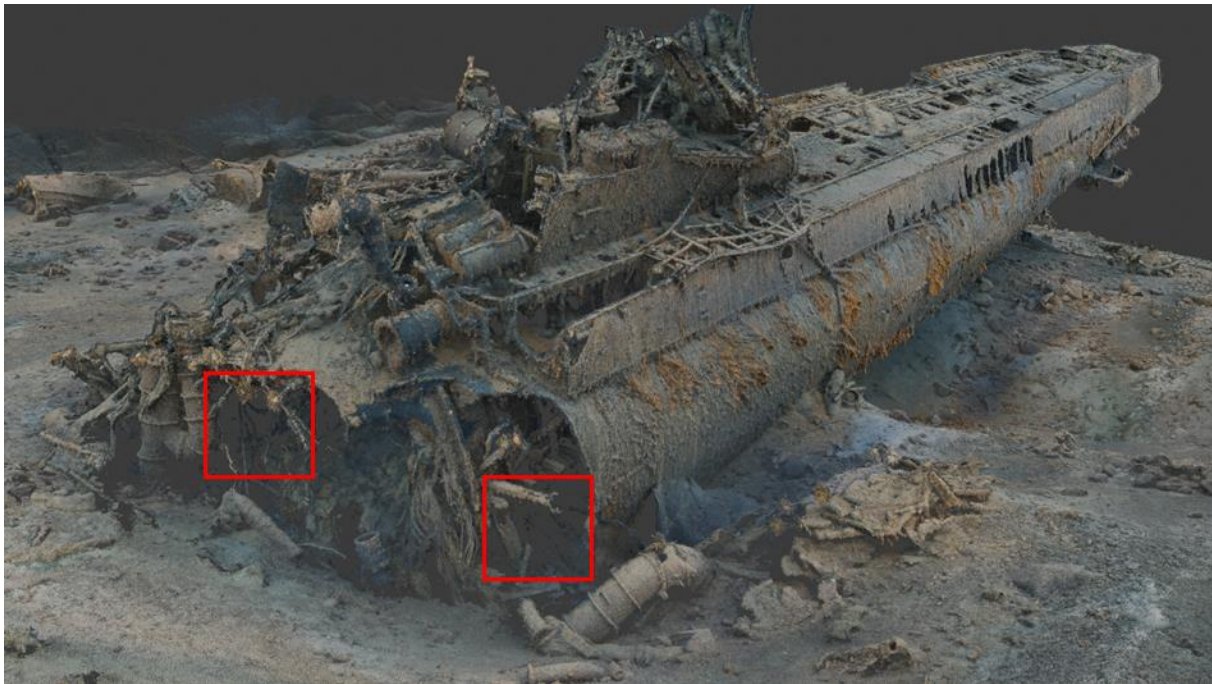


Figure 4-63 Photogrammetry data example showing the stern fracture point. The red squares show where the internal inspection was conducted



Figure 4-64 Photogrammetry model showing the location of the cut-out where the lance was inserted

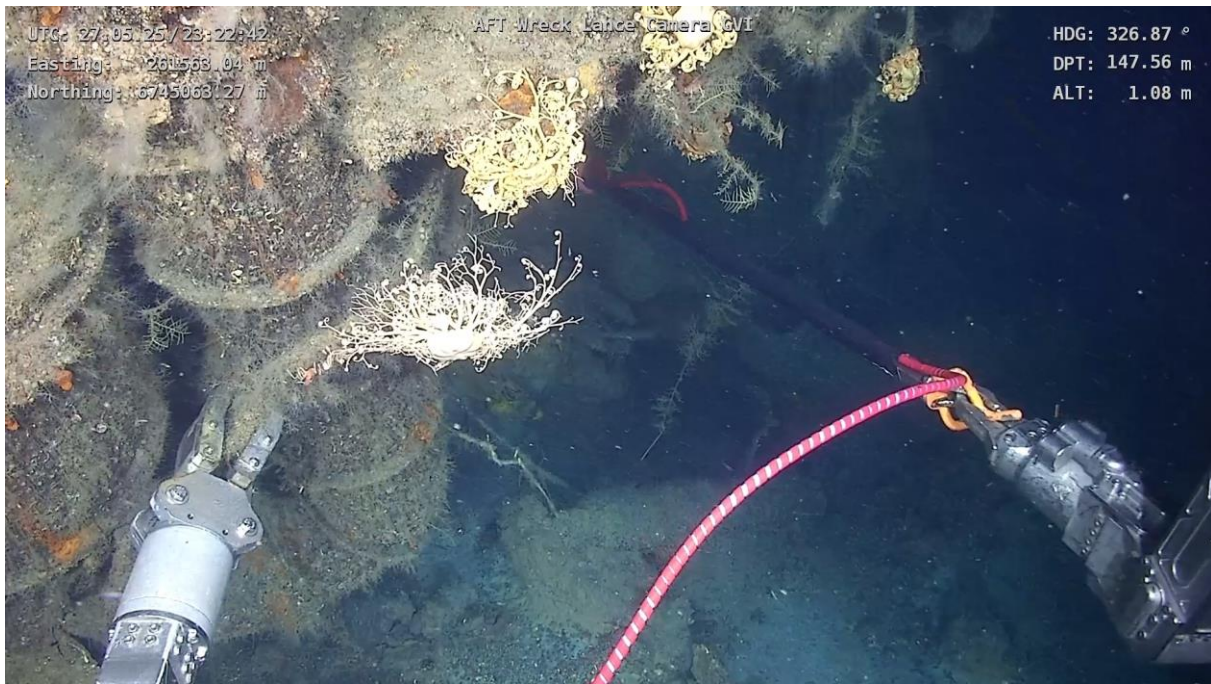


Figure 4-65 Video image showing the lance camera extended into the stern fracture point



Figure 4-66 Lance camera example showing several cables inside the fracture point



Figure 4-67 Lance camera example showing the inside of the stern fracture point

The second location was a small cut-out from a previous survey where the lance camera was inserted (Figure 4-68). The camera was inserted approximately 1 m into the torpedo bay; however, due to the extent of debris, it could not be advanced further, and no torpedoes were identified. The deterioration of the materials within the wreck made it very difficult to assess any significant details from the video. An example of this is displayed in Figure 4-69, where a damaged case seems to be containing an unidentified object or objects.

In addition, the lighting source for the lance camera was not powerful enough to illuminate the open space, resulting in less-than-optimal visibility. Suspended organic material also reduced the visibility of the camera (Figure 4-70). For future surveys, a more powerful light source could possibly illuminate the open space more effectively, and provide more details of its contents.



Figure 4-68 Video image example showing the lance camera inserted into the cut-out location



Figure 4-69 Lance camera example showing a possible container inside of the torpedo bay



Figure 4-70 Lance camera example highlighting the poor visibility and suspended organic material

4.4 REMOVAL OF DECK AND STORAGE INSPECTION

One of the objectives of the external inspection was to inspect and identify possible steel storage containers beneath the deck of the submarine. To access the storage containers, the deck would have to be removed. During removal, it was discovered that the presumed wooden deck was composed of metal. The fact that the deck was made of metal, rather than wood, had no impact on the operation.

The inspection of the bow wreck showed that the deck was mainly intact up to the fracture point, with occasional missing panels (Figure 4-71 and Figure 4-72). Even though some parts of the deck were open, none of the external storage containers were open and their contents could not be observed. At the fracture point, a gas container was protruding out of the wreck (Figure 4-73). The location of the protruding gas container is highlighted in Figure 4-74.



Figure 4-71 Video image example of the bow section deck with some missing panels

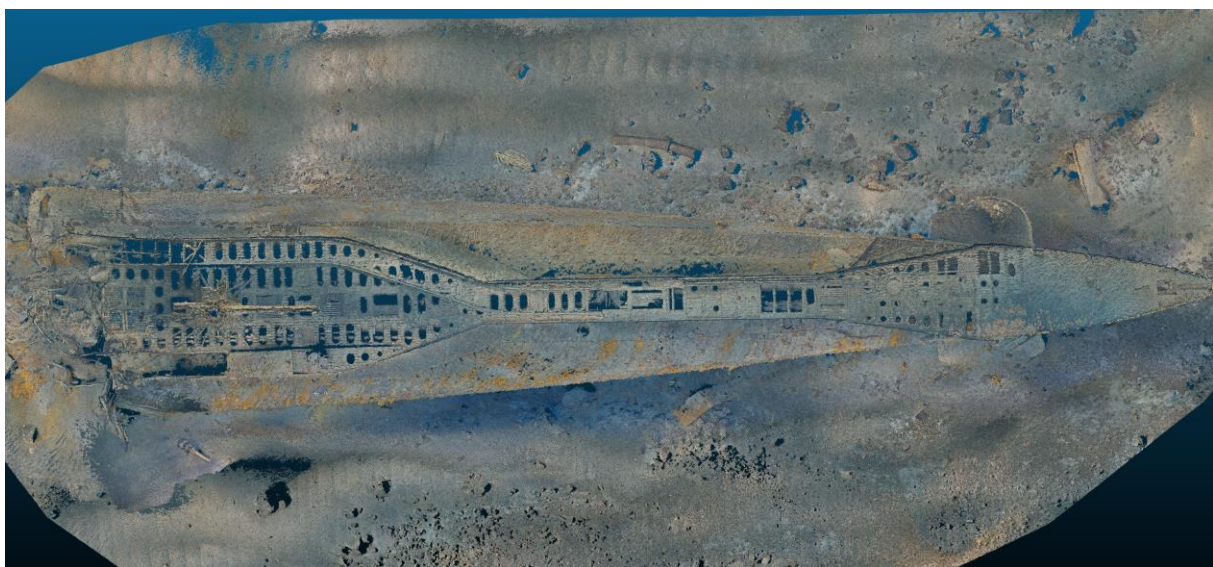


Figure 4-72 Photogrammetry model from above showing that most of the deck is still intact



Figure 4-73 Video image example showing what is believed to be gas containers at the bow fracture point



Figure 4-74 Location of the gas container

The deck on the stern section was found to be in various stages of degradation (Figure 4-75 and Figure 4-76). At multiple locations, marine life was observed moving along and between the various storage rooms below the deck, indicating significant degradation of the walls.

The external inspection identified multiple external storage containers for the client representative to review, two of which were chosen for further inspection (Table 4-5). Multiple other sections of the deck were open and exposed, containing what are believed to be gas containers (Figure 4-77).

Both locations for the deck removal were on the starboard side of the wreck, with the first location close to the cut-out location and the second location closer to the middle of the wreck (Figure 4-78).



Figure 4-75 Video image example of the stern section showing the degradation of the deck



Figure 4-76 Photogrammetry model, from above, showing the state of the stern deck

Table 4-5 Inspected External Storage Containers

Location ID	Easting (m)	Northing (m)	Description
1	261545	6745088	Starboard side stern
2	261552	6745076	Starboard side midpoint

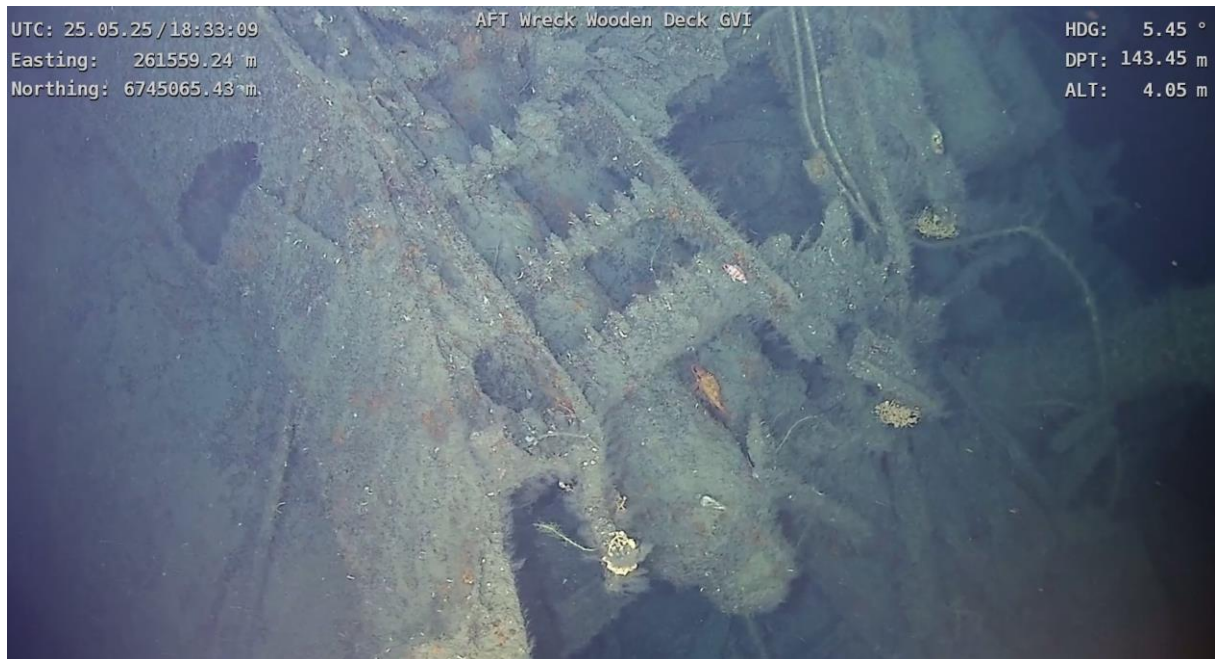


Figure 4-77 Video image example showing what is believed to be gas containers at the stern fracture point

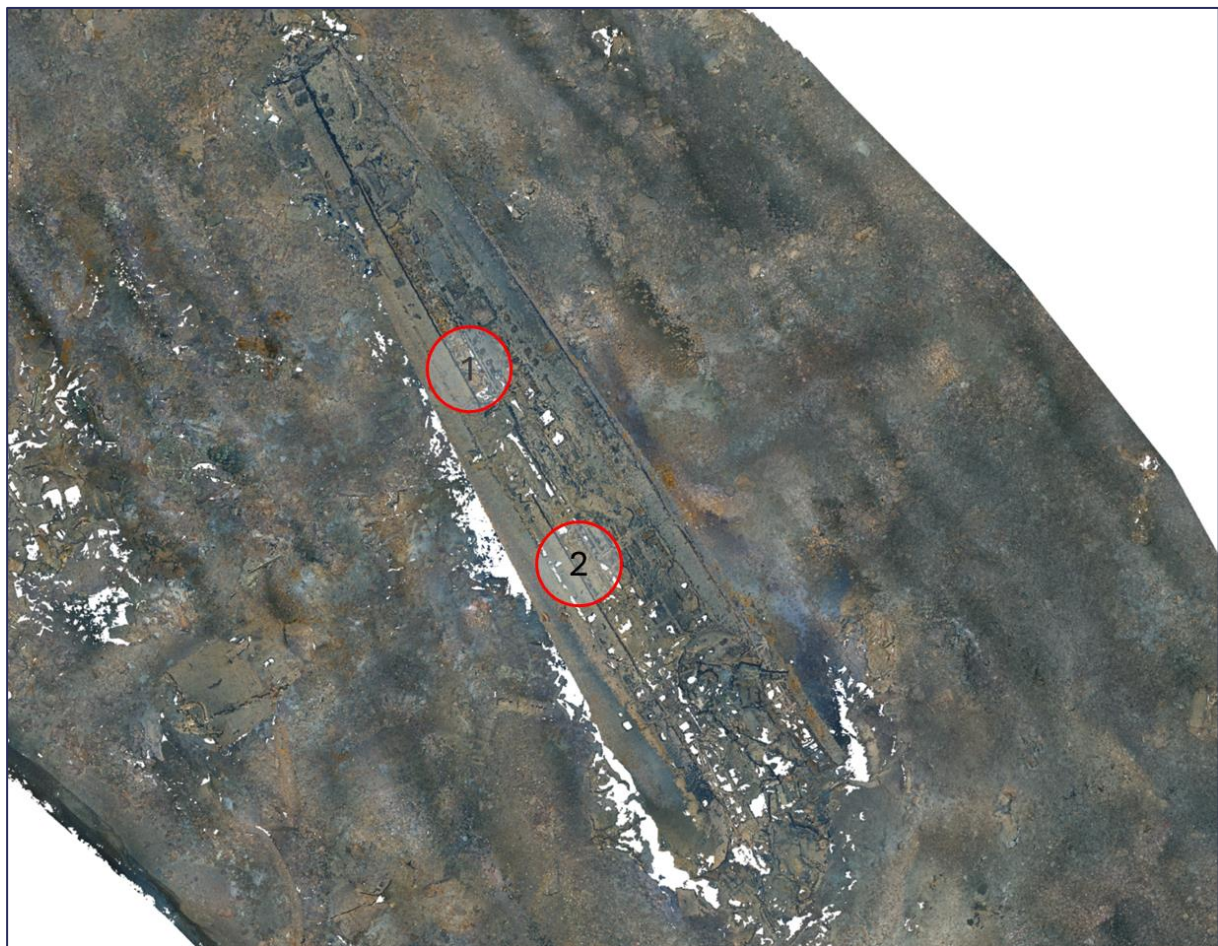


Figure 4-78 Deck removal locations

At location 1, a large section of the container roof was removed, revealing a cylinder approximately 8 m long and approximately 0.7 m in diameter. A hex nut could be seen at the exposed end of the cylinder as well as a grab handle. The cylinder was not found to have any serious defects nor were any signs of leakages observed. The cylinder is believed to be containing some kind of fuel.

Figure 4-79 - Figure 4-83 display the conditions of the external storage container before, during and after removal of the deck.



Figure 4-79 External storage container at location 1 before removal

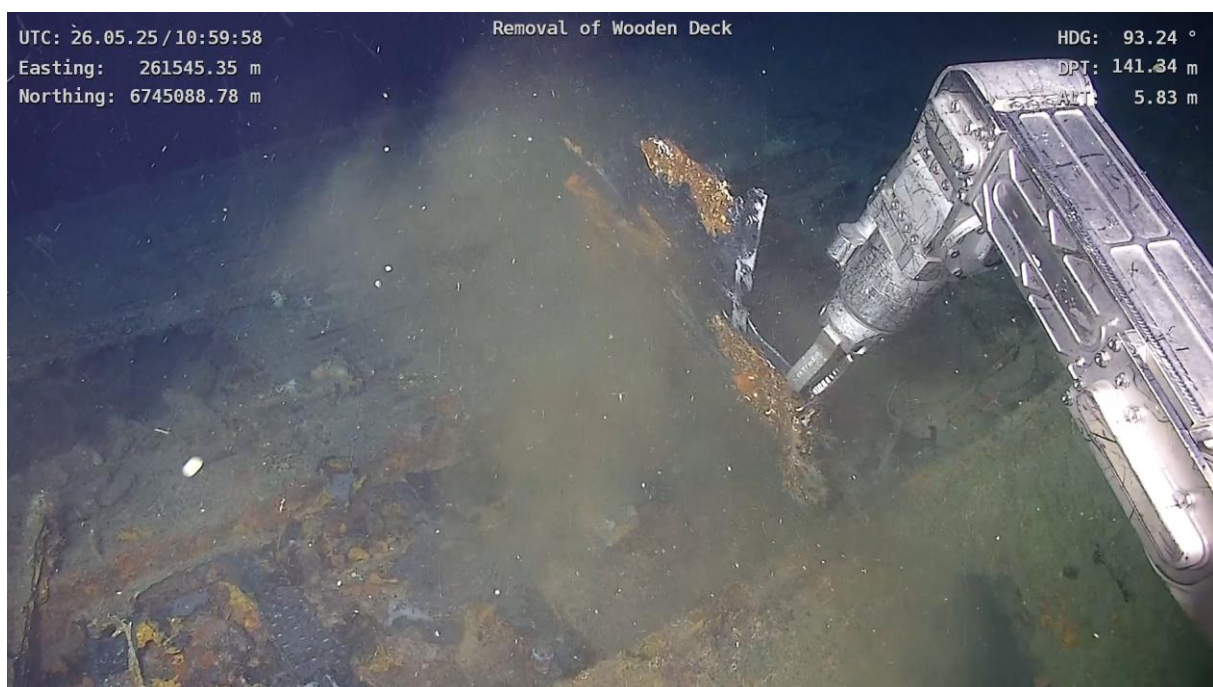


Figure 4-80 Container roof at location 1 being removed



Figure 4-81 More container roof removed at location 1



Figure 4-82 Water jet being used to clean debris from the opening at location 1



Figure 4-83 External storage container at location 1 after removal showing a large cylinder

At location 2, the container roof was removed revealing a cylindric container approximately 3m long and approximately 0.6m in diameter. The cylinder had protruding grooves around the radius of the body. During the jetting of the container, bubbles were seen emanating from the container. Figure 4-84 - Figure 4-88 display the conditions of the external storage container before, during and after removal of the deck.



Figure 4-84 External storage container at location 2 before removal



Figure 4-85 Container roof at location 2 being removed



Figure 4-86 Bubbles emanating from the cylinder just above the manipulator



Figure 4-87 End of the cylinder, no visible damages or features observed



Figure 4-88 External storage container at location 2 after removal

4.5 PHOTOGRAMMETRY SURVEY

The images taken during the photogrammetry survey resulted in highly detailed 3D point clouds and meshes for both the bow and stern section of the wreck. Each model also covers some seabed and debris spread around the site. The details obtained from the photogrammetry model are down to 2 mm, resulting in extremely detailed models of the submarine. Examples of the point clouds extracted from the images are presented in Figure 4-89 -Figure 4-92.



Figure 4-89 Bow, port side orthoimage



Figure 4-90 Bow, starboard side orthoimage



Figure 4-91 Stern, port side orthoimage

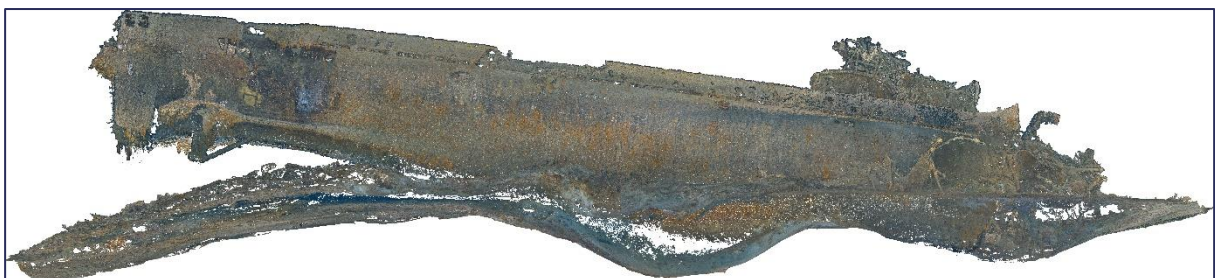


Figure 4-92 Stern, starboard side orthoimage

The details obtained from the photogrammetry models were able to highlight the overall deteriorating condition of the submarine and provided a more complete image of U-864. Video images have previously been able to document the conditions of U-864; however, photogrammetry was able to generate a complete model in 3D, which makes evaluation easier.

The level of details obtained from the photogrammetry did not only reveal the conditions of the outer hull but were also able to give a much more detailed view of the seabed surrounding the wreck. Based on the photogrammetry models, in combination with the video and CPTs, it was discovered that the seabed around the bow wreck was much firmer than originally believed. The seabed was originally believed to be very soft, and that debris and possible mercury canisters would sink into the seabed. However, the photogrammetry model showed that debris and small boulders have not subsided below the surface, indicating a coarser and denser surface sediment than originally believed (Figure 4-93). This is further supported by core samples (CPT125-127) taken by NGI in 2006 (Reference 3). The samples show a thin top layer of denser sand on top of softer clay.

The extent of the photogrammetry data extracted from the images is presented in Figure 4-94.



Figure 4-93 Photogrammetry model of the bow section showing coarse sediment and debris



Figure 4-94 Extent of the processed photogrammetry dataset

4.5.1 LONGITUDINAL PROFILE

One of the advantages with the photogrammetry models is that they can be used with design drawings to illustrate areas above and below the surface in very high detail. Drawings of IXD2 submarine, made available by Kystverket, were used as a base for overlaying point clouds. The point clouds were rotated with the average roll values calculated. It's important to note that the point clouds presented in the figures are viewed perpendicularly to the side of the submarine, rather than horizontal. Local coordinate systems were used to generate the figures. The hand drawn GA-drawing in the background was scaled to the point cloud.

The seabed has been removed from the point clouds to highlight the submarine with the background drawing. The lower edges of the point clouds show the seabed elevation along the hull. The dimensions are taken from drawing rather than field measurements and should be used with caution, as the background drawing was visually scaled to align with the point clouds. The distances are relative to the wreck's coordinate system, not horizontal/vertical distances.

By superimposing the point cloud onto the design drawings, it was possible to make an estimation of how much of the submarine is buried. Figure 4-95 and Figure 4-96 display the starboard and port side view of the photogrammetry models on top of the design drawings. From the port side view, it was estimated that less than 2.5 m of the bow section is located below the seabed surface, when measuring the base of the point cloud to the keel of the drawing. Given that CPT 126 (Figure 4-8) indicates that the bedrock is approximately 2.5 m – 3 m below the surface, it is possible that the keel did not come in contact with the bedrock upon impact with the seabed. Consequently, the keel may not be as damaged as would be expected from making direct contact with the bedrock. This assumes that the top of bedrock does not become shallower directly under the bow section and that the overall impact with the softer seabed surface did not destroy the keel.

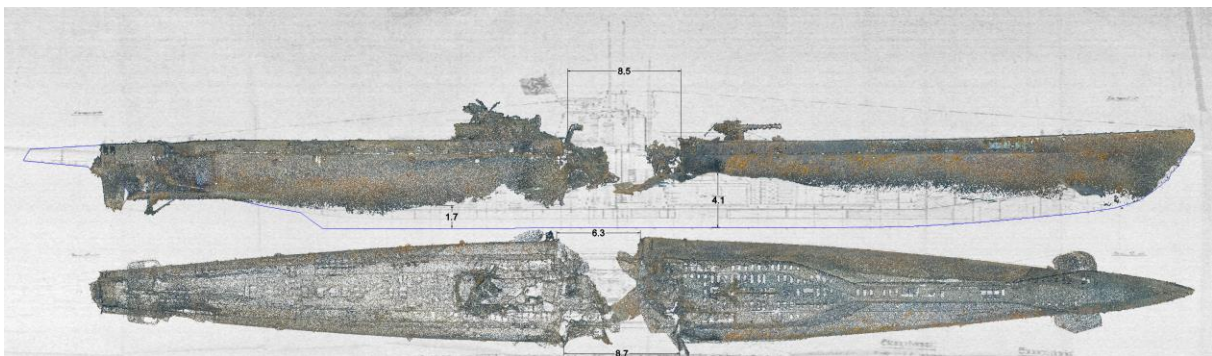


Figure 4-95 Starboard side view and top view

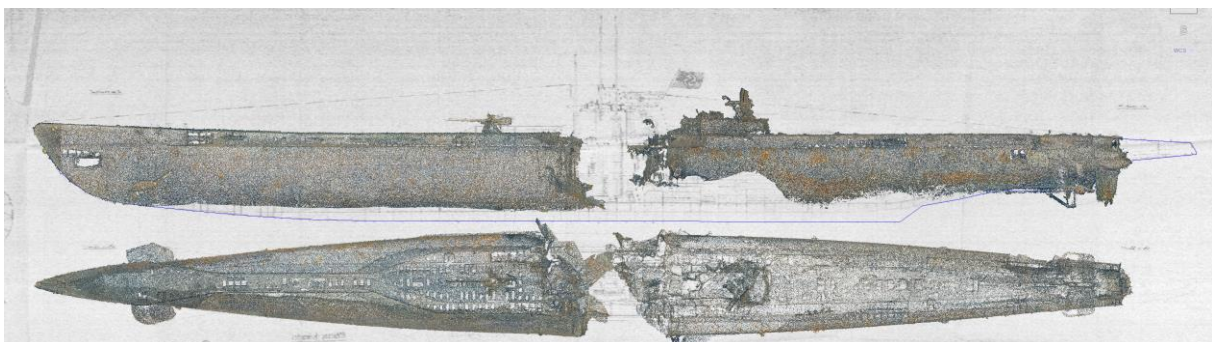


Figure 4-96 Port side view and top view

4.5.2 CROSS PROFILES

Cross profiles of the wreck, in combination with provided frame drawings, were utilised in order to gain a better understanding of the burial. Cross profiles were extracted from the photogrammetry point clouds and then combined with frame drawings to illustrate the buried sections of the wreck. The scale of the point cloud is kept fixed (true scale). The background GA-drawing is scaled to fit the point clouds.

The cross profiles were extracted to the vessel coordinate system, defined by a line alongships. The cross profiles are perpendicular to this line – i.e. the cross profiles are not strictly vertical but defined by the pitch of the wreck parts. This is done to correctly align cross profiles to the drawings.

4.5.2.1 BOW

For the bow section, two frame drawings were available. Figure 4-97 and Figure 4-98 display the location of the frame drawings while Figure 4-99 displays where cross profiles from the point cloud were extracted.

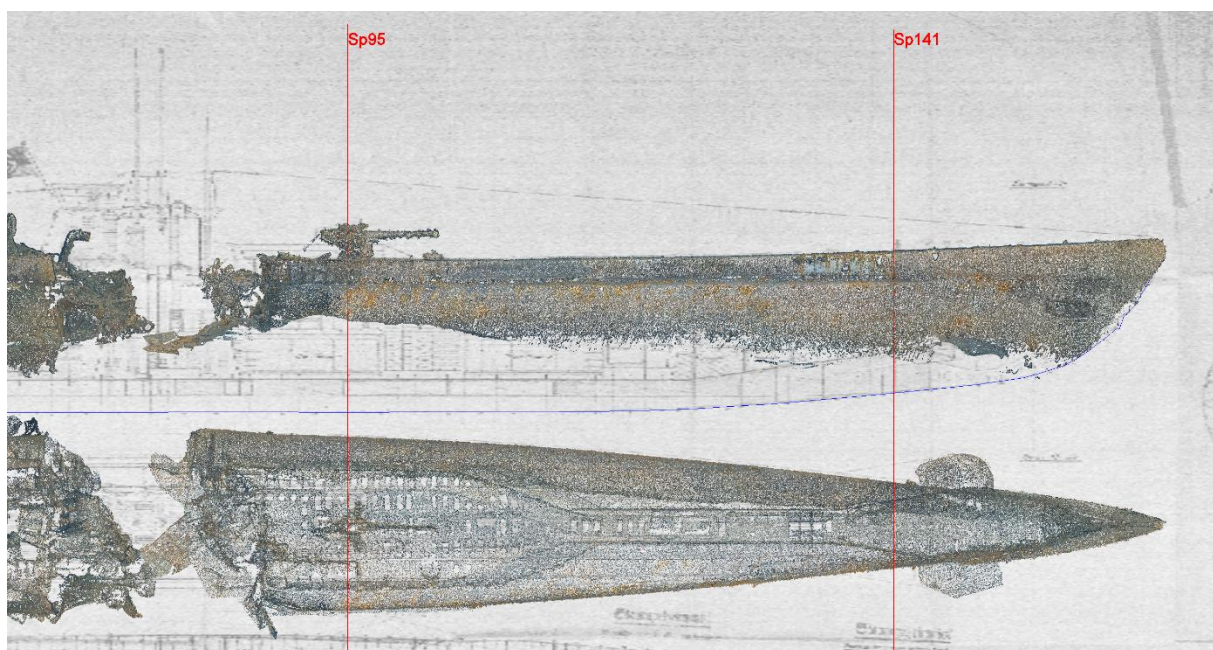


Figure 4-97 Side profile view of extracted cross profiles bow section (starboard/top down view)

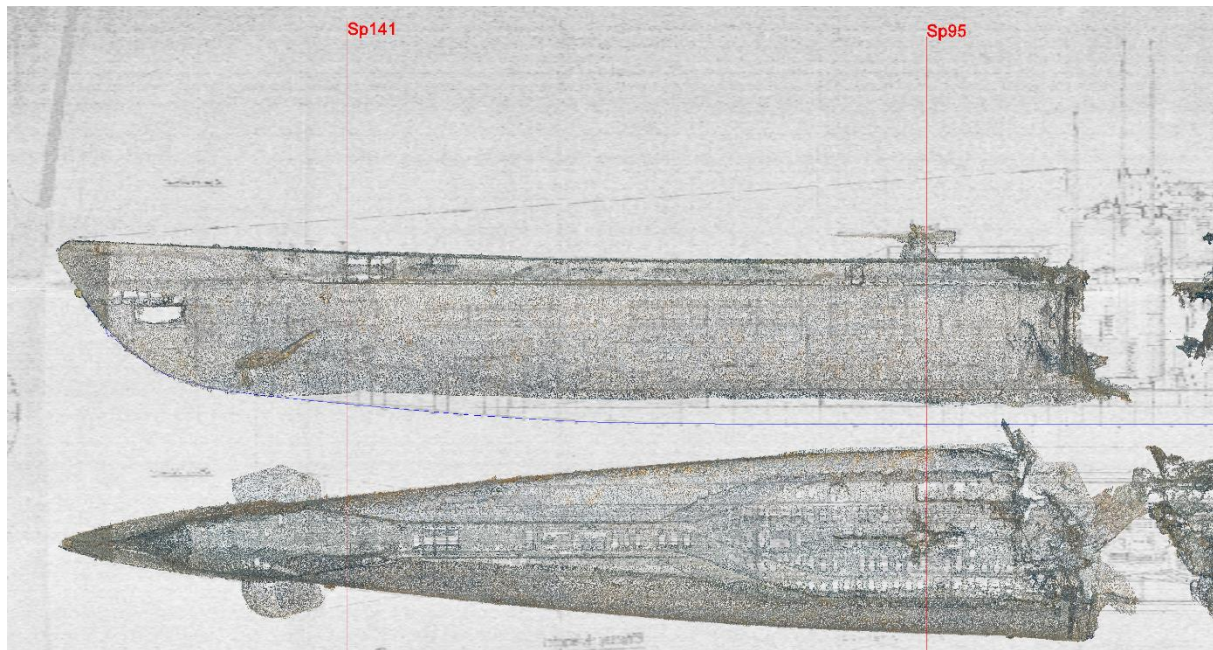


Figure 4-98 Side profile view of extracted cross profiles bow section (port/top down view)

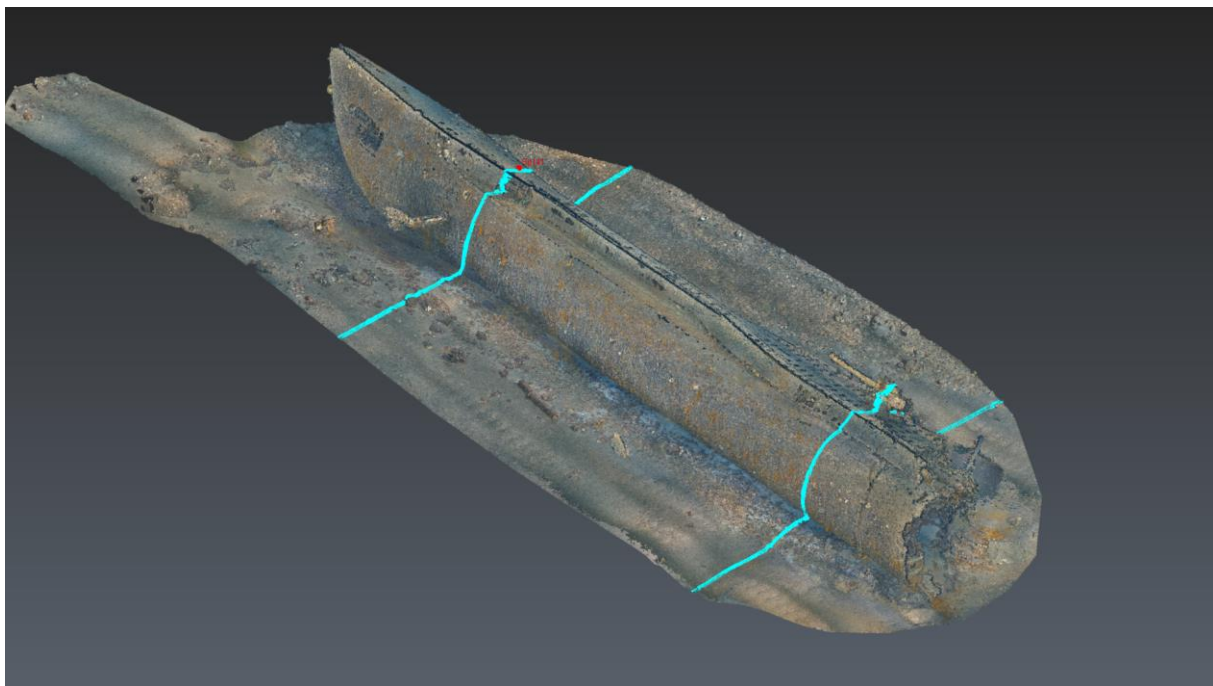


Figure 4-99 3D-view of extracted cross profiles, bow section (port side view)

The cross profiles illustrate how the keel is positioned relative to the seabed, given that the keel is not deformed/crushed (Figure 4-100 and Figure 4-101). The actual condition of the keel is not known, however, CPT data close to frame 95 indicates that bedrock is found between 2.5 m – 3 m below surface. Based on the cross profiles, the keel may not be deep enough to have been destroyed during impact.

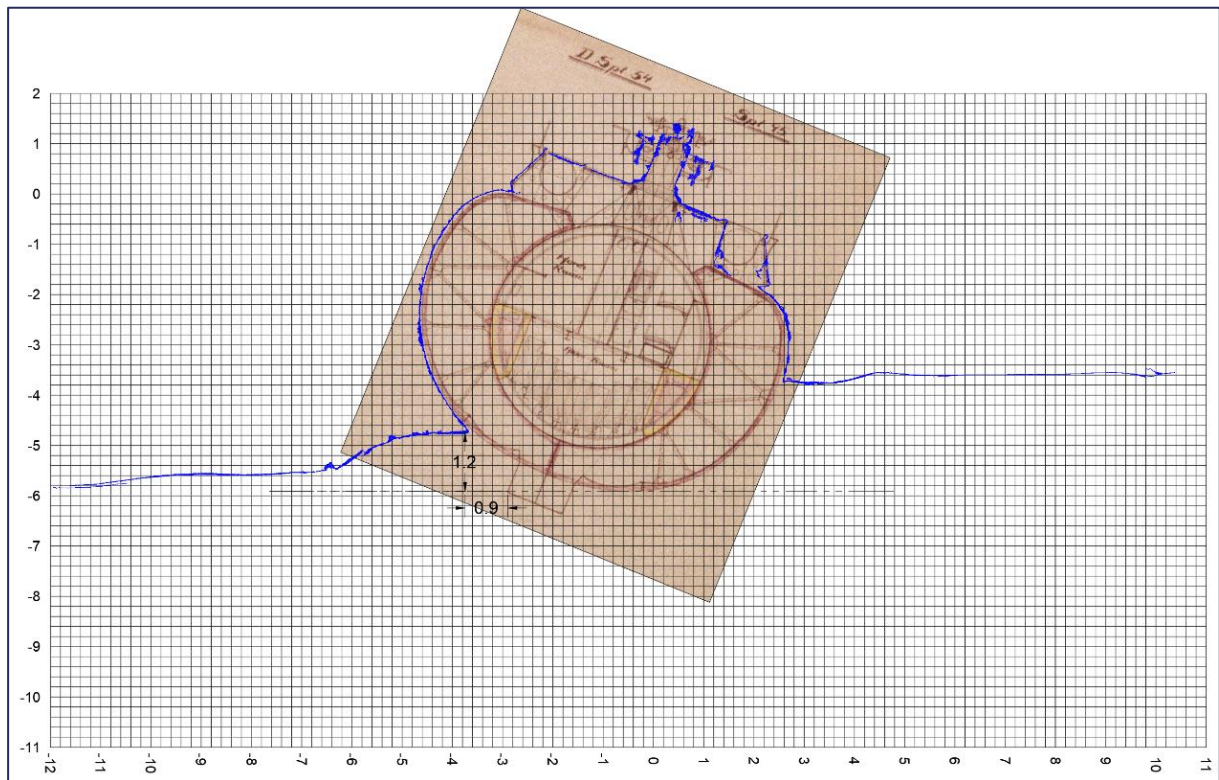


Figure 4-100 Deck frame 95. Axis represents metres

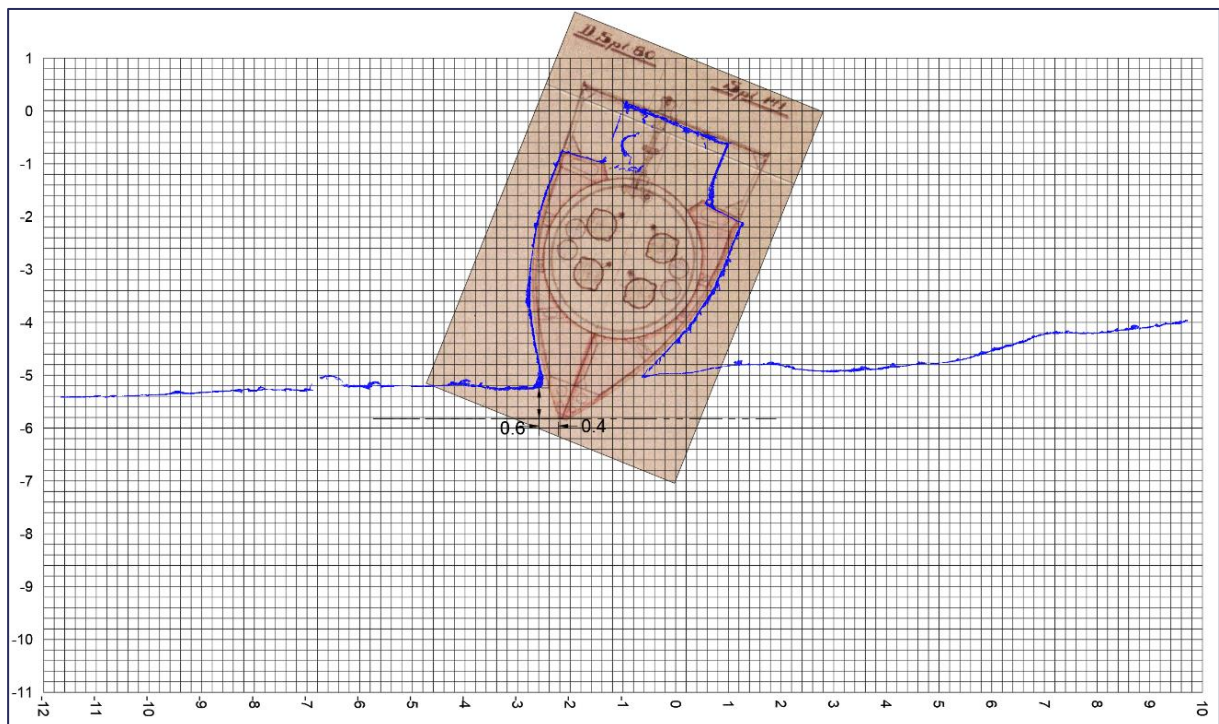


Figure 4-101 Deck frame 141. Axis represents metres

4.5.2.2 STERN

For the stern section, four frame drawings were available. Figure 4-102 and Figure 4-103 display the locations of the frame drawings and Figure 4-104 displays the extracted cross profiles.

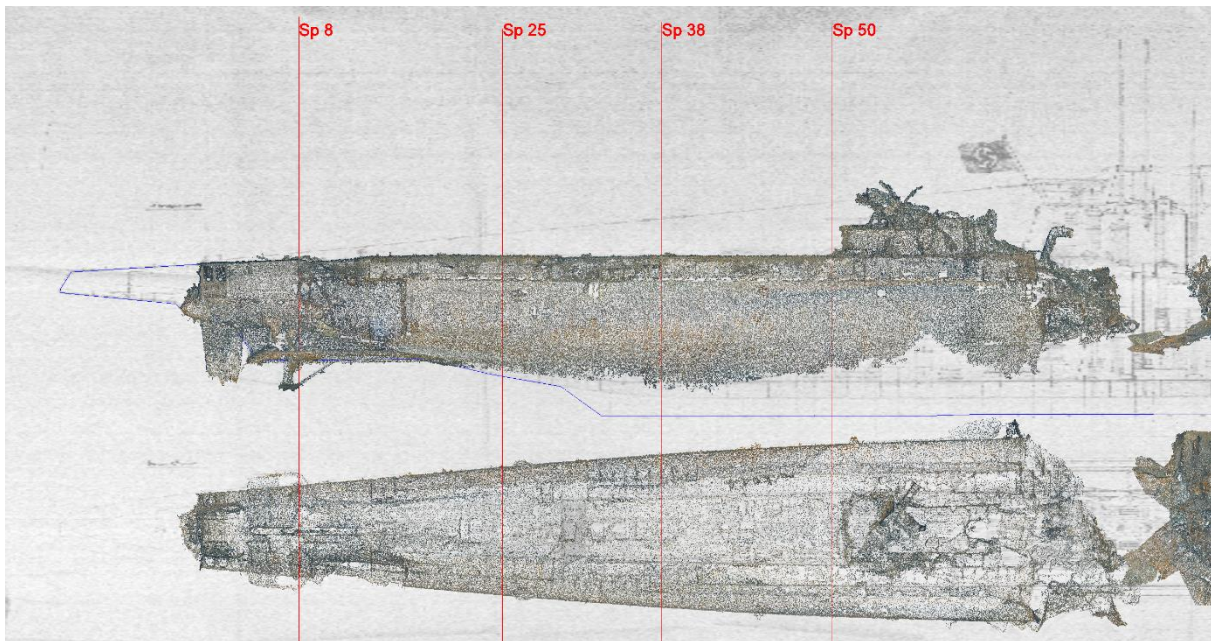


Figure 4-102 Side profile view of extracted cross profiles stern section (starboard/top down view)

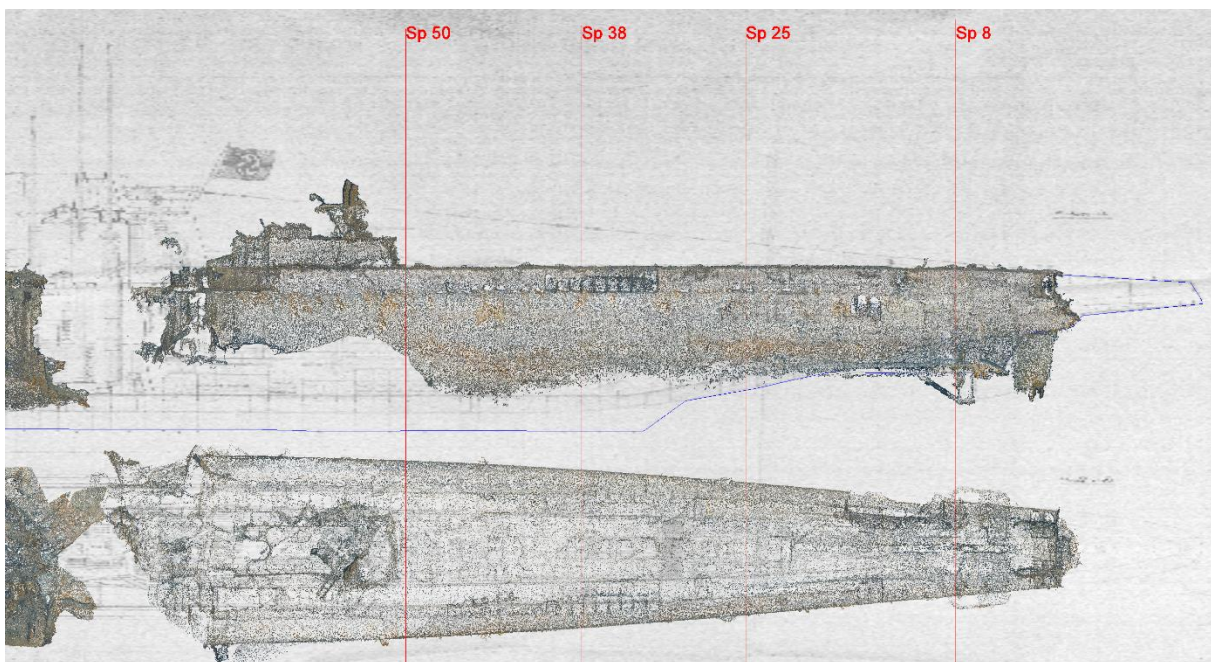


Figure 4-103 Side profile view of extracted cross profiles stern section (port/top down view)

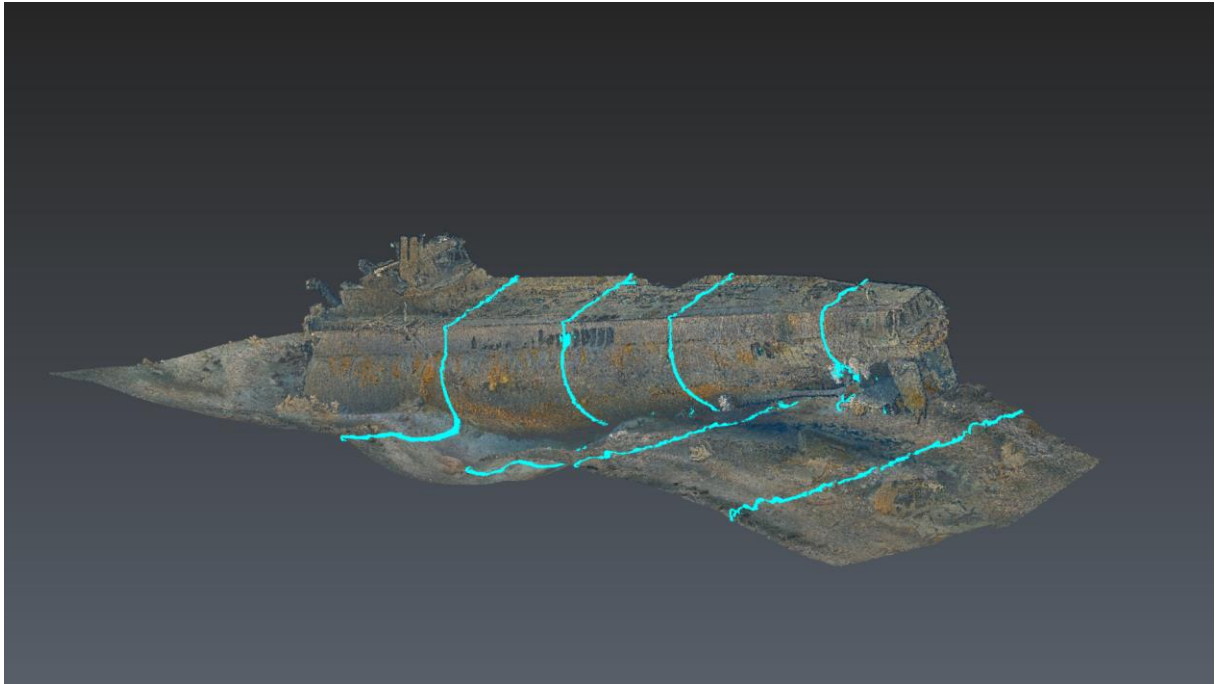


Figure 4-104 3D-view of extracted cross profiles, stern section (port side view)

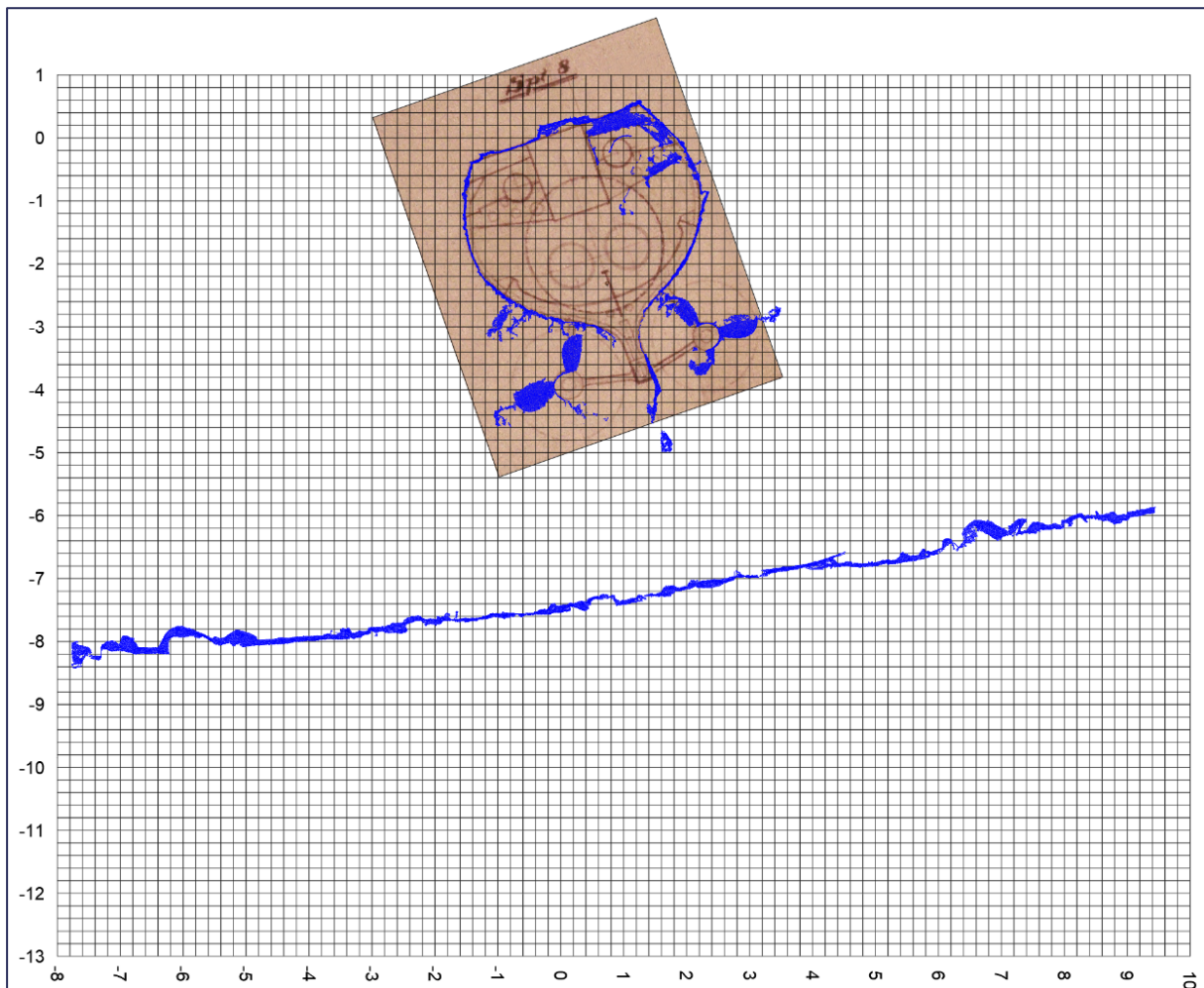


Figure 4-105 Deck frame 8. Axis represents metres

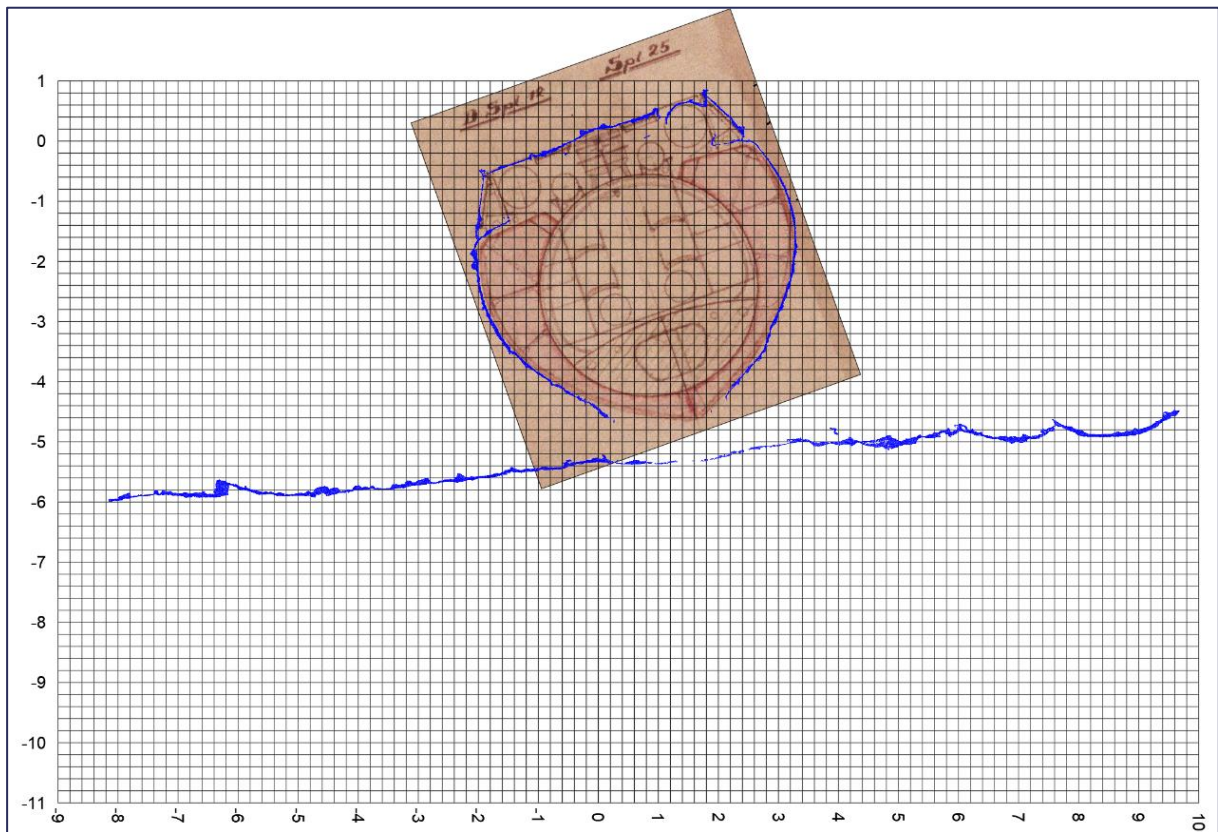


Figure 4-106 Deck frame 25. Axis represents metres

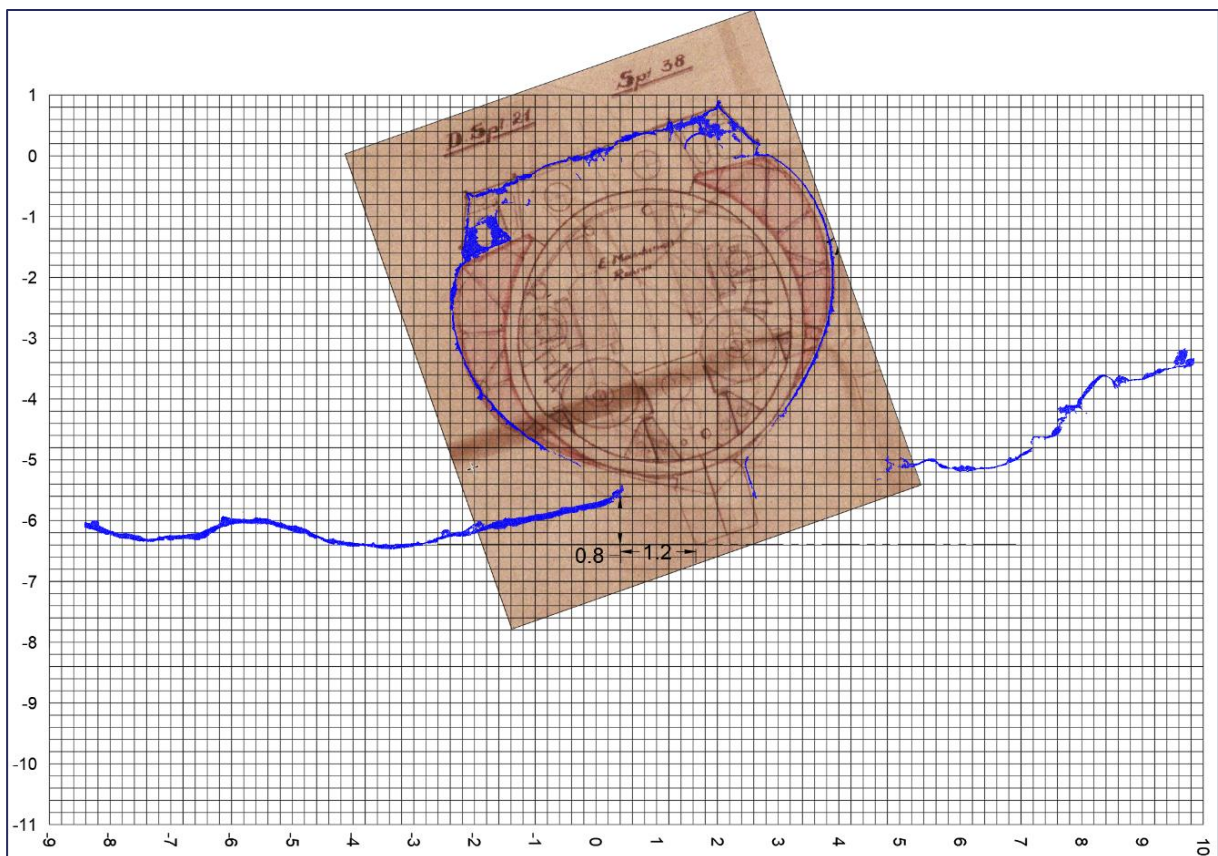


Figure 4-107 Deck frame 38. Background image slightly scaled to fit cross profile. Axis represents metres

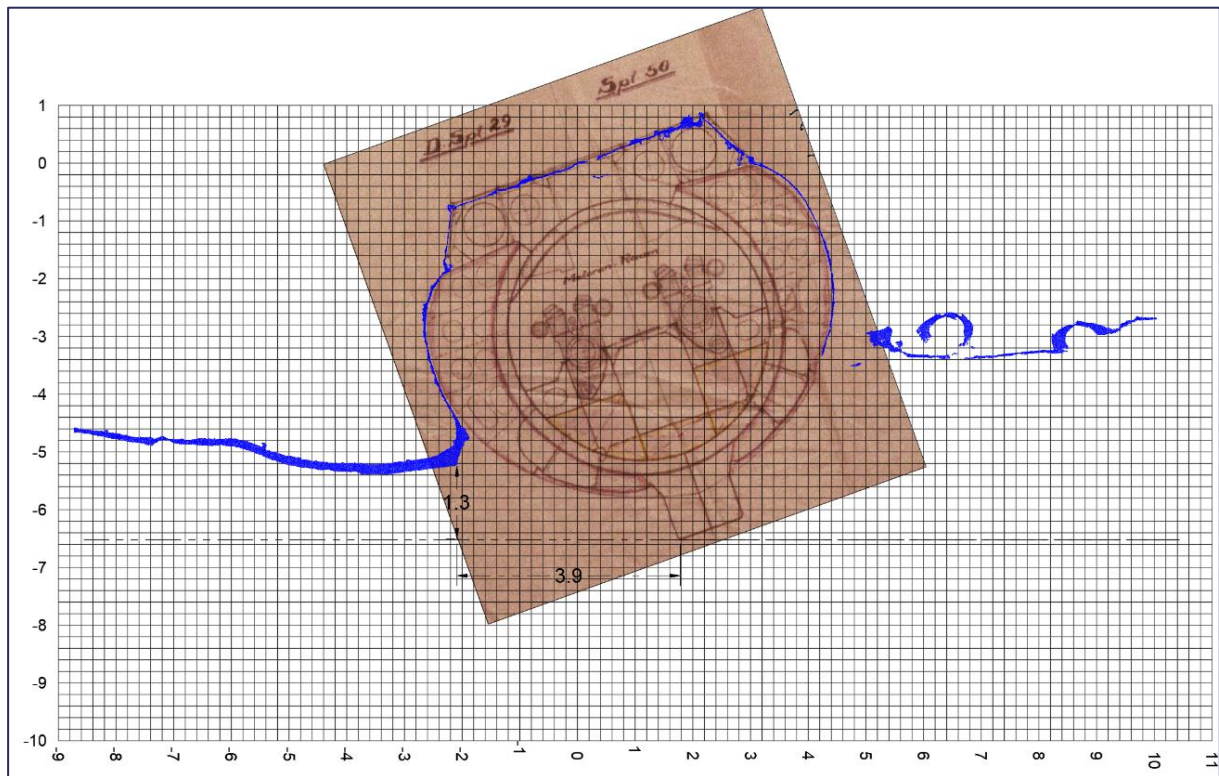


Figure 4-108 Deck frame 50. Axis represents metres

4.5.3 U-864 INCLINATIONS

The inclinations of the bow and the stern wrecks were calculated based on photogrammetry point clouds and verified visually using multibeam echo sounder soundings. No designated depth measurement was completed in the 2025 survey campaign.

The points were selected from the photogrammetric point cloud. Two pairs of points were selected for pitch and roll calculations, and the results are given as the average of these measurements. Both pitch and roll calculations were carried out for the top deck. A summary of the measurements is presented in Table 4-6.

Table 4-6 Summary of Calculated Inclinations

Section	Parameter	Degree (°)	Comment
Bow	Average Roll	20.98	Starboard Down
Bow	Average Pitch	14.60	Bow Up
Stern	Average Roll	-19.38	Starboard Up
Stern	Average Pitch	-7.99	Bow Down

4.5.3.1 BOW - PICKED POINTS AND PROFILES

Table 4-7 outlines the results of the inclination calculations and Figure 4-109 - Figure 4-112 display the location of where the points were located on the bow wreck.

Table 4-7 Bow inclination picked points

Point	Easting	Northing	Height	3d Range (m)	Dz (m)	Angle (deg)
A-1	261555.29	6745131.59	-152.10			
A-2	261552.50	6745132.59	-153.23	3.18	-1.13	20.80
B-1	261561.11	6745144.86	-156.62			
B-2	261559.93	6745145.27	-157.10	1.35	-0.49	21.17
C-1	261560.52	6745147.26	-158.76			
C-2	261555.24	6745135.98	-155.42	12.89	3.33	14.98
D-1	261562.94	6745146.31	-157.77			
D-2	261558.07	6745136.96	-155.10	10.87	2.67	14.23

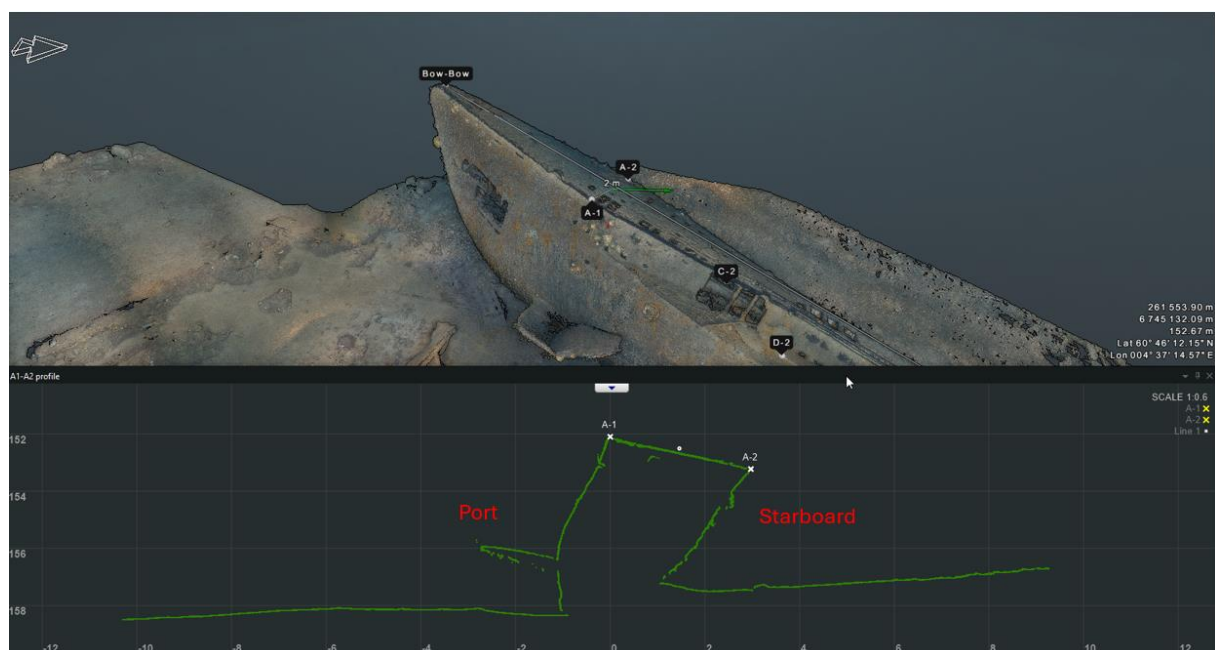


Figure 4-109 Profile A1 - A2



Figure 4-110 Profile B1 - B2

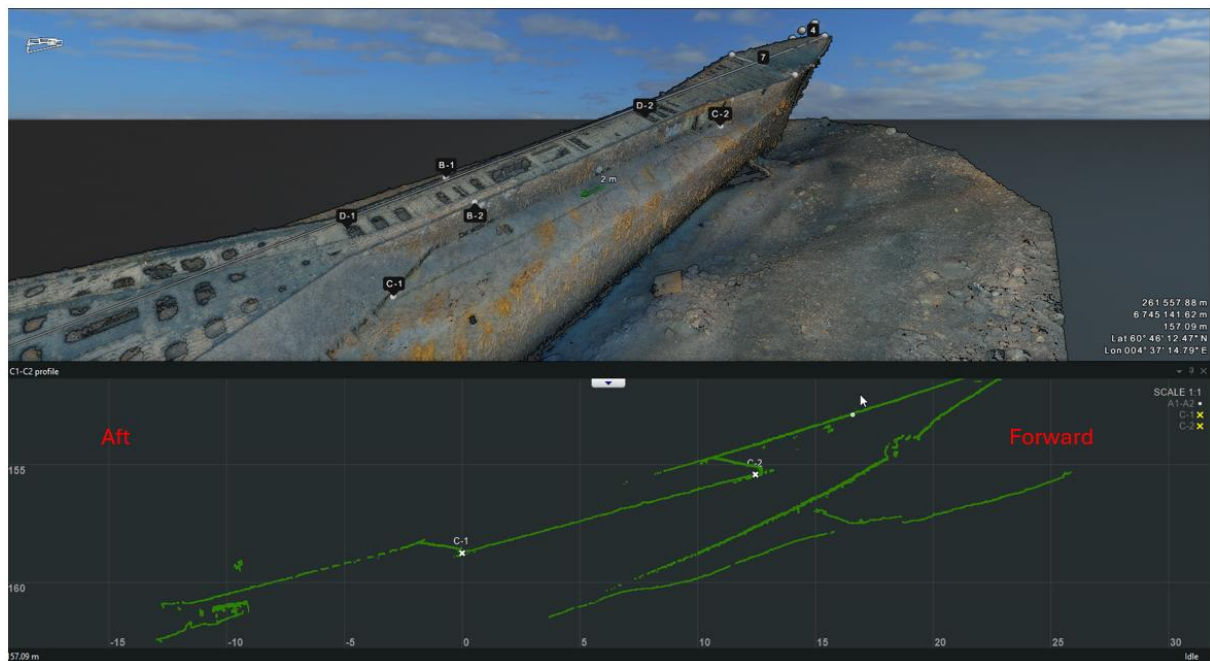


Figure 4-111 Profile C1 - C2

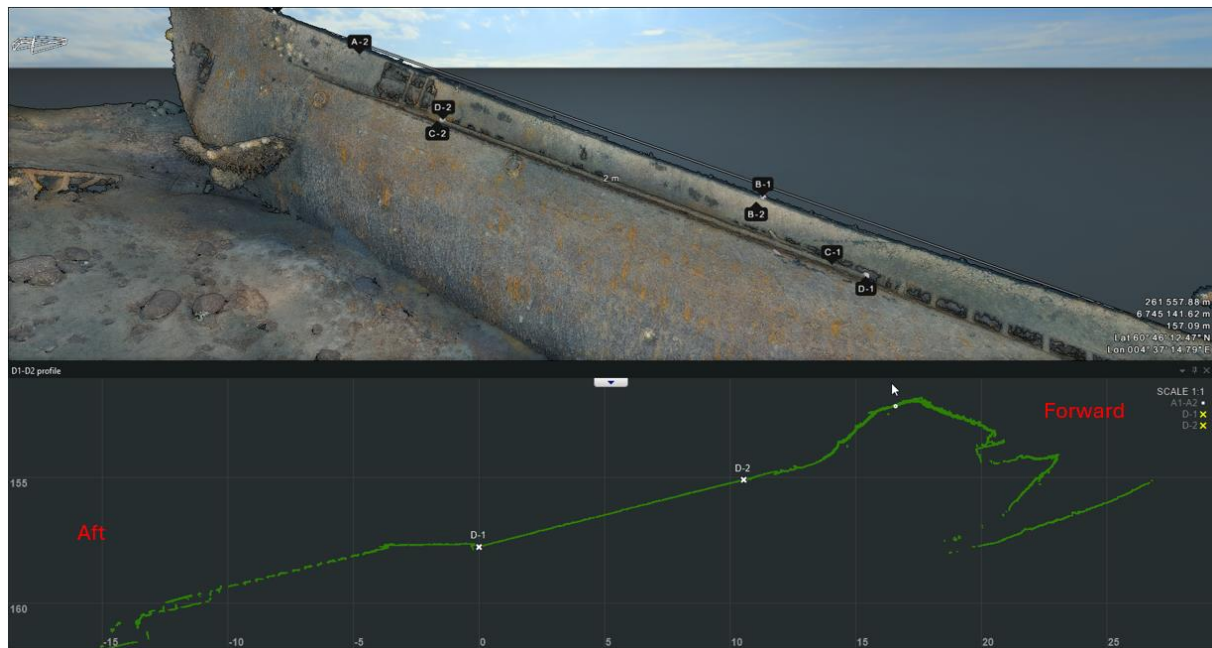


Figure 4-112 Profile D1 - D2

4.5.3.2 STERN - PICKED POINTS AND PROFILES

Table 4-8 outlines the results of the inclination calculations and Figure 4-113- Figure 4-116 display the location of where the points were located on the stern wreck.

Table 4-8 Stern inclination pick points

Point	Easting (m)	Northing (m)	Height (m)	3d Range	Dz	Angle (deg)
E-1	261555.19	6745072.98	-144.13			
E-2	261558.56	6745075.76	-145.62	4.62	-1.49	-18.77
F-1	261548.38	6745086.10	-142.47			
F-2	261549.93	6745087.25	-143.17	2.05	-0.70	-19.99
G-1	261559.13	6745074.89	-145.77			
G-2	261548.68	6745090.42	-142.95	18.93	2.82	-8.56
H-1	261554.11	6745076.89	-144.07			
H-2	261550.90	6745081.88	-143.30	5.99	0.77	-7.42



Figure 4-113 Profile E2- E1



Figure 4-114 Profile F2 - F1

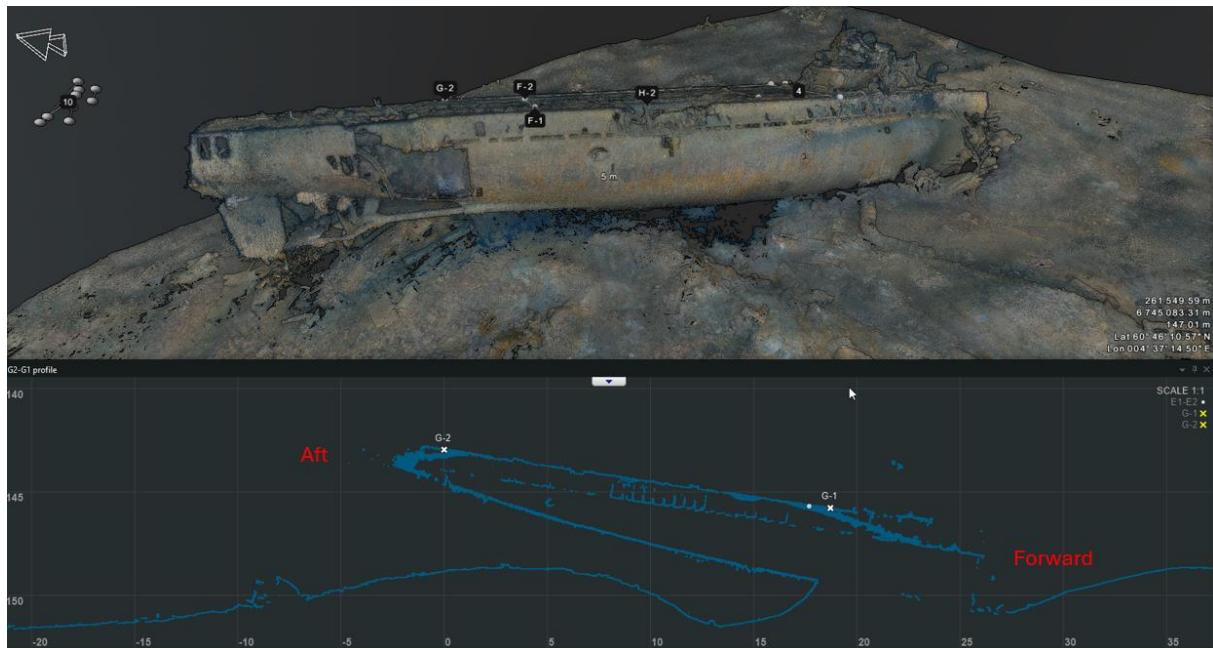


Figure 4-115 Profile G2 -G1

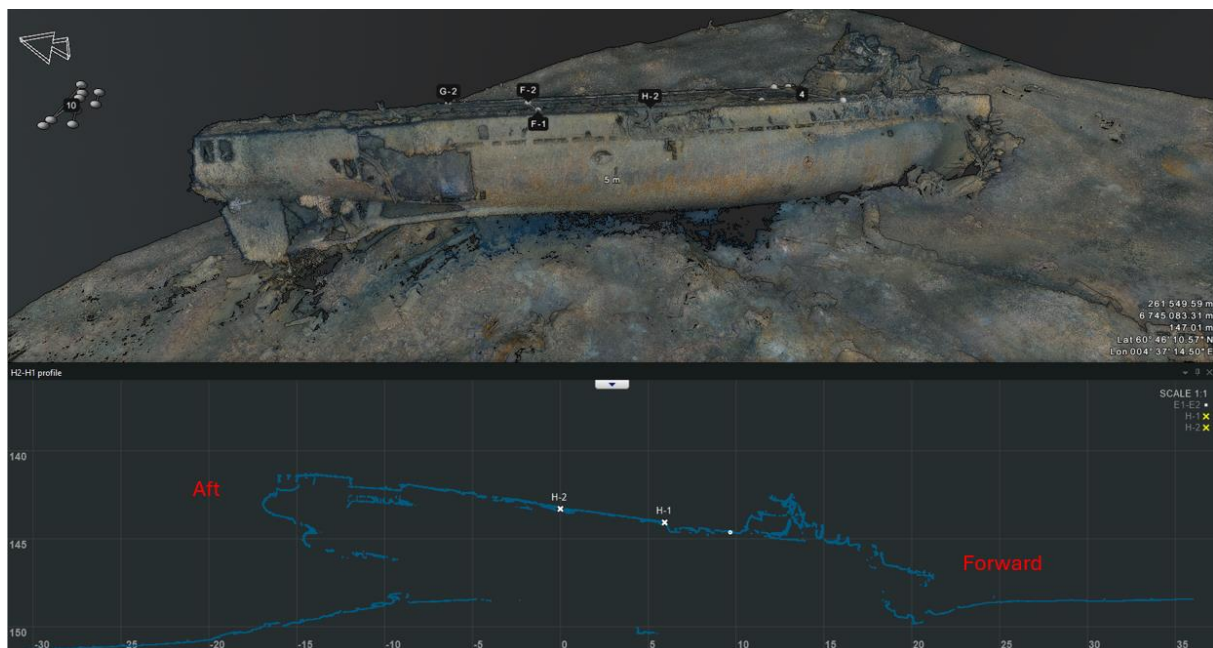


Figure 4-116 Profile H2 - H1

4.6 THICKNESS MEASUREMENT

A total of five locations were investigated and at each location, two to three separate measurements were completed to ensure accuracy. The measurements at each location were taken in close proximity to each other. The five predetermined locations for the UT measurements are presented in Table 4-9 and an overview of their locations are presented in Figure 4-117. The estimation of the remaining material is based on the average thickness values from the 2005 survey. An overview of the 2005 thickness measurements is presented in Appendix G.

Table 4-9 Ultrasonic Measurement Locations

Location	Easting (m)	Northing (m)	Approximate Depth (m)
A – Bow Starboard Casing	261561	6745154	160.93
B – Bow Starboard Casing	261562	6745157	161.73
C – Stern Port Pressure Hull	261563	6745065	147.06
D – Conning Tower Pressure Hull	261562	6745047	145.48
E – Conning Tower Bunker Tank	261562	6745048	145.59

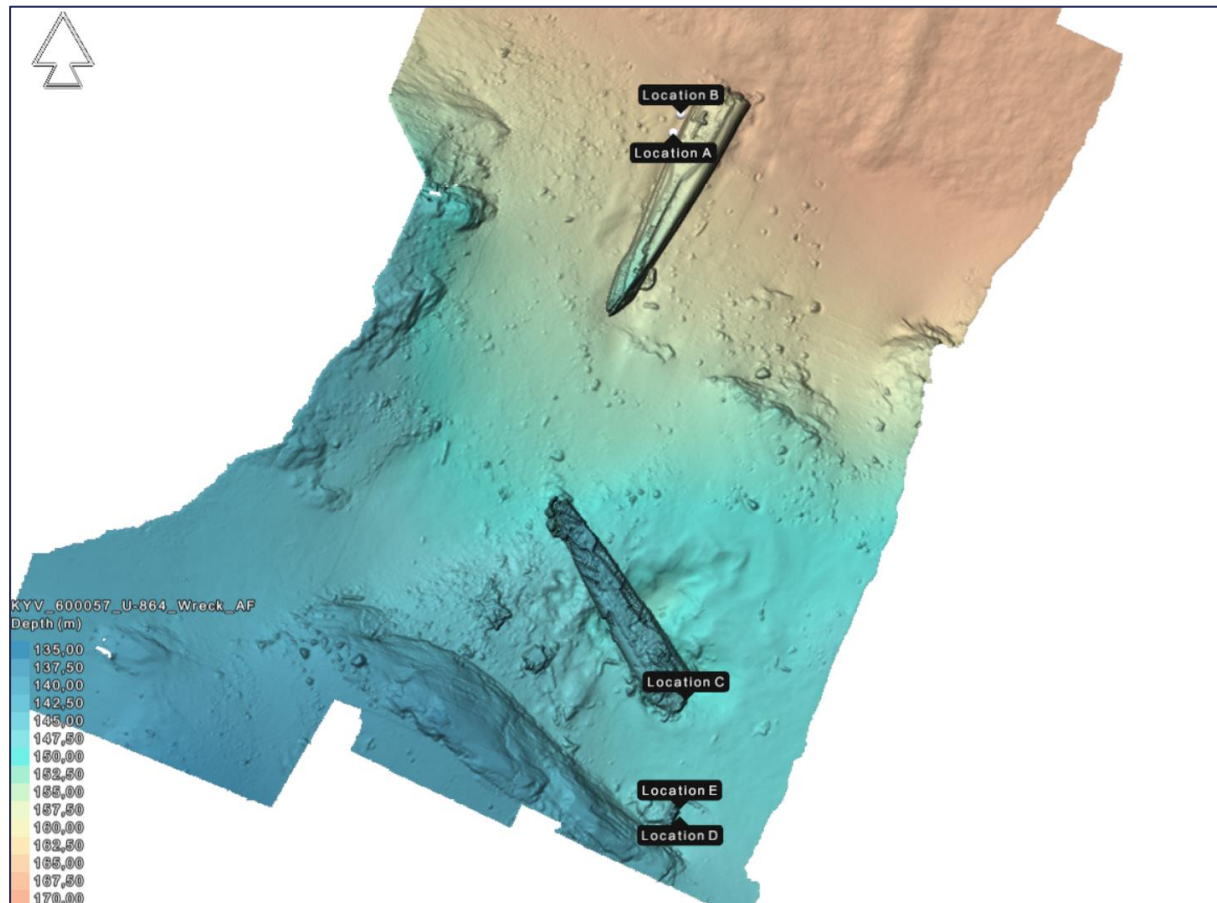


Figure 4-117 Overview of UT measurement locations

The measurements at location A were taken at the upper section of the submarine casing, approximately 10 m from the fracture point. The two readings indicate that the thickness of the casing has been reduced by 0.6 to 0.75 mm from the last reading (Table 4-10). Figure 4-118 displays the UT probe attached to the casing and Figure 4-119 displays the location in relation to the bow-section wreck.

Table 4-10 UT Measurement Details for Location A

Measurement	Previous Reading (mm)	Previous Reading Average (mm)	Latest Reading (mm)	Material Remaining	Reduction (mm)*
1	5.35	5.25	4.65	88.57%	0.6
2	5.15	5.25	4.5	85.71%	0.75
Note *Reduction is based on the previous average reading					

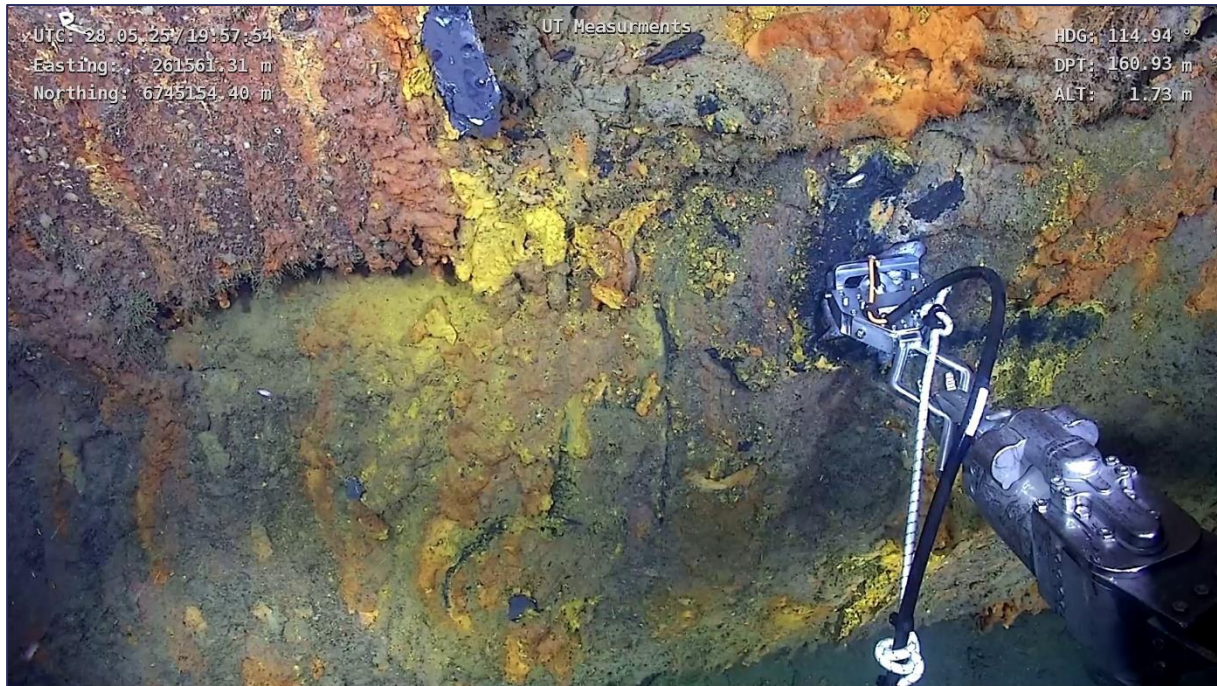


Figure 4-118 Ultrasonic measurement at location A



Figure 4-119 Location A and B alongside the bow section

The measurements at location B were taken at the upper section of the submarine casing, approximately 6 m from the fracture point, and 3 m away from location A (Figure 4-119). The two readings indicate that the thickness of the casing has been reduced by 0.6 to 0.85 mm from the last reading (Table 4-11). A photo of the measurement process, taken from location B, is presented in Figure 4-120.

Table 4-11 UT Measurement Details for Location B

Measurement	Previous Reading (mm)	Previous Reading Average (mm)	Latest Reading (mm)	Material Remaining	Reduction (mm)
1	4.75	5.35	4.75	88.79%	0.6
2	5.95	5.35	4.5	84.11%	0.85
Note *Reduction is based on the previous average reading					

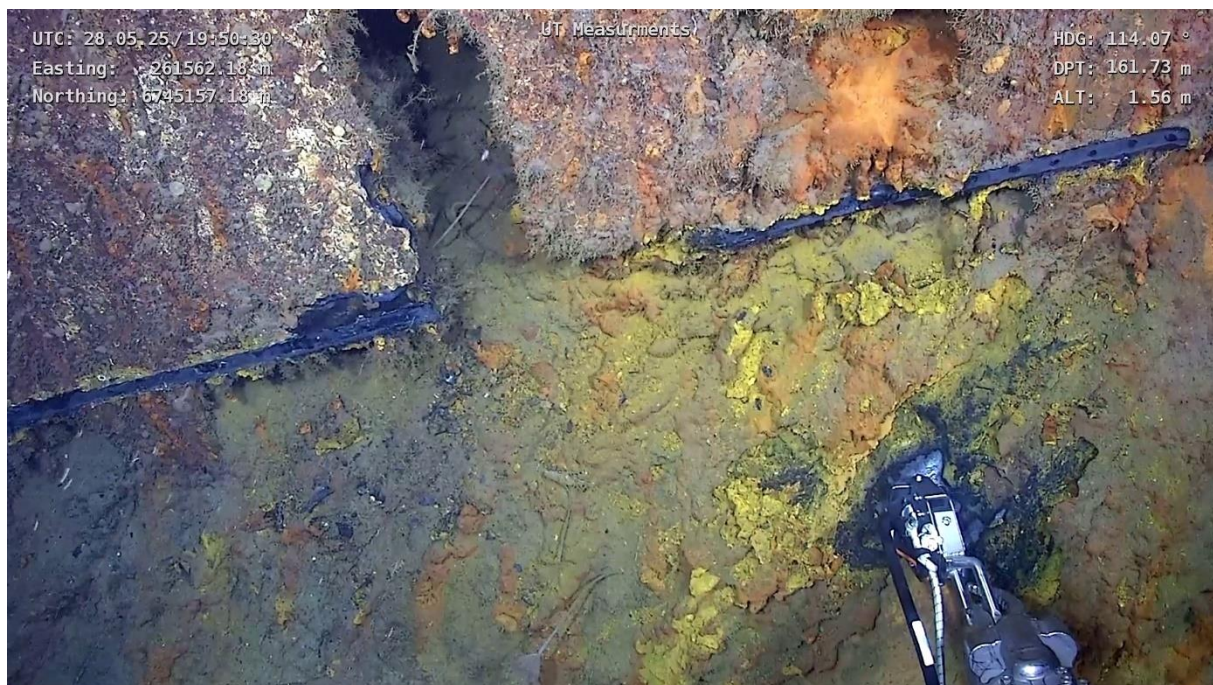


Figure 4-120 Ultrasonic measurement at location B

The measurements at location C were taken at an exposed section of the pressure hull on the port side of the fracture point (Figure 4-121). Three separate measurements were taken at location C, since the initial two measurements showed a difference of more than 1.5 mm. The third measurements confirmed the second reading, as they only showed a difference of 0.5 mm. Details of the readings are presented in Table 4-12 and a photo from the measurement is presented in Figure 4-122.

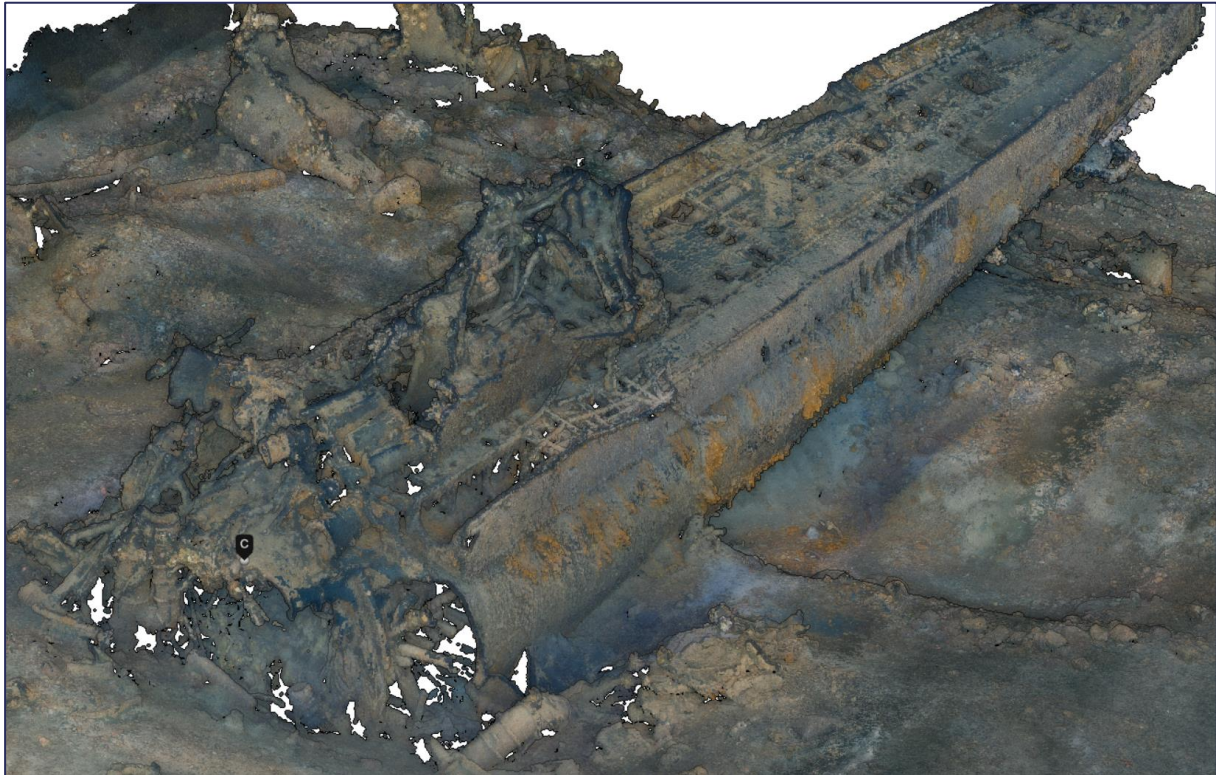


Figure 4-121 Location C at the fracture point of the stern

Table 4-12 UT Measurement Details for Location C

Measurement	Previous Reading (mm)	Previous Reading Average (mm)	Latest Reading (mm)	Material Remaining	Reduction (mm)
1	17.05	17.57	13.2	75.13%	4.37
2	18.10	17.57	14.85	84.52%	2.72
3	-	17.57	14.8	84.23%	2.77
Note *Reduction is based on the previous average reading					



Figure 4-122 Ultrasonic measurement at location C

Measurements at location D were taken at the exposed pressure hull at the conning tower (Figure 4-123 and Figure 4-124). The two readings indicate that the thickness of the casing has been reduced by 0.4 to 0.5 mm from the last reading (Table 4-13).

Table 4-13 UT Measurement Details for Location D

Measurement	Previous Reading (mm)	Previous Reading Average (mm)	Latest Reading (mm)	Material Remaining	Reduction (mm)
1	-	16	15.6	97.50%	0.4
2	16	16	15.5	96.88%	0.5
Note *Reduction is based on the previous average reading					

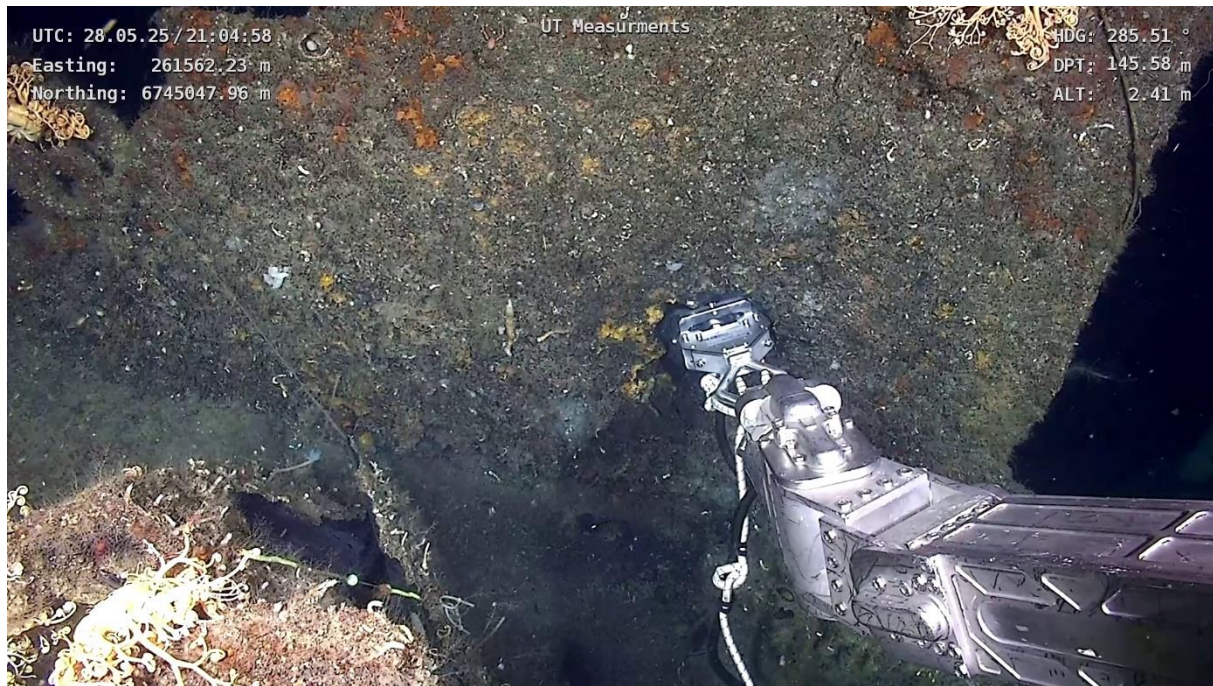


Figure 4-123 Ultrasonic measurement at location D

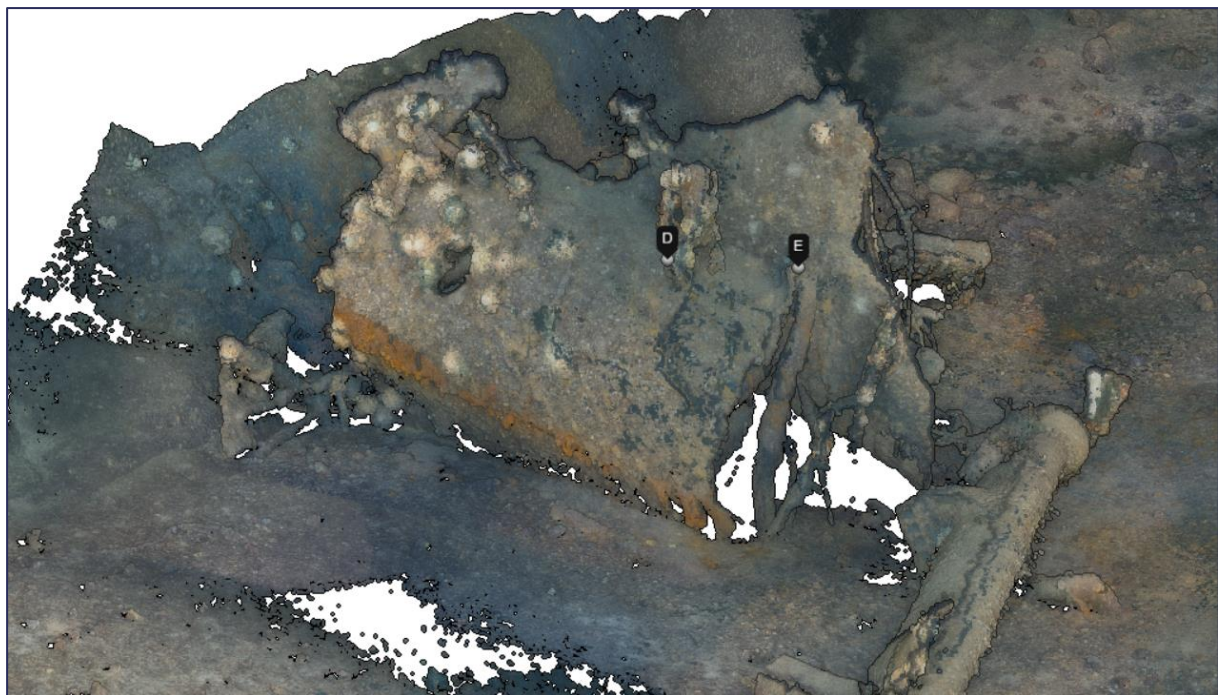


Figure 4-124 Location D and E at the conning tower

The measurements at location E were taken at the conning tower bunker tank (Figure 4-124 and Figure 4-125). The two readings indicate that the thickness of the casing has been reduced by 1.16 to 1.21 mm from the last reading (Table 4-14).

Table 4-14 UT Measurement Details for Location E

Measurement	Previous Reading (mm)	Previous Reading Average (mm)	Latest Reading (mm)	Material Remaining	Reduction (mm)
1	6.15	6.61	5.45	82.45%	1.16
2	7.08	6.61	5.4	81.69%	1.21
Note *Reduction is based on the previous average reading					

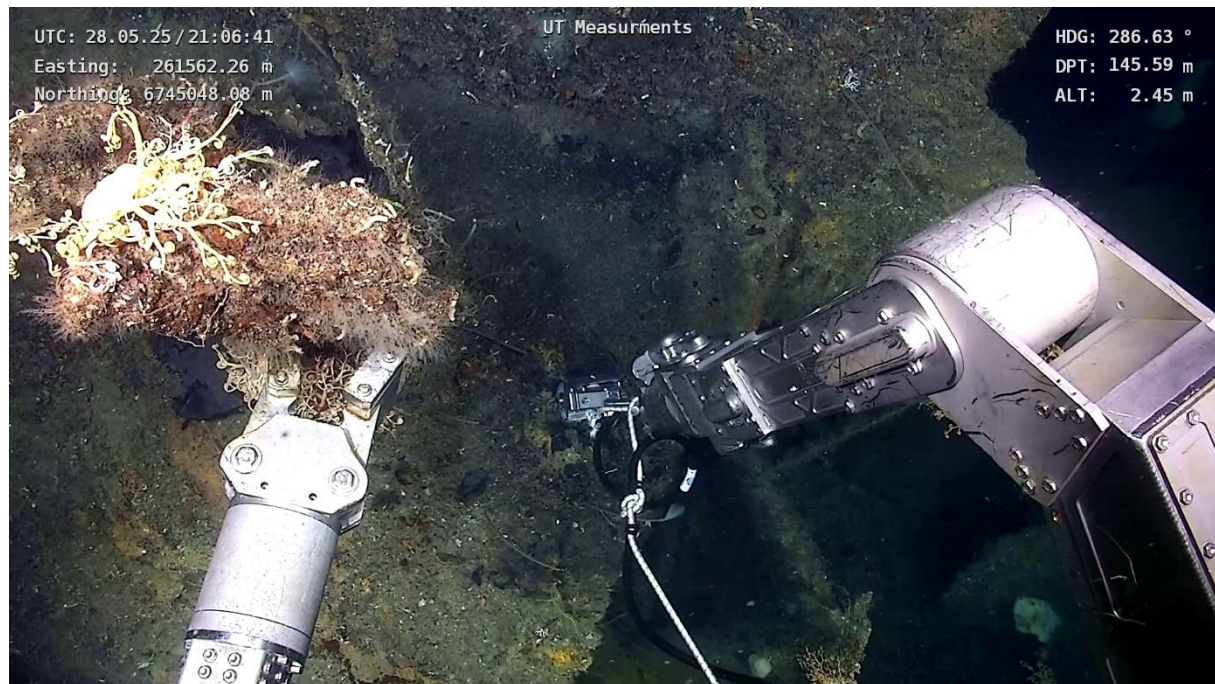


Figure 4-125 Ultrasonic measurement at location E

The overall results from the ultrasonic measurement probe show that the thickness of the wreck has been reduced between 19 % and 3 % from the previous readings. The reduction in material on the two large wreck pieces are relatively similar, measuring an average of 84 % reduction in material compared to the previous measurement. The thickness measurements indicate that the pressure hull is thinning compared to the previous survey. It should be noted that the measurements from 2005 show a bigger difference, between the two independent measurements, than from the current survey. The larger difference between the independent measurements at each location does question the validity of the previous results. Accurately determining how much the thickness has been reduced is therefore difficult.

5 ENVIRONMENTAL CONCERNS AND MITIGATIONS

During the survey campaign of U-864, there were no issues or incidents related to health, safety and environment (HSE). All offshore tasks were conducted in a safe and secure manner, prioritising the safety of personnel and equipment over the completion of an individual task. Dedicated task plans were prepared before mobilisation and toolbox talks (TBT) were held before any survey task was initiated. Task plans and TBTs are found in Appendix A and B respectively. All personnel working with and within the ROV hangar were equipped with PPE.

One of the most important requirements set by Kystverket was that the survey of the submarine U-864 be non-intrusive. This meant that all mapping activities had to be conducted from within the water column, without any contact between the ROV or equipment and the seabed. The seabed in the survey area is known to be contaminated with liquid mercury, making any physical interaction potentially hazardous if not handled with extreme caution.

During operations, the ROV was not in contact with the seabed at any stage nor did the thrusters suspend any significant amount of sediment whenever it operated close to the seabed. At times, the ROV was flying less than 1 m above the seabed without causing significant suspension. On one occasion, during the internal video inspection, the ROV caused sediments within the wreck to become suspended. The space to manoeuvre the ROV was limited causing it to be positioned closer to the seabed, which caused the suspension. Considering the ROV only caused sediments within the wreck to become suspended, it indicates that the sediments are finer on the inside of the wreck than on the outside.

Prior to the survey, concerns regarding the surficial sediment conditions and potential contamination due to suspension were raised. During visual inspection, the surficial sediments close to the wreck were found to consist of coarser sediments, such as sand (Figure 5-1 and Figure 5-2). This was also supported by core samples from 2006 (Reference 3), which showed a thin upper layer of sand followed by a layer of soft clay. Flying over the surficial sediments did not result in significant suspended material, limiting any potential contamination of the ROV and the sensors. The coarser seabed can also be seen in the 3D model from the photogrammetry (Figure 5-3 and Figure 5-4).

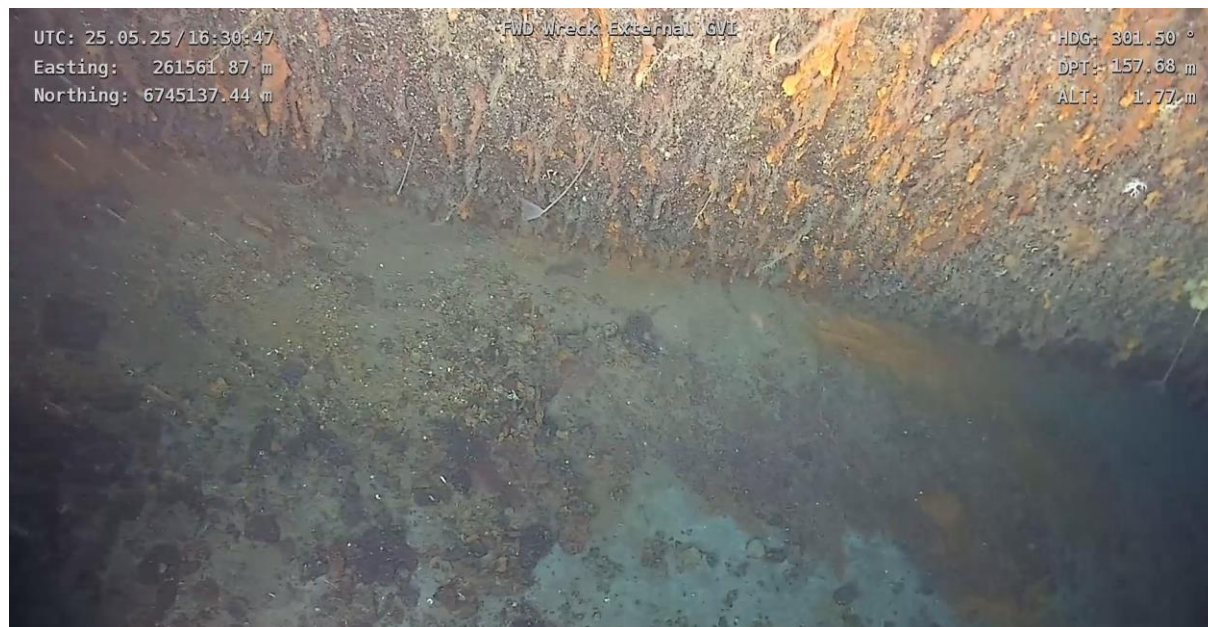


Figure 5-1 Image example from the bow section, showing coarser seabed than anticipated



Figure 5-2 Image example from the stern section, showing coarser seabed than expected



Figure 5-3 Photogrammetry data example, along the eastern side of the bow section, showing coarse sediments. The lack of submersion of debris and boulders support a coarser seabed than initially believed



Figure 5-4 Photogrammetry data example, of the stern section, showing coarse sediments. The lack of submersion of debris and boulders support a coarser seabed than initially believed

Whenever the ROV was returned to deck, it remained in latch and washed down before it was allowed to enter the hangar. This step was performed in order to mitigate any hazardous material entering the vessel and stop any contamination onboard the vessel. Washing of the ROV and equipment was a precautionary measure since the possibility of mercury contamination could not be 100% disproven. The ROV and a few sensors were also in direct contact with the submarine pressure hull during the visual inspection and thickness measurements. Consequently, returning the ROV to deck without washing was considered a health and safety risk.

During the surrogate item test (SIT), a mercury canister was placed on the seabed. The canister was placed on the seabed in order to provide an in-situ response for the electromagnetic surveys. After the calibrations were completed the surrogate canister was washed before it was returned and stored on the vessel. The SIT was performed outside of the area considered to be contaminated with mercury; however, a precautionary wash was performed to limit any exposure towards other equipment and personnel.

6 CONCLUSION

The survey of U-864 was completed successfully and without operational issues. The planned scope of work was mostly completed, with two survey tasks deemed unnecessary and of little additional value to the overall campaign. The majority of the survey data was of very good quality throughout the survey, with some of the geophysical and electromagnetic sensors achieving less than optimal results. The results from the video and photogrammetry resulted in extremely detailed images and models of the wreck and surrounding areas. The images captured were able to generate mm accuracy of the photogrammetry models, achieving new levels of details of the wreck and surrounding seabed. An overview of the planned and completed tasks is outlined in Table 6-1.

Table 6-1 Overview of Survey Tasks

Planned Survey Tasks	Status	Comments
Bathymetry (MBES)	Completed	The survey was considered to be successful and yielded the expected results. A complete 3D depth model of the wreck pieces and surrounding area was achieved
External GVI	Completed	The survey was considered to be successful and yielded the expected results
Electromagnetic (TSS 440)	Completed	The survey was considered to be successful and yielded the expected results. The data could not positively identify buried canisters
Electromagnetic (Octopulse)	Completed	The survey was considered to be successful and yielded usable results. The data was able to detect objects with the same signature as the mercury canisters
Photogrammetry	Completed	The survey was considered to be successful and yielded better than expected results. A comprehensive and extremely detailed 3D model of U-864 was achieved. The model achieved an accuracy of 2 mm
Sub-bottom traditional	Completed	The survey was not considered to be successful as the data quality was sub-par. Survey equipment could not reach desired resolution
Sub-bottom tilted	Completed	The survey was not considered to be successful as the data quality was sub-par. This was expected due to the interference from the wreck
Internal GVI	Completed	The survey was considered to be somewhat successful. The lance camera was able to record the insides but could not determine if bow torpedo bay hatch was open
Removal of wooden deck	Completed	The survey was considered to be successful and yielded the expected results. Deck was easily removed and inspection of crates was completed
Thickness measurements	Completed	The survey was considered to be successful and yielded the reliable thickness measurements
Depth measurements	Not completed	Depth measurements could be derived from photogrammetry and MBES models, therefore a dedicated depth measurement survey was considered unnecessary
Gradiometer (Dragonet)	Not completed	The gradiometer survey was not expected to perform effectively within the survey area due to significant debris and was therefore omitted to allocate time to other surveys

The sensor which struggled the most was the sub-bottom profiler data, where the geology and seabed conditions within the area proved challenging and limited the penetration. Surface debris and shallow bedrock limited penetration, causing the resolution at multiple locations to be poor. The minimal penetration resulted in limited details below the surface and introduced uncertainty in the interpretation. It should be noted that the same survey sensor (EdgeTech chirp) was used during a survey in 2016 with similar penetration and results. Based on the results from this survey and the 2016 survey, it is evident that the chirp system was not the ideal solution due to the challenging geological setting. Geological samples and logs were made available to support the interpretation of the sub-surface. By combining the CPT data with sub-bottom profiler results, an estimation of the hard ground below the seabed surface was obtained. The tilted sub-bottom profiler survey did not yield any usable results.

The sub-bottom profiler interpretation around the bow section, together with two nearby CPTs east of the wreck, indicate a sediment thickness of 3 m or more. Combining the geological information from the CPTs with the longitudinal and cross profiles derived from the photogrammetry and the design drawings, it is possible to make an educated guess on the status of the keel. From the design drawings (frame 95), it can be estimated that the keel is less than 2.5 m below the seabed surface. If the bedrock does not become shallower directly beneath the wreck, the keel may not have made contact and could therefore be intact. Any future excavation around the bow section should be made close to frame 95, as this location has the most information regarding the depth of the keel. Around the stern section, the sub-bottom interpretation and multiple CPTs indicate a sediment thickness between 1.5 m and 2 m. It is very important to understand that the interpretations are associated with a high degree of uncertainty due to data limitations. For the stern section, it is known that the keel is not completely destroyed. However, the overall status of the bow keel is uncertain and might be completely destroyed.

Another objective of the sub-bottom profiler survey was to determine if any pools of mercury could be identified within the sub-surface layers. No pools were seen in the sub-bottom data. The lack of identification could be a result of two things, one being the poor quality of the data and the other being that the mercury has not pooled together within the survey. The wreck is located at a slope and with a top layer of sand it is possible that the mercury has migrated away from the survey area. If the sand is permeable enough, the mercury could migrate within the layer without causing significant pooling of the liquid.

The challenges with the TSS 440 were mostly related to the abundance of metallic debris and the magnetic signature of U-864 itself. The submarines magnetic signature led to a masking area around the wreck. Consequently, distinguishing smaller magnetic anomalies related to mercury canisters was not possible. The lack of any visual confirmation also limits the usability of the electromagnetic survey, as the magnetic signature of mercury canisters are not unique enough to distinguish them from other debris.

The Octopulse system was able to detect 15 possible targets matching the expected signature of the mercury canisters. The Octopulse system was not impacted by the hull of the wreck, indicating its ability to detect single objects without interference from large nearby objects. Many of the potential targets were located within an area with multiple boulders and/or surface debris. Their locations introduce some uncertainty to the results, as it is possible that the system is detecting the signature of debris rather than mercury canisters. The visual survey could not confirm any canisters on the surface, hence the accuracy of the results could not be confirmed. The lack of any SBP interpretation in that area introduces more uncertainty. The thickness of the surface sediment could not be established and determining if a canister could be buried completely was not possible. If the thickness of the softer sediments is too thin, no canister could be completely submerged. However, the Octopulse system showed that it can more easily detect single targets without interference, and these targets should be examined in a future survey.

No mercury canisters could be positively identified and confirmed based on the geophysical, electromagnetic and visual inspection. The visual debris inspection did not find any new mercury containers on the seabed, nor could any potentially buried canisters be confirmed. Several unidentified debris items were observed; however, their dimensions did not correspond to previously found canisters. The previously found canisters had a width of 20 cm and a height between 40-60 cm.

The internal video inspection did not yield the desired results. The fracture points of the wreck sections contained too much debris, hindering the lance camera to extend far enough into the wreck. Therefore, determining if the forward torpedo bay hatch was open was not possible. It was also difficult to achieve optimal lighting, as the ROV could not move far into the wreck. However, the lance camera did provide some insight into the conditions of the wreck. The wreck was filled with sediments and debris at the fracture points, and cables or wires were observed hanging from the ceiling.

The actual volume of sediments within the wreck could not be determined due to insufficient photogrammetry data within the fracture opening. The photogrammetry images could not extract data far enough into the opening to be able to generate a sediment surface in the model. Without the top of the sediment inside of the wreck the model cannot produce an accurate estimation of the sediments volume observed from the video. A digital design drawing was also not available for determining the thickness of the sediments at the opening.

For any future survey, the use of a longer lance equipped with a better light source could possibly provide more details of the wreck's interior. The light source on the Imenco Lizard Shark camera used four 3 W LEDs, which did not sufficiently illuminate the inside. Cutting open another hatch in the bow hull could provide access to the torpedo bay. Another option is to deploy a micro-ROV into the fracture points. This would allow for the collection of additional visual data from the interior and could help determine whether the torpedo bay hatch remains open. However, it should be considered that the micro-ROV could be lost. The main reason why a micro-ROV was not utilised during this survey was the high risk of losing the equipment.

Access to the storage containers below the was achieved after the deck was removed. The deck was originally believed to be made of wood, but during the removal it was found to be metallic. The deck was easily removed so that the storage containers could be inspected. At the two inspected locations, cylindrical containers were observed. The contents of the cylinders were not identified, but they were believed to contain some kind of fuel or gas. One of the containers had bubbles emanating from it during the inspection.

The thickness measurements showed that the material thickness had been reduced at all locations. The measurements estimate that the thickness had been reduced between 3% and 19% at the different locations. At each locating, two measurements were done to verify the result. The differences between the two measurements in this survey showed less difference than the readings performed in 2005. Consequently, the current measurements represent an accurate result of the current thickness and the reduction of material.

A key objective for the next phase of the U-864 survey is to gain access to the bow section keel. To get access to the keel, a suitable location, where the keel is intact is critical to find. Even though the sub-bottom survey results were less conclusive than originally hoped, a combination of sub-bottom, photogrammetry, CPT data and frame drawings were able to estimate a depth to bedrock. From the isopachs, generated from SBP and CPT data, depth to bedrock is estimated to be deepest at the eastern side of the wreck. The depth below surface is estimated to be between 2.5 m and 3.0 m. At deck frame 95, close to the fracture point, the depth of the keel is estimated to be buried less than 1.5 m below the surface. Assuming the keel is intact, excavating close to frame 95 would be the best option considering the location has the most information regarding burial depth. This location (264568 mE, 6745149 mN) was noted as a location of interest during a data presentation with DNV.

7 DELIVERY STRUCTURE

Table 7-1 Summary of Delivery

Folder	Subfolder	Delivery	File Type	Comments
01_REPORTS	-	Mobilisation and calibration report final survey report Elwave results report	.pdf	
02_BATHY	Gridded Soundings Contours Raster Shaded Relief	Processed multibeam data	.xyz .shp .dxf .tif .las	
03_SBP	SEGY IMAGES	Processed sub-bottom profiler data	.sgy .png	
04_PHOTOGRAMMETRY	Pointcloud Mesh IMG	Processed photogrammetry 3d models and raw images	.las .slpk .jpg	
05_ELECTROMAGNETIC	-	TSS 440 rasters	.tif	
06_GIS	-	Geodatabase Target list	.gdb	GIS database with 3D scene Target list includes new targets observed during visual inspection
07_UT	-	Thickness measurements	.pdf	
08_VIDEO	Multiple	Video for all survey	.MPG	
09_CAD	-	Cross profiles Longitudinal profiles	.zip	Long and cross profiles superimposed with design drawings
10_EIVA_SOFTWARE	REACH-600057-NMP-U-864 Total Model	Software to view bathymetry and photogrammetry in 3D	.nmp .exe	Project include historic DTMs provided by Kystverket

8 REFERENCES

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2. Geoconsult (2006): *Sluttrapport U-864 - Fase 2 2006: Kartlegging og fjerning av kvikksølvforurensning* (2 November 2006). Report no. 14021-SUR-O15-00001-06C, pp. 43
3. NGI (2006): *Kartlegging og fjerning av kvikksølvforurensning U864: Geotekniske undersøkelser og vurderinger* (06 November 2006). Report no. 20061348-1, pp. 16 + attachements
4. DOF (2013): *Phase 3A Survey and Geotechnical Campaign Report* (18 April 2013). Report no. 600225-DSNO-O15-0002, pp. 92 + attachements
5. DOF (2014): *Phase 3B Keel Inspection U-864 Report* (14 May 2014). Report no. 600246-PJ-O15-0001, pp. 29 + attachements

LIST OF APPENDICES

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- A.1 REACH-600057-TP-001 SIT
- A.2 REACH-600057-TP-002 MBES SURVEY
- A.3 REACH-600057-TP-003 GVI
- A.4 REACH-600057-TP-004 EM SURVEY
- A.5 REACH-600057-TP-005 PHOTOGRAMMETRY SURVEY
- A.6 REACH-600057-TP-007 SBP TARGET VERIFICATION
- A.7 REACH-600057-TP-008 SBP GEOPHYSICAL SURVEY
- A.8 REACH-600057-TP-009 KEEL SHAPE MEASUREMENTS
- A.9 REACH-600057-TP-010 UT MEASUREMENTS
- A.10 REACH-600057-TP-011 REMOVAL OF EXTERNAL DECK

B. TOOL BOX TALKS

C. MOBILISATION REPORT

D. ELWAVE REPORT

E. INSPECTION REPORT

F. HISTORIC TARGET LIST

G. 2005 THICKNESS MEASUREMENTS

A. TASK PLANS

A.1 REACH-600057-TP-001 SIT



A.2 REACH-600057-TP-002 MBES SURVEY



A.3 REACH-600057-TP-003 GVI



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