Odyssey Papers 32

HMS *Victory* (Site 25C). Preliminary Results of the Non-Disturbance Shipwreck Survey, 2012

Gerhard Seiffert, Neil Cunningham Dobson, Frederick Van de Walle
Odyssey Marine Exploration, Tampa, Florida, USA

Sean Kingsley
Wreck Watch Int., London, UK

In 2012, Odyssey Marine Exploration conducted an extensive non-disturbance survey of the wreck of the *Victory* (site 25C), lost in the western English Channel on 5 October 1744. The fieldwork combined visual documentation and recording of surface features with geophysical analyses that included side-scan, magnetometer and multibeam surveys. Two new photomosaics demonstrated that the wreck had been subjected to site-wide impacts since 2008.

FADE and TSS surveys designed to identify both surface and buried ferrous and non-ferrous anomalies, plotted against the results of a pioneering sub-bottom imaging survey, have produced a far more detailed understanding of the geographical and stratigraphic parameters of site 25C, including two formerly undetected offsite debris fields. Photographic data were collated for an environmental and marine biological site assessment. Wood and metallic samples attached to three sacrificial frames were buried offsite as a core component of the environmental study program.

These holistic archaeological and environmental activities were conducted in a consultancy capacity for the Maritime Heritage Foundation in compliance with, and exceeding, Phases 1-2 of *HMS Victory, 1744 (Site 25C) – Project Design*, which have now been completed. The result is an enhanced understanding of the site and context of the wreck of the *Victory*.

1. Introduction

In 2012, Odyssey Marine Exploration conducted a detailed non-disturbance archaeological survey program on the wreck of the First Rate warship HMS *Victory* (site 25C), lost in the western English Channel on 5 October 1744 (Cunningham Dobson and Kingsley, 2010). The non-disturbance activities detailed in *HMS Victory, 1744 (Site 25C) – Project Design* (2012) required a complex package of geophysical and ROV (Remotely-Operated Vehicle) surveys to be undertaken to enhance understanding of the site's character prior to proposed future phases of excavation of cultural materials.

All activities described in this report were conducted in a consultancy capacity for the Maritime Heritage Foundation and pursuant to the Project Design, which through the inclusion of a sub-bottom imaging survey (for which data was collated on-site on 20 October 2011), and the extension of some survey grid sizes, exceeded the pre-established specifications. The current fieldwork resulted in the completion of all separate Phase 1A and Phase 1B-2 activities (Tables 1-2).

The incorporation of processed results from the October 2011 sub-bottom profiling survey into the 2012 non-disturbance analysis was a major initiative. This powerful tool has contributed to a far more advanced understanding of the potential three-dimensional complexity of the wreck of the *Victory*. The activities conducted and preliminary results achieved through these phases of the project are summarized below. Analysis of the data and surveys at the site are ongoing, and will comprise a component of the final published results.

Collation of data acquired to produce a study of the site-specific marine biology and shipwreck's oasis effect was completed during the survey. Surface sediments were sampled from Area F as part of the environmental study (Figs. 12, 53-55). Both sets of data were submitted to the University of St. Andrews for analysis.

2. Side-Scan & Magnetometer Sonar Survey

The non-disturbance study commenced with a high-resolution side-scan sonar and magnetometer survey conducted over 32.5 hours. The project requirement was to cover a search area extending over 2,000 x 2,000m (4km square), which was exceeded. A total of 41 survey lines

Phase	Action	Area Examined 2012	Compliance
1A	Test fly ROV systems	Off-site, 14 hours & 49 minutes	Yes
1A	Establish array transponder beacons & datum markers	Off-site	Yes
1A	Imposition virtual site grid	Central site	Yes
1A	Side-scan survey, 2 x 2km	5.5km square, 32.5 hours	Exceeded
1A	Multibeam survey, 400 x 200m	5.5km square, plus use of wider Wessex Archaeology multibeam data	Yes
1A	Visual survey, 200 x 200m	200 x 200m zone	Yes
1A	FADE survey, 200 x 200m	280 x 200 metres, 5.6km square	Exceeded
1A	TSS survey, 200 x 200m	200 x 200m	Yes
1A	Sub-bottom imaging survey *	225 x 190m	Exceeded
1A	Burial offsite of modern sacrificial materials	Burial 70m northeast of wreck	Yes

* Not stipulated in the Project Design, but conducted on 20 October 2011 & processed for Phase 1A site interpretation.

Table 1. Summary of Phase 1A non-disturbance Project Design survey deliverables on site 25C, 2012.

Phase	Action	Area Examined 2012	Compliance
1B	High-resolution photomosaic, 65 x 40m	64 x 45m	Yes
1B	Photographic record surface artifacts & archaeological features	200 x 200m	Yes
1B	Measurements salient surface artifacts	Site-wide	Yes
2	Environmental analysis: current directions & speed, temperature, salinity, water ph.	Monitoring device fitted to the ROV for live data stream logging	Yes
2	Sampling sediment stratigraphy	Surface sediments recovered	Yes
2	Marine biological site assessment	Video & photographic survey completed	Yes
2	Intrusive pollutant assessment & recording	200 x 200m	Yes

Table 2. Summary of Phase 1B & Phase 2 non-disturbance Project Design survey deliverables on site 25C, 2012.

were covered (5.5km square in area, total line length 92.5km). The equipment used was an Edgetech 4200 Sonar and Geometrics 822 Magnetometer operated at 410 kHz, 75m range, 50m line spacing and 10m fish altitude tied to USBL positioning (Fig. 7).

The data indicated that the location and form of the characteristic low-lying sandwave to the east of the site (designated Sandwave 1) remained unchanged. Fifteen anomalies off the main wreck mound nucleus were identified for further ROV investigation. Six of these were visual targets with a related magnetometer anomaly, another six solely visual, and three manifested as non-visual magnetometer anomalies (Fig. 8).

3. Multibeam Sonar

The Project Design required an area of 400 x 200m to be surveyed by multibeam geophysical analysis. The equipment used was a ROV-mounted Reson Seabat 7125 and related PDS 2000 data processing software (Fig. 1). A total of 35 lines were surveyed (14km total line length) during the course of eight dives. The dives included patch tests and technology tweaking in order to maximize reliability between the multibeam technology, newly installed Sonardyne SPRINT Inertial Navigation System and optimization when used on the ROV Zeus.

The core data was collated in the course of 22 hours during three dives. Line spacing was 50m wide, 20m altitude above the sea bottom and the resolution of grid files was 10cm, which was sufficient to pick up details down to the size of cannon trunnions and cascabels exposed on the site's surface (Figs. 13-14).

Viewed in 3D ArcScene software, the resultant multibeam image revealed the macro environment to lie within a depth range of between 68.1m and 74.1m. The wreck appears as a discretely bounded artificial ellipsoidal mound with a 50cm elevation (72.0-72.5m depth) above the surrounding sea floor, and flanked around 22m to the east by Sandwave 1, part of a continuous northeast/southwest oriented sedimentary feature extending at least 750m in length. The wreck and sandwave comprise elevated highs on an otherwise even and featureless seabed.

To the west the seabed descends smoothly down to bedrock at a depth of 74.1m. To the east the seabed descends smoothly in a gentle depression towards Sandwave 1, which reaches a localised high of 68.1m. East of the sandwave the seabed descends to a depth of 74.1m before rising to form a second sandwave located about 125m east (Sandwave 2). These sedimentary features comprise two of a series of seven examples generally parallel and all trending northeast/southwest across an east/west axis of 3km. The orientations of the sandwaves and low-lying parallel ripples on site 25C reflect a dominant northeast/southwest tidal current (180º cyclical daily rotation). The character of a series of approximately eight small depressions to the northwest of the main wreck mound (natural, impact craters formed upon the ship's original deposition on the seabed or scoured depressions) requires future investigation by ROV in a subsequent phase of the Project Design.

Fig. 1. Multibeam transducers mounted on the ROV Zeus.

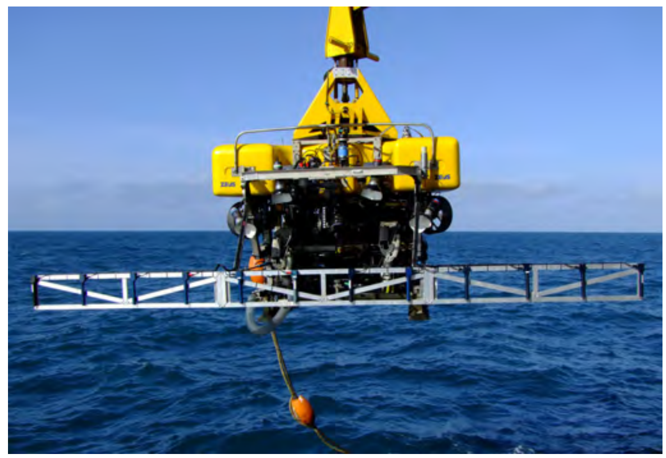


Fig. 2. FADE equipment wings extended in front of the ROV Zeus in preparation for survey.

Fig. 3. TSS equipment attached in front of the ROV Zeus.

4. FADE Survey

The *Victory* Project Design required a FADE (Ferrous Anomaly Detection Equipment) magnetometer survey to be conducted across an area of 200 x 200m. This system identifies ferrous anomalies down to buried depths of 2m. The array was installed onto the ROV Zeus in the form of 12 vertically mounted fluxgate gradiometer units, with 60cm separation, giving a total frame width of 6.6m (Fig. 2). In actuality, the geographical parameters of this survey were extended eastwards, which resulted in a final search area covering 280 x 200m. A total of 40 lines (total line length 11.2km) were flown by the ROV Zeus at 5m spacing over 32.5 hours (Fig. 5).

The plotting of absolute values for the FADE signals resulted in 2,108,855 x,y data points being measured. Values of less than 40 were defined as background noise. As anticipated, in size, abundance and intensity the resultant anomalies were concentrated within the main wreck mound, forming a subtle ship-shape perimeter when plotted in ArcScene 3D (Figs. 17-18). Isolated anomalies, mostly situated to the northeast (anchor A2 region) and east of the wreck mound, were recorded. Anomalies east of Sandwave 1 were previously unrecorded and reveal the presence of what may be a significant cultural debris field in this area.

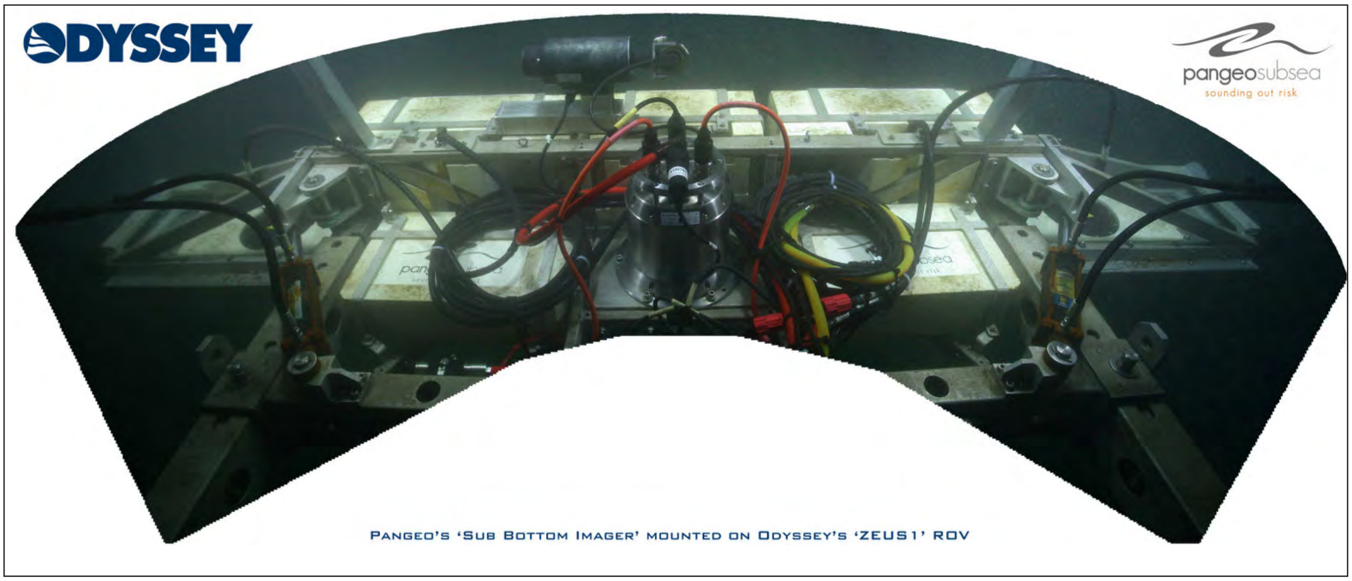


Fig. 4. PanGeo Subsea Inc. sub-bottom imaging equipment attached to the ROV Zeus.

5. TSS Survey

The 2012 non-disturbance survey examined an area of 200 x 200m, centred on the wreck mound, using a TSS array of three horizontally ROV-mounted pulse induction sensor units giving a total frame width of 1.9m (Fig. 3). Unlike FADE, which solely identifies ferrous materials, the TSS equipment detects both ferrous and non-ferrous metals to depths of approximately 2m depending on their mass. Since the TSS frame is much narrower than the FADE frame (1.9m compared to 6.9m), a tighter line spacing of 1.5m was required compared to 5m for the FADE survey. A total of 134 lines were surveyed by the ROV during four dives taking 61 hours and 15 minutes to complete (total line length 26.8km; Fig. 5).

Signal values obtained ranged between 0 and 32,766 (device maximum) and 883,030 data points were measured and plotted as x,y features. Signal values of less than 50 were defined as background noise. Once again, in size, abundance and intensity the anomalies proved to represent a concentration across the main wreck mound. Gridding of the data points and plotting in ArcScene 3D once more revealed a subtle ship-shaped outline (Figs. 19-20).

A large area of scattered small-scale weak anomalies, 83 x 83m, was identified northwest of the wreck nucleus (designated Debris Field 1). The single cannon C32, isolated 48m southwest of the wreck mound, appeared as a high-value signal. A second notable concentration of smaller anomalies, but with high value returns, was recorded 57m southeast of the wreck nucleus (designated Debris Field 2) across an area of about 40 x 40m, significantly east of Sandwave 1 in association with cannon C38, which partly explains the high FADE and TSS readings for this area.

The TSS survey proved highly informative for qualifying the metallic mass and scale of scattered cultural wreck debris. The signals' scales in Debris Field 2 seem to signify the presence of more significant material culture in this zone, perhaps explicable as a second cluster of contextualised wreckage. Significantly, this material lies east of Sandwave 1, which consequently is most likely to have formed after Debris Field 2 was deposited (as opposed to extensive debris having been dragged such a distance over or through this geological feature).

6. Sub-Bottom Imaging (SBI) Survey

In addition to the above survey initiatives, Odyssey incorporated the results of a proprietary, experimental, high-resolution acoustic sub-bottom imaging (SBI) survey as part of the site 25C non-disturbance analysis, based on data obtained during 10 hours and 40 minutes on 20 October 2011 (Fig. 4).

The equipment utilized was a PanGeo Subsea Sub-Bottom Imager™ (SBI™), which provides real-time 3D high-resolution sub-seabed surveys, previously typically exploited for commercial and military high-resolution sub-bottom imaging requirements, such as pipeline and HVDC cable surveys, for defence and security (UXO detection, route clearance) and offshore renewable energy. The SBI interfaces with an ROV and uses unique acoustic intensity imaging to delineate sub-seabed strata and buried geohazards with a resolution exceeding 5cm. The SBI delivers high-resolution georeferenced volumetric images with a 5m swath. The SBI data stream is combined with other sensor survey data, such as multibeam, and viewed in 3D within EIVA NaviModel software. Its operational systems comprise:

- 5 x 8 channel hydrophone arrays.
- 1 x Parametric: 200 kHz primary with 5-35 kHz secondary.
- 3 x HF chirp projectors: 4-14 kHz.
- INS - IXSEA PHINS or similar c/w DV.
- An array that folds for launch/recovery.
- Maximum operating depth: 1,000m survey altitude, 3.5m above seabed, survey speed up to 2 knots.

A total of 55 survey lines were covered during the 2011 SBI survey with line spacing of 3.4m. The area originally surveyed measured 225 x 190m (42,750m square, total line length 121.2km). However, due to the vast volume of raw data collated (569 Gb) and processing requirements, the data processed currently represents a 100 x 80m block centred on the wreck mound nucleus (Fig. 5).

The SBI survey generated a 3D-representation of a 4m thick layer that profiled the surface and strata below the seabed in the wreck vicinity. Since PanGeo currently has no software-supported workflow that automatically analyses the dataset to reveal buried objects, all data interpretation was accomplished manually strictly based on a subset of the provided raster image slices. Using this method, buried objects could be identified and consisted of a total of 78 linear anomalies ('Cannon Shaped Returns', CSR's) and 63 irregular anomalies ('Multiple Hard Returns', MHR's). The possibility that further objects are buried in depths exceeding 80cm, the maximum depth processed to date, cannot be excluded. The dataset will be reviewed again as soon as new revisions of PanGeo's analytical software permits such an analysis.

The SBI layer was thin-sliced horizontally in software to create 10cm deep image layers. Hard objects composed of any medium (metal, wood, rock, etc.) appeared as bright anomalies. The system successfully identified 88 anomalies of possible Multiple Hard Returns and Cannon Shaped Returns seemingly cultural in character (Figs. 24-25). Post-processing identified examples of visual anomalies. For instance, a cannon-shaped object that first appeared at a water depth of 76.4m remained visible in seabed slices down to a depth of 76.7m, giving a resultant object thickness of approximately 30cm (Fig. 21). In a second example, a cannon-shaped object emerged at a water depth of 77.3m, 70cm below the seabed surface depth of 76.6m

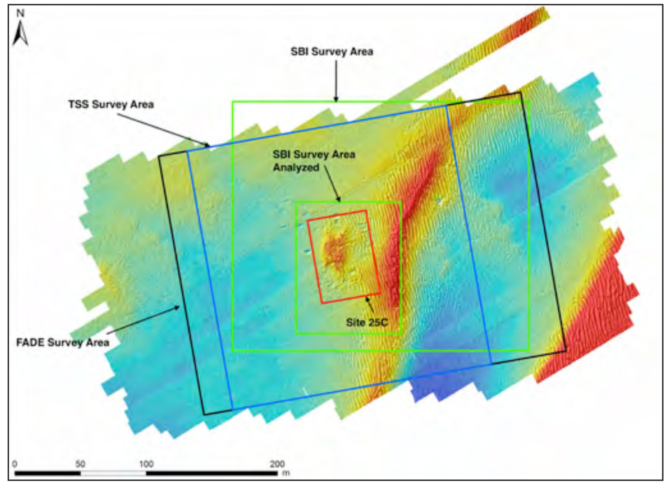


Fig. 5. Non-disturbance survey zones established and examined on site 25C (October 2011 and 2012).

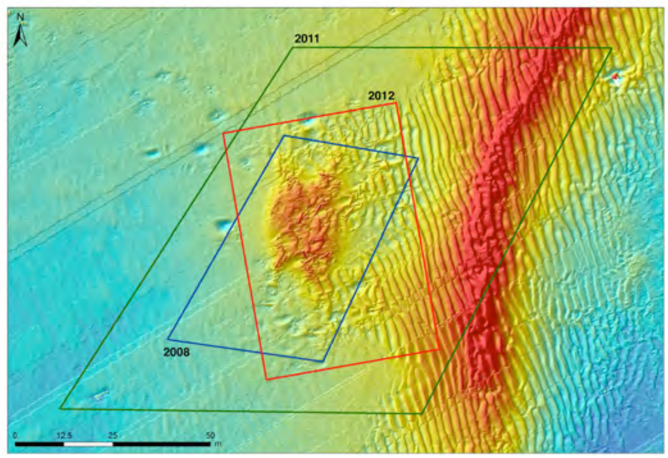


Fig. 6. 2008, 2011 and 2012 comparative photomosaic areas produced for site 25C.

(Figs. 22-23). The SBI anomalies associated with the main wreck mound nucleus range in length from 1.39-4.07m (average 2.65m) and 0.1-0.6m in thickness. Burial depths range from 0-0.8m, with 79% located between 0-0.2m deep and 8% over 0.3m. (Unlike the accurate multibeam data, the SBI depths provided to Odyssey are only relative: the SBI survey was seemingly not tide corrected.)

This cutting-edge remote sensing tool has provided significant results by predicting object locations and depths. The method is time consuming and exhibits some errors experienced in both x,y positioning data, which expose the current limitations and scope for refining this new technology. A better prediction of burial depths could possibly be achieved by supporting the interpretation of manual data with algorithms.

Nevertheless, the method shows promise for future site analysis. An advantage of SBI over magnetic and pulse-induction methods like TSS and FADE is that the

Area	2008 Guns	2011 Guns	2012 Guns	2012 Changes
A	7	8	8	10-15cm sediment erosion, surface concretions due south C3 broken up & fragmented. Rigging south C1 displaced. C2 relocated, C45 newly exposed. Area A surface gun totals 2008-2012: 8.
B	9	7	8	Fluctuating sediments: 5-10cm erosion to north, 10cm sediment cover north of A1 shank, south of A1 unchanged. C37 buried, C41 newly exposed, C20 relocated. New rigging exposed in Area B2, copper kettle K1 & lobster pot displaced 90º. Area B surface gun totals 2008-2012: 10.
C	3	2	4	New planking exposed north of C4; 2008 surface to its south buried. C4 rotated 90º. C44 & C49 newly exposed, C36 buried. Area C surface gun totals 2008-2012: 5.
D	6	4	5	Area west of C9 impacted: surface structures, wood & concretions fragmented and displaced, area populated with hermit crabs, crabs & lobsters; new fishing cable. C10 & C11 silted by 5-10cm. Cannon C13 & associated plank disappeared (looted 2011). Area D surface gun totals 2008-2012: 6.
E	4	5	5	2011: C21 & C22 changed orientations & shunted, C20 relocated from Area B, C23 buried, C50 newly exposed, large broken tubular concretion dragged. 2012: C23 exposed, C50 buried, planking & concretions under C20 cascabel newly uncovered, 5.5m-long plank due south of C22/C23 uncovered. Area E surface gun totals 2008-2012: 6.
F	2	2	2	2008: around 32 concreted iron ballast ingots; 2012: around 26 iron ingots, C30 displaced, 5-10cm sediment reburial to north & east, new fishing net & cable to south. Area F surface gun totals 2008-2012: 2.
G	5	6	6	C24 buried, C28 recovered by Odyssey (2008), C39, C40, C48 newly exposed. Extensive disarticulated planking exposed in central north/south strip. Two 2011 guns (C51-52) buried 2012: total Area G gun count 2008-12 is 9. Area G surface gun totals 2008-2012: 8.

Table 3. Summary of bronze cannon numbers and surface characteristic changes on site 25C by Area, October 2008, October 2011 and 2012.

imagery delivers a sharp representation of the object's shape plus a depth reading, not just a 'cloud' impression. Assumptions concerning the object's nature ('cannon shaped') are much easier to propose than with magnetic or pulse-induction anomalies.

7. Photomosaics & Surface Survey

Two photomosaics were formulated during the 2012 survey season. The first was produced across an area of 64 x 45m (2,880m square). A total of 81 lines were flown by the ROV Zeus at a spacing width of 0.80m and an auto altitude of 3.0m, when 4,536 digital photographs were taken (Fig. 9). A second photomosaic was also produced across an area of 64 x 45m (2,880m square). A total of 82 lines were flown by the ROV Zeus at a spacing width of 0.80m and an auto altitude of 3.0m, when 4,709 digital photographs were taken (Fig. 10).

The 2012 photomosaic area was smaller than the 2011 photomosaic zone, but of comparable size to the 2008 photomosaic (Fig. 6). Utilizing the newly installed INS navigation and surveying system, the positioning in 2012 was superior to previous work. Highly accurate matching was achieved between the superimposed photomosaic and multibeam data (Figs. 15-16).

The 2012 photomosaic enabled every natural and cultural object on the seabed to be distinguished down to the size of cooking galley hearth brick fragments, pebbles and individual hermit crabs. Localized changes in sediment cover between 2008 and 2012 ranged from -15cm to the northeast (Area A) to +5-10cm (Area D), giving a total amplitude of approximately 25cm in these measured areas. Significant cannon impacts were recorded in all areas in the form of displaced cannon (shunted and changed orientations), relocated guns (no longer present

Dive No.	841	842	843	844	845	846	847
Temperature °C low	11.51467	11.54986	11.59524	11.63277	11.65387	11.74135	11.74472
Temperature °C high	11.53338	11.70965	12.04167	11.78511	12.31164	11.76948	11.80102
Temperature °C average	11.51874931	11.57984	11.62382	11.66048	11.68973	11.75078	11.75869
Oxygen saturation ml/l (Weiss) low	6.094799	6.072719	6.078442	6.062896	6.050372	6.088714	6.125709
Oxygen saturation ml/l (Weiss) high	6.097682	6.093462	6.143142	6.082856	6.132967	6.141337	6.133986
Oxygen saturation ml/l (Weiss) average	6.096538309	6.08892	6.126913	6.078723	6.105206	6.138772	6.132561
Salinity PSU low	35.42483	35.385	33.80263	35.38428	33.93333	33.50641	33.65703
Salinity PSU high	35.44992	35.48481	35.45602	35.48342	35.14625	34.88516	33.7712
Salinity PSU average	35.44365407	35.43509	34.29523	35.42814	34.63671	33.55371	33.68831
pH low	8.2103	8.2103	8.2486	8.2454	8.0702	8.1799	8.2243
pH high	8.2729	8.267	8.2703	8.2606	8.2655	8.2437	8.2406
pH average	8.26609678	8.259838	8.257445	8.253024	8.246794	8.236085	8.233308

Table 4. Environmental data obtained from site 25C in 2012.

in their original contexts) and scratched surfaces (Kingsley *et al.*, 2012). Some significant surficial hull elements originally observed on the site were no longer present in 2011 and 2012, and prominent contexts had deteriorated or had been destroyed (eg. a circular feature surrounded by planking, concreted surfaces and a barrel stave in western Area D).

Other than an intact dark brown glass bottle observed in the April 2011 video survey (still present in 2012 in Area F; Fig. 42) and limited iron rigging (Area B2), few major new artifacts were recorded in 2012. Exceptions include a bronze tap-like object with a handle contextualized with galley bricks in Area C (Fig. 43), in form resembling the tap attached to the copper kettle recovered on the Goodwin Sands from the 1703 wreck of the Third Rate warship the *Stirling Castle* (Lyon, 1980: 340), a cluster of concreted cannonballs in southwest Area C, a large cylindrical iron concretion in south Area D (Fig. 44), and a 4m-long plank underlying C22 and C23 in Area E.

Several intact wooden and bronze sheave rigging blocks lie alongside cannon (Figs. 45-47), some examples of which still contain a tampion within the gun mouth (Figs. 48-51). No ceramic or glass vessels or sherds were otherwise present on the site's surface. The most prominent surface deposit of red brick fragments is clustered in Area C1, which correlates with the general original horizontal deposition point of the ship's cooking galley.

A total of 39 bronze cannon were recorded on site 25C in 2008 (36 on-site plus C32, C33 and C38 presumably dragged by fishing trawlers 48-57m off-site). The 2011 visible cannon total was 34 (excludes C28 and C33 recovered by Odyssey and C13 salvaged without permission by a Dutch company, giving a total known 2011 count of 37 guns). The 2012 photomosaic cannon count amounted to 39 (includes C47 dragged by trawlers 233m offsite to the northeast, Fig. 41). Taking all activities into consideration for 2008-2012 (gun reburial, fresh exposures, salvage, recovery, offsite contexts), as a whole 50 cannon are currently known from site 25C (45 on-site, C49 site outlier, and four offsite) (Table 3). The 2012 gun positions and all other archaeological site features are presented on the 2012 pre-disturbance site plan (Fig. 11).

8. Environmental Sampling

Environmental data (Phase 2 Project Design) were collected throughout the 2012 non-disturbance survey program operations using a SBE19PlusV2 Seacat Profiler CTD.[1] The sensors are enclosed within a hard-fastened casing, which makes it suitable for sensing the water ambient to its mounting position, but not appropriate for use as a probe to penetrate the seabed. A redox potential or EH probe was not mounted on the SBE19PlusV2 because measuring the water ambient to its mounting position would be inaccurate. The profiler automatically takes measurements

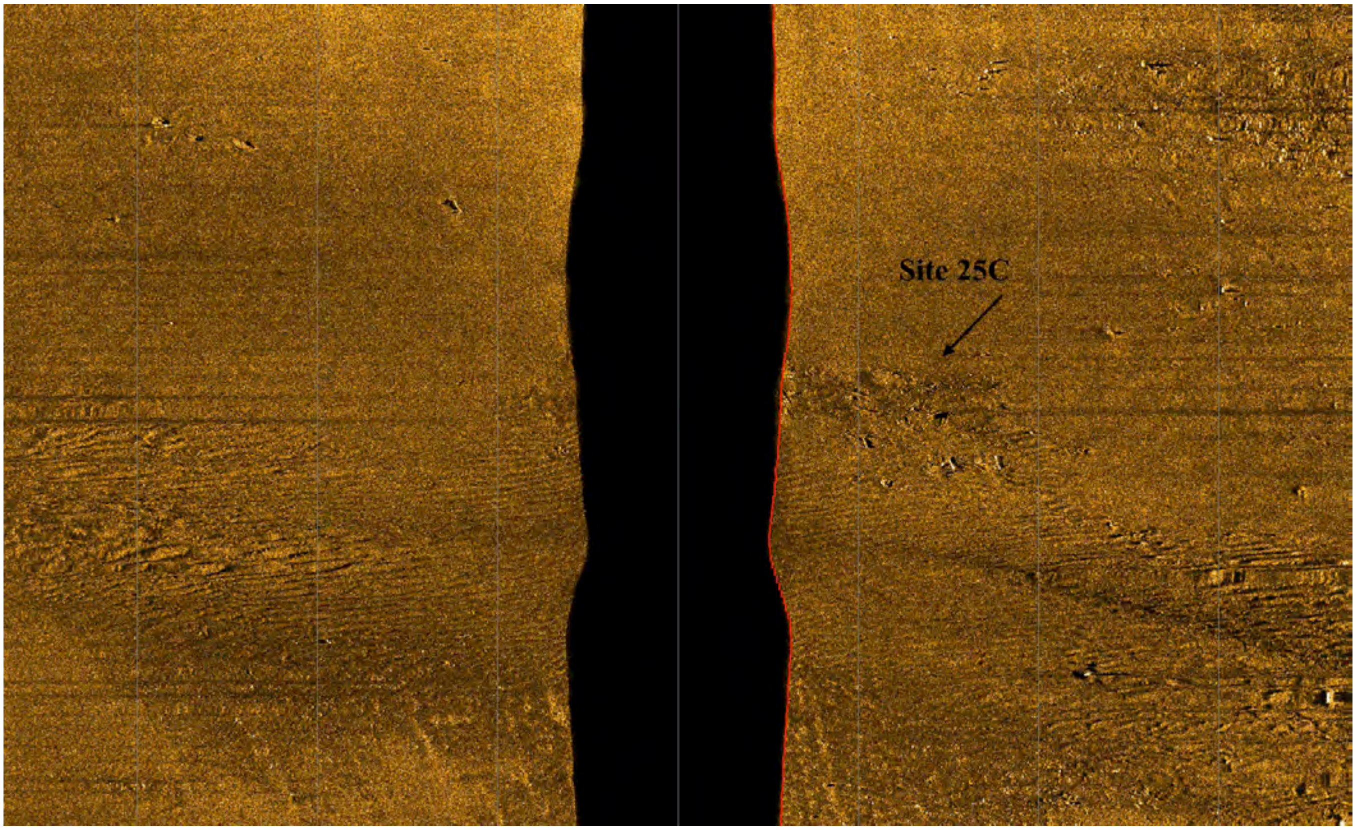


Fig. 7. High-resolution side-scan sonar image of site 25C (2012).

at five-second intervals as soon as the ROV reaches the sea bottom and ends prior to recovery.

The following data were provided by the different sensors mounted on the SBE19PlusV2:

- Scan count.
- Time elapsed (sec).
- Latitude (deg).
- Longitude (deg).
- Temperature (deg C).
- Conductivity S/m or Siemens per meter.
- Pressure, Strain Gauge (db).
- Depth (Salt Water, m).
- Oxygen, SBE 43 (ml/l).
- Oxygen, SBE 43 (% saturation).
- pH.
- Oxygen Saturation, Weiss (ml/l).
- Salinity, PSU or practical salinity unit.
- Sound Velocity (Wilson, m/s).

Minimum, maximum and average environmental data readings were recorded. Following completion of the collation of substantial data, synthesized results may provide key information about contextual levels of preservation encountered on site 25C, including why some cannon are concreted, seem to have corroded at a different speed or seem to have different corrosion patterns. The results will also help guide conservation choices and processes, as well as future decisions related to site preservation and management.

The main factors influencing the rate and mechanism of corrosion are strongly interrelated, and a change in one usually produces a change in others. As a result, the relationships between site, artifact condition and corrosion products are often complex. The measurements taken to date are in the normal range of expectations (Table 3). The rationale underlying such sampling is:

1. Temperature: water temperature is measured because of its effect on corrosion rates. However, measuring the corrosion rate is complicated by the effect of temperature on biological growth. In the absence of biological effect, the rate of corrosion would be expected to approximately double for every 10°C rise in temperature.

2. Dissolved oxygen (DO)/oxygen saturation: for metal exposed to seawater, the main cathodic reaction is usually

oxygen reduction. The corrosion rate in such cases is frequently controlled by the availability of DO at the cathodic site. In the upper layers of the ocean, to a depth of 500m, the oxygen content is highly dependent on the biological activity and the rate of mixing with surface layers. Low oxygen levels are encountered underneath marine concretions and below the seabed, even on well-oxygenated sites. In this case the low levels are mainly the result of biological uptake of oxygen combined with the slow exchange with external seawater. In such cases the rate of corrosion may well be controlled by sulphate-reducing bacteria rather than DO.

3. Salinity: in general metal corrosion rates escalate with increasing salinity. The salinity of seawater is defined as the total amount of dissolved salt, in grams, contained in one kilogram of water. Salinity in open ocean is generally around 35ppt. Salinity can affect metal corrosion in a variety of ways. For example, by providing an ionic conducting solution for the transfer of ions between anodic and cathodic areas, by forming protective surface layers on some metals and destroying those on others, by altering the amount of oxygen dissolved in the water, and by supplying ions which can catalyze corrosion reactions. In general, an increase in salinity produces an increase in metal corrosion rates.

4. Seawater pH: normal seawater has a pH range between 7.5 and 8.2, but pH can vary from 6.5 to 9.5 in the sediment beneath the seabed. Some changes may be caused by the action of sulphate-reducing bacteria. Values of pH below 6.5 are found in the concretions surrounding actively corroding metals – in the case of iron, the pH is usually 4.8. To obtain a better understanding of corrosion rates and mechanisms, the on-site pH of the *Victory* should be measured not only in seawater, but also in sediments and beneath the concretions on a range of different metals. If values of both Eh and pH are available, then it is possible to make use of Pourbaix diagrams to help understand the corrosion mechanisms and product.

5. Water movement: movement of water across the wreck site can affect corrosion rates through metal erosion, destruction of protective films or indirectly by changing the rate of oxygen supply to the cathodic reaction. At one extreme of water movement are classes of wreck sites in high surge areas, where the current and wave actions are so strong that artifacts are physically rolled and bumped back and forth across the seabed. In this case mechanical damage and abrasion are the main causes of 'corrosion' and generally artifacts do not survive long under these conditions. Slightly less extreme are those sites where the surge action

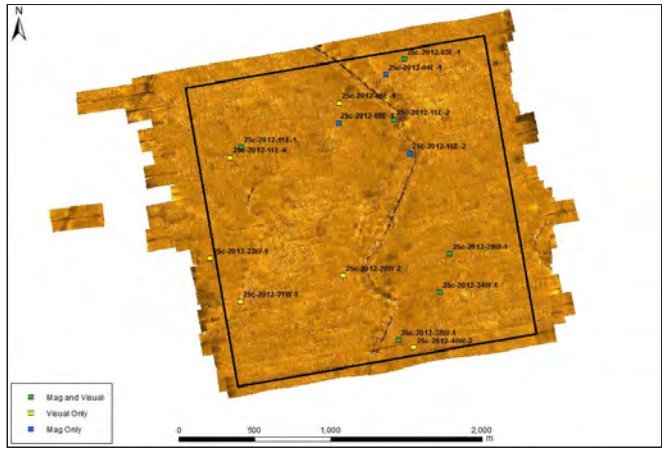


Fig. 8. 2012 side-scan sonar image of site 25C and outlying off-site areas, with positions of anomalies identified.

is normally not strong enough to shift the objects, but is fast enough to pick up and carry seabed debris (sand, grit, shells, etc.). Under these conditions the metals are subject to a form of 'sandblasting' that can cause significant erosion over time. This effect is most pronounced on copper alloys, where formation of protective marine growth is limited. The movement of water across a metal surface can prevent the formation of protective corrosion product films. These films are formed when the accumulation of metal ions from the anodic reaction reaches saturation and precipitation follows. If water movement rapidly removes the ions as they are formed, saturation is not achieved and films do not form. Corrosion rates are generally much higher in the absence of corrosion product films.

6. Sulphate reducing bacteria: if the oxygen content of water immediately in contact with the metal becomes very low, then the Eh of this water can fall below the hydrogen evolution potential. Such oxygen depletion occurs when the seawater itself becomes anaerobic due to pollution or high microbiological activity, when the metal is buried beneath the seabed and oxygen diffusion from the overlying seawater is restricted or when the artifact becomes covered by a thick layer of marine growth, which restricts the oxygen supply.

7. Current profiles: these values have been collated from Total Tide sheets for the period of safe operational activities conducted on site 25C in an optimum weather window. Current strengths varied widely from a minimum of 0.1 knots to a maximum of 1.8 knots. These surface current measurement values are considered to be accurate for the depth of site 25C. Results are being processed, analyzed and quantified.

Fig. 9. Site 25C non-disturbance photomosaic (2012).

Fig. 10. Second site 25C non-disturbance photomosaic (2012).

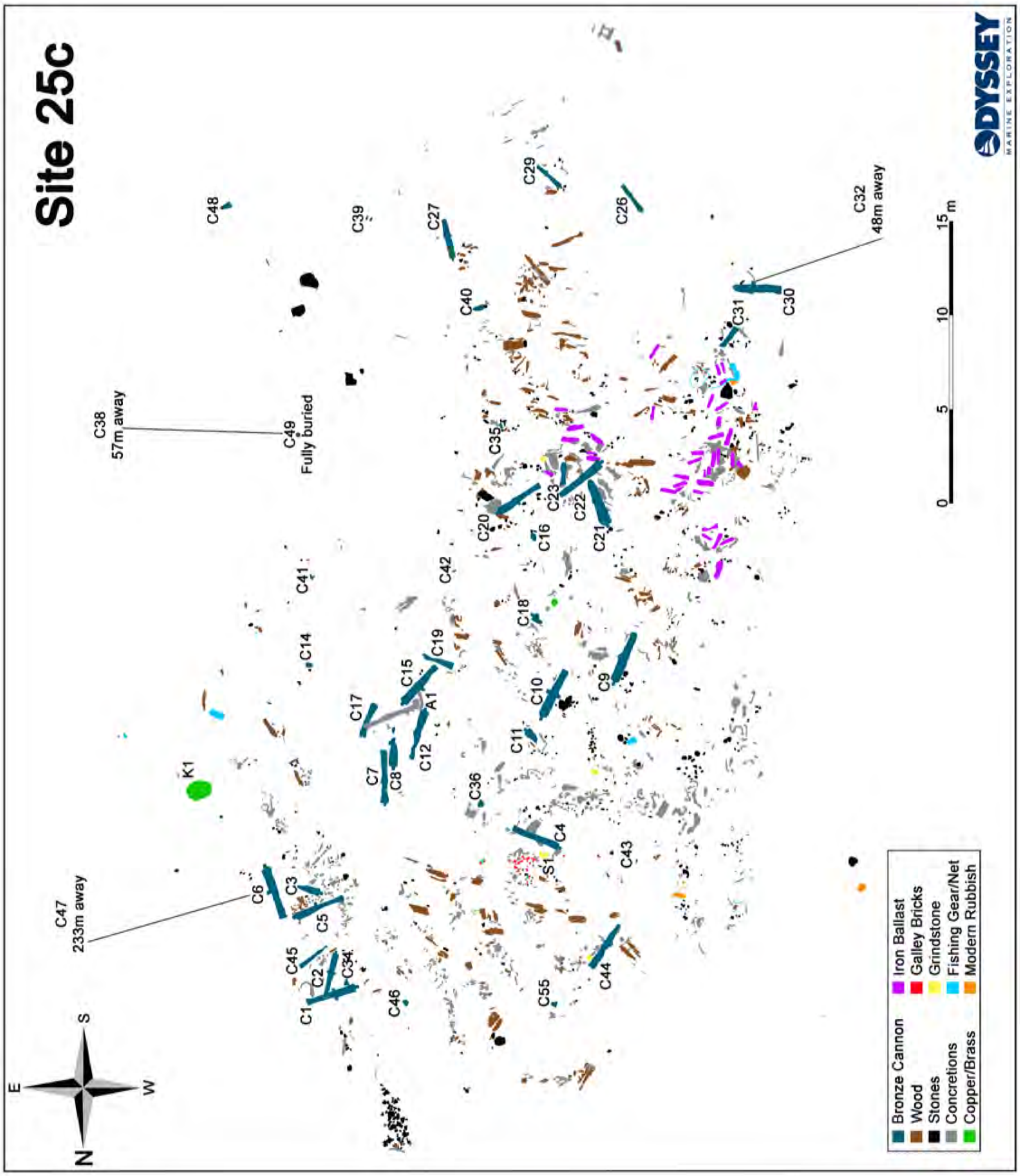


Fig. 11. Site 25C non-disturbance site plan (2012).

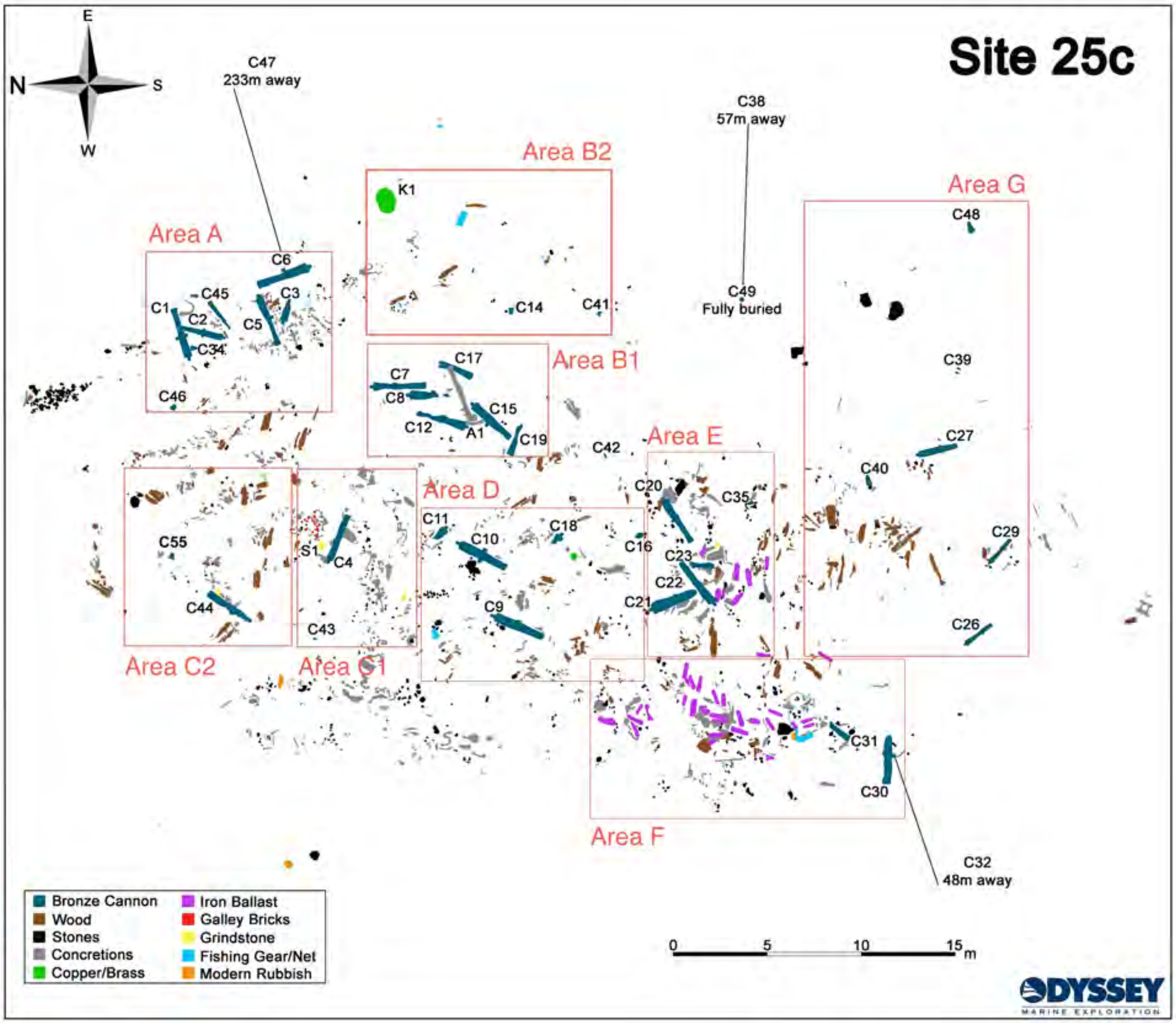


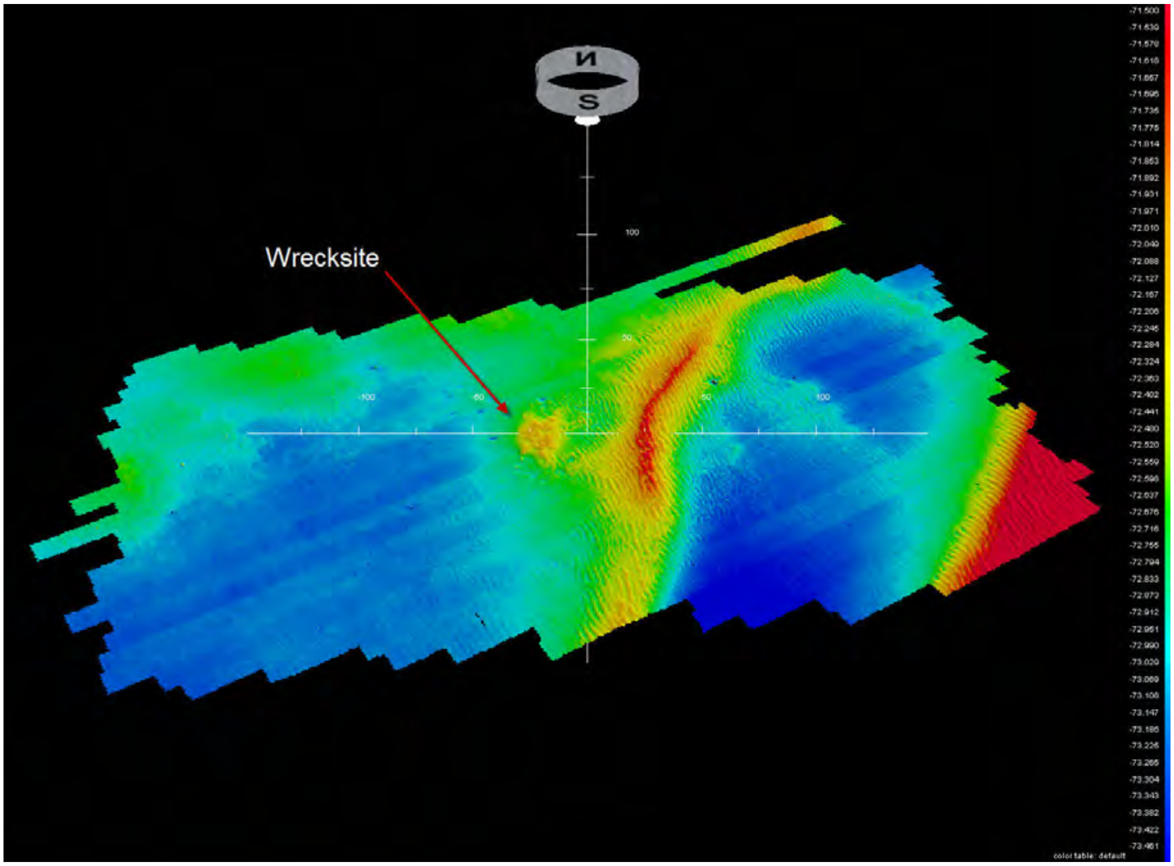
Fig. 12. Site 25C non-disturbance site plan with designated Areas.

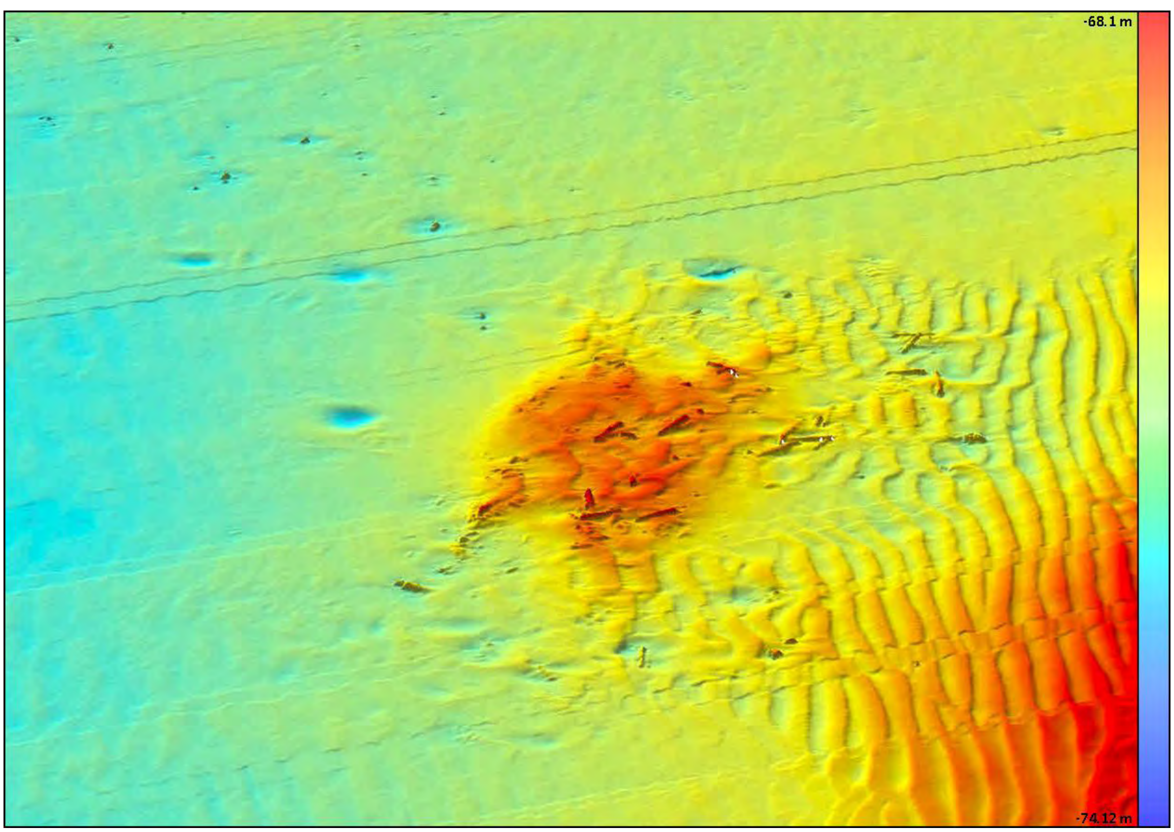
9. Environmental & Marine Biological Site Assessments

The 2012 *Victory* Project Design survey (Phase 1A) included an initiative to construct and deposit offsite a series of sacrificial organic and metallic samples in order to study active degradation processes within the wreck environment, to anticipate the degree of preservation of archaeological wood and metal on-site and to develop methods suited to site stabilization.

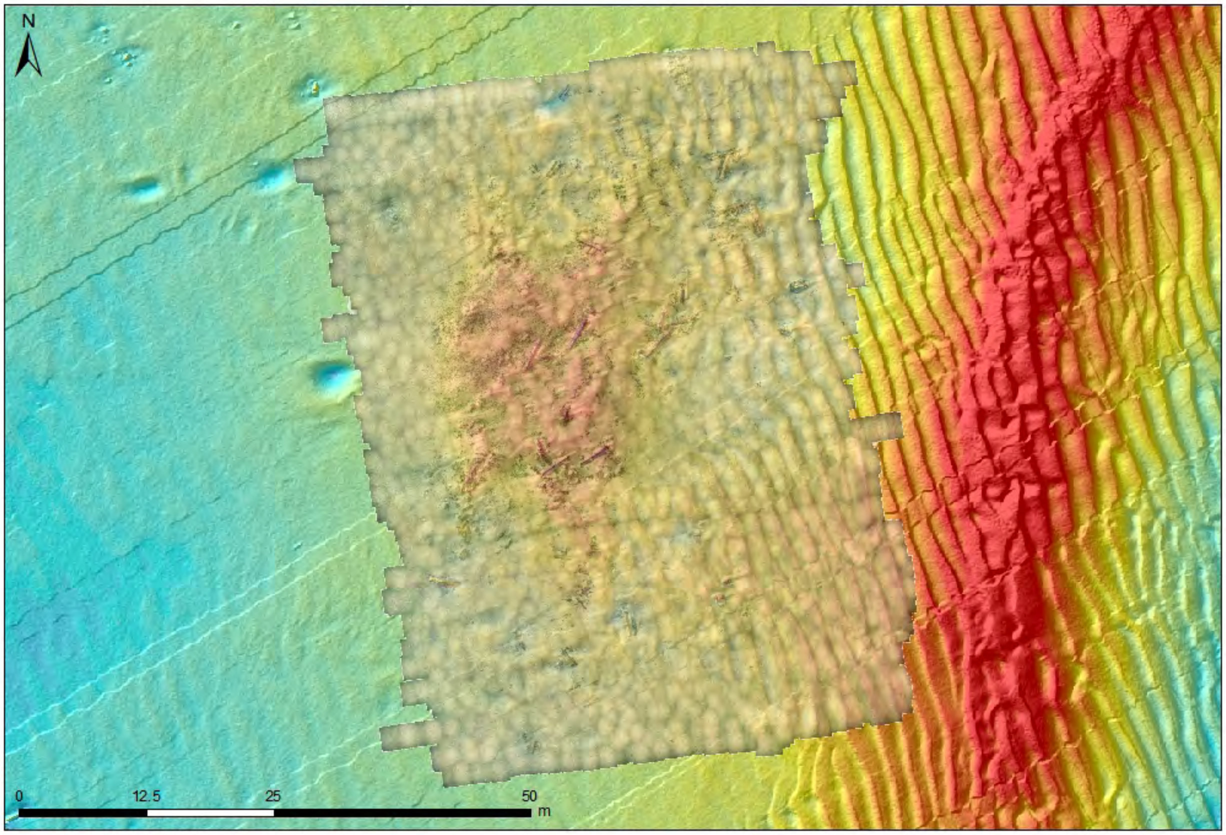
To this end three identical sample frames were assembled from white PVC plastic plumbing pipe, PVC plastic elbows and 'T' connectors, each 210cm long, 75cm wide and 2.15cm thick. The frame was divided in half and a horizontal dividing section of pipe inserted 17cm below the frame edge. This configuration created three rows of nine samples (27 samples total per frame), each spaced 22cm apart and, from left to right, with an alternating metal/wood order: mahogany, birch, oak, pine, mild steel, bronze, brass, copper and aluminium (Figs. 34-35). All samples were suspended and secured within the frame using plastic cable ties.

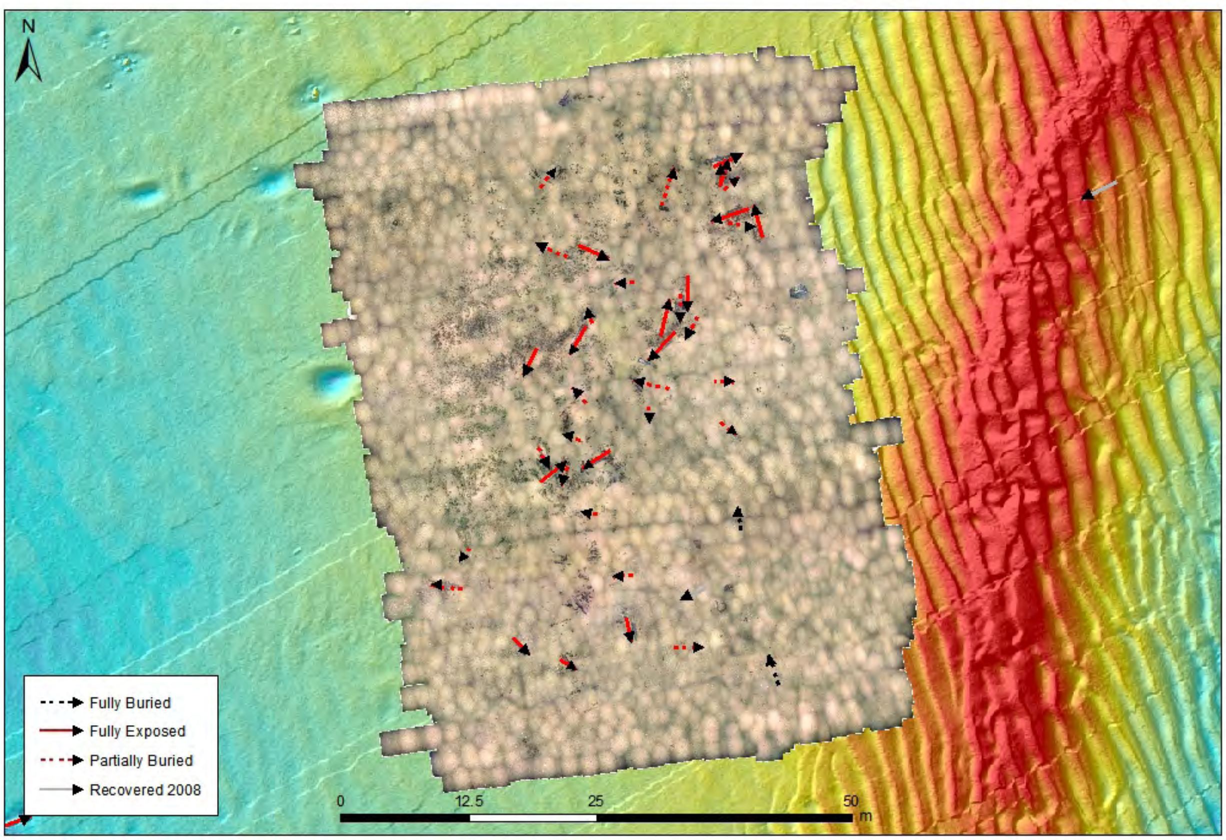
The wood samples measure 13 x 7 x 1cm and the metal samples 5 x 5 x 0.2-0.3cm. The wood samples are accompanied by identification labels and the metal samples have holes drilled through them to signify their medium (mild steel: no holes; bronze: one hole; brass: two holes; copper: three holes; and aluminium: four holes).





Figs. 13-14. Multibeam images of site 25C.





Figs. 15-16. The photomosaic and cannon visible on site 25C's surface closely match positional multibeam data.

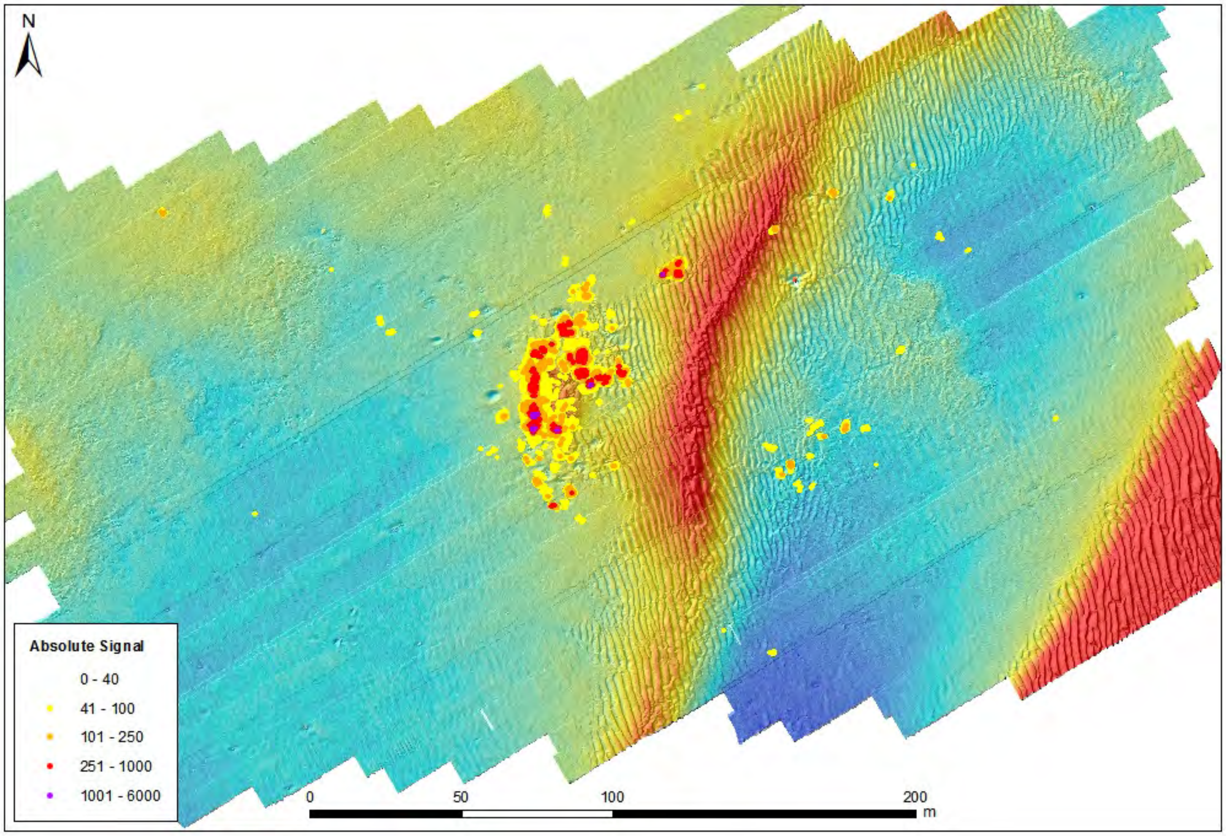


Fig. 17. FADE (Ferrous Anomaly Detection Equipment) magnetometer survey results.

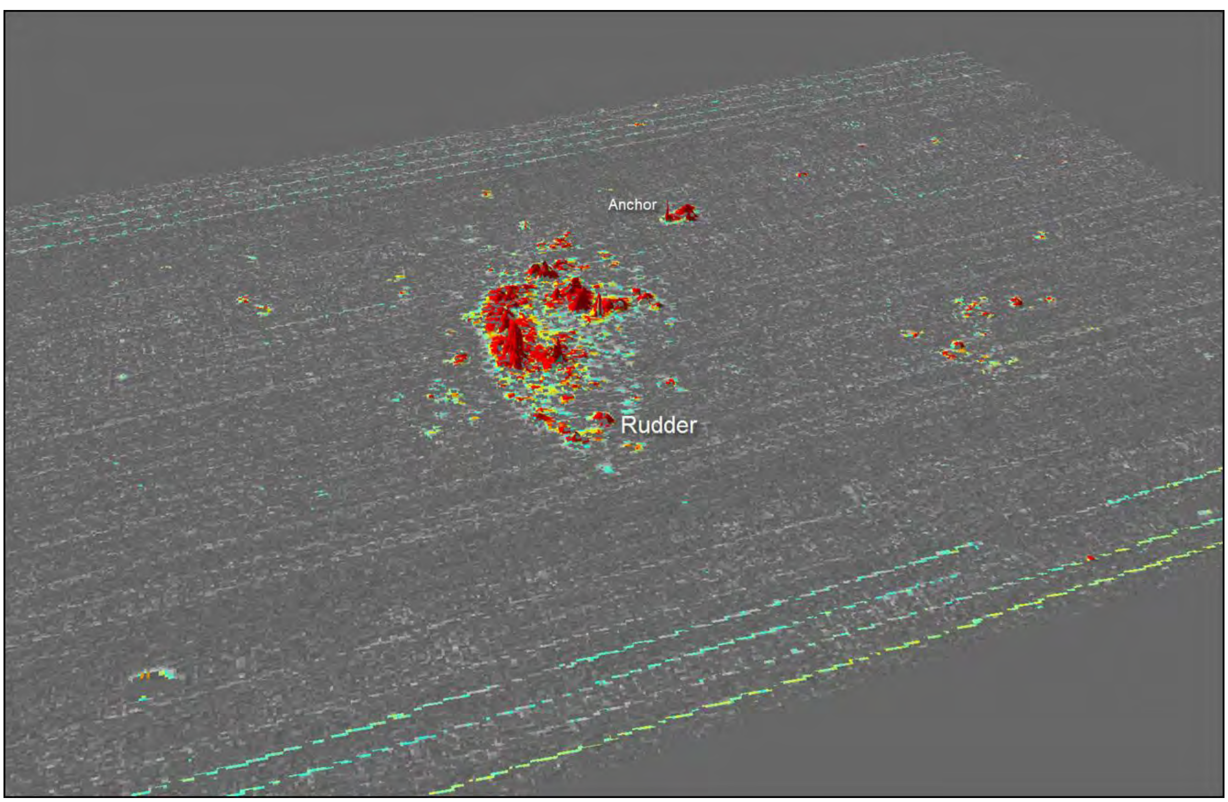


Fig. 18. A ship-shaped wreck profile generated after plotting the 3D FADE magnetometer survey results.

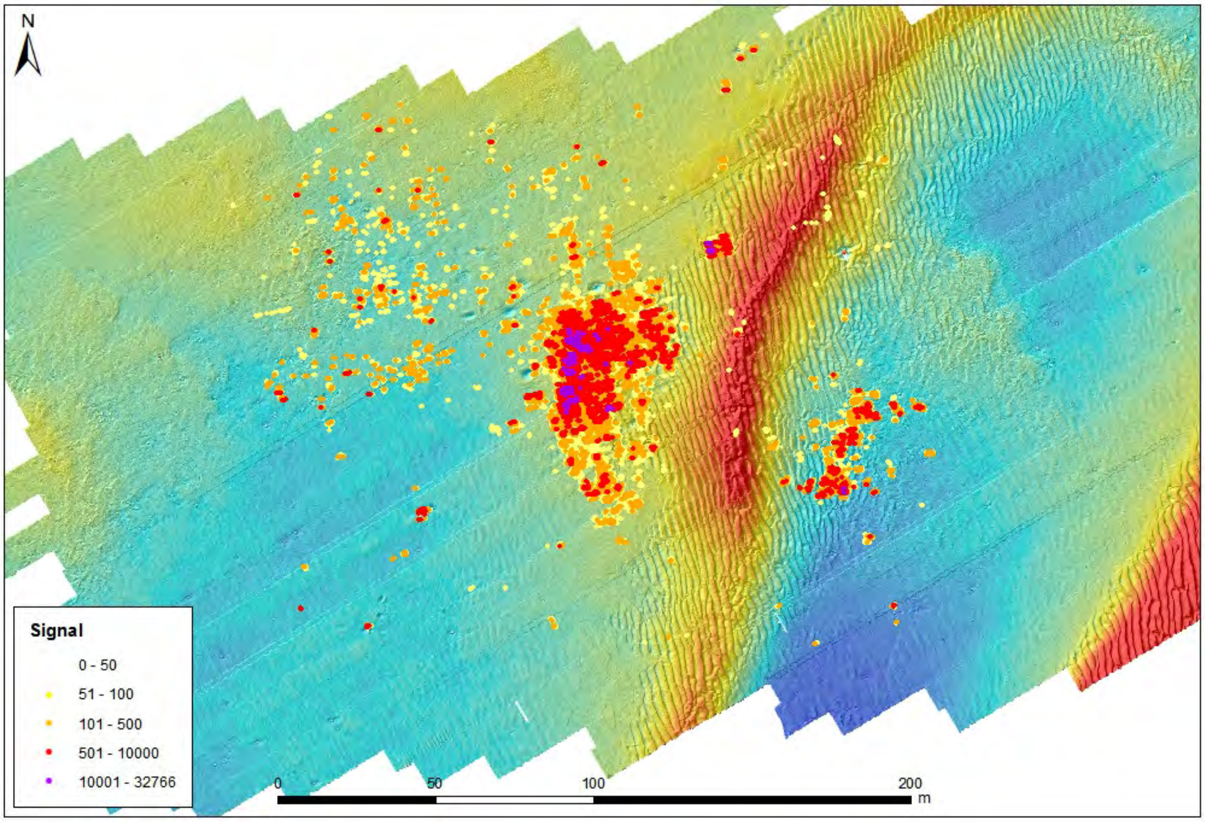


Fig. 19. TSS magnetometer survey results. Note the scattered readings to the northwest (Debris Field 1) and concentration east of Sandwave 1 (Debris Field 2).

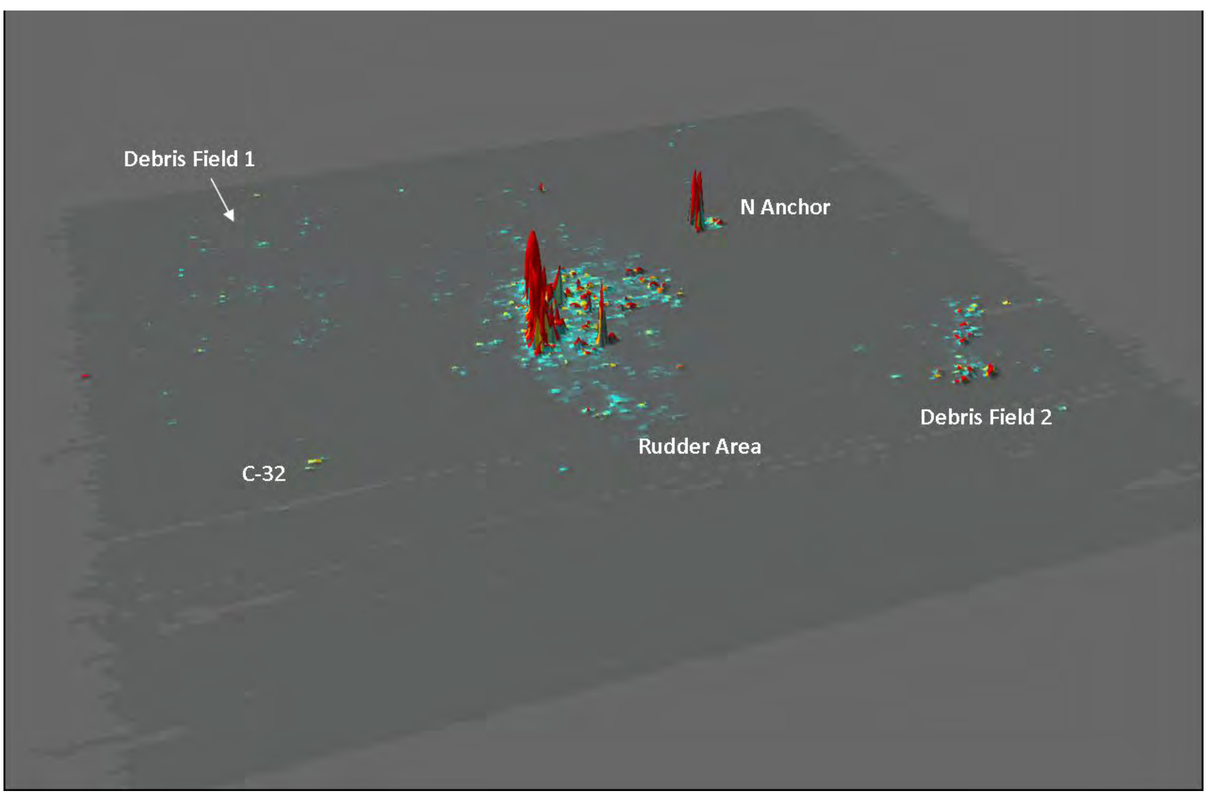


Fig. 20. A ship-shaped wreck profile generated after plotting the 3D TSS magnetometer survey results.

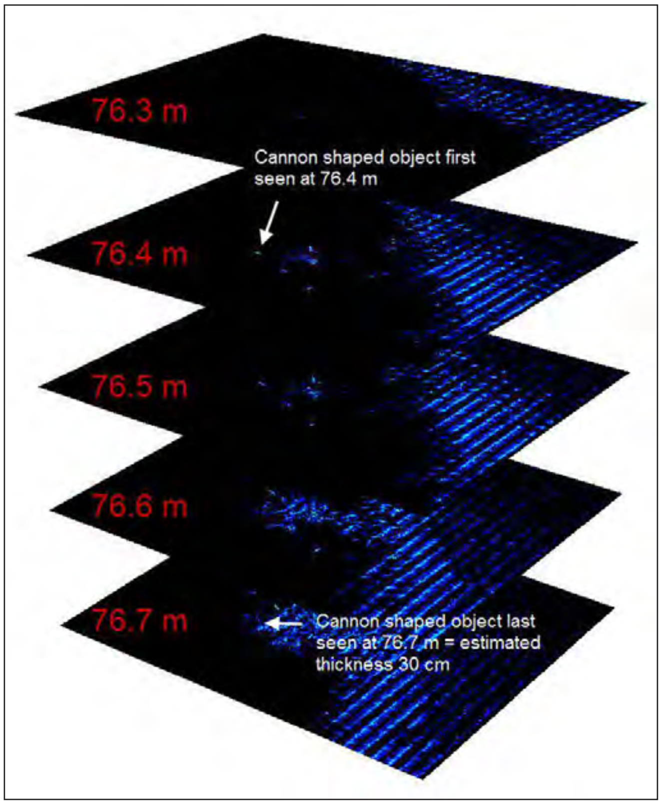
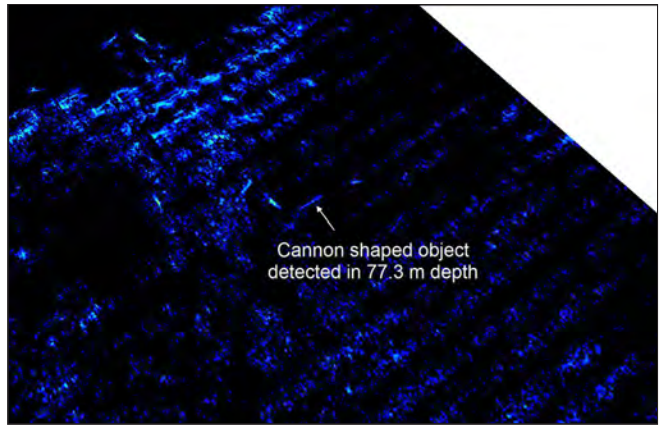
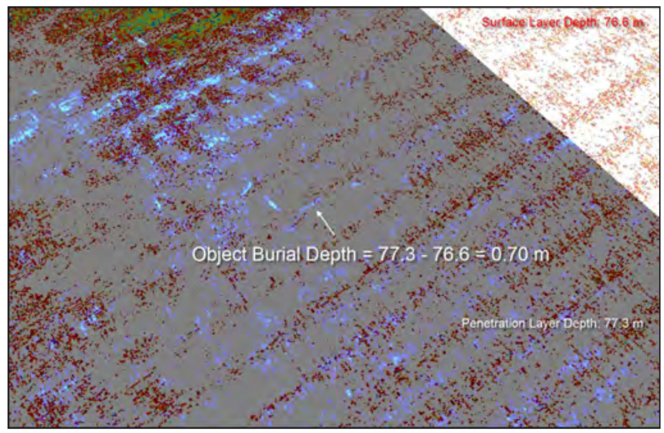


Fig. 21. A 40-centimetre slice through site 25C from the sub-bottom imaging survey shows a probable cannon emerging at a water depth of 76.4m, which is no longer present below a burial depth of 76.7 metres.





Figs. 22-23. A cannon-shaped object appears during the site 25C sub-bottom imaging survey at a water depth of 77.3m, 70cm below the sediment surface.

The sample frames (SF-1, SF-2, SF-3) were transported by ROV to the seabed and deployed 70m northeast of the wreck mound on the eastern flank of Sandwave 1. SF-1 was deployed at 72.3m, SF-2 at 72.5m and SF-3 at 72.0m (Figs. 36-40). The samples' production, form and burial followed the methodology formulated for the RAAR project (Reburial and Analysis of Archaeological Remains: Godfrey, 2009). The Project Design recommended recovery of the samples after six, 12 and 24-month intervals to study degradation processes on these different materials.

The environmental component of the Project Design (Phase 2) also required sedimentological analyses to be conducted, and four samples were recovered from site 25C (GO1-GO4) for grain size and bulk geochemical compositional analyses. This study was intended to enhance understanding of the wreck's environmental context and its suitability or inappropriateness for considering future *in situ* preservation initiatives. The samples were submitted to the Centre for Earth Resources at St. Andrews University, Scotland, and visually comprised:

• GO1 (Context 1): mixed, fine, large-grained sand and large shell fragments (occurring as surface deposits).

• GO2 (Context 2): identical sedimentological matrix, but displaying a dark gray color due to its sub-surface deoxygenated origin.

• GO3 (Context 3): small stones, pebbles and flint nodules emerging in association with Context 1 deposits (found at surface and sub-surface).

• GO4 (Context 4): hardpan composed of stone and flint nodules (found at surface and sub-surface).

The samples were subjected to X-Ray Fluorescence Spectrometry and X-Ray Diffraction, while a Beckman-Coulter LS-230 was used to measure the sediment particles' volume percentages. The results determined that samples contained 38% (GO2), 53% (GO1) and 59% (G03) by volume very coarse sand (1-2mm) and gravel particles

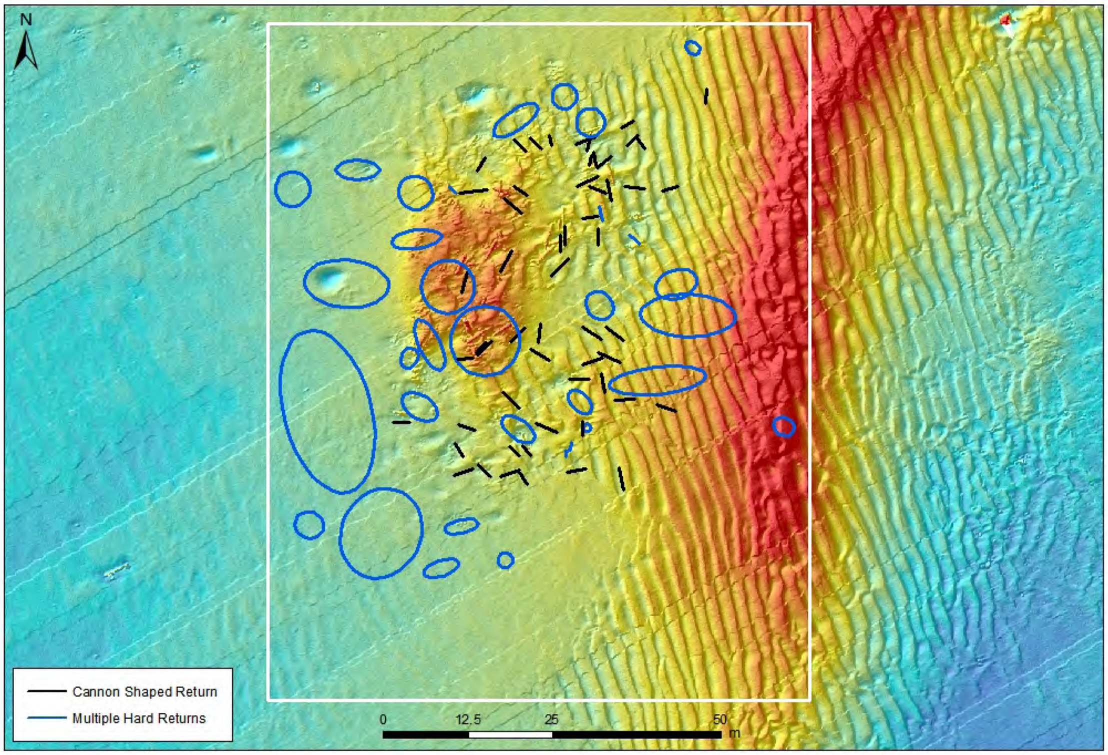


Fig. 24. A total of 88 anomalies identified through the site 25C sub-bottom imaging survey were categorized into 'Multiple Hard Returns' and 'Cannon Shaped Returns'. The first describes clusters of irregular-shaped objects, the second elongated 'cannon-shaped' objects.

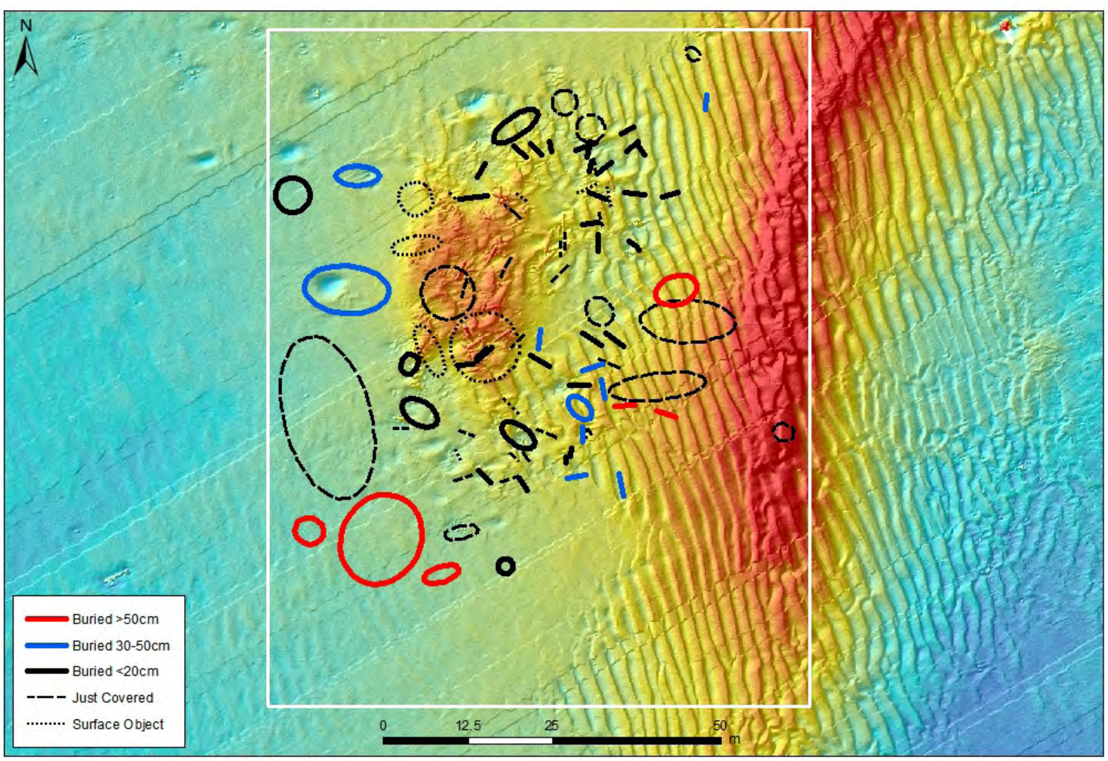


Fig. 25. Identified anomalies by burial depth – site 25C sub-bottom imaging survey.

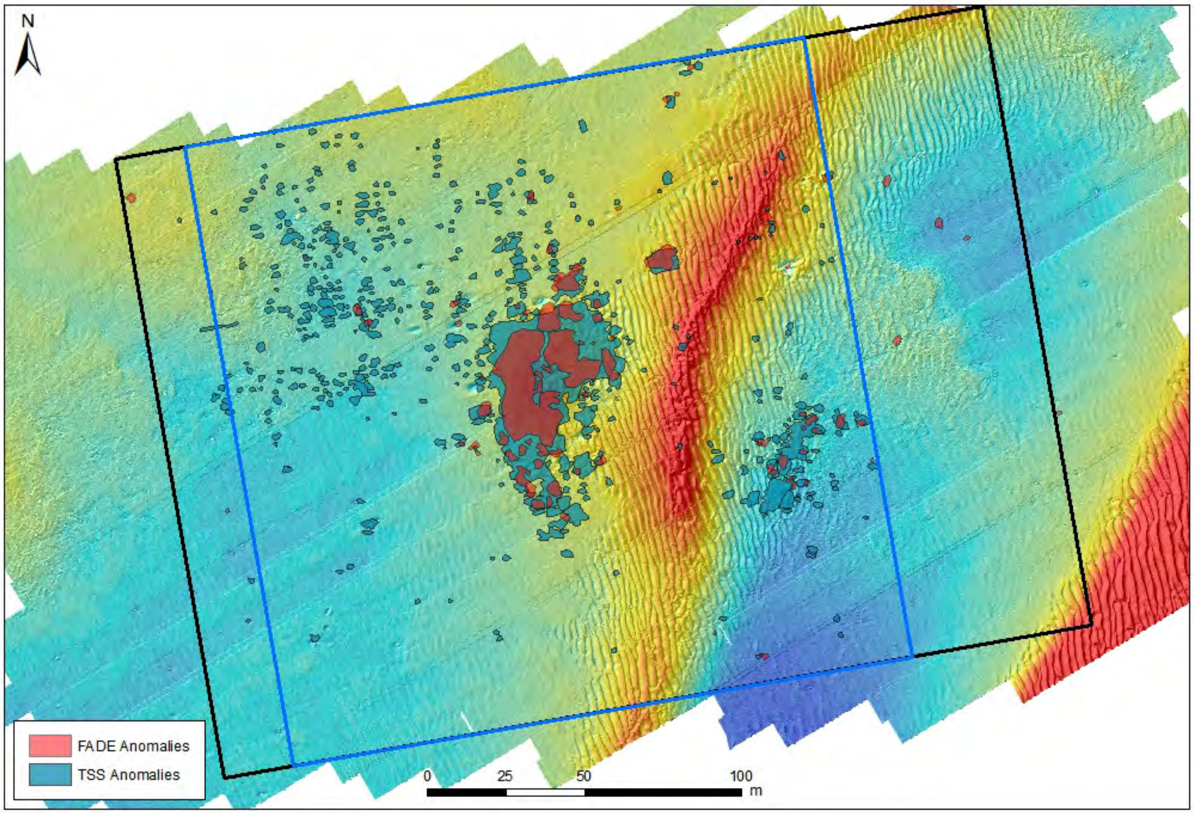


Fig. 26. FADE anomalies in relation to TSS anomalies on site 25C.

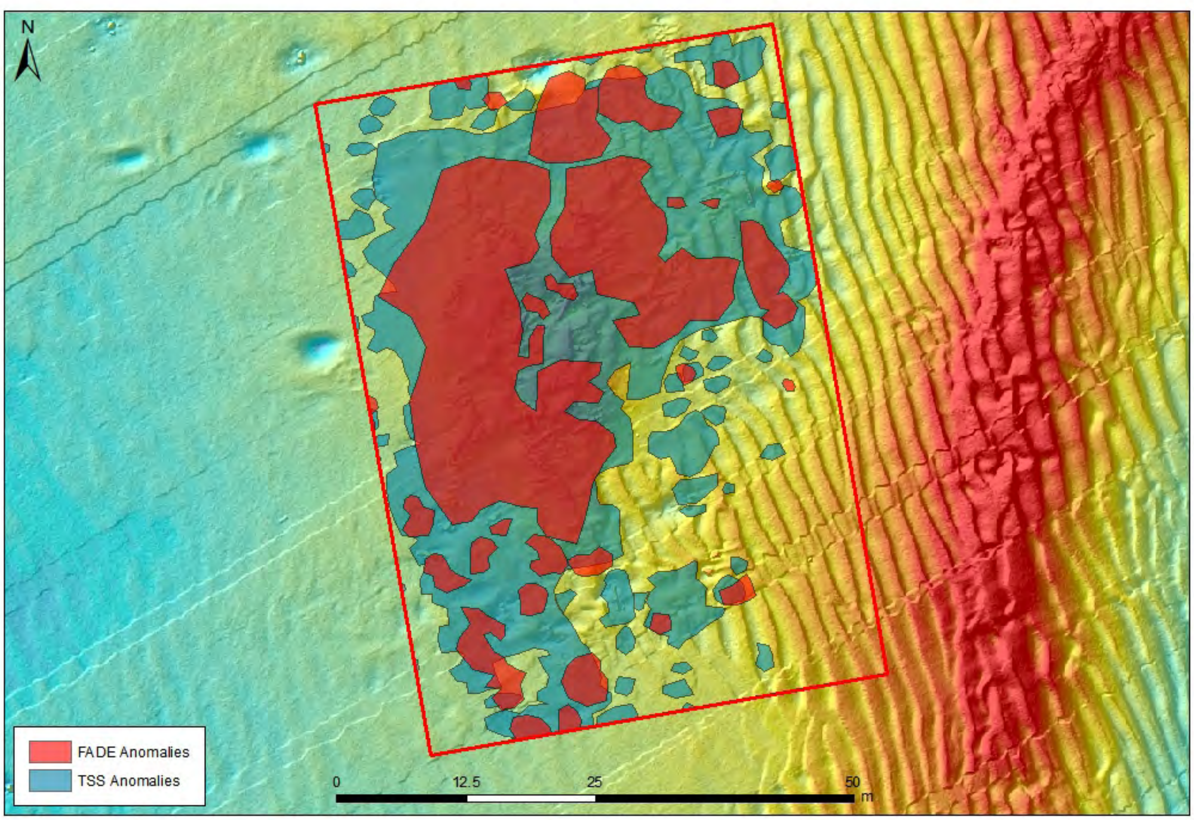


Fig. 27. Detail of FADE and TSS anomalies over the main site 25C wreck mound.

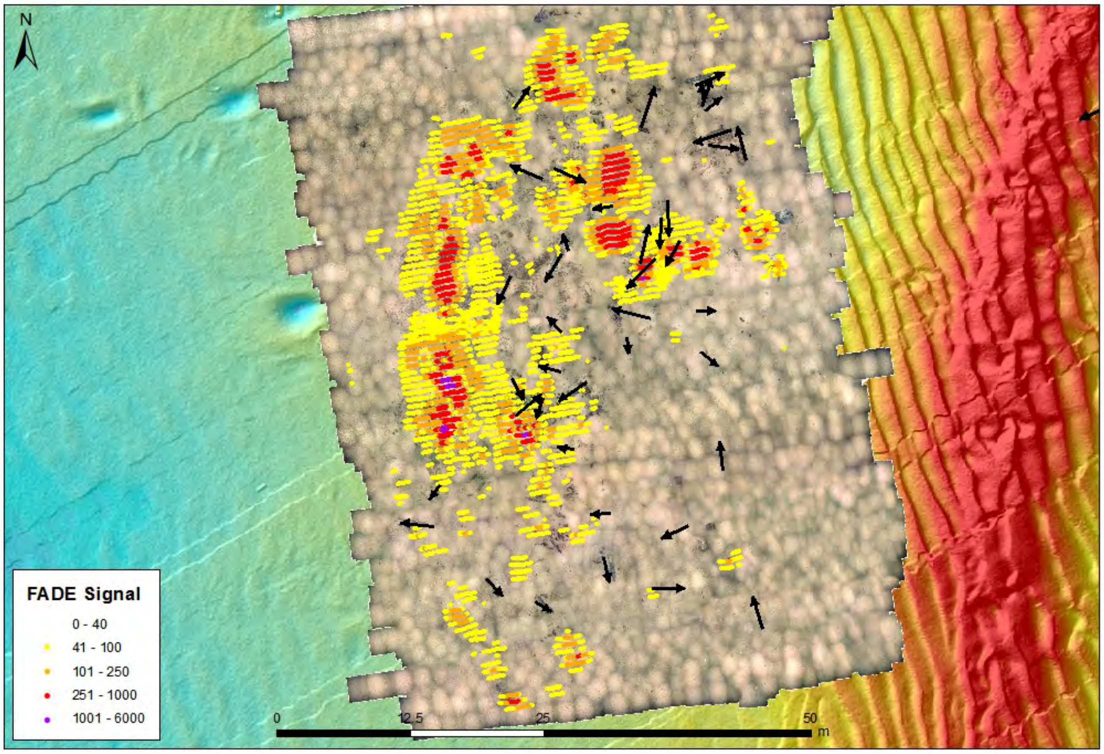


Fig. 28. FADE anomalies superimposed over the 2012 photomosaic. The maximum signals correlate with the area of iron ballast (Area F) and anchor A1. The rudder at far southwest also yields a strong reading. Black arrows show the positions of surface cannon in relation to the FADE data.

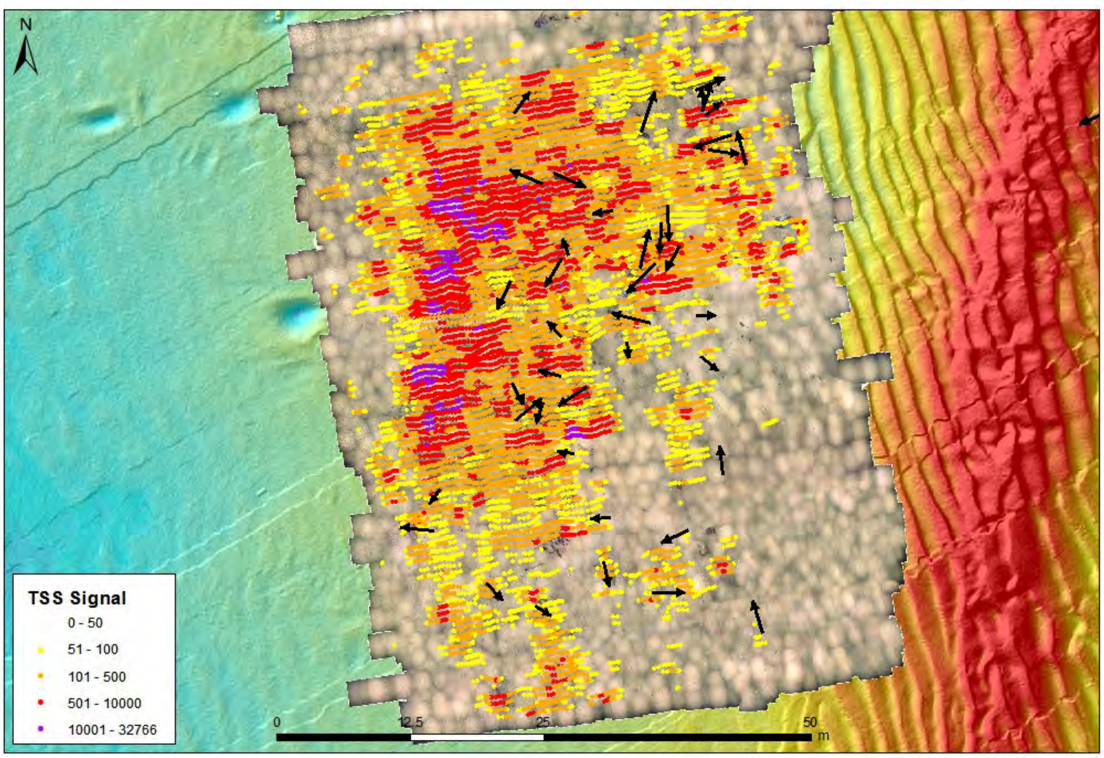


Fig. 29. TSS anomalies superimposed over the 2012 photomosaic. The maximum signals again correlate with the area of iron ballast (Area F). The TSS anomaly map is far denser than the FADE map. Black arrows show the positions of surface cannon in relation to the TSS data.

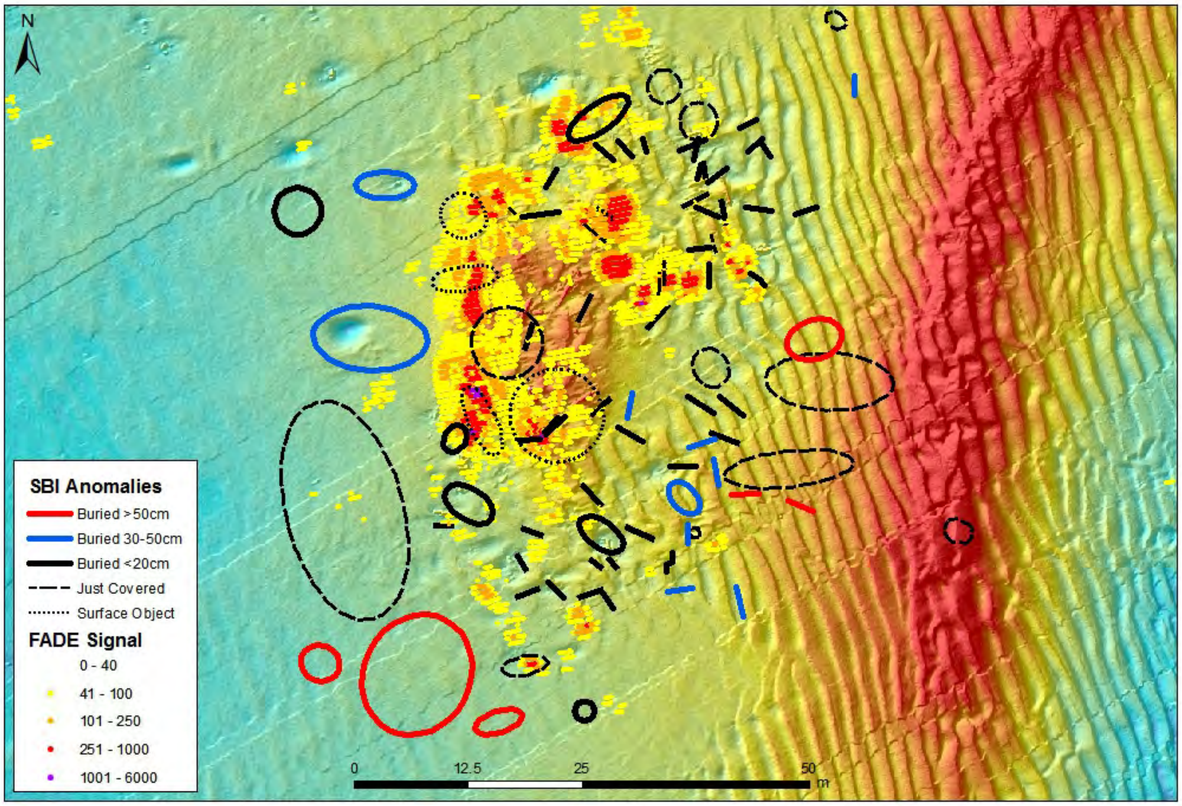


Fig. 30. Comparison of SBI and FADE anomalies.

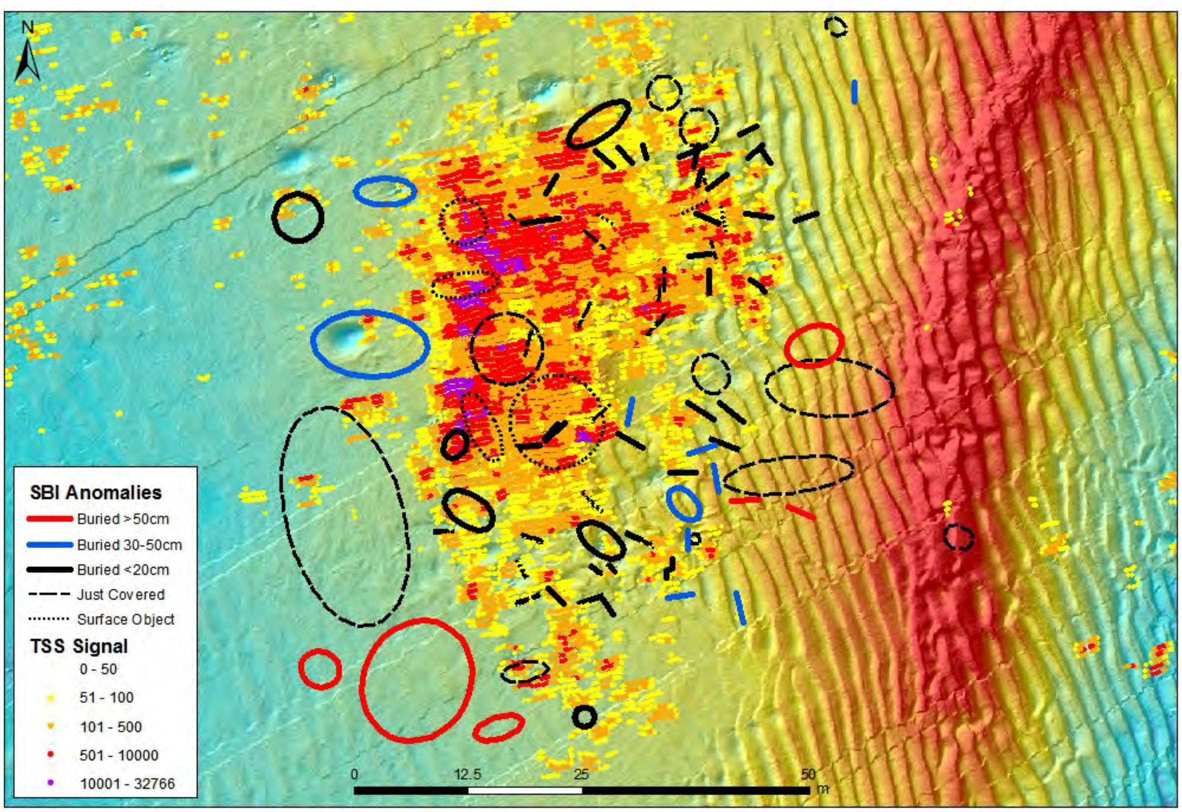


Fig. 31. Comparison of SBI and TSS anomalies.

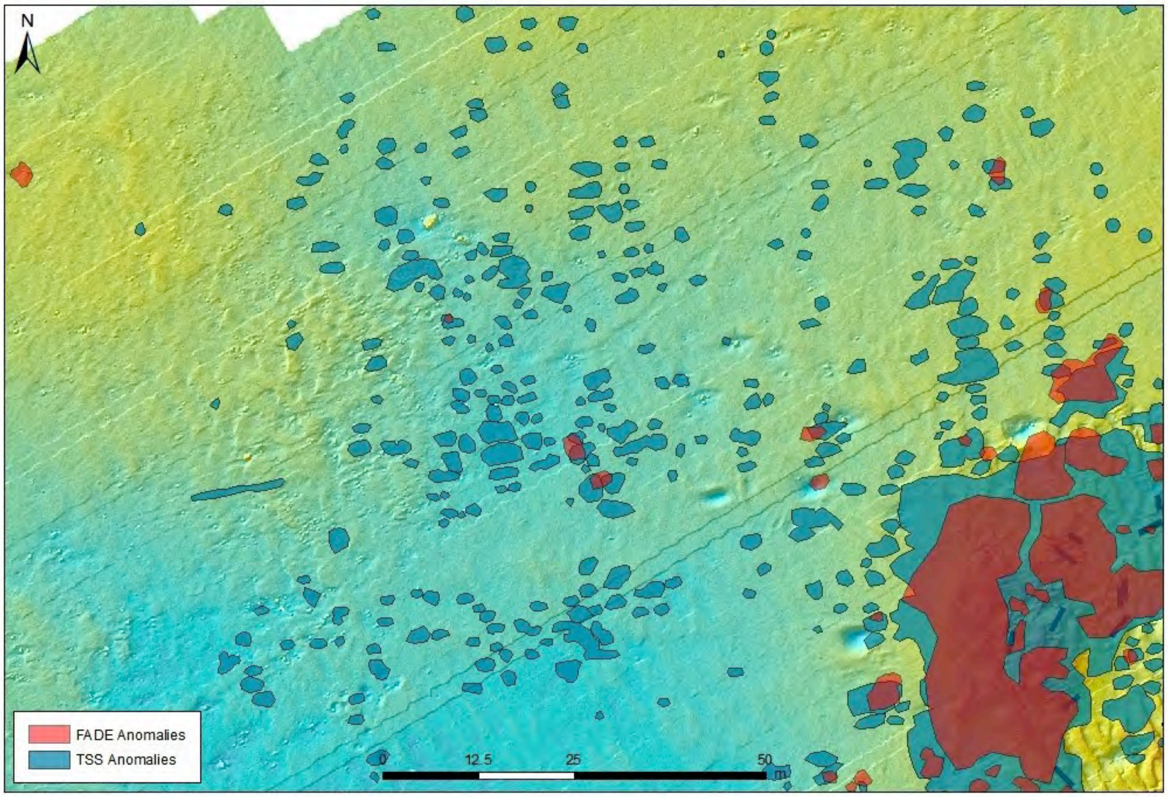


Fig. 32. Detail of the FADE and TSS readings plotted northwest of the site 25C wreck mound (Debris Field 1).

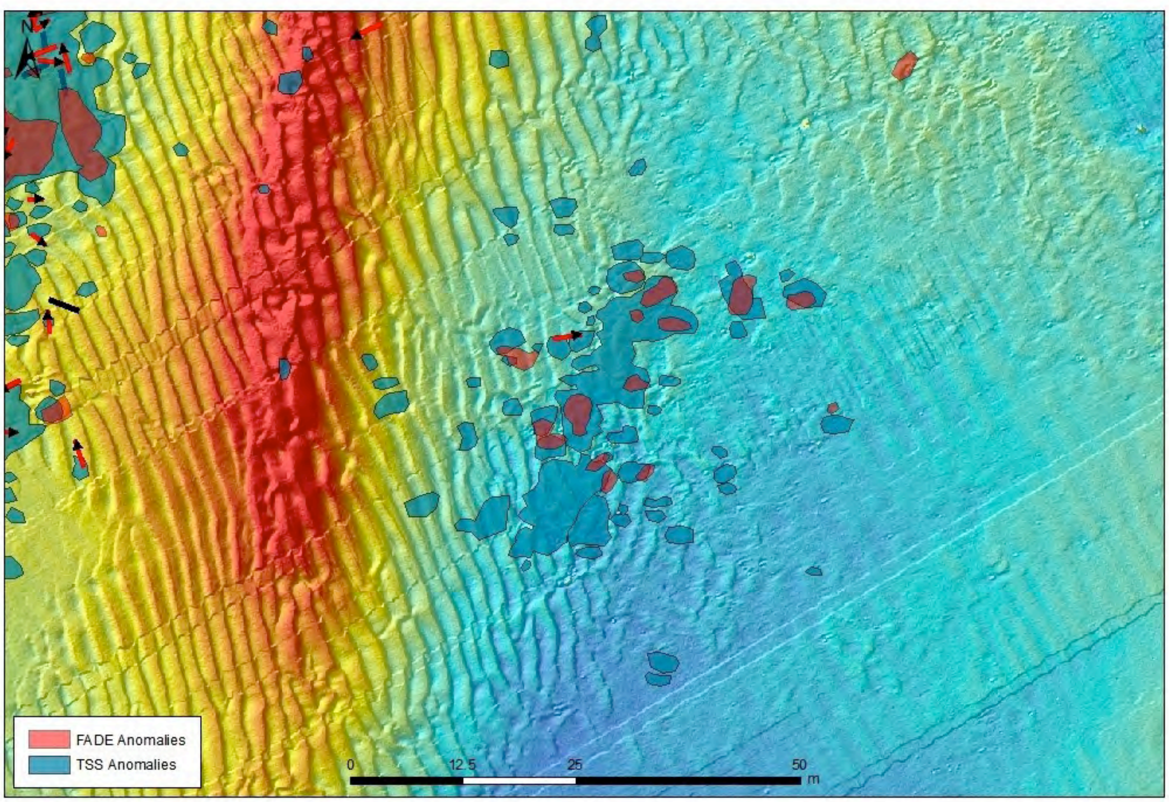
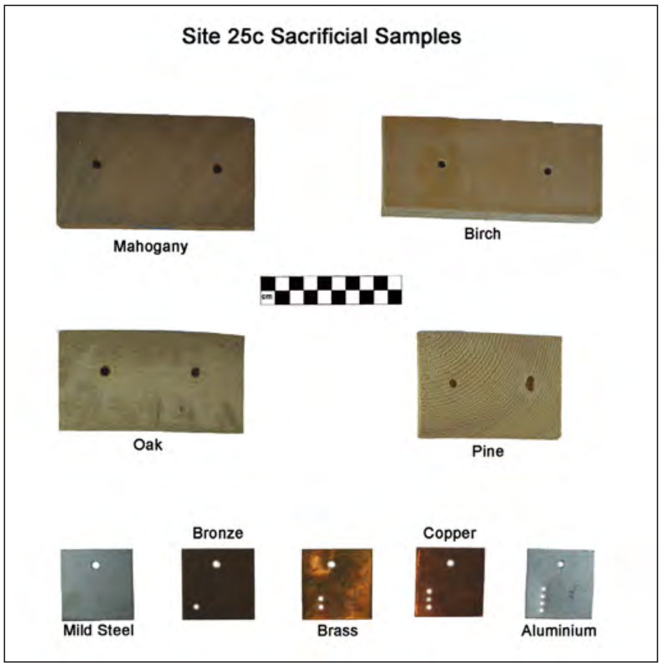


Fig. 33. Detail of the FADE and TSS readings plotted east of the site 25C wreck mound (Debris Field 2), with Sandwave 1 prominent at west.

(>2mm). Finer than coarse sand (<0.5mm) comprised only *c*. 1-2% by volume in each sample. The bioclastic components of samples GO1-GO3 consisted of 70-75% highly abraded bivalve mollusc fragments (mostly indet, but including pectinids), 10-15% abraded smaller bivalve disassociated valves (mainly thin-shelled, shallow-infaunal, shallow-burrowing forms such as *Cerastoderma sp*. and Tellinids) and a further 10-15% comprised abraded and separated barnacle plates (*sp. indet.*).

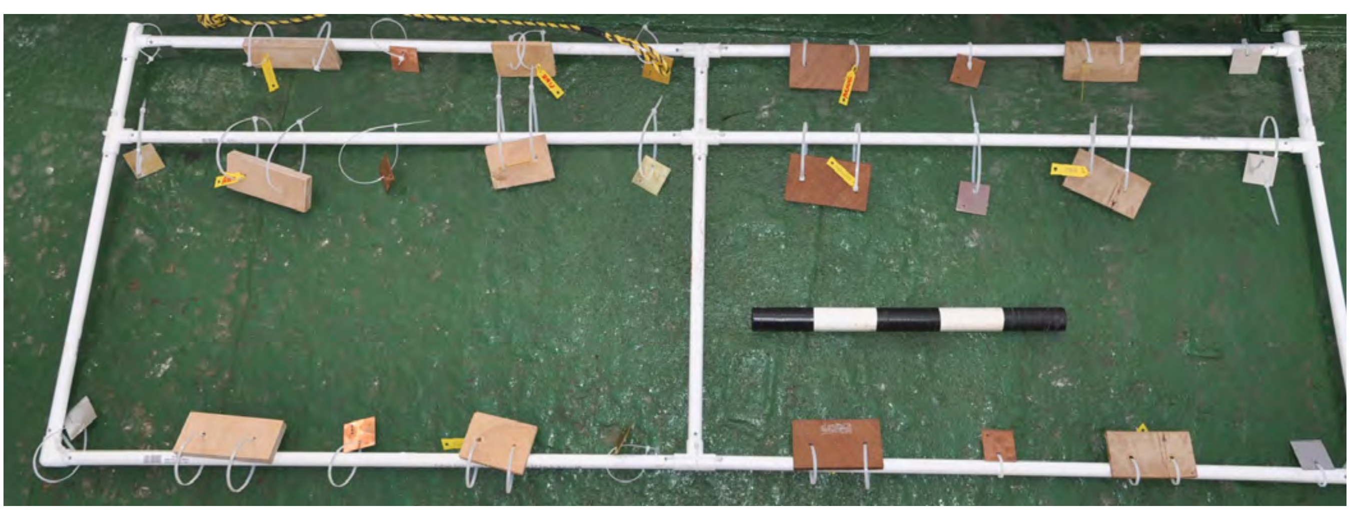
Sample GO4 consisted of pebble and cobble-sized clasts dominated by chalk-flint lithologies, some exhibiting a greenish tinge likely reflecting a glauconitic-chloritic component. The next most abundant are calcareous and dolomitic grainstone followed by mafic and intermediate composition volcanites (likely basaltic/andesitic) and meta-igneous rocks (gneissic granitoids and meta-felsites). A plausible geological match for the GO4 samples is the Armorican basement-cover sequences of Brittany in Normandy.



In summary, the few small, well-preserved, thin-shelled infaunal elements (Tellinids and echinoids) may reflect a thinness of sediment and its susceptibility to temporary removal from the site. The relative lack of borings on the shell surfaces suggests high rates of reworking and abrasion (i.e. strong currents). The genesis of the 3-D large bedforms in the vicinity of the wreck, as visible on multibeam sonar and indicative of a mobile substrate, perhaps reflects a constriction of currents around the wreckage causing a local enhancement of flow velocities upward into the bed stability field for 3-D large ripples. This has important implications for how the exposed archaeology on site 25C causes scouring, erosion and re-cover.

The large bedforms within the *Victory* site's environment, combined with the coarse nature of the sediments studied, are indicative of strong current action causing dynamic sedimentological forms to be extensively sorted. Hence, environmental site conditions are likely to be well aerated. As such, this would not be a suitable setting for the anaerobic preservation of artifacts.

The ongoing marine biological study of the *Victory* wreck site (Project Design Phase 2) conducted at the Scottish Oceans Institute, University of St. Andrews, identified 50 biological species on its surface, including urchins (*Echinus*), sea cucumbers (*Holothuroidea*), anemones (*Hydrozoan* and *Metridium*), sponges (*Porifera*) and green sea mats



Figs. 34-35. Detail of the wood and metal sacrificial samples secured to a plastic frame in preparation for burial northeast of Sandwave 1.

(*Zoanthids*). A total of 34 of the species are edible, such as crabs, scallops, gurnard, cod, haddock and monkfish. Lobster has also been visually observed on-site. The shipwreck has been subjected to by-catch dumping, while AIS monitoring revealed common on-site English and French fishing boat presence, whose function (benign steaming or intrusive trawling) is undetermined. AIS monitoring demonstrates that at least one boat continuously uses the wreck and its environs for the laying of pot lines.

The shipwreck and its immediate environs are subjected to common fishing pressures. Site 25C is most probably not identified as a historical wreck by the majority of users, but is likely misidentified as a viable marine reef. Obstructions elevated less than 50cm above the seabed are likely to appear as natural phenomena on fishing boats' sonar equipment (pers. comm. Prof. Michel Kaiser, School of Ocean Sciences, University of Bangor, May 2009).

10. The TSS, FADE & SBI Data: Results Compared

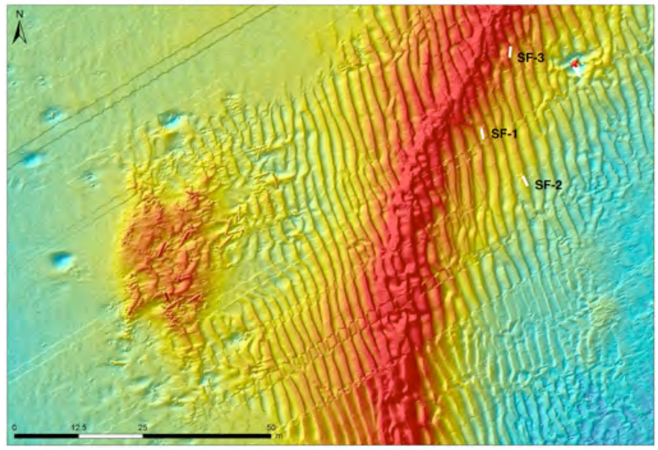
In theory, since TSS, FADE and the sub-bottom imaging scientific tools deliver different results (FADE: ferrous metals to 2m depths; TSS: ferrous and non-ferrous metals to 2m depth; SBI: all forms of solid objects irrespective of medium to 4m depths), their combined application on the *Victory* site provide complementary maximized three-dimensional characterizations of buried anomalies.

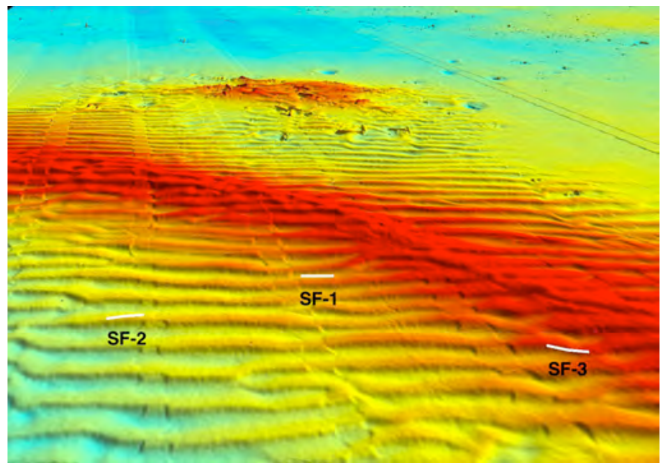
Despite the wider survey area covered by the FADE survey, all anomalies and scatters proved to lie within the boundaries of the 200 x 200m TSS survey box. A total of 3% of this area contained FADE anomalies, compared to 9% for TSS anomalies (1,215m square versus 3,590m square). However, the different tools revealed contrasting profiles. The ferrous FADE signals are almost exclusively confined to the main wreck mound, except for minimal signals detected to the northeast (Debris Field 1), a spike associated with anchor A2 located 26m northeast of the wreck perimeter, and a significant cluster east of Sandwave 1 (Debris Field 2).

Reducing the area of analysis further to the 2012 photomosaic area tightly focused on the wreck mound (2,880m square), 32% of the surface area contained FADE anomalies compared to 61% for TSS anomalies (925m square versus 1,788m square). Since concretions are common throughout the surface wreck mound, the FADE profile is not unexpected. The FADE signals are largely confined to a continuous central and northern zone of the wreck mound (30 x 12.5m), in particular with a major reading correlating with the 20 x 5m north/south oriented iron ballast cluster in Area F that may further corroborate the shipwreck's hypothesized keel orientation. Anchor A1 is represented by another high reading, and three additional spikes were registered in the wreck's northeast quadrant (Figs. 26-27).

The TSS anomalies, by contrast, are nearly continuous across the whole wreck nucleus (60 x 42m), confirming the positional boundaries of the primary central wreck mound. Another major contrast is the wide scatter of TSS targets defining Debris Field 1 (83 x 83m) and Debris Field 2 (40 x 40m) (Figs. 32-33). Five isolated FADE anomalies east and northeast of the Sandwave 1 may comprise ferrous wreckage dragged off-site by trawlers (Fig. 26) or deposition through some other unknown process.

The TSS anomaly distribution is far denser than the FADE profile, which makes interpretation difficult without excavation. However, the areas of strongest signals and presumed densest buried wreckage correlate with the FADE profile. The superimposition of known bronze cannon positions over the TSS anomaly area suggests that buried guns may be one explanation for the wide TSS distribution (Fig. 29).





Figs. 36-37. The positions of the three plastic sacrificial frames (wood and metal samples) buried offsite northeast of Sandwave 1.

Fig. 38. SF-1 buried at a depth of 72.3m offsite northeast of Sandwave 1.

Fig. 39. SF-2 buried at a depth of 72.5m offsite northeast of Sandwave 1.

Fig. 40. SF-3 buried at a depth of 72.0m offsite northeast of Sandwave 1.

Fig. 41. Cannon C47 discovered during the 2012 side-scan sonar survey 233m northeast of the wreck mound.

The SBI results radically change our understanding of site 25C's character. Comparisons between the SBI anomalies and the FADE and TSS profiles suggest that the FADE methodology does not trace the specific contours of buried SBI targets accurately. The volume of buried noise is significant, in areas down to maximum depths of 4m. Results seem to confirm that the western wreck boundary, defined by a concentration of iron ballast in Area F, represents the wreck's perimeter. Minimal scatter is located west of this point (Figs. 30-31).

The SBI equipment detected a total of 60 linear anomalies buried between less than 20cm and over 50cm deep. These are currently interpreted as most likely representing bronze cannon. They coincide mainly with areas of high TSS signals. If correct, this would increase the maximum potential number of guns on the site to 109 (49 recorded visually on the site surface, including three dragged outliers, plus 60 buried). When correlated with a TSS signal but no FADE signal, these hits could also represent concentrations of non-ferrous metals.

The SBI data also suggest that a major concentration of wreckage may lie buried on the east edge of the wreck mound manifestation in the form of what are potentially 37 buried cannon. The fact that these do not appear to be associated with strong FADE or TSS signals, and thus not with extensive structural remains, supports the theory that the *Victory* listed to starboard when it struck the seabed and that over time the portside decks and cannon collapsed eastwards. This data point towards the possibility that the *Victory* sank without jettisoning any guns and that the total original collection of ordnance survives on site 25C.

11. Conclusion

The 2012 survey of site 25C successfully completed 100% of the Project Design Phase 1-2 deliverables and revealed the following broad archaeological characteristics and details. The central site has a maximum elevation of 50cm above the seabed. The discontinuous site boundaries extend across a total area 84m north/south (anchor A2 to

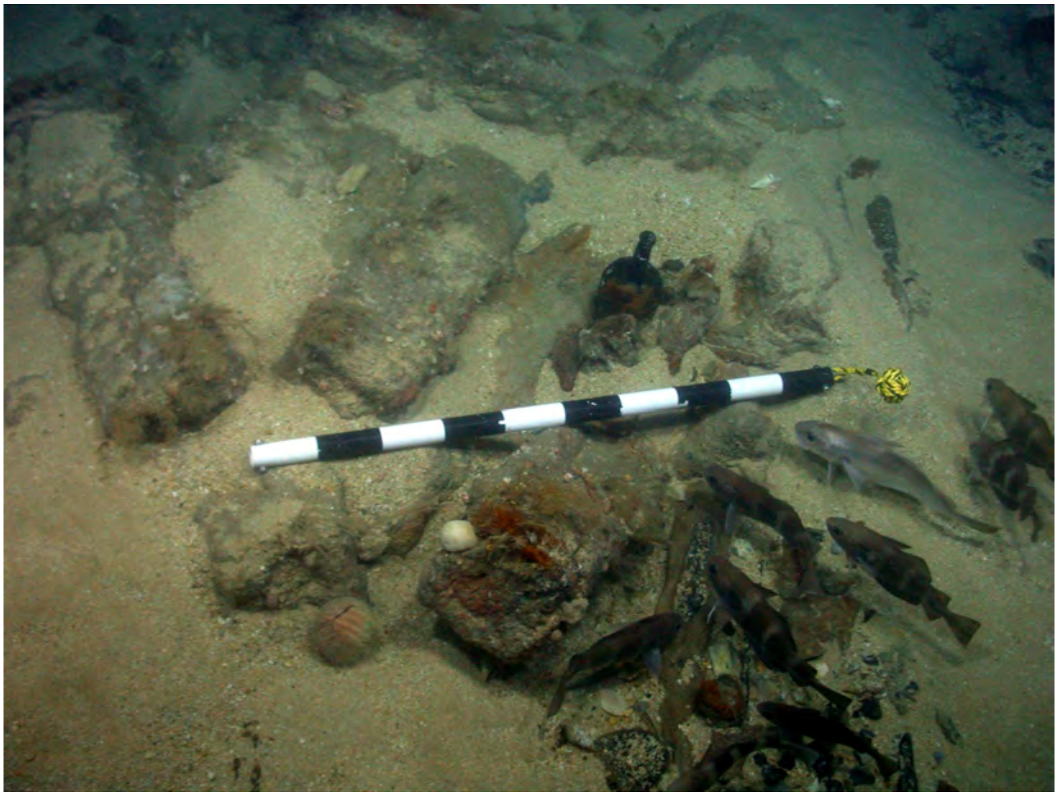


Fig. 42. A glass bottle surface find in Area F, the first intact glass or ceramic artifact identified on site 25C (Phase 1B non-disturbance site survey).

Fig. 43. A bronze tap in Area C (exposed length 30cm), composed of a main cylinder and a side valve, associated with galley brick (Phase 1B non-disturbance site survey).

the rudder) and 305m east/west (cannon C32 to C47). The continuous site boundaries defined by the central elevated wreck mound cover an area of 60m north/south and 42m east/west.

Two potentially significant debris fields were identified: Debris Field 1, covering 83 x 83m, is located northeast of the wreck mound perimeter; and the 40 x 40m Debris Field 2 is located 57m southeast of the wreck mound perimeter and 30m east of Sandwave 1.

A total of 39 bronze cannon were visible on the site surface in 2012. The updated total number recorded between 2008 and 2012 amounts to 50 guns on site 25C. A combined 19 cannon located in all seven Areas (Areas A-G) displayed evidence of human impacts since 2008. Archaeological features and extensive lengths of planking have been destroyed and new fishing cable and net identified in Areas D and F. The high-resolution side-scan sonar identified a new outlying cannon C47, 233m northeast of the wreck mound, evidently dragged off-site by a fishing trawler/s. Sixty large elongated anomalies, seemingly at least partly buried bronze cannon, were detected using sub-bottom imagery equipment across the site down to depths of 0.8m. This paper presents preliminary results. Interpretation of the 2012 site 25C non-disturbance survey data is ongoing

Acknowledgments

Odyssey Marine Exploration would like to extend sincere thanks to Lord Lingfield and the Trustees of the Maritime Heritage Foundation for facilitating the pre-excavation survey of the *Victory* wreck site. We are extremely grateful to the further guidance of Dr. Margaret Rule, John Bingeman and Ivor Noël Hume from the Scientific Advisory Committee of the Maritime Heritage Foundation.

Notes

1. For the specification of the SBE19PlusV2 Seacat Profiler CTD, see: http://www.comm-tec.com/Prods/mfgs/SBE/brochures_pdf/19plusV2brochure.pdf.

Bibliography

Cunningham Dobson, N. and Kingsley, S., 'HMS *Victory*, a First-Rate Royal Navy Warship Lost in the English Channel, 1744. Preliminary Survey & Identification'. In G. Stemm and S. Kingsley (eds.), *Oceans Odyssey: Deep-Sea Shipwrecks in the English Channel, the Straits of Gibraltar and the Atlantic Ocean* (Oxford, 2010), 235-80.

Godfrey, I.N., 'Reburial and Analyses of Archaeological Remains (RAAR). Investigations of the Effects of Burial on Material Used at Archaeological Excavations to Separate and Mark Objects'. In K. Strætkvern and D.J. Huisman (eds.), *Proceedings of the 10th ICOM Group on Wet Organic Archaeological Materials Conference, Amsterdam, 2007* (Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten, 2009), 215-51.

Kingsley, S.A., Cunningham Dobson, N. and Van de Walle, F., *Balchin's Victory (Site 25C): Shipwreck Monitoring & Cannon Impacts, 2008-2012* (OME Papers 24, Tampa, 2012).

Fig. 44. An elongated iron concretion in Area D (Phase 1B non-disturbance site survey).

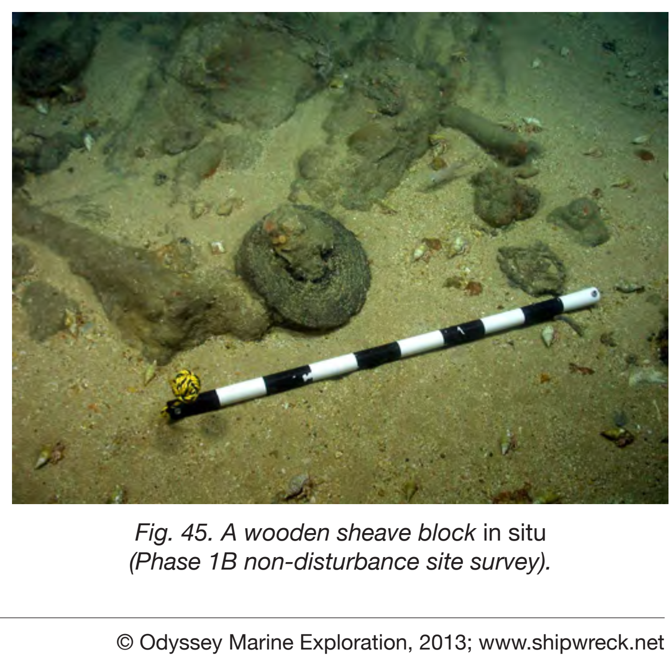
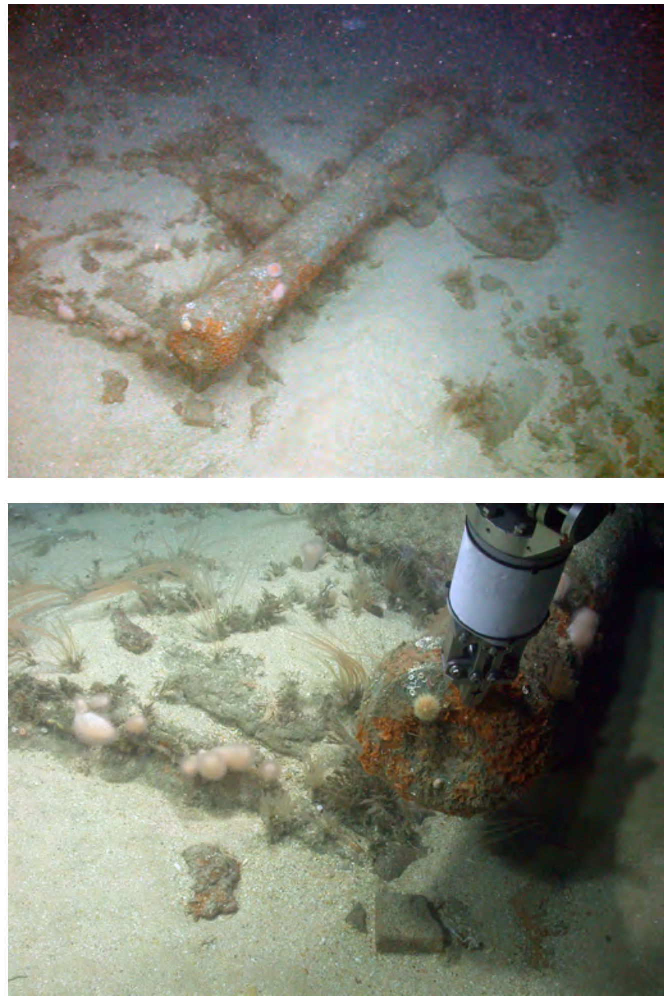


Fig. 45. A wooden sheave block in situ *(Phase 1B non-disturbance site survey).*

Fig. 46. A wooden sheave block in situ *next to cannon C44 (Phase 1B non-disturbance site survey).*

Fig. 47. A bronze sheave (alongside a modern glass bottle) recorded south of Area B1 (Phase 1B non-disturbance site survey).

Fig. 48. Bronze cannon C2 (Area A) with its wooden tampion in place (Phase 1B non-disturbance survey).



Figs. 49-50. Bronze cannon C4 (Area C1) with its wooden tampion in place being measured by the ROV Zeus's manipulator arms. A new cannon was recorded adjacent to C4 in 2012 (top, right foreground) (Phase 1B non-disturbance site survey).

Fig. 51. Bronze cannon C22 (Area E) with its wooden tampion in place (Phase 1B non-disturbance site survey).

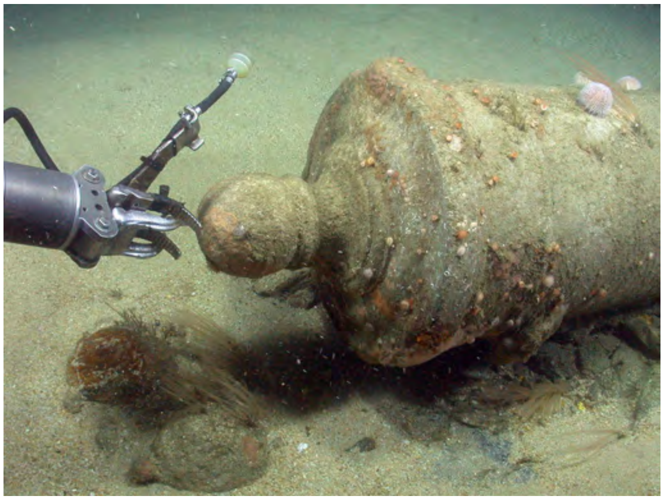


Fig. 52. Bronze cannon C21 (Area E) being measured by the ROV Zeus's manipulator arms (Phase 1B non-disturbance site survey).

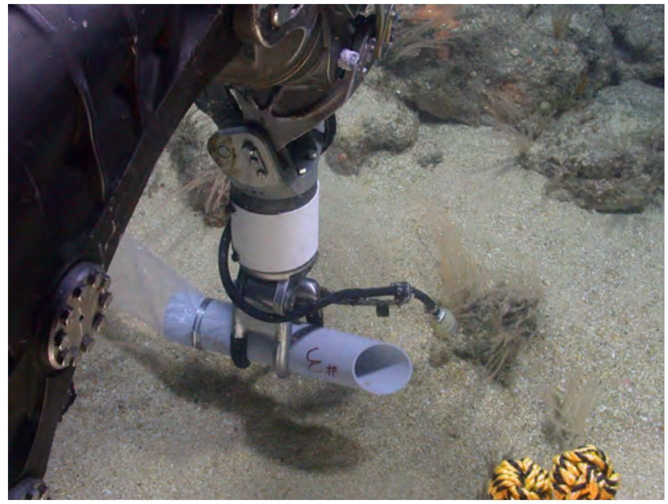
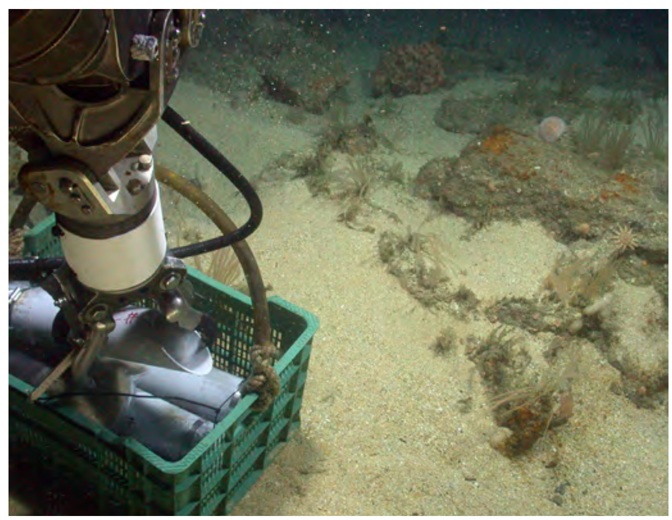


Fig. 53. Sediments being sampled from the top stratum of Area F (Phase 2 non-disturbance site survey).



Figs. 54-55. Sediments being sampled from the top stratum of Area F (Phase 2 non-disturbance site survey).