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HIGH RESOLUTION ACOUSTIC IMAGERY FROM A SHALLOW ARCHAEOLOGICAL SITE: THE GRACE DIEU A CASE STUDY.

Ruth M.K. Plets[a,c], Justin K. Dix[a,b,c], Jon R. Adams[b], Angus I. Best[c], David A. Mindell[d]

[a]School of Ocean and Earth Science, University of Southampton, Southampton, UK
[b]Department of Archaeology, University of Southampton, Southampton, UK
[c]Southampton Oceanography Centre, Southampton, UK
[d]Deep Water Archaeology Research Group, Massachusetts Institute of Technology, Cambridge, USA

Ruth Plets, School of Ocean and Earth Science, Southampton Oceanography Centre, University of Southampton, European Way, Southampton, SO14 3ZH, UK. (Tel: +44(0)2380 596544. Fax: +44(0)2380 596554. Email: rmkp@soc.soton.ac.uk)

Abstract: *Shallow water (< 5 m) archaeological shipwreck sites present unique challenges to geophysical investigation. Retrieval of reliable data is very difficult due to issues of water column bubble turbulence and the restricted acoustic geometry of the system. This paper will present an acquisition method that tackles these problems through the combination of a high resolution sub-bottom system, DGPS navigation and a non-motorised deployment method.*
The test site for this system was the Grace Dieu (1418), the 'great ship' of Henry V's fleet, which was scuttled at its berth in the Hamble River (UK). The site is typically covered by 2-5 m of water, and is partially buried within muddy inter-tidal sediments. At exceptionally low tides, during the spring equinox, a few of the marginal timbers are exposed.
Close survey line spacing (< 2.5 m), accurate navigation and decimetre resolution acoustic data enable a full 2D and pseudo-3D interpretation, including amplitude analysis, of the site to be undertaken. This data has identified the true plan form and dimensions of the remaining segments of this historic vessel supporting the assertion that it was the most significant naval design for over two centuries. It has also been possible to identify the presence of a horizon of incoherent timbers associated with the scuttling of the vessel. Through an archaeological case study the potential of imaging buried objects in extremely shallow environments has been effectively demonstrated.

Keywords: *Chirp, Maritime archaeology, Shipwreck sites, Shallow water, Geophysics*

1. INTRODUCTION

High-resolution marine acoustic surveying for small buried objects in the shallow waters of the inter-tidal to immediate sub-tidal zone is one of the major challenges to many sectors of the marine surveying community. This is a consequence of a number of issues including the relationship between water depth and acoustic acquisition geometry; the problems of dissipating vessel induced bubble clouds that significantly reduce signal-to-noise (SNR) ratio; and the necessity for high spatial survey accuracy in three-dimensions. The challenge of these marginal environments is particularly acute for the marine archaeological community, who are frequently required to non-destructively investigate shallow-water (< 5 m) sites from both a terrestrial and marine perspective in order to provide a seamless interpretation.

This paper outlines a seamless marine archaeological investigation of Henry V’s flagship the *Grace Dieu* (1418), a shallow water wreck site in the Hamble River (Burlesdon, UK). The *Grace Dieu* was the ‘great ship’ of Henry’s fleet and was the largest ship ever built in England, up to that time. Indeed she was bigger than almost every other ship built for another two hundred years. She was built for war with France but never saw action and by 1420 was in reserve, functioning more as a technological marvel to impress foreign dignitaries. She was scuttled at her berth after being struck by lightning in 1439.

Although a wreck site in the Hamble had been known since 1850, it was not until archaeological investigations in the 1930’s, that the site of the *Grace Dieu* was finally identified. It took a further sixty years until a full archaeological survey (spread over several field seasons: Fig. 1a) of the exposed timbers of the site was finally completed [1]. Today, the site is typically covered by 2 – 5 m of water (except during exceptionally low tides) and is buried beneath a veneer of coarse silt.

Although the *Grace Dieu* site has been studied for over 150 years, there is still very limited information on the basic dimensions and shape of the remaining hull. Consequently, the data presented here not only demonstrates the effectiveness of adapted strategies for shallow water surveying but also increases our knowledge of this exceptional vessel.

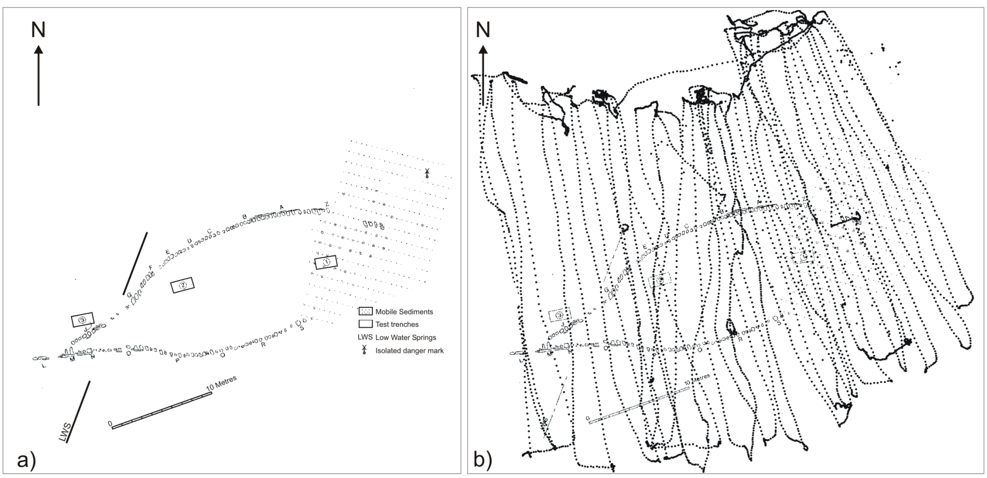

Fig. 1: a) Georectified published drawing of exposed timbers (after [1]), and b) Chirp survey (•) in relation to the known position of the wreck.

2. METHODOLOGY

The marine survey was conducted using a quadratic array of four Chirp transducers, mounted on a catamaran along with a, co-located, DGPS system, allowing navigational accuracy within a metre. The Chirp sub-bottom profiler produced a 16 ms, 1.5 – 11.5 kHz linearly swept pulse, shaped with a Blackmann-Harris envelope and was transmitted at a rate of 8 pulses per second. Modelling experiments have demonstrated that the theoretical vertical resolution for this sweep, with a –3dB bandwidth of 3.47 kHz, is in the range of 22 to 32 cm.

Previous marine surveys over the wreck, using a similar Chirp source, have failed to image sections through the site. This was the results of excessive acoustic blanking in the water column, created by the wake bubble cloud of the survey vessels propellers. This effect was enhanced by the bubbles being unable to dissipate due to the shallow tidal wedge typical of such environments. In order to increase the signal-to-noise ratio (SNR), the traditional surveying method (i.e. an acoustic source towed behind the survey vessel, and a hydrophone unit offset ± 2 m behind the source) has been adapted. Firstly, bubble turbulence in the water column was avoided through a non-motorised deployment: the catamaran was towed over the site by divers, from a survey vessel anchored upstream of the target. Secondly, the system has effectively been made monostatic by mounting the hydrophone adjacent to the source.

During the exceptionally low tides of the spring equinox, the surviving timbers protruding from the mud were exposed and accessible, and have been surveyed with a terrestrial Real Time Kinematic (RTK) – GPS system. This provides ± 0.02 m positioning accuracy of the timbers, data which was then used to georectify a scanned image of the extant survey plan [1], thus providing an accurate basemap for comparison with the marine geophysical data. A dataset of 39 Chirp lines has been acquired over the known wreck site (Fig. 1b), resulting in a total of c. 1250 metres of acoustic data over an area of 1800 m^2 with an average shot point spacing of 4 cm and a maximum line spacing of 2.5 m.

The chirp data was collected in an uncorrelated format, recorded at a 25 kHz sample frequency. All data processing was undertaken using PROMAX seismic processing software. After integrating the navigational data with time synchronised acoustic data, a simple processing flow was applied, which included: (1) correlation of the raw data with the Chirp sweep, (2) automatic gain control, and (3) instantaneous amplitude calculation. Visualisation and interpretation has been undertaken using Kingdom Suite.

3. RESULTS

The newly acquired marine Chirp data is of much better quality than acoustic data sets obtained during previous surveys of the site due to a significant increase in the SNR. Within a number of the Chirp sections (Fig. 2), a high amplitude acoustic anomaly is recognisable within a 2.5 ms TWT window beneath the river bed, and is always associated with an acoustic blanking zone directly beneath it. In cross-section the anomaly is seen to truncate the sub-horizontal reflectors interpreted as being associated with the local geological stratigraphy. Calculation of reflection coefficients of the anomaly (using the method [2]) gives an average value of -0.34. This atypically large and negative reflection coefficient is characteristic of degraded oak buried in fine grained marine sediments [3] which supports an interpretation of the anomaly being the buried oak timbers of the *Grace Dieu*.

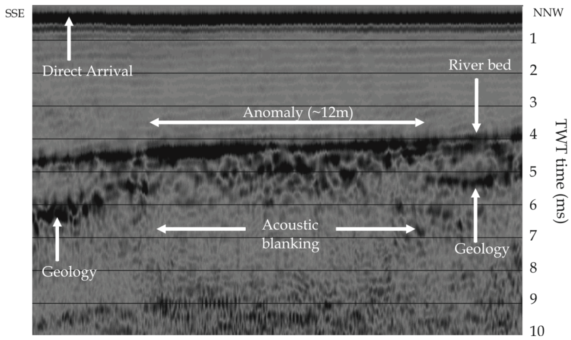

Fig. 2: Typical 2D chirp line acquired over the wreck site

Two complimentary approaches have been taken to the visualization and interpretation of the three-dimensional nature of this anomaly. Firstly, an amplitude analysis of the acoustic data has been made by generating time slices at regular, 0.1 ms TWT intervals. This is equivalent to slices every 7.5 cm, the metric conversion being based on a sediment velocity of 1517 ms^{-1} calculated from the quadratic regression equations for inter-tidal sediments of Robb et al. [4] and using a mean grain size for the site of 4.7 φ. The time slice equating to the river bed (Fig. 3a) shows no discernible amplitude pattern associated with the known location of the exposed timbers. However, a time slice at 0.8 ms TWT (c. 0.6 m) below the bed (Fig. 3b), illustrates a high amplitude zone with an ovate plan form which is coincident with the location of the vessel. The presence of the high amplitude zone at c. 1.3 m above the lowest point of the keel imaged is interpreted as representing an horizon of timbers/planking within the structure. Such vessels would not have had a coherent deck structure so low in the keel and thus this horizon probably represents collapsed timbers associated with her scuttling. The deeper time slices at 1.4 ms (c. 1.05 m below the bed, Fig. 3c) and 2.1 ms (c. 1.6 m below the bed, Fig. 3d), again show a distinct ovate plan form outline, but one enclosing lower amplitudes indicative of the surrounding sedimentary sequence. The length and breadth of these outlines reduce with depth from a maximum of 36.7 m x 11.3 m at 0.6 m depth to 24.8 m x 8.5 m at 1.6 m depth. These values are comparable to those acquired from the RTK georectified terrestrial survey (Fig. 1a) which gives maximum dimensions for the exposed timbers of 36.1 m x 11.5 m. Construction of ships with these dimensions were not exceeded until late into the 17th Century. It is hoped that the further analysis of this data will enable the construction of a keel section profile of the vessel and ultimately a full three-dimensional reconstruction.

The outline of the anomaly has also been manually picked on each cross section, the data then being interpolated to create an isopach of this feature (Fig. 4a). The isopach contours suggest a well defined and pronounced axial (keel) symmetry. By comparison, the stern section is more clearly defined than the truncated bow segment. This is a product of overall higher amplitude reflections towards the eastern, bow, end of the site (Fig. 3b), making manual picking difficult. These ambient higher amplitudes are associated with a coarsening of the sediment towards the river margin. Comparison of the outline of the anomaly from the interpreted Chirp data with both the RTK survey collected this year and the 1980's site plan show a strong correlation between the anomaly and the known wreck location (Fig. 5).

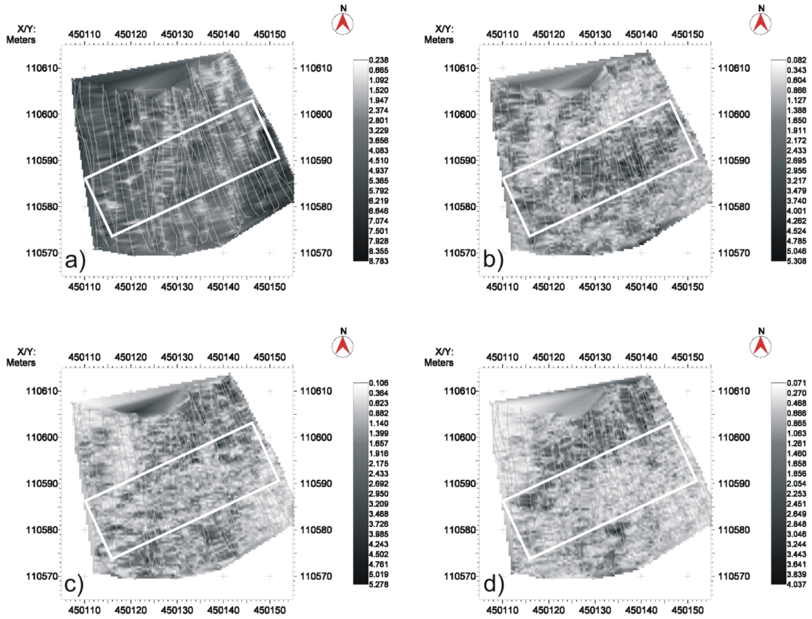

Fig. 3: Amplitude maps of a) the river bed, b) 0.8 ms, c) 1.4 ms and c) 2.1 ms beneath the river bed. The white box indicates the area of exposed timbers. The colour bar represents relative amplitude values.

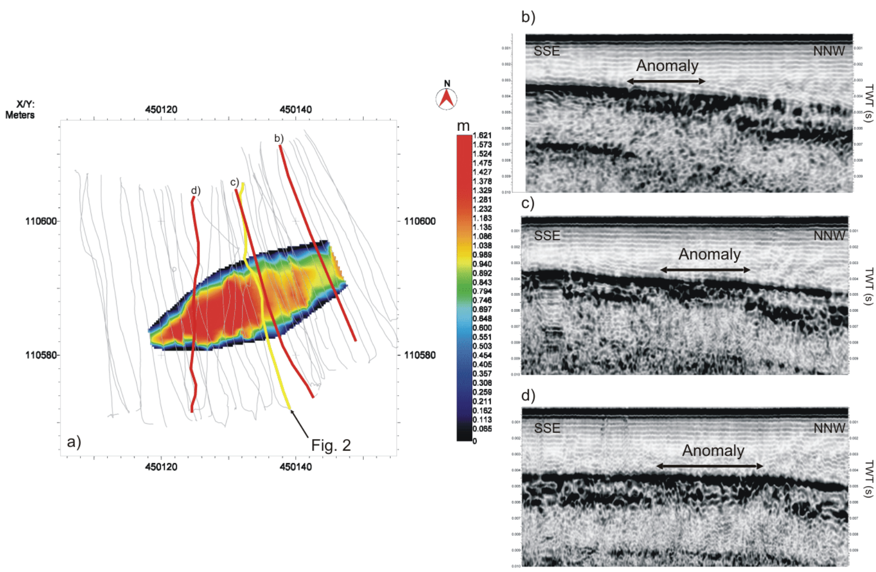

Fig. 4: a) Isopach map showing the thickness of the anomaly (in metres), and cross sections through b) the eastern side, c) the centre and d) the western side. Depths converted using a velocity of 1517 ms^{-1} for coarse silts

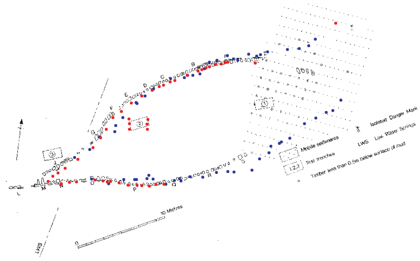

Fig. 5: Comparison of the Chirp data(•) and the terrestrial RTK (•)data

4. CONCLUSION

This paper demonstrates the effectiveness of a diver deployed, catamaran based, monostatic 2D Chirp system for shallow water archaeological site survey. As a result of the closely spaced, high pulse rate, survey design, a successful pseudo-3D imagery of the wreck of the *Grace Dieu* has been acquired. The wreck is represented by an assemblage of high amplitude reflectors, with an associated blanking zone beneath, which truncate the local stratigraphy. Through correlation of the anomaly with an RTK georectified survey plan, and the identification of large negative reflection coefficient for the anomaly (characteristic of buried archaeological wood) supports its interpretation as the *Grace Dieu*.

The vessel has maximum dimensions near the surface of 36.7 m x 11.3 m, making it the largest vessel to have been built during the period. The marked keel symmetry suggest coherent timbers exist to a depth of at least 1.9 m beneath the seabed with the length and breadth dimensions decreasing towards the keel. A horizon of strong reflectors 1.3 m above the keel is interpreted as a horizon of incoherent timbers related to the scuttling of the vessel.

The detail extracted from this data set shows the potential of such an approach to accurately detect a wide variety of buried objects in the complex environment of the shallow inter-tidal zone.

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