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3D RECONSTRUCTION OF A SHALLOW ARCHAEOLOGICAL SITE FROM HIGH-RESOLUTION ACOUSTIC IMAGERY – A CASE STUDY

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Abstract*: This paper compares a 2D and 3D-Chirp geophysical investigation of a buried shipwreck: the Grace Dieu (1418). The site, covered by 2-5m of water, is buried within muddy inter-tidal sediments. At exceptionally low tides, a few of the marginal timbers are exposed. The marine survey utilised a 2D-Chirp systems with a DGPS navigational system, and a 3-Chirp system with RTK-positioning capability. In both cases, the source was towed over the site by divers. Close survey line spacing, accurate navigation and decimetre scale resolution data enabled the construction of a pseudo- and full 3D-image of the site, which were calibrated against an RTK-GPS-terrestrial survey. The exercise demonstrated the improved spatial resolution provided by the 3D-Chirp system and the ability of a well-constrained 2D survey to produce a pseudo-3D reconstruction of the gross ship structure.*

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 (<5m) sites from both a terrestrial and marine perspective in order to provide a seamless interpretation.

Plets et al. [1] have demonstrated that a well-constrained 2D acoustic survey can provide a robust pseudo-3D reconstruction of a buried shipwreck. This paper presents a comparison of this pseudo-3D marine investigation of Henry V's flagship the *Grace Dieu* (1418), with a true 3D reconstruction using the 3D-Chirp system designed by the University of Southampton and GeoAcoustics Ltd. [2].

The *Grace Dieu* was the ‘great ship’ of Henry V’s fleet and was the largest ship ever built in England, up to that time. Bigger than almost every other ship constructed for another two hundred years, she was built for the war with France, but never saw action. By 1420 she was in reserve, functioning as a technological marvel to impress foreign dignitaries. After being struck by lightning in 1439, the *Grace Dieu* sunk at her berth in the River Hamble (Bursledon, UK).

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 [3]. Today, the site is typically covered by 2–5m 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.

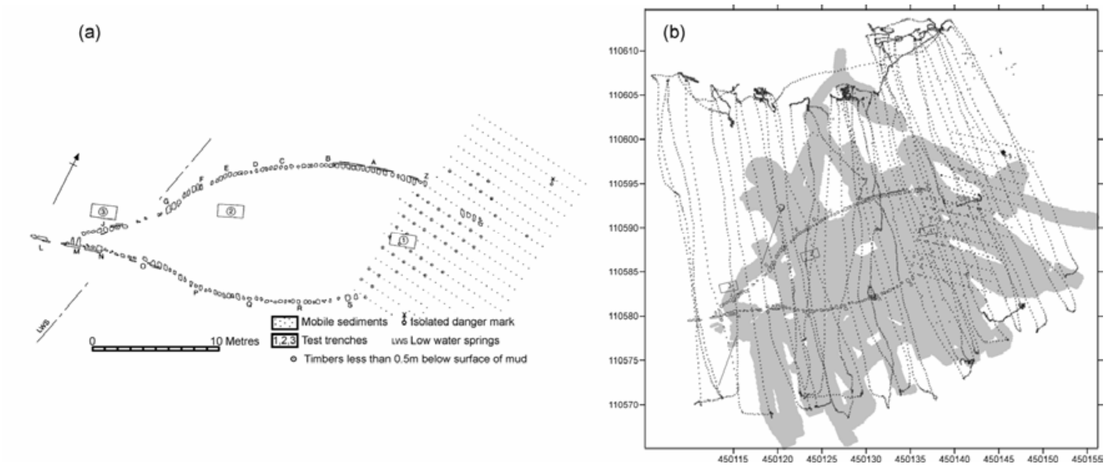

Fig. 1: (a) Published site plan [3], and (b) 2D Chirp survey (•) and 3D Chirp(•) survey in relation to the georectified site plan.

2. METHODOLOGY

The 2D 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 to within ± 1m. The 2D system has effectively been made monostatic by mounting the hydrophone adjacent to the source. The Chirp sub-bottom profiler produced a 16ms, 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 32cm.

The 3D system is made of a rigid 2.2m x 2.5m frame on which the same Chirp transducers, now in a Maltese Cross configuration, and 60 receiver groups with a 25cm horizontal spacing are fixed [2]. An RTK (Real-Time-Kinematic) – GPS positioning and GPS-attitude system provide the position of the source arrays and receiver groups with centimetric accuracy. A sweep with greater vertical resolution (7.6 to 11cm) was transmitted at a rate of 8 pulses per second: a 16ms, 1.5 – 13 kHz linearly swept pulse shaped with a Sine-Squared 8^{th} Envelope and -3dB bandwidth of 9.89 kHz.

A major problem encountered when using traditional survey methods is excessive acoustic blanking in the water column, created by the wake bubble cloud of the survey vessel's propellers. This effect is generally 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), bubble turbulence in the water column was avoided through a non-motorised deployment: the catamaran and 3D frame were towed over the site by divers, from a survey vessel anchored upstream of the target.

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 a relative positional accuracy of ± 0.02m for the timbers, data which was then used to georectify a scanned image of the extant survey plan [3], thus providing an accurate basemap for comparison with the marine geophysical data.

A 2D 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 $1800m^2$ with an average shot point spacing of 4cm and a maximum line spacing of 2.5m. This 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.

The 3D survey resulted in a data volume with a surface area of 50m x 50m. This data was recorded in an uncorrelated format, with a sample frequency of 50 kHz. The data processing in PROMAX consisted of: (1) bandpass filtering, (2) correlation with the Chirp sweep, (3) geometry processing, (4) binning of the data into 0.125m x 0.125m bins, (5) normal move-out correction, (6) instantaneous amplitude calculation, (7) stacking, and (8) automatic gain control.

Visualisation and interpretation of both the 2D and 3D data has been undertaken using Kingdom Suite Software.

3. RESULTS

A typical 2D and 3D cross section can be seen in Fig. 2. On a number of the 2D Chirp sections (Fig. 2a), a high amplitude acoustic anomaly is recognisable within a 2.5ms TWT (two-way travel time) 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. A similar high amplitude anomaly, truncating sub-horizontal reflectors, is represented on the 3D sections (Fig. 2b). Due to the binning and stacking process performed on the 3D volume, the 3D sections are generally less noisy than the 2D cross-sections. This higher SNR combined with the greater vertical resolving power of the Chirp sweep used for the 3D survey, resulted in better resolved and crisper seabed and internal reflectors.

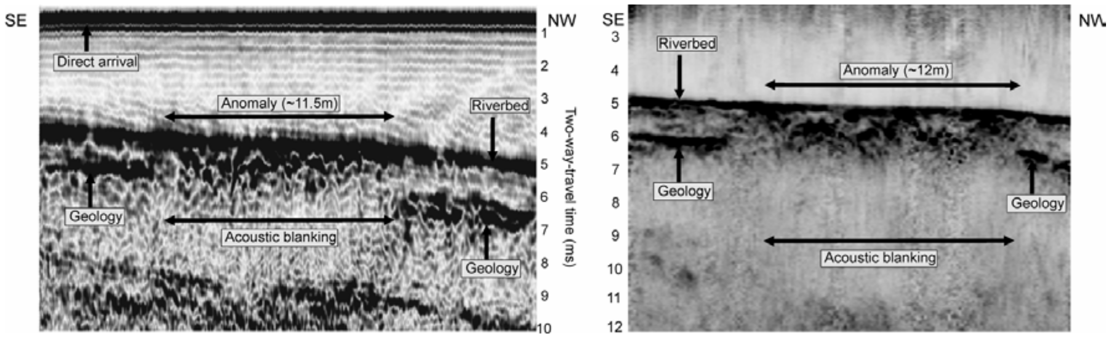

Fig. 2: Typical chirp line acquired over the wreck site; (a) 2D and (b) 3D.

In order to visualise this anomaly, amplitude maps were created from the processed data from time-slices parallel to the riverbed, at regular 0.1ms TWT (c. 7.6cm) intervals. A nearest neighbour gridding method was used to interpolate the amplitude data between the 2D acoustic lines. The 2D time-slice at 0.7ms TWT (c. 0.5m) (Fig. 3a) illustrates a high amplitude zone with an ovate plan form which is coincident with the location of the vessel. Further, a zone of high amplitudes is imaged within this delineated area which is interpreted as representing a horizon of timbers within the structure. Deeper 2D time-slices at 0.9ms (c. 0.7m) and 1.3ms TWT (c. 1.0m) show a smaller and less clearly delineated ovate shape (Fig. 3b & c). On 2D time-slices beneath the anomaly (e.g. 2.7ms TWT (c. 2.0m)), the high amplitudes have disappeared from the wreck site zone and the local geology dominates the picture (Fig. 3d). A similar image can be seen on the 3D time-slices (Fig. 3e-h). However, due to a higher horizontal and vertical resolution of the 3D volume, the boundary between the anomaly (possibly wood) and the surrounding sediment is much sharper. Even deeper time-slices (Fig. 3f & g) still show a distinct ovate plan shape. Furthermore, although bigger structures and objects were detectable on the 2D time-slices, a clearer picture of potentially archaeological important small, metre scale, objects within and around the wreck is displayed on the 3D slices. A good example is shown on Fig. 3f where a striking square feature with a 2m x 2m dimension is depicted within the remains of the hull (aft of amidships).

With the help of the features seen on the time-slices, the anomaly was picked manually on each cross-section of both datasets by selecting the lower boundary of the higher amplitudes, the data then being used to create an isopach of the remains of the hull of the *Grace Dieu* (Fig. 4 a&b). All depth conversions are based on a sediment velocity of 1517m/s calculated from the quadratic regression equations for inter-tidal sediments [4] and using a mean grain size for the site of 4.7φ. The interpolated 2D isopach shows maximum dimensions of 35.4m x 11.4m and a maximum burial depth of 2m. Although the 2D isopach suggests a well defined and pronounced longitudinal and lateral axial (keel) symmetry, the 3D isopach, however, indicates that the wreck is slightly tilted towards port side. Similar dimensions were found from the 3D dataset: minimum length of 33.2m, maximum breadth of 12.2m and a maximum burial depth of 2m. Using the outlines of the buried timbers on the amplitude maps and the picks on the cross-sections, a pseudo-3D (for the 2D data set) and full 3D (for the 3D data set) reconstruction of the remains of the hull of the *Grace Dieu* was created.

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 visual correlation between the anomaly and the known wreck location supporting the interpretation of the anomaly being the buried oak timbers of the *Grace Dieu*.

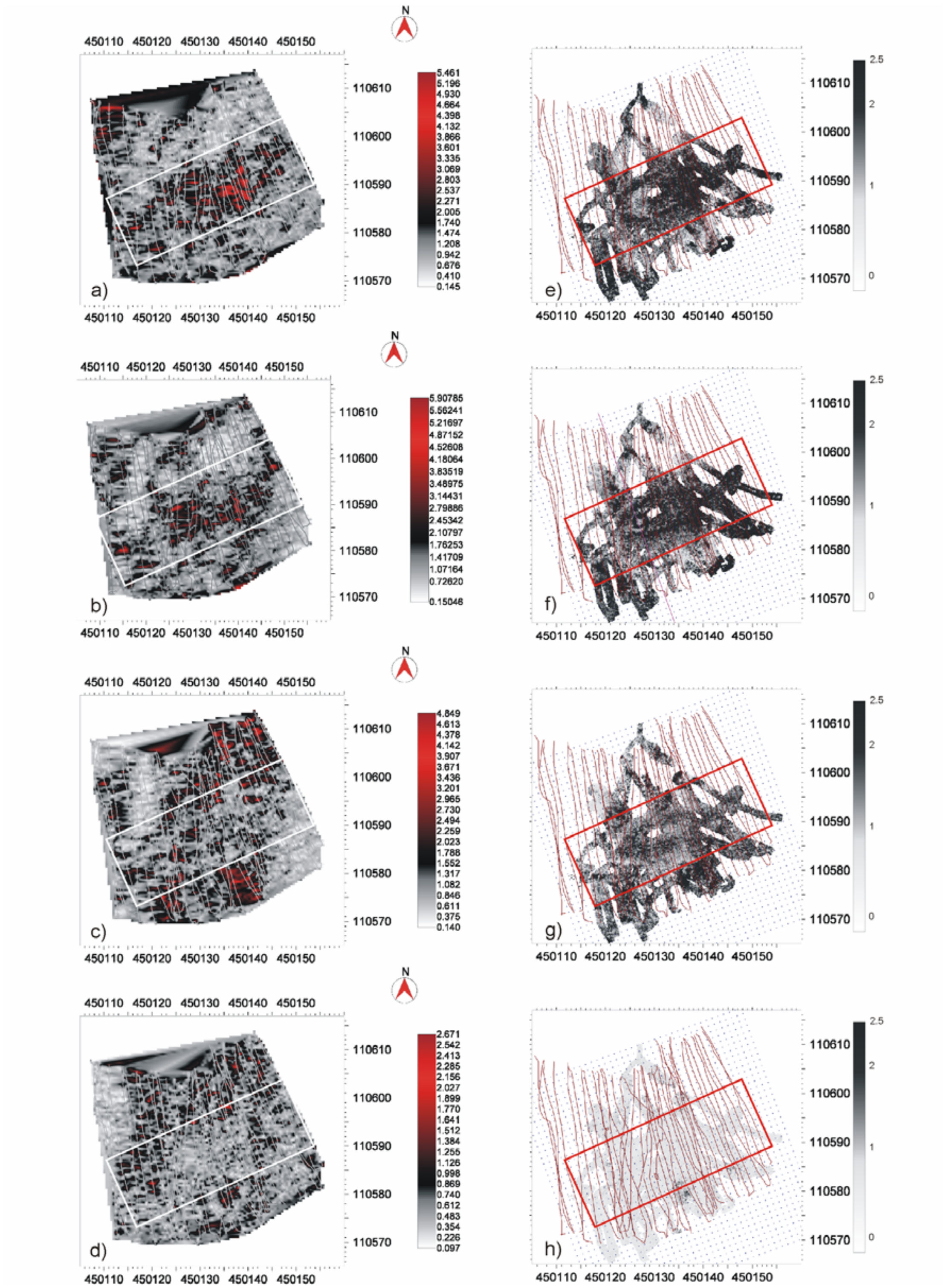

Fig. 3: Amplitude maps of the 2D (a-d) and 3D (e-h) data. (a & e) 0.7ms, (b & f) 0.9ms, (c & g) 1.3 and (d & h) 2.7ms TWT below the river bed. The colour bar represents absolute amplitude values.

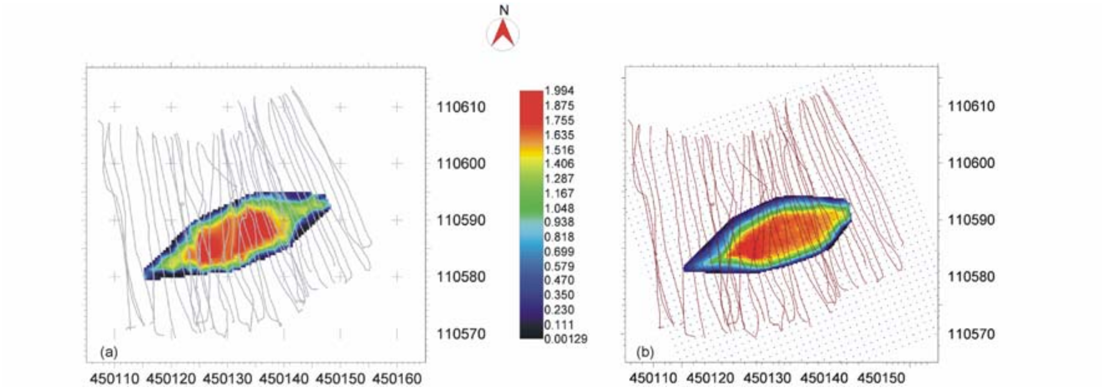

Fig. 4: Isopach map showing the thickness of the anomaly (in metres) for (a) the 2D data and (b) the 3D data. Depths converted using a velocity of 1517 m/s for coarse silts.

4. CONCLUSIONS

Although buried object detection in shallow water often proves to be difficult, this research has demonstrated the successful imaging of an archaeological target in the inter-tidal zone using standard geophysical methods (Chirp) under well controlled surveying circumstances (no bubbles and accurate navigational surveying method).

As a result of the closely spaced, high pulse rate, 2D survey design, a successful pseudo-3D imagery of the wreck of the *Grace Dieu* has been acquired. This model has been tested against true 3D data, which had a higher resolution and greater navigational accuracy. From the 2D data, a symmetric shape with maximum dimensions of the vessel of 35.4m x 11.4m and a burial depth of 2m has been found. The 3D data resulted in similar dimensions (33.2m x 12.2m x 2m) but a less symmetric shape. The detail in the 3D data has proven useful for detailed detection of small objects in and around the wreck.

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