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The *Invincible* (1758) site—an integrated geophysical assessment

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Introduction

Invincible (originally *L'Invincible*), a 74 gun 3rd rate, was built at Rochefort, France in 1744, captured by the British in 1747 and subsequently lost off Portsmouth, in February 1758. The history of *Invincible* is well documented (Bingeman, 1981, 1985; Lavery, 1988); her importance lies in the fact that at the time she was regarded as the finest 3rd rate and was used as the design basis for a whole new generation of ships (Bingeman, 1981). The location of *Invincible* was rediscovered in 1979 by Arthur Mack on Horsetail, East Solent, UK (50°44.34'N, 01°02.23'W—Fig. 1a). In September 1980, the Secretary of State designated the site under the Protection of Wrecks Act 1973 (1980 No. 2, 1980/1307). Subsequently an excavation licence was issued and the wreck has been the subject of an ongoing programme of excavation and survey since then. Figure 1b shows the results of diver investigations (with diver interpretation) of the site between 1983 and 1987.

When inspected in March 1758, the wreck of *Invincible* was lying on her port side at an angle of about 30° from vertical (Lavery, 1988: 104). Diver excavations conducted between 1984 and 1996 indicate that the current angle of heel is between 45° measured at the bow and 15° at the sternpost (Bingeman pers. comm.).

Today, the wreck of *Invincible* lies in an average water depth of 8 m, with surface currents over the Protected Area oriented northwest–southeast (Tidal Diamond E, 50°43.7'N, 01°03.8'W). Transverse bedforms interpreted from side-scan sonar data acquired over the site are aligned northeast–southwest, suggesting that prevalent bottom currents are oriented northwest–southeast, coincident with surface currents. Sediment analysis from the site reveals that the substrate comprises well-sorted, fine-grained (2·25–2·47ϕ) quartzose sands.

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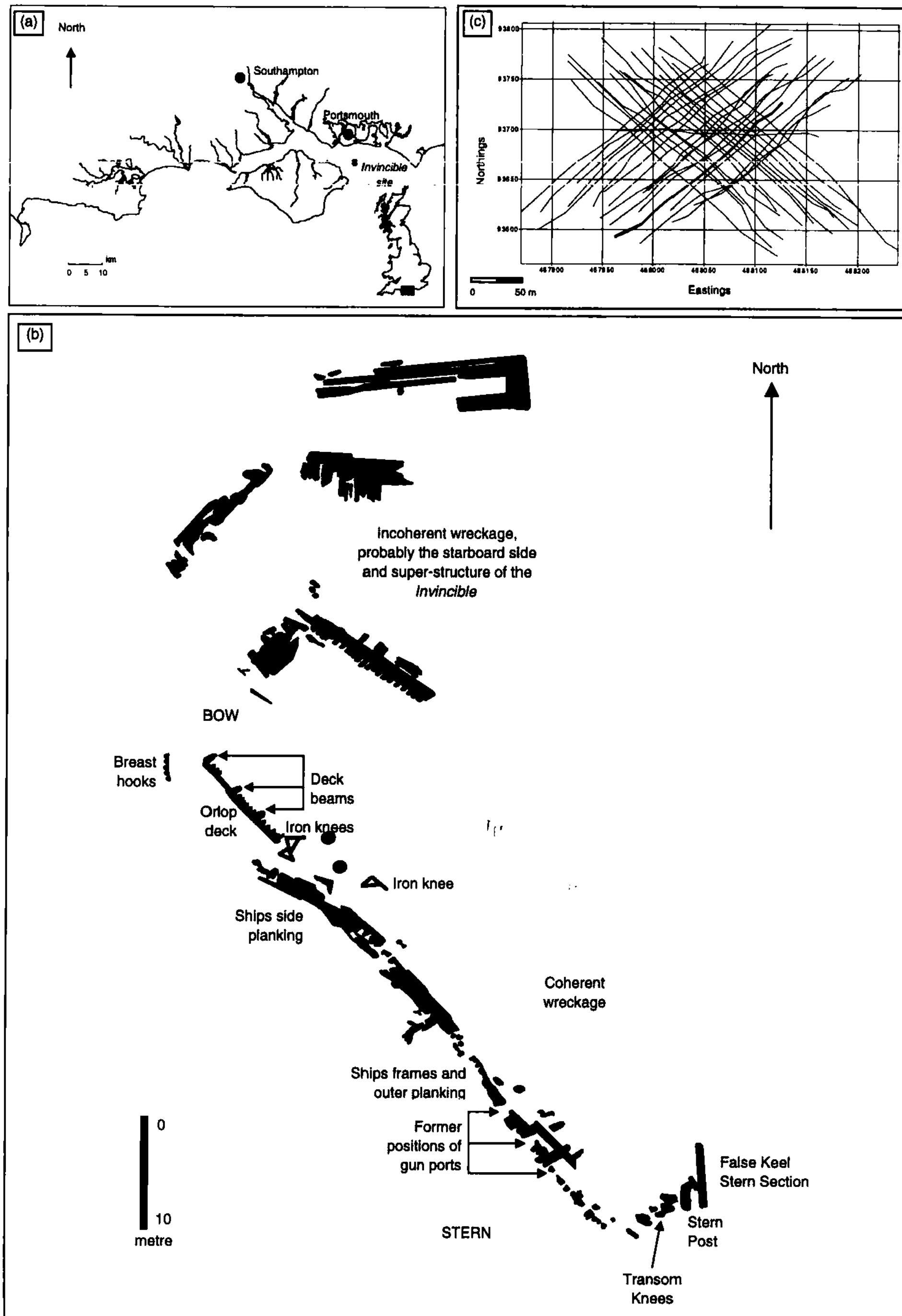

Figure 1. (a) Location map of the *Invincible* site, Horsetail, East Solent, UK. (b) Detailed plans of the *Invincible* (1758) wreck-site from 1984–1987, with diver interpretation (after Lavery, 1988). (c) Trackplot of the geophysical surveys conducted over the *Invincible* site; the 1995 and 1997 surveys utilized the same survey grid. The survey track highlighted by the heavy line corresponds to the geophysical data presented in the test (Illustration: R. Quinn).

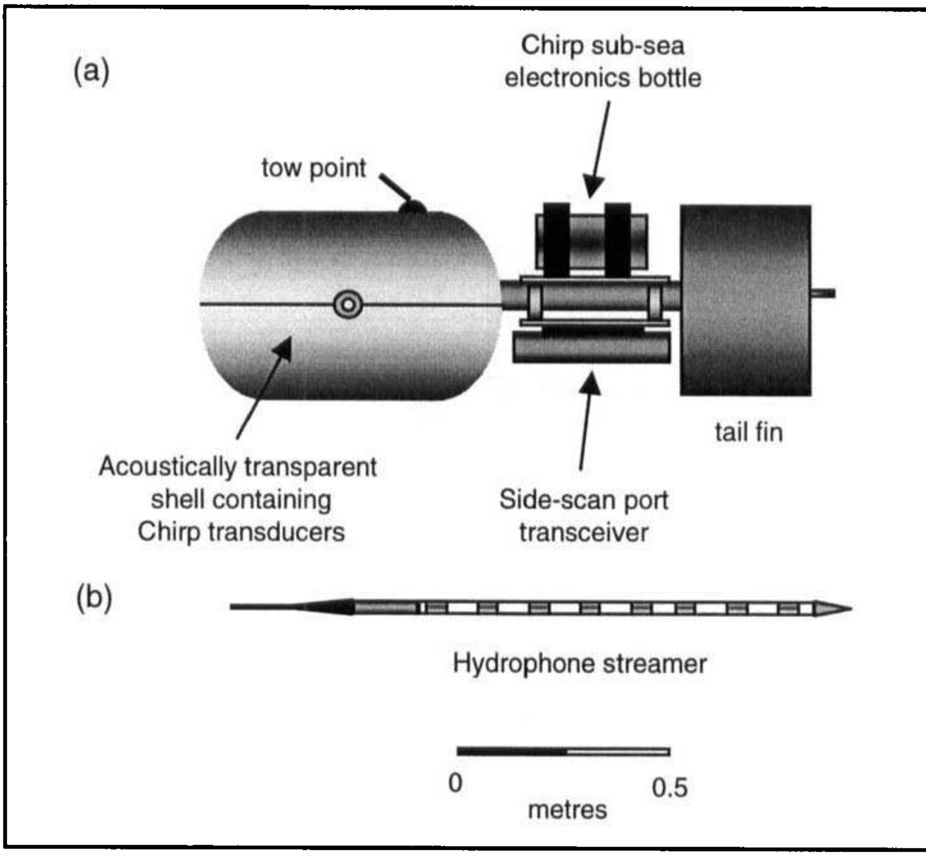

Figure 2. Diagram illustrating the combined Chirp and digital side-scan deployment configuration: (a) GeoAcoustics Model 136A towfish (b) 8-section neutrally buoyant hydrophone streamer. Throughout the survey, the sub-sea electronics bottles and side-scan transceivers are mounted on the towfish and the Chirp hydrophone is towed directly from the rear of the towfish (Illustration: R. Quinn).

Two geophysical surveys were conducted over the *Invincible* site, on 26 May 1995 and 10 August 1997 (Fig. 1c). The rationale was to investigate the processes of site formation, the change in the wreck site over the survey period of 26 months and to examine the effectiveness of marine geophysical surveying for archaeological site monitoring. The following sections relay the results of this survey, propose a wrecking history for the site and discuss the potential use of geophysics as a management tool for the maritime archaeological resource.

Survey equipment and methodology

High-resolution sub-bottom geophysical surveys were conducted utilizing a GeoAcoustics 2 to 8 kHz swept frequency Chirp sub-bottom profiling system (Fig. 2). Throughout the surveys, a 32 ms pulse length and a system transit rate of four pulses per second was used in the acquisition of digital sub-bottom data. The 1995 side-scan sonar surveillance utilized a 100 kHz digital side-scan system with a transmit rate of 4 pulses per second and the 1997 side-scan survival utilized a 500 kHz source (to provide higher resolution data), with a transmit rate of 10 pulses per second. Survey navigation was provided by a differential global positioning system (DGPS), with an accuracy of ± 1 m. An area of approximately 300 m^2 was surveyed, centred on the site of *Invincible*. A total of 8 km of digital sub-bottom and side-scan data were acquired over the 2 surveys (Fig. 1c).

Cross-sections of the wreck-site were acquired at 10 m spacing using the Chirp profiler, while plan images of *Invincible* and the surrounding seabed were provided by the side-scan sonar. The geophysical instrumentation was deployed in co-registration mode, that is, using coincident Chirp and side-scan pulse triggering to ensure the same portion of the wreck structure was imaged simultaneously during surveys. This survey methodology ensured that full 3-dimensional coverage of the wreck was obtained. Furthermore, a 4th dimension (time) was added by repeating the survey over a 26 month period.

Inherent in side-scan data of the sea floor is a spatial distortion due to towfish altitude[1]. This means that the initial return to the transceiver mounted on the towfish is almost vertical, and the returns from a distance are almost horizontal. Each data point in between has some lateral (or range) distortion (Fish & Carr, 1990). In order to correct for this lateral distortion, a slant range correction can be applied to side-scan sonographs to produce a laterally consistent interpretation of the seafloor.

Side-scan sonar data is in effect a tonal map of the seafloor. Dark areas on the sonograph indicate strong acoustic returns (and conversely light tones indicate weak returns), where the strength of the return is a function of material type and seafloor topography. Coarse sedimentary material and wood provides strong returns, while relatively fine-grained sediment returns weaker signals. Likewise, sub-bottom data recorded by the Chirp system is affected by the physical characteristics of the material causing the reflection of the transmitted pulse. Exposed or buried wooden artefacts present a high acoustic impedance contrast with surrounding unconsolidated sediments (Quinn *et al.*, 1997a), and so appear as strong (high-amplitude) reflectors on the sub-bottom profiles.

Results

The results of the geophysical surveys are presented in the following three diagrams, and discussed in detail in the Interpretation section below. Figures 3a and 3b show the results of the 1995 side scan and Chirp sub-bottom survey of the wreck-site. In the sonograph shown in Fig. 3a, the port side is almost completely exposed, whilst the majority of the north-eastern portion of the wreck material is covered by a thin veneer of sand (average thickness of 0·75 m), evident in the Chirp sub-bottom profile of Fig. 3b. Figure 3c is an enlarged, filtered portion of 3b, where the buried oak wreck structure is imaged as a high-amplitude reflector[2]. An idealized midship section of *Invincible* (after Lavery, 1988—scaled to correspond to the Chirp profile), lying on her port side at an angle of 30° to vertical, is displayed in Fig. 3d. A reflection coefficient (a measure of the strength of reflection) of − 0·27 is calculated for the oak reflector (Bull *et al.*, in review). This large, negative reflection is diagnostic of buried wooden artefacts in the marine environment as identified from theoretical and experimental work (Quinn *et al.*, 1997a). The results of the 1995 and 1997 side-scan surveys of the wreck-site are displayed in Figs 4 and 5, respectively.

Interpretation

Site formation process

Comparisons between the idealized midship section of *Invincible* (Fig. 3d) and the sub-bottom profile in Fig. 3c indicate that the extent of exposed and buried wreck

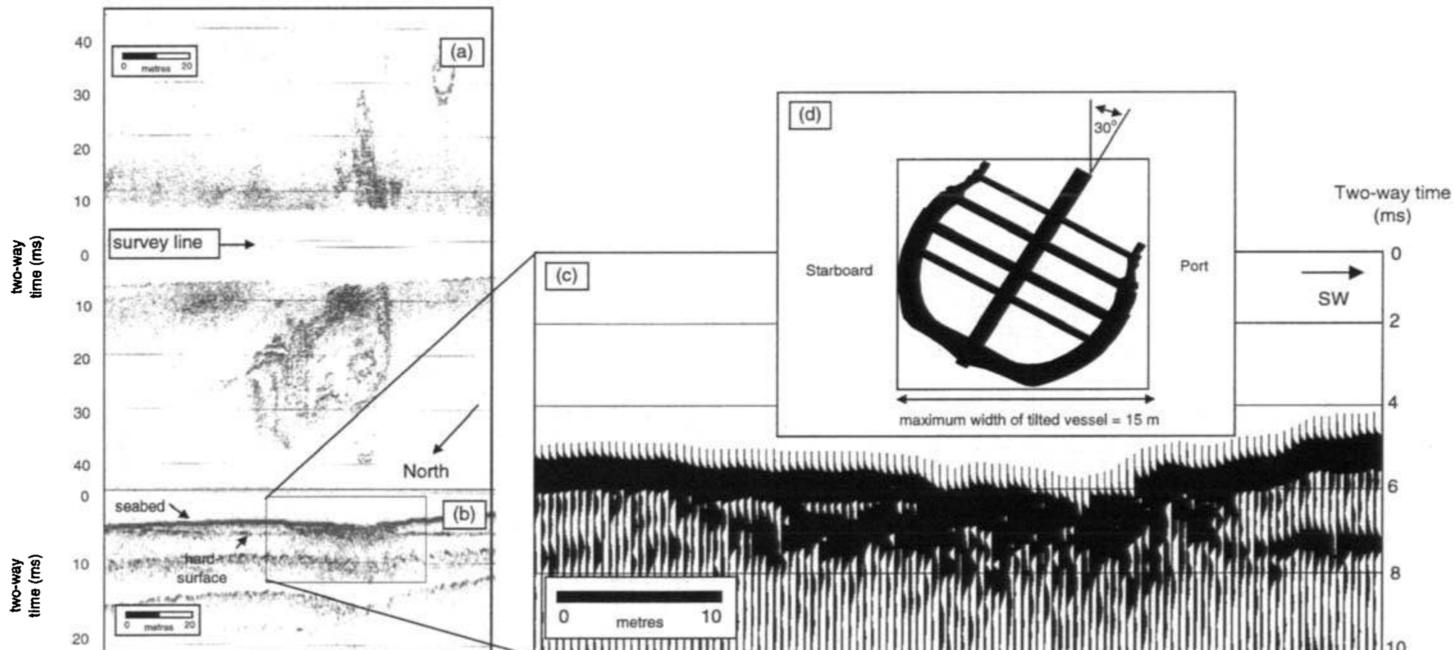

Figure 3. Composite image of the *Invincible* (1758) wreck-site: (a) 100 kHz side scan sonograph of the wreck-site acquired in May 1995; (b) corresponding Chirp sub-bottom profile displaying a NE–SW orientated cross-section of the wreck-site; (c) enlarged, band-pass filtered portion of 3b; (d) idealised midship cross-section (after Lavery, 1988) tilted at an angle of 30° from the vertical (Illustration: R. Quinn).

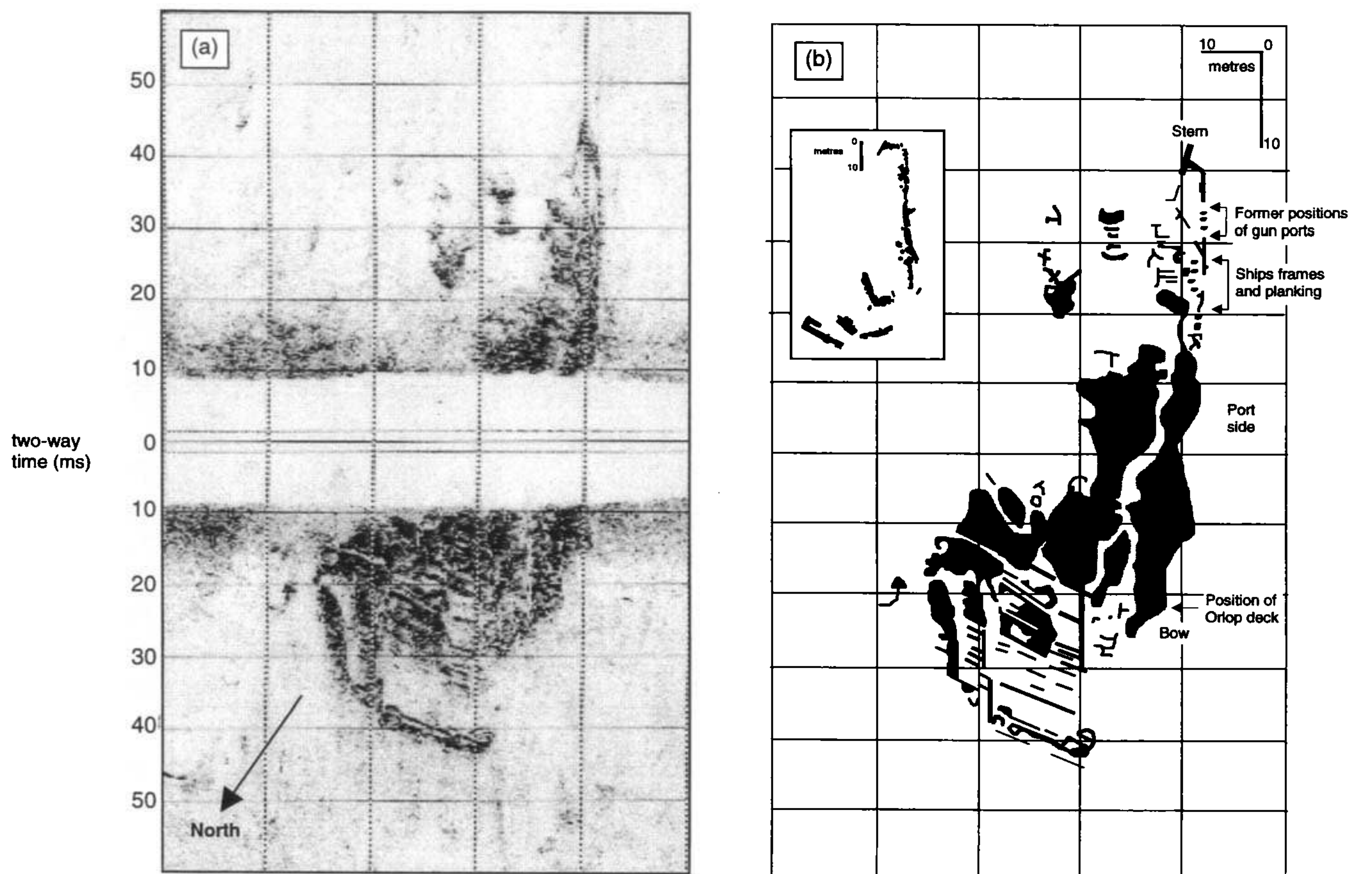

Figure 4. (a) Side scan sonograph of the *Invincible* (1758) wreck-site acquired in May 1995; (b) corresponding isometric plot of the site (subsequent to slant-range correction (see main text for more details)). Divers' plans (after Lavery, 1988) are displayed in the isometric plot for comparison (Illustration: R. Quinn).

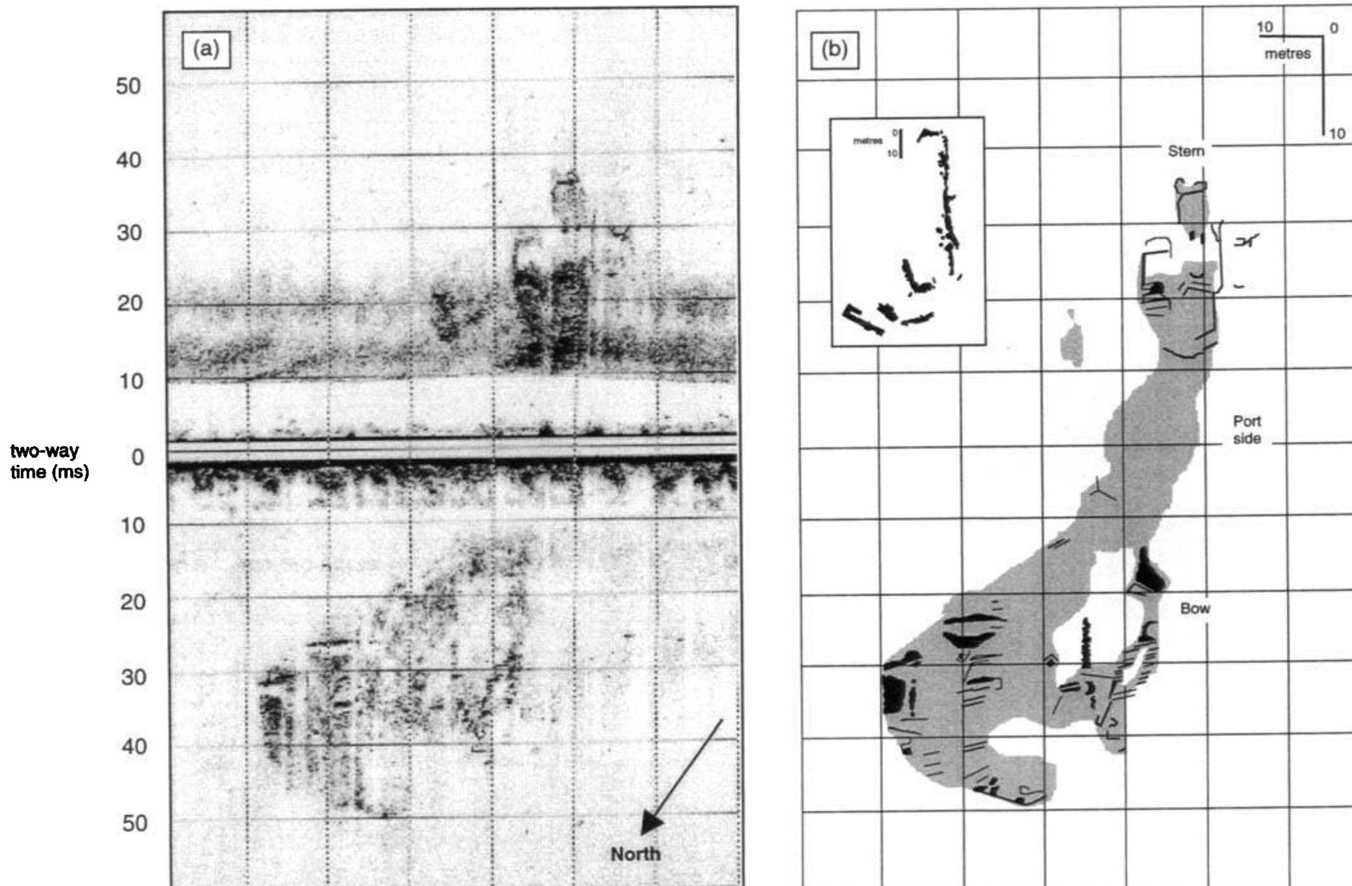

Figure 5. (a) Side scan sonograph of the *Invincible* (1758) wreck-site acquired in August 1997; (b) corresponding isometric plot of the site (subsequent to slant-range correction (see main text for more details)). Grey areas denote exposed wreck-structure, whilst black areas denote individual structural components. Divers' plans (after Lavery, 1988) are displayed in the isometric plot for comparison (Illustration: R. Quinn).

structure imaged in the Chirp profile exceeds the maximum width of the vessel lying on her side at an angle of 30° to vertical (15 m), by more than 15 m at this position (i.e. a total width of 30 m at this point). Examination of the side-scan and sub-bottom data acquired over the whole of the wreck-site indicates that additional wreck structure to that outlined on the divers' plans is located to the north and north-east of what is labelled coherent wreck structure in Fig. 1 (the port side of the ship). Evidence from the isometric plots in Figs 4 and 5 indicates that the majority of this additional wreck material is structurally coherent, comprising a series of parallel and sub-parallel reflectors in the side-scan images.

Tidal data over the site (Tidal Diamond E) shows that the predominant tidal flow over the site is in the direction 311° (see rose diagram (a) in Fig. 6), indicating that the net material transport direction over the site is in a northwesterly direction. This does not explain the distribution of the fragmented wreck structure lying to the North and northeast of the coherent wreckage. However, storm data from the Solent over the past 70 years reveals that more than 90% of storm events of Force 8 or higher were south and south-westerlies (Peace, in press), that is, dominant storm wave action in the Solent acts in a north and north-easterly direction.

The *Invincible* wreck site lies in an average water depth of 8 m, a depth at which wave action due to heavy storm events would significantly affect a structure lying on and above the seabed. Figure 6 is a synthesis diagram in which the original diver's plans of the site are indicated, together with the extent of site interpreted from the geophysical records. It is proposed that destructive storm force, rather than the more acquiescent tidal forces acting on site have dominated the formation of the wreck-site.

These site formation processes operating on the *Invincible* site are in direct contrast to those proposed by the authors for the nearby *Mary Rose* wreck site (Quinn *et al.*, 1997b). The *Mary Rose* site lies in an average water depth of 12 m, a depth at which the effects of storm events is less noticeable. Whereas *Invincible* was a far larger vessel part of which remained above the surface after grounding, the *Mary Rose* hull was completely submerged. The *Mary Rose* also impacted several metres into the seabed, further reducing wave effect (Rule, 1982: 45; Quinn *et al.*, 1997b). Evidence that the *Mary Rose* hull structure still stood fairly high in the water column for many years is provided by the Elizabethan Admiral Sir William Monsom who reported being able to see her timbers (Rule, 1982: 41).

The historical account of the protracted struggle to refloat the *Invincible* after grounding states the ship had dug a bed for itself in the sandbank and was afloat at low water (Lavery, 1988; 102). Then on 22 February, the third day after striking the bank, the ship heeled violently breaking many timbers (Lavery, 1988: 102). When inspected in May 1758, she was described as 'greatly twisted, waiving and cambered'. It was concluded that the ship was 'bilged' and beyond recovery (Lavery, 1988: 104). It is hardly surprising that the hull should have taken a heavy battering during this period. Even before the capsize, water was already deep in the hold and it is possible the shingle ballast had shifted. Subsequent archaeological work established that *Invincible* had broken her back.

Once heeled over, the decks were exposed to the force of the prevailing seas. Sediment would have begun accumulating rapidly in the hull, further adding to the stress imposed on the structure. The reference to 'twisting' and 'waiving' is significant. With the lower hull held firmly in the seabed by the weight of ballast and

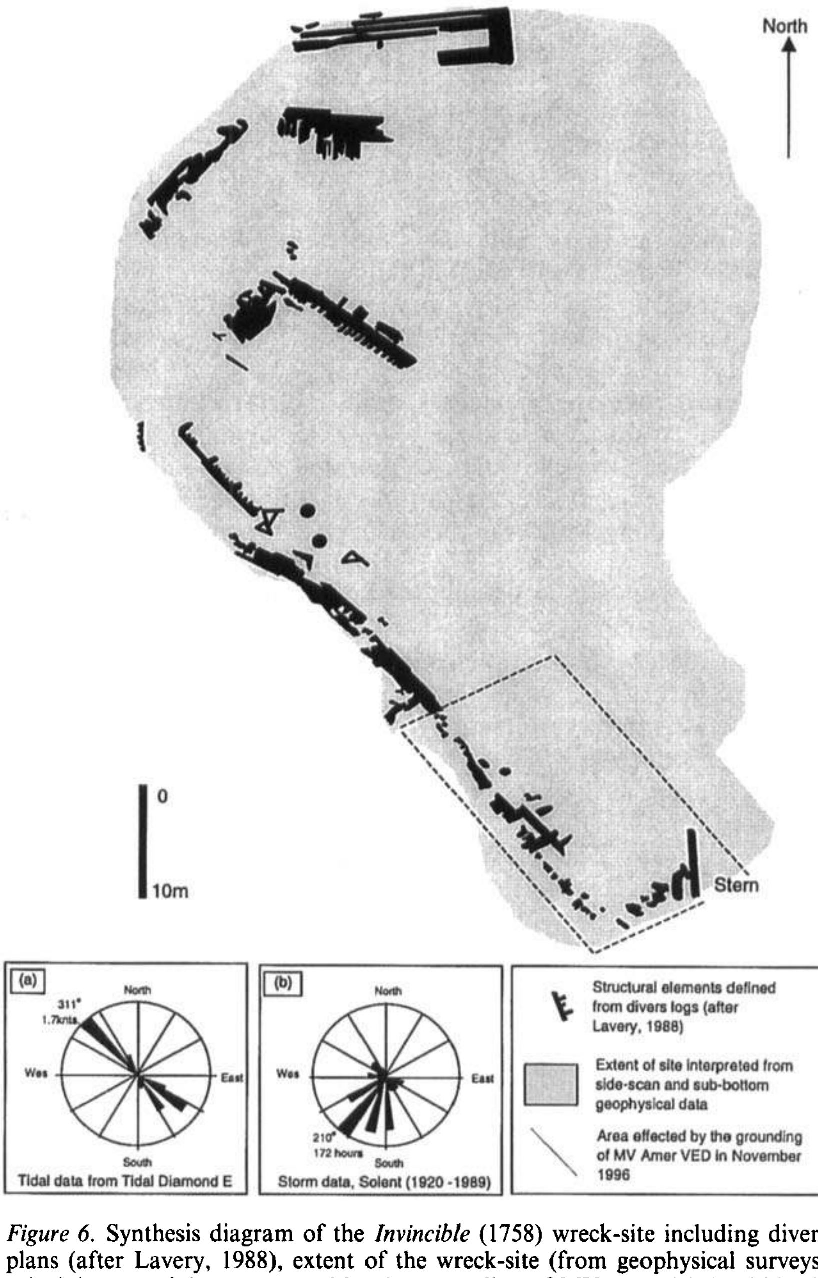

Figure 6. Synthesis diagram of the *Invincible* (1758) wreck-site including divers' plans (after Lavery, 1988), extent of the wreck-site (from geophysical surveys), principle area of damage caused by the grounding of MV *Amer* VED within the Protected Area and rose diagrams indicating (a) prevalent tides and (b) storm forces acting on the site (Illustration: R. Quinn).

sediment, the starboard side would have taken the full force of storm-induced wave action, effectively levering it open. Once the starboard side had been torn away, the port side appears to have further subsided, possibly exacerbated by scour action, reaching the angle of heel observed during excavation.

The evidence therefore indicates that the *Invincible*'s hull progressively hinged open, failing along the lines of weakness, presumably the alignments of futtock joints and beam scarfs. As the prevailing storm direction is from the SW the structure would tend to collapse outwards. This is supported by a probe survey carried out in 1990 that made several shallow, firm contacts up to 26 m east of the port side structure (Bingeman, 1990: 5). Figure 7 shows a schematic midship section of *Invincible*, summarizing the proposed wrecking process. The angle of heel is an estimated mean between the 46° measured at the bow and 15° at the sternpost. The authors propose that the continuous strong reflector in the sonographs is in fact largely coherent wreckage of the starboard side (Fig. 7), lying at a low angle on the hard-surface imaged in the Chirp profile (Fig. 3c).

Environmental impact

In 1991, a sewage outfall was constructed 1300 m to the west of the wreck-site. Tidal currents within the East Solent result in sewage being consistently swept over the Protected Area, presenting a hostile environment for diving archaeologists. Furthermore, on 19 November 1996, MV *Amer* VED dragged her anchor and went aground within the Protected Area (Bingeman, 1996). The merchant vessel carried away the wreck buoy marking the site and was floated off later that night.

The development of transverse bedforms (interpreted from side-scan sonar data), along with diver observation (Lavery, 1988: 108), indicate the sandy substrate over the *Invincible* site is mobile, alternatively exposing and covering sections of the wreck structure with time. This is supported by evidence from side-scan data (Figs 4 & 5), indicating that overall exposure of the wreck was greater in May 1995 than in August 1997. However, the length of acoustic shadows in the 1997 sonographs indicate that the seabed level in the northern portion of the wreck site was lower in August 1997, exposing proportionally more of the timbers at this position to environmental disturbance.

Comparisons between the two vintages of side scan data (Figs 4 & 5) indicate the stern section of the wreck-site has been affected by the grounding of the *Amer* VED within the Protected Area on 19 November 1996. Diver inspection in December 1996 and April 1997 concluded that substantial damage was caused to the wreck-site by the merchant vessel over a distance of at least 20 m to her port side and stern quarter (Bingeman, 1996). These findings are consistent with interpretation of the side scan traces. The false keel section and sternpost, which are clearly imaged in the 1995 side scan data (Fig. 4), are absent in the 1997 data (Fig. 5). Furthermore, the stern section and port side of the wreck in the 1997 data are less structurally complex than the corresponding section in the 1995 sonograph, indicating overall structural degradation to this portion of the wreck (confirmed by diver observation, Bingeman, 1996).

Discussion

The interpretation of marine high-resolution seismic reflection data, in conjunction with local meteorological data, has culminated in a wrecking history of *Invincible*. It is proposed that the arrangement of the wreck-site was primarily controlled by southwesterly storm forces acting over the site. Distribution of wreck material was constrained by storm-associated wave action in a north-easterly orientation, which deposited the bulk of fragmented wreck structure to the north and northeast of the *in-situ* port side.

The proximity of the sewage outfall and shipping channels close to the wreck site make it a hazardous site for diver investigation. Marine geophysical techniques are particularly suited to hostile environments, such as areas where marine pollution, poor

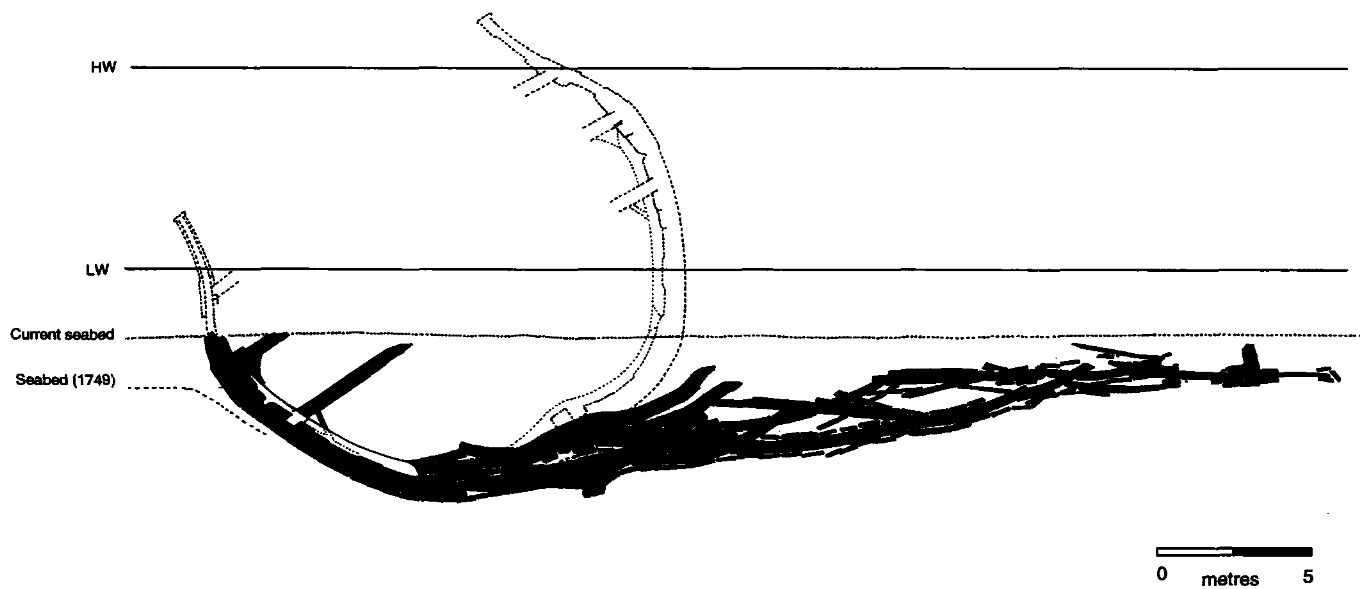

Figure 7. The diagram shows a schematic midship section of *Invincible* summarising the proposed wrecking process. HW, LW indicate mean high and low water springs. Depth to the seabed in 1749 is estimated from contemporary descriptions (Lavery, 1988: 104), and 'Current seabed' is an estimated mean relative to the surviving structure monitored during recent excavations and survey. The angle of heel is an estimated mean between the 46 degrees measured towards the bow and 15 degrees at the sternpost (Illustration: J. Adams).

visibility and other anthropogenic related hazards can significantly affect the performance of the diving archaeologist. The high correlation between the seismic reflection data, the historical sources and archaeological observation demonstrates the integrated geophysical approach adopted here is an efficient, non-intrusive investigative technique. The differences seen in the 1995 and 1997 datasets also demonstrate it is an effective strategy for the monitoring of archaeological sites, whether hazardous or not.

Of particular relevance to management is the ability of current geophysical techniques to demonstrate the true areal extent of a site. In the survey of both *Mary Rose* (Quinn *et al.*, 1997b) and of *Invincible*, geophysical survey has shown the extent of the site to be greater than was apparent through direct observation. Although the respective project staff knew the sites extended beyond the areas investigated during excavation and recording, this was difficult to quantify. Enhanced ability to define the extent of an archaeological site has implications for site management, for example in determining the appropriate size of a protected area around those historic wrecks designated under the Protection of Wrecks Act 1973.

Increasing emphasis is being placed on national and regional initiatives designed to quantify the submerged archaeological resource and compile Sites and Monuments Records (Ferrari, 1995; English Heritage, 1996). A key element of their rationale is their active role in heritage management, particularly in archaeological assessment, site monitoring, and the identification of threat. In this light, repeated 3-dimensional (Chirp and side scan) surveys over archaeologically sensitive areas in the proximal coastal zone offer a highly effective strategy for managing the marine archaeological resource.

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Notes

[1] A full explanation on the theory of operation of side-scan data acquisition systems can be found in Fish & Carr, 1990.

[2] All seismic processing was conducted in ProMAX® 6.0 software package (Advance Geophysical Corporation) mounted on a SUN Ultra workstation.

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