

11 | Marine Geophysics: integrated approaches to sensing the seabed

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Abstract: This paper looks at the use of geophysics and remote sensing in marine archaeology, with the emphasis on their use in field evaluation. Single- and multibeam echosounder, sub-bottom profiler, sidescan, and magnetometer are addressed as geophysical methods; coring, seabed sampling, video and still cameras, Remote Operated Vehicles and divers are all considered as forms of remote sensing. Different motivations, themes, scales and types of operation are discussed, as are their implications for methodological innovation in three areas: position-fixing; event-based recording; and decision-oriented recording.

Introduction

Wessex Archaeology (WA) is a large not-for-profit company principally involved in land-based development-led archaeology. We have become increasingly involved in marine archaeology over the last 15 years and marine geophysics is now a central and substantial part of that work. We also use a variety of techniques that can be described as remote sensing. But rather than looking at individual results, this paper focuses on the integration of archaeological recording.

Our geophysical work usually has a direct consequence for subsequent interventions, whether they are construction works, statutory protection, or further investigations. Whilst the sensors we use – sidescan, sub-bottom profiling, single- and multi-beam echosounder, magnetometer – are common tools in marine surveying, the strength of the link between geophysics and ‘what happens next’ archaeologically has prompted approaches to recording that are novel. Consequently, this paper shows how integrated approaches to archaeological recording can significantly improve the contribution of marine geophysics to understanding the archaeological heritage of the seabed.

As for many others, much of our work can be characterised with reference to three broad phases of investigation: desk-based assessment; field evaluation; and mitigation. Whilst these phases are normally associated with development-led investigations, this phased approach is common in other scenarios.

Both marine geophysics and remote sensing are especially relevant to the field evaluation phase, that is, to establishing the presence (or absence) of archaeological material on or in the seabed, including its position, extents, period, character and so on. The use of marine geophysics and remote sensing overlaps in the evaluation phase with marine geophysics, providing data and/or imagery directly relating to material on the seabed, but through indirect means (predominantly sound and magnetic disturbance).

Remote sensing – as used here – provides physical contact but from a distance, usually a boat on the surface.

Marine geophysics and remote sensing both provide field-based evidence, hence their status as methods of evaluation. The overlap is complementary: the indirect measures applied by marine geophysics are generally effective over a broad area, providing context in terms of a site’s overall form and wider setting; remote sensing generates direct physical data but usually in a highly localised manner. Consequently, field evaluation in the marine sphere often comprises a combination of localised physical evidence with more extensive indirect evidence.

Whilst their main application is in field evaluation, marine geophysics and remote sensing are also relevant to desk-based assessment and mitigation. In desk-based assessment it is important to include as sources the results of previous geophysical and remote-sensing surveys, which might involve re-interpreting survey data or core logs not originally obtained for archaeological purposes but which can yield archaeological information nonetheless, as a sort of ‘latent’ data. The conduct of desk-based assessment should also anticipate marine geophysics and remote sensing in the evaluation phase, identifying key questions and targets for investigation, so that costly field methods are deployed efficiently.

Equally, marine geophysics and remote sensing need to be conducted in a manner that maximises opportunities for field data to inform mitigation and, in some instance, to provide the data that will form the basis of the mitigation itself. For example, high resolution geophysics can in itself serve as a record of a site that is to be destroyed or that needs to be monitored; geophysics data can also be used to provide an outline site plan that can be augmented by limited, targeted diving work, for example. With respect to remote sensing, it is becoming commonplace for mitigation

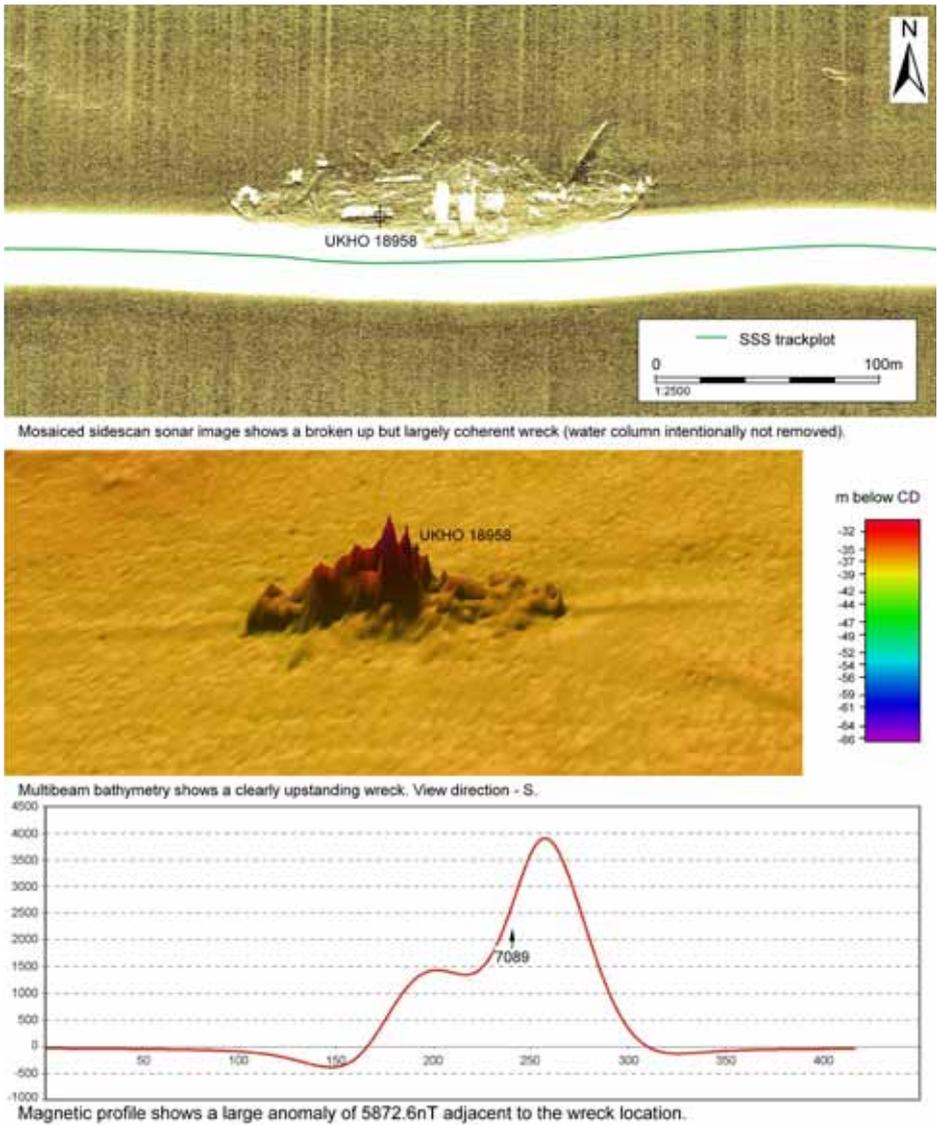


Figure 11.1: Different marine geophysical techniques furnish different types of information about the seabed and are most productive when used in combination rather than in isolation. The data show the wreck of the SS *Mendi*, a troopship sunk by a collision in February 1917 with the loss of over 600 lives. © Wessex Archaeology, Crown Copyright.

in the form of detailed palaeo-environmental analysis and scientific dating of key sediment units to be based on sub-samples obtained during the evaluation phase, rather than requiring a further episode of coring.

Geophysics

The principal marine geophysical methods that we use are set out below. A key characteristic of marine geophysics is that these instruments – because they work in different ways – each say something different about the seabed. They are at their most powerful when used in conjunction with each other, to compare and contrast the different datasets for any particular patch of seabed (Figure 11.1). Whilst it was usual to record marine geophysical data on paper even in the recent past, it is now much more usual for data to be recorded digitally, and there are various software packages available to facilitate complex data processing and interpretation.

Single beam echo sounder (SBES)

Single beam echo sounders use a pulse (*‘ping’*) of sound that rebounds from the seabed. The time that

the *ping* takes to return can be calculated to give a value for depth, which can be corrected for tide to give an absolute height. Conventional echosounders provide depth data directly underneath the sensor, which is usually mounted in a vessel’s hull or on a pole over the side. By sailing multiple lines, fixed by dGPS, it is possible to build up an elevation model. We usually use survey-specification echosounders in conjunction with sub-bottom profilers to calibrate the ‘first return’ (see below).

Multibeam echo sounder (MBES)

Multibeam works like a fan of single beam echo sounders to obtain depth data from a swathe of seabed beneath the vessel. This means that each line covers a considerable width of seabed and, by sailing lines that abut each other it is possible to create an elevation model covering 100% of the survey area. The high density of data is very good for imaging complex topographic features such as wreck sites.

Sub-Bottom Profiler (SBP)

Sub-bottom profilers, also referred to as ‘shallow seismics’, use a pulse of sound like a single beam echo sounder but at a frequency such that some of the energy

penetrates the seabed and bounces off the boundaries between layers of different sediment. The returning data provides a vertical section through the sediment, which can be interpreted for different characteristics and for features such as cuts and fills indicating palaeo-landforms. The 'first return' represents the seabed, which can be calibrated with an echo sounder to give good control over the absolute depth of layers. Different sound sources are used, with different frequency and power characteristics. There is generally a trade-off between penetration and resolution: low frequency 'boomers' provide good penetration of horizons of interest to archaeologists, but at a lower resolution than higher frequency 'pingers' which do not penetrate as far. 'Chirp' sub-bottom profilers use a package of frequencies to combine both penetration and resolution. Parametric sonars work on different principles but still use sound to obtain high resolution images of layers of sediment. As sub-bottom profilers only collect data from below the sensor then a series of parallel lines and perpendicular cross-lines are usually acquired in order to build up a picture of the seabed, where the detail of the picture depends on the density of the lines.

Sidescan Sonar

Sidescan also uses sound but projected from either side of a 'fish' towed close to the seabed from behind the vessel. If the sound is reflected from sediments or objects on the seafloor straight back to the fish then they contrast with areas from which sound is deflected away, or from areas of acoustic shadow behind upstanding items or in depressions. The pattern of bright returns and shadows provides a qualitative but detailed image of the seabed that can be used to identify wrecks, rock outcrops, small anomalies, sediment characteristics and bedforms (such as sand waves and ripples caused by water flow). Again there is trade-off between range and resolution: high frequency sidescan creates a very detailed image but has limited range; lower frequency sidescan has greater range, but may not be capable of resolving the small and ephemeral anomalies of greatest interest to archaeologists. As sidescan sonar obtains data from a swathe each side of the fish, then – depending on the spacing of the lines and the range of the side scan – it is possible to build up 100% coverage of the survey area.

Magnetometer

Magnetometers detect minor variations in the Earth's magnetic field using a fish towed close to the seabed and far enough behind the vessel to avoid the interference from the vessel itself. Once the magnetic data have been processed it is possible to identify localised variations caused by the presence of ferrous material indicative of wrecks or other debris. The size of anomaly is proportional to the amount of ferrous material and its distance from the sensor: a small anomaly could be something large but deeply buried, for example. Magnetometers provide data for lines rather than swathes, so the detail of a survey is dependent on line density.

Remote sensing

In this paper, remote sensing is used in a relatively broad sense with respect to marine archaeology, encompassing a variety of methods where archaeologists are remote from the seabed. The environmental constraints on human access – needing a boat or breathing apparatus on one hand; weather, tides and poor visibility on the other – are such that all marine archaeology is, in effect, remote sensing. Archaeologists are highly reliant on technology, which mediates their access. Technological dependence combined with the highly changeable character of the environment means that the costs of investigation are high. In turn, investigations have to be of limited duration and high intensity.

The remote sensing methods discussed here are all concerned with achieving a degree of physical access to the seabed from a remote position. The main methods we have employed are as follows.

Coring

To obtain a core of sediment from the seabed to investigate its vertical sequence and the composition of each layer we typically use vibrocores, where a rig is dropped to the seabed on a cable (e.g. Figure 15.30). Within the rig, a vibrating weight drives a core barrel into the seabed. The core is then withdrawn and the rig is recovered to the ship. The core is then removed and cut into 1m sections for examination. Conventional 'shell and auger' coring is also carried out, using a drilling rig on a platform jacked-up on legs above sea level. Whilst vibrocores typically penetrate up to 6–8m into the seabed, conventional cores are often drilled tens of metres into the seabed. In both cases, cores are typically 100mm diameter and are suitable for archaeological recording and for obtaining sub-samples for palaeo-environmental assessment, analysis and scientific dating.

Seabed sampling

Different sorts of grabs and scientific trawls can be used to recover samples from the (near-) surface of the seabed. Typically used for examining flora and fauna that live on the seabed or buried just below its surface, seabed samples can also be used to obtain artefacts and other archaeological indicators. These tools are usually dropped to the seabed on a cable and then recovered to the vessel where the contents are sorted, recorded and sampled, or bagged for processing onshore.

Drop Cameras and Sleds

Video and still cameras can be deployed to the seabed from the surface, either as stationary 'drop' instruments that obtain vertical images of the seabed, or on towed sleds that can be dragged along the seabed with both vertical and oblique cameras. Again, used primarily for ecological purposes, drop cameras and sleds can be used archaeologically to obtain photographs of the seabed.

Remote Operated Vehicles (ROVs)

ROVs are manoeuvrable submersible platforms on which video and still cameras can be mounted. They can be piloted from the surface towards and around

archaeological sites without the risks or limitations associated with divers, generating large volumes of imagery and mapping. Larger models have manipulator arms and can be used for complex tasks.

Divers

Although diving does place the archaeologist in direct physical contact with archaeological material on the seabed and might therefore not be regarded as remote, its characteristics as a method are not dissimilar from the other remote sensing methods described here. Generally, diving is constrained by weather, tidal currents, decompression requirements and expense, so that it must be used in a highly targeted way. As well as being brief in duration, the spatial range of a diver is often relatively limited. On the positive side, divers are usually equipped with helmet-mounted video cameras and voice communications so that archaeologists on the surface can see what is present and discuss it with the archaeologist who is diving; in this way the diver serves as a remote sensor for the archaeological team as a whole.

Motivations

As indicated above, the combination of marine geophysics and remote sensing is relevant to field evaluation arising from different motivations.

Development-led

The phasing of investigations in terms of assessment, evaluation and mitigation is associated primarily with investigations prompted by development proposals, where the intent is to establish whether archaeological material is likely to be affected by development and, if significant material is shown to be present, to carry out work to avoid or offset the impacts in a cost-effective manner. Investigations prompted by marine development have strongly influenced our methodological approach, especially with respect to maximising the use of previously-obtained geophysical and geotechnical data, and seeking integration with proposed surveys and their interpretation (Firth 2004; Evans *et al.* 2009).

Strategic research

A major drawback with development-led investigations is that their parameters are fixed by the scope of the development, whilst many of the questions that marine development raises – both methodologically and historically – clearly extend beyond such scope either spatially or in terms of available time or resources. Consequently there are numerous key questions that have to be addressed as a matter of research, albeit research that is closely tied to practical concerns. Our strategic research has been directed towards questions concerning the overall distribution, character and importance of particular types of monument, or of developing methods of data gathering and usage that will enable such questions to be addressed. In such cases we have used both geophysics and remote sensing to acquire data, and experimented with new uses of geophysics and remote sensing techniques (Bickett 2011; Hamel 2011).

Statutory support

Since 2002, a significant element of our work has been to assist the national heritage agencies in England, Wales, Scotland and Northern Ireland in their implementation of statutory heritage protection legislation. Typically our role has been to provide field-based data to establish whether statutory designation is warranted and to monitor sites that are already designated. Whilst greatest emphasis used to be placed on the use of diving archaeologists, in recent years we have increased the use of marine geophysics as a tool for confirming position, establishing extents, guiding the diver to key features and providing the base for site survey.

Multidisciplinary marine science

The high cost of marine survey, for any purpose, places a premium on integration so that the survey can be shared across disciplines. The benefit is all the greater for archaeology as it tends to be the minor partner to engineering, resource mapping, geology and sediment transport, navigation and hazard identification (e.g. ordnance) or ecology (habitats). Whilst we have become adept at the archaeological re-use of geophysical and remote sensing data acquired for other disciplines, there is increasing recognition of the value of building-in archaeological objectives and archaeological staff into multidisciplinary surveys. In particular, the recent and extensive Regional Environmental Characterisation (REC) surveys funded by the UK Aggregates Levy Sustainability Fund (ALSF) have been genuinely multidisciplinary with archaeology taking its place alongside geology and ecology (e.g. EMU Ltd 2009; James *et al.* 2010). It is to be hoped that multidisciplinary surveys will emerge even more strongly as a key driver for the acquisition of marine geophysical and remote sensing data for archaeological use.

Learning and access

A further motivation for using marine geophysics and/or remote sensing is to facilitate learning and access. In our own experience, learning and access has not usually been the main driver for geophysical or remote sensing investigations, but it has been a very valuable outcome, achieved opportunistically or as a planned 'secondary' outcome. Technological advances that enable the integration and scientific interpretation of features on the seabed are also – perhaps incidentally – creating results that are much more readily appreciated by non-specialist audiences. On the one hand, we are acquiring data that is much higher resolution and clearer than previously, whilst on the other we have interpretative tools and delivery mechanisms that allow us to present information more widely and in accessible formats. The contrast could hardly be greater between a few murky slides from underwater and overheads copied from paper rolls of barely discernable sidescan traces, shared with a face-to-face audience, and high quality digital images, clips and visualisations that are shared around the globe using Flickr, YouTube and the like. Technological advances are also creating new forms of public access, whether it is podcasts of diver's underwater descriptions, or learning about geophysical methods by modelling sidescan and multibeam traces using plasticine (Figure 11.2).

Figure 11.2: The increased accessibility of marine geophysical results enables much wider audiences not only to explore monuments on the seabed, but also to learn about the science that underpins the methods. © Wessex Archaeology.

Themes

Marine geophysics and remote sensing are directed towards features, sites and their wider setting relating to four major archaeological themes: prehistory; coastal activity; maritime remains (e.g. shipwrecks); and aviation.

Prehistory

The potential presence and significance of prehistoric material from former dry-land sites that are now submerged is currently high on many agendas (see Fitch *et al.* this volume). Sea level change driven by the cycle of glacial and inter-glacial periods that has characterised the UK over the past 700,000 years when our human ancestors have been present, if intermittently, has meant that areas of the Continental Shelf currently lying under tens of metres of sea water distant from today's shore were formerly inhabitable. Artefacts discovered offshore demonstrate that the 'in principle' argument for submerged prehistoric sites is borne out by physical evidence, yet trying to identify the presence of such artefacts beneath the waves is extremely difficult. The approach has, therefore, generally been landscape based – seeking to identify remnants of land surfaces and palaeo-geographic features where palaeo-environmental and scientific dating evidence might survive, and then using such geographical and environmental evidence to develop hypotheses about how the landscape might have been inhabited, including possible 'hot spots' where artefacts might survive. This landscape-based approach undoubtedly reflects the strengths of marine geophysical and remote sensing data and survey tools, as echosounders, sub-bottom profilers, coring and seabed sampling are most suited to area-based investigations.

Coastal activity

Whereas the early prehistoric features we seek to investigate may have been many miles from the contemporary coastline, from later prehistory to the present day there are examples of archaeological sites directly concerned with use or exploitation of the coastal environment and which lie close to the current coast. Coring is a key method of investigating the effects of reclamation on former marine and estuarine areas, for example (Firth 2000), and sidescan can be used to map fishtraps. In some cases, structures have been built in the water whereas in other cases, structures built on land or above water have become submerged as a result of erosion, collapse or subsidence (Figure 11.3).

Maritime

In many respects, maritime sites, especially shipwrecks, are the traditional core theme for marine investigations. The key means of investigation has been by diver, with ROVs increasingly used for investigations in deep water. In terms of geophysics, sidescan and magnetometer



have been the main tools, though predisposed towards sites dating to the last 150 years that are likely to have substantial amounts of ferrous (i.e. magnetic) material and be prominent on the seabed on account of the use of metal and industrial construction techniques. In recent years, the use of high resolution multibeam has resulted in eye-catching digital elevation models of wreck sites that can be manipulated and visualised in a very engaging way. Like sidescan and magnetometer though, multibeam – being sensitive to topography – is best suited to prominent and therefore predominantly more modern wrecks. Wrecks that leave only an ephemeral trace on the seabed, and which do not contain large amounts of ferrous material, are difficult to identify using the geophysical tools currently available. High resolution sidescan – used and interpreted by experienced archaeologists – holds the greatest promise for identifying older wreck sites.

Aviation

Aircraft crash sites have become a focus for archaeological interest in the UK only in relatively recent years. Several distinct phases of operations during World War II resulted in numerous losses in the sea around the UK, and these waters have probably the greatest number of aircraft wrecks of any comparably-sized sea area in the world and may hold unique information. Although relatively recent in date it is worth noting that some aircraft types are represented only by their wrecks; there are no surviving examples

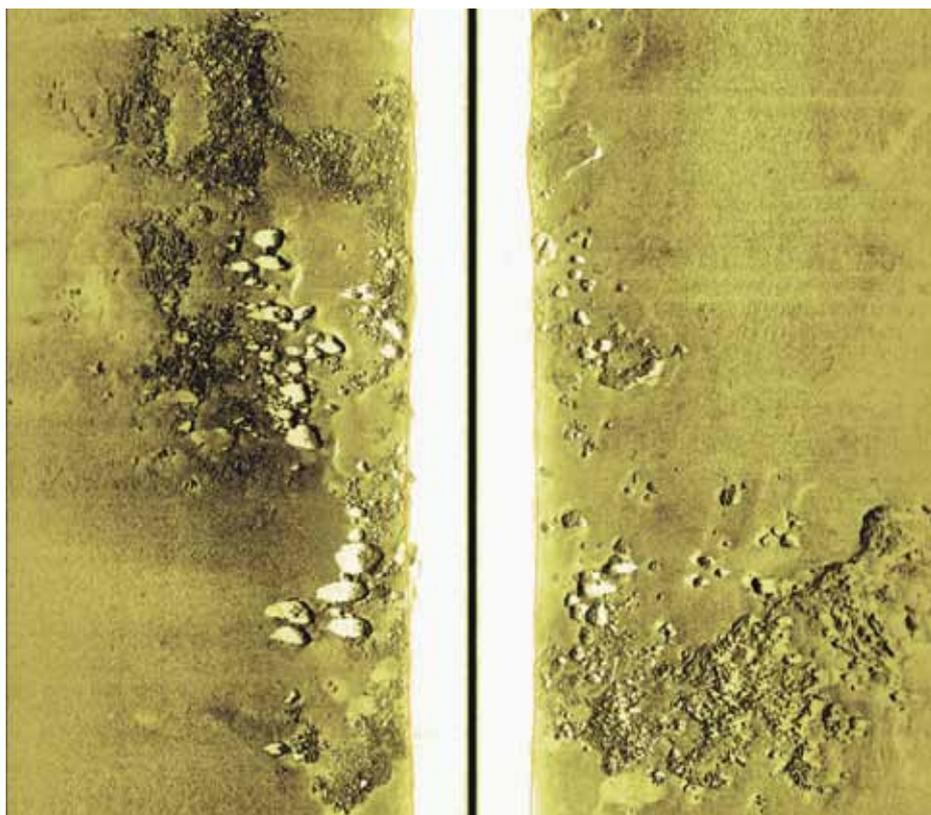


Figure 11.3: As well as wreck sites and remains of prehistoric land surfaces, geophysics can be used to identify the remains of structures that were once at the coast or on land. This sidescan image is thought to show the remains of a church from the once prosperous medieval port of Dunwich in Suffolk, which has largely been lost to the sea. © Wessex Archaeology, courtesy English Heritage.

in preservation (Holyoak 2002; English Heritage 2002). And, whilst the fixed infrastructure of 20th century warfare on land has received a fair amount of archaeological attention (e.g. Bacilieri & Thomas 2010), the aircraft crash sites are the principal monuments to combat itself, especially from key campaigns such as the Battle of Britain, the different phases of the Blitz, the Battle of the Atlantic, the Allied strategic bombing offensive, Operation Overlord (D-day) and so on. Military air crash sites are also automatically protected under the Protection of Military Remains Act 1986 (English Heritage 2002). As with shipwrecks, sidescan is the main marine geophysical method for investigating aircraft wrecks, with divers and/or ROVs serving as remote sensing. However, air crash sites are smaller and even more ephemeral than shipwreck sites due to their fragile construction and the often catastrophic nature of their impact with the sea.

Scales

Our involvement in the use of marine geophysics and remote sensing has to accommodate investigations at widely different scales, from broad regional studies to recording and analysis within a site.

Regional

A relatively recent development – at least in terms of archaeological involvement – has been regional surveys encompassing entire sea areas. Following a Government led assessment of aggregate resources and constraints in the Bristol Channel, and anticipating the introduction of Strategic Environmental Assessment (SEA), the marine aggregate industry in the UK carried out its first Regional Environmental Assessment (REA) in

the Eastern English Channel, published in 2002 (Posford Haskoning 2002). Although archaeology only featured in the desk-based element of this first REA, subsequent assessments of the Thames, South Coast and Anglian regions have involved archaeological interpretation of newly-acquired data. In a linked but parallel development, ALSF-funded Regional Environmental Characterisation surveys have come to include archaeological objectives – and archaeologists – directly in the acquisition phases. In contrast, Government-led SEAs for the energy industry (oil and gas at first, but later including offshore renewables) have involved only desk-based archaeological work, though even this has been very influential. The approach to licensing offshore wind farm developments has also become regional, with extensive ‘zones’ subject to assessment, and (at least in some cases) involving archaeologists in survey work. Dealing with such very large areas has required a new approach to the application of marine geophysics and remote sensing, for archaeology as well as other disciplines. The investigations are intended to characterise the sea area, to provide an evidence base for understanding possible cumulative and in-combination effects, and to facilitate more focussed Environmental Statements that will speed the process of seeking consent. As a result of these objectives, surveys can be partial, spatially selective samples rather than seeking 100% coverage. The RECs adopted a ‘corridor’ approach whereby narrow strips of seabed separated by several kilometres are surveyed. Inferences are then made by using the results from the corridors to ‘characterise’ the whole area. At least some of the wind farm zones are also adopting a corridor approach, either in acquisition or through selective interpretation of datasets.

Area

The majority of our involvement in development-led archaeology has been at development-scheme scale, i.e. of an area of seabed coinciding with the footprint of the development. The extent and overall form of the survey area varies considerably, reflecting the variety of development schemes. Cables and pipelines, like linear schemes on land, result in a long narrow strip of seabed being investigated. New navigation channels accompanying new ports are also linear, but tend to be quite broad. Aggregate dredging areas are very variable in shape, whilst offshore wind farms usually comprise an irregular but large polygon accompanied by a long corridor to shore for power cables. In each case, the survey area is not driven by what might be most productive or appropriate to understand the archaeology of the area, but by the footprint of the anticipated impact. This is obviously problematic where archaeological questions need answers that lie outside the footprint, hence the value of the regional characterisation approach referred to above. However, the approach to investigation normally encompasses a reasonable margin beyond the immediate footprint, either as a buffer or to enable flexibility and 'micro-siting' (moving elements of the development to reduce impacts) in the detailed design of the development. As well as the form and extent of the survey area being driven by development rather than archaeology, the detailed design of the survey will be optimised for the development, not necessarily for obtaining the best data in archaeological terms. For example, geophysical surveys will usually be carried out in a series of parallel lines spaced at a uniform distance. These lines may not be optimal for imaging wreck sites or palaeo-channels, for example, and there will often be little scope to run additional lines to address new discoveries. Similarly, seabed sampling and coring will be carried out on a grid or will be targeted according to engineering or ecological questions, which may not be optimal for archaeology. Nonetheless, there have been instances when it has been possible for archaeologists to change plans to enable archaeological questions to be addressed alongside the primary concerns. Whilst the majority of our area-based surveys are development-led, we have done some area surveys for primarily archaeological purposes, though generally only where there is an extensive feature (such as a known navigational hazard) where the density of archaeological material is expected to be high.

Site

In contrast to the predominantly development-led area approach to investigation, our archaeologically-led investigations have tended to be site-specific. That is to say, we carry out smaller, localised surveys around the known/presumed position and extent of an archaeological feature in order to obtain the best possible data for archaeological purposes. In the case of shipwrecks, for example, sidescan survey lines will be run along and perpendicular to the apparent long axis of the wreck and slightly offset so that we get the best possible image of the site. Equally, if trying to investigate a palaeo-channel, sub-bottom profiler lines will be run across the channel to obtain a series of cross sections. Seabed sampling may be based on grids or transects if trying to identify broad

spatial relationships, or judgement-led where specific elements (e.g. sedimentary horizons) are targeted.

Intrasite

For several decades, geophysical instruments have made it possible to identify the presence and position of an archaeological site such as a wreck. Once located, however, subsequent survey of the site itself had to be based on diver or ROV based methods, such as taped measurements, photomosaics and so on. However, in the last decade or so, major improvements in equipment and positioning have considerably improved the resolution of geophysical surveys, so that it is possible to record the details of a site directly from geophysics. This is most apparent in high resolution multibeam survey, where the digital elevation model is a fully quantified 3D survey from which further measurements and dimensions can be obtained. Although offering qualitative rather than quantitative data, sidescan can offer even better resolution than multibeam, especially of wrecks in deeper water, enabling individual timbers to be discerned, or the position and orientation of individual cannon to be recorded. Although the geo-referencing process can reduce the clarity of sidescan images, it is possible to use the resulting data for obtaining precise positions and dimensions, and for mapping the extent of wreck elements. Notwithstanding, intrasite survey directly from geophysics does need to be supplemented by on-site observations by divers or ROVs because the methods are only capable of recording topographical anomalies; they do not necessarily reveal the archaeological item or feature that caused the topography to be anomalous; or what features or items may be present without causing an anomaly. We have had considerable success, however, in combining geophysics with diver or ROV based investigations, with the general extent and form of a site being derived from the geophysics (thereby limiting the call for time-consuming in-water surveying by divers) and then annotating the basic plan with comments and details based on diver / ROV observations.

To conclude this section, it should be obvious that these different scales of investigation serve different purposes and are complementary rather than alternatives. The greatest advantage and efficiency accrues where there is scope to 'nest' different scales of surveys as appropriate, pinning down regional characterisations with site-specific details, and placing individual aspects of a site within its wider contexts.

Operations

Our approach to marine geophysics and remote sensing has to encompass four phases of operations: data acquisition (i.e. the survey itself); re-use of data (where the data has already been acquired for another purpose); processing and interpretation; and archiving.

Acquisition

In comparison to our interpretation of data acquired by others, new acquisition forms a relatively small proportion of our work. Nonetheless, involvement in acquisition means that we can have direct experience

of the entire process and, in particular, has allowed us to explore methodological developments in achieving high resolution datasets and in adapting existing technologies to archaeological objectives. Another aspect of our involvement in acquisition is where we are not carrying out the survey ourselves, but are engaged alongside the survey company, providing a form of watching brief or using the opportunity afforded by the investigation to acquire records and samples for specifically archaeological purposes. Our staff are often called upon, therefore, to attend geophysical or geotechnical surveys, to take part in joint recording and sampling of cores, or to join existing diving teams as 'embedded' archaeologists.

Re-use

The predominant mode of our involvement with geophysical and geotechnical data arising from development-led work is in re-use of data (see also Fitch *et al.* this volume). For the majority of development-led projects, geophysical and geotechnical data is acquired to meet the needs of a wide range of engineering and environmental studies. The timing, objectives and strategy for the survey are not usually determined by archaeological concerns. Effort is required, therefore, to optimise and streamline the processes whereby this non-archaeological data can be used to satisfy archaeological objectives. One methodological consequence is that we carry out a data audit as a first stage of any major project, to ensure that all the relevant data is available in the right format, is suitable for archaeological use and covers the required area. The audit also forms a basis for discussing processing strategies with the client, and to fix estimates of timescale and costs.

Processing and interpretation

Whether we have acquired the data ourselves or are re-using data acquired for other purposes, the subsequent processes are the same. Whatever the type of data, various processes are undertaken to convert, check, collate and optimise data for interpretation. Depending on the data, processing might take place within proprietary software, or through processes we have developed ourselves. Processing needs to be conducted systematically, consistently and conscientiously so that interpretation takes place on a firm foundation. Far-reaching and costly decisions may be made on the basis of our results – relating to a statutory designation or the layout of a wind farm, for example – so our work must be open to scrutiny; a transparent framework that enables our results to be worked-back and contested is one of the important objectives of the processing phase. Interpretation – the conversion of data into meaningful archaeological information – also makes use of a variety of procedures depending on the data type, again ranging from proprietary solutions to in-house mechanisms. Interpretation is predominantly a question of judgement, as there are no practical tools capable of automatically identifying features of archaeological interest. For the reasons outlined above, however, interpretations must be contestable so we have developed working practices to ensure that the exercise of judgement is consistent and can be revisited in the light of queries or further data becoming available.

Archiving

Archiving marine archaeological data is a burgeoning problem that, in the absence of imminent resolution, results in contractors such as WA becoming *de facto* archives, nominally temporary and without the facilities or procedures of a recognised publicly-accessible archive. Part of the reason for this unfortunate situation is that marine archiving is a complex matter. A project archive may include paper and drawn records, environmental sub-samples and artefacts (which, if waterlogged from the sea, present particular problems), plus digital material ranging from video and still photographs to major datasets. Even the digital datasets may be complex, requiring distinctions to be maintained between 'raw', 'processed' and 'interpreted' data, and making problems for the future because of the need to keep migrating digital archives as software and hardware becomes obsolete or is updated. There are also differences in the anticipated purpose of archiving; in some cases it is intended primarily to provide a secure, permanent record, whereas in others the intention is to enable widespread re-use of the data. Such different approaches have implications for how archive material is best stored and managed. A further level of complexity is added by differences between archiving trends in the marine data and archaeological data communities, exacerbated in some cases by different approaches in each of the UK's home countries. For all of this complexity, archiving is an important operational phase for us to be involved in, because it is vital to anticipate the final form that data will take when considering how best to conduct operations in acquisition, re-use, processing and interpretation.

Implications

Our application of marine geophysical and remote sensing methods, whilst focussed on evaluation, has to accommodate both desk-based assessment and mitigation. As I've shown above, there is very considerable variety in the circumstances we address across motivations, themes, scales and operations. Both our need to cope with such variety, and our experience of it, have brought several methodological concerns to the fore and have propelled us towards some innovative approaches. Three such concerns, which are set out in more detail below, concern position-fixing, event-based recording and decision-orientated recording.

Position-fixing

Our marine work generates numerous datasets. Whilst we can make inferences from each dataset in isolation, using multiple datasets in combination, comparing and contrasting, supports incisive inferences and greater confidence in the results. Accurate horizontal and vertical position-fixing provides a common frame to relate different datasets to each other.

Positioning is also critical as our investigations are often motivated by questions that are themselves spatial. In research, for example, the absolute depth of a horizon identified by sub-bottom profiling or vibrocore helps relate the data to sea level curves. In development, it is

critical to know the distance between an archaeological feature and the proposed position of a cable, foundation or dredging area. In statutory protection, areas designated by law must adequately cover the feature they are intended to protect.

Position-fixing to relate datasets to each other and to the real world is vital at sea because, other than a distant coastline or a few navigational buoys, there are no fixed features such as walls, roads or buildings that can be used as a visual reference. Furthermore, the seabed is usually at a distance from the operational platform, separated by a water column that moves laterally and vertically with considerable force and is often so turbid that through-water visibility may be a few metres or zero. As we have to pass equipment or people through this medium, knowing where we are on the surface is a very important aspect of trying to know where we are on the seabed, and where we have been. With visibility so poor, movement so restricted and the costs of investigations so high, achieving an absolute accuracy of 5m is a realistic expectation for equipment that is dropped or towed, with sub-metre accuracy being our aim for divers or ROVs that can be navigated underwater.

In practical terms, dGPS has had a radical impact in marine archaeology. Within Wessex Archaeology, for example, our exploration and take-up of dGPS was much quicker in investigations at the coast and offshore than on land. In the horizontal plane we were quickly confronted by the need to be very careful about geodesy – knowing what projection and co-ordinate system was being used and how transformations were calculated. This need was, of course, driven in part by the increasing inaccuracy of familiar land-based systems as distance offshore increases, and by the variety of systems that are available at sea. Features on the seabed can appear to be displaced by tens of metres by different projections and co-ordinate systems, which was not a concern when position-fixing at sea was itself accurate only to tens of metres. The lack of geodetic information for legacy data that was acquired historically (perhaps only 10 years ago!) is a real limitation on the utility of this information. Having learned the hard way, we have instituted specific protocols for recording geodetic information as metadata and for processing transformations so that they are rigorously checked and are auditable.

Conventional dGPS is not especially strong in the vertical plane, which is challenging because our working level (the sea's surface) changes with short-term impacts (waves and swell) and with longer term tidal cycles. Correcting for these effects is critical in collating data from height-sensitive sensors such as multibeam. Elevation models of the seabed can only be constructed if all of the movement of the multibeam sensor can be cancelled out and its position related to an absolute vertical datum. An array of onboard sensors and fast processing can be used to calculate a 'fixed' position for the multibeam head, which can be related to a vertical datum using tide predictions, very accurate positioning (RTK GPS) or using data from a tide gauge to make corrections afterwards.

Our main methodological development has been in adapting acoustic-tracking technologies for day-to-day use by diving archaeologists or on ROVs. Acoustic tracking is commonplace in offshore engineering, but they are packaged and priced for major industrial applications rather than archaeologists. The advantages it presents over conventional diver-based archaeology are, however, radical. Relating the position of a feature such as a wreck on the seabed to the real world has tended to require extensive relative measurements (themselves often difficult to obtain because of the environment) tied back somewhat imperfectly at a small number of points to a GPS (at best) on the surface. Navigating a diver to such a feature, especially for the first time or, if prospecting across an area of seabed that might, or might not, contain such a feature was even less satisfactory. The diver would start from a nominally fixed point and then work their way from it using a tape measure or offsets from a baseline. In contrast, acoustic tracking uses one or more beacons whose real world position can be calculated to work out the position of a beacon on the diver or ROV. The diver's position can be seen by the surface team on a screen and they can be navigated towards a target. Once at the target, the diver's beacon can be used to build up a network of 3D points delineating the feature. And if no feature is found, there is at least an accurate record of the area that has been searched.

Recognising that we needed to bring the technology in-house if we were to work out how it might best be used, we invested in two different systems and in the software development needed to marry the acoustic tracking outputs to a GIS. This aggregation of two systems was especially important, as it enabled us to bring other georeferenced datasets – charts, previous site plans, and geophysical data – into direct use in the course of diving / ROV operations. That is to say, the diver could be directed around the seabed on the basis of such other data in real time, rather than just using the acoustic tracking data as an overlay post-fieldwork. The integration of acoustic tracking and GIS also enabled the development of a digital recording system for diver- and ROV-based archaeology (below).

Event-based recording

Our approach to recording is informed by the Monument-Event-Source model, with particular emphasis on recording events. In particular we record a variety of sub-events, which are the individual observations that enable archaeologists to assemble an overall 'picture' of a monument. This concern for recording events is directly attributable to the character of the environment and our reliance on geophysical and remote methods. On land, the position, form and character of a monument can be discerned quite readily and there is generally no great difficulty in proceeding directly to make a record of the monument itself. At sea, we tend to get brief glimpses over very short distances, in which much is obscured or unfamiliar. The knowledge gained from these glimpses is quite likely to be challenged or changed by the next observation. Inferences have to be drawn from multiple sources, all of which are partial; none comprehensive. Whilst uncertain, earlier observations may not be 'wrong', so we need to be able to add information without earlier

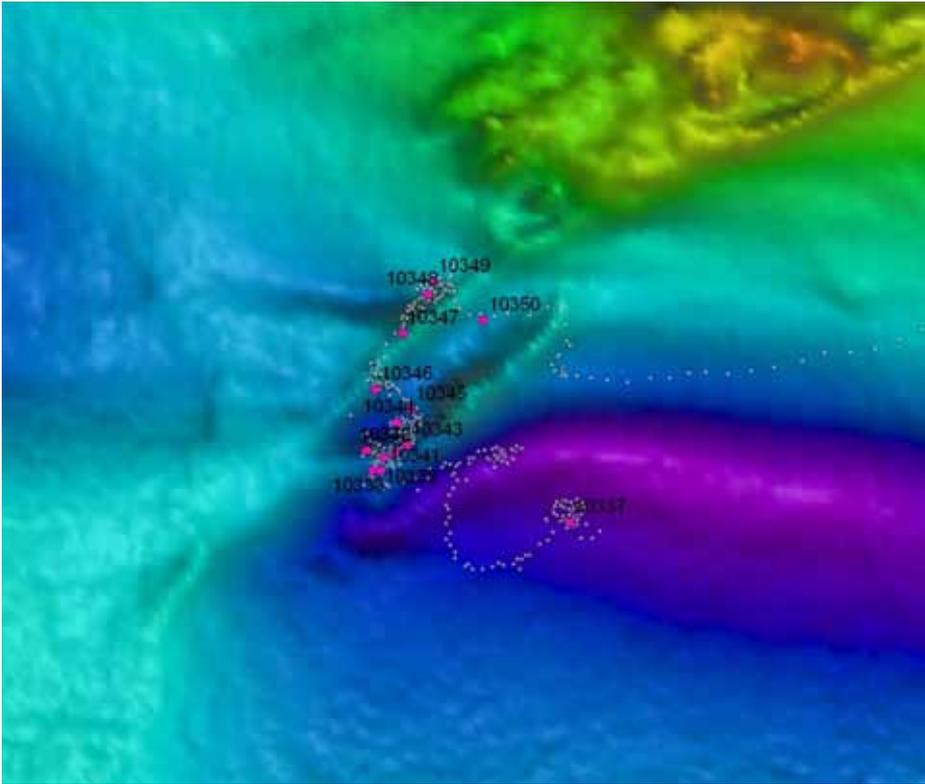


Figure 11.4: Acoustic tracking enables diving archaeologists to be navigated around sites in very low underwater visibility on the basis of geophysical images, and for observations to be recorded spatially. This image shows a diver's track and observations on the site of the *London*, lost in the Thames in 1665. © Wessex Archaeology, Crown copyright.

information being deleted or replaced. Further, our recording process has to be transparent, auditable and contestable – by others and indeed by ourselves as new information comes to light. It is this transparency and contestability that renders our observations 'objective' despite their provisional and contingent character. Building up observation on observation, sub-event by sub-event, it can be seen that monument records are an interpretation towards which we progress, not our starting-point.

Two examples show how this works in practice. We have a digital recording system known as Diva that operates through a database attached to the same GIS that we use in conjunction with acoustic tracking, as discussed above. Whilst the diver is being navigated around the geophysics image, they can make a comment on what they find. At the surface, an archaeological recorder using Diva makes a new, uniquely numbered Observation record, which is fixed in space by the acoustic tracking (Figure 11.4). The Diva recording system opens digital pro forma that prompts the recorder for information, including querying the diver on the seabed for further details. If the diver takes photographs or samples, these can be recorded and cross referenced to the Observation. Observations can also be classed so that they are represented in different colours in the GIS as the dive progresses. Where a ROV is being used rather than a diver, then the archaeological recorder at the surface can make Observation records directly in response to their own findings. On completion of the dive, Diva collates the Observations so that they can be reviewed as a whole and in conjunction with other Observations from previous dives. It is on this basis that a Monument record can be developed, still within Diva, in a manner that preserves the link to the original observations.

The second example is our approach to interpreting marine geophysical data. Although not as explicit as in Diva, a similar approach prevails. Each source of information has a unique number block: monument records from desk-based information start at 1,000, sidescan anomalies at 2,000, magnetometer anomalies at 3,000 and so on. Monument records and anomalies might seem to be real 'things' in the first instance, but in conceptual terms they are better regarded as observations. That is to say, a signal returning to an instrument that appears anomalous is really a sub-event of the survey; it only becomes 'an anomaly' through interpretation. Equally, existing records of wrecks and other features on the seabed are often so poor that they are themselves best regarded as time-specific observations, which must be corroborated if they are to afford confidence.

Our way of working is to examine each dataset in its own right and to identify all the anomalies we see in each dataset alone. This is in contrast to approaches that look at datasets in conjunction from the start, implicitly focussing on the more obvious and directly corroborated features rather than on highly ephemeral traces that may be of greatest potential interest to archaeologists. The character of geophysical surveying is that datasets will overlap because different instruments are deployed on the same survey lines and because survey lines run adjacent to each other and are intended to overlap slightly. In addition, there may be crosslines perpendicular to the main survey lines or lines from previous surveys, plus underlying data from monument or wreck records. Using GIS, the records from each data source can be viewed as a whole in order to identify 'groups' which are given their own unique identifiers. A group may be made up of a variety of underlying records – a couple of sidescan

anomalies, a magnetic anomaly and an historic reference to somewhere a fisherman snagged his nets, for example – all of which might be some distance apart but, taken as a whole, can be interpreted as a single feature. Importantly, single records are also treated as a ‘group’ as even uncorroborated records need to be carried forward as possible features pending further information. The grouped anomalies are characterised to arrive at the best interpretation possible taking all the sources into account. Many will be set aside as being unlikely to have an archaeological origin, but nothing is deleted. The next bit of survey work could challenge the earlier interpretation and we need to be able to re-trace our steps, all the way back to the individual observations.

Decision-oriented recording

The difficult environment, uncertainty and cost of investigation all place a premium on maximising the return from every minute of fieldwork; this is no exaggeration. Our efforts – and our clients’ cash – have to be focussed precisely on the project aim and objectives, whilst other possible lines of enquiry are ignored. Our fieldwork is thus selective, which is not necessarily different from land-based investigations except that the gradient of selectivity is steeper and more explicit. Strongly selective fieldwork cannot, however, be arbitrary, just a matter of the personal predilection or interest of the principal investigator. Rather, selectivity has to be based robustly on wider considerations about what is important about the historic environment.

The case for a rational system of selective prioritisation of fieldwork makes sense when considering individual sites, but the need is more pressing when there are numerous sites that multiply the pressure on resources and time available, as occurs on major construction projects. Contemplating major fieldwork in connection with the proposed new port at Dibden Bay in Southampton Water, WA drew on recent work on a complex urban scheme in Stonehouse, Plymouth, where conditions requiring extensive building recording were framed around a system of recording levels published by the Royal Commission on the Historical Monuments of England (RCHME). The RCHME levels were adapted to make them applicable to marine

sites of all forms, though in practice we have used them predominantly for informing wreck recording.

Our system comprises five principal levels of recording, each of which has an explicit objective tied to decision-making. The basic levels are split into subsidiary levels (see Table 11.1). The levels are not stages; it is not necessary to progress from one to the other, or that the higher levels can only take place once lower levels have been achieved (though the decision to carry out recording to level 3, 4 or 5 may presuppose that information equivalent to level 1 and/or 2 is already available). In practice, investigations are often targeted at a couple of levels (i.e. level 1/2; level 2/3), acknowledging that environmental constraints may limit what can be achieved, and that decisions about deploying and targeting resources may have to be made quickly in the field if the site proves to be more/less interesting than indicated prior to investigation. In this, a key strength is that this system of levels provides an explicit indication of the overall intention of any particular investigation. Staff can make their own decisions on how best to proceed based directly on local circumstances, informed by the overall objective but not tied to a prescriptive list of observations to be made or dimensions obtained. Also, the objectives are clearly related to the decisions that will have to be made by third parties such as developers, regulators or local authorities. Even if they encounter difficulties and recording is partial, field staff can apply the specific objective as a ‘test’ of what they have achieved, to see whether they have done enough to inform third parties’ decision-making.

Although developed with field-based recording in mind, the system of levels can incorporate geophysics and remote-sensing based recording, either as a contributing component that helps meet some of each objective, or as the primary means of investigation, at least for levels 1-3. Practically, geophysics and remote sensing are the predominant means of achieving level 1 recording, often providing the main evidence-base for desk-based assessment and Environmental Impact Assessment. Geophysics and remote sensing also predominate in establishing overall extent and character at level 2; depending on the site, geophysics and remote sensing may also enable generalised

Table 11.1: The five principal levels of recording applied by Wessex Archaeology.

Level	Type	Objective
1	Assessment	A record sufficient to establish the presence, position and type of site.
2	Evaluation	A record that provides sufficient data to establish the extent, character, date and importance of the site.
3	In situ Recording	A record that enables an archaeologist who has not seen the site to comprehend its components, layout and sequences.
4	Removal	A record sufficient to enable analytical reconstruction and/or reinterpretation of the site, its components and its matrix.
5	Inter-site Analysis	A record that places the site in the context of its cultural environment and other comparable sites.

evaluation of date and importance, where the form of a wreck, for example, places it in a broad category of site. Components, layout and sequences (level 3) can also be established using geophysics and remote sensing, especially where high-resolution data can be acquired. We are increasingly using high-resolution geophysics as a basis for in situ recording of extensive sites; and in the case of submerged prehistoric land surfaces and deposits, then geophysics and remote sensing are critical to understanding sequence.

Conclusion

As this paper has demonstrated, geophysics and remote sensing already provide a powerful suite of techniques for evaluating the archaeological heritage on the seabed. Irrespective of motivation, theme, scale or operational phase, effective investigation requires methodological integration. Whilst marine archaeology is demanding and costly, it is also stimulating and engaging, and can – as I hope I have indicated – make a useful contribution to discussion about approaches to geophysics and remote sensing on land as well as offshore.

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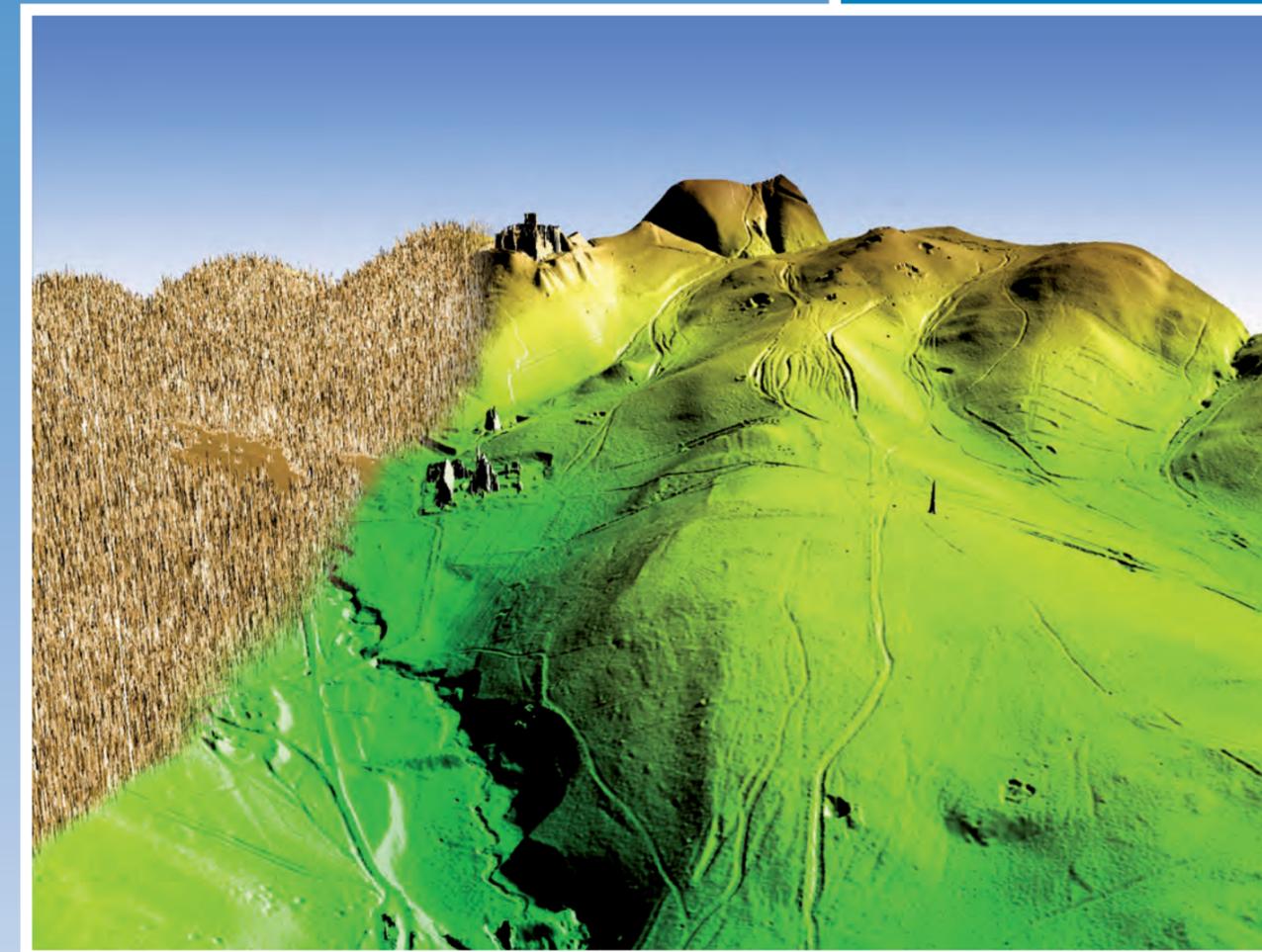
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Airborne Laser Scan (LiDAR) of a forested area before and after filtering

(St. Anna in der Wüste, Austria). © *Michael Doneus and Klaus Löcker, LBI-ARCHPRO, Vienna*

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