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Geoffrey N. Bailey
Jan Harff
Dimitris Sakellariou *Editors*

Under the Sea: Archaeology and Palaeolandscapes of the Continental Shelf

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Preface

This volume is one of two volumes that are the outcome of a conference held at the University of Szczecin in September 2013 to mark the end of the SPLASHCOS Action. SPLASHCOS—Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf—is a research network funded under the EU's COST (Cooperation in Science and Technology) programme as COST Action TD0902 (TD standing for Trans-Domain), which ran officially from November 2009 to November 2013. The conference itself served two purposes: first, to review progress in the work of the Action over the preceding 4 years and, second, to act as an open scientific meeting for anyone interested in the conference themes whether or not they were formal SPLASHCOS members. In the event, the meeting drew over 100 participants from across Europe and from further afield in Australia, China, South Africa and the USA.

The aim of this volume is to present a selection of the papers from the Szczecin meeting that cover the various themes addressed during the SPLASHCOS Action. It is aimed at all those with an interest in the sea floor of the continental shelf and the archaeological and social impact of sea-level change—especially archaeologists, marine scientists, geographers and cultural-heritage managers, but also commercial and governmental organisations, policymakers and interested members of the public.

The original aims of the SPLASHCOS Action, as set out in the COST Memorandum of Understanding, were to promote research on the archaeology, climate and palaeoenvironment of the drowned landscapes of the European continental shelf; to stimulate collaboration across national and disciplinary boundaries; to bring together interested parties from the worlds of academic science, commerce and government; to encourage participation and training of young and early-stage researchers; and to facilitate exchange of ideas, planning of research projects, application for research funds and dissemination through publications and other media. Target audiences included not only the disparate scientific disciplines concerned with researching the continental shelf—archaeology, marine geology, geophysics, biology, climatology, palaeoenvironment and oceanography—but also wider audiences including government officials responsible for the marine environment and its cultural heritage, industrial operators working on the seabed, funding agencies, school children and a wider public. In short, our aim was to promote an emerging new field, variously labelled as 'submerged landscape archaeology', 'submerged prehistoric archaeology', 'continental shelf archaeology' or 'continental shelf prehistoric research', as an integrated discipline in its own right, and to plant it more firmly on the international research agenda and in the wider public consciousness.

COST Actions are the longest-running form of European funding, intended to foster coordination of research and transfer of ideas and expertise across national boundaries within Europe and its neighbouring countries. Funds are provided for regular meetings, workshops, conferences, training programmes, research planning and coordination and publication, but not for the conduct of new research programmes (see http://www.cost.eu/about_cost). During its 4-year history, the SPLASHCOS Action grew to include 25 member states and an active membership of over 120 individuals from a wide

range of institutions and disciplines. The Management Committee, comprising representatives from all member states, with Geoff Bailey and Dimitris Sakellariou as elected chair and vice-chair, respectively, held 8 major meetings in different European centres and a number of smaller workshops, organised 16 training schools or smaller short-term missions that provided experience and training to 65 early-stage researchers, stimulated a wide range of publications and successful applications to national and European funding agencies for new research and created a strongly international and interdisciplinary sense of common purpose. Details of SPLASHCOS activities and achievements can be found on the dedicated website at http://www.splashcos.org/.

In practice, activities were focussed around a core group of individuals who led the work through four formally constituted Working Groups (WGs): Archaeological Data and Interpretations (WG1) led by Anders Fischer; Environmental Data and Reconstructions (WG2) led by Jan Harff; Technology, Technical Resources and Training (WG3) led by Ole Grøn and Tine Missiaen; and Commercial Collaboration and Outreach (WG4) led by Julie Satchell. Some of this work is in preparation for publication elsewhere, notably the work of WG2 and WG1, dealing, respectively, with the Quaternary geology and palaeoenvironment of the European continental shelf and the underwater archaeological record. These volumes are intended to provide a comprehensive overview of the current state of knowledge around the European coastline and in all the major marine basins. A third volume already published is the outcome of a conference session organised at the 34th International Geological Congress in Brisbane in 2012, with papers made available online in 2014 and the final volume published in 2016 as a special publication of the Geological Society of London: *Geology and Archaeology: Submerged Landscapes of the Continental Shelf* (edited by Jan Harff, Geoff Bailey and Friedrich Lüth), which includes examples from across the world. Web-based guides to techniques and resources and to collaboration with marine industry are available online on the SPLASHCOS website, and a searchable website with maps and information about all known underwater prehistoric archaeological sites in European waters has recently been posted online at http://www.splashcos-viewer.eu.

The original conference was structured around the Working Groups, and we have adopted that structure as a basis for organising this volume, but with some modification in the light of the contributions finally delivered. All the chapters have been extensively rewritten, updated, comprehensively edited and independently reviewed. The geographical focus is primarily European, but we have not attempted to include a comprehensive range of examples from all the marine basins around the European coastline—that is the task of the other SPLASHCOS volumes. Our chapters focus on issues of method and interpretation and on wider issues of management and outreach. They also include examples from other parts of the world, and many of the discussions of method and interpretation presented here, though focussed on European case studies, have worldwide relevance.

The second volume arises from a parallel workshop incorporated in the Szczecin conference, representing the final meeting of the separately organised CoPaF Project *Coastline Changes of the Southern Baltic Sea—Past and Future Projection*, which ran from 2010 to 2014, in parallel with SPLASHCOS Working Group 2, led by Jan Harff and funded by the Polish Ministry of Science and Higher Education. The two projects thus have overlapping membership, but complement each other in their objectives and primary focus. In this volume, the emphasis is on examples from the marine basins of Western Europe and the Mediterranean, on archaeological investigations of submerged landscapes extending back into the Pleistocene or on the archaeological implications of environmental reconstruction. The CoPaF volume focusses on the geological and climatic conditions that have shaped changes in sea-level and coastline configuration during the past millennium in the southern Baltic and the likely trajectory of future changes and comprises contributions mainly from Germany, Poland, Lithuania and Estonia.

In producing these volumes, we thank, first and foremost, the COST Office, who provided administrative and financial support throughout the Action and funds for the Szczecin conference. We thank, in particular, the COST science officer, Luule Mizera; the COST administrative officer, Leo Guilfoyle;

the COST rapporteurs, Dr. Ipek Erzi (Scientific and Technological Research Council of Turkey, TUBITAK) and Prof. Daniela Koleva (Sofia University St. Kliment Ohridski); the COST external evaluators, Prof. Peter Veth (University of Western Australia) and Prof. Dr. Gerold Wefer (MARUM, University of Bremen); and the grant holder and administrative secretary of SPLASHCOS, Cynthianne DeBono Spiteri, all of whom gave invaluable advice and support.

We also thank the University of Szczecin for hosting the conference and generously providing facilities and hospitality and Helmholtz-Zentrum Geesthacht and Szczecińska Energetyka Ciepina (SEC) for additional financial support. We are also indebted to Prof. Andrzej Witkowski (University of Szczecin), who acted as chair of the Local Organising Committee and, together with the other Committee members, Prof. Marian Rębkowski, Dr. Przemyslaw Krajewski, Dr. Karolina Bloom, Marcin Wroniecki, Marta Chmiel and Michal Adamczyk, ensured the efficient organisation and smooth running of the whole enterprise.

We also express our gratitude to the many individual specialists who acted as peer reviewers and who have contributed significantly to the final outcome. Finally, we acknowledge the following institutions, who generously contributed towards the production of this volume: the European Research Council through ERC Advanced Grant 269586 DISPERSE, the German Archaeological Institute Berlin, the Hellenic Centre for Marine Research and the University of York.

York, UK — Geoffrey N. Bailey
Szczecin, Poland — Jan Harff
Anavyssos, Greece — Dimitris Sakellariou

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Chapter 1
Archaeology and Palaeolandscapes of the Continental Shelf: An Introduction

Geoffrey N. Bailey, Jan Harff, and Dimitris Sakellariou

Abstract The past decade has seen a rapidly widening interest in archaeological and scientific exploration of the submerged landscapes that were flooded by sea-level rise at the end of the Last Glacial period. That interest is shared by many different disciplines and constituencies, including archaeologists who recognise the potential significance of these underwater archives to improved understandings of world prehistory, palaeoclimatologists interested in modelling sea-level change, and government agencies charged by national and international legislation with managing the underwater cultural heritage in the light of expanding industrial exploitation of the seabed. This introductory chapter sets out the background to these developments and the role of the European network – SPLASHCOS – in promoting awareness of this new agenda to the many scientific disciplines involved in underwater research, government agencies, commercial and industrial interests, and a wider public. Here we set out the major themes that we have used to structure the chapters in this volume, ranging across techniques and strategies of underwater investigation, examples of underwater archaeological excavations, reconstructions of underwater landscapes, the role of the continental shelf in shaping patterns of early human dispersal and geographical expansion, and issues of training, outreach and management. Examples are drawn widely from Europe and other parts of the world. We summarise the individual chapters, identify their inter-relationships with each other and with the themes of which they form a part, and highlight their wider significance.

1.1 Background

It is by now a well-established fact that for most of human history on this planet over at least the past 1 million years, sea-levels have been substantially lower than the present, oscillating between short periods of extreme high sea level as today and low stands of −100 m or more at glacial maxima, with many lesser perturbations in between, and a long-term average some 40–50 m below the present level. When sea levels were low, extensive tracts of new territory, amounting to some 4 million km^2 around the coastlines of Europe and the Mediterranean, and at least 20 million km^2 at the global scale, became available for terrestrial plants and animals and, of course, for human populations. Much of that territory most likely represented some of the most fertile, well-watered and ecologically diverse land

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available, especially given the relatively arid climates that persisted during glacial periods. These coastal lowlands and their immediate environs presumably supported denser concentrations of human settlement than the more remote continental hinterlands where most of the currently-known surviving evidence of the Stone Age era has been recovered.

The last period of high sea level was about 130,000 years ago during the Last Interglacial period, commonly referred to Marine Isotope Stage (MIS) 5. As the continental ice caps grew again in the succeeding millennia, sea level dropped, reaching a maximum depth of −130 m at the Last Glacial Maximum 20,000 years ago. When the ice started melting, sea level rose again, progressively drowning these ancient landscapes, their coastlines and the material traces of their previous inhabitants until the present level was reached about 6000 years ago. This long period of lowered sea level spans some of the most important developments in human prehistory: the emergence and world-wide dispersal of anatomically modern humans with new technologies, skills and cognitive abilities; early experiments in sea travel including the earliest colonisation of New Guinea and Australia; exploitation of shorelines, marine resources and offshore islands; and the early development of agriculture and its dispersal around the coastlines and islands of the Mediterranean and NW Europe. It must follow from the history of sea-level change that a very significant part of the evidence for these developments lies hidden on the continental shelf.

In the past decade, the expanding industrial and commercial exploitation of the seabed, our growing knowledge of the inexorable and continuous effect of changes in sea level and climate on human affairs, and the development of national legislation and international conventions to protect the underwater cultural heritage, have all combined to focus attention on the potentially valuable archives of cultural and natural data locked up on the seabed of the continental shelf.

These underwater archives are of great interest and relevance to many different disciplines and constituencies—to archaeologists interested in the long-term record of human development and dispersal, to climatologists interested in obtaining well-dated index points for low sea-level stands to develop better predictive models of sea-level change, to geomorphologists interested in processes of coastal change and large-scale patterns of erosion and sedimentation, to geophysicists and geologists interested in the dynamics of plate motions and changes in the Earth's crust, to governmental agencies and heritage organisations charged with managing and protecting the underwater heritage, and to a wider public perennially fascinated by the idea of lost civilizations slipping beneath the waves.

Alongside this growing interest, industrial exploitation of the seabed has intensified. Beam-trawl fishing, drilling for oil and gas, sand and gravel extraction, laying of pipelines, building of wind farms, and engineering works associated with new harbours, bridges, tunnels and other infrastructure all pose a threat to the cultural and natural features of the pre-inundation landscape, to say nothing of natural changes in the underwater environment that lead to erosion or burial of ancient land surfaces. At the same time, as on land so underwater, these destructive processes can also have a potentially positive effect in exposing to discovery material that would otherwise remain deeply buried and hidden from view.

It was with all these factors in mind that the European SPLASHCOS research network came into being in November 2009 (COST Action TD0902 SPLASHCOS—Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf), originating from an earlier series of meetings in 2008 and early 2009 to discuss ways of raising large-scale research funding for a pan-European research project entitled Project Deukalion (see Flemming et al. 2017). From the beginning, the SPLASHCOS network was organised around the need to address simultaneously not only the scientific evidence, both archaeological and palaeoenvironmental, but also issues of training, public outreach, management and industrial collaboration.

The chapters in this volume cover all of the above topics, and are organised around five principal themes that move progressively from method to interpretation, and from the study of individual sites to the wider landscape setting, beginning with a discussion of techniques and research strategies (Part I), progressing to examples of underwater archaeological investigation (Part II) and palaeolandscape

reconstruction (Part III), moving on to issues of interpretation in relation to broader themes in prehistory (Part IV), and concluding with examples of wider public outreach and management (Part V). The organisation is thus primarily thematic, but with a subsidiary axis of organisation whereby chapters dealing with geographically neighbouring regions are put together, wherever possible and appropriate. The divisions between these major Parts or sections are not, of course, watertight, and some issues recur in different sections. In this introductory chapter, we highlight important issues that arise from the chapters in each section, cross-referencing wherever possible those topics that occur in more than one section.

1.2 Techniques and Strategies

The chapters in Part I address the three key questions that are usually the first to be raised by the interested outsider or the novice investigator. (1) How do we set about finding underwater traces of the submerged landscape and its archaeology, given the specialised skills and the costly technology required and the rarity of upstanding features that can be easily spotted on the seabed? (2) What are we likely to find preserved under water, given the likelihood of damage and destruction, or burial under marine sediments, during and after inundation by sea-level rise? (3) Having found a target, whether a landscape feature such as a palaeo-river channel or traces of an archaeological settlement, how do we extract the evidence for dating and other analytical investigations, and in the case of an archaeological site how do we conduct excavation to the same standards as on dry land?

Chapter 2 provides the first step in seeking answers to these questions, presenting a comprehensive review of the varied technologies available for underwater investigation. As Missiaen et al. emphasise, the challenge is considerable, with needs that range from survey and detection of submerged landscapes extending over thousands of square kilometres at one end of the scale, to discovery of tiny artefacts such as microlithic stone arrow heads at the other. Diving surveys, acoustic techniques and drilling or coring of sediments play a major role, augmented by underwater photography, airborne and satellite remote-sensing, and the development of underwater vehicles and robotics. New technologies and equipment are under continuous development, much of it driven by the needs of commercial exploitation of the seabed and the need to investigate deeply buried geological structures. Moreover, discovery of landscape features and especially archaeological remains often requires more sensitive instrumentation capable of producing high resolution images of shallow deposits and materials. Increasingly, the particular requirements of archaeological and geoarchaeological investigation are stimulating the development of new technological solutions. For example, during the course of the SPLASHCOS meetings, discussions between specialists in acoustics and archaeology led to pioneering experiments in the development of sensitive remote-sensing techniques for detecting buried flint artefacts (Hermand et al. 2011). These experiments are ongoing with underwater excavations currently in progress to test the validity of the acoustic signatures (Ole Grøn, pers. comm., 2016).

Turning from methods of detection and discovery to the question of what might survive inundation, the issue of sea-level change becomes paramount. There is now an extensive and growing body of knowledge about the rate and pattern of sea-level rise and fall during the Last Glacial (and earlier)—both absolute changes resulting from changes in the volume of sea water in the world's oceans, and relative changes resulting from vertical movements of the Earth's crust (e.g., Lambeck et al. 2002, 2014; Harff et al. 2017a, b). From the geoarchaeological point of view, it is not so much the rate of vertical movement that is important during sea-level rise as the rate of shoreline retreat in the spatial dimension. This in its turn is a complex function of the interaction between relative sea-level rise, the slope of the continental shelf and locally and regionally variable topography. Chiocci et al. address this issue in detail in Chap. 3 and develop an algorithm for measuring 'transgression velocity', the rate of shoreline retreat (or advance when sea level is dropping). This measure can be applied at different

geographical scales depending on the detail and accuracy of the available information. The examples presented highlight significant variation at every geographical scale with important implications for evaluating the human impact of sea-level change and some predictive power in identifying areas most likely to have preserved material in the face of inundation.

The next challenge that has to be faced is the sheer complexity and cost of the technology needed, especially if it requires large research vessels and ship time. One solution is to enlist the cooperation of industrial companies engaged in exploitation of the seabed. Provided that archaeologists and government agencies engage with industry at an early stage in the planning process, the incorporation of underwater research can be achieved with minimal interruption to the timetable of the commercial operation. The scientific work gains enormously from free access to equipment and resources, and sometimes from direct financial contributions to research personnel and analytical work, the costs of which would otherwise far exceed even the most generous scientific grants, but which represent a relatively minor amount in relation to the total budget of the industrial operation. Commercial companies in their turn gain good publicity and can point to the wider educational and social benefits of the collaboration. Some excellent examples have taken place in NW Europe in recent years, for example with North Sea oil companies and with the Port of Rotterdam authority, producing quite spectacular and unexpected results generating wide interest and publicity (see also Glorstad et al. Chap. 19, Gaffney et al. Chap. 20, Momber and Peeters, Chap. 21, Satchell, Chap. 25, Sturt et al. Chap. 28).

Homlund et al. describe another type of commercial collaboration in Chap. 4, between an archaeological research institute and a company that provides commercial technological services in underwater investigation. The examples they present offer an illuminating illustration of the benefits of long-term collaboration, the technologies that can be deployed in underwater research, the results that can be achieved, and how such collaboration can be developed to mutual advantage at little extra cost, not only generating wider publicity for the commercial company involved, but stimulating new technological solutions in response to the demands of archaeological investigation that can have subsequent commercial application.

Not all underwater research requires big ships and big budgets. The last two chapters in this section (Chaps. 5 and 6) give good examples of what can be achieved in shallow water with divers and relatively simply equipment. Both projects were carried out as part of the SPLASHCOS training programme and provide good examples of the various constraints that limit the discovery and investigation of underwater archaeological sites, detailed guides as to how to go about conducting underwater excavation, the techniques and technologies required, and something of the detail and quality of material that can be preserved in underwater anaerobic sediments. They also demonstrate the importance of training and capacity building (see also Satchell, Chap. 25).

Denmark and Sweden are the pioneering countries for developing underwater research on submerged remains of prehistoric archaeology, as Uldum et al. emphasise in Chap. 5, with a long history of systematic investigation going back to the 1970s (Fischer 1996; Skaarup and Grøn 2004; Andersen 2013, see also Skriver et al. Chap. 8, Larsson, Chap. 11). In Denmark, professional archaeologists, with the support of the government agency responsible for the cultural heritage, currently known as the Danish Agency for Culture and Palaces, have over a long period developed protocols of investigation that include regular inspection of shorelines aided by reports from members of the public, methods of site monitoring and excavation, and predictive modelling of site discovery that takes account both of coastal locations attractive to prehistoric people and also of preservation conditions. The outcome is the discovery of many hundreds of underwater Stone Age finds, the largest concentration in the world, including well-known underwater settlements with unusual preservation of organic artefacts such as Tybring Vig and Møllegabet II.

The discovery and investigation of the Falden site described in Chap. 5 was the result of active exploration and test excavation made possible by the funding of a SPLASHCOS training exercise. The authors draw attention to the importance of public engagement and note that the majority of Denmark's underwater finds have been discovered by members of the public. Monitoring and

reporting of chance finds, however, have their limitations. Lack of research funds except for rescue excavations of important finds under threat of destruction by new engineering developments, reporting only of those finds that are visible because of erosion near the modern shore, and lack of time and money for intrusive excavation or more extensive underwater survey, all mean that the many underwater sites in the Danish government records may represent a quite biased picture of the original site distribution.

Exploratory work at Falden included hand-fanning of sediments and test-pitting in an area deemed potentially productive of preserved prehistoric material. A 10-day test excavation revealed a site with undisturbed deposits rich in flint artefacts in an area that had not previously given any such indications. The training programme also made possible experimentation in methods of photogrammetry and computerised imagery, with great potential for future development and use elsewhere. Uldum et al. emphasise the importance of funding systematic investigation of sites such as Falden in correcting and advancing existing knowledge—and in protecting undisturbed sites from further loss and destruction—even if the resulting material is not as spectacular as the more famous sites. Above all, they emphasise the need to provide a sustained international training facility that can promote understanding and expertise. This is important not only for those intent on a research career but for those destined for employment in cultural-heritage organisations and government agencies responsible for informed evaluation and management of the underwater cultural heritage.

Underwater investigations have as long a history in Israel as in southern Scandinavia (Raban 1983), and have produced evidence of comparable importance. The 9000-year-old Pre-Pottery Neolithic site of Atlit-Yam, described by Galili et al. in Chap. 6 was first discovered in 1984 and has been subject to regular inspection and periodic excavation over a long period. It is arguably one of the best-known and best preserved underwater prehistoric sites in the world, with its remarkable evidence of a fishing-farming village with stone-structures and stone-lined wells. The details set out in Chap. 6 are an object lesson in the preparatory work, procedures and methods required for systematic excavation of an underwater settlement.

One of the interesting aspects of the Atlit-Yam site is the circumstances of its discovery. Originally buried under a protective layer of marine sand, the site is intermittently exposed by storms that temporarily remove the overlying cover. The time-window of opportunity for discovering the archaeological remains is clearly quite limited before they are either covered again by sand, or are destroyed and damaged by prolonged exposure to underwater currents. Discovery therefore depends to a very large degree on chance. But the chances can be improved by regular monitoring, whether by professional underwater archaeologists, sports divers, fishermen or other members of the public.

1.3 Underwater Archaeological Sites

Part II provides a range of examples of projects that amplify the results of the Falden and Atlit-Yam case studies, illustrating the various ways in which underwater archaeological sites are discovered and excavated, and the scientific impact of the resulting discoveries.

Examples of the ways in which material is exposed to discovery include: removal of sand cover by seasonal storms (Chap. 7, see also Chap. 6); commercial sand extraction (Chaps. 7 and 9); reporting of chance finds of artefacts or submerged tree trunks by sports divers (Chaps. 7, 9 and 10); expansion of harbour facilities, bridge building and other offshore constructions (Chaps. 7 and 11); dredging of marine channels (Chap. 11); natural erosion of overlying sediments by marine currents (Chap. 8); and scientific sampling of the sea bottom for zoological or other scientific investigations (Chap. 11). Additional examples of excavation and recovery methods include coring and auguring, the use of divers to excavate gridded trenches, and the application of induction dredges for removal and sieving of deposits.

These chapters also provide a range of examples of the types of evidence that can be recovered from submerged settlements, evidence of importance both to archaeological interpretation and to the development of more precise chronologies of sea-level change—and evidence that would rarely if ever be preserved on terrestrial sites.

In Chap. 7, Galili et al. present detailed findings from a group of eight Pottery Neolithic settlements discovered in the shallow offshore and intertidal zone of the Israeli coastline. As with the earlier Pre-Pottery Neolithic site of Atlit-Yam discussed in Chap. 6, the results present an extraordinarily diverse and well-preserved assemblage of artefacts, food remains and structures, including wooden implements and containers, basketry, stone- and timber-lined wells, house foundations, the earliest currently known evidence for olive-oil production, and a large group of human burials. The excellent conditions of preservation and the spatial mapping of site features over a considerable area also highlight one of the factors that may have led to the creation of separately demarcated burial grounds or cemeteries. In the relative confines of a narrow coastal strip, excavation in order to construct wells, house foundations and other structures, perhaps added to by the need for regular removal and renewal by a shifting shoreline, would have regularly disturbed the remains of earlier burials interred in domestic surroundings, leading to competition for sub-surface space and hence eventually to the need for separately defined sacred and domestic areas.

In Chap. 8, Skriver et al. present the results of recent investigations at Hjarnø Sund, another good example of a site first identified because of artefacts observed eroding out of intact sediment near the present shoreline. A small-scale excavation revealed a rich collection of flint, bone, antler and wooden artefacts, typical of other underwater Danish sites, and two other features more rarely recovered. The first is two wooden paddles with paintwork still preserved. Similar paddles have been recovered from two other Danish underwater sites, and the addition of the Hjarnø examples highlights regional differences in design. The authors suggest that these differences might indicate markers of different social or individual identities, especially since paddles would be highly visible artefacts and ones widely travelled during canoe journeys. The other feature is the presence of shell-midden deposits. These are common on shorelines above present sea level, often accumulating numerous thick mounds, most famously in the late Mesolithic Ertebølle examples of Denmark itself. However, underwater examples are rare, with only a few known—from the Danish site of Møllegabet II (Grøn 2004, pp. 41–45) and isolated examples in other parts of the world Faught 2014, pp. 43–44, Hayashida et al. 2014, pp. 283–284)—perhaps because unconsolidated shell deposits are especially vulnerable to erosion and destruction by wave action, or simply through lack of underwater survey. The Hjarnø Sund evidence demonstrates that shell deposits can survive if covered with a layer of protective sediment, but equally that they are vulnerable to rapid erosion by water currents once exposed.

Similar underwater conditions to Denmark are found in the German territorial waters of the western Baltic and in recent years these have begun to produce a comparable range and richness of underwater material (Harff and Lüth 2011). New discoveries from the Strande site LA 163 near Stohl Cliff in the Kiel Bay are presented by Goldhammer and Hartz in Chap. 9 and add to that growing body of information. The site has yielded a typically varied collection of artefacts made of stone, bone and wood, remains of a log boat, plant remains, shells of edible marine molluscs, animal bones including freshwater and marine fish, sea birds and land mammals, and fragments of human bone. Rapid survey over a larger area including the removal of the sand cover shows that more extensive terrestrial sediments with archaeological potential lie beneath the marine sand. Here, as at Hjarnø Sund, preliminary investigations have revealed the potential for the survival of more extensive and substantial archaeological deposits and the need to fund more detailed excavations if valuable material is not to be lost.

In addition, radiocarbon dating and high precision dendrochonological dating of the abundant wooden remains at Stohl Cliff have given a precise measure and date of sea level position. Similar evidence is present at the nearby location of Friedrichsort in the Kiel Fjord, and is discussed by Feulner in Chap. 10. This site is of interest in demonstrating the value of regular monitoring by an archaeological diver, and the preservation of intact sediments in a location subject to disturbance by

regular ship movements. As at Stohl Cliff, the first indication of a submerged land surface was the discovery of remains of a submerged forest. Radiocarbon dating of a sample from a tree stump adds to the growing evidence of sea-level change in the area, and points to the possibility of discovering intact and well-preserved archaeological remains, given the frequent association of submerged forests and artefacts (e.g., Homlund et al., Chap. 4, Hansson et al. Chap. 13).

Finally, in Chap. 11, Larsson, who was involved in some of the earliest underwater work in southern Scandinavia in the 1970s and 1980s, brings together the results from a number of underwater discoveries in the Öresund Strait that separates Denmark and southern Sweden. None of these are individually spectacular or especially well-preserved, but in their collective totality they demonstrate how the cumulative growth of information from different underwater locations, combined with regional reconstructions of changing shorelines and palaeogeography, can lead to new interpretations at a regional scale of spatial and temporal patterns in the distribution of settlements, anticipating a theme that is developed in greater detail in Parts III and IV. Coastal settlements are notoriously absent from the earlier Holocene record, as in so many other regions, not least because the shorelines are mostly submerged and under-investigated, but perhaps also because earlier peoples showed less interest in coastal and marine resources. Hints of an earlier coastal interest are present from the terrestrial record in Sweden—coastal sites on uplifted shorelines further north, and hints of early contacts with the coast in the form of occasional marine shells and other marine indicators in inland sites. However, it is the underwater record that has provided fuller archaeological evidence of early coastal settlements, even if the evidence is not yet sufficient to show whether marine and coastal resources were exploited with the same intensity as demonstrated in the later coastal sites on shorelines above present sea level. In any case, interpreting the changing intensity of exploitation of coastal and hinterland resources, and their relative palaeoeconomic importance, is greatly complicated by the fact that the available environments and resources on the coast and in the hinterland in southern Scandinavia were continuously changing because of postglacial changes in climate, environment and forest cover (see also Hansson et al. Chap. 13, Glorstad et al. Chap. 19). Large samples of environmental and archaeological data from many points in time and space will be necessary to unravel these changing relationships, and further underwater research has a vital role to play.

One final point of interest in this Chapter is that one of the best known Mesolithic coastal settlements in southern Scandinavia on the present shoreline, including evidence of numerous human burials, the Swedish site of Skateholm II, was flooded by sea level rise and then exposed again because of land uplift, giving some insight into how well different sorts of materials survive inundation. In this case, interestingly, the human graves, perhaps because they were buried and covered over when first created, seem to have survived better than the remains from domestic activities.

Two final comments arise from a consideration of these chapters as a whole. The first is that they are dominated by evidence from just two major geographical centres: the coastlines of the western Baltic, especially Denmark; and the Mediterranean coastline of Israel. It could be argued that this results from uniquely favourable conditions for underwater archaeological preservation and discovery in these two regions. However, that is far from demonstrated. Rather, what the present concentration demonstrates is the importance of long-term engagement. Both regions have a long history, extending over many decades, of interest in and development of protocols for regular monitoring and recording of finds as they become exposed, in the refinement of methods of underwater survey and excavation, and in the continuity of expertise and interest sustained by the dedication of key individuals.

Conditions of survival and discovery are unlikely to be uniformly similar around all the coastlines of Europe—or indeed further afield. Nevertheless, increasing numbers of underwater finds are beginning to appear elsewhere (some are referred to in later chapters of this volume). There is no reason to doubt that similar settlements as substantial as the best-known from Israel and Denmark will eventually be forthcoming from other regions, and every reason for optimism given the number of new finds that are now appearing elsewhere—off almost every coastline in Europe (see the online data base at http://splashcos-viewer.eu/). Long-term scientific engagement and funding support, encouragement

of public interest, regular offshore monitoring to check for the appearance of new finds, and training programmes for the next generation stand out as key ingredients for future success.

The second comment is that all the examples so far considered are from the early Holocene, and that is for the simple and obvious reason that the submerged shorelines of this period belong to the final stage of postglacial sea-level rise and are therefore relatively shallow and easily accessible to inspection on or close to the modern shoreline and by diving in shallow water. What about earlier and more deeply submerged shorelines? What if sites like Atlit-Yam and Tybrind Vig existed 25,000 or even 60,000 years ago, and now lie hidden on these earlier shorelines? Galili et al. (Chap. 6) address this question and suggest that the likelihood of encountering preserved prehistoric settlements decreases with depth: because of the technical challenges of working beyond the limit of SCUBA; because shorelines would have been exposed for shorter periods before inundation by sea-level rise; and because the remains left by hunter-gatherer activity might have been more ephemeral. The technical challenges of working at much greater depths are formidable and should not be played down. But there is no reason to suppose that periods of low sea-level at much earlier periods would not have stabilised long enough to create suitable conditions for the development of substantial and permanently occupied coastal settlements, assuming that environments and resources were available to support such a possibility, and that people were sufficiently numerous and sufficiently motivated to take advantage of it.

The belief that settlements with an elaborate material culture, permanent and substantial structures, and a sedentary way of life could not have existed 20,000 years ago (or earlier) is based on a circular argument, which assumes that the final rungs of ascent in a ladder-of-progress interpretation of human history—intensification of resources, especially marine resources, permanent village settlements, social stratification, population growth and ultimately agriculture—could not have happened before about 10,000 years ago at earliest. Why not, we might ask? Because there is no earlier evidence is the standard answer. And why is that? Because—as any informed reader must now be aware—the coastlines where such evidence would be mostly located are now deeply submerged and have scarcely begun to be investigated. We know from isolated artefacts and faunal remains recovered from the seabed that prehistoric material is preserved at great depth in the 60–>100 m depth range (e.g., Long et al. 1986; Fedje and Josenhans 2000; Stanford et al. 2014) . The discovery of settlements like Atlit-Yam or Tybrind Vig on much earlier and now deeply submerged shorelines would radically overturn current preconceptions about world prehistory, and for that reason alone should become a target for future investigation—even if we are still far from having the skills and resources to reach that target (but see chapters in Part IV for projects with that target in view).

1.4 Underwater Landscapes

The chapters in Part III move the focus of attention away from individual sites to the reconstruction of submerged palaeolandscapes at a larger geographical scale. The emphasis is mostly on geophysical and palaeoenvironmental techniques of reconstruction rather than underwater archaeological finds. Nevertheless, all the studies are motivated by archaeological questions and many involve multiple collaborations between archaeologists and geoscientists, underscoring the need to integrate many different types of expertise. They also illustrate a number of different archaeological uses of palaeogeographical and palaeoenvironmental reconstruction: as a means of identifying the distribution of significant concentrations of food resources and water supplies on the pre-inundation landscape (all Chapters); as a first step in assessing where underwater prehistoric sites and settlements are likely to be located and archaeological material is likely to be preserved (Chaps. 12, 13, 15, and 16); as a guide to the interpretation of underwater finds where they are already known (Chaps. 13 and 15); and as a

means of refining the explanation and interpretation of archaeological sites and archaeological sequences on the present-day coastline (Chaps. 12 and 16).

Approaches presented in these chapters divide broadly into two categories: those that use bathymetry and other geophysical techniques to locate or infer the position of submerged shorelines and other physical features of the submerged landscape such as palaeo-river channels and physical topography (Chaps. 12 and 16); and those that use intrusive methods such as coring of sediments or sampling of speleothems, sometimes in combination with geophysical techniques, to recover dateable sequences of palaeobotanical and geochemical indicators of past environmental and climatic conditions (Chaps. 13, 14, 15, and 17). In an ideal world, the full range of geophysical and palaeoenvironmental techniques would be combined. However, the extent to which that is possible or necessary will depend on the nature of the offshore topography, the balance between sedimentation and erosion on the submerged shelf, the budget available to the research team, the availability of relevant equipment and expertise, and the nature of the archaeological problems to be addressed.

One important point about underwater mapping emphasised by Bicket et al. in Chap. 12, and one that recalls the approach developed by Chiocci et al. in Chap. 3, is that datasets of bathymetry or other underwater features are often already in existence and publically available and can be exploited to good effect (a point also made by Goldhammer and Karle in Chap. 15). In this Chapter, the authors show how far one can go in using existing data to map the changing configuration of coastlines and sea channels of relevance to routes of travel and communication by sea, to identify broad-scale changes in shoreline geomorphology and resource potential such as the varying width of the intertidal zone or the balance between rocky and sandy shores, to make sense of the location of existing settlements on the present shoreline, and to assess underwater areas promising for future exploration. Such publically available datasets, because they have usually been collected for other purposes, may not be ideal in their detail or resolution for archaeological purposes. Local shoreline positions taking account of glacio-isostatic movements may have to be estimated by reference to more generalised models of relative sea-level change (see also Harff et al. 2017a), so too the depth and character of the seabed in the absence of sub-bottom profiles. Nevertheless, such data provide usable information for many purposes, and a guide to where more detailed and localised investigation would be worth pursuing.

In Chap. 13, Hansson et al. provide a good example of how geophysical measurements and coring of sediments can be integrated to provide a detailed, high resolution reconstruction of environmental conditions on the submerged palaeolandscape. Detailed examination in this case was made possible through the collaboration of geoscientists, marine geologists and archaeologists with access to commercial ships and equipment and was focussed by the existence of already-known underwater archaeological remains (see also Holmlund et al. Chap. 4). One point that emerges very clearly from this presentation is the extraordinarily complex, dynamic and often subtle changes of shoreline configuration, environments and hydrogeological regime associated with the final stages of deglaciation and global sea level rise in the study area. The complexity arises from the interaction between sea-level rise, melting of ice barriers, regionally variable isostatic adjustments, and periodic damming back or release of Baltic waters. Such complexity places a high premium on the location, accuracy and detail of geophysical reconstructions and dateable palaeoenvironmental sequences.

Another point of interest, given the claims that have been made in other regions, notably the Black Sea, for catastrophic flood events and their human impact (Ryan et al. 1997; Lericolais et al. 2009; Yanko-Hombach et al. 2011), is the evidence in the western Baltic region for periodic, rapid and dramatic changes of water level through an amplitude of up to 25 m. As the waters of the Baltic were periodically dammed back to create a vast freshwater lake and then released again to connect with the world oceans, so they created large areas of newly exposed coastal lowland territory, only to flood them again, a sequence that occurred on at least two occasions over a period of less than 2000 years. Such a rapid complex of changes must have occasioned almost continuous disruption, re-adjustment and adaptation of settlement patterns and subsistence strategies for the human populations of the region, no doubt with more far-reaching social and demographic consequences.

This theme of dynamic and rapid change carries through to the work described in the following two chapters, both of which integrate a variety of geophysical and palaeoenvironmental techniques and reconstructions. Hepp et al. in Chap. 14, in another example of combined geophysical and palaeoenvironmental analysis, demonstrate what can be achieved by way of reconstruction over quite extensive areas, focussing on the submerged rivers systems of the 'Duck's Beak', which connected with the Palaeo-Elbe Valley, and the slightly later Palaeo-Ems. These are both part of a major system of river channels which drained northwards from the NW German land mass into the vast territory of 'Doggerland' exposed at lowered sea levels in the southern part of the North Sea Basin (see Glorstad et al. Chap. 19, Gaffney et al. Chap. 20, Momber and Peeters, Chap. 21). These valley systems would almost certainly have been a major focus of attraction for late Upper Palaeolithic populations already established in NW Europe during the closing stages of the Last Glacial, and most probably major arteries of communication, movement and animal migration (see Fischer 2004).

Karle and Goldhammer in Chap. 15 examine the southern rim of the North Sea, the Wadden Sea, one of the largest coastal and intertidal wetlands in the world. Here, because of long-term subsidence of the North Sea Basin, the sea has continued to encroach on dry land up to the present day, accompanied by rapid accumulation of marine, fluvial, estuarine and terrestrial sediments in a complex and ever-changing mosaic of drainage patterns and environmental conditions. The authors focus on the German sector of the Wadden Sea, between the estuaries of the Ems and Elbe Rivers, and thus complement the deeper offshore research of Hepp et al. discussed in Chap. 14. The approach adopted here is to exploit existing datasets including seismic profiles, borehole data representing some 3000 cores, geological and historical maps, nautical charts, and databases of archaeological finds. The primary output is environmental reconstruction with archaeological objectives: to audit the status of the information currently available with a view to ensuring effective management of the cultural heritage; to aid the interpretation of existing archaeological material; and to assess the potential for future discoveries and the most likely target locations.

Most of the known archaeological material, which is recorded from over 100 locations ranging from settlement data to individual finds, belongs to the past 2000 years, and that reflects the rapid rate of sedimentation and the fact that only the most recent millennia of the archaeological sequence have left a visible mark in the present-day offshore and intertidal mudflats. Much of that archaeological record is of intrinsic interest in demonstrating the various ways in which people attempted to protect themselves against encroaching flood waters, for example by building artificial mounds and constructing dykes. The corollary, of course, is that earlier material, particularly from the Stone Age, must be more deeply submerged beneath a thick overburden of later sediments, posing a considerable challenge to future discovery. Nevertheless, the authors point out that their mapping work has already led to the discovery of a previously unknown site, a 300-year-old farmstead destroyed by flooding, and to other locations with high archaeological potential where investigation should be carried out in advance of any offshore engineering or construction work.

Chapter 16 switches attention back to the Mediterranean and to the very different offshore conditions of the south Italian coastline, where steeper topography, predominance of erosion over sedimentation and tectonic activity pose very different challenges in assessing the effects of sea-level change on coastal topography. In this Chapter, Scicchitano et al. bring together a wide variety of geophysical and archaeological data to examine the relationship between coastline change and evidence of changing belief systems and social identities associated with a rich sequence of archaeological sites on the present-day coastline extending from the Neolithic through to the historical period. A combination of publically available mapping data, specially commissioned LiDAR and bathymetric survey, the use of underwater vehicles, isostatic modelling, and dating of uplifted sea-level indicators shows how a commanding promontory with a major settlement became progressively isolated and ultimately cut off from the mainland with corresponding changes from residential to ritual activity.

Finally, in Chap. 17, Radić Rossi and Cukrov highlight the significance of freshwater supplies located deep in coastal caves formed in karstic limestone country. The caves usually have a

connection with the sea even if their entrances are above modern sea level. Accumulated freshwater floats on the surface of seawater and many of these freshwater sources are well below present sea level. Over 100 such caves are present in Croatia alone and they are well known to seafarers and the local inhabitants as a source of freshwater and in some cases for their medicinal benefits because of the presence of trace quantities of chemicals such as sulphur. They play an important role in supporting settlements in arid regions, and archaeological data within some caves show that they have been exploited since at least the Bronze Age. Many have been submerged since the time of formation and dating of speleothems provides evidence for the history of their formation and index points for refining sea-level curves. Little research has been devoted to their archaeological significance despite their potential importance. One intriguing question is how widespread they were during periods of low sea level. There is considerable interest in the significance of coastal springs in reinforcing the attractions of coastal regions during periods of low sea level when climate conditions were generally more arid (Faure et al. 2002, see also Bailey et al. Chap. 23). Anchialine caves in karst regions close to palaeoshorelines could have further enhanced these attractions.

1.5 Landscapes of the Continental Shelf and Human Dispersals

In Part IV, discussion moves out onto a much broader geographical canvas, looking at whole sections of the continental shelf and deploying a range of archaeological, geophysical and palaeoenvironmental data and techniques, including more ambitious explorations of more deeply submerged landscapes. The central problem that motivates all these chapters is the grand theme of early human dispersals. This refers for the most part to human range-expansion into wholly new territory by our immediate ancestors, anatomically modern members of *Homo sapiens*, believed according to the current consensus to have originated in Africa and to have spread out from there at some time after about 200,000 years ago. This theme can also extend to include much earlier expansions from an African centre of origin by earlier members of the genus *Homo*. Range expansion may refer to territory never previously occupied, such as the Americas and Australia, territory made available again for human occupation after periods of abandonment, for example the recolonization of NW Europe following deglaciation, or territory already occupied by earlier human populations. The term may also refer, secondarily, to later colonising movements, for example the expansion of Neolithic farmers into European landscapes with already established hunter-gatherer populations. Since these processes of dispersal, for the most part, were in train when sea level was lower than present, they cannot be properly understood without systematic investigation of the submerged landscape, a point made by Flemming in Chap. 18 which provides a world-wide review of the issues relating to *Homo sapiens* dispersal.

As Flemming emphasises, an important source of new information lies in the rapidly expanding field of palaeogenetics, which has opened up many new ideas about the timing and pathways of population dispersal. However, new and sometimes contradictory interpretations are constantly emerging from this new research field along with conclusions that have not yet been tested against independent field data. Claims that genetic similarities between modern populations living in, for example, East Africa and the Indian subcontinent, can be used to derive not only a reliable date for the timing of the earliest dispersal between the two continents, but also the specific geographical pathway of movement—usually expressed as the shortest distance that can be drawn between them on a small-scale map—look over-optimistic and open to challenge. Uncertainties about the uniformity of mutation rates, methods of inferring dates that are subject to margins of error much greater than those typically associated with radiometric dates, the possibilities of multiple dispersals, overprinting of earlier genetic signatures by later dispersals, two-way movements and alternative geographical pathways, all need to be factored into the assessment. Ancient DNA, where preserved in human bone, offers an additional refinement and a check on palaeogenetic inferences.

At any rate, there is a need here for greater communication and collaborative research between the various disciplines involved, and especially more intensive research on the changing configuration of palaeoshorelines and palaeoenvironments on the submerged landscapes of the continental shelf, and a wider understanding of their significance. In his review, Flemming assesses what is currently known about all the relevant shelf areas in relation to these issues and the likelihood of further discoveries, drawing on the experience of submerged landscape reconstructions in Europe, and focussing on the key regions of particular significance for early human dispersal: the Mediterranean, the Red Sea, SE Asia, Australia-New Guinea, and Beringia.

Chapters 19, 20, and 21 form a group that deals with different aspects of 'Doggerland', the large area of the southern North Sea that united Britain, southern Scandinavia and the NW margins of continental Europe into a single territory during glacial periods, and which was progressively flooded by sea-level rise during the late Pleistocene and early Holocene. Since Coles (1998) first coined the term Doggerland and reviewed the existing evidence, new investigations have taken place, most notably the work of the Birmingham North Sea Palaeolandscapes Project (Gaffney et al. 2007, 2009). Palaeoenvironmental reconstructions and the recovery of artefacts and terrestrial fauna dredged up from the seabed by commercial operations all point to this region as a major focus of human settlement, and of movement and communication between the adjacent land masses.

Chapter 19 examines the timing and pathways of population expansion along the Norwegian coast following deglaciation. This issue is of particular significance because an ice-free corridor seemingly suitable for human occupation and accessible either from Doggerland or from southern Sweden and Denmark became available as early as 16,000 years ago, but there is no reliable archaeological evidence of settlement until about some 5000 years later (Bjerck 2008). One explanation for the time lag is that populations already established to the west and the south were primarily reindeer hunters, and that it would have taken time for them to adapt to the new conditions and develop the skills and motivation necessary to develop a way of life dependent on sea-mammal hunting and seafaring, both necessary for successful colonisation of the northern Norwegian coastline.

Glorstad et al. suggest a simpler explanation. Taking advantage of an evaluation project financed by the Norwegian Government in advance of offshore wind-farm construction, and exploiting already existing seismic profiles and bore-hole sediment data made available by oil companies working in this sector, they were able to reconstruct the sequence of landscape changes associated with the most likely pathway between Doggerland and Norway, using techniques for seismic profiles pioneered by the North Sea Palaeolandscapes Project referred to above. Their results demonstrate that this route would always have been blocked, initially by an ice-dammed lake and then by a marine channel in the vicinity of the present day Norwegian Trench, both too wide to be easily crossed by boat. To the south, the principal access route was blocked by an ice barrier, and it was only when that melted that easy passage northwards became available at about the time when archaeological evidence of settlement further north first appears.

In Chap. 20, Gaffney et al. outline the objectives of the newly funded Lost Frontiers Project to carry out more extensive reconstruction of the early Holocene Doggerland landscape, following on from their original work in the North Sea Palaeolandscapes Project. In the new project, they aim to bring together all the available seismic data to provide a comprehensive topographic mapping of the region, and to conduct a programme of coring in two target areas with evidence for well-established early Holocene river networks. The plan is to recover 100 cores and to conduct a range of dating and palaeoenvironmental analyses of their contained sediments.

One important innovation is the analysis of traces of ancient DNA incorporated in the sediments (sedaDNA) for clues to the plants and animals present on the now submerged palaeolandscape. Pilot research on sedaDNA has already been conducted at the submerged Mesolithic site of Bouldnor Cliff on the English south coast (Momber et al. 2011). The Bouldnor site, excavated over a period of many years by Garry Momber and his team, and referred to in the following chapter, is equivalent in importance to the Danish sites referred to earlier and elsewhere in this volume. Recent sedaDNA analysis

there has established the presence of cultivated wheat in deposits sealed by later marine sediments, demonstrating the introduction of domestic cultigens from Europe at a much earlier date than previously suspected. This and the presence of Neolithic pottery recovered from the floor of the North Sea suggest that early farmers were already moving into this region before it was fully inundated by sea-level rise. Hence, another focus of this project will be to explore the significance of the Doggerland submerged landscape and the impact of its changing configuration on the socio-economic transitions associated with the spread of farming and the Mesolithic-Neolithic transition.

The theme of changing social and economic interactions and patterns of population movement and cultural diffusion is taken up by Momber and Peeters in Chap. 21. They examine the role of Doggerland in relation to the surrounding countries at a broad regional scale, looking at late Upper Palaeolithic and Mesolithic culture groupings and the mosaic of their changing distributions against the changing pattern of climate and sea-level change from 16,000 years ago onwards. They draw on recent archaeological discoveries both on existing coastlines and below modern sea level, particularly the underwater sites of Bouldnor Cliff on the English south coast and the Yangtze Harbour finds on the Dutch side of the English Channel (see Satchell, Chap. 25), to identify links and patterns of dispersal and communication as sea level rose. These include connections across the south of Doggerland from the earliest period after glacial retreat, early connections between Scotland and northern Europe perhaps involving seafaring around the northern coastlines and estuaries of Doggerland from as early as early as 12,000 years ago, and growing evidence in the Mesolithic of maritime connections around the coasts and archipelagos of northern and western Britain after about 10,000 years ago.

Also at about 10,000 years ago, semi-sedentary Mesolithic settlements with hut structures and a mixed terrestrial-marine palaeoeconomy appear on the modern coastline in northern Britain (where earlier shorelines are visible because of land uplift compared to southern Britain). The authors raise the interesting question of whether this phenomenon represents a new phase of intensification and adaptation to the loss of lowland territory with progressive sea-level rise, or is simply the first visible evidence of an adaptation that was already present at an earlier period on the now submerged coastlines of Doggerland—a question that cannot be resolved without further underwater investigations.

Dating from a little later, the Bouldnor Cliff site on the English south coast, with its well-preserved underwater finds, has evidence of precocious skills in axe manufacture, wood-working technology, including wooden structures and possible boat-construction, and DNA evidence for the presence of cultivated wheat (also discussed by Gaffney et al. Chap. 20) substantially earlier than elsewhere in Britain. These indicate close connections with France at a time when easy travel by boat between southern England and France was still possible around sheltered coastlines and estuaries before sea-level rise finally breached the land connection between the two regions.

The remaining chapters in this section move the geographical focus away from NW Europe, to the Aegean, the Red Sea, and Western Australia, all key regions in relation to early human dispersal patterns, and all with potential for new underwater research. These chapters have a common thread, which is the emphatic assertion in all three cases that the offshore environment, including the submerged landscape at lower sea levels and the marine environment created when sea level rose with its offshore islands, archipelagos and 'seascapes'—or 'aquapelagos', the term used by Ward and Veth in Chap. 24— should be treated as a coherent entity, forming a seamless whole with the adjacent mainlands, a focal centre of interest for the people who lived there as much as for the archaeological investigator.

The Aegean is of particular interest because it is on the major pathway for connections between Europe, the Near East and Africa, both for successive hominin expansions out of Africa during the Pleistocene and also for the later dispersal of farming communities, who left some of their earliest traces on Aegean islands as on islands elsewhere in the Mediterranean. The Aegean, along with Cyprus, has also provided some of the earliest evidence for seafaring—or at any rate sea crossings—in the northern hemisphere, with unequivocal evidence for a human presence on islands from at least

13,000 years ago, long before the spread of agriculture, and claims for even earlier dates on the island of Crete (Ammerman and Davis 2013–2014).

As Sakellariou and Galanidou emphasise in Chap. 22, the relative placement of land and sea, and the status of islands and their connections with—or separation from—their adjacent mainlands, have undergone dramatic changes on the Pleistocene time scale. This is not only because of sea-level change as elsewhere, but because of very active tectonics associated with the collision of the African Plate with Europe and subduction and volcanic activity along the Hellenic Trench, promoting long-term subsidence throughout the Aegean punctuated by more localised episodes of uplift. The authors tackle this puzzle by breaking the Aegean region down into nine sub-regions, and draw on available seismic, geological and archaeological data within each sub-region to reconstruct changing patterns of palaeogeography and the nature of connections and pathways of movement. As with similar mapping projects in other chapters, this exercise plays a double role, illuminating the interpretation of existing archaeological sites on land, and focussing attention on submerged areas worth closer investigation.

The southern Red Sea, discussed by Bailey et al. in Chap. 23, has acquired prominence in recent debates about the dispersal of *Homo sapiens* out of Africa as a key pathway for range expansion, following the so-called southern corridor from The East African Rift to SW Arabia and onward around the coastlines of the Indian Ocean into SE Asia and Australia. The project described here is part of a larger project designed to test these ideas, combining archaeological and landscape investigations on the mainland of SW Saudi Arabia, the Farasan Islands and the submerged shelf. Exploitation of existing core data and bathymetry combined with sea-level modelling shows that, at low sea levels, the Red Sea between Africa and Arabia would have been reduced to a narrow and easily crossable marine channel with the exposure of extensive coastal lowlands some 100 km wide on both sides. Targetted surveys with a research vessel and a full suite of acoustic, seismic and coring equipment and an ROV has demonstrated the presence of a complex topography on this submerged landscape with numerous fault-bounded basins, some of which are likely to have formed freshwater lakes, making this an important refugium during periods of climatic aridity. The results also demonstrate the very different character of the shoreline at lowest sea level. Offshore archipelagos were present that could have facilitated early experiments with seafaring and exploitation of marine resources, with further implications for possible patterns of dispersal via maritime corridors, a theme also discussed in the following chapter.

The Australian continent is the paradigm case of early sea travel as the primary means of colonising a new continent, since it would always have required sea crossings to travel from SE Asia even at lowest sea level stands. As Ward and Veth emphasise in Chap. 24, a maritime aspect to human activity was present from the very outset, with cave sites on steeply shelving or uplifted shorelines on the islands of Wallacea and the Bismarck Archipelago showing evidence of sea travel and intensive exploitation of marine resources from at least 40,000 years ago. Investigation of the offshore landscape and its submerged shorelines is therefore of more than usual importance in understanding the history of dispersal and settlement (see also Flemming, Chap. 18). In this chapter, the authors discuss the coastline of Western Australia. They are reliant mainly on bathymetry and models of sea-level change to chart the changing character of the submerged landscape. But they also have access to well-preserved archaeological sequences on a series of offshore islands that were progressively isolated as sea-level rose, as well as evidence from the adjacent mainland, giving a window into the changing character of the submerged landscape. The changing composition of food remains in these sites through time, together with evidence for the movement of raw materials for making stone artefacts, provide a measure of changing patterns of adaptation and movement in response to rising sea level, with evidence that coastlines and marine resources were important throughout the sequence. More detailed underwater work is planned to further test these conclusions.

1.6 Outreach and Management

The importance of engagement with a wider public, of training, and of collaboration with industrial companies and government agencies is a recurring theme in many of the earlier chapters. In this final section, four chapters address more fully these issues.

Satchell (Chap. 25) draws on the experience of the Maritime Archaeology Trust (MAT) in training, education and public outreach, and the initiatives developed within the SPLASHCOS Action, to identify examples of good practice. She identifies four different audiences that need to be addressed: scientists involved in coastal and underwater investigations of various sorts, who have often accumulated data archives that can be turned to advantage for archaeological purposes; commercial companies, who also often acquire data of archaeological and palaeoenvironmental value and who, in addition, need advice on how to implement national and international directives on the mitigation of damage to the underwater heritage; government agencies and planning authorities responsible for management of the onshore and offshore heritage, who can also benefit from archaeological and geological studies of coastline change; and members of the public, who ultimately pay for underwater research and help to make the wider case with local authorities and government agencies.

A key difficulty is the remoteness of underwater finds and difficulties of access especially for non-divers. However, MAT, which is also involved in the work on the submerged site of Bouldnor Cliff (see Momber and Peeters, Chap. 21) has developed a number of innovative practices for many different audiences ranging from 10-year-old school children to professional archaeologists. These include teaching packs for school teachers, writing of illustrated story books, hands-on experience with post-excavation work, and a travelling 'Maritime Bus' with videos, leaflets and examples of underwater artefacts, experience that has been extended more widely through collaboration with neighbouring European countries and through the SPLASHCOS network. She also gives detail on the training programmes developed during the SPLASHCOS Action (see also Uldum et al. Chap. 5, Galili et al. Chap. 6), and on a variety of initiatives in the UK setting for defining protocols to encourage commercial operators, fishermen and members of the public to record and report underwater artefacts and other features.

Tidbury et al. (Chap. 26) describe case studies that bring together evidence from underwater archaeology, palaeoenvironmental data, historical maps and archives, and old photographs and paintings to chart long-term changes in coastal geomorphology. Their approach has much in common with that described by Karle and Goldhammer (Chap. 15) with the difference that in this chapter the research is aimed primarily at providing evidence of coastal change to inform local authorities and policy makers responsible for coastal management and planning. This approach contributes to a wider research agenda in which the reconstruction of the geological past can be used for future projection of coastline change (see Harff et al. 2017b). For another example of the value of ancient maps for palaeogeographical reconstruction and the refinement of geomorphological models, see also Deng et al. (2016). The examples presented in this chapter give detail on the mapping of small-scale changes, for example in rates of erosion leading to the retreat of the coastline on a time scale of decades and centuries, as well longer-term changes in sea level, and evidence for their human impact and response.

Missiaen et al. (Chap. 27) take up the issue of the threats to the coastal and underwater heritage by intensifying commercial and industrial activity in the Belgian context, particularly in the shallow waters immediately offshore, which are especially vulnerable to damage by engineering and construction work. The authors provide interesting detail on the development of new and efficient methods of underwater survey in shallow water—a good example of how archaeological imperatives are leading to new technological solutions with practical and commercial benefits as well as archaeological ones. They also provide a useful review of the international conventions for protecting the underwater heritage and the issues involved in translating these into a workable legislative framework and in providing advice to commercial operators who have to implement it. The discussion highlights the benefits of three-way collaboration between government agencies, commercial companies and underwater archaeologists.

Finally, in Chap. 28, Sturt et al. reflect on the long-term history of developments in the study of submerged landscapes and archaeology in the English context over the past century, and what we can learn from this history in looking into the future. They bring out the very interesting history of thinking and practice extending back to the discussion of submerged forests at the beginning of the twentieth century, emphasising the changing but closely inter-twined and complex relationships between scientific and academic research, industrial exploitation of the seabed, government legislation, public interest and outreach, and the different historical trajectories of on-land and underwater archaeological research and cultural heritage management. They point to the great mutual benefits that have come about as a result of a co-evolution between these very different interests, particularly in recent decades, but also to the risk of complacency in persisting with a particular way of doing things, simply because it has worked in the past, or because of the particular technologies and datasets made available by current funding budgets or industrial activity. Deciding what scientific and archaeological questions are worth asking, and what techniques and data are needed to answer them, communication across the many boundaries between the different worlds of academic and scientific research, commercial activity and public policy, and above all the engagement of wider public interest, are all essential ingredients, as they see it, in shaping future research agendas. This final chapter usefully draws together the different strands of investigation discussed in the other chapters in this section, and indeed represents a fitting finale to the themes of the volume as a whole.

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Part I
Techniques and Strategies

Chapter 2
Survey Strategies and Techniques in Underwater Geoarchaeological Research: An Overview with Emphasis on Prehistoric Sites

Tine Missiaen, Dimitris Sakellariou, and Nicholas C. Flemming

Abstract Underwater geoarchaeological studies typically involve case studies that vary widely in scale, environment and stage of application. As a result, the range of survey techniques and applied methods is very broad. This paper aims to present an overview of state-of-the-art techniques and survey strategies for submerged prehistoric site evaluation. We focus not only on conventional techniques but also on technologies that were designed and developed for other research applications but which can or could be effectively applied to submerged prehistoric studies. Different techniques discussed in this paper include remote sensing (acoustic seafloor and sub-seafloor imaging, Lidar, electric and (electro)magnetic techniques), direct investigations (coring, sampling and excavation), 2D and 3D photographic techniques, and the use of remotely operated vehicles. Notwithstanding the enormous technological progress that has been made in recent years, a large number of challenges remain not only regarding detection and excavation (especially in deeper water) but also with regard to the cost-effectiveness of submerged geoarchaeological surveys. The set-up of 'best practice' guidelines and close(r) collaboration with industry may provide some solutions.

2.1 Introduction

Systematic mapping of the continental shelf at various scales (regional, local, site) and by means of various techniques and methodologies is of crucial importance for the reconstruction of submerged landscapes and terrestrial palaeoenvironments and the evaluation of possible locations for prehistoric archaeological sites. At this moment a large spectrum of techniques is available, not only in the scientific world but also in the world of the military as well as offshore industry. However, because of

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their cost and leading-edge technology, not everybody has easy access to these methods. Even in the more economically advanced countries, research institutes have difficulty in keeping up with the fast-evolving technology. Moreover, the techniques are not always used in the most efficient/effective way, and in many cases an optimum survey methodology is lacking.

New developments are needed to 'tune' the existing techniques to specific scientific targets, as they were often developed for other purposes—such as purely geological or terrestrial studies, or military research. This modification (or implementation) of existing technologies is probably at present the best possible approach for submerged archaeological and palaeolandscape studies, as there is still not enough industrial/economic/scientific pressure to develop specific, purpose-designed prospection tools. Once there is high probability or proof of a preserved site, further specialist techniques are needed for site survey, assessment, and preservation or excavation.

One of the main technological challenges in continental shelf prehistoric research is the wide variety encountered in scale and environment. Both strongly affect the applied methodology or technique (Fig. 2.1). For instance, the search for extensive palaeolandscapes across wide areas of the continental shelf requires a different approach from surveying or documenting small (buried) structures of a few square meters. Conversely, this also affects the resolution required: what we are trying to resolve in a record from a buried river valley is obviously different from that of a single flint. The need for increasingly higher resolution, in other words the detection/identification of increasingly smaller objects, is pushing the existing technology to the limit. As yet there is no software that can enhance target recognition or pattern recognition that would speed the identification of prehistoric underwater sites.

The local or regional natural environment also influences the technology that is used. Exposed or buried features, sandy or rocky seafloor, hard or soft sediments in most cases require entirely different technologies. In this respect, caves are a specific problem, not only because their detection remains very difficult but also the nature of the topography (inclined walls instead of a more or less horizontal surface) poses major challenges to imaging technology. Local environmental conditions such as currents, waves, sedimentation, and (importantly) visibility also significantly affect the techniques that are used.

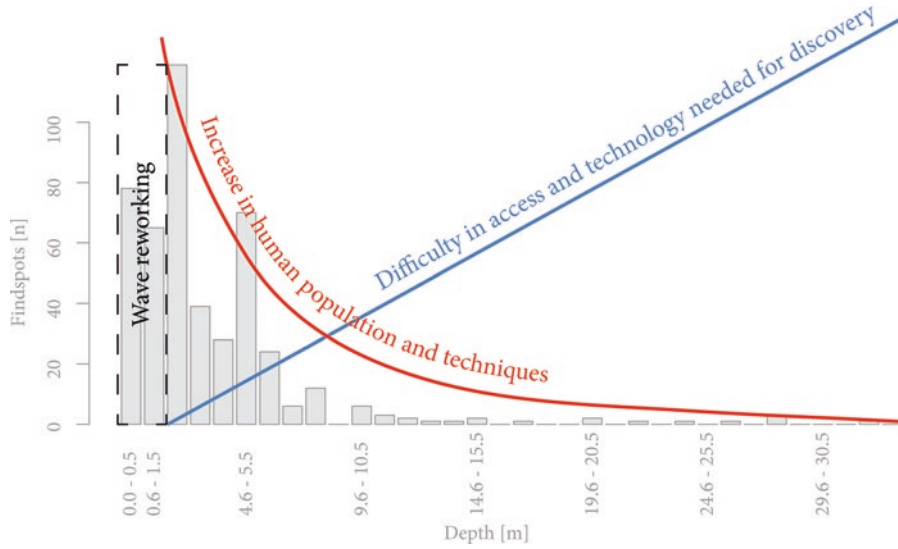


Fig. 2.1 Depth of all submerged prehistoric sites registered by March 2014 in the SPLASHCOS data base. The number of known sites decreases rapidly with depth. The *red curve* uses arbitrary units to indicate that the population density and tool technology decreases as we go back in time and depth; while the *blue line* indicates the increasing cost and technical difficulty of working at depth (After Flemming et al. 2014)

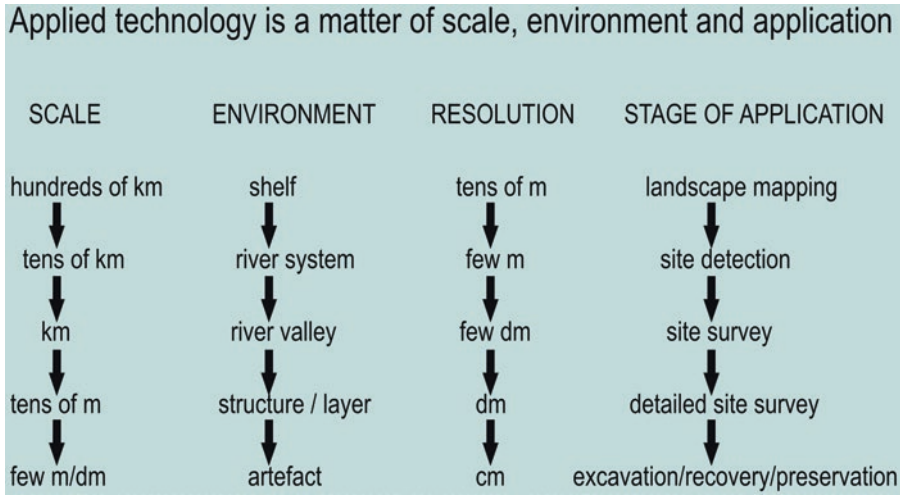


Fig. 2.2 Simplified diagram showing the wide range of scale, environment and application stage encountered in submerged archaeological studies

Water depth plays a crucial role. Until now, the vast majority of submerged prehistoric landscapes and sites on the continental shelf have been found in relatively shallow waters (<10 m), often with good visibility and accessibility (Fig. 2.1, Flemming et al. 2014). Only a small (but significant) number of sites have been examined in the depth range 10–50 m. There is little doubt that a large number of well-preserved sites and landscapes are likely to exist in deeper waters but these are largely unexplored. To open this vast archive will require interdisciplinary cooperation between archaeologists, scientists and engineers.

Closely related to issues of scale is the stage of application, which will determine the technology to be used, going from large-scale, low-resolution landscape mapping through to high-resolution site imaging, sampling, excavation, artefact recovery, site stabilization, documentation, visualization, core interpretation, and site preservation or backfilling (see Fig. 2.2). Different technologies are applied in different phases of a survey e.g., (a) commercial seismic data for a rough reconstruction of the submerged landscapes—river systems, shorelines etc., (b) side scan sonar or multibeam echo sounder to register seafloor features such as preserved tree stumps and fallen trunks exposed on the bottom, (c) 2D or 3D high-resolution subbottom profilers to detect archaeological features or small terrain anomalies embedded in bottom sediments, (d) van Veen samplers and box corers to recover samples from the seafloor and sub-seafloor, (e) photogrammetry derived from imagery.

2.2 Current Survey Technology and its Shortcomings

Due to the large variety in scale, environment and stage of application, the range of survey techniques and methods applied in submerged prehistoric research is very wide (Fig. 2.3). It goes from remote sensing (acoustic seafloor and sub-seafloor imaging, Lidar, and (electro)magnetic techniques) through to direct investigations (coring, sampling and excavation) and 2D/3D photographic techniques and remotely operated vehicles.

In recent decades, enormous technical progress has been made in geophysical recording and documentation methods that are able to provide high resolution data about sediments and structures on and beneath the seafloor. Some of these remote sensing technologies were originally designed and

METHOD	TECHNIQUE	TYPE OF DATA	TECHNOLOGY
REMOTE SENSING	Acoustic	Seafloor map	Side-scan sonar, multibeam echosounder
	Acoustic	Sub-seafloor image (2D)	Sub-bottom profilers
		Sub-seafloor image (3D)	3D Chirp, SES-2000 Quattro
	Lidar	Seafloor topography	Airborne Lidar Bathymetry
	(Electro-) magnetic	Seafloor and sub-seafloor magnetic/resistivity map	EM profilers, gradiometers
DIRECT INVESTIGATION	Coring and sampling	Sedimentological/environmental	Grabs (van Veen, Shipek) Boxcore, vibrocore, gravity core, piston core
	Dive surveys	Sedimentological/archaeological	Swim dive (corridor/jackstay/circular)
			Drift/contour dive
			Excavation
UNDERWATER PLATFORMS	Submersibles (manned/unmanned)	Wide spectre of data (acoustic maps, water/sediment samples, cores, video, ...)	HOV, ROV, AUV
PHOTOGRAPHIC	Photo, video, stereo	Exposed seafloor	Digital 2D/3D cameras, photo/video-mosaicing, video microsope

Fig. 2.3 Simplified diagram showing the wide range of technologies involved in submerged prehistoric research

developed for other research applications, such as mine detection and shipwreck studies, but they can be effectively applied (if needed with slight adaptation) to submerged prehistoric studies. Notwithstanding this technological progress, the identification of artefacts, or other physical evidence of a prehistoric site, on remote sensing data remains a huge challenge. This is even more so the case when the artefacts are buried below the sea floor.

Geophysical recording therefore always needs to be complemented with genuine archaeological investigations. In recent years direct observation methods with regard to documentation, sampling, excavation and preservation of cultural deposits have become increasingly efficient, especially in relatively shallow water environments. However the major challenge lies in the development of specialized techniques for archaeological investigations in deeper water (10–150 m), and/or environments with poor or non-existent visibility.

2.3 Acoustic Mapping Techniques

2.3.1 Acoustic Seafloor Mapping

Where palaeolandscape areas are exposed or shallowly buried, *side-scan sonar* and *multibeam echo sounders* are very powerful tools since they provide detailed 'acoustic maps' of the sea bed. The main advantage of these techniques is that a large area can be scanned relatively fast (on average a few hours for a few square km) and with a high precision (decimeter to meter-range resolution). Over the years side-scan and multibeam systems have been improving towards increasingly higher resolutions, in some cases up to cm-range. This has resulted in an ever finer image of the seafloor morphology, its texture and sediments, and any objects or structures on the seafloor. The continuous advance in materials has moreover resulted in highly compact systems that can be deployed on very small boats and in increasingly shallow water, down to a few metres, e.g., Fig. 2.4 (Sakellariou et al. 2011). Though much improvement has recently been made in the identification of artefacts by a smart combination of backscatter and bathymetry (e.g., Bates et al. 2011), being able to distinguish anthropogenic features from natural phenomena remains very difficult.

Recently a new generation of compact, high resolution imaging sonars also known as 'acoustic cameras' or '3D sonars' has been developed for engineering purposes such as pipeline inspection. These sonar cameras (also called imaging sonars), often mounted on AUVs and ROVs, offer a 3D field-of-view (up to 130°) of the sea bed and are especially useful in low or zero visibility conditions

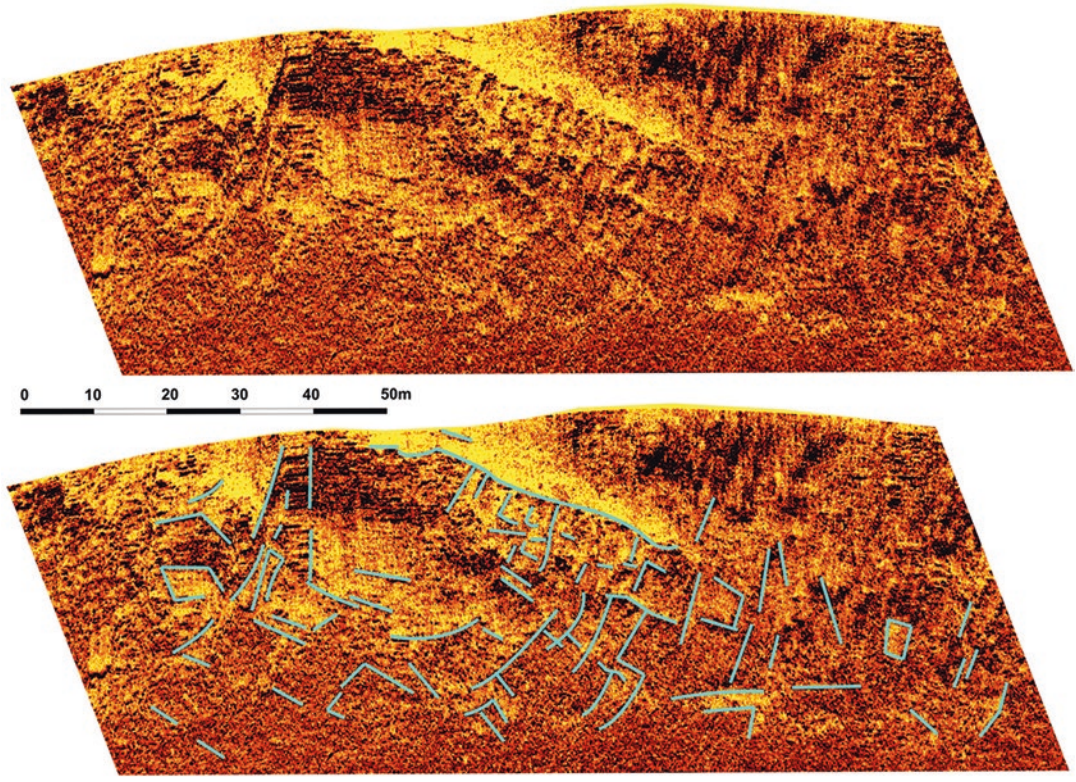


Fig. 2.4 Side-scan sonar image (400 kHz, 2–4 m water depth) of the submerged prehistoric city of Pavlopetri in Greece. *Blue lines* highlight the remains of the walls of the houses (After Sakellariou et al. 2011)

(Johnson-Roberson et al. 2010). Another noteworthy development concerns multibeam echo sounder systems with vertical angular adjustment (by the use of a tilt motor), which can provide accurate images of inclined (even vertical) surfaces. This technique offers a huge potential for cave research, where conventional multibeam systems with a wide swath are not sufficient (Mallios 2014).

2.3.2 *Acoustic Mapping of the Seabed Sub-Surface*

In the case of buried features *seismic remote sensing* (also called sub-bottom profiling) is needed to image the palaeolandscape and possible archaeological remnants therein. The seismic technique involves a wide range of sources (e.g., boomer, sparker, chirp, echosounder) and receivers (single and multichannel streamers). These have been available for decades and they yield increasingly detailed images of the sub-bottom with a resolution ranging between 20 cm and 1–2 m. Yet their full potential for submerged prehistory research is often not well exploited. Ongoing studies in Belgium show that

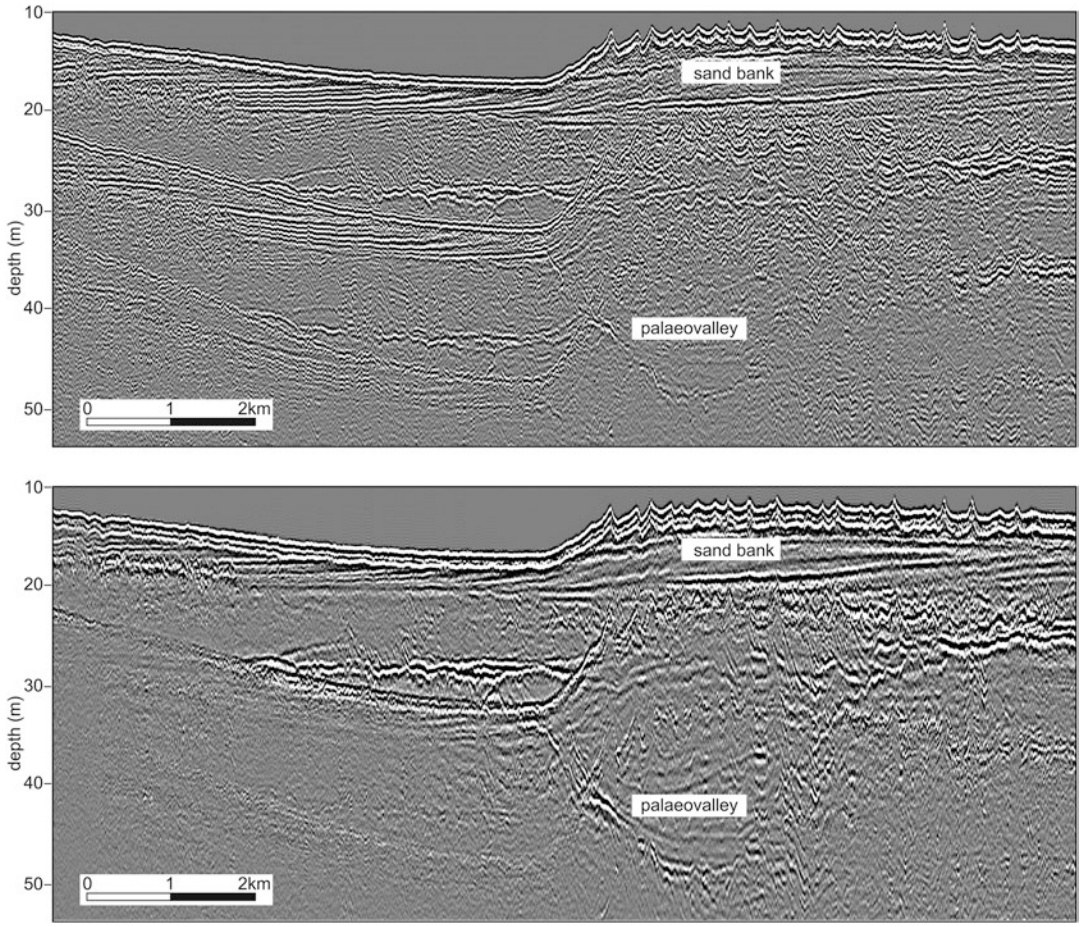


Fig. 2.5 Acoustic sparker profile from the southern North Sea showing the present sea floor (marked by a *sand bank* superimposed with large sand waves) and the underlying buried landscape (including a palaeovalley). *Top image*: single channel data. *Bottom image*: multichannel (24 ch) data. Applying multichannel recording proved advantageous, even for the relatively shallow depths encountered here (After Zurita Hurtado et al. 2014)

with a smart combination of sources and receivers and resourceful data processing the efficiency and performance of sub-bottom profiling for archaeological studies can be significantly increased (Fig. 2.5, Zurita Hurtado et al. 2014).

Prime targets for seismic studies include relief features such as buried palaeochannel systems and shell midden accumulations, but also wooden remains and organic deposits (e.g., peat layers), the latter being good indicators of past coastlines and showing a high preservation potential (e.g., Wunderlich et al. 2005; Grøn et al. 2007; Plets et al. 2007; Missiaen 2010). Unfortunately these organic-rich deposits often give rise to biogenic gas which can completely obscure the seismic image (Missiaen et al. 2002). Moreover the detection of subsurface layers containing archaeological material remains problematic since different features, for instance hard layers or fine-grained deposits, may sometimes yield a similar reflectivity and can therefore be easily mistaken. In the southern North Sea, furthermore, the widespread occurrence of sand banks poses an additional challenge as the short wavelength (i.e., high frequency) sound waves are quickly absorbed in the heterogeneous sandy sediments, resulting in a decrease in penetration depth (e.g., Van Lancker et al. 2009).

A major drawback of conventional seismic profiling is that small buried features or artefacts are extremely difficult to identify. Indeed this technique provides vertical 2D profiles, and (if line spacing is sufficiently close) through data interpolation a (pseudo) 3D image of the sub-seafloor can be constructed that allows adequate imaging of large-scale topographical features (e.g., tens to hundreds of metres in size); but it will easily miss small features of metre and sub-metre scale. The latter require *true 3D imaging techniques*. Yet 3D imaging of the sub-seafloor with high spatial resolution is a complex matter due to the physical constraints placed on sampling and positioning accuracy (Missiaen 2005; Plets et al. 2009).

In recent years, however, two unique acoustic systems have been developed in the UK (3D Chirp) and Germany (SES-2000 Quattro) that allow true 3D imaging of small buried structures with dm-scale horizontal and vertical resolution. The 3D Chirp system, which can be surface-towed from a small survey vessel, incorporates a rigid frame (2.75 × 2.3 m) containing 4 source transducers and 60 receiver elements, and integrated real-time-kinematic GPS (Bull et al. 2005; Gutowski et al. 2008). The SES-2000 Quattro is a multi-transducer parametric echosounder system that consists of a line array of four transducers that are fix mounted onto the survey platform (often a vertical pole) of a small vessel; the distance between two transducers can be varied depending on the investigated target (Lowag 2010; Innomar 2014). Promising results were obtained for buried engineering structures and archaeological wooden artefacts (Fig. 2.6). Most recently, tests in Belgium (2015) have achieved images of peat and salt excavation features in the intertidal zone in the highest detail, thereby setting new standards for shallow water geoarchaeological research (SeArch 2015).

2.4 Non-acoustic Mapping Techniques

Although less frequently used than acoustic methods, *magnetic (or gradiometric)* and *electromagnetic (EM)* techniques may also be valuable tools to image the (sub-)sea floor. This is especially useful when the sediments or archaeological remnants have a magnetic imprint which cannot be detected using acoustic methods (e.g., small ferrous objects, pit hearth/oven). Since the level of detail obtained with these techniques decreases rapidly with the distance to the sensor, towing the equipment close to the seafloor is crucial.

Magnetic surveys at sea often involve the use of two (sometimes more) spatially separated sensors (gradiometric method), which provides a better resolution and is able to detect smaller phenomena. Surveys can be carried out from relatively small vessels. For shallow depths (less than a few metres) the magnetometers can be mounted on a fixed structure; for greater depths they are often mounted on a depth-controlled towfish. Increasingly high-performance magnetometers (Fig. 2.7) and smart data

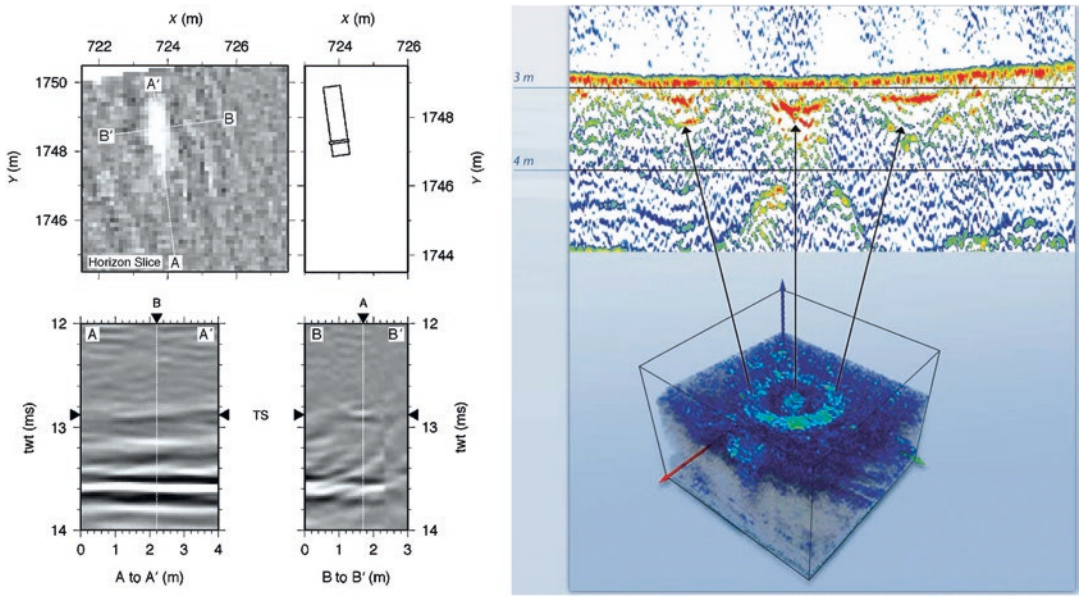


Fig. 2.6 *Left*: **a** Horizontal slice and **b**, **c** vertical slices through a buried acoustic target (location map **d**) in a tidal basin off the SE coast of England (after Vardy et al. 2008). *Right*: Subbottom image in 2D (*top*) and 3D (*bottom*) of a circular buried structure in Wismar Bay, Germany. Dimension of the 3D volume is 40×40×3 m. Data obtained with the new 3D parametric echosounder system SES-2000 Quattro (© Innomar)

processing have resulted in increasingly high resolutions (e.g., Missiaen and Feller 2009). This opens perspectives for the identification of submerged archaeological sites (e.g., Camidge et al. 2010; Boyce and Reinhardt 2004).

Marine EM techniques conventionally involve the use of heavy and bulky equipment which implies the use of relatively large boats. The resolution of the obtained data is generally much lower compared to acoustic techniques. In recent years, marine EM techniques have evolved considerably through the use of sensitive, and smaller, sources and sensors (e.g., Klein et al. 2005). However until now their main use seemed to lie in shipwreck studies, and effective application in submerged prehistoric research lacking. The recent development of a marine EM profiler ('GEM-Shark') in Germany, however, opens up new perspectives for archaeological studies (Fig. 2.7, Müller 2009).

Electric resistivity imaging (ERI) is a well-known geophysical method applied on land, but at sea this technique is much less used. Most of the current marine electrical resistivity work concerns groundwater studies or rock/sediment identification, e.g., for dredging operations or harbour works, (Henderson et al. 2010; Rucker et al. 2011; Tarits et al. 2012). A recent case study in Italy applied the method to shipwreck detection, but the results were not very convincing (Passaro 2010). For the moment the applicability of ERI for underwater archaeological studies seems to be limited to lithological/structural information on palaeolandscapes, complementary to acoustic data.

Airborne LiDAR (Light Detection and Ranging) bathymetry techniques (aka ALB) may be a valuable tool in shallow water areas. This remote sensing technology for 3D mapping of the seafloor has undergone very rapid development over recent years (Pe'eri et al. 2011) and the quality of the data is nowadays often comparable to multibeam (Pastol 2011). Important benefits of this technology are the ability to survey seamlessly across the land-sea boundary (Fig. 2.8), and to map extremely shallow areas with complex and irregular topography that are off-limits and sometimes dangerous to conventional bathymetric acquisition techniques. On retreating coasts where major storms may result in short exposure of lagoon or backshore environments before they are buried again or wiped out by waves, the availability of shallow water remote sensing tools will be especially crucial.

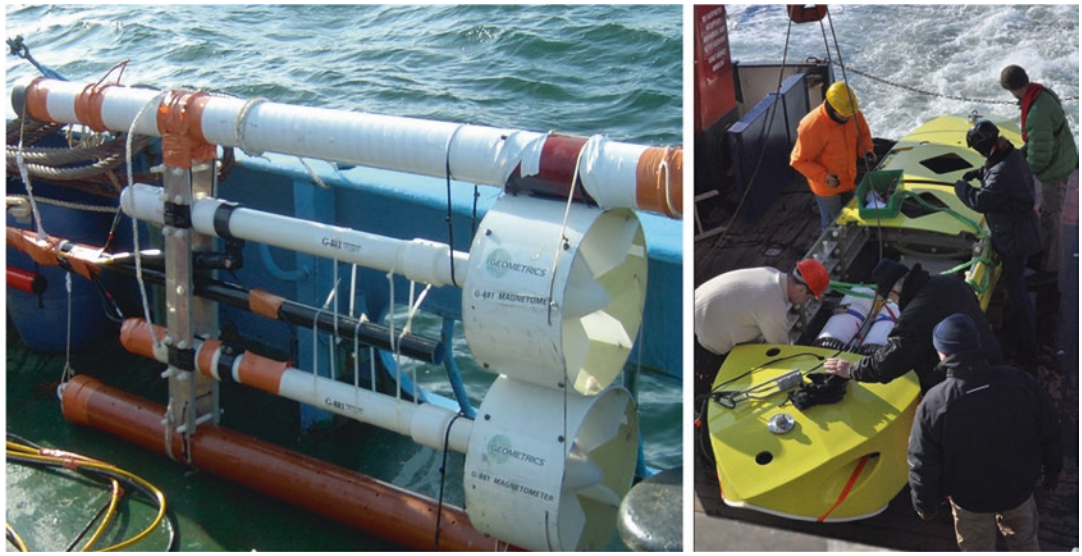


Fig. 2.7 *Left*: Marine magnetometer array in vertical gradient acquisition mode (© G-Tec). *Right*: Electromagnetic profiler array "GEM-Shark" being prepared at sea (© University of Bremen)

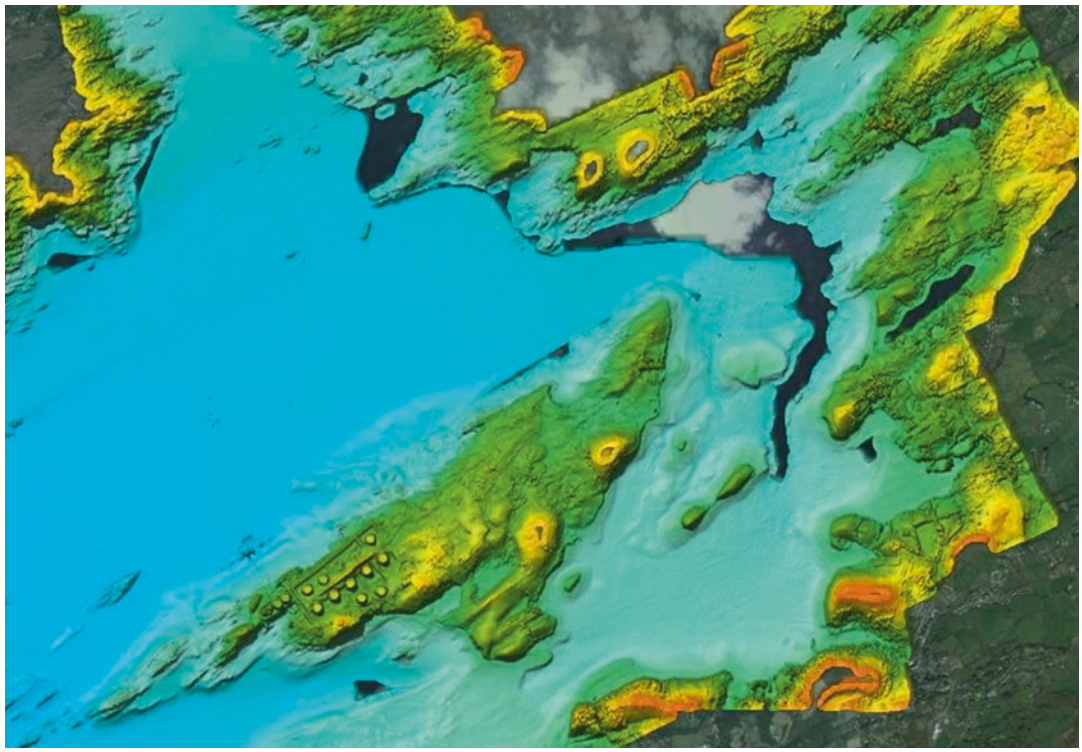


Fig. 2.8 Seamless integration of offshore multibeam data and terrestrial/intertidal LiDAR bathymetry data in Bantry Bay, Ireland, superimposed in Google Earth (© INSS/ INFOMAR)

2.5 Sampling, Coring and Excavation

In order to ground-truth the remote sensing data, samples of the seabed and sub-seabed are necessary. This can be done from boats using either *grab samplers* (e.g., Hamon, Day, Shipek, Van Veen grabs) or *coring devices* (e.g., box, gravity, piston, vibro-corer), or under water by *divers*. By studying how the sediments, and the fossils within them, change over time, a picture emerges of how the landscape, climate and sea-level have fluctuated in the past. In general it can be said that increasing the amount of sampled, cored or excavated sediment will also increase the likelihood of site discovery.

Grab Samplers and Corers Grabs are easy to deploy and can give a very large sample, but they only provide information about the seabed surface. Corers can theoretically reach several tens of metres beneath the seabed, but in reality rarely exceed 10 m. Box corers can recover large undisturbed samples of the seafloor and the uppermost sedimentary deposits up to a few tens of decimetres below the seafloor. Most corers are limited in diameter (roughly 10 cm) and require powerful winches for their deployment and recovery. They are therefore mostly used by purpose-built oceanographic or geotechnical vessels, not easily accessible to the scientific community. Moreover cores or grabs cannot be operate in rocky substrates.

Diver-Controlled Excavation This involves the careful removal of sediment in order to expose archaeological layers and artefacts so they can be carefully recorded. Excavation often involves the use of hydraulic and airlift dredges. Whereas the latter performs better at greater depths, the former is very effective in shallow water (Faught 2014). The dredged material can be sieved to recover any artefacts. When dealing with very small items (e.g., prehistoric flints) it can be appropriate to recover material in sample boxes. In the case of loose deposits, coffer structures are necessary for deeper excavations to prevent slumping of the sides. Rigid frames may also be used to provide fixed points from which to measure, or as support for divers to help them keep clear of delicate material (Fig. 2.9).

So far, surprisingly little research has been done to identify the sedimentary signatures of the deposits that make up submerged archaeological sites. Yet Gagliano et al. (1982) showed already several decades ago that detailed recording of colour, bedding, and contact descriptions



Fig. 2.9 Divers excavating the Mesolithic pit dwelling at Møllegabet II, Denmark, from a wooden platform positioned above the cultural layer under excavation (Photo M. Gull)

complemented with point counting, grain size analysis and multiple geochemical analysis make it possible to distinguish probable archaeological sites from 'natural' sites. This is an important technique for further research and calibration of proxy indicators.

2.6 Submersibles and Underwater Vehicles

Manned underwater submersibles (or Human operated vehicles, HOVs) and remotely operated vehicles (ROVs) have been used by marine scientistists, military and offshore industry for over 40 years. During recent years the use of AUV[1] (autonomous underwater vehicle) technology for the survey of the seafloor has become increasingly available and economical. Due to the relatively limited bottom time (5–6 h on average), slow speeds and human pilots, HOVs are best suited for direct-observation mapping and sampling rather than fine-resolution surveys. ROV surveys do not have the constraint on bottom time, but often require a dynamically positioned support ship. However, the tethered configuration limits the efficiency and effectiveness, as robot and surface ship have to move in concert, and strong currents may also be a problem. AUVs have proven their utility as a stable, controlled near-bottom survey platform. They are capable of flying precisely controlled fixed-altitude survey lines, making full use of the sonar resolution. They can operate from modest support ships (or from shore) and can survey large areas of the seafloor for 24–72 h without returning to the surface (Bingham et al. 2010).

The most commonly used sensors mounted on ROVs, HOVs and AUVs include navigation sensors for positioning, optical sensors (video, photographic, stereoscopic still cameras), sonar sensors for mapping the seafloor and its features (multibeam, side scan sonar, subbottom profiler) and chemical/environmental sensors for quantifying the oceanographic environment. Modern digital image recording, combined with accurate position fixing, facilitates the merging of hundreds or thousands of digital images into continuous optical maps (Mahon et al. 2011; Mallios 2014).

Though considerable progress has been made in underwater robotics, and a variety of underwater vehicles has been used in shallow and deep water for different applications, from mapping to sampling and excavating deep water wrecks and carrying different payloads and sensors, so far their application to seabed prehistory and submerged shoreline studies has been astonishingly limited. One of the few exceptions is the Pavlopetri project where an AUV was used for the optical identification of small surface artefacts (Fig. 2.10, Henderson et al. 2011). This approach could be developed for deeper work.

2.7 Photogrammetry

The aim of photographic techniques is to produce a precise, three-dimensional map and image of the archaeological site. In recent years rapid progress has been made, as increasingly high precision navigation and vehicle control permit high precision positioning of the acquired photographic data (McCarthy and Benjamin 2014; Uldum et al., Chap. 5). Furthermore, photo- and video-mosaic techniques can combine photographic images with precise positioning.

Most common techniques for automated creation of mosaics make use of simultaneous localization and mapping (SLAM), augmented with techniques from computer vision and photogrammetry, to create a consistent set of image transformations (e.g., Bingham et al. 2010). These techniques enable automated generation of strip mosaics, using data association between sequential images to

[1] AUVs operate independently from the ship whereas ROVs are connected by a cable to an operator on the ship.

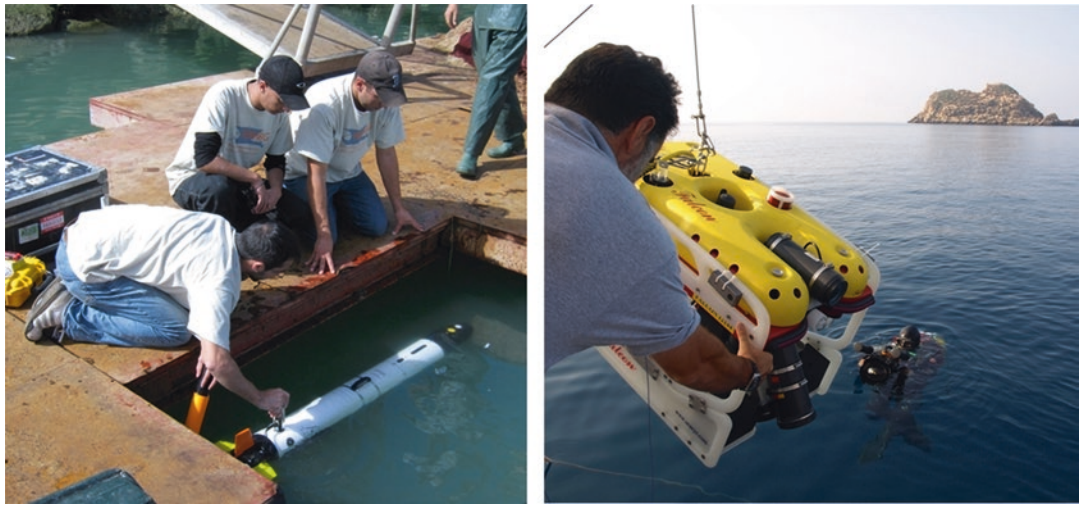


Fig. 2.10 Launching of an Autonomous Underwater Vehicle (AUV, *left*) and Remotely Operated Vehicle (ROV, *right*) for underwater archaeological surveys (© MMRG and Archivo ARQUA)

produce a mosaic representing a single pass over the site. Currently, active research is ongoing with regard to multiple omnidirectional transects (Eustice et al. 2008).

One of the latest advance in underwater photographic techniques is the creation of 3D reconstructions in parallel with generation of 2D photomosaics (Pizarro et al. 2009) and the development of visually augmented navigation (VAN) (Fig. 2.11, Eustice et al. 2008). These techniques extract three-dimensional bathymetry estimates based on the collected photographic images Recent software developments allow three-dimensional models of outcrops reconstructed from video and photographic data, facilitating quantitative measurements and photo mosaics within a georeferenced framework. The compiled data enable post-cruise 'virtual fieldwork' on the seafloor, providing the possibility for field data interpretations at a variety of scales from hand specimens to outcrops based on the quantified optical data (Kwasnitschka et al. 2013). Integration of photographic and sampling technology is perfectly illustrated with the 'Sandcam' microscope camera, a so-called contact video microscope, which provides high magnification CCTV images of seafloor sediments that are in contact with the viewing port of the camera (Puleo and Pearre 2008).

Most of the discussed improvements in 2D and 3D optical imagery are related to the use of autonomous underwater vehicles, since AUVs often prove more stable platforms compared to ROVs and HOVs and are capable of travelling at constant altitude and speed above the seafloor (Bingham et al. 2010). Given that acoustical detection of small surface artefacts is still problematic, optical identification of artefacts (in reasonably clear water), for instance using an AUV patrolling close to the seabed, would greatly help to identify sites.

One of the drawbacks of photography and videography is that these techniques do not provide accurate dimensional information of underwater archaeological sites. The latter is possible with underwater laser scanning (USL), which allows extremely high-detail (mm or sub-mm level) 3D images of exposed targets (Gillham 2011). USL can be deployed by ROV, AUV or divers, and has a maximum range of 5 m. The technique was applied successfully in 2014 on the Monohansett shipwreck site, where the 3D scans enabled detailed understanding of the current condition of the wreck (2GRobotics 2015).

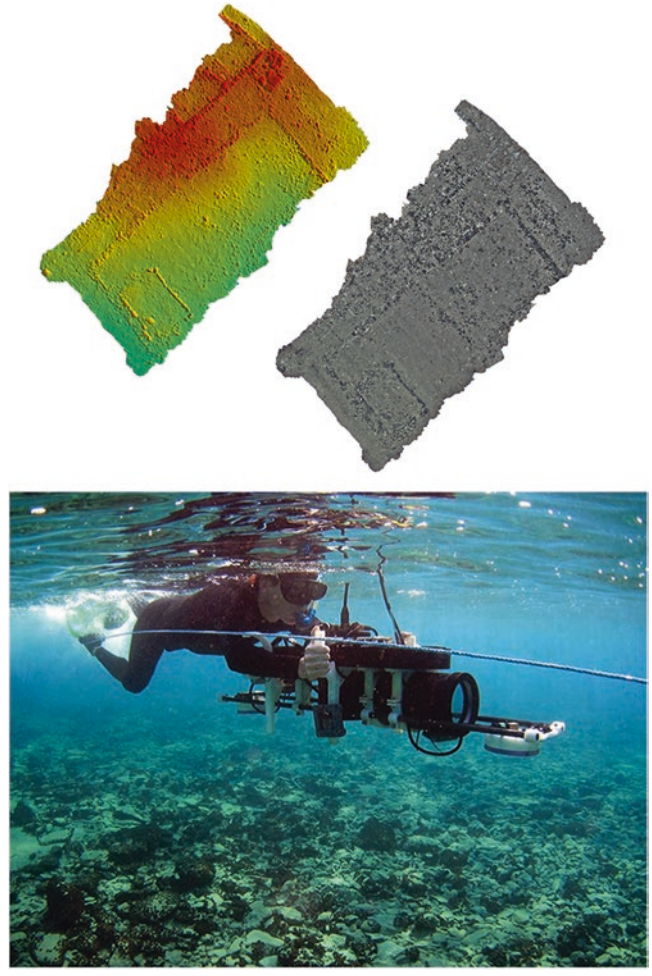


Fig. 2.11 3D coloured relief (*top left*) and 2D photo-mosaic (*top right*) showing a chamber tomb (approx. 4 × 5 m, cut 3 m into the surrounding bedrock) at the submerged archaeological site of Pavlopetri, Greece. The image was produced by geo-referenced stereo imagery from a diver-propelled platform (shown below) combined with mapping techniques (After Henderson et al. 2013; Mahon et al. 2011

2.8 Challenges for the Future

Notwithstanding the current availability of high-performance technology and the technological advances that are being made, a large number of challenges for the future remain. Perhaps the most important one is to develop methods that can increase the ratio of archaeological finds discovered by purposeful exploration to those discovered by chance. This will not only require more reliable remote sensing data (i.e., the confirmation of a prehistoric site without actual seabed examination or large-scale physical sampling), but also better cost-effectiveness (i.e., improved search efficiency and integration of existing data). A second important overall challenge lies in direct observations—once the site has been found—i.e., efficient sampling, documentation and excavation, especially in deeper water.

In addition to these general challenges a number of specific technological challenges exist. A few of these are highlighted here.

Detection of Small Buried Artefacts and Bones Identifying small objects buried beneath the seabed is still a major challenge. This is due not only to the resolution of the current acoustic imaging systems (limited to a few dm at best), but also to the likelihood that the (acoustic) contrast between the object and the surrounding sediments may not be sufficient. Ongoing Danish-Belgian research