Geology and archaeology: submerged landscapes of the continental shelf: an introduction

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Sea-level change has influenced human populations globally since prehistoric times. Even in early phases of cultural development, human populations were faced with marine regression and transgression associated with the glacial–interglacial climatic cycle, amplified by glacio-isostatic adjustments in some regions. Global marine regression during the last glaciation changed the palaeogeography of the continental shelf, converting former marine environments to attractive terrestrial habitats for prehistoric human occupation, and adding an extensive new increment of land, in the case of Europe amounting to an additional 40% of the existing land area, and on a global scale to some 20 million km^2 of additional territory that is now submerged. These areas of the shelf were used as hunting and gathering areas, and as pathways of dispersal between regions and between continents, until they were resubmerged by the post-glacial marine transgression. They also most probably witnessed the earliest developments in seafaring, marine exploitation and permanent settlements. Based on modern marine research technologies and the integration of large databases, proxy data are now becoming available for the reconstruction of these submerged Quaternary landscapes. Concerted efforts are also now being devoted to the search for prehistoric archaeological sites and artefacts on the seabed, often in collaboration with marine scientists. This search has been stimulated by the increasing amount of material that has demonstrably survived inundation, often with excellent preservation of organic remains, by closer collaboration with offshore industry, and by the growing realization of the importance of these submerged data for understanding human prehistoric developments during periods of rapidly changing climate and environment. Moreover, these new research trends are not simply being driven by an archaeological need for scientific and technological input from other disciplines, but by collaborations involving genuine mutual benefit, in which all partners have something to gain. Archaeological problems often pose new questions about geological change, stimulating new techniques of observation, new technologies and new investigations, which in their turn can offer new data, often at higher resolution and with better dates, in relation to geological and environmental issues such as sea-level change and palaeoclimatic variability on the continental shelf.

The expansion of early human populations to occupy new territory and new continents is one of the great narratives of human evolution. It is currently a theme of wide interest and topicality, and has received significant impetus and publicity from the new science of palaeogenetics. Together with ongoing discoveries of new fossil and archaeological material, and new studies of palaeoclimate and palaeoenvironment, the field itself is rapidly expanding, leading to new discoveries and new controversies (Grine *et al.* 2009; Gamble 2013; Smith & Ahern 2013). All the current indications are that the human species originated in Africa, with at least two major episodes of dispersal. The earliest, some time after about 2 myr ago, led to the expansion of *Homo ergaster/erectus* populations across southern Europe and Asia, extending from Britain in the west to China and Indonesia in the east and south. The second involved our own species, *Homo sapiens* (Anatomically Modern Humans or AMH), and took place some time after about 200 ka. This resulted in the replacement of earlier hominin populations in Europe and Asia, and expansion further afield: into New Guinea and Australia, certainly involving sea crossings over distances of at least 50 km, by about 50 ka; to the higher latitudes of northern Eurasia, with entry into the Americas by at least 15 ka; and into new territory exposed by the melting of the northern hemisphere ice sheets less than 10 kyr ago.

Anthropological and archaeological investigations of these processes are directly connected

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to palaeoclimatological, palaeogeographical and palaeooceanographic studies. The major episodes of AMH expansion, in particular, mostly took place during the last glaciation and the early post-glacial period – a time of extreme climate fluctuations. These fluctuations not only affected living conditions on the Earth's surface by shifts of climate zones, they were also associated with major changes in sea level. According to Milankovitch (1930), the external energy supply to the Earth is mainly dependent on periodical variation in the Earth's orbital parameters around the sun. Cyclical changes in boreal summer insolation are responsible for the cyclical build-up of continental ice sheets during glacial periods and their decay during interglacials. This process in its turn leads to cyclical redistribution of water from the ocean to the continents, where it is stored during the glacial periods as ice and from where it returns by melting during the interglacials to the oceanic basins. Therefore, global sea level during the Quaternary mainly reflects the ratio of continental ice volume to the volume of water in the marine basins.

Global sea-level curves are now quite well established in broad outline (Fig. 1) both for the Quaternary period (Waelbroeck *et al.* 2002) and, in more detail, for the Last Glacial Cycle (Grant *et al.* 2012). Comparing the extremes of these curves with global bathymetric data, it becomes obvious that during lowstands, with sea level at a maximum depth of 130 m below the present, wide areas of the continental shelf emerged, creating new territory for occupation and new pathways for movement between continental land masses. Conversely, sea-level rise due to global warming led to the flooding of these former territories, the removal of land bridges, and major dislocation and reconfiguration of geographical boundaries, plant and animal distributions, and social connections between human communities. In northern Eurasia and North America, glacio-isostatic uplift caused by the loading and unloading of ice and seawater on the Earth's crust was superimposed on these eustatic fluctuations, amplifying sea-level transgression or regression processes and their palaeogeographical consequences.

These changes must have had profound effects on patterns of cultural and biological interaction, and past social and economic organization, creating new opportunities for territorial expansion, or for removing formerly productive hunting grounds and disrupting lines of communication. This is especially likely given that coastal lowlands tend to benefit from improved water supplies, more equable climates and greater ecological diversity. In the past, as today, these regions were often the most attractive places for human occupation and had the highest population densities, and were therefore the regions most vulnerable to these large-scale fluctuations in sea level. Moreover, although the cumulative effect of major sea-level changes through a full glacial–interglacial cycle took many centuries and millennia to accomplish, and is only obviously apparent to us as external observers with a long-term perspective, some effects of sea-level change, especially in fairly gently sloping terrain, would have been readily apparent within the lifetime of individuals or within living memory, and, perhaps, were dramatically so. Hence, we may expect that sea-level change would have affected past systems of belief and cosmology, as well as more practical matters of subsistence and social interaction.

Sea-level change not only had an impact on past people, it has also had a major distorting effect on the archaeological record available for study. While it has long been apparent that Quaternary sea-level changes could affect patterns of human dispersal by creating and destroying land bridges between continents, it is only during the past decade that archaeologists have engaged more fully with the implications of sea-level change, notably the huge loss of critical data beneath the waves. The most recent period of sea-level rise stabilized at the present level only about 7 kyr ago. Earlier periods of high sea level close to the present level are of similarly short duration (Fig. 1). This means that coastlines and large areas of coastal hinterland available for human occupation for most of the Quaternary period are now submerged, along with the archaeological evidence of their exploitation. That evidence in its turn, if it has survived and can be recovered, may represent some of the most important evidence of human biological, social and cultural development, offering a range and quality of evidence not available on dry-land sites above modern sea level, insights into the past human impact of sea-level change, and, most likely, types of settlement patterns and environmental conditions that have no analogue in the terrestrial record. This is of particular relevance to AMH dispersal, which, according to some current hypotheses, preferred coastal pathways of dispersal in association with simple seafaring skills, and fishing and shell gathering, during lower sea-level periods of the Last Glacial. That realization, coupled with the growing body of evidence for the preservation of underwater Stone Age sites and new technological developments in marine research, has stimulated a number of recent multidisciplinary collaborations in the search for underwater evidence of Quaternary landscapes and archaeology (Harff & Lüth 2007, 2011; Bailey & Flemming 2008; Benjamin *et al.* 2011; Bailey *et al.* 2012; Evans *et al.* 2014).

This Special Publication brings together geologists, archaeologists and climatologists interested in sea-level dynamics, palaeoclimatology and the

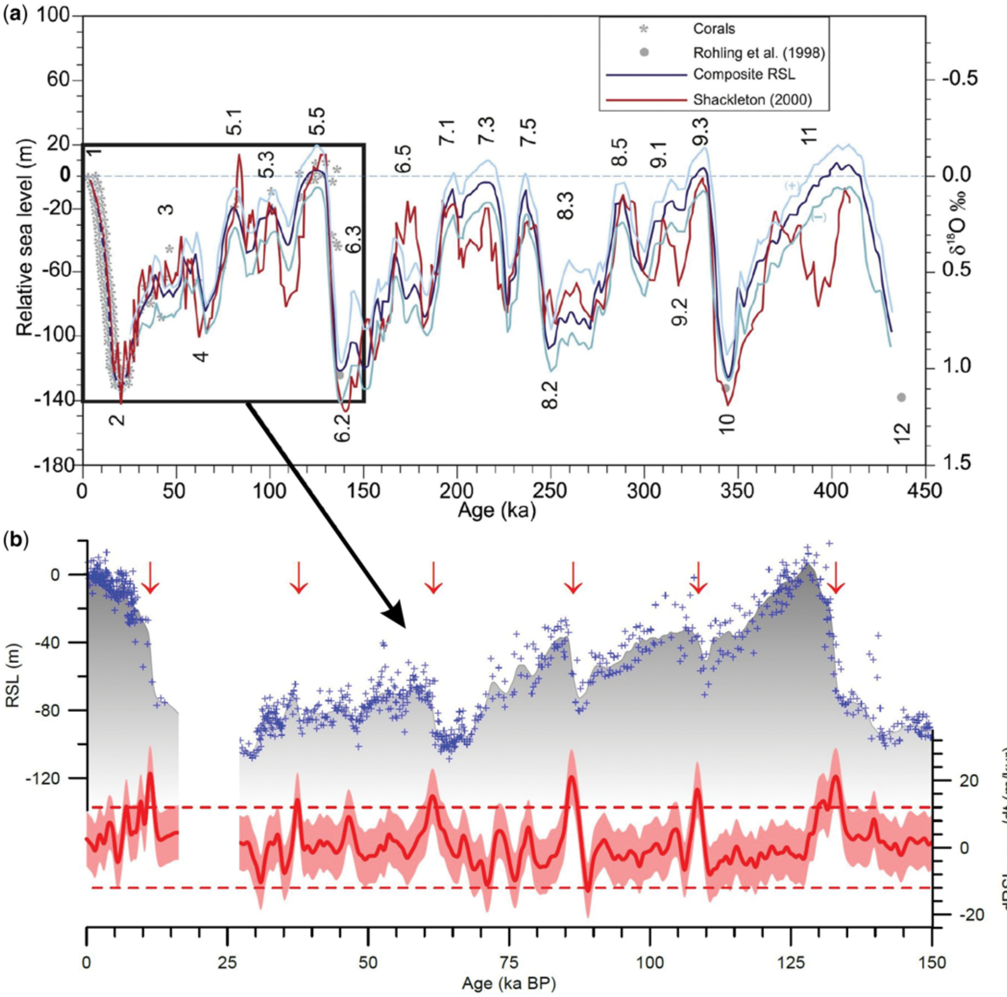

Fig. 1. Summary of the pattern of sea-level change during the Quaternary. (**a**) Pattern of sea-level change over the last 450 kyr from different oxygen isotopic sources with an RSL (relative sea-level) composite and associated confidence intervals (Rohling *et al.* 1998; Shackleton 2000), after Waelbroeck *et al.* (2002); marine isotopic stages are marked. (**b**) Relative sea-level data (blue crosses) and maximum probability of relative sea level (grey shading) for the last 150 kyr, with an indication of the rates of sea-level change (red line) with a 95% confidence interval (pink shading). Higher rates are indicated by dashed lines, and high rates of sea-level rise (more than 12 m per 1 kyr) are indicated by red arrows (modified from Waelbroeck *et al.* (2002) and Grant *et al.* 2012).

investigation of submerged landscapes, and originates in Symposium 3.2 ‘Geology and Archaeology: Submerged Landscapes of the Continental Shelf’ held at the 34th International Geological Congress in Brisbane, Australia, on 8 and 9 August 2012. From the oral presentations given in Brisbane, six manuscripts have been selected for this publication, and combined with six additional papers specially solicited for this volume.

These chapters give an overview of the current state of the art and some of the latest results in key regions. Case studies have been selected in order to facilitate comparison and contrast between regions representing distinctive combinations of sea-level history and crustal movements, posing different sorts of challenges and opportunities in the reconstruction of submerged landscapes and in the assessment of their archaeological potential. The examples from northern Europe are from the Fennoscandian Shield and the Baltic, typical of cratons that have been heavily influenced by glacio-isostatic submergence and rebound, and by complex interactions between sea-level change and glacial history. The Mediterranean examples are from a region of highly active and complex tectonics with divergent interplate motions at the junction between the African, Eurasian and Arabian plates, resulting in topographically complex landscapes and substantial regional variations in the history of tectonic uplift and subsidence. The examples from the South African and Australian shelves are from relatively stable cratons with limited or minimal isostatic or tectonic influence. In presenting the chapters, we have grouped them according to these three major regional categories and ordered them broadly in geographical sequence, beginning with Norway in the NW and concluding with an example from SE Australia.

The themes covered in each chapter show some similarities within each of these regional categories because of similar histories of geological change, but also cut across these geographical boundaries. They include technological advances in the reconstruction of deeply submerged palaeolandscapes and assessment of their archaeological potential (**Cawthra *et al.* 2015**; **Foglini *et al.* 2015**; **Sakellariou & Galanidou 2015**), detailed predictive modelling of the environmental and archaeological potential of submerged landscapes (**Ward *et al.* 2014**), the discovery, interpretation and wider significance of underwater archaeological sites (**Abelli *et al.* 2014**; **Nutley *et al.* 2014**), detailed analysis of shoreline changes and their human impact combining geological, palaeoenvironmental and archaeological evidence (**Ryabchuk *et al.* 2014**; **Galili *et al.* 2015**; **Kulkova *et al.* 2015**), and the effect of sea-level changes on patterns of human dispersal in key areas (**Antonioli *et al.* 2014**; **Glørstad 2014**; **Wurster & Bird 2014**).

Glørstad (2014) describes the peopling of Norway following the retreat of the Scandinavian ice sheet. Here, because of isostatic uplift of coastlines, are preserved some of the earliest coastal sites in Europe showing a heavy dependence on marine resources. Yet, despite evidence for the presence of attractive landscapes and human occupation on 'Doggerland' – the submerged territory lying between Norway and the British Isles – and the appearance of an ice-free corridor along the Norwegian coast at an early date in the deglaciation process, human entry was delayed until 10 kyr ago. Detailed palaeogeographical analysis shows that the combined history of sea-level change, isostatic rebound and glacial retreat created physical barriers to the west and south. These were only removed at a relatively late stage, permitting entry from the Swedish west coast (Bohuslän) to the south through a newly created archipelago environment that offered sheltered conditions for sea travel, and abundant and accessible marine resources.

The Baltic Sea lies between the glacio-isostatically uplifting Fennoscandian Shield, the relatively stable Russian Plate and the subsiding NE flank of the North German–Polish Depression, and experienced a special sea-level history different from the Norwegian coast. A permanent connection of the Baltic Basin to the northern Atlantic was opened about 8 kyr ago. Before this opening, changing melt-water levels in an isolated freshwater lake had determined changes in water level and shifts in the shoreline. An area sensitive to vertical crustal movement and sea-level change is the Gulf of Finland, which is morphologically connected to the White Sea by the Karelian lowlands. The case studies of **Ryabchuk *et al.* (2014)** and **Kulkova *et al.* (2015)** both refer to this area.

Kulkova *et al.* (2015) describe the environmental changes due to the deglaciation of the area, which finally terminated about 9 kyr ago. A combination of isostatic uplift and eustatic changes produced a complex pattern of transgressions and regressions that affected changes of lake levels well into the Holocene. Archaeological sites provide a detailed and well-dated record of changes in shoreline positions and their associated environments, and the resulting pattern of environmental changes in its turn resulted in changing patterns of economy and adaptation to environmental conditions that help to explain some of the shifts visible in a culture-historical sequence extending from the Mesolithic period through to the Iron Age.

Ryabchuk *et al.* (2014) examine the post-glacial geological history of the eastern Gulf of Finland, and use a similar combination of archaeological and geoarchaeological evidence to track the complex pattern of Holocene sea-level transgression and regression associated with the isostatic history of the area. The results help to explain gaps in the chronology of the archaeological record, attributed to a late Holocene transgression that submerged earlier coastlines, and also provide predictions about target areas for future archaeological survey.

Key questions for population movements between Africa and Europe are related to possible pathways around and across the Mediterranean Sea. The conventional view is that the only possible pathway out of Africa during the Pleistocene was the land route via the Sinai Peninsula and the Levant around the eastern coastline of the Mediterranean Basin. Sea crossings are generally associated with the Neolithic period and the dispersal of agriculture. However, the possibility of early sea crossings or land connections at lowered sea level has been repeatedly proposed, and evidence of Mesolithic sites on Aegean islands demonstrates that seafaring of some sort certainly precedes by several millennia the expansion of Neolithic farmers. Present-day islands may represent the tip of more extensive landmasses when sea level was lower and some may have been connected to the mainland via emerged land bridges or easily traversed sea crossings shorter than the present-day. Geologically informed underwater investigations are vital to test such propositions, and the Mediterranean group of chapters provides a variety of approaches to this issue.

The Maltese archipelago is a prime candidate as a link in a potential pathway between North Africa and southern Europe, and **Foglini *et al.* (2015)** pursue this theme with extensive underwater mapping of the continental shelf around Malta. Using high-resolution bathymetric mapping methods, such as multibeam surveys, LiDAR-derived digital terrain models (DTMs), chirp-sonar records and bottom sampling, they demonstrate the presence of a variety of subaerial landforms exposed at low sea level, which have undergone relatively little modification by subsequent sea-level rise. Submerged features include river valleys, alluvial plains, karst features (sinkholes, limestone plateaux), landslides, palaeoshorelines and potential palaeolakes. The submerged land was obviously more extensive, combining the three present-day islands into a single land mass, and is clearly one with potential attractions for human exploitation, although it would always have required sea crossings to gain access. The mapping is intended as a first step towards further investigation of that potential, although targeted investigations aimed at locating archaeological sites have not yet been undertaken.

Abelli *et al.* (2014) focus on Pantelleria, a smaller island to the NW of Malta, lying on the shortest route between Tunisia and Sicily. Pantelleria is a favoured source of obsidian, a much sought after raw material for making stone artefacts, and certainly exploited from the Neolithic period onwards. This chapter examines the possible existence of earlier occupation. The authors focus on a small target area on the east coast where underwater investigation of shipwrecks has been carried out, and, using a combination of high-resolution bathymetry and scuba-diving, has succeeded in discovering a submerged assemblage of artefacts at a depth of 18–21 m, including some made on local obsidian. The analysis focuses on reconstructing the shoreline conditions and obtaining a date for the site. The shoreline reconstruction shows that the submerged palaeoshoreline was quite different from the present day, offering a shallow, protected bay suitable for accessing the area by boat. Dating is only possible by indirect means, using the eustatic sea-level curve, modified to take account of estimates of vertical tectonic movement related to volcanic activity, and gives a date between of 9.6 and 7.7 ka BP. The results do not take us far enough back in time to shed light on the possibility of earlier sea crossings. However, they are of particular interest in providing an early date for human presence, and in demonstrating the use of methods for detecting and excavating an underwater Stone Age site and its local landscape setting

Another key area is the submerged sill in the Strait of Messina, separating Sicily from the Italian mainland, which is located today at a minimum depth of 81 m below sea level. **Antonioli *et al.* (2014)** provide a detailed analysis of the history of the Strait, integrating information from underwater investigations using bathymetry, geological investigations using ROVs (remotely operated vehicles) and scuba-diving, modelling of eustatic sea-level change, tectonic movements and palaoetidal velocities, and archaeological and palaeontological data. All the evidence points to the emergence of the sill as a land bridge for a period of about 500 years between 21.5 and 20 kyr ago, and radiocarbon dating of palaeontological and archaeological data shows that the earliest human presence on the island coincides with this time interval. Despite the short sea crossing – only 4 km at the present sea level – the authors argue that sea conditions, notoriously dangerous for seafaring as expressed in the famous myth of Scylla and Charybdis, would have been even more hazardous because of violent currents at earlier periods, sufficient to deter any sea crossing. This evidence casts doubt on the possibility of people reaching the Italian mainland at earlier periods of low sea level by island hopping from North Africa via the Maltese archipelago, or else it requires us to suppose that Sicily was avoided in such a putative crossing.

The possibilities of sea crossings further to the east in the Aegean are greater, and the tectonic history of subsidence and changes in palaeogeographical conditions more complex. **Sakellariou & Galanidou (2015)** take up this theme and provide a series of detailed palaeogeographical maps of submerged landscapes at different time periods, taking account of the complex tectonic history of the region. On this basis, they subdivide the Aegean region into nine geographical units based on their specific geotectonic and morphological histories, and discuss each region in relation to actual and potential archaeological evidence of human exploitation and possible pathways of movement and dispersal, including sea crossings. This marks an important step forward from the very broad-brush reconstructions that have hitherto characterized palaeogeographical reconstructions of this region, and a guide to future geoarchaeological investigations.

Finally in this group, **Galili *et al.* (2015)** examine changing sea-level and shoreline conditions on Cyprus to assess their impact on the earliest colonizers to reach the island, the earliest confirmed dates being about 10 kyr ago associated with the

Pre-Pottery Neolithic. The authors studied 22 Pleistocene beach deposits 3–22 m above the present sea level, using radiometric dates where available, marine gastropods as index fossils, beachrocks, abrasion-platforms, wave-cut notches and late Holocene fish tanks to plot a sea-level curve for the past 125 kyr. Differential tectonic uplift has affected the shoreline, but the amount of vertical movement is considered to be small relative to eustatic changes in sea level. Important outcomes of this analysis are that the earliest dates for the arrival of Neolithic colonists occurred when sea level was some 40–50 m lower than present, and that the earliest inhabitants understood the geological conditions that generate freshwater springs and dug wells to enhance the supply of permanent water, some of the earliest so far recorded anywhere in the wider archaeological record.

A different geological environment is investigated by **Cawthra *et al.* (2015)** on the tectonically stable continental margin of South Africa. This region is of particular importance because caves along the present-day coast have long stratified sequences with some of the earliest evidence for AMH populations and indications of early use of marine resources reaching back as far as 160 kyr ago. At the same time, there is an extensive continental shelf exposed by lowered sea level, so that reconstructions of submerged landscape features and palaeoshorelines are crucial in assessing the significance of the archaeological record. High-resolution geophysical and bathymetric mapping provides a first-order approximation of the subaerial environment that can be interpreted by analogy with features on the present-day coastline. As the shelf is sediment starved, ancient geomorphological landforms are not covered by younger sediments, making the area ideal for palaeogeomorphological studies, and also for the discovery of ancient stone artefacts. Landforms identified include barriers, palaeoshorelines, submerged cliffs, terraces, incised palaeochannels, depressions and shelf sands, and the authors are able to correlate these features with variations in the geological substrate and the slope of the submerged shelf.

Moving eastwards to SE Asia, we come to a region quite different from any of the others so far examined. Here, **Wurster & Bird (2014)** highlight the challenge posed by the vast extent of the landscape exposed at lower sea levels, representing a land mass that connected the islands of Borneo, Java and Sumatra to each other, and to the Asian mainland in a huge territory known as Sundaland. This region is crucial to our understanding of human dispersal in important respects. Although the fossil and archaeological record is sparse, combined with genetic modelling it suggests that this vast region may have been a source of evolutionary change in human populations, as well as a receiver of incoming populations from elsewhere. The region was also subject to major shifts in the relative distribution of closed rainforest, open savannah and mosaic environments, which would have imposed important constraints on habitable areas and dispersal pathways. The authors evaluate the evidence in relation to the sparse archaeological record, and suggest that the distribution of savannah corridors may have been crucial to human dispersal, either on the now-submerged coastal plain or as a narrow, high-altitude corridor running through central Sundaland. They point to coastal areas that might be profitable for more targeted investigation. In addition, extensive depressions on the submerged landscape may have harboured freshwater lakes. This region represents one of the largest gaps in our knowledge of early human dispersal and development, and the extent of the submerged landscape is one of the greatest challenges to underwater investigations. It was also the stepping-off point for the seaborne colonization of Sahul (the combined land mass of New Guinea and Australia formed at lower sea levels), a process that took place during a period of sea level much lower than the present, further emphasizing our ignorance about the nature of the submerged landscapes and coastlines that must have provided the preconditions for the colonization of Sahul.

Turning to Australia, **Ward *et al.* (2014)** give an example of modelling to understand the change in littoral and offshore environments of relevance to human occupation over the last 50 kyr. Groups of islands off the NW Australian coast, including the Montebello and Barrow Islands, and those of the Dampier archipelago were connected to the mainland during low sea-level stands, becoming progressively more isolated by rising sea level. Faunal records and archaeological evidence on the islands and the adjacent mainland provide markers of this transition, and evidence of changing environmental conditions and human responses to them. These can be used to highlight suitable regions for underwater exploration, and the authors are optimistic about the likelihood of finding submerged archaeological sites and terrestrial landscape features. Important outcomes of this analysis are: (i) the demonstration that the pattern of sea-level change (stable or changing) cannot by itself be used as a proxy for changes in coastal productivity; and (ii) the emphasis on integrating the investigation of the submerged landscape with the on-land archaeological, faunal and environmental record.

Finally, **Nutley *et al.* (2014)** return to a theme that lies at the heart of understanding the nature and human impact of sea-level change, and that is the ability to find underwater archaeological evidence of human occupation on now-submerged palaeoshorelines and land surfaces. They focus on the question of how archaeological sites may be deformed or destroyed by the process of inundation, and the likelihood of successful preservation and discovery. Rock shelters form a prime candidate for investigation, as they are known to provide attractive locations for human activity and to preserve stratified sediments containing archaeological material. Stone fish traps might provide another promising target, since they are likely to be resistant to the destructive impact of inundation and their locations can be predicted from the mapping of underwater stream channels. The authors report on the first phase of a project in the South West Arm of Port Hacking near Sydney on the SE coast of Australia. Divers conducted underwater surveys to search for submerged sandstone cliffs likely to harbour rock shelters similar to those known on the present-day coastline. They located, photographed and mapped similar formations under water and recorded 12 submerged rock overhangs. No excavation has yet taken place to follow up this preliminary study, but it provides an instructive example of the use of predictive modelling based on known sites on land to target underwater material, and the stepwise process involved in moving from investigations on land to offshore exploration. Systematic discovery of submerged archaeological sites, as opposed to the chance recovery of prehistoric material, continues to be one of the major technical challenges for the future.

In conclusion, we emphasize that underwater investigations of submerged landscapes have increasingly become a multidisciplinary enterprise, as is clearly demonstrated in the chapters of this volume, and often an international one, requiring collaboration across many disciplinary boundaries, especially between geosciences and archaeology. The demand for such collaborative work is likely to intensify, and will pose ongoing intellectual, logistical and financial challenges, but we believe that the potential rewards in terms of new knowledge and understanding about the history of the world and our place within it will be worth the effort.

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