ARTICLE IN PRESS
JID: OCEANO [mNS;December 11, 2021;21:18]
Oceanologia xxx (xxxx) xxx

Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.journals.elsevier.com/oceanologia

The significance of sea-level change and ancient submerged landscapes in human dispersal and development: A geoarchaeological perspective

Geoff Bailey[a,b,*], **Hayley C. Cawthra**[c,d]

[a] *Department of Archaeology, University of York, King's Manor, Exhibition Square, York, United Kingdom*
[b] *College of Humanities, Arts and Social Sciences, Flinders University, Adelaide, SA 5001, Australia*
[c] *Geophysics and Remote Sensing Unit, Council for Geoscience, Western Cape Regional Office, Bellville, Cape Town, South Africa*
[d] *African Centre for Coastal Palaeoscience, Nelson Mandela University, Gqeberha, Eastern Cape, South Africa*

Received 3 July 2021; accepted 21 October 2021
Available online xxx

KEYWORDS
Continental shelf;
Last Glacial Maximum;
Postglacial marine transgression;
Integrated palaeoscience;
Seabed mapping;
Underwater archaeology;
Underwater palaeoenvironments

Abstract In this paper we highlight the impact of sea-level change on the archaeological record of key developments in human history that took place during the late Pleistocene and the early Holocene. Before modern sea level became established from ~7 ka onwards, most palaeoshorelines and large areas of coastal hinterland were exposed as habitable land and then drowned again by sea-level rise. We summarise the archaeological implications of this pattern and the conditions in which archaeological and geoarchaeological evidence from these submerged landscapes is preserved despite the potentially destructive erosional impact of sea-level rise. We provide examples of palaeolandscape reconstruction made possible through multi-disciplinary collaboration between archaeology and marine science, drawing on recent underwater research in the North Sea, the Red Sea and on the Cape Coast of South Africa, and discuss evidence of past human responses to sea-level change. We identify the types of modelling procedures that need to be developed to advance this field of research, emphasise the importance of inter-disciplinary collaboration involving two-way exchange of ideas and information between archaeology and marine science, and highlight the value of a long-term perspective in understanding the present and future human impact of sea-level rise.

* Corresponding author at: Department of Archaeology, University of York, King's Manor, Exhibition Square, York, YO1 7EP, United Kingdom
E-mail address: geoff.bailey@york.ac.uk (G. Bailey).
Peer review under the responsibility of the Institute of Oceanology of the Polish Academy of Sciences.

Production and hosting by Elsevier

https://doi.org/10.1016/j.oceano.2021.10.002

1. Introduction

Our aim in this paper is to introduce the new and rapidly growing field of submerged landscape archaeology. This theme refers to the drowned landscapes of the continental shelf that were exposed as dry land around all the continental margins down to a maximum depth of ~130 m below present sea level during the last glacial period, and their significance for developments in early human history. This field has grown slowly over many decades because of the technological challenges of investigating underwater Stone Age archaeology, and uncertainties about what might have survived the destructive impact of sea-level rise. In the past decade, however, research activities have accelerated, due to a variety of new developments (Bailey et al 2017a, 2020a; Benjamin et al. 2011, 2017; Evans et al. 2014; Fischer and Pedersen 2018; Flemming et al. 2014, 2017; Harff et al. 2016; Sturt et al. 2018). These include:

- An increasing number of underwater archaeological finds — many discovered initially by chance by fishermen and sports divers but including systematic underwater excavations by archaeologically trained divers.
- Improved knowledge about the pattern of long-term sea-level change.
- A clearer realisation by archaeologists of just how large a gap exists in our knowledge of earlier developments in human history because of evidence now lost under the sea.
- Technological developments in underwater exploration driven by offshore industrial and commercial activities.
- The legal requirement in many countries to investigate remains of cultural and natural heritage in advance of offshore industrial development.
- An increased, world-wide awareness of the threats posed by global warming and future sea-level rise, and the valuable archives of palaeoenvironmental and archaeological data preserved on the continental shelf that can bring a long-term perspective to bear on present and future trends.

The result has been a growing number of collaborative research projects involving archaeologists, marine geologists, marine geophysicists, climatologists, palaeoenvironmental specialists and oceanographers. Achieving the archaeological objectives of these projects depends on the input and expertise of marine science, but equally marine science has much to learn from the collaboration, including the stimulus to collect new data on past sea-level change and the geology and geomorphology of the continental shelf in response to archaeological questions about the human significance of palaeolandscape change. A dominating question at the forefront of these investigations is the nature and human impact of past sea-level change. Two-way exchange of knowledge and ideas between archaeology and marine sciences, and mutual adaptation to different traditions of study, concepts and methods of investigation, are necessary ingredients of progress in this new field of research.

In this paper, we first present some background information about the influence of sea-level change on the archaeological record and the conditions under which archaeological material is preserved in the face of sea-level rise and its potentially destructive impact. We then illustrate the results of recent multi-disciplinary collaborations in palaeolandscape reconstruction and archaeological exploration of the continental shelf, drawing on summaries of recent projects in the North Sea, the Saudi Arabian sector of the Red Sea, and the Cape Coast of South Africa. Finally, we give some examples of past human responses to sea-level change and identify the types of modelling procedures and research strategies that need to be developed to progress such investigations. We conclude by emphasising the value of a long-term perspective in understanding present and future trends in sea-level rise and their human impact, and the need for international and inter-institutional networks of research and communication.

2. Background

2.1. Sea-level change and the archaeological record

Sea levels have been lower than present almost everywhere for 95 per cent of the last glacial-interglacial cycle (Grant et al. 2014; Lambeck et al. 2014). During the Last Glacial Maximum (LGM), low sea levels exposed ~20 million km^2 of new territory around the world's continental margins (Dobson 2014; Spada and Galassi 2017), much of it offering some of the most attractive territory available for human settlement and dispersal (Figure 1). This long period of low sea levels hides palaeoshorelines and coastal landscapes that likely contain some of the most important archaeological and palaeoenvironmental evidence for human developments during the past ~125,000 years. These developments include:

- Intensification in the exploitation of marine resources, including shellgathering, fishing and hunting or scavenging of sea mammals.
- Early developments in seafaring.
- First human entry into Australia and New Guinea in the southern hemisphere.
- Earliest human entry into North America, and population expansion more generally into the deglaciated regions of the northern hemisphere.
- The growth of population size and sedentary settlements, which, as we know from ethnographic records of hunters and gatherers living in the Americas and Australia, tend to concentrate in coastal regions because of the diversity of marine and terrestrial resources available there in close proximity and their relatively high productivity.
- The earliest expansion of farming communities, which, in the eastern Mediterranean and southern Europe, included a major theme of seaborne colonisation around coastlines and to offshore islands.

All these developments were taking place when sea levels were lower than present, and most of the settlements and much of the relevant archaeological and palaeoenvironmental evidence has been drowned by sea-level rise at the end of the last glacial period and is now located offshore on and under the seabed.

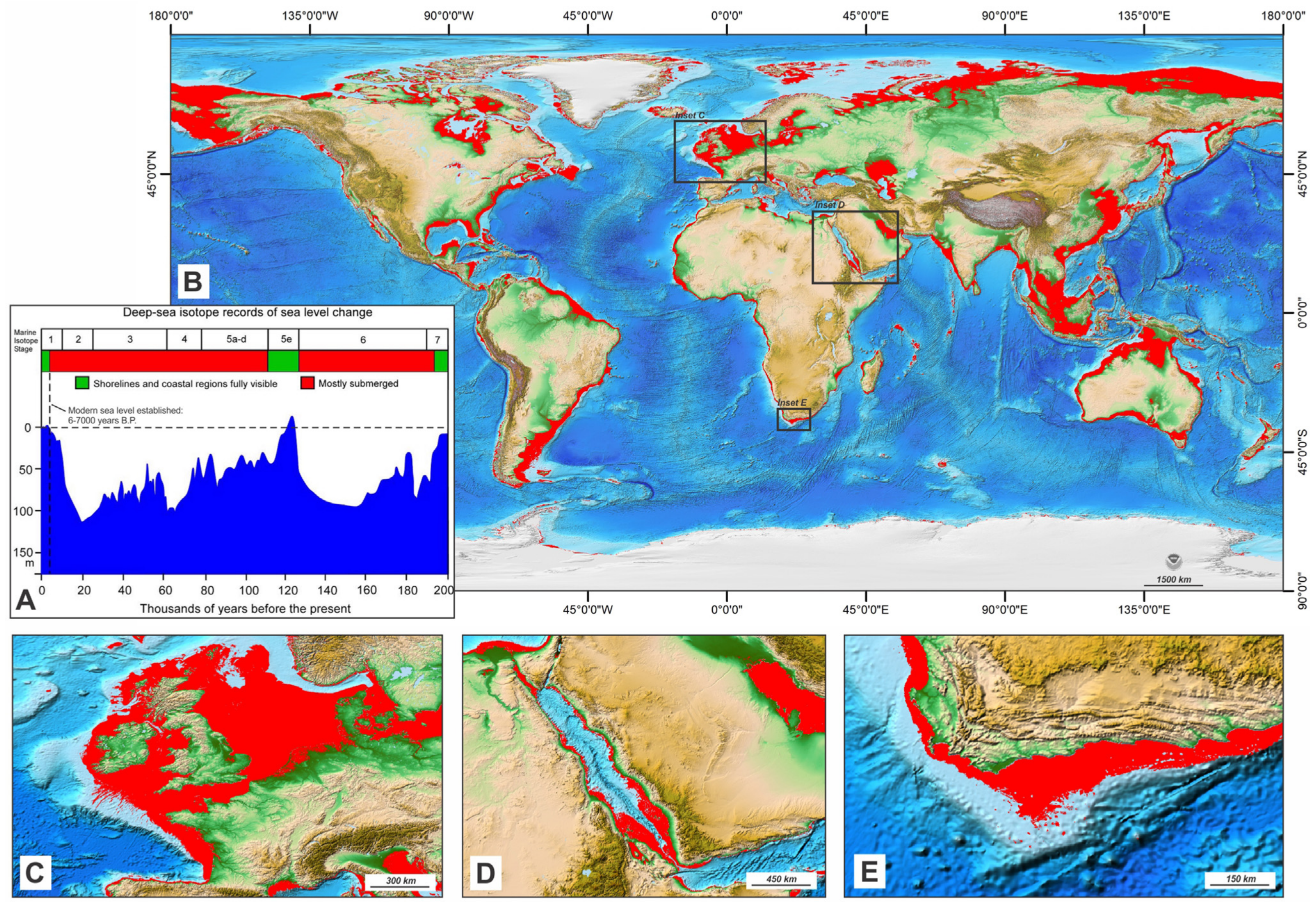

Figure 1 (A) Sea-level data from Marine Isotope Stage 7 to the Present and a modern benchmark shown as a horizontal dashed line. Sea-level curve simplified after Grant et al. (2012, 2014); Lambeck et al. 2014. (B) World map showing areas of land (in red) that are now submerged but emerged as terrestrial landscapes during Quaternary glacial maxima, for example the Last Glacial Maximum (LGM). The bathymetric data are derived from NOAA (2009)(NOAA National Geophysical Data Center 2009) and the red zone is the area between 0 and 130 m below modern sea level. The variable width of this zone in different geographic areas is dependent on the width of the continental shelf. Zoomed areas in the insets of C, D and E are the North Sea, the Red Sea and the Southern African southern Cape, respectively. These provide location maps for the case studies discussed in this paper. These maps represent the glacio-eustatic fluctuation in sea level and do not take account of subsidence or uplift. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

2.2. Conditions of archaeological preservation and discovery

Archaeological finds from the Stone Age comprise relatively insubstantial remains: accumulations of stone artefacts; food refuse such as animal bones and shells from molluscs; modifications of the land surface such as pits and postholes for dwelling structures built from tree branches or timber supports; and more rarely stone structures. Also, shorelines are generally exposed to the potentially destructive impact of surf action and turbulent water currents during the initial stage of inundation by sea-level rise. It is, therefore, easy to assume that most archaeological evidence and much of the physical evidence of the surrounding landscape associated with submerged shorelines would have been disturbed, destroyed, or buried out of sight under marine sediments. Caves and rockshelters are also common targets of investigation in terrestrial archaeology because they afforded shelter for the original inhabitants and because they provide an easily identified and protective environment for the preservation of stratified sediments. Underwater caves and rockshelters therefore offer another target for archaeological investigation, but these too are vulnerable to destruction of evidence because of the removal of sediments by wave action.

Despite these generalisations, a surprisingly large quantity of Stone Age evidence has survived. In Europe alone, there are at least 3000 underwater finds (Bailey et al., 2020a). Comparable evidence is known from North America and more scattered and isolated finds in other parts of the world (Sturt et al., 2018). Many are finds of single artefacts or animal bones, or materials dredged up by fishing boats that lack details of the original provenance. However, a significant proportion of the European finds are in situ remains of human settlements or cultural activity areas, often with preservation of organic materials such as wooden artefacts, plant fibres, textiles and uncharred remains of plant foods, materials that are rarely preserved at terrestrial sites on dry land.

The largest concentrations of evidence in Europe are in north-west Europe, especially along the coastlines of the western Baltic and the Danish straits (Germany, Denmark and Sweden), the Black Sea coast of Bulgaria, and the Mediterranean coastline of Israel (Andersen, 2013; Bailey et al., 2020b; Fischer and Pedersen, 2018; Galili et al., 2020; Harff and Lüth, 2007, 2011; Jöns et al., 2020; Nilsson et al., 2020; Peev et al., 2020). These concentrations reflect long-standing local traditions of archaeological interest and diver investigation going back over 40 years (Andersen, 1985; Fischer, 1995; Galili and Weinstein-Evron, 1985; Masters and Flemming, 1983; Porozhanov, 1991). Most of these finds and especially those that have been systematically investigated by underwater excavations are in relatively shallow water easily accessible to divers, and therefore represent relatively recent periods of the archaeological sequence when sea-level rise was approaching the modern level — ~9000—6000 years ago. But occasional finds in deeper water suggest that similar evidence awaits discovery from earlier palaeocoastlines at greater depth and further offshore.

The European evidence provides important clues to the conditions in which archaeological material is preserved under water and can be identified. In Denmark and northern Germany, the best- preserved sites are along the coastlines of the western Baltic and the Danish straits, with relatively calm and shallow waters, restricted tidal range and limited accumulation of marine sediment. Moreover, the best-preserved material at these sites occurs in 'refuse areas' — areas of shallow water alongside settlements on the shoreline, where material was thrown away from the adjacent dwelling area, such as discarded artefacts and food remains, or abandoned in situ, such as logboats and stationary fish weirs built out from the shoreline. These refuse deposits were in shallow water with soft bottom sediments at the time of occupation, and material left on the seabed surface rapidly sank into the soft sediments ensuring preservation of wood and plant material in anaerobic conditions before sea-level rise further sealed these deposits under a covering of marine sands and gravels. The evidence of domestic activities and dwelling structures on the adjacent dry land was largely eroded away by sea-level rise, leaving only traces of the former activity — stone tools, rare traces of hearths and dwelling structures, and an occasional grave with a human burial or a refuse pit saved from erosion because they were already dug beneath the level of the surrounding surface with a protective covering before inundation by sea-level rise (Bailey et al., 2020b; Fischer, 1995).

Excavated sites that provide good illustrations of these processes are the Mesolithic sites of Tybrind Vig and Møllegabet II in Denmark (Andersen 2013; Skaarup and Grøn 2004), and Neustadt and Timmendorf-Nordmole I in Germany (Harff and Lüth, 2007, 2011; Jöns et al., 2020). The Bulgarian sites comprise wooden posts and planks as well as large quantities of pottery and other artefacts, notable examples being the sites of Urdoviza and Ropotamo (Angelova and Draganov, 2003; Peev et al., 2020). Here the actual settlement areas were located on boggy ground liable to flooding, and the wooden remains represent dwelling structures and platforms intended to provide a dry and stable dwelling surface. In Israel, structures were built of stone and therefore more durable in the face of sea-level rise and periodically exposed when the protective covering of sand was removed by storm action. Here too, the best-preserved remains are in sub-surface features, the best-known site being the pre-pottery Neolithic site of Atlit Yam (Galili et al., 1993, 2020). These sites have remains of stone dwelling structures, stone-lined human burials, refuse pits, and water wells constructed of stone and timber. The wells were dug below the surface to reach the water table and later filled with partially water-logged refuse before the sites were finally abandoned as sea level rose and covered the site with marine sands.

The paradox of underwater preservation revealed by these examples is that the best chances of preservation, especially of organic materials, are when material is buried in anaerobic and protective sediment before, during and after inundation. However, burial beneath marine sediment removes the archaeological evidence from view, and it can only be discovered if the buried material is exposed subsequently by erosion, either by natural processes or by human activities such as trawler fishing or engineering works. Of course, the process of erosion not only exposes the material to discovery but also to increased risk of destruction. The site of Bouldnor Cliff in southern England gives a good illustration of this process. Here, a bench of peat and terrestrial deposits capped by marine sediment at about 11 m below present sea level extends for at least a kilometre laterally along the northern coastline of the Isle of Wight in the Solent Strait. Underwater currents have created a submarine channel that has excavated into the original land surface, exposed the peat layer, and caused artefacts to erode out from the excavated section, including flint implements and large quantities of worked wood (Momber et al. 2011, 2021).

3. Case studies in multidisciplinary collaboration

3.1. The North Sea

The seafloor of the North Sea has been an intensive zone of commercial and industrial activity over many decades. Palaeolithic and Mesolithic stone artefacts, and large quantities of bones of Pleistocene fauna and occasional human remains have been dredged up by trawler fishing, aggregates extraction or other industrial activities since early in the 20th century (Bailey et al., 2020c; Maarleveld, 2020; Peeters and Amkreutz, 2020). Three projects demonstrate what can be discovered through targeted underwater exploration and some of the procedures used. All involved collaboration with industrial partners, who played a significant role in provision of funding and equipment.

The first project is the North Sea Palaeolandscapes Project initiated by Vince Gaffney and colleagues in the early 2000s (Gaffney et al. 2007, 2009). This was a research-led project involving the analysis of 2D and 3D seismic records made available by oil companies operating in the North Sea. Although these records are intended to discover geological deposits at depth, the archaeological

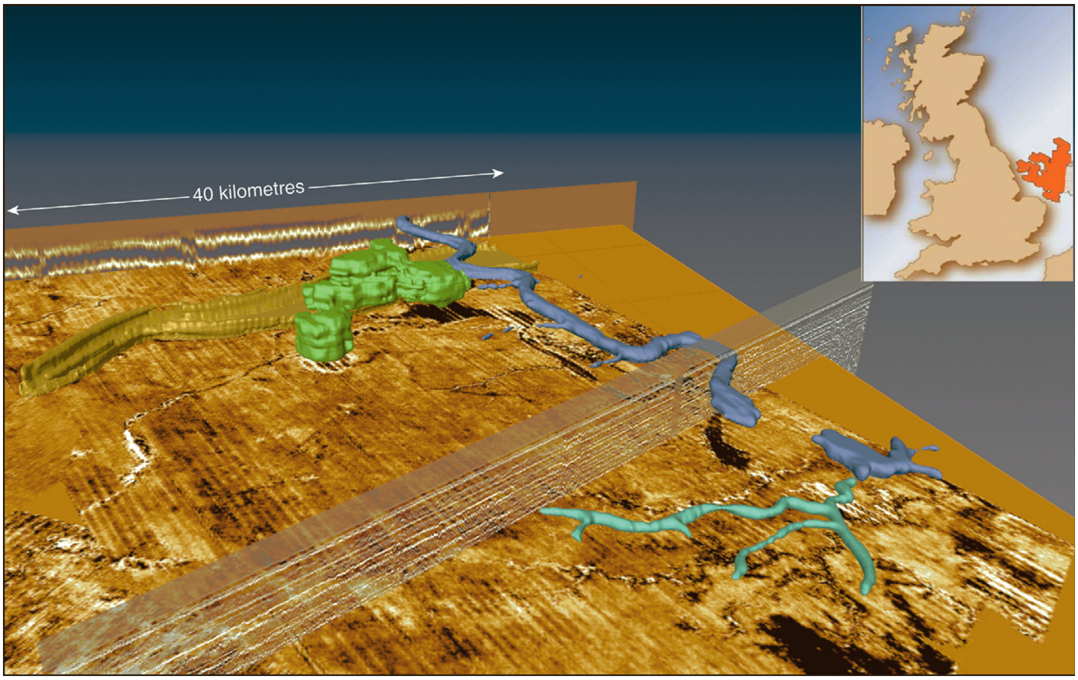

Figure 2 Map of a drowned landscape in the North Sea reconstructed from 3D seismic data collected by the hydrocarbon industry. The reconstruction shows an early Holocene river-system (in blue) and marshy areas (in green). An earlier, Late Glacial, landscape is also visible with a tunnel valley (in gold). After Gaffney et al. (2009, Figure 5.15). Courtesy of Vince Gaffney. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

team were able to show that, with suitable computing algorithms, the seismic signal passing through the uppermost sediments of the seabed had sufficient resolution to allow the extraction of details about the now-submerged Holocene and late Pleistocene land surface. The result was a series of maps with details of palaeocoastlines, river channels, hills and valleys, lakes, and areas of wetlands (Figure 2). The research was funded by the Aggregates Levy Sustainability Fund, a UK government tax on gravel-extraction companies, and overseen by the UK government agency responsible for management of the underwater cultural heritage (currently known as Heritage England).

A second project, also associated with the gravel-extraction industry, concerns the discovery of the A240 Palaeolithic site 11 km off the east coast of England at water depths of 18—35 m. This site was first identified when flint artefacts and faunal remains were found in aggregate stockpiles at a harbour in the Netherlands (Figure 3). The original source of the material was identified, and geophysical survey, coring and the use of a remotely operated vehicle (ROV) and grab sampling equipment recovered a dated sequence of estuarine sediments with more than 120 Middle Palaeolithic artefacts, faunal remains and palaeoenvironmental data dated at 250,000—200,000 BP (Tizzard et al., 2014, 2015). Much of the material was undisturbed and had survived successive cycles of exposure and submergence by sea-level change. This is one of the oldest sites currently known from offshore exploration of the seabed at depth. It highlights the likelihood that similar material can be recovered from sediments associated with submerged Quaternary floodplains and river systems.

More recently, the Gaffney team has led new investigations in the southern North Sea using high resolution acoustic methods better suited to shallow sub-surface exploration and identification of target areas for sediment sampling and recovery of artefacts, resulting in the recovery of proxy data through coring of sediments to test palaeolandscape reconstructions based on seismic records and fresh archaeological discoveries (Fitch et al., 2021; Gaffney et al., 2017).

The third project is the Rotterdam Harbour project in the Netherlands, where geoarchaeological investigations were incorporated into the work of deepening and expanding the harbour. Here the port authority, the government agencies responsible for marine planning and heritage protection, and archaeological and geological specialists were involved from the beginning in planning scientific investigations alongside the construction work (Moree and Sier, 2015; Weerts et al., 2012). The research began with modelling of the seabed surface geology and sediments at depths of 17—22 m below present sea-level using geological mapping, seismic data, and sediment cores. This identified a system of dunes associated with river channels thought likely to offer attractive locations for hunter-gatherer settlements. Areas of high potential were further targeted by coring and the cores recovered traces of cultural activity including Mesolithic artefacts. This was followed up by excavation using specially constructed equipment for large-scale grab sampling and sieving of sediments (Figure 4). This resulted in the recovery of thousands of fragments of animal

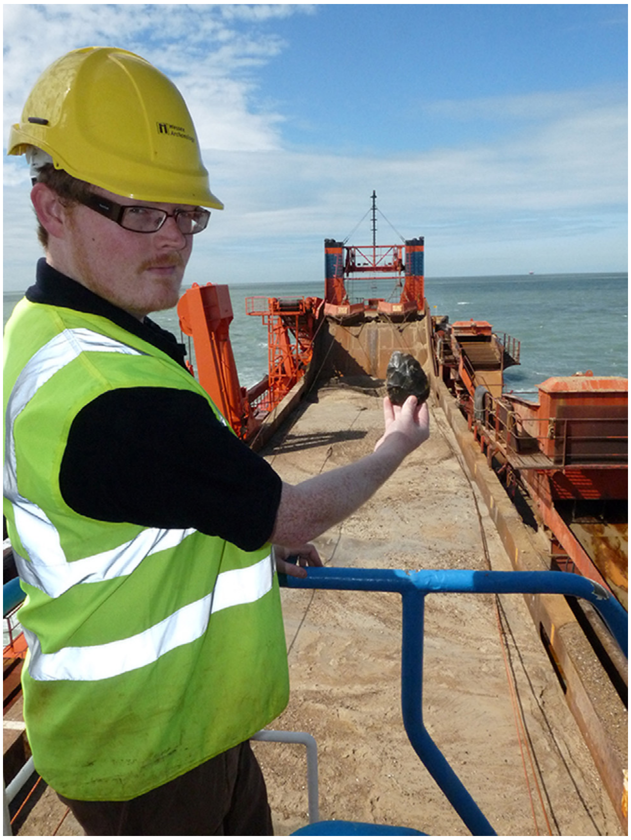

Figure 3 An archaeologist holding a handaxe recovered from monitoring on board a vessel belonging to Hanson Aggregates Marine Limited used in extraction of aggregates in the North Sea. A similar find led to the discovery of in situ fluvial sediments, flint artefacts and faunal remains preserved beneath the seabed at Site A240. See text for further detail. ©Wessex Archaeology, courtesy of Louise Tizzard.

bone, flint artefacts, and charred plant remains dating from ~10,400 cal BP onwards. Coupled with high-quality piston cores for high-resolution paleoenvironmental reconstruction, the overall results have produced the earliest evidence for Preboreal early Mesolithic coastal activity in this sector of the North Sea.

All these examples demonstrate the scale of research, the type of equipment needed, and what can be achieved in collaboration with offshore industrial partners. They also demonstrate the virtues of a planning regime enforced by national and EU legislation, which requires offshore commercial and industrial developers to undertake environmental impact assessments, including assessment of cultural heritage, in consultation with government agencies, and to carry out mitigation work in advance of commercial construction work or other potentially destructive activity. Norway, Denmark and Germany provide other examples of large-scale industrial developments, such as road and rail tunnels and bridges, pipelines and construction of offshore wind farms, which have resulted in important archaeological and palaeoenvironmental discoveries (Peeters et al., 2020).

The cost of the geoarchaeological research described above is high in relation to typical research funds available for scientific research, representing millions of Euros, but relatively small in relation to the budgets of the commercial developer. For the developer, the inconvenience and cost are relatively small, provided that the scientific research is incorporated into the development work at the planning stage. The upside for the developer is good publicity and community relations; for the geoarchaeologist, resources to conduct research that would not otherwise be possible, but with the limitation that the scientific results are constrained by the location and time pressures of the industrial work.

3.2. The Red Sea

From 2006—2013, underwater explorations were undertaken in the Saudi Arabian sector of the southern Red Sea in the vicinity of the Farasan Islands, as part of a research-led project — the DISPERSE project — driven by archaeological and palaeoanthropological interests in the role of the southern Red Sea and the Arabian Peninsula in early hominin history and dispersal out of Africa. Work included investigation of deeply submerged palaeoshorelines using mixed-gas deep diving, use of SCUBA diving in shallow water to search for underwater shell middens comparable to those that are present in large numbers on the modern shorelines of the Farasan Islands dating from ~6 ka onwards, mapping and modelling of changes in the width of the strait at the southern end of the Red Sea with changes in sea level, and mapping of the submerged geology, topography and palaeoclimate of the shelf using a fully crewed research vessel (r/v AEGAEO) with seismics, acoustics, ROV and coring capabilities (Bailey et al., 2007a, 2007b, 2015, 2017b, 2019; Inglis et al., 2019; Lambeck et al., 2011; Momber et al., 2019; Sakellariou et al., 2019; Sergiou et al., in press).

This region is of great interest as a potential pathway for early human dispersals out of Africa and especially for the dispersal of anatomically modern *Homo sapiens*, believed by some to have involved seafaring abilities, increased emphasis on marine resources and coastwise dispersal (Groucutt et al. 2015; Mellars et al. 2013). Since this hypothesis of marine-based dispersal is also thought to have taken place during periods of low sea level, it focuses attention on the nature of the landscapes and palaeoshorelines of the submerged continental shelf and the need to search for underwater archaeological and palaeoenvironmental evidence.

Here we briefly summarise some of the results of the r/v AEGAEO survey, which targeted two areas covering a total of 500 km^2, the outer shelf area encompassing the coastline at the maximum sea-level regression, and an inner shelf area with depressions representing deep solution hollows resulting from salt diapirism (Figure 5). Over a 12-day period, the area was totally covered with multi-beam bathymetry and criss-crossed with a series of 10 ci airgun seismic profiles, 3.5 kHz subbottom profiles and side-scan sonar tracks, with the recovery of 20 gravity and box cores, and 5 dives of an ROV Max Rover.

These investigations revealed a series of coral terraces that dip gently to the south-west at depths of 40 m and 70—90 m. These would have been fully exposed as subaerial land surfaces at the LGM. At the edge of the shelf at

Figure 4 Use of industrial-scale excavation equipment during expansion of the Port of Rotterdam specially designed to obtain grab samples of sediment from the seafloor for archaeological study. The photograph shows a sack filled with sediment recovered from a sand layer at 18 m below sea level that is being lifted clear by a crane mounted on a pontoon. The sediment was then passed through large-scale metal sieves and searched for artefacts and animal bones. Photo by Dimitri Schiltmans, BOOR (Bureau Oudheidkundig Onderzoek Rotterdam), courtesy of Henk Weerts and Hans Peeters.

depths corresponding to the likely position of the LGM coastline, there is evidence of a valley opening out onto the coastline facing a series of offshore islands (Figure 6). The inner shelf is punctuated by deep, circular or elongate depressions representing solution hollows formed by salt tectonics. Seismic stratigraphy and sedimentological data confirm that these depressions were filled permanently or ephemerally with water and accumulated sediments, some of which have dated sequences extending through Holocene marine sediments into LGM lacustrine layers (Figure 7). The hydrographic charts of the Farasan Islands show many similar deep depressions on the inner shelf. In addition, the presence of valleys and canyons indicates that surface water run-off eroded the shelf under subaerial conditions (Figure 8). Finally, the seismic stratigraphy below the shelf, with horizontal or gently dipping sedimentary layers, is likely to have favoured the development of groundwater aquifers and the occurrence of springs along the edges of the valleys when subaerially exposed (Faure et al., 2002).

Geochemical, micropalaeontological and radiometric analyses of these sediment-filled basins are ongoing, but the details revealed so far indicate a subaerial landscape and palaeoenvironment that would have been attractive to vegetation, large mammals and their human hunters. This is of especial significance, given that the hinterland of the Arabian Peninsula suffered conditions of extreme aridity during the LGM, although it periodically benefited from 'green' episodes at other periods of the glacial-interglacial cycle (Jennings et al., 2015).

3.3. The Cape Coast of South Africa

The Cape Floristic Region (CFR) lies within and around the Cape Fold Belt mountains (Figure 9A). Although it is a relatively small region on a global scale, it contains a highly diverse and unique flora, and concentrated along its current coastline are a large sample of caves and rockshelters that contain some of the oldest archives of early modern human biology, behaviour, and culture extending back to 167 ka (Marean et al., 2014; Wadley, 2015). These sites contain some of the earliest remains of anatomically modern *Homo sapiens* and evidence of modern cognition including art. Of particular interest is that these sites are bounded by an extremely wide continental shelf, and hiatuses in their archaeological sequences coincide with periods of low sea level, suggesting that early humans relied on coastal resources and followed the shifting coastline as sea level changed.

In the past decade a multi-disciplinary team has undertaken an integrated 'Palaeoscape Project' to describe the submerged landscape and broader ecosystem of this

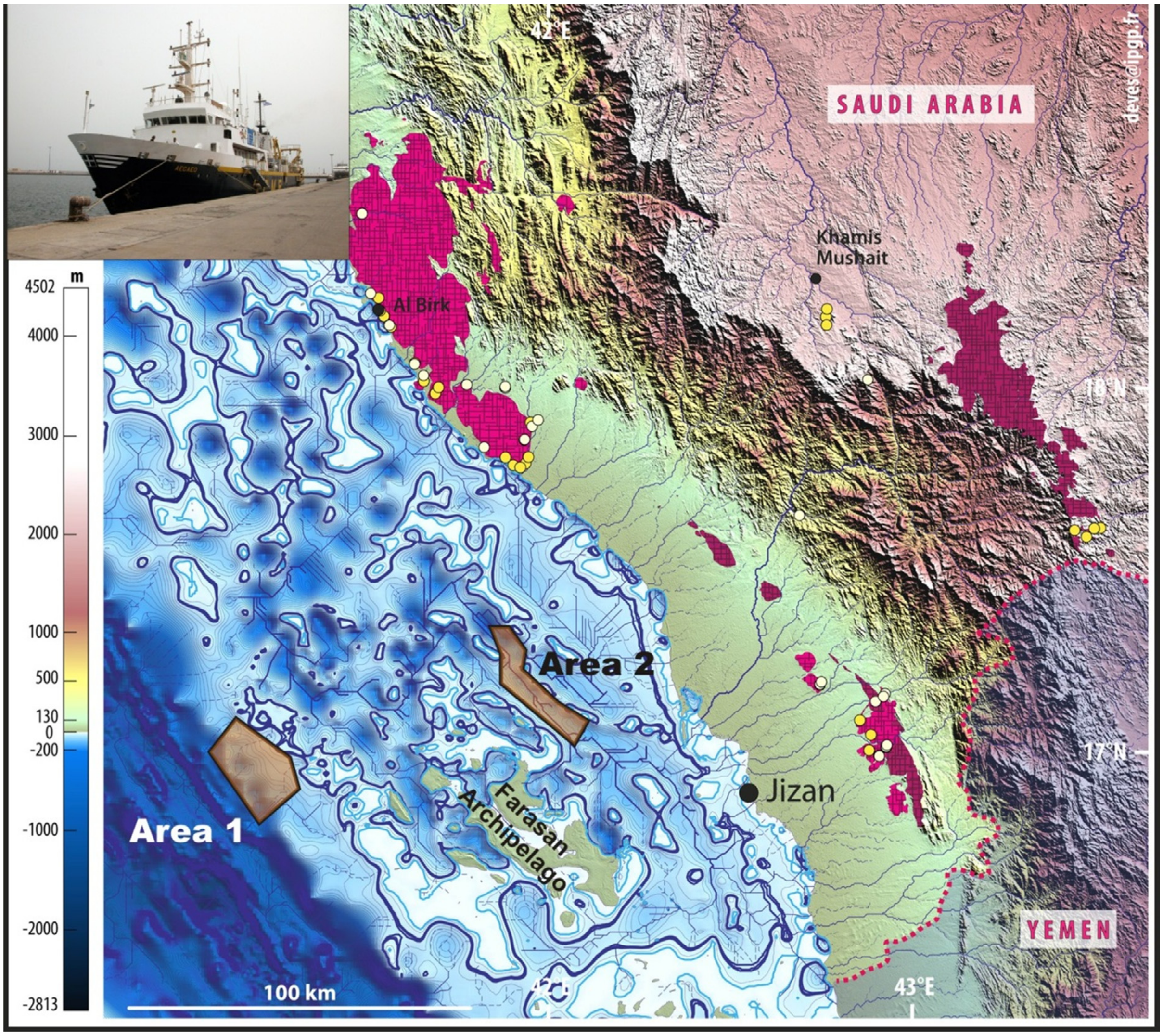

Figure 5 Location map showing the survey region of the Red Sea. Terrestrial elevation data are taken from the CGIAR-CSI SRTM 90 m v4.1 database and ASTER-GDEMv2, the bathymetry from GEBCO_08 30 arc-second grid. ASTER-GDEM is a product of METI and NASA. The light blue area offshore shows the area exposed at sea levels of −120 m, and the dark blue line encloses areas of land at −20 m. Area 1 and Area 2 are the areas surveyed in detail by R/V AEGAEO (shown in the top left inset berthed in the port of Jizan). The dark blue circles are solution hollows in the seabed resulting from salt tectonics. The purple colour refers to volcanic outcrops on the mainland, the yellow circles to Palaeolithic sites. The map was produced by Maud Devès (IPGP) with additional information supplied by Dimitris Sakellariou (HCMR) and is reproduced here courtesy of the DISPERSE Project. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

region, following several years of archaeological excavation at Pinnacle Point led by Curtis Marean (e.g., Marean et al., 2007). This research has shown that the offshore region, known as the Agulhas Bank, when exposed as a subaerial landscape during glacial periods, represented an almost extinct terrestrial ecosystem, with a maximum extent of 80,000 km^2, equivalent to the land mass of modern Ireland, with only one small onshore analogue of 70 km^2 at the present day. This submerged region, currently referred to as the Palaeo-Agulhas Plain (Marean et al., 2014), not only added a sizeable increment of new land but also hosted an extensive ecosystem that largely disappeared during periods of high sea level or was reduced to tiny fragments along the steep coastline that characterises the topography at high sea level stands, as today.

During full glacials when the continental shelf was completely exposed, the Palaeo-Agulhas Plain was likely a refuge for hominin and ungulate populations (Compton, 2011; Marean et al., 2014). In addition to the fossil records in the faunal assemblages of the archaeological sites, fossil trackways of large mammals and hominins preserved in aeolianite and cemented beaches on the modern coast are testament to the extant and extinct Pleistocene occupants of this environment (Helm et al., 2018, 2020; Roberts et al., 2008).

South Africa is also an ideal region to examine Pleistocene sedimentary facies in light of sea-level changes

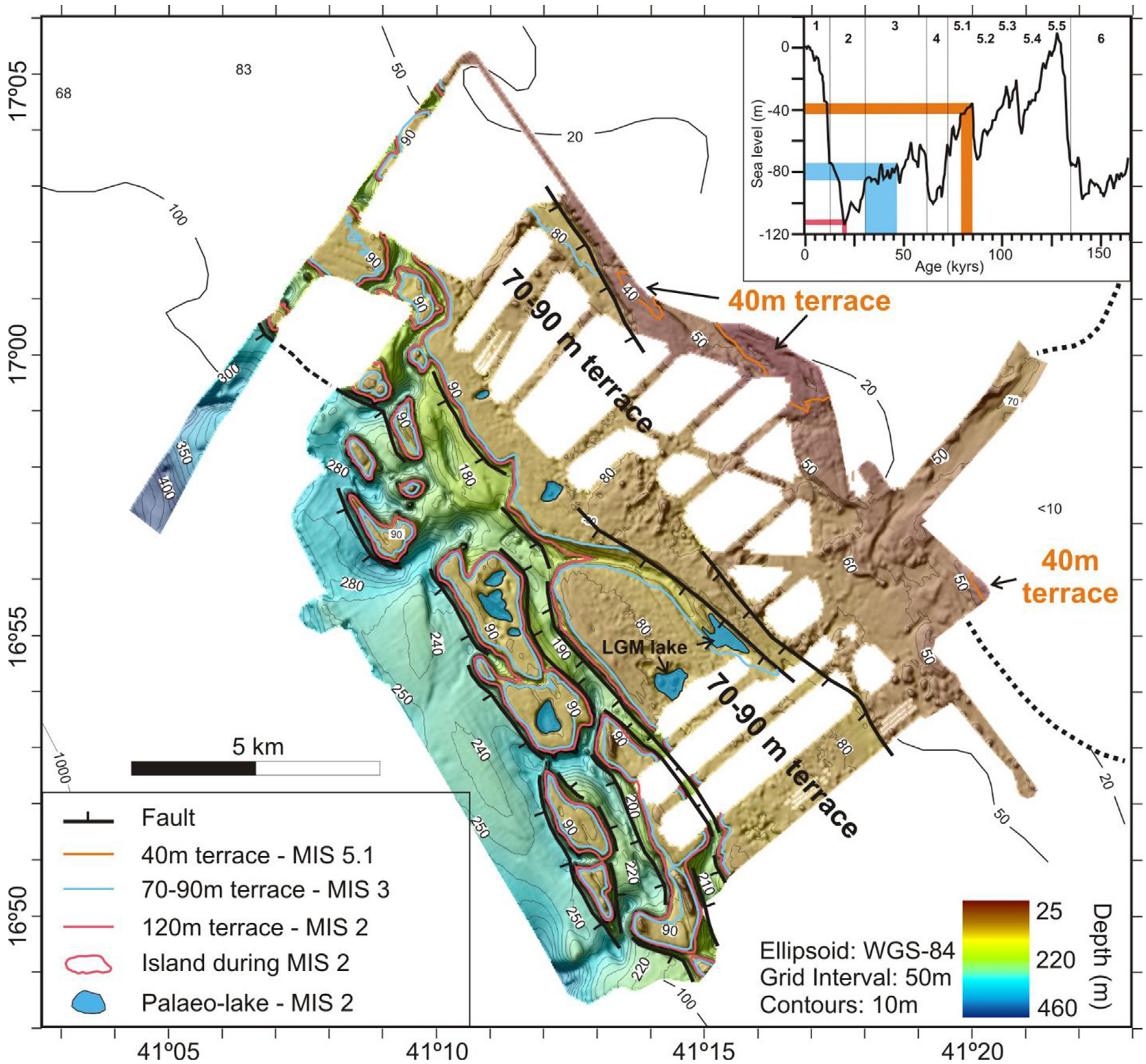

Figure 6 Bathymetry and tectonic and geomorphological features in Area 1 on the outer continental shelf offshore of the Farasan archipelago (see Figure 5 for general location), with interpretation of features. Data are derived from multibeam bathymetry of the area shown in colour, seismic and pinger profiles, sidescan sonar, sediment coring and ROV dives detailed in Sakellariou et al. 2019. The background contours are depths in metres from the International Chart Series, UK Hydrographic Office Sheet 157. Inset shows correlation of underwater terraces with the sea-level curve of the Red Sea. Image produced by Dimitris Sakellariou. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

because it is a 'far-field' location in relation to melting ice (Murray-Wallace and Woodroffe, 2014). These far-field coastlines have preserved Quaternary deposits, well-documented onshore Pleistocene sequences (e.g., Roberts et al., 2012), substrates that are considered relatively stable tectonically and sediments that can be dated with luminescence dating techniques. There is a geological preservation bias towards the Pleistocene cemented sequences rather than younger Holocene rocks in this area and this has allowed a unique view into Pleistocene palaeoenvironments.

Scientists have known for half a century that a submerged landscape, most widely expressed on the central southern shores of the CFR, existed underwater (Dingle and Rogers, 1972; Van Andel, 1989) but the significance of this has only come to the fore relatively recently. Following largely on the observations of Van Andel, research based at Pinnacle Point built a GIS computer model of the Cape South Coast offshore landscape that combined topography and sea-level curves to track coastline distances associated with base-level changes (Fisher et al., 2010). This model provides coastline distance estimates across the Palaeo-Agulhas Plain at 1500-year time steps from ~420 ka to the present. Based largely on these emerging results, combined with theoretical grassland ecosystem ecology, Marean (2010) proposed that the Palaeo-Agulhas Plain, overlooked by the major modern human-origins cave sites along the coast, would have been highly significant in

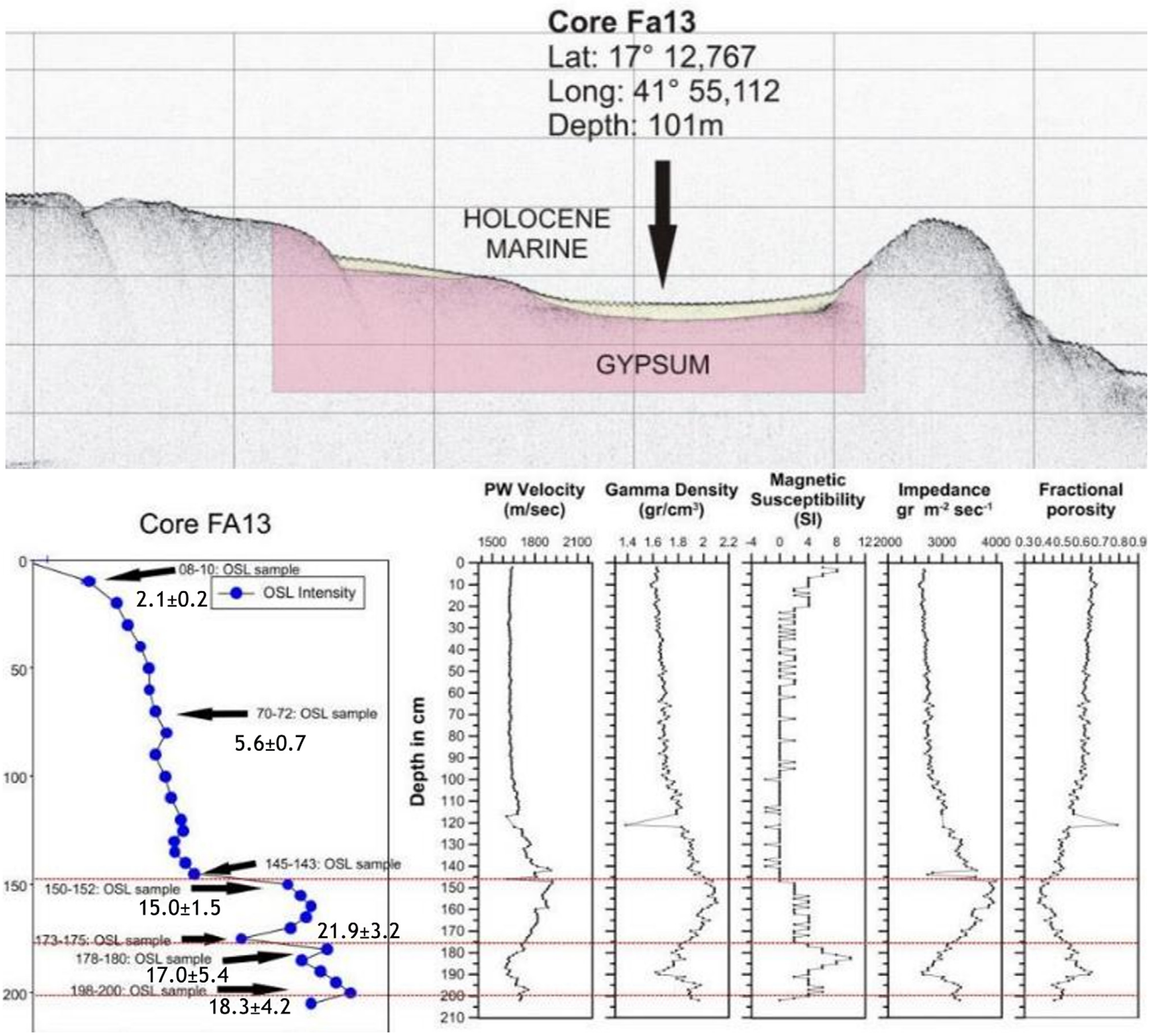

Figure 7 Profile of sediments from core FA13 in the shallow valley of Area 2 of the Farasan survey. Upper image shows the seismic reflection profile across the valley, lower left image shows OSL profile and ages (in thousands of years), and lower right image shows variations in physical properties of the core sediments. For location of core see Figure 7. For details of OSL measurements, see Sanderson and Kinnaird 2019. Images courtesy of Dimitris Sakellariou and David Sanderson. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

the development of the hunter-gatherer foraging system. Compton (2011), drawing on the earlier geological mapping of Dingle and Rogers (1972), further argued that Pleistocene hominins on the Palaeo-Agulhas Plain would have been isolated during glacial phases and thus subject to allopatric evolution, and then subjected to intense evolutionary pressure during periods of rising sea level. Marine geophysics and geological investigations followed from 2011 onwards to map and sample this shelf. In this review we focus mostly on these palaeolandscape elements of the broader project.

Marine geoscience investigations (Figure 9B) had the following specific aims: (1) to map and sample the seafloor to determine the structural-geological framework and quantify evidence of Pleistocene sea levels; (2) to reconstruct the situation at the time of the LGM by 'removing' the modern sediment wedge and applying geological modelling to interpolate between areas not mapped or sampled in high resolution (Figure 9C); (3) to use the geology and an integrated climate model to infer soil distributions from which to propose contemporaneous vegetation (Figure 9D); and (4) to construct a 'resource-scape' of available food and raw materials for hunter gatherers. The data collected intermittently over a period of five years included: multibeam bathymetry, side-scan sonar and shallow seismics (boomer and pinger sub-bottom profiling) in Mossel Bay and Vlees Bay (8–60 m below MSL) (Cawthra et al. 2016); a regional pinger sub-bottom profiling survey from Knysna

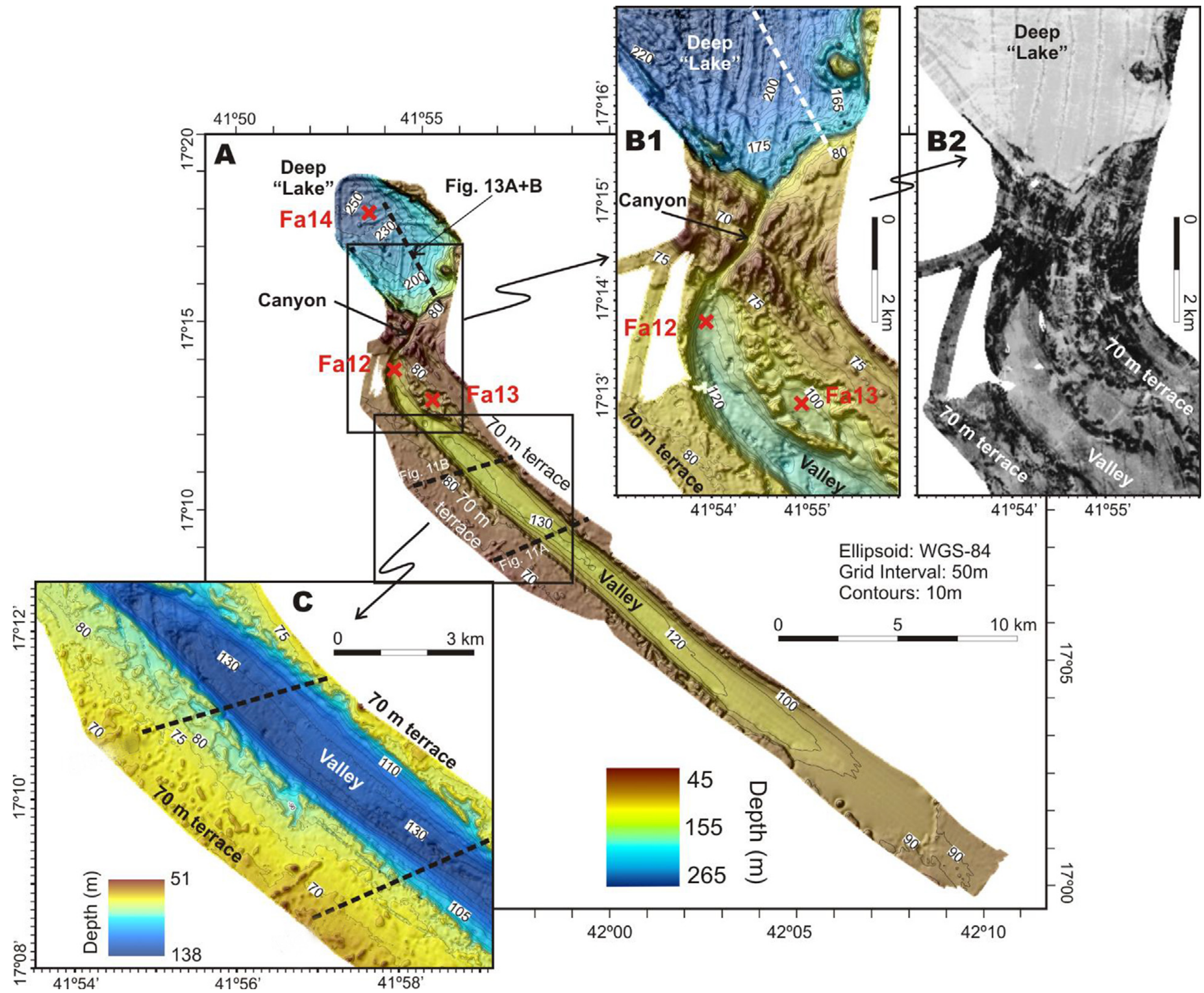

Figure 8 Bathymetry and geomorphological features in Area 2 on the inner continental shelf offshore of the Farasan archipelago (see Figure 5 for general location). Interpretation of features is based on multibeam bathymetry, seismic and pinger profiles, sidescan sonar, sediment coring and ROV dives detailed in Sakellariou et al. 2019. (a) General view; (b1) Detail showing a narrow gorge connecting the deep depression to the north with a shallower valley to the south; (b2) Backscatter image of area in b2 showing variability in seafloor reflectivity; (c) Detail showing bathymetry in valley flanked by the 70 m terrace. Image courtesy of Dimitris Sakellariou. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

to Still Bay (Cawthra et al., 2020a); 41 scuba dives from 9—43 m to sample Pleistocene rocks from palaeocoastlines; 120 sediment grab samples across the shelf from modern and relict units (Cawthra et al., 2018) and 6 vibracores and parasound profiles collected on the vessel Meteor as part of the RAiN project (Hahn et al., 2017; Zabel et al., 2017).

In parallel with new data collection, legacy datasets (Birch 1980; Dingle and Siesser 1975; Gentle 1987; Martin and Flemming 1986) were digitised in order to grid Pleistocene surfaces using statistical Kriging and produce a geological map of the LGM land surface.

Remnant elements of a submerged landscape that were mapped, described, and dated using Optically Stimulated Luminescence (OSL), include submerged cliffs and caves (Figure 10A), beach and dune ridges, palaeo-lagoons and wide, shallow incised river channels with sizeable floodplains (Cawthra et al., 2018; 2020b). A key finding from geology was mapping evidence of Meltwater Pulse (MWP) 2B (Figure 10B), which occurred on Termination II from MIS 6 to MIS 5e (133±1 ka; Grant et al. 2012), when global sea levels rose as much as 70 m over ~2000 years, with a sea-level rise reaching rates of 28±8 m per thousand years (Grant et al. 2012). On the Palaeo-Agulhas Plain, we noted that with the subdued morphology and broad shelf, people were already making use of this area since at least 167 ka (Marean et al., 2007) and almost certainly would have witnessed loss of landscape and habitat within a human lifetime. On this part of the shelf where MWP 2B deposits were sampled and dated, a 0.4—0.7 m rise in sea level over 20 years translates to 0.8—1.5 km of landward shift of the coastline in the spatial dimension. Beach morphodynamics and coastline change through changing sea-level regimes were analysed and proposed changes in the proportion of rocky vs sandy beaches were compared to records of mollusc shells and their habitat preferences in the coastal caves (Cawthra et al. 2020c). Tendencies toward dissipa-

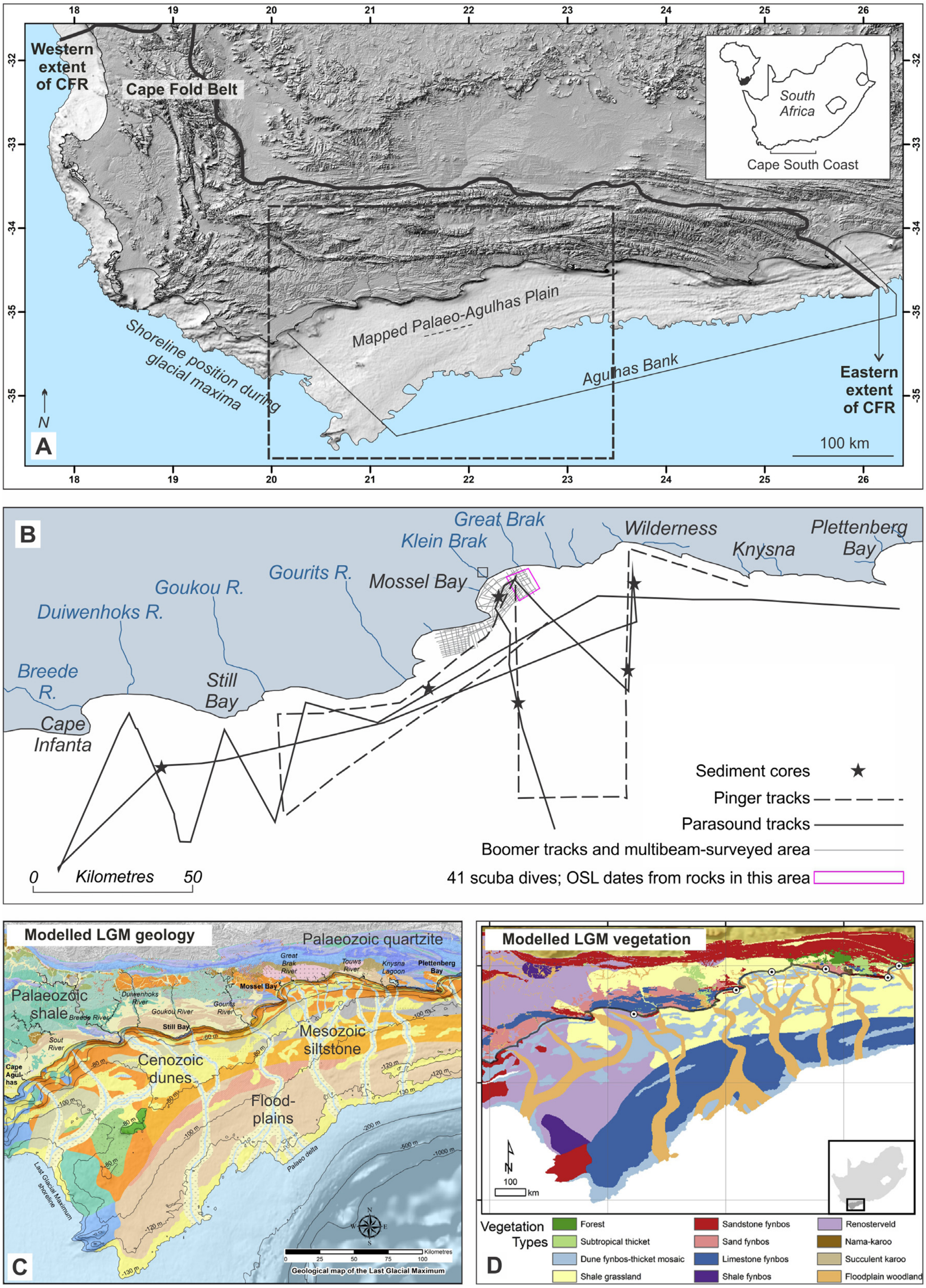

Figure 9 Mapping of the continental shelf on the Cape South Coast: (A) Locality of the geophysical profiles in relation to the Cape South Coast with terrestrial background data from the SRTM 90 m grid (Jarvis et al., 2008) and continental shelf bathymetry from de Wet (2013); (B) Positions of sub-bottom profiles, areas mapped in high resolution, core sites and sampled areas of the Palaeo-Agulhas Plain; (C) Geological map of the LGM (from Cawthra et al., 2020b); (D) Vegetation map of the LGM (from Cowling et al., 2020). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

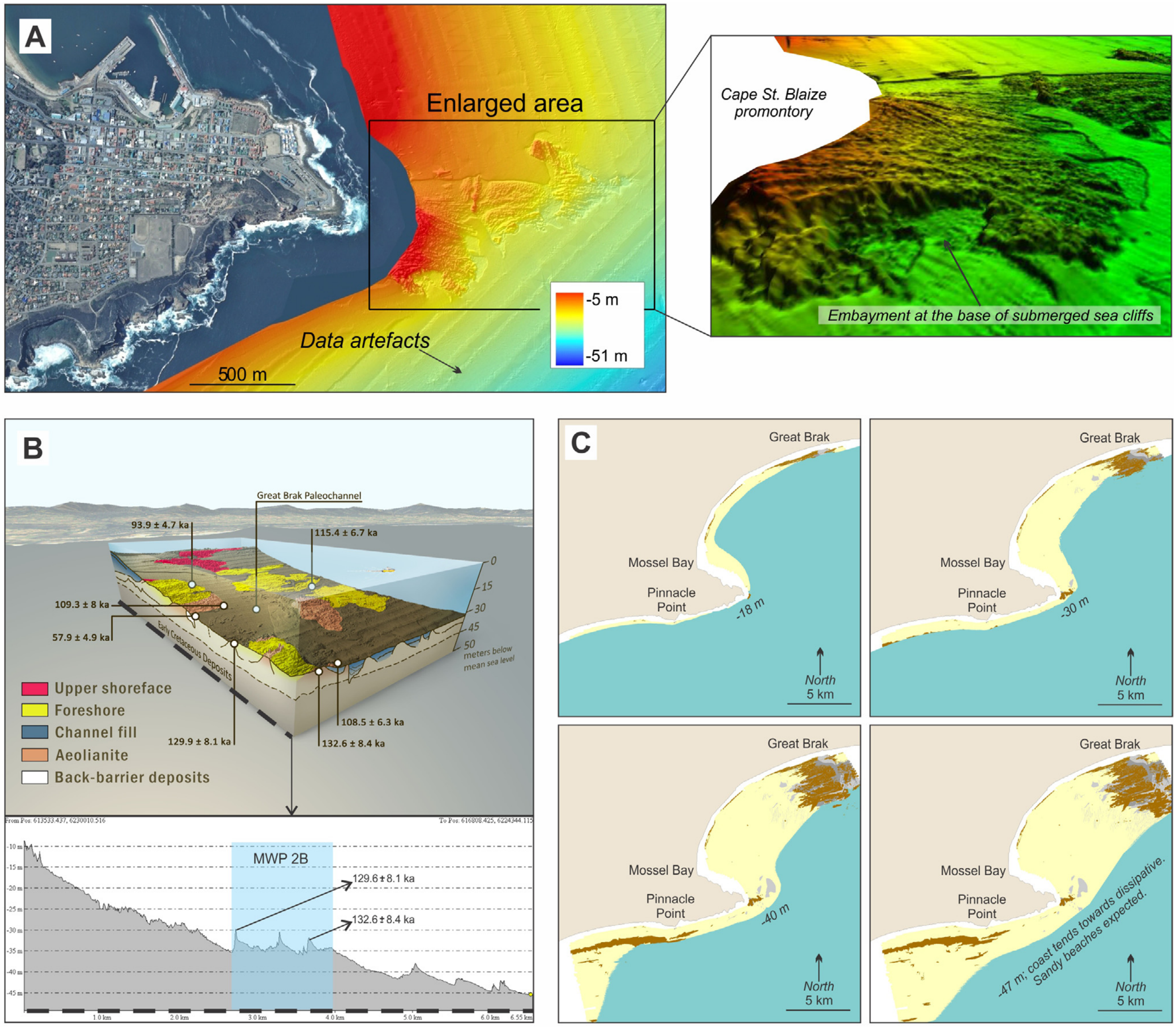

Figure 10 Details of submerged landscape features in the vicinity of Mossel Bay and Pinnacle Point: (A) Submerged sea cliffs offshore of Cape St Blaize, 6 km east of Pinnacle Point (from Cawthra et al., 2016); (B) Upper: Multibeam echosounder and boomer sub-bottom data superimposed to create a cross section of the seafloor of Mossel Bay, showing Optically Stimulated Luminescence dates on scuba-dived Pleistocene rocks representing palaeocoastlines at 9—43 m below sea level; Lower: Bathymetric cross section of the seafloor at this site showing samples dated to the time of MWP 2B (from Cawthra et al., 2018); (C) Beach morphodynamics of the Mossel Bay continental shelf indicated, with a tendency towards sandy dissipative beaches at times of sea-level lowstand (from Cawthra et al., 2020c). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

tive, sandy beaches were noted when the coast was ~50 m lower than at present (Figure 10C).

The Palaeo-Agulhas Plain differed markedly from the contemporary coastal foreland. It was flat, had large meandering rivers and abundant fresh water, was more fertile than the interior of the CFR and had expansive grasslands. The Cape South Coast Palaeoscape Project has now generated a nearly fully coupled abiotic-biotic-human behaviour computer model. Marean et al. (2015) have laid out a research strategy where palaeoscientists can develop linked computer simulation models, constantly under improvement, that would begin with models of land, sea, geology, soil, and climate and ultimately integrate human activities and patterns of resource exploitation. The majority of the abiotic characteristics come from field and laboratory study starting with geology and marine geophysics (described above), and climate was projected onto these reconstructions using climate modelling validated using palaeoarchive data (Engelbrecht et al., 2019). Vegetation modelling was then undertaken (Cowling et al., 2020) to map the flora across this modelled palaeolandscape, and again those projections were validated with palaeoarchive data. Since this study has a strong palaeoanthropological objective, reconstructing various aspects of a resource scape for humans was attempted. An overview of this work is presented in Cleghorn et al. (2020) and Marean et al. (2020).

4. Human responses to sea-level change

Archaeological evidence for the human impact of sea-level rise in the late Pleistocene and early Holocene is at present very limited because we do not yet have enough underwater archaeological sites to track the ways in which early societies responded to sea level rise. However, the case studies described above already provide some insights into the likely human consequences and pressures of sea-level changes. Generalising from these examples, it is possible to identify three types of response. One response to the loss of land and resources by marine transgression is to intensify the exploitation of other resources, for example by devoting more effort to terrestrial hunting, fishing and shellgathering, or the adoption of plant cultivation in place of simple gathering of plant foods. The huge expansion in the numbers of shell middens and other coastal sites from about 7000–6000 years ago onwards has sometimes been interpreted as evidence of intensification in this way. However, it is equally likely that this pattern reflects the differential survival and visibility of coastal sites on the modern coastline as compared to earlier palaeocoastlines that are now submerged. Finding evidence to choose between these alternatives is challenging because it has generally been assumed that coastal settlements on palaeocoastlines formed at lower sea levels, and especially shell middens, would have been washed away. However, recent research in Denmark and North America has shown that shell middens can survive inundation, at least partially intact, and can be identified under water by a combination of acoustic surveying, sediment coring, and geochemical and soil-micromorphological analysis (Astrup et al., 2021; Cook Hale et al., 2021). There are also sufficient indications from underwater remains of early Holocene fish weirs in Sweden and Denmark (Bailey et al., 2020b, Nilsson et al., 2020) and evidence of marine shells carried inland to demonstrate exploitation of marine food-resources along now-submerged shorelines, and therefore to cast doubt on the idea that people ignored coastal and marine resources until forced to change because of loss of land by sea-level rise.

A second possibility is that people simply moved their settlements further inland in an orderly retreat without any disruptive impacts on the wider society and economy. The best example of this comes from underwater investigations on the Baltic coastline of northern Germany, where sufficient underwater excavations have been conducted to show a progressive move from earlier, Mesolithic, sites at greater depths to later Mesolithic and early Neolithic sites in shallower water (Harff and Lüth, 2007, 2011; Jöns et al., 2020). The extent to which such moves had disruptive effects on the communities forced to move, or on pre-existing patterns of settlement and economy further inland, would clearly depend on the rate at which land was lost by marine inundation. As the Cape example described above shows, the rate at which land was lost in a landscape of shallow topography especially during episodes of rapid sea-level rise, might be sufficient to have a disruptive impact within a human lifetime.

The third possible response to sea-level rise is to stay in place and build defences against the rising waters. Before the era of permanent settlements on the coast, and most likely for most settlements before the modern era, the possibilities for building work to protect coastal settlements from sea-level rise were probably quite limited. However, an interesting early example comes from the construction of a seawall at the ~7000-year-old submerged early Neolithic village of Tel Hreiz in Israel (Galili et al., 2019). The site is a good example of the type of underwater evidence discussed above from the Israeli coastline. The evidence comprises a linear feature of boulders ~100 m long, built in parallel to the shoreline, and located to seaward of the village settlement. Dating evidence shows contemporaneity between the wall and the settlement (Figure 11). The settlement was occupied during a period of rising sea-level. Eventually, continued sea-level rise over-topped the seawall and forced the abandonment of the settlement.

Large mounded shell middens are often associated with hunter-gatherer settlements in coastal regions. Some of the largest and tallest reach heights of 10 m or more and occur in coastal areas liable to seasonal or permanent flooding, for example in the coastal mangrove regions of northern Australia and southern Brazil, and have been interpreted as attempts to create a dry living surface above the flood level (Bailey et al., 1994; Gaspar et al., 2011). Whether this was the intended result of shell accumulation or simply the by-product of repeated use of the same location for shellfood consumption and shell discard over a long period, with a raised living surface the unintended and beneficial longer-term consequence of such activity, is unclear. But these shell mounds are, at the very least, evidence of the ways in which human activities can lead to modifications of the local environment and habitat. Evidence for the deliberate construction of settlement mounds as flood defences comes from later periods, notably the Iron Age 'terpen' mounds occupied in the Netherlands and the lowlands of north-west Germany in the 1st millennium BC (Kooijmans et al., 2005; Van der Noort, 2011).

The above examples discuss response to the effects of rising sea level. However, it is worth emphasising that on the Pleistocene timescale, a fall in sea level may have been equally consequential in human terms, making available new territory and resources into which human and animal populations could expand and facilitating more widespread dispersal.

5. Discussion and future directions

The examples discussed above demonstrate that a substantial body of archaeological, palaeoenvironmental and palaeoclimatic evidence awaits recovery from the submerged landscapes of the continental shelf. Recovery of this evidence depends on a wide range of specialist expertise and specialist technologies, with many opportunities for multi-disciplinary collaboration as well as challenges, amongst which inter-institutional collaboration and collaboration with offshore industrial companies and government agencies are likely to figure prominently. These challenges involve the development of the following modelling procedures:

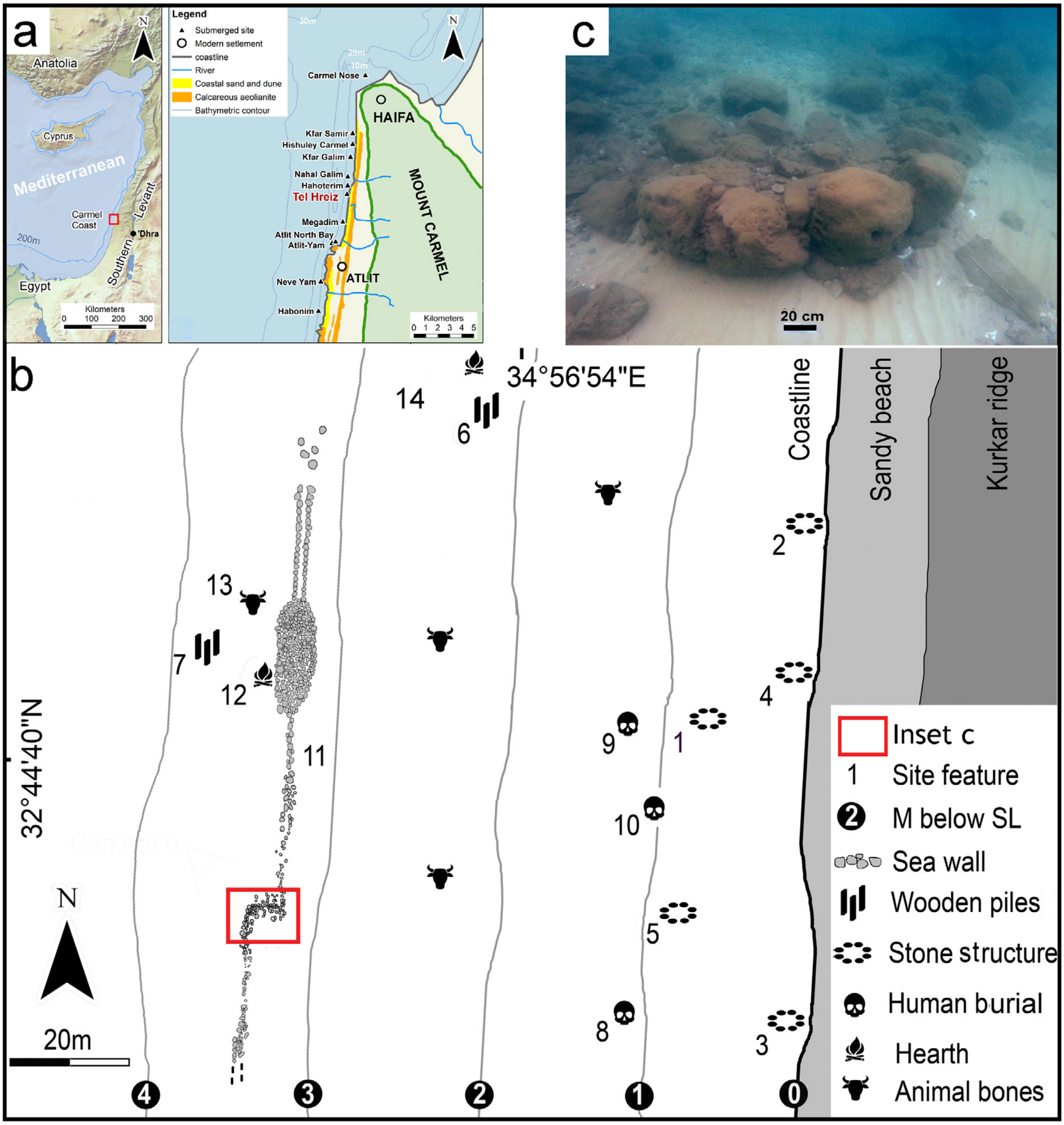

Figure 11 Images of the seawall built of stone boulders at the submerged Neolithic site of Tel Hreiz on the coast of Israel: (a) General location map; (b) plan of site showing features in relation to the modern shoreline; (c) photograph of seawall where it forms a sharp bend. The seawall is located 3–4 m below present sea level, and the area of the contemporaneous settlement lies on the shoreward side and includes remains of circular and rectangular stone structures, human burials including one in a stone-lined cist grave, concentrations of wooden piles, remains of hearths and animal bones. Modified from Galili et al. (2019). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article).

(1) Modelling, at a regional 'human' scale, of the geology, hydrology, vegetation and topography of these drowned landscapes, their spatial and geographical variation, and their variation over time with changes in sea levels and palaeoclimate. The case studies described above illustrate a variety of approaches to this type of modelling involving testing of modelled landscape features using proxy data of varying levels of detail and geochronological resolution. This type of investigation is one that collaborating specialists can most easily comprehend and participate in. But it is not without challenges, the principal challenge being the integration of geographical and chronological variation in the evolution of the submerged landscape at a scale appropriate to human land use and exploitation of resources. It is also the type of investigation that is most likely to provide new evidence that can be fed into larger-scale models of sea-level and climate change.

(2) Predictive modelling of the likely location of submerged archaeological sites in the light of results under (1) using remote sensing methods, coring of sediments, grab sampling and diver investigation. This is a major challenge because of the elusive nature of archaeological evidence and the need for high-resolution investigative techniques. However, recent projects are beginning to make significant progress in the purposeful search for archaeological remains and to create the foundation for further developments (Benjamin et al., 2020; Fitch et al., 2021; Grøn et al., 2018, 2021; Wiseman et al., 2021).
(3) Modelling of the ways in which original features of the landscape and archaeological sites and materials might have been variously transformed, destroyed or obscured by marine processes of erosion or sedimentation associated with marine transgression. We might call this an exercise in 'landscape taphonomy'. It is an integral step in the modelling of palaeolandscapes and resources as in step (1) above (e.g., Cawthra et al., 2020a, 2020b). It is also a critical step in the discovery of archaeological sites, since not all predicted locations of archaeological material will have an equal likelihood of preservation, visibility, and discovery. It is difficult to specify general principles of differential survival and visibility because so much depends on local conditions of coastal geomorphology, sedimentation and oceanography. Progress here is likely to depend as much on field investigations and the development of a body of case studies that exemplify different conditions of preservation as on the elaboration of top-down theoretical principles.
(4) Modelling of human demographic, cultural and technological responses to changes in the geographical extent and rate of change of territory and resources available for human exploitation and settlement with changing sea levels and palaeoclimate. This is the ultimate goal of geoarchaeological investigation of submerged landscapes and also the most challenging, because it depends on input from all the other modelling procedures.

6. Conclusions

In summarising the wider significance of the research discussed above, we first emphasise the fact that for most of the Quaternary, and especially for the Middle—Upper Pleistocene and early Holocene, sea levels have been lower than present. The seafloor of the continental shelf therefore provides a rich archive for investigating Quaternary processes and resulting landscape change. It also represents a former land surface that was of great human significance, harbouring much of the evidence for major developments in the earlier periods of human history. These submerged landscapes therefore represent a common arena of great interest and importance in the investigation of a wide range of natural and cultural processes.

This combination of natural and cultural evidence, in its turn, highlights the importance of collaboration between scientific disciplines including archaeology and palaeoanthropology. The examples described above illustrate the ways in which a variety of geoscientific, palaeoenvironmental and archaeological investigations have been integrated, and the range of disciplines involved extends more widely to include additional expertise, for example in climate science, oceanography and phylogenetics. Inter-disciplinary collaboration thus poses attractive opportunities for broadening our understanding of earth history and humanity's place within that broader history.

However, interdisciplinarity also poses enormous challenges. These include the development and refinement of geophysical and digital technologies suitable for underwater investigations with new questions in mind, the formulation of research strategies for locating deeply submerged and potentially elusive data, especially where the recovery of archaeological remains is concerned, and above all the necessity to build bridges between different disciplines and develop new ways of thinking at the intersecting boundaries between different scientific perspectives.

The challenges of interdisciplinarity should not be minimised. It is a common feature of so-called interdisciplinary or multi-disciplinary investigations that the proponents of the various participating disciplines tend to work within the 'comfort zone' of their own discipline with its established conventions, assumptions and methods, and to prefer results obtained in that way. However, the boundary zone between disciplines is often one of contradictory data and conflicting ideas. Integration, if it is to be successful, requires flexibility, bridge-building between disciplines, mutual adaptation to new ways of thinking and working, and sometimes the abandonment of cherished assumptions that have remained unquestioned or even unrecognised until exposed to the challenge of unfamiliar scientific and intellectual ideas and data.

Finally, we emphasise the importance of a long-term perspective in both the natural and the cultural domain. Geologists and climatologists have long recognised that present-day trends cannot be properly understood or placed in a wider context without such a perspective and that time-series data from deep time are essential in making predictions about future trajectories. Similarly, ecological studies concerned with issues of overexploitation, extinction, biodiversity and conservation increasingly recognise the need for historical and pre-historical data to evaluate the natural baseline against which to judge contemporary human impacts and management policies (Jackson, 2001; Svenning and Faurby, 2017).

Similar thinking applies in the human domain. An archaeological perspective demonstrates that sea-level change and coastline modifications have been a continuous accompaniment to human life and activity on all time scales from the daily to the millennial throughout human history. They have been intimately interwoven with long-term social and evolutionary trajectories, causing a variety of human impacts and evoking a variety of human responses, some of which, in their turn, have impacted the behaviour of natural systems (Erlandson and Rick, 2008). The threat of rising sea level currently facing humanity over the next century, and the current estimate of rates of sea-level rise, are nothing new, and past societies have met similar challenges in various ways, some of which we have illustrated in our examples described above.

Such an archaeological perspective may not provide a basis for predicting future social change or a recipe for mitigating action, but it can certainly better prepare us for an uncertain future, provide a humanistic perspective on the way we think about the current human condition, and facilitate effective decision making about how best to manage coastal zones that are sensitive to imminent sea-level rise. Incorporated within these concerns are the threats to the underwater cultural heritage of ancient populations that once inhabited the continental shelf and to the cultural heritage on present day coastlines that are vulnerable to loss or damage from future sea-level rise. These threats come from many different directions and include the effects of human population growth, climate change and intensifying commercial and industrial activity in coastal zones.

Central to the successful development of new ways of thinking in the face of the challenges described above is the creation of international networks to facilitate communication across existing boundaries — between scientific disciplines, between the world of scientific research and academia and the world of policy makers and government agencies, many of whom are looking to develop sustainable 'blue economies' that improve employment prospects and living conditions in the coastal zone, and between the worlds of science and government and the world of commercial and industrial organisations.

International networks established to investigate submerged landscapes and encourage collaboration across national, institutional and disciplinary boundaries started with the SPLASHCOS network — Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf, funded by an EU COST Action (2009—2013; Bailey et al., 2020a; Flemming et al., 2017). Dialogue on these topics continues through the SPLOSH network (Submerged Palaeolandscapes of the Southern Hemisphere), focused on the Southern Hemisphere and indigenous knowledge (INQUA funded, duration 2020—2023), the Neptune network that considers technologies applied to mapping and sampling submerged landscapes (INQUA funded, duration 2020—2023) and the newly established Marginal Seas network.

Other initiatives developed in recent decades reflect a growing realisation that the ocean environment represents a last frontier, and a growing recognition of the importance of mapping the world's ocean floors. These include the specification of regulatory frameworks for conservation of both the natural and the cultural underwater heritage through treaties such as the 1982 United Nations Convention on the Law of the Sea; the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage, EU Directives requiring Environmental Impact Assessments in advance of offshore industrial development and the work of national and international agencies such as EMODnet in Europe and BOEM and NOAA in the United States (Dromgoole 2020; Pater 2020; Salter et al. 2014). Some of these are global in their scope and participation, including the recently established United Nations Decade of Ocean Science for Sustainable Development, and SEABED 2030, concerned with mapping the ocean floor.

Increasingly, these various initiatives are recognising areas of common or overlapping interest and helping to develop a global response to scientific and social challenges that are global in scope. Geoarchaeological investigations of the continental shelf have a central role to play in meeting these challenges.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The research for the case studies summarised here was supported by the following grants: for the North Sea, the UK Aggregates Levy Sustainability Fund; and the European Research Council, grant number ERC Advanced Grant 670518; for the Red Sea, the European Research Council, grant number ERC Advanced Grant 269586. For the Cape coast, the offshore marine geophysical surveys were funded by the National Geographic Society (#EC0482-10) and the Council for Geoscience (Statutory project ST-2011-1139) as part of a larger ongoing project, SACP4, which is funded by the National Science Foundation grants BCS0130713, BCS-0524087, BCS-1138073, the Hyde Family Foundations and the Institute of Human Origins at Arizona State University. We thank Jan Harff for the invitation to participate in the 'Marginal Seas — Past and Future' online conference in December 2020 and for his encouragement to prepare our conference presentation for publication. We thank Ehud Galili, Vince Gaffney, Dimitris Sakellariou, David Sanderson and Wessex Archaeology for permission to use their illustrations. This is DISPERSE contribution no. 64.

References

Andersen, S.H., 1985. Tybrind Vig. A preliminary report on a submerged Ertebølle settlement on the west coast of Fyn. Dan. J. Archaeol. 4, 52—69. https://doi.org/10.1080/0108464X.1985.10589935.

Andersen S.H., 2013. Tybrind Vig. Submerged Mesolithic settlements in Denmark. Jutland Archaeological Society Publ. Vol. 77. Jutland Archaeological Society, Højbjerg.

Angelova H., Draganov V., 2003. Underwater archaeological excavations of submerged Late Eneolithic and Early Bronze Age settlements in Kiten and Sozopol. South Bulgarian Black Sea coast). In: Angelova H. (ed.) In Honorem Mihaili Lazarov. Thracia Pontica 6(2), 9—22

Astrup, P.M., Benjamin, J., Stankiewicz, F., Woo, K., McCarthy, J., Wiseman, C., Baggaley, P., Jerbić, K., Fowler, M., Skriver, C., Bailey, G., 2021. A drowned Mesolithic shell-midden complex at Hjarnø Vesterhoved, Denmark and its wider significance. Quat. Sci. Rev. 258, 15106854. https://doi.org/10.1016/j.quascirev.2021.106854.

Bailey, G.N., Chappell, J., Cribb, R., 1994. The origin of *Anadara* shell mounds at Weipa, North Queensland. Australia. Archaeol. Oceania 29, 69—80. https://doi.org/10.1002/arco.1994.29.2.69.

Bailey, G.N., AlSharekh, A., Flemming, N., Lambeck, K., Momber, G., Sinclair, A., Vita-Finzi, C., 2007a. Coastal prehistory in the southern Red Sea Basin: Underwater archaeology and the Farasan Islands. Proc. Sem. Arab. Stud. 37, 1—16. http://www.jstor.org/stable/41224054.

Bailey, G.N., Flemming, N., King, GCP, Lambeck, K., Momber, G., Moran, L., Al-Sharekh, A., Vita-Finzi, C., 2007b. Coastlines, submerged landscapes and human evolution: The Red Sea Basin and the Farasan Islands. J. Island Coast. Archaeol. 2 (2), 127–160. https://doi.org/10.1080/15564890701623449.

Bailey, G.N., Devès, M.H., Inglis, R.H., Meredith-Williams, M.G., Momber, G., Sakellariou, D., Sinclair, A.G.M., Rousakis, G., Al Ghamdi, S., Alsharekh, A.M., 2015. Blue Arabia: Palaeolithic and underwater survey in SW Saudi Arabia and the role of coasts in Pleistocene dispersal. Quat. Int. 382, 42–57. https://doi.org/10.1016/j.quaint.2015.01.002.

Bailey, G.N., Harff, J., Sakellariou, D. (Eds.), 2017a. Under the sea: Archaeology and palaeolandscapes of the continental shelf. Springer, Cham https://doi.org/10.1007/978-3-319-53160-1.

Bailey, G., Sakellariou, D., Alsharekh, A., Al Nomani, S., Georgiou, P., Kallergis, M., Kalogirou, S., Manousakis, L., Mantopoulos, P., Meredith-Williams, M., Momber, G., Morfis, I., Pampidis, I., Panagiotopoulos, I., Renieris, P., Rousakis, G., Stasinos, V., Stavrakakis, S., 2017b. Africa-Arabia connections and geoarchaeological exploration in the southern Red Sea: Preliminary results and wider significance. In: Bailey, G.N., Harff, J., Sakellariou, D. (Eds.), Under the sea: Archaeology and palaeolandscapes of the continental shelf. Springer, Cham, 361–373. https://doi.org/10.1007/978-3-319-53160-1_23.

Bailey, G.N., Meredith-Williams, M., Alsharekh, A., Hausmann, N., 2019. The Archaeology of Pleistocene coastal environments and human dispersal in the Red Sea: Insights from the Farasan Islands. In: Rasul, N.M.A., Stewart, I.C.F. (Eds.), Geological setting, palaeoenvironment and archaeology of the Red Sea. Springer, Cham, 587–608. https://doi.org/10.1007/978-3-319-99408-6_26.

Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), 2020a. The archaeology of Europe's drowned landscapes. Springer, Cham https://doi.org/10.1007/978-3-030-37367-2.

Bailey, G., Andersen, S.H., Maarleveld, T.J., 2020b. Denmark: Mesolithic landscapes submerged. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 39–76. https://doi.org/10.1007/978-3-030-37367-2_3.

Bailey, G., Momber, G., Bell, M., Tizzard, L., Hardy, K., Bicket, A., Tidbury, L., Benjamin, J., Hale, A., 2020c. Great Britain: The intertidal and underwater archaeology of Britain's submerged landscapes. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 189–219. https://doi.org/10.1007/978-3-030-37367-2_10.

Benjamin J., Bonsall C., Pickard C., Fischer A. (eds.), 2011. Submerged prehistory. Oxbow, Oxford.

Benjamin, J., Rovere, A., Fontana, A., Furlani, S., Vacchi, M., Inglis, R.H., Galili, E., Antonioli, F., Sivan, D., Miko, S, Mourtzas, N, Felia, I, Meredith-Williams, M, Goodman-Tchernov, B., Kolaiti, E., Anzidei, M., Gehrels, R., 2017. Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean Basin: An interdisciplinary review. Quat. Int. 449. https://doi.org/10.1016/j.quaint.2017.06.025, 29–5https://doi.org/.

Benjamin, J., O'Leary, M., McDonald, J., Wiseman, C., McCarthy, J., Beckett, E., Stankiewicz, F., Leach, J., Hacker, J., Baggaley, P., Jerbić, K., Fowler, M., Morrison, P., Jeffries, P., Ulm, S., Bailey, G, 2020. Aboriginal artefacts on the continental shelf reveal ancient drowned cultural landscapes in northwest Australia. PLoS ONE 15 (7), e0233912. https://doi.org/10.1371/journal.pone.0233912.

Birch, G.F., 1980. Nearshore Quaternary sedimentation off the south coast of South Africa (Cape Town to Port Elizabeth). Government Printer 1 pp Source: Department of Mineral and Energy Affairs (South Africa). Geol. Survey Bull. 67, 20.

Cawthra H.C., Compton J.S., Fisher E.C., MacHutchon M.R., Marean C.W., 2016. Submerged terrestrial landscape features off the South African south coast. In: Harff, J., Bailey G., Lüth F. (eds.), Geology and archaeology: Submerged landscapes of the continental shelf. Geol. Soc. Lond. Spec. Pub. 411, 219–233. http://dx.doi.org/ 10.1144/SP411.11

Cawthra, H.C., Jacobs, Z., Compton, J.S., Fisher, E.C., Karkanas, P, Marean, CW., 2018. Depositional and sea-level history from MIS 6 (Termination II) to MIS 3 on the southern continental shelf of South Africa. Quat. Sci. Rev. 181, 156–172. https://doi.org/10.1016/j.quascirev.2017.12.002.

Cawthra, H.C., Frenzel, P., Gander, L., Hahn, A., Compton, J.S., Zabel, M., 2020a. Seismic stratigraphy of the inner to mid Agulhas Bank, South Africa. Quat. Sci. Rev. 235, 105979. https://doi.org/10.1016/j.quascirev.2019.105979.

Cawthra, H.C., Cowling, R.M., Andò, S., Marean, C.W., 2020b. Geological and soil maps of the Palaeo-Agulhas Plain for the Last Glacial Maximum. Quat. Sci. Rev. 235, 105858. https://doi.org/10.1016/j.quascirev.2019.07.040.

Cawthra, H.C., Anderson, R.J., de Vynck, J., Fisher, E.C., Jacobs, Z., Jerardino, A., Kyriacou, K., Marean, C.W., 2020c. Migration of Pleistocene shorelines across the Palaeo-Agulhas Plain: evidence from dated sub-bottom profiles and archaeological shellfish assemblages. Quat. Sci. Rev. 235, 106107. https://doi.org/10.1016/j.quascirev.2019.106107.

Cleghorn, N., Potts, A.J., Cawthra, H.C., 2020. The Palaeo-Agulhas Plain: A lost world and extinct ecosystem. Quat. Sci. Rev. 235, 106308. https://doi.org/10.1016/j.quascirev.2020.106308.

Compton, J.S., 2011. Pleistocene sea-level fluctuations and human evolution on the southern coastal plain of South Africa. Quat. Sci. Rev. 30, 506–527. https://doi.org/10.1016/j.quascirev.2010.12.012.

Cook Hale, J., Benjamin, J., Woo, K., Astrup, P.M., McCarthy, J., Hale, N., Stankiewicz, F., Wiseman, C., Skriver, C., Garrison, E., Ulm, S., Bailey, G., 2021. Submerged landscapes, marine transgression and underwater shell middens: Comparative analysis of site formation and taphonomy in Europe and North America. Quat. Sci. Rev. 258, 106867. https://doi.org/10.1016/j.quascirev.2021.106867.

Cowling, R.M., Potts, A.J., Franklin, J., Midgley, G.F., Engelbrecht, F., Marean, C.W., 2020. Describing a drowned Pleistocene ecosystem: Last Glacial Maximum vegetation reconstruction of the Palaeo-Agulhas Plain. Quat. Sci. Rev. 235, 105866. https://doi.org/10.1016/j.quascirev.2019.105866.

Dingle, R.V., Rogers, J., 1972. Pleistocene palaeogeography of the Agulhas bank. T. Roy. Soc. S. Afr. 40, 155–165. https://doi.org/10.1080/00359197209519415.

de Wet, W., 2013. Bathymetry of the South African continental shelf. University of Cape Town Unpublished MSc thesis.

Dingle R.V., Siesser W.G., 1975. Geology of the continental margin between Walvis Bay and Ponta do Ouro. Geological Survey of south Africa Series 2 (map). Government Printer.

Dobson, J.E., 2014. Aquaterra *incognita*: Lost land beneath the sea. Geogr. Rev. 104 (2), 123–138. https://doi.org/10.1111/j.1931-0846.2014.12013.x.

Dromgoole, S., 2020. Continental shelf archaeology and international law. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 495–507. https://doi.org/10.1007/978-3-030-37367-25.

Engelbrecht, F.A., Marean, C.W., Cowling, R.M., Engelbrecht, C.J., Neumann, F.H., Scott, L., Nkoana, R., O'Neal, D., Fisher, E., Shook, E., Franklin, J., 2019. Downscaling last glacial maximum climate over southern Africa. Quat. Sci. Rev. 226, 105879. https://doi.org/10.1016/j.quascirev.2019.105879.

Erlandson, J.M., Rick, T.C., 2008. Archaeology, marine ecology, and human impacts on marine environments. In: Rick, T.C., Erlandson, J.M. (Eds.), Human impacts on ancient marine ecosystems. University of California Press, Berkeley, 1–19. https://doi.org/10.1525/9780520934290-003.

Evans A.M., Flatman J.C., Flemming N.C. (eds.), 2014. Prehistoric archaeology on the continental shelf: A global review. Springer, New York. https://doi.org/ 10.1007/978-1-4614-9635-9

Faure, H., Walter, R.C., Grant, D.R., 2002. The coastal oasis: Ice age springs on emerged continental shelves. Global Planet. Change 33, 47–56. https://doi.org/10.1016/S0921-8181(02)00060-7.

, 1995. Man and sea in the Mesolithic: Coastal settlement above and below present sea level. In: Fischer, A. (Ed.), Proceedings of the International Symposium. Kalundborg, Denmark 1993. Oxbow Monograph 53. Oxbow, Oxford.

Fischer A., Pedersen L. (eds.), 2018. Oceans of archaeology. Jutland Archaeological Society Publ. Vol. 101. Jutland Archaeological Society, Højbjerg.

Fisher, E.C, Bar-Matthews, M., Jerardino, A., Marean, C.W., 2010. Middle and Late Pleistocene paleoscape modeling along the southern coast of South Africa. Quat. Sci. Rev. 29, 1382–1398. https://doi.org/10.1016/j.quascirev.2010.01.015.

Fitch, S., Missiaen, T., Muru, M., Harding, R., Fraser, A., De Clercq, M., Garcia Moreno, D., Versteeg, W., Busschers, F.S., van Heteren, S., Hijma, M.P., Reichart, G.-J., Gaffney, V., 2021. Targeting the Mesolithic: Interdisciplinary approaches to archaeological prospection in the Brown Bank area, southern North Sea. Quat. Int. 584, 141–151. https://doi.org/10.1016/j.quaint.2020.05.004.

Flemming N.C., Cagatay M.N., Chiocci F.L., Galanidou N, Jöns H., Lericolais G., Missiaen T., Moore F., Rosentau A., Sakellariou D., Skar B., Stevenson A., Weerts H.. 2014. Land beneath the waves: Submerged landscapes and sea level change. A joint geoscience-humanities strategy for European continental shelf prehistoric research. Chu NC, McDonough N (eds) Position Paper 21 of the European Marine Board, Ostend, Belgium.

Flemming, N.C., Harff, J., Moura, D., Burgess, A., Bailey, G.N. (Eds.), 2017. Submerged landscapes of the European continental shelf: Quaternary paleoenvironments. John Wiley & Sons, Chichester.

Gaffney, V., Thomson, K., Fitch, S. (Eds.), 2007. Mapping Doggerland: the Mesolithic landscapes of the southern North Sea. Archaeopress, Oxford.

Gaffney V., Fitch S., Smith D. (eds.), 2009. Europe's lost world: The rediscovery of Doggerland. CBA Res.Rep. 160. Council for British Archaeology, York.

Gaffney, V., Allaby, R., Bates, R., Bates, M., Ch'ng, E., Fitch, S., Garwood, P., Momber, G., Murgatroyd, P., Pallen, M., Ramsey, E., Smith, D., Smith, O., 2017. Doggerland and the Lost Frontiers Project (2015–2020). In: Bailey, GN, Harff, J, Sakellariou, D (Eds.), Under the sea: Archaeology and palaeolandscapes of the continental shelf. Springer, Cham, 305–319. https://doi.org/10.1007/978-3-319-53160-1_20.

Galili, E., Weinstein-Evron, M., 1985. Prehistory and paleoenvironments of submerged sites along the Carmel coast of Israel. Paléorient 11, 37–52. https://doi.org/10.3406/paleo.1985.4360.

Galili, E., Weinstein-Evron, M., Hershkovitz, I., Gopher, A., Kislev, M., Lernau, O., Horwitz, L.K., Lernau, H., 1993. Atlit-Yam: a prehistoric site on the sea floor off the Israeli coast. Journal of Field Archaeology 20, 133–156. https://doi.org/10.1179/jfa.1993.20.2.133.

Galili, E., Benjamin, J., Eshed, V., Rosen, B., McCarthy, J., Horwitz, L.K., 2019. A submerged 7000-year-old village and seawall demonstrate earliest known coastal defence against sea-level rise. PLoS ONE 14 (12), e0222560. https://doi.org/10.1371/journal.pone.0222560.

Galili, E., Rosen, B, Weinstein Evron, M., Hershkovitz, I., Eshed, V., Horwitz, L.K., 2020. Israel: Submerged prehistoric sites and settlements on the Mediterranean coastline—the current state of the art. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 443–481. https://doi.org/10.1007/978-3-030-37367-2_23.

Gaspar, M., Klokler, D., Deblasis, P., 2011. Traditional fishing, mollusk gathering, and the shell mound builders of Santa Catarina. Brazil. J. Ethnobiol. 31 (2). https://doi.org/10.2993/0278-0771-31.2.188, 188–21https://doi.org/.

Gentle, R.I., 1987. The geology of the inner continental shelf and Agulhas Arch: CT to PE. Geological Survey of South Africa Bulletin 20, 29.

Grant, K.M., Rohling, E.J., Bar-Matthews, M., Ayalon, A., Medina-Elizalde, M., Ramsey, B., Satow, C., Roberts, A.P, 2012. Rapid coupling between ice volume and polar temperature over the past 150,000 years. Nature 491, 744–747. https://doi.org/10.1038/nature11593.

Grant, K.M., Rohling, E.J., Ramsey, C.B., Cheng, H., Edwards, R.L., Florindo, F., Heslop, D., Marra, F., Roberts, A.P., Tamisiea, M.E., Williams, F., 2014. Sea-level variability over five glacial cycles. Nat. Commun. 5, 1–9. https://doi.org/10.1038/ncomms6076.

Groucutt, H.S., Petraglia, M.D., Bailey, G.N., Parton, A., Clark-Balzan, L., Jennings, R.P., Lewis, L., Blinkhorn, J., Scerri, E.M.L., Drake, N.A., Breeze, P., Boivin, N., Inglis, R.H., Devès, M.H., Meredith-Williams, M.G., Thomas, MG, Scally, A., 2015. Rethinking the dispersal of *Homo sapiens* out of Africa. Evol. Anthropol. 24, 149–164. https://doi.org/10.1002/evan.21455.

Grøn, O., Boldreel, L.O., Hermand, J.-P., Rasmussen, H., Dell'Anno, A., Cvikel, D., Galili, E, Madsen, B., Nørmark, E, 2018. Detecting human-knapped flint with marine high-resolution reflection seismics: A preliminary study of new possibilities for subsea mapping of submerged Stone Age sites. Underwater Technol 35 (2), 35–49. https://doi.org/10.3723/ut.35.035.

Grøn, O., Boldreel, L.O., Smith, M.F., Joy, S., Tayong Boumda, R., Mäder, A., Bleicher, N., Madsen, B., Cvikel, D., Nilsson, B., Sjöström, A., Galili, E., Nørmark, E., Hu, C., Ren, Q., Blondel, P., Gao, X., Stråkendal, P., Dell'Anno, A., 2021. Acoustic Mapping of Submerged Stone Age Sites—A HALD Approach. Remote Sens 13 (3), 445. https://doi.org/10.3390/rs13030445.

Hahn, A., Schefuß, E., Andò, S., Cawthra, H.C., Frenzel, P., Kugel, M., Meschner, S., Mollenhauer, G., Zabel, M., 2017. Southern Hemisphere anticyclonic circulation drives oceanic and climatic conditions in late Holocene southernmost. Africa. Clim. Past 13, 649–665. https://doi.org/10.5194/cp-13-649-2017.

Harff, J., Bailey, G.N., Lüth, F. (Eds.), 2016. Geology and archaeology: Submerged landscapes of the continental shelf. Geol. Soc. Lond. Spec. Pub. 411. https://doi.org/10.1144/SP411.

Harff, J., Lüth, F. (Eds.), 2007. SINCOS – Sinking coasts: Geosphere, ecosphere and anthroposphere of the Holocene southern Baltic Sea. Bericht der Römisch-Germanischen Kommission 88.

Harff, J., Lüth, F. (Eds.), 2011. SINCOS II – Sinking coasts: Geosphere, ecosphere and anthroposphere of the Holocene southern Baltic Sea. Bericht der Römisch-Germanischen Kommission 92.

Helm, C.W., MacCrae, R., Cawthra, H.C., Cowling, R.M., Marean, C.W., Thesen, G.H.H., 2018. A new Pleistocene hominin track site from the southern Cape coast. South Africa. Sci. Rep. 8, 3772. https://doi.org/10.1038/s41598-018-22059-5.

Helm, C.W., Cawthra, H.C., Cowling, R.M., de Vynck, J., Lockley, M.G., Marean, C.W., Thesen, G.H.H., Venter, J., 2020. Pleistocene vertebrate tracksites on the Cape south coast of South Africa and their potential palaeoecological implications. Quat. Sci. Rev. 235, 105857. https://doi.org/10.1016/j.quascirev.2019.07.039.

Inglis R, Bosworth W, Rasul NMA, Al Saeedi A, Bailey GN. 2019. Investigating the fossil coral terraces and coastal archaeology of the southern Red Sea. In: Rasul N.M.A., Stewart I.C.F. (eds.) Geological setting, palaeoenvironment and archaeology of the Red

Sea. Springer, Cham, 553—581. https://doi.org/10.1007/978-3-319-99408-6 25

Jackson, JBC., 2001. What was natural in the coastal oceans? PNAS 98, 5411—5418. https://doi.org/10.1073/pnas.091092898.

Jarvis A, Reuter HI, Nelson A, Guevara E. 2008. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database http://srtm.csi.cgiar.org

Jennings, R.P., Singarayer, J., Stone, E.J., Krebs-Kanzow, U., Khon, V., Nisancioglu, K.H., Pfeiffer, M., Zhang, X., Parker, A., Parton, A., Groucutt, H.S., White, T.S., Drake, N.A., Petraglia, M.D., 2015. The greening of Arabia: Multiple opportunities for human occupation of the Arabian Peninsula during the Late Pleistocene inferred from an ensemble of climate model simulations. Quat. Int. 382, 181—199. https://doi.org/10.1016/j.quaint.2015.01.006.

Jöns, H, Lüth, F, Mahlstedt, S, Goldhammer, J, Hartz, S, Kühn, H-J., 2020. Germany: Submerged sites in the south-western Baltic Sea and the Wadden Sea. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 95—123. https://doi.org/10.1007/978-3-030-37367-2_5.

Kooijmans, L, van den Broeke, PV, Fokkens, H, von Gijn, AL., 2005. The prehistory of the Netherlands. Amsterdam University Press, Amsterdam.

Lambeck, K, Purcell, A, Flemming, N, Vita-Finzi, C, Alsharekh, A, Bailey, GN, 2011. Sea level and shoreline reconstructions for the Red Sea: Isostatic and tectonic considerations and implications for hominin migration out of Africa. Quat. Sci. Rev. 30 (25—26), 3542—3574. https://doi.org/10.1016/j.quascirev.2011.08.008.

Lambeck, K, Rouby, H, Purcell, A, Sun, Y, Sambridge, M, 2014. Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. PNAS 111 (43), 15296—15303. https://doi.org/10.1073/pnas.1411762111.

Maarleveld, TJ., 2020. Beam trawls and bones: A reflection on Dutch fisheries. In: Bailey, G, Galanidou, N, Peeters, H, Jöns, H, Mennenga, M (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 521—535. https://doi.org/10.1007/978-3-030-37367-2_27.

Marean, CW, Bar-Matthews, M, Bernatchez, J, Fisher, E, Goldberg, P, Herries, AI, Jacobs, Z, Jerardino, A, Karkanas, P, Minichillo, T, Nilssen, PJ., 2007. Early human use of marine resources and pigment in South Africa during the Middle Pleistocene. Nature 449 (7164), 905—908. https://doi.org/10.1038/nature06204.

Marean, CW., 2010. Pinnacle Point cave 13B (Western Cape Province, South Africa) in context: The Cape Floral Kingdom, shellfish, and modern human origins. J. Hum. Evol. 59, 425—443. https://doi.org/10.1016/j.jhevol.2010.07.011.

Marean, CW, Cawthra, HC, Cowling, RM, Esler, KJ, Fisher, EC, Milewski, A, Potts, AJ, Singels, E, De Vynck, J., 2014. Stone Age people in a changing South African Greater Cape Floristic Region. In: Allsopp, N, Colville, JF, Verboom, T (Eds.), Ecology and evolution of fynbos: Understanding megadiversity. Oxford Univ. Press, Oxford, 164—199.

Marean, CW, Anderson, R, Bar-Matthews, M, Braun, K, Cawthra, HC, Cowling, RM, Engelbrecht, F, Esler, KJ, Fisher, EC, Franklin, J, Hill, K, Janssen, M, Potts, AJ, Zahn, R., 2015. A new research strategy for integrating studies of paleoclimate, paleoenvironment, and paleoanthropology. Evol. Anthropol. 24 (2), 62—72. https://doi.org/10.1002/evan.21443.

Marean, C.W., Cowling, R.M., Franklin, J., 2020. The Palaeo-Agulhas Plain: Temporal and spatial variation in an extraordinary extinct ecosystem of the Pleistocene of the Cape Floristic Region. Quat. Sci. Rev. 235, 106161. https://doi.org/10.1016/j.quascirev.2019.106161.

Martin, A.K., Flemming, B.W., 1986. The Holocene shelf sediment wedge off the south and east coast of South Africa. In: Knight, R.J., McLean, J.R. (Eds.), Shelf sands and sandstones. Canadian Society of Petroleum Geologists, Calgary, Canada, 27—44.

Masters, P.M., Flemming, N.C. (Eds.), 1983. Quaternary coastlines and marine archaeology. Academic Press, London.

Mellars, P.A., Gori, K.C., Carr, M., Soares, P.A., Richards, M.B., 2013. Genetic and archaeological perspectives on the initial modern human colonization of southern Asia. PNAS 110, 10699—10704. https://doi.org/10.1073/pnas.1306043110.

Momber G., Tomalin D., Scaife R., Satchell J., Gillespie J. (eds.), 2011. Mesolithic occupation at Bouldnor Cliff and the submerged prehistoric landscapes of the Solent. CBA Res. Rep. 164. Council for British Archaeology, York.

Momber, G., Sakellariou, D., Rousakis, G., Bailey, G.N, 2019. The multi-disciplinary search for underwater archaeology in the southern Red Sea. In: Rasul, N.M.A., Stewart, I.C.F. (Eds.), Geological setting, palaeoenvironment and archaeology of the Red Sea. Springer, Cham, 609—632. https://doi.org/10.1007/978-3-319-99408-6_27.

Momber, G., Mason, B., Gillespie, J., Heamagi, C., Satchell, J., Ferreira, R, Noble-Shelly, J., 2021. New evidence from Bouldnor Cliff for technological innovation in the Mesolithic, population dispersal and use of drowned landscapes. Quat. Int. 584, 116—128. https://doi.org/10.1016/j.quaint.2020.11.048.

Moree, J.M., Sier, M.M. (Eds.), 2015. Interdisciplinary research programme Maasvlakte 2 Rotterdam. BOOR, Rotterdam.

Murray-Wallace, C.V., Woodroffe, C.D., 2014. Quaternary sea-level changes: A global perspective. Cambridge Univ.Press, Cambridge.

Nilsson, B., Hansson, A., Sjöström, A., 2020. Sweden: Submerged landscapes and seascapes of the Early Mesolithic. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 77—93. https://doi.org/10.1007/978-3-030-37367-2_4.

NOAA National Geophysical Data Center. 2009. ETOPO1 1 Arc-Minute Global Relief Model. NOAA National Centers for Environmental Information. Accessed May 2021.

Pater, C., 2020. Seabed Infrastructure Projects, Underwater Cultural Heritage and The Environmental Assessment Process: The UK Example. In: Bailey, G, Galanidou, N, Peeters, H, Jöns, H, Mennenga, M (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 509—520. https://doi.org/10.1007/978-3-030-37367-2_26.

Peeters, H., Amkreutz, L., 2020. The Netherlands: Probing into the submerged landscapes, archaeology and palaeontology of the Dutch continental shelf. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 157—174. https://doi.org/10.1007/978-3-030-37367-2_8.

Peeters, H., Bailey, G., Galanidou, N., 2020. The legal, historical and industrial context of underwater cultural heritage: Introduction. In: Bailey, G., Galanidou, N., Peeters, H., Jöns, H., Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 485—493. https://doi.org/10.1007/978-3-030-37367-2_24.

Peev, P., Farr, R.H., Slavchev, V., Grant, M.J., Adams, J., Bailey, G., 2020. Bulgaria: Sea-level change and submerged village settlements on the Black Sea. In: Bailey, G, Galanidou, N, Peeters, H, Jöns, H, Mennenga, M. (Eds.), The archaeology of Europe's drowned landscapes. Springer, Cham, 393—412. https://doi.org/10.1007/978-3-030-37367-2_20.

Porozhanov, K., 1991. Le site submergé d'Ourdoviza. Thracia Pontica 4, 109—112.

Roberts, D.L., Bateman, M.D., Murray-Wallace, C.V., Carr, A.S., Holmes, P.J., 2008. Last interglacial fossil elephant trackways dated by OSL/AAR in coastal aeolianites, Still Bay, South Africa. Palaeogeogr. Palaeoclimatol. Palaeoecol. 257 (3), 261—279. https://doi.org/10.1016/j.palaeo.2007.08.005.

Roberts D.L., Karkanas P., Jacobs Z., Marean C.W., Roberts R.G., 2012. Melting ice sheets 400,000 yr ago raised sea level by 13 m: Past analogue for future trends. EPSL 357—358, 226—237. https://doi.org/ 10.1016/j.epsl.2012.09.006

Sakellariou, D., Rousakis, G., Panagiotopoulos, I., Bailey, G.N., 2019. Geological structure and geomorphological evolution of the Farasan Islands continental shelf, southern Red Sea, SW Saudi Arabia. In: Rasul, N.M.A., Stewart, I.C.F. (Eds.), Geological setting, palaeoenvironment and archaeology of the Red Sea. Springer, Cham, 633—656. https://doi.org/10.1007/978-3-319-99408-6_28.

Salter, E., Murphy, P., Peetes, H., 2014. Researching, conserving and managing submerged prehistory: National approaches and international collaborations. In: Evans, A.M., Flatman, J.C., Flemming, N.C. (Eds.), Prehistoric archaeology on the continental shelf: A global review. Springer, New York https://doi.org/10.1007/978-1-4614-9635-9_9.

Sanderson, D.C.W., Kinnaird, T.C., 2019. Optically stimulated luminescence dating as a geochronological tool for late Quaternary sediments in the Red Sea region. In: Rasul, NMA, Stewart, ICF (Eds.), Geological setting, palaeoenvironment and archaeology of the Red Sea. Springer, Cham, 685—707. https://doi.org/10.1007/978-3-319-99408-6_31.

Sergiou S., Geraga M., Rohling E.J., Rodríguez-Sanz L., Hadjisolomou E., Sakellariou D., Paraschos F., Bailey G. (submitted), Influences of sea level changes and the South Asian Monsoon on the southern Red Sea oceanography over the last 30 kyr. Quat. Res.

Skaarup, J., Grøn, O., 2004. Møllegabet II. A submerged Mesolithic settlement in southern Denmark. BAR Int. Ser. 1328 Archaeopress, Oxford.

Spada, G., Galassi, G., 2017. Extent and dynamic evolution of the lost land aquaterra since the Last Glacial Maximum. C. R. Geosci. 349 (4), 151—158. https://doi.org/10.1016/j.crte.2017.06.004.

Sturt, F., Flemming, N.C., Carabias, D., Jöns, H., Adams, J., 2018. The next frontiers in research on submerged prehistoric sites and landscapes on the continental shelf. Proc. Geol. Soc. 129 (5), 654—683. https://doi.org/10.1016/j.pgeola.2018.04.008.

Svenning, J.-C., Faurby, S., 2017. Prehistoric and historic baselines for trophic rewilding in the Neotropics. PECON 15, 282—291. https://doi.org/10.1016/j.pecon.2017.09.006.

Tizzard, L., Bicket, A.R., Benjamin, J., de Loecker, D., 2014. A Middle Palaeolithic site in the southern North Sea: Investigating the archaeology and palaeogeography of Area 240. J. Quat. Sci. 29, 698—710. https://doi.org/10.1002/jqs.2743.

Tizzard, L., Bicket, A.R., de Loecker, D., 2015. Seabed prehistory: Investigating the palaeogeography and early Middle Palaeolithic archaeology in the southern North Sea. Wessex Archaeology Rep 35 Wessex Archaeology, Salisbury.

Van Andel, T.H., 1989. Late Pleistocene sea levels and the human exploitation of the shore and shelf of southern South Africa. J. Field Archaeol. 16, 133—155. https://doi.org/10.1179/jfa.1989.16.2.133.

Van der Noort, T., 2011. North Sea archaeologies: A maritime biography, 10,000 BC — AD 1500. Oxford Univ. Press, Oxford.

Wadley, L., 2015. Those marvellous millennia: the Middle Stone Age of southernmost Africa. Azania 50 (2), 155—226. https://doi.org/10.1080/0067270X.2015.1039236.

Weerts, H., Otte, A, Smit, B, Vos, P, Schiltmans, D, Waldus, W, Borst, W, 2012. Finding a needle in a haystack by using knowledge of Mesolithic human adaptation in a drowning delta. eTopoi Journal for Ancient Studies 3 (SV), 17—24.

Wiseman, C., O'Leary, M, Hacker, J., Stankiewicz, F., McCarthy, J., Beckett, E., Leach, J., Baggaley, P., Collins, C., Ulm, S., McDonald, J., Benjamin, J., 2021. A multi-scalar approach to marine survey and underwater archaeological site prospection in Murujuga, Western Australia. Quat. Int. 584, 152—170. https://doi.org/10.1016/j.quaint.2020.09.005.

Zabel, M., 2017. Climate archives in coastal waters of southern Africa — Cruise No. M123 — February 03—February 27, 2016 — Walvis Bay (Namibia) — Cape Town (Rep. of South Africa). ISSN: 2195-8475. DFG-Senatskommission für Ozeanographie Bremen 50 DOI:10.2312/cr_m123.