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Archaeology of the Continental Shelf: Marine Resources, Submerged Landscapes and Underwater Archaeology

Geoffrey N. Bailey^a (corresponding author)

Nicholas C. Flemming^b

^a Department of Archaeology, University of York, King's Manor, York, YO1 7EP, UK
email: gb502@york.ac.uk

^b Sheets Heath, Sheets Heath Common, Brookwood, Surrey, GU24 OEN
email: n.flemming@sheetsheath.co.uk

Abstract

We provide a critical review of the evidence for the long-term use of marine resources and coastal environments in human evolution and later development. We emphasise the importance of the coastal archaeological record in understanding patterns of human settlement and dispersal and draw attention to the large potential biases introduced by the destructive or obscuring effects of Pleistocene sea-level change. We note that lowered sea levels have been the norm for most of the Pleistocene and that periods of high sea level have been too short-lived to provide other than a fragmentary coastal record and one that is beset with ambiguities and uncertainties. We examine the geological processes of coastal uplift and underwater preservation that may help to mitigate these biases. Coastlines elevated by isostatic and tectonic processes, or with very steep offshore drop-offs at plate boundaries, are important in providing a potential window into coastal landscapes and archaeology formed during periods of lowered sea level. However, we conclude that the opportunities afforded by these geological factors are too limited to obviate the need for underwater exploration. We review the evidence now available from submerged landscapes across the Africa-Eurasia interface from the Atlantic coastlines of Northwest Europe to the southern Red Sea. We show that geomorphological conditions for the preservation of archaeological and palaeoenvironmental data are commonly present, that much material has already been discovered, and that new techniques, technologies and projects are providing the momentum for a rapidly expanding field of investigation. The results do not simply add to what we already know from sites on land, but are likely to produce qualitatively different evidence for coastal adaptations and landscapes that have no analogue on present-day coastlines. We note the strong probability that many coastal landscapes exposed at lowered sea level provided relatively fertile and productive refugia for plants, land mammals and humans at a time when increased aridity would have reduced or deterred hinterland occupation. We conclude that underwater investigation is essential if hypotheses of early human adaptation and dispersal are to be fully tested.

Keywords: Coastal Archaeology, Molluscs, Prehistoric Coastlines, Sea-level change, Shell mounds, Submerged landscapes

1. Introduction

The large fluctuations of sea-level associated with the glacial-interglacial cycle have been known about for over forty years, and it is now well established that the maximum amplitude of sea-level variation in response to continental glaciation was approximately 120 m, with relatively short periods when sea level was at or above the present level, and much longer periods when it was at least 40 m lower (Figure 1). The pattern of sea-level change is best known for the last glacial-interglacial cycle, but earlier cycles were almost certainly accompanied by similar fluctuations, at least back to about 0.9 Ma, and most probably back to 2.5 Ma but with a lower amplitude of variation (Lambeck et al., 2002).

The archaeological implications of these changes have been recognised for a long time and early work used simple maps of present-day bathymetry to explore their impact on a range of issues, including the varying visibility of marine resources at different periods in the Pleistocene, the differential preservation of coastal archaeological sites, the constraints on human dispersal imposed by the creation and submergence of land bridges, changes in shoreline ecology, and alterations more generally in the palaeoeconomic potential of coastlines following the extension or contraction of coastal territory (Bailey, 1978, 1983; Richardson, 1978; Shackleton et al., 1984; Shackleton and Van Andel, 1986). Early attempts were also made to explore the nature of the submerged landscape in more detail using remote sensing techniques (Van Andel and Lianos, 1984a,b), and to excavate underwater sites, most famously the Mesolithic site of Tybrind Vig in Denmark (Andersen, 1980, see also Masters and Flemming, 1983). But these pioneer investigations were rarely followed up, except that underwater excavations have continued, especially in Danish waters (Fischer, 1995, 2004), but usually at shallow depths and therefore confined to shorelines little earlier than those exposed today. The costs of underwater investigation, the risks of failure, and the uncertainties that any new data so acquired would be informative have all acted as a powerful inhibition to further archaeological investigation (Bailey, 2004a,b).

More recently there has been renewed interest stimulated by the following factors:

1. Increasing evidence that marine resources were important far back in time and more widely and intensively exploited than suggested by the bursts of evidence associated with high sea levels in the Holocene and the Last Interglacial period, and a fuller understanding of how much may have been lost by marine inundation (Erlandson, 2001; Bailey and Milner, 2002)
2. Continued accumulation of underwater evidence demonstrating the survival of archaeological sites following marine submergence, extending in some cases well back into the Palaeolithic period, and sometimes with exceptional preservation and quality of evidence (Flemming 1998, 2004a,b; Werz and Flemming, 2001)
3. Renewed interest in coastlines and marine resources as a potentially significant factor in hominin dispersals, especially the dispersal of anatomically modern humans (Stringer, 2000; Walter et al., 2000; Mannino and Thomas, 2002; Oppenheimer 2003; Macaulay et al., 2005; Thangaraj et al., 2005; Mellars, 2006; Bailey et al., 2007a; Bulbeck, 2007; Erlandson, 2007; Turner and O'Regan 2007)
4. Greater precision in the mapping of palaeoshorelines, resulting from refinements of geophysical modelling, often in combination with dated evidence from sediment cores and elevated marine terraces (Lambeck, 1996, 2004; Shennan et al., 2000a,b)
5. Improved technologies and techniques for remote sensing and vastly increased computing power, which are helping to demonstrate the detail of the original terrestrial landscape that can be reconstructed, and to facilitate a sharper focus on the impact of such changing landscapes on human ecological and social dynamics (Coles, 1998; Fedje and Josenhans, 2000; Faught, 2004; Gaffney et al., 2007).

6. A greater appreciation that now-submerged coastal landscapes may have provided more productive conditions on land during glacial periods compared to generally arid or inaccessible hinterlands, and important refugia for plants and animals and hence for human populations (Mandryck et al., 2001; Faure et al., 2002; Bailey et al., 2007a).

For most of the 20th century, coastlines and marine resources were discounted in human evolution and social development (a notable exception was Carl Sauer (1962), and such neglect demanded advocacy, which was rarely forthcoming, or else exercised from outside the boundaries of the professional disciplines of palaeoanthropology and archaeology. Since the turn of the millennium the position has been almost completely reversed and coastal and marine resources have assumed a central role, especially in the discussion of early human dispersals. The evidence of Australian colonisation, now placed at ca. 50 ka, has exerted an important influence in this regard. The fact that crossing the Wallace Line was accomplished with seafaring abilities and presumed exploitation of marine resources has been known about for over thirty years (Allen et al., 1977). Yet its wider implications for coastal settlement and dispersal elsewhere were long discounted, despite early recognition of their potential importance (Bowdler, 1977). Now that genetic modelling has powerfully reinforced a growing consensus that Australia and New Guinea were first colonised by modern humans, and that modern humans originated in Africa, a new and compelling synthesis has emerged, which sees the whole process of expansion and dispersal out of Africa as the result of novel adaptations to marine foods and sea travel, resulting in rapid dispersal across the southern end of the Red Sea and around the coastlines of the Indian Ocean, with the occupation of Australia as the culmination of a process initiated in Africa at some earlier time (cf. Oppenheimer, 2003). Such enthusiasm, often on the basis of very limited evidence, now requires critical scrutiny.

The aim of this paper is to explore some of the key issues arising from the new emphasis on coastal dispersal, to examine more carefully the evidence, to highlight areas where new evidence is needed and can be obtained, and to provide a brief review of underwater evidence. We highlight three questions:

1. What is the direct evidence for use of marine resources in the Pleistocene and how reliable or useful is that evidence as an indicator of changing patterns of human adaptation and dispersal, given the powerful distorting effects of sea level change?
2. What geological processes need to be taken into consideration in assessing the loss of coastal evidence and coastal landscapes and the possibilities for overcoming that loss?
3. What was the likely role of now submerged coastal landscapes and shorelines in modifying the resources available for early human populations and what sorts of evidence can we reasonably hope to recover from this underwater realm?

In surveying the evidence, we will concentrate on the main zone of contact between Africa and Eurasia, the Mediterranean and Red Sea Basins, together with the Atlantic coastlines of Northwest Europe where much recent and important work on submerged landscapes has been carried out, drawing on examples from elsewhere as appropriate.

2. The Long-Term History of Marine Resources

Shell middens – concentrated deposits of shells accumulated as food remains – are known in their tens of thousands around the coastlines of the world. They include famous examples such as the mounds of Mesolithic Portugal and the Danish Ertebølle (Milner et al., 2007), San Francisco Bay in California (Luby et al., 2006), Jomon Japan (Habu, 2004), Australia (Hall and McNiven, 1999), and the sambaquis of Brazil (Gaspar, 1998). All these groupings include individual

mounds containing thousands of tonnes of shell debris along with other evidence of human activity, including artefacts and other food remains. The tallest mounds are 5–10 m high, and the largest in Brazil is reported to have been over 30 m tall. Almost without exception these large concentrations of sites date from about 8–7 ka (all dates given in this form are cal BP) onwards.

Earlier sites are not unknown, but they are far fewer and smaller and most are found in the protective environment of coastal caves. To give some idea of the difference in quantities, the mound of Ertebølle itself is estimated to have comprised 2000 cubic metres of shell deposit representing some 50 million molluscs, mostly oysters, accumulated over a 1000-year period (Bailey 1978), the Weipa shell mounds around Albatross Bay in northern Queensland represent an estimated 200,000 cubic metres and 10 trillion (10^{10}) shells accumulated over a 1.5 ka period (Bailey 1994). By contrast, the shells from the Upper Palaeolithic levels of La Riera Cave in Northern Spain numbered some 19,600 accumulated over a 10 ka period between 23 and 13 ka (Ortea 1986), those from the Middle Palaeolithic levels of Moscerini Cave in Italy 401 (MNI) shells accumulated over a 55 ka period between 115 and 60 ka (Stiner, 1994), and from a recently reported 160 ka deposit in the cave of Pinnacle Point in South Africa just 79 shells (Marean et al., 2007).

An earlier generation of interpretations saw in this sort of evidence symptoms of a postglacial ‘revolution’ associated with a worldwide increase in human populations and an intensification in the exploitation of marine resources accompanied by new technological developments such as boats, harpoons, fishhooks and food storage (cf. Binford, 1968; Flannery, 1969; Osborn, 1977; Beaton, 1985). Others have noted the apparent correlation of this vast increase in postglacial evidence with the establishment of modern sea level, and suggested that comparable sites may have existed earlier but are now destroyed or submerged by sea-level rise. The larger coastal middens and midden groupings are generally associated with shallow embayments, river estuaries and extensive intertidal mudflats capable of supporting the enormous quantities of shells needed to generate the largest mounds, and hence with shallow onshore and offshore topography. These environments and middens would be the first to be submerged or destroyed by sea-level rise and the last to be re-established after stabilisation at some new level (Figure 2).

Earlier sites, particularly from the late glacial and early postglacial, are usually associated with less productive rocky shorelines, steeper topography and locations that have survived by virtue of elevated positions in relation to the contemporaneous shoreline. In most cases the steeper offshore profile means that the sites would have remained close enough to the contemporaneous shoreline to provide suitable bases for the exploitation of marine resources, even when sea level was somewhat lower than the present. But all would have been at least 5 km from the coastline as sea level approached its maximum regression, and most much further inland. In those circumstances we would expect most of the shells and other remains of marine subsistence to disappear from the archaeological record and leave their archaeological mark closer to the contemporaneous shoreline in locations that are now submerged, depending on the width of the shelf (Figures 3 and 4).

Many coastal caves around the Mediterranean and on the Atlantic coastline of northern Spain fit this pattern, with greatly increased quantities of marine shells and other marine resources in their uppermost levels associated with Epipalaeolithic or Mesolithic and later deposits and much reduced quantities in earlier levels of Upper Palaeolithic and Middle Palaeolithic date. Examples include Franchthi Cave in Greece (Shackleton, 1988), Uzzo Cave in Sicily (Tagliacozzi, 1993), the Haua Fteah in Libya (McBurney, 1967), La Nerja in southern Spain (Morales et al., 1998; Cortes et al., 2008), Gorham's and Vanguard Cave in Gibraltar (Stringer et al., 2000; Finlayson et al., 2006, with Middle and Upper Palaeolithic marine indicators but lacking later material), and

La Riera in northern Spain (Clark and Straus, 1986) (See also Bicho and Haws, 2008, for Portuguese examples). At first sight the progressive increase of marine indicators in late glacial and postglacial deposits looks like a case of intensification, but close analysis of shell quantities and other palaeoeconomic and palaeoenvironmental indicators in the sequence of La Riera demonstrates that the dominant signal is the changing distance between site and sea shore with sea-level change, implying that the small numbers of shells in the earlier deposits are just the few shells brought inland by people who conducted a more extensive exploitation of marine resources and deposited most of the remains at sites that are now lost to view (Bailey and Craighead, 2003).

Residual indicators of marine intensification occur at La Riera, notably a slight increase in shell remains in Solutrean (Upper Palaeolithic) deposits during the glacial maximum at a time when sea level was furthest away from the site, and there is similar evidence at La Nerja (Morales et al., 1998; Cortes et al., 2008). But, as pointed out in the case of La Nerja, this evidence may be explained in other ways without implying intensification or growth in human populations. It might indicate a change in the function of the cave, for example from a hunting camp to a residential base, or a widening of the site catchment, with people travelling further afield and bringing resources back from more distant locations in a logistic pattern of exploitation (cf. Binford 1980), which might well be predicted under the harsher environmental conditions of the glacial maximum.

In the long sequences of the coastal caves in South Africa, there appears to be a similar pattern of increase in marine shells apparent in late glacial-postglacial sequences, for example at Eland's Bay (Parkington et al., 1988). In addition, the longest sequences go back to earlier periods of high sea level associated with MIS 5 and 4, notably at Blombos Cave, Klasies River Mouth and Die Kelders (Avery et al., 1997; Henshilwood et al., 2001; Henshilwood and Marean, 2003; Klein et al., 2004), with the re-appearance of considerable quantities of marine shells and the presence of bones of sea mammals, penguins and fish. There are also open-air sites of similar early date with marine shells in South Africa, such as Sea Harvest and Hoedjies Punt, and the MIS 5e site of Abdur on the Red Sea coastline of Eritrea (Walter et al., 2000). This record has now been extended back to 160 ka with the presence of marine shells at Pinnacle Point (Marean et al., 2007).

Here too, however, we are presented with exactly the same dilemma as with the postglacial evidence. Are we seeing a genuine case of more intensive use of marine resources, or perhaps even the very earliest evidence of human interest in marine resources in the case of these African sites? Or is this simply another case of differential visibility of marine food remains relative to earlier periods when sea level was lower? The small number of shells at Pinnacle Point accumulated at a period of low sea level when the site was many kilometres inland from the contemporaneous shoreline is strongly reminiscent of the similar evidence in the deposits of European coastal caves accumulated during the low sea level stand of the last glacial maximum, and poses similar ambiguities of interpretation. Without factoring in the effects of sea-level change, it is impossible to evaluate the significance of this evidence or to assess claims that it represents the earliest case of human interest in marine resources and a novel adaptation developed by modern humans.

There are additional problems in the interpretation of this early evidence. All the marine foods represented in these early sites could have been easily collected or scavenged on the sea shore, molluscs at the shore edge and some inshore fish, seals when vulnerable during the breeding season, and other sea mammals, sea birds and fish beached by storms. There is nothing in this material that presupposes technological or cognitive advancement. Similar evidence is found in

Gorham's Cave on Gibraltar, including molluscs, fish bones and cut-marked sea-mammal bone, and here it is indisputable that the occupants of the cave were Neanderthals (Stringer et al., 1999, 2000; Finlayson et al., 2006; Finlayson, personal communication, 2007, Finlayson, 2008). Even earlier evidence of mollusc shells and fish bones is present at the 400 ka site of Terra Amata on the French Mediterranean (De Lumley, 1966).

Taphonomic and ecological variables also need to be carefully assessed. Natural agencies may be responsible for the accumulation of shells and other marine resources and this factor needs especially careful evaluation for archaeological deposits formed on or very close to the seashore (Bailey et al., 1994; Stiner, 1994, p. 177, 182). This is evidently a problem at the Abdur site in Eritrea, where the oyster shells originally claimed as evidence of food remains (Walter et al., 2000) later turned out to be a natural death assemblage (Bruggeman et al., 2004) with no demonstrable connection with the artefacts and animal bones found nearby. The marine remains in Middle and Upper Palaeolithic deposits in Mediterranean coastal sites are also relatively few compared to those in the South African caves, but this almost certainly reflects the relatively low marine productivity of the Mediterranean and especially the limited extent of the molluscan habitat in a basin with almost no tidal range (Fa, 2008), rather than a less intensive or less skilled exploitation of marine resources; the marine remains in postglacial deposits in the Mediterranean are similarly sparse in relation to similar-aged middens on Atlantic coastlines and elsewhere.

Finally, we need to consider what sorts of subsistence patterns are implied by the presence of marine shells in archaeological deposits. Even the astronomical numbers of shells in the largest postglacial shell mounds are not evidence of economies dominated by shellfood or even of marine specialists. When converted into annual food equivalents, the molluscs turn out to represent a relatively small but by no means unimportant supply of food (Bailey, 1975; Meehan, 1982), and the mounds to be associated with a broad spectrum of other resources including marine and terrestrial plants and animals according to local circumstances. Claims that the abundance of shell remains suggests otherwise almost always fail to take account of the notorious over-representation of shells in archaeological deposits in relation to other food remains. There are very few if any precedents for such specialisation anywhere in the voluminous ethnographic and archaeological records of coastal hunters and gatherers in recent prehistory or the ethnographic record (Bailey and Milner, 2002). Erlandson (1991) has cited one archaeological example from part of the Santa Barbara coast in California, where subsistence was apparently based largely on marine molluscs and plant foods during the early Holocene, but it is not clear that the full range of resources has been correctly identified, and the circumstances seem in any case to refer to relatively low population densities on a coastline with a restricted hinterland. Most so-called marine specialists obtained terrestrial resources locally, or from a more distant hinterland by seasonal moves, or through forms of trade and exchange with hinterland groups. Other cases of marine specialists are associated with environments where a hinterland either does not exist or is largely inaccessible, for example in the Aleutian Islands, Southeast Alaska, the desert coastline of southern California and Tierra del Fuego. Even here the coastal groups took terrestrial foods whenever they were available and suffered occasional hardship and even starvation notwithstanding the great abundance of marine resources in some of these areas (Schalk, 1979).

Stable isotope analysis of human bone collagen offers an alternative approach to palaeodietary reconstruction and some studies have produced claims for extreme specialisation on marine foods or their apparent avoidance (Richards and Hedges, 1999). However, these claims are open to challenge on the grounds that they are contradicted by archaeological evidence of palaeodiets, represent an unwarranted extrapolation from the diet of individuals to general palaeoeconomic patterns, or are otherwise based on methods with uncertain and untested margins of error (Milner

et al., 2004; Hedges, 2004; Richards and Schulting, 2006; Milner et al., 2006). They are best used to provide indications of general dietary tendencies rather than precise dietary reconstructions.

It is of course possible that patterns of subsistence existed in the much earlier time ranges of prehistory that have no analogue in recent millennia, and entirely plausible that over the long run there has been a general growth of human populations and intensification of economic exploitation. Klein et al. (2004), for example, note that size dimensions of limpets in South African cave sites suggest more intensive collection of molluscs in the Later Stone Age deposits of late-glacial and postglacial date compared to the Middle Stone Age deposits of Last Interglacial sites such as Die Kelders and Blombos. But the extrapolation from small numbers of mollusc shells to specialised shellgathering or marine subsistence economies seems unwarranted in light of the evidence presented above. In earlier prehistory as in more recent periods, the general tendency of the human economy is likely to have been towards adaptive flexibility, omnivory, and the integration of marine and terrestrial resources – and of coastal and inland environments – in varying combinations according to locally variable conditions. The further implications for interpretation of the long-term record are that in ignoring sea-level change, we are not only at risk of misreading substantial parts of the record of marine resources and arriving at interpretations that are fundamentally wrong, we may also be missing evidence of whole landscapes in the coastal zone that are quite different from those present in the same regions today, and critical to the testing of hypotheses about patterns of earlier hominin subsistence and dispersal.

3. Geological Issues

If we are to move beyond the obvious difficulties identified above, we need to examine two geological issues. One is the possibility of local crustal movements in coastal regions sufficient to create uplifted coastlines where the elevation of coastal material has outpaced the rise of sea level. This would make it possible to study glacial-period low sea-level coastal environments and associated archaeology without having to work below present sea level. The second is to identify the geological and geomorphological conditions most conducive to the underwater preservation and discovery of submerged landscapes and associated archaeology.

3.1. Coastal Uplift

Coastal classification systems have conventionally distinguished between coasts that are uplifted and those that are subsiding, as well as tilting margins where the hinterland is uplifting and the outer edge of the continental shelf is subsiding (Valentin, 1952; Inman and Nordstrom, 1971; Finkl, 2004). If we are going to find prehistoric sites formed during periods of Pleistocene low sea level that were then uplifted above the present shoreline, there must have been net uplift of the shelf zone itself. This is most likely to occur in areas of continental glaciation where glacio-isostatic rebound has occurred following deglaciation, or in zones of plate convergence, island arcs, and back-arc volcanism. Diapiric structure can also have significant local effects (Bailey et al., 2007a; Gracia et al., 2008)

Glacio-isostatic rebound is greatest in those areas which were under the thickest ice cover such as central Scotland and Norway and parts of North America (Lambeck, 1995; Shennan et al., 2000a,b). Uplift can exceed 200 m, as on parts of the Norwegian coastline, well in excess of the maximum Pleistocene sea-level amplitude, but is much less as one moves away from the affected zones (Figure 5). The impact of local ice offloading has little or no effect on the coasts of the Mediterranean or the Red Sea, or only with much attenuated effect mediated through global adjustments in the Earth's mantle. On the other hand, the regional hydro-isostatic contribution to net relative sea level rise, that is the crustal movement effected by the changing mass of water on

the continental shelf, needs to be taken into account and may amount to as much as 30 m of displacement on shallow coastlines (e.g. Lambeck 1996, 2004; Bailey et al., 2007a).

The major drawback of regions with high rates of glacio-isostatic uplift is that they were by definition uninhabitable for most of the period that we are interested in. After the ice had melted, extreme climatic conditions and periglacial landscapes would have continued to pose considerable challenges for human occupation for many millennia. Even in regions where there were ice-free coastlines with suitable resources for human occupation, and uplifted coastlines where we would expect to find early coastal sites, there seems to be a considerable time lag before the appearance of human settlement. In Norway an ice-free coastline became available at least as early as 15 ka and perhaps earlier, and palaeontological evidence suggests that some mammalian resources were available on land as well as marine resources at the coast edge. The shorelines from that period are now at or above the present-day shore position in some areas of Norway, but there is no unequivocal archaeological evidence of a human presence until about 11.5 ka, when new settlements of maritime communities dispersed rapidly along the full length of the Norwegian coastline (Bjerck, 2008). This time lag may reflect the unsuitability of the environment for sustained human occupation until the opening up of the hinterland with final deglaciation at about 11.5 ka, or the onset of more productive marine conditions with the northward movement of the North Atlantic current to Norwegian waters at that time. Or it may reflect time lags in the development of the technology and social organisation necessary to build and maintain seaworthy boats capable of dealing with Atlantic maritime conditions and strong tidal current, without which coastal occupation in Norway would have been scarcely possible. In Scotland the earliest sites are similarly present only after about 10 ka, and similar considerations apply, although here the relationship between sea level change and isostatic uplift is also locally variable and stretches of coastline with evidence of earlier archaeological sites may exist that have yet to be explored (Dawson and Smith, 1997; Smith et al., 2006; Wickham-Jones and Dawson, 2006; Karen Hardy, personal communication, 2007).

On the Pacific coast of Northwest America, current interest is focussed on the possibility of human dispersal into the Americas via an ice free corridor along the coast, exposed at an early stage of deglaciation of the Cordilleran ice sheet. Here, an extensive coastal plain with terrestrial resources and a productive marine environment at the coast edge was available from as early as 16 ka, but archaeological evidence of coastal sites earlier than 13–12 ka has yet to be found (Josenhans et al., 1997; Mandryk et al., 2001; Erlandson, 2007; Erlandson et al., 2008). However, the relationship between isostatic uplift and sea level rise is complicated and locally variable, because both land and sea levels were moving at different rates. Coastlines formed as recently as 13 ka are now at least 120 m below present sea level, while those formed at 10 ka are now 20 m above present sea level and some distance inland. Since the earliest verified dates of human occupation in the Americas south of the ice sheet are 14.5 ka, underwater exploration of the shelf region on the Northwest coast will be necessary to test the hypothesis of coastal dispersal (Fedje and Josenhans, 2000).

The other type of situation where sufficiently rapid uplift can occur is at plate boundaries, where tectonic uplift of coastlines, or offshore steepening of the topography by subduction and underthrusting, means that sites that were once on the shore when sea level was much lower than the present, are still available for discovery and investigation in locations above modern sea level on or close to the present day coastline (Figures 5 and 6). Some of the best and archaeologically most significant examples of this effect are in the southern Pacific, in the New Guinea region and along parts of the coastline of Peru. The coastal cave of Matenkupkum on the island of New Ireland in the Bismarck Archipelago east of New Guinea is an outstanding example of an early dated shell midden at 37 ka with substantial shell deposits and remains of other marine resources

(Gosden and Robertson, 1991), which appears to owe its unusual record to an extremely steep offshore profile. The cave of Jerimalai on East Timor is similarly situated with dates of at least 43 ka and an abundant marine fauna that includes pelagic fish such as tuna, reef fish, sea turtles and rocky-shore molluscs (O'Connor, 2007). Full details of faunal data have yet to be published, and detailed studies of local bathymetry and tectonics have yet to be integrated with the archaeology in these regions, but it seems likely that these sites owe the high visibility of marine resources at an early date to tectonic effects. Tectonics may also account for the enigmatic finds of early material dated at 0.8 Ma on the island of Flores, later the home of *Homo floresiensis* (Morwood et al., 1999, 2004). The island is now some 25 km from the Indonesian mainland, but the region is tectonically very active and the island could formerly have been connected to the mainland. In view of the potential significance of sea crossings at this early period (cf. Bednarik, 2003), analysis of local tectonic effects is of high priority in resolving this issue. Early dated shell middens as early as 13 ka in Peru may also reflect similar tectonic effects (Sandweiss et al., 1989). However, both these Pacific regions were colonised at a relatively late period by modern humans, and can give no insight into the nature of earlier hominin adaptations to coastal environments during low sea level stands.

At the interface between Africa and Eurasia, the main zones of tectonic activity related to plate motions in coastal regions with potential for coastal uplift are in the Mediterranean region where the convergence of African and European plates produces a regionally complex and variable pattern of crustal compression and stretching, and in the rift zone of the Red Sea. In the Mediterranean, intensive study has been devoted to plate tectonic boundaries (McKenzie 1970; Vita-Finzi 1987; Hubert et al., 1996), historical seismicity (Ambraseys 1971; Ambraseys and Bilham, 2003), and rates of vertical movement on coastlines during the last 2000 years (Flemming and Webb, 1986; Woodworth and Flemming, 1988; Flemming, 1993). Although raised Pleistocene beaches occur at many places, the same regions are associated with steep continental shelves and submerged cliff and terrace features formed at low sea level stillstands (see Bicho and Haws, 2008 for Portugal). In these cases, the relief at the coast is increasing, and possible prehistoric sites now located offshore are not uplifted. Areas of exceptional local uplift include the south-west corner of Crete, with uplift of the order of 9 m in the last few thousand years (Spratt, 1860; Hafeman, 1965; Flemming and Webb, 1986; Pirazolli et al., 1992), and parts of the nearby islands of Antikythera and Rhodes. These coasts are very steep and only small areas of land a few tens of metres wide are exhumed by the uplift. None have any credible evidence of human settlement earlier than the Holocene.

In other coastal regions of the Mediterranean, tectonic movements in the last two thousand years have been biased towards subsidence at rates of the order of 1 m per thousand years (Flemming and Webb, 1986). Other coastlines show long-term stability or only slow rates of uplift. On the Rock of Gibraltar, for example, the rate for the last 200 ka is $0.05 \pm 0.01 \text{ mm yr}^{-1}$, or 0.5 m ka^{-1} which equates with an uplift of 5 m in the last 100 ka (Rodriguez-Vidal et al., 2004), although diapiric structures have resulted in localized variations (Gracia et al., 2008). Hence, the uplift since the last glacial maximum at 20 ka is ca 1 m. Clearly if such modest rates of uplift continued over time spans of one million years or more, major uplift might result, and archaeological materials deposited on a glacial-period shoreline in, say, MIS 18 at 750 ka might now be lifted clear of modern sea level. However, they would have been exposed to several episodes of submergence and re-exposure by the more rapid cycle of sea-level change in the earlier stages of their history, and subjected to other vagaries of erosion or burial by sediment.

Nevertheless, even slight tectonic effects become more marked over very long periods. Southern Britain, for example, appears to have undergone progressive regional uplift throughout the Pleistocene at 0.07 to 0.1 m ka^{-1} , resulting from a variety of longer-term isostatic and tectonic

processes (Maddy et al., 2000). Such rates, though lower even than in Gibraltar, could have a significant impact on the visibility of coastline archaeology from very early periods. Two of Britain's earliest Palaeolithic sites, at Boxgrove (Roberts and Parfitt, 1999) and Pakefield (Parfitt et al., 2005) are in what would have been coastal or near-coastal locations when occupied at 0.8 Ma and 0.48 Ma respectively. Though they are necessarily associated with temperate conditions (given the impossibility of early occupation in Britain during glacial conditions) and hence with relatively high sea levels, nevertheless they provide a tantalising insight into conditions of archaeological preservation, coastal palaeoenvironment and palaeoeconomy in these early periods, and highlight the transformations of coastal palaeogeography brought about by long-term crustal movements.

The Red Sea Basin is a rift zone resulting from thinning and separation of the Earth's crust accompanied by volcanism and faulting, seafloor spreading, separation of the Arabian and African plates, subsidence of the rift floor, and progressive uplift of the rift flanks to form mountain escarpments. There have been two main phases of seafloor spreading, the first between 41–34 Ma, and a later phase from about 5–4 Ma onwards, which created the modern outlines of the current basin with a permanent connection to the Indian Ocean and a central graben some 2850 m deep (Girdler and Styles, 1974; Bonatti, 1985; Braithwaite, 1987; Omar and Steckler, 1995; Purser and Bosence, 1998). Recent vertical movements of coastal regions are therefore possible in such circumstances. An additional and more localised effect is salt tectonics, where beds of salt hundreds of metres thick have been overlain by denser sedimentary rocks, creating instability and diapiric structures (Purser and Bosence, 1998; see also Gracia et al., 2008).

Despite these tectonic processes, the coral terrace from the Last Interglacial high sea level consistently occurs at an elevation within a few tens of metres of that expected globally (Bantan, 1999), indicating very little regional uplift over the past 100 ka. Rates of tectonic uplift are not well established for earlier periods, and while higher rates cannot be ruled out, there appears little reason to expect major vertical displacements over the past 2 Ma (Bailey et al., 2007a). Very steep offshore topography occurs in the north of the Basin and particularly in the Gulf of Aqaba, but the possibility of finding early coastal sites with marine resources here is compromised by the relatively low marine productivity of the northern Basin, especially during low sea level stands when marine inflow from the Indian Ocean was reduced and salinities in the north were high enough to inhibit marine production (Sidall et al., 2003). In the south, close to the mouth of the Red Sea, with more productive marine conditions, the discovery of early coastal sites is compromised by a shallow offshore topography, which would have extended the coastline by about 100 km at the maximum of marine regressions. At any rate, early human dispersal across the southern end of the Red Sea appears always to have required sea crossings of some sort, even at lowest sea-level stands, whether or not the human groups in question were exploiting marine resources (Bailey et al., 2007a; Bailey, in press).

It is clear that geological processes can uplift coastlines formed when sea levels were substantially lower than the present. However, most of these conditions are in regions of the world that were uninhabitable, or colonised by human settlement too recently to provide any useful information about earlier hominin adaptations, or otherwise unlikely to provide appropriate evidence. There may be other parts of the world worth investigating from this point of view, for example the margins of plate boundaries in southern and eastern Asia, and we do not rule out completely this avenue of exploration. Nevertheless, the search for uplifted coastlines is not going to circumvent the need for underwater exploration, and there are good geological reasons for supposing that relevant palaeoenvironmental and archaeological evidence is preserved underwater and can be found.

3.2. Underwater Preservation

What then of the possibilities for the preservation of prehistoric deposits remaining on the sea floor during and after marine inundation, either in primary stratigraphic context, or as scattered or transported items? What processes are most conducive to the survival or destruction of prehistoric sites during inundation and their subsequent preservation and discovery and how much of the now submerged landscape can be reconstructed in the form in which it existed before inundation?

A prehistoric deposit of stone artefacts, faunal remains, shells or other cultural materials, if it is to be discovered underwater, must first be deposited and survive in the land conditions of its origin. It must then survive at least one marine transgression, followed by the oceanographic conditions of submergence and subsequent sediment movement in the area. The greatest threat of destruction occurs when the site is in the surf zone and exposed to the direct impact of breaking waves, and during the period when the water is only a few metres deep over the site and the oscillatory water motion at the seabed is still violent. Assuming that an archaeological deposit survives these stages of inundation, it will only be discovered centuries or millennia later if an observer using diving gear, or a remotely operated vehicle or manned submersible can see artefacts or other related material exposed on the sea floor, or if coring or dredging or some other mechanical device extracts indicators which are buried in sediment. Thus re-working of the Pleistocene terrestrial deposits by the sea and the subsequent deposition of modern marine sediments are critical factors (Dix et al., 2006).

Since visibility underwater is restricted to a range of the order of 1–20 m, and careful examination of the seabed is relatively rare, the probability of finding prehistoric materials and terrestrial environmental indicators *in situ* by targeted survey is inevitably low. Paradoxically, the number of recoveries by chance is remarkably high. Prehistoric artefacts and Pleistocene terrestrial palaeontological materials are regularly recovered by trawlers (Louwe Kooijmans, 1970/71; Glimmerveen et al., 2004), found by sports divers, and found in dredge spoil from aggregate recovery or harbour engineering works.

Stright (1986, 1990) made an inventory of submerged prehistoric sites on the continental shelf of the USA, and Flemming (1998) provided a statistical outline of the submerged marine prehistoric sites known globally with country by country counts, and an assessment of the trends in rates of discovery. At that time the number of sites discovered was increasing rapidly off the coast of many countries, and the maximum age of oldest known sites and the depth of discovery were increasing exponentially. Since the deepest known artefact is from a depth of 145 m (Long et al., 1986), and the oldest known artefacts recovered from offshore are now the Acheulean handaxes from Table Bay off Cape Town (Werz and Flemming, 2001), the scope of prehistoric artefacts already recovered extends out to the edge of the continental shelf, and for a period of several hundreds of thousands of years. The sample is undoubtedly very sparse, but it is not possible now to object that sites cannot survive inundation, and we can even assert that, in suitable circumstances, prehistoric artefacts can survive multiple marine transgressions.

The conditions which occur under different circumstances of shoreline configuration and supply of sediments as they affect the taphonomy of submerged prehistoric sites are summarised by Dix et al. (2006). They review the literature on the re-working of different types of coastal geomorphological features such as beaches, deltas, lagoons, coastal dunes, marshes, beach ridges and estuaries as the sea inundates them. Flemming (2003, 2004b) stresses the importance of detailed topographic configuration at the sub-1 km scale in determining the survival of undisturbed archaeological strata during inundation. Generalisations made on the basis of ‘typical profiles’ ignore, almost by definition, the peculiar chance configurations which can

guarantee survival. Standard navigational charts do not indicate submerged cliffs or profiles with vertical faces, since soundings are measured at discreet spatial intervals usually of hundreds of metres, and interpolation of the soundings will imply a relatively gentle gradient. Divers and submersible operators have long known that cliffs and vertical coral reef faces are quite common; these are often associated with caves and other coastline indicators, and are now being more routinely mapped by continuous mapping techniques such as swath bathymetry.

Other factors enhancing site survival include interior archipelago environments with limited wind fetch in all directions, coastal indentations with low energy exposure, coasts with very low gradients and constructive wave action, cohesive sediments such as clay or compacted peat, concreted deposits inside caves, and material trapped in crevices and gullies in bedrock. Areas of known prehistoric occupation, sites in stratigraphic context, and scattered artefacts on the seabed tend to be associated with zones of modern seabed erosion, though this correlation is not exact. Nevertheless, there is a strong indication from known sites which have been studied for several years that the substrate is being eroded and destroyed. It follows that the total resource of submerged prehistoric sites is being steadily depleted through natural processes.

This brief review should be sufficient to show that the conditions for survival of prehistoric sites during and after marine inundation are quite common. The situation is by no means as hopeless or unpromising as might be supposed, especially if one takes account of the equally wide range of potentially destructive processes that can obscure the terrestrial record, including ice movement, frost action, cliff falls, river erosion, soil creep, bioturbation, and agricultural, industrial and urban development.

4. The Coastal Shelf

The limitations discussed above provide a strong motive for trying to obtain *in situ* archaeological data from prehistoric sites on the continental shelf. Sufficient data have been obtained in the last four decades to reinforce that motive, demonstrating that the taphonomy of submerged marine sites is now quite well understood, and that sites can be located and studied in the context of submerged landscapes on the broader scale. Here we elaborate this point with a brief review of examples taken from the Afro-Eurasian interface area, beginning with the Atlantic margins and working from North to South.

4.1. Baltic and Northern North Sea

Andersen (1980), Fischer (1991, 1995, 2004), Pedersen et al., (1997), Lübke (2001, 2002a,b, 2003), and Skaarup and Grøn (2004) have described a wide range of Mesolithic and Neolithic sites found on the floor of the Baltic Sea from the shoreline out to depths of the order of 15 m. Primary deposits show multi-family settlements with huts and waterfront structures including wooden jetties, fish weirs, and artefacts such as canoes, paddles, hearths, burials, and tools of stone, bone and antler. Survival of artefacts within sedimentary deposits of peat and clay has been enhanced by the very limited fetch for wind and waves within the Danish archipelago and amongst the smaller islands of the German Baltic coast. Some submerged Mesolithic sites have been found on the Swedish coast (Larsson, 1983). More than 2000 underwater sites are now known from Danish waters, many of them in locations that can be predicted by identifying topographic conditions favourable for fishing camps and communal fish weirs (Fischer, 2004, 2007).

On the North Sea coast of Denmark and Germany, no archaeological deposits have so far been found offshore with artefacts in primary context, but fishermen have trawled up bones of Pleistocene megafauna off the Danish coast (Post, personal communication, 2003). Since much work suggests that the earliest Mesolithic occupants of this area alternated coastal fishing and

exploitation of coastal marshes with foraging trips up-river for inland hunting of large mammals, there is much interest in examining the drowned valley of the Elbe across the North Sea floor (Fischer, 2004). Further north in the North Sea, a single flint artefact was found by Long et al., (1986) in a core from the Viking Bank between Scotland and Norway at a water depth of 145 m, and the location and probable date of 13 ka correlate well with the land boundaries identified by Lambeck (1995). The conditions for survival of prehistoric deposits in the northern North Sea are not good due to the exposure to Atlantic storm waves, but they are not zero (Flemming, 2003). Archaeological investigations along the Northumberland coastline of northern England have also revealed on-shore coastal sites dated at about 10 ka on a coastline that has undergone modest isostatic uplift with little lateral movement of the shoreline following the postglacial flooding of the North Sea, encouraging the search for offshore archaeology but so far without definitive results (Engen and Spikins, 2007; Waddington, 2007; Waddington and Pedersen, 2007).

4.2. Southern North Sea and English Channel

This area offered an extensive and potentially productive lowland territory for late Palaeolithic and Mesolithic hunters and gatherers following the retreat of ice sheets. This territory extended unbroken from northern England to Denmark, though it was progressively reduced by the final stages of sea level rise until the land connection between Britain and France was finally severed by about 9 ka (Coles, 1998; Waddington, 2007). Today, this area has reduced wave action and a higher input of sediments from large rivers compared with the northern North Sea. The sedimentary regimes have been described by Kenyon et al., (1981) and Gibbard and Lautridou (2003). Pleistocene megafauna dating from the period 30–20 ka has been dredged from the seafloor by fishermen and sand-aggregate dredgers at the rate of c. 20 tonnes of bones per year (Post, personal communication, 2003). Dutch and British archaeologists are collaborating to develop a management plan for this important area (Peeters, 2007, 2008). A small but significant number of Mesolithic artefacts and human bones have been recovered from the central southern area in the region of Brown Bank (Glimmerveen et al., 2004, 2006), which complements the antler harpoon recovered from the Leman and Ower Bank further north and dated at ca 11.5 ka (11,950–11,300 cal BP) (Tolan-Smith, 2008), and the overall potential of this sector has been analysed in detail by Ward et al. (2006). A small number of Palaeolithic artefacts have been recovered and are being catalogued by Glimmerveen (personal communication, 2007).

The Pleistocene and Holocene sediments of the central North Sea have been studied through re-analysis of offshore hydrocarbon geophysical acoustic records (Gaffney et al., 2007). This technique reveals an intriguing network of overlaid drainage patterns, indicating major rivers, coastal marshes, braided channels, creeks, and palaeoshorelines, all buried beneath modern marine sands. The pattern of wetlands, deltas, and narrow marine inlets is reminiscent of the topography of the Danish archipelago, and would have provided a rich environment for Mesolithic populations exploiting marine resources and coastal wetlands. The detailed topographic data provided by Gaffney et al. (2007) could be followed up by coring and sampling in the locations which seem most suitable for Mesolithic occupation and the search for artefacts.

In the English Channel two important sites have revealed *in situ* deposits of prehistoric artefacts. In the sheltered waters of the Solent, a Mesolithic settlement has been found by divers at a depth of 11 m (Momber, 2000, 2001, 2004, personal communication, 2007, Momber and Campbell, 2005). The remains include posts, cut timbers, some probably associated with boat building, a mesh of wood which could be the floor of a hut, worked flints, and hearths with charcoal and burnt flints. The site off the north shore of the Isle of Wight is very sheltered from Atlantic wind and waves, but the strong tidal currents are winnowing away the sedimentary matrix of clay and peat, so that more artefacts are exposed each year. Radiocarbon dating of cut timbers provides a

date of 8565–8345 cal BP (Beta 140104). A general review of the potential of the English Channel for preservation of prehistoric sites is given by HWTMA and Flemming (2007)

Directly opposite the Isle of Wight on the southern side of the English Channel is the Cotentin peninsula on the French coast, and off the headland of Cap Levi near the village of Fermanville is a submerged Palaeolithic site at a depth of 20 m (Scuvée and Verague 1988; Verague et al., 1991; Margot, 1998; Coutard, 2000; Cliquet et al., 2002; Coutard and Cliquet, 2005). Over 2000 lithic artefacts were recovered by divers prior to 1988, including bifaces, cores and debitage. The tool assemblage is Middle Palaeolithic, though without precise dating. The site is in a depression near the foot of a rock known as Biéroc, which breaks the surface about 900 m off the headland of Cap Levi. The artefacts are found in the depression, adjacent to eroding layers of silt and peat. Divers continue to find artefacts, indicating that the site has not been completely eroded away and that some artefacts may still remain in situ.

4.3. Western Mediterranean

A key early consideration of prehistoric occupation of the Mediterranean shelf is given by Alimen (1975). Shackleton et al. (1984) examined the broad topography of the western Mediterranean to evaluate what areas of the continental shelf would have potentially been exposed for subaerial vegetation and fauna during glacial low sea levels, and Flemming et al. (2003) provide a general review of known submerged prehistoric sites in the Mediterranean. More detailed studies of the Straits of Gibraltar have shown that at no time were they closed during the Pleistocene, and the sea channel would have remained open to a width of at least 10 km. To the west, now-submerged islands might have offered stepping stones for a crossing from North Africa, but neither faunal nor archaeological data provide decisive evidence in favour of sea crossings (Derricourt, 2005; O'Regan, 2008; see also Ramos et al., 2008; Rodríguez-Sánchez et al., 2008).

Submerged caves at a depth of 21 m off the Southwest tip of Gibraltar have been surveyed and subjected to trial excavation for potential human occupation (Bailey et al., in press). A row of small caves has formed in the northern face of a ridge of tectonic breccia, situated so that they are protected from the Atlantic waves incoming from the Southwest. The caves contain a surface layer of modern debris and marine sands, under which there are strata of cobbles and fine sediments indicating a coastal or beach environment. One of these caves was selected for excavation, and this work is in progress. It is being accompanied by comprehensive acoustical survey of the whole shelf region around the rock of Gibraltar, using swath bathymetry, side-scan sonar and sub-bottom profiling techniques in order to identify other potential locations of archaeological material that can be investigated using deep-diving techniques and terrestrial sediments that can be sampled by coring. The shelf area here is compact and relatively circumscribed, ranging in width from 2–5 km and lends itself to such a comprehensive underwater survey, extending from the present-day shoreline to the outer edge of the continental shelf. It was also a key environment for the inhabitants of the famous on-shore caves such as Gorham's Cave, which have produced a long and rich archaeological sequence from the Last Glacial period, including one of the largest concentrations of Neanderthal finds in Europe (Stringer et al., 1999, 2000; Finlayson et al., 2006). The wider region appears to have been a last refugium for the Neanderthals (Finlayson, 2008) and detailed reconstruction of the now-submerged landscape and the manner in which it was exploited at successive periods is a critical piece of missing information in understanding the pattern of Neanderthal occupation and ultimately replacement by modern humans.

Other important sites in the western Mediterranean basin include the submerged cave with rock-art paintings near Marseille, entered through a tunnel which has its mouth at a depth of 40 m

below sea level (Clottes and Courtin, 1994, 1996), and the great sea caves at Palinuro, where Blanc (1940) found bone breccia cemented on the walls. These caves descend to an eroded shoreline terrace at a depth of 50 m below present sea level.

4.4. Eastern Mediterranean

The most complete prehistoric site with artefacts undisturbed in stratigraphic context in the eastern Mediterranean is at Atlit on the coast of Israel (Galili and Nir, 1993; Galili et al., 1993). This is a Neolithic village site submerged by 10 m and dated at about 9–8.5 ka with many preserved organic materials, including woven basket-work, charcoal, burials, and a fresh-water well, and subsistence evidence demonstrating fishing alongside crop cultivation and animal husbandry. The materials were recovered in clay sediments retained between offshore sand ridges and sealed by a later covering of marine sand, thereby ensuring protection of the material, together with occasional exposure when storms removed parts of the sand covering, thus allowing discovery of archaeological deposits during exploratory diving.

In contrast, the Neolithic site at Aghios Petros, in the northern Sporadhes islands, Greece, consists of lag deposits (Flemming, 1983). In this case the original strata of accumulated soil and artefacts has been slowly winnowed by gentle wave action in a sheltered location in the lee of an island, removing all the fine sediments, so that animal bones, pottery, and lithics have been compacted together on the sea floor.

4.5. Red Sea

Purser and Bosence (1998) include several chapters referring to lithic artefacts found in the context of fossil coral reefs on the Red Sea coast. Faure and Roubet (1968) pioneered the idea that Palaeolithic materials might survive in association with interglacial high sea level deposits, indicating past marine exploitation, an idea taken further by Walter et al., (2000), though the direct evidence in its favour remains weak (see earlier discussion in section 2). In 2006 a team of divers worked around the Farasan Islands at the southern limit of the coast of Saudi Arabia, examining the coastal geomorphology and submerged shorelines, in order to assess the potential for occupation of the adjacent continental shelf during the last glacial cycle. Over 800 shell middens, many consisting of large mounds of shell with contained ash layers and animal bones, were found above sea level on the islands, dating back to about 8 ka, and almost always in association with the edge of a coral terrace. Below sea level the divers found undercut notches in submerged coral terraces down to a depth of about 60 m, indicating previous low sea levels. Local fishermen have reported underwater shell deposits, and the complex offshore topography, with varied relief and occasional deep depressions that could have retained freshwater, suggests potentially favourable conditions for occupation when this landscape was exposed at lowered sea level. The underwater topography also suggests that the present-day conditions of archipelagos and indented and protected shorelines would have been replicated at lower sea levels, offering favourable conditions for the preservation of archaeological deposits during and after inundation by sea-level rise (Bailey et al, 2007a,b; Bailey, in press).

5. Conclusions

Sea levels have been substantially lower than the present for most of human existence, certainly throughout the Middle and Upper Pleistocene and most probably for the greater part of the Plio-Pleistocene time-range associated with the full story of human origins and development. The current interest in the possible significance of marine resources and coastal environments in this long-term story has sharpened understanding of the large potential biases in the surviving record of coastal settlement. Our review of the issues highlights how little we really know about the nature of the coastal resources or archaeological evidence associated with periods of lower sea level, and emphasises how important the search for underwater evidence is if we are to fill out

the details of this picture and find the decisive evidence to test existing preconceptions and hypotheses. A considerable body of underwater archaeological evidence and experience of underwater work now exists, and new technologies for underwater survey and new projects that are probing the deeper levels of the submerged landscape are lending new momentum to this research agenda. Moreover, the discovery of evidence for submerged landscapes and submerged archaeology is not simply extending further out to sea the patterns of environment and archaeological occupation that we already know about on the present-day land surface. There is every indication that both archaeological and palaeoenvironmental records on the seabed are likely to reveal evidence that is qualitatively different from that on land. Archaeological results have the potential to reveal patterns of settlement and exploitation, for example in relation to marine resources, which have no known counterpart in the contemporaneous archaeology available on land. In the palaeoenvironmental sphere, there are reasons to think that the coastal environments that are now submerged may have provided productive conditions for plant and animal life that have no analogue on modern coastlines. Most interesting in this regard is the coastal oasis hypothesis of Faure et al. (2001), who have suggested that as sea level dropped, the water from underground springs would have found an easier exit onto the adjacent coastal areas, creating a well-watered coastal lowland and potential refugium for plant and animal life during glacial periods over precisely the time range when overall climatic conditions were becoming more arid in the adjacent hinterland, with profound implications for the understanding of early human settlement and dispersal. All of these possibilities are hypotheses in need of testing, and they will remain untested and untestable without the development of underwater investigations of the type that we have described above.

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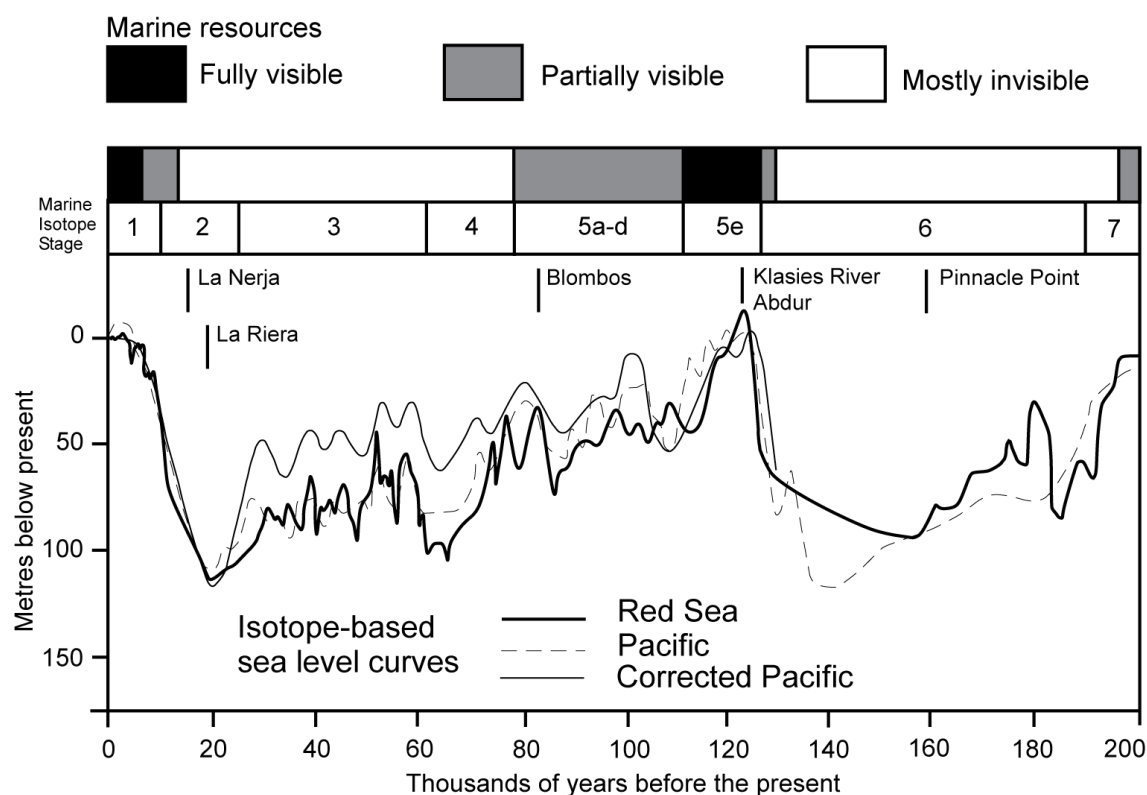


Figure 1. Sea level curves for the past 200 ka, showing archaeological sites with evidence of marine resources (see text for further details). The Red Sea and Pacific records are derived from $\delta^{18}O$ measurements of benthic foraminifera. The corrected record is based on corrections derived from elevated coral terraces. Sources: Chappell and Shackleton, 1986; Shackleton, 1987; Imbrie et al., 1984; Lambeck and Chappell, 2001; Lambeck, et al., 2002; Walbroek et al., 2002; Sidall et al., 2003; Antonioli et al., 2004.

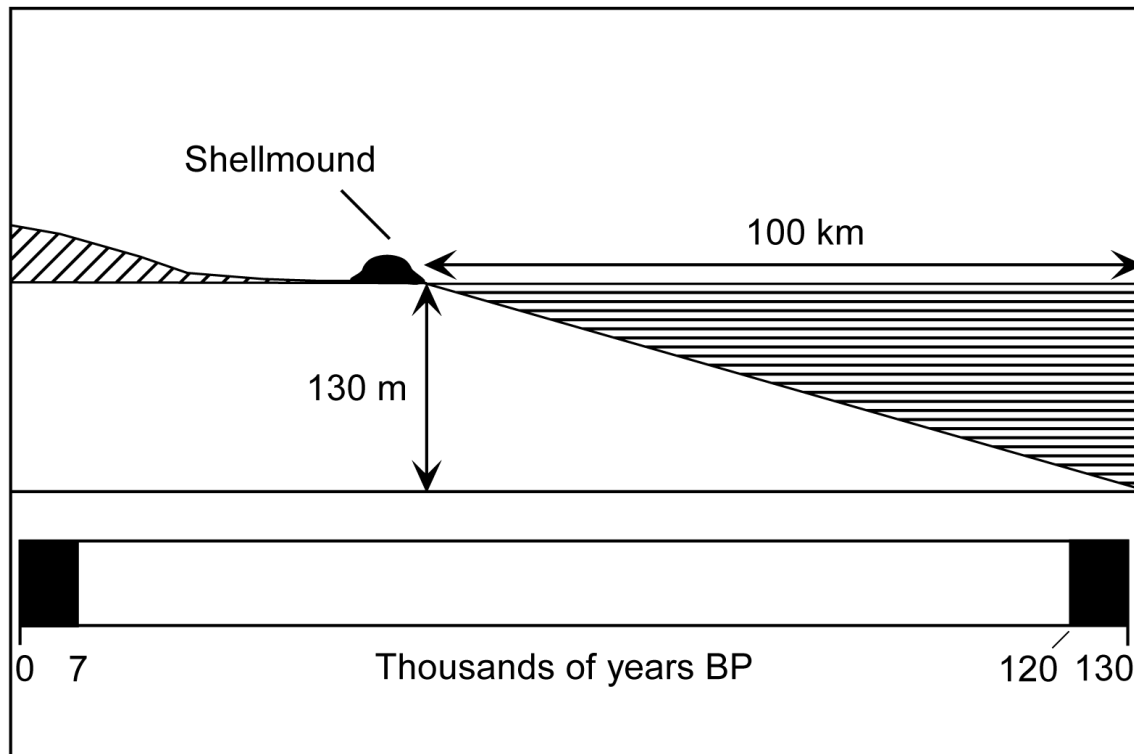


Figure 2. Window of visibility above sea level for shell mounds adjacent to a shallow shelf. Black = visible, white = invisible. Shell mounds or other coastal sites with marine resources are expected to be visible only at highest sea levels, those associated with lower sea levels to be submerged.

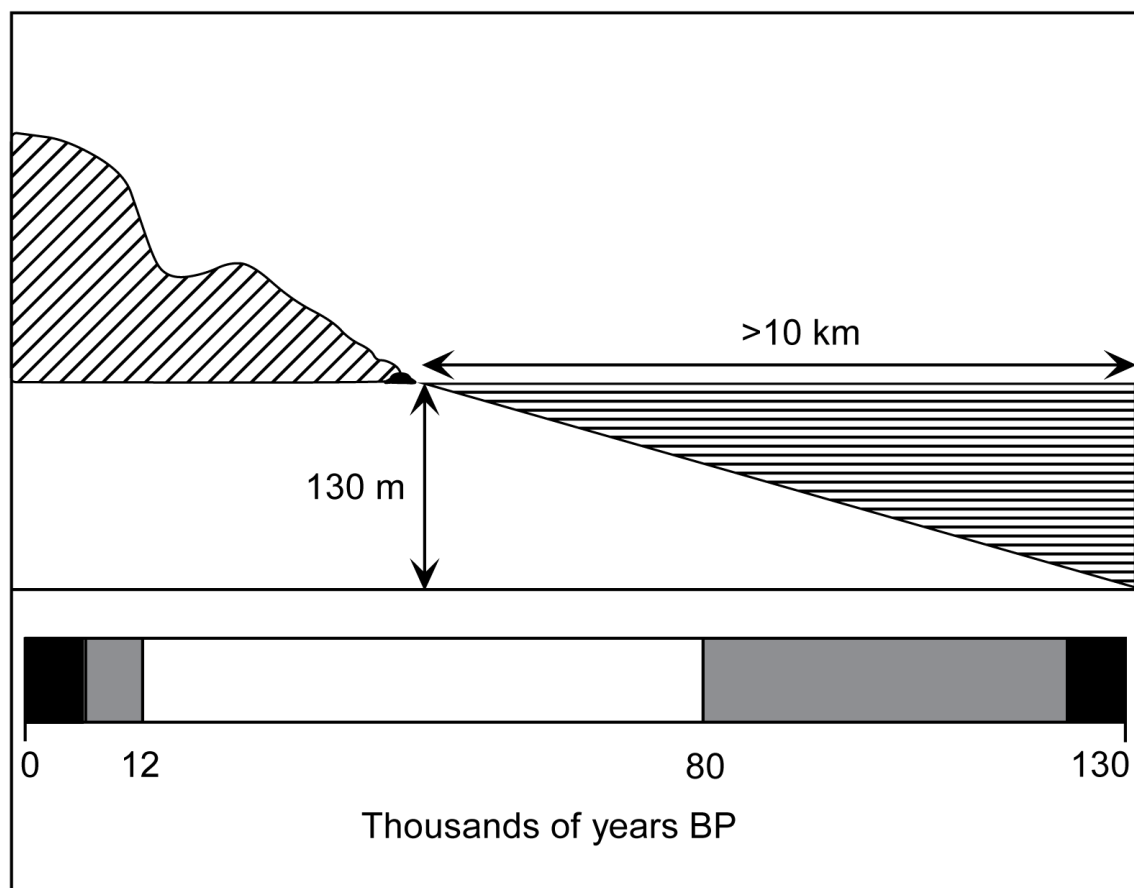


Figure 3. Window of visibility for shell mounds near a narrower shelf. Conventions as in Figure 1. Gray = some marine resources visible in deposits on present-day land and some deposited in now-submerged locations.

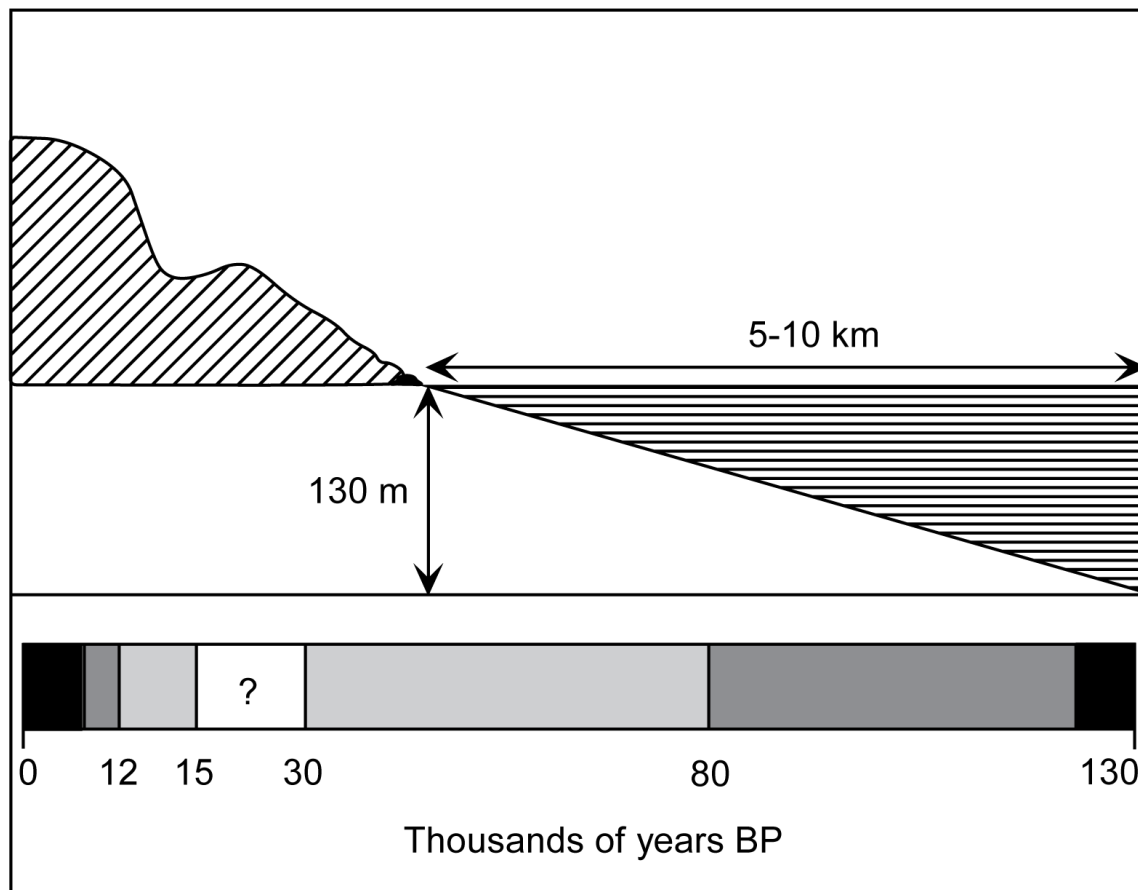


Figure 4. Window of visibility for shell mounds near a very narrow shelf. Conventions as in Figure 2 and 3. Lightest gray = only minor evidence of marine resources visible on present-day land and most deposited in now-submerged locations. The duration of the window depends on the width of the shelf but is expected to be largely closed at lowest sea levels during the glacial maximum.

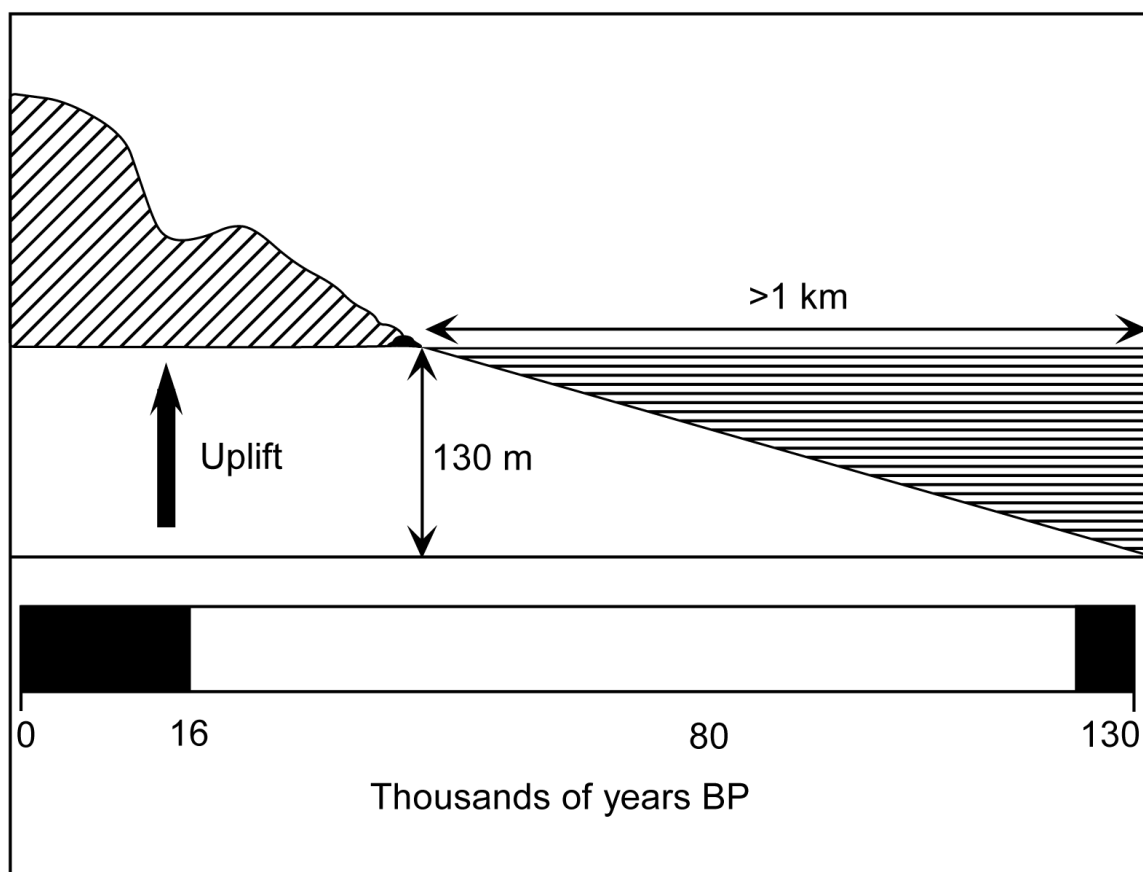


Figure 5. Window of visibility for shell mounds on a coastline uplifted by isostatic or tectonic movement. The duration of the window depends on the amount of uplift of the coastal site since its deposition. Conventions as in Figure 3. Theoretically sites could be visible throughout the full glacial period on coastlines with sufficiently rapid uplift, but this is rare in practice. See text for further discussion.

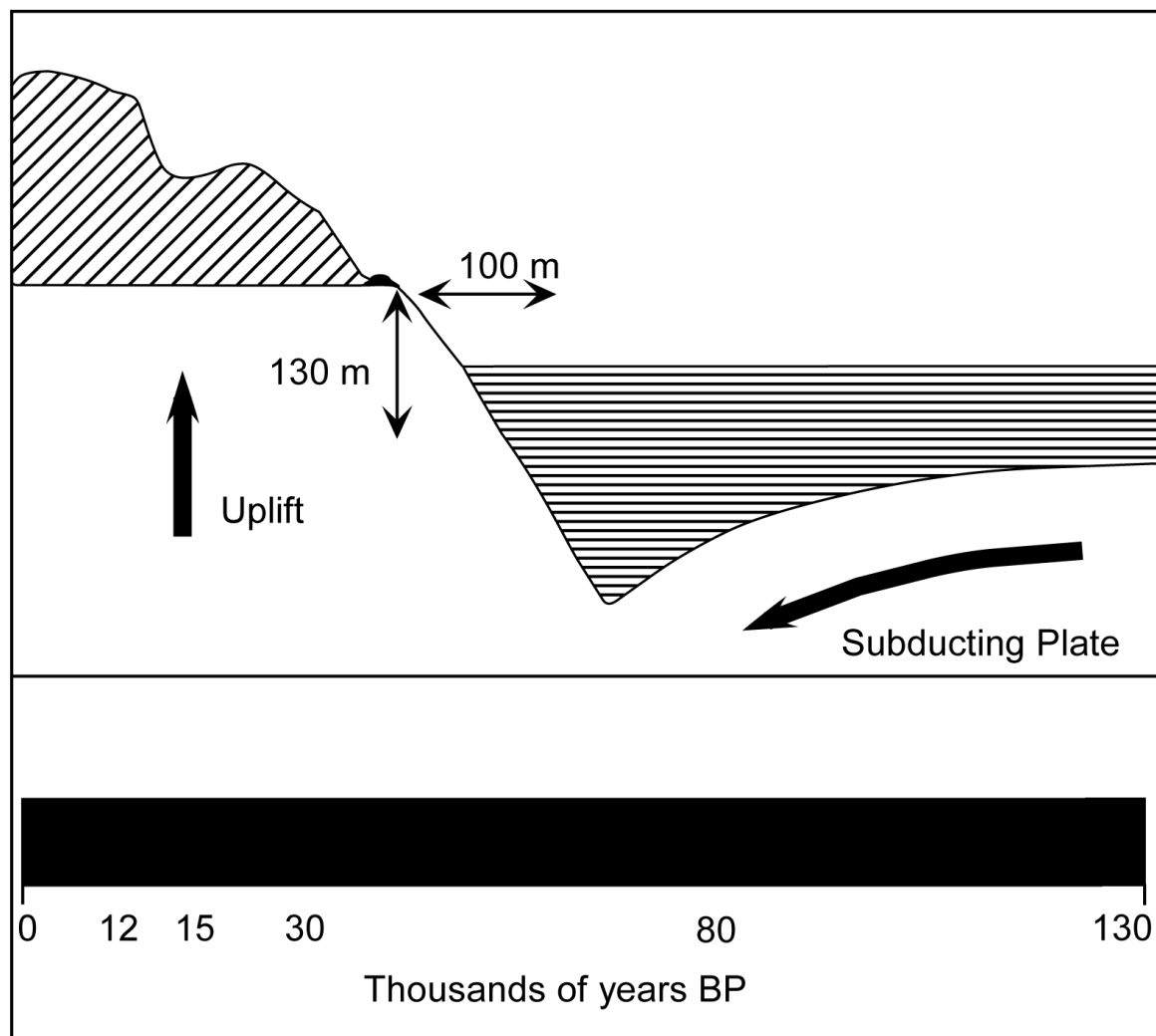


Figure 6. Window of visibility for shell mounds on a subducting coastline. Conventions as in previous figures. Subduction may be associated with uplift as in Figure 5.