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Editors

Macro-engineering Seawater in Unique Environments

Arid Lowlands and Water Bodies Rehabilitation

Springer

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Living with Sea Level Change and Dynamic Landscapes: An Archaeological Perspective

Geoffrey N. Bailey and Geoffrey C. P. King

1 Introduction

For most of human existence on this planet over the past 2 million years, sea level has been substantially lower than the present and has swung through changes of more than 100 m in response to the glacial–interglacial climatic cycle. At a time when modern society is increasingly concerned about the potentially destructive impact over the coming decades of a sea-level rise of 3 m or so, it is sobering to realize that prehistoric societies across the world faced a sea-level rise between about 16,000 and 6000 years ago of 130 m (Fig. 1). That change of course was spread over many human generations and many millennia, so that the full effects would not have been experienced within a single human lifetime. Nevertheless, the long-term cumulative effect of sea level rise and loss of territory would have been dramatic. On a world scale, substantial areas of continental shelf were successively exposed, creating potentially attractive territories for human settlement and migration and land connections between major land masses, and then removed again by sea level rise (Fig. 2). In Europe, during the last glacial period, the total land mass of the continent was extended by as much as 40% at the maximum marine regression (Fig. 3), with a corresponding loss of land when sea levels rose as the continental glaciers melted into the oceans. In some parts of the sea-level cycle, and especially in regions where the slope of the continental shelf is shallow, the effects would have been noticeable and sometimes dramatic within the lifetimes and memories of the people affected. Moreover, these changes have taken place repeatedly over the long Pleistocene history of human existence.

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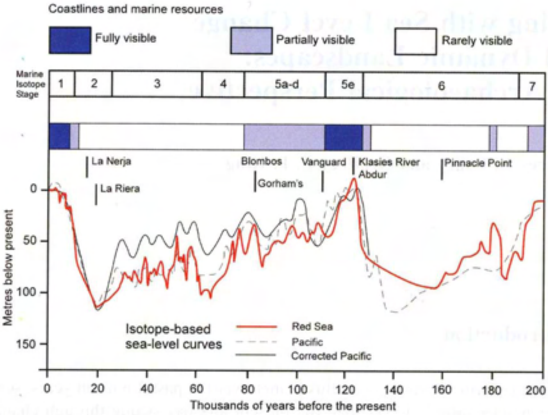

Fig. 1 Smoothed curve of sea-level change over the past 200,000 years, showing amplitude of sea-level change and impact on the visibility of palaeoshorelines and archaeological sites with evidence of coastal and marine exploitation. Site names refer to coastal sites in Africa and Mediterranean Europe, mostly caves sites, with long stratified sequences of archaeological material, associated with steeply shelving coastlines or periods of high sea level, and showing some evidence of marine food remains (shells of marine molluscs and marine vertebrates). Similar cycles of sea-level change repeated at similar intervals back to about 0.8 million years, with long periods of low sea level punctuated by short episodes of high sea level as high as or higher than today. Before that the amplitude of sea-level change appears from the deep-sea isotope record to have been less, but sea levels lower than present were the norm back to at least 2 million years ago. Sea-level data from Lambeck and Chappell (2001), Shackleton (1987), Siddall et al. (2003), Van Andel (1989), Waelbroeck et al. (2002). For information on archaeological sites see Bailey et al. (2008a, b), © G. Bailey

Sea level change is only one component of an unstable land surface. Changes of the Earth's crust have been continuously remolding many of the landscapes in which human populations have made their living, whether through tectonic plate motions and rifting, or isostatic adjustments in response to varying loads of ice and water associated with sea level change and high latitude glaciation. Superimposed on these geological changes, of course, were the major climatic changes associated with the glacial cycle, sometimes involving dramatic changes on a time scale of decades and even years. In short, the world in which we have evolved as a species is highly unstable, geologically speaking, and will continue to be so.

What impact did these changes have on prehistoric societies, how did people cope with such changes in the deeper past, and what can we learn from this long-term archaeological perspective about the challenges which confront our own society and civilization? We cannot hope to cover the full range of environmental changes associated with human development in the space of a short chapter.

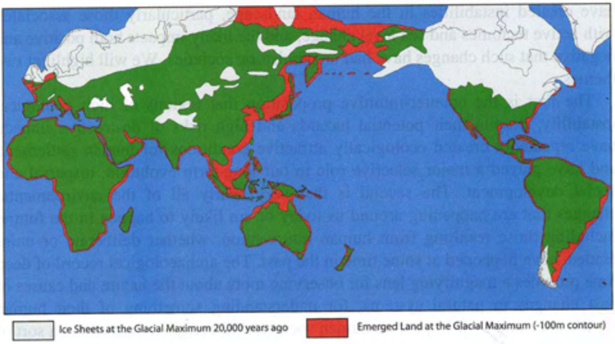

Fig. 2 World map showing maximum extent of the continental sheets 20,000 years ago (*pale blue*), and the extent of new land created by a corresponding drop in sea level of 100 m (*red*)

Fig. 3 Map of Europe showing the extra land (in *red*) exposed by the maximum lowering of sea level at the last glacial maximum, 20,000 years ago. Picture supplied courtesy of Simon Fitch and Ben Geary, University of Birmingham, with data from USGS NED and ETOPO2

Long-term climate change in particular is a vast topic, and is well covered elsewhere (e.g., Elias 2006; Maslin and Christensen 2007), though we touch on climate factors to the extent that they interact with or are modified by geological changes. What we will concentrate on here are the major geological processes that have created instabilities in the human landscape, particularly those associated with active tectonics and sea level change, and the likely impacts both positive and negative that such changes have had on prehistoric societies. We will highlight two themes.

The first is the counter-intuitive proposition that regions of high geological instability, despite their potential hazards and high risks of destructive impact, have repeatedly created ecologically attractive conditions for human settlement, and have played a major selective role in our long-term evolution, dispersal and social development. The second is that very nearly all of the environmental changes that are happening around us today or are likely to happen in the future, including those resulting from human intervention, whether deliberate or unintended, have happened at some time in the past. The archaeological record of deep time provides a magnifying lens for observing more about the nature and causes of past changes in natural systems, for understanding something of their human significance and their impact on human society; at the same time it offers a sort of large-scale laboratory for observing their long-term consequences and disentangling the relative contributions of different processes operating on different time scales.

2 Active Tectonics

Tectonic processes such as plate motions, mountain uplift and basin submergence have generally been assumed to operate too slowly to be of relevance to the scale of human activity or human history. Over the past 25 years, however, detailed studies of earthquake activity, beginning with the El Asnam earthquake of 1980 in Algeria (King and Vita-Finzi 1981; King and Yielding 1984; Philip and Meghraoui 1983), and the Coalinga earthquake of 1983 in California (King et al. 1988; Stein and King 1984; Stein et al. 1988), have demonstrated the intimate relationship between earthquakes and changes in the surface morphology of the physical landscape. The fault displacement or folding episode caused by a single earthquake, or a short series of earthquakes repeating on the same fault zone, can modify topography over relatively short time spans ($10–10^3$ years), with the creation of localized barriers, disruption of surface drainage, and damming back of stream flows and sediment. Over longer time spans ($10^4–10^8$ years) the cumulative effect is major fault scarps and depressions, and ultimately large-scale basins and mountain ranges.

In the El Asnam case, the earthquake was one of the largest recorded in Algeria, and its immediate effects were widespread damage to buildings, the deaths of over 2000 people, and homelessness for a further 300,000 (Ambraseys 1981). The earthquake caused surface faulting that extended horizontally over a distance of 24 km, raised the local Ser el Maarouf ridge by 5 m, and by partially damming back the flow of the Chelif River, re-created a lake in the neighboring basin that had been recorded as a wetland environment on historical maps but had

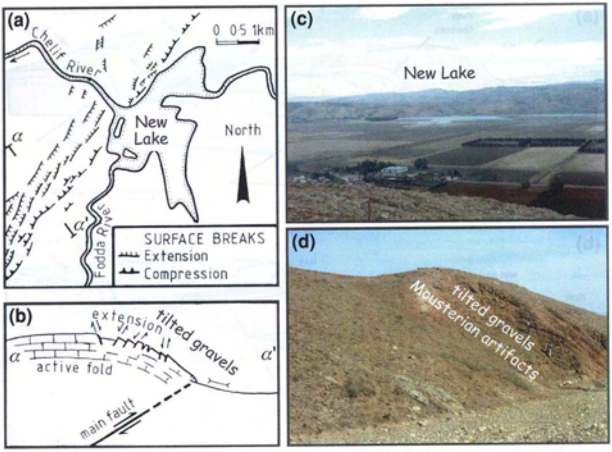

Fig. 4 Map of the El Asnam area, showing zones of faulting, uplifted ridge and local lake basin, © G. Bailey

subsequently dried out (Fig. 4). Progressively tilted gravels making up the local ridge, the earliest with Mousterian artifacts dating back at least 30,000 years, indicated that the ridge had undergone progressive uplift as a result of repeating earthquakes on the same fault over a long period, each earthquake accentuating or rejuvenating a complex topography of barrier and basin. The short-term effect of the earthquake was highly destructive, but the longer-term effects in the wider landscape could be regarded as beneficial, creating a region of localized topographic complexity and a well-watered basin that was clearly attractive to the prehistoric hunter-gatherers of the region and would have offered ecological benefits to local populations at any period whatever their technology and mode of subsistence.

These effects are especially marked near plate boundaries. Where terrestrial plates are converging, the dominant large-scale effect is crustal contraction, uplift and mountain building, and the local effect is reverse faulting and folding of the surface topography (Fig. 5a). Where plates are diverging, the dominant large-scale effect is crustal stretching, subsidence and formation of marine basins with some uplift at the margins, and the local effect is normal faulting (Fig. 5b). Where plates are moving sideways with respect to each other (strike-slip), both effects may be observed locally (e.g., Bilham and King 1989). Earthquakes are active in all these examples and can be accompanied by volcanic activity in regions of crustal stretching, strike-slip or rifting. In some regions of the world, notably in the

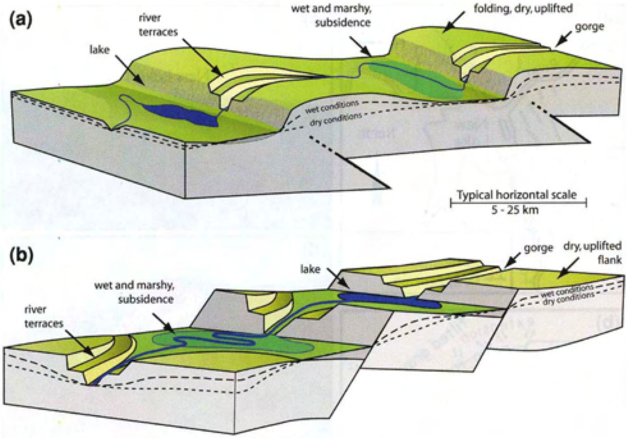

Fig. 5 Schematic illustration of the effects of changing water table in a tectonically active landscape: **a** contractional (reverse-faulting); **b** extensional (normal-faulting) environments. In **a** the surface expression of faulting appears in the form of folds rather than faults that cut the surface. In **b** faults usually fully cut the surface. The *scale bar* is approximate. Both figures show how faulting and folding can trap water and sediments to sustain intermittent areas of well-watered and fertile conditions even when the water table changes because of climate change. In each figure two faults are shown that could host repeated earthquakes with Richter magnitudes between 6 and 7. Smaller events in the same region with magnitudes between 3 and 4 will occur 10,000 times more frequently. In regions of Greece or Western Turkey major events repeat every 200 years or less and create both major and minor features (e.g. Armijo et al. 1996). Secondary effects are important, creating deep river valleys and gorges and faulting that produces small private valleys or secluded bays at a range of scales. Greece and Western Turkey are very active, but tiny fractions of that rate can create and maintain features. Overall rates for the East African Rift are a factor of one hundred smaller, and less is known historically, but motion can still generate spectacular features within a human life time. Fault scarps tens of metres high can be created by repeated movement on such fault lines in less than 100 years, © G. Bailey

Eastern Mediterranean, overall convergence of major plates is mediated by smaller platelet motions, resulting in a complex interplay of extension, contraction and strike-slip (e.g. Flerit et al. 2004).

These processes can be rapid in human terms. The Gulf of Corinth, now nearly 1 km deep has been created within the past 1 Ma, well within the time span of human interest (Armijo et al. 1996). On shorter time scales the Gulf of Corinth has dropped 25 m since 500 BC, and the Byzantine chapel of Kenchreai was partially submerged by earthquake activity (Vita-Finzi and King 1985).

At first sight the main effect of such processes appears disruptive or destructive, especially at the smallest scale of the spatio-temporal spectrum, that of the individual earthquake or volcanic eruption. However, over longer time scales, the effects are potentially beneficial, creating a complex topography with ecological diversity, rejuvenation of local water supplies and fertile sediments. Uplifted barriers and ridges afford opportunities for hunter-gatherer populations dependent on the hunting of elusive prey animals to use the topography to tactical advantage, and similar advantages to pastoralist populations concerned to protect their livestock from theft or predation. This may explain the apparent paradox that many of the largest concentrations of archaeological sites and evidence of past human activity are concentrated in tectonically active zones close to plate boundaries or rift zones, whether we are talking about our earliest ancestors in the African Rift, the advanced Palaeolithic hunters of Mediterranean Europe, the earliest Old World civilizations, or the population centers of more recent times (Jackson 2006; King and Bailey 2006; Force 2008). As long as activity is maintained over the longer run of centuries, millennia, and longer, these advantageous features are constantly maintained or rejuvenated. Without repeated activity resulting from regional tectonic activity, the long-term effect would be erosion and smoothing of the land surface and a drop in the water table (Fig. 6). Without active tectonics there would be no topographic complexity, and without complex topography human evolution and social development might have taken a very different turn.

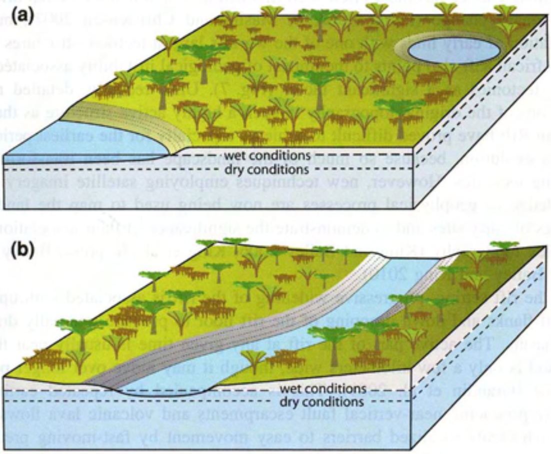

Fig. 6 Schematic illustration of effects of changing water table in a flat landscape: **a** a region with water-holes and lakes; **b** a region with a river flowing through it. In these conditions, the water table is sensitive to climatically induced changes in precipitation, © G. Bailey

3 The African Rift and Human Evolution

According to current consensus, Africa is the cradle of early human evolution, with the earliest dated and most numerous finds of human fossils and stone-tool assemblages, documenting the transition from a tree-dwelling, plant-eating ape-like ancestor to omnivorous ground-dwelling humans. The first steps on this evolutionary trajectory were towards some form of bipedalism combined with continued tree-climbing abilities, and occurred at least 4.5 million years ago with *Ardipithecus ramidus*, evolving through the Australopithecines, and leading to the evolution of the genus *Homo* after 2.5 Ma. The emergence of *Homo ergaster* and *Homo erectus* ~1.8 million years ago saw a fully developed bipedal capacity to range widely over open terrain, increased brain capacity, the widespread use of stone tools, a greater dependency on animal protein whether by scavenging or hunting, and dispersal more widely within and beyond Africa (Cachel and Harris 1998, Delson et al. 2000, Klein 1999). The longest sequences, and the most complete record of successive biological and cultural assemblages occur in the East African Rift and in South Africa, and the evolution of anatomically modern humans (*H. sapiens sapiens*) also appears to have taken place in Africa some time after about 150,000 years ago both on grounds of early dated fossil finds and the phylogenetic mapping of modern DNA lineages (McDougall et al. 2005; Stringer and Andrews 1988; Torroni et al. 2006).

Climate change has most often been invoked as a significant external driver of evolutionary change (Potts 1996a, b; Maslin and Christensen 2007), but the association of early finds with one of the world's largest tectonic structures in the East African Rift also points to the impact of geological instability associated with active tectonics as a significant factor (Fig. 7). Until recently, detailed reconstructions of the original topography in such a highly active structure as the East African Rift have proved difficult to achieve, especially for the earliest periods of human evolution, because so much of the landscape has been transformed by ongoing tectonics. However, new techniques employing satellite imagery and a knowledge of geophysical processes are now being used to map the landscape settings of early sites and to demonstrate the significance of their association with complex topography (King and Bailey 2006, King et al., in press; Bailey et al. 2010; Bailey and King 2010).

In the rift setting, progressive widening of the rift is associated with uplift of the rift flanks and down dropping of the rift floor to produce internally draining lake basins. The active part of the rift at any given time is usually near the rift axis and is only a few kilometers wide, though it may move over longer periods of time (Grandin et al. 2009). This is accompanied by repeated earthquake activity producing near-vertical fault escarpments and volcanic lava flows, both of which create localized barriers to easy movement by fast-moving predators. Water supplies and fertile sediments are sustained and rejuvenated by repeated movement on fault zones, leading to ecological richness and habitat diversity. Moreover this process can maintain favorable and stable conditions of food and

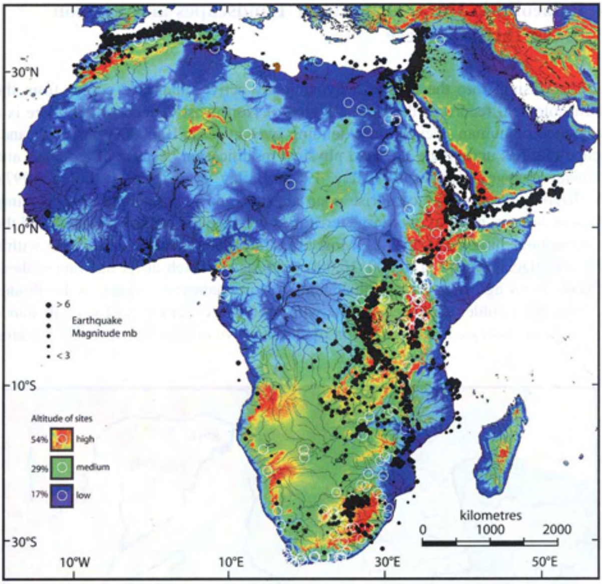

Fig. 7 Map of Africa showing distribution of fossil and archaeological sites (*white circles*), earthquake activity (*black circles*) and topography, © G. Bailey

water supplies independently of climate change, offering a measure of buffering against climatic aridification. The combination of localized barriers and partial enclosures created and sustained by active faults and lava flows forms a complex topography which an intelligent hominin can use to tactical advantage to avoid predators, find safety for vulnerable young, and improve access to mobile or elusive prey animals. These features provide a powerful set of external selection pressure favoring the human evolutionary trajectory towards the development of an unspecialized omnivore with a significant dietary component of meat to feed an enlarged brain, a requirement for abundant water supplies, an extended period of infant dependency, and locomotory adaptations to the negotiation of broken topography (King and Bailey 2006). In South Africa, where many early finds have also been found, the tectonic style is different but tectonic activity is present and produces many of the same topographic features present in the Rift (Bailey et al. 2010).

4 Palaeolithic Hunters, Tectonic Landscapes and Erosion in Northwest Greece

Further insight into the role of a dynamically active landscape comes from the archaeological record of the Epirus region of Northwest Greece, where there is a sequence of human occupation extending over at least 100,000 years in a landscape that has undergone repeated physical modification because of tectonics and climate change (King and Bailey 1985; Bailey et al. 1993; Bailey 1997). Archaeological deposits comprise open air sites and rock shelters used as camp sites by hunters moving over large territories between the coastal lowlands and the mountainous hinterland (Fig. 8). Most of the archaeological evidence falls within the last glacial period (110,000–10,000 years ago), which at its maximum about 20,000 years ago saw the establishment of a permanent ice sheet in the Pindus mountains, a colder and drier climate with little tree cover except for small stands in sheltered valleys, and the creation of an extensive coastal lowland with lowered

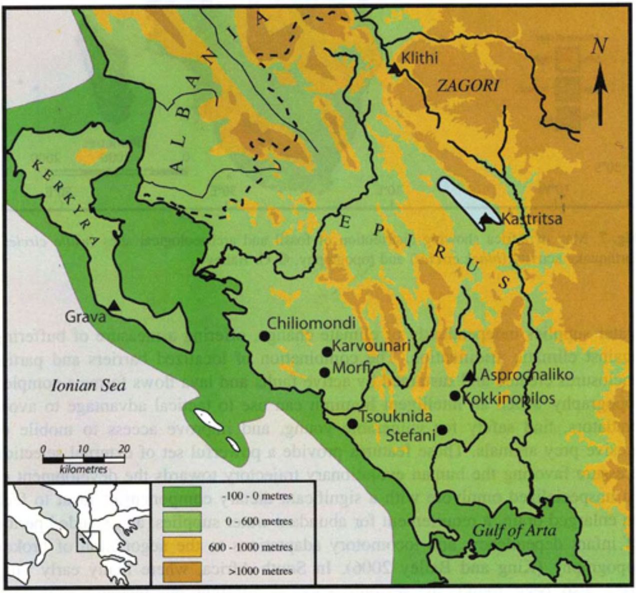

Fig. 8 The Epirus region of Northwest Greece, showing principal topographic features and Palaeolithic sites, © G. Bailey

sea level. Large herds of red deer (*Cervus elaphus*), wild ass (*Equus hydruntinus*), wild cattle (*Bos primigenius*), ibex (*Capra ibex*), and chamois (*Rupicapra rupicapra*) formed the main supplies of animal food for the Palaeolithic hunters.

The region is prone to earthquakes and the dominant tectonic style is compression and uplift, with some strike-slip and normal faulting because of the interaction of smaller plates in the eastern Mediterranean region. The surface expression of these geophysical processes is a complex topography with Northwest–Southeast trending mountain ranges alternating with broad basins, some, such as the Ioannina basin, with long-standing lakes. Some of these topographic features have persisted and been accentuated throughout the past 1 million years and more, notably the Ioannina lake basin and its impressive surrounding limestone ridges. However, other parts of the landscape have been transformed by long-term tectonic deformation, and areas that were formerly basins with accumulations of fluvial and lacustrine sediments have now been uplifted locally and transformed into barren badlands with slopes stripped bare of vegetation by soil erosion, most famously the red beds of Kokkinopilos, where the uplift and erosion of sediments originally formed in a well-watered basin have exposed some of the earliest stone age artifacts of the region.

The dominant bedrock geology is limestone, and this bedrock-type tends to support the most attractive grazing for herd animals. There are also substantial areas of a younger, softer rock, known as flysch, comprising laminated siliceous sandstones and siltstones, which produce soils more quickly than the limestone but with lower fertility and more susceptibility to erosion. Long-term tectonic processes of compression have uplifted and disturbed the younger flysch, so that it tends to form extensive areas of eroded topography on the flanks of the limestone ridges (Fig. 9). The result is extensive tracts of inaccessible country, which even

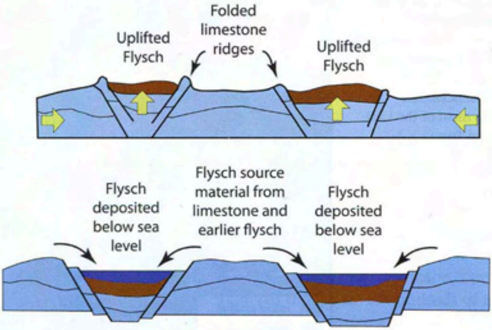

Fig. 9 Block diagram showing the effects of tectonic compression on the configuration of limestone and flysch terrain. *Lower figure* shows earlier phase of deposition, upper figure shows a later phase after compression, © G. Bailey

today have little productive capacity and low population densities, and in the prehistoric past would have formed barriers to the movement of animals, circumscribing basins and valleys of more attractive terrain.

It is clear from the distribution of Palaeolithic sites close to the entry and exit points of these major grazing basins that prehistoric hunters were capable of using these topographic features as a means of monitoring and controlling animal movements on a regional scale (Fig. 10). Locally, sites are located on or close to fault zones and are well placed to take advantage of local fertility and local barriers to trap animals during the course of their migratory movements (Fig. 11).

Much of the erosion that creates badlands landscapes on the flysch geology and more localized areas of erosion on the limestone is typical of the eroded landscapes visible more widely in the Mediterranean (Van der Leeuw 1998; Hordern and Purcell 2000; Grove and Rackham 2001), and has usually been attributed to over exploitation in recent millennia, because of overgrazing by goats, cutting down of trees for timber and firewood, and overexploitation by mechanized agriculture.

However, if we consider the archaeological time scale, it is clear that erosion has been going on in the Epirus landscape long before the agricultural and technological developments of recent millennia. During glacial periods erosion took

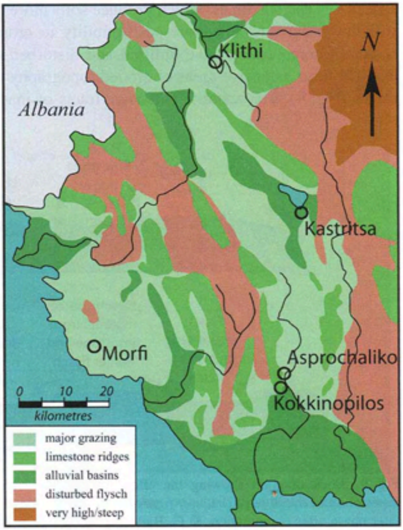

Fig. 10 Regional map showing the relationship between major grazing basins, geological barriers and archaeological site distributions. Kokkinopilos and Morfi are open air sites with Mousterian and Upper Palaeolithic artefacts spanning at least the past 150,000 years. Asprochaliko, Kastritsa and Klithi are rockshelters with stratified sequences that together span most of the Last Glacial period from 100,000 years to 10,000 years ago, © G. Bailey

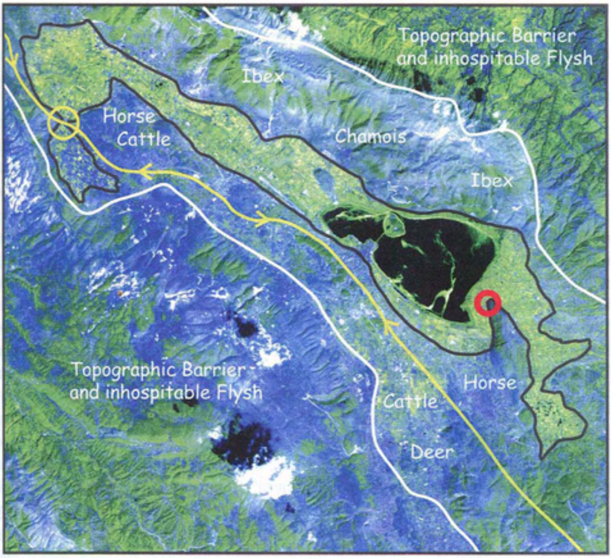

Fig. 11 Local topographic features in the vicinity of the Palaeolithic rockshelter of Kastritsa. This site was used repeatedly as a hunting base from at least 26,000 years ago to 12,000 years ago, a period spanning climatic conditions of maximum cold and aridity at the Last Glacial Maximum. The site is well placed to monitor the movements of animals in the region without disturbing them, while also combining the local topographic features of limestone ridges and the lake edge to divert the animals into a topographic cul-de-sac where they could easily be trapped and killed, © G. Bailey

place on a massive scale, creating huge fans of sediment at the foot of the higher mountains, and the accumulation of thick alluvial deposits in river and lake basins (Macklin et al. 1997). This erosion far outweighs the supposed impact of recent human intervention and most of it took place long before the appearance of domestic animals or the increasing demands of agricultural and urban populations.

Undoubtedly some of the erosion has been caused by recent land-use practices, but there are at least two other processes at work in this landscape, operating on different time scales. On a time scale of tens of thousands to hundreds of thousands of years, repeated cycles of cold and dry glacial climates periodically removed most of the tree cover and accelerated the breakdown of soil and bedrock through freeze–thaw effects. On a time scale of millions to tens of millions of years, the Epirus landscape has been subjected to progressive tectonic compression and uplift, in which offshore sediments created by earlier cycles of erosion have been compacted and uplifted to produce the hard-rock geology we see today. Thus the underlying tectonic instability has made the land surface especially susceptible to disturbance, whether triggered by earthquakes, climatic effects or human intervention (King et al. 1997).

The humanly-induced erosion of recent millennia, far from appearing to be an exceptional effect, turns out to be a relatively minor continuation of processes that have been operating in this landscape over a much longer period of time and at a much larger scale. Since erosion has a much longer history than the domestic goat, it becomes hard to pin all the blame on the latter. On the contrary, from this longer-term perspective, it seems more likely that goat husbandry, so far from being the cause of erosion, represents a successful adaptation to a chronically degraded landscape that was in existence long before human settlement and cannot be made productive for human benefit in any other way. Whereas on the shorter time scale of the recent historical period, it appears that goats cause erosion, on the longer time scale of the Pleistocene the roles of cause and effect are reversed, so that it would more appropriate to say that erosion 'causes' or 'selects for' goats (Green and King 1996; Bailey 2007).

Moreover, if we expand the spatial scale of observation, it is clear that erosion in one place results in the accumulation of sediment somewhere else. The massive Pleistocene fans of sediment that form low hills at the foot of the more prominent mountain ridges are often the focus of modern village settlements because of their attractive soils and water supplies. In a complex topography, then, erosion may have a more generally beneficial effect in bringing together soil that is thinly distributed over hill and mountain slopes, and concentrating it in basins and lowland river valleys and coastal plains, where it provides some of the most important agricultural land for the modern economy. Thus erosion, which seemed at a local scale to be largely negative, turns out at a larger spatial scale to be positively beneficial. Such observations have serious implications for modern conservation policies and technological interventions (Van der Leeuw 1998; Van der Leeuw and Redman 2002).

5 Sea Level Change and Coastal Prehistory

We return to the issue of sea-level change, with which we began. During the past decade, archaeologists have become more acutely aware that the periodic drop in sea level during glacial periods exposed large tracts of coastal territory that are now submerged, and which probably represented some of the most attractive territory for prehistoric populations. This was already apparent in the Epirus example discussed above (see Fig. 8). However, it is only very recently that archaeologists have begun to recognize that the surviving archaeological record on dry land is most probably a severely truncated fragment of the original picture, that some of the most important evidence for the earliest developments in human prehistory may be missing because of submerged of earlier landscapes by sea-level change, and that there are realistic possibilities of acquiring new information from this hidden world (Flemming 2004; Bailey et al. 2008a, b; Gaffney et al. 2009; Benjamin et al. 2011, in press).

Coastal territories are often more attractive than their hinterland counterparts, because of better groundwater supplies, more fertile sediments, more equable climates, greater ecological diversity, and the addition of marine resources at the shore edge. They are often tectonically active, especially at plate boundaries where oceanic material is colliding with the margin of a continental plate and being subducted beneath it, and are subject to varying process of long-term uplift or subsidence, resulting both from tectonic and isostatic movements (Inman 1983). Even when sea level is relatively stable, reworking of material at the coast edge by erosion and accumulation of sediments creates an ecologically and geologically dynamic environment. It follows that coastlines are likely to pose many of the same sorts of characteristics of geological instability combined with topographic complexity and ecological attractiveness that are typical of tectonically active regions. Moreover, some of the largest concentrations of population and the largest settlements are likely to have been concentrated in coastal regions in the deeper prehistoric past, as they are today.

However, the impact of Pleistocene sea level change has also been to remove such evidence for most of human prehistory. Occasionally, ancient shorelines that have been uplifted by isostatic rebound in high latitudes, or by subduction and tectonic uplift at plate boundaries, are preserved above sea level and give some insight into the coastal adaptations of much earlier human societies (Bailey and Flemming 2008). Deeply stratified coastal caves also give some indication of coastal activities in short-lived periods of earlier high sea level (see Fig. 1). However, these conditions are exceptional, and most of the evidence is now submerged and will require underwater exploration. Despite some early speculations to the contrary (Sauer 1962), it has usually been assumed by archaeologists from the general absence of evidence, that a serious human interest in coastlines and marine resources only began some time after about 7000 years ago, because it is from that time on that we see abundant evidence in the archaeological record of shell mounds, fishing gear, the use of boats, and intensive exploitation of shellfish, fish and sea mammals—indeed a worldwide explosion of such evidence. However, it now seems more likely that this apparent pattern simply reflects the fact that sea level stabilized at about the present position from about 7000 years ago onwards, and that earlier expressions of human interest in maritime activities and marine resources have a much deeper history that has been lost beneath the ocean. The fact that Australia and New Guinea are now known to have been first colonized by human populations 50,000 years ago (Hiscock 2008), requiring sea journeys over distances of at least 60 km, is a very significant indicator in support of such a proposition.

It now seems likely that if we are to obtain a fuller picture of early patterns of human migration and dispersal, the extinction of the Neanderthals and their replacement by modern humans spreading out of Africa, early developments in seafaring, fishing and the exploitation of marine resources, the earliest dispersal of agriculture and even the earliest roots of development of the great Old World civilizations, and of course the social impact of sea level change and past human response to it, we will have to look for evidence underwater. All these processes, representing some of the most significant developments in human prehistory, took place when sea levels were lower than present.

The steady accumulation of chance archaeological finds demonstrates that archaeological settlements and whole cultural landscapes can survive inundation by rising sea levels, often with excellent conditions of preservation. New technologies, stimulated by industrial developments on the sea bed, are beginning to offer the prospect of realistic underwater exploration where previously this was regarded as impractical, and new collaborations are under way to develop systematic programs of research (SPLASHCOS 2010). Moreover, these hidden underwater archives of evidence do not simply have a bearing on archaeological issues of human development but include geological and sedimentary records that are likely to refine very considerably our understanding of the processes of long-term sea-level change and the regional and local expression of climate change as it affected these now submerged coastal territories. We are on the threshold of a new phase of investigation that is likely to transform, in the coming decades, our knowledge and understanding of all these interlinked processes. At present, there is a relatively limited base of evidence, but we describe below two examples that show how this new field of research is likely to impact on a broader understanding.

6 The Red Sea and the Arabian Peninsula

The Red Sea region and the Arabian Peninsula (Fig. 12) are currently at the centre of interest about the likely pattern of dispersal of early human populations out of Africa and their adaptations, particularly with regard to the possible role of sea crossings and marine resources in facilitating early patterns of movement and habitat expansion (Petraglia and Rose 2009). It has generally been assumed that the most likely pathway, particularly for the earliest expansion of archaic human populations out of Africa at about 1.8 Ma, but also for the dispersal of anatomically modern humans after about 150 ka, was via the Nile Valley and the Sinai Peninsula into the Near East, mainly on the grounds that this is the only dry land route and that a pathway across the southern end of the Red Sea would have been blocked by a sea crossing of some 30 km and by predominantly arid landscapes in the Arabian Peninsula. More recent discussions and new work have challenged this long-standing assumption, suggesting that a land connection might have existed across the southern end of the Red Sea when sea levels were very low, or that early inhabitants of the region might have already been exploiting marine foods and developing simple craft for crossing sea barriers, perhaps providing an impetus to dispersal out of Africa and around the rim of the Indian Ocean, at least in the case

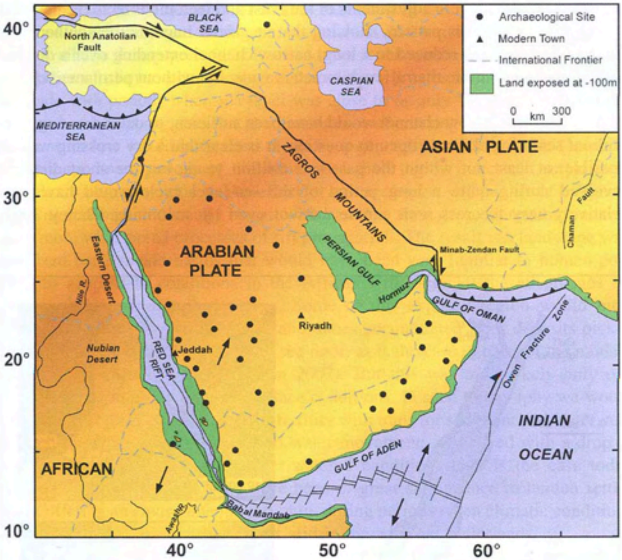

Fig. 12 General map of the Red Sea and the Arabian Peninsula. Archaeological sites are mostly surface finds of Early Stone Age and Middle Stone Age tools that could cover a range of dates from >1 million years to <40,000 years. When sea level was very low, the southern end of the Red Sea would have been reduced to a narrow channel running through extensive coastal lowland territory, and the Persian Gulf would also have been a well-watered lowland basin, © G. Bailey

of anatomically modern humans some time after 150,000 years ago (Stringer 2000; Walter et al. 2000).

Abundant finds of stone tools demonstrate that there has been a human presence, at least intermittently in the southern Arabian Peninsula, extending far back into the prehistoric past, probably as far back as 1 million years and perhaps earlier. Moreover, some of these finds are in regions that today are too dry for habitation, which implies a wetter climate than today (Parker 2009). Detailed analysis of the isotope composition of marine organisms in deep sea cores with sediments extending back over the past 350,000 years (Siddall et al. 2003) demonstrates that at no time in that period, even when sea level dropped to its lowest level at glacial maxima, was the Red Sea cut off from the Indian Ocean at its shallow southern end. Had that happened, evaporation within a closed basin would have taken isotope values to much more extreme values than are in fact recorded. Independent measurements of the position of the palaeoshoreline, taking account of local isostatic adjustments of the crust and tectonic effects (Bailey et al. 2007), corroborate this pattern, showing that at glacial maxima the southern Red Sea would have been reduced to a long, narrow channel extending over a distance of 100 km and no more than a few kilometers wide, but without permanent closure (Fig. 13).

Whether this narrow channel would have been sufficient to deter crossing, even without seafaring skills, is open to question. It is clear that a dry crossing was not possible, at least not within the past half million years, but the short distances involved during quite a long period of the sea-level cycle would have been relatively easy to cross with simple rafts or even by swimming (Bailey 2009).

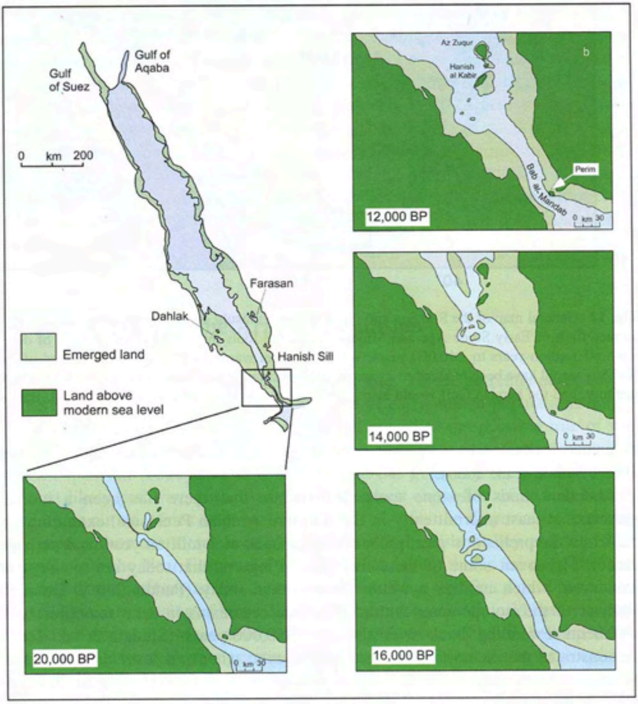

Fig. 13 Palaeoshorelines at the southern end of the Red Sea at different dates in the glacial sea-level cycle. Data supplied courtesy of Kurt Lambeck, © G. Bailey

More relevant to the question of human habitation in the region is the extensive areas of now submerged landscape, as much as 100 km wide, that would have been available during periods of low sea level at the southern end of the Red Sea.

Studies of climate change suggest that wetter climates in the region tended to coincide with periods when sea level was close to or only slightly lower than the present level. This suggests that the greater ease of crossing the Red Sea when sea levels were low would have been offset by a generally arid landscape. However, preliminary investigations of the submerged shelf region indicate a surprisingly complex topography, due to the effect of salt tectonics, with uplift of evaporite deposits accompanied locally by salt withdrawal to form deep depressions, as well as to more widespread processes of rift propagation. The result is a landscape with localized barriers and basins that would have been very familiar to human populations adapted to conditions in the African Rift, with all the advantages for human settlement described earlier. Some of this exposed region would most likely have been covered in linear sand dunes accumulated from deposits picked up by wind action from the exposed sea floor, as is the case in parts of the modern coastal plain (Munro and Wilkinson 2007). But this was most likely only one element in a complex mosaic of surface conditions. In such topography we would expect to find local basins of greater fertility with traps for sediment and water, and it has been hypothesized that ground water movements associated with a drop in sea level would have created better-watered conditions than is the case today (Faure et al. 2002). This would have been of great significance to human settlement, offering an environmental refugium during periods when climatic conditions are likely to have been at their most arid in the adjacent hinterlands.

Conversely, the fertility of the marine environment in this region is at its greatest when sea level is high and relatively stable, as is the case in present-day conditions, with vast quantities of marine molluscs in shallow bays and productive inshore fisheries. These have clearly been exploited throughout the period of modern sea level over the past 6000 years, as is attested by the numerous large shell mounds representing the material expression of former settlements on the Red Sea coastline and its offshore islands. When sea level dropped, particularly to very low levels, restriction of marine inflow from the Indian Ocean would have resulted in increased salinities, injurious to some marine species and possibly high enough to suppress plankton production in some parts of the Red Sea (Siddall et al. 2003). We cannot be sure that similar shell mounds do not exist on the palaeo-shorelines that are now submerged, and underwater explorations are under way to search for their remains. But, rapidly shifting shorelines during a period of sea-level change may have inhibited the establishment of large shell beds on the scale that can be observed in the modern environment.

Thus, the complex cycle of changes in sea-level conditions, climate and local productivity on land and at sea would have created a different balance of advantages and disadvantages for human populations established in the region. Any human populations with the flexibility to switch between terrestrial and marine resources, and between hinterland and coastal territories, would have been able to maintain a permanent presence in the region over long periods in the face of the many shifts in local conditions. Hence this region could have played a key bridging role in facilitating population movements and cultural contact between Africa and southern Asia from the very earliest periods of human development, rather than representing a barren and little visited cul-de-sac that acted as a barrier to such interchange.

7 Sinking Coastlines in Northern Europe

One of the regions of Europe that was more dramatically affected than any other by the sea-level rise at the end of the last glacial period was the Northwest region around the Baltic and the North Sea. The relatively shallow bathymetry of these basins resulted in a very extensive coastal landscape during periods of low sea level (Fig. 14), with correspondingly dramatic changes in palaeogeographic configuration when sea level rose. The melting of the ice sheets that sat over northern Britain and Scandinavia also resulted in isostatic rebound of the Earth's crust, amounting to more than 100 m in northern Norway, and submergence around the southern rim of the North Sea and the Baltic, creating a complex interplay between

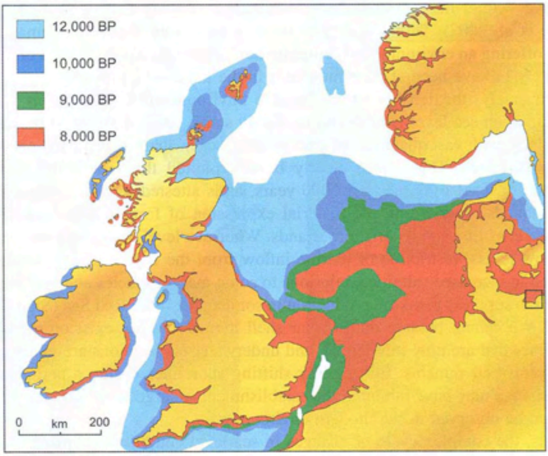

Fig. 14 Map of the North Sea basin and western Baltic showing the successive change of coastline position with progressive sea level rise at the end of the Last Glacial period between 12,000 years ago and the establishment of the modern coastline position about 6000 years ago. The square on the far right marks the position of the Wismar Bay (see Fig. 15). Data from Bailey et al. (2008a), © G. Bailey

sea level rise and vertical crustal movements that varied in different regions and that is still only understood to a general level of approximation by a combination of theoretical models and a limited number of dated benchmarks for the position of the shoreline at different periods and in different regions.

This region has also provided some of the most abundant and well preserved evidence of submerged archaeological sites anywhere in the world, particularly in the shallow waters around Denmark and along the Baltic shoreline of Germany. In this region, over 2,000 underwater archaeological sites are known, mostly dating from the Mesolithic period from about 9000 years ago onwards (Fischer 2004, 2007; Skaarup and Grøn 2004; Harff et al. 2007). These submerged finds include a remarkable wealth of detailed evidence including a substantial body of organic materials and wooden artefacts preserved in anaerobic marine peats, including communal fish traps, dugout canoes, and human burials. Most of this material lies within a water depth of about 10 m, easily accessible to scuba divers. Earlier material may exist in deeper water, particularly on the North Sea side, but investigations here have so far been limited to mapping of the underwater landscape using acoustic records from the oil and gas industries, and the dredging up of artefacts and animal bones by fishing trawlers (Flemming 2004; Gaffney et al. 2009).

The archaeological material is not only important in its own right as a source of information about past human settlement and material culture, but it also provides

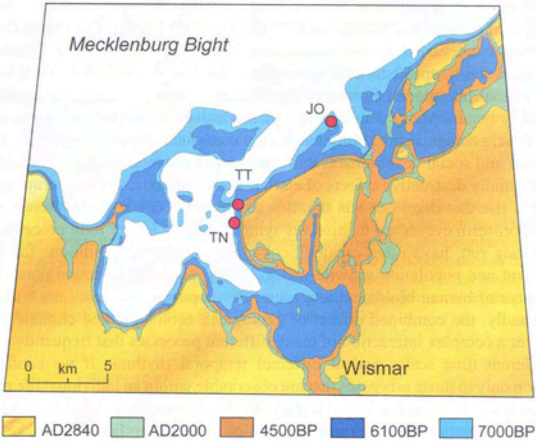

Fig. 15 The Wismar Bay of northern Germany, showing the changing position of the shoreline at successive positions during the past 7000 years and the predicted position of the shoreline at AD 2840. *Red circles* indicate submerged archaeological settlements: *JO* Jäcklegrund-Orth, *TT* Timmendorf-Tonnenhaken, *TN* Timmendorf-Nordmole. Data from Harff et al. (2007)

precisely located and easily dateable materials and environmental indicators in the form of exploited plants, animals and marine fauna. Such information can be used to give precision to patterns of sea level and environmental change, which can be fed into more general models with predictive value. One example of this approach comes from the Wismar Bay of northern Germany (Fig. 15). This region has been sinking slowly as a result of isostatic effects following the ice retreat, and coastlines with Mesolithic and Neolithic settlements are now underwater. Excavation of some of these sites has helped to track in detail the shift from freshwater to marine water conditions as sea level rose, and to model the pattern of relative sea level change. Using these data, projections have been made of what will happen to the position of the coastline between now and AD 2840. The data show that there will be a continued encroachment of the sea on the present-day coastal region, with the inundation of important areas of modern settlement and industrial activity, requiring either relocation of major facilities or the building of defensive structures.

8 Conclusion

The examples considered above provide a range of examples of long-term geological change, their effects on human settlement, and the implications for a deeper understanding of past human history over the long time spans of the prehistoric past. The record is, inevitably, incomplete in many particulars. The search for evidence of the varied environmental conditions that existed on the submerged continental shelf, repeatedly exposed and inundated by the major sea level changes of the glacial-interglacial climate cycle, and the human response to such changes, has barely begun. Many details will remain elusive. Some patterns, however, are clear. First, geological instability has been a continuous accompaniment to human evolution and social development throughout our existence on this planet. Despite the potentially destructive effects of earthquakes, tsunamis, volcanic eruptions and sea-level rise that dominate our attention as observers of our contemporary world, these short-term events are themselves symptomatic of longer term processes that, in the long run, have often created ecologically attractive conditions for human settlement and population growth, and exercised powerful selection pressures on the course of human biological and social development.

Secondly, the combined effects of geological, ecological and climatic change represent a complex interaction of many different processes that frequently operate on different time scales and at different temporal rhythms. If we confine our attention only to those processes that are observable within an individual life time, or over the few centuries of recorded history, we are at risk of missing an important part of the overall picture. As the example of erosion in the Epirus landscape makes clear, changing the time span of observation changes our understanding of cause and effect, and may actually lead to a completely erroneous interpretation of causal factors. In such a complex natural system, causation is unlikely to be a simple matter of linear cause and effect, but a more complex interaction of variables involving varying contributions of proximate triggers and underlying boundary conditions. The latter in particular may appear fixed, until we expand our time span to observe the changes they undergo over longer periods of time.

Finally, the archaeological record is testament to the fact that we have evolved as an adaptive species with flexible behavior patterns capable of responding to changes in our environmental circumstances, or of circumventing them. Many of the geological changes discussed above that appear destructive or damaging from the point of view of a particular place or a particular time, can be seen to have beneficial effects if we expand our geographic or our temporal perspective. One person's soil erosion in one part of the physical landscape is another person's sediment accumulation. The loss of territory as sea level rose at the end of the last ice age was compensated for, in many regions, by the establishment of productive inshore fisheries and intertidal mollusk beds as sea level stabilized at about its present position. Cyclical or repeated geological change, whether caused by tectonics or changes in sea-level, often rejuvenated water supplies and sediment fertility in the longer run, or opened up entirely new landscapes for human settlement, rather than destroying previously productive ones. Mobility and migration were important keys to finding solutions to past environmental problems, and the development of adaptive strategies for avoiding or minimizing their effects. Paradoxically, the geological changes that seem to us so destructive in our perceptions of day-to-day existence were the stimulus to creating the problem-solving species that we have evolved into. In the modern era we have acquired immense capacities for coping with the many threats to our existence, but we have also acquired an equally powerful ability to create new and often unforeseen ones, with consequences that may extend far into the future. Of course, the past record of human interaction with geological or environmental change cannot provide a precise template for predicting the future, but the long-term perspective supplied by such a record can provide many insights that should help to inform our understanding of our present condition and the likely consequences of our present and future actions.

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References

Ambraseys NN (1981) The El Asnam earthquake of 1980; conclusions drawn from a field study. Q J Eng Geol Hydrogeol 14:143–148

Armijo R, Meyer B, King GCP, Rigo A, Papanastassiou D (1996) Quaternary evolution of the Corinth rift and its implications for the Late Cenozoic evolution of the Aegean. Geophys J Int 126:11–53

Bailey GN (ed) (1997) Klithi: palaeolithic settlement and quaternary landscapes in northwest Greece, vol 2. McDonald Institute for Archaeological Research, Cambridge

Bailey GN (2007) Time perspectives, palimpsests and the archaeology of time. J Anthropol Archaeol 26:198–223

Bailey GN (2009) The Red Sea, coastal landscapes and hominin dispersals. In: Petraglia M, Rose J (eds) The evolution of human populations in Arabia. Springer, Dordrecht, The Netherlands, pp 15–37

Bailey GN, Flemming N (2008) Archaeology of the continental shelf: marine resources, submerged landscapes and underwater archaeology. Quat Sci Rev 27:2153–2165

Bailey G, King GCP (2010) Dynamic landscapes and human evolution: tectonics, coastlines and the reconstruction of human habitats. Quat Sci Rev doi: 10.1016/j.quascirev.2010.06.019

Bailey GN, King GCP, Sturdy DA (1993) Active tectonics and land-use strategies: a Palaeolithic example from northwest Greece. Antiquity 67:292–312

Bailey GN, King GCP, Flemming NC, Lambeck K, Momber G, Moran LJ, Al-Sharekh A, Vita-Finzi C (2007) Coastlines, submerged landscapes and human evolution: the Red Sea Basin and the Farasan Islands. J Isl Coast Archaeol 2:127–160

Bailey G, Barrett J, Craig O, Milner N (2008a) Historical ecology of the North Sea basin: an archaeological perspective and some problems of methodology. In: Rick T, Erlandson J (eds) Human impacts on ancient marine ecosystems. University of California Press, Berkeley, pp 215–242

Bailey G, Carrión JS, Fa DA, Finlayson C, Finlayson G, Rodríguez-Vidal J (eds) (2008b) The coastal shelf of the Mediterranean and beyond: corridor and refugium for human populations in the Pleistocene. Quat Sci Rev 28:23–24

Bailey G, Reynolds S, King GCP (2010) Landscapes of human evolution: models and methods of tectonic geomorphology and the reconstruction of hominin landscapes. J Hum Evol. doi: 10.1016/j.jhevol.2010.01.004

Benjamin J, Bonsall C, Pickard K, Fischer A (eds) (2011, in press) Underwater archaeology and the submerged prehistory of Europe. Oxbow, Oxford

Bilham RG, King GCP (1989) The morphology of strike slip faults; examples from the San Andreas, California. J Geophys Res 94:10204–10216

Cachel S, Harris JWK (1998) The lifeways of *Homo erectus* inferred from archaeology and evolutionary ecology: a perspective from East Africa. In: Petraglia MD, Korisettar R (eds) Early human behaviour in global context. Routledge, London, pp 108–132

Delson E, Tattersall I, Van Couvering JA, Brooks AS (eds) (2000) Encyclopedia of human evolution and prehistory, 2nd edn. Garland, New York

Elias SA (ed) (2006) Encyclopedia of quaternary science. Elsevier, Oxford

Faure H, Walter RC, Grant DR (2002) The coastal oasis: ice age springs on emerged continental shelves. Global Planet Change 33:47–56

Fischer A (2004) Submerged stone age—danish examples and north sea potential. In: Flemming NC (ed) Submarine prehistoric archaeology of the North Sea: research priorities and collaboration with industry. CBA Research Report 141, London, pp 23–36

Fischer A (2007) Coastal fishing in Stone Age Denmark—evidence from below and above the present sea level and from human bones. In: Milner N, Craig OE, Bailey GN (eds) Shell niddens in Atlantic Europe. Oxbow, Oxford, pp 54–69

Flemming NC (ed) (2004) Submarine prehistoric archaeology of the North Sea: research priorities and collaboration with industry. CBA Research Report 141, London

Flerit F, Armijo R, King GCP, Meyer B (2004) The mechanical interaction between the propagating North Anatolian fault and the back-arc extension in the Aegean. Earth Planet Sci Lett 224:347–362

Force E (2008) Tectonic environments of ancient civilizations in the eastern hemisphere. Geoarchaeology 23(5):644–653

Gaffney V, Fitch S, Smith D (2009) Europe's lost world: the rediscovery of Doggerland. CBA Research Report 160. Council for British Archaeology, York

Grandin R, Socquet A, Binet R, Klinger Y, Jacques E, de Chabalier JB, King GCP, Lasserre C, Tait S, Tapponnier P, Delorme A, Pinzuti P (2009) September 2005 Manda Hararo-Dabbahu rifting event, Afar (Ethiopia): constraints provided by geodetic data. J Geophy Res 114:B08404. doi:10.1029/2008JB005843

Green S, King GCP (1996) The importance of goats to a natural environment: a case study from Epirus (Greece) and southern Albania. Terra Nova 8(6):655–658

Grove AT, Rackham O (2001) The nature of Mediterranean Europe: an ecological history. Yale University Press, New Haven

Harff J, Lemke W, Lampe R, Lüth F, Lübke H, Meyer M, Tauber F, Schmölcke U (2007) The Baltic Sea coast—a model of interrelations among geosphere, climate, and anthroposphere. Special Paper 426. Geological Society of America, New York, pp 133–142

Hiscock P (2008) Archaeology of ancient Australia. Routledge, London

Hordern P, Purcell N (2000) The corrupting sea: a study of Mediterranean history. Blackwell, Oxford

Inman DL (1983) Application of coastal dynamics to the reconstruction of paleocoastlines in the vicinity of La Jolla, California. In: Masters PM, Flemming NC (eds) Quaternary coastlines and marine archaeology. Academic Press, London, pp 1–49

Jackson J (2006) Fatal attraction: living with earthquakes, the growth of villages into megacities, and earthquake vulnerability in the modern world. Philos Trans R Soc A 364:1911–1925

King GCP, Bailey GN (1985) The palaeoenvironment of some archaeological sites in Greece: the influence of accumulated uplift in a seismically active region. Proc Prehist Soc 51:273–282

King GCP, Bailey GN (2006) Tectonics and human evolution. Antiquity 80:1–22

King GCP, Vita-Finzi C (1981) Active folding in the Algerian earthquake of 10 October, 1980. Nature 292:22–26

King GCP, Yielding G (1984) The evolution of a thrust fault system: processes of rupture initiation, propagation and termination in the 1980 El Asnam (Algeria) earthquake. Geophys J R Astron Soc 77:915–933

King GCP, Stein R, Rundle J (1988) The growth of geological structures by repeated earthquakes: 1. Conceptual framework. J Geophys Res 93:13307–13318

King GCP, Sturdy DA, Bailey GN (1997) The tectonic background to the Epirus landscape. In: Bailey GN (ed) Klithi: Palaeolithic settlement and Quaternary landscapes in Northwest Greece. Volume 2: Klithi in its local and regional setting. McDonald Institute for Archaeological Research, Cambridge, pp 541–559

Klein RG (1999) The human career, 2nd edn. University of Chicago Press, Chicago

Lambeck K, Chappell J (2001) Sea level change through the last glacial cycle. Science 292: 679–686

Macklin M, Lewin J, Woodward J (1997) Quaternary river sedimentary sequences of the Voïdomatis basin. In: Bailey GN (ed) Klithi: Palaeolithic settlement and Quaternary landscapes in Northwest Greece. Volume 2: Klithi in its local and regional setting. McDonald Institute for Archaeological Research, Cambridge, pp 347–360

Maslin MA, Christensen B (2007) Tectonics, orbital forcing, global climate change, and human evolution in Africa. J Hum Evol 53(5):443–634

McDougall I, Brown FH, Fleagle JC (2005) Stratigraphic placement and age of modern humans from Kibish, Ethiopia. Nature 433:733–736

Munro RN, Wilkinson TJ (2007) Environment, landscapes and archaeology of the Yemeni Tihāmah. In: Starkey J, Starkey P, Wilkinson T (eds) Natural resources and cultural connections of the Red Sea. British Archaeological Reports International Series 1661. Archaeopress, Oxford, pp 13–33

Parker AG (2009) Pleistocene climate change in Arabia: developing a framework for hominin dispersal over the last 350 ka. In: Petraglia MD, Rose JI (eds) The evolution of human populations in Arabia. Springer, Dordrecht, The Netherlands, pp 39–49

Petraglia MD, Rose JI (eds) (2009) The evolution of human populations in Arabia. Springer, Dordrecht, Netherlands

Philip H, Meghraoui M (1983) Structural analysis and interpretation of the surface deformation of the El Asnam earthquake of October 10, 1980. Tectonics 2(1):17–49

Potts R (1996a) Humanity's descent: the consequences of ecological instability. William Morrow, New York

Potts R (1996b) Evolution and climate variability. Science 273:922–923

Sauer CO (1962) Seashore—primitive home of man? Proc Am Phil Soc 106:41–47

Shackleton NJ (1987) Oxygen isotopes, ice volume and sea level. Quat Sci Rev 6:183–190

Siddall M, Rohling EJ, Almogi-Labin A, Hemleben C, Meischner D, Schmelzer I, Smeed DA (2003) Sea-level fluctuations during the last glacial cycle. Nature 423:853–858

Skaarup J, Grøn O (2004) Møllegabet II: a submerged Mesolithic settlement in southern Denmark. British Archaeological Reports International Series 1328. Archaeopress, Oxford

SPLASHCOS (2010) Submerged prehistoric archaeology and landscapes of the continental shelf. EU COST Action TD0902. http://php.york.ac.uk/projects/splashcos/. Accessed 10 June 2010

Stein R, King GCP (1984) Seismic potential revealed by surface folding: the 1983 Coalinga, California, Earthquake. Science 224:869–872

Stein R, King GCP, Rundle J (1988) The growth of geological structures by repeated earthquakes: 2 field examples of continental dip-slip faults. J Geophys Res 93:13319–13331

Stringer CB (2000) Coasting out of Africa. Nature 405:53–55

Stringer CB, Andrews P (1988) Genetic and fossil evidence for the origin of modern humans. Science 239:1263–1268

Torroni A, Achilli A, Macaulay V, Richards M, Bandelt H-J (2006) Harvesting the fruit of the mtDNA tree. Trends Genet 22:339–345

Van Andel T (1989) Late Quaternary sea-level changes and archaeology. Antiquity 63:733–745

Van der Leeuw SE (ed) (1998) The Archaeomedes Project—understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean Basin. Office for the Official Publications of the European Community, Luxembourg

Van der Leeuw S, Redman CL (2002) Placing archaeology at the center of socio-natural studies. Am Antiquity 67(4):597–605

Vita-Finzi C, King GCP (1985) The seismicity, geomorphology and structural evolution of the Corinth area of Greece. Philos Trans R Soc Lond A 314:379–407

Waelbroeck C, Labeyrie L, Michel E, Duplessy JC, McManus JF, Lambeck K, Balbon E, Labracherie M (2002) Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records. Quat Sci Rev 21:295–305

Walter RC, Buffler RT, Bruggemann JJ, Guillaume MMM, Berhe SM, Negassi B, Libsekal Y, Cheng H, Edwards RL, von Gosel R, Neraudeau D, Gagnon M (2000) Early human occupation of the Red Sea coast of Eritrea during the Last Interglacial. Nature 405:65–69