Springer Earth System Sciences

Najeeb M.A. Rasul
Ian C.F. Stewart
Editors

The Red Sea

The Formation, Morphology, Oceanography and Environment of a Young Ocean Basin

Springer

The Red Sea

Springer Earth System Sciences

For further volumes:
http://www.springer.com/series/10178

Najeeb M.A. Rasul · Ian C.F. Stewart
Editors

The Red Sea

The Formation, Morphology, Oceanography and Environment of a Young Ocean Basin

هيئة المساحة الجيولوجية السعودية
SAUDI GEOLOGICAL SURVEY
www.sgs.org.sa

Springer

Editors
Najeeb M.A. Rasul
Saudi Geological Survey
Center for Marine Geology
Jeddah
Saudi Arabia

Ian C.F. Stewart
Stewart Geophysical Consultants Pty. Ltd.
Adelaide, SA
Australia

ISSN 2197-9596 ISSN 2197-960X (electronic)
Springer Earth System Sciences
ISBN 978-3-662-45200-4 ISBN 978-3-662-45201-1 (eBook)
DOI 10.1007/978-3-662-45201-1

Library of Congress Control Number: 2014956496

Springer Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer-Verlag GmbH Berlin Heidelberg is part of Springer Science+Business Media (www.springer.com)

Preface

The Red Sea is unique in all respects, including its tectonic history, environment and biology. It is a young ocean basin that along its length has undergone or is undergoing the transition from a continental rift to true oceanic seafloor spreading, the nature of which is still open to vigorous debate. In addition, due to its semi-enclosed nature and location within an arid region, the environment is affected by high evaporation rates that together with limited contact with the Indian Ocean results in high temperatures and salinities. Lower sea levels in the past have also led to extensive evaporite deposition within its basin, while brines and metallic deposits in the axial deeps have been the subject of considerable research; the metalliferous muds may be exploited at some stage in the future. The conditions in the Red Sea have in turn governed the flora and fauna in the sea and along the coast, notable among which are the extensive coral reefs that fringe the sea. The adjacent areas are undergoing rapid development that together with the associated changes are placing some stress on the environment in many areas.

Various topics, from the geology to the past and present environment and the effects of human activities are examined in this volume, which aims to present the current thinking and summaries of research in each field of study. Each chapter aims to give a reasonably comprehensive overview of its subject matter, including useful reference lists for further study. The chapters in the volume were presented at a workshop held in Jeddah, Saudi Arabia, from February 3 to February 5, 2013, under the auspices of the Saudi Geological Survey (SGS). We wish to thank Dr. Said J. Alqahtani of Jubran Holding for assistance in funding the workshop. The support of the Survey in the preparation of this volume is greatly appreciated, and we would like to thank all those who have been involved in its production. We would especially like to thank Dr. Zohair A. Nawab, President, Dr. Abdullah M. Alattas, Assistant President, Mr. Abdullah F. Al-Khattabi, Chief Geologist and Mr. Nasir S. Aljahdli, Director, Survey Department of the Saudi Geological Survey for their encouragement in planning this volume. Colleagues at the SGS Center for Marine Geology, and Mr. Louiesito Abalos are also thanked for making the workshop a success. The contributions of the many technical referees to improving the contents of the chapters as well as the assistance of Ms. Radhika Sree of Springer and Dr. Geoff Bailey in preparing this volume for publication are also greatly appreciated.

Najeeb M.A. Rasul
Ian C.F. Stewart

Contents

The Evolution of the Red Sea as a Human Habitat During the Quaternary Period

Geoff Bailey

Abstract

This chapter summarises current knowledge about the deep history of human occupation in the Arabian Peninsula and more specifically examines the likely role of the Red Sea escarpment and coastal region both as a major zone of human occupation in early prehistory and as a key pathway for the movements of people and the transmission of cultural ideas between Africa and Eurasia. This is a highly topical issue in the international literature at present both because of new archaeological investigations that are providing new dates for early Stone Age settlements in various parts of the Arabian Peninsula and because of genetic studies that highlight the southern Red Sea and southern Arabian Peninsula as a major 'corridor' of early human settlement and connection between Africa and Asia. The time range of these processes covers at least the past 150,000 years and could extend to 1 million years or more and therefore places a high premium on new understandings about the impact of climate change, sea-level change and other geological processes on the suitability of different areas of the Arabian landscape for human settlement and dispersal. This chapter discusses the archaeological and climatic evidence for Quaternary occupation, the effect of sea-level changes on the possibility of sea crossings of the southern Red Sea, the evidence for coastal archaeological settlements demonstrating early human interest in the exploitation of marine resources and seafaring, and new investigations in the Farasan Islands region that are searching for traces of submerged landscapes and archaeological sites formed at periods of lower sea level.

Introduction

The Red Sea coastal region and western escarpment of the Arabian Peninsula form the gateway between the African continent and the rest of the world. As such, they are of pivotal importance in understanding the great narrative of human dispersal from an original homeland in Africa. All the evidence currently available in the form of human fossils, stone tools, geochronology and genetic evidence shows that all human populations distributed throughout the world today had an origin that is deeply rooted in Africa, and that during the Quaternary period[1] there have been at least two major episodes of human expansion out of Africa (Oppenheimer 2003; Bellwood 2013). The first, associated with the genus *Homo* (*Homo ergaster* or *Homo erectus*), took place after about 2 million years ago, resulting in the expansion of these archaic human populations across southern Europe and Asia, extending from southern Britain in the west to Northeast China, and southwards as far as Indonesia (Grine et al. 2009). A second major dispersal occurred with the development in Africa of anatomically modern humans (AMH), *Homo sapiens sapiens* (White et al. 2003), who are thought to have evolved from earlier archaic populations in Africa and then dispersed across the Old World, replacing

G. Bailey (✉)
Department of Archaeology, University of York, King's Manor, York YO1 7EP, UK
e-mail: geoff.bailey@york.ac.uk

[1] The Quaternary period is defined as beginning at 2.58 million years and comprises two epochs, the Pleistocene, lasting until 11,500 cal BP (calibrated radiocarbon years before present), marking the conventional end of the Last Ice Age, and the Holocene, marking the period up to the present day (Gibbard et al. 2010).

N.M.A. Rasul and I.C.F. Stewart (eds.), *The Red Sea*,
Springer Earth System Sciences, DOI 10.1007/978-3-662-45201-1_34,

the pre-existing populations there, such as the Neanderthals, possibly with some admixture (Green et al. 2010), and expanding further than before to colonise the cold high latitudes of northern Eurasia, the Americas and the southern continent of Sahul (Australia, New Guinea and Tasmania).

Yet the Arabian Peninsula has been persistently discounted as an attraction to very early human settlement, except for a narrow corridor through the Sinai Peninsula in the north, on the grounds that the Red Sea would have acted as a barrier further south and that the extensive desert and semi-arid conditions of the interior would have been a further disincentive to human occupation. However, it has long been known that wetter conditions with lakes and extensive grasslands periodically and repeatedly spread across the desert interior during the past 2 million years and more (Edgell 2006; Vincent 2008), and the possibility of a 'southern corridor' across the southern end of the Red Sea, perhaps at a time when a land crossing was possible during periods of low sea level, has also been raised, particularly for AMH dispersal (Lahr and Foley 1994).

AMH dispersal must have occurred after about 200,000 years ago (the earliest date for currently known AMH remains in Africa), and before about 50,000 years ago, which is when modern humans first reached Australia. Moreover, the entry into Sahul involved sea crossings over distances of at least 60 km, which implies the use of simple boats or rafts and some skill in seafaring clearly linked to familiarity with marine resources such as fish and shellfish (O'Connell et al. 2010; O'Connor 2010; O'Connor et al. 2011). This has given rise to the hypothesis that the earliest populations to depart from Africa also had these skills and used them to facilitate dispersal along coastlines, across other sea barriers such as the southern end of the Red Sea, and around the rim of the Indian Ocean into the Indian subcontinent and Southeast Asia, an hypothesis of dispersal frequently linked, on the basis of indirect inference from mapping of genetic relationships among present-day populations, to a date of 60,000 years ago (Stringer 2000; Walter et al. 2000; Macaulay et al. 2005; Mellars 2006; Mellars et al. 2013). However, the basis for this hypothesis has been strongly contested on both archaeological and genetic grounds (Bailey 2009; Petraglia 2012; Boivin et al. 2013). The pathway of AMH dispersal into the Arabian Peninsula, whether via the Sinai Peninsula in the north or across the southern end of the Red Sea, the date of its occurrence, whether at 60,000 or earlier, and the mode of dispersal, whether or not involving some degree of dependence on marine resources and seafaring, are all matters of opinion in need of further investigations and observations.

The language used in describing these patterns of human expansion sometimes implies that they represented 'events', involving purposeful migrations of people trekking (or sailing) over long distances with some distant goal in view, involving a time span of decades or centuries, rather on the analogy of the earliest Europeans to enter North America in the C17th AD. However, this is likely to be a misconception in most cases. The expansion of the human habitat and the colonisation of new territory visible in the archaeological record are better viewed as a long-term process involving incremental range extensions of small social groups and their offspring into adjacent areas to fill the available habitat and involving many human generations and perhaps many hundreds or even thousands of years to accomplish the colonisation of new territory on a continental scale. The actual rate of expansion would, of course, have been determined in the first instance by the natural rate of population increase, but even very slow rates of population growth would have populated large areas quite rapidly on Quaternary timescales given suitable environmental conditions. The term 'dispersal' is more appropriate for such a process.

Another issue is the question of whether human populations would only have expanded beyond some pre-existing limit when driven to do so by a deterioration of environmental conditions within their existing habitat (e.g. Carto et al. 2009). Climate change during the Quaternary is clearly a major variable that is likely to have influenced patterns of early human evolution and dispersal (Maslin and Christensen 2007; DeMenocal 2011). However, populations are more likely to have expanded when environmental and climatic conditions improved, making larger areas available for human settlement, and to have contracted when conditions worsened, although examples of the latter could also occur and have been invoked, for example, in the first colonisation of the island of Cyprus by seafarers seeking new offshore resources during the climatic downturn of the Younger Dryas some 11,000 years ago (Ammerman et al. 2011). More potent facilitating or delaying factors would have been the availability of favourable environments with familiar resources in adjacent terrain, the adaptability of the pre-existing populations and their capacity to cope with new resources and environmental conditions, and the presence of physical, climatic and environmental barriers to further expansion. These barriers, in their turn, are likely to have changed significantly on Quaternary timescales because of changes in climate and changes of topography and palaeogeography brought about by changes in sea level, volcanism and tectonic activity (Petraglia and Rose 2009; Petraglia et al. 2011; Bailey and King 2011; Lambeck et al. 2011; Bosworth, this volume). All of these variable factors —of climate, sea level and tectonics—would have been powerfully active in the Red Sea and Arabian context.

The aim of this chapter is to summarise current knowledge about the deep history of human occupation in the Arabian Peninsula, the nature of changes in climate and sea level and their likely impact on the accessibility and suitability of the region for human occupation and the likely role

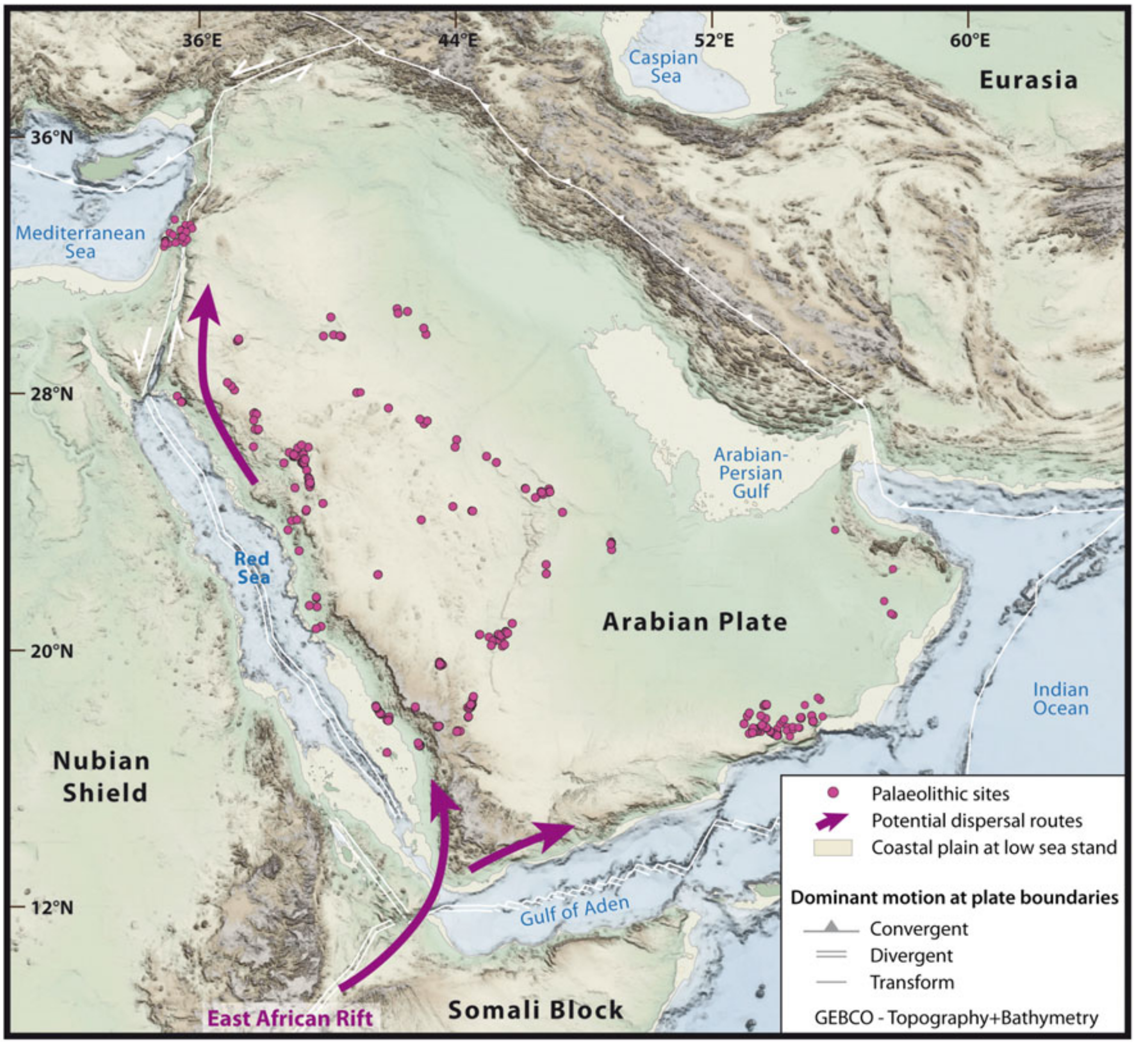


Fig. 1 Map of the Arabian Peninsula showing major geological and geographical features and distribution of Stone Age find spots (courtesy of Maud Devès)

of the Red Sea escarpment and coastal region as a major zone of human occupation, as a source of terrestrial and marine food resources and as a key pathway for the movements of people and the transmission of cultural ideas between Africa and Eurasia. Particular attention will focus on sea-level change, since this affects the likelihood of sea crossings at the southern end of the Red Sea, the visibility of coastal archaeological evidence, and also the varying productivity of the Red Sea as a source of marine resources for human consumption. It also affects the evidence for coastal archaeological settlements demonstrating early human interest in the exploitation of marine resources and seafaring. Also discussed here are new investigations in the Farasan Islands region that are searching for traces of submerged landscapes and archaeological sites formed at lower periods of sea level.

Quaternary Archaeology

Geographically speaking, the Arabian Peninsula forms a key stepping stone between Africa and Eurasia (Fig. 1), and one would expect an early history of Stone Age occupation, with human populations entering the Peninsula from the north via the Sinai Peninsula, or from the south across the southern end of the Red Sea. In fact, early Stone Age material has long been known. The Comprehensive Archaeological Survey Program of Saudi Arabia (CASP), which took place during the late 1970s and 1980s (Zarins et al. 1979, 1980, 1981), and the work of American and Russian archaeologists working at about the same time (Whalen et al. 1983, 1984, 1986, 1988; Amirkanov 1991), demonstrated the presence of many finds of Stone Age artefacts, indicating a human presence extending well back into the Pleistocene. However, until very recently, the significance of this material was not widely appreciated, mainly because the great majority of the stone artefacts are surface finds without stratigraphic integrity or accurate and reliable radiometric dates, and because of the assumption that the main pathways for human dispersal and cultural transmission between Africa and Asia were always through the Sinai–Levantine land corridor to the North and that semi-arid to desert conditions would have inhibited dispersal into the Arabian Peninsula. In the past decade, however, different areas of the Arabian Peninsula have opened up to exploration, resulting in a number of new and important finds and new dates (Fig. 1).

The Stone Age material in the Arabian Peninsula falls into two broad categories. First, there are a number of find locations with Lower Palaeolithic or Early Stone Age material of Acheulean type showing obvious similarities to Acheulean sites in Africa and the Near East, with large cores, simple flaking techniques, bifacially flaked hand axes and cleavers. Some of these sites are extensive with many thousands of stone tools, particularly at the Wadi Fatimah in the western Arabian escarpment, associated with a major river system, and at Dawadmi in the arid interior, where the material is associated with evidence of former springs (Petraglia et al. 2009). A number of uranium-series dates at the site of Saffaqah at Dawadmi give a date range of 60–204,000 years on calcrete attached to the stone artefacts, giving a very approximate and minimum age for their manufacture. Otherwise, this material can only be dated by analogy with similar sites in Africa and the Near East and on that basis may be as early as 1.4 million years, though Petraglia et al. (2009) suggest that the bulk of the material may date from 800,000 years onwards. This material is clearly associated with an early episode or episodes of human expansion out of Africa, though whether dispersal occurred via the North or the South cannot be determined from the available archaeological evidence.

A second category of finds comprises stone tool assemblages of Middle Stone Age or Middle Palaeolithic type, characterised by more complex and efficient patterns of core preparation and core reduction to produce regular-shaped flakes and blades. These sites include Jubbah in the north of Saudi Arabia, where Stone Age material has been found in stratigraphic context alongside a now-dry lake in the Nefud Desert, with optically stimulated luminescence (OSL) dates of the associated sand sediments of 75,000 years (Petraglia et al. 2011). The stone tools include material that is typical of Middle Palaeolithic or Middle Stone Age technology found widely across the Near East and North Africa, including Levallois cores, a distinctive technology for removing successive flakes of predetermined shape from a specially prepared nodule, some of which are retouched along the edge to form notched and denticulated pieces. At Jebel Faya in the United Arab Emirates, a sequence of stone tool industries has been found in deposits originally accumulated in the mouth of a rock shelter, with earliest OSL dates of about 125,000 years (Armitage et al. 2011). The earliest stone tool assemblage here includes a Middle Palaeolithic Levallois technology with the addition of bifacially flaked leaf-shaped pieces that show some similarities with contemporaneous assemblages in Northeast Africa. Aybut Al Auwal in Oman is one of a number of sites located on the Nejd plateau in Oman (Rose et al. 2011). Here, the stone tools are associated with fluvial gravels dated by OSL to 107,000 years and include distinctively shaped Levallois cores known as Nubian cores, with close parallels to material of similar age in the desert oases of the Eastern Sahara, the Nile Valley and the Red Sea Hills, but with nothing comparable in the Levant. Finally, at Shi'bat Dihya in the Wadi Surdud of Yemen, a stone tool assemblage has been found associated with alluvial sediments dated by OSL at about 55,000 years (Delagnes et al. 2012). Here, the technology involved a type of prepared-core reduction to produce flakes and blades for tool use, but using a simpler pattern of flake removals than that used in the classic Levallois technique. Similar stone tool industries of a similar age have been found in the upper levels of the Jebel Faya sequence. These later industries have no obvious parallels in Africa or the Levant, or elsewhere, as yet, in Arabia, and have been interpreted as evidence for the development of more localised cultural traditions resulting from increased localisation and isolation of human populations during the more arid climatic conditions at the height of the Last Glacial (MIS 3 and MIS 2), approximately from about 60,000 to 20,000 years (Armitage et al. 2011; Delagnes et al. 2012).

Quaternary Climate Change

A critical variable affecting the likelihood of early human occupation is climate change, particularly increases in precipitation. Many of these early Stone Age sites are found in the desert interior in regions that have too little surface water today to support human life without modern technological aids. It is clear from this fact, and from the presence of fossil tufas indicating former spring activity, dried up lake beds and wadis filled with alluvial sediments indicating much greater stream competence than today, that conditions must have been periodically wetter in the past, allowing the spread of grasslands, grazing mammals and human hunters into the desert interior and multiplying the pathways for movements and contact across the Peninsula from the Red Sea escarpment to the Gulf Coast. Mapping of palaeochannels, dating of lake sediments and analyses of proxy climate indicators in speleothem sequences are beginning to create a clearer picture of the temporal and spatial pattern of climate variability,

geoff.bailey@york.ac.uk

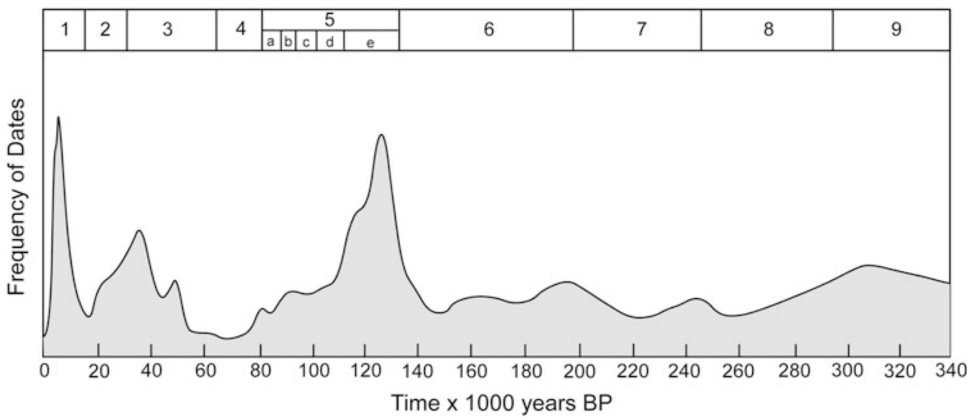


Fig. 2 Variations in climate in the Arabian Peninsula over the past 350,000 years (after Parker 2009). The *curve* represents the probability of wetter climate intervals based on the number of dated indicators for a given period. *Peaks* in the *curve* represent well-dated wet intervals rather than unusually wet intervals. *Numbered intervals* indicate marine isotope stages. For further details, see Parker (2009)

at least for the last 350,000 years (McClure 1976; Schultz and Whitney 1986; Sanlaville 1992; Parker et al. 2006; Fleitmann et al. 2007; Parker and Rose 2008; Parker 2009; Crassard et al. 2013; Rosenberg et al. 2013; Fig. 2).

The principal driver of climate change in the Arabian Peninsula during the Quaternary was shifts in the intertropical convergence zone (ITCZ) associated with the glacial–interglacial cycle, which led periodically to northward incursion of the Indian Ocean monsoon (IOM) weather system. Today, rainfall associated with the IOM falls mainly on the southern edge of the Arabian Peninsula, especially in the coastal regions of Oman, and extends as far north as Jizan in Saudi Arabia, with high rainfall over the Asir and Yemeni highlands in the southwest. This northward shift during the Pleistocene brought increased rainfall to present-day desert regions throughout Arabia, activating networks of stream channels and creating numerous shallow lakes of greater or lesser extent across desert regions such as the Rub al-Khali, the Mundafan Basin and the Nafud in the north. An additional influence may have been the extension southwards of the Mediterranean cyclonic system, bringing winter rainfall into areas further south than is the case today.

The onset, timing and duration of these wetter episodes are matters of ongoing investigation. As a very general rule, there is a broad correlation between the marine isotope curve and increased precipitation, with the wettest conditions in interglacials (odd-numbered MIS) and maximum aridity in glacial periods (even-numbered MIS). But when sufficient dates are available, the pattern in detail appears more complex. Over the past 130,000 years, there is a clear and strong correlation between wetter periods and the early part of the interglacial cycle, in MIS 5e at 130–120 ka, and again in the early Holocene (the early part of MIS 1) from about 11.5–6 ka (Fig. 2). The latter part of the Last Interglacial, MIS 5a, 82–74 ka was also wet. MIS 4 witnessed the onset of increased aridity but was punctuated by at least one wetter interval at 61–58 ka (Parton et al. 2013). During MIS 3, associated with progressive onset of Northern Hemisphere glaciation, the position is less clear. The predominant climatic signal is one of increased aridity, reaching its peak at the Last Glacial Maximum at 22 ka, but a number of wet intervals have been claimed between 40 ka and 20 ka and a short-lived wetter phase at about 15–13 ka on the basis of radiocarbon-dated alluvial and lacustrine sediments (see, in particular, Parker 2009 for details). However, more recent OSL dating of lacustrine sediments does not show any evidence of these wetter intervals (Crassard et al. 2013; Rosenberg et al. 2013), and it appears that the radiocarbon dates are unreliable because of contamination by younger carbon. Going further back in time, both the MIS 7 and MIS 9 interglacials were associated with wetter conditions indicated by OSL dating of lacustrine sediments and U/Th dating of speleothems, centred at about 193 ka and 319 ka, respectively. MIS 6 was another arid period, but one punctuated by brief episodes of increased precipitation at 147, 152, 160, 170 and 174 ka according to Parker (2009). Earlier still, in the Middle Pleistocene, arid indicators are present between 700 and 560 ka, and wet indicators between about 560 and 319 ka, but the broad duration of these climatic zones may be misleading because of scarcity of dates and cannot be resolved into a more detailed record to compare with the later part of the Quaternary record. Earlier again, carbon isotope evidence ($\delta^{13}C$) in Early Pleistocene faunas associated with palaeolake deposits in the western Nafud desert indicates an open savannah landscape with lakes, buffalo and hippopotamus between about 3.5 and 1.2 Ma (Thomas et al. 1998).

There are difficulties in generalising with confidence and in detail from this evidence, except perhaps for the very end of the Quaternary sequence, given the irregular and generally sparse spatial and chronological sampling of the climatic record, and the increasing margins of uncertainty associated with dating methods as one goes further back in time. It remains unclear to what extent the spot dates for wet indicators such as lake and river sediments, for example in MIS 6, represent short-lived wet intervals separated by more arid conditions, or irregular sampling of the same prolonged and continuous climatic episode. McClure (1976), on the basis of radiocarbon dates in the Rub al-Khali, suggested a duration of about 800 years for these lakes, but these dates are no longer considered reliable. The more recent OSL dating work of Rosenberg et al. (2013) suggests relatively short durations for periods of lake formation, but the margin of error in the dating method does not allow further refinement. The best chronological indicator comes from annual laminations of lake sediment in Nafud, which indicate a duration of about 1,400 years for lake formation during MIS 9. An additional complexity is the possibility that the spread of wetter conditions induced by the IOM was time transgressive from south to north. Continuous records from speleothems and the deep-sea marine record are subject to their own uncertainties, and discrepancies between them and the discontinuous terrestrial record may reflect either problems of dating, or divergence of local climate conditions in particular landscape settings from a generalised climate curve derived from marine sediments or speleothems. Allowing for these uncertainties, the broad pattern seems to be one of persistent and periodic spread of wetter conditions throughout the Quaternary, with the wettest and longest intervals occurring during the early part of interglacials, and perhaps periodic bursts of increased precipitation but of shorter duration at other times.

Sea-Level Change and Sea Crossings

A factor of potential importance in determining the likely attractiveness and importance of coastal regions is the possibility afforded by marine and oceanographic conditions in the Red Sea for the development of simple methods of seafaring and the availability of easily accessible marine resources such as inshore fish and intertidal shellfish. Here, however, we face a fundamental problem and that is the fact that for long periods of the Pleistocene epoch under review here, sea levels were much lower than present. This has serious implications for reconstructing the position and configuration of past coastlines and island archipelagos and hence the need for sea crossings, the nature of varying oceanographic conditions and their impact on currents and marine productivity within the Red Sea Basin, and the visibility of archaeological evidence for human activity on these ancient but now-submerged shorelines.

The broad pattern of sea-level change over the past 2 million years is now well known. Analysis of oxygen isotope variations in foraminifera stratified in deep-sea sediments has demonstrated that the isotope signal closely maps changes in ocean volume in response to the glacial–interglacial cycle of the Quaternary period (Fig. 3). Indeed, one of the most recent and most detailed sea-level curves comes from deep-sea sediments in the Red Sea (Siddall et al. 2003). Here, a detailed pattern of sea-level change has been reconstructed over the past 400,000 years, using a model of salinity change resulting from changes in the degree of mixing between the Red Sea and the Indian Ocean. When sea level was low, ocean flow into the Red Sea was restricted, and the salinity of the Red Sea was elevated above the ocean average because of higher rates of evaporation. One important consequence of this analysis is to demonstrate

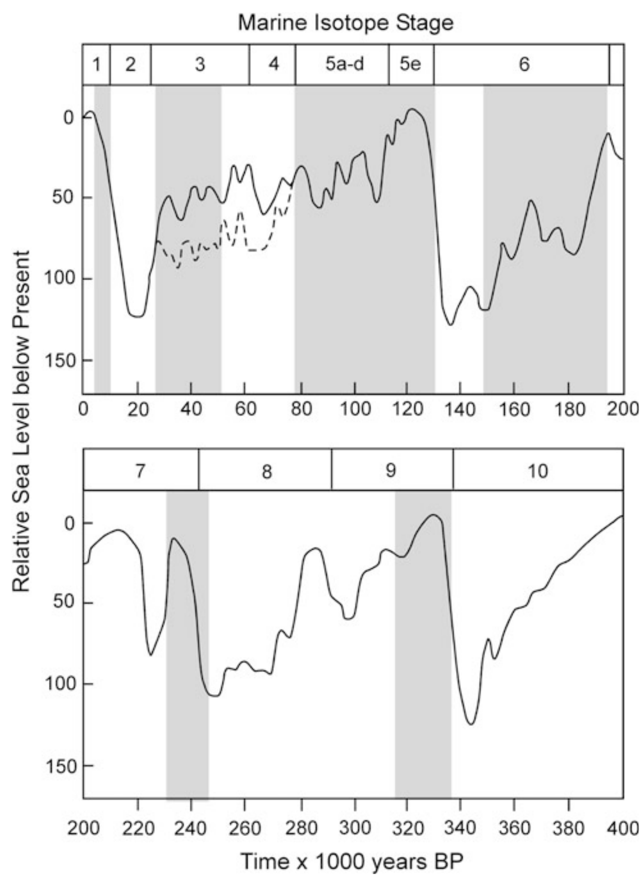


Fig. 3 Variations in eustatic sea level (ocean volume) according to the deep-sea isotope record over the past 350,000 years. *Sources* Chappell and Shackleton (1986), Shackleton (1987), Imbrie et al. (1984), Lambeck and Chappell (2001), Waelbroek et al. (2002), Sidall et al. (2003), Lambeck et al. (2011). The *dotted part* of the *curve* shows the original isotope readings and the *solid line* above it the sea-level curve after removal of temperature effects from the isotope readings. *Shaded columns* give an approximate indication of the relationship between sea-level position and climate change as derived from Fig. 2. See also Fig. 6 and the text for further discussion of climate data

that salinity in the Red Sea over this time range never reached very high values that would imply evaporation within a closed basin. In other words, at no time in the past 400,000 years was it possible for people to cross the southern end of the Red Sea between Northeast Africa and the Arabian Peninsula across dry land.

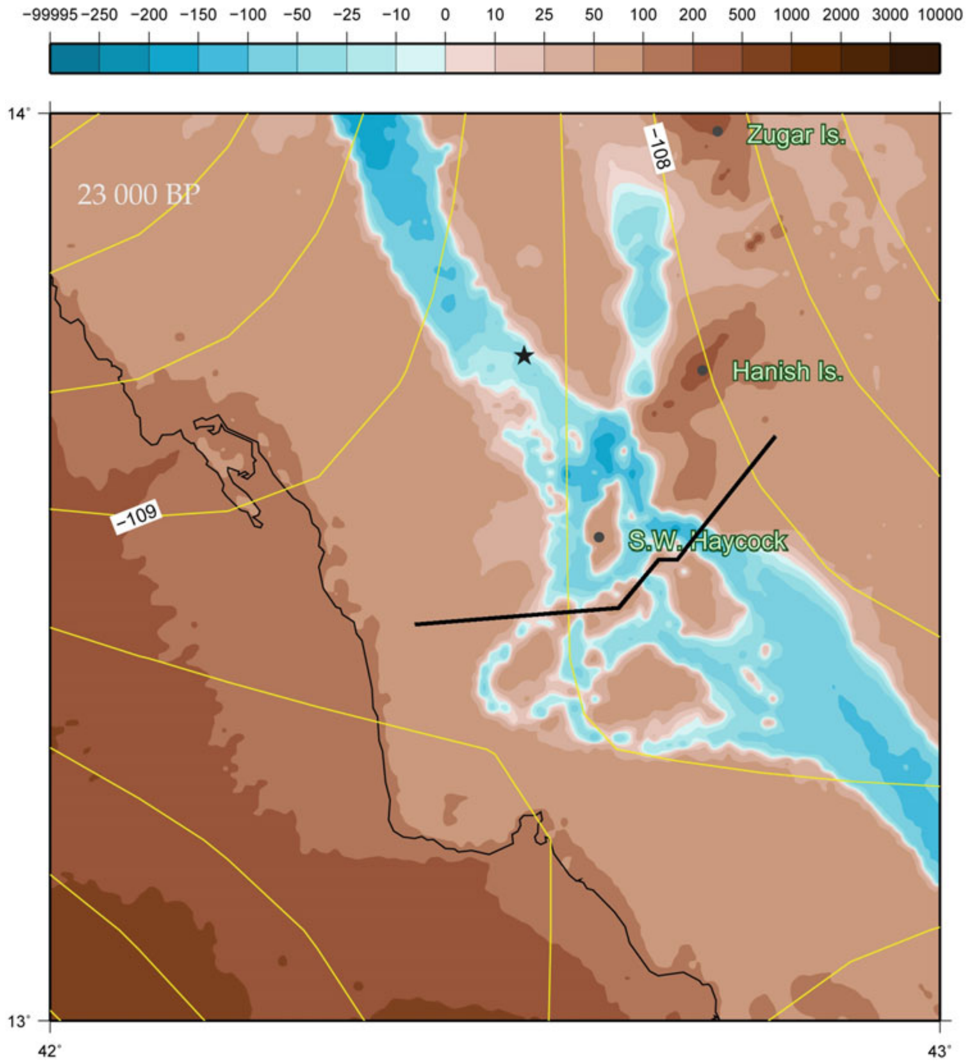
In order to pursue these implications, it is necessary to convert the sea-level curve into maps of shoreline position at different stages of the glacial–interglacial cycle. This is a complex procedure and cannot be done simply by mapping sea-level positions against modern seabed bathymetry, because the coastal crust has been warped and flexed by hydro-isostatic loading and unloading of water masses on the continental shelf, by large-scale propagation of the Red Sea rift and tectonic uplift of the rift flanks, by localised processes of salt doming and withdrawal, by variable accumulations of sediment on the sea bed and by localised volcanic activity (Bosworth, this volume; Ligi et al., this volume; Hovland et al., this volume; Pugh and Abualnaja, this volume). Modelling of these processes in the southern Red Sea, incorporating all available dates for raised or submerged beaches throughout the Red Sea region, has been carried out by Kurt Lambeck working with the Saudi–UK archaeological team working in the region (Lambeck et al. 2011).

The reconstruction of coastal palaeogeography in the southern Red Sea, and the data and theoretical models on which it is based, are set out in detail in Lambeck et al. (2011) and are only briefly summarised here (see also Pugh and Abualnaja, this volume). The key sources of required information are the following: (1) bathymetry of the shallowest part of the southern Red Sea, namely the Hanish Sill; (2) variations in ocean volume with time (variations in eustatic sea level); (3) variations in the isostatic loading of the Red Sea region over time and in different parts of the Red Sea region; (4) earth model parameters on the thickness and viscosity of the underlying mantle in the Red Sea region, which determine the way in which the Earth's crust responds locally to isostatic loading effects; and (5) rates of tectonic uplift. Variable (1) is known approximately from actual measurements taken by Werner and Lange (1975) and the minimum depth is 137 m, although the possibility of deeper channels cannot be excluded (Lambeck et al. 2011, pp. 3570–3571). Variable (2) is known from information on raised shorelines in far-field locations such as Western Australia where isostatic and tectonic effects are absent or independently known and can be further corroborated against the marine isotopic record of changes in ice volume. Isostatic deformation, variable (3), is usually associated with regions close to the continental ice sheets of the Northern Hemisphere, where crustal depression by ice sheets and rebound following deglaciation (glacio-isostatic) can elevate shorelines by hundreds of metres. In more distant locations such as the Red Sea, the glacio-isostatic effect is small though not entirely absent and is supplemented by additional effects resulting from the loading and unloading of water masses on the continental shelf (hydro-isostatic effects). These effects can be modelled, taking into account glacio-isostatic effects and the best available data on hydro-isostatic loading in adjacent sea basins, and can have a significant impact. Variable (4) is known but with some degree of uncertainty that can be assessed by applying different assumptions within a range of likely possibilities. Variable (5) is the unknown variable in this equation and is estimated by comparing the position of the shoreline at selected time intervals (Early Holocene, Last Glacial Maximum, Last Interglacial), as predicted by isostatic modelling, with the actual elevation of dated shoreline features. The latter are represented by a large and somewhat scattered sample of data points available for this purpose from the Red Sea, including dates from uplifted coral terraces that are especially prominent in the northern Red Sea, coral reefs or other shoreline features that are close to the present shoreline elevation and some that are now submerged. Any resulting differences between predicted and observed shoreline elevations can be used to estimate the effect of tectonic uplift associated with long-term rifting, and this amounts to at least 0.1 mm year^{-1} (or 1 m per ten thousand years) in the northern Red Sea. Once these adjustments have been made, they can be applied to the reconstruction of shoreline configurations at selected time intervals and in different regions.

The shortest sea crossing at modern sea level today is about 29 km across the Bab-al-Mandab Strait, a crossing that is almost impossible except with seaworthy boats and navigational skills, something that is generally assumed by archaeologists to have been feasible only during recent millennia. However, palaeogeographic modelling shows that a narrow channel would have extended for about 100 km from the Bab-al-Mandab Strait in the south to the Hanish Islands in the north and that the shallowest part of the channel is over the Hanish Sill (Fig. 4). Moreover, the shape of the channel in the Hanish region is such that for more than half the period of time encompassed by a single glacial cycle, that is to say whenever sea level was lower than 50 m below present, for a period of about 60,000 years in every 100,000 year cycle, sea crossings of about 4 km or less were possible via small islands in the Hanish region (Fig. 5). During these periods of lower sea level, crossings via island hopping across the Hanish Sill could easily have been accomplished with little risk by swimming or simple rafting. This greatly increases the likelihood of human crossings, whether by accident or intention, not only over an extensive proportion of the past 250,000 years, but much further back into human prehistory.

Further research is needed on the precise bathymetry of the channel region of the Hanish Sill to test in more detail these palaeogeographical reconstructions and the models on

Fig. 4 Map showing the position of palaeoshorelines at the southern end of the Red Sea during the maximum sea-level low stand at the Last Glacial Maximum. The shortest sea crossings at this period would have been in the region of the Hanish Sill, via the Haycock Islands, as shown by the black line (after Lambeck et al. 2011)



which they are based. More well-dated palaeoshoreline features, whether from submerged shorelines that are now under water, or from raised coral reefs such as the impressive sequence visible at Umm Lajj in the north (Vincent 2008, Fig. 2.3), are also needed to refine and test the models. Another question is the effect that the formation of a long and constricted channel at lowered sea level between the Bab-al-Mandab and the Hanish Islands would have had on tidal currents and the extent to which these would have been faster and more hazardous for human sea crossings. Answers to this question must remain speculative for the moment, but new research on palaeotidal modelling is now under way that may help to constrain the likely pattern of sea currents during these periods of lower sea level (Lambeck, pers. comm., September 2013).

It is of interest to compare the periods when sea crossings would have been most easily feasible with minimal technology, as identified by the above reconstructions, and those periods of increased rainfall when the territory available for human occupation would have been most attractive and most extensive (Fig. 6). The comparisons can only be approximate because of uncertainties in the dating and duration of some of the climatic intervals and smoothing effects in the drawing of the sea-level curve. Of course, the absence of easy sea crossings in the south during periods of favourable climate would not have deterred a human presence in the Arabian Peninsula, since entry into the Peninsula and dispersal within it would always have been possible from the north via the Sinai route. The point is that a conjunction of favourable climates and easy sea crossings would have afforded the maximum opportunities for dispersal and interpopulation contact between Africa and Arabia, whereas the absence of one or the other, and even more so the absence of both, would have tended to reinforce bottlenecks in dispersal and regional isolation. On these grounds, the most striking feature of Fig. 6 is that periods of wetter climate and periods of easy sea crossing are almost largely mutually exclusive. A favourable conjunction of

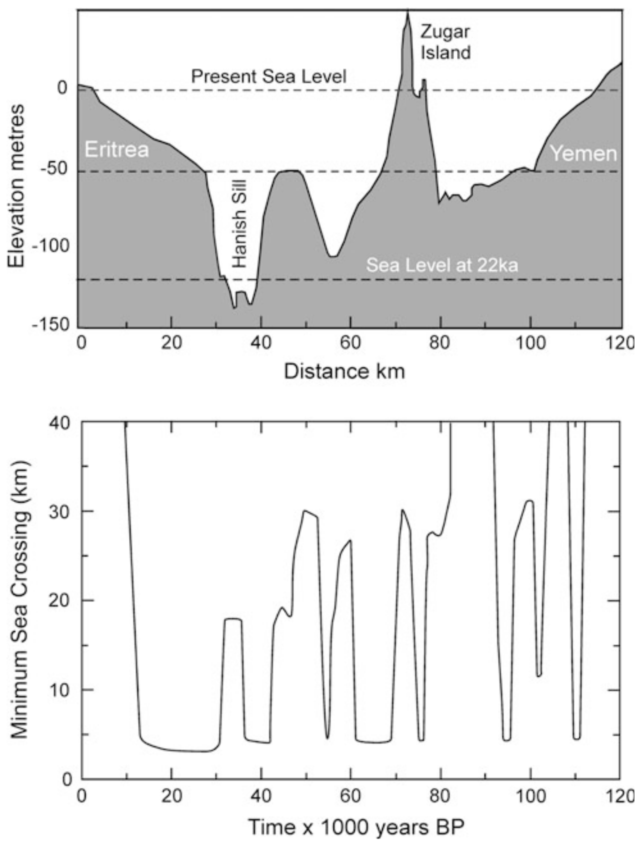


Fig. 5 Cross section of the Hanish Sill region. The cross section is marked by the *black line* in Fig. 4. The *upper* diagram shows the effect of channel geometry on sea crossing distances at different sea-level positions and the *lower* diagram the periods when short sea crossings would have been possible during the past 120,000 years (after Lambeck et al. 2011)

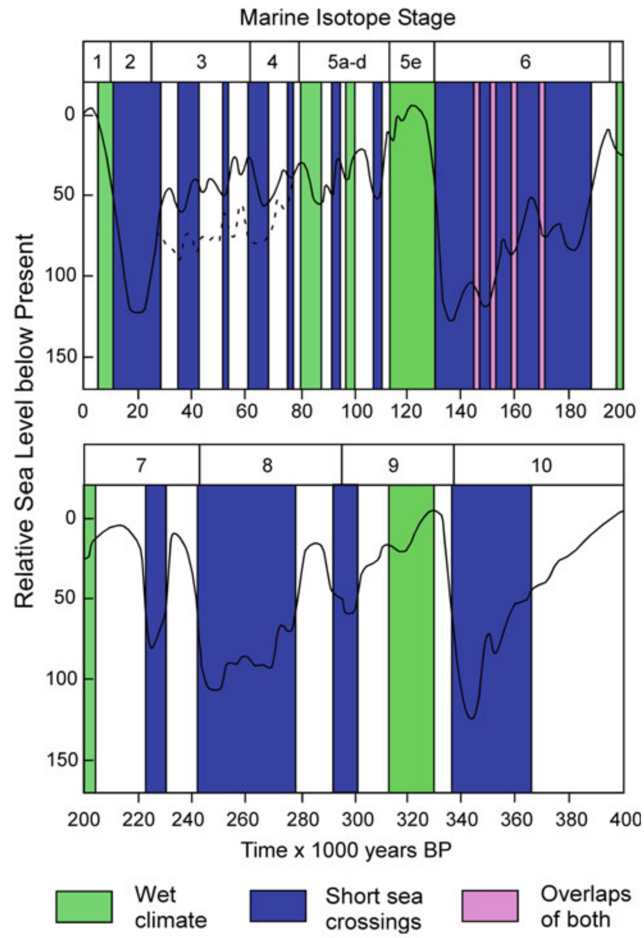


Fig. 6 A comparison of wet periods when climatic conditions would have been most favourable and sea level stands sufficiently lowered to facilitate easy sea crossings at the southern end of the Red Sea over the past 350,000 years. *Blue* short sea crossings; *Green* wetter climates; *Pink* overlap of periods with short sea crossings and wetter climates. Climate data are taken from Fig. 2, modified according to the more recent work of Rosenberg et al. (2013) and data on sea crossings from Lambeck et al. (2011)

circumstances may have occurred in the wetter intervals of MIS 5 but only for very short intervals. The longest period of overlap occurred in MIS 6, between about 140 and 180 ka, if Parker's (2009) dates are followed, but these wet intervals are not recorded in Rosenberg et al.'s (2013) data. Interestingly, the most favourable climatic periods during the interglacials of MIS 1, 5e, 7 and 9 and the late glacial episodes in MIS 2 appear to be periods when sea crossings would have been most difficult or would have required skilful seafaring abilities. Least favourable periods, combining maximum aridity with high sea levels, appear to be rare, the most notable example being the latter part of MIS 1 (the Late Holocene after about 6 ka), and perhaps part of MIS 7, but the climate record is incomplete in this period to say nothing of earlier MIS stages. Other periods of combined aridity and high sea level may have existed, but they are either disguised by poor resolution in the dating, or else they were of short duration.

Coastal Archaeological Sites and Offshore Landscapes

Sea-level change is not only of importance in narrowing the crossing distances between opposite shorelines. It also has two additional archaeological consequences. First, any evidence for the use of marine resources and a maritime way of life must be invisible except during periods of high sea level like the present. Palaeoshorelines formed when sea level was lower than the present are now deeply submerged and some distance offshore, and we can only expect to see archaeological evidence of coastal settlements and use of marine resources on or near the present-day coastline for periods of high sea level such as those that have existed during the past 6,000 years, or during earlier periods of high sea level such as MIS 5e about 130,000 years ago. Coastal shell mounds, which are the most durable and visible archaeological indicator of coastal settlement, appear in their tens of thousands on many coastlines of the world from about 6,000 years ago onwards (Bailey et al. 2013a). Coastal sites, mainly cave deposits, with stone tools and evidence of shell gathering and other marine resources such as bones of fish and sea mammals, are also known from the high-sea-level periods of MIS 5 and 4, notably in South Africa, together with smaller quantities of shells in the 160,000 year-old deposits of Pinnacle Point (Erlandson 2001; Jerardino and Marean 2010). Sites in the intervening period are very rare and are confined to coastal caves adjacent to steeply shelving offshore topography, where the shoreline remained close even during periods of low sea level, or to coastlines in high latitudes where the land has undergone very substantial glacio-isostatic uplift, notably in Norway and Alaska (Bailey and Flemming 2008). This problem of missing coastal sites is a worldwide problem, not confined only to the Red Sea, and increasing attention is now being devoted to underwater investigation and the search for submerged landscapes and coastal archaeological sites in many parts of the world (Benjamin et al. 2011; Evans et al. 2014).

Secondly, lowered sea levels would have exposed extensive areas of land available for human occupation, especially in the southern Red Sea, where the continental shelf is quite shallow (Fig. 7). Here, an additional increment of land some 100 km wide extended seaward of the present coastline, and there was a similar extension of land on the African side offshore of Eritrea. Both shelves host a concentration of islands—the Dahlak Islands on the Eritrean side, and the Farasan Islands on the Saudi Arabian side, formed by salt tectonics, which would presumably have projected as a clump of low hills in this extensive coastal terrain when sea level was lower. Moreover, both theoretical considerations (Faure et al. 2002) and inspection of the available bathymetry suggest that this now-submerged landscape may have been quite attractive for plant and animal life, and hence for humans, because of a complex topography with fault-bounded basins, extensive spring lines and accumulation of groundwater in solution hollows, providing attractive conditions in these coastal regions even during periods of relatively arid climate.

We are now exploring these ideas through new investigations in the region of the Farasan Islands. These islands were connected to the mainland when sea level was about 50 m below present or lower. Their archaeological interest stems from the fact that there are more than 3,000 coastal archaeological sites, most of them shell middens, but covering a wide range of site types from surface finds with few

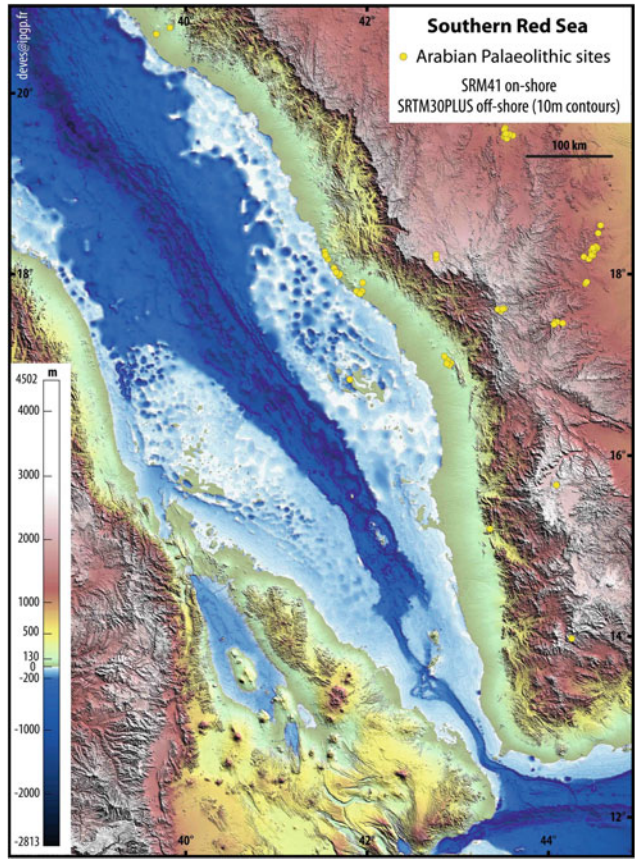


Fig. 7 Enhanced satellite imagery of the southern Red Sea showing the position of the Farasan Islands, and the extent of the submerged landscape at maximum sea-level regression during glacial periods, and the general nature of the seabed topography. ASTER GDEM is a product of METI and NASA (courtesy of Maud Devès)

or a limited scatter of shells to large mounds up to 5 m high, some of which contain almost nothing but discarded mollusc shells, while others include remains of fish bones and land mammals in addition to the mollusc shells (Bailey et al. 2013b; Fig. 8). These are not to be confused with the Farasan Banks, which are further to the north, or the ‘shell banks’ of the geological literature (Dabbagh et al. 1984). They are not natural deposits of shells thrown up by storms but the remains of settlements of prehistoric coastal peoples who collected the marine molluscs for food and perhaps also for fish bait. These sites began forming at or soon after about 6,000 years ago and clearly relate to the establishment of modern sea level. As such, they are recent in date, but at the same time, they give a useful insight into the visible archaeological features that are associated with a fully maritime way of life involving seafaring, fishing and shell gathering among other activities. They are a useful benchmark for the sorts of evidence that we would expect to see in relation to hypotheses for the existence much further back in the prehistoric period of maritime peoples around the coastlines of the Red Sea and the Arabian Peninsula, given

Fig. 8 Shell mound in Janaba Bay on the main island of Farasan, showing the position of the shell mound on a modern shoreline undercut by marine erosion (photograph by Hans Sjoeholm 2006)

that consumption of molluscs was a universal accompaniment to shoreline settlement or activity in the Arabian context and that in any case, the shells of the molluscs are the primary factor giving visibility to shoreline activity of whatever type.

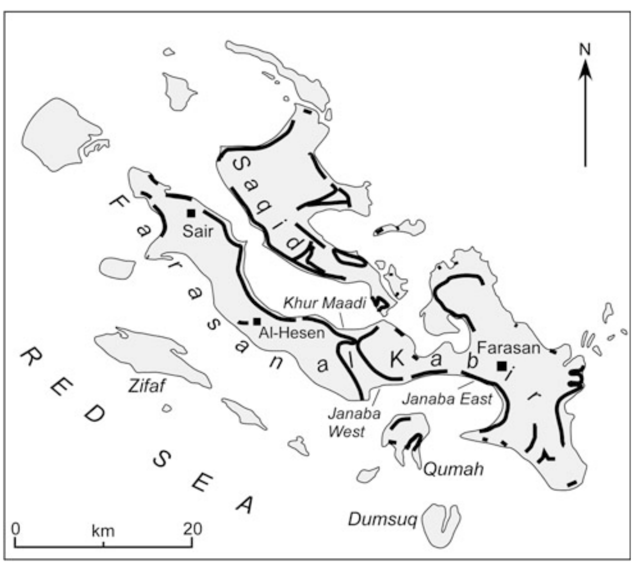


Fig. 9 Distribution of shell mounds on the Farasan Islands. The number and density of sites is such that they cannot be shown individually on a map of this scale. Instead, a more or less continuous line is used to provide a representation of the distribution. Sites that appear to be inland of the present-day shoreline are located on palaeoshorelines that are now located inland because of tectonic uplift and sediment infilling of shallow bays and channels

The majority of the sites are on the large islands of Farasan Kabir and Saqid, but there are also shell mounds on the island of Qumah and on some of the smaller islets to the north of Farasan (Fig. 9). The largest mounds are up to 4–5 m high and the largest extend for hundreds of metres along the shoreline. The bulk of these shell deposits appear to have been formed between about 6,000 and 5,000 years ago. Later deposits also exist, extending up to the Islamic era, but these are thinner shell deposits or shell scatters, often associated with remains of buildings made from naturally cemented beach rock or coral. The reasons for this difference in volume of shell deposits remain unclear, but part of the explanation may have to do with the existence of an ecological window of opportunity for extensive beds of marine molluscs in shallow embayments that came into being for only a short period and were then subsequently filled in with sand.

Excavations show that the shell mounds comprise a wide range of shallow water and intertidal molluscan species variously associated with sandy substrates or coral reefs. The dominant species is a small gastropod, *Strombus fasciatus*, but other common species are the large gastropods, *Pleuroploca trapezium* and *Chicoreus ramosus*, and bivalve species such as *Chama reflexa*, *Spondylus marisrubri* and *Pinctada* sp. Extensive ash layers are interleaved with the shell deposits, representing the remains of fireplaces, and fish bones and the bones of gazelle have also been recovered from some shell layers, along with very rare and isolated finds of stone tools and potsherds.

The huge quantity of mollusc shells implied by the number and volume of shell deposits does not necessarily mean that the mounds were created by very large numbers of people, or by people who subsisted mainly on shell food. The amount of food represented by the shells is actually relatively small, once one takes into account the high ratio of shell to meat in most shell species, and the time over which the mounds have accumulated. Detailed measurements show that the amount of food represented by these large shell deposits may be as little as 5–10 % of total food intake and that the impressive appearance of the resulting shell mounds is mainly the result of the large amounts of debris created by shell gathering and the durability and resistance to decay of the dead shells compared with most other food remains or by-products of human activity.

Since the Farasan shell mounds are clearly late in date, the question arises as to whether similar evidence can be found or might be expected in association with earlier periods of high sea level. An obvious candidate for inspection is the high-sea-level period of MIS 5e. Walter et al. (2000) have reported evidence of marine mollusc shells collected as food at the 130,000 year-old site of Abdur on the Eritrean coast in association with stone tools and mammal bones. Full details have not been published so that the quantity of material and the status of the mollusc shells as food items have yet to be evaluated. Similar sites occur on the Arabian side of the Red Sea in the vicinity of the extensive lava fields found in the coastal region of Al Birk. Here, stone tools of Middle Stone Age and Early Stone Age type have been found on elevated coral terraces that refer to earlier periods of high sea level, most probably MIS 5 (Bailey et al. 2007a; Bailey 2009). However, the artefacts so far recovered are surface finds and cannot be dated with confidence or associated with remains of shell food or other subsistence activity. Ecological conditions that allow the accumulation of substantial shell mounds like those of the Farasan Islands are only patchily distributed along any given coastline. Moreover, even shells are vulnerable to fragmentation and dispersal if exposed on the surface for many millennia. Hence, the absence of thick or extensive shell deposits on coastlines where stone artefacts have been found is not decisive refutation of an interest in marine resources by the stone tool makers. What is needed is archaeological material in stratified context, where there are good chances of obtaining geochronological control and contextual information on environment and subsistence, including marine shells discarded as food, or other indicators of marine exploitation. Sites with these features of MIS 5 age or older are rare, and usually only preserved and recovered in cave deposits, such as those recorded in South Africa and on parts of the Mediterranean coastline. Abdur is an exception, showing that relevant material can be preserved in open-air locations. The search for similar material in Saudi Arabia is ongoing (Devès et al. 2013).

An even greater challenge is the question of whether coastal archaeological material was deposited on palaeo-shorelines that are now submerged. The fact that the Farasan shell mounds appear almost exactly at the moment when sea level stopped rising and shorelines became visible on the present-day land surface is a strong indicator that earlier coastal sites could have existed and have escaped discovery so far for no better reason than that they are now submerged, and no one has yet gone underwater to look for them. That possibility, in its turn, demands underwater investigation. One possible objection to pursuing this hypothesis is that during periods of lower sea level, the reduced inflow of water from the Indian Ocean and the resulting increase in salinity would have inhibited marine productivity and reduced the availability of marine resources. Sidall et al. (2003) have identified 'aplanktonic' levels in the deep-sea sediment sequence associated with low-sea-level episodes. The more general significance of such evidence is unclear. Many marine species can tolerate conditions of high salinity, as is clearly demonstrated by the presence of an endemic marine fauna in the Red Sea that has persisted through many cycles of sea-level change. That people might have been deterred from exploiting the resources of the sea during the periods of low sea level, such as those of early MIS 1, and MIS 2–4, because marine resources were absent is highly speculative and can only be tested by searching under water for relevant evidence. In any case, whether or not people present in the region during periods of lowered sea level took an interest in marine resources or ignored them, it is certain that an extensive terrestrial landscape would have existed with potential for the pursuit of plant and animal resources on land. There is, therefore, a strong imperative for underwater exploration from a number of points of view.

Since 2006, we have been pursuing underwater investigations alongside archaeological survey on land in the Farasan Islands and on the Gizan mainland (Bailey et al. 2007a, b; Devès et al. 2013; Alsharekh and Bailey 2014). Experimental deep diving in 2006, with the help of Saudi Aramco and its vessel the M/V Midyan as an offshore platform, demonstrated that palaeoshorelines do exist underwater and can be identified as potential targets for more detailed investigation (Figs. 10 and 11). We also conducted diving work in shallow water in 2008 and 2009, including exploration and excavation of underwater caves and under-cut palaeoshorelines. This work is slow and painstaking. The way in which the original landscape and its associated archaeology were transformed by inundation and sea-level rise is not yet well understood. Many sites may be washed away, degraded or buried beneath marine sediments. Others may be well preserved because of a complex topography that provided protection from the full force of wave action during inundation or by burial beneath marine sediment followed by subsequent partial erosion and exposure. We know from

Fig. 10 Palaeoshoreline showing characteristic features at a depth of about 20 m (photograph by Hans Sjoeholm 2006)

extensive underwater investigations elsewhere that underwater features can be preserved, often with excellent conditions of organic preservation, and can survive even in high-energy coastal environments and through several cycles of sea-level change (Benjamin et al. 2011; Evans et al. 2014).

There is every reason to suppose that similar features are preserved in the Red Sea region. The next essential step in underwater exploration is to examine the seabed more extensively in the Farasan region for traces of palaeoshorelines and other topographic features, using the full range of modern technological aids including seismic and acoustic

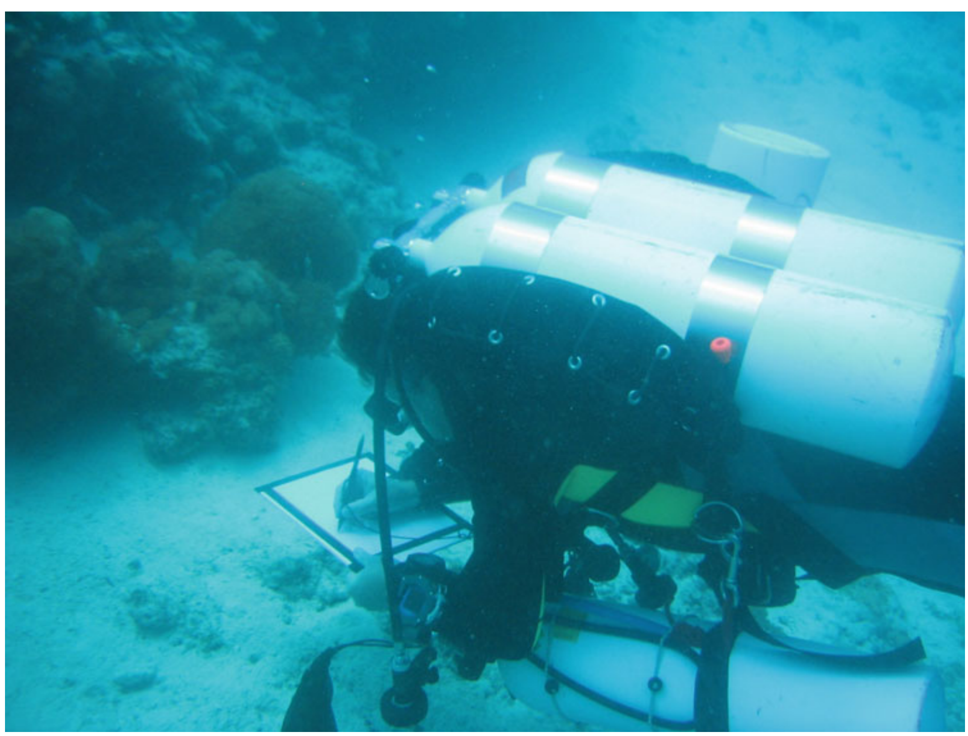


Fig. 11 A diver recording features and collecting samples from a submerged palaeoshoreline during a deep dive to a depth of over 60 m using mixed gas (trimix) technology (photograph by Trevor Jenkins 2006)

recording, remotely operated vehicles, and sediment coring. Suitable equipment has now been sourced for this phase of investigation, and a preliminary survey took place in June 2013 using the facilities of the R/V Aegaeo of the Hellenic Centre for Marine Research. The survey carried out a series of transects extending from the edge of the continental shelf to shallower channels between the Farasan Islands and the Gizan mainland. Surveys included multibeam bathymetry to characterise seabed topography, sub-bottom profiling to identify geological and geomorphological structures such as faulting and sediment thickness, a side-scan survey to highlight surface anomalies, the use of a remotely operated vehicle with cameras for visual inspection and the collection of a large sample of sediment cores. It is too early to report in detail on that survey, but preliminary results indicate that the landscape that was exposed when sea level was low was a landscape of considerable topographic complexity, with fault-bounded basins that trapped water and sediment, deep solution hollows that could also have collected freshwater and an extensive network of drainage channels.

It is axiomatic that when climate change resulted in the extension of wetter and greener conditions into the desert interior, those improved conditions would have applied also to coastal regions. Conversely, when the interior became uninhabitable because of increased aridity, coastal regions would have remained relatively well-watered because of capture of orographic rainfall on the Red Sea escarpment and the presence of high water tables and springs. In short, coastal regions would always have been attractive relative to the desert interior, regardless of climatic conditions, and especially during more arid climatic episodes, providing the stable, core regions of human settlement from which populations would have periodically expanded into the interior or retreated again according to the pattern of climatic change as summarised in Fig. 6. As is clear from this diagram, many periods of arid climate coincided with low sea levels, and so did some of the wetter episodes, including the Early Holocene wet period, when sea levels were rising at the end of the last glaciation but were still as much as 50 m below the present. If this hypothesis of relative coastal attractiveness is correct, then we should expect archaeological sites to occur in greater number in coastal regions than in the interior, regardless of whether marine resources were part of the coastal subsistence economy or not, and with greater persistence, both when sea level was high and when it was low. During periods of low sea level, the coastline of the southern Red Sea shifted by as much as 100 km seaward of its present position, exposing an extensive coastal region with many potential attractions for human settlement including relative abundance of water supplies and terrestrial plant and animal resources. This is likely to have shifted the geographical focus of human population to the now-submerged landscapes of the region. This in its turn reinforces the need for underwater investigation, without which we will remain in ignorance about the nature of these submerged landscapes, the records they contain of changes in palaeoenvironment, palaeoclimate and sea level, and of course their archaeological significance in illuminating a long and crucial period of human history in the Arabian Peninsula.

Conclusion

During the past decade, there has been a steady increase in field surveys and investigations of the Stone Age prehistory of the Arabian Peninsula including the Red Sea region and of palaeoenvironmental and palaeoclimatic investigations directed by archaeological questions or relevant to them. These investigations are highlighting the central geographical importance of the Arabian Peninsula in the earliest stages of human prehistory and its role in creating the foundations for later developments in more recent millennia. They indicate that fluctuations in climate and sea level have periodically expanded the opportunities for human settlement and dispersal throughout the Arabian Peninsula and then contracted them, providing a highly dynamic context for the early history of human settlement. As the primary gateway of human contact between Africa and Eurasia, the Red Sea region is of particular interest and importance. New research includes surveys for Stone Age archaeological sites dating far back into the Quaternary, studies of palaeoclimate from onshore and offshore sediment sequences and speleothems and studies of sea-level change and its palaeogeographical and marine–oceanographic consequences, excavation of coastal shell mounds, underwater exploration of submerged landscapes and palaeoshorelines, and improved geochronological control. This intersection of many different scientific interests provides a potentially fertile ground for interdisciplinary collaboration and a need for such collaboration if new hypotheses and lines of future enquiry are to be pursued effectively.

Acknowledgments Field observations on the archaeology and submerged landscapes of the Gizan region and the Farasan Islands have been made possible through the support and collaboration of the Saudi Commission for Tourism and Antiquities (SCTA), in particular its President, HRH Prince Sultan bin Salman bin AbdulAziz al Saud, theVice President, Professor Ali Al-Ghabban, and the Director General, Jamal al Omar. Underwater work has been supported by permits from the Department of General Survey of the Ministry of Defense and further facilitated through the assistance of Saudi Aramco, Shell Companies Overseas, the Saudi British Bank and the Hellenic Centre for Marine Research (HCMR). The work has been supported by grants from the European Research Council (Advanced Grant 269586 DISPERSE under the 'Ideas' Specific Programme of FP7), the Natural Environment Research Council (NERC), UK, under its EFCHED (Environmental Factors in Human Evolution and Dispersal) Programme, the British Academy and the National Geographic Society. This field research is a joint Saudi–UK project in collaboration with Professor Abdullah Alsharekh of King Saud University and also draws on the specialist expertise and assistance of a number of colleagues, whose assistance is gratefully acknowledged: Saud Al-Ghamdi and Abdarrazzack Al Maamary (King Saud University), Maud Devès and Geoffrey King (Institut de Physique du Globe, Paris), Nicholas Flemming and Garry Momber (National Oceanography Centre, and Marine Archaeology Trust, Southampton), Kurt Lambeck (Australian National University), Eva Laurie, Robyn Inglis and Matthew Meredith-Williams (University of York), Najeeb M.A. Rasul (Saudi Geological Survey), Dimitris Sakellariou (HCMR, Greece) and Claudio Vita-Finzi (Natural History Museum, London). Thanks are also due to Simon Holdaway and Michael Petraglia for additional information and comments that have improved the text. This is DISPERSE contribution no. 13.

References

Alsharekh AM, Bailey GN (eds) (2014) Coastal Archaeology in Southwest Saudi Arabia and the Farasan Islands: 2004–2009 investigations. Saudi Commission for Tourism and Antiquities, Riyadh

Ammerman AJ, Howitt Marshall D, Benjamin J, Turnbull T (2011) Underwater investigations at the early sites of Apros and Nissi Beach on Cyprus. In: Benjamin J, Bonsall C, Pickard K, Fischer A (eds) Submerged prehistory. Oxbow Books, Oxford, pp 263–271

Amirkhanov KM (1991) The palaeolithic of Southern Arabia. Nauka, Moscow (In Russian)

Armitage SJ, Jasim SA, Marks AE, Parker AG, Usik VI, Uerpmann HP (2011) The southern route “Out of Africa”: evidence for an early expansion of modern humans into Arabia. Science 331:453–456

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

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

Bailey GN, King GCP (2011) Dynamic landscapes and human dispersal patterns: tectonics, coastlines and the reconstruction of human habitats. Quatern Sci Rev 30:1533–1553

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

Bailey GN, Al-Sharekh AM, Flemming NC, Lambeck K, Momber G, Sinclair AGM, Vita-Finzi C (2007b) Coastal prehistory in the southern Red Sea Basin, underwater archaeology and the Farasan islands. Proc Semin Arabian Stud 37:1–16

Bailey GN, Hardy K, Camara A (eds) (2013a) Shell energy: mollusc shells as coastal resources. OxBow, Oxford

Bailey GN, Meredith-Williams MGM, Alsharekh A (2013b) Shell mounds of the Farasan Islands, Saudi Arabia. In: Bailey GN, Hardy K, Camara A (eds) Shell energy: mollusc shells as coastal resources. OxBow, Oxford, pp 241–254

Bellwood P (2013) First migrants: ancient migration in global perspective. Wiley-Blackwell, Chichester

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

Boivin N, Fuller DQ, Dennell R, Allaby R, Petraglia MD (2013) Human dispersal across diverse environments of Asia during the Upper Pleistocene. Quatern Int 300:32–47

Carto SL, Weaver AJ, Hetherington R, Lam Y, Wiebe EC (2009) Out of Africa and into an ice age: on the role of global climate change in the late Pleistocene migration of early modern humans out of Africa. J Hum Evol 56:139–151

Chappell J, Shackleton NJ (1986) Oxygen isotopes and sea level. Nature 32:137–140

Crassard R, Petraglia MD, Drake NA, Breeze P, Gratuze B, Alsharekh A, Arbach M, Groucutt HS, Khalidi L, Michelsen N, Robin CJ, Schiettecatte J (2013) Middle Palaeolithic and Neolithic occupations around Mundafan palaeolake, Saudi Arabia: implications for climate change and human dispersals. PLoS ONE 8(7):1–23 e69665

Dabbagh A, Hotzl H, Schnier H (1984) Farasan Islands. General considerations and geological structure. In: Jado AR, Zötl JG (eds) Quaternary period in Saudi Arabia, vol 2. Springer, New York, pp 212–220

Delagnes A, Tribolo C, Bertran P, Brenet M, Crassard R, Jaubert J, Khalidi L, Mercier N, Nomade S, Peigné S, Sitzia L, Tournepiche J-F, Al-Halibi M, Al-Mosabi A, Macchiarelli R (2012) Inland human settlement in southern Arabia 55,000 years ago. New evidence from the Wadi Surdud Middle Paleolithic site complex, western Yemen. J Hum Evol 63:452–474

DeMenocal PB (2011) Climate and human evolution. Science 311:540–541

Devès M, Inglis R, Meredith-Williams M, Al Ghamdi S, Alsharekh AM, Bailey GN (2013) Palaeolithic survey in Southwest Saudi Arabia: methodology and preliminary results. Adumatu 27:7–30

Edgell HS (2006) Arabian deserts. Nature, origin and evolution. Springer, Dordrecht

Erlandson JM (2001) The archaeology of aquatic adaptations: paradigms for a new millennium. J Archaeol Res 9:287–350

Evans A, Flemming NC, Flatman J (eds) (2014) Prehistoric archaeology of the continental shelf: a global review. Springer, New York

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

Fleitmann D, Burns SJ, Mangini A, Mudelsee M, Kramers J, Villa I, Villa I, Neff U, Al-Subbary AA, Buettner A, Hippler D, Matter A (2007) Holocene ICTZ and Indian monsoon dynamics recorded in stalagmites from Oman and Yemen (Socotra). Quatern Sci Rev 26:170–188

Gibbard PL, Head MJ, Walker MJC, the Subcommission on Quaternary Stratigraphy (2010) Formal ratification of the Quaternary System/Period and the Pleistocene Series/Epoch with a base at 2.58 Ma. J Quat Sci 25:96–102

Green RE, Krause J, Briggs AW, and 53 other co-authors (2010) A draft sequence of the Neandertal genome. Science 328(5979):710–722

Grine FE, Fleagle JG, Leakey RE (eds) (2009) The first humans—origin and early evolution of the genus Homo. Springer, Dordrecht

Imbrie J, Hays JD, Martinson DG, McIntyre A, Mix AC, Morley JJ, Pisias NG, Prell WL, Shackleton NJ (1984) The orbital theory of Pleistocene climate: support from a revised chronology of the marine δ^{18}O record. In: Berger AL, Imbrie J, Kukla G, Saltzmann B (eds) Milankovitch and climate, Part 1. Reidel, Dordrecht, pp 269–305

Jerardino A, Marean CW (2010) Shellfish gathering, marine paleoecology and modern human behaviour: perspectives from cave 13PPB, Pinnacle Point, South Africa. J Hum Evol 59:412–424

Lahr M, Foley R (1994) Multiple dispersals and modern human origins. Evol Anthropol 3(2):48–60

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

Lambeck K, Purcell A, Flemming N, Vita-Finzi C, Alsharekh A, Bailey GN (2011) Sea level and shoreline reconstructions for the Red Sea: isostatic and tectonic considerations and implications for hominin migration out of Africa. Quatern Sci Rev 30(25–26):3542–3574

McClure H (1976) Radiocarbon chronology of late Quaternary lakes in the Arabian Desert. Nature 263:755–756

Macaulay V, Hill C, Achilli A et al (2005) Single, rapid coastal settlement of Asia revealed by analysis of complete mitochondrial genomes. Science 308:1034–1036

Maslin MA, Christensen B (2007) Tectonics, orbital forcing, global climate change, and human evolution in Africa: introduction to the African paleoclimate special volume. J Hum Evol 53:443–464

Mellars PA (2006) Going east: new genetic and archaeological perspectives on the modern human colonization of Eurasia. Science 313:796–800

Mellars PA, Gori KC, Carr M, Soares PA, Richards MB (2013) Genetic and archaeological perspectives on the initial modern human colonization of southern Asia. In: Proceedings of the National Academy of Science 110:10699–10704

O'Connell JF, Allen J, Hawkes K (2010) Pleistocene Sahul and the origins of seafaring. In: Anderson A, Barrett JH, Boyle K (eds) The global origins and development of seafaring. McDonald Institute for Archaeological Research, Cambridge, pp 57–80

O'Connor S (2010) Pleistocene migration and colonization in the Indo-Pacific region. In: Anderson A, Barrett JH, Boyle K (eds) The global origins and development of seafaring. McDonald Institute for Archaeological Research, Cambridge, pp 41–55

O'Connor S, Ono R, Clarkson C (2011) Pelagic fishing at 42,000 years before the present and the maritime skills of modern humans. Science 334:1117–1121

Oppenheimer S (2003) Out of Eden: the peopling of the world. Constable, London

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, pp 39–49

Parker AG, Rose JI (2008) Climate change and human origins in southern Arabia. Proc Semin Arabian Stud 38:25–42

Parker AG, Goudie AS, Stokes S, White K, Hodson MJ, Manning M, Kennet D (2006) A record of Holocene climate change from lake geochemical analyses in southeastern Arabia. Quatern Res 66 (3):465–476

Parton A, Farrant AR, Leng MJ, Schwenninger J-L, Rose JI, Uerpmann H-P, Parker AG (2013) An early MIS 3 pluvial phase in Southeast Arabia: climatic and archaeological implications. Quatern Int 300:62–74

Petraglia MD (2012) Toba volcanic super-eruption of 74,000 years ago: climate change, environments and evolving humans. Quatern Int 258:1–4

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

Petraglia MD, Drake NA, Alsharekh AM (2009) Acheulean landscapes and large cutting tools assemblages in the Arabian Peninsula. In: Petraglia MD, Rose JI (eds) The evolution of human populations in Arabia. Springer, Dordrecht, pp 103–116

Petraglia MD, Alsharekh AM, Crassard E, Drake NA, Groucutt H, Parker AG, Roberts RG (2011) Middle Paleolithic occupation on a marine isotope stage 5 lakeshore in the Nefud Desert, Saudi Arabia. Quat Sci Rev 30(13–14):1555–1559

Rose J, Usik V, Marks A, Hilbert Y, Galletti C, Parton A, Geiling JM, Cerný V, Morley M, Roberts RG (2011) The Nubian complex of Dhofar, Oman: an African Middle Stone Age industry in southern Arabia. PLoS ONE 6(11):e28239

Rosenberg TM, Preusser F, Risberg J, Plikk A, Kadi KA, Matter A, Fleitmann D (2013) Middle and Late Pleistocene humid periods recorded in palaeolake deposits of the Nafud desert, Saudi Arabia. Quatern Sci Rev 70:109–123

Sanlaville P (1992) Changements climatiques dans la Péninsule Arabique durant le Pléistocène Supérieur et l'Holocène. Paléorient 18(1):5–26

Schultz E, Whitney JW (1986) Upper Pleistocene and Holocene lakes in the An Nafud, Saudi Arabia. Hydrobiologia 143:175–190

Shackleton NJ (1987) Oxygen isotopes, ice volume and sea level. Quatern 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

Stringer C (2000) Coasting out of Africa. Nature 405:24–27

Thomas H, Geraads D, Janjou D, Vaslet S, Memesh A, Billiou D, Bocherens H, Dobigny G, Eisenmann V, Gayet M, Lapparent de Broin F, Petter G, Halawani M (1998) First Pleistocene fauna from the Arabian Peninsula: An Nafud desert, Saudi Arabia. Comptes rendus Academie des Sciences, Paris, Sciences de la Terre et des Planèts 326:145–152

Vincent P (2008) Saudi Arabia: an environmental overview. Taylor and Francis, London

Waelbroeck C, Labeyrie L, Michel E, Duplessy JC, Lambeck K, McManus JF, Balbon E, Labracherie M (2002) Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records. Quatern 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

Werner G, Lange K (1975) A bathymetric survey of the sill area between the Red Sea and the Gulf of Aden. Geologisches Jarbuch D 13:125–130

Whalen NM, Sindi H, Wahidah G, Siraj-Ali JS (1983) Excavation of Acheulean sites near Saffaqah in al-Dawadmi (1402/1982). Atlal, J Saudi Arabian Archaeol 7:9–21

Whalen NM, Siraj-Ali JS, Davis W (1984) Excavation of Acheulean sites near Saffaqah, Saudi Arabia, 1403 AH 1983. Atlal, J Saudi Arabian Archaeol 8:9–24

Whalen NM, Siraj-Ali JS, Sindi H, Pease DW (1986) A lower Pleistocene site near Shuwayhitiyah in northern Saudi Arabia. Atlal, J Saudi Arabian Archaeol 10:94–101

Whalen NM, Siraj-Ali J, Sindi HO, Pease DW, Badein MA (1988) A complex of sites in the Jeddah-Wadi Fatimah area. Atlal, J Saudi Arabian Archaeol 11:77–85

White T, Asfaw B, DeGusta D, Gilbert H, Richards DG, Suwa G et al (2003) Pleistocene *Homo sapiens* from Middle Awash, Ethiopia. Nature 423:742–747

Zarins J, Ibrahim M, Potts D, Edens C (1979) Saudi Arabian archaeological reconnaissance 1978. The preliminary report on the third phase of the Comprehensive Archaeological Survey Program —the coastal province. Atlal, J Saudi Arabian Archaeol 3:9–42

Zarins J, Whalen N, Ibrahim M, Abd al Jawad M, Khan M (1980) The Comprehensive Archaeological Survey Program. Preliminary report on the central and southwestern provinces. Atlal, J Saudi Arabian Archaeol 4:9–36

Zarins J, Al-Jawad Murad A, Al-Yish KS (1981) The Comprehensive Archaeological Survey Program. The second preliminary report on the southwestern province. Atlal, J Saudi Arabian Archaeol 5:9–42