Tectonic Geomorphology and Soil Edaphics as Controls on Animal Migrations and Human Dispersal Patterns

Simon Kübler, Geoffrey C. P. King, Maud H. Devès, Robyn H. Inglis, and Geoff N. Bailey

Abstract

This chapter examines the relationship between the changing geomorphology of physical land forms in tectonically and volcanically active regions, topography, soil nutrients, movements of large mammals, and patterns of human subsistence and dispersal in the early stages of human evolution. We place particular emphasis on the ways in which minor topographic barriers—for example, river gorges, fault scarps and basaltic lava flows—constrain the movements of large mammals during their seasonal migrations and offer opportunities for early humans to take advantage of predictable natural constrictions to ambush animals. We also emphasise the importance of soil edaphics—the mineral composition of soils as a source of trace elements essential for animal growth and health—as another key variable in determining the distribution and movements of animals and their human hunters. Soil edaphics are closely related to the nature of the underlying regolith or bedrock, and are consequently highly variable in their distribution, providing additional constraints on animal movements. We show how the combination of topographic and soil-edaphic mapping in conjunction with the observed locations of stone-tool or fossil assemblages can highlight patterns of early human behaviour, using examples from the East African and Jordanian Rifts and the Arabian margin of the Red Sea. Finally, we note that these methods have the potential to be applied more widely in other regions of the world and to problems of animal and human health at the present-day.

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1 Introduction

The physical landscape forms the basis for the development of animal and human habitats. Studying the interaction between the fauna and the environment therefore requires an understanding of the character and evolution of landscapes. Here we provide examples demonstrating that the knowledge and techniques derived from tectonic geomorphology can provide this information and be adapted to research in palaeoanthropology, archaeology and ancient and modern land use. Combining evidence in the fossil and archaeological record with an understanding of landscape processes allows an additional insight into past human and animal behaviour, and is an important complement to the data derived from excavation and the study of artefacts and fossils alone. The approach we have developed combines extensive fieldwork with satellite-derived data to produce maps of the landscape as it would have existed at an earlier time, taking account of the animal species that would have been the primary food supply and their habitat preferences, and incorporating evidence of changes in land forms brought about by tectonic activity and other geomorphological processes.

This work was originally inspired by the need to place archaeological sites and other evidence of past human behaviour into their wider landscape setting in order to

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illuminate the patterns and causes of early human dispersal and colonisation of new territory in the very earliest stages of human development in Africa and adjacent regions. As the work has progressed, it has become clear that the results of our approach have considerable relevance not only to the past but also to a better understanding of environmental factors that affect animal and human health at the present day (Winder et al. 2013; Devès et al. 2014, 2015; Bailey et al. 2015; Kübler et al. 2015, 2016).

In this chapter we consider selected aspects of reconstructing the ancient use of the landscape, with particular emphasis on the role of topography and soil edaphics in constraining the distributions and seasonal movements of the large herbivores on which human subsistence largely depended for long periods of the past (Owen-Smith 1988). By soil edaphics we mean the ability of the soil to provide essential nutrients in the form of trace elements necessary for the growth and survival of large herbivores. We summarise the relationship between tectonic topography and the early stages of human evolution, and set out in more detail the variables we consider as significant in palaeolandscape reconstruction and the methods we use to reconstruct ancient topography and soil edaphics. We show how soil edaphics are closely linked to the nature of the underlying rock substrate, and how the constraints imposed on animal movements by a combination of topography and soil edaphics would have facilitated the capture of large mammals by early human hunters. We do not enter here into the debates about whether early hominins obtained meat by scavenging or by hunting (see debates in Blumenschine et al. 1994; Domínguez-Rodrigo 2002; Pickering 2013), but note that our reconstructions are consistent with ambush hunting of large and dangerous animals by early members of the genus *Homo* with no need for equipment other than hand-thrown missiles or thrusting spears.

For examples, we draw on case studies from the East African Rift in Kenya, from the Dead Sea Rift in the southern Levant and from SW Arabia (Fig. 1). Although these are widely disparate regions, they are united by several features in common. First, they are all regions with evidence of human occupation in the earliest (Lower Palaeolithic) periods of the Stone Age; more specifically they are associated with similar stone-tool assemblages of Acheulean type, made by some of the earliest members of the genus *Homo* (*H. ergaster* or *H. erectus*), the earliest of our examples extending back in time to 1.4 Ma. We examine selected archaeological sites from each region, chosen because they are substantial sites indicating repeated use of favoured locations in a wider landscape and because they provide good illustrations of landscape reconstruction. Secondly, they occur at different points along one of the major axes of earliest dispersal of the genus *Homo*, namely the East African Rift and the Red Sea and Levantine corridors, and illustrate features that we consider to be significant in promoting or permitting population dispersal. Thirdly, they are associated with different geomorphological expressions of the Afro-Arabian tectonic system.

The dominant feature of this tectonic system is the East African Rift. Rifting is thought to have been initiated with the massive flood-basalt eruptions that occurred in Ethiopia at 30 Ma, with propagation southwards for over 1000 km as far as Mozambique and the borders of South Africa, exploiting weaknesses in the Earth's crust. Throughout, the Rift displays typical features of rifting, with progressive uplift of the valley margins by normal faulting, creation of lake basins on the rift floor formed by internal drainage, and substantial volcanic activity. North of Ethiopia, the 'Proto Red Sea' was a northward extension of the East African Rift, but subsequently widened into a young ocean as the Arabian Plate began to move north away from Africa, creating the Gulf of Aden in the south and colliding with Europe to the north. North of the Red Sea, the transform faults along the western margin of the Arabian plate as it moved northward created the so called Syrio-Jordanian Rift. This is not, strictly speaking, a rift but is the result of strike-slip motion. The cross-sectional profile of the resulting valleys is narrower than in a true rift, but in other respects there are many similar tectonic features including high levels of earthquake activity, significant episodes of magmatism and internally draining lake basins.

We begin with examples from Kenya in the classic landscape setting of the East African Rift. This is one of the earliest and best studied centres of early human origins and development, and the region which offers the most detailed application and illustration of our methods. We then move to the southern Levant, another region with a long history of geological and archaeological investigation that provides a solid platform for palaeolandscape reconstruction. Finally, we turn to the intermediate region of the western Arabian escarpment. Here, there is a shorter history of investigation, and discovery of new archaeological sites and palaeoenvironmental investigations are ongoing (see the other chapters in this volume).

2 Landscape and the Evolution of *Homo*

It is widely accepted that a progressive drying of the climate resulted in the gradual disappearance of tropical forest and thus affected the range of forest species in substantial parts of Africa, and specifically in East Africa (Bobe 2006; Cerling et al. 1997; deMenocal 2004). As forest cover reduced after 5 Ma, fauna began to exploit more open savannah conditions characterised by grasslands, small trees and shrub vegetation. Today, although forest contains a larger diversity of species, savannah supports a very much larger faunal

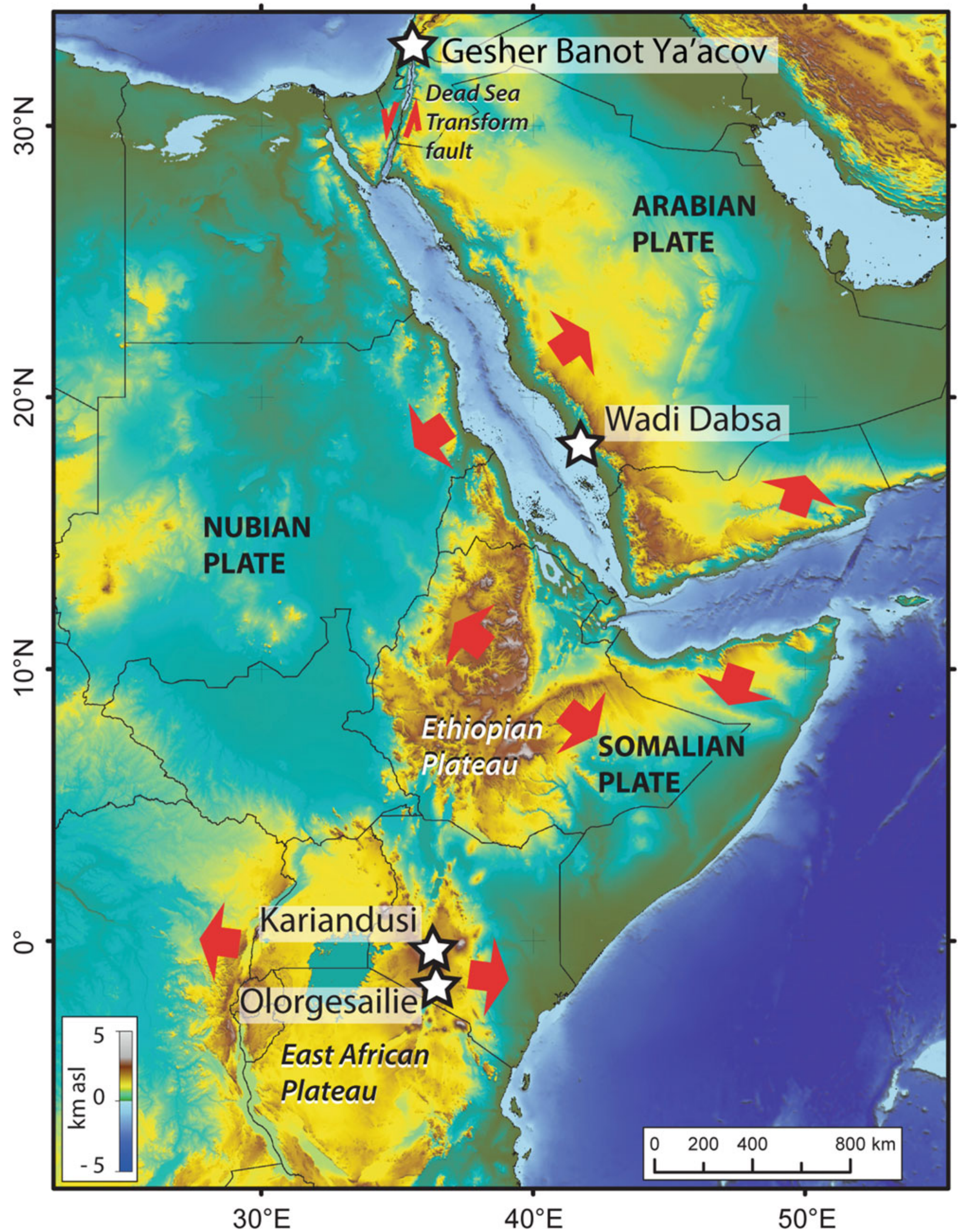

Fig. 1 Location map of case studies and archaeological sites plotted on a map of the Afro-Arabian tectonic system showing general relief and major tectonic features. Red arrows indicate separation of the African Rift and the relative motions of the Arabian and African plates. Uplift of the Ethiopian and East African Plateaus is the result of thinning and swelling of the Earth's crust over hot plumes rising from deep within the Earth's core. The Ethiopian plume broke through the crust with massive eruption of flood basalts at ~30 Ma. This is thought to have triggered the initial separation of the African Rift to the south and the proto Red Sea to the north, with subsequent separation and northward motion of the Arabian Plate by ocean spreading in the Gulf of Aden and the Red Sea, creating the Dead Sea transform fault in the north-west and collision with Plates to the north (not shown)

biomass per square kilometre than any other zone of the planet (Maglio and Cook 1978). Several faunal lineages show radiations as species began to exploit the rich new ecological niches associated with the increasing grassland (Bobe and Eck 2001; Bobe and Behrensmeyer 2004). This is also true for hominins; the fossil record indicates several early hominin genera (*Sahelanthropus, Orrorin, Kenyanthropus, Ardipithecus, Australopithecus*), which may reflect different evolutionary strategies to living in new habitat types. Of these genera, only *Homo* has remained, becoming with time the top predator (e.g., Wood 2005).

The key to how hominins may have adapted to living in novel environments may well lie in the types of landscapes they exploited. Here we refer to the physical landscape that Earth scientists are used to exploring, that is, landforms, rocks, sediments and soils, and we use the term environment to mean the combination of vegetation and the physical landscape. Within this context, savannah corresponds more to a vegetation type as part of the environment, rather than to the physical landscape. While vegetation types are quite sensitive to climate change, features of the physical landscape are not affected to the same extent. Landscapes evolve in response to geodynamical processes such as active tectonics, volcanism, erosion and deposition. These processes shape landscape geomorphology and hydrology, and act on the geology and on soil composition, which can in turn affect the edaphic properties of the soils. The simple picture one might have of savannah becomes more complex when one starts considering the features of the underlying physical landscape. This can be made of various types of rocks and soils. It can be rough or smooth, covered by volcanic lavas or deformed by active tectonics. As a result, it can vary in its sensitivity to climatic oscillations. Habitats are the suitable environmental (vegetation and landscape) conditions that pertain to a particular species (Vrba 1982). Suitable regions for hominins need to meet key habitat requirements, namely a range of forage (C3 browse and C4 grass food types), refuge from predation and a source of drinking water (e.g., Reynolds et al. 2011). There are specific geomorphological contexts that can provide these habitat requirements, notably those affected by volcanic or tectonic activity.

We have shown that the locations of Palaeolithic sites in many regions are closely associated with tectonically active and topographically complex landscapes (King and Bailey 2006; Bailey et al. 2011). In almost all cases, tectonic and/or volcanic activity was ongoing when Palaeolithic people were present in these regions. Continuing activity rejuvenates features and prevents them from being smoothed by erosion. Such areas are associated with a wide variety of landforms, for example, rocky outcrops, cliffs, gorges, ridges, offering plenty of look-out and observation points, opportunities for shelter and protection from most predators and key strategic advantages for hunting (e.g., King et al. 2010; Bailey and King 2011).

Early humans, being slow moving, would have been vulnerable to fast-moving cursorial predators in flat, featureless landscapes. For the same reason, throughout history, persecuted people have always moved to mountainous regions to escape cavalry, trucks or tanks. Tectonic activity is particularly efficient at creating complex landscapes including: (1) cliffs and river gorges, which hominins and other primates could exploit for safety and sleeping roosts; (2) catchment of drinking water; and (3) heterogeneous environments, potentially associated with a range of food types. A key advantage of tectonically active areas is that faulting or folding activity can disrupt water tables and create lakes and swamps that are constantly renewed as long as the activity persists. Faulting can thus provide a range of uplifted, dry areas where grazing animals would predominate, with down-dropped, wetter areas that would provide ecological heterogeneity within a relatively small spatial range and sources of drinking water and other resources. This pattern fits well with existing inferences about hominin habitats from many sites in Africa (see Reynolds et al. 2011 for a review).

Early hominins, such as *Australopithecus*, are considered to have exploited trees for security and adapted to the savannah by means of anatomical adaptations, progressively acquiring effective bipedalism. The energetically (relatively) efficient *Homo* body form appeared at about 2 Ma (Wood 2005). The most widely accepted view is that this adaptation allowed more rapid movement on flat ground, and freed the arms for carrying. An extreme version of this is the 'Endurance Running Hypothesis' (Bramble and Lieberman 2004), which proposes an ability to run prey animals to exhaustion as a primary hunting technique (but see Pickering 2013, p. 99–102 for a critique). Other possibilities are thermoregulatory efficiency that allowed exploitation of a day-time hunting niche (Wheeler 1993). Recently, an alternative hypothesis that considers the role of topography in the evolution of the early *Homo* body form has been proposed (Reynolds et al. 2011; Winder et al. 2013, 2014; Devès et al. 2015). This 'Scrambler Man' hypothesis argues that rough topography would have selected for a progressive transition to an upright posture associated with bipedal locomotion through climbing and scrambling activities. This view contrasts with previous models based on adaptations to forest or flat savannah in favour of physical incentives presented by steep, rugged terrain. Using rugged topography to monitor and trap migratory mammals could have selected for greater speed and agility in hominin populations over time. This hypothesis explains well the key anatomical changes observed over the course of human evolution (e.g., Winder et al. 2013).

3 Key Variables in the Reconstruction of Landscapes and Animal Movements

We argue that complex topography has not only played a role in human evolution and land use but is also a critical factor in defining the habitats and seasonal movements of large herbivorous mammals, imposing constraints that facilitate human exploitation. We consider two physical attributes of a landscape that can affect animal movements: (1) the roughness of the topography itself; and (2) soil characteristics that indicate areas of good and poor pasture quality.

By roughness we mean irregularities in surface morphology (Bailey et al. 2011, p. 4–5). A rough topography may be contrasted with a smooth topography—one with surfaces that are smooth and level. But roughness can occur at different scales, ranging from steep mountain slopes and vertical cliffs to surfaces that appear flat but are difficult to cross because of jagged erosional features, such as some limestone karsts and lava flows. In assessing roughness, we use measurements of slope angles derived from Digital Elevation Models (DEM) (Bailey et al. 2011, p. 277), supplemented by field observations. Our interest is particularly in identifying topographic features that are sufficient to block or deter the movements of large herbivores, channel their movements along predictable pathways, and make them more vulnerable to human predation.

The majority of herbivores are thought to migrate in response to changes in available water, grazing and seasonal temperature variations. In modern landscapes, seasonal movements of wild animals are limited by humans fencing off large areas, but historical documents record these types of migrations. For example, early European explorers to southern Africa recorded mass migrations of springbok (*Antidorcas marsupialis*) and other animals to areas of fresh grazing (Skinner and Louw 1996). The seasonal migrations of wildebeest (*Connochaetes taurinus*) and other grazing animals in the Serengeti continue today. Seasonal resource variations are still exploited by transhumant shepherds in many parts of Europe, who move their animals in the same way that wild species such as the red deer (*Cervus elaphus*) would have moved in the past without human intervention (Sturdy et al. 1997).

With regard to soil attributes, we pay particular attention to edaphic factors as a guide to pasture quality, though we also note the importance of water retentiveness, especially in arid or semi-arid regions. Edaphic factors, or the shorthand term 'edaphics', concern the ability of the regolith (i.e., soils and subsoils) to supply, by plant take-up, the nutrients necessary for herbivore growth, health and reproduction. These edaphic factors are critical to the growth of young animals and the continued health of younger and older individuals. They can shape animal movements within a landscape as a result of the presence or absence of vital nutritional components in the vegetation of certain areas. The availability of soluble phosphate is especially important, as this supports bone development. Its limited availability plays an important role in Serengeti wildebeest migrations today (Murray 1995).

Simple phosphorus or phosphate levels in soils and subsoils are not, on their own, guides to the edaphic quality of the soils. Tricalcium di-orthophosphate, the main constituent of animal bones, is only soluble in ionised acidic water, and its release into soils in a form which can be taken up by plants is normally very slow. So, for high edaphic quality in relation to phosphates, not only is an adequate source of the minerals required, but the conditions must be such that the minerals can actually be taken up by the fodder which the herbivores eat (Henkin et al. 1995). Even where the regolith provides abundant sources of the main minerals and nutrients in a form which can be taken up by plants, specific trace elements may be missing, for example, elements, such as selenium, cobalt, copper or potassium (Burrows et al. 1979; Corah 1996; Formigoni et al. 2011; Kadim et al. 2003; Ruess 1984). In such cases, animals may need to make periodic movements to areas that supply the missing elements. Nowadays, fodder supplements and fertilisers often provide this requirement for domestic animals without the need for extensive movements.

We distinguish soil edaphics from soil fertility. Soils may be fertile in the sense that they can support lush vegetation, but may nevertheless be lacking in the nutrients essential for animal health, especially for the growth of young animals. A given soil might support abundant vegetation, but this may be of poor quality when viewed as a source of food and trace elements for herbivores. Over wide areas of the Mediterranean, for example, until the recent substantial fall in grazing pressures resulting from changes in modern human economies, the edaphically poorer areas often carried more abundant plant vegetation precisely because they were less exploited by animals, while the vegetation in the edaphically richer areas was bitten down hard, reflecting their differential attractiveness to herbivores (Sturdy and Webley 1988; Sturdy et al. 1997).

4 Methods of Palaeolandscape Reconstruction

The aim of palaeolandscape reconstruction is to derive a digital landscape model (palaeoDEM) at the time of hominin occupation for the desired study region. The starting point for reconstructing ancient landscapes is a present-day DEM, usually derived from freely available Shuttle Radar Topographic Mission (SRTM) data. This is then corrected by subtracting a correction displacement field (CDF) across the DEM to restore earlier elevations. Creating a CDF requires information on (1) fault motions, (2) erosion and deposition of sediments, (3) volcanic activity, (4) other sources of surface motion such as subsidence from groundwater disposal. Each of these variables needs to have a temporal component (absolute or relative) to allow the CDF to be determined for a specific time interval. This can be judged by analysing the relationships of geological units and structures, for example, tilted lake beds or lava flows overlying tectonically faulted structures, and combining them with geochronological data, which are available with varying degrees of accuracy in our individual study regions. Tectonic motion can be restored with computer models and codes using dislocations in a 2D half-space based on analytical expressions (Okada 1982). Vertical motion from non-tectonic processes such as groundwater disposal or collapse of magma chambers can be reconstructed by creating palaeo-contour lines from a large number of topographic profiles, which are then corrected for subsidence and erosion using Geoinformation Software packages (GIS). A more detailed description of this methodology can be found in the supplementary material of Kübler et al. (2015), and has been applied in greatest detail to the Olorgesailie case study discussed below, where tectonic changes have had the most significant effects on landscape morphology.

5 Edaphic Analysis

The objective of chemical analysis of soils and plants in the context of understanding edaphic properties is to gather information on nutrient variability in the individual rock units and sediments in the study region. Usually three to five soil and plant-tissue samples per rock unit are taken to allow for nutrient variability. Composite soil samples are taken from five sampling points in a 5×5 m square from the uppermost 25 cm of a soil profile. For deep soil profiles in unconsolidated sediments, additional samples along a depth profile (core or soil pit) are taken. Plant sampling usually focuses on collecting grass and other shallow-rooted plants at the soil sampling site. Soil and plant samples are then tested for the concentration of the most important macronutrients and trace elements such as calcium, copper, iron, manganese, magnesium, nitrogen, phosphorus, potassium, sodium, and zinc. Further soil samples are tested for pH-value, electrical conductivity and total organic carbon.

6 The Kenyan Rift

Olorgesailie in the southern Kenya Rift lies in the centre of a 60 km-wide rift floor (Fig. 2) and is famous for its abundance of Acheulean artefacts, fossil mammals and palaeoenvironmental indicators together with a cranial specimen of *Homo* preserved in sediments spanning $\sim$1.2 to <0.5 Ma (Isaac 1977; Potts 1989; Behrensmeyer et al. 2002; Potts et al. 2004). The site is adjacent to a palaeolake. Prey animals include elephant, hippopotamus, giant baboon, equids and bovids, with evidence of carcase butchery.

The geology of the region comprises extensive trachyte flows laid down between 0.7 and 1.4 Ma, overlapping the period when the site was in use (Fig. 3). These are the dominant rock type on the rift floor. Also present are Plio-Pleistocene basalts and tuffs dated to 1.4–2.7 Ma associated with the volcanoes of Mt. Olorgesailie and Mt Esayeti. There are many sub-parallel fault scarps, and these are nearly vertical in places, especially on the trachyte, which is particularly resistant to erosion, and these constrain east–west movements of large animals and humans (Kübler et al. 2015). Sediments carried from the north and the rift flanks are present in small patches, but uplift and back tilting prevent the entry of sediments from outside the main rift.

The landscape around Olorgesailie today is significantly different from when the hominins were present, resulting from ongoing faulting and the partial collapse of the Olorgesailie volcanic caldera (Fig. 4a). Tectonic motion on two north–south trending normal faults has resulted in tilting of the Legemunge lake beds that contain the archaeological material. These deposits were originally laid down horizontally, so that the fault motions must postdate the archaeological occupation. The caldera collapse of the northwestern Olorgesailie edifice resulted in draining of the palaeolake. The past and present geometry of the landscape is defined by its tectonic structure, allowing reconstruction of the palaeo-morphology by modelling fault displacements. By removing the effects of fault motion and making corrections for erosion and deposition of sediment (Fig. 4c, d), a palaeo-DEM of the landscape can be created as it would have appeared during the period when hominins were present (Fig. 4b).

Modern analyses of macronutrients and trace elements from soils on a representative sample of lithological and sedimentary units demonstrate a consistent relationship between edaphic quality and the underlying regolith (Kübler et al. 2015, 2016). Trachytes with poor-quality soils dominate the region (Fig. 3), with richer soils developing only on some other volcanic rocks and on sediments brought by rivers from the north and east. This is supported by

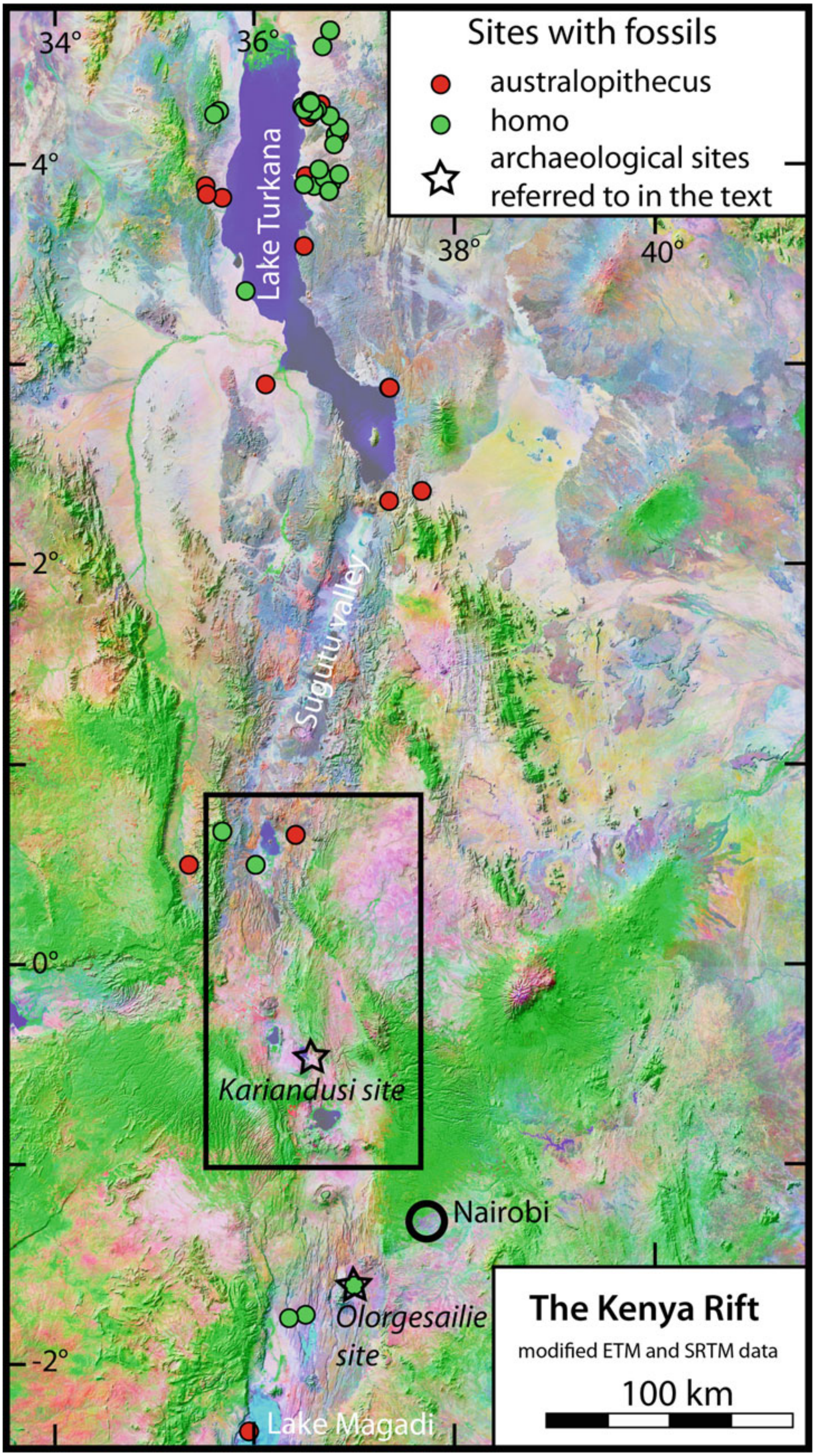

Fig. 2 General location map of sites in the central and southern Kenyan Rift in relation to topography, showing position of Olorgesailie and Kariandusi. The locations of other sites with hominin fossils are also shown. Data from the Paleobiology database (https://paleobiodb.org). After Kübler et al. (2016). The image is based on ETM + legacy data. Topography from SRTM v4.1. Maps created by SK and GK using Adobe Illustrator CS 5.1, Adobe Photoshop CS 5.1, MAPublisher 9.4.0, and Global Mapper

Fig. 3 Oblique 3D view of the South Kenya Rift centred on the Olorgesailie hominin site, showing faults and other geological features. The region is heterogeneous with some areas well-vegetated and others with thin vegetation. Thin vegetation can result from soils that do not favour plant growth, but can also result from heavy grazing and browsing of favoured vegetation. The image is based on ETM + legacy data. Topography from SRTM v4.1 data with a vertical exaggeration of ∼8. A red star indicates the Olorgesailie site. Maps created by SK and GK using Adobe Illustrator CS 5.1, MAPublisher 9.4.0, Global Mapper 16, and ENVI 5.1

interviews with Masai shepherd families who are well aware where animals must graze and browse to remain healthy.

In the past, soils close to the palaeolake would have provided an attractive focus for animal grazing and browsing, especially during the dry season. But this area is comparatively small, so that large herds would need to move to the more distant rift flanks 30 km away, where more extensive grazing would have been available particularly during the wet season. Routes of animal migration to or from the flanks were greatly constrained by the numerous north–south fault scarps and would need to pass along a predictable route between the lake and the volcanic edifice (Fig. 4b). It is on this route that the archaeological site is located.

We conclude that a key reason why the Olorgesailie site was attractive to hominins and repeatedly used over a long period is its proximity to a nearby area that has excellent edaphics in a wider region that is highly deficient, and that it controlled the only route allowing movement of large animals between east and west, facilitating trapping by ambush hunting. Proximity to a reliable source of drinking water, suitable volcanic stone for making artefacts, and good look-out points for monitoring animal movements are additional advantages of the Olorgesailie location, but are not sufficient to explain why the site remained a repeated focus of human activity over such a long period. When the caldera collapsed and the lake was drained, the topographic

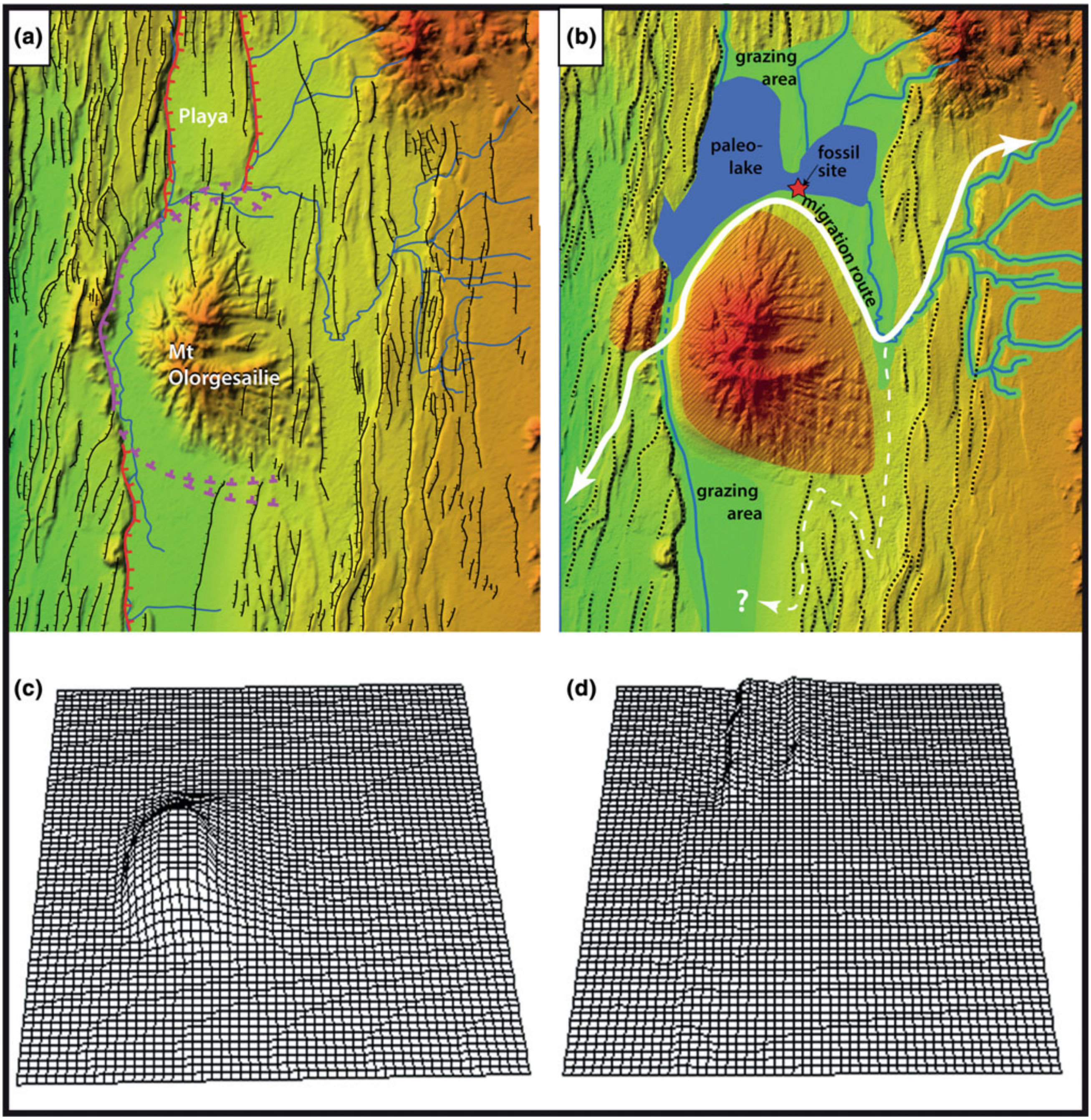

Fig. 4 Digital elevation models (DEMs) of the Olorgesailie region. **a** Present day topography. Prominent fault scarps are indicated in black and those indicated in yellow and white are used in the modelling of earlier topography in (**b**). The yellow faults are young faults, and post-date the lake and the period of hominin activity at Olorgesailie. The white faults result from caldera collapse. **b** PalaeoDEM of the Olorgesailie region. White circle indicates the position of the Olorgesailie site. The volcanic edifice of Mt. Olorgesailie was already in place and impeded drainage to the south, resulting in the formation of the lake. A possible late lower lake level is indicated in dark blue. Some faults in the trachytes do not cut basalts of the Olorgesailie edifice and therefore clearly pre-date it. Dotted lines show faults that formed barriers to animal movement and are thought to have existed when the site was used by hominins. The drainage system was limited by a barrier in the same place as hypothesized by Behrensmeyer et al. (2002), so the barrier could have been higher than the lake without fully blocking drainage from the lake. Likely grazing areas are indicated. Routes to the flanks of the Rift negotiable by large animals are shown. Fault scarps and the volcanic edifice would only be accessible to smaller and more agile animals. **c** Correction displacement field (CDF) for caldera collapse. (d) CDF for faulting. Only the largest effects are visible. Images are based on SRTM v4.1 data. Maps created by GK using Adobe Illustrator CS 5.1, and Global Mapper 9.4.0. Landscape reconstruction and fault mechanisms are calculated with Almond 7.05 software (www.ipgp.jussieu.fr/ king) based on the program developed by Okada (1982)

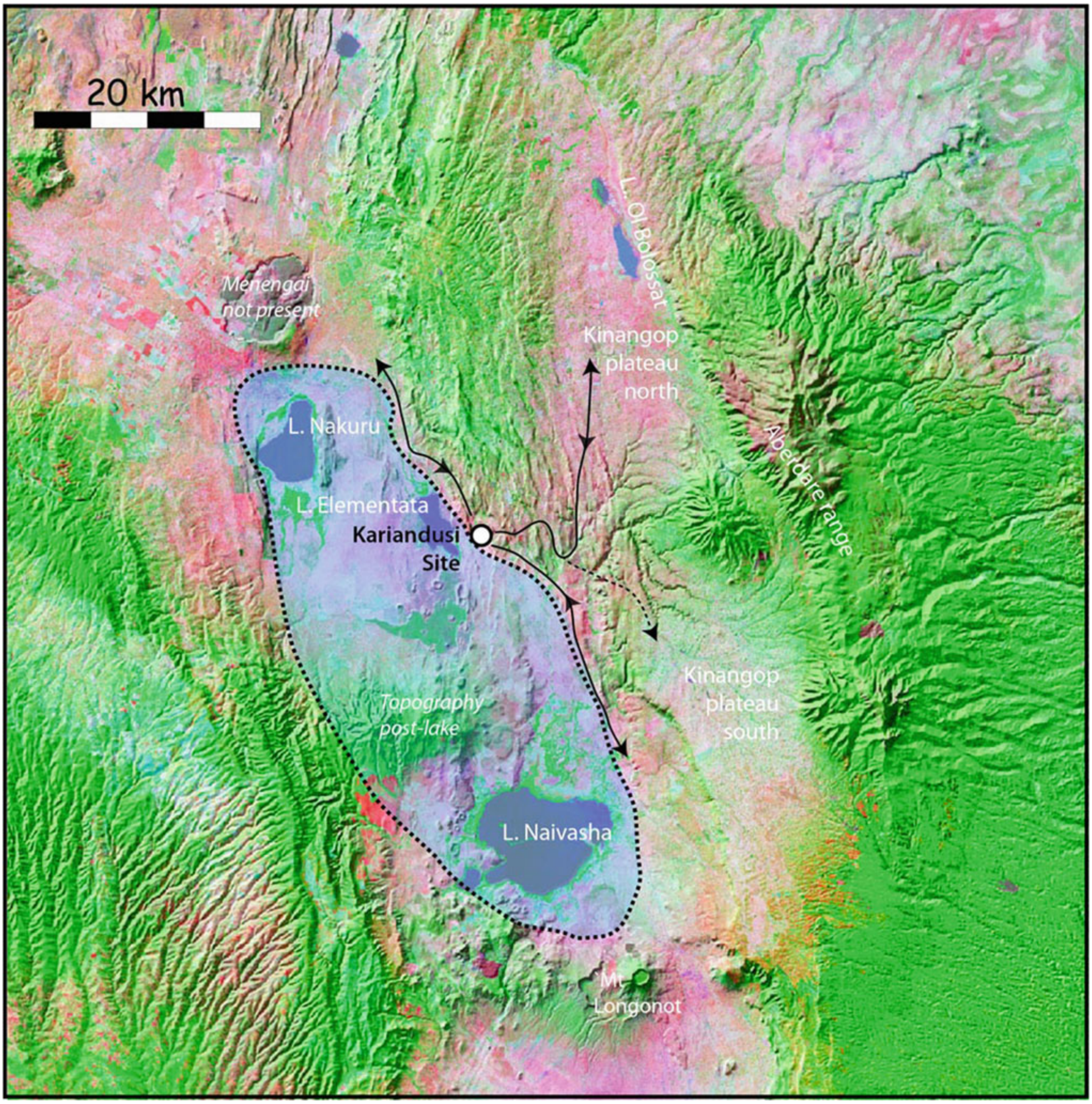

Fig. 5 Map of the Kariandusi region, showing the location of the site, major topographic features, proposed movements of large mammals and the outline of the expanded lake at the time when the site was in use. Maps created by SK and GK using Adobe Illustrator CS 5.1, Adobe Photoshop CS 5.1, MA Publisher 9.4.0, and Global Mapper 16

constraints that favoured ambush hunting disappeared and occupation ceased.

The site of Kariandusi in the central Kenyan Rift provides an informative comparison, showing similar features to Olorgesailie, except that it was used over a much shorter period. The material was originally deposited on a tributary of the Kariandusi River draining into the adjacent Lake Elmentaita, and comprises numerous Acheulean bifaces and other stone artefacts, with dates bracketed dated between 0.79 and 0.98 Ma (Leakey 1931; Gowlett and Crompton 1994; Shipton 2011). There are few faunal remains, consisting only of some equid teeth because of poor conditions for preservation of organic materials.

The distribution of edaphically-rich soils in the wider region is patchy, with the best concentrations on the rift flank to the east of the site. Here, an extensive upland basin is

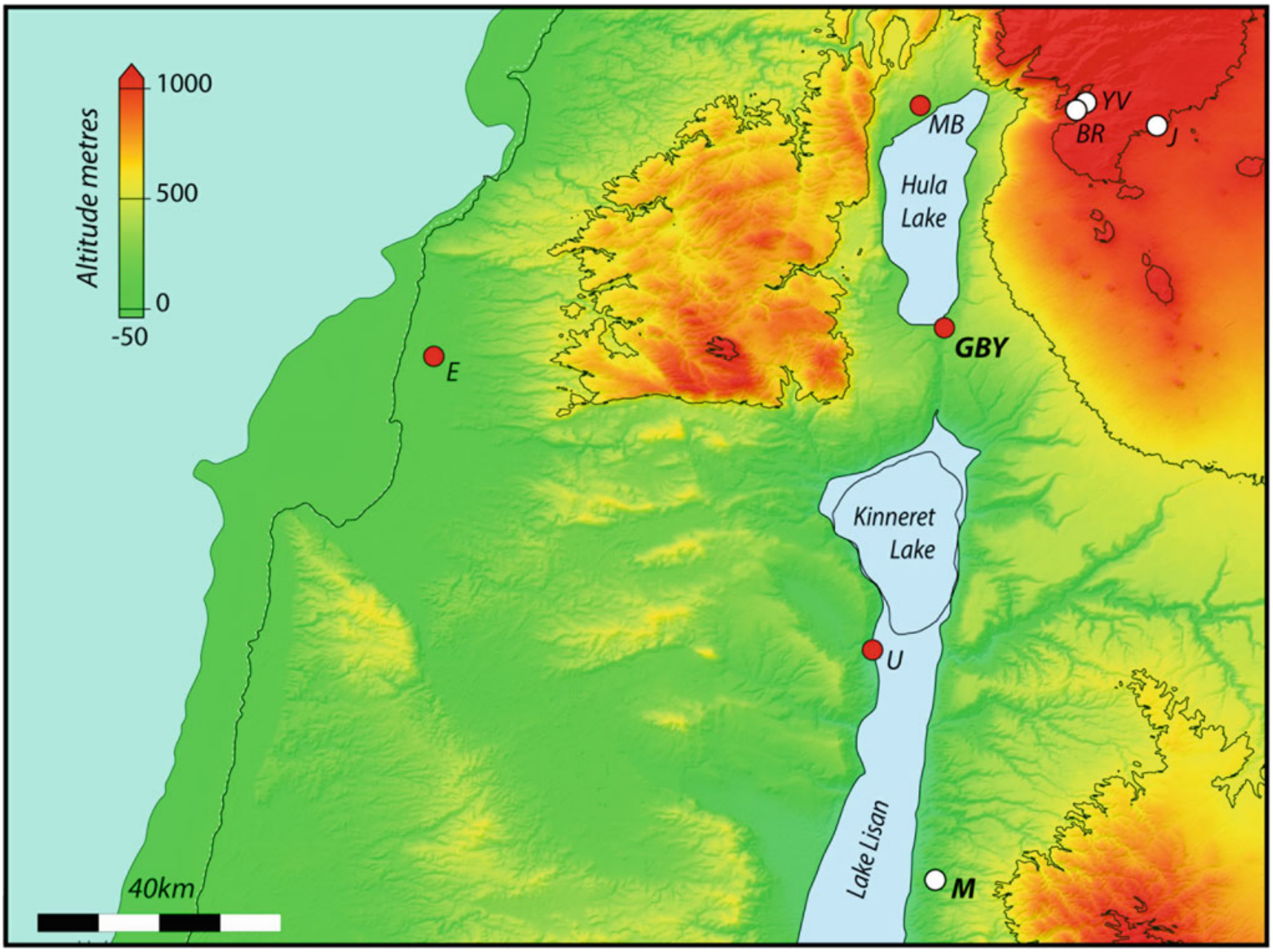

Fig. 6 The central Dead Sea Rift and adjacent regions showing relief, the coastline at lowered sea level and Lake Lisan at its maximum extent. A selection of major Lower Palaeolithic sites is shown. Red circles are Acheulean sites with faunal remains including elephant, white circles are Acheulean sites without fauna. After Devès et al. (2014). Sites referred to are as follows: J. Joubbata; YV. Yaafouri Valley; BR. Berekhat Ram; MB. Maayan Baruch; E, Evron; GBY, Gesher Banat Ya'aqov; U. Ubeidiya; M. Mashari'a (Ronen et al. 1980; Goren 1981; Goren-Inbar 1985; Tchernov 1988; Bar-Yosef and Goren-Inbar 1993; Tchernov et al. 1994; Macumber and Edwards 1997; Goren-Inbar et al. 2000; Ronen 2003). After Devès et al. (2014)

enclosed by steep faults and easily accessible to herds of large animals only from the rift floor to the west and northwest (Fig. 5). At the time when the site was occupied, much larger areas of the rift floor were submerged under an enlarged freshwater lake, and the lakeshore was at a higher level, forming a barrier to animal movements from west to east except through a narrow corridor close to Kariandusi (Kübler et al. 2015). As at Olorgesailie, freshwater, raw material for making stone artefacts and good viewpoints were all locally available throughout the Pleistocene. However, the Kariandusi site appears to have been used only during the period when high lake levels gave the location strategic advantage in relation to topographic barriers to ambush large mammals during their seasonal migrations. This reinforces the importance of complex faulted terrain and topographic barriers as a determinant of Acheulean site location and use.

7 Southern Levant

The Jordanian or Dead Sea Rift, comprising the system of valleys and lakes that extend northward from the Gulf of Aqaba on the Red Sea through to the Lebanon and Syria, is not strictly speaking a rift in the same sense as the East African Rift. It is, rather, a strike-slip structure resulting from the northward rotation of the Arabian Plate away from Africa. Nevertheless, it has many similar geological and topographic features, including high levels of earthquake activity and faulting, volcanic activity with extensive basaltic lava flows, elongated valleys with lake-filled basins subject to variations in lake level, marked changes of elevation over relatively short distances, and generally-speaking a complex topography (Enzel and Bar-Yosef 2017).

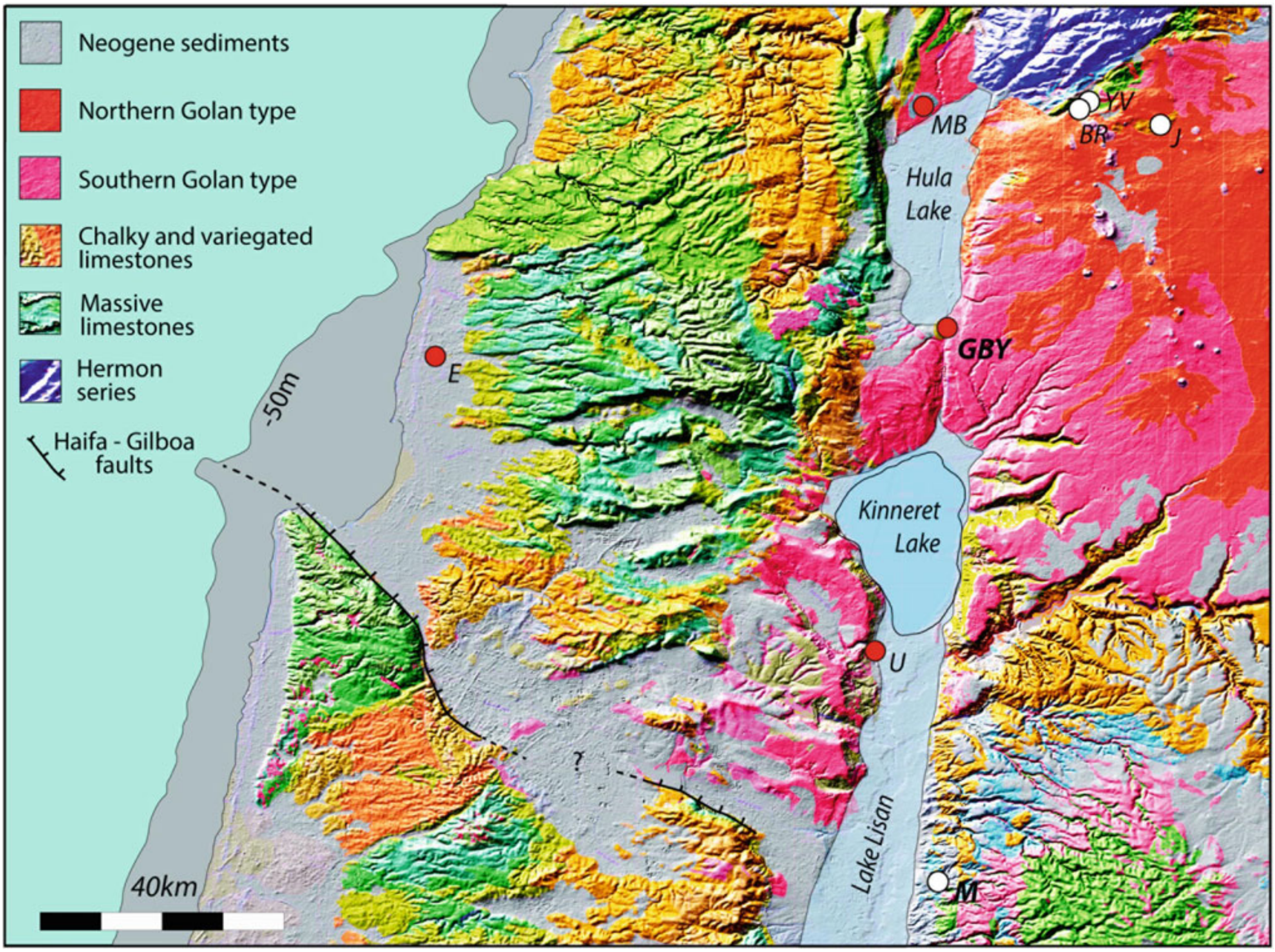

Fig. 7 Simplified geology plotted on a relief map of the area shown in Fig. 6 and used to identify areas of differing soil edaphic quality. Of particular importance are the basalt regions, which develop soils with high levels of soluble phosphate. Site information as in Fig. 6. After Devès et al. (2014)

The long history of archaeological investigation has resulted in many sites of Lower and Middle Palaeolithic age (Fig. 6; Enzel and Bar-Yosef 2017). The Galilee region of Israel, centred around and west of the Sea of Galilee, is particularly rich in sites. Possible reasons for this are the complexity of the landscape with numerous cliffs and deep, steep-sided valleys that provided human groups with security and tactical access to large mammals. The geology of the region is dominated by limestone and basalt, which can offer attractive environments for herbivores including good edaphic properties. These bedrock-types can also erode to form surfaces with small-scale roughness (known as angry karst on limestone). And these rougher surfaces provide significant impediments to animal movement and opportunities for human hunters.

Devès et al. (2014) considered topographic and edaphic constraints on access and how the region could have been exploited by large animals (e.g., elephant, rhinoceros, aurochs) in the Lower Palaeolithic (Fig. 6). The altitude can reach 1000 m in the Golan, and other regions are above 500 m, resulting in substantial differences in temperature between summer and winter which promote seasonal movements of large herds of animals between upland and lowland pastures. Many areas would have been inaccessible to large mammals such as elephants because of steep slopes and complex topography. These features provide major constraints on seasonal animal movements. The geology includes sedimentary rocks typical of many regions around the Mediterranean plus basalt flows, some of which have been active in historic times (Fig. 7). An earlier study in Greece (Sturdy and Webley 1988) has characterized soils on similar geology and provides a guide to edaphics and water retentiveness in this region (Fig. 8). While some of the sedimentary rocks provide edaphically adequate soils, water retention can be poor. The best soils, edaphically speaking, are associated with basalts on the Golan. The superiority of

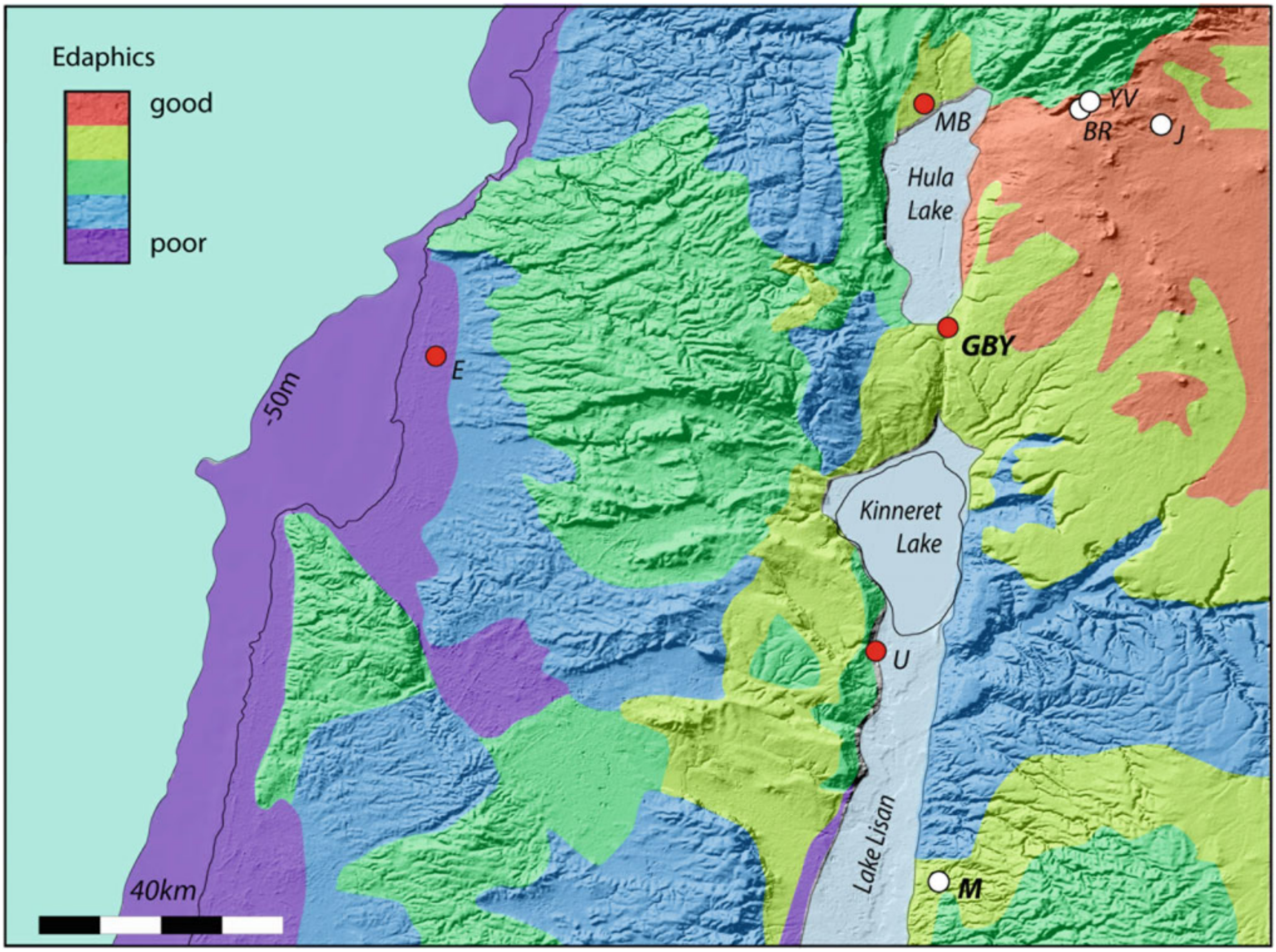

Fig. 8 Interpreted edaphic categories based on geology and plotted on a relief map. Site information as in Fig. 6. After Devès et al. (2014)

animals raised on these soils has been known since biblical times and results from high levels of soluble phosphate (Devès et al. 2014).

Mapping of these different features makes it possible to reconstruct the likely annual movements of large animals (Fig. 9). Winter graze and browse could be found near the coast but in general would lack important trace nutrients. The Golan would have attracted animals in spring and summer. Here, they they would have had their young in a region with the best soils to provide important nutrients for growth. In late summer and autumn, they would have moved to lower altitudes to take advantage of a region of high water retentiveness.

One of the major sites of the Lower Palaeolithic in the region is the Acheulean site of Gesher Banot Ya'acov (GBY) with thousands of stone artefacts including Acheulean bifaces, smaller flakes designed for hafting, and evidence for the use of fire (Goren-Inbar et al. 2000; Rabinovich et al. 2012; Alperson-Afil and Goren-Inbar 2016). The site extends over several kilometres with a deep sequence of sediments and a long series of archaeological layers indicating repeated used over a period of about 150,000 years between about 0.7 and 0.85 Ma. The stone-tool assemblage shows similarities with African sites, suggesting a new wave of human expansion out of Africa at about this time. The site is located near the edge of the palaeo-Hula Lake, and part of it remains waterlogged, with preservation of organic remains including wood, bark, fruits and seeds. Animals exploited include elephants, hippo, rhino, gazelle, horse and bovids, with evidence of carcase butchery. Subsistence also included plant foods and fish (Rabinovich et al. 2012; Melamed et al. 2016).

At the time of its occupation, the site was strategically located to intercept large mammals moving through one of the few available corridors for east–west movement across the Jordan valley (Fig. 10). Immediately to the north were the margins of the expanded Hula Lake. To the south was the palaeo-Lake Lisan, with an intervening area dissected by

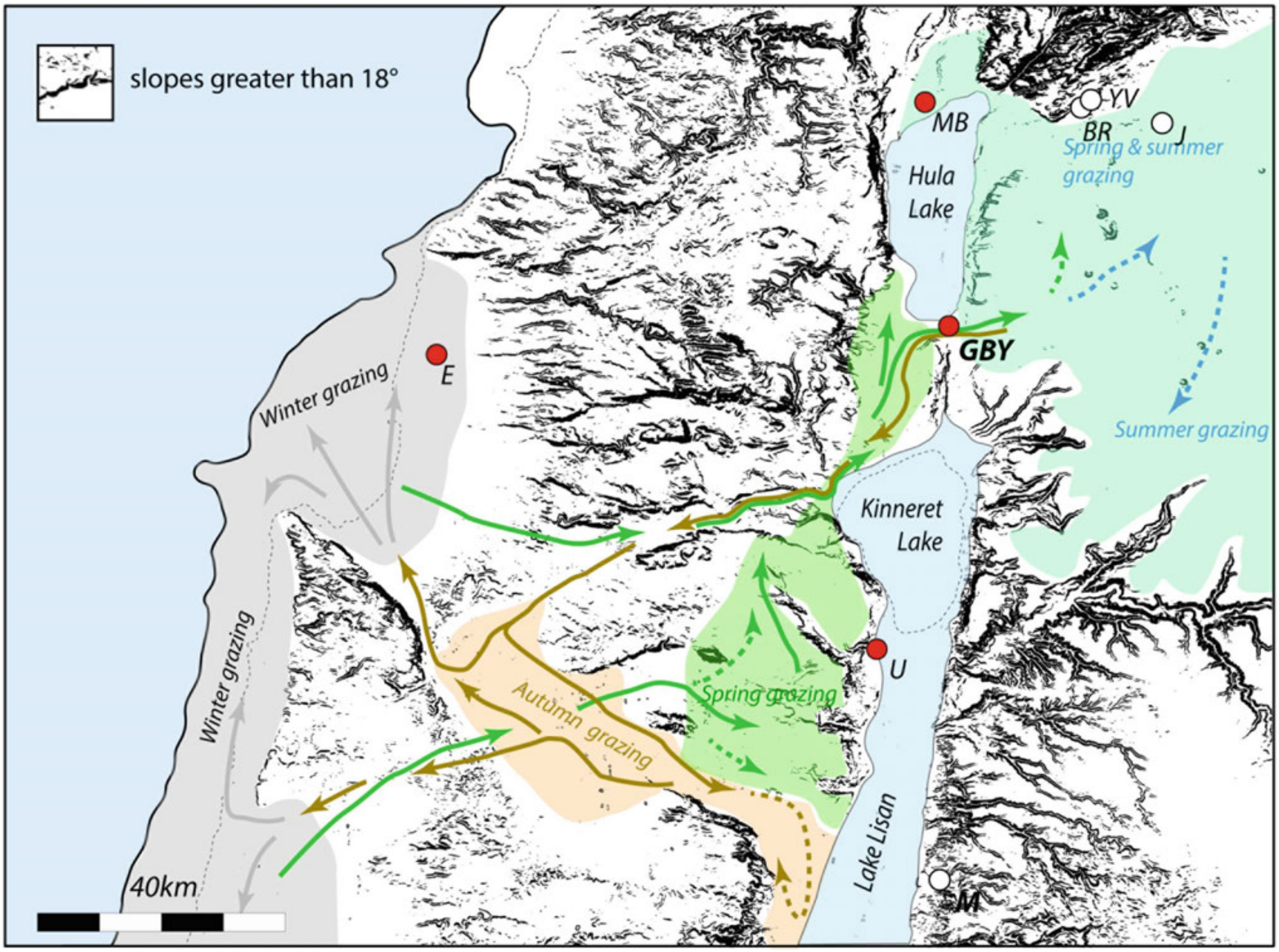

Fig. 9 Reconstructed seasonal movements and grazing areas of large mammal herbivores. The map also shows slopes greater than 18°, which constrain areas accessible to large mammals and routes for seasonal movement. Water retentive soils play an important role on the inner edge of the coastal plain and contribute to the identification of favoured spring, summer and autumn areas. Site information as in Fig. 6. After Devès et al. (2014)

rough topography and steep slopes. Like the African sites already discussed, the location of the site has many advantageous features including proximity to freshwater, volcanic material for artefact manufacture, and, in the GBY case, additional food supplies of non-migratory animals such as wild boar, plants and fish. However, given that the large herbivores, particularly elephant and fallow deer, were the major sources of the subsistence economy, the location of the site on one of the few crossing points from west to east, combined with the tactical opportunities for bringing down large prey, including miring along lake edges, must be a prime factor in the importance of this site (Devès et al. 2014, p. 152–3). By the end of the Lower Palaeolithic, large animals such as elephants had disappeared, the distribution of archaeological sites changed, and evidence of human occupation in regions inaccessible to large animals becomes important.

8 Southwest Saudi Arabia

The western escarpment of the Arabian Peninsula is the result of uplift associated with rifting and seafloor spreading of the Red Sea since at least the Miocene (Jado and Zötl 1984; Coleman et al. 1983; Purser and Bosence 1998; Bonatti et al. 2015; Bosworth and Stockli 2016). In contrast to the other areas already discussed, there is little earthquake activity or evidence of fault scarps on the present-day land surface, apart from localised earthquakes in the vicinity of volcanoes. This is because the active rift margin where major earthquake activity and faulting take place is in the central axial trough of the Red Sea over 2000 m below present sea level. The present terrestrial landscape is on the uplifted rift flank and the major features of relevance to the present discussion are the numerous volcanic cones and extensive

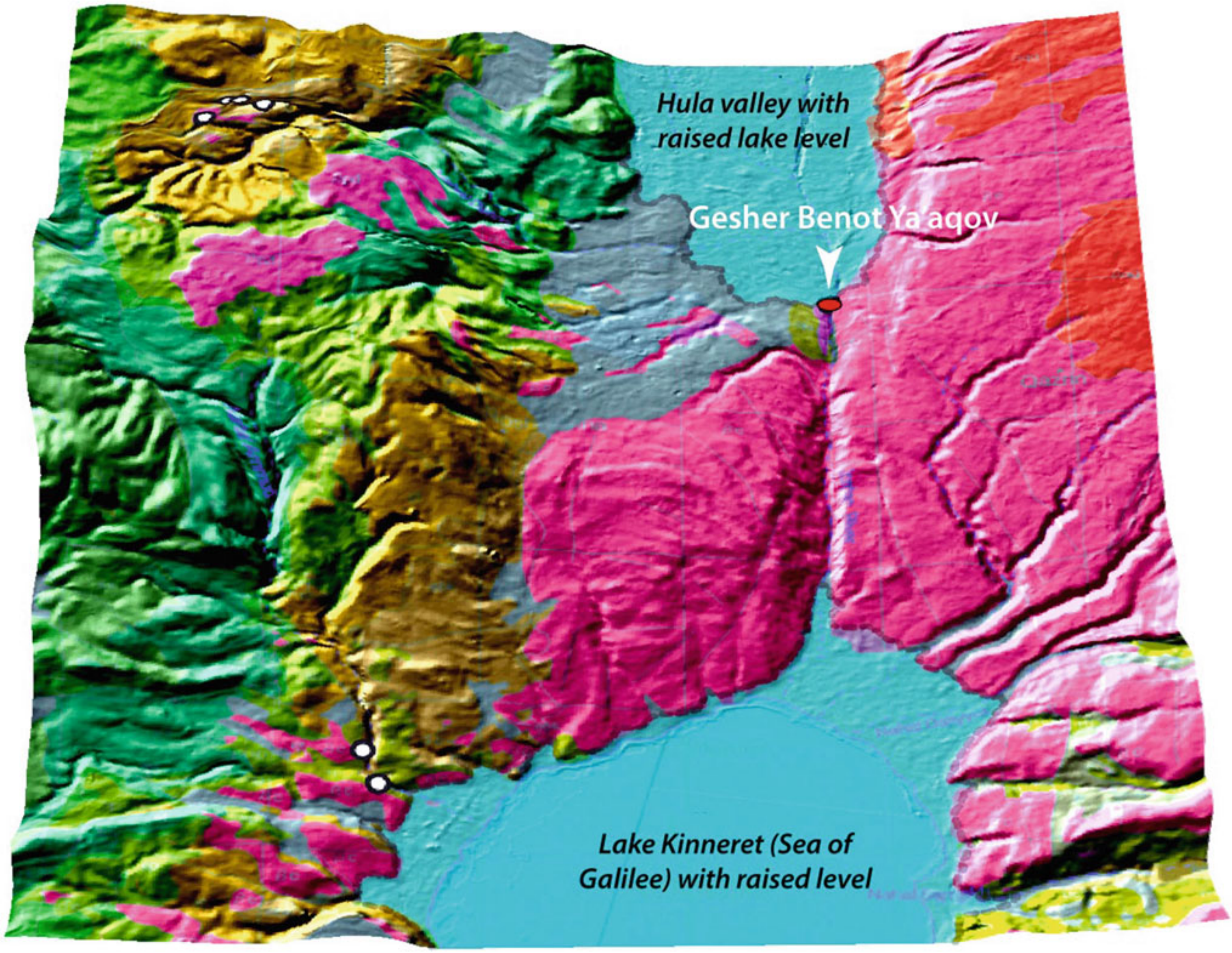

Fig. 10 Oblique 3D view of the region around Gesher Banat Ya'aqov in relation to geology and topography at the time of its occupation. The image is based on etm + legacy data. Topography from SRTM v4.1 data with a vertical exaggeration of ~ 8. Colour coding of geology as in Fig. 7. Note the restricted corridor between the expanded Lake Hula to the north and the steep-sided Upper Jordan valley to the south. This forms a natural ambush for trapping large mammals moving between the grazing lands west of the Rift valley and the Golan Heights. After Devès et al. (2014)

lava flows that form a belt of volcanic activity extending in a broadly north–south orientation. Dating and interpretation of these volcanic deposits are ongoing but substantial volcanic activity took place during the Pleistocene, extending in some regions into the Holocene period.

Also, in contrast to the other case studies, the history of archaeological investigation is much shorter. Major surveys during the 1980s identified numerous surface finds of Palaeolithic material over large areas, but intensive investigation using modern survey and excavation methods has taken place only very recently (see Petraglia et al., this volume; Sinclair et al., this volume). Very few sites have so far been found with stratified remains that can be independently dated or with preservation of animal bone. An added complication in coastal regions is that thousands of square kilometres of new territory were made available during periods of lower sea level. Investigation of this now-submerged landscape has only just begun, but it is clear that extensive tectonic activity associated with salt deposits has created a rapidly evolving landscape of complex topography with hills, fault-bounded depressions, springs and lake basins likely to have been attractive to the earliest human populations of the region (Bailey and King 2011; Dabbagh et al. 1984; Devès et al. 2011, 2013; Bailey et al. 2015, and this volume; Sakellariou et al., this volume; Momber et al., this volume).

Surveys in the Jizan and Asir provinces over the past 5 years have identified over 100 locations with Palaeolithic artefacts (Fig. 11). These have yielded some 6000 stone artefacts, mostly of Lower or Middle Palaeolithic type (Devès et al. 2012; Inglis et al. 2013, 2014a, 2014b, 2015, 2017; Sinclair et al., this volume). Most are surface finds with small numbers of artefacts, reflecting the heavily deflated nature of

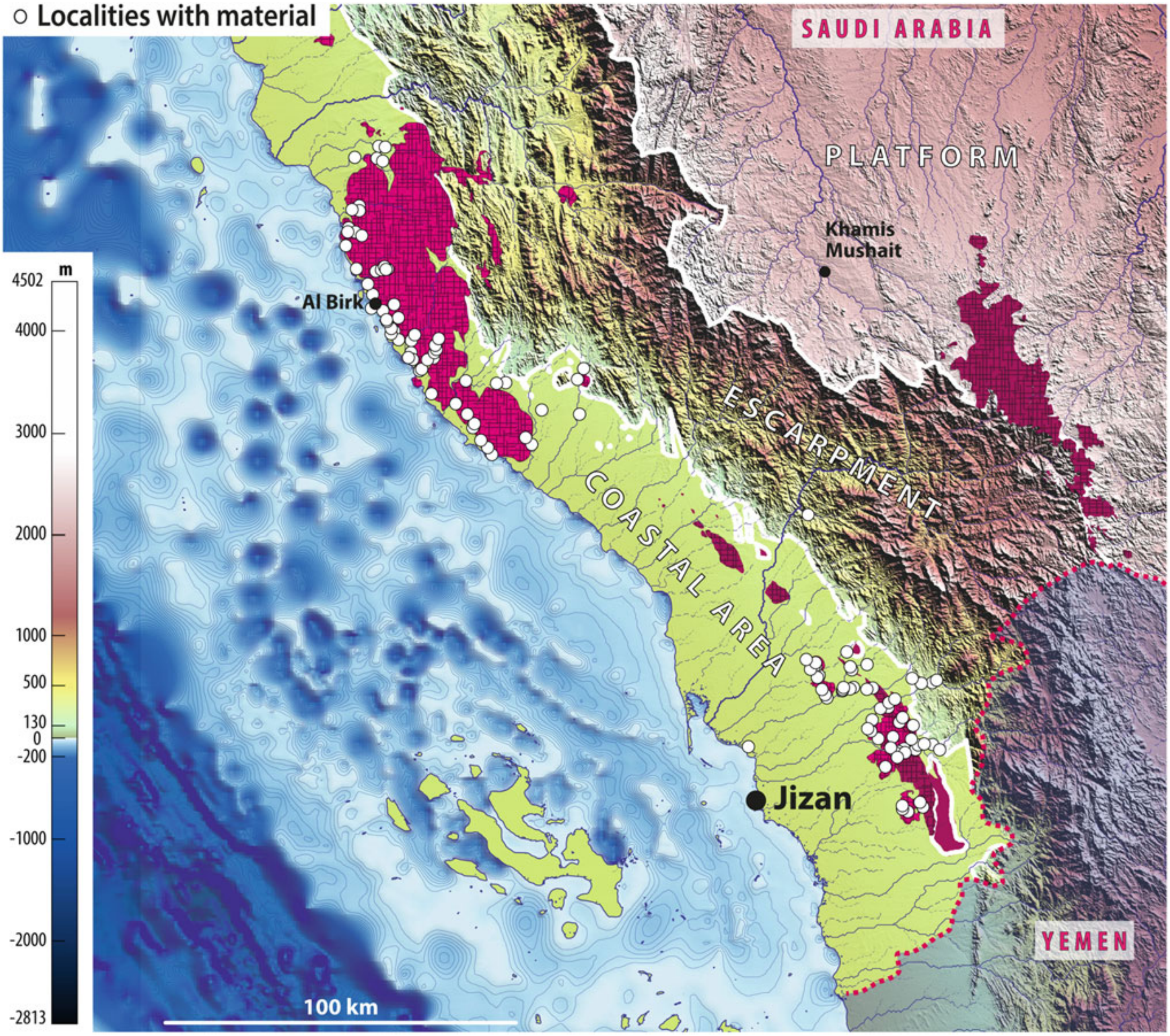

Fig. 11 The Asir and Jizan provinces of Southwest Saudi Arabia showing major features of topography and geology, and the distribution of localities with Palaeolithic artefacts. Note the amount of new land exposed at lowest sea level (light blue). The dark blue circles are deep depressions formed formed by withdrawal of evaporites. Topographic data from SRTM41 and bathymetry from SRTM30PLUS. Image prepared using Adobe Illustrator and MaPublisher by Maud Devès

the land surface, but some have been found in exposures of stratified deposits. Preserved faunal remains have not yet been discovered, and known faunal assemblages of Pleistocene age are rare in the Arabian Peninsula. By analogy with discoveries elsewhere, large mammals present likely included elephant, equids, and bovids, particularly *Oryx* (Thomas et al. 1998; Stimpson et al. 2016). Surveyed localities are mostly distributed on the inner edge of the coastal plain and many are associated with Quaternary volcanic deposits. The distribution is likely biased by the fact that sites that might once have existed on the coastal plain have been buried under more recent alluvial and aeolian deposits, and those in the more mountainous hinterland have been removed by erosion (Devès et al. 2013). The surviving artefacts may also owe their discovery in part to the easy identifiability, and general durability, of stone artefacts made from nearby basaltic lavas. However, this association is by no means the only factor, and other widely available raw materials were used for making artefacts including metamorphic and sedimentary rocks. Despite these cautions, the available artefact distribution provides some insights into the relative attractiveness of different landscape settings.

By far the largest concentration of artefacts occurs at Wadi Dabsa, where a concentration of over 3000 artefacts,

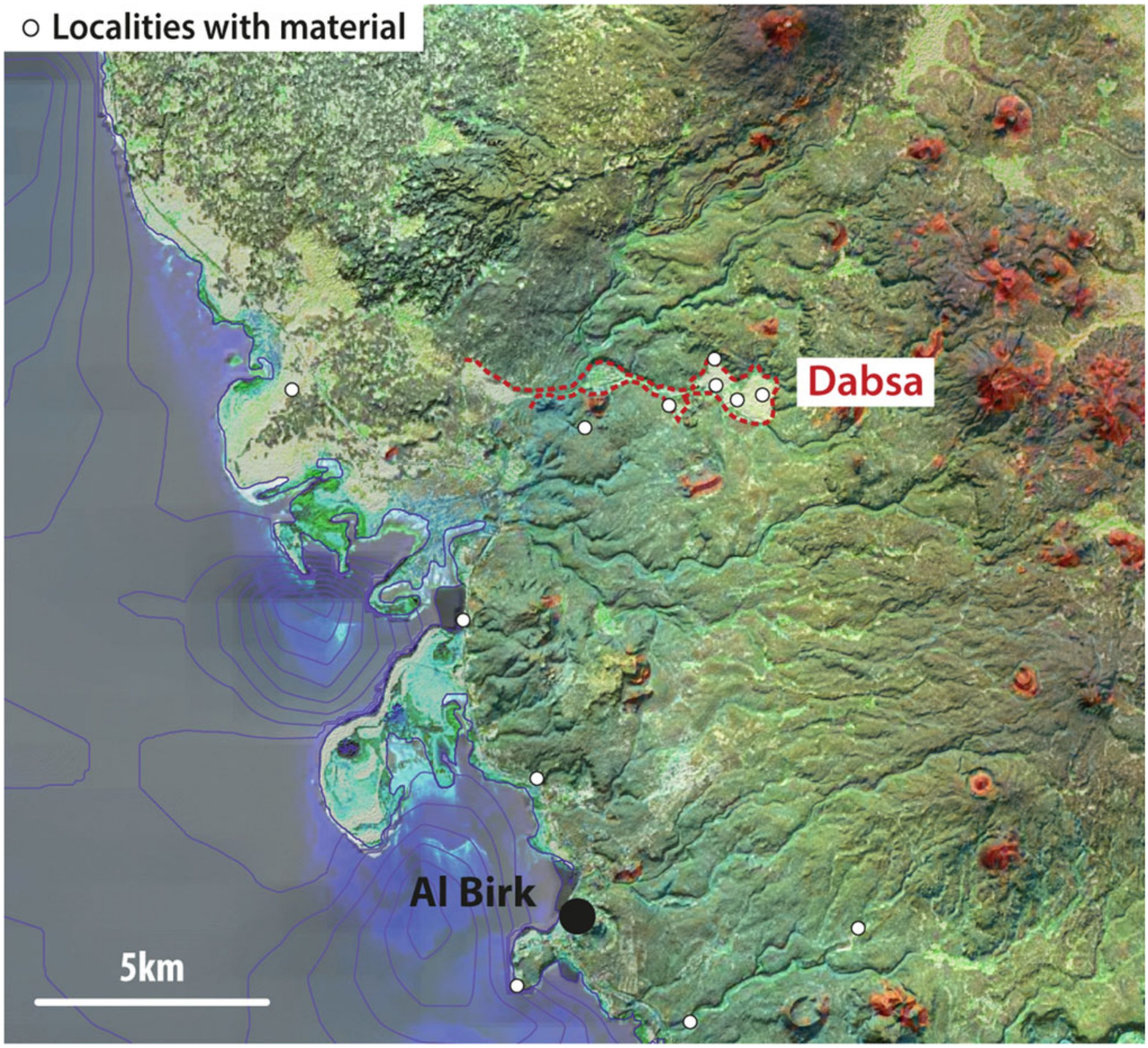

Fig. 12 The region around the site of Wadi Dabsa, showing its relationship to major topographical features and geology. Topographic data are from TanDEM-X. Bathymetry is from SRTM30PLUS with bathymetric contours at 10 m intervals. Topographic information combines slope angles superimposed on elevation with a vertical exaggeration of 4:1. This in its turn is superimposed on a LANDSAT image. Features in orange are volcanic cones and the geology deeply incised by rivers is predominantly basaltic lavas. The tufa in the Wadi Dabsa basin shows up as a light-coloured patch. The location of Palaeolithic localities are shown as white circles. The red dotted line shows the approximate line of barriers formed by basaltic lava flows that would have provided significant constraints on the movement of large mammals, and enclose a series of basins that open out to the west onto the flatter terrain of the coastal plain, which would have extended further out from the present coastline during periods of lower sea level (see also Fig. 11). Image prepared by Maud Devès

mostly of Lower and Middle Palaeolithic type, has been found in an enclosed basin (Inglis et al. 2015, 2017; Foulds et al. 2017; Sinclair et al., this volume). The site occurs in the Harrat al Birk volcanic region, where volcanic cinder cones and extensive basalt flows dissected by stream channels create an extensive and characteristically rough and complex topography (Fig. 12). The most extensive areas of grazing for large animals and large herds would have been on the coastal plain. Access to alternative seasonal grazing inland and at higher altitude is heavily constrained by volcanic lava flows and boulder fields.

The Dabsa site is unusual in its location in the centre of a large area of tufa extending for over 1 square kilometre and almost completely enclosed by lava flows that are difficult to cross. It is clear from stratigraphic observations that the tufa postdates the surrounding lava flows and that at least some of the artefacts were deposited at or before the time of tufa formation. The tufa indicates extensive conditions of water flow and water retention, creating conditions that are likely to have been especially attractive to grazing animals, and particularly so during dry seasons or during semi-arid climate episodes. This forms one of a series of smaller, partially enclosed basins that could have channelled animal movements inland toward attractive conditions, culminating in a virtual cul-de-sac at Dabsa.

Stratigraphic, geochronological, archaeological and palaeoenvironmental analysis is ongoing, and edaphic information is not presently available, but we hypothesise that alluvial sediments derived from the surrounding basalt are likely to have concentrated the best available mineral nutrients. As in our other examples, raw materials for artefact manufacture, water supplies and topographic constraints that facilitated easy access to large mammals are key factors in the choice of site location.

9 Discussion and Conclusions

By common consensus Africa is considered to be the original evolutionary centre of the genus *Homo* (*Homo habilis, H. ergaster, H. erectus*), and members of this genus first expanded out of Africa by about 1.8 Ma. We suggest that the use by hominins of complex and dynamic landscapes was critical to allowing our ancestors to develop and expand their range. We further propose that climbing and scrambling to exploit the tectonically active and topographically complex environments of Africa promoted the evolution of the *Homo* body form. Today we are better than most other animals at exploiting complex topography to our strategic advantage. Historically, minority groups have commonly retreated to the safety of mountainous regions. The Druze and Christians of Mount Lebanon and the Shia in Iraq retreated from the reach of Ottoman cavalry, and the English found the Welsh in their mountain retreats difficult to subdue. In these cases, escaping from cavalry was a motivation, but in more recent conflicts these advantages apply equally well to escaping from tanks and other mechanical adjuncts to war.

There is agreement that the large brain of *Homo* required a reliable supply of fatty protein. It is commonly thought that this must have been supplied by scavenging the kills of other predators and that systematic hunting did not appear until around 400 ka, as documented by the discovery of wooden spears at the Schöningen site in Germany (Thieme 1997). The analysis of the Olorgesailie site in southern Kenya suggests that at 1 Ma or earlier, *Homo* was using ambush hunting to trap large and dangerous animals. Analysis of sites of similar age in other regions provides additional support for this hypothesis and for the view that our earliest ancestors of the genus *Homo* developed survival methods that were critical to their ability to spread out of Africa.

Finally, we emphasise that the analysis of soil edaphics in the Kenyan Rift, based on large numbers of measurements in the field (Kübler et al. 2015, 2016) has demonstrated a close relationship between the nutrient properties of the soils and the mineral constituents of the underlying regolith, whether that is the underlying bedrock, or underlying sediments that have acquired their mineral properties by erosion from bedrocks elsewhere. Moreover, this work has highlighted areas that are deficient in critical nutrients today. In the Kenya Rift, nutrient related problems of human and animal health are common. Examples are severe cobalt deficiency in the Lake Nakuru region leading to starvation of ruminants (locally known as Nakuruitis) or calcium deficiency combined with excessive fluoride levels causing dental and skeletal deformations in humans and wildlife (Maskall and Thornton 1996). Our analysis shows that in a region of variable bedrock geology, the edaphic properties of the soils are highly variable. Extrapolation from bedrock geology, supported by mineralogical analysis of soil samples in the field, represents a method with considerable potential for application elsewhere, and not only to studies of ancient land use but also to the present-day, with major implications for animal and human health.

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References

Alperson-Fil N, Goren-Inbar N (2016) Acheulian hafting: Proximal modification of small flint flakes at Gesher Benot Ya'aqov, Israel. Quatern Int 411(Part B):34–43

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, Reynolds SC, King GCP (2011) Landscapes of human evolution: Models and methods of tectonic geomorphology and the reconstruction of hominin landscapes. J Human Evolution 60:257–280. https://doi.org/10.1016/jjhevol.2010.01.004
Bailey GN, Devès MH, Inglis RH, Meredith-Williams MG, Momber G, Sakellariou D, Sinclair A, Rousakis G, Al Ghamdi S, Alsharekh A (2015) Blue Arabia: Palaeolithic and underwater survey in SW Saudi Arabia and the role of coasts in Pleistocene dispersals. Quatern Int 382:42–57. https://doi.org/10.1016/j.quaint.2015.01.002
Bailey GN, Meredith-Williams M, Alsharekh A, Hausmann N (this volume) The Archaeology of Pleistocene Coastal Environments and Human Dispersals in the Red Sea: Insights from the Farasan Islands
Bar-Yosef O, Goren-Inbar N (1993) The lithic assemblages of ‘Ubeidiya: A Lower Palaeolithic site in the Jordan Valley. Qedem. Monograph 14. Institute of Archaeology, Hebrew University of Jerusalem, Israel
Behrensmeyer AK, Potts R, Deino A, Ditchfield P (2002) Olorgesailie, Kenya: A million years in the life of a rift basin. Soc Sediment Geol Spec Publ No. 73:97–106
Blumenschine RJ, Cavallo JA, Caplado SD (1994) Competition for carcasses and early hominid behavioural ecology: A case study and conceptual framework. J Human Evolution 27:197–213
Bobe R (2006) The evolution of arid ecosystems in Eastern Africa. J Arid Environ 66:564–584
Bobe R, Behrensmeyer AK (2004) The expansion of grassland ecosystems in Africa in relation to mammalian evolution and the origin of the genus Homo. Palaeogeog Palaeoclimat Palaeoecol 207:399–420
Bobe R, Eck GG (2001) Responses of African bovids to Pliocene climatic change. Paleobiol Mem 27(2):1–48
Bonatti E, Cipriani A, Lupi L (2015) The Red Sea: birth of an ocean. In: Rasul NMA, Stewart ICF (eds) The Red Sea: The Formation, Morphology, Oceanography and Environment of a Young Ocean Basin. Springer Earth System Sciences, Berlin Heidelberg, pp 29–44
Bosworth W, Stockli D (2016) Early magmatism in the greater Red Sea rift: Timing and significance. Can J Earth Sci 53(11):1158–1176
Bramble DM, Lieberman DE (2004) Endurance running and the evolution of Homo. Nature 432:345–352
Burrows GE, Brodie B, Thedford TR (1979) Selenium supplementation for beef cattle in Kenya. Bull Animal Health Production in Africa 27:139–143
Cerling TE, Harris JM, MacFadden BJ, Leakey MG, Quade J, Eisenmann V, Ehleringer JR (1997) Global vegetation change through the Miocene/ Pliocene boundary. Nature 389:153–158
Coleman RG, Gregory RT, Brown GF (1983) Cenozoic volcanic rocks of Saudi Arabia. US Geol Survey Open-File Report 83–788. https://doi.org/10.3133/ofr83788
Corah L (1996) Trace mineral requirements of grazing cattle. Animal Feed Sci Technol 59(1–3):61–70
Dabbagh A, Emmermann R, Hötzl H, Jado AR, Lippolt HJ, Kollman W, Moser H, Rauert W, Zötl JG (1984) The development of Tihamat Asir during the Quaternary. In: Jado AR, Zötl JG (eds) Quaternary Period in Saudi Arabia, vol 2. Sedimentological, hydrogeological, hydrochemical, geomorphological, geochronological and climatological investigations in Western Saudi Arabia. Springer-Verlag, Vienna, pp 150–173
DeMenocal PB (2004) African climate change and faunal evolution during the Pliocene-Pleistocene. Earth Planet Sci Lett 220:3–24
Devès M, King GCP, Klinger Y, Amotz A (2011) Localised and distributed deformation in the lithosphere: The example of the Dead Sea valleys. Earth Planet Sci Lett 308:172–184. https://doi.org/10.1016/j.epsl.2011.05.044
Devès M, Inglis R, Meredith-Williams M, Alsharekh A, Al Ghamdi S, Bailey G (2012) Preliminary report of reconnaissance fieldwork in southwest Saudi Arabia, May–June, 2012. http://www.disperse-project.org/field-reports
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
Devès M, Sturdy D, King GCP, Godet N, Bailey GN (2014) Hominin reactions to herbivore distribution in the Lower Palaeolithic of the southern Levant. Quatern Sci Rev 96:140–160. https://doi.org/10.1016/j.quascirev.2014.04.017.15
Devès MH, Reynolds S, King GCP, Kübler S, Sturdy D, Godet N (2015) Insights from earth sciences into human evolution studies: The examples of prehistoric landscape use in Africa and the Levant. Comptes Rendus Geosci 347(4):201–211
Domínguez-Rodrigo (2002) Hunting and scavenging by early humans: The state of the debate. J World Prehistory 16:1–54
Enzel Y, Bar-Yosef O (eds) (2017) Quaternary of the Levant: Environments, climate change, and humans. Cambridge University Press, Cambridge
Formigoni A, Fustini M, Archetti L, Emanuele S, Sniffen C, Biagi G (2011) Effects of an organic source of copper, manganese and zinc on dairy cattle productive performance, health status and fertility. Animal Feed Sci Technol 164:191–198
Foulds F, Shuttleworth A, Sinclair A, Inglis R, Alsharekh A, Al Ghamdi S, Bailey GN (2017) A large handaxe from Wadi Dabsa and early hominin adaptations within the Arabian Peninsula. Antiquity 91(359):1421–1434
Goren N (1981) The Lower Palaeolithic in Israel and adjacent countries. In: Cauvin J, Sanlaville P (eds) Préhistoire du Levant: Chronologie et organisation de l’espace depuis les origines jusqu’au VIe millénaire. Colloques internationaux du Centre national de la recherche scientifique, 598. Éditions du CNRS, Lyon, pp 193–205
Goren-Inbar N (1985) The lithic assemblages of Berekhat Ram Acheulian site. Golan Heights. Paléorient 11(1):7–28
Goren-Inbar N, Feibel CS, Verosub KL, Melamed Y, Kislev ME, Tchernov E, Saragusti I (2000) Pleistocene milestones on the Out-of-Africa corridor at Gesher Benot Ya’aqov. Israel. Science 289(5481):944–947
Gowlett JAJ, Crompton RH (1994) Kariandusi: Acheulean morphology and the question of allometry. African Archaeol Rev 12:3–42
Henkin Z, Noy-Meir I, Gutman M, Seligman NG (1995) The effect of phosphorus nutrition, shrub control and fire on the dynamics of Mediterranean batha vegetation in Galilee. Israel, FAO/ CIHEAM Network on Pastures and Fodder Crops, Avignon, France
Inglis RH, Sinclair AGM, Shuttleworth A, Alsharekh AM, Al Ghamdi S (2013) Preliminary report on 2013 fieldwork in southwest Saudi Arabia by the DISPERSE project: (2) Jizan and Asir provinces, February–March 2013. Report to the Saudi Commission for Tourism and Antiquities. http://www.disperse-project.org/field-reports; http://eprints.whiterose.ac.uk/80964/
Inglis RH, Sinclair A, Shuttleworth A, Alsharekh A, Al Ghamdi S, Devès M, Meredith-Williams MG, Bailey GN (2014a) Investigating the Palaeolithic Landscapes and Archaeology of the Jizan and Asir Regions, Southwest Saudi Arabia. Proc Seminar for Arabian Studies 44:193–212
Inglis RH, Sinclair AGM, Shuttleworth A, Meredith-Williams MG, Hausmann N, Budd W, Alsharekh A, Al Ghamdi S, Bailey GN (2014b) Preliminary Report on 2014 Fieldwork in Southwest Saudi Arabia by the DISPERSE project: (1) Jizan and Asir Provinces. Report to the Saudi Commission for Tourism and Antiquities. http://www.disperse-project.org/field-reports; http://eprints.whiterose.ac.uk/80965/
Inglis RH, Foulds F, Shuttleworth A, Alsharekh AM, Al Ghamdi S, Sinclair AG Bailey GN (2015) The Palaeolithic Occupation of the Harrat Al Birk: Preliminary Report on the 2015 Fieldwork in Asir

Province, Southwest Saudi Arabia. Report to the Saudi Commission for Tourism and Antiquities. http://www.disperse-project.org/field-reports; http://eprints.whiterose.ac.uk/84382/
Inglis RH Sinclair AGM, Alsharekh AM, Barfod DN, Chang HC, Fanning PC, Al Othaibi DT, Robson HK, Shuttleworth A, Stone A, Bailey GN (2017) Preliminary report on UK-Saudi 2017 fieldwork at Wadi Dabsa, Asir Province, Saudi Arabia. http://eprints.whiterose.ac.uk/119267/
Isaac GL (1977) Olorgesailie: Archaeological studies of a Middle Pleistocene lake basin in Kenya. University of Chicago Press, Chicago
Jado AR, Zötl JG (eds) (1984) Quaternary Period in Saudi Arabia Volume 2: Sedimentological, hydrogeological, hydrochemical, geomorphological, geochronological and climatological investigations in Western Saudi Arabia. Springer-Verlag, Vienna
Kadim IT, Mahgoub O, Al-Ajmi DS, Al-Maqbaly RS, Al-Saqri NM, Ritchie A (2003) An evaluation of the growth, carcass and meat quality characteristics of Omani goat breeds. Meat Sci 66(1):203–210
King GCP, Bailey GN (2006) Tectonics and human evolution. Antiquity 80:1–22
King GCP, Bailey GN, Reynolds SC (2010) Dynamic landscapes and human evolution. In: Sintubin M, Stewart IS, Niemi T, Altunel E (eds) Ancient earthquakes: Archaeoseismology along the Alpine-Himalayan seismic zone. Geol Soc America Special Paper 471, pp 1–19. https://doi.org/10.1130/2010.2471(01)
Kübler S, Owenga P, Reynolds SC, Rucina SM, King GCP (2015) Animal movements in the Kenya Rift and evidence for the earliest ambush hunting by hominins. Nature Sci Reports 5(14011):1–7. https://doi.org/10.1038/srep14011
Kübler S, Owenga P, Rucina S, Reynolds SJ, Bailey GN, King GCP (2016) Edaphic and topographic constraints on exploitation of the Central Kenya Rift by large mammals and early hominins. Open Quatern 2(5):1–18. https://doi.org/10.5334/oq.21
Leakey LSB (1931) The Stone Age cultures of Kenya Colony. Cambridge University Press, Cambridge
Macumber PG, Edwards PC (1997) Preliminary results from the Acheulean site of Mashari'a 1, and a new stratigraphc framework for the Lower Paleolithic of the east Jordan Valley. In: Kebel HGK, Kafafi Z, Rollefson GO (eds) The prehistory of Jordan II: perspectives from 1997. Studies in early Near Eastern production, subsistence and environment, vol 4. Ex Oriente, Berlin, pp 23–44
Maglio VJ, Cook HBS (eds) (1978) The evolution of African mammals. Harvard University Press, Cambridge, MA
Maskall J, Thornton I (1996) The distribution of trace and major elements in Kenyan soil profiles and implications for wildlife nutrition. In: Appleton JD, Fuge R, McCall GJH (eds) Environmental geochemistry and health. Geol Soc, London, Special Publ 113, pp 47–62. Ddoi:https://doi.org/10.1144/gsl.sp.1996.113.01.05
Melamed Y, Kislev ME, Geffen A, Lev-Yadun S, Goren-Inbar N (2016) The plant component of an Acheulian diet at Gesher Benot Ya'aqov. Israel. Proc National Acad Sci 113(51):14674–14679. https://doi.org/10.1073/pnas.1607872113
Momber G, Sakellariou D, Rousakis G, Bailey G (this volume) The multi-disciplinary search for underwater archaeology in the southern Red Sea
Murray MG (1995) Specific nutrient requirements and the migration of the wildebeest. In: Sinclair ARE, Arcese P (eds) Serengeti II—dynamics, management and conservation of an ecosystem. University of Chicago Press, Chicago, pp 231–256
Okada Y (1982) Internal deformation due to shear and tensile fault in a half-space. Bull Seismol Soc America 82:1018–1040
Owen-Smith N (1988) Ecological links between African savanna environments, climate change and early hominid evolution. In: Bromage TG, Schrenk F (eds) African biogeography, climate change, and human evolution. Oxford University Press, New York, pp 138–149
Petraglia MD, Breeze PS, Groucutt HS (this volume) Blue Arabia, green Arabia: examining human colonisation and dispersal models
Pickering TR (2013) Rough and tumble: Aggression, hunting, and human evolution. University of California Press, Berkeley and Los Angeles, CA
Potts R (1989) Olorgesailie: New excavations and findings in Early and Middle Pleistocene contexts, southern Kenya rift valley. J Human Evolution 18:477–484
Potts R, Behrensmeyer AK, Deino A, Ditchfield P, Clark J (2004) Small Mid-Pleistocene hominin associated with East African Acheulean technology. Science 305:75–78
Purser BH, Bosence DWJ (eds) (1998) Sedimentation and tectonics of rift basins: Red Sea—Gulf of Aden. Chapman and Hall, London
Rabinovich R, Gaudzinski-Windheuser S, Kindler L, Goren-Inbar N (2012) The Acheulian site of Gesher Benot Ya'aqov Volume III. Mammalian taphonomy. The assemblages of Layers V-5 and V-6. Springer, Dordrecht
Reynolds SC, Bailey GN, King GCP (2011) Landscapes and their relation to hominin habitats: Case studies from Australopithecus sites in eastern and southern Africa. J Human Evolution 60: 257–280
Ronen A (2003) Evron Quarry, western Galilee, Israel. In: Burdukiewicz JM, Ronen A (eds) Lower Palaeolithic small tools in Europe and the Levant. British Archaeological Reports International Series 1115. Archaeopress, Oxford, pp 113–120
Ronen A, Ohel MY, Lamdan M, Assaf A (1980) Acheulian artifacts from two trenches at Maayan Barukh, Upper Galilee, Israel. Isr Explor J 30:17–33
Ruess RW (1984) Nutrient movement and grazing: Experimental effects of clipping and nitrogen source on nutrient uptake in Kyllinga nervosa. Oikos 43(2):183–188
Sakellariou D, Rousakis G, Panagiotopoulos I, Morfis I, Bailey G (this volume) Geological structure and Late Quaternary geomorphological evolution of the Farasan Islands continental shelf, southern Red Sea, SW Saudi Arabia
Shipton C (2011) Taphonomy and behaviour at the Acheulean site of Kariandusi, Kenya. African Archaeol Rev 28:141–155. https://doi.org/10.1007/s10437-011-9089-1
Sinclair A, Inglis RH, Shuttleworth A, Foulds F, Alsharekh A (this volume) Landscape archaeology, Palaeolithic survey and coastal change along the southern Red Sea of Saudi Arabia
Skinner JD, Louw GN (1996) The Springbok Antidorcas marsupialis (Zimmermann, 1780). Transvaal Museum Monograph No. 10:1–49. Transvaal Museum, Pretoria
Stimpson CM, Lister A, Parton A, Clark-Balzan L, Breeze PS, Drake NA, Groucutt HS, Jennings R, Scerri EML, White TS, Zahir M, Duval M, Grün R, Al-Omari A, Al Murayyi KSM, Zalmout IS, Mufarreh YA, Memesh AM, Petraglia MD (2016) Middle Pleistocene vertebrate fossils from the Nefud Desert, Saudi Arabia: Implications for biogeography and palaeoecology. Quatern Sci Rev 143:13–36
Sturdy DA, Webley DP (1998) Palaeolithic geography: Or where are the deer? World Archaeology 19:262–280
Sturdy DA, Webley DP, Bailey GN (1997) The Palaeolithic geography of Epirus. In: Bailey GN (ed) Klithi: Palaeolithic settlement and Quaternary landscapes in Northwest Greece, vol 2. Klithi in its local and regional setting. McDonald Institute for Archaeological Research, Cambridge, pp 541–559
Tchernov E (1988) Les mammifères du Pleistocene inferieur de la Vallée du Jordain à Oubediyeh. Memoires et Travaux du Centre de Recherche Français de Jerusalem 5. Association Paléorient, Paris, pp 191–212

Tchernov E, Horwitz LK, Ronen A, Lister A (1994) The faunal remains from Evron Quarry in relation to other Lower Paleolithic hominid sites in the Southern Levant. Quatern Res 42(3):328–339

Thieme H (1997) Lower Palaeolithic hunting spears from Germany. Nature 385:807–810. https://doi.org/10.1038/385807a0

Thomas H, Geraads D, Janjou D, Vaslet D, Memesh A, Billiou D, Bocherens H, Dobigny G, Eisenmann V, Gayet M, de Lapparent de Broin F, Petter G, Halawani M (1998) First Pleistocene faunas from the Arabian Peninsula: An Nafud Desert, Saudi Arabia. Comptes Rendues de l'Acad des Sci Paris 326:145–152. https://doi.org/10.1016/s1251-8050(97)87459-9

Vrba ES (1982) Biostratigraphy and chronology, based particularly on Bovidae, of southern hominid-associated assemblages: Makapansgat, Sterkfontein, Taung, Kromdraai, Swartkrans; also Elandsfontein (Saldanha), Broken Hill (now Kabwe) and Cave of Hearths. In: de Lumey H, de Lumley MA (eds) Premier Congrès International de Paléontologie Humaine, Tome 2. CNRS, Nice, pp 707–752

Wheeler PE (1993) The influence of stature and body form on hominid energy and water budgets: A comparison of Australopithecus and early Homo physiques. J Human Evolution 24:13–28

Winder IC, King GCP, Devés M, Bailey GN (2013) Complex topography and human evolution: The missing link. Antiquity 87:333–349

Winder IC, King GCP, Devès MH, Bailey GN (2014) Human bipedalism and the importance of terrestriality: A reply to Thorpe et al. (2014). Antiquity 88:915–916

Wood B (2005) Human evolution. Oxford University Press, Oxford