Landscapes of Human Evolution

Contributions in honour of John Gowlett

edited by

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and Rob Hosfield

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Rift Dynamics and Archaeological Sites: Acheulean Land Use in Geologically Unstable Settings

Simon Kübler, Geoff Bailey, Stephen Rucina, Maud Devès and Geoffrey C.P. King

Introduction

Our aim in this chapter is to examine the reconstruction of physical landscapes in rift settings and their relevance to archaeological interpretation and to reflect on the challenges and opportunities of such research, with particular reference to the Kenyan sector of the East African Rift. We focus on the mapping of physical landforms and how they change in relation to variations in geology, topography, hydrology, soils and sediments, their relationship to the dynamic underlying processes of tectonic activity in different sorts of geological and geodynamic settings, and the implications of these relationships for the surface distribution of plant and animal resources and physical features of potential human significance.

We take it as axiomatic that investigating the location of archaeological or human-fossil sites and site distributions in relation to their physical surroundings at many different geographical scales provides a valuable source of information about the types of landscapes that were of particular significance to their human occupants, how they were used and what this tells us about broader processes of human evolution, adaptation and dispersal.

Our geographical scale is that of the site catchment (the area within a 10–20 km radius) and the wider region beyond. We distinguish this from other landscape approaches, particularly those applied in Africa, which look at a much more localised scale of tens of metres to kilometres (Potts et al. 1999; Blumenschine and Peters 1998; Blumenschine et al. 2012; Bunn et al. 1980; Isaac 1981; Kingston 2007; Kroll 1994; Stern 1994).

At the same time, we acknowledge a major problem in pursuing such goals, especially when dealing with the earlier time ranges of human evolution. The first generation of site catchment studies applied to the prehistoric period took the present-day landscape as a starting point for evaluation, incorporating evidence of changes as opportunity offered but generally treating them as relatively minor impediments to interpretation (Bailey 2005; Higgs and Vita-Finzi 1972; Vita-Finzi and Higgs 1970). However, as one goes further back in time, and especially in geologically active regions such as rifts and plate margins, such an assumption is of doubtful validity; on the contrary the opposite assumption may hold sway – that so much has changed that any attempt at reconstruction is doomed to failure. The latter assumption is often allied to the belief that no useful statements can be made about the determinants of archaeological or fossil occurrences other than the banal – sites are associated with food and water; or that a more detailed investigation is hopeless – discovery of sites is the result of fortuitous conditions of preservation and exposure resulting from geological change that are beyond further investigation. It is probably these two reasons above all others – the reliance on an assumption of little or no physical change that may be unwarranted, or a belief that so much has changed that detailed investigation is impossible – that account for widespread scepticism and lack of progress in catchment-scale studies as applied to the earlier time ranges of the archaeological record.

We show here that it is possible to steer between these extremes, and that the key to doing so is an understanding of the underlying geodynamic processes that determine the nature of land forms. We have elsewhere shown how tectonically active environments can create and maintain features of long-term benefit to human land use. This can be achieved through the creation and rejuvenation of a complex topography and hydrology that traps water in lake basins, creates spring lines along fault boundaries, sharpens topographic features of tactical advantage in avoiding predators and accessing prey, maintains variations in relief over short distances that juxtapose different plant and animal communities within a relatively small area, protects against climatic extremes, renews the fertility of soils and shapes patterns of soil erosion and sedimentation (Bailey and King 2011, Bailey et al. 2011, Deves et al. 2014, 2015; King and Bailey 2010, Kübler et al. 2015, 2016; Reynolds et al. 2011; Winder et al. 2013, 2014). Here we expand on this theme. We review the variety of geodynamic processes that need to be taken into account when undertaking landscape reconstruction, and examine specific archaeological examples.

The study of Earth geodynamics and active tectonics is a rapidly evolving field, with many different sorts of interacting processes. The Earth's crust, or lithosphere, is highly unstable and irregular in its surface morphology, and there is no place on Earth that is immune from these instabilities. These processes include the effects of convection currents in the Earth's interior associated with plate motions and plumes, and isostatic movements associated with differential loading and unloading of mountain and water masses. The scale and rate of change varies enormously across the globe and through time, but there is no such thing as a static landscape. Even geodynamic processes that operate very slowly and over very long periods of time (millions of years) can give rise to short-term phenomena such as volcanic eruptions and earthquakes with immediate human impact, or in their cumulative effect sustain physical features advantageous to human land use. Paradoxically, the processes that provide long-term human benefit are also those that make for difficulties of landscape reconstruction. A static landscape would in time undergo erosion and removal of topographic features, depletion of soil nutrients and environmental degradation of little human benefit.

Of course, geodynamic processes can also damage or destroy. They also play an important role in the taphonomic effects that determine the burial, exposure, preservation and discovery of archaeological and fossil material. From every point of view, an understanding of their effects on human landscapes is indispensable to archaeological interpretation, and we do not minimise the complexities involved in unravelling their impact. There is much that is still unresolved in understanding the geodynamic history of the lithosphere and how the various processes interact, and we outline these issues here.

For examples of landscape reconstruction, we draw on early Acheulean localities in Africa and the Levant but with a particular focus on the central and southern Kenyan Rift. We emphasise this archaeological period and region not only because it provides a good illustration of our approach, but because it has also been the focus of John Gowlett's own field research, beginning with his PhD research at Kariandusi in the early 1970s (Figure 1, Figure 2), and subsequently at Chesowanja and Kilombe (Gowlett 1991, 1999; Gowlett et al. 2015). We present this chapter both as a tribute to John's fieldwork in the region and also more generally as a contribution to debates about archaeological and fossil materials in their landscape setting.

Figure 1. The site of Kariandusi looking southeast. The tin-roofed structure visible at the top of the cliff is the open-air museum built over the area excavated by John Gowlett in 1974. The white deposits represent lake sediments accumulated when lake level was higher than the present. They are quarried today for their diatomites, which have many applications in building and agriculture. Photo by Geoff Bailey, February 2012

Figure 2. Left: view of section and artefacts in situ on John Gowlett's excavation at Kariandusi. Right: the sign at Kariandusi, marking the location of the Gowlett excavation. Photos by Geoff Bailey, February 2012.

Earth geodynamics

Plates

Ever since the acceptance of plate tectonic theory in the 1960s, plate motions driven by ocean-spreading have dominated understanding of geodynamic processes. According to plate-tectonic theory, the lithosphere (the rigid ~100km-thick outer crust of the Earth's surface) is broken up into seven major plates, and these plates are in continuous motion relative to each other, sliding over the more viscous material of the underlying mantle where rocks are in a more fluid or semi-plastic state as a result of heat and pressure. These plates are composed either of continental crust including blocks of geologically very ancient rocks known as cratons, or of relatively young oceanic crust composed primarily of basaltic lava, or of continental crust with a piece of oceanic crust attached.

The primary driving force for these plate motions is the emergence of fresh lava at mid-ocean ridges, the best known being the mid-Atlantic ridge. Here basaltic lava erupts from relatively shallow sources in the mantle along cracks or seams in the lithosphere, resulting in the creation of a ridge formed by volcanoes, a divergent plate boundary with slabs of oceanic crust moving in opposite directions, and the progressive opening up of an ocean basin. As the basaltic lava spreads, it becomes cooler and denser, eventually sinking back into the mantle. Slabs of oceanic crust can also slide against each other resulting in transform boundaries, or collide with continental crust creating subduction boundaries where the denser oceanic material slides underneath the edge of the lighter continental crust. These different types of boundaries are associated with narrow belts of intense earthquake and volcanic activity, and are often associated with large-scale uplift and subsidence. These processes, which create and destroy oceanic crust, have resulted in the almost complete renewal of the ocean floor during the past 65 million years.

Subduction systems do not develop in continents because the continental lithosphere is not dense enough to sink back into the mantle. Instead the crust becomes squashed and thickened by convergent plate motions, with the result that continental deformation can spread over 1000s of kilometres to form the Earth's major mountain belts, for example the Alpine-Himalayan belt that marks the collision of the African, Arabian and Australian Plates with the Eurasian Plate. Earthquakes are widely distributed over such regions, hosted by complex and continuously evolving fault systems. Transform faults in the form of major strike-slip faults also occur in continental lithosphere, where blocks of continental crust slide past each other, but these can be geometrically more complex than the features found in oceans.

In general, uplift and subsidence on land, and the consequent irregularity or roughness of the surface at many different scales can mostly be explained as a secondary consequence of horizontal compression due to plate motions acting on the boundaries of a deforming region and causing thickening by faulting and folding. However, Earth scientists are increasingly aware that there are other factors at work. No phenomenon has posed a greater challenge to our understanding of uplift and subsidence than the tectonic evolution of the African continent (Burke 1996, Burke and Gunnel 2008).

Plumes

Although a major part of the heat from the Earth's core that reaches the surface is carried by basalt erupting from shallow mantle sources at ocean ridges as part of the plate tectonic process, heat also reaches the surface in other ways. Prominent features, referred to as hot spots, are considered to be associated with hot plumes coming from deep sources (>1000km depth) at the core-mantle boundary of the Earth's interior, much deeper than the shallow source magmas of ocean ridges (Davies 1999). When a plume reaches the lower boundary of the lithosphere the plume head spreads out like a mushroom head to create a swelling of the Earth's surface with kilometre-scale vertical motion and 1000km horizontal extent, which can cause uplift, doming and rupture of the lithosphere. Uplifted regions such as Ethiopia, built up from a 4km-thick sequence of flood basalts that erupted at about 30 Ma, are thought to be the result of plume activity. These plumes are fixed relative to the motions of plates in the lithosphere. Where the overlying plate is relatively stationary, as is the case with the African plate, the effect of the plume head can lead to swelling and uplift, and this probably accounts for the elevation of the Ethiopian plateau, parts of the Kenyan Rift, and the interior of South Africa. Where the overlying plate is moving, it can result in a chain of volcanic activity, and this is thought to be the case for the Hawaiian Islands, resulting from a plate moving over a long-lived plume source.

This plume mode of deformation is not as well understood as the plate mode, mainly because it is difficult to observe, and it has in general and until recently been considered at best of minor importance in comparison with plate motions, and of relevance only to very early periods of Earth's geological history. However, views are changing as a result of new information, in particular tomographic images of heterogeneity in the deep mantle and satellite measurements of earth gravitational anomalies. Also, a growing number of surface phenomena that are not adequately explained by plate motions are increasingly being referred to the effects of the plume mode and to landscape effects that can manifest on shorter (Myr to kyr) geological time-scales (Bunge and Glasmacher 2017; Friedrich et al. 2017; Guillocheau et al. 2017).

Rifts

Rifts were originally described as Graben, first named for the Rhine Valley (Suess 1885) and were thought to be the result of a down-dropped piece of land bordered by parallel faults, creating a wedge-shaped block rather like the V-shaped keystone of an archway. This is now known to be a misconception, and rifts are recognised as resulting from crustal extension and thinning. This can result from mechanical effects associated with either mode of deformation (plate or plume), or from thermal expansion and uplift associated with lithospheric melting and volcanism in the plume mode. In all cases extension is accommodated by normal faulting with progressive uplift of the rift flanks and subsidence of the rift floor. It is this extensional process that allows the formation of new ocean floor, but not all rifts evolve into oceans.

Rifts can vary in scale from 100km or less (e.g., the Gulf of Corinth, Greece) to the >3000km structure that forms the Rhone and Rhine valleys and the axis of the North Sea. The latter is thought to be the result of the nascent extension that finally formed the Atlantic Ocean, but it was abandoned as motion concentrated on other rifts to the west. Rifts can therefore be early features in the creation of new oceans, only to be abandoned, and these are sometimes referred to as Failed Rifts. The status of the East African Rift in this regard is not clear. Is it a new plate boundary in process of being formed that will ultimately become an ocean basin, or will it become quiescent? There is no agreement (e.g., King and King 1967).

To the north, the Red Sea basin is a new ocean that results from the continued widening of an extension of the early East African Rift. This was made possible by the opening of the Gulf of Aden and the creation of the Arabian Plate, which is now moving away from Africa and converging with the Eurasian Plate (Hubert-Ferrari et al. 2003). The boundary of this plate extends through the Levant as a strike-slip feature with compression and uplift in Lebanon and some extension to the north and south.

Rift mechanisms

Rifts are characterised by a single main fault (sometimes with closely spaced subparallel branches) and are normally asymmetric in cross section (Figure 3). The main fault can occur to the left of the rift axis, or to the right, and there is no general rule in this regard. Faulting on one side of the rift (the foot wall) dominates and shows upward flexure and uplift, while the other side of the rift (the hanging wall) shows downward flexure and antithetic faulting with no more than 10% of displacement compared to the main fault (Figure 3a).

The lithosphere associated with old cratons, as is the case throughout much of the East African Rift, is generally thicker than elsewhere, and the elastic properties associated with the lithosphere therefore extend to greater depth. Hence, the flexure associated with faulting has a greater lateral extent than would otherwise be the case, which is why the African Rift valleys are mostly wider than those in other parts of the world.

The main fault is commonly complex, composed of several subparallel faults, which create a ragged main scarp (Figure 3b). The faults associated with tension structures at the surface of the footwall create local narrow valleys, well-illustrated by the Delphi valley in the Gulf of Corinth (Armijo et al. 1996). Unlike many other rift valleys, volcanoes are common within the African Rift and are considered to be related to thinning of the crust associated with extension, which is thought to be greatest along the rift axis. However large volcanoes also appear on the footwall and are

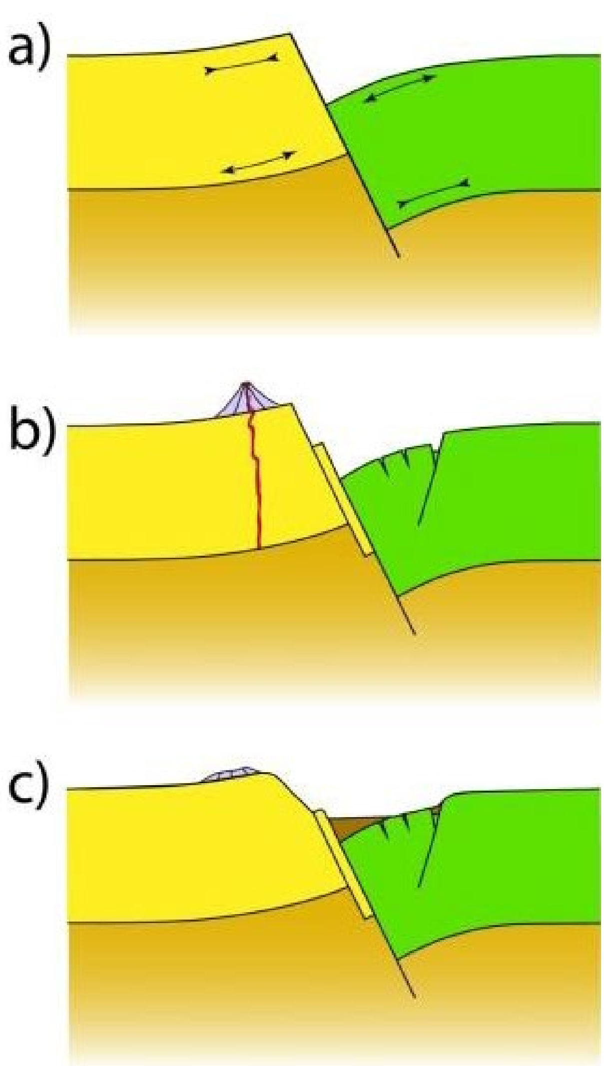

Figure 3. Diagrammatic sections showing normal faulting resulting from extension in the Rift setting. (a) Simplified diagram, with a single fault, demonstrating the asymmetric nature of displacement associated with faulting. The footwall, shown in green, is put into compression at depth and extension at the surface (shown by the arrows). The hanging wall, in yellow, shows compression at the surface, and extension at depth. (b) This shows that the main fault may be a series of faults – indicated by the extra slab. Also shown is the antithetic fault in the footwall and the small clean faults created by extension at the surface of the footwall. Extension of the hanging wall at depth allows the entry of magma, which is then able to force its way to the surface to create volcanoes in the hanging wall, counterintuitively, given that the surface is under compression. Mt. Kenya and Mt. Kilimanjaro are examples of volcanoes formed in this way on the hanging wall of the Rift. (c) This shows the effects of erosion from the Rift wall and accumulation of sediments in the trough formed at the base of the main fault. This gives the impression of a flat surface on the Rift floor and hence contributes to the mistaken belief that a whole block has dropped down.

offset from the main rift axis, such as Mt. Kenya and Mt. Kilimanjaro. They are probably the result of extension at depth that creates tensional features aiding the rise of magma (Ellis and King 1991) (Figure 3b). In time, the effects of erosion smooth the visible part of the main fault making it a less obvious feature than some of the much smaller (antithetic) faults in the hanging wall. Sediments derived from slope erosion of the uplifted rift flanks accumulate on the rift floor where they can obscure the original morphology of the fault scarp in the valley bottom (Figure 3c).

The East African Rift

The East African Rift extends for about 1200km, from Ethiopia in the north to Mozambique and the borders of South Africa in the south, and is a composite structure with different segments of clearly identifiable rift broadly aligned on a north–south axis but with some branching and divergence (Figure 4, Figure 5). Rifting is thought to have been initiated with the massive flood-basalt eruptions that occurred in Ethiopia at 30 Ma. Propagation of the Rift appears to have proceeded generally from north to south exploiting weaknesses between cratonic blocks, splitting into an Eastern Rift passing south through Kenya and Tanzania, and a Western Rift curving around the border of the Democratic Republic of the Congo, before re-joining the Eastern Rift to propagate further south through Malawi. Further south again, the Rift begins to break up and spread out with structures developing in different directions towards Mozambique, the Zambesi and the Okavango Delta. The asymmetry associated with local rifting is clearly visible in a series of cross-sections taken at different points along the Rift (Figure 4).

Geology

Rock types include cratonic basement rocks, volcanic lavas such as basalt and trachyte, sedimentary and metamorphic rocks of various types, and Quaternary sediments (Figure 5b). Quaternary sediments are patchy and of limited extent, being confined to lake basins and valley bottoms. Volcanic rocks, on the other hand, are more common than in most other rifts, and are especially prominent in Ethiopia, Kenya and Tanzania.

Altitude and drainage

There are substantial variations of altitude of the rift floor, ranging from close to sea-level to nearly 2000m (Figure 5a). These differences of elevation are related to uplift from mantle heating in some regions associated with plumes. Considerable differences also occur at a more local scale within some parts of the Rift valley,

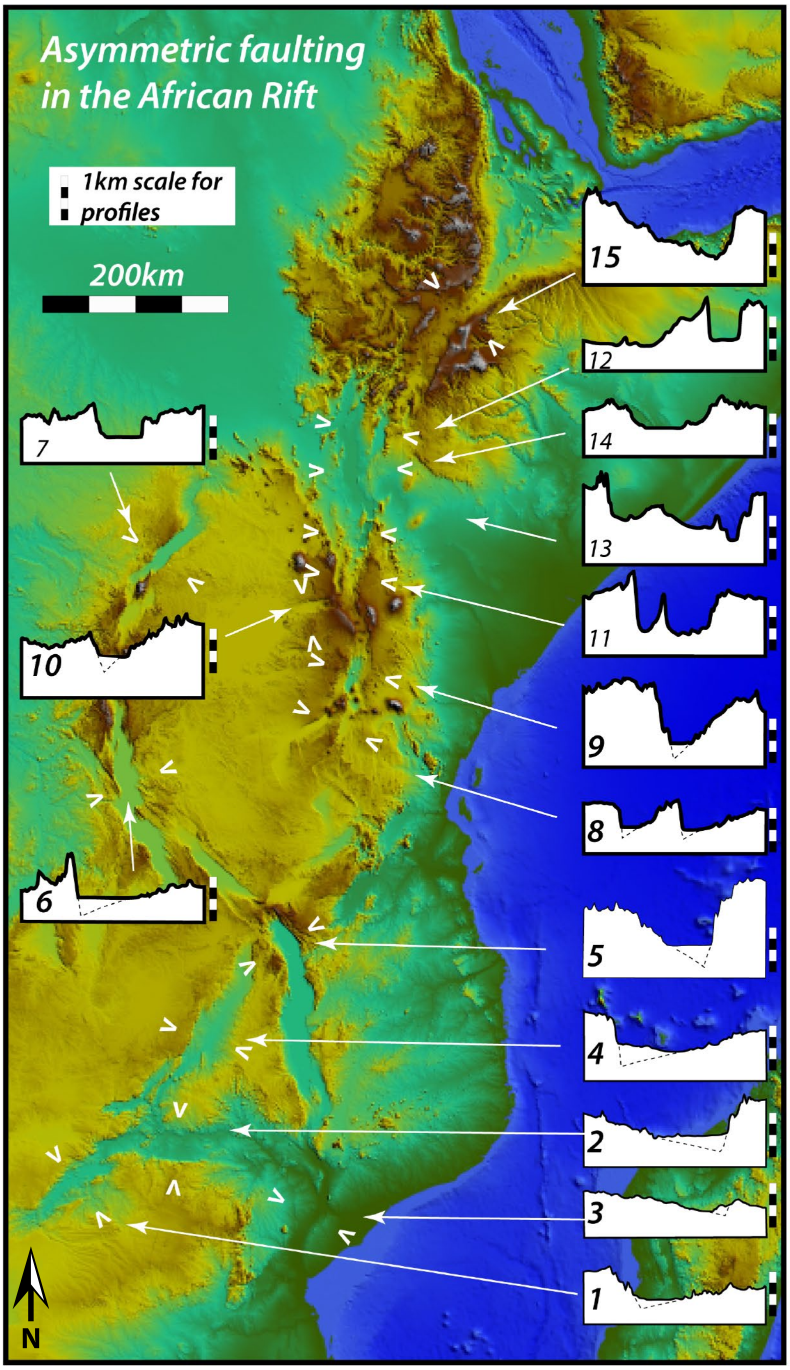

Figure 4. An overview of the main sectors of the East African rift, showing a series of cross-sectional profiles. Note that the main fault and the hanging wall may be on either the left side or the right side of a given rift segment.

with differences in elevation of 1000m or more between the Rift floor and the crest of the major fault scarps, resulting from progressive uplift of the rift flanks by fault motions. As a result, there are considerable variations in climatic conditions, both regionally and locally, with semi-arid or desert conditions at low altitude, particularly towards the lower latitudes of the northern Rift, and higher rainfall and forest cover on the highest elevations (much of which has been cleared for agricultural purposes in recent times). The relative extent of these different climate zones has varied according to global climate changes, especially changes in rainfall patterns.

Some of the depressions created by rifting are filled with lakes, the largest being Lake Turkana in northern Kenya, Lake Tanganyika in the Western Rift and Lake Malawi in the south (Figure 5a). The Turkana basin is very deep (>3km) but filled with sediment brought in from Ethiopia by the Omo River. Lake Turkana has at times been connected to the Indian Ocean and may in the past have drained west into the River Nile. Lake Victoria is a relatively shallow lake in a depression formed between the uplifted flanks of the Western and Eastern Rifts. Other lakes contained within the rift are fed by internal drainage from the surrounding slopes, with relatively thin sediment cover on the valley floor and in lake bottoms.

Lake levels of all Rift lakes have varied significantly during the Plio-Pleistocene, responding both to global changes in climate, particularly precipitation falling on the major catchments such as the Ethiopian highlands, and to tectonic movements.

Vegetation and relief

For much of the Rift, savannah (grassland and scrub with some trees) is the main vegetation type, but conditions vary locally between semi-arid desert and forest, largely as a function of altitude and local climate conditions (Figure 5c). The well-known savannah hypothesis, that reduction of forest cover and the need to seek food on the ground was the primary agent selecting for a bipedal gait has now been largely discredited, mainly because the earliest anatomical evidence of habitual bipedalism occurred in hominins such as the Australopithecines, who were still semi-arboreal and living in environments with extensive tree cover. However, the characterisation of the African Rift as a savannah environment is misleading in another way. Savannah is a type of vegetation and usually associated with an image of flat or gently rolling and smooth topography. In reality it is associated with a wide range of topographic conditions and land forms, ranging from basaltic lavas to heavily weathered basement and metamorphic rocks, and from flat

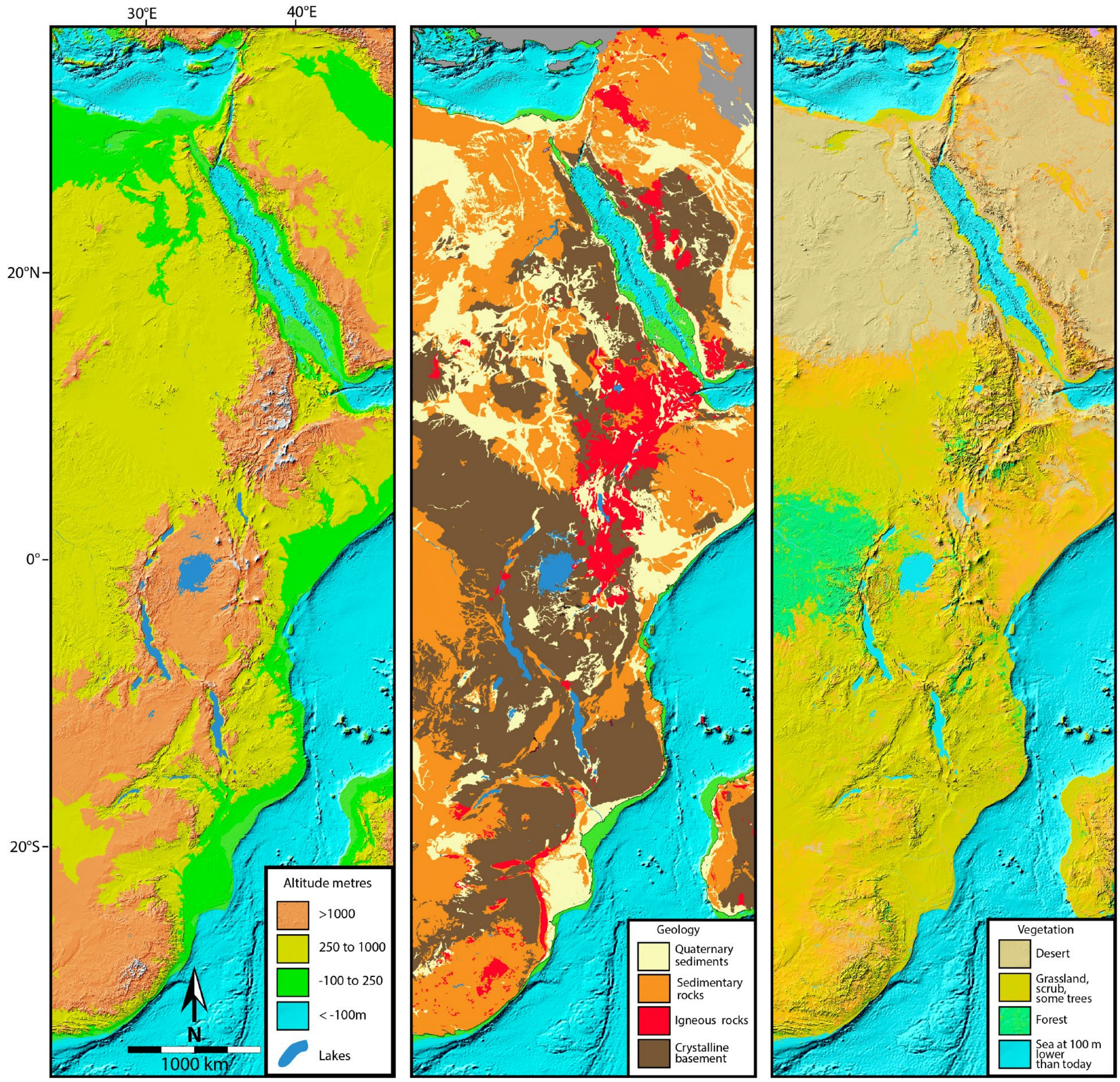

Figure 5. Simplified maps of the East African Rift and its northward extension to the Red Sea and the Levant. 5a, geology; 5b, altitude; 5c vegetation. Note that the coastline is placed at the –100m bathymetric contour. The amount of land between the modern coastline and the –100m contour is shown in Figure 5a by the dark green shading

valley bottoms to steep slopes, fault scarps and rough topography. Concentration on the term savannah has therefore tended to obscure the immense variations of topography and topographic roughness that occur within the savannah vegetation zone and how this may have influenced the evolution of the human body form (Reynolds et al. 2011; Winder et al. 2013).

The Red Sea and the Levant

Structures to the north of Ethiopia are often considered to be an extension of the African Rift. This is true for the 'Proto Red Sea', which extended from the Ethiopian rift into the Gulf of Suez during the Oligocene. However, at about 30Ma the Arabian Peninsula started to move to the north resulting in the formation of the Gulf of Aden, extension in the Afar region of Ethiopia and the widening of the 'Proto Red Sea'. The original rift flanks formed land escarpments on either side of the Red Sea, with a more pronounced escarpment on the Arabian side (Figure 6).

The Gulf of Aden is typical of what may be expected in the early stages of the formation of an ocean, with a central spreading ridge associated with basaltic volcanism of mantle origin. The water depths are less than for an ocean over a fully formed ocean-ridge, probably because the basaltic magmas in this region are modified by lighter elements derived from the Ethiopian 'Hot Spot', and are in consequence less dense

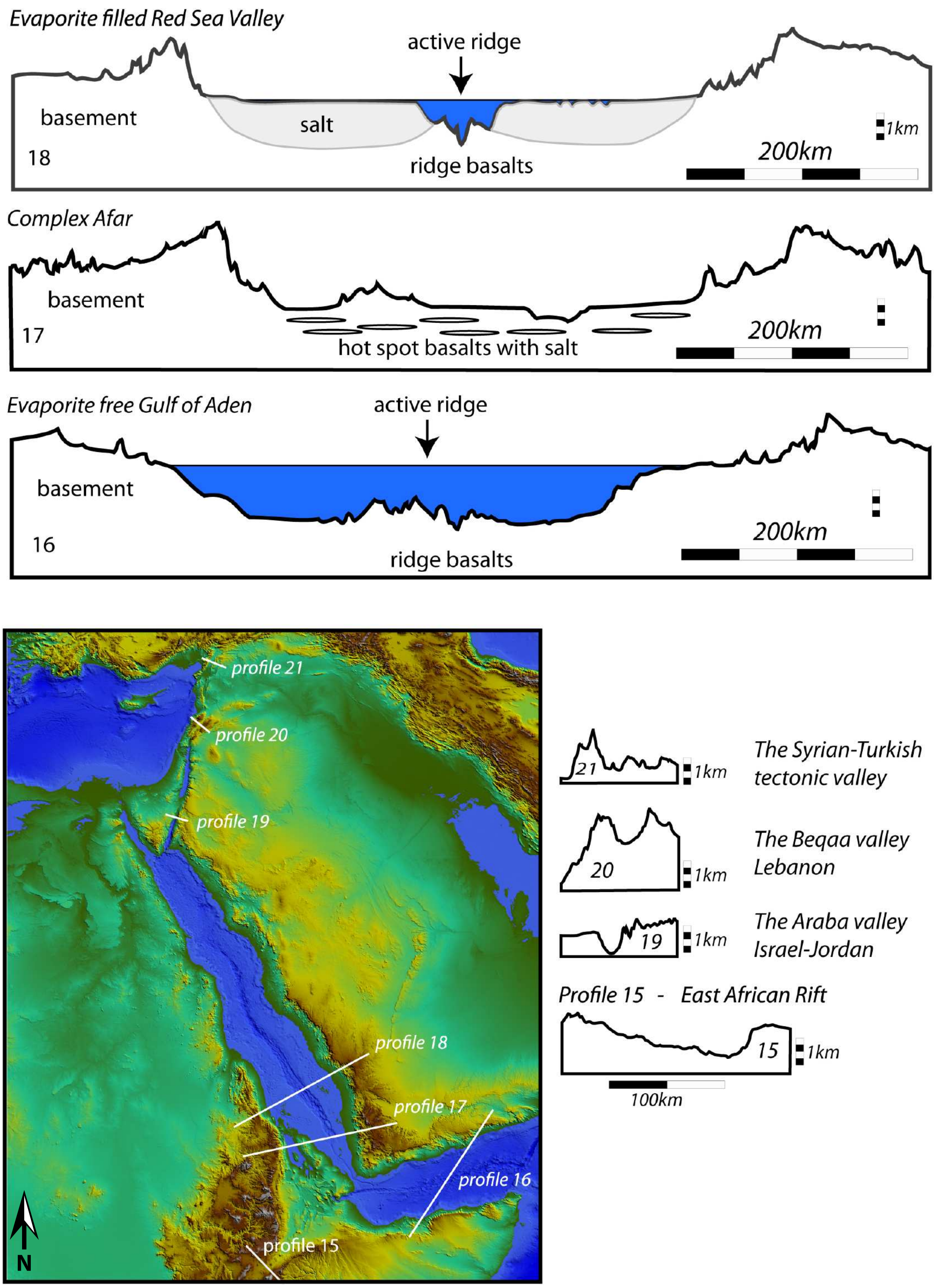

Figure 6. Cross-sectional profiles across the Gulf of Aden, the Red Sea and the Syrio-Jordanian Rift, drawn to the same vertical and horizontal scale as those shown in Figure 4. Profile 15 from the African Rift is shown for comparison. The Gulf of Aden and the Red Sea show a much wider opening than the East African Rift. In the Gulf of Aden a mid-ocean ridge is beginning to form in the centre (profile 16). In the Afar depression, the basalt from the Afar Hot Spot is mixed with patches of salt, producing material that is less dense than the ridge basalts in the Gulf and the Red Sea, putting most of the floor of the Afar rift above sea level (profile 17). The Red Sea is filled with massive deposits of salt (evaporite) formed during the Miocene when the basin was closed off from the oceans, but with a bit of central ridge poking through (profile 18). The main activity is near the centre of these depressions with less activity on the sides. The Levantine profiles show a much narrower opening, resulting from strike-slip movement with some extension. There is very little normal faulting, the main exception being the Haifa fault in Israel, which is not in the Rift zone proper.

than the basalts extruded from other mid-ocean ridges. Similarly, the basalt-dominated Afar is within the Hot Spot region and is above sea level.

In the Red Sea, water depths are even shallower than in the Gulf of Aden, except in the deep axial trough, most probably due to the filling of the basin with very large thicknesses of Miocene-age salt (Figure 6).

Today's Arabian topography and geology have been shaped by the opening of the Gulf of Aden and the Red Sea and the progressive separation of the Arabian plate from the African and Indian Plates. The Arabian Plate is continuing to move away from Africa, to slide along the large transform faults that define its western and eastern boundaries and to collide with the Eurasian continent to the north. The whole process has been associated with episodes of deformation and magmatism, with uplift of the rift shoulders, especially on the Arabian side. This deformation, with a possible contribution from the Afar hotspot, has created the major mountain chains observed along the coasts of the Red Sea and the Gulf of Aden, rising to about 3000m in the southwest corner of the Arabian Peninsula.

The Syrio-Jordanian valley produces very different profiles from the Red Sea, the Gulf of Aden, or any of the profiles in the African Rift (Figure 6, profiles 19, 20 and 21). The main valley is much narrower with a U-shape and little evidence for bounding normal faults considered characteristic of true rift valleys (Devès et al. 2011). This reflects the major tectonic processes at work in this region, which are dominated by strike-slip motion. Earthquake activity and fragmented oblique slip faulting are present along with extensive areas of volcanic activity, generating similar combinations of rough topography and lake-basins to those found in the African Rift.

Methods of landscape reconstruction

In our reconstructions, we place particular emphasis on topographic features such as faults formed by repeating earthquakes that form low barriers or cliffs, and on volcanic lava flows which can act in a similar way as impediments to animal movement. We do so on the assumption that large mammals are a major source of food and that minor barriers can create predictable pathways of animal movements and natural constrictions that facilitate interception and capture. These features can also act as traps for sediment and water, creating lake basins or spring lines. Faulting and volcanic activity are dynamic and episodic processes that can change the landscape setting. In some cases, these changes can be beneficial to human subsistence activity, rejuvenating and sustaining advantageous topographic features such as barriers, lakes and springs, and renewing soil nutrients through surface disturbance and erosion or addition of new material. In other cases, ongoing change can destroy previously advantageous conditions or obscure earlier landscapes and their archaeological remains, for example through the blanketing effect of extensive lava flows. We therefore pay particular attention to the dates of geological features where these are available and to the modelling of fault motions to re-set parts of the landscape to an earlier configuration.

We also pay particular attention to the edaphic properties of different rock and soil formations, namely the presence of minerals and trace elements important to animal health and especially to the growth of young animals. In regions of variable bedrock geology and geomorphological processes, these edaphic properties can be highly variable in their geographical distribution. Both ecological studies, for example of wildebeest migrations (Murray 1995), and our conversations with Masai herders show that these factors play an important role in animal migrations today and that the animals move towards advantageous conditions at the appropriate season without the need for human encouragement or intervention. Also, systematic measurements of the nutrient properties of soils and plants in the African context (Kübler et al. 2015, 2016) show a close relationship between their edaphic properties and the bedrock geology, allowing the use of bedrock geology as a proxy for mapping edaphic properties over larger areas. More general field observations and anecdotal evidence in other parts of the Near East and the Mediterranean suggest that a similar relationship holds elsewhere (Devès et al. 2014; Sturdy et al. 1997; Sturdy and Webley 1998). Finally, in a digital age, we make full use of satellite imagery, digital elevation models and computer software to map geologically and topographically significant variables and to construct visual images. This greatly facilitates our ability to place local features in the immediate vicinity of sites into their wider regional context.

The Kenyan Rift

Here we concentrate on just two sites, Kariandusi and Olorgesailie, in the central and southern Kenyan Rift, although we note that there are concentrations of sites with archaeological or fossil material to the north, in the Baringo and Turkana basins, and to the south across the Tanzanian border at Olduvai Gorge as well as sites such as Kilombe in the central Rift (Figure 7). We summarise key features of their surrounding regions, drawing on more detailed analyses in Kübler et al. (2015, 2016) which provide supporting detail.

Kariandusi

This site consists of two closely adjacent concentrations of stone tools including flakes and numerous Acheulean bifaces, the first investigated by Louis Leakey between

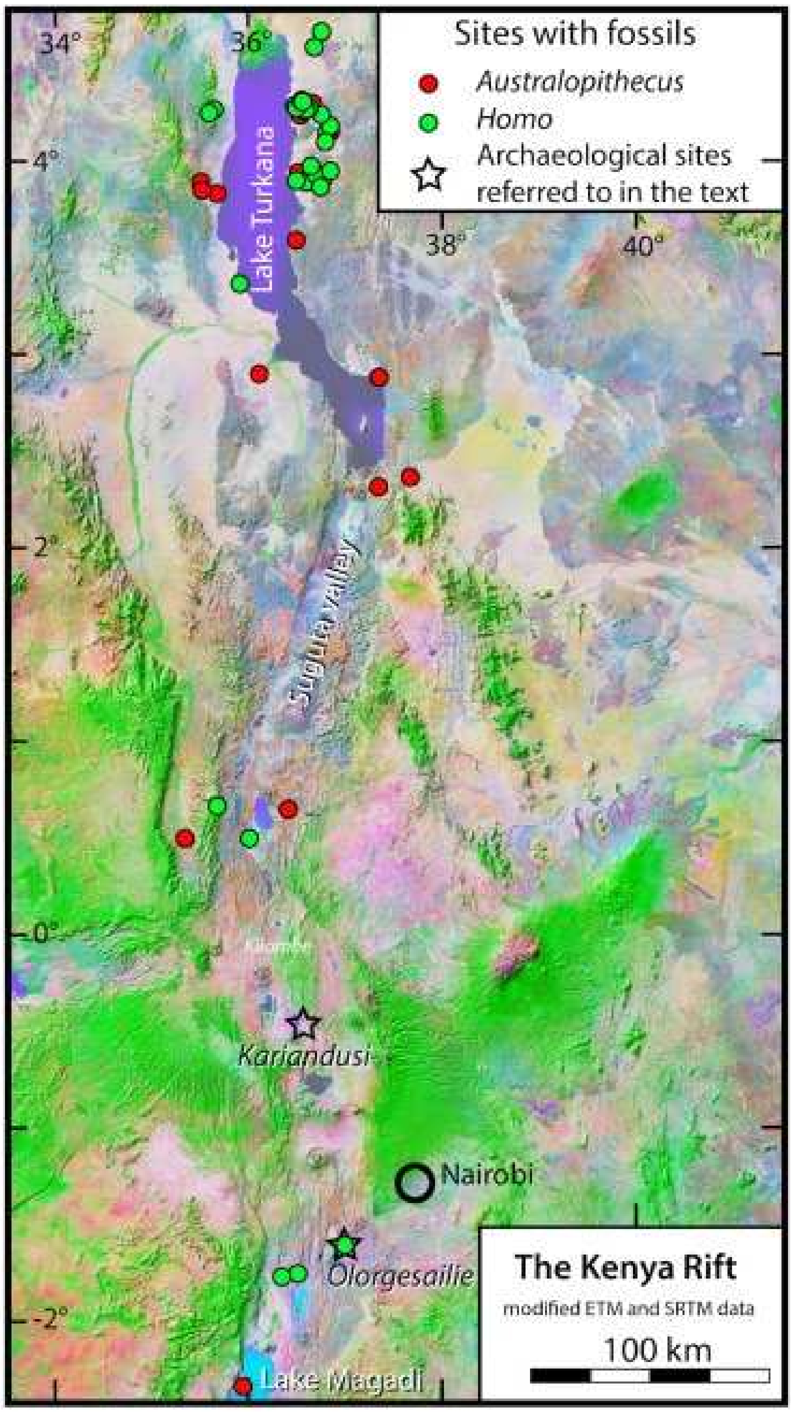

Figure 7. General location map of sites in the central and southern Kenyan Rift in relation to topography, showing position of Olorgesailie and Kariandusi. Other sites with hominin fossils are also shown. Data from the Paleobiology database (https://paleobiodb.org). After Kübler et al. 2016. The image 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.

1928 and 1931, the second by John Gowlett in 1974 (Gowlett & Crompton 1994; Leakey 1931; Shipton 2011) (Figure 2). The material was originally deposited on the banks of a small tributary of the Kariandusi River at a time when it drained into an expanded Lake Elmentaita that filled a large part of the rift basin (Figure 8). Faunal remains are rare because of preservation conditions and consist only of some equid teeth. The material is bracketed between 0.73 and 0.98Ma and this corresponds to a period of high lake level some 80–90m above the present rift floor.

The region is a typical asymmetric rift with uplifted flanks reaching to 3000 to 4000m and a rift floor at about 1800m. Rifting is aligned on a NNW–SSE axis and started in the late Miocene, between 12 and 6Ma, with further spells of activity between 5.5 and 2.6Ma, when the 30km-wide Kinangop Plateau and the 40km-wide inner rift depression were formed. The inner rift was subsequently covered by trachytic, basaltic and rhyolitic lavas and tuffs and continues to be cut by normal faulting around a central axis. Thus, the major faults that define the topography of the flank region around the Kinangop Plateau were already in place when the site was occupied. However, the younger structures of the inner rift and much of the volcanic activity visible today post-date the occupation of the Kariandusi site and limit what can be said about the landscape features and edaphics of these areas at the time when the site was in use (Figure 9).

The other major change in physical conditions is variations in lake level, with evidence of at least three episodes of high lake levels associated with wetter climate over the past one million years: at ~1ma, 150–60ka, and 15–4ka (Bergner et al. 2009; Trauth et al. 2005), the first episode coinciding closely with the Acheulean occupation at Kariandusi.

The tectonic history has created a complex topography with extensive upland basins such as the Kinangop plateau bounded by faults that form steep cliffs and limited points of access for large mammals (Figure 8). Edaphic properties are also variable in their distribution, with the best conditions on some of the volcanics and on the lake sediments of the rift floor. 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

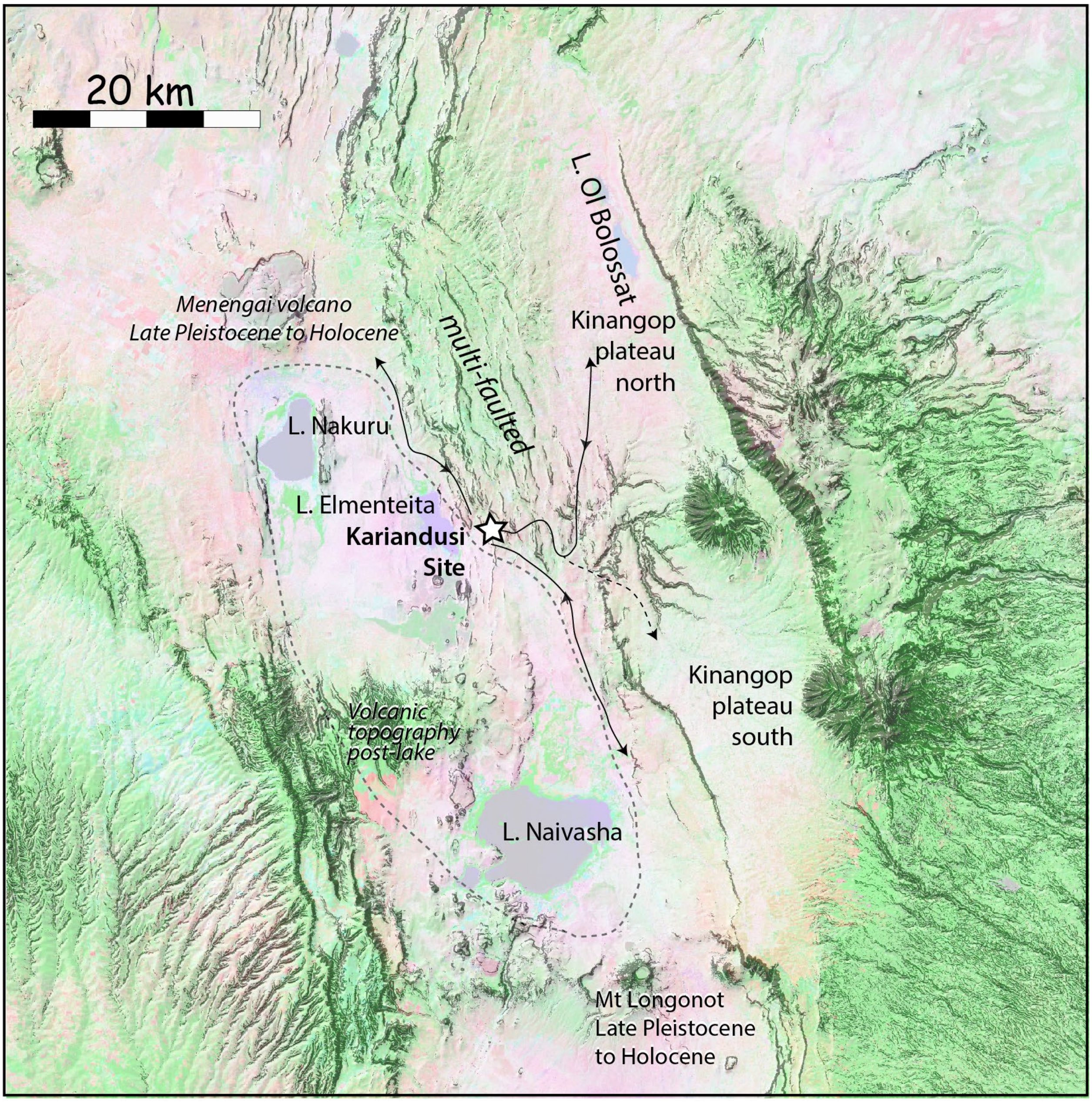

Figure 8. Morphology of the region including Lakes Nakuru, Elmenteita, Naivasha and Bolossat. Slopes greater than 15° are indicated by grey shading, and would have restricted movements of large animals to well defined areas and restricted pathways that converge on the Kariandusi location. Lakes Nakuru, Elmenteita and possibly Naivasha were joined to form a single lake, shown by the blue area enclosed by a dashed line, during periods of high lake level. Some earlier features (that pre-date the Kariandusi site) have been masked by later volcanism between Elmenteita and Naivasha and around Menengai volcano and Mt. Longonot (see Figure 9)

is enclosed by steep faults and easily accessible to herds of large animals only from the rift floor to the west and northwest (Figure 10). 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 (Figure 11).

Freshwater, raw material for making stone artefacts and good viewpoints for tracking animal movements were all locally available throughout the Pleistocene. However, the 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 target large mammals during their seasonal migrations.

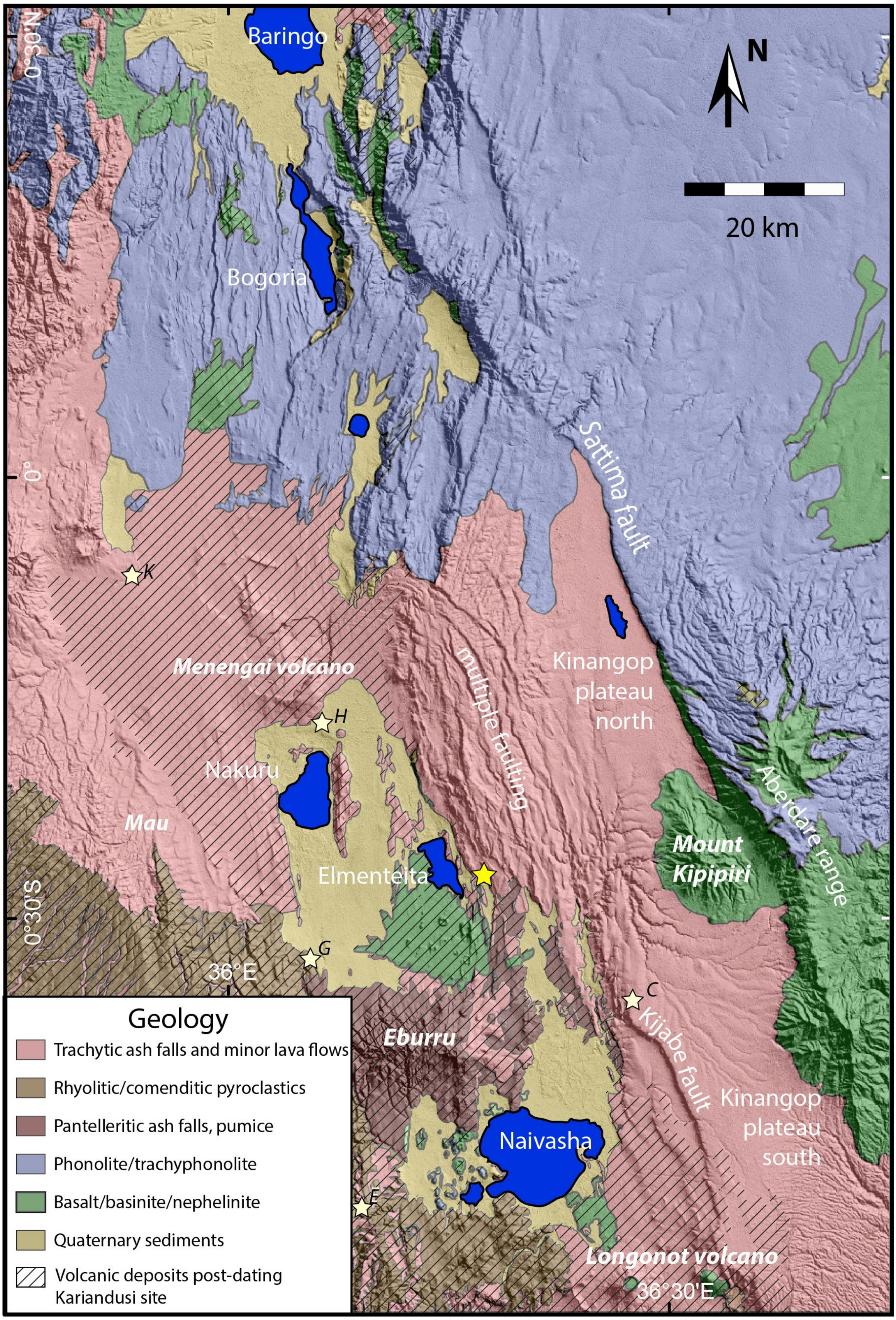

Figure 9. Geological map of the rift and flanks from Lake Naivasha to Lake Baringo. Kariandusi is indicated by a yellow star. Cross hatching indicates volcanic deposits c. 700 ka – postdating the Kariandusi site. Small stars indicate other sites. C: Cartwright's site, E: Ekapune Ya Munto site, G: Gamble's site, H: Hyrax Hill, K = Kilombe site (After Kübler et al. 2016).

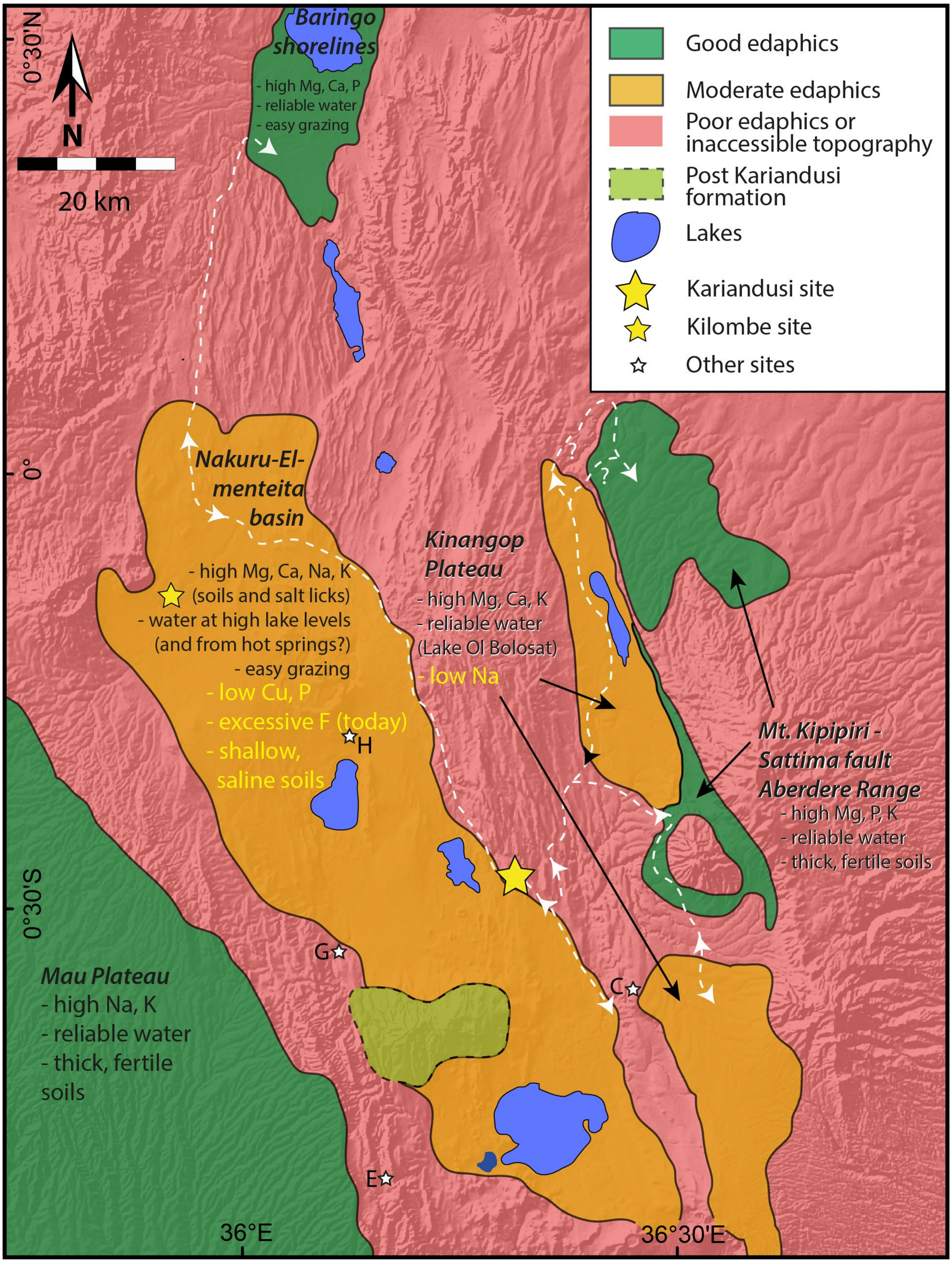

Figure 10. Map of edaphic variation. Routes for movements of large mammals on the eastern side of the rift are shown. At very high lake levels, large animals would have to pass the Kariandusi site. After Kübler et al. 2016.

Olorgesailie

Olorgesailie lies in the centre of a 60km-wide rift floor adjacent to a palaeo-lake (Figure 1). Numerous Acheulean artefacts, fossil mammals including elephant, hippo, giant baboon, equids and bovids with evidence of carcase butchery, and part of a *Homo* skull are preserved in sediments spanning ~1.2 to <0.5Ma (Behrensmeyer et al. 2002; Isaac 1977; Potts 1989; Potts et al. 2004).

Trachyte flows laid down between 0.7 and 1.4Ma are the dominant rock type, together with Plio-Pleistocene basalts and tuffs (1.4–2.7Ma) associated with the volcanoes of Mt. Olorgesailie and Mt Esayeti. There are also small areas of sediment carried from the rift flanks, but uplift and back tilting prevent the entry of sediments from outside the main rift. There are many sub-parallel fault scarps, and these are nearly vertical in places, especially on the trachyte, which is particularly resistant to erosion, creating a complex topography that would have constrained east–west movements of large animals and humans (Figure 12).

Ongoing faulting and the partial collapse of the Olorgesailie caldera have created a modern landscape that has clearly changed during the past million years (Figure 13a). In particular tectonic motion on two north–south trending normal faults has resulted in tilting of the Legemunge lake beds that contain the archaeological material. Also, partial collapse of the Olorgesailie caldera has resulted in draining of the palaeolake. The geometry of the landscape past and present is defined by its tectonic structure, allowing reconstruction of palaeo-morphology by modelling fault displacements. By removing the effects of fault motion and making corrections for erosion and deposition of sediment, a palaeo-DEM of the landscape can be created as it would have appeared during the period when hominins were using the Olorgesailie locality (Figure 13b).

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). The trachytes, which dominate the region, have poor-quality soils; richer soils develop only on some other volcanic rocks and on sediments brought by rivers from the north and east. This is supported by 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. Routes of

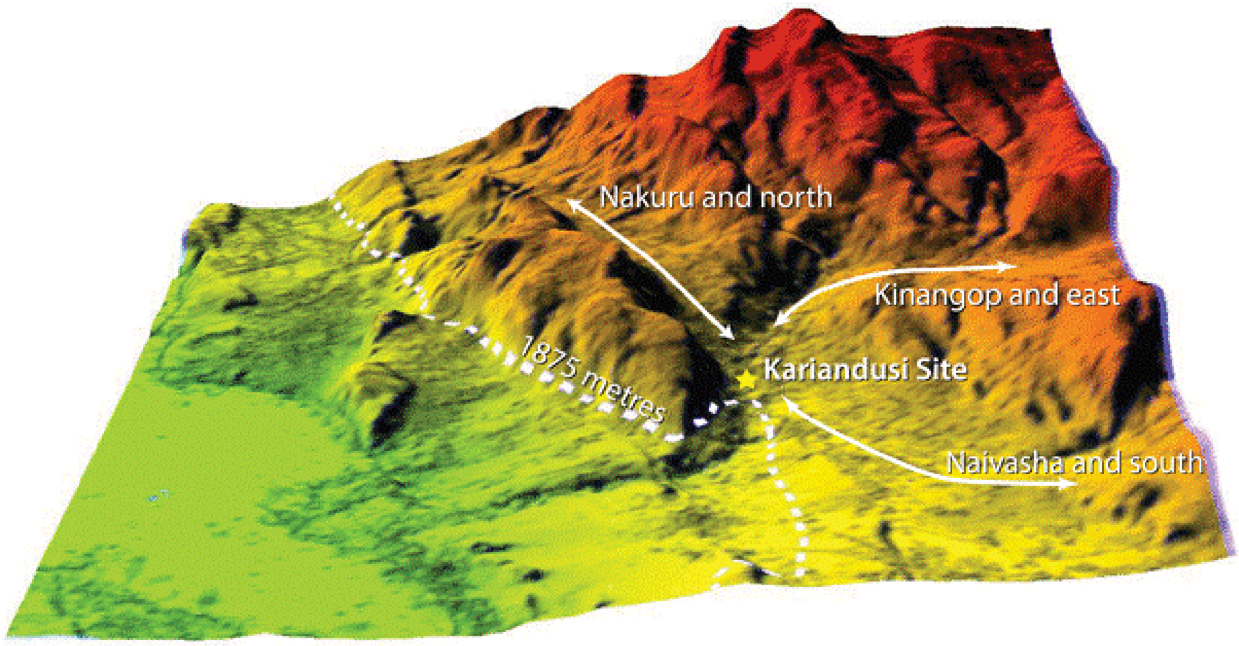

Figure 11. Oblique 3D view looking north showing the routes for large animals when the level of Lake Elmenteita is high. Lake levels of greater than 1875m completely block access along the lake-shore. For lower lake levels, movements along the lake shore would have been straightforward and the lake sediments would also have provided good grazing or browsing. At high lake-levels, animals moving to or from Nakuru and the north would have to pass along a valley bounded by fault scarps and cliffs. Kariandusi is ideally located to intercept animals crossing the Kariandusi River. The DEM used for this figure is a product of two World View 2 scenes processed with "Stereo Pipeline" software. Data made available through collaboration with Ryan Gold, USGS. After Kübler et al. 2016.

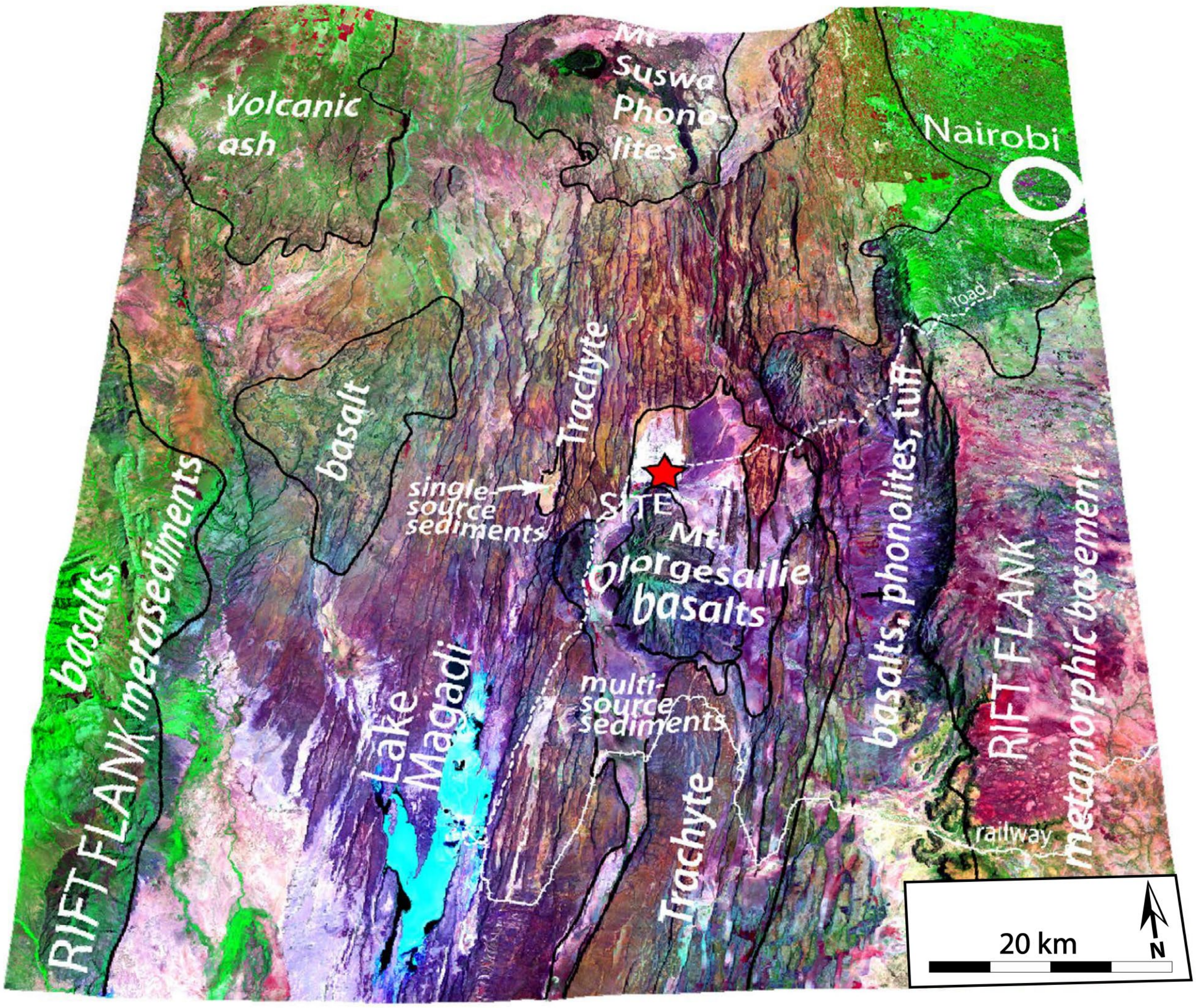

Figure 12. Oblique 3D view of the South Kenya Rift centred on the Olorgesailie hominin site, showing faults and other geological features. The region is heterogeneous with some areas well-vegetated and others with thin vegetation. Thin vegetation can result from soils that do not favour plant growth, 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.

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 (Figure 13b). 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 constraints that favoured ambush hunting disappeared and occupation ceased.

The Southern Levant

Although the Jordanian Rift is a strike-slip structure rather than a rift, it nevertheless has many similar features to the East African Rift, with high levels of earthquake activity and faulting (Devès et al., 2011), 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 a complex topography with numerous cliffs and deep, steep-sided valleys. The geology is dominated by limestone and basalt, which offer attractive environments for herbivores including

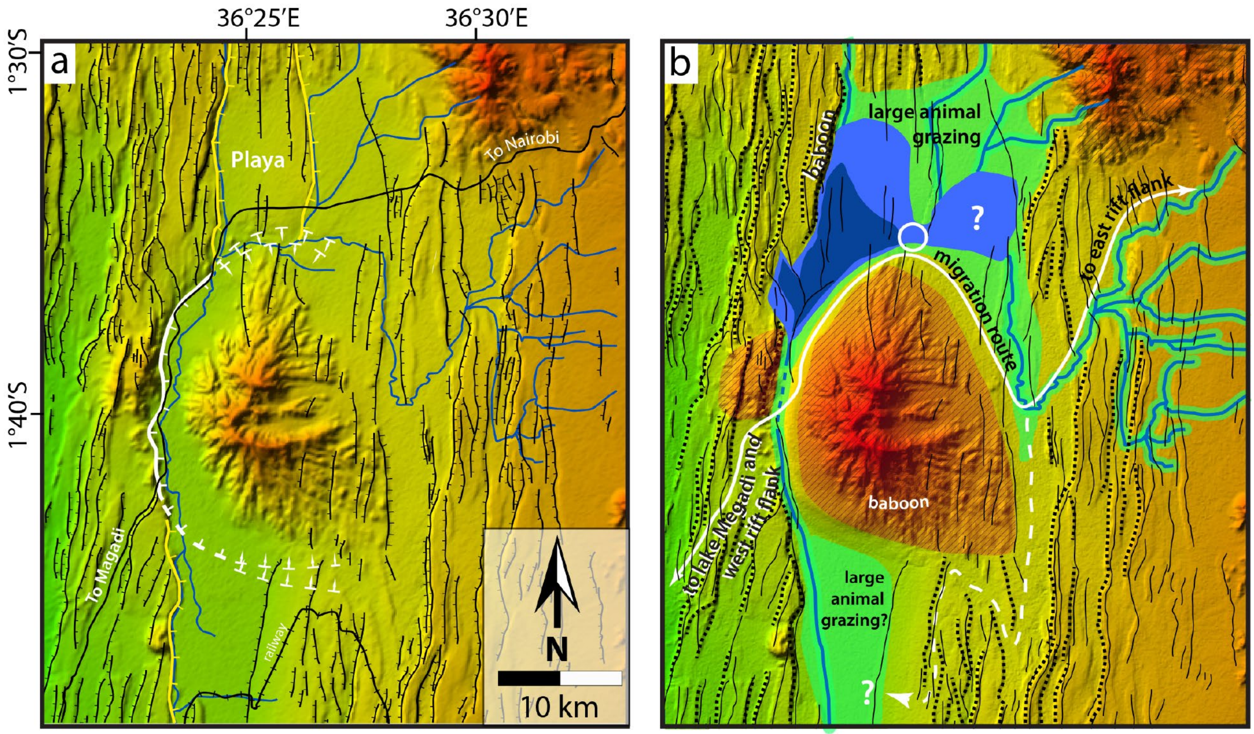

Figure 13. Digital elevation models (DEMs) of the Olorgesailie region. (a) present day topography. Prominent fault scarps are indicated in black and those indicated in yellow and white are used in the modelling of earlier topography in (b). The yellow faults are young faults, and post-date the lake and 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 and colleagues (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. 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)

good edaphic properties (Figure 14). It is also a region with a long history of archaeological and geological investigation and many Palaeolithic sites dating back to over 1 Ma (Enzel and Bar-Yosef 2017)

Gesher Banat Ya'aqov

One of the major sites of the Lower Palaeolithic in the region is the Acheulean site of Gesher Banot Ya'acov with thousands of stone artefacts including Acheulean bifaces, smaller flakes designed for hafting, evidence for the use of fire and repeated use over a period of about 150,000 years between about 0.7 and 0.85Ma (Alperson-Afil and Goren-Inbar 2016; Goren-Inbar et al. 2000; Rabinowich et al. 2012). 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, and evidence of plant foods. Animals exploited include elephants, hippo, rhino, gazelle, horse and bovids, with evidence of carcase butchery, and fish from the lake.

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 (Figure 14, Figure 15). 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 rough topography and steep slopes. Like the African sites already discussed, the location of the site has a number of advantageous features including proximity to freshwater, volcanic material for artefact manufacture, and, in the case of Gesher Banot Ya'acov, 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 support of the palaeoeconomy, 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, is a prime factor in the importance of this site (Devès et al. 2014: 152–153).

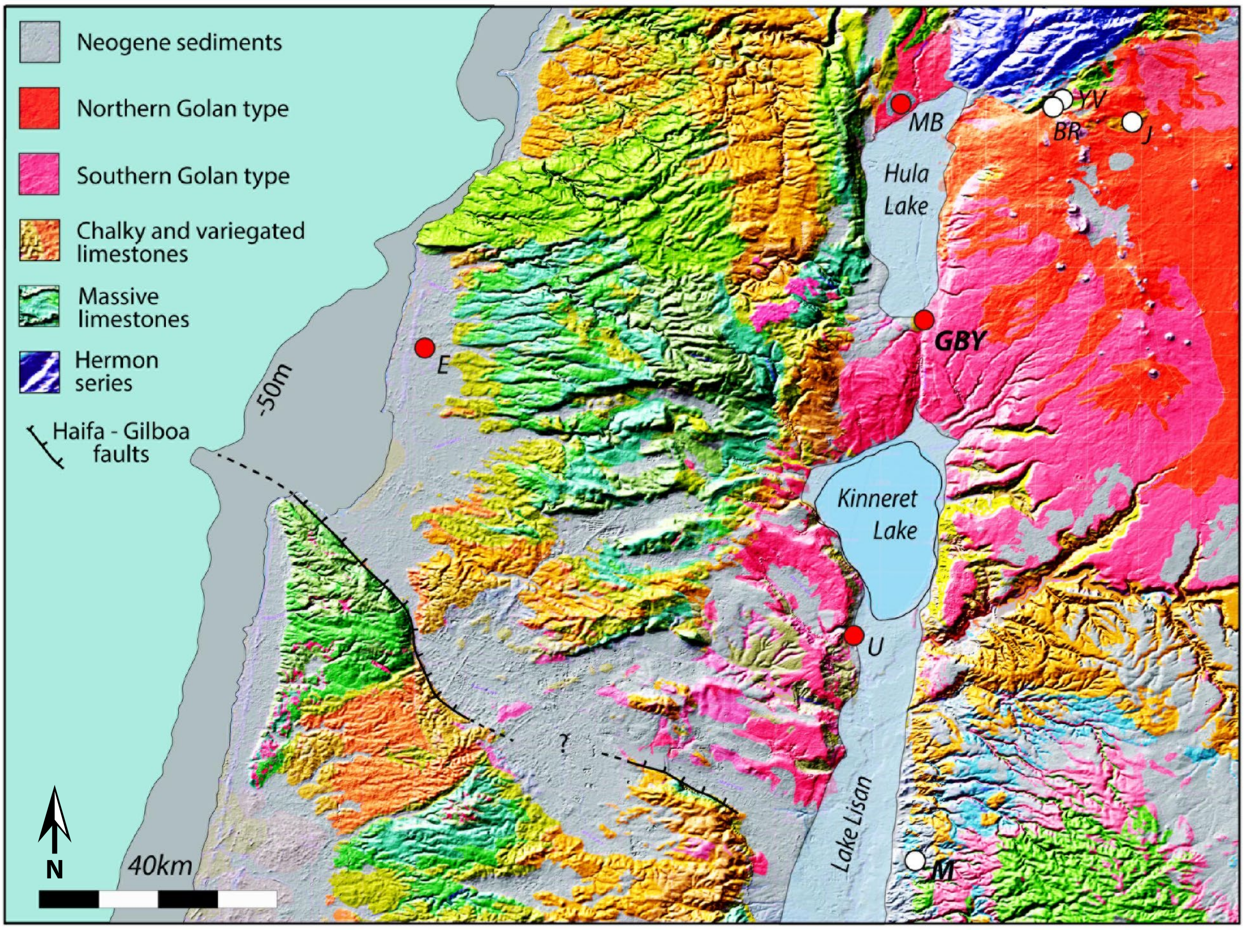

Figure 14. Map of simplified geology and topographic roughness in the central Jordanian Rift, showing the position of the palaeo-Lisan Lake and Lake Hula at their maximum extent. Red circles indicate Acheulean sites with fauna, white circles Acheulean sites without fauna. Steep slopes and rough topography render large areas inaccessible to large mammals such as elephants, with the smoothest terrain on the Golan Heights to the top right and on the Neogene sediments towards the coast. The Golan Heights also have the largest extent of edaphically rich conditions. Gesher Banat Ya'acov (GBY) is located on the only feasible pathway for large mammals moving between summer grazing territories on the Golan Heights and winter territories on the coast. Moreover the site is located on a narrow neck of land ideal for trapping large mammals as well as providing access to the resources of the nearby lake (see Figure 15). After Devès et al. 2014.

Conclusion

We draw two main conclusions from the above observations, the first is about the adaptive strategies implied by our landscape approach, the second is about our methods of landscape reconstruction in tectonically active environments and their feasibility and wider applicability.

Regarding adaptive strategies, all three sites that we have examined have a number of features in common. In the first place they are all sites which have accumulated large assemblages of stone artefacts, numbering thousands of specimens, with large cutting tools of the Acheulean tradition including bifaces and cleavers. Two of the three sites (Olorgesailie and Gesher Banot Ya'acov) also have large assemblages of large-mammal bones with evidence of on-site butchery of large animals such as elephants, hippos, bovids and equids, while the third site hints at similar activity but is largely lacking in evidence apparently because of poor conditions of bone preservation. They are all 'large' sites in the sense that the quantities of material indicate either intensive activity in one place, or repeated visits over a long period, or most likely both. In relation to their wider landscape setting they are all located on corridors of movement that represent almost the only feasible pathway of travel for large mammals moving between different feeding territories. In relation to their immediate surroundings they are all located close to natural topographic barriers that would have greatly facilitated the trapping and capture of large and dangerous animals.

They are also all in lake-edge settings that would have provided abundant freshwater, perhaps an additional attractor for large mammals, and potential additional food supplies such as fish (with certain evidence of

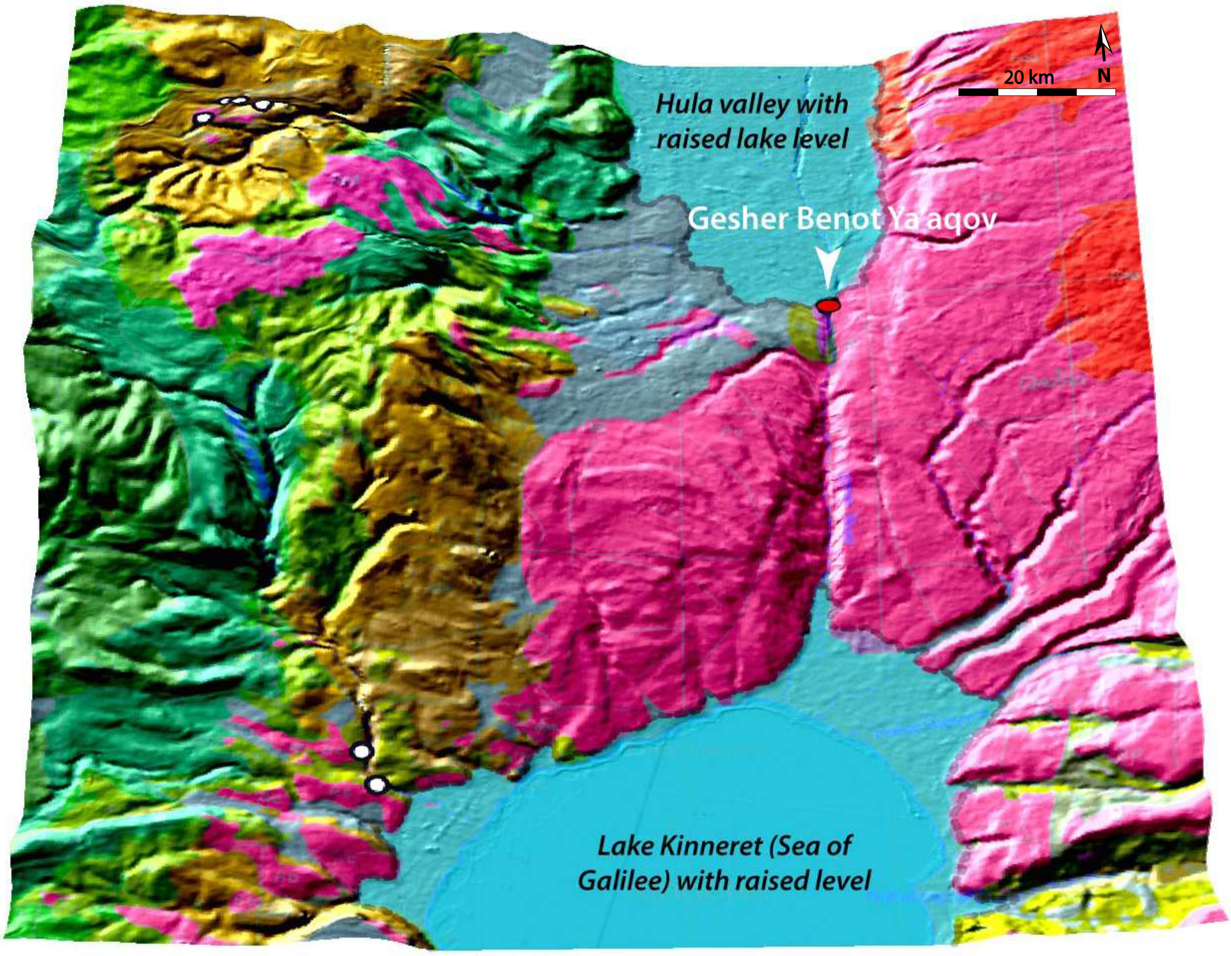

Figure 15. Oblique 3D view of the region around Gesher Banat Ya'aqov in relation to geology and topography at the time of its occupation. The image is based on etm+ legacy data. Topography from SRTM v4.1 data with a vertical exaggeration of ~8. Colour coding of geology as in Figure 14. Note the restricted 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.

their exploitation at Gesher Banot Ya'acov). Supplies of water and raw materials for stone tool manufacture, though offering added attractions, are widely available elsewhere. They do not in themselves uniquely determine why the sites we have discussed are located where they are or why they attracted so much activity over long periods. It is the added factor of their position in relation to the local and regional topography and the likely pattern of large-mammal movements that is significant. We infer from these features that their occupants were using the topography as an aid to ambush hunting.

Kariandusi is of particular interest in relation to the other sites, because it has the shortest time-depth of occupation, and one that appears to have coincided with a short-lived period of high lake level. Since the lake shore at its highest level was essential to creating the funnel that compelled animals to move through the Kariandusi trap, we conclude that the site was not viable for regular visitation before or after that time because large mammals were able easily to bypass the Kariandusi location when lake level was lower. We recognize that other hypotheses could be advanced in this case, for example that Acheulean occupation in the Central Rift was only possible during wet climatic episodes, hence the association with high lake levels, or that proximity to the lake shore was important for other reasons such as potable water or fish. However, we reject the climatic hypothesis as implausible (the large mammal community has persisted in the region through periods of low lake level, as today). We also reject the hypothesis of proximity to lake resources as an insufficient factor for reasons explained above.

We conclude that the use of topography to ambush large mammals was a strategy widely practised by early *Homo* populations making Acheulean tools from at least 1.2Ma onwards, and one that contributed to their successful dispersal within and beyond Africa.

Regarding our methods of landscape reconstruction, we note that despite ongoing tectonic and volcanic activity, we have been able to show that many details of topography and landscape can be reconstructed both locally and over large areas with some confidence as they would have existed many hundreds of thousands of years ago. This includes not only physical features such as cliff lines and lake shores but also the edaphic properties of rocks and soils of importance to animal movements and health. Of course, some features have changed substantially, but they are also those features that are most amenable to mapping and dating: changing lake levels as inferred from lake sediments, volcanic lava flows, and changes in fault scarps as inferred from stratigraphic observations and modelling of fault motions.

Of course, questions arise as to whether the same methods of reconstruction can achieve similar results in other parts of the Rift, or whether similar features of dynamic landscapes are associated with major Acheulean sites elsewhere. We have noted that even within the central Kenyan Rift a large part of the area around the site of Kilombe is covered by volcanic lavas that postdate the occupation of the site and limit what can be said about the local landscape at that time. Other parts of the East African Rift have undergone more dramatic changes.

At Olduvai Gorge, one of the richest source of fossils and archaeological materials in Africa (Ashley et al. 2010), it is clear in general terms that the palaeo-Olduvai lake was created by damming of lava flows from the Ngorongoro volcano and that archaeological deposits are associated with lake-shore settings intimately associated with continued extension and normal faulting on the west side of the Rift together with associated volcanic activity. Variable edaphics in the wider region around Olduvai have probably also played a significant role in animal migrations (Murray 1995). However, subsequent fault motion created a gorge that cut through earlier sediments and destroyed many of the details of the original landscape setting. It is that erosion of course that has facilitated the exposure and discovery of archaeological and fossil material. This in its turn has given rise to the belief that rift tectonics destroys local environments and, through uplift and erosion, provides a sufficient explanation for the burial and subsequent exposure and discovery of early finds. However, our earlier examples demonstrate that this taphonomic factor cannot be universally true and is not a sufficient explanation for the occurrence of large sites.

The Lake Turkana region is another rich source of early finds and is different again. Although, this is one of the deepest parts of the East African Rift system, unlike other deep valleys (e.g. Lake Tanganyika) it is completely filled with Plio-Pleistocene sediments and contains only a shallow lake. On both sides of the lake and in the Omo valley these sediments contain hominin and other animal fossils. The sediments on the east side of the Lake, notably at Koobi Fora, are close to outcrops of basement rocks, basalt lava flows, small faults and river terraces. The relief is modest and at a small scale but includes features that hominins could have exploited for security and perhaps to facilitate access to prey. However, we currently lack the information to reconstruct the earlier environments in sufficient detail to test alternative hypotheses of hominin exploitation. Further north in the Afar, many early sites were associated with the active rift, a highly dynamic setting where a great deal has changed, and we have previously suggested that the original setting of the early sites can only be understood at best by analogy with the area where the present-day Awash River enters the currently active rift (Bailey et al. 2011: 265–267).

South Africa lies outside the Rift zone proper, yet it is another region rich in early finds of human fossils and Oldowan and Acheulean stone assemblages over a wide time range. Here too there is evidence of geological disturbances that create features similar to those we have described in the Rift. In the region of Makapansgat and Taung, minor rifting and faulting has created uplifted areas next to down-dropped wetlands with river drainage cutting into fault scarps to form a steep-sided gorge (Bailey et al. 2011). In the Cradle of Humankind region, faulting cross-cuts older geological structures and disturbed river profiles are evidence of more recent activity. However, fault scarps are absent and the complexity of the topography is mainly the result of differential erosion acting on rocks of differential hardness, resulting from a much longer geological history of uplift and erosion of the South African dome, and rejuvenation and headward erosion of the Limpopo and Crocodile Rivers (Bailey et al. 2011: 268–269).

On the western Arabian escarpment, faulting associated with the active rift mainly takes place deep beneath sea level in the axial trough of the Red Sea. Fault scarps are rare on land and the main expression of tectonics is extensive volcanic lava flows that impede drainage to create fertile local environments and create physical barriers and constraints on animal movements. A further challenge in this region is the effect of Quaternary sea-level change, which has obscured large parts of the landscape likely to have been important to prehistoric hunters and the archaeological evidence of their presence (Bailey et al. 2015).

Tectonically informed research is ongoing in many of these regions, and we believe that the application of the concepts and methods described here will in due course enable reconstruction of more landscapes with the same degree of confidence, producing a richer dataset of comparative examples, more extensive tests of existing hypotheses, and most likely a wider variety of patterns of human land use and site function associated with different sorts of archaeological and fossil deposits, different regions and different stages in the hominin evolutionary trajectory.

Acknowledgements

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