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Dynamic landscapes and human evolution

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ABSTRACT

This paper discusses the relationship between dynamic landscape change resulting from tectonic activity and patterns of human land use and human development. Archaeological studies of human settlement in its wider landscape setting usually focus on climate change as the principal environmental driver of change in the physical features of the landscape, even on the longer time scales of early human evolution. Tectonic processes are usually assumed to operate too slowly to be of any significance except as the source of occasional disruptive events, or at best to have some indirect effect on climate change as a result of long-term regional uplift. Herein, examples are shown from Europe and Africa to illustrate the ways in which changes of significance to human settlement can occur at a range of geographical scales and on time scales that range from lifetimes to tens of millennia. We emphasize that these changes are not always or necessarily destructive in their impact but can also create and sustain attractive conditions for human settlement and that these conditions have exercised powerful selection pressures on human development.

INTRODUCTION

Growth in our understanding of active tectonics and tectonic geomorphology during the past 25 yr has made it clear that tectonic processes happen at a variety of scales relevant to human history. These effects range from an individual earthquake at the shortest end of the spectrum to modifications of regional topography resulting from the cumulative effect of earthquake activity over centuries and millennia, and on a time scale of tens to hundreds or thousands of millennia, to more substantial modifications resulting in the creation of major mountain ranges and rifts. Interest in archaeoseismology naturally focuses on individual earthquakes or volcanic eruptions as the most obviously visible expression of tectonic processes on the human scale, on recent periods of the archaeological record where the effect of earthquakes and volcanoes is most easily visible in terms of its impact on the built environment, and hence on the negative or destructive consequences of such activity. For the earlier periods of prehistory, the consequences of seismic activity rarely register in the archaeological or geoarchaeological record, except as occasional dramatic effects like tsunamis (e.g., Bondevik et al., 1997) or comparable catastrophic events such as major volcanic eruptions (e.g., Ambrose, 1998). Otherwise, reconstructions of regional settlement patterns and land use have tended to proceed on the assumption of an essentially static physical land surface, which changes only as a result of climatically induced variations in erosion, sedimentation, vegetation, and water supply. In this view, tectonics are relegated to the role of an episodic source of disruption or to a time scale of operation considered too large or too far back in time to be of relevance to human activity and human

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history or prehistory. Our aims in this paper are to show how processes of faulting and folding can modify landscape features to produce conditions inherently attractive to human settlement, even over short time spans or in conditions when rates of activity are modest, to review a range of examples from Europe and Africa that illustrate these effects, and to highlight their significance in the broader patterns of human evolution and dispersal.

BACKGROUND

El Asnam Earthquake

A key source of evidence for changing views of earthquake processes and active tectonics is the 1980 El Asnam earthquake (Ms ~7.2) in Algeria (King and Vita-Finzi, 1981; King and Yielding, 1984; Philip and Megharoui, 1983). During the earthquake, the Sera el Maarouf ridge lifted ~5 m as a result of coseismic anticlinal folding (Fig. 1). This impeded the flow of the Chelif River, resulting in the development of a lake upstream of the fault/fold front that could be identified from old maps as having existed in the past. While the event was the result of motion on a buried reverse fault, reverse ruptures were only modestly expressed at the surface. On the other hand, normal surface breaks were extensive as a consequence of flexure due to the folding. These observations have had far reaching effects on our understanding. First, they demonstrated that motion on small faults such as those visible on the surface of the Ser el Maarouf ridge may not represent a "regional stress field" and that folds can be active and are evidence for seismic hazard (Stein and King, 1984). The seismogram of the event was shown to be the result of a series of subevents that could be correlated in space with the location of fault fold segments that had moved at the time of the earthquake; a direct correlation between the nature of fault slip at the time of the event and mappable surface features was demonstrated. Second, the distribution of these features also showed that the longer-term morphology was a cumulative consequence of earthquakes similar to that in 1980 repeating every few hundred years. Estimates of the rate of folding could be made from the presence of ceramics and radiocarbon dates in uplifted terraces of Vita-Finzi's Younger Fill (Vita-Finzi, 1969), and the rate of the folding

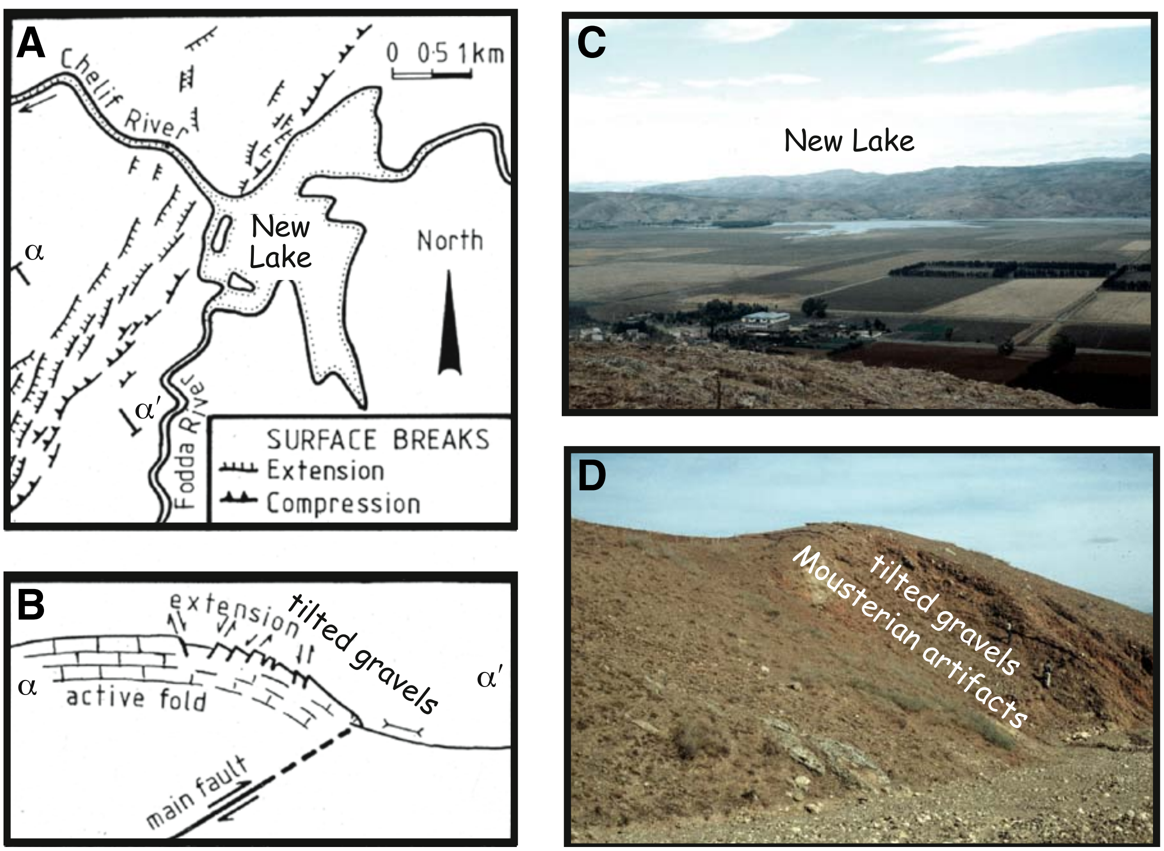

Figure 1. Features associated with the 1981 El Asnam earthquake. (A) A map of the region where the Chelif River cuts through the Sera el Maarouf anticinal ridge. A new lake and old maps show that a marshy region existed in the past. Reverse faulting surface breaks could be identified and mapped, but subparallel normal faulting was more extensive. (B) A section though the anticline from α to α′ as indicated in A. The extensional normal faulting resulted from the flexure associated with the folding. Tilted gravels outcrop extensively along the front of the anticline. (C) A view of the new lake and the Sera el Maarouf ridge. (D) Tilted gravels. The gravels rotated by slip along bedding planes (bookshelf faulting). This can be seen most clearly at the surface.

process could be estimated from the presence of Mousterian artifacts in tilted gravels along the anticline front.

Vita-Finzi (1969), working some years earlier in the same region, had demonstrated the effect of climatic controls on the behavior of the Chelif River sediments. Between about A.D. 500 and A.D. 1500, the period of Vita-Finzi's Younger Fill, the river was aggrading, producing a fertile sediment-filled valley with a high water table. At the end of this episode, the river began to incise through the earlier sediments, the water table dropped, and the fertility of the valley reduced dramatically in consequence. However, this transition did not occur uniformly throughout the river basin. On the contrary, the river on the upstream side of the El Asnam anticline remained continuously depositional and continuously fertile. This example demonstrates how localized folding and faulting transverse to the main axis of drainage can impede water flow, sustain local conditions of fertility, and moderate the impact of climatically induced changes in hydrology. It was appreciated retrospectively that the extensive evidence of human activity in the earthquake region in Mousterian times was not simply a convenient source of evidence for dating earthquake repeat times. It provided evidence for the attractions of a fertile and well-watered basin for human settlement in an otherwise relatively arid region as a consequence of the repeated uplift of the anticline, the damming back of water and sediments, and the long-term maintenance of lacustrine or marshy conditions (Megraoui and Doumaz, 1996) favorable to plant and animal life and human subsistence.

Paleolithic Landscapes of Epirus

Since the 1960s, archaeological projects centered on the Epirus region of northwest Greece (Fig. 2) have been dedicated to developing methods of analyzing, at a regional scale, the relationship between archaeological sites occupied during the Paleolithic

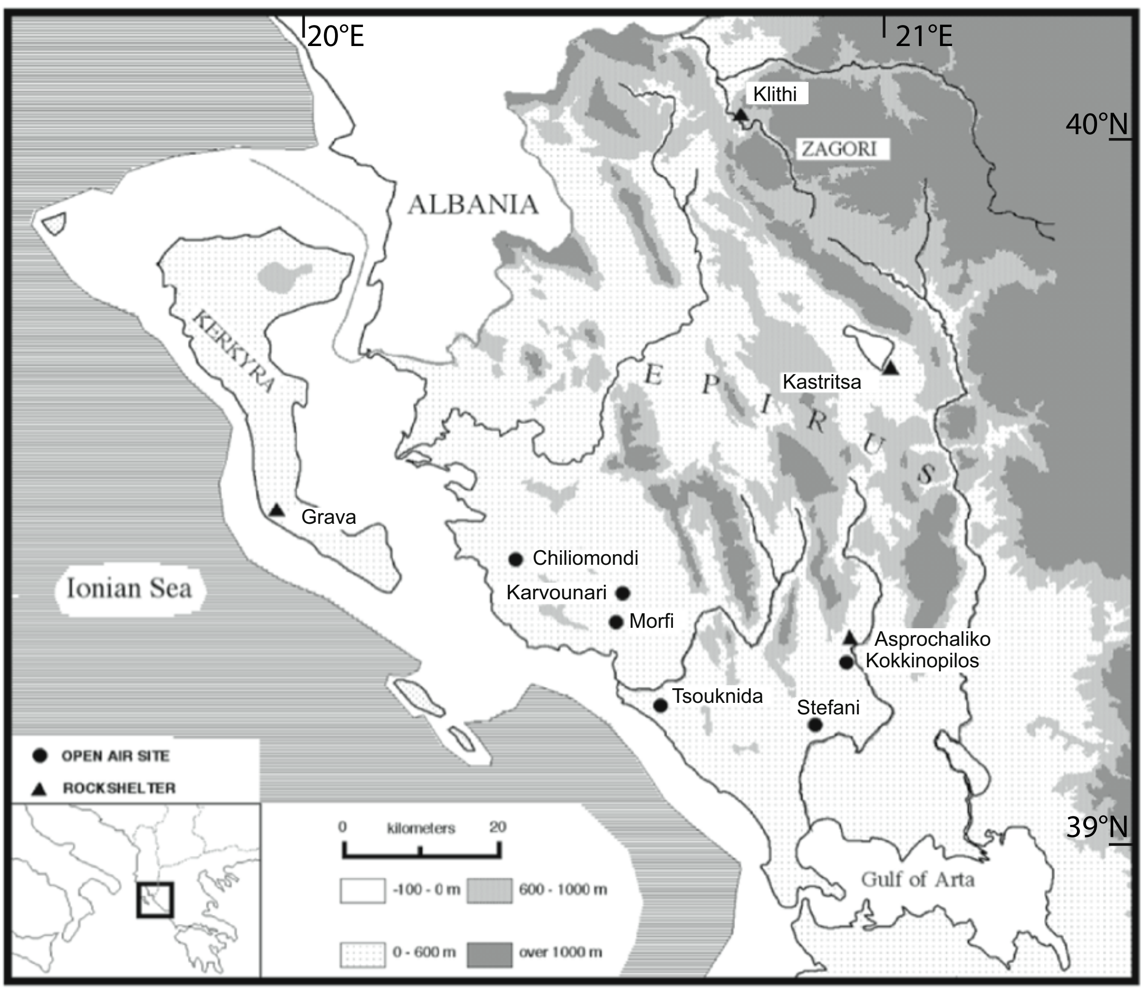

Figure 2. The Epirus region of northwest Greece. Sites showing substantial evidence of Paleolithic human occupation are named. Circles indicate open-air sites, and triangles indicate rock-shelter sites with substantial deposits containing both stone artifacts and bone material. The Asprochaliko and Kokkinopilos sites are discussed in the text and referred to in Figures 3 and 4. The present coastline is shown and the region of seafloor that would have been land when sea level was100 m lower is indicated in white.

period and their local and regional environmental setting (Bailey, 1997). Mapping of Paleolithic rock shelters and open-air sites in relation to topographic features and Quaternary deposits, and interpretations of landscape and vegetational change, was central to the original research strategy. Major deposition and erosion of Quaternary sediments had already been documented in an earlier phase of investigation (Dakaris et al., 1964; Higgs and Vita-Finzi, 1966; Higgs et al., 1967), including the famous "red beds," many of which contained Paleolithic artifacts, and seemed to refer to an earlier land surface that had been modified subsequently by geomorphological change. The most famous of these, the site of Kokkinopilos (literally red clay), with its Paleolithic artifacts eroding out of deep gullies in massive beds of red sediment (Fig. 3), had generated considerable interest and controversy about how and when such a thick deposit of fine-grained sediments had come to be deposited on an elevated interfluve, whether by the action of wind or water, and the timing and causes of the subsequent erosion. Tectonics had not yet entered the picture, in retrospect, a surprising omission given the seismic activity of the region (King et al., 1983), but once tectonic influence was appreciated, it not only suggested a solution to the Kokkinopilos puzzle (Fig. 4), but it indicated that other Paleolithic sites in the region were typically associated with tectonic controls similar to the El Asnam region of the Chelif River (King and Bailey, 1985).

The rock shelter site of Asprochaliko (Fig. 3B), for example, is located in a narrow gorge between the edge of an extensive plain to the south and a smaller sedimenting valley to the north. With the longest Paleolithic sequence of the region, extending over some 100,000 yr, and containing Mousterian, Upper Paleolithic, and probably later activity, Asprochaliko was clearly a place of repeated occupation, suggesting a preferred location with enduring attractions for human visitation and activity over a long period of time. One obvious attraction of the site lies in its location in a narrow gorge close to a major animal migration route between an extensive area of coastal lowland and the regional hinterland. A tectonic perspective highlights this feature, because repeated earthquake activity not only sustained and renewed the fertility of fault-bounded basins, it also accentuated and maintained topographic barriers that could be used to tactical advantage in the monitoring, trapping, and control of mobile prey species. Extension of this theme more widely in the region demonstrated a significant relationship between archaeological sites and the juxtaposition of topographic barriers and fertile basins, both at a local scale and at a wider regional

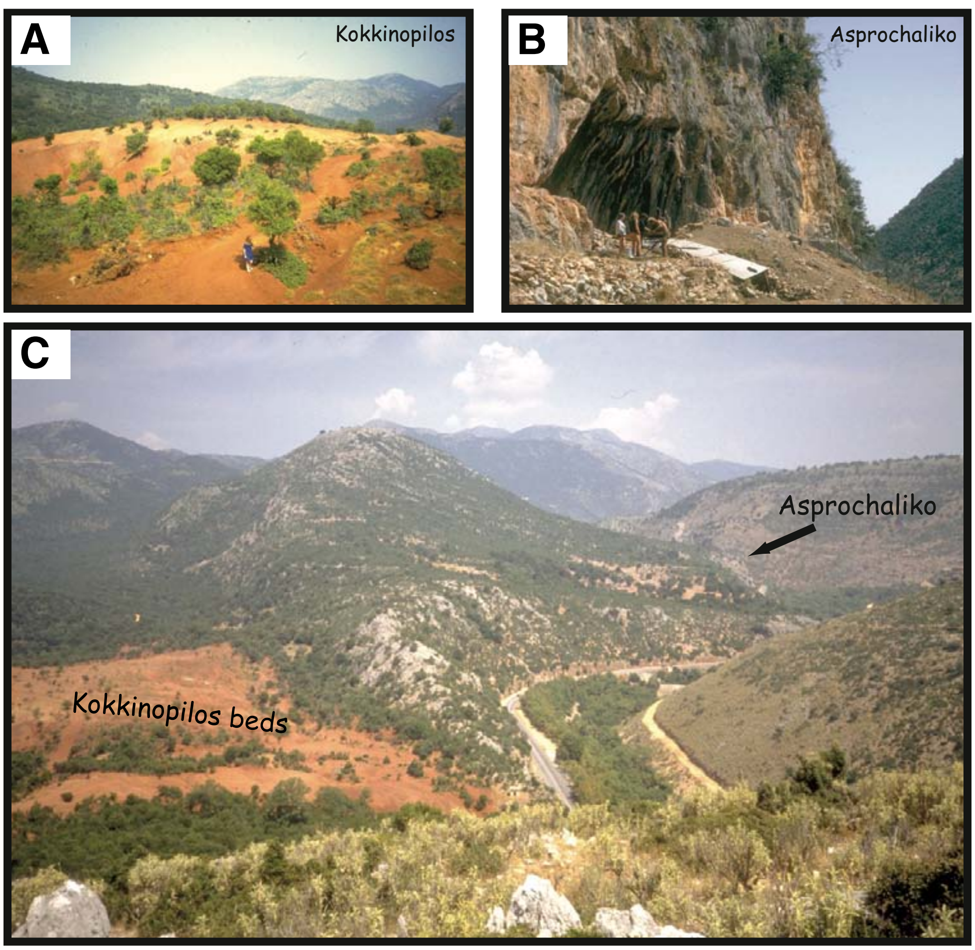

Figure 3. Photographs of the Asprochaliko and Kokkinopilos site regions. (A) The red beds that form the Kokkinopilos deposit. They can be seen to be gently folded. The limestone is folded, but because it lacks clear bedding, this is not easily appreciated at this scale (see King et al., 1993). (B) The Asprochaliko rock shelter. (C) An overview showing the Kokkinopilos beds and the Louros River valley. The anticlinal uplift axis is approximately in the same direction as the photograph (King et al., 1993).

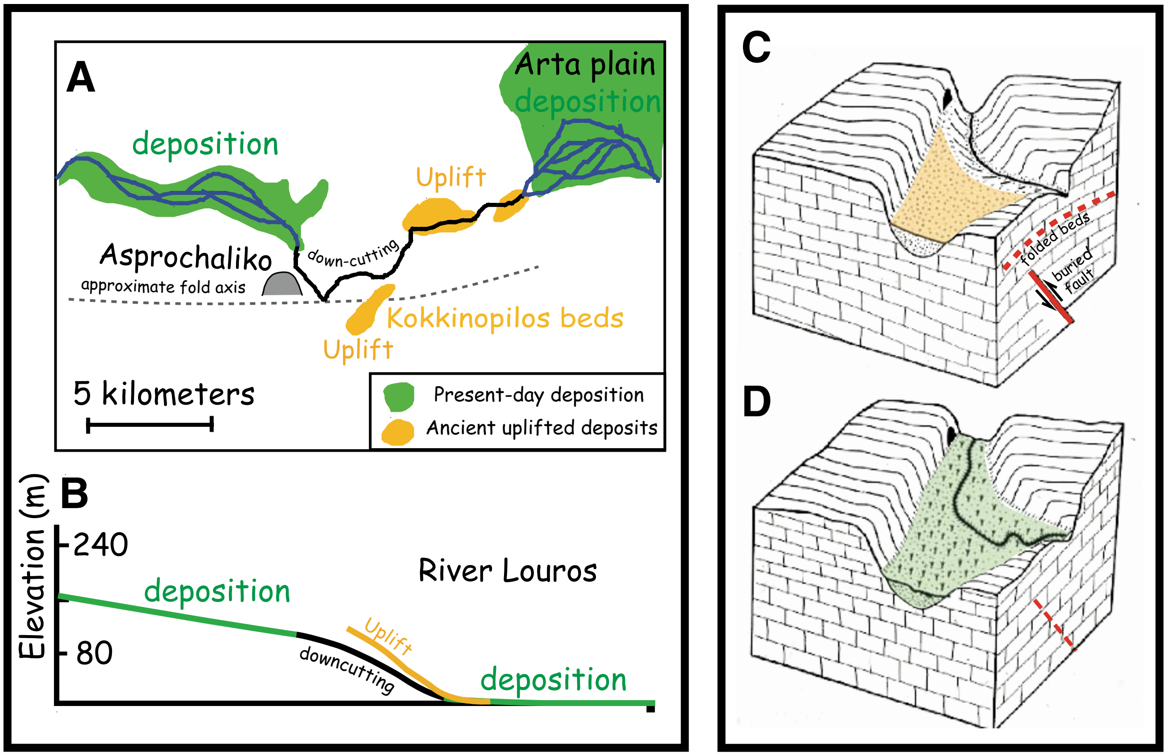

Figure 4. Changes to the region around the Asprochaliko and Kokkinopilos sites due to tectonic activity (anticlinal folding) over ~100 k.y. (A) Map of the site region identifying the Kokkinopilos open-air and Asprochaliko rock-shelter (gray symbol) sites. Regions presently experiencing deposition are indicated in green, and uplifted sediments including the Kokkinopilos beds are shown in orange. (B) The river profile is shown and can be seen to be disturbed by ongoing tectonic activity in a similar way to that found for the Chelif River associated with repeating earthquakes of El Asnam type. Uplifted terraces and terrace fragments can be traced up to the level of the present Kokkonopilos beds, which in the past were at the same level as the current Arta plain. (C) A simplified figure showing the present relation among the Kokkinopilos beds, the Asprochaliko rock shelter, and the present river cut into a narrow gorge. The deformation process appears to be associated with buried faulting indicated on the figure. (D) The environment of the site when it was occupied.

scale, showing how the Paleolithic inhabitants of the region benefited from a tectonically active environment and exploited its features (Bailey et al., 1993; King et al., 1994, 1997). The fact that repeated seismic activity is not uniformly beneficial is demonstrated by the Kokkinopilos site, where a long-standing basin of deposition was eventually transformed into an elevated and eroded badlands landscape.

General Principles

The Epirus example highlights three long-term advantages of a seismically and tectonically active landscape. The first is the rejuvenation of basins with sedimentation and well-watered fertility as originally identified in the El Asnam region. The second is the concomitant creation and accentuation of barriers that offer tactical advantage to human predators dependent on mobile and elusive prey. A third advantage is ongoing creation of a landscape that is not only topographically complex, but one that is often ecologically complex also, offering a variety of resources that may further enhance the attractions for human settlement.

The Epirus and El Asnam examples come from tectonic regions that are undergoing compression near plate boundaries, with reverse faulting and progressive uplift. However, similar features are present in normal faulting and strike-slip environments, and, in these cases, volcanic activity can add an additional contribution to topographic complexity and soil fertility. In both cases, faulting or folding create localized basins of sediment accumulation with high water tables and good water supplies, alternating with a complex uplifted and folded topography made up of barriers and enclosures formed by fault scarps and lava flows that can be used to gain protection and tactical advantage in the control of the wider landscape (Fig. 5). As long as tectonic activity persists over time, these features are regularly rejuvenated. However, if activity ceases, then the topographic complexity in time becomes smoothed by erosion, barriers are removed or reduced, and the water table drops, making water less easily available and more vulnerable to variations in precipitation resulting from climate change. Regions of little or no tectonic activity are thus more vulnerable to the vagaries of climate change (Fig. 6), suggesting the paradox that the geological instability of a tectonically

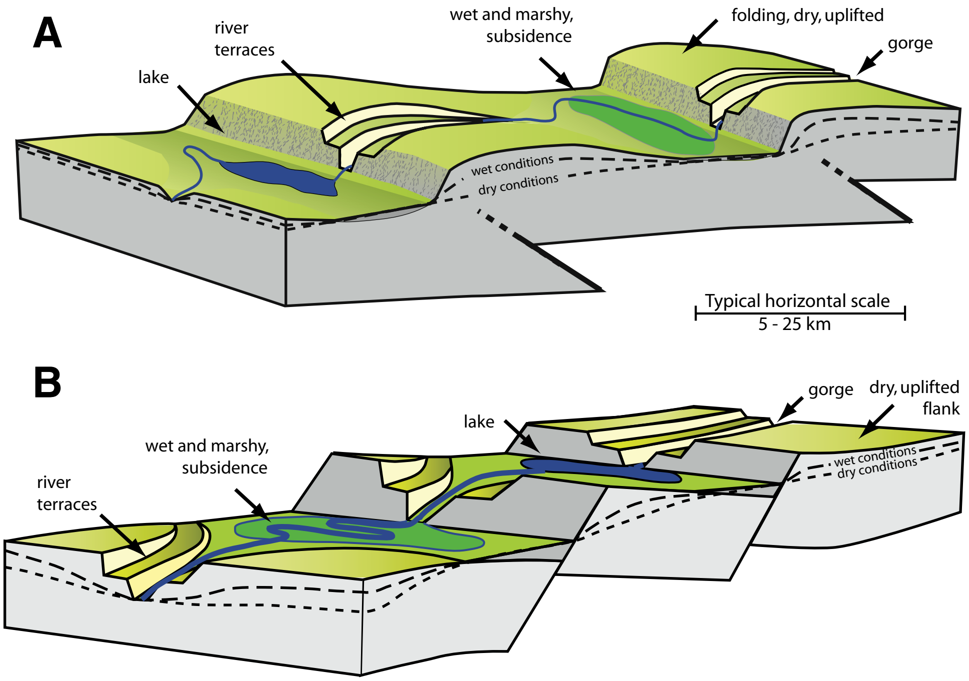

Figure 5. Schematic illustration of the effects of tectonic activity creating landscape features illustrated by examples in this paper. (A) Features typical of contractional (reverse-faulting) environments, where the surface expression of faulting appears in the form of folds as well as faults that cut the surface. (B) Features typical of extensional (normal-faulting) environments. These produce similar features as in A, but the faults usually fully cut the surface.

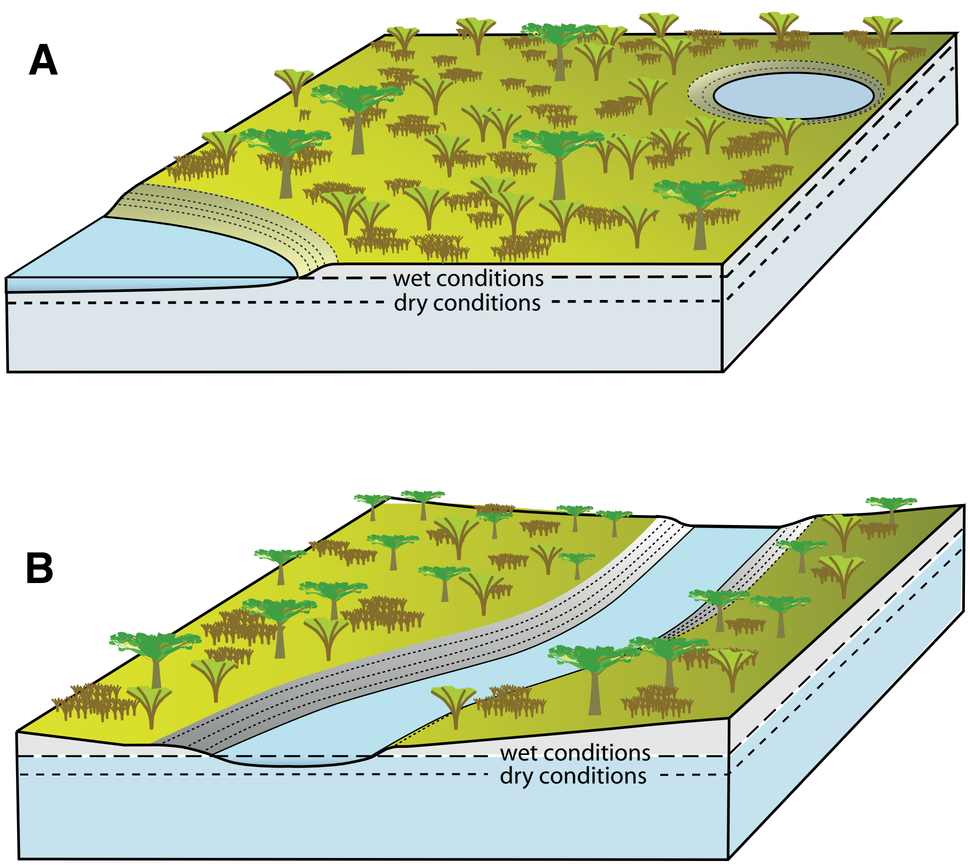

Figure 6. Schematic illustration of effects of changing water table in flat landscapes. (A) In regions of low relief, pans, water holes, and lakes are sensitive to changes of climate and can become dry if the water table drops. (B) Rivers in regions of low relief are also sensitive to changes of water table resulting from climate change and can be perennial or completely dry. If there is a reliable source of water from a high rainfall headwater region, such rivers can be more reliable.

active landscape may actually create more stable conditions for long-term human settlement than an environment that is geologically inactive.

AFRICA

The African Rift

The African Rift is one of the largest and longest-lived on-land tectonic structures in the world, and the fact that it is also home to some of the most concentrated evidence of archaeological sites and human fossils relating to the earliest stages in human evolution suggests a prima facie case for the investigation of tectonic factors (Fig. 7). However, there has been almost no consideration of the impact of tectonics on evolutionary processes, except in terms of their indirect influence on regional climate change, or the possible effect of geological instability and rifting in preserving archaeological and fossil materials in rapidly accumulating sediments and then exposing them to discovery through rifting and erosion. The consideration of external forcing factors on human evolution has almost invariably focused on climate and vegetational change (Maslin and Christensen, 2007) and more rarely on the potential effect of tectonic or volcanic catastrophes.

From our initial studies in Europe and the Mediterranean, it was a small step to the hypothesis that the advantageous features of dynamic landscapes molded by active tectonics were uniquely well developed in an environment such as the African Rift, and might therefore have played a significant selective role in shaping the human evolutionary trajectory (Bailey et al., 2000, 2010; King and Bailey, 2006). The African Rift creates landscapes of complex topography par excellence. The rifting process itself results in the progressive rejuvenation of the rift floor and uplift of the rift flanks and high levels of earthquake and volcanic activity, resulting in vertical fault scarps and lava flows. Uplift and volcanic activity generate high volumes of erodible material, and internally draining basins trap eroded sediments and water to create fertile lake basins. Fault scarps and lava flows afford safe areas for the protection of young and a tactical advantage in the avoidance of predators or the capture of animal prey. Such features offer a niche for an unspecialized but increasingly intelligent omnivore, providing potential selective advantage in the development of features such as bipedalism, which facilitates scrambling and climbing over barriers that deter most quadruped mammals, an omnivorous diet in which meat-eating assumes greater prominence, increased brain size, and the delayed onset of maturity. In short, we argue that a tectonically active environment acted as an evolutionary pacemaker in developing human advantage in the competition for resources against faster moving or more specialized species.

One of the difficulties of pursuing this hypothesis is that levels of landscape change were so rapid and so dramatic in many parts of the African Rift that it is often quite difficult if not impossible to reconstruct the topography as it existed in the vicinity of fossil and archaeological locations that were formed far back in time, as, for example, with the early sites in Ethiopia, such as those of the Awash River Valley in the Afar (region A of Fig. 8; Johanson et al., 1982; White et al., 2003; Semaw et al., 2003). Despite the many reconstructions of vegetation and environmental conditions in the immediate vicinity of these sites (De Heinzelin et al., 1999; Johanson et al., 1982; Kalb et al., 1982a, 1982b; Radosevich et al., 1992; Semaw et al., 2005; WoldeGabriel et al., 1994, 2001), it is not possible to identify the wider configuration of environmental conditions over a larger area except in very general terms, or their relationship to topographic variables, because too much has changed in the past 2 to 3 m.y. At the time when these early sites were occupied, their location was close to the point where the Awash River entered the active rift floor. Today, they are far from the active rift as a result of progressive uplift. Conditions analogous to those of Pliocene-Pleistocene times can be found at the present day in the area where the Awash River emerges onto the currently active rift floor (region B of Fig. 8).

A suitable analogue lies in the area of the Karub volcano in the active rift (Figs. 9 and 10). This region includes a range of environments: an annual lake (shaded gray in Fig. 9B), wetland and swampland (associated with the Awash River) that is now flood-controlled for agriculture (dark green in Fig. 9B), and many smaller zones of grassland currently exploited by modern shepherds (light green in Fig. 9B). The Afar region has in the past been more humid (Gasse, 2001), with a freshwater or slightly brackish lake at >6 ka, that may have been continuous with, or linked to, the present-day lakes Adobada and Abbe. The smaller area in the vicinity of the Gablaytu volcano (Fig. 10) is dissected by active faults that create vertical cliffs, enclosed fertile valleys, and blocky lava flows. The latter are exactly the sorts of features that would have provided some measure of protection against cursorial carnivores and secure areas for vulnerable hominin young. In the locations where Pliocene-Pleistocene fossils are found (region A of Fig. 8), important details of landscape features have now been eroded and smoothed over time, but these details are still clear and uneroded in the analogue are of region B. Features shown there are very common when a rift is active and disappear when activity ceases.

The young geological processes along the active rift zone, well illustrated by the case study around the Karub volcano, demonstrate the fragmented nature of this environment and highlight its implications for human development. However, the rate of geological change is so fast that equivalent parts of the rift when early hominids were present are now located some distance away from the active zone, and the evidence of tectonism, and the key structures that once accommodated it, is muted or obscured. Ironically, we need to shift attention to South Africa, where equally abundant finds of early fossils and archaeological materials occur, but where the rate of geological action is less intense, and there is a better opportunity to capture the association between early human sites and tectonic structures. Although it has long been inferred that this southern region is devoid of neotectonic or modern-day seismic activity, this is not the case. Though less pronounced than in highly active settings, the tell-tale signs of

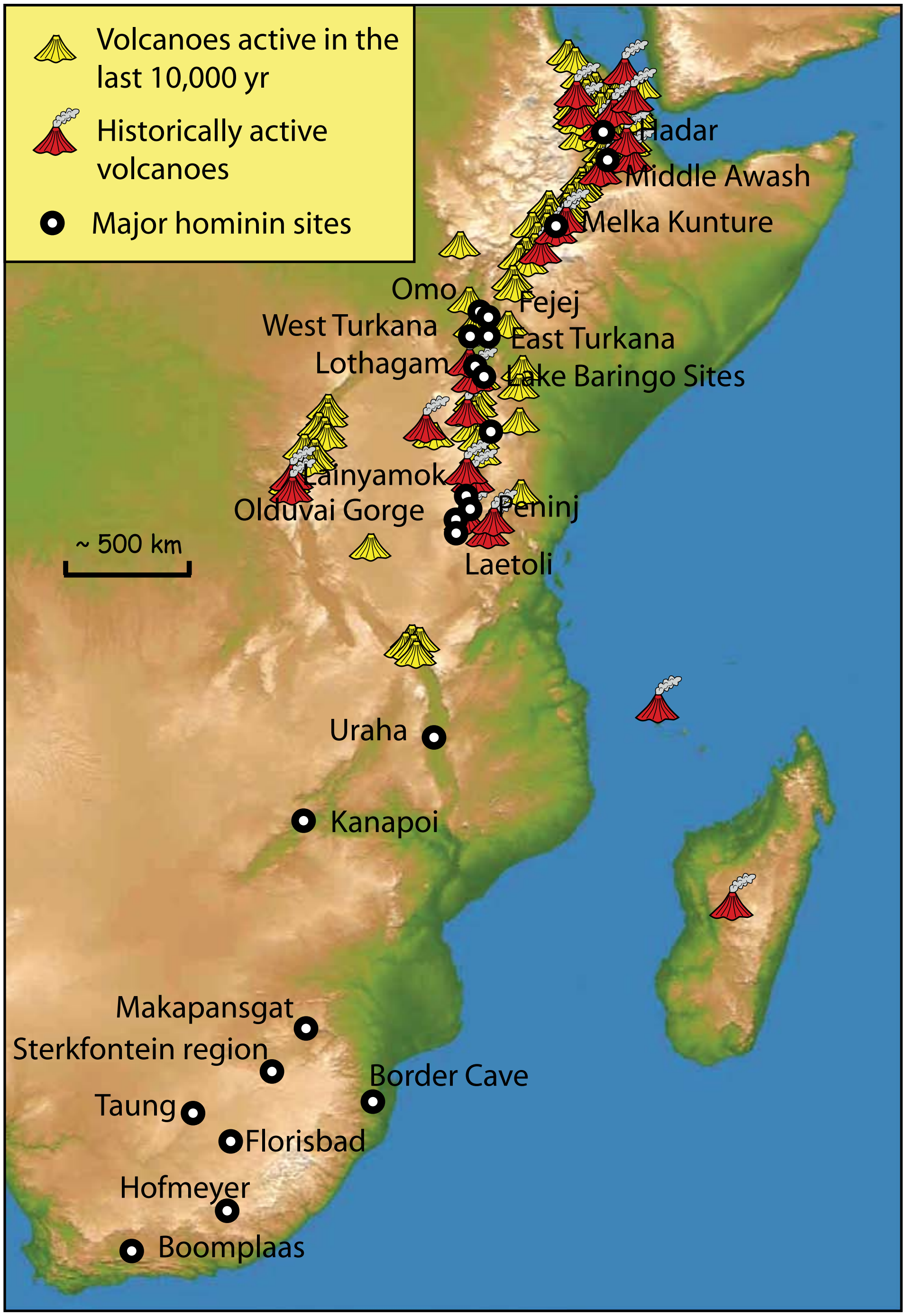

Figure 7. Major sites in Africa.

recent tectonism can still be found in the landscape, as is evident from the following case studies.

South Africa

South Africa has a history of early hominin occupation that extends back into the Pliocene, with a number of famous fossil finds including Australopithecines and specimens of early *Homo*, notably in the Cradle of Humankind region north of Johannesburg, at sites such as Makapansgat, Sterkfontein, and Taung, together with later sites of middle and late Pleistocene ages (region A of Fig. 8; Mitchell, 2002; Partridge, 2000). Border Cave is closely associated with the southern end of the African Rift, and Hofmeyer Site shows some evidence of tectonic

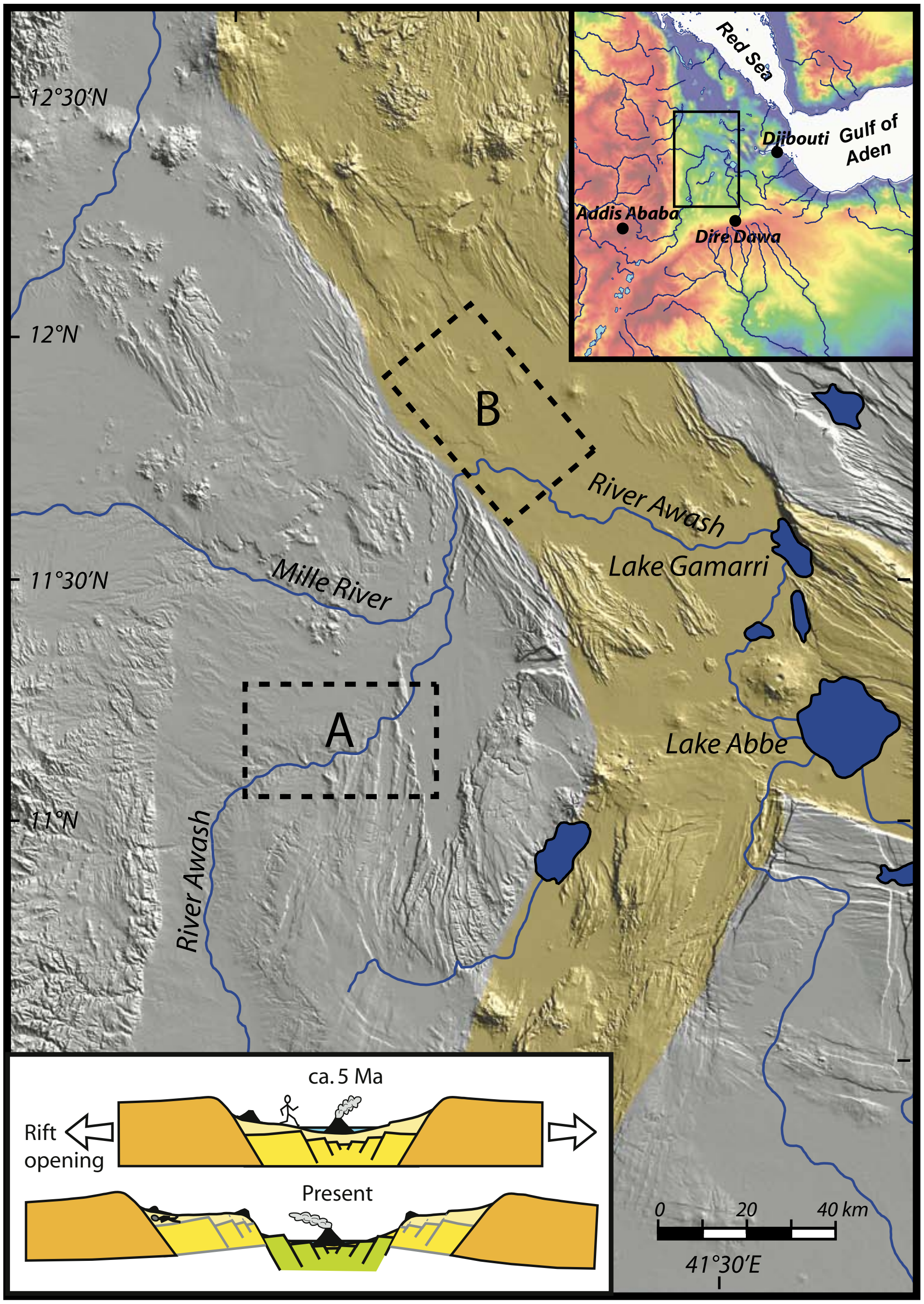

Figure 8. The Afar region of Ethiopia. The area shaded in light brown is the currently active African Rift. Rectangle A shows the region of the fossil sites of the Middle Awash River. It is located on the now-uplifted flank of the active rift, but at the time when the sites were being formed, it was located in the active rift margin (see lower inset). Rectangle B is the region chosen as our analogue in the present active rift margin (Ayele et al., 2007; Manighetti et al., 1998, 2001; Rowland et al., 2007).

activity in the region, but only one river-abraded fossil has been found there. In mining regions, earthquakes can be frequent and large enough to be destructive, but it is commonly assumed that this is due to mining operations, and that in their absence activity would be minimal. Otherwise, there is little reported evidence of tectonic activity, or none that has been recorded. However, the South African seismic network shows a steady level of activity in areas that have no mining activity, and destructive events have been recorded prior to the use of instrumental records (Saunders et al., 2008). As discussed later herein, major earthquakes have left their mark on the geomorphology of regions where many of the South African sites occur, notably at Makapansgat and Taung, although this has not previously been documented. Ongoing tectonic activity is less clear for Sterkfontein although important indicators are described here and are subject to an ongoing study (Dirks et al., 2010). Similarly, Florisbad is located in an area of subdued topography lacking the topographic features typical of active tectonics, although the hot springs that emerge at the

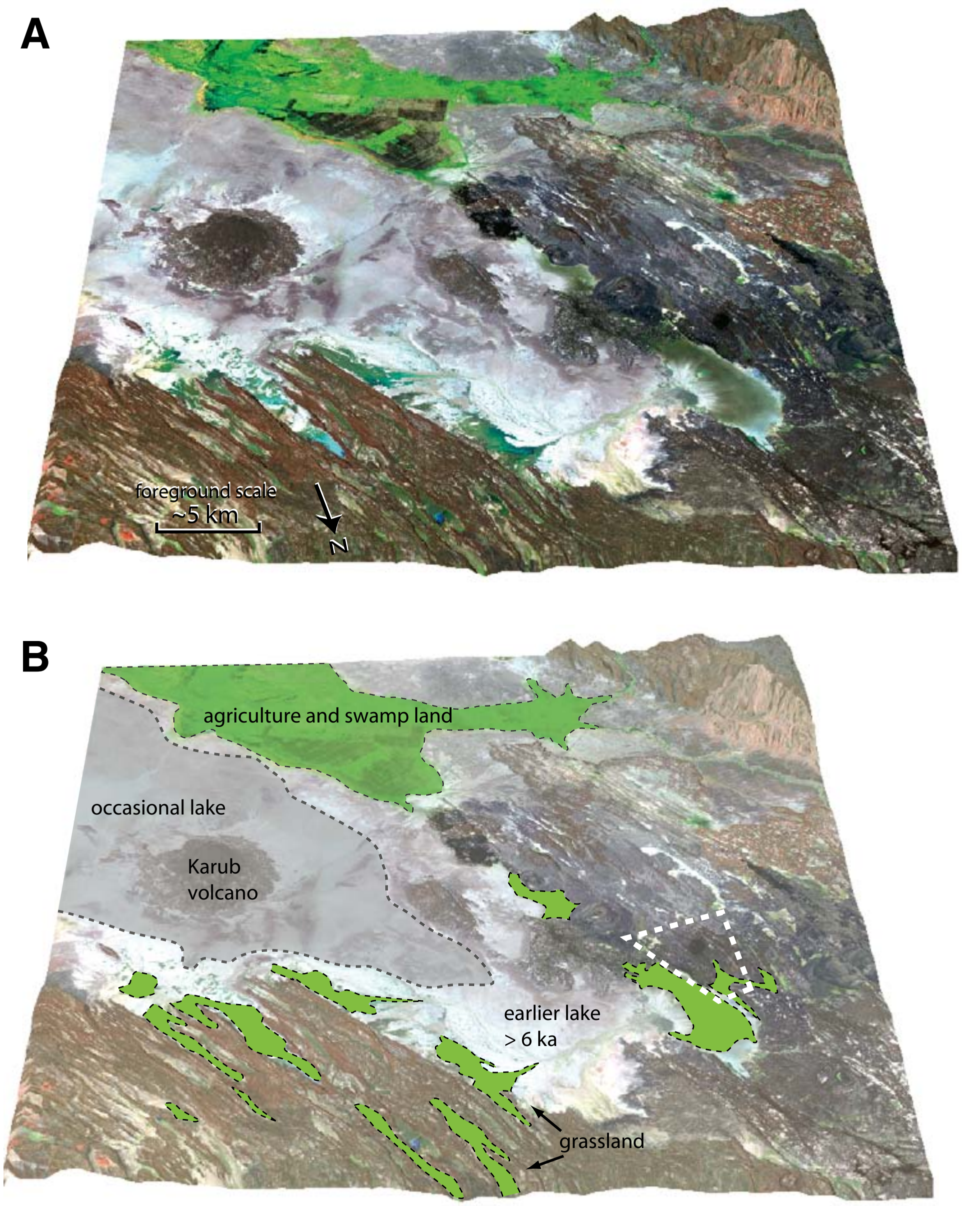

Figure 9. The analogue region situated in the active rift margin (B in Fig. 8). The features found in this region are characteristic of the active rift and could be illustrated in other places. (A) Landsat thematic mapper image (bands 2, 4, and 7 are red, green, and blue, respectively) draped over exaggerated SRTM 3 digital elevation data to give a three-dimensional (3-D) effect of the area in the vicinity of Karub volcano. (B) Interpretation of A showing salient landscape features: a wetland where the Awash River enters the plain (dark green), smaller plains (light green), and a region that hosts an occasional lake under present climatic conditions and a permanent lake prior to ca. 6 ka (Gasse, 2001). A white dashed line outlines the area shown in Figure 10.

site are believed to be related to tectonic activity, and the wider region is seismically active (Douglas, 2006; Kuman et al., 1999). The later site of Boomplaas clearly takes advantage of a favorable environment created by ongoing activity. In other words, all inland sites are associated in some way with tectonically created and maintained features. For the present, coastal sites are excluded because of the complications associated with sea-level variation and coastal change, and we turn to a closer examination of some of the key inland sites next.

Makapan Valley

The Makapan Valley contains a series of caves dating to various periods within the Pliocene-Pleistocene and into historic times, such as the Buffalo Cave, Cave of Hearths, and the famous Makapansgat Limeworks (Fig. 7). From the Limeworks Cave Member 3 and 4 breccias (dated at 3.2–2.7 Ma), 27 fossil specimens of *Australopithecus africanus* have been recovered (Tobias, 2000). Hominins and cercopithecine monkeys were accumulated by various predators, including hyenas, birds of prey, and carnivores (Reed, 1997). The later deposit, Member 5 contains a small assemblage of mammalian fossils but no hominin specimens.

A three-dimensional view highlights the topographic complexity of the Makapan Valley region (Fig. 11A), and faults and other geomorphological features are interpreted in Figures 11B and 11C, with close-up detail shown in Figure 12. In the south (upper part of Figs. 11A and 11B), there is a large plain, now

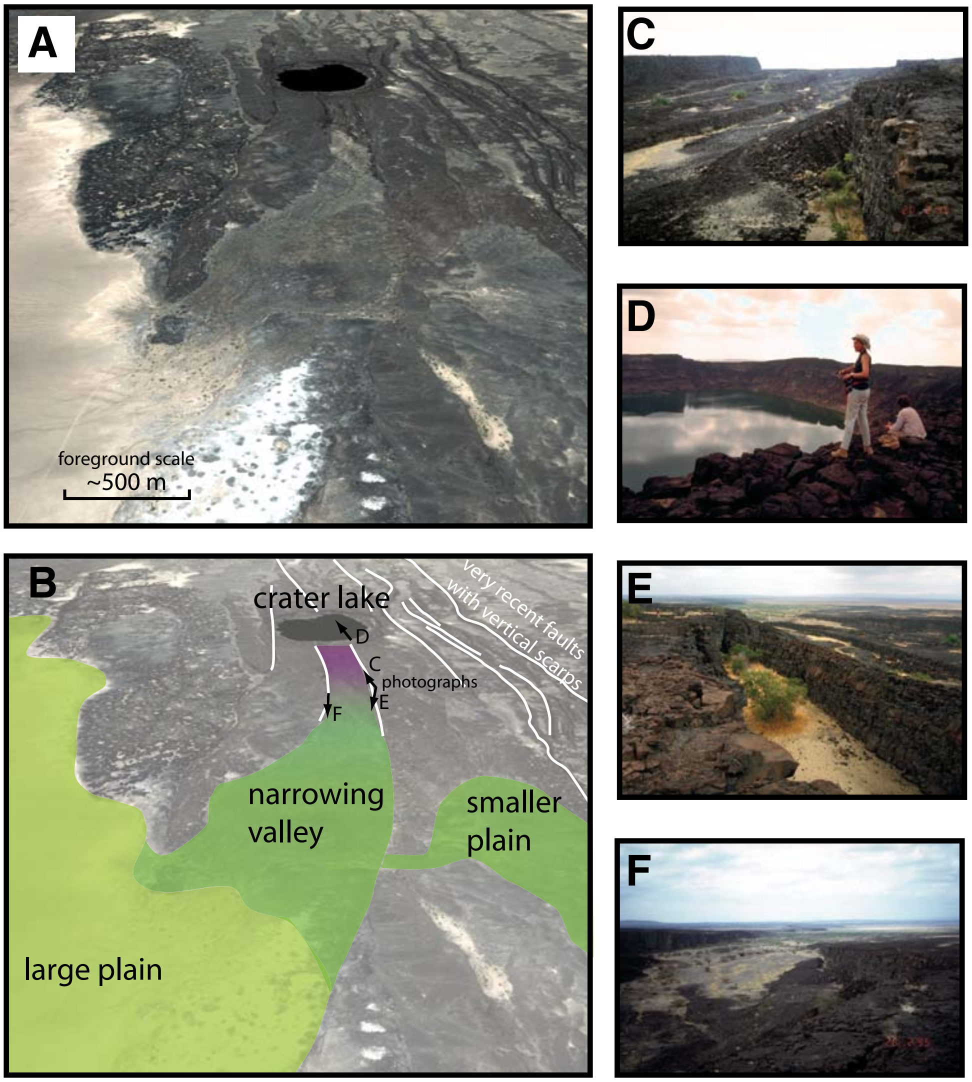

Figure 10. Close-up of the region indicated in Figure 9. (A) Modified Google image showing a crater lake, volcanic lavas, and fault scarps in the vicinity of the Gablaytu volcano. (B) Interpretation of features shown in A, highlighting the Gablaytu crater lake, a narrow valley confined by lava flows and faults, and associated plains of varying size. (C–F) Photographs of features indicated in B, showing, respectively, major fault scarps (C), crater lake (D), and valleys bounded by relatively impassable lava flows and fault scarps (E) and (F).

exploited for agriculture, which is down-dropped with respect to the mountains in the foreground by an active fault system identified as fault Alpha (α). A contemporary feature of this plain is the Nylsvlei wetland, which has long been considered to be possibly related to continued tectonic activity (McCarthy and Hancox, 2000; Wagner, 1927). The active fault scarp probably associated with the creation and maintenance of the wetland forms a geomorphic feature shown in Figure 11C. A second fault, Beta (β), can be identified with the River Nyl running close to its base. The asymmetry of the valley could indicate continued tectonic activity or simply a shift of the river course to the west by sediment that reaches the valley from the east (left). A third fault, Gamma (γ), passes close to the site. It shows unequivocal evidence for ongoing activity (Fig. 12) and is responsible for uplift and consequent down-cutting and sedimentation close to the site, i.e., conditions corresponding to the model outlined in Figure 5B.

The immediate vicinity of the site is characterized by a gorge and associated steep cliffs and rough terrain; these features would have afforded important opportunities for safety and security. The river and the fertile, well-watered, sedimentary plains would have offered good foraging areas nearby. If, as Anton et al. (2002) argued, the foraging range of australopithecines was as small as 38 ha (essentially the area within ~500 m of a given point in the landscape), then this localized combination of rough terrain and productive resources would have been a key feature of their local environment. A viable breeding population would of course require a larger territory, so that the wider area around the Makapan Valley would also be important to long-term viability. The wider area reveals a combination of smaller plains, large open plains, and wetlands within ranging distance of the valley itself. In addition, a variety of valley conditions ranging from dry to marshy would have offered a range of habitats. These features are consistent with on-site indicators suggesting high biodiversity

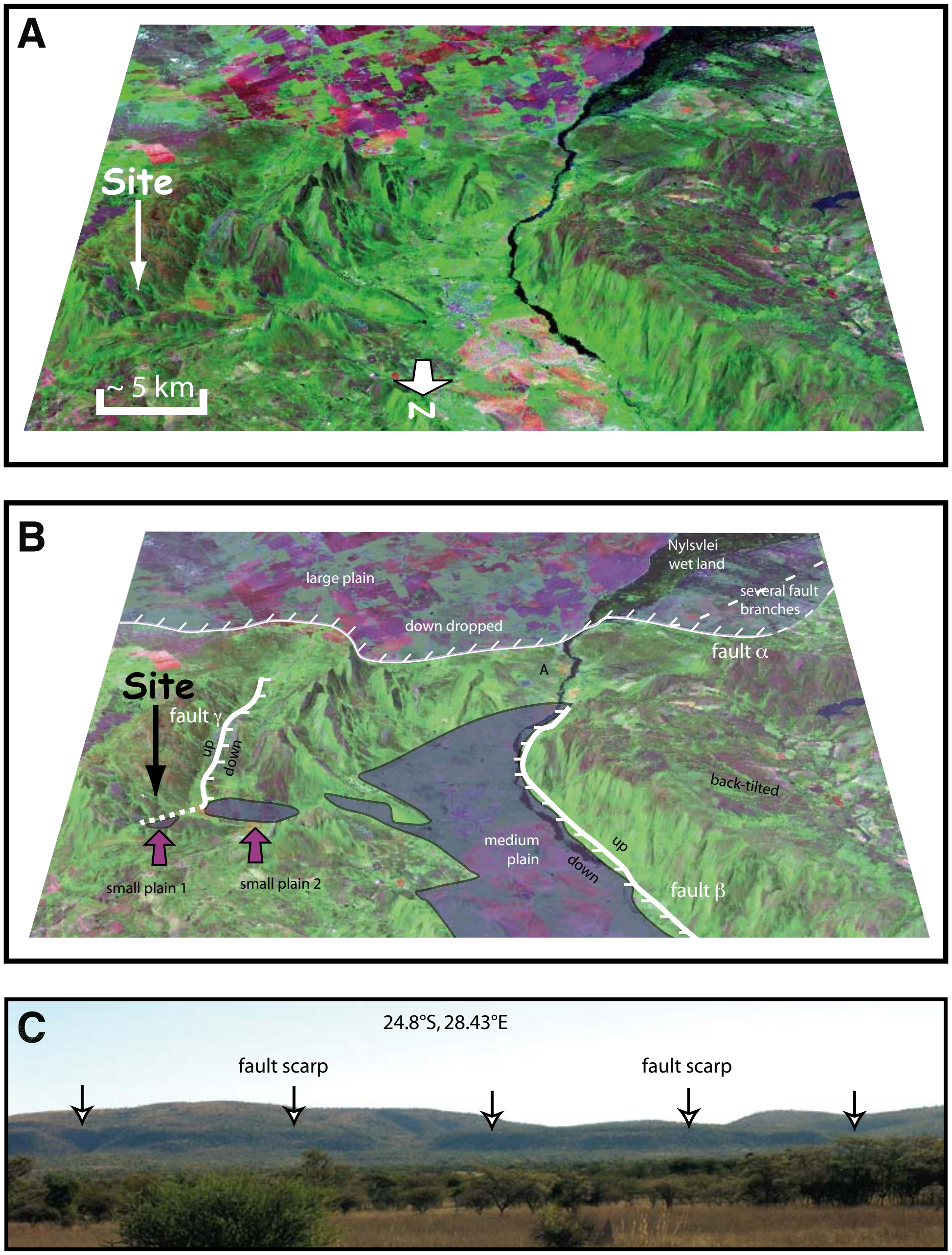

Figure 11. Region around the Makapan Valley, Northern Province, South Africa. (A) Landsat thematic mapper image (bands 2, 4, and 7 are red, green, and blue, respectively) draped over exaggerated digital elevation data to give a three-dimensional (3-D) effect. A vertical exaggeration of between 5 and 10 times the standard elevation is used for oblique images, which enhances the visual interpretation of high-lying versus low-lying regions. The effect of this exaggeration gives an impression similar to that of a land-based observer viewing the topography. (B) Faults α, β, and γ are identified. Recent activity of α is partly demonstrated by the presence of the Nylsvlei wetland, which results from a perturbed river (McCarthy et al., 2004). (C) A fault scarp typical of repeated earthquakes is associated with fault α. Fault β may be active, since the river is displaced to the west side of the valley, but river displacement could also be due to sediment sources coming from the east. Fault γ close to the site is clearly active (see caption to Fig. 12).

and diverse habitat conditions within close range of the site, including both wetland (C3) and dry-land (C4) indicators (Cadman and Rayner, 1989; McKee, 1999; Reed, 1997; Sponheimer and Lee-Thorp, 1999; Vrba, 1982).

Taung

The lime-mining quarry at Taung was the site of the discovery of the type specimen of *Australopithecus africanus* in 1924 (Dart, 1925), though dating based on faunal correlations suggests that it is younger than other australopithecine sites, with an age of ca. 2.6–2.4 Ma (McKee, 1993; Partridge, 2000; Tobias, 2000). Much of the original hominin-bearing tufa deposit was destroyed by mining processes before systematic excavation could be undertaken, so that on-site paleoenvironmental data are lacking, and interpretation depends solely on interpretation of landscape features (Fig. 13).

Two faults on either side of the Taung region create a rift valley (graben) with uplifted, drier flanks on each side and a down-dropped, sedimented plain in the center (Fig. 13). As can be seen in the foreground, this fertile, sedimented plain is today being used for agriculture. The faulting has down-dropped the valley, causing rivers to cut into the uplifted valley sides. These faults

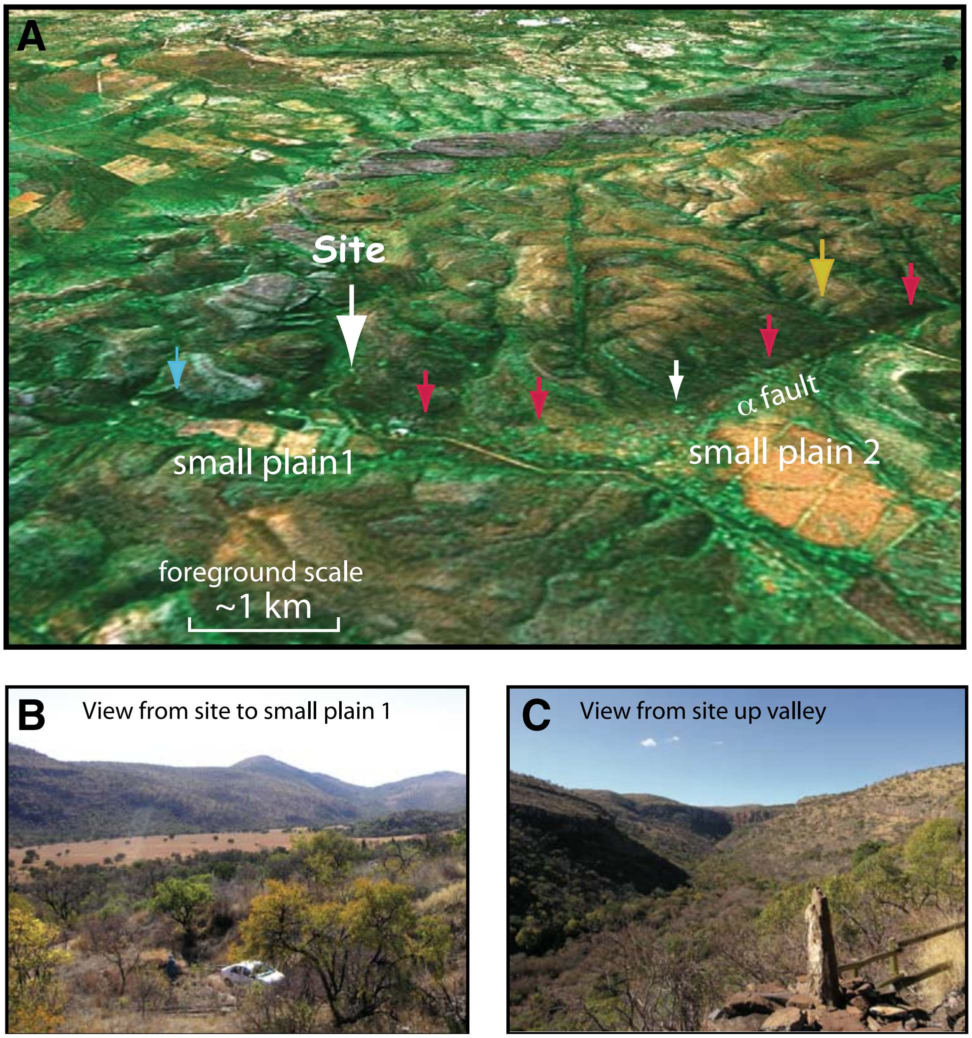

Figure 12. Close-up of Makapan Valley. (A) Closer view of the topography modified from Google Earth image. Fault γ is indicated by arrows. Red arrows indicate steepening of the base of the slope. A yellow arrow indicates a "wine glass," a valley that narrows toward the fault. A blue arrow indicates a spur that has been truncated by the fault. Together, these features are unambiguous evidence of active faulting. Small fertile plains result from sediment back-filling of earlier features as a result of the tectonically modified drainage. (B) Sediment-filled valley resulting from down-dropping on fault γ. (C) Steep topography in the Makapan Valley.

crosscut earlier geological structures and are not controlled by them. Two rivers cut into the rift flanks, with downcutting in the vicinity of the Taung site. All these features indicate essentially similar conditions to those in the Makapan Valley, corresponding to the model outlined in Figure 5B, with varied habitats near the site and a complex topography affording opportunities for protection in the immediate vicinity and for monitoring of resources in the wider landscape.

Sterkfontein

The deposits at Sterkfontein make up seven members, of which two are well studied: Member 4 (ca. 2.8–2.4 Ma), with *Australopithecus africanus* fossils, and Member 5 (ca. 2.5–1.4 Ma), with a succession of Oldowan and Acheulean stone-tool industries as well as two later species of hominins, namely, early *Homo* and *Paranthropus* (Kuman and Clarke, 2000). Faunal remains indicate a mixture of grassland and woodland species in Member 4, and fossilized wood fragments indicate the presence of gallery forest and tropical understory shrubs in the near vicinity of the site (Bamford, 1999). In Member 5 times, all faunal indicators suggest generally more open conditions but with some persisting woodland.

The topographic setting of the site (Figs. 14A and 14B) shows evidence for faulting that crosscuts the mapped geological structures and has disturbed the profile of the adjacent river to create areas of sedimentation and downcutting of several meters, most probably due to continued movement (as in Fig. 5B). However, there are no clear earthquake fault scarps as at Makapansgat and Taung, so that continuing activity cannot be unequivocally established as yet. In the region to the north, the rivers are deeply incised, again suggesting activity. As at Makapansgat, these features are consistent with the presence of environmental signals in the on-site evidence indicating a combination of open grassland and more wooded habitats. A project is currently under way to improve the seismic network coverage in the area and to measure erosion and river downcutting rates using cosmogenic dating.

Boomplaas

Boomplaas cave has an important sequence of deposits dating from ca. 70 ka onward and includes stone tools from the

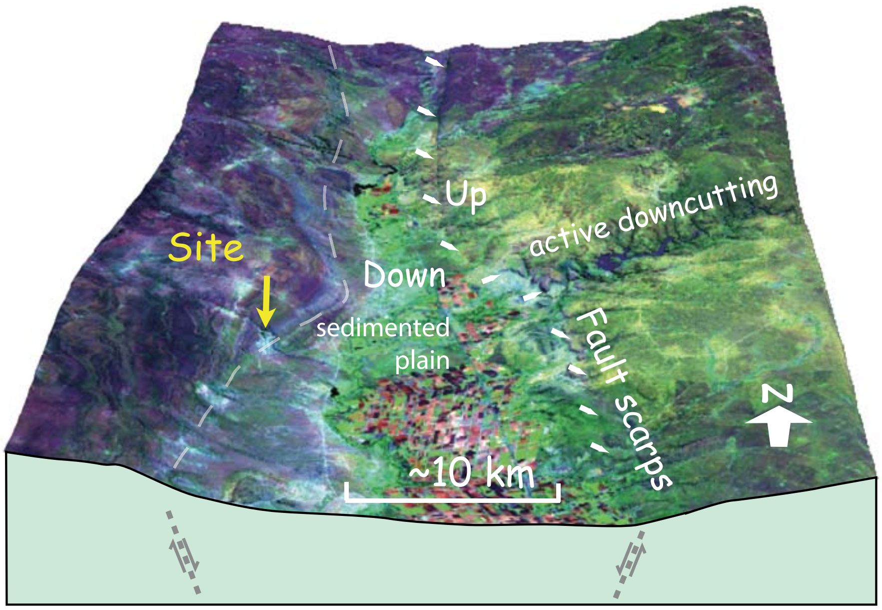

Figure 13. Region around the Taung Valley. Landsat thematic mapper image (bands 2, 4, and 7 are red, green, and blue, respectively) draped over exaggerated digital elevation data to give a three-dimensional (3-D) effect. An earthquake fault scarp on the east side of the valley is indicated by white arrows. The fault crosscuts geological features and varies in altitude and thus cannot be a river terrace or other erosional or depositional feature. Uplifting of the eastern flank has caused rivers to incise, and the down-dropped valley has been filled with sediment. Faulting may also be associated with the western side of the valley, causing the incised valley that hosted the breccia with the hominin fossil. The down-dropped sedimented basin is today used for agriculture. The presumed faults at depth are shown as gray dashed lines.

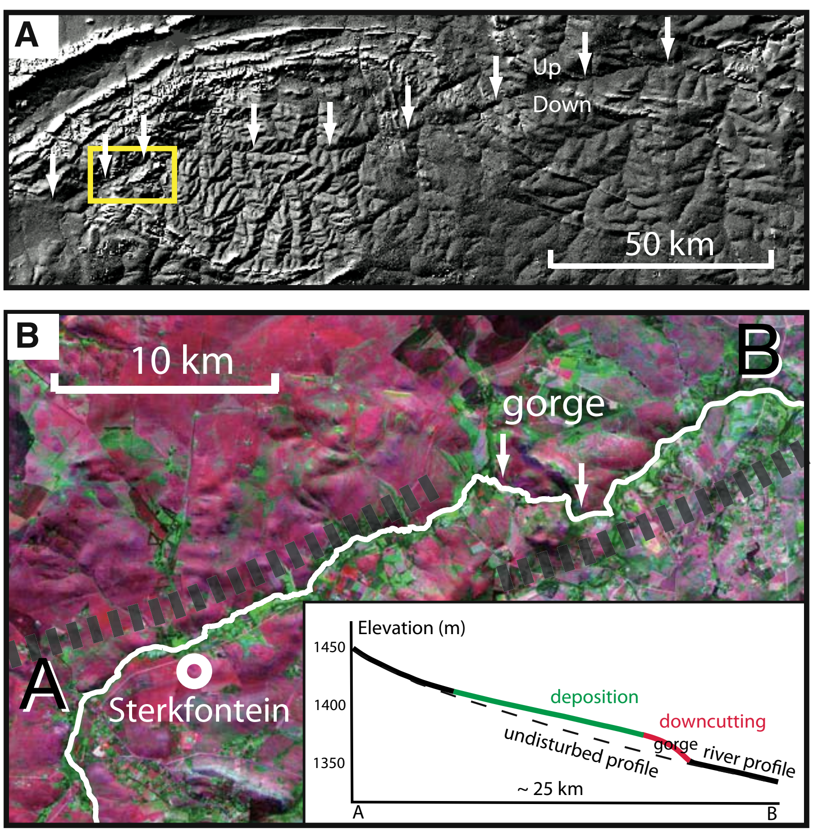

Figure 14. Evidence of tectonic activity in the Sterkfontein region. (A) Shaded relief map of the Sterkfontein "Cradle of Humankind" area (yellow rectangle) and the region to the east. White arrows indicate an east-west fault. This substantial feature extends for >150 km, offsets the morphology (up to the north, down to the south), and crosscuts earlier geological structures. The shaded map uses SRTM 3 data with the light source located at N45°W at an elevation of 5°. (B) Landsat thematic mapper image (bands 2, 4, and 7 are red, green, and blue, respectively) with relief shading based on digital elevation model (DEM; ~10 m resolution) derived from Stereo SPOT images. The fault identified in A passes to the north of the Sterkfontein site (dashed gray line) and apparently controls the position of the Blaaubank River, which follows the northern side of the valley. As it flows to the east, the river passes through a gorge (several meters deep). The inset shows a profile of the river (from SPOT DEM), which is downcutting in the gorge and aggrading above it. Such a profile is commonly associated with active faulting.

Middle Stone Age (MSA) industries of Still Bay and the succeeding Howiesons Poort, Later Stone Age material, and evidence of sheep pastoralism (Deacon, 1995; Deacon et al., 1978; Henshilwood, 2010). The cave itself has an open aspect overlooking a valley filled with sediment, and Deacon (1979) suggested that the site was well placed to intercept migratory animals. From a topographic perspective, the site is located on the boundary between a down-dropped valley and an uplifted scarp (Fig. 15). The valley area has been down-dropped by the fault to the north, and this has caused valleys in the earlier topography to become partly buried, resulting locally in highly fertile sediment-filled valleys. The cave site itself was formed in the earlier topography and is not a consequence of the system that is now active. Fault scarps like those shown in Figure 15 can be found elsewhere in the cape region and may well partly control coastal sites.

DISCUSSION

Our review of key South African fossil and archaeological sites shows that there is considerable evidence for dynamic landscape changes resulting from tectonic activity over the time span during which the sites were formed, and that this evidence has not previously been recognized. The changes are not as rapid or as dramatic as in the African Rift, but they are changes that

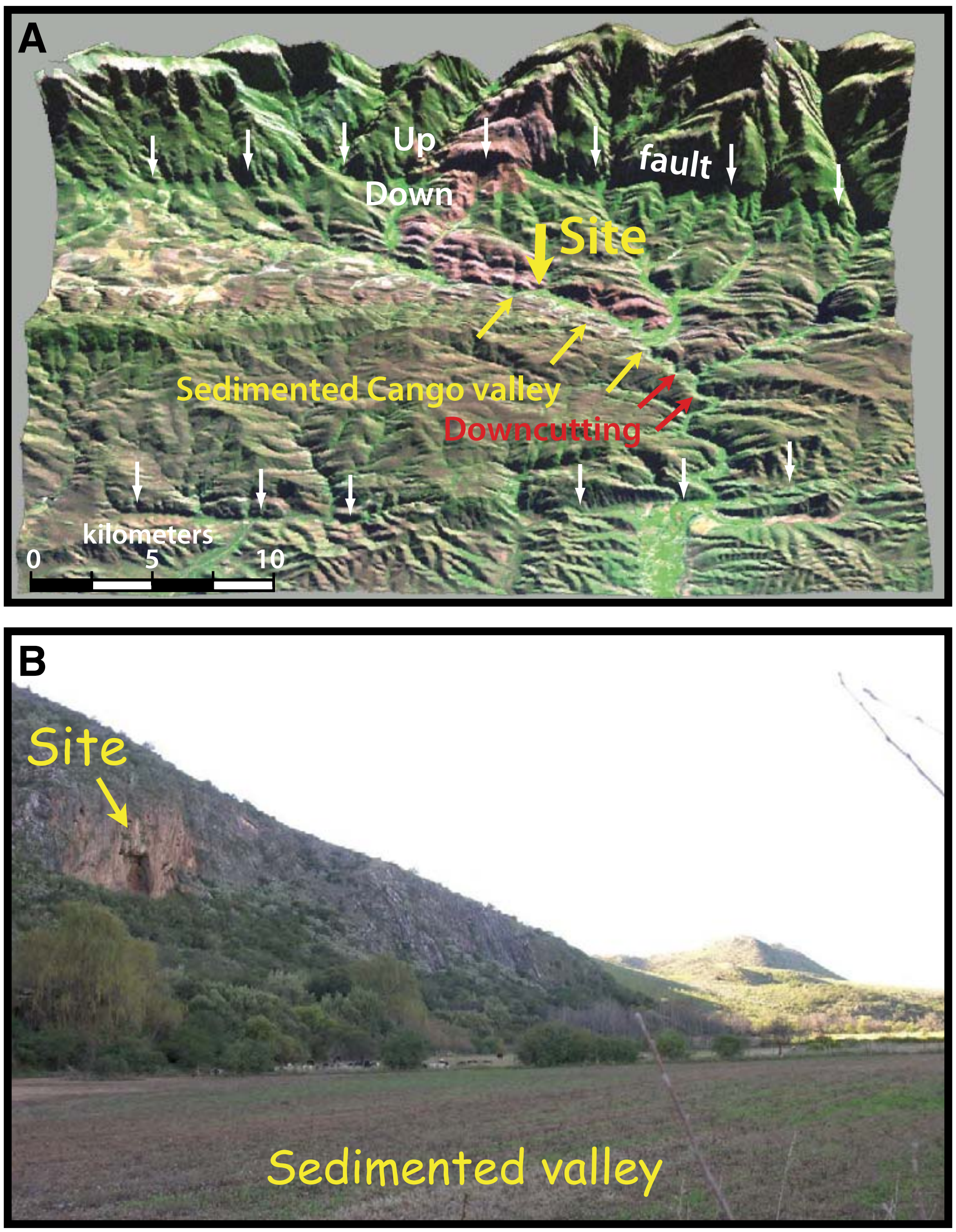

Figure 15. Evidence for tectonic activity in the Boomplaas region. (A) Landsat thematic mapper image (bands 2, 4, and 7 are red, green, and blue, respectively). White arrows indicate two faults. Yellow arrows indicate the sediment-filled Cango valley. Red arrows indicate downcutting. (B) View of cave site showing the Cango valley in foreground. The valley is subject to intermittent flooding and provides rich farmland. Earthquakes are commonly felt in this region.

would have been advantageous for human occupation. They would have created repeated disturbance of drainage networks to sustain localized wetlands with fertile resources and water supplies, and formed or maintained complex local topography affording diversity of resource zones in close proximity and tactical advantages in hiding from predators or accessing mobile prey. The relatively subdued nature of tectonic activity compared to the Ethiopian Rift, which at first sight appears to pose a difficulty for the hypothesis of a close association between tectonically disturbed landscapes and early hominin settlement, turns out to be an advantage, allowing a direct evaluation of the relationship between tectonic structures and human activity without resorting to an analog approach. Three issues for discussion arise from this review.

A first issue is the problem of bias in the distribution of known archaeological and fossil sites resulting from differential preservation and visibility of material. Geological processes in tectonically active areas tend to generate higher rates of sedimentation, which bury and therefore preserve fossil and archaeological material, and high rates of subsequent disruption and erosion, which then expose to view deposits formed at a much earlier period in time. Thus, it can be argued that the correlation between early archaeological and fossil sites and areas of tectonic activity is purely coincidental and is the result of greater visibility and exposure of material in such environments compared with environments where tectonic activity is very low or nonexistent.

A similar argument is sometimes made about caves and rock shelters. These tend to be easily visible targets for archaeological investigations and often provide a protective environment for the accumulation of sediments and the preservation of archaeological material in stratified sequences. Hence, the argument can be proposed that the distribution of prehistoric settlement patterns derived from cave and rock-shelter deposits is unrepresentative and biased by conditions of geological visibility, a proposition pertinent to our South African region, where many key sites are in caves.

Taken to its logical conclusion, this argument would require us to suppose that the distribution of prehistoric archaeological and fossil materials in space and time is solely a function of geological processes affecting visibility, that tectonically active areas of Africa have no particular significance for human evolution, and that actually other regions of Africa or elsewhere were equally important, if not more so, despite the absence of evidence in favor of such a proposition. Such an argument would be simplistic. We doubt that the concentration of finds in East and South Africa is wholly unrepresentative or can tell us nothing about the environmental conditions in which early human populations prospered.

Other areas with early sites are sometimes claimed to lack the tectonic activity or the topographic features to which we have drawn the readers' attention here. A notable case in point is the early finds of hominin fossils in the Chad region (Brunet et al., 1995). However this region, though far from the East African Rift, is one of the most tectonically active areas of sub-Saharan Africa outside the rift (Burke, 1996).

Factors of differential visibility resulting from geological processes are not trivial, and we do not discount them. However, they can be addressed in a variety of ways. In the case of caves and rock shelters, not all that were available for use contain evidence of human activity. Of those that do, some clearly show evidence of more activity than others. Some regions with available caves and rock shelters clearly show greater concentrations of evidence than others. Open-air sites can be targeted to provide a control and are often found once they are sought out. A similar approach can be employed in relation to tectonic factors.

Moreover, it is not necessarily the case that archaeological materials from very early periods will be invisible in areas that are not tectonically active because these areas are likely to have smoothed surfaces that are subject neither to accumulation of obscuring sediment nor to erosion, and artifacts once deposited are likely to remain in place for many tens or hundreds of millennia. Granted, surface artifacts are more difficult to date than stratified material and likely to comprise only stone tools, but if such areas were attractive at an early period, we might expect to find concentrations of distinctive stone tools characteristic of Lower Paleolithic industries. Many such areas exist in the African Rift sensu lato, including the now-uplifted flanks of the rift, which would have been available for occupation at a relatively early stage in the Pleistocene, but little archaeological evidence of human activity was recorded in such areas until much later periods of human development and, in many cases, not until the expansion of pastoralist societies in the Holocene.

A second issue concerns the variability in rates of landscape change resulting from different levels of tectonic activity and the long-term evolutionary implications of variable activity. The South African region as a whole clearly differs in its general rate of activity compared with the most active parts of the East African Rift. Even within South Africa, there appears to be variation between the sites and regions we have discussed, and there are additional sites that we have not included in our review where tectonically informed studies have yet to be carried out. Nevertheless, at a general level our results suggest that even quite modest rates of tectonic activity are likely to generate the sorts of topographic features we have described, and therefore are likely to be advantageous for human settlement, even in regions with few or no earthquakes, or relatively small ones within the lifetime of a human individual.

A critical variable in this equation between rates of tectonic activity and creation of rough landscapes is the rate of erosion. In regions with relatively soft rocks and active forces of erosion, modest rates of tectonic activity may be insufficient to offset the smoothing effects of erosion, and the long-term trend will be toward a flat topography lacking the advantages for human activity that we have described. Conversely, areas with very hard rocks may preserve the rough and complex topographic features created by occasional tectonic disruption for longer periods despite generally low rates of tectonic activity. This is certainly a contributing factor to the topography of the areas we have described in South Africa, where the rock formations are metamorphosed and mostly were formed earlier than the Cenozoic (Hartzer, 1998). These rocks are very hard and resistant to erosion, and they tend to maintain vertical cliffs and fissures rather than degrading to the rounded and flattened features that result from erosion of softer rock formations.

There is, then, a continuum of topographic conditions. At one extreme, regions have so little tectonic activity, and rock formations liable to erosion, such that the resulting topography is likely to be generally smooth. Such plains environments offer little diversity of resources or complexity of topography offering tactical advantage, except at their margins or in localized areas where erosion has created some topographic relief. From this perspective, it is no surprise that extensive plains environments such as the Asian steppes or the Great Plains of North America show limited evidence of human occupation in prehistory until the adoption of the horse as a riding animal. Equally at the other extreme, very active tectonics may have consequences that are as much destructive as constructive, at least at a local or subregional scale, resulting in geographical displacement of favorable areas, and destruction of once-fertile basins.

The implications of such variation for evolutionary trends, particularly with respect to the general pattern of hominin evolution, remain to be worked out, but it is worth noting that Reynolds (2007) related the higher rate of species turnover amongst large mammals in East Africa in comparison with South Africa to the higher rates of tectonic activity in the East African Rift. The selective impact of dynamic topography may take different forms, depending on the scale of the landscape changes involved. One possibility is that populations of large mammals are isolated by insurmountable topographic barriers, resulting in genetic divergence and speciation. Another possibility is that rough topography, by sustaining favorable environmental conditions during climatic downturns, helps to maintain higher levels of population than would otherwise have been the case, and hence maintains a larger pool of genetic variability that can provide the basis for later adaptation and evolutionary change. Finally, a tectonically active and complex topography may select for greater locomotory and cognitive adaptability able to cope with changeable environmental conditions, for example, bipedal movement suitable for moving through rough terrain and climbing rock barriers, and cognitive abilities able to take tactical advantage of complex topography in tracking mobile animal prey or avoiding predators.

A critical factor in exploring further these possibilities is careful reconstruction of topographic conditions at a variety of scales and, in particular, better dating of rates and periodicities of tectonic movement, earthquake repeat times, and volcanic eruptions. Satellite imagery along with a new generation of cosmogenic dating techniques will play an important role in conjunction with existing methods of dating, mapping, and stratigraphic interpretation.

Without a tectonically informed reconstruction of local landscape conditions as they existed during the periods in question, claims that very early archaeological sites or hominin fossils typically occur in regions lacking rough topography or tectonic activity cannot be sustained. Issues of differential preservation cannot be discounted and almost certainly add an extra layer of variability that needs to be addressed alongside other factors. More studies are needed at a regional scale of the type that we have described here, involving a systematic program of dating of geological surfaces and deposits alongside systematic surveys for archaeological and fossil sites.

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