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Landscapes of human evolution: models and methods of tectonic geomorphology and the reconstruction of hominin landscapes

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ABSTRACT

This paper examines the relationship between complex and tectonically active landscapes and patterns of human evolution. We show how active tectonics can produce dynamic landscapes with geomorphological and topographic features that may be critical to long-term patterns of hominin land use, but which are not typically addressed in landscape reconstructions based on existing geological and paleoenvironmental principles. We describe methods of representing topography at a range of scales using measures of roughness based on digital elevation data, and combine the resulting maps with satellite imagery and ground observations to reconstruct features of the wider landscape as they existed at the time of hominin occupation and activity. We apply these methods to sites in South Africa, where relatively stable topography facilitates reconstruction. We demonstrate the presence of previously unrecognized tectonic effects and their implications for the interpretation of hominin habitats and land use. In parts of the East African Rift, reconstruction is more difficult because of dramatic changes since the time of hominin occupation, while fossils are often found in places where activity has now almost ceased. However, we show that original, dynamic landscape features can be assessed by analogy with parts of the Rift that are currently active and indicate how this approach can complement other sources of information to add new insights and pose new questions for future investigation of hominin land use and habitats.

Introduction

We examine the role of active tectonics in shaping complex landscapes as potential selective agents in hominin evolution and dispersal. We approach the problem of reconstructing tectonically active landscapes in two ways. First, we look at methods of characterizing and mapping landscapes using "roughness," techniques that make it possible to visualize complexity at a variety of geographical scales. Second, we examine active tectonic landscapes in relation to case studies of archeological and fossil sites using satellite images and ground observation. This allows us to identify specific features associated with ongoing active faulting and to show how these aid in reconstructing and interpreting paleolandscapes.

The methods we use are adapted from the discipline of tectonic geomorphology, which has evolved from earthquake studies and has limited roots in conventional geomorphology. We provide a brief review of recent developments, since many specialists working within the field of human evolution, including geomorphologists, structural geologists, and sedimentologists, are not familiar with them. We show that tectonic activity creates and sustains characteristic features of surface morphology at spatial and temporal scales that overlap with biological processes of ecological interaction and evolutionary change, and which are therefore potentially important to hominins and other species. In particular, we show how ongoing activity can maintain hydrological regimes, topography, and environmental conditions substantially different from adjacent landscapes that are tectonically inactive.

We describe in detail the techniques we adopt to identify topographic heterogeneity, and we apply these techniques in different ways starting at the scale of the African continent and then focusing down to regions around inland sites in South Africa and the Afar (Ethiopia). We choose South Africa because it is an important region for early hominin fossils and archeological assemblages, but one where ongoing tectonic activity and localized tectonic features have not been identified in previous geological

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studies or recognized as significant in the interpretation of hominin landscapes. We choose the Afar as another important concentration of early hominin discoveries, but one where the rate of tectonic activity has resulted in much more rapid and dramatic geomorphological change, so that local scale reconstructions of Plio-Pleistocene landscapes are only possible through an analogical approach. Finally, we consider the implications of such studies in the interpretation of hominin paleolandscapes and discuss the directions in which future research might be developed, building on the methods presented here.

Models and methods

Earthquake studies and the development of tectonic geomorphology

A key event in the development of earthquake studies was the 1980 El Asnam earthquake (Ms ~7.2) in Algeria, which changed our views on the mechanism of fold formation and initiated a new approach to seismology and the understanding of structural geology (King and Yielding, 1984). Subsequent papers (Stein and King, 1984; King et al., 1988; Stein et al., 1988; Tapponnier and Armijo, 1989) extended to other regions the view that deformation due to repeating earthquakes dominates the form of landscape features in active areas. Of particular relevance to this paper, the uplift and damming of the Chelif River by the El Asnam earthquake and previous events provided the first clear example of how tectonic activity can locally modify the effect of climate change (Vita-Finzi, 1969; King and Vita-Finzi, 1981; King and Bailey, 2006). Although this was noted, the subsequent development of tectonic geomorphology concentrated on the primary objectives of studying earthquake hazards and the growth of mountains and rifts (e.g., Armijo et al., 1996; Tapponnier et al., 2001).

Tectonic geomorphology depends on identifying features of surface morphology that are characteristic of an active landscape. These include fault scarps, modified river terraces, wetlands, or lakes, plus other features that can only persist if ongoing tectonic activity continually renews them. These features are usually studied by tectonic geomorphologists as a means to establishing seismic hazard, but here we consider them in their own right for their potential role in creating and maintaining environments favorable to hominins (for additional examples of this approach see also King and Bailey, 1985; Bailey et al., 1993, 2000; King et al., 1994, 1997; Bilham, 1988; Jackson, 2006; Force, 2008).

Figures 1 and 2 summarize in simplified form some differences between non-tectonic environments and active tectonic ones. In flat landscapes with little topographic relief, water holes, oases, or billabongs occur where the water table intersects the surface (Fig. 1a). These features and associated vegetation such as riverine forest are often seen as likely hominin habitats. However, the availability of surface water in such conditions is vulnerable to fluctuations in water supply. A climatically induced drop in the water table will change water levels, leading in extreme cases to complete desiccation. Similarly, rivers in inactive terrain are vulnerable to climatically induced fluctuations in water flow unless their headwaters lie in upland regions of persistently high rainfall (Fig. 1b). In areas of low relief, even the most reliable rivers or lakes may dry up, creating localized conditions of extreme aridity. Such sensitivity is documented in North Africa (Vita-Finzi, 1969).

In tectonically active areas, the pattern of faulting can be dominated by three types of activity. Reverse faulting (Fig. 2a) is typical of environments where the Earth's crust is contracting. Normal faulting (Fig. 2b) occurs where the crust is being extended. In both cases, tectonic activity results in uplifted and down-dropped blocks of land at a range of scales. At the escarpments of

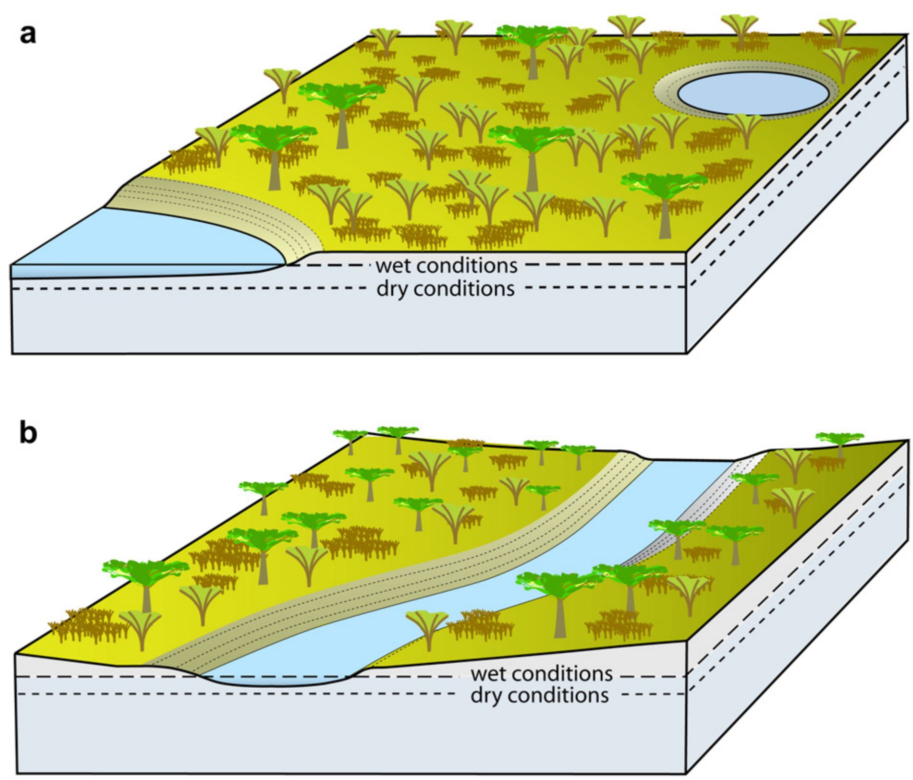

Fig. 1. Schematic illustration of effects of changing water table in flat landscapes: a) In regions of low relief, pans, waterholes, and lakes are sensitive to changes of climate and can become dry if the water table drops; b) Rivers in regions of low relief are also sensitive to changes of water table resulting from climate change and can be perennially or completely dry. If there is a reliable source of water from a high rainfall headwater region such rivers can be more reliable.