1

The context of Quaternary environmental change in southern Africa

JASPER KNIGHT AND STEFAN W. GRAB

Abstract

Climate changes and tectonic processes throughout the Cenozoic, and earlier, provide the context for landscape and environmental change in southern Africa during the Quaternary. Changing land surface properties and resource availability, including rock types, topography, soils, ecosystems and drainage patterns, have exerted a strong impact on the processes and patterns of human evolution, technological innovation and behaviour over millennial timescales. The southern African landscape seen today, and the preserved imprint of its past human activities, resulted from the interplay between climate, tectonics and geomorphology over lengthy Cenozoic timescales.

1.1 Introduction

'The contemporary face of southern Africa owes much to events in the Cenozoic' (Partridge and Maud, 2000a, p3). Thus began the last significant book on the topic of Quaternary environmental change in the subcontinent, sixteen years ago. Although this assessment is still broadly true, advances in the fields of palaeoecology and geochronometry in particular have yielded a far more complex pattern of landscape development in southern Africa during the Cenozoic (66 Ma–present), and more widely from the late Cretaceous onwards. Recent research also highlights a degree of spatial and temporal complexity in patterns of climate and environmental change across southern Africa, and the proxies in which such records have been preserved, that has not been previously recognised (Meadows, 2014). This is especially the case for the Quaternary epoch (last 2.58 Ma; Gibbard and Cohen, 2008). These terrestrial records can also be supplemented by data from marine

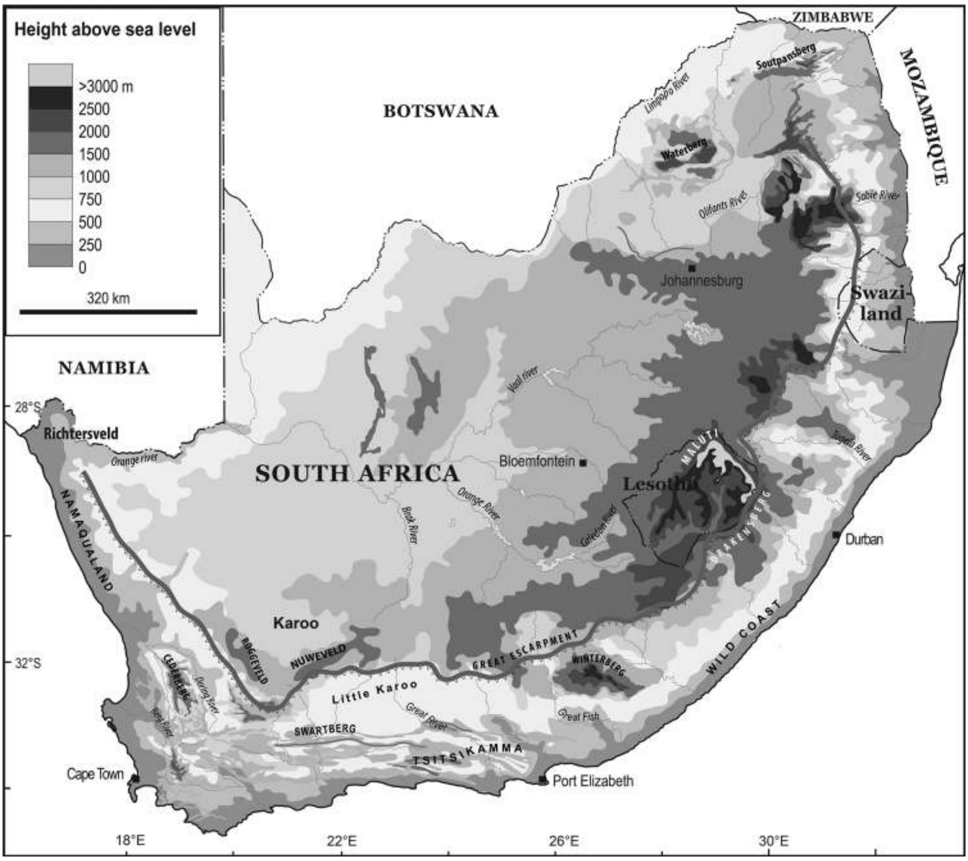

Fig. 1.1. Map of the topography of southern Africa (in m above sea level) and the location of the Great Escarpment (hatched line). Note that other key regional maps are presented elsewhere in this book: regional geology (Fig. 2.1), soils (Fig. 16.2) and ecosystems (Figs. 18.1, 18.2). A black and white version of this figure will appear in some formats. For the colour version, please refer to the plate section.

cores (e.g. *n*-alkanes, $\delta^{18}O$ and ^{13}C records); outputs from the advanced capabilities of climate and land-surface models; and real-time evaluation and modelling of climate and land surface variables on a scale and at a resolution that previously has not been available, based on satellite remote sensing datasets. In addition, there have been significant new palaeo-anthropological finds and modes of data analysis since 2000 that have informed on patterns of human evolution (Beaumont and Vogel, 2006). All of these represent significant advances from Partridge and Maud’s (2000b) volume that have increased the power and complexity of Cenozoic datasets. The contemporary topography, climate and environments of southern Africa are remarkably diverse (Figs. 1.1, 1.2), and thus it can be anticipated that climatic conditions in the past, and the geomorphological (landscape-shaping)

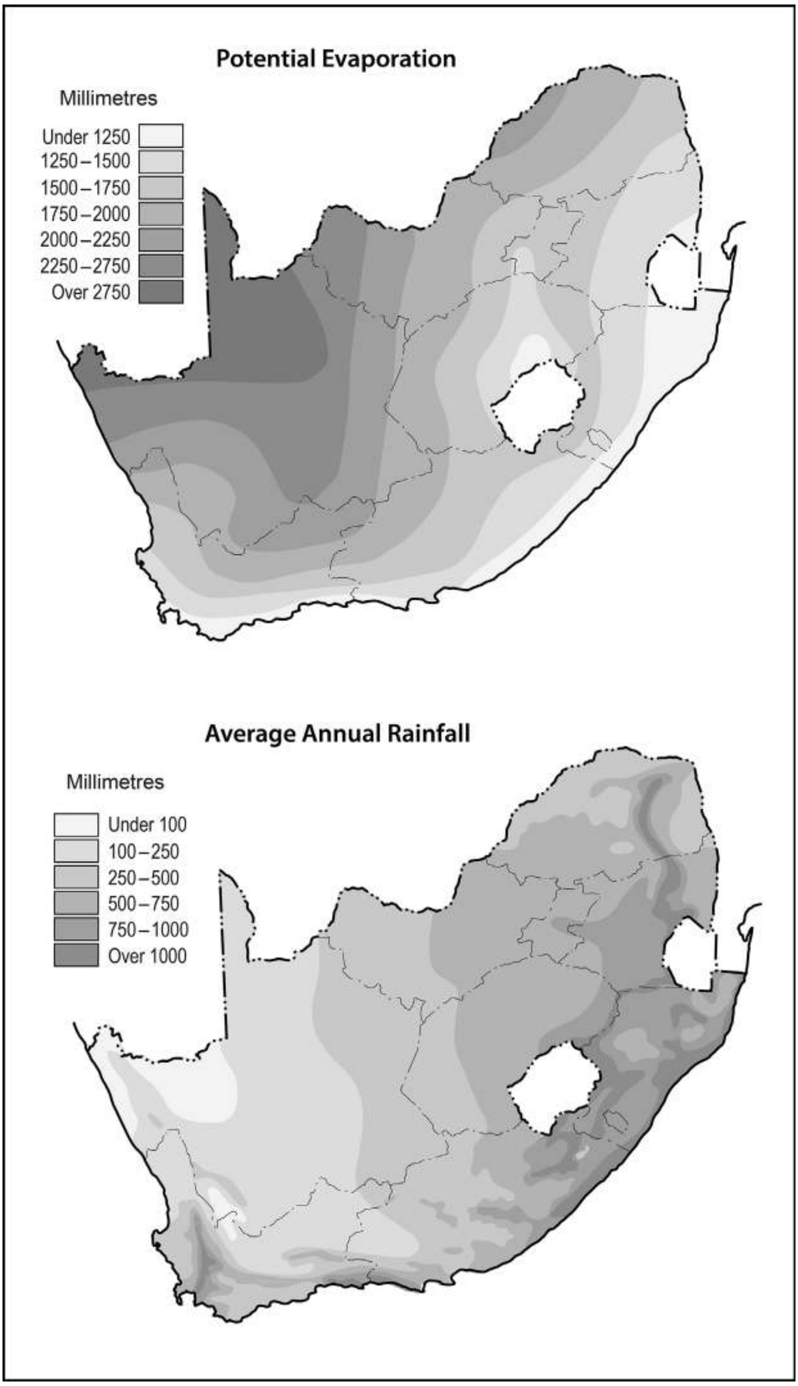

Fig. 1.2. Maps of key climatic features of South Africa, as expressed by potential evaporation (upper panel) and annual average rainfall (lower panel). The contrast between spatial patterns of these parameters shows that northwestern South Africa has a large moisture deficit, which has strongly impacted on geomorphological processes and landforms, ecosystems and the capacity for varied human activities in the region, including agriculture.

processes associated with them, were equally diverse. Many potential palaeoclimatic records in southern Africa remain unexploited, and research is now suggesting that African records, in particular during the Pleistocene, may record climatic events such as Dansgaard–Oeschger cycles and Heinrich events that were previously considered only to be a feature of northern hemisphere records (Itambi et al., 2009). Such results suggest that southern Africa is well placed to record variations in the strength of Southern Ocean overturn, as well as monsoon strength and position of the intertropical convergence zone (Garcin et al., 2007; McGee et al., 2014). These are some of the emerging areas of palaeoclimatic research in the subcontinent.

It can also be said that the 'contemporary face' of southern Africa has changed much since 2000. The impacts of human activity on all parts of the southern African landscape (Binns, 1997), on its geomorphological processes, and on its varied resources (including biodiversity and ecosystem services; soils, agriculture and food security; water security and water quality; waste management) are now recognised as significant issues, not just for environmentalism and landscape conservation and management, but more significantly as a major limitation to achieving sustainable socioeconomic development in the 21st Century (Cole et al., 2014; Ziervogel et al., 2014). Climate assessment reports published by the Intergovernmental Panel on Climate Change (IPCC) also highlight the vulnerability of sub-Saharan Africa to anthropogenic climate change (global warming), and that climate change over coming decades may result in significant, wide-ranging and yet poorly understood impacts on both physical and human environments (Niang et al., 2014).

It is in this wider context that this book is set: there is no more important time than now for developing a better understanding of the Quaternary context of landscape–human relationships in southern Africa. As scientists, we look to the past in both geologic, faunal and cultural records to help inform on the processes and sensitivities of the landscape and its contemporary peoples to future change, and this uniformitarian principle can help us when evaluating the challenges facing southern Africa, its landscapes and peoples, over coming decades (Ziervogel et al., 2014). This chapter considers the wider context of Quaternary environmental change in southern Africa and the nuanced and complex narratives now beginning to emerge from recent inter- and multidisciplinary research into landscape–human relationships. In detail, this chapter (1) discusses the geologic and geomorphic framework whereby such environmental resources are provided; (2) presents models of evolution of the southern African landscape during the Cenozoic, and in particular the Quaternary, that shaped today's landscape; and (3) considers the range of environmental resources offered by the southern African landscape that were (are) of relevance to past (present) patterns of human activity.

1.2 The geologic and geomorphic context of southern Africa

The geological history of southern Africa is exceptionally long, extending from 3600 million years ago to present, and covering a wide range of depositional and tectonic settings (McCarthy and Rubidge, 2005; Hunter et al., 2006). A timeline of critical geological and human evolutionary events over different timescales is given in Figure 1.3. Tectonic processes (continental accretion and rifting, epeirogenic uplift), magmatic processes (intrusion and extrusion of igneous rocks, metamorphism and mineralisation), sedimentary processes (basin formation and infilling), and climate change (land surface weathering and erosion) have been the major regional-scale controls on southern Africa's geological history and resulting rock types. The relationship between underlying geology, topography, geomorphology and climate is complex, and has been examined in several studies (e.g. Bishop, 2007; Partridge et al., 2010).

Cosmogenic dating of exposed and buried rock surfaces can inform on rates of land surface denudation and sediment accumulation, respectively (Decker et al., 2011). Dating studies from different physical environments and locations across southern Africa show different rates of land surface change that vary according to rock type, climate zone and tectonic setting (Portenga and Bierman, 2011), and mesoscale properties such as slope angle, and location relative to hilltops or river valleys (Bierman and Caffee, 2001). The lowest rates of land surface change are found on exposed but isolated summits of mesas, koppies and bornhardts (Bierman and Caffee, 2001), which are preserved largely because of high rock strength and low drainage density (Moon, 1990). Chadwick et al. (2013) demonstrated that landscape-scale weathering and erosion in river catchments of the Kruger National Park (northeastern South Africa) contribute to low but spatially consistent denudation rates of 3–6 m/myr, which are similar to those calculated by independent geochronometric methods. These authors argued that river drainage density and slope gradients within river catchments show a consistent relationship with precipitation, such that climate is the most important control on landscape evolution, rather than geology alone, and that long-term weathering and erosion contributes to downslope sediment supply and sediment yield to river basins, but that this is modified by local geology (Decker et al., 2013). There is a self-limiting relationship between weathering and erosion processes and the evolution of land surface topography. For example, over many footslope locations across southern Africa, an extensive colluvial mantle has developed (Watson et al., 1984), which attests to climatically driven denudation and slope instability from at least the mid-Pleistocene onwards (Dardis, 1990). Valley infilling and decreased slope angle through colluviation reduces slope instability and thus the rate of land surface change. Such a situation, often recorded by large cosmogenic exposure or burial

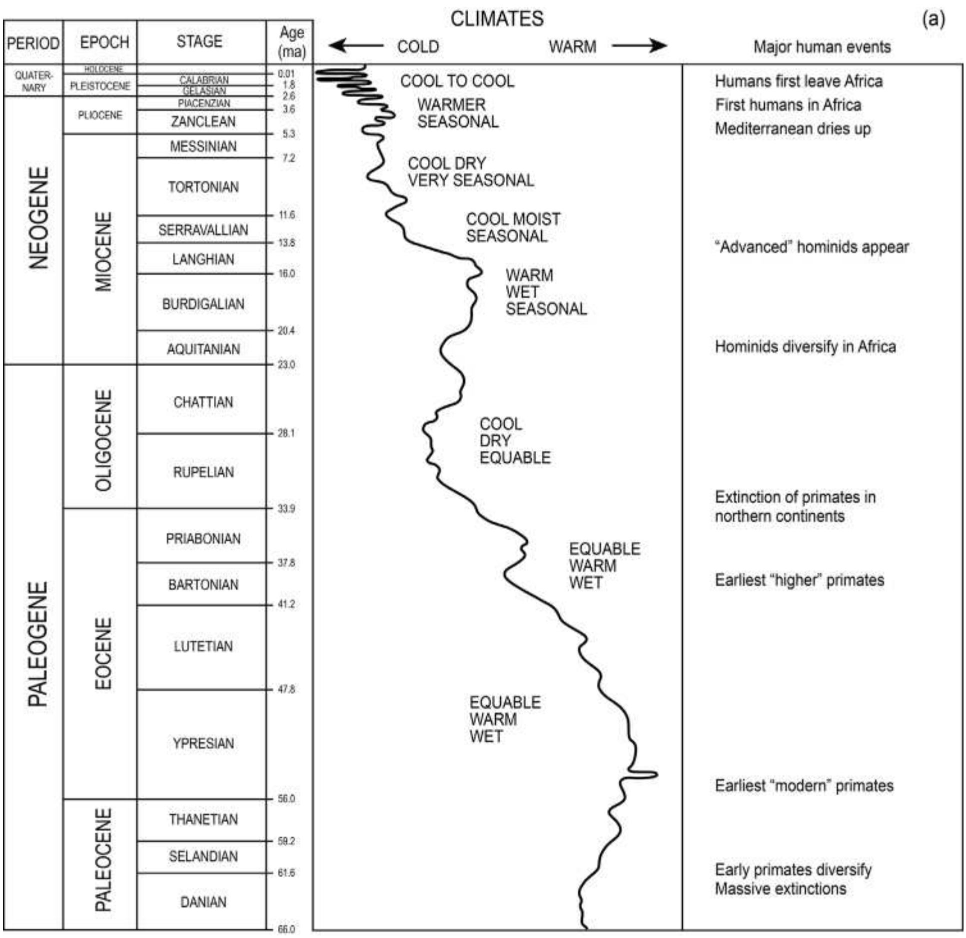

Fig. 1.3. (a) Simplified timeline of the Cenozoic (66 Ma to present), showing the major climatic and human events to have affected southern Africa (adapted from Partridge et al., 1995; geologic timescale from the Geological Society of America; www.geosociety.org/science/timescale/). Note that there is uncertainty on the timing and/or magnitude of climatic and human events. (b) Simplified timeline from the Middle Pleistocene (~460 kyr) to present; showing the δ^{18}O record from SE Atlantic core MD962094 (Stuut et al., 2002); and elemental Fe counts from SE Atlantic core ODP1083 (West et al., 2004), with the major human events over this timescale in southern Africa. LSA: Late Stone Age, MSA: Middle Stone Age. (c) Simplified timeline for the period 25 kyr to present, showing δ^{18}O values from Makapansgat (Limpopo Province, South Africa) speleothem record (Holmgren et al., 2003), where LIA: Little Ice Age, YD/H0: Younger Dryas/Heinrich event 0, H1: Heinrich event 1, H2: Heinrich event 2; principal component analysis scores for moisture variations from three sites (the continuous and dashed lines) at Braamhoek wetland (Free State, South Africa) (Scott et al., 2012), and major human events over this timescale in southern Africa. LSA: Late Stone Age, MSA: Middle Stone Age.

CAMBRIDGE
Cambridge University Press & Assessment
978-1-107-05579-7 — Quaternary Environmental Change in Southern Africa
Edited by Jasper Knight , Stefan W. Grab
Excerpt
More Information

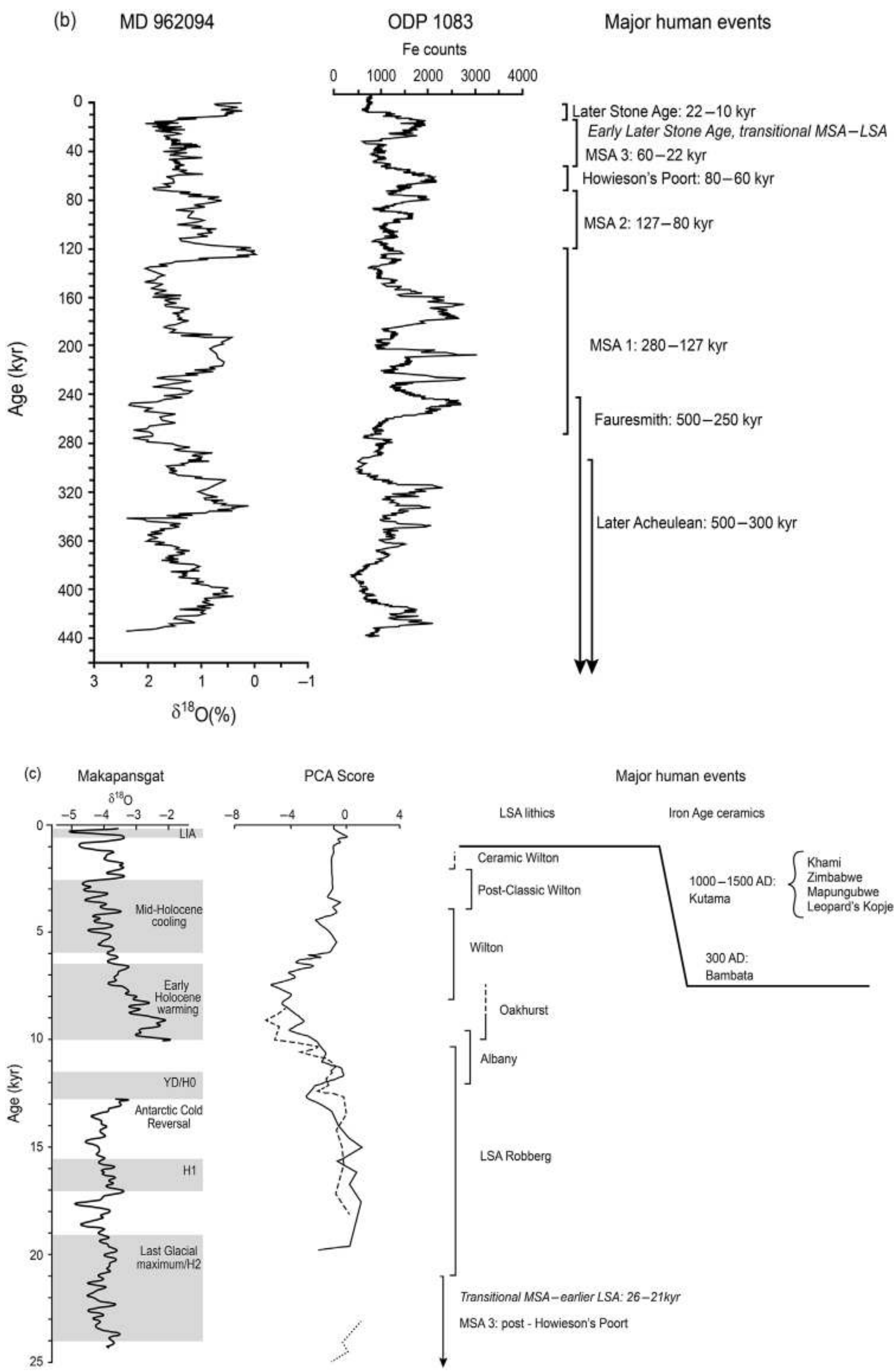

Fig. 1.3. (*cont.*)

ages (thus low denudation rates), does not reflect land surface stability at all, but rather low accommodation space in upland source areas. Cosmogenic dating, although critical for evaluating land surface evolution in southern Africa, has limited applicability where not all physical environments have been dated, or are capable of being dated, and where interpretation of cosmogenic dates is based on limited understanding of their geomorphological and sedimentary context.

However, this viewpoint of 'climatically controlled geomorphology' is but one approach. Other studies have argued that spatial and temporal patterns of land surface denudation in southern Africa can be explained by tectonic processes. For example, based on modelling, thermochronometric and cosmogenic dating evidence, episodes of tectonic uplift from the late Cretaceous onwards are followed by episodes of accelerated rates of land surface denudation (e.g. Braun et al., 2014). However, there are relatively large errors associated with the use of such evidence to calculate denudation rates, and many land surface feedbacks through the accumulation of weathering mantles, ecosystem and carbon cycle responses, and river system responses, are difficult to evaluate (de Wit, 2007).

1.3 Climate and environmental changes in southern Africa prior to the Quaternary

Climate and environmental changes of the late Cenozoic (Neogene; 23.0–2.6 Ma) in southern Africa are set within the wider context of ongoing tectonic evolution, speciation and ecosystem changes, and hominin evolution during this time period (Partridge et al., 1995). These linked changes are often difficult to distinguish in terms of cause and effect, within dating resolution, hence the causal relationships between these components are often still unclear or contentious in many cases (Lavier et al., 2001; de Wit, 2007; Jung et al., 2014). This poses an interpretive challenge with respect to identifying the relative roles of tectonics or climate in macroscale land surface evolution. For example, Cenozoic and pre-Cenozoic volcanism in southern Africa, associated with emplacement of the Karoo and Etendeka igneous provinces, led to considerable topographic land surface changes (Partridge et al., 1995; Phillips et al., 2000). In turn, this resulted in enhanced subsequent land surface weathering and erosion, and river water and geochemical export into surrounding oceans, affecting water chemistry, biotic processes, and hemispheric climate feedbacks (e.g. Roelandt et al., 2011).

Most evidence for Neogene environments and climates comes from isolated onshore and offshore depocentres where mineral and organic sediments have accumulated and been preserved (Fig. 1.4). Marine cores in the South Atlantic show palynological and sedimentary evidence for changes in zonal climate and atmosphere–ocean circulation patterns. For example, a drying trend in the Middle

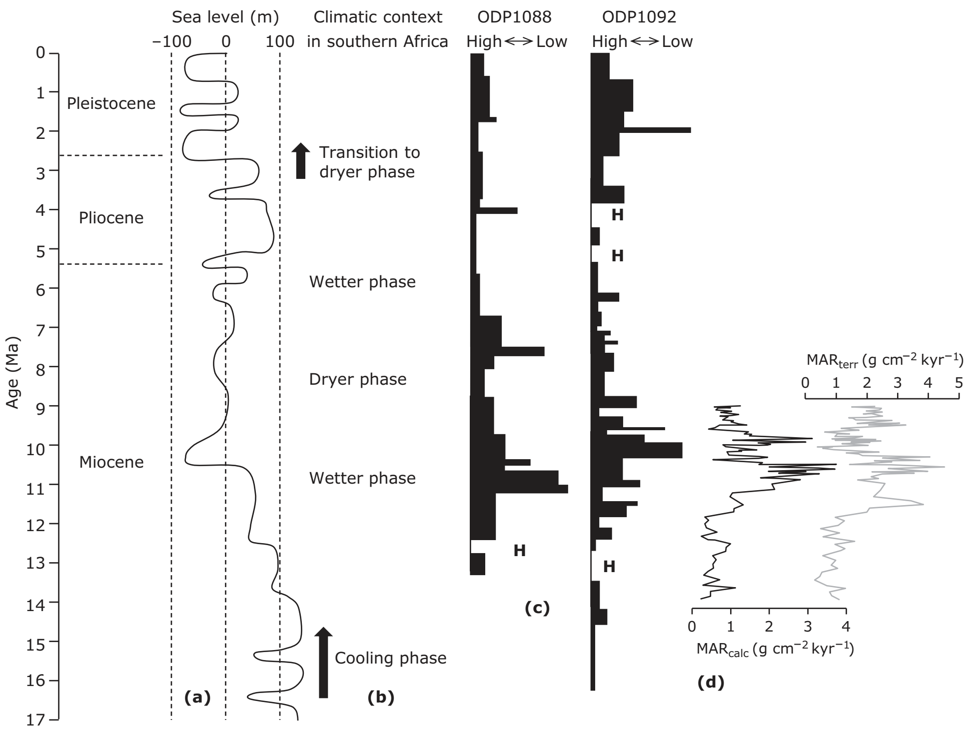

Fig. 1.4. Environmental changes during the late Cenozoic, with a particular focus on southern Africa. (a) Global sea level changes relative to present (Haq et al., 1987); (b) key regional climatic events (from various sources named in the text); (c) relative sediment accumulation rates at South Atlantic ODP sites 1088 and 1092 (Diekmann et al., 2003). H = hiatuses; (d) variations in marine accumulation rates (MAR) for calcium carbonate (calc) and terrigeneous (terr) debris (grey line), ODP1085A, offshore Orange River, South Atlantic (Roters and Henrich, 2010).

Miocene is marked by increased aeolian contribution to ocean sediments from the developing Namib Desert (Senut et al., 2009; Roters and Henrich, 2010), and land surface aridity in southwest Africa (Pickford et al., 2014). This period (around 14–11 Ma) matches with continental glaciation of Antarctica, the spread of cold Antarctic Deep Water, invigorated Benguela Current upwelling, and zonal atmospheric circulation (Jung et al., 2014). In the late Miocene and Pliocene, changes in Polar Front position over the Southern Ocean influenced rainfall seasonality in Namibia, including moisture source (Dupont et al., 2013). Increased winter rainfall and resulting Renosterveld vegetation displaced xerophytic savannah in Namibia as the Polar Front migrated northwards, increasing cold water advection and thus rainfall into the region (Dupont, 2006). This also had an impact on the distribution of C_3/C_4 flora (Franz-Odendaal et al., 2002; Ségalen et al., 2006) and on mammalian fossil assemblages found at key human evolution sites such as Swartkrans (Avery, 2001). Periods of aridity during the Miocene are marked by the development of silcrete and calcrete weathering profiles found on the African Surfaces, discussed later (Blumel and Eitel, 1994; Marker et al., 2002).

1.4 Models of landscape evolution in southern Africa

Cosmogenic dating has invigorated debate on land surface evolution models. These are of particular interest in southern Africa through the ground-breaking work of du Toit (1954) and King (1963). Initially, du Toit (1954, pp. 573–575) invoked Davisian ideas of cyclic episodes of landscape evolution, comprising Tertiary and Quaternary tectonic uplift and/or sea-level change around coastal fringes, followed by formation of peneplains at different levels, which were later incised. Later, King (1963, pp. 49–55) expanded on these ideas and discussed a 'landscape cycle' of pediplanation for the evolution of the southern African landscape. This 'pediplanation' involved a period of river incision followed by one of parallel scarp retreat. Using the Davisian evolutionary stages of youth, maturity and old age, King argued that the youth stage is dominated by river incision, and as this stage progresses, stream density decreases as rivers become larger. The maturity stage is dominated by scarp retreat as river valleys widen and flat land surfaces, inherited from the youth stage, reduce in size. In the old-age stage, opposing scarps meet each other and the resulting ridges gradually decrease in height, forming a low-relief landscape. King mentions some specific examples of these evolutionary stages from southern Africa, arguing that these stages can coexist in different areas.

The persistence of flat-lying surfaces in the landscape, equivalent to King's 'pediplains', has been long noted (Partridge and Maud, 1987, their Appendix A; Partridge, 1998). In broad age-order, these are the African Surface (Cretaceous age), Post-African I (mid-Tertiary), and Post-African II (late Tertiary) Surfaces (Fig. 1.5). Preserved remnants of earlier and later surfaces have also been identified. These surfaces have been used as important markers in the landscape evolution story of southern Africa, but the notion of time-equivalent and accordant surfaces is inherently problematic and involves substantial circular reasoning based on untestable hypotheses. For example, all accordant surfaces of the same altitude are argued to be of the same age and thus affected by the same spatially uniform tectonic regime. Surfaces located at different altitudes must therefore be of different ages or affected by different tectonic regimes. Surfaces are assumed to be of a single 'age' that represents a Davisian-style peneplain that is at equilibrium. The extent of land surface incision has also been used as an indicator of relative age (Partridge and Maud, 1987, 2000a). There are also implications for understanding