World Geomorphological Landscapes

Stefan Grab
Jasper Knight *Editors*

Landscapes and Landforms of South Africa

Springer

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Series Editor Preface

Landforms and landscapes vary enormously across the Earth, from high mountains to endless plains. At a smaller scale, nature often surprises us creating shapes which look improbable. Many physical landscapes are so immensely beautiful that they received the highest possible recognition—they hold the status of World Heritage Sites. Apart from often being immensely scenic, landscapes tell stories which not uncommonly can be traced back in time for tens of million years and include unique geological events such as meteorite impacts. In addition, many landscapes owe their appearance and harmony not solely to the natural forces. For centuries, and even millennia, they have been shaped by humans who have modified hillslopes, river courses, and coastlines, and erected structures which often blend with the natural landforms to form inseparable entities.

These landscapes are studied by geomorphology—'the science of scenery'—a part of Earth Sciences that focuses on landforms, their assemblages, surface, and subsurface processes that molded them in the past and that change them today. To show the importance of geomorphology in understanding the landscape, and to present the beauty and diversity of the geomorphological sceneries across the world, we have launched a book series *World Geomorphological Landscapes*. It aims to be a scientific library of monographs that present and explain physical landscapes, focusing on both representative and uniquely spectacular examples. Each book will contain details on geomorphology of a particular country or a geographically coherent region. This volume presents the geomorphology of South Africa—a country that not only hosts superb and highly diverse landforms and landscapes—basaltic plateaus, imposing escarpments, inselbergs, intriguing sandstone formations, waterfalls, pans, and dunes, but can also be considered as one of the inspirations for modern geomorphological studies, especially that focus on long-term landform evolution. Landscape evolution models associated with workers such as Lester King, which profoundly influenced the thinking of many mid-twentieth century geomorphologists, have been developed in South Africa. In more recent times, since the 1990s, it was South Africa where their reappraisal has been attempted through cosmogenic dating.

The World Geomorphological Landscapes series is produced under the scientific patronage of the International Association of Geomorphologists (IAG)—a society that brings together geomorphologists from around the world. The IAG was established in 1989 and is an independent scientific association affiliated with the International Geographical Union (IGU) and the International Union of Geological Sciences (IUGS). Among its main aims are to promote geomorphology and to foster dissemination of geomorphological knowledge. I believe that this lavishly illustrated series, which keeps to the scientific rigor, is the most appropriate means to fulfill these aims and to serve the geoscientific community. To this end, my great thanks go to Profs. Stefan Grab and Jasper Knight for adding this book to their agenda, successfully coordinating the large team of authors, and delivering such an exciting illustrated story to read and admire. I hope they are as pleased with the final outcome as I am. I also acknowledge the excellent work of all individual authors who accepted to share their expert knowledge of the country with the global geomorphological community. I once happened to spend a day at the foot of the Drakensberg Escarpment, which was an unforgettable experience. Now I have nearly 20 other places in South Africa to visit. I am sure readers of this volume will be equally tempted to see these marvels for themselves.

Piotr Migoń

Preface

The landforms and landscapes of South Africa present a long and diverse geological history and have been of interest to geologists and geomorphologists since Charles Darwin's visit to the Western Cape region in the 1830s. Later, the discovery and then exploitation of many metaliferous and mineral deposits including gold, platinum, and diamonds brought geologists and engineers who, as a result of mining activities, have transformed landscapes in many parts of the country but also inspired much scientific investigation, creating a geomorphological legacy that is still present today. Much work on the landforms and landscapes of South Africa has thus been achieved by incomers from Europe; here, we intend to showcase South African geomorphology to the world and provide the context for inspiring, empowering, and training a new generation of South African students and scientists to make such studies their own—an aim we try to set forth in our own research and teaching at the University of the Witwatersrand, Johannesburg.

South Africa's landscapes are very diverse, not only in their geological history, but in terms of geomorphological processes, ecosystems, land use, and relationships to cultural patterns. These relationships are explored in many chapters in this book, and are explicit in the inscription of many South African landscapes as UNESCO World Heritage Sites, including Mapungubwe Cultural Landscape (inscribed 2003), Richtersveld Cultural and Botanical Landscape (2007), and Maloti-Drakensberg Park (2000). We describe the relationships between different landscape components, and the context of different chapters in this book, in our introductory Chap. 1, to which readers are referred.

We thank all of the chapter authors and peer-reviewers of these chapters for their hard work and excellent contributions. We also thank series editor Piotr Migoń for his encouragement and rigor, Wendy Phillips for drawing many maps, and the National Research Foundation (South Africa) for supporting our South African geomorphological research.

Stefan Grab
Jasper Knight

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1

Landscapes and Landforms of South Africa—An Overview

Stefan Grab and Jasper Knight

Abstract

This chapter introduces the broader context for the diverse South African landscapes and landforms discussed in this book. We briefly summarize South Africa's long geological history, demonstrating that some of the earliest known geomorphic events on Earth are preserved as geological artefacts within the contemporary landscape. Both earlier and more recent theories of landscape evolution are then highlighted, in particular given that some of these were locally founded but applied globally. It is demonstrated that much of the South African macroscale geomorphology and site-specific landform development is controlled not only by geology, but also by past epeirogenic uplift, influencing river divides and drainage networks, and also a regionally diverse climate. Finally, the association between people and landscapes is emphasized as an important theme covered throughout this book.

Keywords

South Africa • Geology • Climate • Geomorphic evolution • Geoheritage

1.1 Introduction

South Africa boasts an extraordinarily diverse range of landscapes and landforms which are the product of an exceptionally long geologic and climatic history. While some of South Africa's landscapes are among the oldest in the world, being underlain by a Pangaea-age continental craton, other landscapes reflect contemporary geomorphological processes and the effects of ongoing climate change. In addition, the varied climate zones and ecosystems across South Africa have given rise to a very diverse contemporary land surface which reflects both past and recent geologic processes as well as the imprint of human activity over long timescales. South Africa's rich geological and mineral resources, such as gold, platinum and diamonds, have also been a primary trigger for geological investigation. Early European explorers, building from indigenous knowledge and prehistoric mineral explorations, were concerned with mapping these resources; indeed, the city of Johannesburg was founded on the wealth of gold mining of the Witwatersrand reefs (Rosenthal 1970). Other commentators have been concerned with landscape features of South Africa. For example, Charles Darwin visited Cape Town in June 1836 aboard *H.M.S. Beagle* and noted in his diary of 2 June, with respect to Table Mountain, that 'I should think so high a mountain… must be a rare phenomenon; it certainly gives the landscape a very peculiar, and from some points of view, a grand character'.

From the early twentieth century, many world-renowned geologists and geomorphologists, like Alexander du Toit, John Wellington, Lester King, Charles Twidale and Andrew Goudie, have used South Africa as a natural research laboratory for developing and testing theories of long-term landscape evolution. This includes du Toit's work on the break-up of Gondwanaland, and King's model for cycles of macroscale land surface erosion (Fig. 1.1; e.g. King 1955). This theme has continued to the present day, with examples such as models of pan evolution (Goudie and Wells 1995) or models of land surface denudation that nod to decades-old ideas of planation surfaces, but which are based here on the use of cosmogenic

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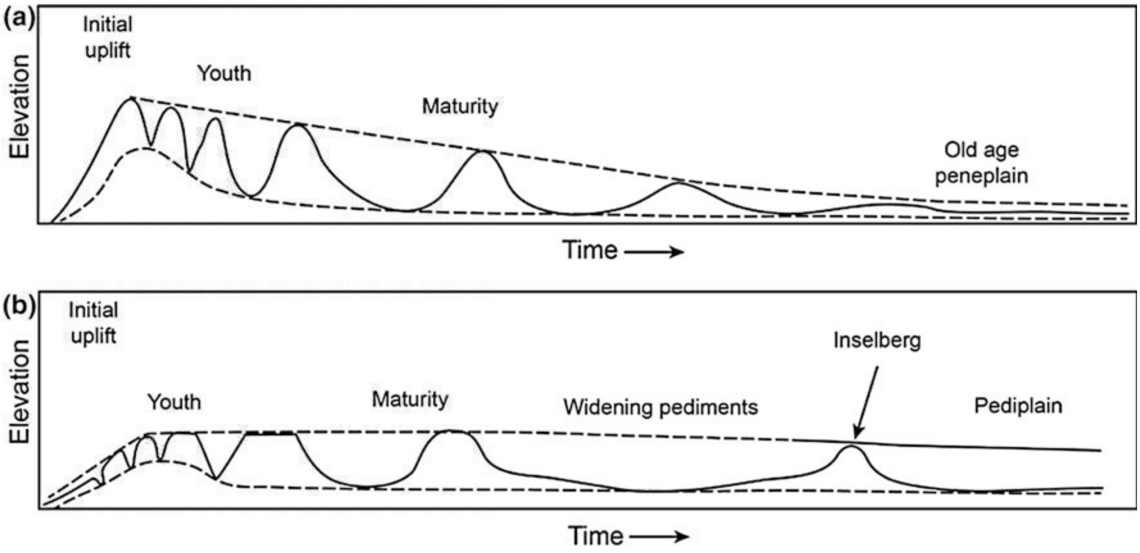

Fig. 1.1 Sketch of common landscape evolution models that have been applied to the South African landscape. **a** The Davisian model, whereby the land surface erodes downwards over time, producing a low-relief peneplain; **b** the King model whereby valleys widen over time as a result of parallel slope retreat, leading to the formation of isolated inselbergs separated by a sloping rocky pediplain (see also Fig. 1.5)

radionuclides (Bierman and Caffee 2001). In that context, therefore, studies of the geology and geomorphology of South Africa draw from a long tradition, but are increasingly focused on twenty-first-century issues of landscape sensitivity, resource management and sustainability, and the impacts of climate change (e.g. Beckedahl et al. 2002). This book helps contextualize these two complementary viewpoints of the South African landscape and its evolution.

Several previous books have included chapters outlining the geological and geomorphological evolution of the South African landscape, reflecting our understanding at the time of publication (e.g. Moon and Dardis 1988; Partridge and Maud 2000a; Holmes and Meadows 2012). This chapter will not repeat such discussions because each chapter in this book takes a geographically specific area and describes or accounts for landscape-scale geomorphology and evolution within the respective area, and does so with reference to the bigger picture of geoheritage and cultural heritage, conservation and tourism. The geographical spread of areas discussed within chapters of this book (Fig. 1.2) means that most areas of South Africa and its geodiversity are covered, including important or iconic tourist sites such as Table Mountain and Kruger National Park.

1.2 Geological Overview

Early Archean rocks exposed in the Barberton area of South Africa represent one of the world's best-known greenstone belts (Fig. 1.3). Despite their age (~2.9–3.2 Ga), these metamorphosed volcanic–sedimentary sequences, which were initially a product of oceanic spreading centres, reveal some of the earliest known geomorphic events on Earth. For instance, the Earth's oldest known siliciclastic (carbonate) tidal deposits have been described from this region (Noffke et al. 2006), as is also the oldest known glaciation (2.9 Ga; Mozaan Group), evidenced by diamictites with striated and faceted clasts contained within stratified siltstone and interpreted as ice-rafted debris (Young et al. 1998). Sedimentary rocks of the Early Proterozoic (~2.2 Ga; Pretoria Group, Magaliesberg Formation) also provide good evidence of subtidal channel systems and ephemeral braid-delta processes, which indicate high-energy macrotidal dynamics and high tidal range during deposition (Button and Vos 1977; Eriksson et al. 1995).

Following evolution of the Kaapvaal Craton, a long accretionary geological history associated with crustal extension and compression continued through to the Neogene (Partridge and Maud 2000b). This period broadly encompassed subsidence from the vertical motion of rigid basement blocks with periods of basin infills which were temporally separated by volcanic episodes. Most sedimentary rocks in South Africa are products of infilling, such as of the Main Karoo Basin and its subsidiary basins such as the Springbok Flats Basin, Ellisras Basin, Waterberg Basin and Tuli Basin. The Karoo Basin developed in south-western Gondwana during the Late Carboniferous, extending well beyond the contemporary southern African continental margin. Subsequent infilling of the basin yielded a total stratigraphic thickness of ~12 km, and although much of this has been subsequently eroded, the Supergroup currently crops out over more than half of South Africa (~600,000 km^2), from the Cape fold belt (a product of active margin development during the Early Paleozoic) in the south-west to the Kaapvaal Craton

Fig. 1.2 Geographic locations of sites discussed in different chapters of this book. Numbers refer to chapter numbers (Chaps. 2 and 19 are applicable countrywide and thus not indicated here)

in the north (Smith 1995). The sandstone succession of the Karoo Basin accumulated from the Late Carboniferous (~300 Ma) to the Early Jurassic (~190 Ma) and was influenced by significant global-scale climate changes. The early Karoo foreland basin was bounded by the Cape fold belt in the south and the Cargonia Highlands in the north, and between these mountains, Dwyka-age glaciers eroded deep valleys and deposited large thicknesses of glacigenic diamicton and glaciofluvial sediments (Isbell et al. 2008). Karoo sedimentation eventually terminated during the early phases of basaltic outpourings around 183 Ma ago. Volcanicity was associated with continental rifting, which also yielded abundant dolerite dyke and sill intrusions through the entire Karoo Sequence. Volcanic activity eventually ended at ~105 Ma (Eales et al. 1984). The coastline of southern Africa, similar to that known today, emerged as South America; the Falkland Plateau and Antarctica separated from southern Africa in the period ~129–121 Ma (Fouché et al. 1992).

1.3 Geomorphic Evolution of the Southern African Landscape

The geologic history of South Africa and the development of its topography and landscapes are very closely linked, particularly over the Cenozoic (last 66 Ma). Debate on the topographic evolution of South Africa over this timeframe has been focused around the development of different models of landscape evolution, based on its tectonic position as a high-elevation passive continental margin. Unfortunately, there has

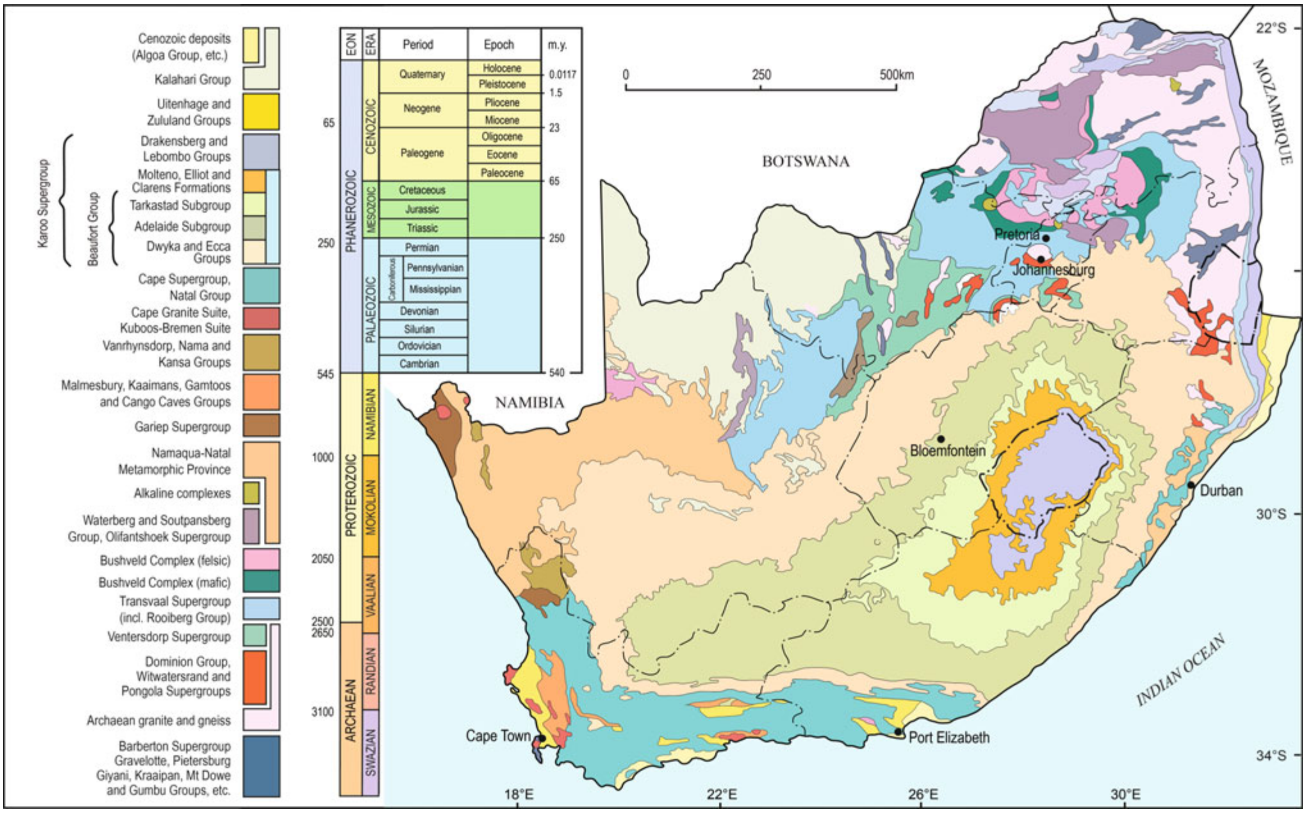

Fig. 1.3 Geological map of South Africa (modified after Council for Geoscience 1997)

been less work to test these models based on empirical evidence from the field.

Regional-scale models of landscape evolution have broadly focused on (a) tectonic lowering of the continental margin and (b) escarpment retreat and land surface denudation (Bishop 2007). Prominent outward-facing escarpments (including the Great Escarpment) that are still parallel to the southern African coastline (and are now located some 50–200 km inland; see Chaps. 3 and 6) were initially considered to be a product of lithospheric rebound following continental rifting and extensive post-Gondwana erosion of the land surface (e.g. Partridge 1998; Gilchrist and Summerfield 1990). According to Partridge (1998), humid climates during the Early Cretaceous enhanced continental weathering, erosion and development of a dense terrestrial drainage network. River erosion of the land surface helped drive backwasting of the Great Escarpment towards the continental interior and resulted in the formation of undulating or gently sloping benches across the widening coastal hinterland. Contrasting base levels of erosion were established on either side of the Great Escarpment. Landwards of this major topographic barrier, base level is provided by major rivers such as the Limpopo and Orange (or Gariep) (see Chap. 8). Seawards of the Great Escarpment, base level is that of sea level. Consequently, erosional surfaces of similar age, yet of contrasting altitude, were able to develop, and to a large extent, these still remain today and include the high plateau (pediplain; Figs. 1.1, 1.4 and 1.5) of central southern Africa and the lower-altitude coastal plains. This view differs from that of King (e.g. 1944, 1967), who grouped these erosion surfaces and referred to them as an older ‘African surface’ and a younger (and lower elevation) ‘post-African surface’. He compared sediment build-up in coastal regions to argue that the ‘African surface’ graded to sea level during the Late Cretaceous to Early Miocene. King (1955) additionally proposed that such crustal erosion prompted isostatic uplift of the continental margin, thus adding elevation to the Great Escarpment. These debates on the nature of land surface evolution over large spatial and long temporal scales have been at the heart of developments in geomorphology during the twentieth century. The model of W.M. Davis involves land surface denudation by weathering and transport of weathered products along river valleys that widen over time. The resulting low-relief peneplain reflects land surface quasi-stability (Fig. 1.1a). The model of Lester King involves parallel slope retreat whereby valleys widen over time, leading to the formation of isolated inselbergs separated by a sloping rocky pediplain (Fig. 1.1b). These models, among others, provide hypotheses for land surface evolution that can be tested against field geomorphic, sedimentary and dating evidence.

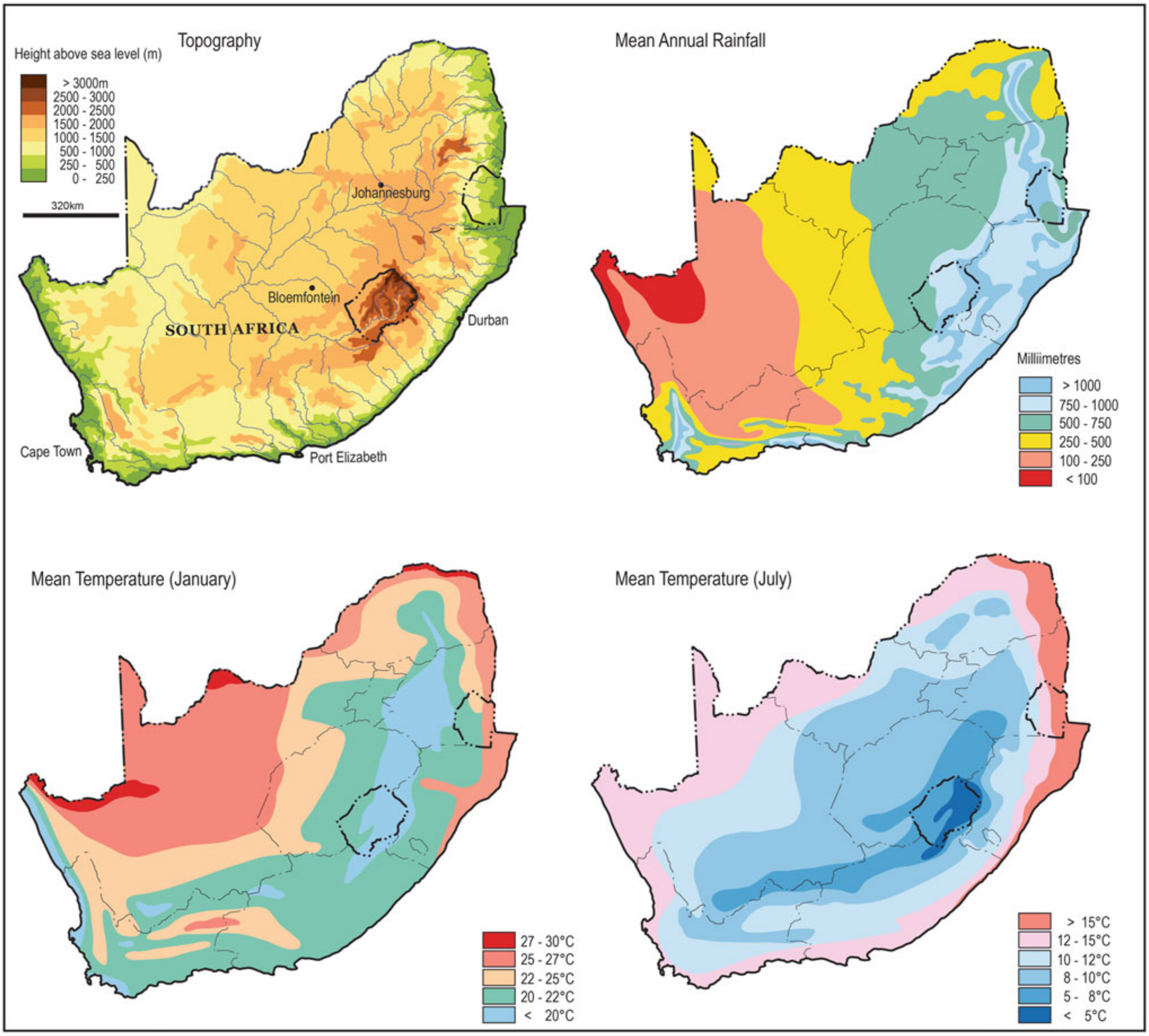

Fig. 1.4 The topography and climate of South Africa

More recently, apatite fission track (e.g. Brown et al. 2002; Tinker et al. 2008) and apatite/titanite U–Th/He geochronometric dating (Flowers and Schoene 2010) have strongly challenged the km-scale initial post-Gondwana denudation rates as argued by King, but rather propose negligible erosion since the Cretaceous. Japsen et al. (2012) use evidence of Cenozoic marine strata and the presence of tilted and truncated Upper Cretaceous sediments off the west coast of South Africa to argue that much of the contemporary land surface elevation is due to post-rift uplift. To this end, southern African drainage systems have been noted for their major reorganization since Gondwana, based on isopachs (stratigraphic thicknesses) in the Kalahari and the numerous palaeo-drainage features over the central interior (Moore and Larkin 2001). Given that major river divides cut across geological boundaries, lithology is not the only drainage control. Rather, much of the regional macroscale topography has been influenced by concentric (i.e. broadly parallel to the southern Africa coastline) epeirogenic uplift in connection with plate-boundary reorganization (Moore et al. 2009). Major uplift events during the Cenozoic have thus shifted river divides and their associated fluvial drainage networks, and consequently controlled cyclic episodes of denudation. The contemporary macroscale topography may thus be more a reflection of plate processes and dynamics (Moore et al. 2009) rather than the longer-standing idea of rising mantle plumes (e.g. Partridge 1997; Burke et al. 2008). Further radiometric dating of the land surface and exposed rocks across southern Africa will help evaluate these competing models.

Fig. 1.5 Karoo pediplain on the high plateau, with a dolerite-capped inselberg in the centre (Mountain Zebra National Park); see also Fig. 1.1 for the Karoo region (*Photograph* S. Grab)

1.4 Geological and Structural Controls on Landscapes/Landforms

The foregoing discussion considered that geology and geologic history have exerted a strong control on the macroscale evolution of South Africa. Many chapters in this book provide good case studies that illustrate these relationships on a meso- to microscale. For example, tectonic history and long-term patterns of land surface denudation are key controls on the geomorphology of Vredefort (Chap. 4) and Pilanesberg (Chap. 5). Microscale weathering processes are important geomorphic controls on sandstones (Chap. 2) and in coastal environments (Chap. 7). The chapters in this book also illustrate important geologic principles of scale (both spatial and temporal), process–form relationships, inheritance, time lags and equifinality. For example, the preservation of old plateau surfaces behind very active slopes, and the inland migration of river knickpoints (Chaps. 3 and 8) illustrate the range of rates at which weathering and erosion can take place, even within the same area. The macroscale geomorphic evolution models of King and others thus still resonate in today's South African landscapes, where geomorphic principles can be seen in action.

1.5 Climate Controls on Landscapes/Landforms

South Africa has a varied climate, both spatially and temporally (Fig. 1.4). Most of South Africa (apart from the south-western Cape) is situated within the summer rainfall zone with a distinct rainy season from November to March, and dry season from May to September. Summers are typically warm and humid along the east coast, and dry and very hot towards the western and northern regions. Summer rains are mostly associated with tropical–temperate troughs and easterly tropical air flow over the interior. A high-pressure system dominates over the interior during winter (June to August), resulting in cold, dry conditions. In contrast, the south-western Cape has a Mediterranean-type climate with wet winters associated with the passage of southerly polar cyclones. However, topographic influences such as the Great Escarpment and Cape Fold Mountains have strong regional and microscale controls on precipitation, humidity, airflow and temperature (e.g. Chaps. 9, 11 and 12). Generally, highest annual precipitation (>1,000 mm) occurs along the eastern sectors of the Great Escarpment and along the southern and eastern coastal belts, while rapid drying occurs landwards of the Great Escarpment which acts as a rain shadow. Northern and western parts of the country receive below 500 mm of precipitation annually, and most of the interior plateau has a net moisture deficit. Snow occasionally occurs along the higher mountain ranges during colder months, and severe frost (below −10 °C) is possible over the plateau in winter. South Africa thus has a diverse climatic influence on contemporary landform development, ranging from hyper-arid, hot aeolian (Chaps. 9 and 15) to cool periglacial (Chap. 6). Region-specific weathering and erosion are also strongly contrasting and climate linked (e.g. Chaps. 2, 8, 10 and 13).

South Africa has also undergone substantial regional climate fluctuations and changes, and sea level changes, through the Cenozoic (see Partridge and Maud 2000b), which geomorphologically is manifested through the

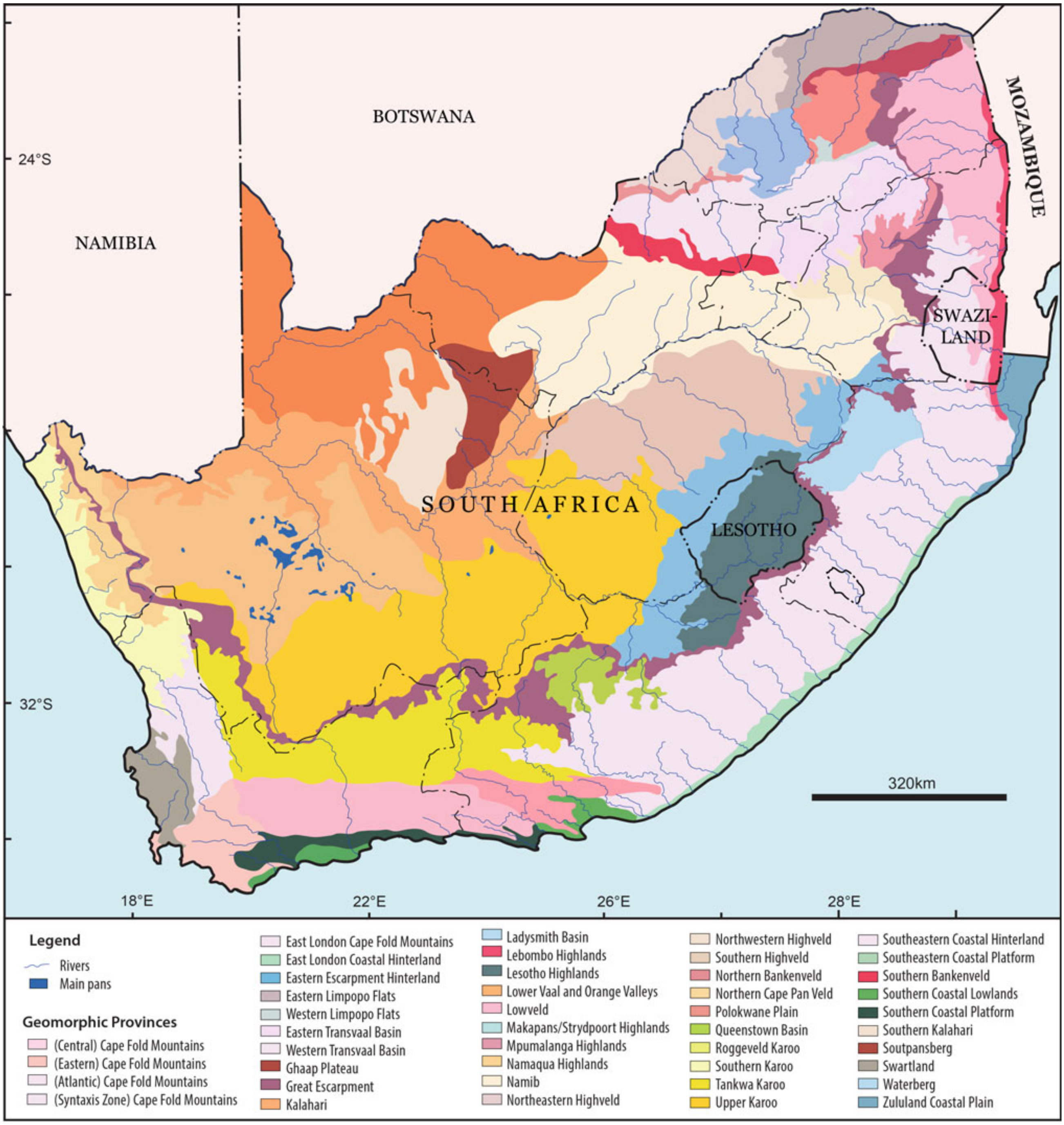

Fig. 1.6 The geomorphic provinces of South Africa (redrafted after Partridge et al. 2010)

preservation of palaeo-landforms such as Late Quaternary glacial deposits (Chap. 6), raised and contemporary coastal shore platforms (Chap. 7), raised Pliocene shorelines and ancient coastal lakes and dunes (Chap. 14), arid zone pans, dunes and palaeo-drainage systems (Chaps. 9, 15 and 16), and subterraneous karstic deposits (Chaps. 3 and 17), to name a few. Using a hierarchy of criteria including geomorphic history, geological structure, climate, location and altitude, Lester King originally delineated 26 geomorphic provinces for southern Africa, but later refined these to 18 (King 1942, 1967). More recently, Partridge et al. (2010) identified 34 geomorphic provinces and 12 subprovinces based on new digital terrain model (DTM)-derived data and statistical techniques which placed a strong focus on drainage structure and slope (Fig. 1.6). These classifications, however, are unable to adequately incorporate local-scale