Chapter 1

Geomorphology of Desert Environments

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The Concept of Desert Geomorphology

The notion that the desert areas of the world possess a distinct geomorphology has a long history and, in many ways, is informed by the popular concept of deserts as places that are different. Not surprisingly, early explorers in deserts, particularly Europeans travelling in the Sahara from the late 18th century onwards, were impressed by, and reported on, the unusual features of these areas. Rock pedestals, sand dunes, and bare-rock hills rising almost vertically from near-horizontal, gravel-covered plains all contributed to the impression of a unique landscape. This spirit of exploration in a totally alien landscape continued into the 20th century, so that as late as 1935 R.A. Bagnold wrote of his travels in North Africa during the preceding decade under the title *Libyan sands: travels in a dead world* (Bagnold, 1935). Emphasis on the unusual and remarkable landforms of desert areas and a coincident emphasis on the hot tropical deserts had a profound impact on attempts to explain the geomorphology of deserts.

Of particular influence in shaping a view of the uniqueness of desert geomorphology, due in large measure to his influence in shaping geomorphology overall, was W.M. Davis who was sufficiently persuaded of the distinctiveness of desert landscapes that in 1905 he published his cycle of erosion in arid climates. Davis held the opinion that, notwithstanding the infrequency of rainfall in desert areas, the landforms resulted primarily from fluvial processes. Only towards the end of his cycle of erosion did aeolian processes come to play a dominant role. Subsequently, there was substantial debate on the relative importance of fluvial and aeolian processes in desert landform evolution, and only in recent times has there been a recognition of, and attention paid to, the links that exist between aeolian and fluvial processes (e.g. Bullard and Livingstone, 2002) and the extent to which desert landforms owe their character to these two sets of processes acting in concert (e.g. Parsons et al., 2003). However, whether through agencies of wind and/or water, the essence of Davis's viewpoint, namely that arid areas are subject to a unique cycle of erosion, was maintained for much of the 20th century in the work of, for example, Cotton (1947) and, in a wider context, in the many writings that stem from the concept of climatic geomorphology (e.g. Birot, 1960; Tricart and Cailleux, 1969; Budel 1963).

As the emphasis in geomorphology moved, in the latter part of the twentieth century, away from cycles of erosion and morphogenesis within specific areas towards the study of geomorphological processes, the distinctiveness of desert geomophology was undermined. Thus, in his study of the anabranching of Red Creek in arid Wyoming (mean annual precipitation of 165 mm) Schumann (1989) drew a parallel between the flashy regime of this river and that of the Yallahs River studied by Gupta (1975) in Jamaica, where the mean annual rainfall exceeds 2000 mm. Likewise, Abrahams and Parsons (1991) compared their finding that resistance to overland flow is related to the concentration of gravel on hillslope surfaces in southern Arizona (mean annual precipitation of 288 mm) to similar findings by Roels (1984) in the Ardeche basin, France (mean annual rainfall of 1036 mm).

In the minds of many (e.g. Young, 1978 p.78) emphasis on short-term, small-scale processes was

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no more than a stepping stone in the history of geomorphology towards an improved understanding of landscapes. However, making the link back from the greater understanding of geomorphological processes that has been achieved in the past half century to a more informed and quantitatively based understanding of landscape evolution has proven to be more complex than at first envisaged (Sugden et al., 1997). Consequently, although geomorphology has showed renewed and increasing interest in long-term landscape evolution (Summerfield, 2005), particularly in response to the development of techniques to date landscape surfaces and deposits, progress in tying such quantitative information on rates of landscape change to process mechanisms has been both limited, often focused within the confines of individual process domains, and poorly linked to the growing record of climatic oscillations.

Central to the concept of desert landforms and landform evolution is the assumption that similarities of climate throughout desert areas outweigh differences that may arise from other influences and similarities (such as those that arise from tectonic history or character of the substrate) that transcend climatic setting. This assumption may be challenged not only from the perspective of the relative importance of other influences and similarities (see Mabbutt, 1977) but also from an assessment of the geomorphological significance of the supposed similarity of desert climates.

Desert Climates

In scientific terms, deserts are usually defined in terms of aridity. However, providing a universally acceptable definition of aridity upon which to base a definition of desert areas has not been straightforward. Several attempts based upon a variety of geomorphic, climatic, and/or vegetational indices of aridity have been made to identify the world distribution of deserts. The UNEP World Atlas of Desertification (UNEP, 1997) classifies deserts on the basis of an Aridity Index. This index is derived from monthly data on temperature and precipitation (P) over the period 1951–1980 for a worldwide network of meteorological stations. From the temperature data, together with monthly data on daylight hours, potential evapotranspiration (PET) is calculated. The aridity index is simply the value of P/PET. For purposes of mapping (Fig. 1.1) the Aridity Index is classified into four:

Hyperarid regions – $P/PET < 0.05$
Arid regions – $0.05 < P/PET < 0.2$
Semi-arid regions – $0.2 < P/PET < 0.5$
Dry-subhumid regions – $0.5 < P/PET < 0.65$

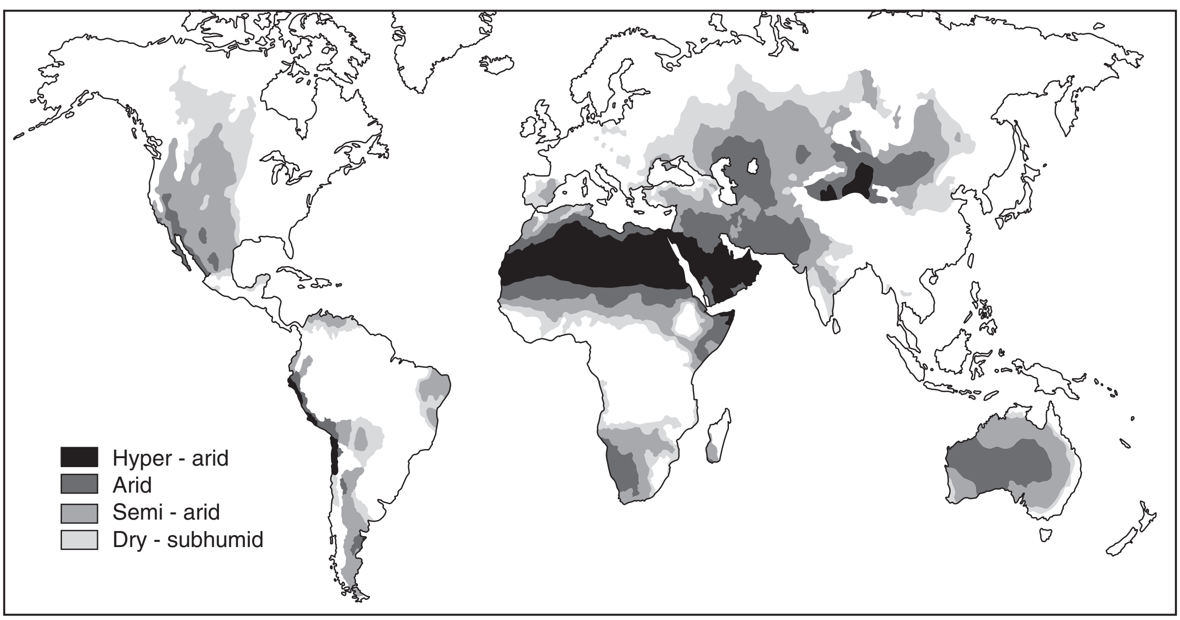

Fig. 1.1 World distribution of deserts (adapted from UNEP 1997)

Table 1.1 Land areas in each of the four Aridity Classes defined by UNEP (1997)

Aridity Class	World Land Area (%)
Hyperarid	7.5
Arid	12.1
Semi-arid	17.7
Dry subhumid	9.9

Global land area in each of these four aridity classes is given in Table 1.1.

To what extent, however, are these aridity zones geomorphologically meaningful? As the subsequent chapters of this book will show, it is not aridity *per se* that is of significance for geomorphological processes in deserts. Rather it is the availability of moisture and the timescales of that availability that matter: directly so in the case of water-driven processes, and indirectly so in the case of aeolian processes through the effects of water availability on vegetation cover.

Similarly, the lack of any simple relationship between current aridity and present-day geomorphological processes raises questions about the inferences that may be drawn from palaeoclimatic information for the geomorphological inheritance of deserts. While it has been recognised that the world's deserts have very different climatic histories (Thomas, 1997; Fig. 1.2), the broad geomorphological implications of these different histories, couched as they are in terms of varying aridity, are far from obvious and almost certainly not straighforward. Indeed questions must arise about the data upon which climatic histories are based. Where the data are drawn from evidence based upon geomorphological processes, then their interpretation in terms of simple aridty may be suspect. On the other hand, where the data come from other climatic sources or proxies, their value in explaining the suite of landforms extant today is dubious.

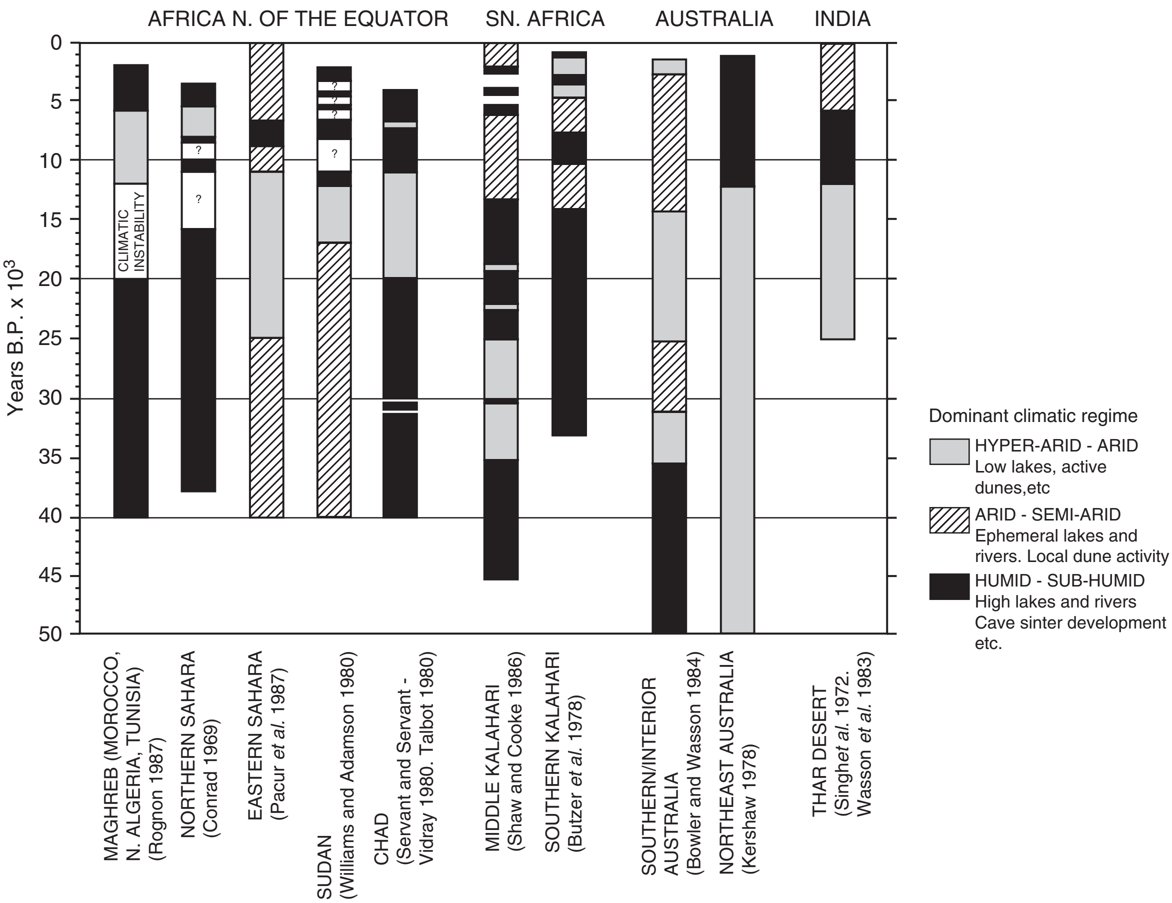

Fig. 1.2 Late Quaternary climatic changes in the world's desert areas (after Thomas 1997)

Is There a Geomorphology of Deserts?

If general scientific notions of aridity are insufficient to characterize a geomorphology of deserts, then what is? Two arguments may be made. The first is that employed by practitioners of geomorphology. A number of geomorphologists focus on the geomorphology of deserts. Whether these geomorphologists are interested in rivers, sand dunes or weathering processes, the environmental context – that is, the totality of desert geomorphology – will be pertinent to their study. There is a geomorphology of deserts because those who study component aspects of it need the totality to exist. The second argument is that which derives from the landscape itself. Notwithstanding all the problems that may be encountered in defining a set of unique and characteristic landforms for the world's arid lands, the fact remains that along transects, either equatorward from temperate areas or poleward from the wet tropics, there are progressive climatic and vegetational changes. Along these transects (i) rainfall diminishes in amount and becomes less frequent, and more sporadic, (ii) vegetation becomes smaller and patchy, and (iii) bare ground becomes more common. Desert geomorphology can effectively be defined as the geomorphic consequences of these climatic and vegetational changes. Under this definition, as in Fig. 1.1, the term desert is used in this volume broadly to include all hot, warm, and temperate arid and semi-arid parts of the world.

However, neither argument creates a watertight definition. Practitioners often extend their expertise outside deserts, and landforms common in deserts are seldom unique to them. Consequently, although many of the luminescence studies conducted by Bateman, for example, focus on environmental change in deserts (e.g. Bateman et al., 2003), others address comparable aeolian processes in quite different environments (e.g. Bateman and van Huissteden, 1999). Understanding the geomorphology of desert environments draws upon knowledge gained in other settings. Likewise, our understanding of deserts is frequently helpful in understanding landforms outside the desert realm.

Organization of the Book

This book focuses on the geomorphic processes that operate in desert environments and the landforms they produce. The effects of most processes are spatially limited so that it is possible to identify within any landscape a set of process domains within which particular processes dominate. The book is mainly organized around these process domains. Because different domains dominate different deserts, a first consideration needs to be the distribution of these domains across the deserts of the world. In the second chapter of the introductory section, therefore, the world's deserts are compared from the point of view of these process domains. Because all deserts are characterised by patchy vegetation and all geomorphological processes are influenced by this vegetation, chapter three of the introductory session considers the nature and geomorphological significance of vegetation in desert environments.

Some processes, particularly weathering and soil formation, are less constrained into specific process domains than others. Because of their widespread effects across all desert terrain types, these processes are considered in the second section of the book. The next five sections examine the processes of the five main process domains of deserts: hillslopes, rivers, piedmonts, lake basins, and aeolian surfaces. In the final section of the book, we step outside the present spatial pattern of processes and process domains, which are no more than a short-term expression of the contemporary climate, to examine how the processes and process domains of deserts respond to and are able to provide information about climatic change.

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