# 1

# Climatic change in deserts: An introduction

The desert shall rejoice, and blossom as the rose.
*Isaiah 35.1*

## 1.1 Introduction

In Book Four of *The Histories*, Herodotus (ca. 485–425 BC) repeats the tale of a group of people from the small town of Sirte in northern Libya who, goaded into an irrational fury by the south wind that had dried out their water storage tanks, declared war on the wind and marched into the desert, where 'the wind blew and buried them in sand'. It was not always thus. A few thousand years earlier, numerous bands of cattle herders roamed what were then the vast grassy plains of the Sahara, and before then herds of African herbivores including antelopes, giraffes and even elephants had ventured into what was at that time a well-watered savanna landscape strewn with perennial rivers and freshwater lakes. The evidence of these past changes is still obvious to the observant traveller. Scattered across the 5,000 km width of the Sahara from Mauritania to the Red Sea is an abundance of beautifully executed rock paintings of Neolithic cattle, sheep and goats, as well as rock engravings of the wild herbivores, all of which were forced out by a progressively drier climate.

As the Saharan example shows, deserts are superb repositories of past climatic events. The very aridity to which they owe their existence has facilitated the preservation of landforms, sediments and soils developed under very different environmental conditions, as well as evidence of the former presence of plants, animals and prehistoric humans in areas now too arid to support much life. Contrary to the popular view of deserts as regions almost entirely covered by sand dunes – only a fifth of the Sahara is so covered – deserts are more likely to consist of rugged mountain ranges and dissected plateaux interspersed with vast gravel plains, intermittently active rivers and sporadically flooded lakes (Figures 1.1 to 1.6). Indeed, many of the landforms that are considered so characteristic of deserts are in fact inconsistent with present-day

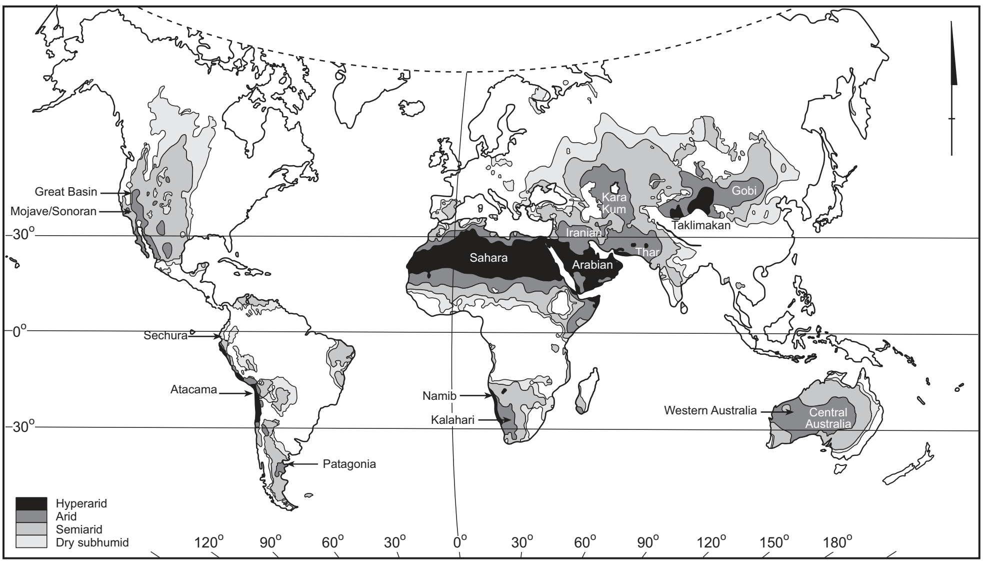


Figure 1.1. Distribution of deserts and their semi-arid and dry subhumid margins. (Adapted from UNEP, 1997, fig. 6.)

aridity, given that they are the results of weathering and erosion processes that are seldom active today. These observations invite us to ask when and why the deserts were once green and why are they no longer able to support much life. A further question is: How might they respond to future change?

Against this background, this volume has three main aims. One is to examine critically the various lines of evidence from geology, biology and archaeology that have been used to reconstruct climatic change within the hyper-arid, arid and semi-arid lands that presently occupy more than one-third of the land area of the globe. If we include the dry subhumid regions, that proportion increases to nearly one-half of the land area (see Figure 1.1). We also discuss both the Arctic – a region associated with globally important changes in ocean circulation initiated in the North Atlantic – and Antarctica – the largest and driest of our cold deserts – because Antarctica has long exerted a powerful influence on the global climate. The second aim, which follows logically from the first, is to trace systematically the climatic history of the deserts from the inception of *Cenozoic* aridity through the fluctuations of the *Quaternary* until the droughts and floods of the present day. (The Cenozoic covers the last 65 million years of geological time, with the final 2.6 million years being termed the Quaternary.) Our last aim is inherently more speculative, but nevertheless worthwhile, because it seeks to use the insights from our study of past events to envisage how human societies are likely to interact with possible future climatic changes in the desert world.

This introductory chapter enlarges on these aims, defines what is meant by a desert, outlines the approach adopted in this work, discusses briefly the scope and limitations of the methods used to infer climatic change and introduces some of the key concepts analysed in later chapters. Our geographical focus is primarily on the tropical and temperate deserts and their margins, although, as we shall see, the cold desert of Antarctica has played a major role in the long-term desiccation of Australia (and possibly even central Asia). Antarctica has the distinction of being the coldest, driest continent on earth, with Australia being the second driest.

## 1.2 What is a desert?

Before proceeding further, it is worth considering what we mean by the term 'desert', starting with a very simple definition. For the purposes of this book, we can define a desert as a region where the precipitation is too little and too erratic and the evaporation is too high to allow many plants and animals to survive, except in a few favoured localities. Indeed, the Arabic word *sahra* denotes a flat wasteland devoid of water, to be traversed as quickly as possible. There is also an economic definition of a desert as a region where viable agriculture is not possible without irrigation – but this depends entirely on the type of crop being grown and begs the question of what is viable.

A more quantitative definition of aridity may be achieved using the ratio of precipitation (P) to evaporation. In practice, because long-term measurements of evaporation are rare for most deserts, evaporation is usually expressed as potential evaporation ($E_{pot}$). Potential evaporation may be calculated using the Penman (1948) formula, but here again there are too few reliable meteorological measurements to allow this approach to be widely used. The Thornthwaite (1948) formula is simpler to use and requires fewer climatic parameters. According to this formula, when $P = E_{pot}$ throughout the year, the index is 0. When $P = 0$, the index is $-100$, and when P greatly exceeds $E_{pot}$, the index is $>100$. Climates with an index below $-40$ are arid, $-20$ to $-40$ are semi-arid, and 0 to $-20$ are subhumid.

A somewhat arbitrary classification of aridity is that used by both the World Meteorological Organization and the United Nations Environment Programme, in which drylands are defined as those regions where the ratio of mean annual precipitation, P, to mean annual potential evaporation, $E_{pot}$, was less than 0.65 for the 1951–1980 period (UNEP, 1992a, 1992b). A modified version of the 1948 Thornthwaite formula was used to calculate $P/E_{pot}$. Using this approach, drylands are classed into hyper-arid, arid, semi-arid and dry subhumid, as shown in Table 1.1. Here again, we need to remember that mean precipitation is an almost meaningless concept in regions where the rainfall is so variable from year to year. It is also worth stressing that low precipitation is a *necessary* but not a *sufficient* cause of aridity. In certain cold areas of the world, such as Patagonia and Greenland, the rates of evaporation may be low enough to compensate for the low rates of precipitation, allowing a relatively dense plant cover and even peat bogs to exist in spite of a very low annual precipitation.

Table 1.1. *Aridity zones defined by $P/E_{pot}$ Ratios (After UNEP, 1992a, UNEP, 1992b)*

| Climate zone | $P/E_{pot}$ ratio | % of the world covered |
|---|---|---|
| Hyper-arid | <0.05 | 7.5 |
| Arid | 0.05–0.20 | 12.5 |
| Semi-arid | 0.21–0.50 | 17.5 |
| Dry subhumid | 0.51–0.65 | 9.9 |
| Humid | >0.65 | 39.1 |
| Cold | >0.65 | 13.5 |

In these instances, the *effective precipitation* is high enough to sustain plant growth, regardless of the absolute amount.

Table 1.1 shows that deserts and their semi-arid margins thus occupy 37.5 per cent of the land area of the globe, and if we include the dry subhumid regions, where mean annual rainfall may range from 750 to 1,500 mm, 47.4 per cent of the terrestrial surface. Given that roughly one in five persons now on this earth live in these drylands, it is important to understand how these lands have evolved through time and how they may change in the future.

## 1.3 Polygenic nature of desert landscapes

Desert landscapes are akin to ancient palimpsest maps in that they consist both of very young depositional landforms and of very old erosional landforms (Mabbutt, 1977; Frostick and Reid, 1987a; Cooke et al., 1993; Abrahams and Parsons, 1994; Thomas, 1997; Williams, 2002a; Laity, 2008; Parsons and Abrahams, 2009; Thomas, 2011; Goudie, 2013). The young landforms include dunes, alluvial fans, salt lakes and alluvial channels. The old landforms include mountains, hills and plateaux (Figures 1.2 to 1.6). It is misleading to assume that the landform assemblages that we find in present-day deserts has developed under entirely arid conditions. In fact, few have done so, because most of the major erosional landforms were shaped under previously wetter climates and have been preserved from further erosion by the onset of aridity.

Many desert landforms are exceedingly old. The vast desert plains of the central Sahara and western Australia have been exposed to subaerial denudation for far more than 500 million years, under very different climates from those prevalent today (Williams, 2009a). Desert monoliths such as Ayers Rock (Uluru) (Figure 1.7) in central Australia or the granite inselbergs of the Sahara (Figure 1.8), far from being diagnostic of aridity, owe their present morphology to prolonged and repeated phases of weathering and erosion under a succession of former climates, few of which were particularly arid. The abrupt juxtaposition of very ancient erosional landforms and

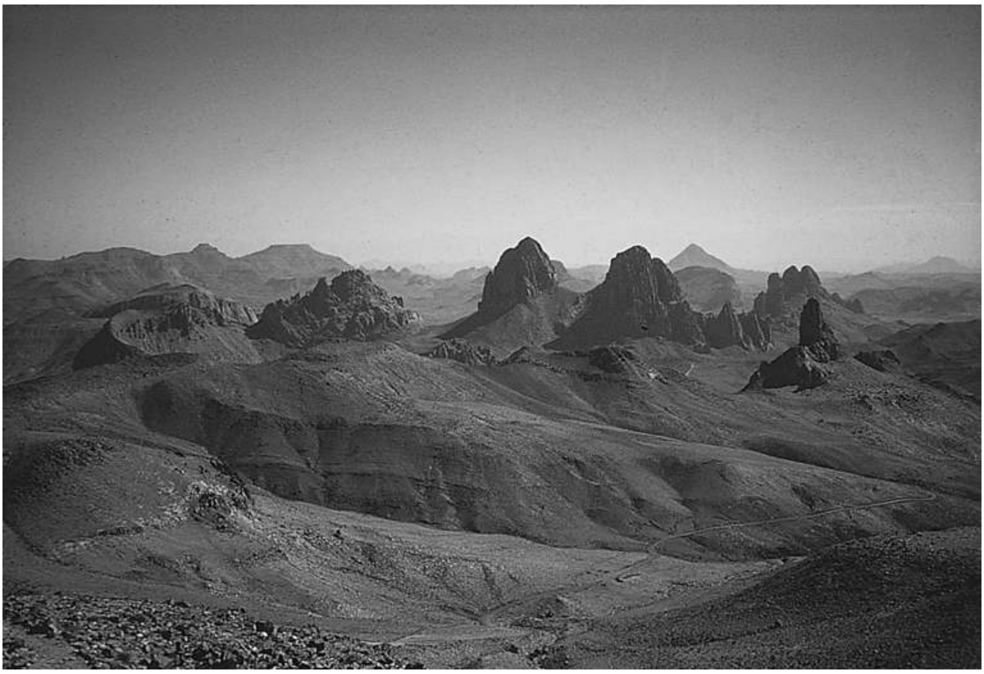

Figure 1.2. Dissected volcanic upland, Hoggar massif, central Sahara.

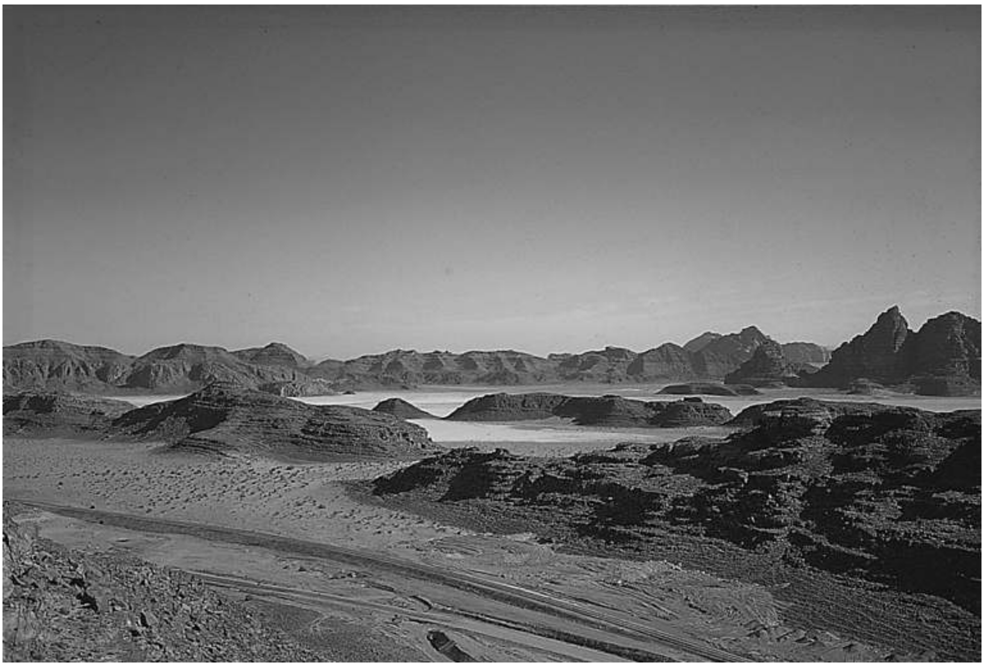

Figure 1.3. Dissected sandstone uplands, Wadi Rum area, Jordan.

Figure 1.4. Dissected sandstone plateau, or *mesa*, Arizona.

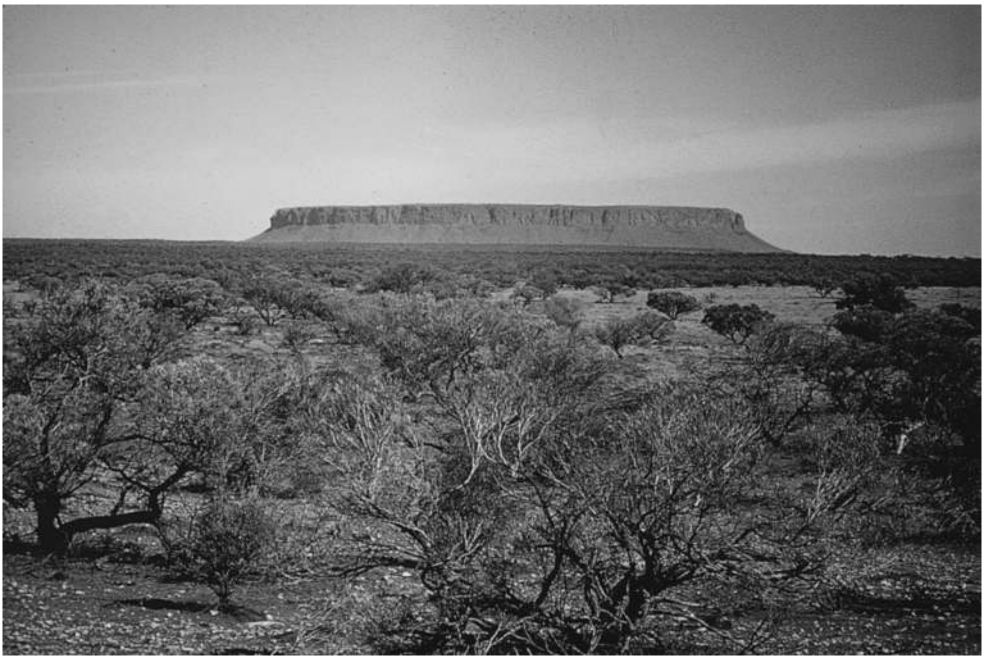

Figure 1.5. Mount Connor, central Australia.

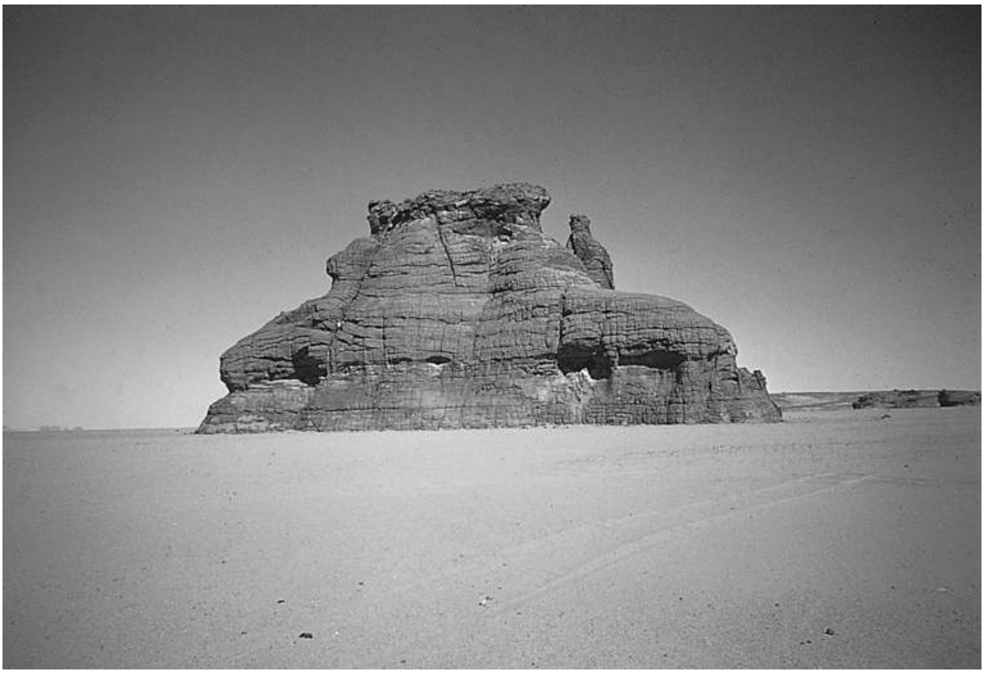

Figure 1.6. Isolated sandstone hill, central Sahara.

Figure 1.7. Uluru (Ayers Rock), central Australia.

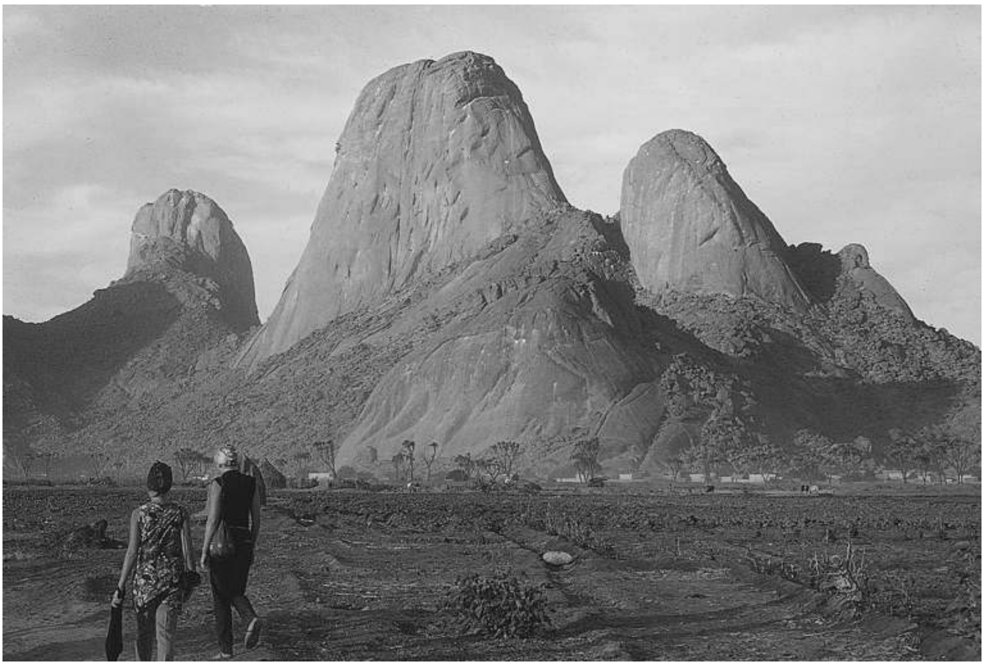

Figure 1.8. Granite inselbergs, Jebel Kassala, eastern Sudan.

very young depositional landforms, together with the absence of vegetation and the sharp breaks of slope, give desert landscapes their peculiar and somewhat paradoxical character. These young landforms and sediments, whether eolian, fluviatile or lacustrine, contain the best record of past environmental changes, most notably the rapid climatic fluctuations of the late Cenozoic that provide the focus of much of this book.

### 1.4 Ambiguous quality of the evidence for climatic change in deserts

Early studies of desert regions tended to focus on specific desert landforms such as dunes, alluvial fans, river terraces, playa lakes and deflation hollows. In the last thirty years, particularly since the use of radiocarbon dating became widespread, paleoclimatic research in deserts has focussed on using alluvial and lacustrine deposits and their associated plant and animal fossils to reconstruct the history of desert rivers and lakes (Cooke et al., 1993; Abrahams and Parsons, 1994; Thomas, 1997; Parsons and Abrahams, 2009; Thomas, 2011; Goudie, 2013). One of the problems inherent in using high lake levels as evidence of formerly wetter climates lies in the complex hydrology of many desert lakes. Some are fed primarily from groundwater and may respond slowly to local changes in climate. Others may be fed solely from surface run-off. If the rivers that flow into these lakes originate in some distant, well-watered upland areas, the lake levels will fluctuate in response to distant changes in rainfall and may again not accurately reflect local conditions. Where the lakes are full and overflowing and are merely enlarged portions of a through-flowing river system, they will also tend to be highly insensitive to local climatic fluctuations. Finally, is a lake high because of high rates of precipitation over the lake basin or because of much lower rates of evaporation related to colder or cloudier conditions?

Interpreting river sediments and landforms is equally fraught with ambiguity. Does widespread sedimentation reflect a river no longer competent to transport its load because of aridity in the headwaters and reduced discharge? Or does it reflect an increase in the supply of sediment from increased erosion in the headwaters, perhaps related to glacial and periglacial processes? Or might it represent a change from regular perennial flow to a more seasonal flow regime? To use a river terrace to infer a particular climate and then use the inferred climate to interpret other river terraces is to indulge in circular argument. None of these questions is easy to answer. Each requires accurate dating and careful scrutiny of many independent lines of evidence for its proper resolution. Throughout this work, we emphasise the different scales at which evidence of climatic change is to be considered, noting that the evidence is often fragmentary. The discerning reader needs to be fully aware of the scope and limitations inherent in the various proxies and archives used to reconstruct past changes in desert environments. For that reason, this book seeks to highlight the sometimes labyrinthine chain of reasoning involved in proceeding from environmental change to climatic change, noting that it is often more useful to know how the environment has fluctuated than to be overly concerned about distilling some imprecise climatic signal from inappropriate data. Table 1.2 summarises the types of evidence used to reconstruct past environmental change and the variable of interest in this type of investigation.

There will be many cases in which a straightforward interpretation of past events is simply not possible with existing information. For example, it is perfectly feasible that quite different sets of processes can lead to the formation of a particular landform – a concept termed *equifinality* – so that the landform in question does not provide a clear signal as to how it formed. Likewise, a small initial perturbation can often trigger a *complex response*, one that is often unexpected. A simple example is strong wind scouring out a hollow in the lee of a small desert hill and eventually reaching the local groundwater table, so that a shallow lake comes into being without the need to invoke a wetter climate. This is easy enough to demonstrate experimentally but harder to show in the real world, because the groundwater table may have risen some unknown time after the deflation hollow was created. Another example of a complex response, again demonstrated experimentally, is the creation of a multiple set of alluvial terraces following the incision of a small channel under flume conditions (Schumm and Parker, 1973). Sounding a cautionary note to those of us involved in using river sediments to reconstruct Quaternary alluvial history, the authors of this elegant flume experiment found that 'initial channel incision and terrace formation were followed by deposition of an alluvial fill, braiding and lateral erosion, and then, as the drainage system achieved stability, renewed incision followed by a low alluvial terrace' (Schumm and Parker, 1973, p. 99).

Table 1.2. *Evidence used to reconstruct environmental change. (Adapted from Williams et al., 1998 and Williams, 2011.)*

| Proxy data source | Variable measured |
|---|---|
| *Geology and geomorphology-continental* | |
| Relict soils | Soil types; isotopic composition of pedogenic carbonate concretions |
| Lakes and lake sediments | Lake level; varve thickness; facies changes; mineralogical composition; geochemistry |
| Eolian sediments: loess, desert dust, dunes, sand plains | Mineralogical composition; surface texture; geochemistry; provenance |
| Speleothems, tufas | Stable isotopic composition; geochemistry |
| *Geology and geomorphology-marine* | |
| Ocean sediments | Accumulation rates; fossil planktonic assemblages; isotopic composition of planktonic and benthic fossils |
| Continental dust; fluviatile inputs | Mineralogical composition; surface texture; geochemistry; provenance |
| Biogenic dust: pollen, diatoms, phytoliths | Provenance; assemblage composition |
| Marine shorelines | Coastal features; reef growth |
| *Glaciology* | |
| Mountain glaciers; ice sheets | Terminal positions |
| Glacial deposits and features of glacial erosion | Equilibrium snow-line<br>Distribution and age |
| Periglacial features | |
| Glacio-eustatic features | Shorelines |
| Layered ice-cores | Stable isotopic composition; physical properties (e.g., ice-fabric); trace element and microparticle concentrations |
| *Biology and biogeography-continental* | |
| Tree rings | Ring-width anomalies and density; isotopic composition |
| Fossil pollen and spores; plant macrofossils and microfossils; vertebrate fossils; invertebrate fossils: mollusca; ostracods; diatoms; insects | Type; relative abundance and/or absolute concentrations; age; distribution<br>Type; assemblage; abundance<br>Refugia: relict plant and animal populations |
| Modern population distributions | Phylogenetics; phylogeography |
| Molecular biology and genetics | |
| *Biology and biogeography-marine* | |
| Diatoms; foraminifera; coral reefs | Abundance; assemblage; trace element geochemistry; oxygen isotopic composition |
| *Archaeology* | |
| Written records; plant remains; animal remains, including hominids; rock art; hearths, dwellings, workshops; artefacts: bone, stone, wood, shell, leather | Age; distribution; morphology; provenance; geochemistry |