7

Deserts

'Now the wind grew strong and hard and it worked at the rain crust in the cornfields. Little by little the sky was darkened by the mixing dust, and the wind felt over the earth, loosened the dust and carried it away.'

J. Steinbeck, *The Grapes of Wrath*, 1939

What is a desert?

'The deserts of the world, which occur in every continent including Antarctica, are areas where there is a great deficit of moisture, predominantly because rainfall levels are low. In some deserts this situation is in part the result of high temperatures, which mean that evaporation rates are high. It is the shortage of moisture which determines many of the characteristics of the soils, the vegetation, the landforms, the animals, and the activities of humans' (Goudie and Watson, 1990).

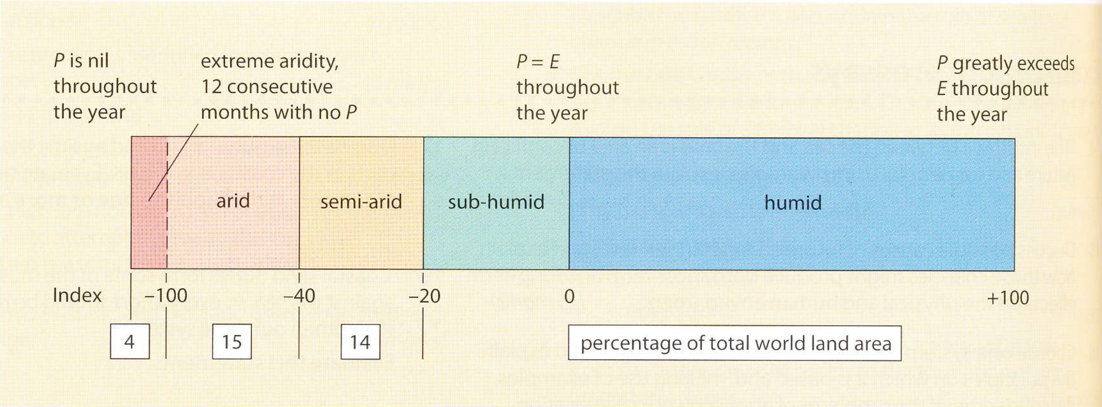
A desert environment has conventionally been described in terms of its deficiencies – water, soils, vegetation and population. Deserts include those parts of the world that produce the smallest amount of organic matter and have the lowest net primary production (NPP, page 306). In reality, many desert areas have potentially fertile soils, evidenced by successful irrigation schemes; all have some plant and animal life, even if special adaptations are necessary for their survival; and some are populated by humans, occasionally only seasonally by nomads but elsewhere permanently, e.g. in large cities like Cairo and Karachi.

The traditional definition of a desert is an area receiving less than 250 mm of rain per year. While very few areas receive no rain at all (Places 24, page 180), amounts of precipitation are usually small and occurrences are both infrequent and unreliable. Climatologists have sometimes tried to differentiate between cold deserts where for at least one month a year the mean temperature is below 6°C, and hot deserts. Several geomorphologists have used this to distinguish the landforms found in the hot sub-tropical deserts – our usual mental image of a desert – from those found in colder latitudes, e.g. the Gobi Desert and the tundra.

Modern attempts to define deserts are more scientific and are specifically linked to the water balance (page 60). This approach is based on the relationship between the input of water as precipitation (*P*), the output of moisture resulting from evapotranspiration (*E*), and changes in water held in storage in the ground. In parts of the world where there is little precipitation annually or where there is a seasonal drought, the **actual evapotranspiration** (*AE*) is compared with **potential evapotranspiration** (*PE*) – the amount of water loss that would occur if sufficient moisture was always available to the vegetation cover. C.W. Thornthwaite in 1931 was the first to define an **aridity index** using this relationship (Figure 7.1).

Figure 7.1

The index of aridity



Location and causes of deserts

On the basis of climatic characteristics, including Thornthwaite's aridity index, one-third of the world's land surface can be classified as desert, i.e. arid and semi-arid. Alarmingly, this figure, and therefore the extent of deserts, may be increasing (Case Study 7).

As shown in Figure 7.2, the majority of deserts lie in the centre or on the west coast of continents between 15° and 30° north and south of the Equator. This is the zone of sub-tropical high pressure where air is subsiding (the descending limb of the Hadley cell, Figure 9.34). On page 226 there is an explanation of how warm, tropical air is forced to rise at the Equator, producing convectional rain, and how later that air, once cooled and stripped of its moisture, descends at approximately 30° north and south of the Equator. As this air descends it is compressed, warmed and produces an area of permanent high pressure. As the air warms, it can hold an increasing amount of water vapour which causes the lower atmosphere to become very dry. The low relative humidity, combined with the fact that there is little surface water for evaporation, gives clear skies.

A second cause of deserts is the rainshadow effect produced by high mountain ranges. As the prevailing winds in the sub-tropics are the trade winds, blowing from the north-east in the northern hemisphere and the south-east in the southern hemisphere, then any barrier, such as the Andes, prevents moisture from reaching the western slopes. Where plate movements have pushed up mountain ranges in the east of a continent, the **rainshadow effect** creates a much larger extent of desert (e.g. 82 per cent of the land area of Australia) than when the mountains are to the west, as in South America.

Aridity is increased as the trade winds blow towards the Equator, becoming warmer and therefore drier. Where the trade winds blow from the sea, any moisture which they might have held will be precipitated on eastern coasts leaving little moisture for mid-continental areas. The three major deserts in the northern hemisphere which lie beyond the sub-tropical high pressure zone (the Gobi and Turkestan in Asia and the Great Basins of the USA) are mid-continental regions far removed from any rain-bearing winds, and surrounded by protective mountains.

A third combination of circumstances giving rise to deserts is also shown in Figure 7.2. Several deserts lie along western coasts where the ocean water is cold. In each case, the prevailing winds blow parallel to the coastline and, due to the Earth's rotation, they tend to push surface water seaward at right-angles to the wind direction. The Coriolis force (page 224) pushes air and water coming from the south towards the left in the southern hemisphere and water from the north to the right in the northern hemisphere. Consequently, very cold water is drawn upwards to the ocean surface, a process called **upwelling**, to replace that driven out to sea. Any air which then crosses this cold water is cooled and its capacity to hold moisture is diminished. Where these cooled winds from the sea blow onto a warm land surface, advection fogs form (page 222 and Places 24).

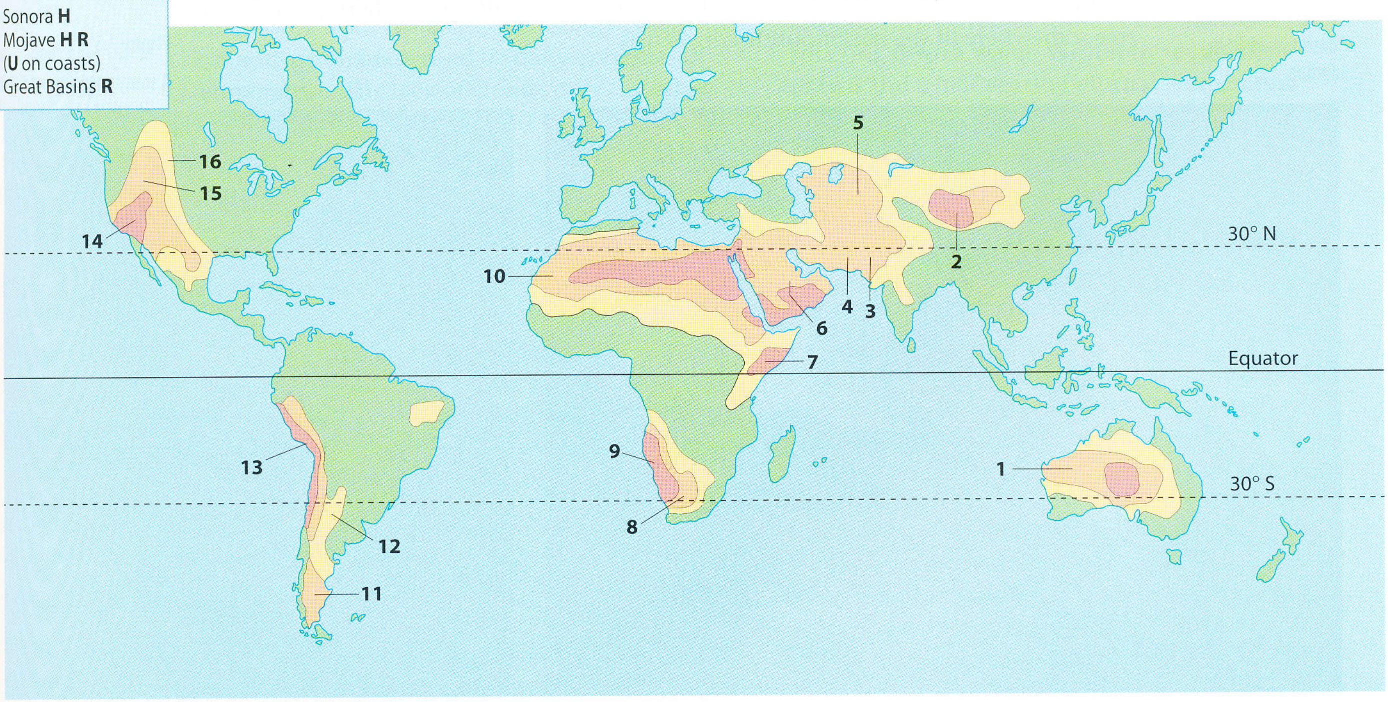
Figure 7.2

Arid lands of the world

extreme aridity
arid
semi-arid

H high pressure
R rainshadow
M mid-continent
U upwelling of cold water

1 Australia (e.g. Simpson Great Sandy) **H R M**
2 Gobi **M**
3 Thar **H**
4 Iran **H M**
5 Turkestan **M**
6 Arabia **H**
7 Somalia **H**
8 Kalahari **H M**
9 Namib **H U**
10 Sahara **H** (**U** in west, **M** in centre)
11 Patagonia **R**
12 Monte **H**
13 Atacama **H R U**
14 Sonora **H**
15 Mojave **H R** (**U** on coasts)
16 Great Basins **R**



Places 24 The Atacama Desert: climate

Figure 7.3

The Atacama Desert

The prevailing winds in the Atacama, which lies in the sub-tropical high pressure belt, blow northwards along the South American coast. These winds, and the northward-flowing Humboldt (Peruvian) current over which they blow, are pushed westwards (to the left) and out to sea by the Coriolis force as they approach the Equator. This allows the upwelling of cold water from the deep Peru–Chile sea trench (Figure 1.12) that provides the rich nutrients to nourish the plankton which form the basis of Peru's fishing industry. The upwelling also cools the air above which then drifts inland and over the warmer desert. The meeting of warm and cold air produces advection fogs (page 222) which provide sufficient moisture for a limited vegetation cover. Inland, parts of the Atacama are alleged to be the only truly rainless desert in the world, but even here the occasional rainfall event does occur.

Desert landscapes: what does a desert look like?

Deserts provide a classic example of how easy it is to portray or to accept an inaccurate mental picture of different places (or people) in the world. What is your image of a desert? Is it a landscape of sand dunes similar to those shown in Figures 7.15–7.18, perhaps with a camel or palm tree somewhere in the background? Large areas of dunes, known as **erg**, do exist – but they cover only about one-quarter of the world's deserts. Most deserts consist either of bare rock, known as **hammada** (Figure 7.4), or stone-covered plains, called **reg** (Figure 7.5). Deserts contain a great diversity of landscapes. This diversity is due to geological factors (tectonics and rock type) as well as to climate (temperature, rainfall and wind) and resultant weathering processes.

Figure 7.4

A rocky (hammada) desert, Wadi Rum, Jordan

Figure 7.5

A stony (reg) desert, Sahara

Arid processes and landforms

In their attempts to understand the development of arid landforms, geographers have come up against three main difficulties:

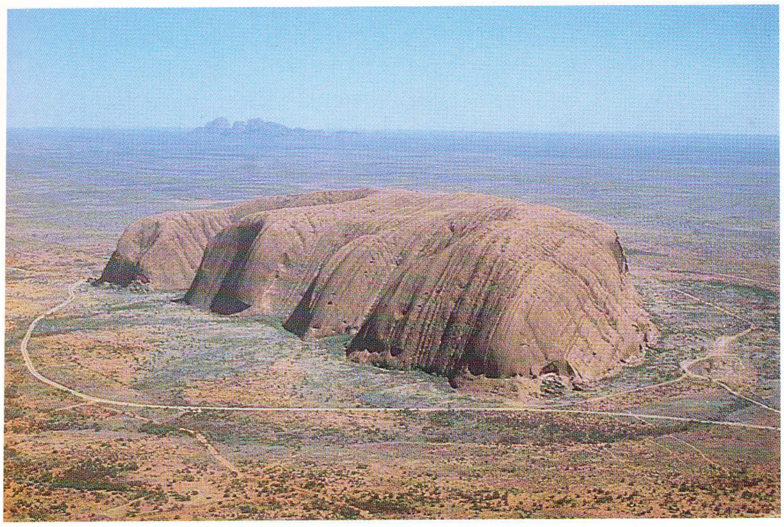
1. How should the nature of the weathering processes be assessed? Desert weathering was initially assumed to be largely mechanical and to result from extreme diurnal ranges in temperature. More recently, the realisation that water is present in all deserts in some form or other has led to the view that chemical weathering is far more significant than had previously been thought. Latest opinions seem to suggest that the major processes, e.g. exfoliation and salt weathering, may involve a combination of both mechanical and chemical weathering.
2. What is the relative importance of wind and water as agents of erosion, transportation and deposition in deserts?
3. How important have been the effects of climatic change on desert landforms? During some phases of the Quaternary, and previously when continental plates were in different latitudes, the climate of present arid areas was much wetter than it is today. How many of the landforms that we see now are, therefore, relict and how many are still in the process of being formed?

Mechanical weathering

Traditionally, weathering in deserts was attributed to mechanical processes resulting from extremes of temperature. Deserts, especially those away from the coast, are usually cloudless and are characterised by daily extremes of temperature. The lack of cloud cover can allow day temperatures to exceed 40°C for much of the year; while at night, rapid radiation often causes temperatures to fall to zero. Although in some colder, more mountainous deserts, frost shattering is a common process, it was believed that the major process in most deserts was **insolation weathering**. Insolation weathering occurs when, during the day, the direct rays of the sun heat up the surface layers of the rock. These surface layers, lacking any protective vegetation cover, may reach 80°C. The different types and colours of minerals in most rocks, especially igneous rocks, heat up and cool down at different rates, causing internal stresses and fracturing. This process was thought to cause the surface layers of exposed rock to peel off – **exfoliation** – or individual grains to break away – **granular disintegration** (page 41). Where surface layers do peel away, newly exposed surfaces experience pressure release (page 41). This is believed to be a contributory process in the formation of rounded exfoliation domes such as Uluru (Figure 7.6) and Sugarloaf Mountain (Figure 2.3).

Figure 7.6

An exfoliation dome: Uluru (formerly called Ayers Rock), Uluru-Kata Tjuta National Park, Australia (compare with Figure 2.3)



Doubts about insolation weathering began when it was noted that the 4500-year-old ancient monuments in Egypt showed little evidence of exfoliation, and that monuments in Upper Egypt, where the climate is extremely arid, showed markedly fewer signs of decay than those located in Lower Egypt, where there is a limited rainfall. D.T. Griggs (1936) conducted a series of laboratory experiments in which he subjected granite blocks to extremes of temperature in excess of 100°C. After the equivalent of almost 250 years of diurnal temperature change, he found no discernible difference in the rock. Later, he subjected the granite to the same temperature extremes while at the same time spraying it with water. Within the equivalent of two and a half years of diurnal temperature change, he found the rock beginning to crack. His conclusions, and those of later geomorphologists, suggest that some of the weathering previously attributed to insolation can now be ascribed to chemical changes caused by moisture. Although rainfall in deserts may be limited, the rapid loss of temperature at night frequently produces dew (175 nights a year in Israel's Negev) and the mingling of warm and cold air on coasts (e.g. of the Atacama) causes advection fog (page 222). There is sufficient moisture, therefore, to combine with certain minerals to cause the rock to swell (hydration) and the outer layers to peel off (exfoliation). At present, it would appear that the case for insolation weathering is neither proven nor disproven and that it may be a consequence of either mechanical weathering, or chemical weathering, or both.

The second mechanical process in desert environments, **salt weathering**, is more readily accepted although the action of salt can cause chemical, as well as physical, changes in the rock (page 40). Salts in rainwater, or salts brought to the surface by capillary action, form crystals as the moisture is readily evaporated in the high temperatures and low relative humidities. Further evaporation causes the salt crystals to expand and mechanically to break off pieces of the rock upon which they have formed (page 40). Subsequent rainfall, dew or fog may be absorbed by salt minerals causing them to swell (hydration) or chemically to change their crystal structure (page 42). Where salts accumulate near or on the surface, particles may become cemented together to form **duricrusts**. These hard crusts are classified according to the nature of their chemical composition. (Students with a special interest in geology or chemistry may wish to research the meaning of the terms **calcretes**, **silcretes** and **gypcretes**.) Another form of crust, **desert varnish**, is a hard, dark glazed surface found on exposed rocks which have been coated by a film composed largely of oxides of iron and manganese (Figure 7.7) and, possibly, bacterial action. It is hoped that the dating of desert varnish may help to establish a chronology of climatic changes in arid and semi-arid environments.

Figure 7.7

Carvings in desert varnish, Wadi Rum, Jordan

The importance of wind and water

Geomorphologists working in Africa at the end of the last century believed the wind to be responsible for most desert landforms. Later fieldwork, carried out mainly in the higher and wetter semi-arid regions of North America, recognised and emphasised the importance of running water and, in doing so, de-emphasised the role of wind. Today, it is more widely accepted that both wind and water play a significant, but locally varying, part in the development of the different types of desert landscape.

Aeolian (wind) processes

Transport

The movement of particles is determined by several factors. Aeolian movement is greatest where winds are strong (usually over 20 km/hr), turbulent, come from a constant direction and blow steadily for a lengthy period of time. Of considerable importance, too, is the nature of the regolith. It is more likely to be moved if there is no vegetation to bind it together or to absorb some of the wind's energy; if it is dry and unconsolidated; if particles are small enough to be transported; and if material has been loosened by farming practices. While such conditions do occur locally in temperate latitudes, e.g. coastal dunes, summits of mountains and during dry summers in arable areas, the optimum conditions for transport by wind are in arid and semi-arid environments.

Wind can move material by three processes: suspension, saltation and surface creep. The effectiveness of each method is related to particle size (Figure 7.8).

Suspension Where material is very fine, i.e. less than 0.15 mm in diameter, it can be picked up by the wind, raised to considerable heights and carried great distances. There have been occasions, though perhaps recorded only once a decade, when red dust from the Sahara has been carried northwards and deposited as 'red rain' over parts of Britain. Visibility in deserts is sometimes reduced to less than 1000 m and this is called a **dust storm** (Figure 7.9). The number of recorded dust storms on the margins of the Sahara has increased rapidly in the last 25 years as the drought of that region has intensified. In Mauritania during the early part of the 1960s, there was an average of only 5 days/yr with dust storms compared with an average of 80 days/yr over a similar period in the early 2000s.

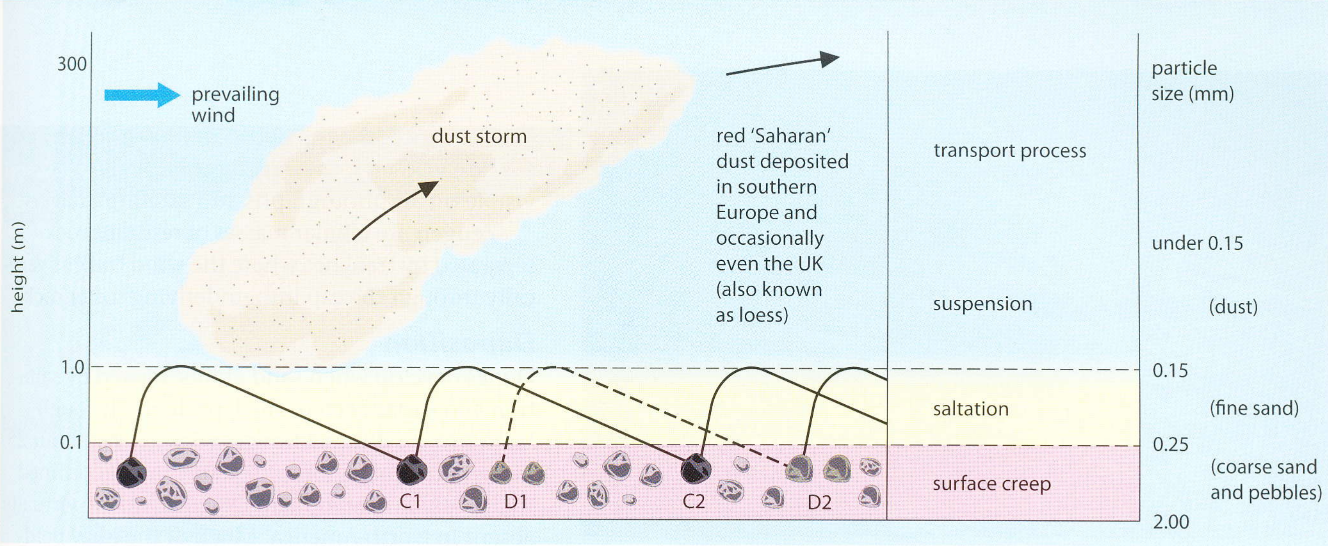


Figure 7.8

Processes of wind transportation

Saltation When wind speeds exceed the threshold velocity (the speed required to initiate grain movement), fine and coarse-grained sand particles are lifted. They may rise almost vertically for several centimetres before returning to the ground in a relatively flat trajectory of less than 12° (Figure 7.8). As the wind continues to blow, the sand particles bounce along, leap-frogging over one another. Even in the worst storms, sand grains are rarely lifted higher than 2 m above the ground.

Surface creep Every time a sand particle, transported by saltation, lands, it may dislodge and push forward larger particles (more than 0.25 mm in diameter) which are too heavy to be uplifted. This constant bombardment gradually moves small stones and pebbles over the desert surface.

4x4 vehicles are being accused of damaging the ecology of the Sahara Desert and contributing to the world's growing dust storm problem. Since the 1990s, 4x4 Land Cruisers have replaced the camel as the vehicle of choice (a process referred to as 'Toyotarisation'). These vehicles, according to Professor Goudie, are gradually destroying the thin layer of lichen and gravel that keeps the desert surface stable in high winds. In the worst-affected regions, estimates suggest that 1270 million tonnes of dust are thrown up each a year – ten times more than half a century ago. The dust, which may contain harmful microbes and pesticides, is transported high into the atmosphere during storms and deposited (known as blood rain in certain places) as far afield as the Alps (seen as a red layer on top of the snow), the Caribbean (where fungal pores carried with it have been blamed for destroying coral reefs) and on cars and property in southern England.

Figure 7.9

Dust storms created by human activity

Figure 7.10

A desert pavement with ventifacts in Jordan, created by deflation

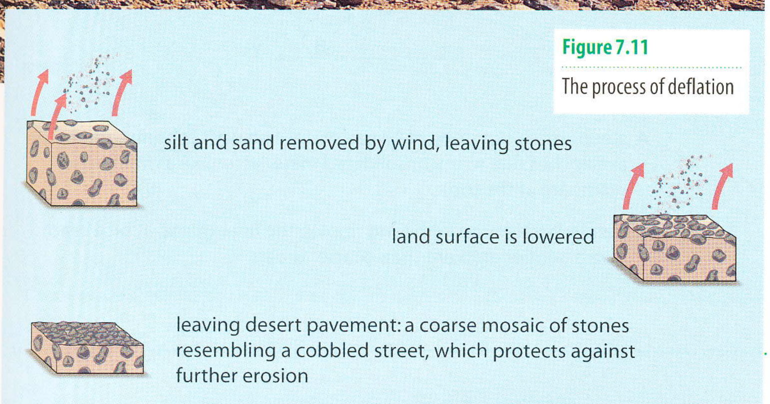


Figure 7.11

The process of deflation

Erosion

There are two main processes of wind erosion: deflation and abrasion.

Deflation is the progressive removal of fine material by the wind leaving pebble-strewn desert pavements or reg (Figures 7.10 and 7.11). Over much of the Sahara, and especially in Sinai in Egypt, vast areas of monotonous, flat and colourless pavement are the product of an earlier, wetter climate. Pebbles were transported by water from the surrounding highlands and deposited with sand, clay and silt on the lowland plains. Later, the lighter particles were removed by the wind, causing the remaining pebbles to settle and to interlock like cobblestones.

Elsewhere in the desert, dew may collect in hollows and material may be loosened by chemical weathering and then removed by wind to leave **closed depressions** or **deflation hollows**. Closed depressions are numerous and vary in size from a few metres across to the extensive Qattara

Figure 7.12

Landshore yardangs, Western Desert, Egypt

Depression in Egypt which reaches a depth of 134 m below sea-level. Closed depressions may also have a tectonic origin (the south-west of the USA) or a solution origin (limestone areas in Morocco). The Dust Bowl, formed in the American Mid-West in the 1930s, was a consequence of deflation following a severe drought in a region where inappropriate farming techniques had been introduced. Vast quantities of valuable topsoil were blown away, some of which was deposited as far away as Washington, DC.

Abrasion is a sandblasting action effected by materials as they are moved by saltation. This process smooths, pits, polishes and wears away rock close to the ground. Since sand particles cannot be lifted very high, the zone of maximum erosion tends to be within 1 m of the Earth's surface. Abrasion produces a number of distinctive landforms which include ventifacts, yardangs and zeugen.

Ventifacts are individual rocks with sharp edges and, due to abrasion, smooth sides. The white rock in the foreground of Figure 7.10 has a long axis of 25 cm.

Yardangs are extensive ridges of rock, separated by grooves (troughs), with an alignment similar to that of the prevailing winds (Figure 7.12). In parts of the Sahara, Arabian and Atacama Deserts, they are large enough to be visible on air photographs and satellite imagery.

Zeugen are tabular masses of resistant rock separated by trenches where the wind has cut vertically through the cap into underlying softer rock.

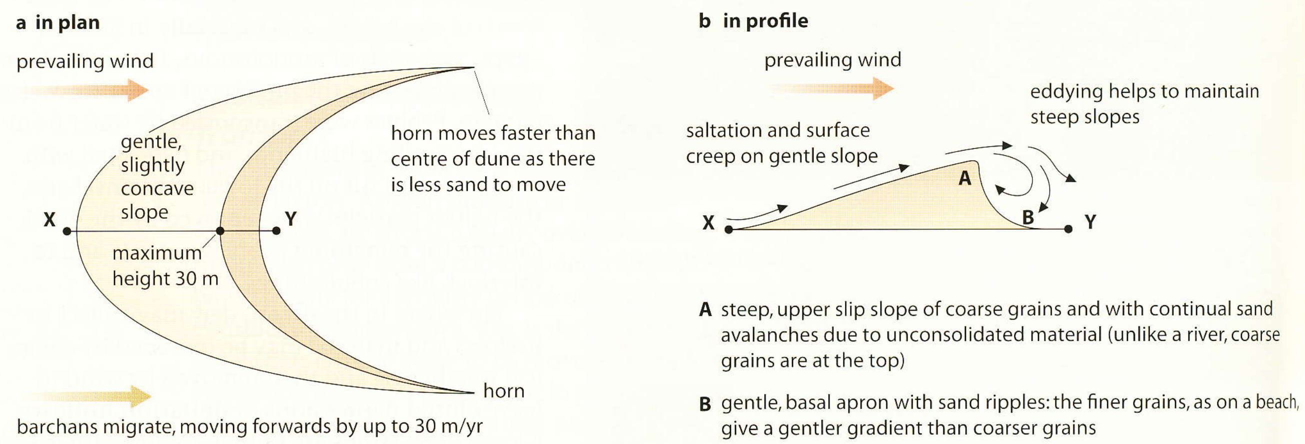
Deposition

Dunes develop when sand grains, moved by saltation and surface creep, are deposited. Although large areas of dunes, known as ergs, cover about 25 per cent of arid regions, they are mainly confined to the Sahara and Arabian Deserts, and are virtually absent in North America. Much of the early fieldwork on dunes was carried out by R.A. Bagnold in North Africa in the 1920s. He noted that some, but by no means all, dunes formed around an obstacle – a rock, a bush, a small hill or even a dead camel; and most dunes were located on surfaces that were even and sandy and not on those which were irregular and rocky. He concentrated on two types of dune: the barchan and the seif. The **barchan** is a small, crescent-shaped dune, about 30 m high, which is moved by the wind (Figures 7.13 and 7.15). The **seif**, named after an Arab curved sword, is much larger (100 km in length and 200 m in height) and more common (Figure 7.17), although the process of its formation is more complex than initially thought by Bagnold. Textbooks often overemphasise these two dunes, especially the barchan which is a relatively uncommon feature.

While Bagnold had to travel the desert in specially converted cars, modern geographers derive their picture of desert landforms from aerial photographs and Landsat images. These new techniques have helped to identify several types of dune, and the modern classification, still based on morphology, contains several additional types (Figure 7.14). Dune morphology depends upon the supply of sand, wind direction, availability of vegetation and the nature of the ground surface.

Figure 7.13

The movement of a crescent-shaped barchan



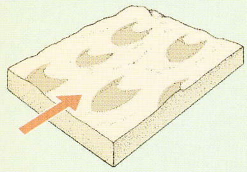
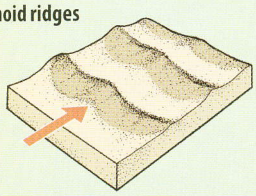
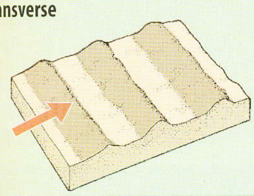
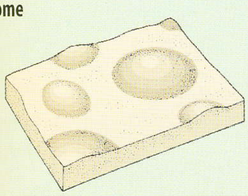
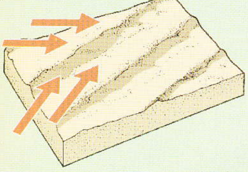
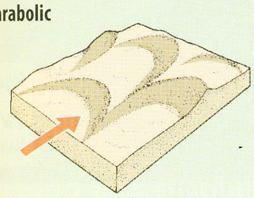
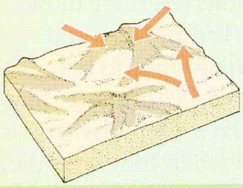
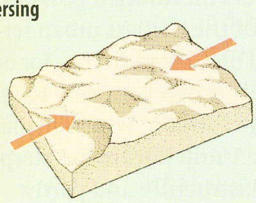
Type of dune	Description	Supply of sand	Wind direction and speed	Vegetation cover	Speed of dune movement
barchan 	individual dunes, crescent shape with horns pointing downwind (Figures 7.13 and 7.15)	limited	constant direction, at right-angles to dune	none	highly mobile
barchanoid ridges 	asymmetrical, oriented at right-angles to wind, rows of barchans forming parallel ridges	limited	constant direction, at right-angles to dune	none	mobile
transverse 	oriented at right-angles to wind but lacking barchanoid structure, resemble ocean waves (Figure 7.16)	abundant (thick) sand cover	steady winds (trades), constant direction but with reducing speeds, at right-angles to dune	vegetation stabilises sand	sand checked by barriers, limited mobility
dome 	dome-shaped (height restricted by wind)	appreciable amounts of coarse sand	strong winds limit height of dune	none	virtually no movement
seif (linear) 	longitudinal, parallel dunes with slip faces on either side, can extend for many km (Figure 7.17)	large	persistent, steady winds (trades), with slight seasonal or diurnal changes in direction	none	regular (even) surface, virtually no movement
parabolic 	hairpin-shaped with noses pointing downwind, a type of blowout (eroded) dune where middle section has moved forward, may occur in clusters	limited	constant direction	where present, can anchor sand	highly mobile (by blowouts in nose of dune)
star 	complex dune with a star (star-fish) shape (compare arêtes radiating from central peak) (Figure 7.18)	limited	effective winds blow from several directions	none	virtually no movement
reversing 	undulating, haphazard shape	limited	winds of equal strength and duration from opposite directions	none	virtually no movement

Figure 7.14

Classification of sand dunes (*after* Goudie)

Figure 7.15
Barchan dunes near Lüderitz, Namibia

Figure 7.1
Transvers
Djanet, Al

Figure 7.17
Seif (linear) dunes, Sossusvlei, Namibia

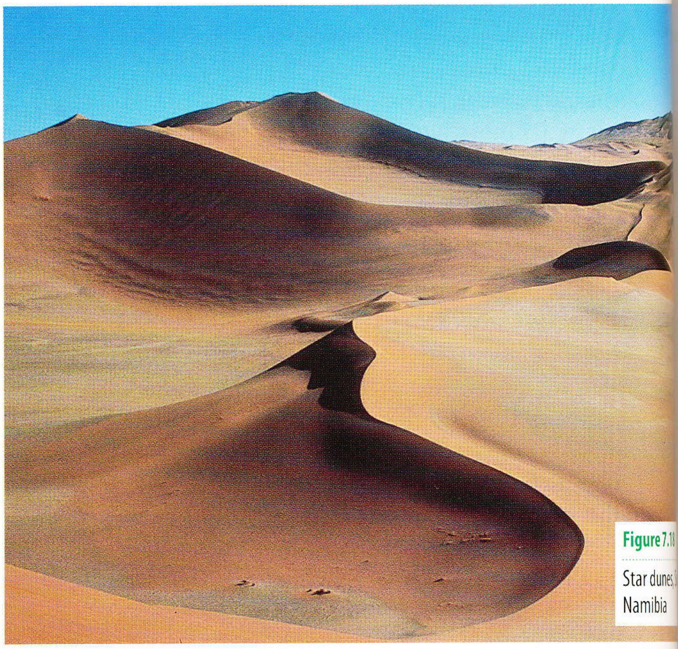


Figure 7.1
Star dunes
Namibia

The effects of water

It has already been noted that, in arid areas, moisture must be present for processes of chemical weathering to operate. We have also seen that often rainfall is low, irregular and infrequent, with long-term fluctuations. Although most desert rainfall occurs in low-intensity storms, the occasional sudden, more isolated, heavy downpour, does occur. There are records of several extreme desert rainfall events, each equivalent to the three-monthly mean rainfall of London. The impact of water is, therefore, very significant in shaping desert landscapes.

Rivers in arid environments fall into three main categories.

Exogenous Exogenous rivers are those like the Colorado, Nile, Indus, Tigris and Euphrates, which rise in mountains beyond the desert margins. These rivers continue to flow throughout the year even if their discharge is reduced by evaporation when they cross the arid land. (The last four rivers mentioned provided the location for some of the earliest urban settlements – page 388.) The Colorado has, for over 300 km of its course, cut down vertically to form the Grand Canyon. The canyon, which in places is almost 2000 m (over 1 mile) deep, has steep sides partly due to rock structure and partly due to insufficient rainfall to degrade them (Figure 7.19).

Figure 7.19
The Grand Canyon, Arizona, USA

Endoreic Endoreic drainage occurs where rivers terminate in inland lakes. Examples are the River Jordan into the Dead Sea and the Bear into the Great Salt Lake.

Ephemeral Ephemeral streams, which are more typical of desert areas, flow intermittently, or seasonally, after rainstorms. Although often shortlived, these streams can generate high levels of discharge due to several local characteristics. First, the torrential nature of the rain exceeds the infiltration capacity of the ground and so most of the water drains away as surface runoff (overland flow, page 59). Second, the high temperatures and the frequent presence of duricrust combine to give a hard, impermeable surface which inhibits infiltration. Third, the lack of vegetation means that no moisture is lost or delayed through interception and the rain is able to hit the ground with maximum force. Fourth, fine particles are displaced by rainsplash action and, by infilling surface pore spaces, further reduce the infiltration capacity of the soil. It is as a result of these minimal infiltration rates that slopes of less than 2° can, even under quite modest storm conditions, experience extensive overland flow.

Studies in Kenya, Israel and Arizona suggest that surface runoff is likely to occur within 10 minutes of the start of a downpour (Figure 7.20). This may initially be in the form of a **sheet flood** where the water flows evenly over the land and is not confined to channels. Much of the sand, gravel and pebbles covering the desert floor is thought to have been deposited by this process; yet, as the event has rarely been witnessed, it is assumed that deposition by sheet floods occurred mainly during earlier wetter periods called **pluvials**.

Very soon, the collective runoff becomes concentrated into deep, steep-sided ravines known as **wadis** (Figure 7.22) or **arroyos**. Normally dry, wadis may be subjected to irregular flash floods (Figure 7.20 and Places 25). The average occurrence of these floods is once a year in the semi-arid margins of the Sahara, and once a decade in the extremely arid interior. This infrequency of floods compared with the great number and size of wadis, suggests that they were created when storms were more frequent and severe – i.e. they are a relict feature.

Figure 7.20
A flash flood

Pediments and playas

Stretching from the foot of the highlands, there is often a gently sloping area either of bare rock or of rock covered in a thin veil of debris (Figures 7.21 and 7.24). This is known as a **pediment**. There is often an abrupt break of slope at the junction of the highland area and the pediment. Two main theories suggest the origin of the pediment, one involving water. This theory proposes that weathered material from cliff faces, or debris from alluvial fans, was carried during pluvials by sheet floods. The sediment planed the lowlands before being deposited, leaving a gently concave slope of less than 7° (Figure 7.24). The alternative theory involves the parallel retreat of slopes resulting from weathering (King's hypothesis, Figure 2.24c).

Playas are often found at the lowest point of the pediment. They are shallow, ephemeral, saline lakes formed after rainstorms. As the rain water rapidly evaporates, flat layers of either clay, silt or salt are left. Where the dried-out surface consists of clay, large **desiccation cracks**, up to 5 m deep, are formed. When the surface is salt-covered, it produces the 'flattest landform on land'. Rogers Lake, in the Mojave Desert, California, has been used for spacecraft landings, while the Bonneville saltflats in Utah have been the location for land-speed record attempts.

Figure 7.21

Pediment at foot of highlands, Wadi Rum, Jordan

Places 25 Wadis: flash floods

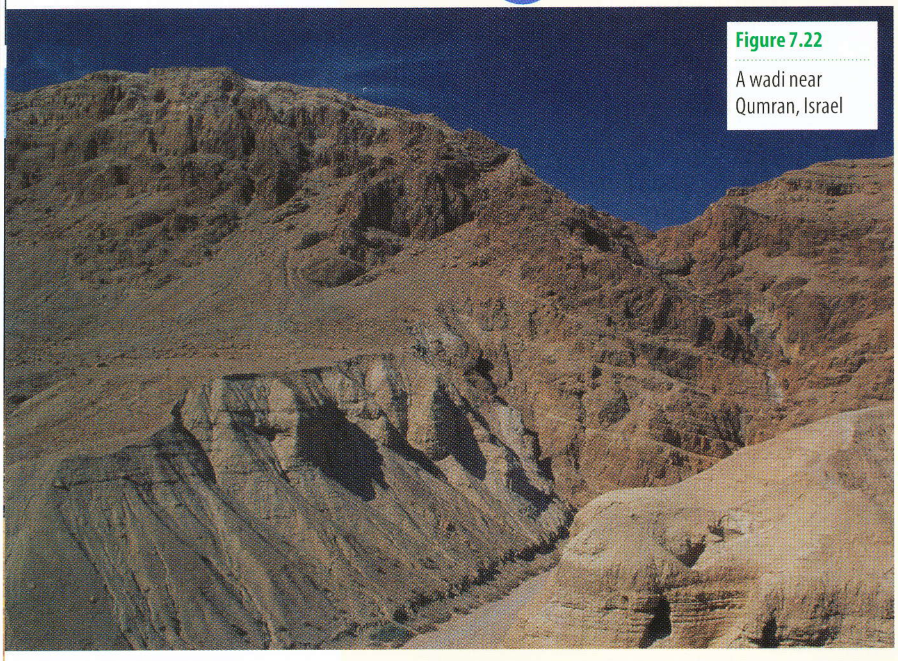


Figure 7.22

A wadi near Qumran, Israel

Camping in a wadi is something that experienced desert travellers avoid. It is possible to be swept away by a flash flood which occurs virtually without warning – there may have been no rain at your location, and perhaps nothing more ominous than a distant rumble of thunder. Indeed, the first warning may be the roar of an approaching wall of water. One minute the bed of the wadi is dry, baked hard under the sun and littered with weathered debris from the previous flood or from the steep valley sides (Figure 7.22), and the next minute it is a raging torrent.

The energy of the flood enables large boulders to be moved by traction, and enormous amounts of coarse material to be taken into suspension – some witnesses have claimed it is more like a mudflow. Friction from the roughness of the bed, the large amounts of sediment and the high rates of evaporation soon cause a reduction in the stream's velocity. Deposition then occurs, choking the channel, followed by braiding as the water seeks new outlets. Within hours, the floor of the wadi is dry again (Figure 7.23).

The rapid runoff does not replenish groundwater supplies, and without the groundwater contribution to base flow, characteristic of humid climates, rivers cease to flow. At the mouth of the wadi, where the water can spread out and energy is dissipated, material is deposited to form an **alluvial fan** or **cone** (Figure 7.24). If several wadis cut through a highland close to each other, their semi-circular fans may merge to form a **bahada (bajada)**, which is an almost continuous deposit of sand and gravel.

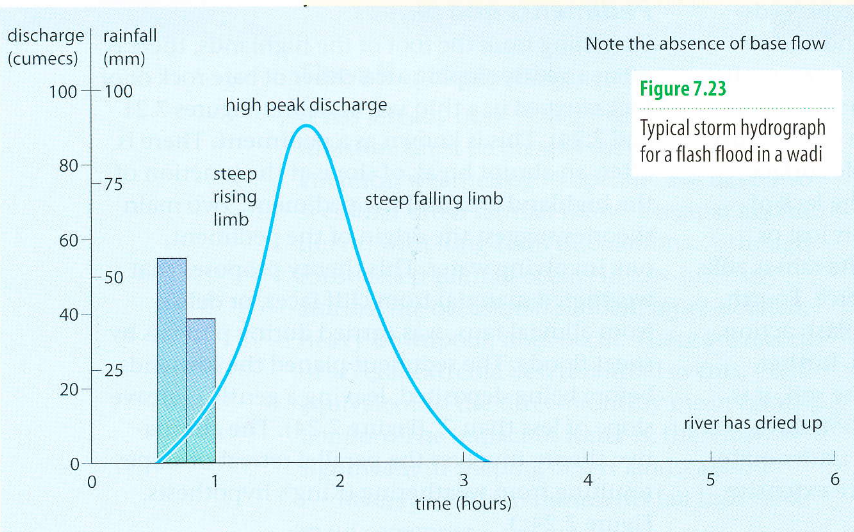


Figure 7.23

Typical storm hydrograph for a flash flood in a wadi

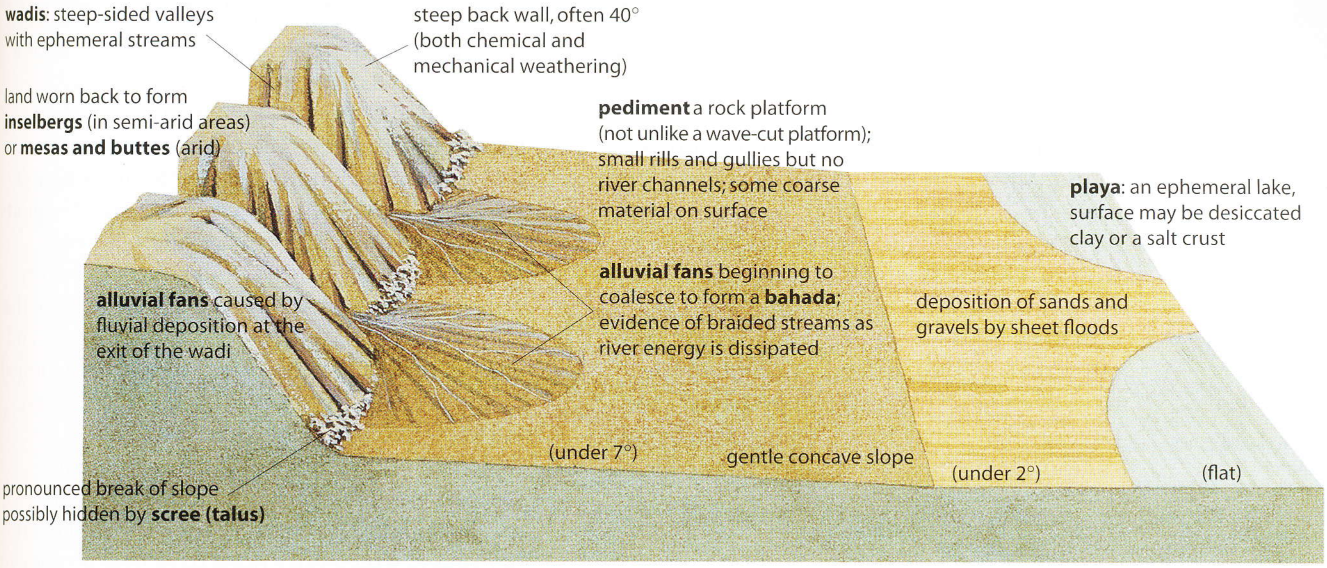


Figure 7.24

Pediments and playas

Occasionally, isolated, flat-topped remnants of former highlands, known as **mesas**, rise sheer from the pediment. Some mesas, in Arizona, have summits large enough to have been used as village sites by the Hopi Indians. **Buttes** are smaller versions of mesas. The most spectacular mesas and buttes lie in Monument Valley Navajo Tribal Park in Arizona (Figure 7.25).

Relationship between wind and water

Some desert areas are dominated by wind, others by water. Areas where wind appears to be the dominant geomorphological agent are known as **aeolian domains**. The effectiveness of the wind increases where, and when, amounts of rainfall decrease. As rainfall decreases, so too does any vegetation cover. This allows the wind to transport material unhindered, and rates of erosion (abrasion and deflation) and deposition (dunes) to increase. **Fluvial domains** are those where water processes are dominant or, as evidence increasingly suggests, have been dominant in the past. Vegetation, which stabilises material, increases as rainfall increases or where coastal fog and dew are a regular occurrence.

Evidence also suggests that wind and water can interact in arid environments and that landforms produced by each do co-exist within the same locality. However, the balance between their relative importance has often altered, mainly due to climatic change either over lengthy periods of time (e.g. the 18 000 years since the time of maximum glaciation) or during shorter fluctuations (e.g. since the mid-1960s in the Sahel). At present, and especially in Africa, the decrease in rainfall in the semi-arid desert fringes means that the role of water is probably declining, while that of the wind is increasing.

Figure 7.25

Mesas and buttes, Monument National Park, Arizona, USA

Climatic change

There have already been references to pluvials within the Sahara Desert (page 181). Prior to the Quaternary era, these may have occurred when the African Plate lay further to the south and the Sahara was in a latitude equivalent to that of the present-day savannas. In the Quaternary era, the advance of the ice sheets resulted in a shift in windbelts which caused changes in precipitation patterns, temperatures and evaporation rates. At the time of maximum glaciation (18 000 years ago), desert conditions appear to have been more extensive than they are today (Figure 7.26). Since then, as suggested by radiocarbon dating (page 248), there have been frequent, relatively short-lived pluvials, the last occurring about 9000 years ago. Evidence for a once-wetter Sahara is given in Figure 7.27.

Herodotus, a historian living in Ancient Greece, described the Garamantes civilisation which flourished in the Ahaggar Mountains 3000 years ago. This people, who recorded their exploits in cave paintings at Tassili des Ajjers, hunted elephants, giraffes, rhinos and antelope. Twenty centuries ago, North Africa was the 'granary of the Roman Empire'. Wadis are too large and deep and alluvial cones too widespread to have been formed by today's occasional storms, while sheet floods are too infrequent to have moved so much material over pediments. Radiating from the Ahaggar and Tibesti Mountains, aerial photographs and satellite imagery have revealed many dry valleys which once must have held permanent rivers (compare Figure 6.44). Lakes were also once much larger and deeper. Around Lake Chad, shorelines 50 m above the present level are visible, and research suggests that lake levels might once have been over 100 m higher. (Lake Bonneville in the USA is only one-tenth of its former maximum size and, like Lake Chad, is drying up rapidly.) Small crocodiles found in the Tibesti must have been trapped in the slightly wetter uplands as the desert advanced. Also, pollen analysis has shown that oak and cedar forests abounded in the same region 10 000 years ago. Groundwater in the Nubian sandstone has been dated, by radio-isotope methods, to be over 25 000 years old, and may have accumulated at about the same time as fossil laterite soils (page 321).

Figure 7.26

Extent of sand dunes in Africa

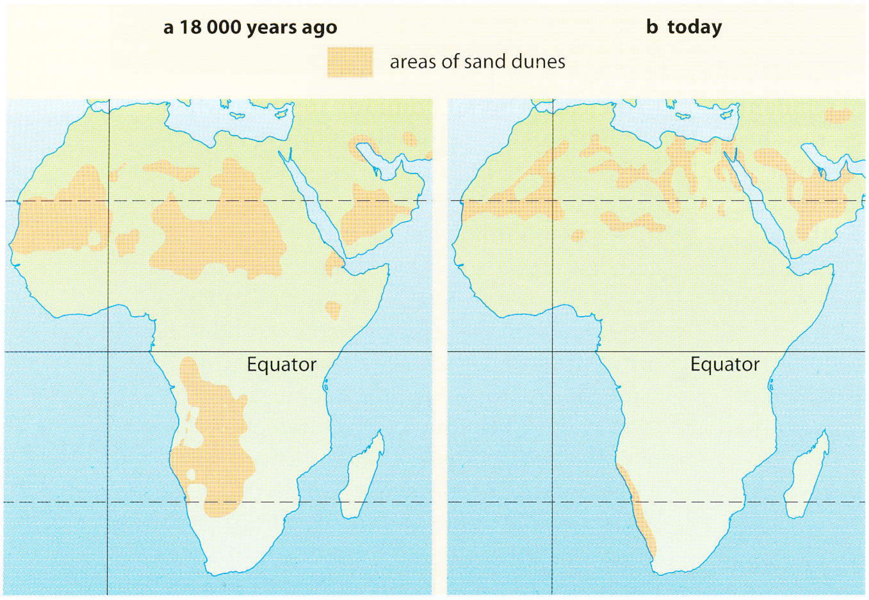
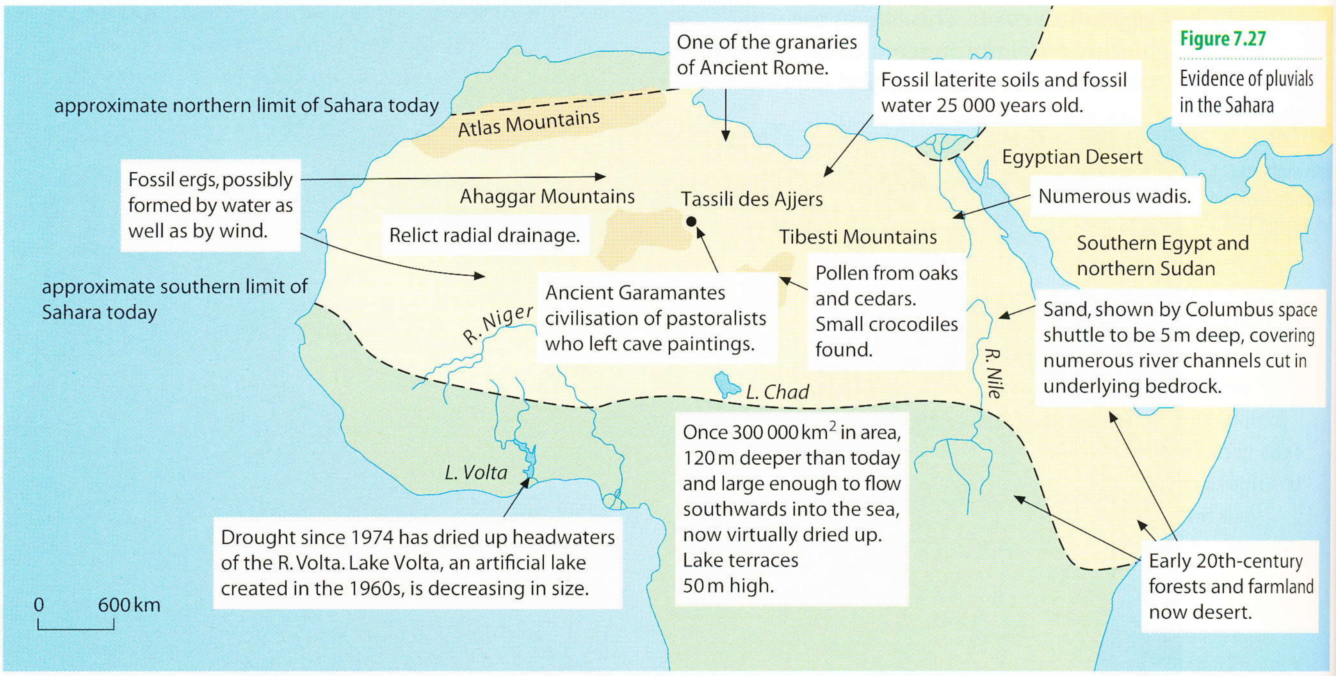


Figure 7.27

Evidence of pluvials in the Sahara



Desertification: fact or fiction?

Case Study 7

In the mid-1970s, desertification, not global warming, was perceived as the world's major environmental issue. Since then the nature, extent, causes and effects of desertification have become shrouded in controversy. Taken literally, desertification means 'the making of a desert'. More helpfully, it has been defined as 'the turning of the land, often through physical processes and human mismanagement, into desert'. Even so, although the term has been in use for over half a century, few can agree on exactly what it means. The diversity of definitions – there are over 100 – is due largely to uncertainty over its causes.

Goudie says that 'the question has been asked whether this process is caused by temporary drought periods of high magnitude, is due to longer-term climatic change towards aridity, is caused by man-induced climatic change, or is the result of human action through man's degradation of the biological environments in arid zones. Most people now believe that it is produced by a combination of increasing human and animal populations, which cause the effects of drought years to become progressively more severe so that the vegetation is placed under increasing stress.'

Those places perceived to be at greatest risk from desertification are shown in Figure 7.28. In 2005 the UN claimed that desertification directly affected over 250 million people and threatened another 1 billion living in at-risk countries. It is generally agreed that the desert is encroaching into semi-arid, desert margins, especially in the Sahel – a broad belt of land on the southern side of the Sahara (**2**–**4** in Figure 7.28).

Some of the main interrelationships between the believed causes of desertification are shown in Figure 7.29.

Worst areas	Percentage of population at risk
1 Ethiopia	18
2 Sudan	23
3 Chad	30
4 Niger	42
5 Somalia	26

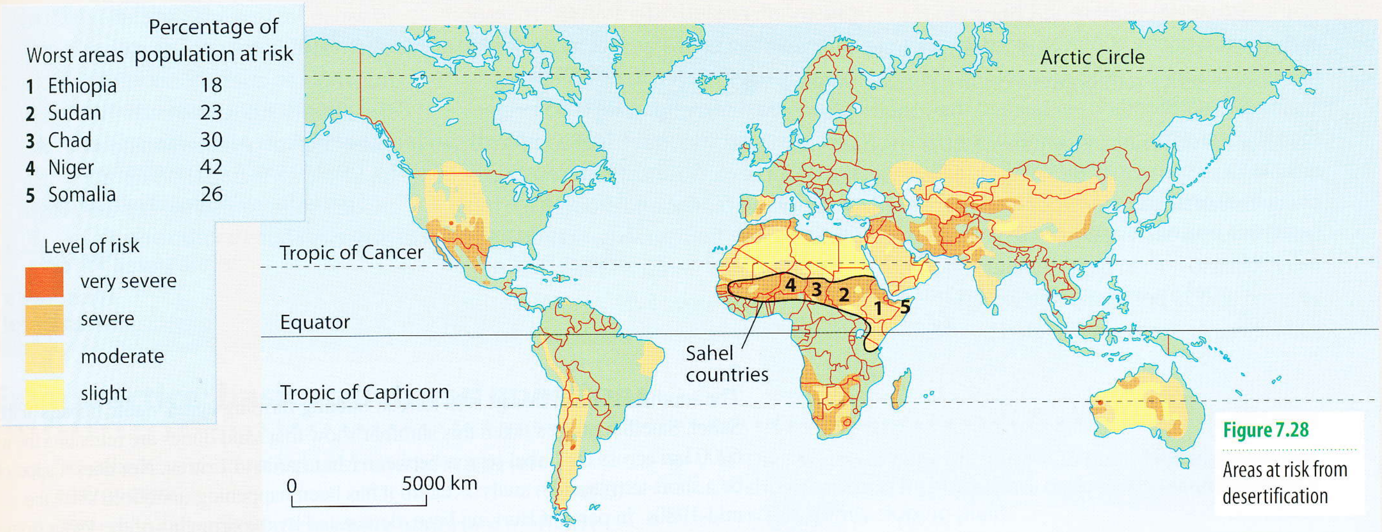


Figure 7.28
Areas at risk from desertification

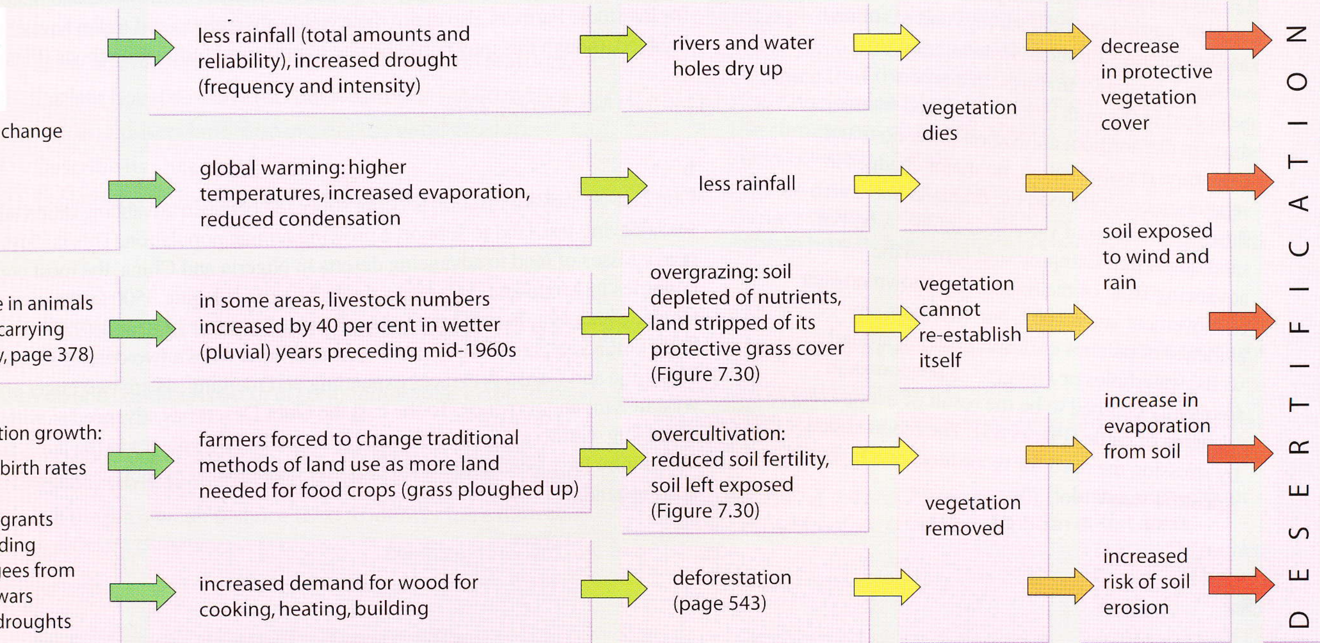


Figure 7.29
Causes of desertification in the Sahel

Desertification: fact or fiction?

Figure 7.30

Desertification and
a overgrazing
b overcultivation

In 1975, Hugh Lamprey, a bush pilot and environmentalist, claimed that, since his previous study 17 years earlier, the desert in the Sudan had advanced southwards by 90–100 km. In 1982 and at the height of one of Africa's worst-ever recorded droughts, UNEP (United Nations Environmental Programme) claimed that the Sahara was advancing southwards by 6–10 km a year and that, globally, 21 million hectares of once-productive soil were being reduced each year to zero productivity, that 850 million people were being affected, and 35 per cent of the world's surface was at risk (figures quoted by UNEP at the 1992 Rio Earth Summit). Since then scientific studies using satellite imagery and more detailed fieldwork (Figure 7.31) have thrown considerable doubt on the causes, effects and extent of desertification. Today, certain early statistics regarding its advance have proven to be unreliable. It is believed that overgrazing is no longer considered so important, fuelwood has not become exhausted as previously predicted, while famine and drought are more likely to result from poverty, poor farming techniques, civil unrest and war than from natural causes (page 503). In contrast, the extent and effects of salinisation (page 273 and Figure 16.53) appear to have increased.

The semi-arid lands are a fragile environment whose boundaries change due to variations in rainfall and land use. It is often difficult to separate natural causes from human ones and short-term fluctuations from long-term trends (Figure 7.32). The effects of global warming are as yet an unknown factor, although computer models suggest that the climate will get even drier.

Figure 7.31

Scientific evaluation in the mid-1990s

Researchers at the University of Lund, in Sweden, carried out field surveys and examined satellite pictures of Sudan in an attempt to confirm Lamprey's findings. In a report published in the mid-1990s they stated 'no major shifts in the northern cultivation limit, no major sand dune transformation, no major changes in vegetation cover beyond the dramatic but short-term effects of variable rainfall'. A belt of sand dunes that Lamprey said formed the advancing front of the Sahara had shown no sign of movement since 1962, nor was there any evidence of patches of desert growing around wells, waterholes or villages – a phenomenon frequently claimed to be the result of overgrazing by herds of cattle [Places 65]. The report ended by stressing the need for recordings of a high scientific standard.

Figure 7.32

a Desert retreat or
b desert advance?

a

The southern Sahara Desert is in retreat, making farming again viable in parts of the Sahel. Satellite images taken this summer show that sand dunes are retreating the whole 6000 km across the Sahel region between Mauritania to Eritrea. Nor does it appear to be a short-term trend – analysts claim it has been happening unnoticed since the mid-1980s. In parts of Burkina Faso, devastated by the droughts of the 1980s, some of the landscape is now showing green, with more trees for firewood and more grassland for livestock. Farmers also claim their yields of sorghum and millet have nearly doubled, though this may partly be due to improved farming methods [Figure 10.40].

Adapted from *New Scientist*, 2002

b

Our 21st-century civilisation is being squeezed between advancing desert and rising seas, leaving less land to support a growing human population. This is illustrated by the heavy losses of land to advancing deserts in Nigeria and China, the most populous countries in Africa and Asia respectively. Nigeria is losing 3500 km² a year, whereas China, which lost on average 1500 km² a year between 1950 and 1975, has been losing 3600 km² a year since 2000. Satellite images have shown two deserts in Inner Mongolia and Gansu provinces expanding and merging, as are two larger ones to the west in Xinjiang province. To the east the Gobi Desert has advanced to within 250 km of Beijing. Chinese scientists report that some 24 000 villages in the north and west of the country have been abandoned or partly depopulated as they were overrun by drifting sand.

Adapted from *Earth Policy Institute*, 2006

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http://geoweb.tamu.edu/courses/geo1101/grossman/Deserts.html

Unitarian Service Committee of Canada: www.usc-canada.org/

UN Convention to Combat Desertification: www.un.org/ecosocdev/geninfo/sustdev/desert.htm

UN Environment Programme Global Deserts Outlook: www.unep.org/Geo/gdoutlook/

Questions & Activities

Activities

1 a Describe the characteristics that define a hot desert climate. *(4 marks)*

b Study Figure 7.2 (page 179) and describe the location of the world's deserts. *(4 marks)*

c Explain two causes of a desert climate. *(4 marks)*

d Write a paragraph to explain to someone why the typical view of a desert as a 'sea of sand' is often not true. *(4 marks)*

e What is 'exfoliation' weathering? *(4 marks)*

f Explain one other denudation process that operates in hot desert areas. *(5 marks)*

2 a Describe and name an example of a wadi. *(4 marks)*

b i Sometimes a 'flash flood' rushes through a wadi. Explain what a flash flood is. *(3 marks)*

ii Why is there little or no warning that a flash flood is about to happen? *(3 marks)*

iii Why do rivers stop flowing very soon after a flood in a desert area? *(3 marks)*

c In the area where a wadi opens onto lowland there is often an alluvial fan. Describe an alluvial fan and explain how it is formed. *(6 marks)*

d Describe a playa and explain how playas are formed. *(6 marks)*

Exam practice: basic structured questions

3 a Describe how wind transports material in a desert environment. *(6 marks)*

b Why is wind transportation a more important method of movement in deserts than in wet environments? *(3 marks)*

c Choose **one** type of sand dune.

i Draw an annotated diagram to show its main features.

ii Explain how the dune has been formed. *(8 marks)*

d Choose **one** desert landform created by wind erosion.

i Describe its shape and size.

ii Explain the processes that have formed it. *(8 marks)*

4 a On a sketch or copy of Figure 7.25 page 189, add labels to show: caprock; free face; bare rock; rectilinear slope; loose scree; gently sloping plain. *(6 marks)*

b Explain why the loose material you can see in the photograph has not been moved away. *(5 marks)*

c i In the Sahara Desert in North Africa there is evidence that the climate has not always been like this. Choose **one** piece of evidence to show that the climate has changed, state it and explain how it shows climate change. *(7 marks)*

ii Choose **one** piece of evidence to suggest that the climate of North Africa is changing now. State it and explain how it shows climate is changing. *(7 marks)*

Exam practice: structured question and essays

5 a Why do arid conditions occur in continental areas in the tropics? *(10 marks)*

b Making good use of examples, describe **two** ways in which plants adapt to drought conditions in desert areas. *(8 marks)*

c Explain the term 'water balance' used to identify the extent of tropical desert climates. *(7 marks)*

6 'Semi-arid lands are fragile environments.'

Discuss this statement with reference to semi-arid areas that you have studied. *(25 marks)*

7 Using Figures 7.3, 7.4 and 7.5 (page 180), describe and account for the range of surface conditions found in desert areas. *(25 marks)*