Our Planet's Extreme Environments

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Contents

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Author: title page, 1.1, 1.3, 1.5, 1.6, 1.7, 1.9, 1.10, 1.11, 1.12, 1.14, 1.15, 1.17, 1.18, 1.21, 1.22, 1.23, 1.24, 1.25, 1.26, 1.27, 1.28, 1.29, 1.30, 1.31, 1.33, 1.34, 1.35, 1.36, 1.37, 1.38, 1.39, 1.40, 1.41, 1.42, 1.43, 1.44, 1.45, 1.46, 1.47, 1.48, 1.50, 1.51, 1.53, 1.54, 1.55, 1.56, 1.57, 1.58, 1.60, 1.61, 1.64, 1.65, 1.66, 1.67, 1.68, 1.69, 1.70, 1.71, 1.72, 1.73, 1.76, 1.78, 1.79, 1.80, 2.1, 2.2, 2.3, 2.4, 2.6, 2.7, 2.9, 2.10, 2.11, 2.12, 2.13, 2.16, 2.17, 2.18, 2.19, 2.20, 2.21, 2.22, 2.27, 2.28, 2.29, 2.30, 2.31, 2.32, 2.33, 2.34, 2.35, 2.36, 2.37, 2.38, 2.39, 2.40, 2.41, 2.42, 2.43, 2.44, 2.45, 2.46, 2.47, 2.48, 2.49, 2.50, 2.51, 2.52, 2.53, 2.54, 2.55, 2.56, 2.57, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.10, 3.11, 3.12, 3.13, 3.14, 3.15, 3.16, 3.17, 3.18, 3.19, 3.20, 3.21, 3.22, 3.23, 3.24, 3.25, 3.26, 3.27, 3.28, 3.29, 3.30, 3.31, 3.32, 3.33, 3.34, 3.36, 3.37, 3.38, 3.39, 3.40, 3.41, 3.42, 3.43, 3.44, 3.45, 3.46, 3.47, 3.48, 3.49, 3.50, 3.51, 3.52, 3.53, 3.54, 3.55, 3.56, 3.57, 3.58, 3.60, 3.61, 3.63, 3.64, 3.65, 3.66, 3.67, 3.68, 3.69, 3.70, 3.71, 3.72, 3.73, 3.74, 3.75, 3.76, 3.77, 3.78, 3.79, 3.80, 3.81, 3.82, 3.83, 3.84, 3.85, 3.86, 4.1, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.12, 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, 4.20, 4.21, 4.22, 4.24, 4.25, 4.26, 4.27, 4.28, 4.29, 4.30, 4.31, 4.32, 4.33, 4.34, 4.35, 4.36, 4.37, 4.38, 4.39, 4.40, 4.41, 4.42, 4.43, 4.44, 4.45, 4.46, 4.47, 4.48, 4.49, 4.50, 4.51, 4.52, 4.53

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Preface

Our Planet's Extreme Environments is one of seven monographs written to support the options for the International Baccalaureate Diploma Geography (IBDP) course. These seven monographs complement three larger books that span the entire content of the IBDP Geography Program. *Our Changing Planet* covers the SL and HL Core (Paper 2), *Our Connected Planet* covers the Higher Level Core Extension (Paper 3), and *Our Dynamic Planet* includes material on all seven options in the SL and HL themes (Paper 1).

As with all the books in the *Planet Geography* series, my aspiration is that every reader of this book will acquire knowledge and wisdom to become an effective steward of our planet, committed to ensuring its healthy survival and vibrant flourishing.

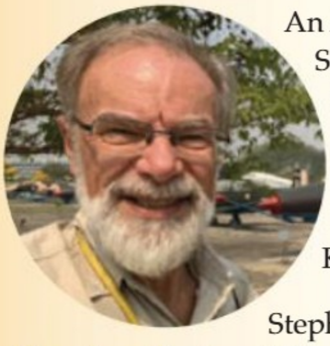
Any comments or suggestions to improve future editions of this book are always welcome. I hope you, the reader, will enjoy learning more about the geography of our fascinating planet as I have over the years.

Stephen Codrington.

The Author

Dr Stephen Codrington has a Ph.D. in Geography, and has taught the subject in several countries at both the high school and university level. He is the author or co-author of 69 books, mainly books that focus on his life-long passion for Geography.

Following his highly successful career as a teacher of Geography and Theory of Knowledge, including serving as the Head of five International Baccalaureate (IB) schools in four countries, he now works with school boards and leaders through Optimal School Governance, educates trainee teachers at Alphacrucis College, and is Chair of the Board at Djarragun College.



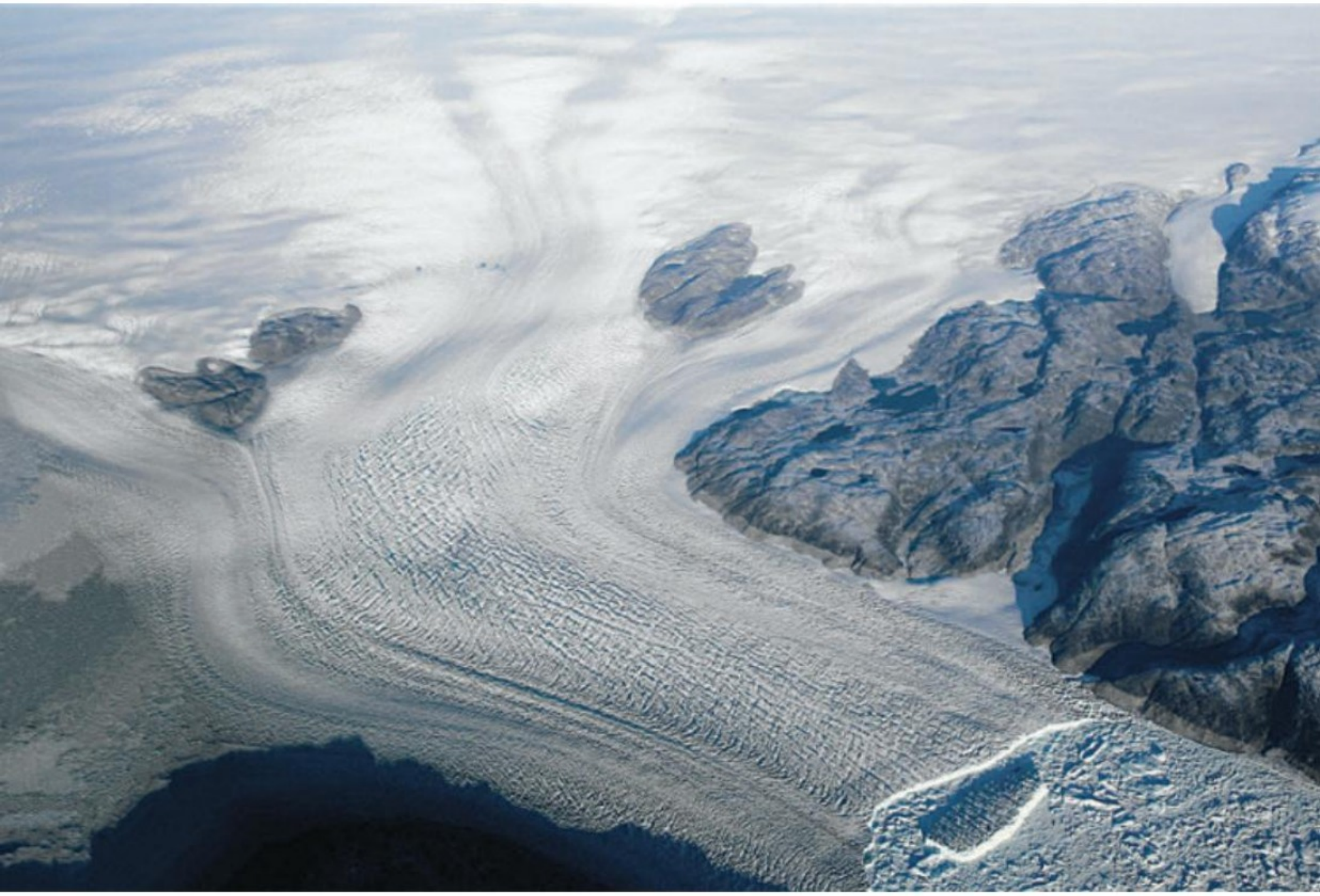
An Australian by birth, Stephen is a former President of both the Geographical Society of New South Wales and the Geography Teachers' Association of New South Wales (twice). He edited Geography Bulletin, the journal of the Geography Teachers' Association of New South Wales for seven years, and is now a Councillor and Treasurer of the Geographical Society of New South Wales. He has taught in schools in Australia, the United Kingdom, New Zealand, Hong Kong and the United States.

Stephen has been honoured with election as a Fellow of the Australian College of Education, the Royal Geographical Society (UK), and the Geographical Society of NSW. He was appointed to the role of IB Ambassador in 2014 and honoured with life membership of the Geographical Society of New South Wales in 2018. He is a former Chairman of HICES (Heads of Independent Co-educational Schools). Stephen's work has taken him to 161 countries, and he has been listed in Who's Who in Australia every year since 2003.

From 1996 to 2001 he served as Deputy Chief Examiner in IB Diploma Geography, setting and marking examination papers, assisting with curriculum development, and leading many teachers' workshops.

He maintains a personal website at www.stephencodrington.com that contains links to travel diaries and other items of geographical interest.

Chapter 1 Characteristics of extreme environments



1.1 Extreme environments are usually inaccessible and generally inhospitable to human habitation. This glacier flowing towards the west coast of Greenland from the ice sheet that covers most of the island demonstrates both inaccessibility and inhospitableness.

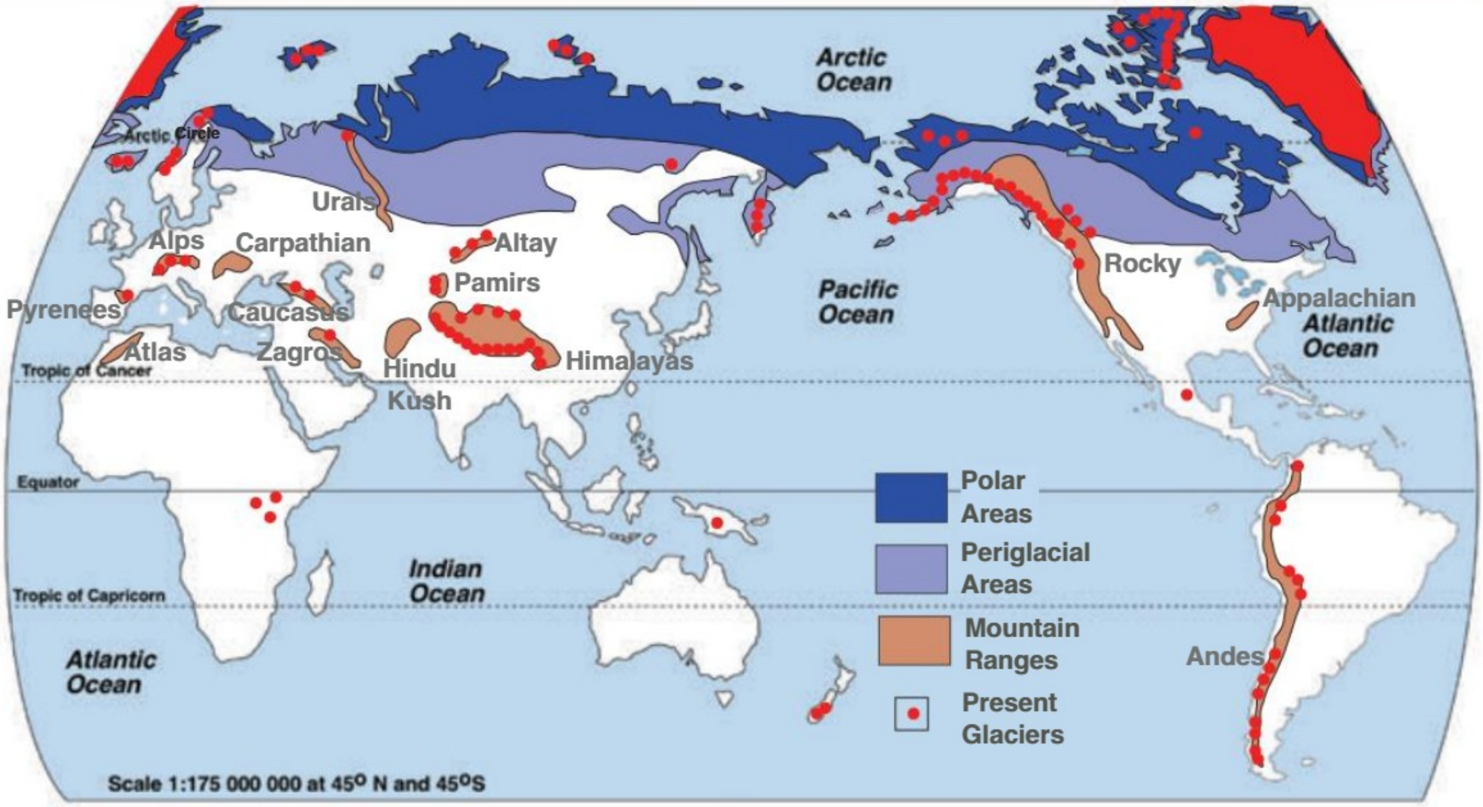
Extreme environments

What makes an environment extreme?

This book looks at two different types of extreme environments. One type of extreme environment comprises **hot and arid areas**, which are the world's deserts and semi-deserts. The second type is **cold and high altitude environments**, which comprise a mix of polar, glacial and periglacial areas, together with the high mountains of non-tropical latitudes.

Although these two types of environments contrast with each other in many ways, they share the common characteristic of being inhospitable to human habitation as well as being relatively inaccessible. Nonetheless, people do live in these areas and they provide opportunities — as well as many challenges — for economic activity. For the geographer, the natural processes operating in these environments make an excellent study in contrasts.

All hot and cold extreme environments tend to have harsh climates, rugged landforms, shortages of usable water, and a lack of productive vegetation. These extreme conditions pose



1.2 Global distribution of the world's cold and high altitude environments.

significant challenges for humans who live and work there. Consequently, population densities are sparse, settlements are few and far between, and food production is difficult.

On the other hand, some areas with extreme environments have rich mineral resources. The harsh climate often creates problems in exploiting these resources, increasing costs as well as the demands made for technology and capital equipment.

In both hot and cold extreme environments, it can be difficult for people to maintain a sustainable lifestyle. This challenge arises because of the high energy demands that are often made. Today, this is also true of indigenous peoples who are abandoning their traditional lifestyles in pursuit of greater comfort and affluence.

Global distribution

Global distribution of cold and high altitude environments

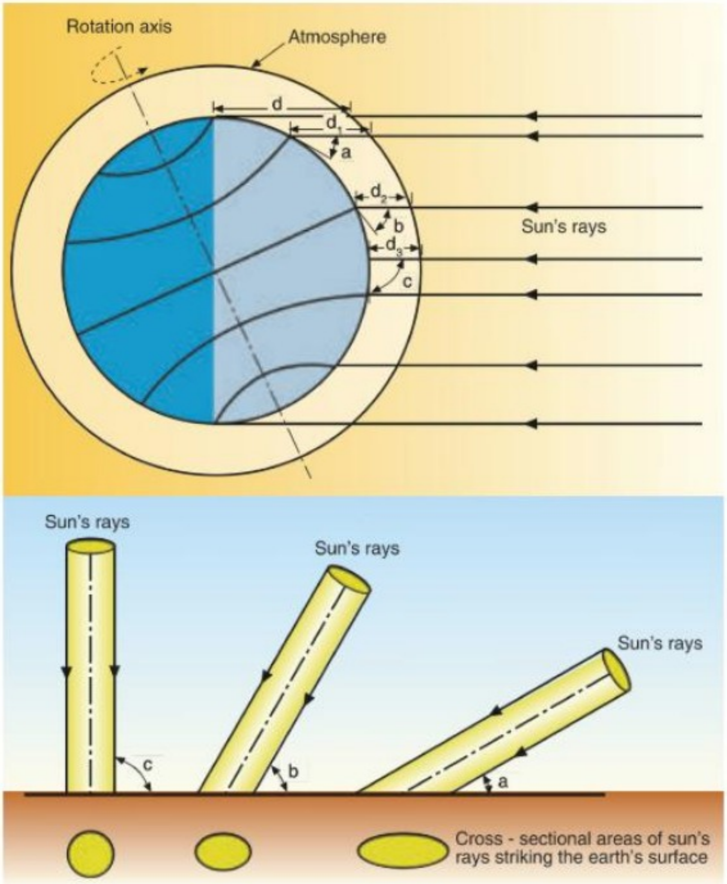
Polar environments

Polar environments are found near the South Pole (on the continent of Antarctica) and near the North Pole (in the Arctic region along the northern

1.3 An example of a polar environment; the snow-covered landscape around Priestley Glacier, Antarctica.

coastlines of Russia, Canada and the US state of Alaska, as well as along most of Greenland's coastline (figure 1.2). These areas are covered by snow all year because the level of **insolation** (incoming solar radiation) is so low.

As shown in figure 1.4, the amount of heat received at the earth's surface varies according to latitude. Less solar energy is absorbed by the ground in polar areas than equatorial areas for three reasons. First, the sun's rays strike the earth's surface at a **lower angle** near the poles. Therefore, the same quantity of solar energy approaching the equator and the poles must be spread over a larger area in



1.4 The intensity of solar radiation depends on the angle which the sun's rays meet the earth's surface. The angle of the sun's rays (a, b and c in the lower diagram) and the thickness of the atmosphere through which the sun's rays must pass (d_1, d_2 and d_3 in the upper diagram) depend on the latitude. At high latitudes near the poles, the same amount of insolation is spread over a larger area, making the heat less intense.

polar areas, meaning that there is less heat per square metre on the surface. This is shown in the lower part of figure 1.4.

The second reason the poles receive less solar radiation is that the sun's rays must penetrate a **greater thickness of atmosphere** near the poles than near the equator. This is because the rays penetrate the atmosphere at an oblique angle, shown as distance "d" in figure 1.4. As a result of this, dust and gases in the atmosphere absorb more heat and light near the poles, and less light and heat reach the earth's surface.

The third reason the earth's surface at the poles absorbs less solar radiation is that more of the light that does manage to reach the surface there is **reflected back into space**. The shiny white ice and snow of the poles has a much higher **albedo** (reflectivity) than the water and vegetation of the equatorial zones. In fact, snow and ice reflect about 80% of the solar energy whereas grass and trees will absorb between 65% and 85% of solar energy, thus reflecting only 15% to 35% of the sun's energy. Moreover, any surface becomes shinier when light hits it at a low angle — even a black bitumen road seems shiny when viewed at a low angle. The light that reaches the polar surfaces does so at a very low angle, and therefore much of it is reflected rather than absorbed.

Periglacial environments

Although they do not have year-round snow cover like polar environments, periglacial environments usually have **permafrost**, which is a thick layer of soil beneath the ground surface that remains frozen throughout the year.

1.5 This tunnel beneath the Russian city of Yakutsk has been excavated through the permafrost. The build-up of ice on the tunnel walls is from the breath exhaled by people walking through the tunnel. The year-round temperature in the tunnel is a constant -8°C, almost balmy in winter when the temperature outside may be -20°C.

Periglacial environments are found beside and near glaciers or ice sheets in areas where the average annual air temperature remains below -7°C. The southern boundary of periglacial environments with discontinuous permafrost occurs where the annual average temperature is about -2°C. However, much of the discontinuous permafrost zone is a remnant of former ice ages and is out of equilibrium with today's climate. With global warming, the southern boundary of the periglacial environment is migrating northwards.

Periglacial environments have intense frost action, especially near the fringes of glaciers and ice sheets. They often have a large annual temperature range, which creates an annual cycle of freezing and thawing on the ground surface. This annual cycle changes the ice to water and back again, and with each cycle of freezing and thawing, there is a change in volume (as water expands when frozen). Thus, many of the landforms in periglacial areas arise because of the annual partial melting of the upper layer of the permafrost each summer.

As shown in figure 1.2, periglacial environments are found in a broad belt spanning northern Europe, Russia and Canada. The periglacial environment may be thought of as a zone of transition between the permanently cold polar areas to the north and the forested zones to the south.

Like the polar areas, periglacial environments present severe challenges for human activity, which helps explain their sparse population density.

Glacial environments

Figure 1.2 shows the distribution of the world's glacial areas (in red). A **glacier** is a slowly moving mass or river of ice formed by the accumulation and compaction of snow on mountains or near the poles. Glaciers form when snow is compressed so that it recrystallises as ice which then advances downhill under the influence of gravity.

Although composed of solid ice, glaciers behave like an extremely thick liquid, bending and flowing at a very slow rate under the influence of gravity. Areas that are shaped and influenced by glacial ice are known as glacial areas, and they tend to be found at high altitudes in non-tropical latitudes or at lower altitudes in high latitude (polar and sub-polar) regions.

1.6 This summer view of a glacial landscape shows typical landform features that have been shaped by the action of moving ice. The location is Hidden Lake in Glacier National Park, Montana, USA.

Glacial ice covers about 10% of the earth's surface and contains almost 3% of the planet's fresh water. Glaciers tend to be found in mountainous areas where frozen rivers both provide drainage and erode the land in distinctive ways.

Within the last two and a half million years of the earth's history (the period known as the Pleistocene, which ended about 12,000 years ago), there were at least four great ice ages. During these ice ages, the ice sheets and glaciers expanded to cover about one-third of the earth's surface. As the ice sheets and glaciers expanded from the polar regions into the mid-latitudes, they scraped and scratched the rocks beneath, eroding the land to form distinctive landscapes that remain quite different to areas shaped by the action of running water or wind.

Mountain environments

1.7 Wangbur Mountain in the Himalayas of Tibet is home to the Ganden Monastery. Situated at an altitude of 4,300 metres above sea level, it shows the bare mountain slopes that are typical of high altitude environments where very few types of vegetation can tolerate the harsh cold temperatures and lack of moisture.

A **mountain range** is a group or chain of mountains that are clustered together and thus form a continuous belt of elevated land. The world's longest mountain range is the Andes on the west coast of South America, which has a length of over 7,000 kilometres. The highest mountain range in the world is the Himalayas, which contains the highest mountains in the world, including Mount Everest on the border of Nepal and China which has a summit altitude of 8,848 metres. The

Himalayas have more than 30 peaks with summits higher than 7,600 metres.

The distribution of the world's mountain ranges is shown in figure 1.2. The pattern of the mountain ranges is closely related to the pattern of **tectonic plates** as mountains form on the constructive boundaries where two converging plates meet. The crustal material buckles upwards to form complex folded mountain chains that mark the approximate plate boundary. Older, lower mountain ranges may be remnants for former plate boundaries that are now inactive, or they may occur along lines of weakness called faults where the energy from moving plates is transferred.

Global distribution of hot arid environments

Aridity occurs when there is a severe lack of available water. An area is considered **arid** if the potential evaporation exceeds the average precipitation. Arid conditions hinder and prevent the growth and development of plant and animal life. Areas that are dry without being extremely arid are known as **semi-arid areas**, and they can usually support short or scrubby vegetation.

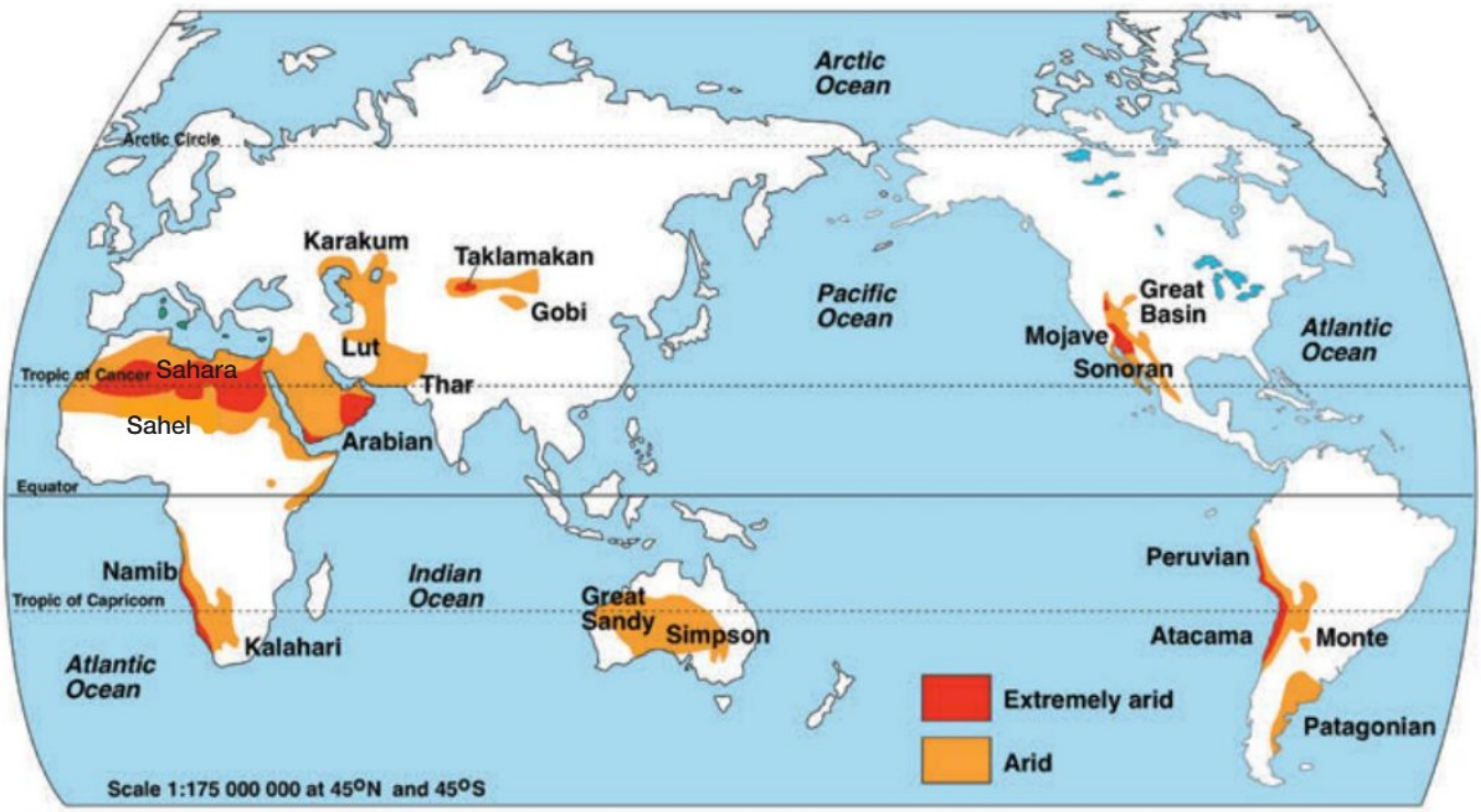
The distribution of the world's deserts – arid and semi-arid lands – is shown in figure 1.8. It is possible to classify hot deserts and semi-arid environments into four groups according to the way they formed, although the four types can sometimes overlap.

The four types are inland deserts, rainshadow deserts, subtropical high pressure deserts, and west coast deserts.

Inland deserts

The largest **inland deserts** are found in Central Asia, and examples include the Taklamakan and Gobi Deserts of north-western China and Mongolia, and the Karakum Desert of Kazakhstan, Uzbekistan and Turkmenistan. Although these deserts are hot in summer, temperatures fall markedly in winter, when they can become bitterly cold. In other words, the inland deserts have a very high annual range of temperatures.

The most important **cause** of inland deserts is their location; they are situated at vast distances from sources of moisture such as the oceans. In these remote areas, rain-bearing winds have to cross great expanses of land and high mountain ranges



1.8 Global distribution of the world's hot deserts and semi-arid environments.

1.9 Part of the Karakum Desert in central Turkmenistan, an example of an inland desert.

before reaching the interior of the continent. As the winds travel inland, they drop most of their moisture. The huge size of the Asian continent is ideal for forming inland deserts, and so several are found in the continental interior between latitude 35°N and latitude 50°N.

Rainshadow deserts

When moist air mass blows onshore from the ocean, it is immediately forced to rise. When the moist air encounters a mountain barrier, such as the Rocky Mountains of North America or the Andes Mountains of South America, it must rise to significant altitudes. As the moist air rises, it cools **adiabatically**, which means the temperature decreases as the air expands and its pressure is reduced. This increases the relative humidity of the air mass, which means its ability to carry moisture is reduced. As a result of the adiabatic cooling of the rising air, precipitation falls on the windward side of the mountains. This rainfall is known as **orographic rain**.

By the time this air mass has passed across to the leeward side of the mountains, its moisture content has been greatly reduced. As a result, the air mass is dry and further precipitation is unlikely, especially if the air descends and experiences an adiabatic rise in temperature. The reduced rainfall area leeward of mountains is known as a **rainshadow area**.

There are several deserts of this type in the south-west of the United States. The driest of these deserts is Death Valley, just east of the High Sierra Mountains, which obstruct the moisture-laden westerly winds blowing in from the Pacific Ocean. In the southern hemisphere, the best known rainshadow deserts are the Monte and Patagonian deserts east of the Andes in South America. The Patagonian desert extends right across to the east coast of Argentina where its aridity is partly due to the cold Falkland current.

1.10 Monument Valley on the border of Arizona and Utah, in south-western USA, is an example of a rainshadow desert environment.

Deserts of the subtropical high pressure areas

As we saw in figure 1.4, the equatorial zone receives more constant heating from the sun than anywhere else on earth. As the air is heated it expands, rises, and in the upper atmosphere spreads both north and south away from the equator. Eventually, the air descends in the subtropical zones about 25° north and south of the equator. As the air descends it becomes warmer through an **adiabatic rise in temperature**.

The warmer the air becomes, the more moisture it can contain in the form of water vapour, and the less chance there is for precipitation to occur. This latitude zone therefore has clear skies and dry weather. It is known by different names, such as the zone of subtropical high pressure, the subtropical belt of anticyclones (**high pressure areas**), and sometimes by the old term 'horse latitudes'.

The world's largest desert, the Sahara, is a subtropical high pressure desert. Other northern hemisphere examples are the deserts of Arabia, Iran, north-west India (the Thar) and the Sonora

1.11 The Sahara Desert is the world's largest subtropical high pressure desert. Much of the Sahara Desert comprises sand dunes, making settlement and transport difficult. The nomadic Tuareg people have adapted to this harsh environment, as shown in this view north of Timbuktu in Mali.

desert of North America; all these deserts are situated between latitudes 20°N and 30°N. In the southern hemisphere, the subtropical high deserts are located between latitudes 20°S and latitude 30°S. Examples of subtropical high pressure desert in the southern hemisphere include the Kalahari Desert of southern Africa, and most of the desert areas of Australia.

West coast deserts

Although coastal deserts are found in many parts of the world, the most distinctive group occurs in the tropics and subtropics on the west coasts of continents. In these areas, aridity is partly due to the subtropical high pressure systems that were described in the previous section. However, the main factor is the **cool ocean currents** that flow along the western coasts of most continents. The cold sea water cools the air above, making it difficult for the air to rise, form clouds and release moisture. Although the cooling process often leads to fogs (a form of condensation), there is not usually enough atmospheric activity to cause rain.

1.12 The sands of the Namib Desert in Namibia extend right to Atlantic Ocean coastline.

There are only two west coast deserts in the northern hemisphere. These are the Baja California sector of the Sonoran desert in Mexico, and the extreme western sector of the Sahara Desert. In the southern hemisphere, important west coast deserts include the Peruvian and Atacama deserts of South America, the Namib Desert of southern Africa, and the coastal parts of the Great Sandy Desert in Western Australia.

Question Bank 1A

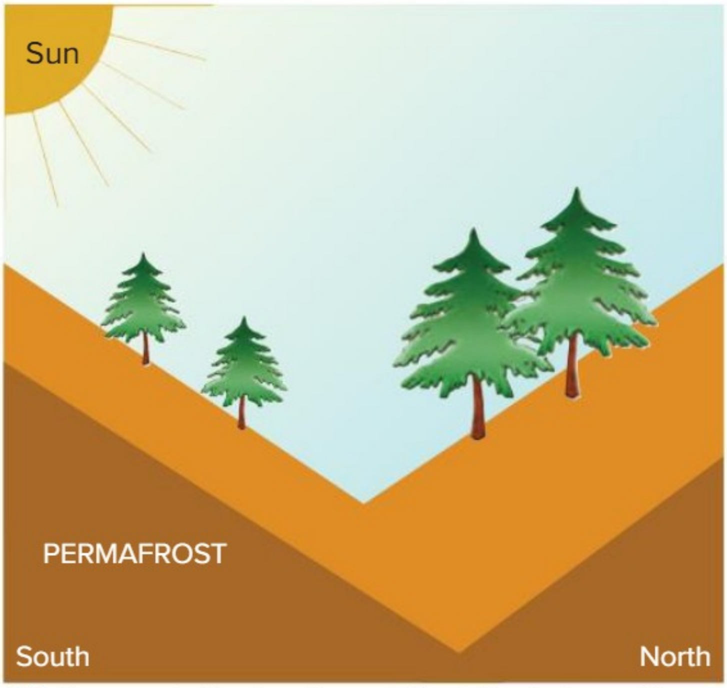
1. *Explain what is meant by the terms (a) arid environment, (b) semi-arid environment, (c) polar environment, (d) periglacial environment, (e) permafrost.*
2. *Draw up a table that lists the four types of deserts in column 1, summarises the cause of each type in column 2, and lists two examples of each in column 3.*
3. *Explain why the polar areas of the world are cold.*
4. *Describe and account for the world distribution of (a) polar environments, (b) periglacial environments, (c) the world's high mountain ranges, and (d) the world's ice sheets and glaciers.*

Relief and climatic characteristics

Why are cold and high altitude environments extreme?

Polar environments are one of the most extreme environments on the planet. They are **cold** all year because of the low amount of heat and light they receive (figure 1.4), and they are often affected by bitterly **cold winds** that blow unimpeded across the barren landscape. Polar regions typically receive very little rainfall, and for that reason they are sometimes referred to as **cold deserts**. The inhospitable nature of the polar regions explains why very few live in the region, and those who do so often demand high inputs of energy for heating, lighting, transport and the import of food.

The climate in **periglacial areas** is not quite as harsh as the polar regions, but they are still inhospitable for human habitation. Although summers are warm in periglacial areas, winters are as almost as cold as the polar regions. However, it is presence of **permafrost** that poses special challenges in periglacial areas.



1.13 The aspect of a slope (its angle in relation to the sun) is a strong influence on the permafrost beneath the surface. North-facing slopes become warmer in the northern hemisphere, causing the soil temperature to increase. This melts the permafrost beneath the surface, causing an asymmetrical pattern to develop where taller vegetation with a higher density can grow where the depth of unfrozen soil is greater.

1.14 The snow-covered Yukon River flows past the town of Dawson City in Canada's Yukon Territory, a periglacial environment. This view looks towards the south-west, so the slope on the right of the photo faces south while the slope on the left of the photo faces north. The warmer south-facing slope (on the right of the photo) shows higher and denser vegetation than the cooler north-facing slope to the left of the photo.

There are two types of permafrost:

- **perennially frozen ground**, where the water in the pores of the soil or rock is frozen all year; and
- **seasonally frozen ground**, where the ground remains frozen only during winter, thawing each summer.

The relief and aspect have a significant impact on the permafrost beneath the surface of periglacial environments. In the northern hemisphere, where all significant periglacial areas occur, south-facing slopes receive more sunshine than north-facing slopes. The additional warmth on south-facing slopes means that the permafrost there is found at a deeper level than the permafrost on the colder north-facing slopes (figures 1.13 and 1.14).

1.15 Snow on the peaks of these mountains in the Eastern Himalayas shows the cooler temperatures at higher altitudes.

A wide range of hazards occur in periglacial areas where the permafrost freezes and thaws annually. The expansion and contraction of the melting ice causes problems for buildings, roads and other constructions.

In **mountain areas**, the main factor causing differences in the landscape is **altitude**. The temperature differences that are found globally from latitude 0° (the equator) to 90° (the poles) are mirrored by the temperature differences we see as we climb from sea level up to 9,000 metres elevation. In terms of temperature changes, the distance from the equator to the poles is the same as from sea level to the highest point in the world, the summit of Mount Everest, even though the vertical distance is less than 10,000 metres.

There is a clear relationship between **altitude, air pressure** and **temperature**. This is shown by the average figures in table 1.1. The fact that the

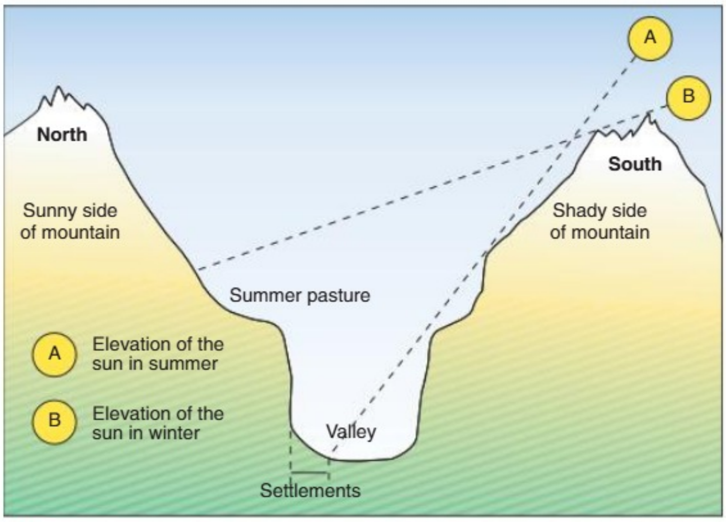
Table 1.1
The Relationship between Altitude, Air Pressure and Temperature

Altitude (metres)	Air Pressure (kilopascals)	Temperature (°C)
-500	806.2	18.3
0	760.0	15.0
500	716.0	11.7
1000	674.1	8.5
1500	634.2	5.2
2000	596.2	2.0
2500	560.1	-1.2
3000	525.8	-4.5
3500	493.2	-7.8
4000	462.2	-11.0
4500	432.9	-14.2
5000	405.1	-17.5
5500	378.7	-20.8
6000	353.8	-24.0
6500	330.2	-27.3
7000	307.8	-30.5
7500	286.8	-33.7
8000	266.9	-37.0
8500	248.1	-40.3
9000	230.5	-43.5
9500	213.8	-46.7
10000	198.2	-50.3
10500	183.4	-53.3
11000	169.7	-55.0
11500	156.9	-55.0
12000	145.0	-55.0

Source: Panday (1995), p.375

temperature of the atmosphere becomes cooler with increasing altitude (i.e. a negative, or inverse, relationship) is the reason that countries located fairly close to the tropics may have high mountains with summits that are permanently covered in snow.

Altitude affects more than just air pressure and temperature. As altitude increases, there are also decreases in **air density, water vapour, carbon dioxide** and **impurities**. With the fall in air pressure with altitude, the boiling point of water also decreases, and at the summit of Mount Everest (8,848 metres) water would boil at 72°C. On the other hand, increases in altitude bring increases in the intensity of ultra violet radiation, which is why sunburn is more likely at higher altitudes. Indeed, as a result of the reflected heat from the snow that can occur in the clear high altitudes, temperatures of 80°C have been recorded in the Swiss Alps at 2,070 metres, the maximum ever recorded on the earth.



1.16 The impact of aspect on a typical mountain valley in the northern hemisphere.

At high altitudes, a greater **proportion of sunlight** reaches the earth's surface than is the case at lower altitudes because of the cleaner, clearer air at high altitudes. However, the heat that is then reflected from the ground cannot be retained very effectively in the thinner air. Therefore, temperatures vary greatly in alpine areas according to whether the sun is shining or not at the time.

Another factor that affects temperatures with altitude is **slope aspect**. In the northern hemisphere, where most of the world's high mountains are located, slopes facing the south (i.e.

towards the equator) receive sunshine for longer intensive periods than slopes with a northern aspect (figures 1.16 and 1.17). A slope receiving direct sunlight will warm up very quickly, but will also cool quickly as soon as the sunlight disappears. Thus, slopes facing south receive more solar radiation and are exposed to the summer prevailing winds, raising the air and soil temperatures. As a result of this, there are significant differences in the vegetation and land uses found on the northern and southern slopes of alpine areas.

1.17 Hills on the edge of the Southern Alps in New Zealand, north of Invercargill, are covered with snow on the southern sides (facing away from the sun), whereas snow on the north-facing slopes has melted.

Because mountains interfere with and change the **circulation of air**, mountain regions often have their own **microclimates**. For example windward slopes may receive **heavy precipitation** as moist air is forced to rise (orographic rainfall), while leeward slopes remain a **rainshadow** zone, leading to almost desert-like aridity.

Wind direction and wind strength change with altitude. **Wind speed** increases with altitude, sometimes creating gale force winds in one direction for hours or even days on end (figure 1.18). Winds on exposed slope and summits are much stronger than winds in the valleys, especially as there is much less friction between the air and the land surface at high altitudes. In general, winds blow up the slopes during the day as the sun warms the land creating areas of low pressure. At night, as the air cools, the winds reverse and blow down the slopes. This flowing downwards of cool air is known as **katabatic wind**.

1.18 The strong winds blowing from left to right near the summit of this mountain in the Himalayas near Mount Everest in Nepal are shown by the snow being blown from the tops of the arêtes.

Mountain ranges such as the Himalayas, the Swiss Alps, the Rockies and the Andes have been formed by **tectonic uplift**, caused by the collision between two crustal plates. For example, the Himalayas are forming on the edge of the Indo-Australian plate that is moving northwards into the Asian land mass. This process is still occurring, and thus the Himalayas are still being pushed higher and higher. Because of the continuing instability, countries in the Himalayas such as Nepal suffer from periodic earthquakes (figure 1.19). Particularly severe earthquakes occurred in Nepal in 1833, 1934, 1988 and 2015. In the 2015 earthquake, which measured 7.8 on the Richter scale, more than 8,000 people were killed, over 21,000 people were injured, perhaps a million people were left homeless and an estimated $US 5 billion damage was caused.

1.19 Extensive damage in Kathmandu, capital city of Nepal, following the earthquake in April 2015.

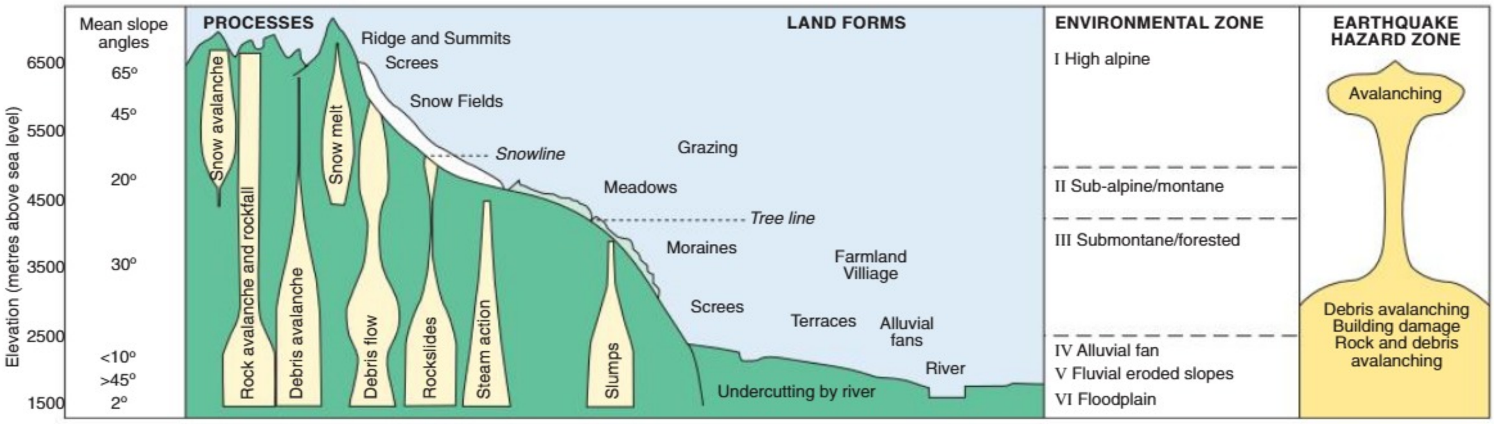
The Swiss Alps are also situated on the boundary between two crustal plates. The mountains are forming as the land is pushed upwards as the African Plate forces its way into the Eurasian Plate to its north. This is the same plate boundary that causes earthquakes and volcanic activity in Italy, Greece and Croatia. Although Switzerland experiences earthquakes, they tend to be less severe than those in the Himalayas, where Nepal is located. Moreover, being a more economically developed country, Switzerland can afford to construct its buildings to withstand earthquakes and to provide extensive rescue services in the event of a disaster. Indeed, the major effect of Switzerland's relatively minor earthquakes is to destabilise accumulated snow on steep slopes, leading to major avalanches that can kill people and damage property.

Mountain areas experience a range of hazards caused by landforms, and a summary of these is shown in figure 1.20. One landform hazard of these extreme environments is **avalanches**, which occur when a mass of snow, ice or rock falls rapidly down a mountainside. As figure 1.20 shows, there are two altitude belts where **snow avalanches** occur. The first zone is above the snow line. In this zone, avalanches can occur all year round, although they are more common in the summer when some snows melt a little. These are not usually harmful to settlements because they stop in the cirque basins about the zone of habitation.

The second zone of avalanches occurs below the snow line. Freezing during the night and melting during the day makes the underlying rock very weak, and only a minor disturbance may cause a great avalanche. These avalanches are very dangerous as they often come without warning and occur in areas of settlement or tourism.

The high mountains of the world are geologically young structures formed by folding and faulting. Therefore, they have **steep gradients** and **weak rock structures**. The loose structures, steep slopes and the action of water and ice combine to make many mountain areas unstable and prone to weathering, erosion and mass movement due to gravity. The **high diurnal** (daily) **range of temperatures** in alpine areas helps to shatter rocks as they expand and contract, perhaps with the assistance of water freezing and expanding in the cracks of the rocks. This process is especially strong on the exposed mountain slopes (figure 1.21).

The steep slopes that are often found in mountain areas also make **soil formation slow and difficult**. The cool temperatures mean vegetation growth is slow, so the amount of decaying vegetation (humus) tends to be small. This is especially so at high altitudes where the climate is too harsh for trees to grow. Furthermore, the steep slopes may not allow humus to settle. Indeed when rocks



1.20 The vertical zonation of landforms and landform hazards in mountain areas (using Nepal as an example).

1.21 This slope in the Altay Mountains of western Mongolia shows the somewhat unstable shattered rock debris typical of alpine areas. The thin, patch vegetation cover is evidence of the slope's instability. This is a summer view of slopes that would be covered in snow during winter.

break down in mountain areas, it is often the result of sudden freezing and thawing, and so the weathered material does not settle long enough for fertile soils to form. Consequently, mountain soils tend to be thin, infertile and unstable. Indeed, many steep mountain slopes may be completely devoid of soil (figure 1.22).

1.22 This steep slope in Glacier National Park (Montana, USA) is completely bare of both soil and vegetation.

Why are hot, arid environments extreme?

The word **desert** literally means a deserted land or wasteland. Although the common mental image of a desert is endless sand dunes, the word has come to be used in everyday speech for any arid land, whether it is occupied or not (figures 1.23).

1.23 The traditional stereotypical view of deserts; sand dunes, sparse population, camels, nomads. This view shows an area of the Sahara Desert near Aswan in Egypt.

As we saw earlier in this chapter, we can define an arid environment, or desert, as one where the potential evaporation exceeds the average precipitation. This definition helps us understand why deserts are viewed as extreme environments.

Traditionally, deserts have been described in terms of **deficiencies** – rain, soil nutrients, vegetation – and these deficiencies constrain human development. We now understand that many desert areas have quite fertile soils, and can be very productive if there is enough water available and they are managed wisely. Furthermore, most desert areas have quite an abundance of vegetation and wildlife, although the types of plant and animals species in deserts have adapted to cope with the aridity. It is important that aridity is not confused with infertility.

Moisture deficit defines deserts, and this helps us understand their environmental challenges. It is the **lack of precipitation,** as well as the **unreliability** and **unpredictability** of rainfall, that pose challenges. In some desert areas, several years might pass between falls of rain.

River valleys are formed, and become deeper, when flowing water erodes the rock and soil beneath. Because rain falls so infrequently in desert areas, drainage channels are poorly developed. Thus, on the rare occasions that heavy rain does fall, **flash flooding** may occur. A heavy fall of rain delivers a volume of water that cannot be absorbed quickly by the soil, leading to **overland flow**. With little vegetation to restrict the flow of water, the overland flow can quickly develop into a dangerous torrent

1.24 'Wadi' is an Arabic term meaning a drainage channel that is generally dry, becoming flooded only after heavy rains. This road sign in Wilayat Mahdah, Oman, warns drivers that what looks like an open expanse of stony desert could become covered by water during a flash flood without further warning.

1.26 Sand dunes in the Namib Desert, north-western Namibia. It is very difficult for plants to become established on the shifting wind-blown dunes. By contrast, sparse vegetation has managed to grow in the dry river bed in the background, drawing on supplies of scarce underground water.

1.25 This flat plan near Furnace Creek in Death Valley (USA) shows evidence of erosion during a recent flash flooding event.

1.27 This view near Jebel Fihrayn, Saudi Arabia, shows an area of hamada (bare rock) desert. The only vegetation that can grow in such a harsh environment is found in the dry river beds that meander through the area.

of water flowing across the landscape. Widespread erosion, including gullying, can occur during flash floods.

Although deserts typically have large patches of bare earth between plants, there are very few desert areas of the earth that are completely devoid of vegetation. There are, however, some significant exceptions, such as areas of moving sand (known as **erg**), areas of bare rock (known as **hamada**), areas without soil or areas swept constantly by very strong winds. The **vegetation** of arid areas is another reason that these environments are often labelled as 'extreme'.

Deserts typically have a very high diurnal (daily) range of temperatures, placing great stress upon the vegetation. **Plant species** that can survive in desert areas have had to develop special drought-resisting adaptations to cope with the extreme aridity; such plants are known as **xerophytes**. Xerophytes adapt to the dry conditions by developing mechanisms to obtain as much water as possible, to retain as much moisture as possible for as long as possible, and to minimise moisture loss.

In order to obtain as much moisture as possible, xerophytes have extensive root systems. Some xerophytes have very deep roots to reach deep reserves of groundwater; some varieties of acacia have tap-roots as deep as 8 metres for example. Other xerophytes have shallow root systems that spread out over a large area; the saguaro cactus of Arizona, for example, has shallow fibrous roots that

1.28 An example of a saguaro cactus in Arizona, USA.

can spread over a radius of 15 metres. The shallow roots enable plants to make use of water from a very light fall of rain or even a heavy dewfall.

1.29 This low succulent protects its moisture-filled fleshy leaves with sharp spikes.

Xerophytes use a variety of techniques to store moisture. Plants that store water in their roots, stems or fleshy leaves are called **succulents**. A large saguaro cactus may store as much as 10 tonnes of water in its stems, which have a tough fibre structure to prevent the plant wilting or collapsing during fry periods. The 'accordion-like' stems allow for expansion during wet periods and contraction during droughts. The chollah uses its soft, fleshy structure to reproduce - if an animal brushes against part of the plant, the spines attach to the animal and it readily breaks away. These broken off sections then fall to the ground, and quickly establish as new plants.

Water loss can be minimised in many ways. Many succulents have **waxy surfaces** to minimise moisture loss and keep the plant cool, while others have very **small leaves** or **needle-like leaves** to minimise the surface area of the leaves. Other plants have a hairy covering to provide shade and reduce moisture loss, while still others are deciduous, only producing leaves when there is enough water.

1.30 This desert grass in Monument Valley (USA) has sharply pointed leaves and thin leaves to minimise moisture loss by transpiration.

Another way in which water can be lost by plants is due to being eaten by herbivores. Xerophytes often defend themselves against such moisture loss by having a cover of **sharp needles** or by having **sap** which is either poisonous or which tastes very unpleasant. Many desert plants are slow growing, further minimising the need for water. For example, the saguaro cactus takes about 25 years to reach its first one metre in height, it does not develop branches until it is 75 years old, and plants may live to 200 or 250 years of age.

Grasses and low shrubs are an important part of the vegetation in most desert areas. The species vary from desert to desert. In Australia spinifex and mulga are common, whereas in North America the creosote bush is equally common. Desert shrubs are extremely hardy, with small leaves, extensive root systems, well-protected seeds, and minimal amounts of green chlorophyll in the leaves to slow the process of photosynthesis. Moreover, the leaves of small shrubs are **sclerophyllic**, which means that they have a hard layer of cells within them that prevents wilting during dry periods.

1.31 Ephemerals in the Australian Desert near Uluru burst into their short life cycles after a fall of rain.

Whereas xerophytes have adapted to the desert's aridity, **ephemerals** evade the aridity. Ephemerals have seeds that lie dormant in the desert soil for long periods of time. These seeds have a coating which is a water-soluble growth inhibiting chemical. When rain falls, the coating dissolves and the seed will germinate. Ephemerals have a very short life-cycle, germinating, shooting, flowering, seeding and dying all within a few weeks. Once the rains have finished and the ephemerals have completed their growth cycle, the seeds may lie dormant in the ground for years until the next fall of rain.

Some very dry areas have a significant vegetation cover, and they could at first sight be mistaken for a semi-arid or sub-humid land. On the other hand, some semi-arid areas have very sparse vegetation and look more like true deserts. The reason for these differences is often the characteristics of the **soil**. Good soils that can hold water help the growth of vegetation, whereas poor soils, or thin immature soils such as **skeletal soils**, or **lithosols**, may have difficulty in supporting vegetation at all.

Question Bank 1B

1. *Outline the problems that permafrost causes in periglacial areas, and explain why permafrost causes more problems in some periglacial areas than others.*
2. *Plot the data in table 1.1 on two graphs, one showing the relationship between altitude and air pressure, and the other showing the relationship between altitude and temperature.*
3. *Express in words the impact of aspect on mountain valleys that are shown in figures 1.16 and 1.17.*
4. *Why do mountain areas receive heavy rain on their windward side, but very little rain on the leeward side?*
5. *Many mountain ranges form by 'tectonic uplift'. Define this term, and explain why it can cause hazards for people in these areas.*
6. *What are avalanches, and why do they occur in mountain areas?*
7. *Make a point form list of the ways in which relief and climatic characteristics make (a) cold environments, and (b) arid environments uncomfortable or hazardous for humans.*
8. *How does flash flooding occur in arid environments, and why is it dangerous?*
9. *In what ways does the vegetation in arid environments indicate that deserts are extreme environments?*

Challenges faced by humans in extreme environments

Extreme environments, whether cold or arid, share one important common characteristic — **low population densities** that are typically between zero and three people per square kilometre. These sparse population densities can be explained because of the hostile, uncomfortable conditions found there, such as the extreme cold in polar environments and extreme dryness in arid environments.

Other factors also affect humans in these areas, such as the **relief** (landforms), the **hazards** in these environments, and their **isolation**. Remoteness has the effect of increasing transportation costs of food and consumer goods into the area, and making the export of goods produced difficult and expensive.

Challenges for humans in cold environments

Despite the harsh conditions found in polar and periglacial environments, indigenous peoples have lived there for many hundreds of years following sustainable practices.

One example of an indigenous group living sustainably is the **Koriyak** people, who live in the northern and central parts of the Kamchatka Peninsula in Russia's far east.

1.32 The area inhabited by the Koriyak people is shown in red. Russia is shown in dark grey.

Koriyak people have traditionally been **nomadic**, meaning that they do not stay in fixed settlements. Instead, they **adapt** by migrating according to the seasonal changes in the weather; northwards when the summer sun melts the northern snows, and south when the snowfields expand. Although some Koriyak people have now integrated into Russian society and live in cities, many still follow traditional ways of life that fit within the confines of the environment, adapting to conditions rather than trying to change their environment.

1.33 A nomadic Koriyak encampment in summer near Avachinsky Volcano. The shelter, called a 'chum', is made from reindeer skins, and can be folded up and moved elsewhere using reindeer for transport.

1.34 Inside the shelter shown in figure 1.33, a Koriyak woman prepares a meal on an open fire.

Traditional Koriyak life uses reindeer as their primary resource. Reindeer are herded, and moved seasonally according to the weather conditions. Milk and meat from reindeer provide the Koriyak people's main sources of food, and reindeer skin is used for clothing and shelter. The traditional Koriyak shelter, called a 'chum', is made from reindeer skin, which is sewn together using needles made from reindeer bones. Reindeer were also used as the Koriyak people's main form of long distance transport.

Most people who live in polar and periglacial environments prefer a more comfortable, if less environmentally sustainable, lifestyle than traditional Koriyak people. To cope with the cold conditions, **heating** is necessary, and this is usually provided by energy sources such as wood, coal or electricity (which in turn may be generated by burning coal or by hydro power).

Constructing **permanent dwellings** in periglacial environments poses several challenges. For example, it is only possible to build with concrete for a few months during summer, because concrete freezes during most of the year. For that reason, many buildings in periglacial environments are constructed using timber. Even when using timber for construction, the period of the year when construction is possible is severely limited by the cold conditions. Further problems arise when building over **permafrost**. When the interiors of buildings are heated, the permafrost beneath the buildings may thaw, causing the building above to slump or even collapse. To overcome this problem, many newer buildings, especially multi-storey buildings that are constructed of brick or concrete, are elevated above the ground using strong pillars that descend into the permanently frozen permafrost.

Permafrost creates further problems for the provision of services, such as water and gas. It is impractical to bury water and gas pipes underground because the annual freezing and thawing of the permafrost would break the pipes. A common solution in periglacial environments is to build the pipes above the ground, sometimes wrapping the pipes in heavy duty insulation to protect them from the harsh weather.

1.35 These water pipes in the Russian town of Artik have been built above the ground to avoid the inevitable breakage that would occur if they were buried in the permafrost. The pipes are insulated to protect them from the harsh weather, and a small bridge has been built so residents can use the pathway to get to their homes.

1.36 Service pipes have been built to cross over the main street of the small city of Ust-Nera in the Russian far east.

Permafrost causes further problems for transport. The annual freezing and thawing of the permafrost near the surface causes roads to crack, and may sometimes even affect the stability of bridges. To overcome these problems, many of the roads in periglacial environments are left as unsealed gravel. Despite the challenges, good roads are essential for transport in periglacial areas because for much of the year the ground surface turns to soft marshland that makes driving impossible. Whatever road surface is used, however, constant repairs are needed to overcome the effects of the harsh climate.

High mountain areas present a different set of challenges for humans. In general, people in mountainous areas prefer to live at lower altitudes (figure 1.37). In Switzerland, for example, only 5% of the population live at altitudes above 1000 metres, which is approximately half the country's total land area. However, in Nepal, the proportion of people living at higher altitudes (above 900 metres) is approximately 50%, as table 1.2 shows.

1.37 Huayllabamba is typical of many settlements in the Andes Mountains of Peru, being situated in a sheltered valley near a reliable source of water, in this case the Urubamba River.

Features of high altitudes that discourage settlement include the **harsh climate**, **lack of communication facilities**, **difficulty of cultivation** and the additional expense in **bringing in materials** to build warm, substantial housing.

In many mountainous areas, the vertical distribution of population is **seasonal**. Farming activities move to higher altitudes during summer and down to lower altitudes during winter – a process known as **transhumance**. In Nepal, transhumance applies mainly to cattle grazing activities. Animals such as sheep, goats and yak are

Table 1.2
Population distribution by altitude in Nepal

	Below 300m	300 to 900 m	900 to 1500 m	1500 to 2100 m	2100 to 2700 m	2700 to 3300 m	Above 3300 m
% of population	38.6	11.5	27.4	14.8	5.4	1.7	0.6

well adapted to high altitudes, and they make good use of higher altitude grazing pastures up to 4,100 metres during the summer months. During the cooler winter months, the herds are brought to lower altitudes of between 2,000 and 3,000 metres. As lower altitude livestock such as cows, buffalo and pigs also use these altitudes, there is quite a bit of pressure on feed supplies during the winter months.

In the Swiss Alps, a typical farm comprises arable croplands in the valley floors, leading up to the forest zone and above that the natural pastures that are used only in summer. The main type of animal raised is the cow, usually for the production of milk although increasingly also for meat. In recent years, goats and sheep have also been introduced. Traditionally, the cows in Switzerland were taken to higher alpine grazing pastures during summer and then brought back to the valley floors for the winter months where they were housed inside a barn attached to the farmer's house.

Agricultural production is ceasing in upper altitude lands in Switzerland because of the difficulty of making a living from farming in the harsh environment. These difficulties are caused by a combination of the area's **thin soils**, **rocky ground**, **steep slopes**, **heavy precipitation** and pastures covered by **snow** for up to six months of each year.

Swiss farms tend to be very small, with an average size of only five hectares. Many farmers are choosing to leave their farms in search of higher incomes in office jobs in the towns or in the tourist industry, which is performing strongly. The Swiss government is trying to stop the exodus of farmers by setting artificially high prices for farming products, and by providing generous grants for farm improvement. In spite of these measures, the number of Swiss farmers continues to decline.

1.38 A typical low altitude goat farm near Grindelwald, Switzerland. The small timber buildings are often used to house the animals at night time and during the colder months.

CASE STUDY
Challenges for humans in Yakutsk

Yakutsk is a large city with a population of about 350,000 people in the Russian Far East. It is the capital city of the Sakha Republic (a 'republic' in Russia being the equivalent of a 'state' in the US or Australia, or a province in Canada or China).

Yakutsk's precise location is latitude 62°N, longitude 130°E. This places Yakutsk just 450 kilometres south of the Arctic Circle, meaning it experiences a **periglacial environment**.

Yakutsk's inland location means that it has a **large annual temperature range**. In January (winter), the average temperature falls to -39°C, while in July (summer) it rises to 20°C. The average annual climatic statistics are shown in table 1.3.

Table 1.3
Climatic statistics for Yakutsk, Russia (Latitude 62°N, Longitude 130°E, Altitude 100 metres)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature °C	-39	-34	-20	-5	8	16	20	15	6	-8	-27	-38
Average Precipitation (mm)	9	8	7	8	20	35	39	37	31	18	16	10

1.39 Yakutsk is the capital of Russia's Sakha Republic. This summer view shows the city centre, known as Lenin Place, with the white Ministry of Health building across the road.

An indigenous Turkic group of people, known as the Sakha (or Yakut) people first settled the area in the 12th and 13th centuries. A fort was built by the Russians in 1632, and this soon led to the establishment of a permanent settlement. By 1917, Yakutsk's population had grown to 10,000 people, The city developed rapidly under Stalin as industrialisation occurred, and the population grew by 500% between 1926 and 1939. Recent growth has been based on the region's mining industry, leading to the present population figure of about 350,000 people, a figure that comprises 40% indigenous Sakha people, 40% Russians, with the remaining 20% a broad mix.

1.40 Mammoths lived in the Yakutsk area until they died out about 9,600 years ago. This mammoth head is preserved in a room excavated in the permafrost in Yakutsk where the temperature is a constant -8°C.

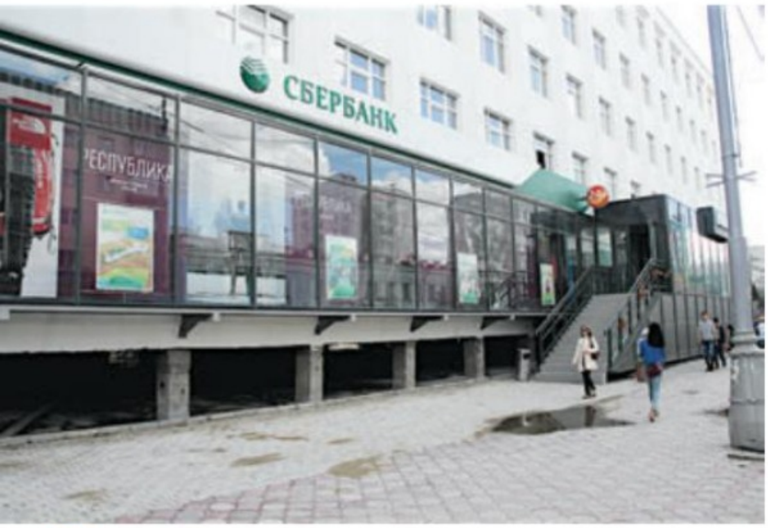
1.41 Very few of Yakutsk's old timber remain because they have been destabilised by the annual thawing and freezing of the permafrost beneath them.

Some of the coldest temperatures ever recorded on Earth were measured near Yakutsk. The city's lowest recorded temperature was -64°C, while the hottest recorded was +38°C. Yakutsk's overall average annual temperature is -9°C, so the entire city overlies a deep layer of permanent **permafrost**. Permafrost affects almost every aspect of living in Yakutsk, causing some buildings to sag and collapse, blocking drainage, causing upheavals in the earth and emitting climate-changing methane gas.

Even though Yakutsk's permafrost is permanent, the upper layer near the surface experiences some annual thawing every summer ands re-freezing in winter. The seasonally frozen ground is referred to as the **active zone**.

1.42 This old timber building in Yakutsk has suffered severe structural damage because of the unstable permafrost on which it was built. Examples of new high-rise concrete housing that are replacing the old timber buildings can be seen in the background.

All the early buildings in the city were constructed with timber. However, very few of Yakutsk's **traditional timber buildings** remain today because their foundations have been shifted by the repeated annual thaw-freeze cycles of the permafrost on which they were built.



1.43 This new building, with shops and a bank on the lowest level and housing apartments above, shows the elevated construction used in Yakutsk to overcome some of the challenges posed by permafrost.

Yakutsk's new buildings are constructed using concrete, with **deep pilings** that extend to great depths into the permanent permafrost zone. The buildings are almost always elevated to provide ventilation between the building and the ground so that the heating in the buildings does not transfer to the frozen ground beneath. This system allows multi-storey buildings to be constructed, and some newer housing blocks in Yakutsk exceed 20 floors in height.

Permafrost also causes problems for the supply of **water** to Yakutsk's residents. It is impossible to obtain groundwater because the permafrost is so deep. In any case, there are so many rivers in the region that there is simply no need to drill for water. Therefore, Yakutsk obtains its water from the River Lena, a large stream that flows northwards to the Arctic Ocean along the city's eastern perimeter. In winter, some people melt ice that is quarried from the thick layer that freezes over the surface of the river.

The challenge is getting the water into residents' homes. Underground pipes would be frozen for most of the year, so the solution is to build pipelines overground. Much of Yakutsk is therefore criss-crossed by a network of **overground pipes**, many of which are **insulated** to provide protection from the harsh climate. The result is not pretty, but it is necessary to ensure a reliable supply of water.

1.44 Large overground pipes near a housing estate in Yakutsk. The silver coating with the orange underlay is insulation.

1.45 Buildings in Yakutsk are heated by hot water that is pumped in from a centrally located oil-fired boiler house. Overground pipes carry the hot water throughout the city, together with gas supplies and electricity lines, which form arches when they need to cross streets and roadways.

Despite these measures, disruptions are commonplace. In January 2102, for example, abnormally cold temperatures caused a crack in a major pipeline that flooded the basements of several blocks of flats and left the eastern part of the city without water, and therefore heating, for a few days.

The annual thaw-freeze cycle of the active zone in permafrost causes another problem for residents in Yakutsk, which is destruction of roads and paths by **frost heaving**. Frost heaving is an upwards swelling of soil that occurs when it freezes, caused by the crystallisation and expansion of water as it freezes to form ice. The soil does not rise evenly, but it does so in patches. As the ground rises, it

1.46 Ice heaving has damaged this pathway, made with pavers, in central Yakutsk, creating a hazard for pedestrians.

cracks roadways and damages paths. Because Yakutsk is so cold, very few concrete pathways are made, and prefabricated pavers are used instead. Frost heaving is particularly damaging to paths made in this way because pavers are set in place by resting them on a bed of sand, and sand is very susceptible to destabilisation by underlying movement.

The **cold weather** in Yakutsk during winter forces residents to adapt their lifestyle to the conditions. People wear as many layers of clothing as possible, including several layers of underwear. Bus journeys are planned as precisely as possible to avoid having to stand outside and wait for transport. Buses and taxis operate throughout the cold winter, although taxi drivers usually raise their fares during periods of extreme cold weather.

Life can be especially difficult for people with disabilities, who tend to stay indoors throughout winter as conditions outside are too hazardous. In any case, everyone tends to stay indoors as much as possible to avoid the discomfort of the cold conditions.

Another challenge arises for the people of Yakutsk every spring when rising temperatures cause the snow to melt and the river to rise. Yakutsk often experiences **flooding** during the spring months, typically in May. The floods of 2001, 2010 and 2011 were especially devastating in Yakutsk, caused by large ice blocks jamming the River Lena downstream from the city. When the river becomes blocked with ice, aircraft are used to drop explosives into the river to dislodge the blockage and release the water.

Yakutsk's residents face another challenge that is not related to climate, although it is a common challenge in extreme environments — **inaccessibility** and **remoteness**. The Sakha Republic, of which Yakutsk is the capital, has an area of just over three million square kilometres and a population of just under one million. Its average population density is therefore just 0.3 people per square kilometre.

The city is six time zones to the east of Russia's capital city, Moscow, and a journey by air from Yakutsk to Moscow takes six and a half hours. There is no railway to Yakutsk. The nearest railway station (Tommot) is 450 kilometres away, a drive that takes 14 hours on a poorly formed road that is almost always in poor condition because of the impact of extreme temperatures, snow and ice. The road journey to Moscow would take 111 hours to travel the 8,300 kilometre distance (including the ferry trip to cross the River Lena). Needless to say, no-one drives from Yakutsk to Moscow.

The only major city that can be reached by road from Yakutsk is Magadan, a port city with a population of 100,000 people on Russia's east coast, facing the Sea of Okhotsk. This journey of 2,000 kilometres takes 28 hours of driving time, along the Kolyma Highway, most of which is unsurfaced gravel and mud with bridges unrepaired after being washed away during spring floods. The Kolyma Highway was built by forced labourers who were political prisoners under Stalin's rule.

1.47 A section of the Kolyma Highway (the Road of Bones) that joins Yakutsk to Magadan. This section of the road passes the outskirts of Ust-Nera, a mining town that is approximately half-way between Yakutsk and Magadan, the only intermediate settlement for hundreds of kilometres.

Thousands of labourers died during the construction, and their bodies were buried in the foundations of the road. For this reason, the Kolyma Highway is commonly known as the 'Road of Bones.

For those who might have preferred to fly to Magadan from Yakutsk, there are no direct flights.

Yakutsk is so isolated, and the surrounding Yakutia region is so vast, that the local people use their own **measure of distance** called the 'kirs', which is 10 kilometres. Therefore, rather than saying that the town of Ust-Nera is 800 kilometres from Yakutsk, they say it is 80 kirs. The origin of the word 'kir' is that it represented the time it took to cook meat in soup, which was about 30 minutes, and thus a 'kir' was originally the equivalent of 30 minutes driving time.

Question Bank 1C

1. *Contrast the ways that the challenges of cold environments are managed by nomadic peoples (such as the Koriyak) and urbanised societies such as Yakutsk.*
2. *In what ways do the challenges faced by people in periglacial areas differ from the challenges faced by people in high mountains? (Include specific examples of challenges in both environments in your answer).*

Challenges for humans in arid environments

Just as indigenous groups have lived sustainably in cold environments for many centuries, indigenous communities have adapted to the harsh conditions of arid and semi-arid environments (table 1.4).

1.49 The area inhabited by the Tuareg people is shown in red.

One example of an indigenous group that has adapted well to the extreme aridity of the Sahara Desert is the **Tuareg** people. As shown in figure 1.48, the Tuareg live in the western Sahara Desert, mainly in the countries of Mali, Algeria and Libya, as well as the northern Sahel Desert in Mali, Burkina Faso and Niger.

The Tuareg are **nomadic** people, who move according to the weather conditions in search of water. They are **pastoralists**, meaning that they raise animals — in the case of the Tuareg, mainly camels. Although they inhabit the desert, Tuareg men (but very seldom women) do visit towns to engage in buying and selling.

The Tuareg people wear distinctive **loose fitting** indigo or blue robes that protect them from the fierce heat of the sun while allowing a cooling flow of air between the body and the clothing. Although

1.48 A Tuareg man tends to his camels, who rest near the minimal shade provided by an acacia tree.

1.50 A Tuareg man in a typical blue robe dances in a desert encampment, accompanied by the rhythmic clapping of the women who are dressed in their typical indigo loose-fitting dresses.

Table 1.4

Climatic statistics for Timbuktu, Mali (Latitude 17°N, Longitude 3°W, Altitude 260 metres)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature °C	21	24	27	30	33	34	32	30	31	30	25	22
Average Precipitation (mm)	0	0	0	1	4	16	50	72	30	3	0	0

they are Muslims, the Tuareg women do not wear a veil, although they do cover their heads. On the other hand, the men do wear face covering. Although this is partly because of a traditional belief that it protects them from evil spirits, it has the practical purpose of protecting the face from the harsh impact of wind-blown sand in the face.

1.51 This Tuareg encampment shows a tent made from animal skins and woven strands of grass (in the background), and a small windbreak shelter. This photo was taken in the early evening after the intense heat of the day had dissipated and a cool afternoon breeze was blowing. Tuareg people tend to stay under shelter during the day and come outdoors mainly in the early morning and evening.

The **shelter** used by Tuareg people is designed to mitigate the discomfort of the climate. There is a high diurnal (daily) range of temperatures in the desert. Daytime temperatures may exceed 50°C in the sun, while the temperature may fall as low as 0°C at night.

Tuareg tents must therefore provide **insulation** against both the intense heat and the cold, as well as being portable so they can be packed up and moved on the back of a camel. Camel skins are used, often supplemented by woven mats that can be rolled up for transportation. The tents are supported by light, re-usable wooden structures made from trunks of the scarce trees that are found that are found in desert oases.

In contrast to the extreme heat and aridity where the Tuareg people live, the area inhabited by the **Arbore** people of Ethiopia is somewhat moister and cooler, and is classified as hot semi-arid (table 1.5). The area inhabited by the Arbore is hot all year because it is close to the equator, and rainfall is low all year because the area is in a rainshadow area surrounded by high mountains.

1.52 The area inhabited by the Arbore people is shown in red.

The Arbore people live in the far south of Ethiopia near the border with Kenya. Like the Tuareg people, they are pastoralists, but in contrast with the Tuareg, the Arbore raise goats and cattle. There are only 7,000 Arbore people, a far smaller group than the Tuareg, who number about one million.

The Arbore people wear far fewer clothes than the Tuareg people because they see less need to protect

Table 1.5

Climatic statistics for Dima, Ethiopia (Latitude 4°N, Longitude 37°E, Altitude 1200 metres)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature °C	29	30	30	28	27	26	26	26	27	27	27	28
Average Precipitation (mm)	11	15	32	52	41	14	18	13	12	25	36	14

1.53 Young Arbore women shade their shaven heads with a typical black cloth.

1.54 A typical Arbore hut, made from straw obtained from local vegetation. The perimeter fence is intended to stop the goats eating the house.

themselves from the hot sun. However, the women often cover their heads with a black cloth and children wear hats made from the fruit of gourd vines to protect their heads from the heat of the sun. This is important as most Arbore people shave their heads. The women also wear dense arrays of colourful beads that provide substantial protection from the sun. Both men and women wear leather skirts made from the hides of animals they have killed to eat.

The Arbore are not nomadic like the Tuareg, but **sedentary**. In other words, they live in fixed hamlets. This is because they have less need than the Tuareg to set off in search of water, which although not abundant in the area where the Arbore live, is sufficient to meet the needs of the small population and the animals they raise.

Living in fixed settlements means that the Arbore can construct more durable dwellings than the Tuareg people. The huts of the Arbore people are oval in shape and constructed of **straw** obtained by cutting the long grass that grows beside some local creeks. The shape of the building allows rainwater to flow down to the ground while providing some insulation from the outside temperatures. The open doorways are so low that residents have to crawl in and out; this is to prevent cattle intruding into the homes.

1.55 An Arbore woman carrying water and fuelwood.

Although the Arbore people do not need to move from place to place in search of water, they must carry the water they need from nearby streams back to their hamlets. Similarly, wood for fuel and construction must be carried to the village. Despite the heat and dry conditions, this heavy manual labour is always done by the women as it is seen as men's work to raise and tend the livestock.

Most people who live in hot arid and semi-arid environments do not follow traditional lifestyles like the Arbore or Tuareg people, and they usually demand greater comfort. The two big challenges for people living in hot arid environments is finding **adequate water** and overcoming the discomfort of the **intense heat**.

1.56 Dubai is a spectacular example of using technology and financial investment to address the challenges of its extreme hot and dry climate.

In recent decades, several **large cities** have grown in desert areas in spite of the extreme conditions experienced in those locations. Examples include Las Vegas (USA), Riyadh (Saudi Arabia) and Dubai (UAE). In such places, **air conditioning** is extensively used to lower temperatures in homes, offices, shopping malls and cars, usually at considerable economic and environmental cost. Unlike the Tuareg people, who obtain water from desert oases, and unlike the Arbore people who carry water from streams to their huts, water in large desert cities is delivered by **underground pipes**, often after filtering to remove any dangerous bacteria that might be present.

Question Bank 1D

1. *Using tables 1.4 and 1.5, construct graphs that show the differences between the climates of Timbuktu and Dima.*
2. *Use your answer to the previous question to explain how indigenous people in arid and semi-arid areas cope with the extreme nature of their environments.*
3. *Contrast the ways that the challenges of arid environments are managed by indigenous peoples (such as the Tuareg and Arbore) and urbanised societies such as Dubai.*

CASE STUDY
Challenges for humans in Death Valley

Death Valley is a hot desert valley in eastern California, USA. It is known as the lowest, driest and hottest area in North America. It is a **rainshadow area**, encircled by mountains that rise in places over 3,000 metres. At its lowest point, the dry salt lake of Badwater Basin, Death Valley is 86 metres below sea level, and as we saw in table 1.1, low elevation contributes to heat and aridity.

The name 'Death Valley' implies desolation and lifelessness. Sun-baked, barren badlands rise from the valley floor, and plants and animals seem totally absent. **Travellers** to Death Valley in summer are handed leaflets entitled 'How to survive your summer trip through Death Valley'. The leaflet contains advice such as the following:

- Thirst, like pain, is a warning. Suppressing thirst by sucking a pebble or chewing gum will conceal your body's need, not satisfy it. Carry plenty of water and drink it freely. Stop to drink every hour or so - whether you feel thirsty or not.
- Salt is not a substitute for water. You should replace salt you lose in perspiration, but you cannot slow your perspiration rate with more.
- Clothing retains perspiration and keeps you cooler. Clothing also protects you from solar radiation. If you are not wearing a shirt, sunglasses, and a broad-brimmed hat, you are not prepared to walk anywhere in Death Valley.

1.57 Mudstone badlands scenery at Zabriskie Point , near Furnace Creek, Death Valley.

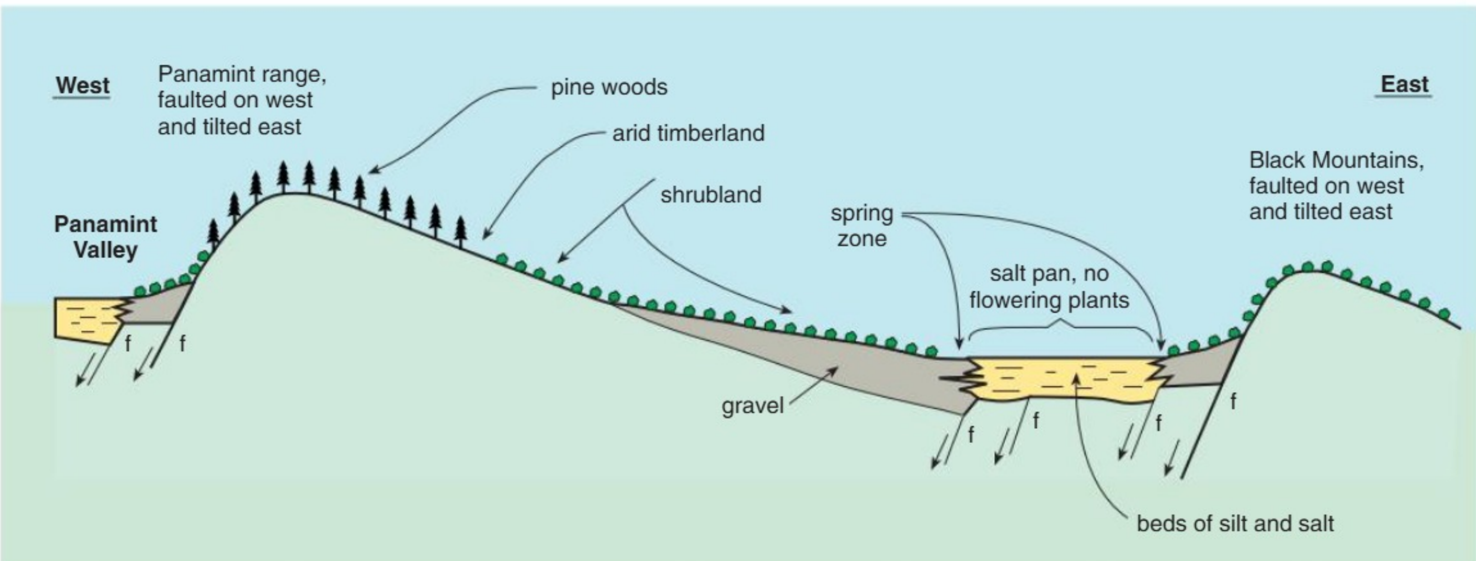
1.58 A view of Death Valley, looking towards the west and the Panamint Range from a peak named Dante's View. The large salt lake in the bottom of the valley is Badwater Basin, the lowest point in North America (elevation 86 metres below sea level).

- Avoid wind. It speeds up your evaporation rate and stirs up the low-level hot air layer created by radiation from the ground.
- Ground temperature in summer is seldom less than 65°C and may reach 93°C. Rest when you need to, but do it in the shade. Do not sit or lie in the sun.
- If storm clouds gather, be alert. Thunderstorms in the mountains can cause flash flooding in the washes that cross the highways several kilometres distant. If there are clouds over the mountains, watch for water running in the washes or road dips even though the sun may be shining.

This travel advice makes Death Valley seem like a very hostile environment for people. Even the names in Death Valley suggest hostility – Coffin Canyon, Deadman Pass, Funeral Mountains and Last Chance Range to name a few.

Death Valley comprises three quite distinct environments (figure 1.59). Bordering Death Valley to the west are high, rocky mountain ranges, known as the Panamint Range, while to the east are another set of mountains known as the Black Mountains. As figure 1.59 shows, these two mountain ranges are both uplifted blocks which have been tilted towards the east, forming steep western slopes and gentle eastern slopes. Death Valley is thus a structural sag, separated from the two mountain ranges by fault lines in the rocks.

Sloping into Death Valley from each of the mountain ranges are **gravel fans** of rock debris washed down from the mountain sides. The gravel fans end at the edge of a broad salt-crusted mud flat which is the dry bed of a **playa** (dry salt) lake which last contained permanent water during the last ice age 10,000 years ago. **Groundwater** is close to the surface at the point where the gravel fans meet the playa lake, and a strip of springs sustains a few plants. The playa lake is too salty for flowering plants to survive, but shrubs grow up to about 2,000 metres on the mountain slopes, and above that pine trees grow.



1.59 Simplified cross-section through Death Valley. Fault lines are shown by the letter 'f'.

With an area of over 500 square kilometres, the Death Valley **salt pan** is one of the world's largest playa lakes. The salt crust, which is mainly sodium chloride, varies from a few centimetres to about a metre in thickness, and rests on damp mud. Because the streams of Death Valley all flow into the playa, the **concentration of salts** becomes stronger and stronger over time, and the concentration of salt is considerably stronger than sea water.

Water in Death Valley comes largely from rain and snow in other places. The water seeps through the ground and enables fresh water to be available from three sources. In the mountain areas, small **springs** bring water to the surface, although it usually seeps away into the surface downslope. In the gravel fans bordering the salt pan, the groundwater is close enough to the surface to allow **hand-dug wells** to retrieve it, although much of this water is too salty to drink. The third source of fresh water is the large **warm springs** which discharge water along some of the rock faults, and it is this source that supplies the small town of Furnace Springs. The springs supply enough water to irrigate a plantation of date palms and a golf course at Furnace Creek.

Death Valley's **landforms** (or **relief**) also pose challenges for people. Although **sand dunes** are found in many desert areas, Death Valley has only one area with dunes, a large zone of several square kilometres. The dunes formed in the north of Death Valley along the course of Salt Creek and Mesquite Flat where the winds have a long tract of open valley to collect the fine sediments into dunes.

The **gravel fans** of Death Valley are very extensive, especially on the western side of the valley beside the Panamint Range. In places, the gravel fans on this western side of the valley are 10 kilometres in length and rise 500 metres higher than the salt pan. On the eastern side, the fans are smaller, being about one kilometre in length and peaking about 50 metres above the salt pan. The difference reflects the slopes of the two mountain ranges as they border Death Valley; with its gentler slope the Panamint Range has a larger source area for gravel.

The sand dunes and the gravel fans include areas that are the driest ground in Death Valley. The gravel fans receive less rainfall than the nearby mountains, and scarcely more than the valley floor.

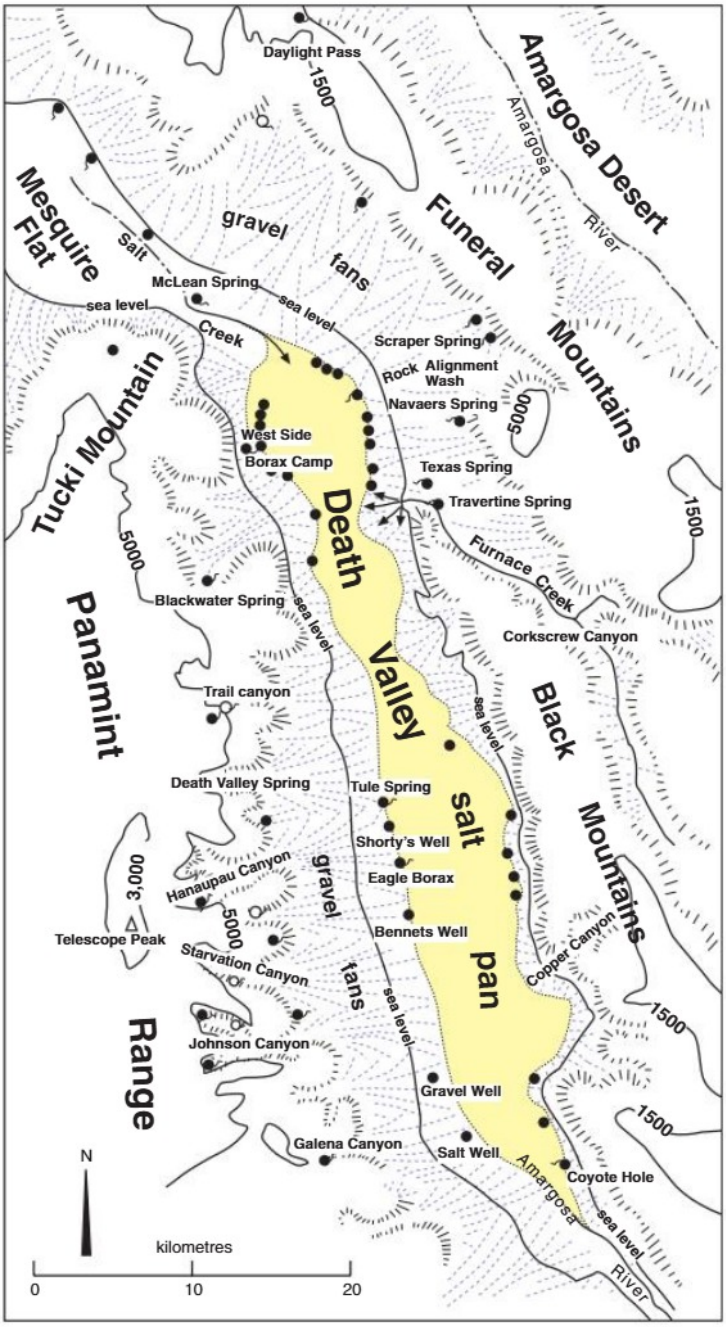
1.60 Sand dunes near Stovepipe Wells in the north of Death Valley. This view looks west towards the Panamint Range.

1.61 Gravel fans on the western edge of Death Valley. The area in the foreground is the salt pan.

However, the gravel fans (like the dunes) are highly **permeable**, and therefore they cannot retain moisture. The water that runs onto them quickly seeps into the ground. Thus, vegetation cannot become established in these areas, and the extreme aridity poses challenges for humans in the area.

Death Valley's **climate** poses huge challenges for humans. Winter **temperatures** rarely fall below 0°C, but summer temperatures average over 40°C and have reached much higher figures. Details of Death Valley's climate are given in table 1.6.

Annual precipitation averages less than 50 mm per annum. Weather records have been kept for less than a century, and twice during that period there have been entire years with no rainfall whatsoever. Only twice has the annual rainfall exceeded 100 mm since records began in 1913 and 1940. Like all desert areas, **rainfall fluctuations** in Death Valley can be very erratic, such as the change from 86 mm



1.62 Map of Death Valley showing the main sources of water. Springs are shown as solid circles and seepage areas are shown as open circles around the salt pan. Heights are shown in metres.

of rain in 1953 to zero in 1954. Over longer periods, the fluctuations have been much greater. In the period from 3000BC to 1AD, Death Valley contained a lake that was 10 metres deep, and during the last ice age (Pleistocene) the lake was almost 200 metres deep.

Although rainfall in Death Valley is **unpredictable**, there tends to be marginally more rain in winter than in summer. At altitudes over 1,800 metres, rainfall is several times higher than on the floor of the valley. When rain does come, it tends to be sudden, causing **flash flooding**, **gullying** and **landslides**.

The aridity of Death Valley is amplified by the high rate of **evaporation**. On the floor of the valley, the potential rate of evaporation is one hundred times greater than the precipitation. The temperature of the ground surface during the day is much higher than the air temperature, and a ground maximum of 95°C has been officially recorded. However, even where extremely high surface temperatures are recorded, the temperatures a few centimetres beneath the surface are much cooler, and this is what enables plants and animals to survive.

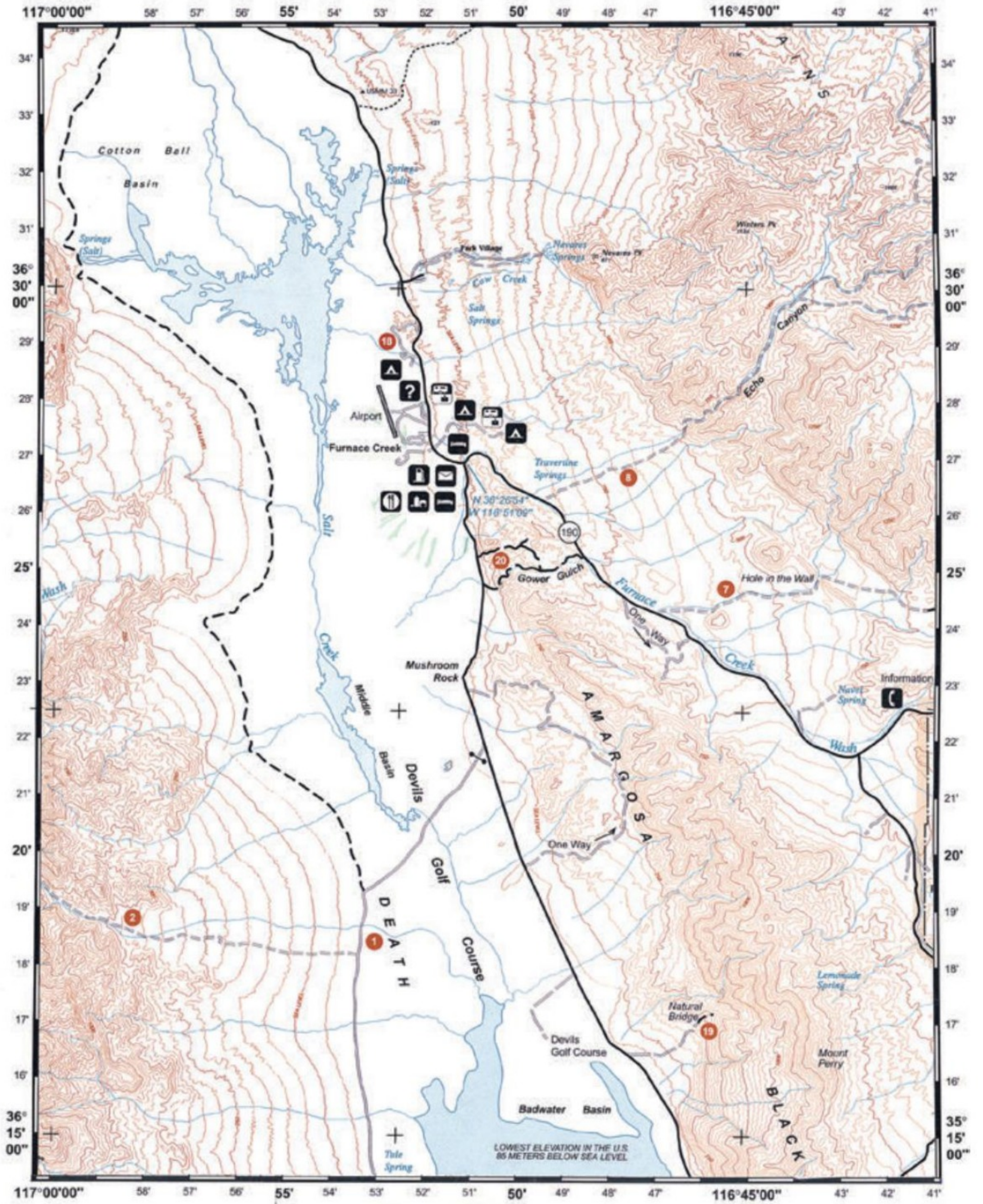
Question Bank 1E

1. *Explain why Death Valley is so dry.*
2. *Referring to figure 1.59, describe the different environments of Death Valley.*
3. *Account for the general distribution of water springs in Death Valley, shown in figure 1.62.*
4. *Draw an east-west cross section of the area shown on the topographic map in figure 1.63 passing through Natural Bridge (labelled number 19 on the map). Label any features which appear on the cross section. Note that the contours are marked in metres at 50 metre intervals.*

Table 1.6

Climatic statistics for Death Valley, USA (Latitude 36°N, Longitude 117°W, Altitude 86 metres below sea level)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum temperature °C	18	23	27	31	38	43	47	45	41	33	24	19
Average minimum temperature °C	4	8	12	16	22	28	31	30	25	17	9	5
Record high temperature °C	31	36	39	44	49	53	57	53	49	45	36	31
Average Precipitation (mm)	6	8	6	3	2	1	3	3	3	2	5	5



1.63 Death Valley 1:160 000 topographic map extract. Map provided courtesy of National Geographic Maps.

Question Bank 1F

1. *Interpret the symbols shown on the map in figure 1.63 to list the services provided in Furnace Creek village.*
2. *Using the data in table 1.6, draw a climatic graph for Death Valley, showing average maximum and minimum temperatures, and average precipitation.*
3. *Explain how and why Death Valley's climate becomes wetter with increasing altitude.*
4. *Why does Death Valley have a high diurnal range in temperatures?*
5. *List the ways in which Death Valley's climate presents challenges for human habitation.*

1.64 Although Death Valley is very dry, evidence of erosion by water is easily found. This photo shows a washout near Furnace Creek.

The wide range of temperature and moisture conditions in Death Valley means that there is quite a variety of **plant and animals** to be found. The length of the growing season for plants is determined by the temperatures, and the centre of Death Valley, the extreme temperatures on the land surface explains for the total absence of vegetation in this area.

Elsewhere in Death Valley, the arid conditions lead to a **sparse plant density**, and making cultivation impossible, posing further challenges for humans in the area. Plants that are found near the shallow groundwater where the gravel fans and the salt pan meet tend to be **salt tolerant** and have **extensive shallow root systems**. These plants, known as **phreatophytes**, send their roots to the water table and thus ensure a permanent water supply for themselves.

Where water is less abundant or is deeper, only plants that have made more extreme adaptations to aridity, called **xerophytes**, are found. These plants have adapted to survive long periods of drought. They depend on ephemeral water in the ground above the water table. Moreover, they have developed mechanisms to conserve water, such as by having very small leaves that minimise moisture loss.

1.65 Encelia (brittlebush) has an extensive root system to obtain water, and has small leaves to reduce moisture loss. It was used by indigenous peoples to make glue and incense, and to treat toothaches.

1.66 The salt-tolerant Desert Holly can survive in Death Valley's most extreme environments.

It is thought that the **first humans** lived in Death Valley about 10,000 years ago. These people were hunters, and from the evidence of their tools that have been found, they hunted large animals such as buffalo or bighorn sheep. This indicates that the **climate** must have been considerably wetter at that time than it is today.

There is also evidence that native Americans lived beside the lake (that has since dried up) about 2,000 years ago. They seem to have hunted smaller game such as rabbits and rodents, and gathered seeds.

The first Europeans visited Death Valley in 1849 on their way to the California gold rushes. However, European settlement did not begin until 1880 when **borax** was discovered. Borax is a compound of boron that looks like small white crystals and which has many diverse uses, such as making glass, porcelain, enamel, soap, detergents, fertilisers, ceramics, cosmetics, building materials, fire retardants, car anti-freeze solutions and as shields for nuclear reactors. The borax mined in Death Valley is used for fibreglass production.

The borax in Death Valley formed in hot mineral springs and was then deposited in the remains of old lake beds. Later, partial alteration and solution of these deposits moved some of the borates to the floor of Death Valley, where evaporation left a mixed crust of salt, borates and alkalis.

1.67 The Harmony Borax Works, just north of Furnace Creek, began operations in 1883, but closed a few years later in 1888.

Death Valley's extreme climate and remoteness caused significant problems for the borax operations. During the summer months, the temperatures were too high for **crystallisation** of the borax to take place, and production had to be moved to a cooler location outside Death Valley.

Transporting the borax to market was difficult because of the area's isolation and long distance from centres of population. In the 1880s, the borax was loaded into double wagons that were pulled by teams of 20 mules a distance of 265 kilometres to the nearest railway siding at Mojave to the west of Death Valley. These mule teams pulled loads weighing up to 33 tonnes, including 4,500 litres of drinking water. The wagon trains, including the mule teams, measured up to 30 metres in length.

1.68 Billie Mine closed in 2005 as Death Valley's remoteness and inhospitable conditions combined to make the mine unprofitable.

Borax mining continued in Death Valley until 2005 when the last mine (Billie Mine) closed. The challenges of operating a mine in Death Valley's extreme aridity, including the **high financial cost** of attracting workers to live in such a harsh, **remote** area and the high cost of transporting the finished product, combined to make the mine non-viable.

Today, the main way humans interact with Death Valley is through **tourism**. Death Valley was declared a **national park** in 1933 to protect its natural environment, and so most of Death Valley's permanent residents are rangers of the National Park Service, people engaged in providing services to visitors.

Ironically, it is now Death Valley's extreme aridity and remoteness that **attract** visitors to the area.

1.69 Tourism in Death Valley National Park is supported by the air conditioned Furnace Creek Visitors Centre, operated by the National Park Service. It provides information and displays, arranges tours with park rangers, and sells books and souvenirs.

1.70 As indicated in figure 1.63, Furnace Creek is the main place where services are available to visitors. In addition to the general store shown here, there is a post office, petrol station, hotel and camp grounds.

1.71 Services provided for visitors, such as this car park and pathway at Zabriskie Point, are designed to protect the natural environment of Death Valley as well as make the area safe within the area's extreme environment.

There are paved roads to many scenic spots and hiking tracks to lookout points. Accommodation is provided in nine camping areas and two hotels, mainly around the service town of Furnace Creek. In addition to sightseeing and hiking, popular activities include star gazing (making use of the area's clear air and lack of artificial lights), sand surfing down the dunes near Stovepipe Wells, and wildflower spotting after falls of rain.

QUESTION BANK 1G

1. *Suggest reasons that Death Valley seems to have had higher population densities in the past than it does today.*
2. *Do you think humans are a genuine threat to the Death Valley environment, or that the environment is a greater threat to humans? Justify your answer.*
3. *It is said that "many environments have a limiting factor, such as solar energy, temperature, water or nutrient supply". What is the major limiting factor in the Death Valley environment? Explain your answer.*
4. *How do relief, climate, human discomfort, inaccessibility and remoteness present challenges for human habitation and resource development in Death Valley?*

The changing distribution of extreme environments over time

Changes in the distribution of cold and high altitude environments

We began this chapter by looking at the world distribution of cold and high altitude environments. It is important to remember that this distribution is not fixed, but has changed over time.

Glaciers and ice sheets grow (**advance**) every winter and shrink (**retreat**) every summer. The annual summer retreat is caused by rising temperatures, which in turn cause a loss of ice through the processes of melting, evaporation and sublimation. In many (but not all) glacial areas, summer also brings a fall in precipitation.

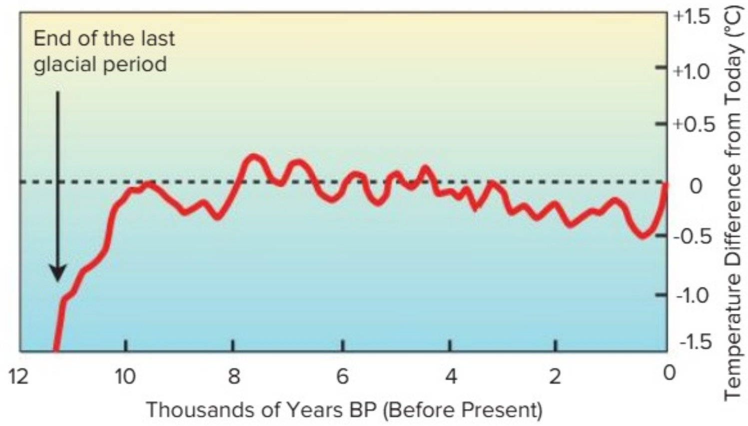
If a glacier or ice sheet melts faster each summer than its ice can be replenished each winter, then over time it will retreat. Many of the world's glaciers have been retreating rapidly since the early 1970s, providing strong evidence that we are presently in a period of **global warming**.

1.72 A summer view of a small stream on the side of Avachinsky Volcano on the Kamchatka Peninsula of Russia showing meltwater flowing from the retreating ice.

1.73 The Athabasca Glacier in the Rocky Mountains of Canada shows the extent of recent glacial retreat. The sign in the foreground shows where the end of the glacial ice extended in 1992. Today, the glacier has retreated, leaving a bed of exposed moraine where the ice used to be.

The landforms found today in many parts of Europe, northern Asia and North America provide evidence that ice once covered vast areas that are presently ice-free. During the period known as the **Pleistocene**, which lasted from 2.5 million years ago to 11,500 years ago, the earth experienced repeated **ice ages**, or glaciations. Figure 1.74 shows the maximum extent of ice during the Pleistocene period.

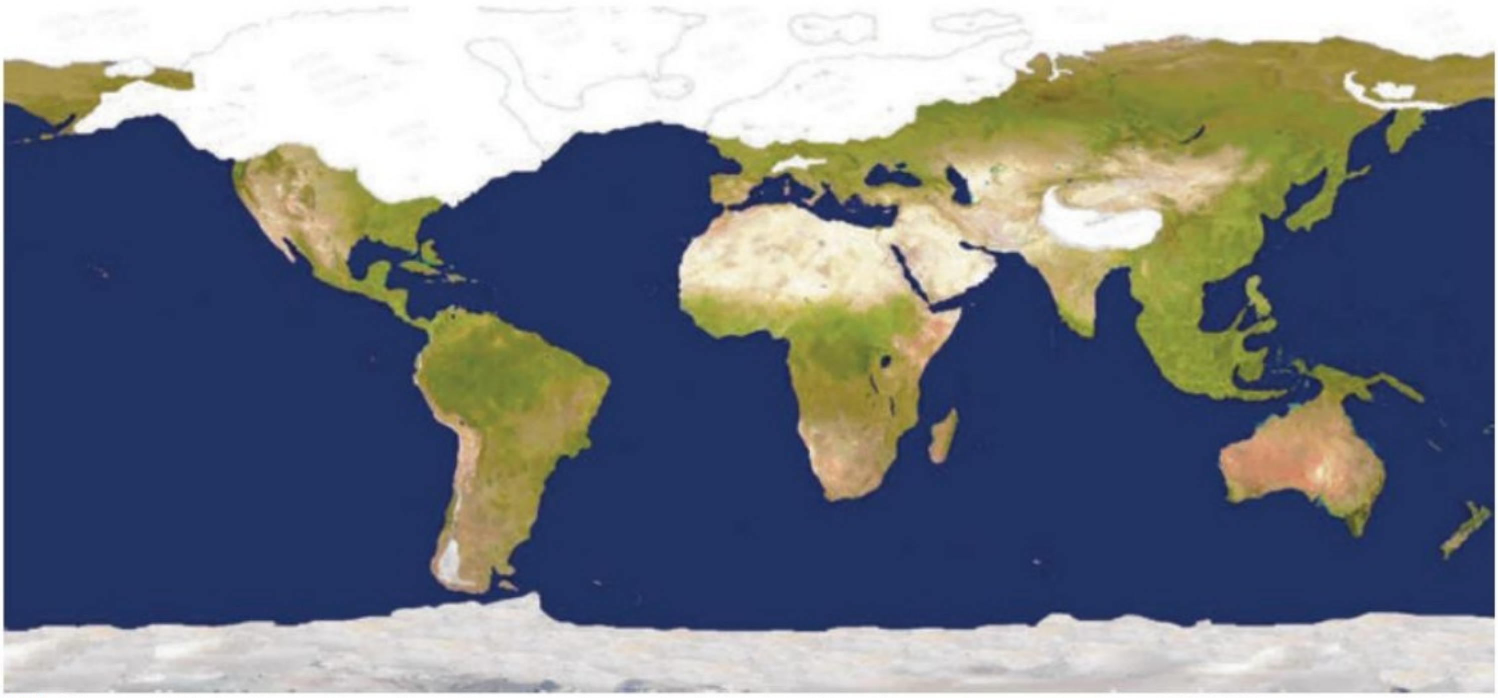
The ice ages ended about 11,500 years ago when a period of global warming known as the **Holocene** began. When the Holocene began, temperatures rose sharply, leading to retreat of the ice sheets and glaciers, and a rise in sea levels. Temperatures continued to rise until about 6,000 years ago, when they hit a peak where temperatures were slightly warmer than today. Figure 1.75 shows the temperature changes during the Holocene period that have led to glacial advance when the temperatures fall and glacial retreat when they rise.



1.75 Temperature variations during the Holocene period.

Changes in the distribution of hot arid environments

Just as the distribution of glacial environments changes over time, the distribution of deserts also changes. Archeological evidence in areas that are now deserts tells us that they were once well watered areas capable of supporting considerable numbers of people.



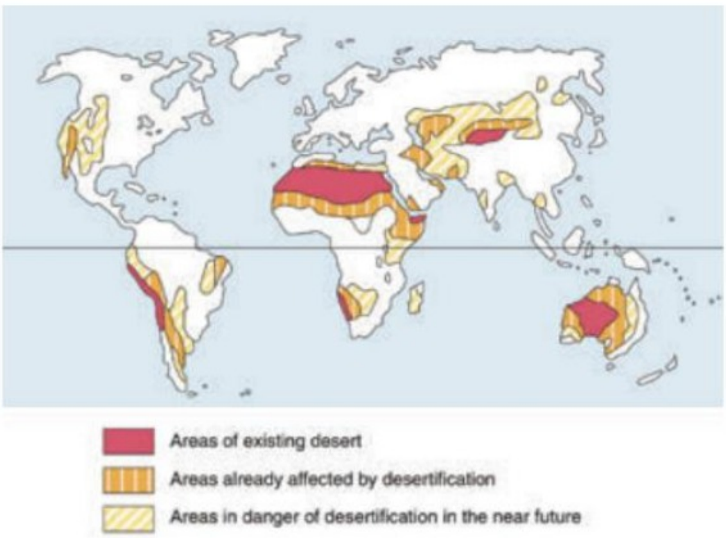
1.74 The world during the last great ice. The map shows glacial ice in white at its maximum extent about 25,000 years ago. At that time, sea levels were about 125 metres lower than today. Map provided courtesy of Bulgarian Geographical Portal/Fenn-O-maniC

At the end of the Holocene period as global temperatures rose, monsoon rains fell on the area that is now the Sahara Desert. The abundant rainfall allowed crops to be cultivated and animals such as goats and sheep to be raised. The monsoon rains retreated from the Sahara about 6,000 years ago, leading to an expansion of the desert.

1.76 The town of El-Atteuf is part of an oasis in the central Algeria, surrounded by the dry, parched land of the Sahara Desert. Between 9,000 and 6,000 years ago, this area received abundant rainfall and was green with lush vegetation.

Desertification is the process whereby deserts expand into semi-arid areas or become more intense by becoming drier and losing vegetation and wildlife. The expansion of deserts is a significant environmental issue in many countries today, and it threatens the livelihood of many people, especially in the world's poorer countries.

Desertification is caused by a combination of human and natural forces. There are three inter-related **natural causes** of desertification: climate change, loss of vegetation and soil erosion.



1.77 Global distribution of areas threatened by desertification.

We know from long-term records that climates fluctuate naturally over time. Areas become wetter or dryer, hotter and colder. The reasons for natural changes in climate are not fully understood, but possible causes for **natural climate change** include fluctuations in the earth's orbit, changes in the level of solar activity, volcanic eruptions, changes in the patterns of ocean currents, variations in carbon dioxide levels in the atmosphere due to the growth of vegetation, and changes in the angle of tilt of the earth's axis.

In areas where there is a long-term trend of declining precipitation, the process of desertification may be triggered. Reduced precipitation may occur either as **reduced amounts** of rainfall or as **less reliable** rainfall. **Droughts** are extended periods of time with unusually low rainfall. When droughts become more frequent in an arid or semi-arid area, then desertification will probably be triggered. Other long-term climatic conditions such as dry **winds**, higher **temperatures**, reduced **condensation** and a higher rate of **evaporation** can combine to exacerbate the effects of reduced precipitation and droughts.

1.78 Reduced rainfall over an extended period of time has led to desertification in the Sahel Desert of West Africa, as seen in this village near Mopti, Mali.

The impact of reduced rainfall and drought leads to the second natural cause of desertification, **loss of vegetation**. Plants cannot survive without water. An initial reduction of water supply may stunt a plant, but prolonged drought will kill many plants, exposing the **soil** to **erosion** by wind and water the third of the natural causes of desertification. Soil that is not protected by a cover of vegetation is likely to blow away in strong winds or be washed away during flash floods.

1.79 The impact of a loss of vegetation in a semi-arid area flows through the food chain to all the inter-related elements of the ecosystem. Although the West African miniature giraffes have adapted to the dry conditions of the Sahel Desert, desertification is limiting their supply of food, endangering the viability of the species. This giraffe has found some leaves to eat on an acacia bush in the Kouré district of Niger.

1.80 Desertification has led to a loss of vegetation near this small village, west of Niamey in Niger. The exposed soil is more vulnerable to erosion, and there is evidence of extensive erosion by water during a heavy fall of rain in various places around the village.

Vegetation not only protects soil from erosion, but it plays an important role in influencing the **mineral** and **nutrient composition** of the soil. Vegetation provides humus (decaying vegetable matter) for soil, which adds minerals and nutrients that maintain soil fertility. Therefore, when vegetation dies in an area, the supply of new minerals and nutrients to the soil is lost, leading to a decline in the quality of the soil.

The natural causes of desertification can be exacerbated by human actions, and these will be examined in chapter 4.

Question Bank 1H

1. *Summarise the evidence that the extent and distribution of cold environments has changed over time.*
2. *Summarise the evidence that the extent and distribution of arid environments has changed over time.*
3. *Explain how the three natural causes of desertification are inter-related.*

Chapter 2 Physical processes and landscapes

2.1 A glacier flows downwards from Koryaksky Volcano on the Kamchatka Peninsula in Russia's far east. In this summer view, meltwater can be seen flowing through the moraine at the side of the glacier. Surface moraine can also be seen on the glacier.

Glacial processes

How are glacial landforms shaped?

Like all environments, the landforms of glacial areas are shaped by inputs and outputs of water, sediment and energy.

In any area, there are inflows of water (such as through rainfall or overland flow), inflows of sediment, and inflows of energy (such as sunlight, gravitational potential energy and running water). The inputs of water may be in non-liquid forms such as ice and snow. All these inflows can be collectively regarded as the **inputs into a system**.

There are also outflows of water, sediment and energy, or **outputs** from the system. The **processes** that occur to shape landforms are the result of the interaction of these inputs and outputs.

If more sediment enters a system than leaves it, the process of **deposition** is said to have occurred. If more sediment leaves a system than enters it, the process of **erosion** has taken place. The processes of erosion and deposition can also affect the balance of water and energy that enter and leave the system. For example, when erosion occurs, energy is used, so an increase in outflow of sediment (erosion) is related either to an increase in the input of energy or to a decrease in energy outflow (or perhaps both). A rise in inflow of energy often occurs because of an increase in the input of moving water, which is why erosion increases after a heavy fall of rain. Energy inputs can also increase because of earthquakes, changes in sunlight, human actions, and so on.

When the earth cools, such as during an ice age, there is a removal of energy and the ice caps and glaciers expand. On the other hand, when the climate warms, energy inputs increase and glaciers retreat.

Mountain areas receive large volumes of orographic precipitation. Depending on the altitude, this can be in the form of rainfall (lower altitudes) or snow (higher altitudes). If the temperature is cold enough, many streams flowing from higher altitudes take the form of glaciers, or 'rivers of ice'. **Glaciers** form where snow that has fallen during winter does not completely melt away, even during summer time. Under the pressure of over-lying snow, the individual crystals of snow are changed into granular particles of snow (called **firn**), and after a few more years of pressure, this is transformed into blue glacial ice.

If the ice is sufficiently thick, the initially rigid ice mass starts to flow like a plastic body, flowing slowly through the valley, scraping its course as it does so. Glaciers typically flow at a few centimetres per day. **Glacial processes** rely on the effects of **moving masses of ice**.

2.2 The Potanini Glacier moves through the Altay Mountains of western Mongolia near the border with Russia, China and Kazakhstan. The lines of moraine indicate the direction of flow through the U-shaped valley.

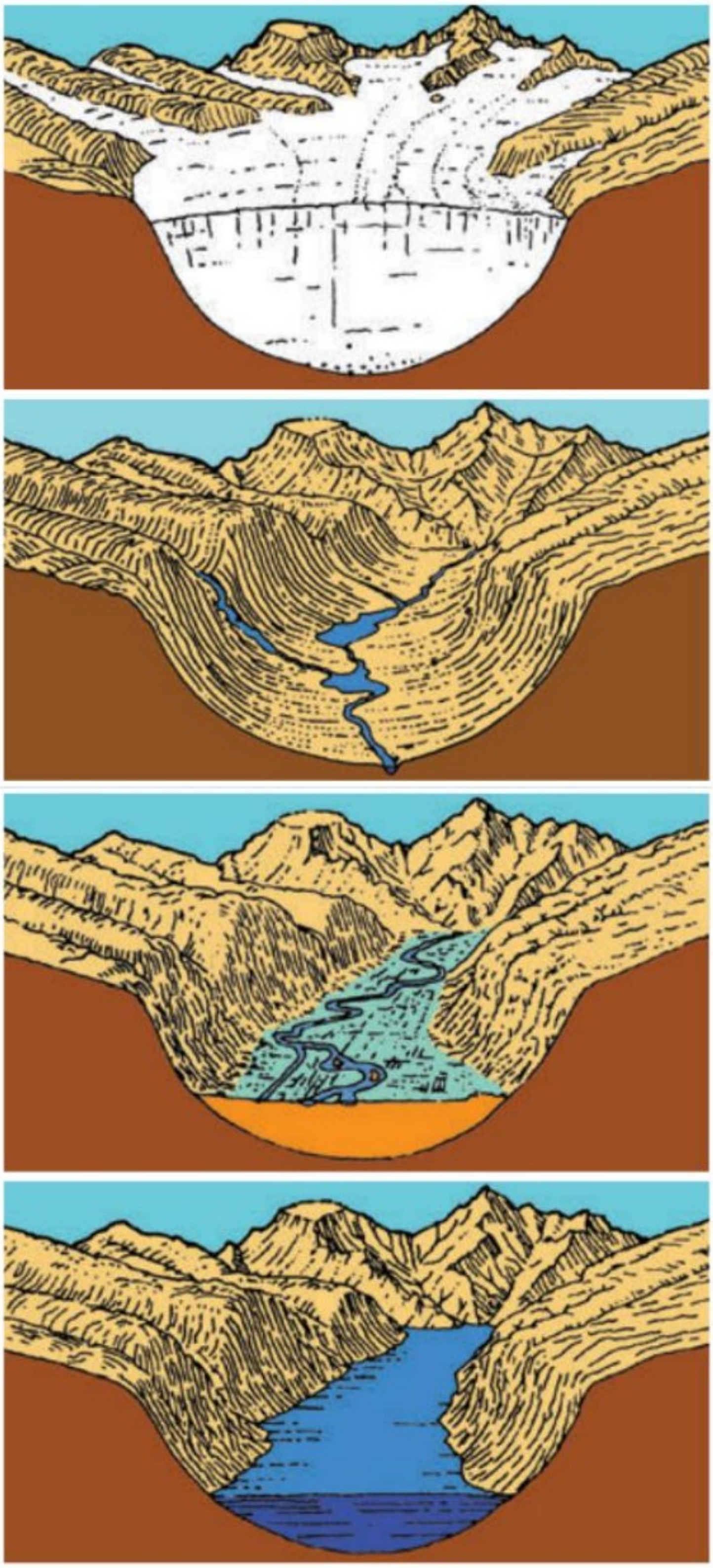
2.3 The closer view of the Potanini Glacier shows the rough surface of the glacial ice.

Landforms shaped by glacial erosion

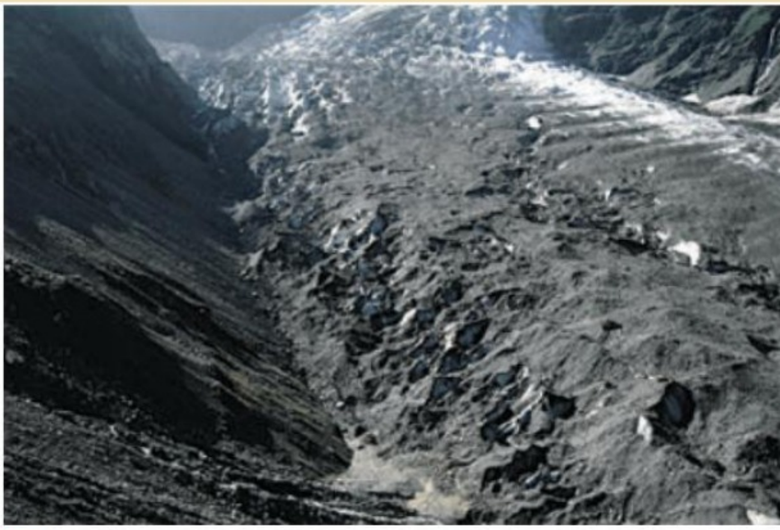
One of the most noticeable features arising from the downward flow of glaciers is the **U-shaped valley**, or **glacial trough**. In U-shaped valleys, the valley floor is usually quite flat and the sides extremely steep. This is the shape left behind by a glacier after it has scraped and plucked rocks from the sides (figure 2.5). In general, U-shaped valleys were formed originally by a non-glacial process, such as the flow of a river in warmer times or erosion by a lava flow.

Quite often the abrasive action of the glacier scraping away the valley sides will make the valley sides steeper, causing them to become unstable. This can lead to major **landslides** where rocks from the valley sides fall onto the surface of the glacier, thus further increasing the steepness of the valley sides and adding to the surface moraine on the glacier.

2.4 A U-shaped valley in Glacier National Park, Montana, USA.



2.5 The process of forming a U-shaped valley.



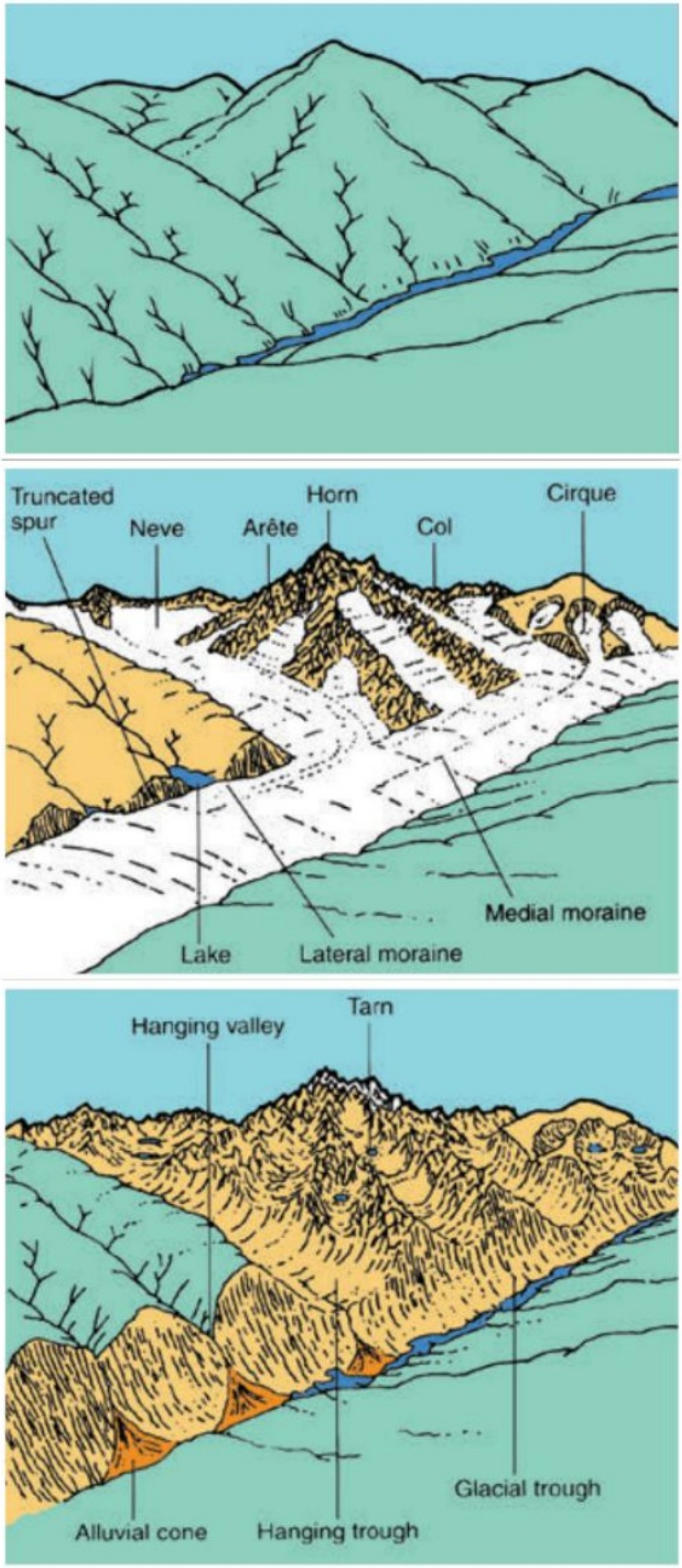
2.6 Surface moraine on a glacier near Grindelwald, Switzerland.

2.7 A waterfall plummets from a hanging valley in Glacier National Park, Montana, USA.

As we can see in figure 2.5, high tributary valleys which used to feed the main glacier, but which were not big enough to carve valleys as deep as the main valley, are often left high above the main valley when the climate warms. These are called **hanging valleys** and the water from them has to drop down the steep slope to reach the present valley floor. The spectacular **waterfalls** that result are often strong attractions for tourists.

In some cases the high tributary valleys will themselves leave distinctive features because of the special action of small glaciers near high alpine peaks. The best known are **cirques**, which are dish-shaped hollows eroded by these glaciers as the ice rotates under the force of gravity. When the ice retreats, the result is often a small lake called a **tarn** and maybe a waterfall.

Where two or more cirques cut into both sides of a ridge, distinctive landscapes are formed that are unique to glacial areas. When cirques cut headward into a smoothly rounded flat or rounded ridge, then a **scalloped upland** results. If the divides between the cirques are eroded backwards into themselves, a narrow, steep, rocky ridge called an **arête** forms. Many examples of arêtes can be seen in the photo of the Central Kamchatka Range in figure 2.9. When an arête is reduced to a single rocky peak by ice erosion on all sides, the angular remnant is termed a **horn**.



2.8 The formation of hanging valleys and other typical landforms formed by glacial action.

2.9 This oblique aerial view of the Central Range of the Kamchatka Peninsula (Russia) shows several typical glacial landforms, including cirque, arête, U-shaped valley, hanging valley, alluvial cone, névé and tarn.

The surface of a glacier varies throughout its length. In its highest parts, a glacier is basically a snow field (the **névé**) with little evidence of erosion. This is because even rock fragments that fall due to freeze and thaw action are quickly buried by the next snow fall. In the middle and lower sections of the glacier, the surface is usually very convoluted with a mixture of dangerous crevasses and tall ice peaks. Cracks initially form as the glacier twists around the curves of its valley. Once formed, the surface irregularities tend to deepen each summer as the surface layer of the glacier melts and the running water flows down and along the cracks and grooves, deepening them as it does so.

As glaciers flow down-slope, they erode and carry material from the sides of the valley. Evidence of the scraping action of glaciers can often be seen by **striations**. These are small scratches on the surface of rocks at the sides of a glacier. The scratches were made by the ice as it moved slowly downhill,

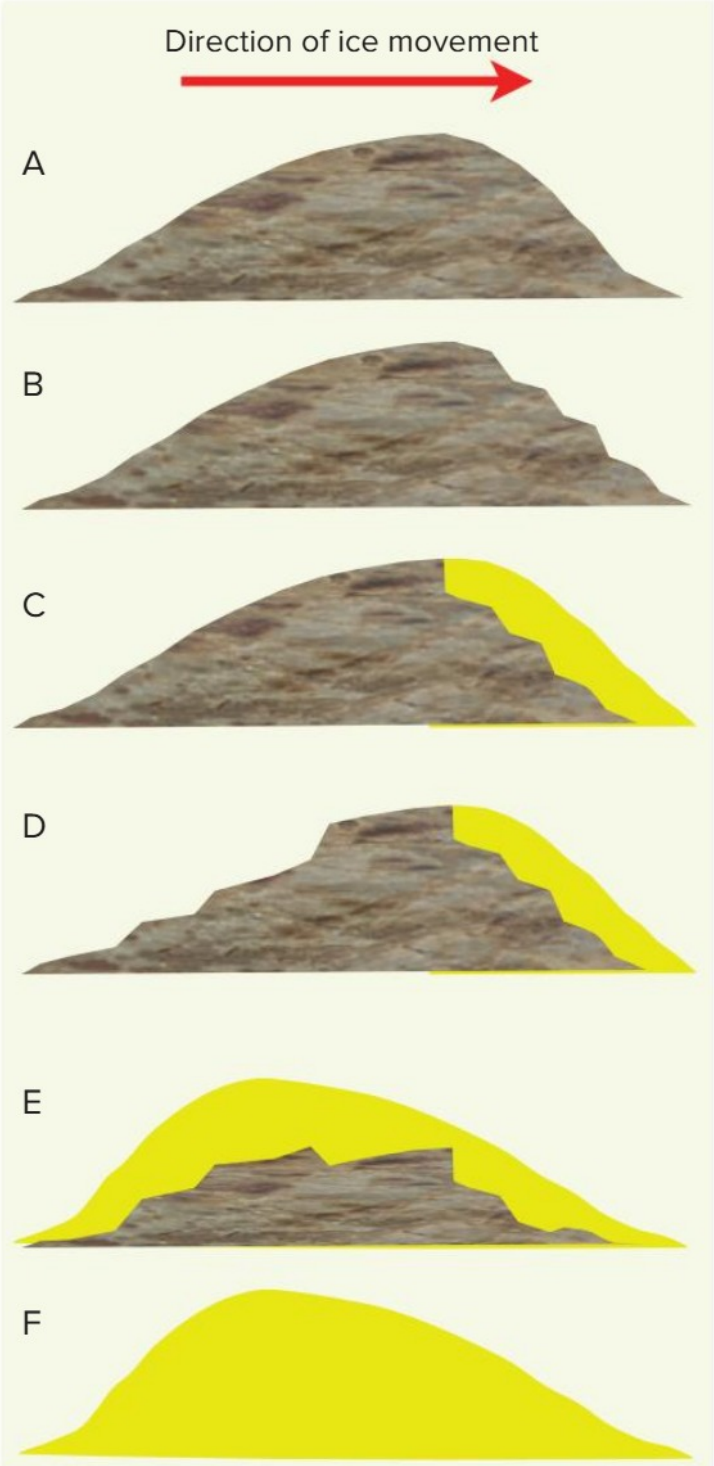
2.10 The peak to the right of this photo is the Matterhorn, perhaps the world's most famous glacial horn. The glacier in the foreground is the Gornergletscher, and it is partly covered with surface moraine. The tributary glacier flowing into the Gornergletscher is the Unter Theodulgletscher, and it is carrying a band of medial moraine. The Matterhorn is situated near Zermatt, Switzerland.

2.11 A large névé in the Canadian Rocky Mountains, near Banff.

2.12 This surface crevasse on the Athabasca Glacier in Canada is being deepened by the flow of melting water during the summer melt period.

2.13 Striations on the rocks in this glacial valley in the Altay Mountains of Mongolia were made when the moving ice scraped rocks (lateral moraine) along the edges of the valley. Two sets of scrape lines can be seen, indicating at least two periods of advancing ice. The ancient animal carvings, known as petroglyphs, have been cut into the striations, evidence that they were made after the last ice age.

carrying smaller rocks with it. Because the scratches were made by the ice as it moved, the scratches indicate the angle of movement of the ice. The scratches are usually parallel, but if the glacier retreated and then advanced at a later date from a different angle, the striations may show multiple sets of parallel scratches.



2.14 Some streamlined glacial landforms. In these cross-section diagrams, brown represents rock and yellow represents deposited sediment. The past ice movement is from left to right in all cases. A and B are roches moutonnées, C and D show crags and tails, E and F are drumlins.

As ice sheets and glaciers expand, the scraping action of the ice has an erosive impact on the surface beneath. When the ice erodes down to bedrock, it can form tear-drop shaped hills that have a streamlined appearance. These are called **roches moutonnées**, and they have smooth gently sloping ends and sides with a steeper leeward side that may be either smooth or plucked. The size of roches moutonnées can vary greatly from miniature examples to large hills.

Landforms shaped by glacial deposition

As we can see in figure 2.14, some glacial landforms are shaped by a combination of erosion and deposition. For example, the steep lee side of a roche moutonnée might be covered with a streamlined tail of glacial debris, such as broken rocks and gravel. This is known as a **crag and tail**, which can vary considerably in shape and form.

Roches moutonnées are erosional landforms because they result from the scouring of the bedrock by moving ice. A similar looking landform, called a **drumlin**, is formed by depositional processes. Drumlins are smooth oval-shaped hills of glacial debris (broken rocks and gravel). Unlike roches moutonnées, the steeper end of a drumlin is on the upstream side, while the leeward side is generally more gently sloping. Although the shape of drumlins can vary, they are always smooth in shape, somewhat like an inverted spoon or an egg that has been split along its axis. Drumlins can vary in size, and some have been observed which are up to 50 metres in height and more than 800 metres in length. They are often found in 'swarms' on flat plains called drumlin fields with other similarly shaped, sized and oriented hills.

The cause of drumlins is not known for certain, and debate about their origins continues among geographers. As the materials in drumlins are always the same as the surrounding ground moraine, deposited in layers, most geographers believe that the base of drumlins were formed at the same time as the ground moraine was deposited. In other words, the material in drumlins was deposited under the ice as the glacier or ice sheet advanced. When the ice melted, the drumlin remained as evidence of the former ice cover.

2.15 This drumlin at Bäckerbichl, near Andech in Germany, emerged when the glacial ice sheet retreated from the area during the Holocene.

Erratics are rocks that are made of a different material from the type of rock native to the area where it rests. The normal explanation is that the rocks were carried to their current location by a glacier or an advancing ice sheet, and then left there when the ice melted. Erratics can vary greatly in size, and some have been estimated to weigh over 5,000 tonnes — strong testimony to the energy of moving ice!

2.16 Glacial erratics in a previously glaciated area of Yosemite National Park, USA.

Loose rocks and sediment that are carried by a glacier is called **moraine**. Rocks that are carried on the sides of glaciers are known as **lateral moraine**.

A moving glacier can also collect rocks and sediments that have fallen from the sides of the valley onto its surface, and this is known as **surface moraine**. Where two glaciers join together, the lateral moraine that was at the sides of the two glaciers becomes a strip of moraine in the middle of the enlarged glacier, known as **medial moraine**. All

2.17 The dark material is surface moraine on a small glacier near Koryaksky Volcano, Kamchatka Peninsula, Russia. An idea of the scale of this glacier can be gleaned by looking at the trekkers who are crossing the glacier.

2.18 The large area of deposited material in the foreground of this photo is the terminal moraine of the Athabasca Glacier, part of the Columbia icefield in the Canadian Rocky Mountains.

2.19 The extensive outwash plain of the Skaftafell Glacier, southern Iceland. In the left foreground, the end (toe) of the glacier's ice can be seen, with a large pool of meltwater in the centre of the photo. The lake drains towards the sea, first crossing the terminal moraine, and then the outwash plain.

the moraine carried by the glacier is then deposited at the snout of the glacier where it melts, and this is known as **terminal moraine**. One way to measure the rate of retreat of a glacier is to examine the terminal moraine that has been left behind after the ice has melted.

Outwash plains form when the meltwater streams from glaciers deposit gravel, sand and moraine from glaciers each year during the summer retreat. Where the outwash of many glaciers has combined, extensive outwash plains may develop. The Canterbury Plains district of New Zealand is an example of a large area that has been built up by the terminal moraine from many glaciers that existed on the Southern Alps in past ice ages.

2.20 Kettles on a glacial outwash plain in Grand Teton National Park, Wyoming, USA.

A **kettle** is a shallow sediment-filled body of water that may form on outwash plains when a glacier retreats. As the glacier or ice sheet retreats, large chunks of ice can break away, and these dig into the soft outwash plain below to form depressions. Over time, the ice melts and the depression becomes filled with water.

QUESTION BANK 2A

1. *Explain why glacial landforms can be seen in areas where there are no glaciers.*
2. *Look at the photos in this section and list as many landform features as you can see under the headings (a) erosional, and (b) depositional.*
3. *Choose four landforms you listed in your answer to the last question, of which two are erosional and two are depositional, and describe their formation.*
4. *Explain the difference between lateral, medial and terminal moraine.*

Periglacial processes

Landforms of periglacial environments

In contrast with glacial environments, where landform processes rely on the effects of moving masses of ice, **periglacial landforms form through the action of frost**, with **permafrost** playing an especially important role. Repeated cycles of **freezing and thawing** cause many of the features of periglacial environments because of the expansion of ice when it freezes.

In periglacial environments, **frost cracking**, which is sometimes called **frost shattering**, is the most important process to break down rocks and create new material for landform formation. When water freezes, its volume expands by 9%. Even very strong rocks cannot withstand the pressures that this expansion creates, which is some ten times greater than the **tensile strength** (the force required to pull something apart) of very strong rocks.

The ability of ice to break a rock apart depends on the type of rock. Rocks that are **porous** contain open spaces that can be filled by water, or ice, and therefore they are more susceptible to frost shattering than **impervious** (or less porous) rocks that allow less moisture to infiltrate. Porous rocks with large spaces for water are especially prone to frost shattering because they allow room for ice crystals to grow, and these exert a strong action to split the rock from within.

The effectiveness of frost shattering depends on the **frequency** of the freeze-thaw cycle. Areas that experience daily freezing and thawing, especially at the ground surface, will experience a greater impact from frost shattering than places that remain frozen for most of the year. The most vulnerable areas to frost shattering are the high, steep, exposed slopes that receive light brushings of snow.

When rocks shatter due to frost action, the broken pieces of rock may fall immediately due to the action of gravity, or they may rest in place until summer when rain or melting snow provides the lubrication needed to dislodge the rock. When rocks begin to fall by gravity, they may dislodge other rocks, leading to a **rock avalanche** or **landslide**. The material from these rock avalanches

2.21 Scree from landslides caused by frost action on the exposed upper slope near Höfn, Iceland.

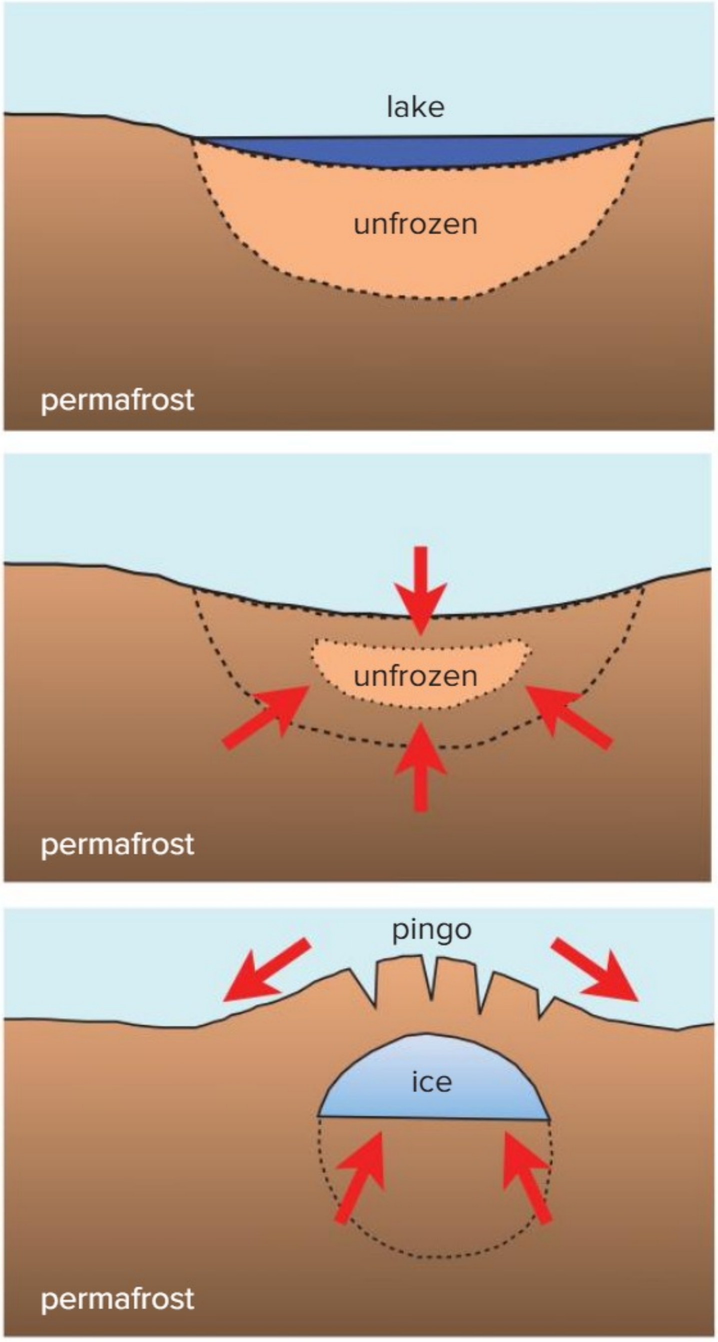
accumulates at the foot of the foot of the slope as **scree**.

Nivation hollows form on the hillsides of many periglacial environments. These are large concave depressions that are normally covered in snow. As a result of the snow cover, freeze-thaw cycles cannot operate in the centre of the hollow because the temperature remains below freezing point. However, the snow prolongs the freeze-thaw cycle at the edges of the nivation hollow, causing the rock to disintegrate and be washed away by the erosive effects of meltwater. Over time, these actions combine to grow the nivation hollow.

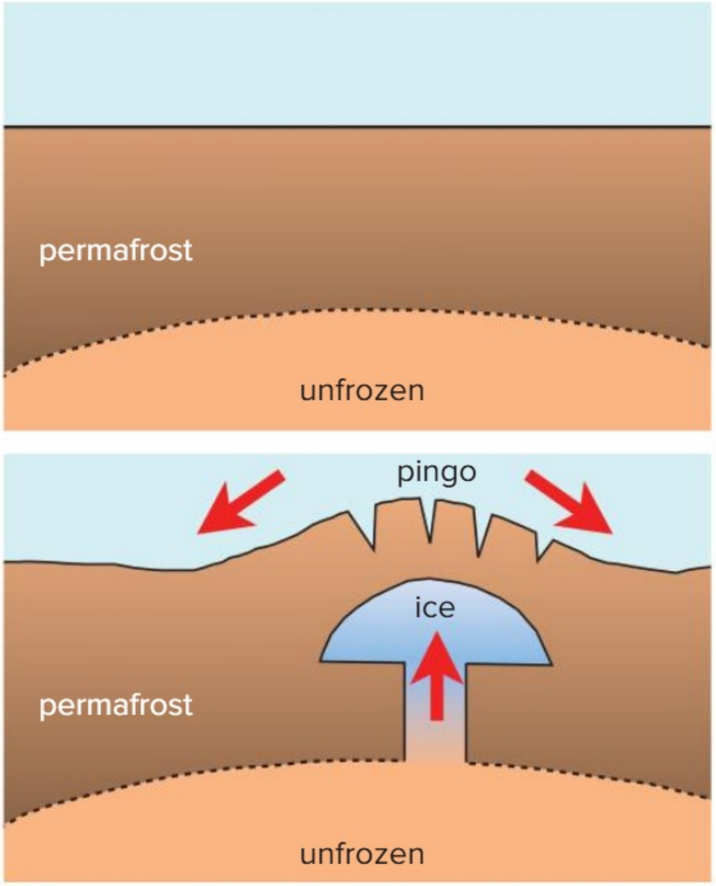
2.22 Nivation hollows on the side of a mountain in the Altai Tavan Bogd National Park near the border of Mongolia and Kazakhstan.

Some periglacial environments have large, isolated hills with cracked summits called **pingos**, or **hydrolaccoliths**. 'Pingo' is an Inuit word for 'hill', and they are domed masses of sediment with a core of ice. They can only form in periglacial environments. Although they range in size, they can be as large as 100 metres in height and up to 700 metres in diameter.

There are two ways that pingos can form (figures 2.23 and 2.24). **Open-system pingos**, also known as **hydraulic pingos**, form by the inward freezing of sediment that is saturated with water. Water that freezes is pushed upwards as the ice expands, forming the hill.



2.23 Open-system pingo formation. (a) The warmth from a river or lake water keeps the saturated rock beneath unfrozen. (b) When the lake is drained or the river is diverted, the saturated material below is able to freeze. (c) An ice lens forms, expands upwards, and causes the ground to rise, forming a pingo.



2.24 Closed-system pingo formation. (a) Liquid water is trapped beneath the permafrost. (b) A rupture occurs in the permafrost, allowing water to rise. As the water rises to the cold surface, it freezes, forming an ice lens, causing the ground above to rise and form a pingo.

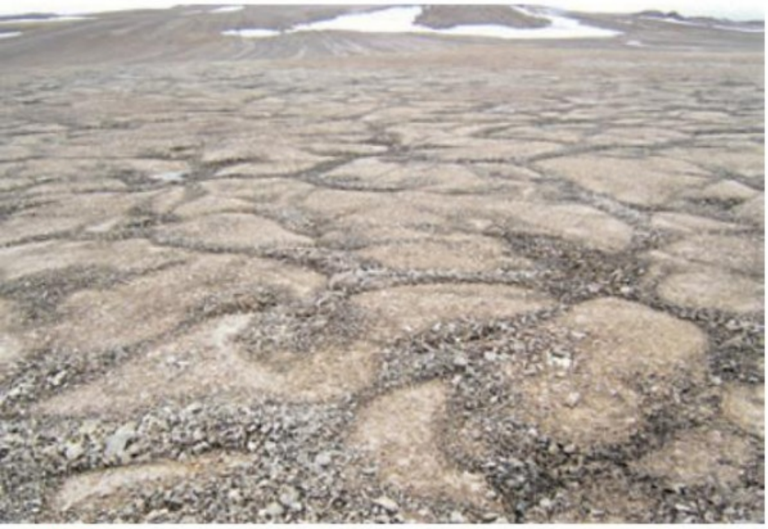
Closed-system pingos, also known as **hydrostatic pingos**, are formed by the upward movement of groundwater from a layer beneath the permafrost. As the groundwater rises towards the cold surface, it freezes, expands, and forms an **ice lens** that pushes upwards to form the pingo.

2.25 Pingos near Tuktoyaktuk, Northwest Territories, Canada.

If the climate of an area becomes warmer, the ice core of a pingo may melt. When this happens, the pingo collapses, leaving just a circular ridge of sediment, perhaps with a pond in the middle. Collapsed pingos provide evidence of climate change, indicating that an area's climate was once colder.

The ice lenses that form pingos are horizontal growths of underground ice. Ice can also grow downwards into soil, producing **ice veins**. If an ice vein grows in size, it may become an **ice wedge**.

The growth of ice veins into ice wedges occurs as soils crack year after year along the same lines. Over time, the freeze-thaw cycles of ice wedges move and sort the stones and sediments on the surface, leading to the formation of patterned ground.



2.26 Patterned ground on Devon Island, the largest uninhabited island in the world. It is located in Baffin Bay, Qikiqtaaluk Region, Nunavut, Canada.

Patterned ground is a general term for the regular geometric shapes that form on the ground surface of periglacial areas as a result of sediment sorting. Typically, the perimeters of the circles or polygons of patterned ground comprise coarse sediment, while the centres contain only fine material. This is because larger stones conduct heat more quickly, so when air cools, the ground beneath larger stones cools more quickly than the ground under fine sediment. Water under larger stones will thus freeze more quickly than water under fine sediment, causing the larger stones to be shifted by the expanding ice while fine sediments remain in place. As temperatures fall further, the smaller stones and finer sediment will start to move as the ground beneath them freezes, pushing these smaller stones into the spaces vacated by the larger stones that moved earlier. Later, when thawing begins, the smaller stones collapse into the spaces below the larger stones, preventing the larger stones returning to their original positions. Over time, the repeated cycles of freezing and thawing sort the stones of different sizes, thus forming patterned ground.

When viewed from above, many periglacial areas can be seen to have irregular surface features with marshy hollows and small hummocks (or hills). This is known as **thermokarst**. The term 'karst' usually refers to the distinctive landscapes that form in areas with limestone when the limestone dissolves. Thermokarst has nothing to do with limestone, however, and the term arose because at first sight, some periglacial areas superficially resembled areas with limestone.

2.27 Oblique aerial view of thermokarst landscape in Alaska.

The **hummocks** in thermokarst landscapes are small domes that form each winter in areas where the underlying ground freezes. They form in a similar way to pingos as ice lens form beneath the surface, but unlike pingos, hummocks are seasonal features that collapse each summer when the ice lens melts. When the hummocks collapse, the result is a depression called a **thaw lake**, sometimes called a **wet hollow** or a **cave-in lake**.

QUESTION BANK 2B

1. *For each landform described in this section, describe the role of frost in its formation.*
2. *List the landforms described in this section that could not form without a regular cycle of freezing and thawing.*
3. *Evaluate the claim "patterned ground forms by horizontal movement, whereas pingos form by vertical movement."*

Arid landform processes

The agents of natural change

There are no areas, even in extremely arid deserts, where it never rains. One weather station in the Atacama desert of Chile experienced 13 consecutive years without rain, while another station in the same desert has recorded 25 years with a mean annual rainfall of only 1.7 millimetres. Nonetheless, **water** does play a part in shaping desert landforms.

Rainfall variability, or the extent to which the rainfall for single years varies from the mean annual rainfall, is very high for arid regions. It is difficult to predict if or when rain is likely to fall. It used to be thought that most desert rain comes during thunderstorms. It is true that thunderstorm rain is important in some deserts, like the deserts of south-western United States. However, thunderstorms are not the main source of rain in most deserts of the world.

Temperatures have a large diurnal (or daily) range in arid environments, so heating and cooling also affect landform formation. The heat during the day can be scorching as the sun rises high towards midday, but at night conditions cool off rapidly. Temperatures at a weather station in the Sahara Desert south of Tripoli (Libya) once varied from 37.2°C to -0.6°C within 24 hours, a difference of 37.8C°. It is claimed that this diurnal range is the greatest ever recorded. The highest temperature ever recorded was also at a weather station in Tripoli, where the temperature was 58°C.

Arid environments often have **strong winds**, and these can lead to widespread erosion. One reason for strong winds is the sparse vegetation, because the frictional drag of trees and shrubs (where they are present) reduce wind velocity near ground level. Most of the world's arid lands are fairly flat or undulating, with few obstructions to disperse or slow the wind.

Weathering and erosion

Weathering is the process of breaking down a rock. Weathering is usually classified into two broad categories, physical weathering and chemical weathering. **Physical weathering** is the disintegration of a rock by mechanical forces that do not change the rock's chemical composition. **Chemical weathering** is the decomposition of a rock by alteration of its chemical composition.

Traditionally, geographers assumed that most of the weathering in arid environments was due to **physical weathering**, such as by abrasion by sand blown by the wind. They thought that chemical action requires water, and arid environments are water deficient. However, no desert is completely dry, and even small amounts of moisture can bring about chemical change, given enough time. Since all weathering processes operate very slowly under dry conditions, chemical weathering is very significant in arid regions, and it is generally more effective than physical weathering. In any case, most chemical and mechanical processes are not mutually exclusive, but they operate together and supplement the work of the other.

2.28 Wear on the Great Sphinx at Giza, near Cairo in Egypt, shows the combined impact of chemical and physical weathering over the period of 4,500 years since it was built.

Because arid environments experience large diurnal ranges of temperature, we might think that **insolation weathering** is an important weathering agent. Insolation weathering shatters the rock by alternate heating and subsequent rapid cooling, causing expansion and contraction. In deserts, the temperature of the ground surface may be 20C° hotter than the air temperature. Rock surface temperatures greater than 80°C have been recorded, but because it is such a poor conductor of heat, the temperature just a few millimetres below the surface would be much less.

Because the diurnal changes in temperature are so large, the surface of the rock becomes stressed as it expands relative to the rock beneath. Perhaps

2.29 Insolation weathering — the diurnal cycle of heating and cooling — has led to the shattering of the rocks in the Arizona Desert at Wupatki, USA.

2.30 This rock in Monument Valley (Utah, USA) has been split because of the action of freezing water. As a result of condensation when the temperature cools at night, water collects in small cracks in the rock. When the water freezes, it expands, this forcing the crack to widen until it eventually splits the rock.

surprisingly, measurements have shown that the forces operating through insolation are enough to cause shattering in only a few types of rock. Even in these cases, insolation weathering occurs only when there are unusually sudden temperature changes, such as might result from cool rain falling on very hot rock. In this way, **desert rainstorms** probably aid the breakdown of rocks.

Processes of **chemical weathering** can take place above the ground surface, but they are very much more effective underground where there is more moisture. In most cases, rocks on the surface today that show advanced chemical weathering were weathered long ago when they were underground.

Salt crystallisation can be an important agent of weathering in arid environments. This is the process of breaking down rocks by the growth of salt crystals in cracks. When rain falls in the desert, some of the salts in the soil and rocks are dissolved, and they penetrate porous rocks such as sandstones. Later drying results in recrystallisation of the salts. This process exerts great pressure and often leads to the breakdown of the rock.

All weathering processes that break down rocks are **extremely slow** in arid environments. Weathering is just the first stage in the development of landforms. **Erosion**, or the removal of weathered rock fragments, can only take place when weathering processes have provided enough material to be transported. Therefore, the speed at which landforms can develop is ultimately dependent on the rate of weathering.

2.31 This bare rock surface (hamada) at Wukoki in Arizona (USA) shows loose pieces of rock that have weathered and accumulated downslope.

Weathered products are removed from rocks that have been exposed to the atmosphere almost as soon as they are produced. For this reason, mountains and hills in arid environments display many bare rock surfaces, known as **hamada**. Furthermore, rock faces tend to be angular and sharp as opposed to the more rounded shapes found in wetter environments. Soft rocks and clays that erode easily may give rise to bare, steeply undulating, treeless topography known as **badland**s.

The bare rock surfaces of hills and mountains tend to accentuate the **geological, structural** features of the underlying rocks. Features arising due to rock type, differential erosion, sedimentary bedding, and folds or faults are not only conspicuous but they may actually determine the entire appearance of the landscape. Furthermore, the slow rate of chemical

2.32 An example of badland topography near Holbrook, Arizona, USA.

2.33 The layered bands of rock in the geology of this area of north-eastern Iraq impose a strong influence on the appearance of Gali Ali Beg Gorge, 100 kilometres north-east of Erbil in Iraqi Kurdistan.

2.34 The geology has a strong influence on the appearance of the steeply-sided 300-metre deep Charyn Canyon Gorge in south-eastern Kazakhstan.

weathering on the surface means that the natural colours of the rocks tend to be preserved. Sometimes, these colours are very bright, as in rocks stained by oxides of iron or manganese. The great scenic beauty of the arid environments of central Australia and the south-west of USA owes much to the colour of the rocks.

It is important to remember that most of the world's deserts are old enough to have experienced several periods of wet climates over geological time. Many of the weathered features seen today in arid environments are not the result of current processes, but are **relics** from wet climates thousands, or in some cases millions, of years ago. Erosion, like weathering, is very slow in arid environments, and once the climate has changed from humid to arid, the erosion of landforms produced by weathering in earlier wetter conditions is very slow indeed.

2.35 Located in central Australia, Uluru is the world's largest monolith. It comprises rock material that is more resistant than the softer rocks that once surrounded it, and which have been weathered, eroded and removed.

QUESTION BANK 2C

1. *What is the difference between weathering and erosion?*
2. *List the types of weathering which are important in arid environments. For each type, say whether it is physical or chemical, and comment on the landforms or other features that might result from its actions.*
3. *How could past climatic changes have affected the processes that develop landforms in arid environments?*
4. *Why is it that geological structure (the underlying rocks) tends to have a greater impact on the shape of landforms in arid environments than in wetter environments?*
5. *What is the effect of the slow rate of weathering on the development of landforms in arid environments?*

Arid landforms

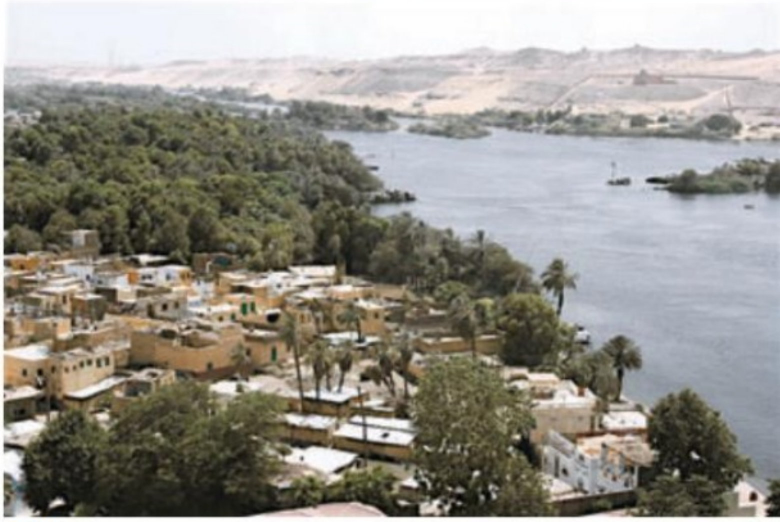
Water and landform development

Although water is scarce in arid environments, it plays a very important part in erosion, transport and deposition. Apart from areas that are covered by sand plains and sand dunes, water is **far more effective** than wind in the processes of arid landform development. When it does rain, the rocky surfaces of the arid hills shed water freely into dry creeks, which then experience flash flooding – a short-lived, fast-flowing stream that results from the sudden heavy fall of rain. Further downslope, where soils cover the surface, some of the rain that falls does penetrate the ground surface.

Because of the sparse vegetation, **runoff** is much greater in arid environments than on similar slopes in wetter regions. In some areas, a thin platy layer of fine sediment caps the soil and this resists penetration by water. Large areas of bare soil are exposed in arid areas, and this aids runoff and aggravates soil erosion. The physical impact of individual raindrops on the soil causes **rainsplash**, which dislodges the soil particles and puddles them. When this happens on a sloping surface, soil particles are easily taken into suspension and carried into stream courses.

Very few streams in arid regions flow to the sea. There are some important exceptions, such as the Nile River in Egypt, the Indus River in Pakistan, and the Colorado River in the United States. These rivers, which have their catchment areas in heavy rainfall country outside the desert boundaries, are known as **exotic streams** because they flow from an outside source region that is in a different type of environment.

Most streams in arid environments follow patterns of **internal drainage**, which means they flow into an inland sea or lake rather than the sea or ocean. Many of the streams are **ephemeral**, which means they either dissipate into the desert surface or terminate in local depressions where water collects briefly, then evaporates. Ephemeral lakes that form in this way are often called **playas** or **playa lakes**. When they dry out, the lakes reveal beds of fine alluvial sediment together with evaporites like salt, calcrete and gypsum. Dry lakes are common



2.36 The Nile River flows through the eastern Sahara Desert in Aswan, Egypt. About 95% of Egypt's population live along the 5% of the country that is watered by the Nile River because of the water that the river brings from its source regions in the wet highlands of Ethiopia and Tanzania.

2.37 An ephemeral stream in Monument Valley on the border of Arizona and Utah, USA.

2.38 Evaporites surround Lake Assal, a large heavily hypersaline lake in central Djibouti. Lake Assal is an endorheic basin, which means it has no outlet. Thus, the salinity becomes more and more concentrated over time as the water evaporates in the heat. It is now ten times more saline than ocean water.

landforms in arid environments, and their beds are very conspicuous when white, salty surfaces are exposed.

The ephemeral streams of arid regions are known as wadis in Arab countries, arroyos or washes in North America, and dry creeks in Australia. Unlike river valleys in wetter landscapes, the channel patterns of streams seldom meander, but their dry beds show a **braided pattern**. Braided streams result when the water flow is highly variable.

2.39 The dry bed of this large ephemeral stream in the Namib Desert of Namibia shows a braided drainage pattern. The scattered stunted trees in the stream bed indicate the presence of underground water.

2.40 These alluvial fans in Death Valley (USA) are growing and joining together to form a bahada where several ephemeral streams flow from the steep hills down to the flat plain.

2.41 A wide box canyon in Death Valley, USA. The stream has recently carried water, as shown by the flow lines in the damp sand in the middle of the photo. Bank collapse caused by water undercutting the sides of the stream course creates the vertical edges, which expand outwards each time the stream flows.

Alluvial fans are found in many types of environment, but they are especially common in deserts. In order to form, alluvial fans require a flat or gently sloping plain near the foot of a hill or plateau, where a stream carrying sediment emerges abruptly from a mountain front and spreads out. As the stream reaches the flat plan, known as a **piedmont**, its velocity slows and it loses competence to carry the sediment load. The sediment is therefore deposited at the junction of the hill and the piedmont, and a fan-shaped deposit builds up. Arid environments often have slopes that erode easily, providing plenty of alluvial material suitable for deposition.

In many deserts, several nearby streams flow from the same mountain scarp to form alluvial fans. When this happens, the edges of adjacent fans may coalesce to build up a continuous mantle of deposition known by the Spanish term **bajada**, often anglicised to **bahada**.

Alluvial fans in arid environments are found only next to escarpments with steep gradients. Where gradients are gentler, desert streams usually have a flat, sandy bed with steep banks. Their rectangular cross-section leads to the common name **box canyon**.

When gradients are even less, a single stream channel may branch into one or more distributaries called **anabranches**. These can flow parallel to the main channel for many kilometres before rejoining it. One example is the Darling River anabranch in western New South Wales, Australia.

On flat plains in arid environments where the gradient is extremely low and the stream flow infrequent, there are often many small channels that continuously divide and converge to form what is known as a **reticulate drainage** pattern.

2.42 Reticulate drainage in the Namib Desert, Namibia.

When occasional heavy floods come, these channels quickly overflow, resulting in wide expanses of shallow water. The Channel Country of south-west Queensland (Australia) provides many examples of this type of drainage, and it is also found in the Namib Desert in Namibia.

When water flows through cracks in the rocks, or through underground channels, the erosion becomes concentrated into narrow watercourses. Over time, these stream flows may result in spectacular rock formations such as **natural bridges**. This erosion usually occurs in short bursts of time, such as during sudden thunderstorms. For example, during just one month (June 1992), 4,000 tonnes of rock fell from just one natural bridge in Utah as a result of stream water erosion. Natural bridges are thus quite delicate features, and it is almost inevitable that given enough time the bridge will collapse as a result of further erosion of the rock, either by rock or by wind.

2.43 Landscape Arch in Arches National Park (USA) is said to be the longest natural arch in the world. Slabs of sandstone continue to fall from the arch, highlighting its fragility.

QUESTION BANK 2D

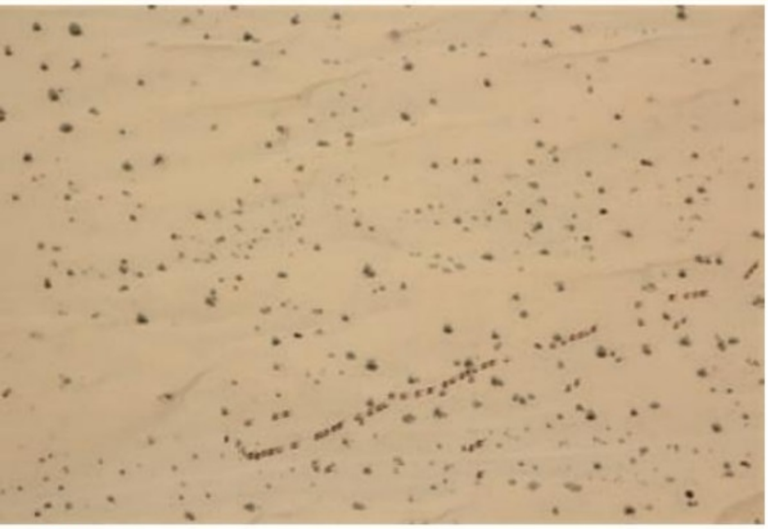
1. *Make a list of landforms typical of arid environments whose formation is dominated by the action of water.*
2. *Why is water so important in developing landforms in deserts when arid environments have so little water?*
3. *What is meant by the term 'internal drainage'? How common is this in arid environments?*
4. *How do alluvial fans form?*

Wind and landform development

Arid environments tend to be windy. Although wind (or **aeolian** action) is not as effective as water in erosion, it plays an important part in the transport of fine sediments and sand. Wind is partly responsible for the transport and deposition of the sand in sandy deserts, and it is wholly responsible for the shaping of sand into dunes.

Dunefields, or **ergs** as they are often called, are spectacular features, but they are not as widespread in deserts as many people think. Sandy surfaces comprise only 2% of the North American deserts, 15% of the Sahara, and 30% of the Arabian desert. Although about 50% of the Australian desert is sandy, the sand is mainly in the form of vegetated sand plains and dunes that do not fit the common image of sandy deserts as moving hills of sand.

Deflation is the term used to describe the removal of any kind of material from the ground surface by wind. In some arid areas, large bodies of sediment may be removed, leaving behind **deflation hollows**,



2.44 Erg desert east of Dubai, UAE. The scattered green dots are stunted bushes, and the line of small dots is a camel train.

2.45 An oasis in the sand dunes of the Gobi Desert at Dunhuang, China.

while elsewhere deflation may merely sort the sediments by taking away the finer particles.

There are several ways in which wind activates and transports dust and sand. At the surface of the ground there is a very thin layer of air which is virtually stationary, regardless of the wind velocity higher above the ground. Because of this, a surface layer of very fine material with a particle size less than 0.06 mm (silt or clay) is very stable until disturbed by an unusual circumstance. This could be an unusual eddy of wind, or some mechanical factor such as moving sand, trampling animals, or the passage of a motor vehicle. Once in the air, the fine particles may be lifted as dust to great heights and carried considerable distances. During droughts, Australian dust has been carried as far as New Zealand and deposited on the snow of the Southern Alps. Sometimes, dust particles are picked up by the wind from the surface of a desert and carried outside the arid region, to be deposited as unstratified material known as **loess**. The famous loess deposits of China, some of which are more than 100 metres thick, comprise sediments blown from the great deserts of Central Asia.

Unlike fine clay and silt particles, coarser particles of sand on the ground surface are large enough for their tops to extend up into the zone of moving air that lies just above the surface. Sand particles can therefore be rolled along the ground surface by the wind. Rolling grains of sand strike one another, and the impact throws some of them into the air, to be blown a short distance downwind before falling back and activating other grains. This kind of jumping action is known as **saltation**, and it mainly occurs with particles of fine sand. Coarse sand is usually too heavy to be lifted by this means, and it is usually rolled along the ground instead.

2.46 The wind blows sand across the road near Bokurdak in the Karakum Desert in central Turkmenistan.

A wind speed of more than 30 kilometres per hour is usually needed to initiate the movement of sand on flat surfaces. On the slopes of dunes, however, a much lower wind speed of only 15 kilometres per hour may be sufficient. Sand blown by the wind is mostly restricted to a zone below 0.6 metres above the ground. Even in quite strong winds, the maximum height to which sand can rise is about two metres.

It is the **quantity** and **particle size** of the sand that largely determines which landforms will develop in sandy deserts. Other important influences are the **velocity** and **direction of the winds**, and sometimes, whether or not the **rock base** is hard.

Sand sheets are areas of sand with more-or-less level surfaces. They form when there is enough

2.47 A dunefield of migrating barchans (foreground), with a high hill of sand behind near Liwa Oasis, United Arab Emirates.

coarse sand to restrict saltation, which therefore prevents the sand from forming dunes.

Barchans are crescent-shaped (crescentic) sand dunes. The wings (or horns) point downwind. Sand is driven up the windward slope, which has a relatively gentle gradient, and rolls over the crest to the leeward side where it falls away to the steep angle of repose for sand, which is constant at 33° to 34°. Barchans form on hard, flat surfaces, where there is a limited sand supply, and where winds usually blow in one direction only.

Parabolic dunes are U-shaped mounds of sand with elongated arms, and they are common in coastal deserts such as the Namib. Unlike barchans, the arms of parabolic dunes follow the movement of the wind rather than lead it, and thus the arms point towards the wind. The arms are usually fixed by vegetation, whereas the bulk of the sand in the dune migrates away from the prevailing wind. Parabolic dunes can become very large, and the dunes at Sossusvlei in the Namib Desert rise to almost 400 metres above the surrounding plain.

2.48 The parabolic sand dunes at Sossusvlei in the Namib Desert rise to almost 400 metres above the surrounding plain.

Unlike barchans and parabolic dunes, **longitudinal** or **seif dunes**, are formed by winds that blow from at least two directions. The general alignment of the dunes reflects the directions of these winds. During the time that a dune is growing longer, sand movement is in the direction of the long axis. The prevailing winds increase the length of dunes, but cross-winds increase their height and width. Longitudinal dunes are parallel to each other, and they may extend for great distances. Indeed, individual longitudinal dunes may reach heights of 100 metres, and they can be as far as 1,000 metres apart. Longitudinal dunes occur in almost all of the world's deserts, but they are particularly extensive in Australia where they make up half of the total area of sandy desert.

2.49 An oblique aerial photo of longitudinal dunes in Central Australia.

Lunettes are crescent-shaped dunes that lie at the leeward, or downwind, edge of some ephemeral lakes. When the lakes are dry, salt crystals in the beds cause clay sediments to re-form into small pellets. These pellets are then blown by the wind and deposited on the downwind edges of the lake's shores. When the lakes are filled, wave action may form sandy beaches on the downwind shores, and some of this sand is then blown on to the dunes. For this reason, lunettes may include amounts of sand even though most of them are essentially made up from clay.

Differential erosion can be caused by the action of wind as well as the action of water. In the case of wind action, differential erosion occurs through sand-blast erosion, where wind-blown particles erode different rocks at different rates according to their relative hardness, and thus resistance to erosion. Some quite spectacular formations can result from sand blasting, including arches and mushroom rocks, as shown in the photos on this page.

Sand blasting was once thought to be the main force in producing **pedestal** or **mushroom rocks**. There is no doubt that sand blasting plays an important role, but we now know that chemical weathering plays an even more important role in undercutting hard rock. Moisture tends to concentrate and remain for longer periods on the lower parts of rock masses, and these are the parts that weather most rapidly. Mushroom rocks in arid environments are therefore the result of both physical weathering and chemical weathering.

2.50 Mesa Arch in Canyonlands National Park, near Moab, USA.

2.51 Although this formation is known as "Balanced Rock", it is actually a mushroom rock formed by wind erosion, and it is the remnant of an older, higher landscape. It is located in Arches National Park, near Moab, USA.

2.52 Delicate Arch in Arizona (USA) is the 20 metre high remnant of a large ancient bed of sandstone. The surrounding sandstone has been weathered and eroded, leaving the arch.

2.53 Wind has eroded these rocks in the Gobi Desert at Yadan, north-west of Dunhuang (China). The prevailing wind direction is from the right hand side of the photo, and this has led to undercutting of the rock near ground level on the side of the rock facing the wind. The people standing in the shade of the rock give an indication of scale.

QUESTION BANK 2E

1. *What does the term 'aeolian landform' mean?*
2. *Make a list of landforms typical of arid environments whose formation is dominated by the action of wind.*
3. *Which is more important for the development of landforms in arid environments: wind or water? Give evidence to support your answer.*

Desert residuals and stony deserts

Many of the landforms found in arid environments today are **relict features**, being remnants from former landscapes. Changing climates over millions of years have transformed areas that were once well-watered into today's deserts. Therefore, much of the present desert landscape could be described as **residual**.

When the term 'residual' is used to describe a landform, it refers to the remains of an ancient landscape that escaped destruction. Residuals are generally elevated landforms such as an isolated mountain or part of a plateau that remains from a former, much more extensive, and usually higher land mass.

Inselbergs are prominent steep-sided residuals rising in isolation above extensive and plains. They usually have somewhat rounded outlines acquired long ago under humid conditions, often as a result of underground weathering. Sometimes, however, the roundness is due to the weathering characteristics of the rock type. Among the best-known inselbergs are Central Australia's Uluru and Kata Tjuta.

Mesas, which are table-topped mountains with steep and often vertical upper slopes, are the most common residuals in arid environments. Mesas can occur in humid as well as arid environments. In arid environments, mesas have a sharp break in slope between the flat top and the scarp, and another sharp break in slope between the scarp and the **talus slope**, which is the accumulated rock debris that has fallen as the rocks above have been eroded.

This distinctive profile shape is particularly obvious because of the absence of vegetation. The top of a mesa is the flat and roughly horizontal **remnant** of some former plateau surface, which is **resistant** to weathering compared with the rocks beneath it. This hard layer may be a basalt flow, a tough sedimentary bed, or a former erosion surface cemented and hardened by weathering products such as silica, or oxides of iron and aluminium.

2.55 A mesa (with a butte in the right background), Monument Valley, Utah (USA).

2.54 Kata Tjuta in Central Australia is an example of an inselberg.

2.56 Talus slopes in the Grand Canyon, USA.

2.57 This former mesa in Monument Valley, on the Utah-Arizona border (USA), has been eroded to form a butte.

2.58 Further erosion of a butte can be expected to remove the last traces of the hard capping rock, leading to the rapid disintegration of the softer rock beneath it. The butte to the left of this photo in Canyonlands National Park (USA) has almost reached this stage. The close view of the mesa in the right of the photo clearly shows the talus slope at the base of the mesa where the eroded rock materials that have fallen from above are accumulating.

Mesas erode by the **backwearing** of slopes, usually assisted by undercutting of the hard, caprock surfaces. As they erode, the angles of the slopes remain constant and their distinctive shape remains the same until all the capping rock disintegrates. Heavily eroded mesas that have very little of their capping rock remaining are known as **buttes**.

As erosion removes material from the surface of an arid environment, some rocks tend to be left behind because they are more resistant to weathering. When a flat stony layer is all that is left behind, the area is termed a **stony desert**. Several types of stony deserts can be identified depending on the nature of the rocks. Where the surface is covered with small rocks, the desert is known as a **gibber desert** in Australia, and reg or serir in the Sahara. When the stones are packed so tightly together that no spaces remain between them, then the surface is termed **desert pavement** or **desert armour**, because the hard surface protects the underlying soil from erosion.

2.59 This reg, or gibber desert, is situated between Goulimime and Er Rachidia in Morocco.

QUESTION BANK 2F

1. *Give two examples of residual landforms, and describe their formation.*
2. *Draw an annotated full page photo sketch of the view shown in figure 2.58. Label as many distinctive desert features as you can identify. For each feature, suggest whether the main agent of its formation is water, wind, or chemical processes.*

Chapter 3 Managing extreme environments

3.1 Women extract water from an underground well to irrigate their food crops, using dishes and buckets to overcome the aridity of their environment. They live in the Sahel Desert near the eastern border of Mali with Burkina Faso.

Agricultural opportunities and challenges

Limiting factors for agriculture

In any environment, there are two important factors that determine the **productivity** of agriculture.

The first factor is the amount of **solar radiation** available to the plants that underpin the farming activity, which are either the crops being grown or the grasses that are used to feed livestock.

The second factor is the **efficiency** with which these plants can convert the solar energy into usable forms by photosynthesis. The efficiency of photosynthesis (energy conversion) is affected by many factors such as **temperature**, **water** availability and **nutrient** supply. If one or more of these factors restricts plant growth, then it is said to be a limiting factor.

In some extreme **arid** environments, there are adequate supplies of nutrients in the soil, abundant sunlight and warm temperatures, but **water** is the limiting factor. In **cold** climates, the water is often plentiful, but inadequate solar radiation (low temperatures) may be the limiting factor.

Agriculture is not just limited by minimum inputs of solar energy, water and nutrients. An **excess** may be just as harmful. For example, all plants require water for growth, but most plants also react badly to an excess of water that leads to waterlogged soils, and many plants are killed by an excess of water during flooding.

Therefore, each limiting factor — solar radiation, water, nutrients — can be thought of as having three critical values:

- a **minimum** below which productivity ceases completely;
- an **optimum** level where productivity is greatest; and
- a **maximum** above which productivity ceases again.

Agricultural opportunities and challenges in arid environments

The most significant limiting factor for agriculture in arid and semi-arid areas is **access to water**. By definition, arid areas have a rainfall deficit, and the problems of low rainfall are aggravated by its unreliability.

Additional factors often compound the difficulties of farming in arid environments, such as strong winds (which often carry sand that can damage crops, or even bury them), saline soils and poorly developed soils that lack key nutrients. However, it is the shortage of water that presents the biggest challenges.

In many countries, **irrigation** is seen as the answer to the problem of water deficiency. Irrigation means bringing water from another area, either manually or through canals or pipes in order to grow crops or vegetation. This can be a very labour intensive process in poorer countries, or an expensive process in countries that can afford large-scale investments, requiring huge amounts of capital to establish and then maintain the infrastructure.

In the deserts of the south-west of the United States, a huge scheme diverts water from the Colorado River across the deserts of southern California. Water is collected in a series of dams on the **Colorado River**. These dams serve other purposes

3.2 Irrigating food crops by hand using buckets of water near a small stream that runs through the Sahel Desert at Kokolo, Mali.

3.3 This shows the same area as figure 3.2, and illustrates how the hot, parched desert landscape can be transformed by irrigation water, overcoming the limitation of water scarcity.

3.4 Irrigated farmlands on the edge of Grand Junction, USA. The transformation of the landscape can be seen by comparing the irrigated farms and urban development beside the Colorado River with the arid terrain beyond.

in addition to water storage. Several are used to generate hydro-electricity, and the lakes of the dams are also used for tourism. From the dams, the water is pumped along several canals to irrigate fruit and vegetable cultivation in southern California. This enables food to be grown that would otherwise have to be brought to the area from elsewhere.

It is important not to confuse **aridity** with **infertility**. Many **soils** in desert areas are quite fertile, having all the minerals and nutrients required for growing crops. All they lack is water. This situation applies especially to the floodplains of exotic rivers that flow through deserts, such as the Nile River in Egypt, where for centuries fertile sediments have been deposited when the river floods. These soils have provided the basis of farming in Egypt for many years, thus enabling population numbers to increase despite the aridity of the environment.

3.5 Irrigated farmland on the fertile soils of the Nile River floodplain near Luxor, Egypt.

Despite this, soils are often the limiting factor for farming in arid environments. Because deserts have sparse vegetation, the soils lack humus (decaying vegetable matter) that provides nutrients. The lack of rain means that the soils tend to be thin and shallow, and they are often coarse and sandy in texture. These conditions combine to limit the agricultural potential of desert soils. On the positive side, the lack of rainfall also means that the minerals and nutrients that are present are unlikely to be leached out of the soil.

Many desert areas lie on lands that were once ancient sea beds. In these situations, the soil contains salts beneath the surface. Salt in the soil, known as **salinity**, makes crop growth impossible if the concentration is high, as food crops are intolerant of saline soils. Even a low concentration of salts will reduce the productivity of agriculture.

3.6 Farmland on the semi-arid fringes of the desert in Western Australia has been adversely affected by salinisation of the soil, shown by the patches of white salt that lie on the surface.

Over time, the concentration of salts in desert soils tends to increase, a process known as **salinisation**. This is because the natural vegetation uses water from the soil but not the salts, which remain in the soil when the moisture is removed. Where this happens, the concentration of salt in the soil must be reduced before farming can begin. This can be achieved by applying irrigation water that dissolves the salts and leaches them downwards to a lower level in the soil and away from the root zone of the crops.

3.7 The white areas on these fields is salt, brought to the surface by poor irrigation practices. Excessive quantities of water have been pumped from the Karakum Canal (the brown channel in the foreground) onto these fields near Ashgabat at the southern fringe of the Karakum Desert in Turkmenistan. The excessively wet soil has freed the salts to rise to the surface, destroying the land for agriculture.

3.8 Ghardaïa in central Algeria is a large oasis in the Sahara Desert. The oasis extends across the flat valley of the River M'Zab, allowing cultivation of vegetables and dates. The surrounding hills rise above the level where water is available.

3.9 A well brings water to the ground surface in this oasis in Beni-Isguen, Algeria. Hand-dug canals then distribute the water through the 'palmerie' (date palm garden) of the oasis.

On the other hand, poorly practised irrigation can also aggravate or initiate salinity. If too much water is applied to a field, a continuous moist zone may be created between the salt and the soil surface. When this happens, the salts become free to rise to the surface by capillary action, thus making the soil impossible to cultivate. It can take many years before desert soil that has become saline can be used again for agriculture.

With all these challenges, why do people try to farm in extreme arid environments? The reason is that arid environments offer significant agricultural **opportunities**.

For people in traditional societies who live in desert areas, food cultivation is a necessity. These communities tend to live in remote areas with poorly developed transport connections, so self-sufficiency in food production means **survival**.

The opportunity available for some of these isolated communities is the presence of oases. An **oasis** is an isolated area in a desert where sufficient water is available to sustain perennial vegetation. Typically, the water is available because an underground source of water in an aquifer rises to the ground surface to form a stream or lake, or rises very close to the ground surface so that wells can be dug to access the water.

Deserts also provide opportunities for large-scale **commercial agriculture** in arid environments. The potential arises from the availability of large expanses of unused land with generous sunlight and, in some areas, soils with nutrients. Examples of large-scale commercial agriculture in deserts — all of which require extensive irrigation to overcome the shortage of water — include fruit and vegetable cultivation in the Colorado River Basin (USA), and cotton production in the Ord River basin (Australia) and along the Karakum Canal in Turkmenistan.

CASE STUDY
Agricultural opportunities and challenges in Turkmenistan

Turkmenistan emerged as an independent country in 1991 as a result of the break-up of the Soviet Union. Most of the country (90%) is covered by the vast sands of the Karakum Desert. In Turkmenistan, aridity is extreme.

Because of Turkmenistan's arid climate, water is the main **limiting factor** for agriculture. Irrigation is

3.10 The Karakum Desert in Turkmenistan.

3.11 Fruit and vegetables, all grown under irrigation in the arid areas of Turkmenistan, are being sold in the market of Turkmenbashi, a large city in western Turkmenistan that is surrounded by desert.

therefore necessary if land is to be cultivated. Many types of fruits and vegetables are grown, most of which are sold in local markets as well as larger markets in the cities.

By far the most important crop in Turkmenistan is **cotton**, which also requires large-scale irrigation. Cotton growing began during the Soviet era, when huge areas of land were transformed from desert to farmland to grow cotton. Despite the high cost of irrigating the desert for cotton growing, the government is continuing to expand the land area for cotton, and there is a program underway to add 3,200 kilometres of irrigation and drainage channels.

In order to support its agriculture, Turkmenistan has the world's longest irrigation and water supply canal, the 1,375 kilometre long Karakum Canal. The canal was a major achievement of Soviet engineering, taking almost 13 cubic kilometres of water annually from the Amu Darya, a major river that flows through the far north of Turkmenistan. The canal begins in the far east of Turkmenistan and flows westwards across the Karakum Desert, past the capital city of Ashgabat to the town of Bereket in western Turkmenistan.

Irrigation for agriculture has caused some significant environmental **problems** in Turkmenistan. The main method of irrigation used is traditional **surface irrigation**, which means the water flows along a hierarchical network of canals through the fields. Efficient management of the water supply using surface irrigation is very difficult, and **over-watering** has been a widespread practice. This has led to a rise in the water table towards the surface, drawing salts to the surface and leading to salinisation of the soil in many areas. In some areas, salinisation is so bad that fields have

3.12 A farmer stands in his irrigated cotton field in eastern Turkmenistan.

3.13 Water being pumped from the Karakum Canal into irrigation channels.

3.14 White salt deposits on the surface indicate salinisation from inefficient irrigation practices.

been abandoned as white salts take over the surface of the soil, making it useless for agriculture.

Further problems arise when the water used for irrigating the fields drains back into the irrigation canals. This water has been percolating through the soils on the farms where large quantities of **pesticides** and **chemical fertilisers** are used. In the case of the cotton fields, it is common to use large quantities of herbicides to defoliate the cotton plants to make harvesting easier for mechanical harvesting. Therefore, the water flowing back into the canal tends to contain a variety of **toxic substances**. As more and more waste water flows back into the canal, the toxicity of the water rises as the water flows further downstream, and it is heavily polluted by the time it reaches western Turkmenistan.

QUESTION BANK 3A

1. *What is meant by the term 'limiting factor'?*
2. *List the three limiting factors for farming in any environment?*
3. *Which limiting factor is most significant in arid environments? Explain your answer.*
4. *Do you think that agriculture in arid environments presents more opportunities or more challenges? Give reasons to support your argument.*

Agricultural opportunities and challenges in cold environments

The **limiting factors** that affect agriculture in cold climates are quite different from the limiting factors that affect arid environments. In cold environments, lack of solar radiation is the most common limiting factor, although low nutrient levels in poor soils may also cause challenges, especially in mountain areas where soils are thin and in periglacial environments where soils may be frozen or waterlogged.

In **polar** environments, the climate is so cold that agriculture is impossible. In **periglacial** environments, agriculture may be possible on soils that are not too waterlogged during the short growing season, but it is very limited in scale. Where farming does occur, it is small scale and usually labour intensive. Crops are limited to quick growing vegetables that can tolerate cold, wet soils (such as potatoes, broccoli, parsnips and cabbages).

3.15 Farmers in Igaliku, south-west Greenland, cultivate vegetables during the short growing season in which the area is not covered by snow.

Most food production in periglacial environments is based on raising animals such as goats or reindeer. Unlike crops, animals can be moved according to seasonal changes. In North America, Europe and Asia, animals may be moved northwards in late spring when melting snows expose fresh pastures for grazing. They return to the south once again when the weather begins to cool and pasture growth has ceased for the year.

In many **mountainous** areas, farming is also based on animal raising. Animals are moved to higher altitudes during summer and down to lower altitudes during winter – a process known as **transhumance**. In the Nepalese and Tibetan parts of the Himalayas, transhumance applies mainly to cattle grazing activities. Animals such as sheep,

3.16 Yaks graze on (very scanty) summer pastures near Ganden, Tibet, at an altitude of 4,300 metres above sea level.

3.17 Crops are grown during summer in the sheltered floor of a highland valley near Lhasa, Tibet.

3.19 Cows grazing on an alpine pasture near Grindelwald, Switzerland, during summer.

goats and yak are well adapted to high altitudes, and they make good use of higher altitude grazing pastures up to 4,500 metres during the summer months. During the cooler winter months, the herds are brought to lower altitudes of between 2,000 and 3,000 metres. As lower altitude livestock such as cows, buffalo and pigs also use these altitudes, there is some pressure on feed supplies during the winter months.

3.18 A summer view of a farm in the Swiss Alps, where arable farming is underway. In this view, grass is being cut for use as hay for animal fodder during the coming winter months.

In the Swiss Alps, a typical farm comprises arable croplands in the valley floors, leading up to the forest zone and above that the natural pastures that are used only in summer. The main type of animal raised is the cow, usually for the production of milk although increasingly also for meat. Traditionally, the cows in Switzerland were taken to higher alpine grazing pastures during summer and then brought back to the valley floors for the winter months where they were housed inside a barn attached to the farmer's house.

Upper altitude lands are tending to cease agricultural use in Switzerland because of the difficulty of making a living from farming due to the limiting factors of thin soils, rocky ground, steep slopes, heavy precipitation and pastures covered by snow for up to six months of each year.

QUESTION BANK 3B

1. *Explain the concept of transhumance.*
2. *Which limiting factor is most significant in cold environments? Explain your answer.*
3. *Do you think that agriculture faces more challenges in arid environments or in cold environments? Give reasons to support your argument.*

Opportunities and challenges for mineral extraction

Mining opportunities and challenges in cold environments

Rich mineral resources are found in many areas of periglacial environments. For example, Siberia and the Far East regions of Russia contain large supplies of coal, diamonds, tin and gold, while northern Canada has a range of minerals including nickel, iron ore, gold, diamonds and uranium.

Mining these valuable minerals creates significant **opportunities** to open up large, poorly developed and under populated regions, providing employment opportunities and generating income from exports. On the other hand, there are many **challenges**, such as the high cost of attracting workers to come and live in hostile environments, the high cost of protecting people and equipment from the extreme cold, the risk of intruding upon the rights of local indigenous peoples, and the danger of damaging the fragile periglacial ecosystems.

3.20 The Dneprovsky tin mine operated in the Russian Far East from 1941 to 1955 using prisoners as labour. Although its operations ceased more than 60 years ago, the environmental consequences of the mining are still very evident.

3.21 Another view of the abandoned Dneprovsky tin mine shows the large hills of tailings that have buried the natural landscape. Although the mine closed more than 60 years ago, the hills of mining waste remain devoid of any vegetation.

3.22 Kadykchan is an abandoned mining town in the periglacial environment of the Russian Far East. It was established in 1936 beside a coal mine to house the miners, all of whom were prisoners at the time. However, the abandoned buildings that are still visible today date from the 1960s onwards when the town was re-populated by idealistic Young Pioneer workers. The mine closed in 1996 following a large explosion, and so the town was officially closed in 2003. A few illegal settlers remained until 2007. At its peak, Kadykchan had a population of 10,000 people.

The risk of damaging the **natural environment** is significant in periglacial areas. Mining makes a considerable impact on the environment, especially when it is large-scale, and periglacial ecosystems often take a long while to recover because the **biological growth rate** of plants is so slow in the cold conditions. Furthermore, the cold conditions mean that **bacterial action** is slow, and therefore pollutants will remain for a long time before they decompose or dissipate.

Permafrost, which underlies the periglacial environment, is especially vulnerable to mining processes. Mining often drills through the permafrost to reach the minerals, and the heat generated may **melt** the permafrost, leading to further problems such as **subsidence** of the land.

Mining almost always produces **waste material** that builds up into hills on the land surface. In periglacial environments, this destroys the natural vegetation and changes the depth of the active zone of the annual freeze-thaw cycle of the permafrost.

New roads and settlements must usually be built to serve mines in remote locations to **overcome their isolation**. The **heat** from the offices and housing poses a further threat to the underlying permafrost, thawing it or extending the active zone deeper underground. This impact may continue long after the mine has closed, and examples can be seen

3.23 The main open-cut pit of the Alrosa diamond mine in Mirny, Russia. Mirny's diamond mine is still the world's largest diamond mine, and this pit is the world's second deepest excavated hole. The pit is 525 metres deep, its diameter is 1.2 kilometres and the length of the road that spirals from the top to the bottom of the pit is 7.7. kilometres long. This open-cut pit was replaced by underground pit mining for safety reasons in 2001 as the sides of the pit were collapsing. The scale of the pit can be seen when looking at the high rise housing on the horizon at the far side of the mine.

throughout the Russian Far East where abandoned towns dot the landscape next to abandoned mines.

Attracting workers to **remote** locations to work in mines is difficult. In the former Soviet Union, this problem was overcome by sending prisoners to work in the mines of Siberia and the Russian Far East. These mine-based prison camps, known as **gulags**, were infamous for their harsh conditions, but they were the basis of opening up the mineral resources in these hostile environments. Today, workers are attracted to remote mining sites in cold climates by the promise of high wages, well heated accommodation and generous vacation leave.

Resource nationalism occurs when governments or the population in general claim control over resources that are found in their territory. This can affect the mining activity in some periglacial environments, as we will see in the following case study.

QUESTION BANK 3C

1. *List the challenges of mineral extraction in cold climates under the headings (a) natural challenges, and (b) human challenges.*
2. *Given reasons and examples, say whether human challenges or natural challenges are more significant for mineral extraction in cold environments.*
3. *Do you think the opportunities are worth the challenges of mining in cold environments? Explain your answer.*

CASE STUDY
Diamond mining in Mirny, Russia

Mirny is located in Eastern Siberia, which is a large remote region that has a periglacial environment in the Asian part of Russia. Mirny's precise location is latitude 63°N, longitude 114°E, and its far northerly latitude means it is located just 450 kilometres south of the Arctic Circle.

Diamonds were discovered in Mirny in 1955 when a diamond-bearing rock called kimberlite was found. The mine was opened in 1957 despite the harsh, **difficult conditions**. The ground is frozen up to surface level for seven months per year, making excavation of the mine difficult.

The winter temperatures are so low that engine oil can freeze, car tyres may become so brittle that they break, and steel can shatter. Therefore, the miners used jet engines to thaw the permafrost in order to dig the mine, and where the ground was too hard for the jet engines, dynamite was used to blast away the ice and rocks to reach the underlying kimberlite. Unlike most diamond mines in the world, water could not be used when processing the kimberlite ore because it would freeze during most of the year, so special 'dry' techniques were especially developed to suit the cold environment.

During the few warmer months of the year, the ground in Mirny becomes waterlogged and turns to slush. Therefore, the land beside the mine pit was judged to be unsuitable for building the mine's diamond processing plant, and it had to be built about 30 kilometres from the mine.

Because of the mine's large size and remoteness, a **residential city** was built beside the pit to accommodate the miners, workers and managers. At first, the buildings were constructed using local timber, but as the city grew, high rise buildings were built using **concrete and steel poles** that were drilled down into the permafrost to provide a firm foundation.

3.24 The residential area beside the Mirny diamond mine. Older timber buildings are in the foreground, while newer high rise buildings with concrete and steel pole foundations are in the background.

Nonetheless, the **opportunities** to earn significant export income persuaded the government authorities to establish and expand the mine. By the 1960s the mine was producing about 2,000 kilograms of diamonds per year. About 80% of the diamonds were for industrial use, with the remaining 20% being of such high quality that they could be used for gems.

From 1957 to 2001, the mining operations were conducted using a huge open pit. The open pit (shown in figure 3.23) has a diameter of more than one kilometre and a depth of more than half a kilometre. The pit is so large that it has created its own **microclimate**, with especially cold air that has been chilled by the exposed permafrost. The cold air induces strong downdrafts, and so helicopters and airliners from the airstrip beside the pit are forbidden from flying over it.

As the open pit became larger and larger, it became dangerously unstable. **Landslips** began to occur more and more frequently as the sides of the pit

3.25 Landslips still occur in the open pit at Mirny.

3.26 The entrance to the new underground mine at Mirny, with associated processing plants.

became unstable, so an underground mine replaced the open pit in 2001. Today, the Mirny diamond mine is the largest diamond mine in Russia.

The Mirny diamond mine owes a great deal to **resource nationalism**. As the Cold War between the USSR and the USA escalated during the late 1940s following the end of World War II, the Soviet leader, Josef Stalin, developed an almost obsessive desire for the Soviet Union to be self-reliant. He was informed that parts of Siberia had kimberlite rocks that appeared very similar to diamond-producing areas in South Africa, which at the time was the world's largest diamond producer.

Stalin's priority was industrial diamonds, which are important in manufacturing processes such as drilling and precision cutting, but which are less valuable than gem diamonds. Diamonds were seen as an important resource that would help Soviet manufacturing to develop, thus advancing the country towards superpower status.

During the Soviet era, the mine was owned and managed by the government (like all enterprises in the USSR at the time). Towards the end of the Soviet era, some diamonds from Mirny were exported for gems to bring much needed foreign currency into the USSR. Following the breakup of the USSR at the end of 1991, the mine passed into private ownership, and today it is owned and operated by **Alrosa**, the world's largest diamond mining company (by volume). Alrosa therefore performs the role that the Soviet Government once played in protecting the country's resource ownership and management.

All the **infrastructure** in Mirny is owned by Alrosa, and everything that has been built since the breakup of the Soviet Union has been built by Alrosa. Alrosa builds and maintains the roads, the housing, and it even built the government's administrative headquarters in the middle of the town, right next to the 'Diamond Palace of Culture', also built by the company. Alrosa has even built a Russian Orthodox church with a school, and almost uniquely in Russia, it has provided a public park with a statue of Josef Stalin.

Apart from the cold climate, **isolation** and **remoteness** pose what perhaps are the biggest challenges to mining in Mirny. Only one road joins Mirny to a city, which is the road to Lensk, a distance of just over 200 kilometres. This journey is only possible in summer, and then only if it has not been raining. The road to Mirny was built in the late 1950s across the permafrost through thick forests, and hundreds of workers died in the hard conditions.

3.27 The 'Diamond Palace of Culture' in the centre of Mirny, one of many public buildings provided by Alrosa in the 'company town'.

3.28 The road from Mirny to Lensk, seen here at the outskirts of Mirny. The sealed surface stops after a few kilometres and continues unsealed to Lensk.

3.29 At the south-eastern edge of Mirny, where from Lensk enters the town, a memorial commemorates the heroic sacrifices of the workers who perished while building the long road in the very harsh weather conditions. The memorial commemorates the year 1957 when construction was finished.

3.30 In an effort to overcome Mirny's remoteness and isolation, Alrosa – the company that operates the mine – runs its own airline. Alrosa operates passenger flights to connect Mirny to relatively close destinations such as Irkutsk and Yakutsk, as well as long distance flights as far away as Moscow.

Because of the difficult driving conditions, almost no-one ever enters or leaves Mirny by car or truck. Flying is the usual means of transport in and out of Mirny to overcome the challenges of long distances and difficult weather conditions. Alrosa operates its own airline in an effort to relieve Mirny's isolation. Alrosa Airlines has a fleet of about 50 aircraft and helicopters. In addition to its passenger fleet, the airline operates several large freighters that are used to bring supplies into Mirny as well as transporting diamonds to the markets.

QUESTION BANK 3D

1. *Rank the following challenges in descending order of importance as they apply to diamond mining in Mirny: inaccessibility; permafrost; resource nationalism. Justify your ranking.*
2. *In what ways is diamond mining in Mirny (a) typical, and (b) unusual as an example of mining in cold climates?*

Mining opportunities and challenges in arid environments

In the same way that mineral resources are found in inaccessible parts of periglacial environments, they are also found in arid environments. For example, the mines in the deserts of north-west Australia are the world's largest producers of iron ore. Uranium is mined in the Sahel Desert (in Niger) and the Namib Desert (in Namibia). Much of the world's oil comes from the hot deserts of the world in countries such as Saudi Arabia, Kuwait, United Arab Emirates, Iran, Iraq, Qatar, Libya and Algeria.

The opportunities and challenges of mineral extraction parallel those in cold climates. Mining creates **opportunities** to open up poorly developed and under populated regions, to provide employment opportunities and to generate significant income from exports. There are, however, notable **challenges** that also parallel the problems faced in cold climates. In arid environments, these include the high cost of attracting workers to come and live in the desert environment, the high cost of protecting people and equipment from the extreme heat and aridity, the risk of intruding upon the rights of local indigenous peoples, and the danger of damaging the local ecosystems.

Mining has an impact on arid environments just as it does on periglacial environments. Like periglacial environments, arid ecosystems often take a long while to recover, in this case because the growth rates of plants are slowed by the arid conditions. Furthermore, as with cold climates, arid conditions mean that bacterial action is slow, and pollutants will remain for a long time before they decompose or dissipate.

Some of the **challenges** of mineral extraction in arid environments are unique to arid environments. For example, **open pit mining** is the most common way in which minerals are mined in arid environments. However, open pit mining can damage arid environments because it may expose dangerous and **toxic minerals** that have been covered for thousands or millions of years. For example, the exposed, crushed rocks may contain radioactive

3.31 An open-cut gold mine is blasted to break up rocks at the bottom of quarry, sending dust into the atmosphere. This is the Fimiston Open Pit, also known colloquially as the 'Super Pit', in Kalgoorlie, Western Australia. It is Australia's largest open cut gold mine, and it is surrounded by desert.

3.32 Another view of the Fimiston Open Pit in the desert of Kalgoorlie, Western Australia. Large trucks transport the gold ore for processing. The pit has a rectangular shape, and is 3.5 kilometres long, 1.5 kilometres wide and 570 metres deep.

3.33 An oblique aerial view showing part of the Fimiston Open Pit gold mine in Kalgoorlie, Western Australia. The large hills of exposed tailings can be seen clearly in this view.

3.34 The impact of mining in arid environments continues for decades after a mine has closed because ecosystem processes are so slow. This photo shows the Humberstone saltpetre refinery in the Atacama Desert of Chile. Saltpetre is potassium nitrate, and it was mined at Humberstone for use in fertiliser and gunpowder. This refinery operated to process the potassium nitrate from 1872 until 1960. Although it has been closed for more than half a century, the impact is still clearly visible.

elements, asbestos or metallic dust. If the ores are separated with water, the **tailings** (waste materials) may contain the same toxic materials, which can then leak into the underlying porous rock if it is not adequately controlled.

Some arid areas have heavily weathered rocks, and so **underground mining** poses the risk of tunnel collapse and land subsidence. Mines with large scale removal of rocks or vegetation are especially vulnerable. If water is used during the drilling, such as to cool the drill tip, there is a risk that toxic contaminants may leach into the surrounding rock strata, enter the groundwater and flow through to pollute the lake into which the groundwater flows.

QUESTION BANK 3E

1. *List the challenges of mineral extraction in arid environments that are the same as the challenges in cold environments.*

2. *Describe the challenges of mineral extraction in arid environments that are different from the challenges in cold environments.*

CASE STUDY
Iron ore mining in the Pilbara, Australia

The Pilbara region is an arid and semi-arid area in the north of Western Australia. The name 'Pilbara' is an adaptation of the local Aboriginal word *bilybara*, which means 'dry'. The Pilbara covers an area of half a million square kilometres, and within that expansive area lie some of the world's largest and richest **iron ore** deposits. Iron ore mining in the Pilbara is thus on a vastly different **scale** to diamond mining in Mirny, which is confined to an area of just a few square kilometres.

Iron ore was discovered in the Pilbara in 1938 by a group of government surveyors. At the time, **political factors** prevented the development of the resource deposits. In the prelude to World War II, the Australian Government imposed a ban on the export of iron ore in 1938 so that Australian iron ore could not be sent to Japan, then seen as a hostile country, to make steel.

The **export ban** was still in place in the 1950s, well after the end of World War II, because Australia's largest steel producing company, BHP, did not want competition from newly rebuilt Japanese steel mills. The ban on iron ore exports was finally lifted in 1960 to relieve Australia's severe foreign trade deficit. This cleared the way for the development of the Pilbara's huge iron ore deposits.

Construction of mines and their associated infrastructure began in the early 1960s, and the first mine opened in 1966 at Mount Tom Price (now known as Tom Price). More mines opened in rapid succession, and the distribution of mines today is shown in figure 3.35. It is estimated that the Pilbara contains iron ore reserves of 24 gigatonnes (24 billion tonnes). At the current rate of extraction, which is 325 million tonnes per year, iron ore in the Pilbara is expected to be exhausted around the middle of the 21st century (around 2050).

3.35 A map of the Pilbara region of Australia, showing iron ore mines and railways used for transporting iron ore.

The **economic opportunities** of mining iron ore in the Pilbara are very evident. The iron ore mines in the Pilbara are owned and operated by four large mining companies: BHP Billiton, Rio Tinto, Fortescue Metals Group and CITIC Pacific Mining. Today, iron ore exports from the Pilbara earn Australia about $US50 billion annually in export income, which is almost 20% of Australia's total annual income from exports. The largest export market for the iron ore is China, which accepts about two-thirds of the region's iron ore. Other significant export markets include Japan, South Korea and Taiwan.

On the other hand, the natural environment in the Pilbara has posed some **challenges** for mineral extraction. All the iron ore mines in the Pilbara are **open-cut pits**, which means the iron-rich mountains are cut away in a series of steps called **benches**. Typically, each bench is between 12 and 15 metres in height.

3.36 Mount Tom Price was the first iron ore mine to begin operations in the Pilbara after the iron ore export ban was lifted in 1960. The open-cut mine opened in 1966, and is operated today by Rio Tinto Iron Ore. Ore is extracted from the red hills in the middle of the photo and then processed on site before being transported by rail to the port of Dampier along the rail line in the foreground of the photo. It is a very capital intensive operation, and employs about 1,500 people to turn out its annual production of 28 million tonnes of iron ore.

3.37 The Mount Whaleback iron ore mine at Newman is the largest iron ore mine in the Pilbara, and the world's largest single open-cut mine. The pit measures 5.5 kilometres long and 2 kilometres wide, and comprises 28 step-like benches, each of which is between 12 and 15 metres high. The mine produces 38 million tonnes of iron ore annually, and the iron ore at Mount Whaleback is of very high quality, with some ores reaching 68.8% iron content.

Ironically, one of the biggest challenges in mining iron ore in the arid Pilbara region is **water**. As the land is cut away, the pits in many areas have extended into the groundwater zone. Much of the Pilbara lies on a water-bearing aquifer that is between 100 and 250 metres below the ground surface. For example, at the Mount Whaleback mine shown in photos on this page, the water table starts at Bench 18, this being the 18th level below the surface. However, ore is being extracted down to Bench 28, which is about 120 metres below the water table.

Water flows into the pit from the aquifer and springs, and if not addressed, the mine would quickly flood. To prevent this happening, and to maintain the mine operations, 46 million litres of water must be pumped out of the pit each week. This process is known as **dewatering** the mine pit.

3.39 Water is sprayed onto the roadway to settle dust at the Mount Whaleback mine.

3.38 One of the challenges of deep open-cut mining is keeping the mine dry as the pit fills with water from surrounding aquifers. This pump in the bottom of the Mount Whaleback mine pumps water into the channel that runs through the bottom of the mine.

This apparent problem is turned into an **opportunity**, as water is a valuable resource in a desert environment. After the water has been pumped out of the mine pit, it is piped into a holding pond, and then used in the processing plants, on the drill rigs and in the water carts that periodically spray water on the roadways to settle the dust. The water cannot be used for drinking as it is **hypersaline**, meaning it is three to four times more salty than seawater.

When open-cut pits in the Pilbara are exhausted at some time in the future, the plan is simply to abandon the pits and allow them to flood from the groundwater in the aquifers. This will create large artificial lakes, although the lakes will have no economic value because the water will be so saline.

The lakes are unlikely even to have a recreational use, as the towns that have been built to service the mines will also become abandoned once the mines are exhausted.

In the meantime, **rehabilitation** and **revegetation** of open-cut mining pits after mining is an ongoing environmental challenge. Slopes that have been over-steepened during mining need to be stabilised to prevent erosion, especially by rainwater as the area does receive rain at the edges of coastal tropical cyclones on rare occasions. All the mines in the Pilbara have environmental departments that co-ordinate revegetation operations, often in consultation with biologists and geographers from universities in Western Australia. Where **topsoil** is removed for mining, it is stored in stockpiles, and then returned to the site when mining has been completed. In general, the environmental officers try to minimise the time that topsoil is stored offsite because a quick return of topsoil increases the chances that seeds in the soil will remain healthy and will regenerate naturally. In general topsoil is stored for no more than two years, and at a depth of no more than two metres.

3.40 Stabilisation of steep slopes created during open-cut mining is needed to prevent erosion. Extensive erosion is evident on the side of this hill at Mount Whaleback, and native spinifex grasses are being planted in an effort to bind the loose soil to minimise further loss.

Slope management is another important aspect of mining rehabilitation. Slopes are usually limited to no more than 20° gradient, and the length of continuous slopes will be limited to minimise erosion. Vegetation is planted or seeded as quickly as possible to enable the slope to stabilise and to protect it from wind and water erosion. Windbreaks are sometimes erected to provide further protection from wind erosion.

Every iron ore mine in the Pilbara can be regarded as being **isolated** and **inaccessible**. The population of the entire Pilbara region is only about 45,000 people, almost all of whom are employees of the mining industry or provide services to the mining industry or its workers. In an attempt to overcome the isolation, the mining companies have all built **residential townships** near their mines to accommodate mine workers and their families.

These towns typically have a population of between 3,000 and 7,000 people, and provide all the services that would be expected in a town of that

3.41 An area of revegetation and rehabilitation beside the Mount Whaleback mine. The landscape is not entirely natural after this process, as the ground surface is left with tracks made by the trucks that brought in the soil and plant seeds.

3.42 The town of Newman was built by BHP Billiton to service the mine at Mount Whaleback, five kilometres away. Newman has a population of about 4,000 people. The green grass of the irrigated parks and yards contrasts with the red desert soils surrounding the town.

3.43 In an attempt to make the town of Newman environmentally sustainable, the company that built the town (BHP Billiton) has constructed solar powered lighting along the town's cycling and running track.

size — shops, school, post office, hotel, sports club and fields, supermarket, basic restaurants and fast food outlets, banks, and so on.

Mine workers who come to live in the **isolated towns** near the mines usually have to be attracted by large wages that are typically double the salaries of professional workers in large cities. Only a small proportion of mine workers bring their families to live in the towns near the mine because of the isolation and lack of 'big city services', choosing instead to follow the 'fly in, fly out' system offered by the mining companies.

Under the **'fly in, fly out'** system, mine workers typically work at the mine for two weeks, completing daily 12 hour shifts for 14 consecutive days, before then taking seven days off back in their home cities. In order to make working attractive in the isolated, harsh environment, the mining companies pay for the mine workers' flights to and from the mines at the beginning and end of each 'fly in, fly out' cycle.

Another facet of the mines' isolation and remoteness is their **distance** from the coastal ports through which the ore is shipped to their export markets. Two coastal ports are used to export iron ore from the Pilbara. Dampier is used by the 13 mines owned and operated by Rio Tinto, while Port Hedland is used by the other ten mines. Both Dampier and Port Hedland are located several hundred kilometres from the iron ore mines; in the case of the largest mine in the Pilbara (Mount Whaleback), the distance is 426 kilometres.

3.44 A BHP Billiton iron ore train arrives in Port Hedland after its 426 kilometre journey from Newman. Like all the BHP trains, this train is 2.6 kilometres long, and consists of 4 diesel locomotives, 248 ore cars and one driver. Each ore car holds 130 to 138 tonnes of iron ore, and the train has a total load of 33,000 tonnes. The train travels at 65 kilometres per hour, so the journey from Newman to Port Hedland takes about seven hours.

3.45 When the iron ore arrives at the port, it is unloaded from the trains and held in stockpiles before loading onto ships for export. This shows part of the Fortescue Metals Group stockpile at Port Hedland.

3.46 A bulk iron ore ship at the loading dock in Port Hedland.

As shown by figure 3.35, all iron ore mined in the Pilbara is transported from the mine to the ports by rail, which is the most efficient way to transport large volumes of freight across long distances overland. Once the iron ore reaches the port at Dampier or Port Hedland, it is stockpiled before being loaded on to bulk ore ships for transport to the market, usually a steelworks in East Asia.

QUESTION BANK 3F

1. *Rank the following challenges in descending order of importance as they apply to iron ore mining in the Pilbara: inaccessibility; availability of water; political factors. Justify your ranking.*
2. *In what ways is iron ore mining in the Pilbara (a) typical, and (b) unusual as an example of mining in arid environments?*

Opportunities and challenges for tourism in extreme environments

Tourism in extreme environments

From the very beginning of tourism, one of the great attractions of travel has been the **allure of different environments**. In the early 1900s, travel posters advertised pictures of exotic places, including extreme environments such as the mountains of Switzerland and the deserts of Egypt.

For some tourists, and perhaps a majority, it is not the extreme environment in itself that has the attraction, but rather sights that happen to be found there (such as the Pyramids in Egypt or the temples of Bhutan).

In recent years, greater **awareness** of environmental issues, together with the growth of **adventure tourism**, has attracted growing numbers of people to extreme environments, both arid and cold. This growth provides a range of both opportunities and challenges, both for tourists and for the destination environments.

Tourism in cold environments

Although tourism is very limited in polar and periglacial environments due to the extreme weather conditions, tourism is an important industry in many **high altitude areas**. The

3.47 Tourists at the Great Pyramids of Giza, near Cairo, Egypt. Most of the tourists who visit the Pyramids are more interested in the ancient historical structures of the Pyramids rather than the extreme desert environment in which they are found.

3.48 High altitude environments offer adventurous tourists many opportunities for physical activities in spectacular environments. These trekkers are walking through the glacial scenery of Vachkazhets Peak in Russia.

3.49 Mountain areas offer seasonally different opportunities for tourism. In winter, activities such as skiing attract tourists, whereas in summer, mountains attract tourists for sightseeing and walking. These tourists are admiring the Grand Teton Mountains in Wyoming, USA.

3.50 An example of the breathtaking mountain scenery that attracts tourists to Switzerland. These tourists are relaxing while admiring the view from the 4,158 metre high summit of Jungfrau.

attractions of mountainous areas for tourists include their scenic beauty, their fresh air, and the vast range of adventure activities that are possible, such as **skiing, trekking, mountain climbing, zip lining and parasailing.**

CASE STUDY
Tourism in the Swiss Alps

Tourism as an industry began in the **Swiss Alps**. In 1863, an English excursionist, Thomas Cook, conducted the first tour to the Jungfrau region of Switzerland from Britain, escorting a large group of 62 people in search of spectacular scenery. When Swiss tourism began, there were no trains or cable cars; part of the adventure was the hardship.

Thomas Cook's trip proved to be a great success, and numbers of tourists to Switzerland began to grow and have continued to grow ever since then. The total contribution of travel and tourism to Switzerland's GDP is approximately 7.5%, and rising. Currently, about nine million tourists visit Switzerland each year, with the main source countries being Germany, USA, UK , China and France.

Table 3.1
The Changing Nature of Tourism in Switzerland

Period	Type of Tourists	Means of Transport	Type of Accommodation	Main Areas Visited
1700s	Scientists interested in alpine plants and wildlife	Horse-drawn carriages	Local houses and inns	Alpine peaks
1800s	Climbers from Europe wanting to climb the main peaks	On foot, or horse-drawn carriages	Local houses and inns	Matterhorn, Eiger, and other alpine peaks
Late 1800s	Aristocrats taking advantage of clean air and water. People suffering from tuberculosis who were sent to health spas (sanatoria) to recover	Train	Large hotels	High altitude areas like St Moritz, famous for spa waters
1920s	Higher socio-economic groups for skiing	Train	Large hotels with access to a variety of skiing areas	New' alpine areas such as Wengen, Mürren and Gstaad
1950s	Most socio-economic groups, for winter and summer holidays	Car, train and air	Smaller hotels and self-catering apartments	Location varies with the time of year. Newer skiing areas in winter and lakeside resorts or walking areas in summer
2000s	Family groups and baby-boomers, with increasing emphasis on domestic tourism	Car, train and air	Hotels, B&Bs, self-catering apartments, wellness destinations.	Newer family-oriented activities such as fun parks, regional and national parks

Source: Adapted and updated from Davis and Flint (1986) p.230

3.51 Waterfalls cascade down the sheer slopes of a glacial valley at Lauterbrunnen, providing the type of spectacular scenery that attracts tourists to the Bernese Oberland (Bernese Highlands) of Switzerland.

3.52 Zip lining is an example of the newer tourist attractions that have been introduced to appeal to younger travellers. This zip line at First offers downhill rides of over 800 metres at

3.53 Trekking in the Swiss Alps offers tourists many opportunities to experience the spectacular landforms of this glacial mountain environment, but there are also hazards when walking in a mountain environment.

While Germans have traditionally been the major source of tourists, the number of tourists from all European countries has decreased in recent years due to the strength of the Swiss franc against the Euro. However, the number of Chinese tourists has increased rapidly over the same time period, driven by increasing wealth of many Chinese, as well as a new interest in winter sports, probably due to the impending Winter Olympics to be hosted by Beijing in 2022.

The **nature of Swiss tourism** has changed over the years, as table 3.1 shows, although most tourists are still attracted by the spectacular scenery of soaring snow-capped mountains, clear alpine lakes, ice-blue glaciers and picturesque flower-decked villages.

Switzerland's **tourism infrastructure** is very well-developed, with comfortable (though often expensive) accommodation, good all-weather roads, extensive transport facilities and well-marked multi-purpose trails with information for walkers, hikers, cyclists, mountain-bikers, canoeists and skaters. Apart from the **attractions** of skiing, snowboarding and tobogganing, many outdoor **activities** have been developed which broaden the appeal of Switzerland as a tourist destination for both local and foreign holidaymakers. Outdoor activities include paragliding, ropes adventure courses, ziplining, hiking trails and canyoning.

Tourism brings both **opportunities** and **challenges** to Switzerland. It certainly generates a great deal of **wealth** for the country, which is invested back into

3.54 Hotels near the railway station in the centre of Grindelwald are examples of tourism infrastructure.

3.55 Fences on the slopes above the Lauterbrunnen Valley are designed to protect tourist settlements below from the hazards of snow avalanches.

Switzerland's tourism infrastructure, benefiting both residents and tourists. Travel and tourism generate approximately 4% of total **employment** in industries directly supported by the travel industry such as accommodation facilities, travel agents, airlines, restaurants and leisure activities. An additional contribution to both employment and the GDP comes from the wider effects of tourism and travel on investment and increased spending on many goods and services.

Rising tourism also brings **disadvantages** such as increased prices for local residents, environmental destruction and the potential for pollution from increased waste. Employment in tourist facilities tends to be seasonal and often requires few skills. As Swiss people have been reluctant to fill these lower-skilled and lower-paid jobs in hotels and restaurants, employers often look to immigrant workers. Although foreigners make up approximately 23% of the population in Switzerland, at least 40% of the workers in the hospitality industry are non-Swiss.

Climate change presents a growing challenge to the tourism industry in Switzerland. There are potential impacts on maintaining buildings, roads and rail services as well as such impacts as the increased possibility of avalanches, and the impact on alpine ecosystems by rising temperatures.

For tourists, the most obvious impact is on **snow cover**. Tourists coming in winter expect to have snow, but snow cover is becoming less reliable due to global warming. In an effort to ensure snow cover, many resorts, especially those located at lower levels, use artificial snow-cannons. While

3.56 Ice and snow cover in alpine areas of Switzerland is shrinking due to climate change, both in summer (seen here) and in winter (when skiing is at its peak). The Grindelwald Glacier is still visible at the top of the photo, but has retreated two kilometres since 1973, exposing the bare slopes below.

artificial snow is used on only about 10% of Swiss slopes, environmental groups are concerned about the potential impact on the environment. The snow-cannons use vast amounts of water and energy to create snow. The water used must be taken from reservoirs and streams, which impacts water supply for other uses, and the extra water may damage underlying soil and plants. Moreover, to allow snow to be made at a higher temperature, a chemical additive is used which may also affect the alpine vegetation.

A further challenge of increased tourism in alpine areas is the potential damage to the **fragile alpine environment**. Highland areas are very slow to recover from damage caused by **trampling** or **littering**.

In an effort to conserve and protect the environment, various approaches have been taken. For example, in the Matterhorn skiing region, **environmental management planning** includes segregated conservation areas for forests and wildlife, an extensive information campaign to inform all visitors and locals of the ecological interrelationships and the sensitivity of wildlife, replanting of damaged areas and environmental monitoring of all building works. Elsewhere, **education programs** inform and encourage responsible use of alpine areas. The provision of public transport, linked with SwitzerlandMobility's networks of hiking, canoeing and walking trails, further encourages responsible use of the environment.

CASE STUDY
Tourism in the Himalayas of Nepal

In contrast to Switzerland's long history of tourism, Nepal was a **closed country** until 1952, with no outsiders being permitted to enter the country. Since then, the number of tourists has grown steadily – 4,017 tourists in 1960, 46,000 in 1970, 223,000 in 1986, 363,000 in 1995, 500,000 in 2008 (despite political instability at the time), reaching a peak of 803,000 in 2012. Since that time, tourism numbers have fallen slightly due to a combination of political instability and severe earthquakes.

In **economic** terms, Nepal is a much poorer country than Switzerland. Nepal's GDP, which measures the total amount of wealth generated each year in

3.57 Tourists are attracted to Nepal's mountain scenery, but ironically this means hotels and tourist facilities are often built in places that can spoil the natural beauty of the landscape. This hotel overlooks the Himalayas from the hill town of Nagarkot.

the national economy, is less than one-thirtieth the size of Switzerland's GDP. Nepal spends 250 times less on health care than Switzerland, and its people's average incomes are one-fortieth the level of incomes in Switzerland.

Like Switzerland, Nepal offers spectacular **scenery** and many **physical activities** for tourists. For mountain climbers, Nepal offers some of the world's most challenging mountains, including the world's highest peak, Mount Everest. Moreover, Nepal offers visitors a rich traditional **culture** that is unique in the world. On the negative side, tourism **infrastructure** in Nepal is poorly developed, with limited accommodation, poor roads and somewhat uncomfortable conditions. In that context, tourism provides great **opportunities** for Nepal to earn

3.58 Tourism infrastructure is poorly developed in the Himalayas of Nepal. The small open-fronted building with the white wall is a restaurant for passing trekkers beside a track through the mountains to the east of Kathmandu.

much needed foreign income, which could be used to develop infrastructure and provide services for the population. In 2014, Nepal's travel and tourism sector directly generated over 487,000 jobs, or 3.5% of total **employment** in the country.

The **financial challenge** for Nepal is that earnings from tourism can fluctuate widely as a result of economic recessions, political disturbances and natural disasters, all of which Nepal has experienced in the last few years. Nonetheless, the importance of tourism to the economy is expected to grow.

When Nepal first opened for tourism, a significant proportion of the tourists were **hippies** who came either in search of spiritual enlightenment from Hindu gurus (teachers) and sadhus (holy men). Other early visitors were young, adventurous travellers driving overland from Britain to South-East Asia along the so-called 'hippie trail' through Turkey, Iran, Afghanistan, India and Thailand. Today, 17% of tourists come from India, 15% from China and 6% from the USA.

During the period of the 1960s, Kathmandu became known as a centre of drug use, chiefly around the area known as Freak Street. However, the hippie days have long since passed in Nepal, and of the tourists who visit Nepal in 2014, just over 50% came for **sightseeing**. While holiday pleasure is the key purpose for most tourists, 13% of tourist arrivals came for **religious pilgrimages**, 12% for **trekking** and **mountaineering**, 3% for **business**, 2% for **conventions** and **conferences**, and just over 16% for other purposes.

Sightseeing and trekking in Nepal are concentrated in eight designated national parks and two conservation areas spanning a wide variety of ecosystems. **Trekking** is controlled to protect the environment as much as possible. Tourists can organise a trek through an agency (an organised trek), by hiring their own guides and porters (a tea shop trek) or by doing the trek themselves unaccompanied (a budget trek).

Trekking fees are imposed to **control numbers**, and treks to environmentally sensitive mountain areas such as Lomanthang and Mustang cost over US $500 per day. Permits for expeditions to different peaks are issued by the Nepal Mountaineering Association, and are limited to approximately 1,200 treks annually. The cost to climb Mount Everest starts at about US$35,000, which includes the mountain permit of about US$11,000 plus about US $24,000 for equipment hire and the team of Sherpa porters, cooks and guides that are required for an ascent. Some climbers report that the cost to climb Mount Everest amounted to US$85,000 per person.

3.59 Climbers on the ascent of Mount Everest.

Tourism in Nepal brings both **opportunities** and **challenges**. The main benefit is **economic** – in 2014, tourism provided 4.3% of Nepal's GDP and 15% of its total foreign exchange earnings. This income generates some **employment** and provides revenue that could be used to develop Nepal's scant **infrastructure**.

The lack of infrastructure imposes a significant **challenge** as it **limits the growth** of tourism. **Electricity** is not widely available, and there are frequent power outages. While there are strong opportunities to develop hydro-electric power, the potential has not been realised due to a lack of agreement between the Nepal Electric Authority and the government. Shortages and frequent power outages impose significant costs on businesses and limit further development by business and tourism sectors.

Poor **transport** infrastructure further limits development. While the physical beauty of Nepal is an asset for tourism, the large changes in elevation, and the harsh climatic conditions also present a challenge for provision and maintenance of roads and electricity lines.

Another **challenge** for the tourism sector is to attract tourists from regions beyond South Asia.

3.60 Transport infrastructure is poorly developed in Nepal. This bus is carrying passengers between villages in the Kathmandu Valley.

The current **marketing strategy** relies on trade shows, which are attended by companies involved in tourism. For the economic benefits of tourism to grow, there is a need to attract higher spending tourists from such countries as the USA, UK, Germany and France.

New product **innovations**, such as **ecotourism** and **adventure tourism**, could help tourism to grow. Further growth could come if higher quality **facilities** for tourists, including better connectivity/ access, better quality hotels with a higher carrying capacity, and improved safety standards could be provided. Currently, neither the government nor the private sector is doing enough to increase the appeal of Nepal to tourists. While Nepal's highly diverse culture could appeal to a much broader spectrum of tourists, current potential for growth is limited by a **lack of education** and a lack of understanding of the needs of the tourism market.

3.61 Signs on a building in Boudhanath advertise some of the activities available for tourists.

Tourism also generates **environmental** and **social problems**. The sudden influx of large numbers of tourists into Nepal's traditional society brought about big social changes in Nepal. Tourists bring new ideas, new modes of dress and new goods with them from elsewhere in the world. In an effort to earn money from tourists, local Nepalese people sometimes compromise their own culture to make tourists feel more at home. The effects of this can be seen in the streets of many towns in Nepal where tourists travel.

The most significant problems caused by tourism affect Nepal's **biophysical environment**. In high mountains where the temperature is often cold, **rubbish** left behind by trekkers does not break down for decades. About 90% of trekkers in Nepal use just three trekking areas, and this places great strains on the fragile local environment.

More than 4,000 climbers from over 20 countries have climbed to the summit of **Mount Everes**t since the first ascent in 1953. Most of these climbs were made after 2000, and rubbish from these climbs still litters the routes to the top of the mountain. Waste consists of thousands of oxygen cylinders, old tents, ropes, human remains and all sorts of rubbish. Even faeces left behind by climbers will still be intact after many decades in the alpine air if it is not buried. In recent years this problem has become even worse as trekkers have begun taking food in plastic as well as metal containers.

It is estimated that there are some 600 tonnes of garbage lying on Mount Everest alone, and each expedition leaves an additional 400 to 500 kilograms of waste. The increasing amount of rubbish that is littering the environment poses a severe threat to the fragile **biodiversity** and ecosystem of the region. While there is a growing concern for the need to address the environmental problem of hazardous waste, prior to 2012 there were no recycling or waste management facilities in the region at all. There was also a lack of local experience or expertise to manage waste disposal in an environmentally sustainable way.

In an effort to keep the mountain environments clean, the Nepalese Government requires US$4,000 **expedition deposits** from climbers, refundable upon return to Kathmandu provided all the group's rubbish and equipment has been removed from the

3.62 Rubbish left behind by climbers on Mount Everest.

mountain. A Nepalese initiative, the Sagarmantha Pollution Control Committee (SPCC) began to **educate** tourists and local people about the importance of not leaving rubbish in alpine areas. Nonetheless, regulations regarding rubbish removal remain poorly enforced, resulting in high pollution of tourism sites.

In response to the problem of the vast amounts of rubbish on Mount Everest, a major international effort called **Saving Mount Everest** (SME) was instituted. In a major rubbish removal operation as part of an organised expedition in 2011, more than eight tonnes of rubbish were brought down from the mountain. More importantly, the SME project brought together local and foreign groups (such as EcoHimal, the SPCC, the Everest Summiteers Association and the Himalayan Club), thus making contact with the wider community. In the process, SME laid the foundation for the first sustainable waste management program on Mount Everest.

SME has now installed **permanent infrastructure**, including 43 waste containers, with separate sections for burnable and non-burnable materials, three permanent toilets, 15 waste plants, 1,300 reusable cloth bags to minimise the need for plastic bags, and one waste management centre. **Jobs** for the local community have been created, generating **income** from waste. Local people have been taught how to melt aluminium and other metals, and create items for use or for sale to tourists.

Rubbish is not the only cause of environmental damage. Trekkers need **fire** for heating and cooking, and this leads to the cutting down of scarce timber. **Fuelwood** is Nepal's main source of energy, and tourists are now competing with local people for the dwindling supply. The lodges in one small village on the Annapurna trekking route consume one hectare of virgin rhododendron forest each year to serve the needs of the trekkers. Each trekker consumes six to seven kilograms of firewood per day. This forces the local people to go further and further away in search of fuelwood.

These problems have led to calls for '**Green Trekking**', where tourists are made more aware of the damage they can cause. Some suggestions made to tourists to **reduce environmental impact** have included:

- trekking with a guide who uses kerosene instead of timber for fuel; this costs more but leaves the forests intact;
- co-ordinating menu and eating times with other trekkers to reduce the use of fuel;
- dressing warmly to reduce the need for heating at night;
- burning paper wastes and burying biodegradable wastes (food wastes and excreta);
- urinating and defecating at least 30 metres away from any water source, and if possible, burning toilet paper and carrying out excreta in plastic bags;
- bathing away from drinking sources and using biodegradable soap;
- avoiding buying hot water from a lodge that does not have a hydro-electric heating system; and
- keeping non-biodegradable wastes to a minimum, especially batteries.

QUESTION BANK 3G

1. *Giving reasons, explain why tourism is, on balance, more beneficial or more detrimental for Switzerland.*
2. *Giving reasons, explain why tourism is, on balance, more beneficial or more detrimental for Nepal.*
3. *Explain why the impact of tourism differs in Switzerland and Nepal.*

Tourism in arid environments

The **scale of tourism** is limited in arid and semi-arid environments due to the uncomfortable weather conditions and the limited quantities of water available to service large numbers of visitors. Nonetheless, despite their low comfort levels and inaccessibility, desert areas are becoming more

3.63 Tourists explore the ruins of Petra, an archeological site in the deserts of south-west Jordan. Dating back to 300BC, the ruins include temples, tombs and other facilities carved into and excavated from the sandstone cliffs.

popular destinations for adventurous tourists.

For some tourists, the attractions focus on **historical** and **archeological sites**, such as Persepolis in Iran, Palmyra in Syria and Petra in Jordan. For others, the attractions focus on **activities** such as camel riding, dune bashing in 4-wheel drive vehicles, dune surfing and hot air ballooning. For some other tourists, the attractions may be exploring the **traditional cultures** that are still found in many arid and semi-arid environments. For still other tourists, the attraction will be the spectacular and unusual **scenery** found in deserts such as the immense sand dunes at Sossusvlei in the Namib Desert, the world's largest monolith at Uluru in Australia, or the grand scale of the Grand Canyon in the USA.

3.64 Quad biking in the dunes of the Namib Desert, Namibia.

3.66 The Roman ruins of Apamea in the desert of central Syria.

3.65 Isolated and inaccessible areas in arid environments provide the homes of many indigenous groups with intact traditional cultures. For tourists who are willing to make the arduous journey into these remote areas, the reward may be contact with the people of these traditional cultural groups. These masked men are from the Dogon tribe on the Bandiagara Escarpment near the border of Mali with Burkina Faso.

3.67 The scenery of the Grand Canyon in Arizona (USA) attracts over four and a half million tourists annually. Although some tourists come simply for sightseeing, a substantial number engage in activities such as hiking, kayaking, rafting, mule riding, and photography.

3.68 Tourist infrastructure is poorly developed in the arid environments of many poorer countries. This complex in the Sahel Desert of eastern Mali offers tours and guide services.

For the residents of arid environments, tourism presents many **opportunities**, especially in economically poorer countries. Tourism provides the possibility of earning **income** and providing **employment** in fields such as guides, drivers, hotel workers and park rangers. On the other hand, these financial benefits may be offset by the high cost of providing the wants and needs of foreign tourists, such as air conditioning, running water, electric lighting and perhaps even wifi access.

Tourism may also provide opportunities to preserve **environmental quality** and **traditional cultures**. Many arid and semi-areas suffer from poor farming practices and over-grazing of livestock, so in areas where tourism reduces dependence on marginal agriculture and workers move from farming to the tourism industry, the pressure on scarce marginal land may be reduced. Similarly, tourism may place an economic value on traditional cultures, encouraging local people to preserve and protect their culture rather than simply abandoning traditions in the name of modernisation. In this way, traditional languages, dances and artistic crafts that were declining may be preserved.

3.69 Tourists trek into a fixed campsite at Mowani in the Namib Desert of Namibia.

At its best, tourism may promote **intercultural understanding**. By bringing tourists and local residents together, friendships, respect and tolerance may be established that would have been impossible without personal contact.

CASE STUDY
Tourism in the Nile Valley of Egypt

Tourism is an important part of Egypt's **economy**, earning more than 10% of the country's GDP, employing about 12% of the national workforce, and earning about 14% of the country's foreign income. Over 90% of Egypt's tourism industry is

3.70 In an effort to attract tourists, sound-and-light shows are performed at the Great Pyramids and Sphinx on many evenings.

3.71 Tourists visiting the Great Pyramids of Giza.

3.72 The Stepped Pyramid of Djoser at Saqqara is the oldest pyramid in Egypt.

3.73 The Bent Pyramid at Dahshur was the first smooth-faced pyramid in Egypt.

located along the banks of the **Nile River**, which flows from the south to the north through the deserts of Egypt.

Tourism in Egypt's Nile Valley is largely based on **historical** and **cultural artifacts**. The Nile Valley provides tourists with the opportunity to visit a vast range of ancient ruins, monuments and temples. Egypt's dry, desert climate has helped **preserve** these ancient structures by minimising water-based mechanical and chemical weathering.

Perhaps the most famous of Egypt's ancient structures are the **pyramids** of **Giza**, on the outskirts of Cairo, Egypt's capital city. Like all Egypt's pyramids, the pyramids at Giza were built as **tombs** to house the bodies of the pharaohs, Egypt's rulers in ancient times. The pyramids at Giza were built between 2589BC and 2504BC.

3.74 The Temples of Karnak were built over a period of 1500 years on the east bank of the Nile River, a few kilometres from the centre of Luxor. They cover an area of two square kilometres. The largest structure (shown here) is the Temple of Arun, which it is claimed was the largest religious building ever constructed.

Although the pyramids at Giza are the most famous of Egypt's pyramids, they are only three of the 130 or so pyramids in the Nile Valley. The oldest pyramid is located a little south of Giza at **Saqqara**, and is known as the Stepped Pyramid of Djoser. Built in 2670BC the pyramid was part of the ancient city of Memphis, which was the world's largest city at the time.

The Bent Pyramid at **Dahshur** is regarded as an especially important pyramid because it was the first of Egypt's pyramids that was designed from the outset to have smooth faces rather than the stepped faces of earlier pyramids. It was built

3.75 The Great Temple of Abu Simbel is carved into mountainside, and is fronted by four 20 metre high sitting statues of the Pharaoh Ramses II at various stages of his life, surrounded by smaller statues of his mother, some of his favourite wives and a few of his 110 children.

3.76 Sightseeing in a traditional sailboat, known as a felucca, on the Nile River at Aswan.

3.77 Several large cruise vessels are shown here moored at Aswan on the Nile River.

between 2612BC and 2589BC. The Bent Pyramid was inaccessible to tourists until 1996 as it was located within a military base up to that time.

The Nile Valley contains many other ancient structures that attract large numbers of tourists. The city of **Luxor**, situated 500 kilometres south of Cairo on the banks of the Nile, is the site of the ancient city of Thebes, which flourished about 4,000 years ago. The ruins of Thebes represent a major tourist attraction, as it was the world's largest city between 1500BC and 900BC.

Further south, near Egypt's southern border with Sudan, lies the ancient archeological site of **Abu Simbel**. Abu Simbel comprises two huge temples cut from the rock of the mountainside in the 13th century BC. The original site of Abu Simbel was flooded in the early 1970s when the High Aswan Dam was constructed, creating one of the world's largest artificial lakes (Lake Nasser). The temples of Abu Simbel were therefore disassembled, stone by stone, and rebuilt on higher land beside Lake Nasser before the lake began to fill.

Although historical and cultural sites are the main attractions for tourists in the Nile Valley, travellers also participate in activities such as camel riding and sightseeing by boat on the river. Nile River cruises are especially popular, and these range in scale from small boat trips lasting a couple of hours up to cruises of several days in large vessels that resemble luxurious floating hotels.

The quality of tourism **infrastructure** therefore varies considerably in the Nile Valley. Hotels range from very basic **locally-owned** guesthouses

3.78 The quality of tourism infrastructure varies in the Nile Valley. Although the region has many luxurious hotels built to international standards, the region also has numerous very basic facilities for budget travellers, such as this small hotel near Aswan.

3.79 In contrast to the hotel shown in figure 3.78, the brown multi-storey building in this view shows the Hilton Hotel in Cairo, one of several internationally-owned hotels on the banks of the Nile River.

through to multi-storey hotels with international standards of luxury that are generally owned and operated by **multinational** hotel corporations such as Sofitel, Intercontinental, Four Seasons, Hilton, Hyatt and Marriott. Very few foreign workers are employed in the Nile Valley tourism industry, and even large international hotels employ local residents for almost all positions.

The backbone of Egypt's **transport** system is the railway network, and many tourists travel between population centres by train. Most trains are air conditioned, and they are said to be reliable, cheap and efficient. Air travel is also possible between the Nile Valley centres of Cairo, Luxor and Aswan, although most tourists prefer to travel by train.

The biggest **challenge** to tourism in recent years has been **political instability** in Egypt. A political revolution in 2011 resulted in a 37% drop in foreign tourists coming to Egypt, the number of arrivals falling from 14 million to 9 million in that year. Terrorist attacks in Cairo and elsewhere in Egypt have caused tourist numbers to remain low, and while this has meant cheaper travel opportunities for foreigners wanting to visit Egypt, it has caused immense hardship for local people working in industries that depend on tourism, including accommodation, rail and air transport, guide services and taxis.

CASE STUDY
Tourism in Etosha National Park, Namibia

Etosha National Park is centred on a large **salt pan** in central Namibia — the word 'etosha' means 'Great White Place'. The park is located about 400 kilometres north of Namibia's capital city, Windhoek. The park provides a good example of how **sustainable tourism** practices in a sensitive, extreme environment can protect environmental quality and integrity.

Its precise location of latitude 19°S, longitude 16°W places the park in a **semi-arid environment**. Little or no rain is received during the hot summer months, but during the cooler winter months, 30mm to 50mm of rain may fall in a month. Average annual rainfall is quite low, being just 265mm per annum.

3.80 Part of Lake Etosha, the huge salt pan that defines Etosha National Park.

In summer (January and February), average daily temperatures exceed 40°C, but in winter (June to August), daily maximums are a more comfortable 25°C.

The salt pan covers about 4,730 square kilometres, and at its widest point it is about 110 kilometres

3.81 Despite the aridity of Etosha, zebras are plentiful.

3.82 Elephants at a water hole in Etosha National Park.

long by 60 kilometres wide. The pan is usually dry, although it does flood after heavy rains swell its two tributary rivers, the Ekuma and Oshigambo, which flow into Etosha from the north.

The **national park**, which covers an area of 22,912 square kilometres, includes the salt pan and its surrounding lands. When the national park was first established in 1907, it covered an area of about 80,000 square kilometres, but several reductions resulted in its present smaller size. Because the salt pan represents a source of moisture, the park has an abundance of wildlife, with 114 mammal species, 340 bird species, 16 species of reptiles and amphibians, and huge numbers of insects. The park contains many well developed water holes that enable visitors to see lions, zebras, giraffes, elephants, springboks, rhinoceros, warthogs, jackals, hyena, wildebeest and kudu, among many other types of animals, with relative ease.

3.83 Animals are attracted to the small supply of fresh water at Okondeka waterhole on the western edge of the salt pan, Etosha National Park.

Because of the area's dry climate, **water usage** is an important aspect of managing the park sustainably. Some animals have **adapted** to the dry climate by developing the ability to obtain the moisture they need from their food. These animals are therefore mostly independent of surface water for their survival. However, most animals and birds in the park, and especially the larger species, must have **access to drinking water** every day. The feeding range of these species is limited to a distance within one day's walk of a water source.

The Etosha salt pan provides no drinkable water. The salt pan only holds water during a few months

3.84 Tourists observe wildlife at a waterhole in the late afternoon sunlight behind safety fences at the Okaukuejo campsite, Etosha National Park.

of the wettest years, and even then, the water is twice as **saline** as sea water, and therefore not drinkable. Fortunately, there are perennial **natural springs** and **water holes** in the lands on the southern rim of the salt pan, and these explain the abundance of wildlife in the park in spite of the aridity.

Etosha's wildlife is its major **primary tourism resource**, attracting about 200,000 visitors each year. The **revenue** from tourism is very important to Namibia's development. Government statistics suggest that the income from tourism in the country's national parks exceeds $US150 million per annum, while the annual cost of maintaining and running the parks is only $US5 million.

Visitor numbers are controlled in two major ways. First, a daily entry fee of $5.60 per person plus 70 cents per vehicle is charged at the entry gate to the park. Second, and more significantly, the amount

3.85 A typical road in Etosha National Park.

3.86 In the dry, semi-arid environment of Etosha National Park, animals always try to remain within range of water supplies. In the evenings, animals are attracted to the water holes, so they become popular places at that time for tourists to observe wildlife. For that reason, the accommodation cabins in the park are all situated beside water holes.

of **accommodation (secondary tourism resource)** within the park is controlled. There are three camps run by NWR (Namibia Wildlife Resorts), a **government** (Ministry of Environment and Tourism) agency that operates campsites throughout Namibia. The three **campsites** — Namutoni, Halali and Okaukuejo — are spaced at intervals of about 70 kilometres along the southern side of the salt pan to **disperse the concentration** of tourists. All visitors must stay in the designated camps, which are within fenced compounds to keep out dangerous animals after dark. Camping or staying outside the compounds is strictly forbidden for safety reasons. Each of the campsites has a floodlit water hole for nocturnal wildlife viewing.

In order to **minimise the impact** of tourists on the park environment, strict enforcement of rules and regulations is carried out. The most common tourist offences are speeding, off-road driving, littering and getting out of vehicles at non-designated areas. Driving speeds within the park are limited to 50 kilometres per hour to protect the wildlife, and park officials are purchasing speed measuring equipment to enforce this limit more strictly.

Other regulations are enforced in Etosha to control human impact on the environment. For example, access to the western part of the park is restricted to registered Namibian tour operators; individual visitors are not allowed to enter this section of the park. Weapons such as firearms, air guns and catapults are prohibited. Furthermore, there is a total prohibition on removing wildlife or plants from the National Park area. Making noise of any kind at any water hole is forbidden between the hours of 9:30 pm and 6:00 am.

QUESTION BANK 3H

1. *Compare and contrast the attractions for tourists in the Nile Valley and Etosha National Park.*
2. *Does tourism have a greater impact in the Nile Valley or in Etosha National Park? Give reasons to support your answer, emphasising whether the impacts are positive or negative.*
3. *Contrast the involvement of global and local stakeholders in tourism in the two areas: the Nile Valley and Etosha National Park.*
4. *To what extent are the patterns of tourism in the Nile Valley and Etosha National Park influenced by aridity?*

Chapter 4 Extreme environment futures

4.1 A girl carries a bucket to collect water, which is becoming scarcer as desertification affects this area of the Sahel Desert to the north of Mopti in central Mali.

Desertification

Acceleration, consequences and management of desertification

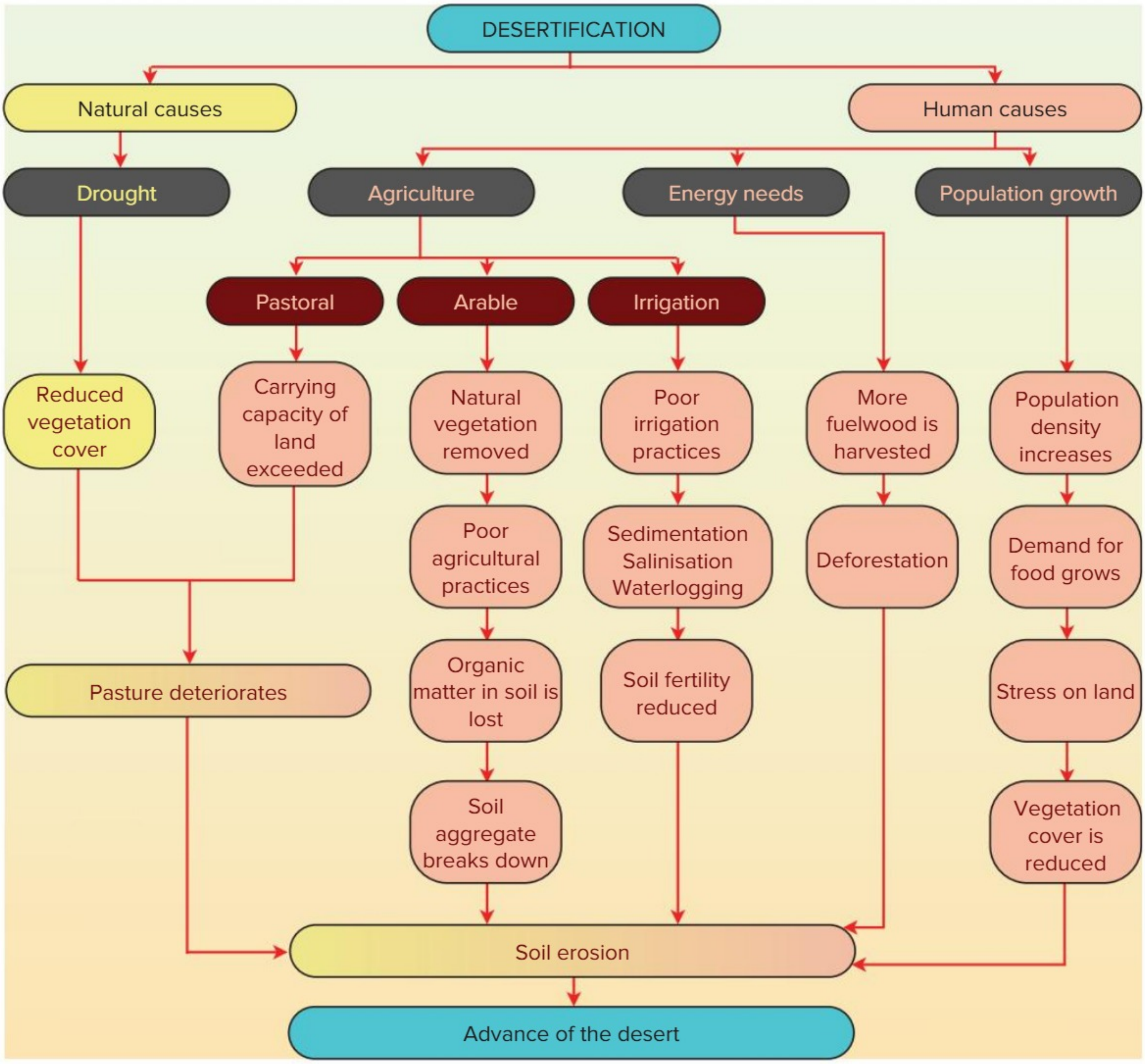
As we saw in chapter 1, desertification can be caused by a combination of natural factors. The negative effects of these natural forces may be amplified by **human actions**. As shown in figure 4.2, human activities that can cause or aggravate desertification fit into three groups: agriculture, energy needs, and population growth.

Many of the areas experiencing natural desertification are poorer countries with rapid **increases in population**, especially in Sub-Saharan Africa and the Middle East. In such societies, where population growth increases the demand for food, people's lives and welfare depend directly on the amount and quality of food that can be produced. Drier conditions reduce the productivity of farmland. This in turn places **pressure on farmers** to produce more and more food within an environment that is making food production increasingly difficult.

If the **demand for food** is increasing (due to population growth), but the **supply of food** is dwindling (due to increasing aridity), it may seem like a rational decision for a farmer to decide to farm the land even more intensively to produce more food. Arable farmers will be tempted to plant crops too densely in their small plots of land, while livestock herders will be tempted to increase the number of animals per square kilometre.

However, farming the land more intensively and increasing livestock numbers accelerates the process of desertification. This can lead to a **spiral effect** in which desertification increases the pressure on farmers to produce more food, but more intensive farming aggravates desertification, which increases the pressure to produce more food, which further aggravates desertification, and so on.

Irrigation in semi-arid areas can aggravate desertification in a different manner. When irrigation is poorly managed, there is a danger that salts in the underlying soil may be liberated and rise to the soil surface. This process of **salinisation** makes the soil unusable for cultivation because the salt clogs the pores in the roots of the plants as they try to draw water from the soil.



4.2 The natural and human causes of desertification.

4.3 Placing too many cattle on marginal semi-arid farmlands is a cause of desertification. This image shows animals grazing on the edge of the Sahel Desert near a small water well on the outskirts of Bobo Dioulasso, Burkina Faso.

4.4 These sheep are being herded in the Haraz Mountains of Yemen, a region that is threatened by desertification. Prolonged drought has removed almost all the edible grass, and unless the farmer reduces her stock numbers, it is inevitable that the remaining animals will become emaciated and probably die.

Poor agricultural practices in all three types of farming — arable, livestock and irrigation — have one common factor; they all lead to deterioration and erosion of the **soil**. Soil deterioration and erosion leads to another **spiral effect**. Soil degradation reduces the quality and quantity of plants, fewer and poorer plants lead to further soil erosion and deterioration, which in turn diminishes vegetation, and so the process continues, thus aggravating desertification.

Population growth not only increases the demand for food, but energy needs also grow with an expanding population. In many of the poorer countries threatened by desertification, the main source of energy is **fuelwood**. This is typically

4.5 Women carry fuelwood to a small market near Addis Ababa, Ethiopia. The fuelwood has been gathered in a nearby semi-arid area threatened by desertification. The area is under heavy pressure because it is situated near Addis Ababa, which is a major population centre.

gathered by women who often walk long distances to gather and cut wood that is suitable for burning before carrying it in heavy bundles to their homes or to markets. As the demand for fuelwood grows, **deforestation** becomes a significant environmental threat. Like poor agricultural practices, deforestation also leads to soil erosion, thus starting a spiral effect into desertification.

Having identified the desertification challenges in semi-arid environments, it is important to remember that some positive changes are also happening. One example is the small country of **Eritrea**, located on the Red Sea coast to the north of Ethiopia. Eritrea is one of the world's poorest countries, so its people are not well equipped to cope with the twin pressures of rising population and increasing aridity.

4.6 Animals forage for scarce food in the arid lands near Massawa in northern Eritrea.

Eritrea is threatened by desertification. Although Eritrea's **nomadic pastoralists** (people who raise animals) may not be living in perfect harmony with nature, they are skilled and knowledgeable herders with a long tradition of making the best of a very tough and often hostile environment. Many of the pastoralists are able to **adapt** quickly to changing circumstances as they apply their traditional techniques.

4.7 Nomadic pastoralists in Eritrea face a difficult existence because of the pressures of desertification. This nomadic camp shows the poor living standards of the animal herders.

Eritrea's pastoralists (as well as other pastoralists in Sub-Saharan Africa) are said to have little incentive to conserve communal grazing lands by reducing the sizes of their herds because they have no guarantee that others will do the same. In reality, land resources in Eritrea are not communally owned, but managed by particular groups.

4.8 Villagers in Hababah, Yemen, depend upon this water cistern for water, both for their own use and for their animals. Prolonged droughts have reduced the water to dangerously low levels, enabling water weeds to start growing in the water, further reducing the volume of water available for humans and animals.

The **local knowledge** thus gained has enabled many of Eritrea's pastoral communities to remain viable in spite of continuing droughts. Indeed, enabling local pastoralists to retain their **traditional methods**, which have served them well for many centuries, may provide much better protection against the threat of desertification than outside 'experts' imposing a system that may not be sustainable in Eritrea's extreme environment.

Desertification can be controlled if people make rational use of scarce water resources, collect and channel water effectively, reduce or substitute activities that are damaging the environment, or manage the soil sensitively. A particularly effective means of arresting desertification is to plant trees (**reafforestation**), as this binds the soil together and reduces erosion as well as increasing humidity, thus potentially increasing precipitation.

4.9 An area of reafforestation at Yadan (China) in the Gobi Desert, which is designed to stabilise the sands and soil of the region's wind-blown landscape.

QUESTION BANK 4A

1. *Is desertification mainly caused by natural or human factors? Give reasons for your answer.*
2. *Why are poorer societies especially vulnerable to desertification?*
3. *Describe two 'spiral effects' that amplify human actions that lead to desertification.*
4. *Explain why soil erosion is a key factor in desertification.*
5. *Rank these factors in descending order of importance in causing desertification: agriculture; energy; population. Justify your ranking.*

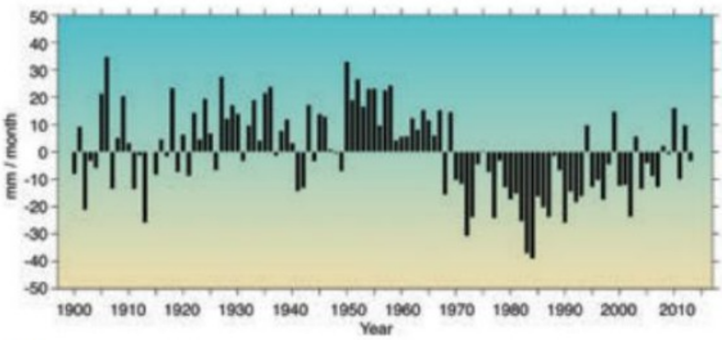
CASE STUDY
Desertification in the Sahel

The Sahel is a semi-arid **zone of transition** between the arid Sahara Desert to the north and the grassland savannas to the south. The region spans the width of the African continent, a distance of 5,400 kilometres from west to east. Its width from north to south varies from a few hundred to a thousand kilometres. The total area of the Sahel is about three million square kilometres, and it is one of the largest areas in the world threatened by desertification.

4.10 The Sahel region is shown in red.

Most of the Sahel comprises slightly **elevated flat land**, with altitudes ranging from 200 to 400 metres. The climate is **hot, dry** and **sunny** — a less extreme version of the arid climate of the Sahara Desert to the north. Rainfall typically ranges from 100mm to 600mm per annum.

The Sahel's climate has been **highly variable** for centuries. It is known that the region experienced an extended drought, known as a **megadrought**, for 250 years from 1450 to 1700.



4.11 Variations from mean rainfall in the Sahel, 1900 to 2013.
Source: University of Washington Joint Institute for the Study of the Atmosphere and Ocean

During the 1970s and 1980s, it was noticed that satellite images showed the Sahara Desert **expanding** southwards into the Sahel at a rate of about five kilometres per year. It was believed that this provided evidence for either global warming or over-grazing of the Sahel lands by the cattle of local herders. However, satellite images of the same area in the 1990s showed the southern boundary of the Sahara **retreating** to the north once again. More recent studies have suggested that expansion and contraction of the Sahara southwards into the Sahel fluctuates every few years.

This situation illustrates why long-term trends should not be extrapolated from a few individual, short-term events. From 1980 to 1984, the Sahara Desert expanded southwards, with the boundary shifting 240 kilometres. However, from 1984 to 1985, the trend reversed and the boundary moved north by 110 kilometres in a single year (1984), and then a further 30 kilometres north the following year. In 1987, the boundary moved southwards by 55 kilometres, and then northward by 100 kilometres in 1988. In 1989 and 1990, the boundary shifted southward by 77 kilometres. Recent satellite measurements suggest that there is **no long-term trend** for the Sahara Desert to expand, although the pressures for farmers to put too many animals on small areas of marginal land continue.

Droughts have often brought **famines** in the past, and between 1970 and 2010 the region was infamous for hunger and malnutrition brought about by repeated droughts. The Sahel's low rainfall since 1970, shown in figure 4.11, seems to have been caused by natural factors, and especially by changes in **sea surface temperatures** in the Gulf of Guinea (to the south of Burkina Faso). When the temperature of the surface of the water in the Gulf of Guinea rises, a belt of moist low pressure in the atmosphere known as the **Intertropical Convergence Zone** (ITCZ) moves to the south. As it does so, rain-bearing monsoon winds also move south, depriving the Sahel of rainfall. On the other hand, when the Gulf of Guinea waters cool, the ICTZ shifts northwards and the Sahel region receives rainfall.

Changes in rainfall are amplified by the **interaction** between the land surface and the atmosphere. When land dries out, vegetation dies or becomes sparser, exposing more of the soil surface to sunlight. This in turn increases the rate of evaporation, drying the soil still further and increasing the risk of **soil erosion** — a key factor in desertification.

The Sahel region contains a **population** of about 260 million people. The population is growing at a rate of 3% per annum, meaning that the number of people doubles every 20 years. The population growth rate is higher than the rate of increase in food production, which is about 2% per annum.

4.12 Cattle being moved by their nomadic owners near Kantchari in eastern Burkina Faso. Even though this area is well vegetated because it is near a perennial lake, the movement of the cattle stirs up dust, making the area susceptible to soil erosion.

The Sahel is one of the most **economically impoverished** regions in the world. The majority of the population depends on agriculture, and many are nomadic or **semi-nomadic livestock herders** (pastoralists). Farmers move their livestock according to the availability of water, a system known as **transhumance**. Given the region's aridity, transhumance is probably the most sustainable way to raise livestock.

The combination of rapid **population growth** and a climate becoming **hotter and drier** has placed pressure on farmers to produce more and more food in an environment where physical conditions have made this more difficult. Unfortunately, many farmers have responded to this pressure by using the land even more **intensively** than previously to compensate for the reduced production, and this has accelerated the process of desertification.

4.13 These cattle have been brought to a watering hole in the Sahel Desert, west of Niamey in Niger. The number of cattle per hectare in this area is very high for such a fragile environment that is vulnerable to desertification.

4.14 As the Sahel becomes drier, farming is becoming more intensive. This vegetable garden, which is surrounded by barren land, is near Mopti in central Mali.

4.15 To overcome expanding aridity, farmers in the Sahel are becoming increasingly dependent on irrigation. This is usually a labour intensive process, with watering cans and buckets used to bring water from wells or streams to the crops. This farm is using water drawn from a well in Djenné, Mali.

Pressure on the fragile Sahel environment is exacerbated by the rising demand for **fuelwood**. Fuelwood is the most commonly used form of energy in Sahel households, where wood is burned for cooking and heating.

Fuelwood can be used **sustainably** if the rate at which it is burnt is less than the rate of regrowth. However, population growth is increasing the demand for fuelwood at the same time as increasing aridity is reducing tree and shrub growth. This squeezes the limits of sustainable fuelwood use. The result is that people (usually women) must travel longer distances to find fuelwood, and they are more likely to cut branches from trees rather than scavenging wood from trees that are already dead. Consequently, vegetation cover is reduced, soil erosion increases, and the threat of desertification grows.

Growing aridity in the Sahel is placing increasing pressure on residents to use the **scarce water resources** that they possess frugally. Unfortunately, the growing population size and lack of finances make this task difficult.

International aid agencies have responded by building wells in some villages to enable residents to draw water from underground storage tanks. **Underground storage** has the advantage that loss of water from evaporation is minimised, although the disadvantage is that some water is lost by infiltration into underlying rocks.

On a larger scale, international aid to combat desertification in the Sahel is provided by organisations such as the FAO (Food and Agriculture Organisation of the United Nations), USAid (the United States Agency for International Development), Muslim Hands UK, Mercy Corps,

4.16 A woman and her daughter carry fuelwood they have gathered in the semi-arid countryside to sell at a market in Djenné, Mali.

4.18 Residents draw water from a village well in Kouré, Niger.

4.17 The extent of this fuelwood market on the outskirts of Segou, Mali, shows the scale of timber harvesting for fuelwood.

4.19 Effective water management in the Sahel Desert is vital if desertification is to be contained. This water well serves the entire village of Sanga, in eastern Mali.

and World Vision. These and other organisations provide advice on sustainable farming techniques and water use, as well as providing health services, nutrition advice and help with water management.

Perhaps the most ambitious proposal to combat desertification in the Sahel is the GGW; the **Great Green Wall**. The proposal has been advanced in stages from 1952 onwards, most recently by the GEF (Global Environment Facility). GEF is an international organisation that initially linked the UNEP (United Nations Environment Program), the UNDP (United Nations Development Program) and the World Bank. The GEF has subsequently expanded into partnerships with 18 additional international agencies and associations with 182 member governments.

4.20 If the Great Green Wall is ever built, it will look something like this, where local species of vegetation are planted and maintained with an effective watering system. This grove of trees has been planted to stabilise desertification-threatened land near Kouré, Niger.

The GGW concept proposes allocating $US115 million to built a 15 kilometre wide forest belt across the entire Sahel region, from west to east. Proponents of the **reafforestation scheme** argue that the GGW would halt any southward expansion of the Sahara Desert into the Sahel by stopping soil erosion, it would protect water sources from moisture loss due to evaporation, and it would provide employment to the people in some of the world's poorest countries.

QUESTION BANK 4B

1. *What is the area and the population size of the Sahel region?*
2. *Calculate the Sahel's population density (people / km²).*
3. *Describe the Sahel's rainfall pattern since 1900.*
4. *Why is the Sahel's rainfall pattern so variable?*
5. *Is the Sahara Desert expanding into the Sahel region?*
6. *How have farmers in the Sahel responded to the twin pressures of population growth and increasing aridity?*
7. *Why is fuelwood use a problem for desertification in the Sahel, and what are the possible solutions?*
8. *List the challenges and opportunities of building the Great Green Wall across the Sahel region.*

Competition for resources

Competition for resources in cold and arid environments

A **resource** is anything that is useful to people. Resources almost always have limited availability, and this scarcity can lead to competition for access.

In both cold and arid environments, the most precious resource is probably **cultivable land**. Without access to land that can produce food, either through arable farming or livestock raising, a society cannot have **food self-sufficiency**, and it will be dependent on food imports from elsewhere for survival. Cultivable land tends to be a scarce resource in both cold and arid environments, especially in areas where land degradation has occurred.

Associated with land availability is another important resource, **water**. In arid environments, the challenge is to find water resources that are accessible for domestic use, and also water for animals and irrigation. Cold environments, on the other hand, usually have plentiful surface and sub-surface water, but it may be inaccessible because it is frozen or in poorly drained marshland.

Cold and arid environments also contain resources whose main value is economic, including **oil**, **gas** and **minerals** such as coal and iron ore. Although these resources are not necessary for survival like land and water, they offer considerable scope for wealth creation, and as such, there is often competition for access to their sites.

As population numbers grow, there is increasing competition for cultivable land and water in

4.21 Cotton grown on irrigated semi-arid land near Samarkand, Uzbekistan.

extreme environments. In some arid environments, such as Sudan, Egypt, Mali and Uzbekistan, the pressure is **financial** as big companies are willing to pay large sums of money to acquire land for **cotton** production for export. Traditional food growing farmers are usually unable to compete with the financial pressures of profit-driven **transnational corporations**, and this has resulted in a shift in land use from food production to production of industrial raw material crops such as cotton. When this happens, biodiversity declines as **interculture** (mixed cropping) is replaced by **monoculture** (plantings of one plant species).

In other areas, competition for land, water and economic resources arises out of conflicts between **indigenous groups**, or between indigenous groups and more powerful authorities. This is especially the case in areas where indigenous law, including land rights, is separate from the country's mainstream legal structure. In extreme cases, this may result in governments displacing indigenous groups, **forcibly relocating** them to areas away from their traditional territory. In many cases, the land to which indigenous groups are relocated are far less productive than the land they were occupying. Forced relocations of disempowered indigenous communities have occurred in many cold and arid areas, including:

- Australia, where many Aboriginal communities that occupied productive lands that could be used for animal raising were either killed or forcibly relocated away from their traditional land;
- Greenland, where the Uummannaq Inuit community was forcibly relocated to make way for a US military base; and
- Russia, where the semi-nomadic groups such as the Tofa and Yakut people were forcibly removed from the land where they raised reindeers to be collectivised during the Soviet era.

4.22 The indigenous Yakut peoples have retained their distinctive culture in spite of past forced relocations.

In some arid and semi-arid environments, such as the Sahel and the Sahara, **militia groups** with a political agenda have increased competition for land and other resources by forcing their presence onto local communities. For example, **Boko Haram** (also known as the 'Islamic State in West Africa') is a terrorist group located in the Sahel region of north-east Nigeria that has killed over 20,000 people and displaced about 2.5 million people who have fled to Chad, Cameroon, Niger and other parts of Nigeria.

Other militia groups operating in the Sahel region include **AQIM** (al-Qaeda in the Islamic Maghreb), which is associated with Tuareg rebels in northern Mali, **GSPS** (Salafist Group for Preaching and Combat) in southern Algeria, and MUJAO (Movement for Unity and Jihad in West Africa). These groups have brought **instability** to the Sahel region, destabilising established patterns of land ownership, farming and economic activities. They have also dissuaded many foreign investors from investing in oil, gas and mining projects, with the result that many resources remain undeveloped and unexploited.

QUESTION BANK 4C

1. *Is the pressure of competition for resources in cold and arid environments mainly driven by natural or human factors?*

CASE STUDY
Issues of resource competition for the Himba people

The **Himba** number about 10,000 people who live in arid terrain in Northern Namibia and southern Angola. The focus of the Himba people's land is the Kunene River that forms the boundary between Angola and Namibia, a region known as Kaokoland.

4.23 The area inhabited by Himba people is shown in red.

Kaokoland has a desert **climate** that receives no rainfall between May and September each year. A few isolated and erratic falls of rain from October to April bring the average annual rainfall to a figure of about 200mm.

Like all desert environments, the region where the Himba live has large diurnal temperature ranges. In summer (January), average maximum temperatures are 27°C, which fall to an average minimum temperature of 16°C at night. In winter (July), average maximum temperatures are 23°C, which fall to an average minimum temperature of 10°C at night.

4.24 A typical Himba encampment in northern Namibia. Cattle are gathered near the family dwellings, while a larger flock of goats grazes on the scant grass to the left of the photo.

The Himba are **semi-nomadic pastoralists** who raise cattle, sheep and goats, moving according to the availability of water in the harsh, desert environment. The food is mainly produced for **subsistence** use; only very rarely do the Himba sell meat commercially.

Livestock provides the bases of the **Himba diet** — meat and milk. These basic foods are supplemented by small quantities of mahangu (pearl millet) which is now grown by some Himba people who live close to the river.

4.25 A Himba compound, with an elderly man and two women watching over the goats while the young men are away with the cattle. The aridity of the region occupied by Himba people is very evident in this view.

The Himba retain many of their **customary practices** and beliefs, including wearing traditional dress and a conviction that the number of cattle a person possesses is the true measure of wealth. Work is strictly segregated by **gender**. **Women** tend to stay within the residential compound, venturing away to collect water and carry it back to the compound. The women are also responsible for maintaining the dwellings by re-plastering with red clay soil and cow manure, cooking and serving meals, milking cows and goats, and generally tending the sheep and goats.

The main responsibility of the **men** is to look after the cattle, taking them away from the compound in search of water and feed. Other responsibilities for the men are slaughtering the animals for meat,

4.26 A closer view of the compound shown in figure 4.25.

4.27 The young women's dwelling in a Himba compound, built with local materials by the men and then maintained by the women.

constructing the dwellings for housing, and maintaining the sacred fire that burns constantly in the middle of the open pathway that connects the two central houses in each residential compound.

When the men take the cattle away from the compound for water and feed, they are typically away from the compound for three to four days, and they may travel distances of 20 to 30 kilometres.

Access to land and water is essential for the Himba people's survival. In one sense, the Himba are fortunate that their environment is so inhospitable, because there is no competition for their land from commercial pastoralists or corporate commercial agriculture organisations. No valuable minerals have been found in Kaokoland, so the Himba do not face competition for land from mining companies.

The Himba are also fortunate because they do not have to compete with **other indigenous groups** for their land; no other group seems to want it. However, this was not always the situation. It is thought that people have lived in Kaokoland since the 16th century. At that time, the **Herero** people, who are ancestors of the Himbas, migrated into the region from the north.

By the 18th century, **population growth** and the associated increase in cattle numbers were placing too much pressure on the scarce resources of the region. Fighting broke out among various groups of Herero people, and as a result, some Herero migrated further south to areas with better pastures, while others were forced to migrate northwards into Angola.

4.28 A Himba compound in the desert near the Kunene River in northern Namibia. Women are cooking on an open fire, using the scarce resource of local timber.

The group that **migrated** northwards thus separated from the Hereroes, and they became a separate group at that time. They were forced to give up their cattle, and they resorted to hunting and gathering. At that time, the Herero **refugees** were given the name 'Himba' by the Angolans who accepted them into their territory. 'Himba' was originally a somewhat demeaning term that meant 'poor people' or 'beggars', but it is readily used by the Himba people today.

Following World War I, which ended in 1918, British-controlled South Africa took control of what had been German-controlled South-West Africa (today's Namibia). The change in political control encouraged many Himba people in Angola, which was then colonised by Portugal, to **return** to

Namibia and regain their land. As most of the Herero people remaining in Namibia had migrated southwards to better pastures by that time, fleeing the effects of a bovine epidemic, the Himba had little difficulty re-establishing their presence in Kaokoland.

4.29 Himba goats grazing on sparse grass growing on sand dunes, northern Namibia.

By the 1970s, with re-established access to their land resources, the Himba had become the wealthiest indigenous pastoralists in Africa. That changed in the late 1970s and 1980s when a severe **drought** coincided with a period of political unrest. As a result of the drought, 90% of Himba cattle died. A **militia group** known as SWAPO (South West Africa People's Organisation) escalated its armed fight for Namibian independence against South Africa. Himba cattle herds were attacked or stolen, some Himba were kidnapped to be soldiers, and most remaining were reduced to poverty.

With peace and stability restored following Namibia's independence in 1990, the Himba have been able to use their **basic resources** of land and cattle once again. They have maintained their traditions, so contemporary Himba lifestyle is really a preserved version of the Herero society in the 18th century from which they separated. Herero people today have little interest in using the harsh lands occupied by the Himba, so there is **no competition** for Himba land and water resources from that group, or any other indigenous group. Today, Herero people are more Westernised than the Himba. Although they still raise cattle, they wear Western clothing, they are well integrated into mainstream Namibian society, and they tend to speak German rather than traditional languages.

Nonetheless, the Himba people's access to land resource is under threat from other sources. Under Namibian law, the Himba have no legal recognition of their **collective land rights**. There are **proposals** to redistribute land from commercial farmers to groups such as the Himba who have no legal rights to their land, and to place communal areas under **traditional authority** through communal land rights registration.

The risk for the Himba people is that they have **no rights** to participate in framing the new laws because the Namibian Government does not recognise that their leaders, or chiefs, have any 'traditional authority'.

4.30 The remains of an oryx near the Kunene River, Namibia. The grass in this area has adapted to dry, nutrient poor soils. Therefore, the grass cannot survive in the area surrounding the carcass of the oryx because the nutrient levels are too high.

Although the Himba do not face competition for land, they do have competition for other scarce resources in Kaokoland. **Wildlife** is one of the resources in the region. The deserts of Kaokoland have elephants that have adapted to the arid conditions, and many species of reptiles, birds, oryx, and crocodiles near the river. The Himba do not hunt animals for food, as they rely on their own cattle and goats for protein. However, the Himba do use wild animals for some basic needs, such as oryx horns for cattle trumpets, giraffe skins for sandals, and ostrich eggs for beads.

Kaokoland experienced **illegal poaching** of wildlife during the 1980s when law and order was breaking down. A number of Himba people were given jobs as wildlife guards, and within a few years almost all the illegal hunting had ceased. This situation continues today.

Water is a critically important resource in the arid surroundings where the Himba live. The Himba obtain water for their cattle from one river (the Kunene River), several small ephemeral streams, and some boreholes. In order to minimise use of their scarce water resource, Himba women almost never use water for bathing or personal washing, but cover themselves instead with a mixture of butterfat and red ochre pigment which cleanses the skin as well as protecting it from the fierce sun.

The biggest threat to the Himba's access to water is a proposal to build a **large hydroelectric dam** on the Kunene River, which flows through the heart of Himba land, and forms the international boundary between Namibia and Angola. The Himba depend on the waters of the Kunene River to provide drinking water for their cattle and goats, to grow the grasses that their animals eat, and to cultivate the mahangu (millet) that forms part of their diet.

The proposal to build the dam the Kunene River was first made in the mid-1990s, but lay dormant for more than a decade. In 2012, the governments of Angola and Namibia announced that work would begin, but this has been **opposed** by the Himba people who live in the region.

The dam, which would cost at least $US1.5 billion to build, will flood 290 square kilometres of Himba land and displace at least 5,000 people. The proposed lake formed by the dam will cover many of the Himba's ancestral burial grounds, a very significant problem in a society that places so much emphasis on honoring the dead and asking ancestral spirits for advice before making big decisions.

4.31 The Kunene River, which will be flooded if the proposal to build a hydroelectric dam is implemented.

4.32 The Kunene River forms the border between Angola (in the background) and Namibia (in the foreground). This shows the type of land that would be flooded if dam construction proceeds.

The Himba campaign to stop construction of the dam has extended beyond the borders of Namibia and Angola. Himba leaders have led protests and endeavored to enlist support from **civil service organisations** and NGOs such as Earth Peoples, the International Rivers Network, and the Habitat International Coalition.

4.33 Himba men move their goats down a dusty hillside towards their compound.

Opposition to the dam has not been very effective because the Himba lack political organisation, and they have no framework for formal or legal participation in government decision-making processes. Although several overseas civil service organisations have publicised Himba opposition to the dam and its environmental consequences on their websites, this has not yet persuaded the Angolan or Namibian Governments to abandon the planned dam.

4.34 Tourist cabins on the banks of the Kunene River.

4.35 Himba women attempt to sell crafts to tourists as a way to earn cash income.

Tourism is very small in scale in Kaokoland because of the area's remoteness and arid climate. Getting to the region involves a long drive, usually by 4-wheel drive vehicle, or flying into one of several small airstrips. Nonetheless, even a small number of tourists introduces additional competition for resources in an area where resources are so few.

Food for tourists, and the building materials used for constructing accommodation, are generally brought into Kaokoland from outside areas, but water is obtained locally. Accommodation for tourists is built on land that the Himba do not use, such as over the reed banks beside the river or on scenic steep hillsides, thus minimising competition with the Himba for land resources.

In some cases, tourism is helping to give the Himba people **access to resources** that they otherwise would not have. For example, one tourist encampment provides a nearby Himba community with monthly rations of food such as maize meal, sugar and lollies, plus non-food items such as vaseline, tobacco and water barrels. The incentive to provide these goods to the Himba is to encourage the group to remain in close proximity to the encampment so they can be visited by tourists.

Tourist encampments are helping the bring Himba people into the cash economy by employing young men and women. Some Himba who are interested in earning money have made tentative steps into the cash economy by selling locally-made jewellery and handicrafts to visiting tourists. These initiatives have had little impact on the Himba people so far as the numbers of tourists are so low, but they do provide options that were not previously available.

QUESTION BANK 4D

1. *Describe the location and the environment where Himba people live.*
2. *What is the most important resource for Himba people? Explain your answer.*
3. *Describe the competition for land resources in the past that resulted in the present location of Himba people.*
4. *How have militant groups affected access to resources for the Himba?*
5. *Describe the threat to the Himba's access to water resources.*
6. *How effective have civil service organisations been in helping the Himba retain access to their water resources?*
7. *Describe the advantages and disadvantages of tourism in giving Himba people access to resources.*

Sustainable development and new technology

Cold and arid environments can be very **fragile** when exposed to the pressures of human activities. These environments have reputations as clean and pristine, and yet when they are examined more closely, even very remote places like Mount Everest may be quite polluted. Sometimes, human impacts can become too severe for nature to repair. This raises the issue of **sustainability challenges**. Three will be considered — air pollution, water quality and deforestation — before solutions are explored.

Air pollution

Air pollution becomes a **problem** for people when it is trapped near the earth's surface in the zone where people live. Both cold and arid environments experience long periods with atmospheric **high pressure areas**, and therefore they are susceptible to prolonged periods of air pollution.

Air pollution is concentrated in **urban areas** where there are concentrations of motor vehicles, factories and residents using high polluting forms of heating such as burning wood. In arid environments, human pollutants are often combined with dust in the atmosphere to create an unpleasant haze.

Cold and arid environments in poorer countries often have **factories** run by managers who feel they cannot afford to clean up their emissions. Although these factories are usually small in size, they tend to be heavy polluters.

4.36 Air pollution over Dubai, United Arab Emirates. This atmospheric pollution is a mix of car exhausts and dust blown in from the adjacent desert sands.

4.37 The Lafarge Cement Plant at Ataqah, east of Cairo in the Sinai Desert, has covered the surrounding desert sands with black deposits that were emitted from the factory as air pollution particulates.

4.38 The Himal Cement Factory, south-west of Kathmandu, pumps large volumes of polluting gases into the air beside the temple of Adinath Lokeshwar, built between 1400 and 1640.

Air pollution comes from many sources, including **dust** from fires and burning, **gases** from motor vehicle exhausts, and both dust and gases from factories. The rapid increase in the number of **motor vehicles** in cities exacerbates the problem of air pollution. Egypt's capital city, Cairo, has more than two million cars, and the number is growing by about 15% per year. The emissions from cars in hot, arid climates cause particular problems because the nitrous oxides in car exhausts 'cook' under hot sunlight to produce **photochemical smog**, which is an especially noxious form of air pollution.

4.39 Cars in Cairo, Egypt's capital city, are a major contributor to the city's severe air pollution problems.

Water quality

Water is necessary for everyone's survival. Sadly, maintaining clean water quality is often seen by developing nations to be a **luxury** they cannot afford. This is especially problematic in arid and cold environments because the scarcity of usable water is so acute.

4.40 This dry canal through an oasis in the Sahara Desert is doubling as a rubbish tip. The location is Beni Isguen, Algeria.

4.41 The water flowing down this street in Mopti, Mali, is actually an open sewer, carrying waste water into the nearby River Niger. Once the waste water enters the river, it will flow about 3,000 kilometres through the Sahel region past villages in Mali, Niger and Nigeria that will use the water for drinking and irrigation.

Nepal is an example of a poorer country in the Himalayas where water pollution is a significant problem. Most people in Nepal follow the **Hindu** religion. Hindus regard several of Nepal's rivers as holy, and the **multi-use demands** made upon the water of such rivers are very great indeed. For example, the **Bagmati River**, which flows through Kathmandu, serves as a source of irrigation water, a

4.42 Pigs forage through rubbish in the bed of the Bagmati River near Kathmandu in the Himalaya Mountains of Nepal. The river bed is strewn with discarded rubbish that people have dumped, where it mixes with faeces from animals and humans. Eventually, when the spring snow melt swells the river, the garbage is washed downstream into India.

4.43 A woman washes clothes in the Bagmati River near the funeral pyres where bodies are cremated before being placed in the waters of the river to float away downstream.

bathing channel for washing, a toilet, a garbage dump, a grazing area for cattle, a source of drinking water, a place for disposing cremated human remains, and an object of worship.

All these competing uses for the water have caused the quality of the water in Nepal's rivers to deteriorate. Water is taken from the Bagmati River and other streams for chlorination and drinking in Kathmandu. Even after chlorination, the water is heavily contaminated, especially with faecal bacteria.

There are many sources of water pollution in Nepal's rivers. Most of the Kathmandu Valley's **factories** are situated beside the rivers, and these factories dump waste chemicals such as chlorides, nitrates and sulphates into the rivers. Most of Kathmandu's **sewage** is dumped into the river, either through pipes from houses or directly into the river by people who have no toilets in their houses.

Water quality is made even worse because of the ways the water is then used. Water is pumped from the river into **wells** distributed throughout the towns for communal clothes **washing**. Here, soap, dirt and animal droppings become mixed with the water before it is returned to the river. The water is then taken further downstream for washing again, and the concentration of pollutants increases. The mixture of pollutants becomes even greater when combined with the remains of bodies cremated beside this holy river.

Mountain areas in **wealthier countries** tend to have better water quality. For example, although **Switzerland** has over 400,000 farmers, the country's waterways are largely free from agricultural wastes and contaminants. Indeed, Switzerland has generally embraced **sustainability** and the **green movement** enthusiastically. On average, each Swiss person produces 450 kg of waste per year, half the figure for each American person.

Switzerland has an active policy of recycling under the slogan 'Reduction, Recovery and Recycling'. Most local government authorities have **recycling** facilities for paper, glass, plastic, aluminium and used oil. Most containers for food and drinks are recyclable, and the rate of recycling is very high. A law designed to reduce excess packaging entitles consumers to unwrap unnecessary packaging in the shop where the purchase was made and leave it for the shop to throw away — and many consumers do exercise this right.

4.44 This gravel mine in the Swiss Alps near Grindelwald causes sediment pollution in the river downstream from the mine.

Most Swiss cantons have introduced specially marked bags for rubbish that cannot be recycled. These are very expensive (up to $US5 each including the incineration fee), and this high cost encourages as much as possible to be recycled. Sadly, the high cost also encourages residents to travel to other cantons that have not introduced the bag tariff and dump their rubbish there.

Water pollution in Switzerland is therefore quite rare. Dumping of chemicals into Swiss waterways is banned, but sometimes other forms of pollution are less easily avoided, such as sediment from river gravel mines.

Deforestation

People in both arid and cold environments use timber as an important resource. The impact of cutting timber is usually greater in poorer countries than in richer nations.

In **arid environments**, timber is scarce because the dry conditions stunt the growth of trees, or make tree growth impossible. Even in areas with very few trees, fuelwood is the main source of energy in poorer countries. As population grows, the demand for fuelwood also increases, and this forces many societies to engage in **unsustainable** timber cutting practices in which the amount of timber burnt is greater than the amount that can regrow. Deforestation is especially significant in areas threatened by desertification such as the Sahel.

4.45 Cooking can use large quantities of scarce timber in arid environments, as seen with this typical outdoors family stove in Segou, Mali.

4.46 This young boy is bringing fuelwood to sell in a market in Koutiala, Mali. Increasing use of fuelwood is placing great strains on remaining timber growth in the Sahel region.

Fuelwood use is also an issue in some **mountain areas**, such as Nepal in the Himalayas. Indeed, loss of forest is one of Nepal's greatest problems. Most of the timber is cut down for fuelwood, which supplies 75% of Nepal's energy needs.

Although some of the cut timber is sold in towns, most of it is gathered by villagers who intend to use it themselves. Many of Nepal's **factories** also use fuelwood rather than other sources of energy. In the Kathmandu Valley's 100 brick kilns, 3 million bricks are produced each year using 24,000 tonnes of coal plus 24,000 tonnes of **fuelwood**. It is claimed that if the cutting continues and Nepal loses its remaining forest, the world will lose ten species of valuable timber, six species of edible fruit tree, four species supplying traditional medicines and fifty species of little known trees and shrubs. The loss of the trees would also wipe out the habitats for 200 species of birds, 40 species of mammals and 20 species of reptiles and amphibians.

4.47 These hills to the east of Kathmandu in the Himalayas of Nepal have been almost completely denuded of trees through over-harvesting timber for fuelwood.

Deforestation has become such a problem in Nepal that the government has conducted a two-decade long campaign to regenerate the country's forests. The government hopes to meet people's timber needs from **sustainably grown plantation forests**. Moreover, it hopes to reduce the overall demand for timber by encouraging people to use **alternative fuels** such as kerosene and animal dung instead of fuelwood. The government plans to connect more households to electricity, thus reducing the need for fuelwood. At present, only 3% of rural households have electricity. The cost of the 20-year program has been about $US2.5 billion, a huge sum for a poor nation like Nepal.

Mountain areas in Europe experience a different set of sustainability challenges. Forests in the Swiss Alps are suffering from the effects of **acid rain**, a **transboundary** factor over which the Swiss have little direct control. Acid rain is caused by air pollution from cars and factories in areas upwind. In the case of the Swiss Alps, this means the acid rain is sourced by pollution in Britain, France and Spain. Sulphur dioxide formed by burning hydrocarbons in motor vehicle engines mixes with water in the atmosphere, producing rain that is a diluted form of sulphuric acid ($SO_2 + H_2O \rightarrow H_2SO_4$). This is then blown by the prevailing winds over to Switzerland where the orographic uplift causes rain — rain which kills the trees on which it falls because of its acidity.

Switzerland faces huge problems in overcoming the problems of acid rain because it is caused in areas over which it has no control. It is for this reason that the Swiss have been at the forefront of efforts to get international agreements limiting the production of air pollution gases.

New technology

Possible solutions to the **sustainability challenges** described above — air pollution, water quality and deforestation — involve implementing new technology and alternative forms of energy. This is easier said than done, especially in poorer societies with few funds to make major investments.

Deserts have an abundance of sunlight, making them ideal environments to use **solar energy**. Solar panels are still relatively expensive to make and to purchase, so they are only affordable in richer countries or in places where governments or aid agencies are able to subsidise their cost. Consequently, traditional desert communities make little use of new technology, using instead long-established sustainable techniques such as **passive cooling** and **convection currents** to make their dwellings more comfortable.

In wealthier countries, much more use is made of solar energy. A cutting-edge example of sustainable housing design for **arid environments** is provided by the earthship houses in the deserts of New

4.48 A forestry ranger compares a healthy branch from a forest tree (left) with one that has been stunted and defoliated as a result of acid rain (right).

Mexico, USA. Earthship houses are passive solar dwellings built from natural and recycled materials that are designed to be 'off-the-grid', which means they do not rely on fossil fuels or the public electricity grid.

Earthship houses are built using **thermal mass** construction, which means they are naturally insulated. This is achieved either by being half-buried into the land, or by having walls built with thick mud brick (adobe), earth-rammed discarded car tyres, or rammed earth walls. The designs of the houses encourage natural **cross-ventilation** using convection currents. Cool air is drawn in through windows or louvres and flows out of the house through the skylights, creating a naturally cool breeze through the dwelling.

4.49 A typical house in the Earthship community neat Taos, New Mexico, USA. The house has solar panels, a wind turbine and passive cross-ventilation.

4.50 Another house in the Earthship community near Taos, USA. In the foreground, the thermal mass construction using rammed car tyres and recycled drink cans can be seen. Windows and solar panels are angled to face the sunlight.

The houses often have unusual shapes to maximise use of solar energy. Windows on sun-facing walls allow light and heat during winter, but are shaded during summer.

Earthship houses are also designed to use **water** sustainably. Rather than drawing water from piped supplies, they gather water from the surrounding environment despite the challenges of extreme aridity. Water is harvested from occasional rainfall, snow in winter and condensation. Water is collected on the roofs of the houses, where it flows through a narrow slot into a storage cistern inside the house. This water is used for drinking and all other household uses except flushing toilets, where greywater (previously used water) is used instead.

Wind energy is used to supplement the solar panels on earthship houses. Each house has one or more wind turbines to generate electricity which is stored in batteries within the house.

The earthship community in Taos, USA, has served as a model for sustainable housing elsewhere in the world. Smaller earthship communities have now been established in South Africa, Belgium, the United Kingdom and Argentina, and more are in the planning stages.

In **cold environments**, the heating needs are greater than in hot arid environments, but the potential to use solar energy is reduced because the strength and duration of sunlight is less. As with arid environments, it is richer societies that can afford new technology.

Sweden is an example of an affluent country in a cold environment. Sweden has invested heavily in alternative energy sources such as wind and solar power. Few countries consume more energy per capita than Sweden (because of its affluent lifestyle and cold climate), and yet Sweden's carbon emissions are among the lowest of any economically developed country.

4.51 The side of this multi-storey building in Malmö, Sweden, is covered with evacuated solar hot water tubes. Compared with flat plate solar panels, evacuated solar tubes capture more sunlight because they have a greater surface area exposed to the sun. They can be used in sub-zero conditions and work in overcast conditions, making them suitable for cold environments.

More than half the electricity used in Sweden comes from renewable sources; hydro, solar and wind. Of these renewable sources, hydro-electricity accounts for 95%, but solar and wind power are growing in importance.

4.52 This factory in Malmö, Sweden, has a vast array of solar panels on its roof. Further insulation is provided with a green roof, which is a roof covered with vegetation planted over a waterproof membrane.

Desalination is a technology used to remove minerals (especially salt) from saline water. It is a useful, if expensive, way of increasing the supply of fresh water for human consumption and agriculture in areas with a severe water deficiency.

The saline water used for desalination may come from various sources such as seawater, overland flow or groundwater. In general, removing the salt from seawater is the most expensive form of desalination because it requires higher amounts of energy.

The most common way of desalinating water is to boil it in a partial vacuum. The partial vacuum reduces the boiling point of the water, thus reducing the amount of energy required. The steam produced from the boiling process is mineral-free, and it is collected, cooled and condensed to produce fresh water. Other techniques are also used, such as passing the saline water through semi-permeable membranes at high pressure to filter out the minerals. Whichever technique is used, the amount of energy required is high, and the initial costs of constructing the desalination plant are also high. The high costs preclude the widespread use of desalination in poorer countries.

4.53 The Ras Abu Fontas Kahrama Water Desalination plant is located about 10 kilometres south of Doha, capital city of Qatar. The plant opened in 2015 and cost $US500 million to build, something that only a wealthy desert nation could afford.

QUESTION BANK 4E

1. *Why is air pollution a problem in some arid and cold environments, but not others?*
2. *Describe and account for the different levels of water quality found in rivers in Nepal and Switzerland.*
3. *In what ways is the use of timber in arid environments unsustainable?*
4. *What is acid rain, and why is it such a difficult problem to solve in the Swiss Alps?*
5. *What are the features of earthship houses that make them a good model of sustainability?*
6. *What is desalination, and why isn't it used more often to overcome water shortages in arid environments?*

Global change in extreme environments

It is generally agreed that the world is experiencing **global warming** at a rate never previously experienced. If this trend continues, there will be significant implications for all parts the world. When the physical conditions are 'extreme', as in the hot-arid and cold-high environments, then the effects of climate change are likely to have serious impacts on the people, settlements and economic activities in those environments.

Climate change in arid environments

One of the effects of climate change that has been observed in recent decades is **reduced rainfall** in arid and semi-arid areas. Deserts and semi-deserts have always experienced erratic, low and unpredictable rainfall. However, since the 1970s, many arid environments have experienced a sustained trend of more prolonged **droughts**, sometimes leading to famine and starvation.

Reduced rainfall leads to a series of impacts on people in arid environments. Primary (or initial) impacts include increasing pressure on scarce **water resources**, reduced **agricultural production**, **lower crop yields**, and consequent **food insecurity.**

These primary impacts lead to a succession of **secondary impacts**. Reduced rainfall means that the daily task of gathering **fuelwood** is becoming even more onerous as scarce vegetation struggles to survive — especially as population pressures continue to increase the demand for fuelwood more quickly than the trees and bushes can grow. If fuelwood becomes even less accessible to indigenous peoples, the impacts will be felt especially by **women**, as it is usually the women's role to carry the heavy bundles of wood in many of the world's arid and semi-arid areas.

4.54 This woman from the Arbore tribe in southern Ethiopia is doing the daily chore of many women in semi-arid environments, carrying the heavy load of fuelwood. As the climate becomes hotter and drier, this task becomes more difficult as she must walk longer distances in search of scarce timber.

4.55 Eritrea is highly vulnerable to climate change induced desertification. This view shows typical arid scenery near Massawa

Climate change is causing **political conflict** for people in the arid regions of the **Horn of Africa** (Somalia, Eritrea, Djibouti and Sudan). Since 2003 there has been a civil war in the **Darfur** region of western Sudan which has led to a 'humanitarian crisis' (to quote the words of UN Security Council) in which as many as 300,000 people have been killed and two million displaced from their homes. Although the direct causes of the conflict are tribal and ethnic differences, climatologists suggest that several decades of **drought**, combined with **desertification** and **overpopulation**, have fuelled the tensions between the various groups. This claim is based on the fact that prolonged drought forced nomadic Arab Baggara animal-herders to take their livestock in search of water onto land that was mainly occupied by other ethnic groups.

Darfur is not the only place where people have been forced to migrate because of environmental change. In **Eritrea**, situated to the east of Sudan, desertification is also a serious problem. The country suffers from frequent droughts and it has still not recovered from a decades-long war for independence. Less than 3% of Eritrea's total land area is forested, and many marginal lands have been cultivated and overgrazed, leading to soil erosion and desertification.

Indigenous peoples leading traditional lifestyles are especially vulnerable to climate change. The ways that indigenous people cope with their extreme environments are often based on **traditional knowledge**. Although traditional knowledge has proven adaptable to many climatic fluctuations in the past, today's more extreme global warming is stretching traditional adaptations beyond breaking point. If farmers plant crops at certain times of the year that are based on past weather cycles, and those weather cycles are disrupted, the consequence could be widespread **famine**. In general, indigenous peoples receive the least 'western' **education** among the general population. Therefore, indigenous peoples are more likely to lack the wider scientific understandings of climate change that would be helpful to illuminate their traditional knowledge to cope with extreme environmental changes.

Despite the adaptability of indigenous peoples, **environmental migration** does occur in hot, arid environments. Environmental migration is the forced movement of people as a result of environmental degradation and resource depletion. It is often associated with poverty, food deficiency, conflicts and inequity. Indeed, historians explain the collapse of many of the world's great civilisations on environmental factors, including climate change.

4.56 Hecang, one of many abandoned settlements in the deserts of western China, provides evidence of thriving settlements based on well managed water resources in the less arid past.

Dr Norman Myers of Oxford University has suggested that the combination of sea level rise and changes in the distribution of agriculture caused by climate changes (global warming) could displace millions of people in the coming decades. The term **environmental refugees** is often used to describe people who must flee (either temporarily or permanently) from their traditional habitat because of an environmental disruption that threatens their existence or seriously affects their quality of life. Myers estimates by 2050, 1.5% of the world's population (150 million people out of 10 billion) will be environmental refugees due to the impact of global warming, compared to 0.2% of the world population who are environmental refugees today.

Climatologists warn that **prolonged drought conditions** (**megadroughts**) are another possible consequence of global warming in desert areas. This creates huge problems for local people, many of whom raise animals for their livelihood, as they are forced to move their animals onto land that is more and more marginal in search of feed and water. When animals are forced to over-graze on marginal semi-arid land, there is a real risk **desertification**.

4.57 Desertification in the Sahel region has forced the owners of these goats to move them to highly marginal lands east of Niamey, Niger.

The large **shanty settlements** that exist on the outskirts of many towns and cities in arid areas are another sign of environmental migration in hot, arid environments. Nomadic peoples who are unable to survive the extreme aridity brought about by global warming are forced to migrate to settlements where water is available, even if employment is not. The Worldwatch Institute estimates that one billion of the world's three billion urban dwellers live in 'slums', which are defined as areas where people have no access to key necessities such as clean water, a nearby toilet,

4.58 Shanty housing on the outskirts of Mopti, Mali, provides accommodation for environmental refugees from the Sahel region who have been forced to leave their traditional lands by the impacts of climate change.

or durable housing. Although it is impossible to quantify the role of climate change in forcing rural-urban migration, there is widespread concern that global warming will aggravate this problem in the years ahead.

Cities have a long history in extreme hot, arid environments. It is said that the world's first city was **Sana'a**, which today is the capital city of Yemen. **Yemen** is located in the deserts of the southern Arabian Peninsula. Tradition says that Sana'a was established about 4,500 years ago by Noah's son, Shem. Whether that is true or not, Sana'a is a very old city with a long history of **adaptation** to changing environmental conditions.

4.59 Sana'a, Yemen's capital city, is claimed to be the world's first city.

4.60 The ephemeral stream known as Wadi as Sa'ilah has been converted into a canal which is used as a roadway for most of the time when the stream is not flowing.

4.61 Fruit and vegetable cultivation within the old city of Sana'a, Yemen, helps fight aridity by adding humidity to the dry atmosphere.

The tall tower houses in Sana'a are built from mud and stone, which are natural **insulators** protecting the people inside from the scorching outside heat. The design of the tower houses uses the natural movement of air to create cooling **convection currents** without the use of any electricity or other energy.

On the western edge of the old city of Sana'a, an ephemeral stream called Wadi as Sa'ilah flows after heavy rainfall. City planners have converted the stream bed into a **canal** which is used as a main road for most of the time. As well as providing a much-needed roadway through the narrow streets of the old city, this canal has also prevented the flooding that used to afflict residents.

Another way in which the residents of Sana'a have adapted to their extreme climate is growing fruit and vegetables within the city wherever possible. Because the city was established on a natural oasis, cultivation provides protection against droughts and aridity in the surrounding countryside. In these ways, Sana'a has shown that traditional thinking can provide protection against the threats of global warming.

Newer cities in hot, arid environments often follow the urban models of cities in Europe and North America, and thus lack the traditional wisdom and planning of settlements such as Sana'a. One example of a modern desert city is **Dubai**, the commercial centre and largest city in the United Arab Emirates. In trying to create a modern city in a desert environment, Dubai uses large quantities of water for irrigation, creating not only green parklands but extensive golf courses and grassy median strips on the roads. This makes the city more vulnerable to the impact of climate change.

4.62 Riyadh, capital city of Saudi Arabia, is an example of a modern desert city with a large energy footprint. This view looks down on a new area of commercial development from the top of the city's tallest building, the 302 metre high Kingdom Centre. Note the large number of cars visible on the city's wide streets. The building with a twisted shape is the Majdoul Tower.

4.63 Irrigation creates verdant gardens and green median strips along many of the roads and expressways in Dubai, UAE.

Dubai also uses large quantities of fuels such as oil to air condition the buildings, which unlike the traditional architecture used in Dubai and other arid areas, are seldom designed to catch the cool ocean breezes and circulate the air. Dubai's use of **fossil fuels** is among the highest in the world on a per capita basis, making the city both a significant contributor to greenhouse gases that are thought to cause global warming as well as increasing vulnerability as the economic pressures of global warming increase.

Climate change in cold environments

The impact of global warming may be even more marked in cold and high altitude environments than in arid environments. Known effects of global warming include **glacial retreat** and shrinking of the **polar ice caps**. In the Arctic, the shrinking of the ice caps is predicted to allow stronger waves to hit the coastlines, thus increasing **coastal erosion**. In mountain areas, melting glaciers are likely to increase **stream discharge**, thus increasing **riverbank erosion**.

In the periglacial expanses of the tundra, global warming is thawing **permafrost**. Permafrost is the thick layer of soil below the ground surface in periglacial regions that remains frozen throughout the year. In the early 2000s, some regions of northern Canada were reporting that during summer the permafrost was thawing, causing the earth to become spongy and the land to sink by as much as a metre, about 20 times more than the 'normal' rate. In parts of Canada and Russia, thawing permafrost is causing damage to infrastructure such as roads, railway lines and buildings. As permafrost melts, it releases large quantities of **greenhouse gases** such as methane that had been frozen in the ice into the atmosphere. In this way, melting permafrost and global warming have a **positive feedback relationship**, with each reinforcing the other.

4.64 Coastlines in many cold environments are susceptible to erosion if sea levels rise as a result of global warming. This vulnerable stretch of coast is north-east of Stafafell on the east coast of Iceland.

Another consequence of glacial retreat and thawing permafrost is that the frequency and size of **landslides** in cold and high environments increases. Water in liquid form on steep slopes acts as a lubricant, reducing cohesion and allowing

4.65 These buildings in Dawson City (Yukon, Canada) show what can happen when heated buildings are built on frozen permafrost. As a result of heating in the building, the permafrost melts, mixing soil with water, forming a paste into which the footings settle at different rates.

4.66 A landslip in the Rocky Mountains of Canada, near Jasper.

gravity to take over and cause **slope failure**. When permafrost melts and the ground slumps, the angle of a slope may become too steep to remain stable, thus triggering landslides.

Warmer temperatures in cold climates are likely to change the balance of **animal species** and their habitat distribution. Researchers predict that many areas, and the peoples within them, will have to adapt to the intrusion of new species and changing patterns of animal movement and **migration routes**. For indigenous peoples such as the Inuit of northern Canada and Greenland, changing distributions of fish could threaten the livelihood of large numbers of people who depend on **fishing** for their survival.

4.67 Indigenous people in Greenland depend on fishing for their survival and livelihood. Fishing in Arctic waters is threatened by global warming.

Indigenous peoples in polar and sub-polar areas depend for their survival on hunting animals such as polar bears, seals and caribou. These activities have always been an important part of indigenous people's cultural identity. As they have moved into the cash economy, this **hunting** has also come to be an important element of the local economies in places such as northern Canada, Greenland and northern Russia. With the threat of global warming, indigenous peoples such as the Inuit are concerned about the future of their traditional food sources.

Concerns have also been expressed by indigenous peoples about the increasing difficulties of **predicting the weather** in cold environments. This is a very important factor for people who depend heavily on the weather and have very little capacity to modify their environment. Indigenous peoples in polar and sub-polar areas have been reporting an increase of rainfall each autumn and winter and more extreme heat each summer. Many have expressed concern about their future if global warming continues.

At a United Nations University (UNU) conference in 2008, the plight of indigenous peoples as they face climate change was summed up by the UNU Director, Dr A Zakri, in these words: "Indigenous peoples regard themselves as the mercury in the world's climate change barometer. They have not benefited, in any significant manner, from climate change-related funding, whether for adaptation and mitigation, nor from emissions trading schemes. Most indigenous peoples practice sustainable carbon neutral lives or even carbon negative life ways which has sustained them over thousands of years."

The **retreat of glaciers** is one of the most obvious effects of global warming. The retreat of many glaciers has been measured for over a century, and in some places it is possible to see markers where the earlier limits of the ice were found.

The retreat of glaciers is expected to have a serious impact on the **economic activities** in cold and high altitude environments if global warming continues. Many of the economies of alpine areas depend on **tourism** which is based on skiing in winter and hiking in summer. It is clear that if the main attractions in the mountain environments of places such as Switzerland, Canada and New Zealand — the glaciers and the snow fields — disappear, then the economies of those places will suffer greatly unless they can adapt. They may have to develop new ways of attracting tourists, such as replacing skiing and snowboarding with attractions like cycling, horse riding and canoeing.

4.68 The marker locates the toe of the Athabasca Glacier near Banff, Canada, in 1959. Today the glacier has retreated out of sight, about 50 metres away behind the large hill of terminal moraine seen in the background.

QUESTION BANK 4F

1. *What are the primary and secondary consequences of reduced rainfall for people living in arid environments?*
2. *Describe an example of political conflict that is thought to arise from climate change.*
3. *Why are indigenous peoples especially vulnerable to the effects of climate change?*
4. *Explain the terms 'environmental migration' and 'environmental refugee'. Why is global climate change likely to increase environmental migration in hot, arid environments?*
5. *Why does climate change sometimes force people to migrate to the city?*
6. *What are the characteristics of settlements in hot, arid environments make them more resilient to global warming?*
7. *Why do melting ice caps pose a threat of coastal erosion?*
8. *What are the consequences of thawing permafrost, both for people living in cold environments and for future climate change?*
9. *How might global warming affect indigenous peoples in cold and high altitude environments?*
10. *Overall, do you think there is more potential for global climatic change to affect hot, arid environments or cold and high altitude environments? Give reasons to support your conclusion.*

Index