

7

Extreme environments

Cold and high altitude environments (polar, glacial areas, periglacial areas, and high mountains), and hot arid environments (hot deserts and semi-arid areas).

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Challenging Environments

Extreme Environments

In this chapter, two quite different extreme environments are examined. One type of extreme environment is **hot, arid environments**, which consist of 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.

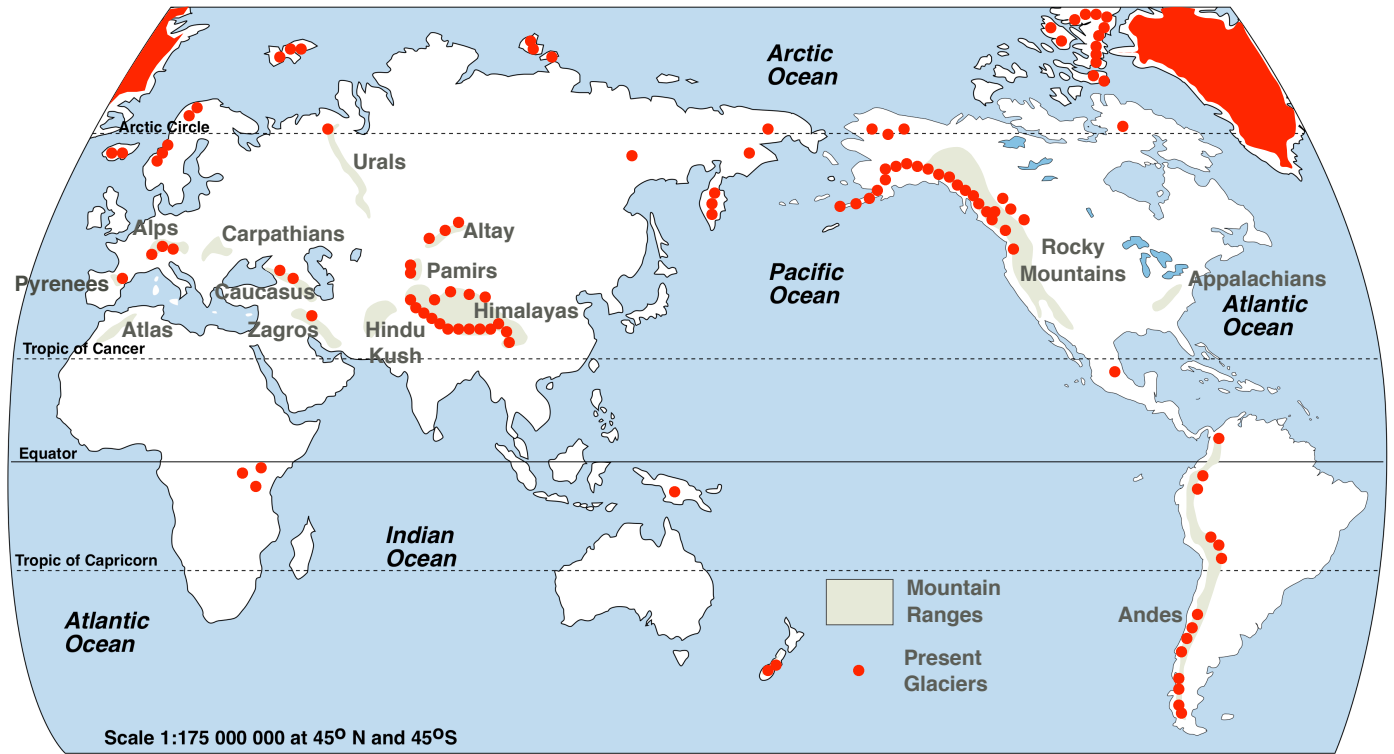
ToK BoX — Page 282 Perception and Theories of Reality

Global Distribution of Cold and High Altitude Environments

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 7000 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 7.1. The pattern of the mountain ranges is closely related to the pattern of tectonic plates that is shown in figure 8.2 in chapter 8. As shown in figure 8.3 (also in the next chapter), mountains form where two converging plates of light sial material meet. The sial buckles upwards forming complex folded mountain



7.1 The distribution of the world's mountain ranges and glaciers.

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.

Figure 7.1 also shows the locations of the world's **glacial areas**. 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. Although composed of solid ice, the glacier behaves 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. The areas adjacent to glaciers or ice sheets that experience repeated freezing and thawing are known as **periglacial areas**.

Why are Cold and High Altitude Environments Extreme?

In chapter 3, we saw that the amount of heat received at the earth's surface varies according to latitude. Figure 3.4 of chapter 3 shows that there is a net heat deficit from 38° north and south of the equator to the poles (90°).

To summarise the information detailed in chapter 3, there are three reasons that high latitudes (latitudes with high numbers) receive less heat from the sun than tropical areas. First, the sun's rays strike the earth's surface at a lower angle near the poles, meaning that an equivalent amount of solar energy is spread over a larger area in po-

lar areas than equatorial areas. Second, the sun's rays must penetrate a greater thickness of atmosphere near the poles than near the equator and therefore less heat reaches the surface. Third, a greater proportion of the heat that does reach the surface in polar areas is reflected back into space because the light shiny surfaces of the high latitudes, such as ice caps and snow, have a high **albedo** (reflectivity).

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

This transition is particularly evident in Nepal, which is situated just north of the tropical zone, between latitudes of 26°N to 31°N. The southern part of Nepal, known as the Terai, is really part of the low flat plain of northern India, and with an altitude of only 60 to 300 metres, it experiences high temperatures and the seasonal wet-and-dry of a monsoonal climate. In contrast, the highest mountains in the world — the Himalayas — make up the northern fringe of Nepal. Because of their high altitude, many of the peaks of the Himalayas are permanently snow-capped, even though they lie close to the tropics.

Switzerland, on the other hand, is situated further from the equator, lying between the latitudes of 46°N and 48°N. Therefore, Switzerland has a cooler, more temperate climate than Nepal. This is shown in the comparative temperature figures given in table 7.1.

Table 7.1

Average Temperatures in Selected Towns in Switzerland and Nepal

Town	SWITZERLAND						NEPAL					
	Geneva		Zürich		Saint Moritz		Biratnagar		Kathmandu		Jiri	
Altitude	375 metres		409 metres		1856 metres		72 metres		1336 metres		2003 metres	
	Min °C	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C	Max °C	Min °C	Max °C
January	-2	4	-3	2	-16	-3	10	22	2	18	-3	13
February	-1	6	-2	5	-14	0	12	26	5	21	0	14
March	2	10	1	10	-10	4	14	26	10	25	3	20
April	5	15	4	15	-4	8	20	36	11	29	6	23
May	9	19	9	19	0	13	24	33	16	31	12	26
June	13	23	11	22	3	18	25	32	19	28	17	24
July	14	25	13	24	5	20	26	32	20	28	18	24
August	13	24	13	23	4	19	26	32	20	28	17	24
September	12	21	10	20	2	16	25	33	19	28	16	23
October	7	14	7	13	-2	10	21	31	14	26	10	22
November	3	8	2	7	-8	3	15	29	8	24	3	19
December	0	5	-1	3	-13	-3	10	26	3	21	-1	15

Both Nepal and Switzerland have a variety of altitude zones. In Nepal, there are three main landform regions:

- The Terai region is the southern region, forming the border region with India. It comprises a long belt of alluvial plains, ranging in altitude from 60 to 300 metres. This belt is between 25 kilometres and 32 kilometres wide, and comprises 17% of Nepal’s area.
- The hilly region stretches across the middle of Nepal, and it ranges from 1,525 to 3,660 metres in altitude, making up 64% of the land area. This region contains some important rivers and valleys that support much of Nepal’s population. Among the important valleys are Pokhara in the west, and Kathmandu, which contains Nepal’s capital city.
- Bordering China’s province of Tibet in the north is the Himalayan region. This is the highest zone, and extends from 3,660 to 8,848 metres in altitude. There are 17 peaks higher than 8,000 metres, and over 240 snow peaks which are over 6,000 metres in altitude.

In Switzerland, the Alps comprise 60% of the country’s area. The other 40% of Switzerland is also elevated, comprising another lower mountain range, the Jura Mountains, near the French border (10%) and the Central Plateau the remaining 30%. The Swiss Alps are not as high as the Himalayas, with the highest peak (Dufour Summit) being 4,634 metres. There are several peaks well over

3,000 metres in altitude, including the famous Matterhorn at 4,478 metres, Jungfrau (4,158 metres), Mönch (4,099 metres) and Eiger (3,970 metres).

QUESTION BLOCK 7A

- Explain the distribution of mountain ranges and glaciers shown in figure 7.1.
- Plot the data shown in table 7.1 on a single sheet of graph paper. Then describe and explain the pattern shown.

Altitude and the atmosphere

There is a direct relationship between altitude, air pressure and temperature. This is shown by the average figures in table 7.2. The tendency for the atmosphere to become cooler with increasing altitude is the reason that countries that are situated fairly close to the tropics may have many high mountains with summits that are permanently covered in snow. To a large extent, the fall in temperature with increasing altitude mirrors the fall in temperature with increasing latitude (figure 7.2).

QUESTION BLOCK 7B

- Plot the data in table 7.2 on two graphs, one showing the relationship between altitude and air pressure, and the other showing the relationship between altitude and temperature.

2. Is rainfall more likely in areas of high air pressure or low air pressure? Use this information to predict on which parts of mountains (the tops or the bottoms) rain is more likely to fall.

Table 7.2

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

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 at high altitudes, temperatures of 80°C have been recorded in the Swiss Alps at 2,070 metres, the maximum ever recorded on the earth.



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

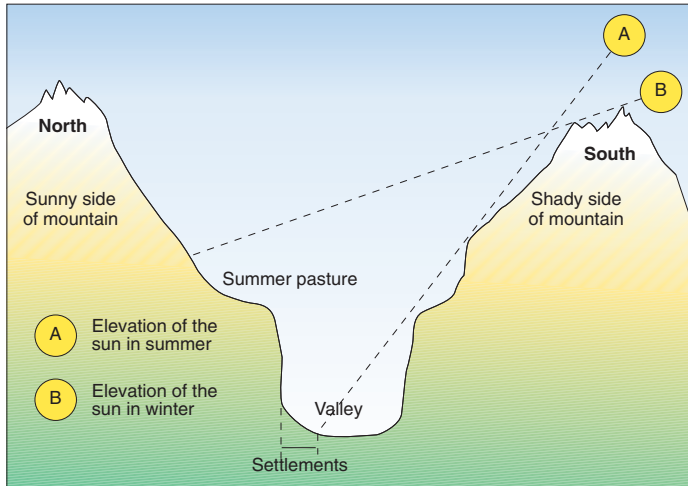


7.3 A typical house in Nepal, showing adaptation to the alpine climate. In Nepal, the houses are made from thick mud brick (adobe), which is an excellent insulator, and have small windows to contain heat loss. They are built on northern slopes to allow heating by the sun's rays.



7.4 In Switzerland, many houses are made from thick timber (a good insulator) and the roofs have spikes to reduce the risk of avalanches of snow from the roof.

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, and therefore temperatures vary greatly in alpine areas according to whether the sun is shining or not at the time. This is the reason that houses in mountainous areas tend to be well insulated (figures 7.3 and 7.4).



7.5 The effect of aspect on a mountain valley in the northern hemisphere.



7.6 Hills on the edge of the Southern Alps of New Zealand, north of Invercargill, are covered with snow on the southern sides, whereas the snow on the northern aspect facing the sun has melted.

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 which face towards the south (i.e. towards the equator) receive sunshine for longer intensive periods than slopes with a northern aspect (figures 7.5 and 7.6). 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, rising 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.

Because mountains change the circulation of air, mountain regions often have their own microclimates; for example windward slopes may receive heavy precipitation while leeward slopes remain almost desert-like.

Wind direction also changes with altitude, and isobars become almost parallel. Moreover, wind speed increases with altitude, sometimes creating gale force winds in one direction for hours or even days on end (figure 7.7). Exposed slope and summit winds are much stronger than those in the valleys, especially as there are 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.

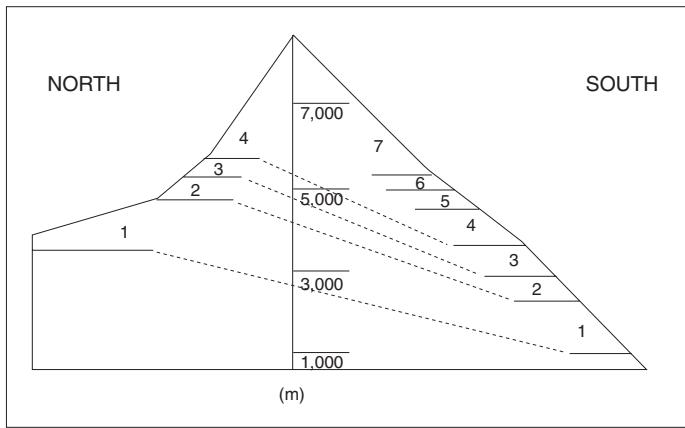


7.7 The strong winds blowing from left to right near the summit of this mountain in the Himalayas near Mount Everest are shown by the snow being blown from the tops of the arêtes.

Altitude and the biosphere

Because altitude affects temperature, mountain areas show a vertical series of bands of vegetation. The precise height at which one type of vegetation ends and another begins varies from mountain to mountain, but the pattern on Mount Everest is shown in figure 7.8. This pattern arises because of a combination of two factors – altitude and aspect. The upper limit at which trees can grow is called the tree line. On the shaded (northern) side of Mount Everest, the tree line is lower than on the sunny side (about 4,000 metres). In Switzerland, the tree line is lower than this, often at about 1,500 to 1,800 metres because of the higher latitude and cooler temperatures. Similarly, the snow line (the lower altitude limit of per-

manent snow) is lower in Switzerland than in Nepal – 2,700 metres on the Matterhorn in Switzerland compared with 5,500 metres on the southern slope of Mount Everest in Nepal (and 3,600 metres on the northern slope).



7.8 Vertical zones of vegetation on Mount Everest. The zones are as follows:

Northern Side	Zone	Southern Side
	7	Alpine névé (permanent snow) [above 5500 metres]
	6	Alpine frozen moraine lichens [5200 to 5500 metres]
	5	Alpine frozen meadow cushion plants [4700 to 5200 metres]
Alpine névé (permanent snow)	4	Sub-alpine cold bush meadow [3900 to 4700 metres]
Alpine frozen moraine lichens	3	Frigid-temperate mountain needle-leaf forest [3100 to 3900 metres]
Alpine frozen meadow	2	Warm temperate mountain needle-leaf and cushion vegetation broadleaf mixed forest [2500 to 3100 metres]
Alpine frigid semi-arid steppe	1	Sub-tropical mountain evergreen broadleaf forest [1600 to 2500 metres]

Because many alpine animals depend on vegetation for their food, the distribution of fauna is also arranged in altitude zones that parallel the vegetation zones. Animal species such as snow leopards, large cats, bears, eagles, wolves and bears are seldom seen in the lowlands where human habitation dominates the natural ecosystems. Furthermore, because of the hostility of highland climates, the number of species declines with increasing altitude. In Nepal, there are 600 different animal species recorded in the cloud forest zone of 2,000 to 2,800 metres altitude, but only 43 recorded species in the sub-alpine cold bush meadows above 4,200 metres. In the high altitudes, only birds of prey such as eagles, buzzards and falcons are found.

Cold-blooded reptiles cannot survive the cold temperatures of high altitudes. In the high altitude grasslands, some herbivorous animals with thick fur and coarse hair can be found, but they migrate down-slope during the winter months. In Nepal, for example, the highest dwelling mammals are yaks, which can adjust to altitudes as high as 6,100 metres.



7.9 Mount Everest, looking towards Tibet to the north from the Nepalese side.

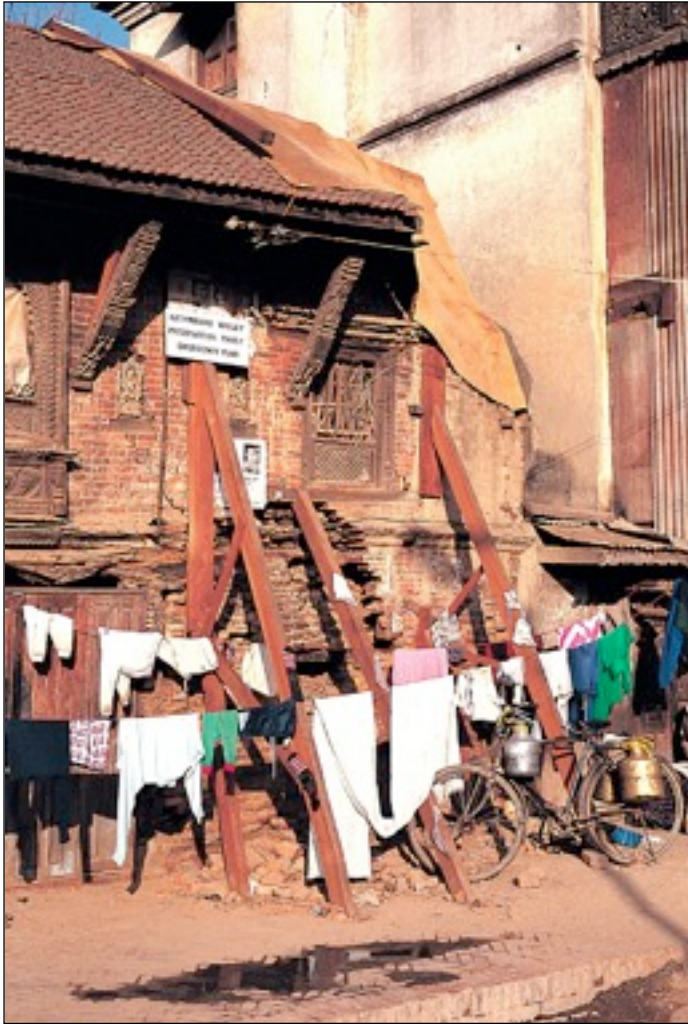
QUESTION BLOCK 7C

- How would the diagram in figure 7.8 be different for a valley in the southern hemisphere?
- Figure 7.9 shows the summit of Mount Everest from the southern (Nepalese) side. Using the information in figure 7.8, state the lowest altitude (in metres) that could be shown in the photograph.

Altitude and the lithosphere, and its effect of population

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 north 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 Bhutan and Nepal suffer from periodic earthquakes (figure 7.10). Particularly severe earthquakes occurred in Nepal in 1833, 1934 and 1988. In the 1988 earthquake, which measured 6.7 on the Richter scale, 121 people were killed, 66 000 houses were destroyed and over \$US100 million damage was caused.



7.10 An earthquake damaged house in Patan, Nepal.

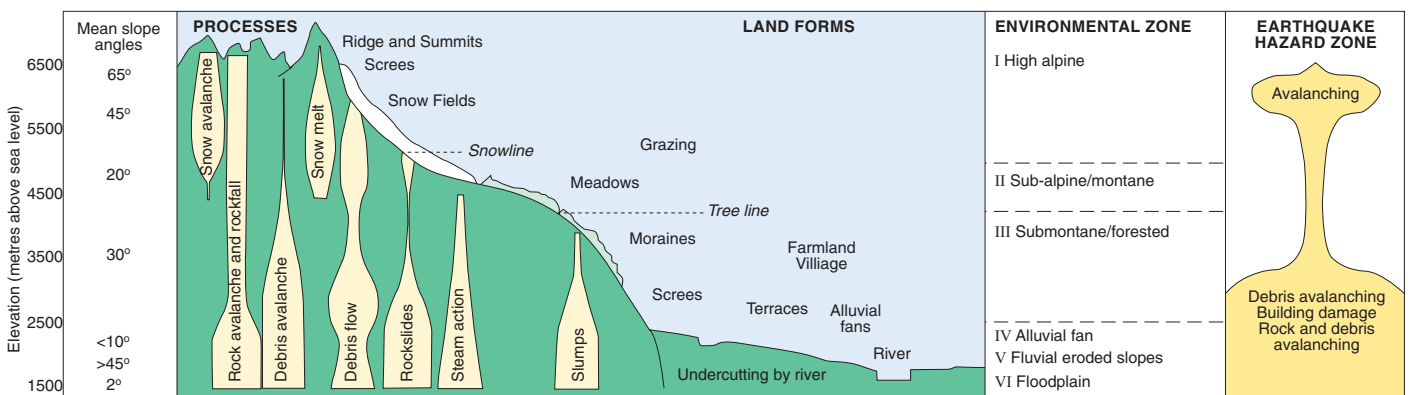
The Swiss Alps are also situated on the boundary between two crustal plates. The mountains are forming as the land is pushed upwards as the African Plate forces its way into the Eurasian Plate to its north. This is the same plate

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 Nepal. Moreover, being a more economically developed country (MEDC), 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.

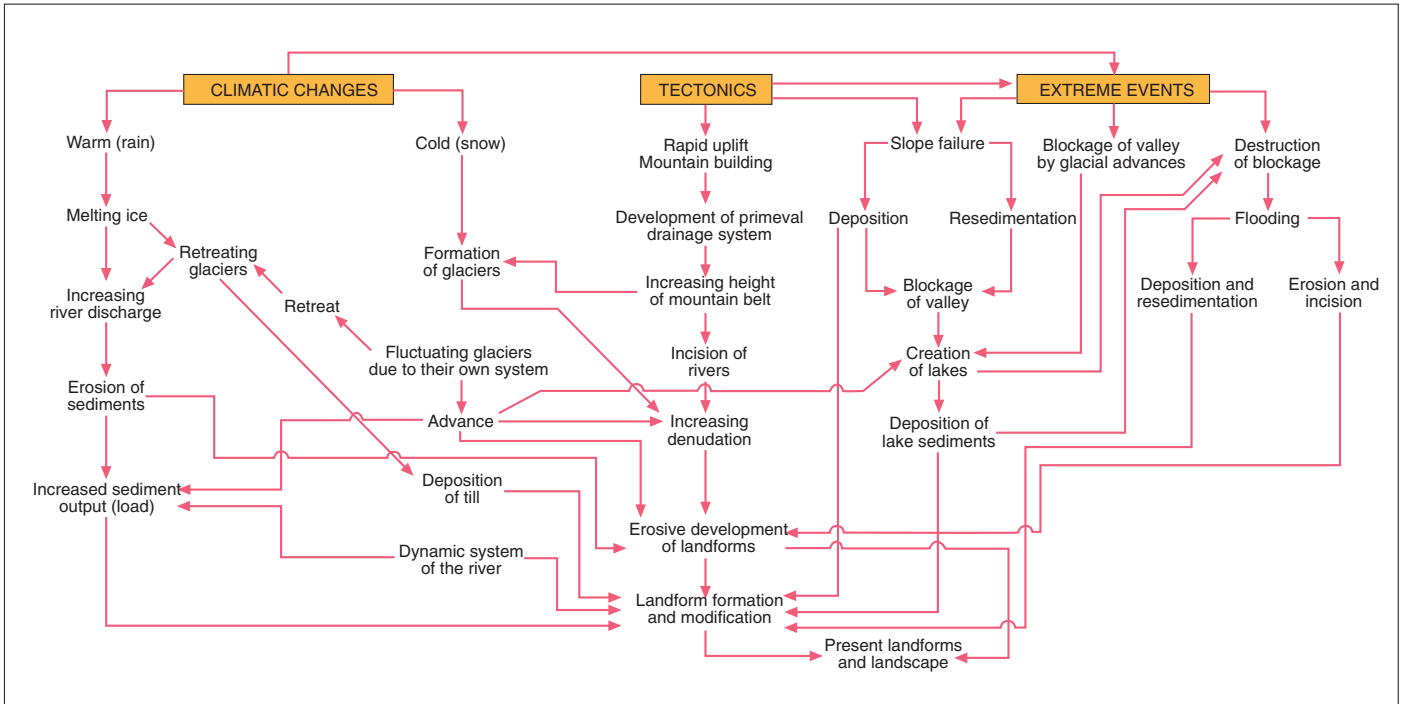
There are two altitude belts where snow avalanches occur. The first is above the snow line. In this zone, avalanches can occur all year round, although they are more common in the summer when some snows melt a little. These are not usually harmful to settlements because they stop in the cirque basins 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. A summary of the different landform hazards that affect people at various altitudes is shown in figure 7.11.

The high mountains of the world are geologically young structures formed by folding. Therefore, they have steep gradients and weak rock structures. The processes that have created today's high mountains are therefore quite complex (figure 7.12). The loose structures, steep slopes and the action of water and ice combine to make many areas unstable and prone to weathering, erosion and mass movement due to gravity. The high diurnal 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 7.13).

All these factors combine to limit the appeal of high mountains as areas of human settlement. The atmospheric and lithospheric hazards described above make the



7.11 The vertical zonation of landforms and landform hazards in Nepal.



7.12 The interaction between the different processes responsible for the evolution of the Swiss Alps and the Himalayas.

high mountains uncomfortable places for human habitation. The steep terrain also limits accessibility, making the high mountains somewhat remote. On the other hand, the steep slopes and cold climate can create excellent ski fields which attract those with the financial means to overcome the obstacles to access.

QUESTION BLOCK 7D

1. Explain how the physical characteristics of high altitude environments affects the density of population.

Why are 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 (figure 7.14). We can define an **arid environment**, or desert, as one where the potential evaporation exceeds the average precipitation. The land areas of the polar regions, and particularly the vast expanses of the Antarctic continent, are sometimes called ‘cold deserts’ because of the very low levels of precipitation that fall there. However, polar landscapes are not usually considered to be ‘arid’, and as the processes that operate on the landscape there are very different from the hot deserts, they are not discussed in this chapter. The term ‘cold desert’, or more correctly ‘cold winter desert’, is often applied to the arid regions of the mid-latitudes, such as those of Central Asia.



7.13 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.

We need to understand arid environments, and particularly the landforms found there, if we are to understand one of the world’s significant global environmental issues – desertification. **Desertification** is the process whereby deserts expand into semi-arid areas or become more intense. The expansion of deserts is a significant environmental issue in many

countries today, and it threatens the livelihood of many people, especially in the Less Economically Developed Countries (LEDCs).



7.14 Sand dunes in the Namib Desert, north-western Namibia.

Traditionally, deserts have been described in terms of deficiencies – rain, soil nutrients, vegetation and population. We now understand that many desert areas have quite fertile soils, and can be very productive if managed wisely. Furthermore, most desert areas have quite an abundance of vegetation and wildlife, although the species found in deserts have made significant adaptations to cope with the aridity. It is important that aridity is not confused with infertility.

Deserts do not have clearly defined boundaries. They are bordered by semi-arid lands, and these in turn have sub-humid margins. Each of the climatic zones merges with the next. Nonetheless, about one-third of the world’s surface can be classified as arid or semi-arid, and

as a result of desertification, this figure is probably growing.

Moisture deficit defines deserts

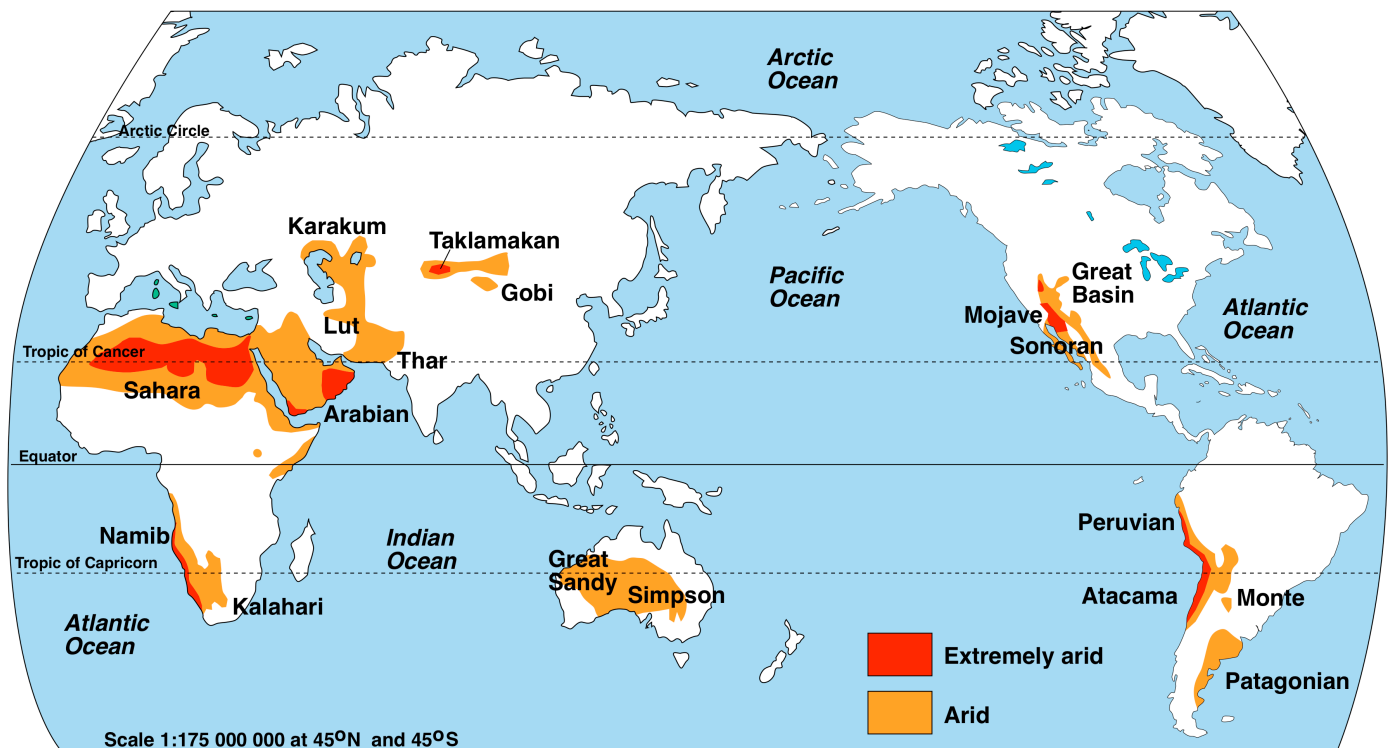
Regardless of the type of desert, it is the lack of rain that determines the characteristics of an arid environment. However, lack of precipitation is not the only influence. Some very dry areas have a significant vegetation cover, and they could at first sight be mistaken for a semi-arid or sub-humid 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 soil characteristics, because good soils that can hold water helps the growth of vegetative, whereas poor soils, or thin immature soils such as skeletal soils or lithosols, which lead to run-off of rain, may have difficulty in supporting vegetation at all. Furthermore, human activities, especially grazing, can cause such deterioration of semi-arid and even sub-humid lands that they lose their natural vegetation, suffer badly from soil erosion, and come to resemble deserts. Such deterioration is a cause of desertification.

Global Distribution of Arid Environments

The distribution of the world’s deserts – arid and semi-arid lands – is shown in figure 7.15. There are four important groups of deserts, although the differences between them are not always precise.

Cold winter mid-latitude deserts

The most important cause of the mid-latitude deserts of Central Asia is remoteness from sources of atmospheric



7.15 The distribution of the world’s deserts.

moisture. In these areas, rain-bearing winds have to cross great expanses of land and high mountain ranges before reaching the interior of the continent. As the winds travel inland, they lose most of their moisture. Consequently, a group of 'cold winter deserts' extends from latitude 35°N to latitude 50°N, and beyond. The most important cold winter deserts are the Karakum Desert of Kazakhstan, Uzbekistan and Turkmenistan, and the Gobi Desert of north-western China and Mongolia (figure 7.16). These deserts have extremely cold winter temperatures.

Rainshadow deserts

When a moist air mass is forced to rise over a mountain barrier, it cools adiabatically, dropping precipitation on the windward side of the mountains that 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, 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.

Deserts of the subtropical highs

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 30° 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, and sometimes by the old term 'horse latitudes'.

The world's largest desert, the Sahara, is an example of a subtropical high pressure desert. Other examples found

in the northern hemisphere are the deserts of Arabia, Iran, north-west India (the Thar) and the Sonora desert of North America. In the southern hemisphere, the Kalahari Desert of southern Africa, and most of the desert areas of Australia are of this type.



7.16 Part of the Karakum Desert in central Turkmenistan.

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, and stabilises it. Although the cooling process often leads to fogs (a form of condensation), there is not usually enough atmospheric activity to cause rain.

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. In the southern hemisphere, important west coast deserts include the Peruvian and Atacama deserts of South America, the Namib of southern Africa, and the coastal parts of the Great Sandy Desert in Western Australia.

The arid environments discussed in this chapter will focus on hot, arid areas (hot deserts and semi-arid areas).

QUESTION BLOCK 7E

1. Explain what is meant by the term 'arid environment'.
2. What is desertification?
3. Draw up a table which lists the four types of deserts, summarises the cause of each, and gives two examples of each.

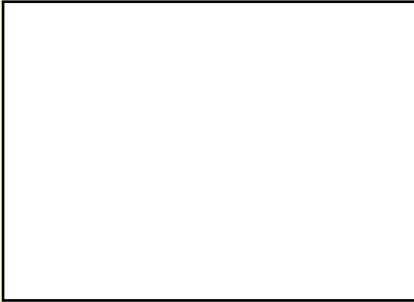
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Perception, and the Theories of Reality.

An ancient Chinese proverb says “Two-thirds of what we see is behind our eyes.”

Consider the illustration below:



When asked to describe it, various people will suggest different things, such as ‘nothing’, ‘a white rectangle’, ‘a white cat in a snowstorm’, or perhaps ‘fibres of paper emitting light of uniform wavelengths’. As the French author Henri Thoreau (1817-1862) commented, “It’s not what you look at that matters, it’s what you see”.

Similarly, when many people asked to describe what they see when they are looking at a desert, they reply ‘nothing’.

The word ‘perception’ is often misused. When two people are having a disagreement, a common expression is “well, that’s my perception”, when they are really trying to say “well, that’s my opinion”. The title of this chapter is ‘Extreme Environments’, but should we argue that whether or not an environment is ‘extreme’ depends on each individual’s perception? An Inuit person from the north of Canada, for example, may argue that the urban environment of Tokyo is ‘extreme’.

It is important to remember, however, that perception is NOT the same as opinion, or understanding, or perspective. It would be a wrong use of the word to say something like “my perception is that Tokyo’s environment is challenging”.

Perception is the awareness of things through our five senses — sight, sound, touch, taste and smell. Some researchers refer to additional senses, such as intuition and sense of balance.

Unfortunately, our senses can be easily tricked into providing false information or incomplete information. Optical illusions are an obvious example of this. In geography, the important thing to remember is that even our own observations may not be as they first appear, and some cross-checking (such as through other people or using some of our additional senses) may be helpful.

In order to overcome the shortcomings of perception, philosophers have developed **theories of reality**, of which three are commonly discussed.

One theory of reality is known as **common-sense realism**. With this approach, the way we perceive the world mirrors the way the world is. Of course, as mentioned above, what we perceive is determined in part by our five senses, so maybe there are good reasons for rejecting the reliability of common-sense realism.

An alternative approach is **scientific realism**. With this approach, the world exists as an independent reality, but it is very different from the way we perceive it. The familiar, comfortable, sensuous world of our everyday experience is replaced by a colourless, soundless, odourless realm of atoms whizzing about in empty space. Consider Sir Arthur Eddington’s description of a kitchen table as an example of scientific realism:

“It does not belong to our comparatively permanent and substantial world, that world which spontaneously appears to me when I open my eyes. My scientific table is mostly emptiness. Sparsely scattered in that emptiness are numerous electric charges rushing about with great

speed; but their combined bulk amounts to less than a billionth of the bulk of the table itself. Notwithstanding its strange construction, it turns out to be an entirely efficient table. It supports my writing paper as satisfactorily as an ordinary table, for when I lay the paper on it the little electric particles with their headlong speed keep on hitting the underside, so that the paper is maintained in shuttlecock fashion at a nearly steady level. If I lean upon this table I shall not go through; or, to be strictly accurate, the chance of my scientific elbow going through my scientific table is so excessively small that it can be negated in practical life”.

The third theory of reality is known as **phenomenalism**. With this approach, matter is simply “the permanent possibility of sensation”. Therefore, it makes no sense to say that the world exists independently of our experience of it. A phenomenalist would interpret “there are tables in the room at school” not as the physical presence of tables, but if you go into the room you are likely to have various table-experiences.

Phenomenalists make no claim that the world does not exist beyond our experience of it, because that too would be to make a claim that goes beyond the limits of our experience. Phenomenalists claim that beyond our experience of reality, there is simply nothing to be said, and that humans have no right to speculate about things we have not perceived or the nature of ultimate reality.

The three approaches can be summed very simply as follows:

Common-sense realism: “What you see is what is there”.

Scientific realism: “Atoms in the void”.

Phenomenalism: “To be is to be perceived”.

The next ToK BoX is on page 345.

Physical Characteristics of Extreme Environments

Processes Operating in Glacial Environments

As discussed in chapter 3, the earth has experienced many changes in climate through its history. The planet is currently experiencing an unusually warm period – the average climatic conditions of the planet suggest that the

‘normal’ state of the world is more like an ice age than the conditions we experience today.

When the earth cools, the ice caps and glaciers expand, retreating again when the climate warms. Although we do not understand the reasons, the warming and cooling of the earth occurs in broad cycles, and we experience severe ice ages about every 200 to 250 million years. Ice ages are known as **glacial periods**, and the warmer periods between ice ages are known as **interglacials**.

During the last ice age, which ended about 12,000 years ago, ice covered about 30% of the earth’s surface – about

three times more than today. The ice caps spread further from the poles in both the northern and southern hemispheres, and ice and snow cover descended to lower altitudes than we find them today. Therefore, we find evidence of glaciation in parts of the world today that are located quite long distances from today's ice caps and glaciers, both in terms of latitude and altitude.

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 temperatures are cold enough, many streams flowing from higher altitudes take the form of **glaciers**, or 'rivers of ice' (figure 7.17). 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.

fresh water, 80% is stored in ice and snow, and thus glaciers are an important resource. Moreover, without the meltwater from glaciers, many rainshadow areas would be deserts or semi-arid grasslands.



7.18 A U-shaped valley in the Altay Mountains of western Mongolia.

One of the most noticeable features arising from this process is the **U-shaped valley**, or **glacial trough**, in which the valley floor may be quite flat and the sides extremely steep (figures 7.18 and 7.19). This is the shape left behind by a glacier after it has scraped and plucked rocks from the sides. In general, these valleys were formed originally by another process such as a river in warmer times or land shaped by lava flows. Quite often the abrasive action of the glacier on the valley sides will lead to major **landslides** onto the surface of the glacier, increasing the angle of the valley sides further and adding dramatically to the surface moraine on the glacier (figure 7.20). Furthermore, meltwater from the glacier can seep into cracks in the rock and as it refreezes and expands it loosens more rock to be carried away by the glacier.

High tributary valleys which fed 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 (figures 7.21 and 7.22).

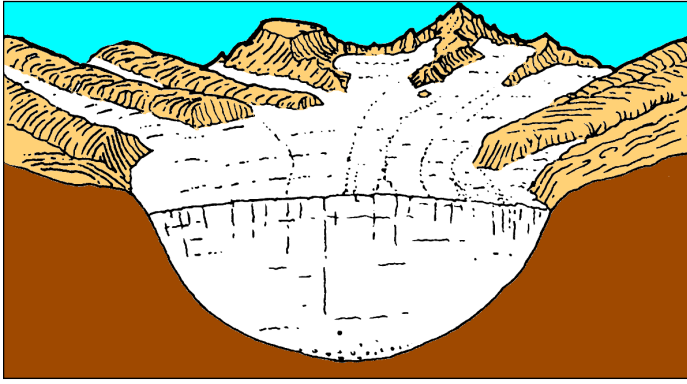
In some cases the high tributary valleys will themselves leave distinctive features because of the special action of small glaciers near high alpine peaks. The best known are **cirques**, which are dish-shaped hollows eroded by these glaciers as the ice rotates under the force of gravity. When the ice retreats, the result is often a small lake called a **tarn** and maybe a waterfall (figures 7.23 and 7.24).

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

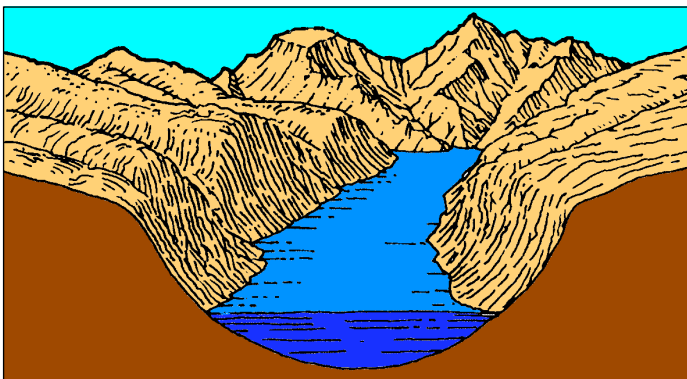
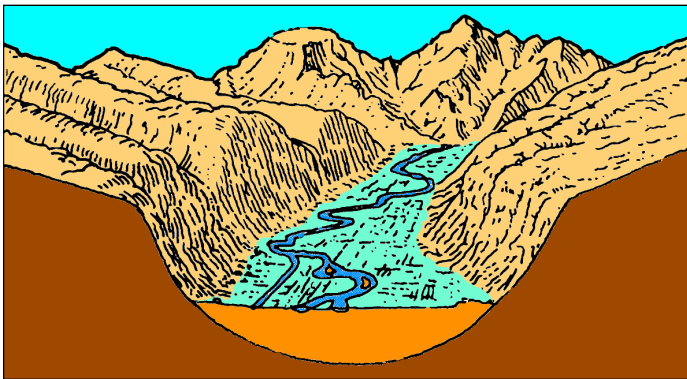
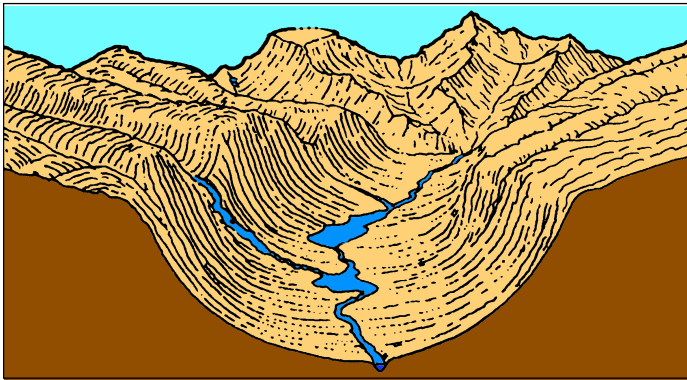


7.17 Two views of the Potanini Glacier in the Altay Mountains of western Mongolia near the border with Russia, China and Kazakhstan. The lines of moraine in the upper view indicate the direction of flow through the U-shaped valley. The lower view shows a closer view of the rough surface of the glacial 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. Of the world's



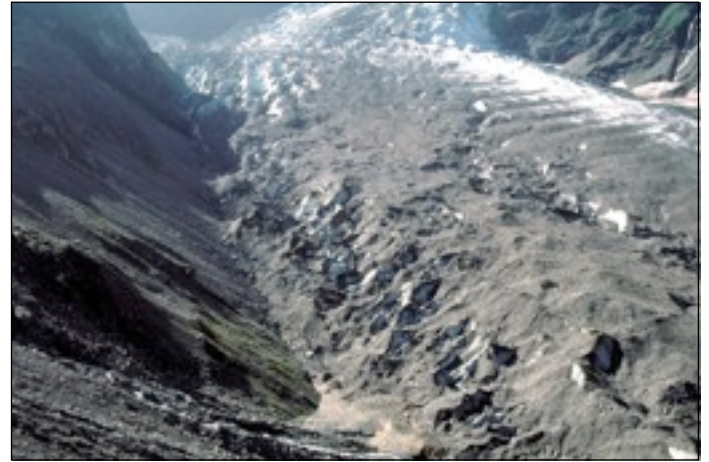
is because even the rock fragments that fall because of freeze and thaw action in any exposed mountain peaks are often buried by the next snow fall. In the middle and lower sections of the glacier, the surface is usually very convoluted with a mixture of dangerous **crevasses** and tall ice peaks (figure 7.29). These 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 (figure 7.30).



7.19 The process of the formation of a U-shaped valley.

backwards into themselves, a narrow, steep, rocky ridge called an **arête** forms. An example of an arête can be seen to the right of the U-shaped valley shown in figure 7.25. When an arête is reduced to a single rocky peak by ice erosion on all sides, the angular remnant is termed an **horn** (figure 7.26).

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 (figures 7.27 and 7.28). This



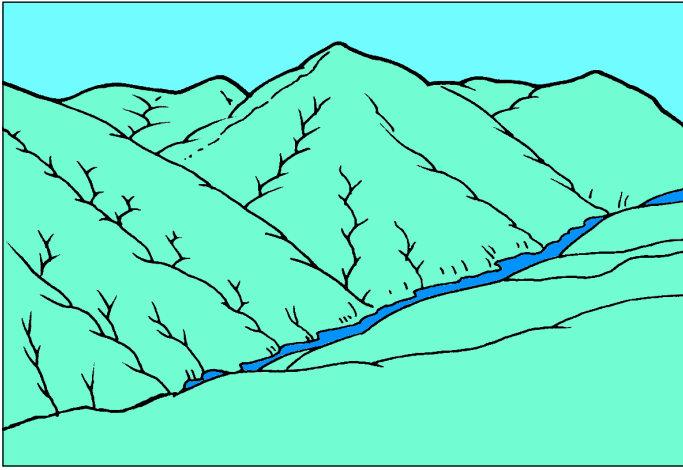
7.20 Surface moraine on a glacier near Grindelwald, Switzerland.



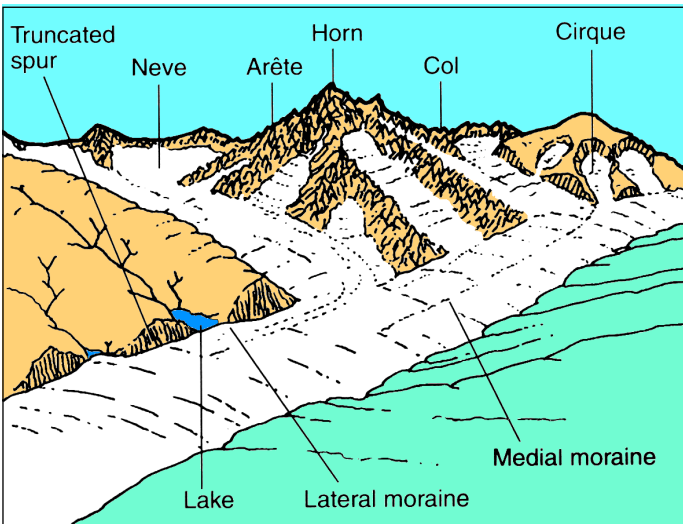
7.21 Waterfalls plummet from hanging valleys in a former glaciated area of Yosemite National Park, USA.

Spectacular **fjords** are formed when glaciers carve valleys that reach or reached the sea, or where sea level rose after the last ice age to flood deep U-shaped valleys. The Atlantic Coast of Norway, the Alaskan Coast and New Zealand's Fjordland are the best known examples of coastlines dominated by fjords. Here the steep sides of the valleys extend into the water resulting in a great depth of water even right at the shoreline (figure 6.41 in chapter 6).

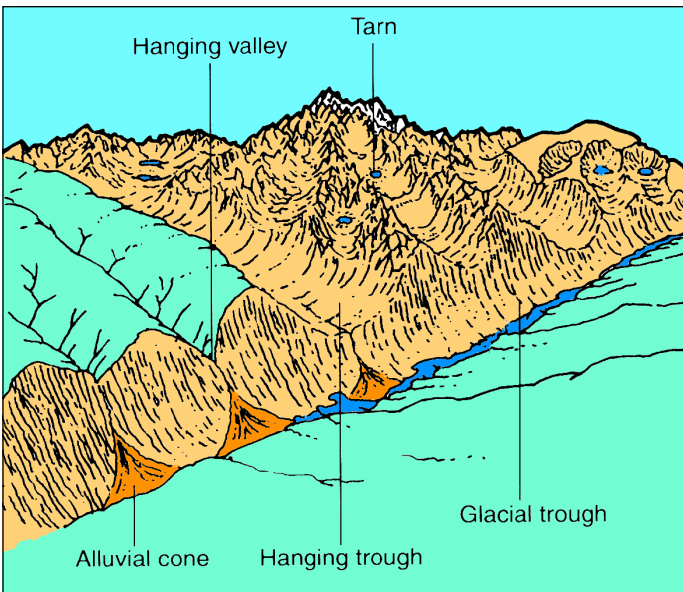
As glaciers flow down-slope, they erode and carry material from the sides of the valley. Evidence of the scraping action of glaciers can often be seen by **striations**, which are small scratches on the surface of the rocks on the sides of a glacier that were made as the ice moved slowly



7.23 A tarn, Snowdonia National Park, north Wales.



7.24 Tarns in cirques, fed by glaciers, Swiss Alps.



7.22 The formation of hanging valleys and other typical glacial landforms.

downhill, carrying smaller rocks as it did so (figure 7.31). 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.

7.25 Arêtes along the right hand edge of a small glacial valley in the Andes Mountains, east of Santiago (Chile).



Rocks and sediment that is carried by a glacier is called **moraine**. Rocks that are carried on the sides of glaciers are known as **lateral moraine**. We can say, therefore, that striations are caused by lateral moraine being scraped against the rocks at the side of a glacier by the moving ice.



7.26 A horn near Zermatt, Switzerland.

is to examine the terminal moraine that has been left behind after the ice has melted.

The ice at the bottom of glaciers may be centuries old. When the ice forms it traps tiny bubbles of air, and studying these bubbles in centuries-old ice helps us to analyse long-term changes in the earth's atmosphere and air pollution. In spite of their huge size, most glaciers are receding and it is feared that several will disappear in the decades ahead (figure 7.35). Although many people claim this is due to global warming, the fact that glaciers in some places are advancing has called this explanation into question. Some scientists suggest that glacial retreat may be due mainly to fluctuations in local rainfall conditions, such as drier conditions, rather than global warming, and cite the example of Mount Kilimanjaro in Tanzania as an example of this.



7.27 A nevé (snow field) feeds a glacier in the Altay Mountains of western Mongolia.



7.29 The surface of most glaciers is very rough, being marked by cracks and crevasses. This example is in southern Iceland.



7.28 This nevé feeds a glacier which in turn feeds a tarn in central Switzerland.

A moving glacier also collect rocks and sediments that have fallen from the sides of the valley onto its surface, and this is known as **surface moraine** (figure 7.32). 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** (figures 7.33). All 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** (figure 7.34). One way to measure the rate of retreat of a glacier



7.30 This surface crevasse is being deepened by the flow of melting water during the summer melt period.

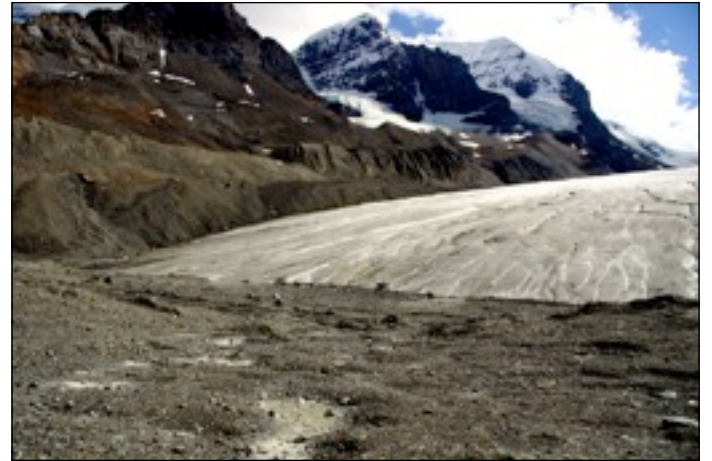


7.31 Striations on the rocks in this glacial valley in Mongolia were made when the moving ice scraped rocks along the edges of the valley. Two sets of scrape lines can be seen, indicating at least two periods of advancing ice. The animal carvings have been cut into the striations, proving they were made after the last ice age.

As ice sheets and glaciers expand, the scraping action of the ice has a drastic erosive impact on the surface beneath. When the ice erodes down to bedrock, it can form teardrop shaped hills that have a streamlined appearance. These are called **roches moutonnées**, and they have smooth gently sloping ends and sides with a steeper lee-ward side that may be either smooth or plucked (figure 7.37). The size of roches moutonnées can vary greatly from miniature examples to large hills.



7.32 Surface moraine on the Potanini Glacier in western Mongolia.



7.34 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 near Banff in the Canadian Rocky Mountains.



7.33 The lateral moraine of two glaciers joins to form medial moraine in this glacier near Zermatt, Switzerland.

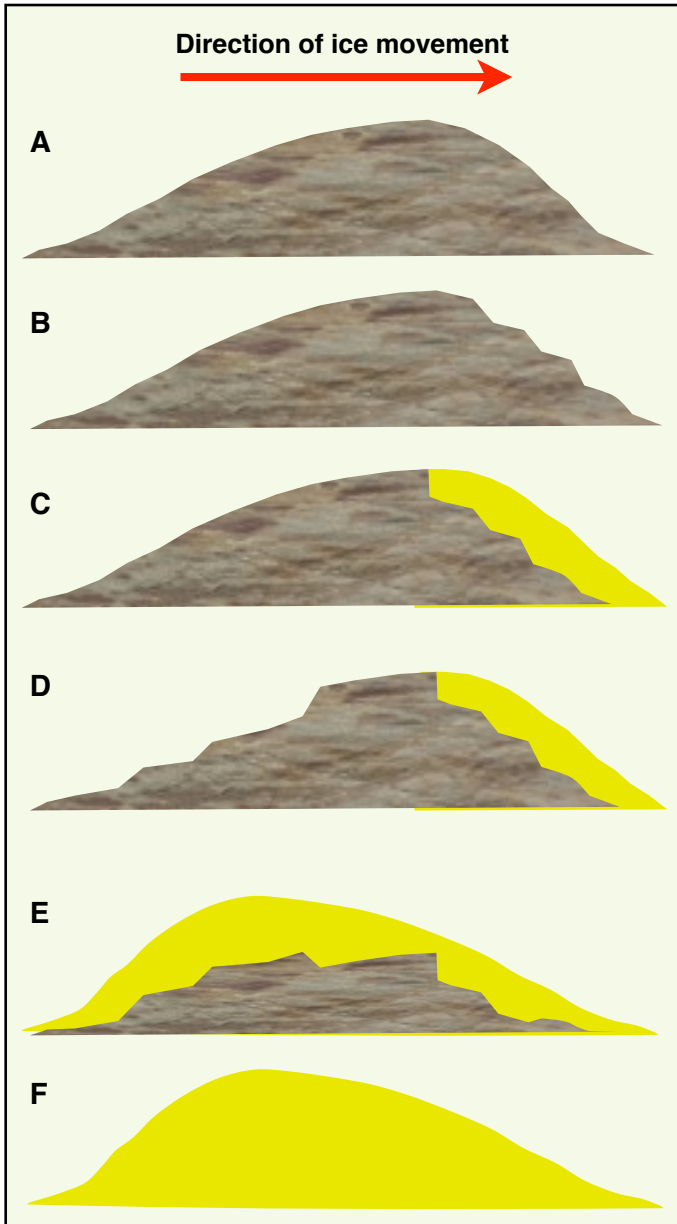


7.35 Another view of the Athabasca Glacier, giving some idea of the glacial retreat since 1992.

Outwash plains form when the meltwater streams from glaciers deposit gravel, sand and moraine from glaciers each year during the summer retreat (figure 7.36). Where the outwash of many glaciers has combined, extensive outwash plains may develop. The Canterbury Plains of New Zealand are 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.



7.36 The extensive outwash plain of the Skaftafell Glacier, southern Iceland.



7.37 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.

Sometimes, 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** and they can vary considerably in shape and form (figure 7.37).

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 (figure 7.37). Although the shape can vary, drumlins 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 academic 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.

Erratics are rocks that are made of a different material from the type of rock native to the area where it rests (figure 7.38). 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!



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

QUESTION BLOCK 7F

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.

Processes Operating in Hot Arid Environments

Before we can explain the processes operating in hot arid environments, we must understand aridity. Aridity, or lack of moisture, is the key characteristic of deserts, but how can aridity be measured?

The degree of aridity is governed by the amount of moisture at ground level. This is heavily influenced by the degree of evaporation, which is in turn determined mainly by temperature. Therefore, the driest deserts are those that experience both low rainfall and high temperatures. It follows that tropical and subtropical deserts are drier than deserts with the same rainfall in mid-latitudes. This is because mid-latitude deserts are affected by seasonal changes, and they experience much lower temperatures in winter than in summer.

Several systems have been worked out for determining the degree of aridity for an area, and for drawing climatic boundaries. Most of these are based on climatic formulae, and some of them are quite complex. The most commonly used system was developed by a scientist called Meigs, and the map of the world's arid lands in figure 7.15 is based on his calculations. As a generalisation, we can assume that most subtropical deserts have a mean annual rainfall of less than 250 mm, while mid-latitude deserts (where evaporation is lower) have less than 200 mm. It is more difficult to suggest a simple definition for semi-arid environments, because more variables can affect them. In southern Australia, most areas with a rainfall less than 450 mm would be regarded as semi-arid.

There are no areas, even in extremely arid deserts, where it never rains. However, 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.

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 occur in arid environments. It used to be thought that most desert rain comes from thunderstorms, and it is true that thunderstorm rain is characteristic of a few deserts, like the Sonora desert in the United States. However this is not generally the case, and it is certainly not the case in Australia except for the far north-west, which experiences summer monsoons and tropical cyclones.

Temperatures in arid regions are notable for their large **diurnal** (or daily) range; the exception to this is deserts on sea coasts. 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 37.8°C. 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; 58°C.

Although the diurnal range is great, there is little **seasonal** change in temperatures in equatorial deserts. In subtropical deserts, however, the variation between summer and winter temperatures may be great, especially at high altitudes. In the mid-latitude deserts, seasonal variation is extreme. Summer temperatures in parts of the Turkestan desert may rise as high as 54°C, while winter lows may sink to -26°C, or even lower. This extreme seasonal range is more than 80°C.

Water is lost to the atmosphere by evaporation directly from the ground surface, and also by transpiration from vegetation. Together, these losses are known as **evapotranspiration**. The evaporation loss from a free water surface in an arid region is many times greater than the precipitation, a fact that causes concern to those storing water in lakes and reservoirs. Even on the rare occasions that rain falls, the dry air and high temperatures above the desert often cause the water to be evaporated even before it reaches the ground (figure 7.39).



7.39 Rain from this evening shower above the Mojave Desert in the USA is evaporating even before it reaches the ground.

Why then is there any water at all in the ground? When rain falls, some water evaporates immediately from the ground surface, some runs off to accumulate in local depressions, and the balance is absorbed by the soil. Moisture in the soil is to some extent protected from evaporating as it is not directly exposed to the atmosphere, and it is this moisture that enables desert plants to grow.

If soil water builds up to the extent that saturation point is reached, then a water table is established, and water from it may be tapped by wells and bores. Sometimes natural depressions are deep enough to cut into the water table, so that permanent or semi-permanent water is available at or near the surface. These areas, known as **oases** (singular **oasis**), can support vegetation and even cultivation because of the availability of water, and some of the oases in the Sahara are depressions of this type (figure 7.40). Not

all water tables yield fresh water; often it is saline and may be unfit for use.

Artesian water is groundwater trapped in porous beds, known as **aquifers**, by relatively impervious beds above and below called **aquicludes**. The source of artesian water is usually far away from the desert, often in the mountains where orographic rain falls before reaching the rain-shadow area of the desert. The rain infiltrates the aquifer and eventually seeps down to the area under the desert. The artesian water is under pressure since it has come from higher altitudes. Therefore, when an artesian aquifer is pierced by a bore, water rises to the surface, and sometimes above ground level. Artesian water was discussed in more detail in chapter 5.



7.40 The oasis of Tinerhir on the western edge of the Sahara Desert in Morocco. Date palms cultivation is possible because of the availability of water in the low valley. The aridity of the surrounding areas can be seen clearly in the background.



7.41 Wind sweeping across this area of desert between Goulmime and Er Rachidia in Morocco, is causing a dust storm as it erodes the surface soil.

Arid areas are notoriously windy, and this can lead to widespread erosion (figure 7.41). One reason for this is the sparse vegetation, because the frictional drag of trees and shrubs (where they are present) can be significant in reducing wind velocity near ground level. Moreover, most of the world's arid lands are comparatively flat or undulating, with little to obstruct the passage of the wind.

One significant cause of wind in the desert is convection. Each day, the sun rapidly heats the ground and the dry air above it, and as this air expands and rises, cooler air from elsewhere rushes in to replace it. Then, with falling temperatures towards sunset, the wind may gradually drop. Most desert nights are cool and still. There is more to wind behaviour in the desert than simple convective replacement of air, however. Most of the subtropical deserts are subject to the influence of anticyclonic swirls. The influence of the seasons can also be very pronounced. Indeed, some desert winds are so regular in their seasonal patterns that they are known by specific names, such as the Sirocco that blows from North Africa across the Mediterranean Sea into Europe, and the Khamsin that blows towards the south-east from North Africa and Arabia.

QUESTION BLOCK 7G

1. What is a typical rainfall in an arid environment? Is this figure the same for all parts of the world?
2. Describe the rainfall variability of arid environments.
3. Comment on the (a) diurnal and (b) seasonal fluctuations in the temperatures of arid environments.
4. How do oases form?
5. Why are arid environments so windy?

Weathering in Hot Arid Environments

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 essentially physical weathering. It was argued 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 in fact it is generally more effective than physical weathering. In any case, most chemical and mechanical processes are not mutually exclusive, but operate together and supplement the work of the other.

Because arid environments experience large diurnal ranges of temperature, we might think that **insolation weathering**, which shatters the rock by alternate heating and subsequent rapid cooling (causing expansion and contraction) is an important weathering agent (figure 7.42). In deserts, the temperature of the ground surface may be 20C° hotter than the air temperature. Rock sur-

face 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 temperature gradient is so steep, stress is placed on the surface of the rock as it expands relative to the rock beneath. Perhaps 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.



7.42 Exfoliation, or onion skin weathering, causes sheets of a rock to fall away like layers of skin on an onion. It is thought to be caused by insolation weathering.

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 tends to break down the rock.

Another process that was once thought to be important, particularly with respect to undercutting rock masses is **sand blasting**. This process was thought to produce **pedestal** or **mushroom rocks**, which are found in some arid regions. There is no doubt that sand blasting can weather soft materials at ground level. Wooden telegraph poles erected last century across inland Australia were undercut in this way, and blasting can also be responsible for polishing rock faces at or close to ground level. However, it is now known that most undercutting of hard rock is due to chemical weathering. 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 dominantly the result of chemical weathering.

It is important to remember that most of the world's deserts are old enough to have experienced episodes 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 under conditions of aridity, and once the climate has changed from humid to arid, the erosion of features produced by weathering in a former humid environment is a very slow process indeed.

QUESTION BLOCK 7H

1. 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.
2. How could past climatic changes have affected arid environments?

Weathering and Landform Development in Hot Arid Environments

It is very significant that all weathering processes are extremely slow in arid environments, because weathering is the initial process in the sequence of events that leads to the development of arid 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 rate of landform development is ultimately dependent on the rate of weathering. It follows from this that landform development is much slower in arid than in humid environments.

Weathered products are removed from rocks 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 (figure 7.43). Furthermore, rock faces tend to be angular and sharp as opposed to the more rounded shapes found in humid environments. Soft rocks that erode easily may give rise to a complex of steep, narrow valleys and knife-edge ridges known as **badland topography** (figure 7.44).



7.43 Bare rock surfaces dominate the desert environment in many desert areas, such as here at Wadi Dhar in Yemen.



7.44 This example of arid mountains with badland topography in the foreground is in Death Valley, California (USA).



7.45 The layered bands of rock in the geology of this area in north-western Namibia have a strong influence on its appearance.

The bare rock surfaces of and hills and mountains tend to accentuate the geological 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 (figures 7.45 and 7.46). Furthermore, the slow rate of chemical 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 (figure 7.47).



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



7.47 Uluru, or Ayers Rock as it is also known, is the world's largest monolith.

QUESTION BLOCK 7I

1. *What is the impact of the slow rate of weathering in arid environments on the development of landforms?*

Water and Landform Development in Hot Arid Environments

Although water is scarce in arid environments, it plays a very important part in erosion, transport and deposition. In fact, 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 humid regions. In some areas, a thin platy layer of fine sediment caps the soil and this resists penetration by water. Much bare soil is exposed in arid areas, and this favours 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.



7.48 The Colorado River, seen here flowing through the Grand Canyon, is an exotic stream that has its source in mountain areas with a high rainfall, well away from the desert. The deep canyon has been eroded by this river.

Very few streams in arid regions flow to the sea. There are exceptions, such as the Nile, the Indus, and the Colorado, which have their catchment areas in heavy rainfall country outside the desert boundaries (figure 7.48). Such rivers are known as **exotic rivers**, because their source is outside the desert area. Most streams in arid environments follow patterns of **internal drainage**, where

streams are ephemeral, and either dissipate on the desert surface or terminate in local depressions where water collects briefly, then evaporates (figure 7.49). The ephemeral lakes formed 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, calcite and gypsum (figure 7.50). Dry lakes are common landforms in arid environments, and their beds are very conspicuous when white, salty surfaces are exposed.



7.49 An ephemeral stream in western Oman, near Wadi Hatta.



7.50 Evaporites surround Lake Assal a large heavily saline lake in Djibouti.

The ephemeral streams of arid regions, known as **wadis** in Arab countries, **arroyos** or **washes** in North America, and **dry creeks** in Australia, have many features in common with those in humid landscapes (figure 7.51 and 7.52). However, some characteristics, particularly those relating to channel patterns, are a distinctive part of an arid environment.

Alluvial fans are characteristic features that may develop in a variety of climatic regions. 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 plain, 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 (figure 7.53). Arid environments are very well suited to alluvial fan development because they are prone to flash flooding. Furthermore, they have hillslopes that erode easily and therefore provide alluvial material suitable for deposition.



7.51 A wadi in Oman, near the UAE oasis of Wadi Hatta.



7.52 The vegetation in the bed of this dry stream in Namibia indicates the presence of underground water.



7.53 A number of alluvial fans have joined together to form a bajada where several ephemeral streams flow from the hills down to the valley near Ulgii (Mongolia).

In many deserts, several nearby streams flow from the same mountain scarp to form alluvial fans. When this happens, the edges of adjacent fans usually coalesce to build up a continuous mantle of deposition known by the

Spanish term **bajada**, usually anglicised to **bahada**. A bahada is thus virtually a piedmont plain composed of fan material (figure 7.54).

Alluvial fans in arid environments are found only next to escarpments, and they are associated with steep gradients. Where gradients are moderate, and the local sediments include a mixture of sand, silt and clay, desert streams have a flat, sandy bed with steep banks. This gives a rectangular cross-section known as a **box canyon** (figure 7.55).



7.54 A large bahada in the Namib Desert of northern Namibia.

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. A well-known example is the Darling River anabranch in western New South Wales, Australia.



7.55 A box canyon near Mount Isa, Australia. The stream has been dry for a long while, as shown by the many animal tracks in the bed of the canyon. Bank collapse caused by water undercutting the edge of the canyon can be seen to the right.

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. 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, incorporating the lower courses of the Georgina, Diamantina, and Cooper's Creek.

QUESTION BLOCK 7J

1. *Why is water more effective than wind in shaping landforms in arid environments? Give specific examples.*
2. *What is meant by the term 'internal drainage'? How common is this in arid environments?*
3. *How do alluvial fans form?*
4. *Make a list of landforms typical of arid environments whose formation is dominated by the action of water.*

Wind and Landform Development in Hot Arid Environments

As noted earlier in this chapter, 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 called in the Sahara, are spectacular features, but they are not as widespread in deserts as many people perceive (figure 7.56). 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 popular image of sandy deserts as moving hills of sand.



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

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**, 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 up. 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 considerable heights and carried great 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 clay and silt particles, particles of sand on the ground surface are large enough to extend up into the zone of moving air, and they can therefore be rolled along 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 is largely restricted to particles of fine sand. In general, coarse sand is too heavy to be lifted by this means, and it is usually rolled along the ground instead.



7.57 The wind blows sand across this road near Liwa Oasis in the United Arab Emirates.

A wind speed of more than 30 kilometres per hour is usually required 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 (figure 7.57). 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 2 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 there is a hard rock base.

Sand sheets are areas of sand with more-or-less level surfaces. They form when there is enough coarse sand to restrict saltation, which therefore prevents the sand from forming dunes.



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

Barchans are crescent-shaped (**crescentic**) sand dunes. The wings (or horns) point away from the wind. Sand is driven up the windward slope, which has a relatively gentle gradient, and rolls over the crest to form, on the leeward slope, the steep angle of repose for sand, which is constant at 33° to 34° (figure 7.58). Barchans form on hard, flat surfaces, where there is a limited sand supply, and where winds usually blow in one direction only. Barchans are quite common in many of the world's deserts, but they are very rare in Australia.



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

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 (figure 7.59).

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 (figure 7.60). 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.

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



7.60 An oblique aerial photograph of longitudinal dunes in Central Australia.

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.



7.61 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 BLOCK 7K

1. What does the term 'aeolian landform' mean? List five aeolian landforms.

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**.



7.62 The rounded shape of this inselberg is a result of the action of running water when the area was less arid. This is part of Kata Tjuta (the Olgas), in central Australia.

When the term 'residual' is used to describe a land-form, the word refers to an elevated topographic feature such as an isolated mountain or segment of a plateau that is a remnant from a former, much more extensive, and usually higher land mass. For example, **inselbergs** are prominent steep-sided residuals rising in isolation above extensive and plains (figure 7.62). 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 (Ayers Rock) and Kata Tjuta (the Olgas) (figure 7.63).



7.63 Kata Tjuta (also known as the Olgas) in central Australia is an example of an inselberg.



7.64 A mesa, near Er Rachidia, Morocco.

The **mesa**, which is a table-topped mountain with steep and often vertical upper slopes, is the most common residual in arid environments (figure 7.64). Mesas can occur in humid as well as arid environments. When humid weathering processes influence mesas, however, they tend to have somewhat rounded profiles. In arid environments, it is the sharp break in slope between the flat top and the scarp on the one hand, and the scarp and the talus slope on the other, which makes mesas so distinctive. This 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.

Mesas erode by the backwearing of slopes, usually assisted by undercutting of the hard, caprock surfaces. As they erode, therefore, the angles of the slopes remain constant and their distinctive shape remains constant until all the capping rock disintegrates (figures 7.65 and 7.66). Mesas that have very little of their capping rock remaining are known as **buttes**.



7.65 This former mesa in Arizona (USA) was eroded to form a butte.



7.67 This reg, or gibber desert, is situated between Goulmim and Er Rachidia in Morocco.

QUESTION BLOCK 7L

1. Give two examples of residual landforms, and describe their formation.



7.66 Further erosion of this butte near Mount Isa in Australia can be expected to remove the last traces of the hard capping rock, leading to the rapid disintegration of the softer rock beneath it.

As erosion removes material from the surface of an arid environment, rocks tend to be left behind because they are more resistant. When a 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 (figure 7.67). 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 surface protects the underlying soil from erosion.

Opportunities and Challenges for Management

Managing Agriculture in High Altitude Environments



7.68 Zermatt is typical of many Swiss villages in that it is situated in a sheltered valley.

In general, people in mountainous areas prefer to live at lower altitudes (figure 7.68). In Switzerland, only 5% of the population live at altitudes above 1000 metres, which is approximately half the country's total land area. In Nepal, the proportion of people living at higher altitudes is greater, as table 7.3 shows. Factors at high altitudes

Table 7.3

Population Distribution by Altitude, 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

Source: Panday (1995) p.196

which 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 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 considerable pressure on feed supplies during the winter months.



7.69 Vegetable farming on the lower slopes near Stalden, Switzerland.

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 (figure 7.69). 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 in the harsh environment with its 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, and many farmers are choosing to leave their farms in search of higher incomes in office jobs in the towns or in the tourist industry. 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. By contrast, there is no similar decline in Nepal, where most farmers are subsistence producers - over 80% of Nepal’s work force are farmers.

QUESTION BLOCK 7M

1. Contrast the willingness of people in Nepal and Switzerland to live at high altitudes.
2. Explain the concept of transhumance.
3. Why are farmer numbers in Switzerland declining?

Managing Tourism in High Altitude Environments

Tourism is an important industry in many high altitude areas where the scenic beauty of the mountains attracts many people each year. Tourism as an industry began in Switzerland. 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 of course no trains or cable cars, and part of the adventure was the hardship (figure 7.70). The trip proved to be a great success, and numbers of tourists to Switzerland began to grow and have continued to grow ever since. Currently, about 120 million tourists visit Switzerland each year, providing 6% of the country’s GNI. Over half the tourists come from Germany, France and the USA, with other important source countries being Britain, Austria and the Netherlands. The nature of Swiss tourism has changed over the years, as table 7.4 shows, although most tourists are still attracted by the spectacular scenery (figure 7.71).

Table 7.4

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 onwards	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

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



7.70 Early posters promoting Switzerland as a tourist destination.

Tourism brings both benefits and problems to Switzerland. It certainly generates a great deal of wealth for the country, which is used to develop roads, services, railways, schools and industry in remote areas (figure 7.72). It generates employment in hotels, transport and other service facilities. It is estimated that one job is created for every six to eight hotel beds, or for every 60 to 80 self-catering apartment beds. The disadvantages are that prices are raised for local people, traditional customs and dances may become commercialised for the tourists' pleasure, and employment opportunities are somewhat seasonal. Because Swiss people do not seem to enjoy working in hotels and restaurants, much of the seasonal labour is supplied by employing migrant workers from other European countries such as Italy and Spain.



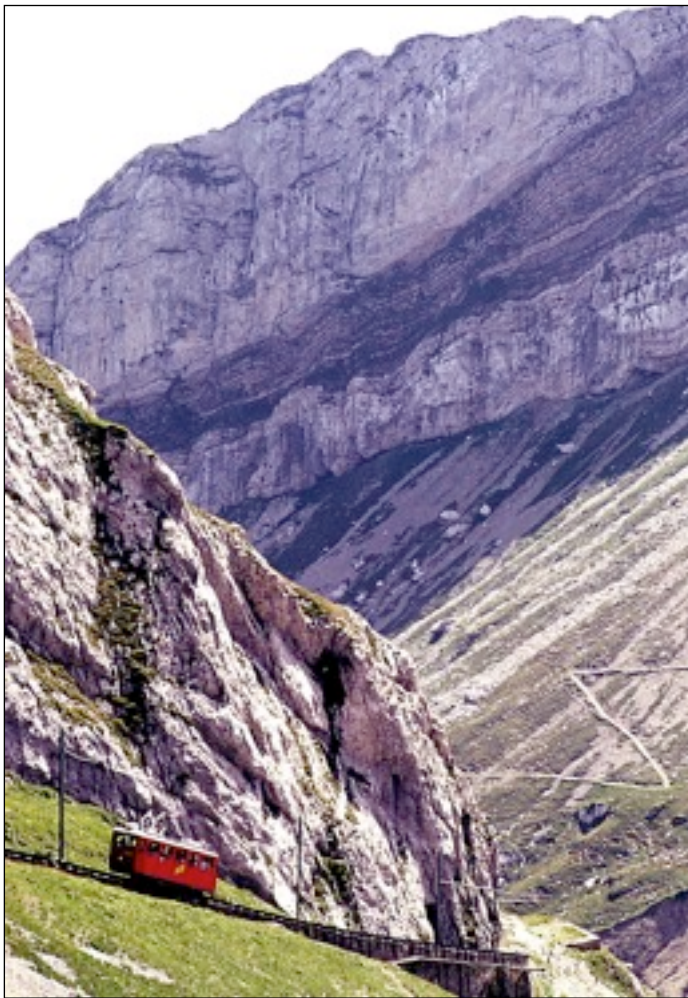
7.71 Tourists relaxing while admiring Switzerland's famous peak, the Matterhorn.

Another problem that can be caused by tourism is damage to the fragile alpine environment. Highland areas are very slow to recover from damage caused by tramping or littering, and the Swiss have undertaken extensive education campaigns to alert tourists from other areas of these problems (figure 7.73).

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, 45,000 in 1970, 223,000 in 1986, 363,000 in 1995 and 550,000 in 2008 (despite political instability at the time). At present, tourism contributes significantly to Nepal's total foreign earnings. However, the earnings from tourism can fluctuate widely as a result of economic recessions, famine and

political disturbances, both within Nepal as happened between 2001 and 2008, and elsewhere around the world.

When Nepal first opened for tourism, a large proportion of the tourists were hippies who came either in search of spiritual enlightenment from Hindu gurus (teachers) and sadhus (holy men), or en route from South-east Asia to Britain, driving overland on what was known as 'the hippie trail' through Thailand, India, Afghanistan, Iran and Turkey. During this 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 came to Nepal in 2008, just over 50% came for sightseeing, 23% for trekking and mountaineering, 6% for business, 5% on government business, 2% for religious pilgrimages, 2% for conventions and conferences, and just over 11% for other purposes.



7.72 An example of tourism leading to transport services being provided in remote areas is the rack railway to the 2132 metres high summit of Mount Pilatus near Lucerne in Switzerland. With a gradient of 48% in places, this is the steepest cog-wheel railway in the world.

Nepal's attraction as a tourist destination lies in its spectacular mountain scenery (figure 7.74). Sightseeing and trekking 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 (organised trek), by hiring their own guides and porters (tea shop trek) or by doing the trek themselves unaccompanied (budget trek). Trekking fees are imposed to control numbers, and treks to environmentally sensitive mountain areas such as Lomanthang and Mustang cost over \$US500 per day, and permits are limited to 1,000 treks annually. The fee for climbing Mount Everest is \$US7,000 per person with a minimum charge of \$US35,000 per expedition.



7.73 This small sign on a seat provided beside a walking track reminds tourists of the need to 'take nothing but photographs and leave nothing but footprints'.

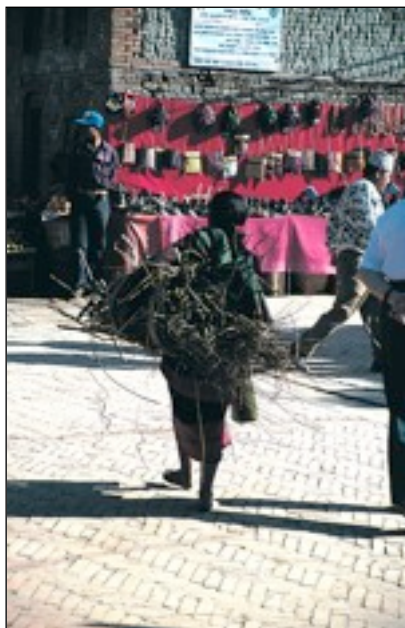


7.74 Tourists are attracted to Nepal's mountain scenery, but ironically this means hotels and tourist facilities are often built in places that can spoil the natural beauty of the landscape. These hotels overlook the Himalayas from the hill town of Nagarkot.

As is the case in Switzerland, tourism in Nepal brings both benefits and problems. The main benefit is economic – tourism contributes 3.5% of Nepal's GDP and 15% of its total foreign exchange earnings. On the other hand, tourism can generate 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, garbage 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. By the end of the 2007 climbing season, there had been 3,679 ascents to the summit of Mount Everest since it was first climbed in 1953, and rubbish from these climbs still litters the routes to the top of the mountain. 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.

In an effort to keep the mountain environments clean, the Nepalese Government now imposes a \$US4,000 expedition deposit from climbers, refundable upon return to Kathmandu on condition that all the group's rubbish and equipment has been removed from the mountain. A Nepalese initiative, the Sagarmatha Pollution Control Project (SPCP) has begun to educate tourists and local people about the importance of not leaving rubbish in alpine areas. However, proposals to install incinerators to destroy rubbish had to be abandoned as local people believe that the smell of burning rubbish is offensive to the mountain gods. Shortly before his death in 2008, Sir Edmund Hillary, who with the Nepalese climber Sherpa Tenzing, was the first person to climb Mount Everest, called for the mountain to be closed for at least five years so that some of the environmental damage can heal.



7.75 A Nepalese woman carries scarce fuelwood past stalls with souvenirs for tourists. Tourists add to the pressure on scarce fuelwood, often being prepared to pay higher prices than local people can afford. Ironically, revenue from selling souvenirs to tourists helps local people to pay for fuelwood!

Rubbish is not the only cause of environmental damage. Trekkers need fire for heating and cooking, and this is leading 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 (figure 7.75).

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:

- trek with a guide who uses kerosene instead of timber for fuel. This costs more but leave the forests intact.
- co-ordinate menu and eating times with other trekkers to reduce the use of fuel.
- dress warmly to reduce the need for heating at night.
- burn paper wastes and bury biodegradables (food wastes and excreta).
- urinate and defecate at least 30 metres away from any water source. If possible, burn toilet paper and carry out excreta in plastic bags.
- bathe away from drinking sources and use biodegradable soap.
- avoid buying hot water from a lodge that does not have a hydro-electric heating system.
- keep non-biodegradables to a minimum, especially batteries.

QUESTION BLOCK 7N

1. *On balance, is tourism beneficial or detrimental for (a) Switzerland, and (b) Nepal? Explain your answer fully.*

Case Study of Managing Agriculture, Mineral Extraction and Tourism in a High Altitude Environment - The Altiplano of Bolivia

Bolivia is the highest, poorest and most isolated nation in South America. It is a landlocked nation, one of only two in South America. This means it has no access to the ocean. Bolivia covers an area of 1,098,581 square kilometres and spans an area from the top of the Andes Mountains down to the floodplain of the Amazon River. Within this area live ten million people, 65% of whom are indigenous people from 'Indian' groups such as the Quechua and Aymará (figure 7.76). The remaining 35% are descended from Spanish immigrants who came to Bolivia in the 14th and 15th centuries in search of silver. The Spanish declared Bolivia a colony in 1531. Spanish culture continues to have quite an influence on Bolivia, even though independence was achieved in 1824.



7.76 Indigenous groups celebrating Carnivale in Bolivia's capital La Paz.

The Altiplano is the most densely populated part of Bolivia. The name 'Altiplano' means 'High Plain', although it is anything but flat. The Altiplano has basins at about 3,500 to 4,000 metres in altitude, but ranges up to snow-capped peaks exceeding 6,500 metres in altitude (figure 7.77). The region stretches down the western side of Bolivia, from the border with Peru down to the border with Argentina.



7.77 La Paz is situated in a valley of the Andes Mountains.

The Altiplano climate

As one would expect in such an elevated area, temperatures are quite cool throughout the year. The statistics for Bolivia's capital city, La Paz, which is just below 4000 metres in altitude, give some idea of the climate (table 7.5).

Most of the rain falls in summer when much of the Altiplano becomes wrapped in mists and cloud. During this time, lakes on the Altiplano grow in size and the cattle

stand knee deep in swamp. In the winter, almost no rain falls, and the area turns shades of brown and grey, becoming like a semi-desert. Because the air is so thin at high altitudes, the temperature drops dramatically every time the sun passes behind a cloud.

QUESTION BLOCK 7O

1. *Where is the Altiplano?*
2. *Why does the Altiplano house a multi-cultural society?*
3. *Why is the temperature in La Paz so even through the year?*
4. *La Paz is located quite close to the equator. Therefore, we might expect temperatures in La Paz to be quite hot. So, why are the temperatures in La Paz so cool?*
5. *Describe the rainfall in La Paz, mentioning when it falls through the year and its amount compared with your own city.*

Silver mining

The Spanish came to Bolivia in search of silver. One of the world's largest deposits of silver was found at Potosi in 1544, and a few years later it had a population of 160,000 people - the largest settlement in the Americas at the time. Other silver mines were found and a huge influx of Spanish people followed. Local Bolivian people were forced to work in the mines in work gangs under terrible conditions. Thousands died, either in accidents or through diseases such as pulmonary silicosis. Nonetheless, it was mining that led to the region's first large-scale immigration of people from other areas.

The mining has also had adverse effects on the biophysical environment. Large areas were cleared of vegetation, and this resulted in massive soil erosion on the steep slopes of the mountainous areas (figure 7.78). Land became wasteland, especially where the soils were soft or comprised fine, clay particles. The eroded soil was washed down the hill side and into the streams below. Many of the Altiplano's rivers and streams have thus become choked with sediment from the mining erosion (figure 7.79).

QUESTION BLOCK 7P

1. *Describe the processes which combined to form the landscape shown in figures 7.77, 7.78 and 7.79.*

Table 7.5

Climatic Statistics for La Paz, Bolivia (Latitude 16°S, Longitude 65°W, Altitude 3759 metres)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Temperature °C	18	18	18	19	17	17	17	17	18	19	19	19
Average Precipitation (mm)	138	87	80	32	2	2	2	3	25	50	51	88



7.78 Badly eroded hillsides in the Valley of the Moon, Bolivia.

areas for the poor people. In La Paz, it is the poor who live at the top of the hills and the wealthy who live in the foot of the valley where the gold used to be found (figures 7.81 and 7.82).



7.80 An oblique aerial view of La Paz. The CBD can be seen in the centre foreground, marked by the large high rise buildings.



7.79 This stream near La Paz is filled with sediments from mining operations upstream.



7.81 A poorer residential area of La Paz, situated on the upper edges of the canyon.

Urban growth - the city of La Paz

With a population of over a million people, La Paz is Bolivia's largest city. Like many of Bolivia's towns and cities, it began as a **mining settlement**. It was founded in 1548 and was named *La Ciudad de Nuestra Señora de la Paz*, which means 'The City of Our Lady of Peace'. The river which flows through La Paz, the Río Choqueyapu, contained alluvial gold, and a settlement was established beside the river in the bottom of a steep canyon specifically as a mining settlement (figure 7.80). The site of the first settlement still marks the centre of La Paz, and it is where the city's modern, high-rise buildings are found. In this respect, La Paz is unusual. Most cities in developing nations have a zone where wealthy people live on the tops of the hills where there is a view, leaving the low



7.82 A wealthier suburb of La Paz, situated in the valley floor near the CBD.

Because La Paz is at a high altitude, its temperatures remain quite cool throughout the year. This enables open air markets to sell foods such as meat without the use of refrigeration (figure 7.83). A poor nation such as Bolivia has limited electricity, and so refrigeration is rare. Other

services often lacking in La Paz are rubbish collection and sewage disposal. Like governments in many developing nations, Bolivia's government raises little taxation to provide services for its people. This means that many areas of La Paz become open garbage tips and open toilets. This poses a hazard for people's health as well as lowering environmental quality (figure 7.84). Diarrhoea is a major problem in La Paz, and many children die each year from the effects of intestinal upsets.



7.83 Meat for sale in open air street markets, La Paz, Bolivia.



7.84 Rubbish and an open drain carrying sewage characterise this slope in a poor residential neighbourhood of La Paz.



7.85 Sub-standard housing in La Paz, Bolivia.

These **environmental problems** have become worse in recent years due to **rural-urban migration**. Thousands of people move to La Paz each year from smaller towns and rural areas of the Altiplano. Many of these people do not have jobs or the money to buy housing. Great pressure is put upon the limited amount of housing in La Paz, and shanty settlements have sprung up to meet the demand for housing (figure 7.85). These shanty settlements appear on vacant land, often land which is too steep for 'normal' building, and put more pressures upon the limited services available in La Paz such as transport, waste disposal and electricity.

QUESTION BLOCK 7Q

1. Describe the impact of mining and landforms on the development of La Paz.
2. In what way is the urban pattern of La Paz different from that in most other cities? Why did these differences arise?
3. Why are there shanty settlements in La Paz?
4. Describe the environmental problems faced by the residents of the shanties.

Agriculture on the Altiplano

Figures 7.86 to 7.90, show aspects of farming and agriculture on the Altiplano. Life is difficult in the harsh, wind-swept climate and most of the people spend their lives producing their own food. The farmers must put up with the bitter cold, strong winds, droughts and the lack of oxygen at high altitudes with little electricity or modern conveniences.



7.86 Animal herding on the Altiplano.

Most farmers produce a mixture of crops and animals. Animal raising is very labour intensive. It is rare to see animals outside without someone in the fields to look after them to prevent them being stolen. Animals raised include pigs, cattle, sheep and llamas. The crops which are grown must have a short growing season to survive in the harsh, cold conditions. Special varieties of vegetables

are produced, often on terraced hillsides where the land is steep.

The surplus food which is produced is usually sold in open markets in the towns and villages of the region. These villages are also centres of communication and exchange of information. In a society with few radios and almost no televisions, information is spread by word of mouth. Towns and villages tend to be small and are often centred on a Catholic church. Buildings tend to be constructed from mud bricks or fired bricks, made with local clay. These provide some protection against the cold winds when used in a building which has glass windows.



7.90 Terraced hillsides near Lake Titicaca.



7.87 A woman and her children look after some sheep.



7.88 The town of Copacabana and its surrounding farmlands.



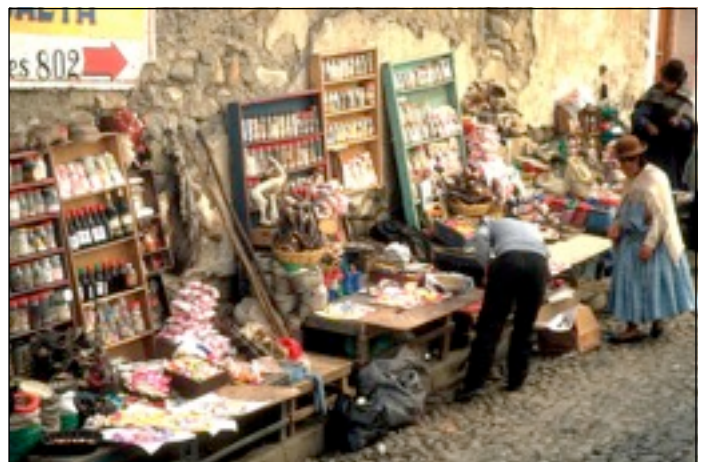
7.89 Hills with very little vegetation are used for animal grazing.

QUESTION BLOCK 7R

1. Are the farmers on the Altiplano affected by their biophysical environment? In your answer, consider how each of the following parts of the biophysical environment might affect farmers: climate, soils, landforms, vegetation.
2. Do the farmers in the Altiplano in turn affect their physical environment? Consider again the parts of the biophysical environment: climate, soils, landforms, vegetation.
3. What is meant by the term 'labour intensive'? What would be the opposite of this term?

Tourism and change in the Altiplano

Although Bolivia is an isolated nation, **tourists** are starting to arrive, although the numbers are still very small. Tourists come in search of the exotic lifestyles and spectacular scenery of the Altiplano, although services for tourists remain poorly developed (figures 7.91 to 7.94). However, tourists bring new ideas with them and change the values of local people. In recent years, there have been increasing reports of robbery, theft and muggings of tourists by local people who envy the material wealth of tourists.



7.91 Selling fetuses and various plants and animals for witchcraft in La Paz.



7.92 A typical village scene in the Altiplano.

Tourism has so far brought few benefits to local people on the Altiplano.

Perhaps more worrying is that some tourists might regard the local people merely as interesting curiosities. Tourists who travel on package tours rarely take the time to learn about the culture and history of the people in the places they are seeing. When this happens, there is a real danger that tourists from the richer nations will simply see the poverty of the people, not the richness of their culture and heritage. Moreover, when tourists are cut off from the local people in air conditioned buses the local people cannot afford, then local people could well feel resentment. They may see the tourists as intruders whom they did not invite into their area.



7.93 Selling household goods in the street markets of La Paz.



7.95 Inter-urban public transport in the Altiplano often relies on old buses or trucks.



7.94 Evidence of transnational corporate investment can be seen in the advertising in central La Paz.

In an LEDC such as Bolivia, where there is little money to provide services, tourists can make great demands upon the limited facilities available. This can lead to local people having to take second place to tourists in the demand for services, and it can lead to problems such as traffic congestion in the cities. If it is well managed and well informed, tourism can break down cultural barriers. However, at its worst, tourism can lead to resentment and environmental degradation.

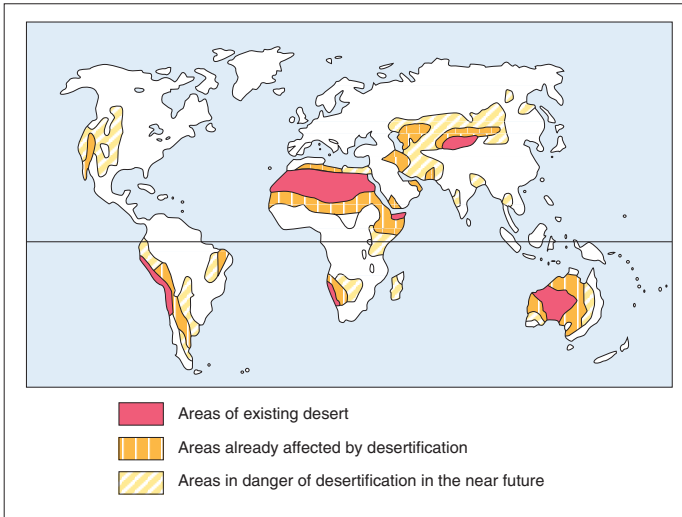
QUESTION BLOCK 7S

1. *Is tourism a positive or negative factor in the Altiplano?*
2. *Outline the effects of tourists on the environment of the Altiplano.*
3. *Why would local people rarely use the air conditioned buses?*

As more and more tourism develops, a demand arises for improved services, known as infrastructure. Often, though, the nation may be unable to afford these improvements. Transport services in the Altiplano provide one example of such services. Bus transport in many parts of the Altiplano are very basic and accidents are common (figure 7.95). Petrol is scarce and very expensive for local people. Petrol stations are few and far between. In recent years, new buses have been bought, some with air conditioning, but these are rarely used by local people.

Management Issues in Hot Arid Environments

Desertification, which is the process whereby deserts expand into semi-arid areas or become more intense, has been identified as a significant global issue (figure 7.96).



7.96 The world distribution of areas threatened by desertification.

Less Economically Developed Countries (LEDCs) are especially vulnerable to desertification, partly because many of the world's semi-arid areas are on the edges of deserts in LEDCs, and partly because poverty pushes farmers in those countries to over-utilise the land in an effort to increase their meagre incomes. Where farmers cannot afford remedies that involve land and water management, or where they are not able to see the 'big picture' because of their own needs driven by poverty, then solutions become very difficult.

impact on their environment. Today, about 16,000 subsistence nomads and farmers occupy similar areas in northern Africa in an environment that is even more degraded (figures 7.97 to 7.100). It therefore comes as no surprise that desertification is a much more serious problem in Africa than in Australia.



7.98 Nomadic animal herders use camels for transport as these animals have adapted to the hot dry conditions of the desert.



7.97 Nomadic Tuareg people camping near their demountable shelter in the Sahara Desert, north-west of Timbuktu, Mali.

More Economically Developed Countries (MEDCs) are also vulnerable to desertification, however. Serious soil erosion is occurring in Australia's arid areas, and most of this has been the result of mismanagement of pastoral grazing activities. As a consequence of the deteriorating environment, the economic productivity of Australia's arid terrains may even now be declining.



7.99 The nomadic animal herders have brought their animals into the town of Timbuktu in search of water. They have erected their huts in an area of vacant land and used mud bricks to build a temporary pen to hold their animals.

The Gascoyne Basin of Western Australia currently supports about 320 people, about 400,000 cattle and an unknown number of wild animals. It produces several million dollars of export income per year in a deteriorating physical environment. Before the arrival of Europeans, the area is thought to have supported 500 Indigenous people, engaged in hunting and gathering, with minimal



7.100 Although it is the largest town in northern Mali, Timbuktu has just one sealed road. Like Timbuktu itself, the road is becoming buried in sands that blow in from the surrounding Sahara Desert.

Most researchers now argue that desertification is caused by a combination of human and natural forces. **Natural causes** of desertification include a long-term trend towards receiving less precipitation, either in the form of reduced amounts of rainfall or as less reliable rainfall. Other long-term climatic conditions such as dry winds, higher temperatures, reduced condensation and a higher rate of evaporation can exacerbate the effect of reduced precipitation.

The negative effects of these natural forces may be exaggerated by **human actions** such as deforestation, the over-exploitation of resources, the mismanagement of water, intensive agricultural or ranching practices. In China, for example, the cultivation of light textured soils in marginal, semi-arid areas for wheat has led to reduced plant productivity, a decline in soil quality and desertification. The problem is that as crop productivity declines, farmers often respond by farming the land even more intensively than previously to compensate for the reduced production, and this accelerates the process of desertification (figure 7.101).



7.101 Placing too many cattle on marginal semi-arid farmlands may be a cause of desertification. This image shows animals grazing near Timbuktu, Mali.

Desertification is not irreversible. Natural processes such as changes in precipitation and temperature seem to come in cycles. During the 1970s and 1980s, it was noticed that satellite images showed the Sahara Desert expanding southwards into the area known as 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 shows the southern boundary of the Sahara was retreating to the north once again. In fact, the trends were somewhat complex. 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 does continue as a response to their poverty.

Desertification can be controlled if people can make more rational use of scarce water resources, collect and channel water more effectively, reduce or substitute activities that are damaging the environment, or manage the soil more 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 (figure 7.102).



7.102 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.

Access to water is a key factor in managing arid environments effectively. In some countries, irrigation is seen as the answer to these problems. **Irrigation** means bringing water from another area through canals or pipes in order to grow crops or vegetation. This can be a very expensive process requiring huge investments to establish and then maintain the infrastructure (figure 7.103).



7.103 This Soviet-era irrigation canal near Lake Issuk-Kul in Kyrgyzstan has fallen into disrepair. Large sections of the concrete structure have been stolen by local people for use as building materials.

In the south-west of the United States, a huge scheme has been built to divert 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 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 (figure 7.104). This enables food to be grown that would otherwise have to be brought to the area from elsewhere (figure 7.105). Water management in the Colorado Basin was discussed in more detail in chapter 5, and this can be compared to water management in Turkmenistan that was discussed in chapter 3.



7.104 An irrigation canal bringing water from the Colorado River to southern California. There is considerable loss of water due to seepage and evaporation.



7.105 Cultivation using irrigation in the Imperial Valley of southern California. The transformation of the landscape can be seen by comparing the irrigated farms in the foreground with the arid terrain of the background.

Arid environments are being used more and more as sources of energy generation. Because they are rarely affected by cloud cover, deserts make excellent places to generate solar energy. Most of Australia's long distance telephone lines have now been replaced with solar powered optical fibre links. Many desert areas comprise wide, flat areas of plains. In such areas, wind power is an effective

way to generate electricity because there are few barriers to block the movement of air. The United States is a leader in this type of power generation, and several large wind farms have been built in the deserts of the south-western USA.



7.106 An isolated homestead near Alice Springs, central Australia.



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

Traditionally, deserts were areas of sparse population where travel was difficult and slow (figures 7.106 and 7.107). Greater ability to harness and divert water supplies has enabled arid environments to develop in ways that were previously thought to be impossible. However, conflicts can arise when competing land uses are incompatible. For example, it is very rare that tourism and mining can co-exist in the same area. Similarly, conflicts can arise when there is competition for scarce water resources among uses such as urban centres, hydroelectricity, irrigation and recreation.

QUESTION BLOCK 7T

1. *Is desertification caused by natural or human factors? Give reasons for your answer.*
2. *Why are LEDCs especially vulnerable to desertification?*
3. *Describe some of the new ways that deserts are being used, and outline the conflicts that may arise as a consequence.*

Case Study of Managing Agriculture, Mineral Extraction and Tourism in a Hot, Arid Environment - Death Valley

The name 'Death Valley' implies desolation and lifelessness. Sun-baked, barren **badlands** rise from the valley floor, and plants and animals seem totally absent (figures 7.44 and 7.107). 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.
- Avoid wind. It speeds up your evaporation rate and stirs up the low-level hot air layer created by radiation from the ground.

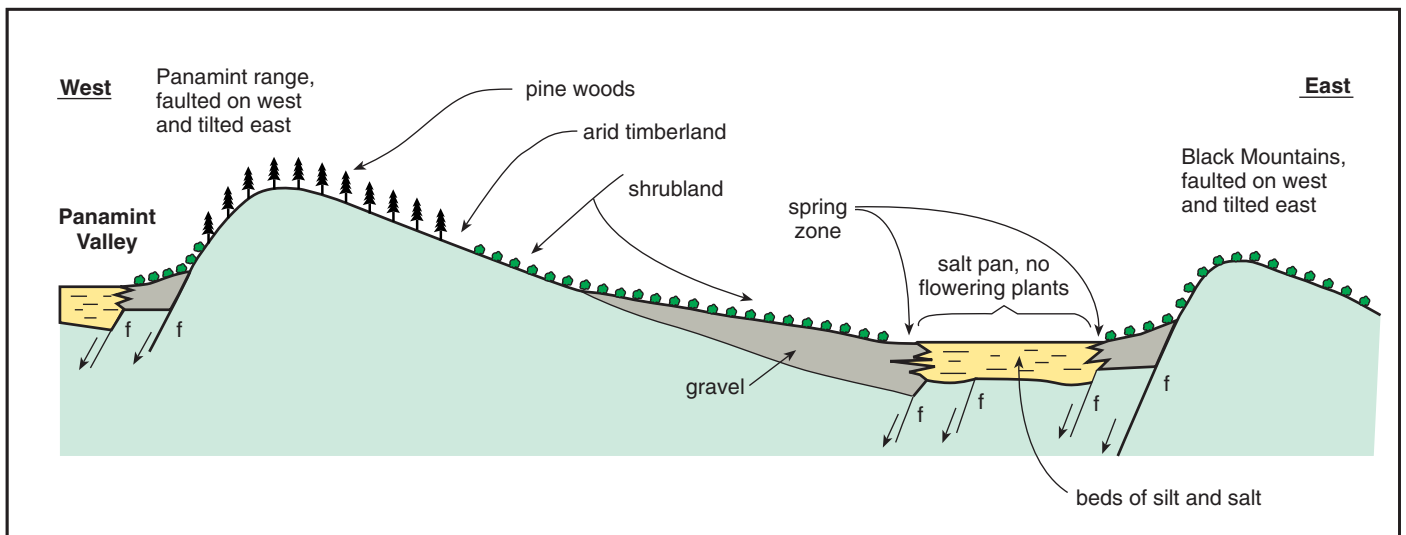
- Ground temperature in summer is seldom less than 65°C and may reach 93°C. Rest when you need to, but do it in the shade. Do not sit or lie in the sun.
- If storm clouds gather, be alert. Thunderstorms in the mountains can cause flash flooding in the washes that cross the highways several kilometres 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. However, it is known that Native Americans have lived in the area for at least 10,000 years before European settlement.

Death Valley is one of many desert basins between the Sierra Nevada mountains near the west coast of California in the United States and the Colorado Plateau to the east. The extreme aridity of Death Valley is the result of this situation – orographic rain falls over the mountains to each side of the valley, creating a rainshadow effect within the valley.



7.108 The sign at the entrance to Death Valley gives a stylised cross-section of the valley.



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

Death Valley is located on the border between the states of California and Nevada, approximately 300 kilometres in straight line distance from Los Angeles. Because of its unique topography (it includes the lowest point in North America) and climate (it is the hottest and driest part of the United States), the area was declared a national park in 1933 (figure 7.108).

Death Valley comprises three quite distinct environments (figure 7.109). 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 7.110 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.



7.110 After crossing the flat land in the foreground, this road climbs the gentle slope of the gravel fan before ascending up across the Panamint Range.

Sloping into Death Valley from each of the mountain ranges are gravel fans of rock debris washed down from the mountain sides (figure 7.110). The gravel fans end at the edge of a broad salt-crusted mud flat which is the dry bed of a playa 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, however. Desert shrubs grow up to about 2,000 metres on the mountain slopes, and above this pine trees grow.

Salt and water

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 (figure 7.112). 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 (figure 7.111).

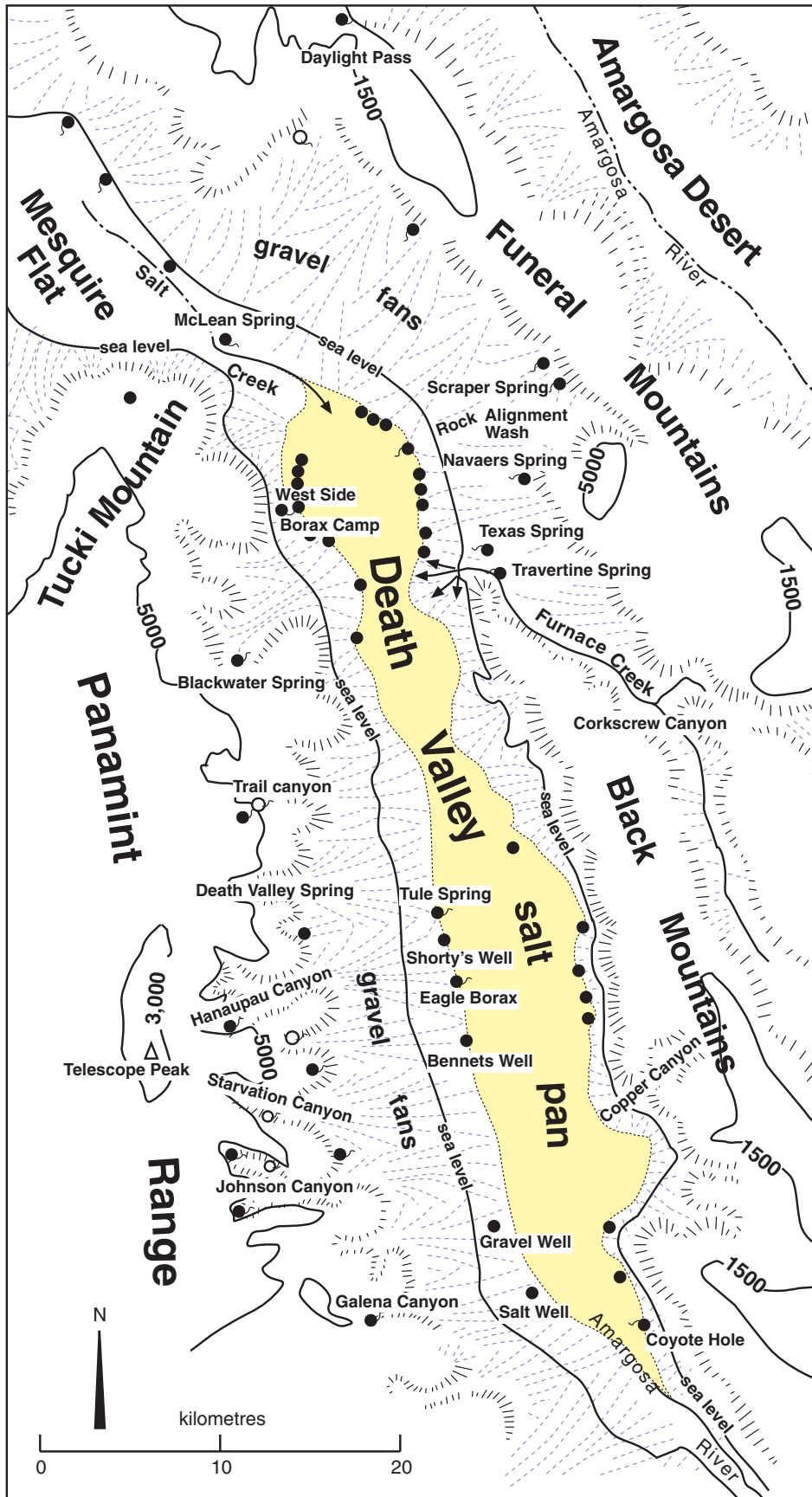
The drainage basin of Death Valley covers about 23,000 square kilometres, with altitudes ranging from 85 metres below sea level on the valley floor near Badwater to 3,350 metres at Telescope Peak in the Panamint Range 21 kilometres west of Badwater (figure 7.113). Within the drainage basin there are several streams, of which Salt Creek brings the largest volume of water into Death Valley. All the streams in the drainage basin flow into Badwater Basin, the lowest point in Death Valley.



7.111 This small creek carries water from a spring east of Furnace Creek into the centre of Death Valley.

QUESTION BLOCK 7U

1. Explain why Death Valley is so dry.
2. Referring to figure 7.109, describe the different environments of Death Valley.
3. Account for the general distribution of water springs in Death Valley, shown in figure 7.112.
4. Draw an east-west cross section of the area shown on the topographic map in figure 7.113 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.
5. Interpret the symbols shown on the map in figure 7.113 to list the services provided in Furnace Creek village.



7.112 Map of Death Valley showing the principal springs (shown as solid circles) and seepage areas (shown as open circles) around the salt pan. Heights are shown in metres.

Deposition - sand dunes and gravel fans

Although sand dunes are found in many desert areas, Death Valley has only one area with them, although this is a large area of several square kilometres (figure 7.114).

They have 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 sand 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 usually about one kilometre in length and peaking about 50 metres above the salt pan. The difference reflects the angles of the two mountain ranges as they border Death Valley; being a gentler slope the Panamint Range has a larger catchment area for the gravel.

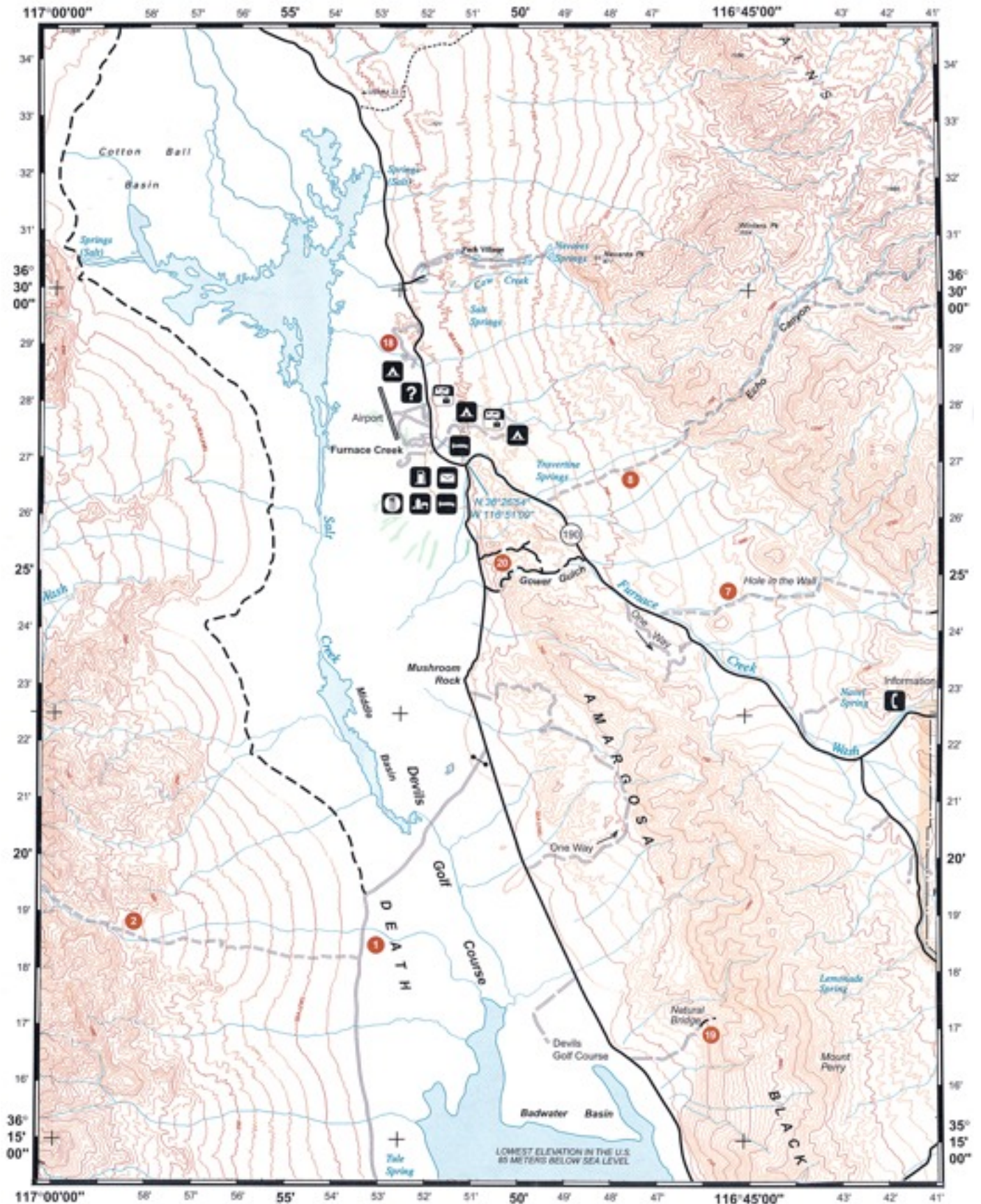
The gravel fans include areas that are the driest ground in Death Valley. The gravel fans receive less rainfall than the nearby mountains, and scarcely more than the valley floor. However, the gravel fans are highly permeable, and therefore they cannot retain moisture; the water that runs onto them quickly seeps into the ground. Thus, vegetation cannot become established in these areas.

Climate

In 1868, the author of the first United States mineral resource report, J. Ross Browne, wrote this of Death Valley's climate:

"The climate in winter is finer than that of Italy, though perhaps fastidious people might object to the temperature in summer... I have even heard complaint that the thermometer failed to show the true heat because the mercury dried up. Everything dries: wagons dry; men dry; chickens dry; there is no juice left in anything, living or dead, by the close of summer".

Death Valley is indeed the hottest and driest part of the United States south-western desert areas. Winter temperatures rarely fall below 0°C, but summer temperatures average over 40°C and have reached much more than this.



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

The specific details of Death Valley’s climate are given in table 7.6.

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 extreme, such as the change from 86 mm of rain in 1953 to zero in 1954. Over longer periods, the fluctuations have been much greater. In the



4. Explain why Death Valley has a high diurnal range in temperatures.

Plants and animals

The wide range of temperature and moisture conditions in Death Valley means that there is quite a variety of plant and animal forms to be found. The length of the growing season for plants is determined by the temperatures, and for this reason there are altitude zones of different plant types found on the edges of the Valley (figure 7.118). In the centre of Death Valley, the extreme tempera-

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 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, gulying and landslides (figure 7.115).

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 BLOCK 7V

1. How do the gravel fans in Death Valley form?
2. 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.

tures to which the land surface is subjected accounts for the total absence of vegetation in this area (figure 7.116).



7.114 A large area of sand dunes near Stovepipe Wells in the north of Death Valley. This view looks east towards the Funeral Mountains.

Near the edges of the Valley, different plant species use different techniques to gather and conserve water. Those plants which 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. The distribution of phreatophytes is governed both by the quantity of water available and its quality (i.e. saltiness). The main types of phreatophytes found in Death Valley are the willow (*Salix* spp.), reed grass

Table 7.6

Climatic Statistics for Death Valley, USA (Latitude 36°N, Longitude 117°W, Altitude 85 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

(*Phragmites communis*), salt grass (*Distichlis stricta*) and pickleweed (*Allenrolfea occidentalis*). The salinity of the groundwater varies from a few parts per million for the willow to 6% for the pickleweed, the most salt-tolerant of the phreatophytes.



7.115 Although Death Valley is very dry, evidence of erosion by water is easily found. These two views show evidence of a washout (upper photo), and a box canyon (lower photo), both caused by the action of running water.



7.116 The extremely high surface temperatures at the centre of Death Valley prevent any vegetation at all from growing.

Where water is less abundant or is deeper, xerophytic plants such as desert holly (*Atriplex hymenelytra*) 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 made special adaptations to conserve water, such as by having very small leaves to minimise water loss and being able to tolerate salty water. The average density of desert holly plants is 10 to 500 shrubs per hectare. In areas which are a little less salty, creosote bushes (*Larrea tridentata*) are found. Creosote bushes, which are shown in figure 7.117, cover most of the lower halves of gravel fans, up to an altitude of about 180 metres. The density of creosote bushes varies from a few to 250 plants per hectare, with the average being about 80. Creosote bushes depend on ephemeral water, and therefore grow better near roads because of the slight additional runoff from the pavement.



7.117 In the zone where the gravel fans meet the flat salt pan, springs allow the growth of a few scrub plants. In this view, the density is about 80 bushes per hectare.

In summary, on the gravel fans where the water table is deep, xerophytes tend to be found, whereas phreatophytes are found at the foot of gravel fans where the groundwater ponds against the lower sediments.

The main types of fauna found in Death Valley are rabbits, rodents, lizards and insects. This wildlife is concentrated in the areas of shallow groundwater where the gravel fans and the salt pan meet. They are less numerous on the gravel fans themselves, and almost totally absent from the salt pan and the badland hills. Indeed, the only type of animal that has been observed to cross the salt pan is the coyote. Most of the pools of water in Death Valley evaporate too quickly or are too salty for fish to survive.

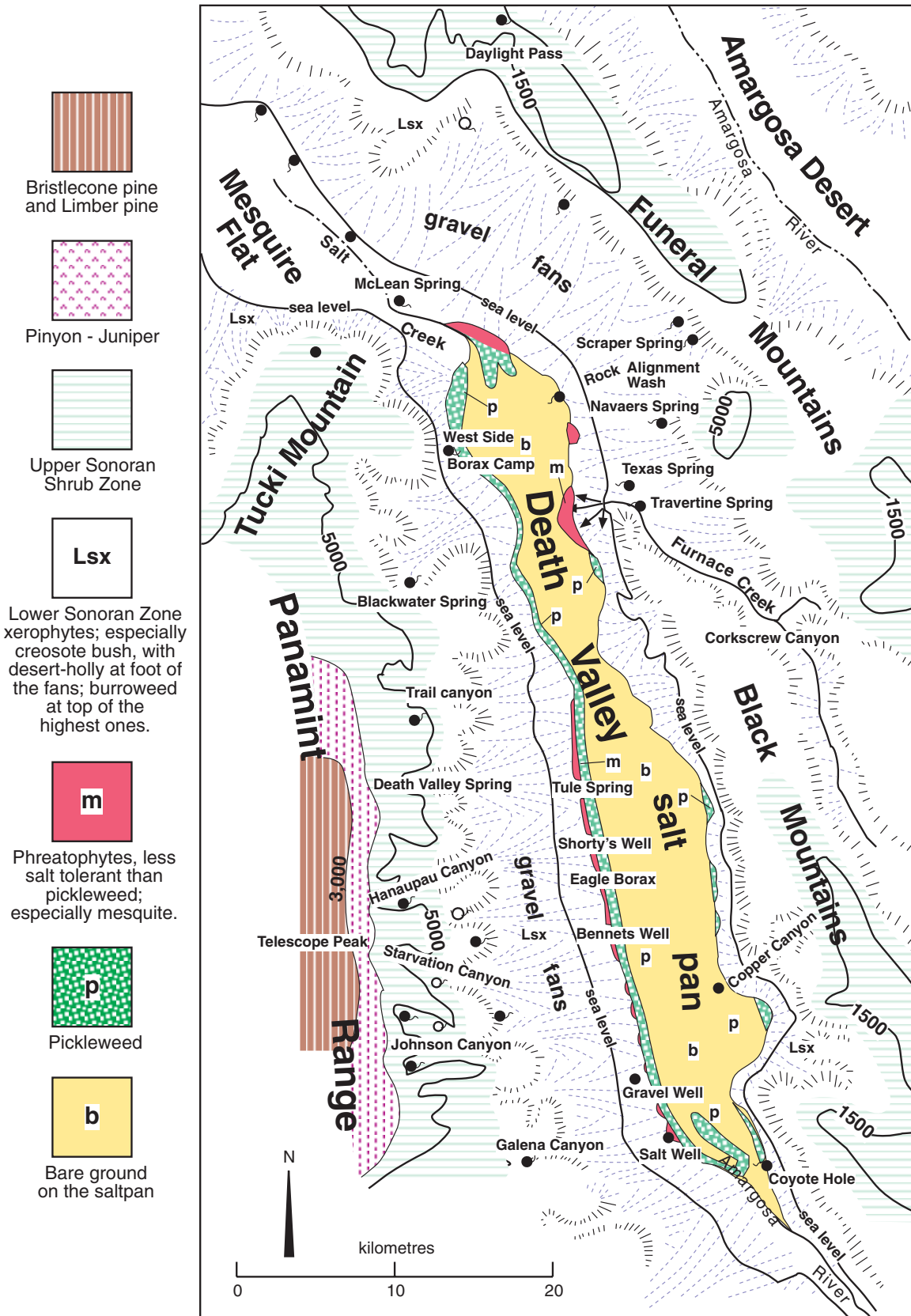
QUESTION BLOCK 7W

1. With reference to figure 7.118, describe the distribution of vegetation in Death Valley.
2. Account for the distribution of vegetation shown in figure 7.118.
3. Describe the ways in which vegetation in Death Valley adapts to the dry conditions.

4. What is the difference between phreatophytes and xerophytes, and where are each found in Death Valley?
5. From what you have studied about the interaction of vegetation and rocks in forming soil, suggest what the soils in Death Valley would be like. Comment on how deep you think they would be, their texture and the amount of humus and water they would contain.

People

The sections above describe the various natural systems which combine to form the Death Valley ecosystem. The natural ecosystem has survived for many centuries without threat of change other than from changes in the climate. However, the presence of humans has brought many changes.



7.118 Vegetation map of Death Valley.

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 (figure 7.119). Later, partial alteration and solution of these deposits moves some of the borates to the floor of Death Valley, where evaporation left a mixed crust of salt, borates and alkalis.



7.119 The ruins of an old house sits in an area of abandoned borax mining.

When Death Valley was declared a national park in 1933, it was left open for mining and prospecting. Therefore, the borax mining continues to the present day. Today, most of the permanent residents of Death Valley are rangers of the Parks Service, people engaged in providing services to visitors, and some miners who continue to extract borax and talc. Although there is a post office in Death Valley, the nearest primary school is 80 kilometres away in Shoshone.

QUESTION BLOCK 7X

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 ecosystem 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 limiting factor in the Death Valley environment? Explain your answer.

Sustainability

Human Impact on High Altitude Environments

High altitude environments can be very fragile when exposed to the pressures of human activities. All the mountain environments explored earlier in this chapter — Switzerland, Bolivia and Nepal — have reputations as clean, pristine mountain environments, and yet as we saw when we looked at tourism on Mount Everest, the reality may be quite different. It is impossible for people to live in fragile mountain environments without making any environmental impact, and sometimes this impact can become too severe for nature to repair. Environmental impact can take many forms as the following sections indicate, developing the contrast between a high altitude environment in an LEDC (Nepal) with one in an MEDC (Switzerland).

Air pollution



7.120 Oblique aerial view over Kathmandu showing the polluted air over the city.

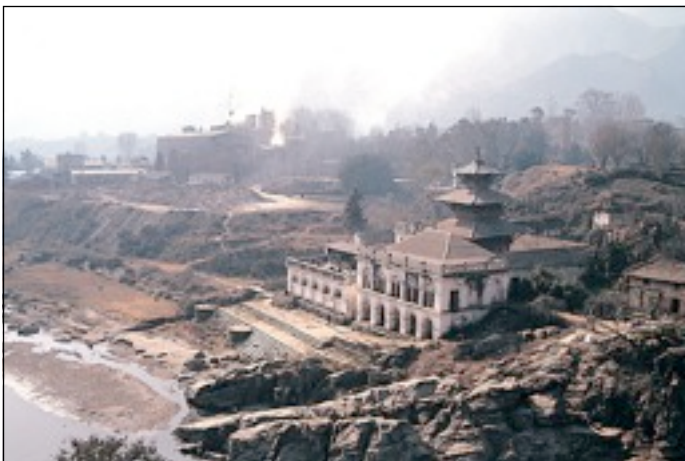
Although Nepal’s air is clean compared with many parts of the world, it is heavily polluted in the towns. Furthermore, Nepal’s **urban air pollution** is becoming rapidly worse as more and more second hand cars and trucks are imported from India. In 1989 there were 100,000 motor vehicles in Nepal; by 2008 this figure had risen to about

300,000. Air pollution comes from many sources, including dust from fires and burning, gases from motor vehicle exhausts, and both dust and gases from factories. On the other hand, although Switzerland has many more motor vehicles than Nepal (over 4 million), it imposes strict emission controls on exhaust gases, and therefore Switzerland has cleaner air than Nepal's urban areas (figures 7.120 and 7.121). Along with its neighbouring countries, Switzerland signed the Alpine Convention in 1991; this is an international agreement seeking to minimise the damage caused to the environment by motor traffic and tourism. This is an important need in Switzerland, which receives about 120 million tourists each year.



7.121 Oblique aerial view over Grindelwald showing the clean air of Switzerland.

Most of Nepal's factories are small-scale, but they are concentrated in certain areas. The Kathmandu Valley has the biggest concentration of factories (figure 7.122). Most of the motor traffic also occurs in this region. In contrast, Switzerland's manufacturing industries are dispersed across the country, and tend to be non-polluting activities.



7.122 The Himal Cement Factory, south-west of Kathmandu, is seen here pumping large volumes of polluting gases into the air beside the Buddhist temple of Adinath Lokeshwar, built between 1400 and 1640.

Deforestation

People in both Switzerland and Nepal use timber from their forests as an important resource (figure 7.123). The impact of forestry is much greater in Nepal than in Switzerland. Indeed, loss of forest is one of Nepal's greatest problems. Between 1965 and 1979, Nepal lost about 70,000 hectares of forest every year. Since then the rate of loss has been reduced to about 12,000 hectares per year, but this is still a major problem. Most of the timber is cut down for fuelwood, which supplies 75% of Nepal's energy needs.



7.123 Fuelwood stored at the houses of a family in Patan, Nepal (top) and near Brienz, Switzerland (bottom).

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 humid tropical forest, the world will lose ten species of valuable timber, six species of edible fruit tree, four species supplying traditional medicines and 50 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.



7.124 A forestry ranger comparing a healthy branch from a forest tree (left) with one which has been stunted and defoliated as a result of acid rain (right).

Switzerland's forestry industry is managed with tight government regulations controlling the quantities of timber that can be cut. However, Switzerland's forests are suffering from the effects of another factor over which the Swiss have little direct control – acid rain. **Acid rain** is caused by air pollution from cars and factories in areas upwind of Switzerland, which means principally in Britain, France and Spain. Sulphur dioxide caused by burning hydrocarbons mixes with the water in the atmosphere producing rain that is a diluted form of sulphuric acid ($\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$). This is then blown by the prevailing winds over to Switzerland where the orographic uplift causes rain - rain which, because of its acidity, kills the trees on which it falls (figure 7.124).

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 plantation forests. Moreover, it hopes to reduce the overall demand for timber by encouraging people to use other fuels, such as kerosene and animal dung, instead. 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. Switzerland faces even greater problems in halting its deforestation because the acid rain affecting its forests 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.

Soil erosion

Soil erosion is a major problem in Nepal, but much less so in Switzerland. Switzerland's population is growing much more slowly than Nepal's, and for this reason there is less pressure placed on the land to produce more.

Deforestation in Nepal leads to soil erosion, but other factors are also important. Nepal has thin, shallow, stony soils that are easily eroded. On average, Nepal loses the equivalent of between 20 and 50 tonnes of fertile topsoil per hectare per year due to soil erosion. In some areas, 200 tonnes of topsoil per hectare are lost annually and entire hillsides have been laid bare. Each year, about 240 million

tonnes of Nepal's soil are washed away from Nepal down to the Bay of Bengal. So much soil erosion has occurred that a new island has risen from the sea off the coast of Bangladesh in the Bay of Bengal. Although this island, which is hundreds of square kilometres in size, comprises the eroded soil from Nepal, it is India and Bangladesh that are each claiming sovereignty (ownership) of it.

Some of Nepal's soil erosion occurs because of natural factors. These natural factors are the steepness of Nepal's hillsides, the coarse texture of the soils and the frequent earthquakes and tremors. However, the main causes of soil erosion are human activities such as grazing too many cattle on small parcels of land, expanding villages on steep land without planning permission, and over-farming (figure 7.125).



7.125 Severe gullying near Kathmandu is eroding farmlands. Some efforts to stabilise the erosion can be seen near the mouth of gully where tree planting has taken place.

Landslides are a very extreme form of soil erosion in which both lives and property are lost. The higher a slope, the greater is the potential energy exerted by gravity. Like soil erosion, landslides can occur naturally but human actions often make them worse. It is estimated that of every 15 landslides in Nepal, 14 are the result of human actions while only one is entirely due to natural factors. Most landslides occur in the summer months of June to September when the monsoon winds bring heavy rainfall to Nepal. At this time, the topsoil gets soaked, making the soil waterlogged and much heavier, as well as better lubricated, and so more likely to slide downhill.

Landslides are also a major problem in the mountain areas of Switzerland. In Switzerland, however, the causes are usually natural. Many of the alpine areas of Switzerland have slip-off slopes – areas of unconsolidated rock sediments that have fallen from upslope and come to an angle of rest that is usually about 35° (figure 7.126). If something happens to destabilise the slope, such as a mild earth tremor, a period of heavy rain, or even a person walking on the slope, then the rock material can slide downhill, taking with it anything and anyone in its path.



7.126 A large slip-off slope on the side of Mount Pilatus. The size of the slope can be seen by the size of the walkers at the foot of the slope. Such slopes are very unstable, which is why vegetation has not been able to establish itself.



7.127 Terraces are a major feature of water management in Nepal. Water is used by the top terrace first and then re-used by each successive terrace down the slope. These terraces are at Nagarkot.

The Nepalese government is making a strong effort to remedy soil erosion because it is costing so much money in lost production. Among the soil conservation practices being encouraged are:

- improving terraces to improve the flow of water down hillsides (figure 7.127);
- re-routing walking trails so that they do not go straight up and down steep slopes;
- planting grass in gullies that have been eroded to stabilise them;
- stabilising the banks of rivers so that they do not get undercut and washed away;
- planting trees on hillsides.

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. Although Switzerland has over 400,000 farmers, the country's waterways are remarkably free from agricultural wastes and contaminants. Indeed, Switzerland has generally embraced 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.

Most Swiss cantons have introduced specially marked bags for rubbish that cannot be recycled. These are very expensive (up to \$5 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 (figure 7.128).

As an LEDC (less economically developed country), water pollution is a more significant problem in Nepal, especially near the urban areas. Hindus regard several of Nepal's rivers as holy, and the demands made upon the water of such rivers are very great indeed. For example, the Bagmati River which flows through Kathmandu is at the one time a source of irrigation water, a 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 (figures 7.129 and 7.130).



7.128 This gravel mine in the Bernese Oberland causes sediment pollution in the river downstream.



7.130 This view of the Bagmati River flowing through Kathmandu shows the garbage that has been dumped in the river-bed in preparation for the higher waters in the monsoon season to flush it away.

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 (figure 7.131). 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.



7.129 A funeral ghat has a body being cremated in preparation for remains to be dumped into the Bagmati River in the background. Cattle are grazing on the stream bed between the ghat and the river channel.



7.131 Washing clothes in river water. The dirty water will be returned to the river, causing a problem for those downstream needing clean water.

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.

QUESTION BLOCK 7Y

1. Draw up a table to compare the state of the environment in the high altitude areas of Switzerland and Nepal.
2. Why is Nepal's environment dirtier than Switzerland's?
3. What realistic policies could be introduced to improve Nepal's environment? Is the Swiss experience of environmental management applicable to Nepal?
4. Having examined human impacts on the environments of Nepal and Switzerland, to what extent do you think human activities in high altitude areas in general are unsustainable?

The Impact of Global Climatic Change on Extreme Environments

There is a growing consensus among geographers that the world is experiencing global warming at a rate never previously experienced on the planet. As discussed in chapter 3, 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 treated in this chapter, then the effects of climate change are likely to have serious impacts on the people, settlements and economic activities in those environments.

Some degree of speculation is needed to predict the future impacts of global warming. Many of the effects of global warming are thought to be non-linear in nature, which means the potential exists for certain changes to trigger further feedback effects. Some researchers claim that this means that the earth's climate could enter a critical state where even quite small changes could trigger runaway or catastrophic climate change. Other researchers dismiss such claims as alarmist.

Nonetheless, some trends do appear clear. For example, NOAA (National Oceanic and Atmospheric Administration) research suggests that the impacts of global warming are already irreversible. The reports of the IPCC (Intergovernmental Panel on Climate Change) claim that human actions are the major cause of global warming, although the IPCC reports do not attempt to quantify the proportions of global warming that arise from human and natural causes. Among the expected direct consequences of global warming, the IPCC lists rising sea levels, retreat of glaciers and polar ice caps and changing distribution of agriculture. Secondary and regional consequences predicted by the IPCC include greater frequency of extreme weather events, further spread of tropical diseases, altered seasonal patterns in various ecosystems, and severe impact on the economies of many nations.

One of the consequences of global warming is that rates of evaporation increase. Perhaps surprisingly, during the 20th century, the world's average evaporation rates decreased. Geographers speculate that the reason evaporation rates declined was **global dimming**, which is the gradual reduction in the amount of solar radiation received on the earth's surface. Although the measurements of solar radiation received in different parts of the world vary, there was an average global decline of 4% during the 30 year period from 1960 to 1990.

Measurements since 1990 have been less clear. Some measurements in the mid-1990s showed an increase in solar radiation received at the earth's surface, possibly because 1990 was about the time that the world-wide use of aerosols began to decline, thus reducing the amount of particulates in the atmosphere.

If that trend continued, and the earth's climate continued to become warmer, evaporation rates would increase as the surface of the oceans become warmer bringing increased rainfall to arid and semi-arid areas.

An **increase of rainfall** in hot, arid environments would bring some benefits for people as more grass and bushes will grow in areas where there is presently too little rainfall to support such growth. On the other hand, it would also increase soil erosion as the desert soils are not capable of absorbing large increases in rainfall, and this would lead to **desertification**.

However, more recent measurements released by the UNEP (United Nations Environment Program) in 2009 seem to confirm that the world is becoming progressively dimmer, and the 1960 to 1990 trend has re-established itself. This is the result of pollution from human activities creating semi-permanent **atmospheric brown clouds** (ABCs). According to the UNEP, a three-kilometre thick layer of soot and other particles produced by burning fossil fuels and biomass stretches from the Arabian Peninsula to China and the western Pacific Ocean, and other smaller ABCs are found over Europe, North America, southern Africa and the Amazon Basin. The UNEP found that dimming was especially severe over some cities such as Karachi, Delhi, Beijing, Shanghai and Guangzhou.

Global dimming represents a special danger because it may mask the full impact of global warming, making people complacent. The **masking** of the full impact of global warming occurs because atmospheric brown clouds reflect solar radiation back into space and absorb heat. In other words, the human causes of global warming may be having a more severe effect than the measurements at ground level indicate.



7.132 A small oasis near Zakati, Yemen.

If global dimming is increasing as the UNEP suggests, then **evaporation rates** would decrease from the surface of the oceans, reducing the rainfall to arid and semi-arid areas. This could lead to the **expansion of deserts** and the drying up of oases and other sources of water (figure 7.132). The drying up of limited water supplies also increases the concentration of pathogens in drinking and

bathing waters used by indigenous community, increasing the risk of serious **water-borne diseases** and health problems (figure 7.133).

Lower rainfall in arid and semi-arid areas would mean that the daily task of gathering **fuelwood** may become even more onerous as scarce vegetation struggles to survive — especially 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 (figure 7.134).



7.133 This polluted water hole in Djibouti is used as a source of drinking water for the local population.



7.134 This woman from the Erebara tribe in southern Ethiopia is doing the daily chore of many women in LEDCs — carrying a heavy load of fuelwood.

It has been suggested that climate change may already be causing problems 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 2 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 ill-will 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 (figure 7.135).



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

This has led many outside observers to assume Eritrea’s nomadic **pastoralists** (people who raise animals) are locked into a destructive cycle of increasing their numbers of livestock to survive at the times when drought should be forcing them to reduce livestock numbers. Although Eritrea’s pastoralists 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.

Outside observers have accused Eritrea’s pastoralists (as well as other pastoralists in Sub-Saharan Africa) of having 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, however, land resources in Eritrea (and most other places) are not communally owned, but managed by particular groups. The local knowledge thus gained has enabled many of Eritrea’s pastoral communities to remain viable in spite of continuing droughts and global warming.

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 global warming than outside 'experts' imposing a system that may not be sustainable in Eritrea's extreme environment.

Similar pressures exist in even more arid environments. The Himba people of southern Angola and northern Namibia are nomadic pastoralists who survive by raising goats and sheep in the driest parts of the Namib Desert (figure 7.136). In the 1980s, a severe drought killed 90% of the Himba's livestock and many gave up their herds and became refugees. Many fear that of global warming continues, the pressures on the Himba could become impossible to bear and their traditional lifestyle will be lost forever. On the other hand, the Himba have shown a deep understanding of the climatic fluctuations of the desert as shown by their survival for many centuries. This has led some researchers to investigate traditional societies such as the Himba to learn more about ways of adapting to climate change in extreme environments.



7.136 The nomadic Himba people of the Namib Desert have developed a lifestyle that enables them to survive by raising goats and cattle despite the area's extreme aridity.

One of the factors that makes the Himba so resilient to the pressures of their extreme environment is their **tribal structure**. The Himba organise their society around a system called **bilateral descent**. Every person belongs to two clans, one through the father and another through the mother. The relatives in both clans are equally important for emotional ties and for the transfer of property or wealth. Sons live with their father's clan and when daughters marry they go to live with the clan of their husband. However, the inheritance of wealth does not follow the father's side of the family but is determined by the mother's clan. In this way, a son does not inherit his father's animals, but he inherits the animals of his mother's brother. The bilateral descent system seems to give groups such as the Himba that live in extreme environments a huge advantage in adapting to the pressures of climate change because individuals can rely on two sets of families living in different local conditions over a wide area.

Having said this, indigenous peoples leading traditional lifestyles may be vulnerable to climate change in other ways. The ways that indigenous people cope with their extreme environments are often based on traditional knowledge, and although this traditional knowledge has proven adaptable to many climatic fluctuations in the past, some researchers worry that more extreme global warming may stretch traditional adaptations beyond their breaking points. For example, if farmers plant crops at certain times of the year that are based on 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 (figure 7.137).



7.137 Hecang, one of many abandoned settlements in the deserts of western China that provide evidence of thriving settlements based on well managed water resources in the less arid past.

In the context of today's world, Dr Norman Myers of Oxford University has suggested that the combination of sea level rise and agricultural distribution caused by climate changes (global warming) could displace millions of people in LEDCs in the coming decades (figure 7.138). The term **environmental refugees** is often used to describe people who must flee (either temporarily or permanently) from their traditional habitat because of a marked environmental disruption that threatened their existence or seriously affected their quality of life. Myers estimates by 2050, 1.5% of the 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.

Scientists warn that prolonged drought conditions are another possible consequence of global warming in desert areas. This presents another possible adverse impact on local people, many of whom raise animals for their livelihood, as they will be forced to move their animals onto land that is more and more marginal in search of feed and water (figures 7.139, 7.140 and 7.141). When animals are forced to over-graze on marginal semi-arid land, there is a real risk that the land may turn into desert.



7.140 These goats are resting in the shade of some trees in the marginal arid to semi-arid lands of the Erebor tribe in southern Ethiopia.



7.138 Global warming could make the arid conditions in countries such as Eritrea (shown here) even less hospitable in the future.



7.141 Himba herders in the Namib Desert moving their goats, and stirring up soil erosion as they do so.



7.139 Goats grazing on marginal arid lands at Dimeka in southern Ethiopia.



7.142 Shanty settlements made by rural-urban migrants from Eritrea on the outskirts of Djibouti City.

The large **shanty settlements** that exist on the outskirts of many towns and cities are another sign of environmental migration in hot, arid environments (figure 7.142). 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, or durable housing. Although it is impossible to quantify the role of climate change in forcing rural-urban migration, there is 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 (figure 7.143). Tradition says that Sana'a was established by Noah's son, Shem, but whether that is true or not, Sana'a is a very old city with a long history of adaptation to changing environmental conditions. For example, the tall tower houses 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 city, 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 (figure 7.144). 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 (figure 7.145). Because the city was established on a natural oasis, this 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.



7.143 Sana'a, Yemen's capital city, is claimed to be the world's first city.



7.144 The ephemeral stream known as Wadi as Sa'ilah, in Sana'a, has been converted into a canal which is used as a roadway when the stream is not flowing.

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 (figure 7.146). 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 (figure 7.147). Dubai also uses large quantities of fuels such as oil to air condition the buildings, which unlike the traditional architecture used in Dubai, 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.



7.145 Fruit and vegetable cultivation within the old city of Sana'a, Yemen.

The impact of global warming may be even more marked in **cold and high altitude environments**. Glacial retreat and shrinking of the polar ice caps has been widely noted in recent decades, and global warming is the main cause suggested to explain these trends. 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.



7.146 Dubai, the largest commercial centre in the United Arab Emirates, is an example of a modern desert city with a large energy footprint.



7.147 Irrigation creates a verdant green median strips along many of Dubai's roads and expressways.

In the periglacial expanses of the tundra, global warming is thawing permafrost. **Permafrost** is a thick layer of soil below the ground surface in polar 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 already causing damage to infrastructure such as roads, railway lines and buildings (figure 7.148). As permafrost melts, it releases large quantities of greenhouse gases such as methane that had been frozen into the atmosphere. In this way, melting permafrost and global warming are thought to have a **positive feedback relationship**, with each reinforcing the other.



7.148 These buildings in Dawson City (Yukon, Canada) show what can happen when heated buildings are placed on frozen permafrost ground. The permafrost melts, mixing soil with water forming a paste into which the footings settle at different rates.

Another consequence of glacial retreat and thawing permafrost is that the frequency and size of **landslides** in cold and high environments are expected to increase. Water in liquid form on steep slopes acts as a lubricant, reducing cohesion and allowing gravity to take over and cause slope failure (figure 7.149). 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 people 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 (figure 7.150).



7.149 A landslide in the Rocky Mountains of Canada, near Jasper.

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, and 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 have expressed concern about the future of their traditional food sources.



7.150 Indigenous people in Greenland depend on fishing for their survival and livelihood. The fishing may be threatened by global warming.

Concerns have also been expressed by indigenous peoples about the increasing difficulties of **predicting the weather** in cold environments, a very important factor for people who depend so 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 Darwin in 2008, the plight of **indigenous peoples** in the face of climate change was the focus of discussions. In summing up the conference, the UNU Director, Dr A Zakri said “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.”



7.152 A summer walker in the Swiss Alps, near Zermatt.

7.151 Another view of the Athabasca Glacier in Canada, shown earlier in figures 7.34 and 7.35. The marker locates the toe of the glacier in 1959. Today, the glacier has retreated out of sight behind the large hill of terminal moraine seen in the background.



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. For example, the marker in figure 7.151 shows the extent of the Athabasca Glacier in the Rocky Mountains of Canada; this is the same glacier that was shown in figure 7.35 earlier in this chapter. The current end of the glacier is still visible from the 1992 marker, but to walk from the 1959 marker past the 1992 marker to the current limit of the glacier, one must walk about 50 metres over the large hill of terminal moraine shown in the background of figure 7.151.



7.153 Visitors stand on the outwash plain to study information about the Skaftafell Glacier in southern Iceland from a board, while viewing the glacier (background).

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 (figures 7.152 and 7.153). 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 and develop new ways of attracting tourists, perhaps replacing skiing and snowboarding with attractions such as cycling, horse riding and canoeing (figure 7.154).

Any collapse or contraction of the tourist industry in alpine areas would have a wider impact beyond the tourist industry itself, as many supporting industries and enterprises cluster in settlements based on tourism. Indeed,

many of the settlements in high altitude environments would probably not exist if it were not for the tourist industry (figure 7.155).



7.154 Preparing to go canoeing on Moraine Lake, Alberta, Canada.



7.155 Substantial infrastructure supports tourism in alpine areas these days. These accommodation chalets are in the Canadian town of Jasper.

Despite the hot and dry conditions, many desert areas have small but growing tourism industries. In some areas this is based on the lure of exploring stark and beautiful environments, while in other areas the dry climate attracts tourists from cool, moist climates who are in search of sunny weather (figure 7.156).



7.156 Tourists ride on the backs of camels to explore the large sand dunes of the Gobi Desert near Dunhuang, China. The area also provides facilities for paragliding and sand boarding.



7.157 Some places have very basic facilities to cater for tourists. This view shows Liwa Oasis in the United Arab Emirates.

However, if global warming continues at the accelerating rate that many scientists predict, perhaps the future of tourism in more and more parts of the world will be something resembling the scene in figure 7.157!

QUESTION BLOCK 7Z

1. Explain what is meant by global dimming. Describe the trend of global dimming and its relationship to global climate change.
2. There is disagreement among scholars whether global warming will increase or decrease rainfall in desert areas. However, most of the predictions seem negative either way. Giving examples, explain why this is so.
3. Although indigenous peoples in hot, arid environments are among the most vulnerable groups when global warming occurs, they may also be among the most resilient. Giving examples, explain why this is so.
4. Explain the terms 'environmental migration' and 'environmental refugee'. Why is global climate change likely to increase environmental migration in hot, arid environments?
5. What are the characteristics of settlements in hot, arid environments make them more resilient to global warming?
6. What are the consequences of thawing permafrost?
7. How might global warming affect indigenous peoples in cold and high altitude environments?
8. Overall, do you think there is more potential for global climatic change to affect hot, arid environments or cold and high altitude environments?