8

Rock types and landforms

'At first sight it may appear that rock type is the dominant influence on most landscapes ... As geomorphologists, we are more concerned with the ways in which the characteristics of rocks respond to the processes of erosion and weathering than with the detailed study of rocks themselves.'

R. Collard, *The Physical Geography of Landscape*, 1988

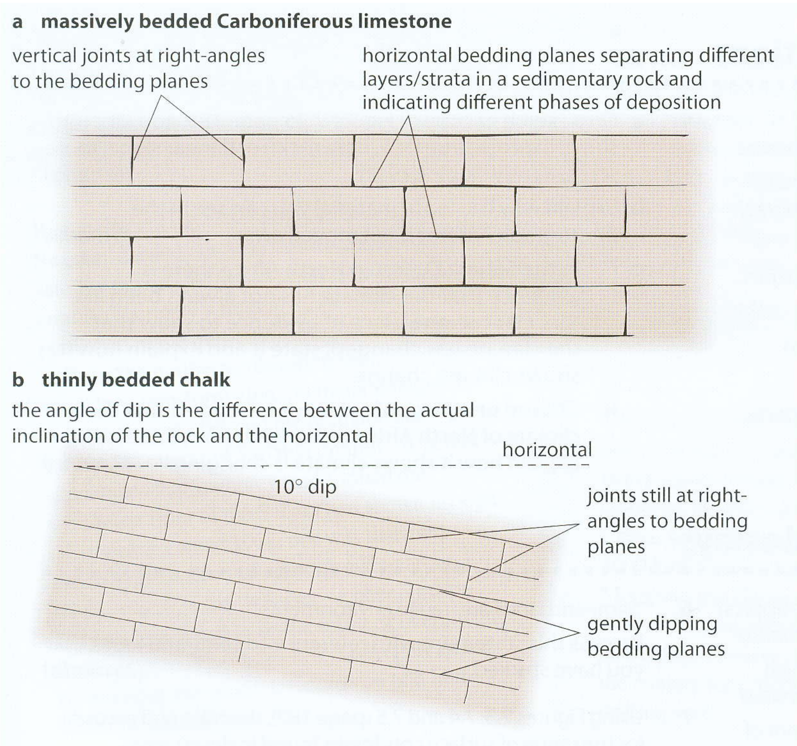
Previous chapters have demonstrated how landscapes at both local and global scales have developed from a combination of processes. Plate tectonics, weathering and the action of moving water, ice and wind both create and destroy landforms. Yet these processes, however important they are at present or have been in the past, are insufficient to explain the many different and dramatic changes of scenery which can occur within short distances, especially in the British Isles.

Lithology refers to the physical characteristics of a rock. As each individual rock type has different characteristics, so it is capable of producing its own characteristic scenery. Landforms are greatly influenced by a rock type's vulnerability to weathering, its permeability and its structure.

To show how these three factors affect different rocks and to explain their resultant landforms and potential economic use, five rock types have been selected as exemplars. Carboniferous limestone, chalk and sandstone (sedimentary rocks), and granite and basalt (both igneous) have been chosen because, arguably, these produce some of the most distinctive types of landform and scenery.

Figure 8.1

Bedding planes with joints and angle of dip



Lithology and geomorphology

Vulnerability to weathering

Mechanical weathering in Britain occurs more readily in rocks that are jointed. Water can penetrate either down the **joints** or along the **bedding planes** (Figure 8.1) of Carboniferous limestone, or into cracks resulting from pressure release or contraction on cooling within granite and basalt (page 41 and Figure 1.31). Subsequent freezing and thawing along these lines of weakness causes frost shattering (page 40).

Chemical weathering is a major influence in limestone and granite landforms. Limestone, composed mostly of calcium carbonate, is slowly dissolved by the carbonic acid in rainwater, i.e. the process of carbonation (page 43). Granite consists of quartz, feldspar and mica. It is susceptible to hydration, where water is incorporated into the rock structure causing it to swell and crumble (page 42), and to hydrolysis, when the feldspar is chemically changed into clay (pages 42–43). Quartz, in comparison with other minerals, is one of the least prone to chemical weathering.

Mottershead has emphasised that 'the mechanical resistance of rocks depends on the strength of the individual component minerals and the bonds between them, and that chemical resistance depends on the individual chemical resistances of the component minerals. Mechanical strength decreases if just one of these component minerals becomes chemically altered.'

Permeability

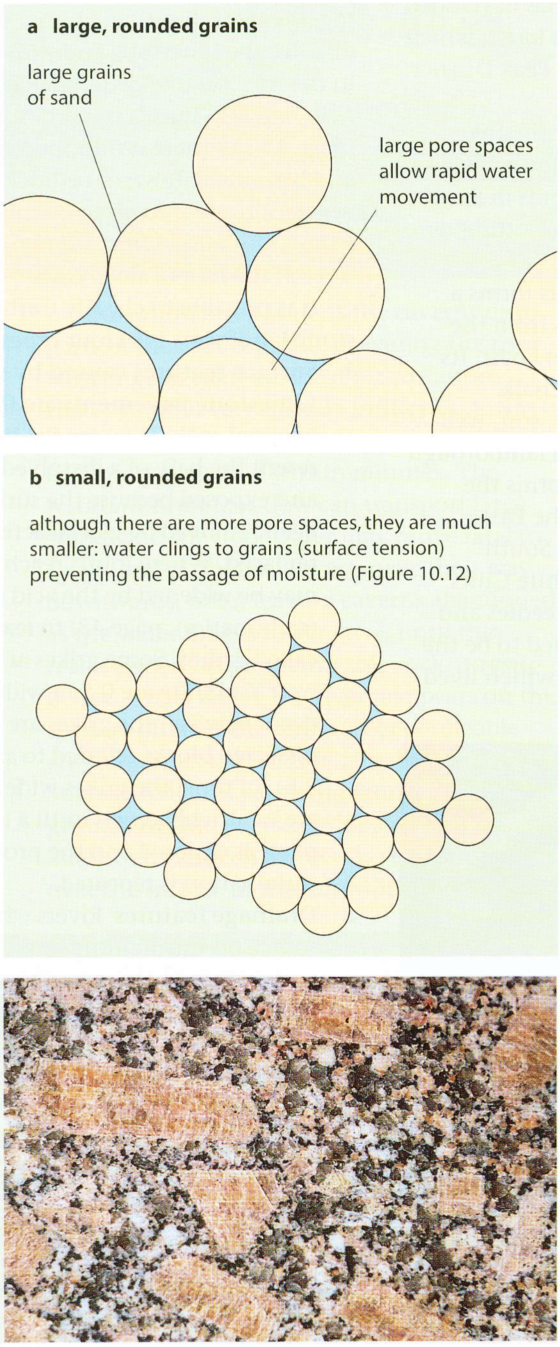
Permeability is the rate at which water may be stored within a rock or is able to pass through it. Permeability can be divided into two types.

1 **Primary permeability or porosity** This depends on the texture of the rock and the size, shape and arrangement of its mineral particles. The areas between the particles are called **pore spaces** and their size and alignment determine how much water can be absorbed by the rock. Porosity is usually greatest in rocks that are coarse-grained, such as gravels, sands, sandstone and oolitic limestone, and usually lowest in those that are fine-grained, such as clay and granite. (It is possible to have fine-grained sandstone and coarse-grained granite.) **Infiltration capacity** is the maximum rate at which water percolates into the ground. The infiltration capacity of sands is estimated to average 200 mm/hr, whereas in clay it is only 5 mm/hr. Pore spaces are larger where the grains are rounded rather than angular and compacted (Figure 8.2). Porosity can be given as an index value based upon the percentage of the total volume of the rock which is taken up by pore space, e.g. clay 20 per cent, gravel 50 per cent. When all the pore spaces are filled with water, the rock is said to be **saturated**. The water table marks the upper limit of saturation (Figure 8.9). Permeable rocks which store water are called **aquifers**.

2 **Secondary permeability** or **perviousness** This occurs in rocks that have joints and fissures along which water can flow. The most pervious rocks are those where the joints have been widened by solution, e.g. Carboniferous limestone, or by cooling, e.g. basalt. A rock may be pervious because of its structure, though water may not be able to pass through the rock mass itself. Where rocks are porous or pervious, water rapidly passes downwards to become groundwater, leaving the surface dry and without evident drainage – chalk and limestone regions have few surface streams. **Impermeable rocks**, e.g. granite, neither absorb water nor allow it to pass through them. These rocks therefore have a higher drainage density (page 67).

Figure 8.2

Pore spaces and infiltration capacity



c crystals in granite

these fit together more closely than rounded grains, limiting the amount of water held and inhibiting the movement of moisture

Structure

Resistance to erosion depends on whether the rock is massive and stratified, folded or faulted. Usually the more massive the rock and the fewer its joints and bedding planes, the more resistant it is to weathering and erosion. Conversely, the softer, more jointed and less compact the rock, the more vulnerable it is to denudation processes. Usually, more resistant rocks remain as upland areas (granite), while those that are less resistant form lowlands (clay).

However, there are exceptions. Chalk, which is relatively soft and may be well-jointed, forms rolling hills because it allows water to pass through it and so fluvial activity is limited. Carboniferous or Mountain limestone, having joints and bedding planes, produces jagged karst scenery because although it is pervious it has a very low porosity.

Limestone

Limestone is a rock consisting of at least 80 per cent calcium carbonate. In Britain, most limestone was formed during four geological periods, each of which experienced different conditions. The following list begins with the oldest rocks. Use an atlas to find their location.

Carboniferous limestone This is hard, grey, crystalline and well-jointed. It contains many fossils, including corals, crinoids and brachiopods. These indicate that the rock was formed on the bed of a warm, clear sea and adds to the evidence that the British Isles once lay in warmer latitudes. Carboniferous limestone has developed its own unique landscape, known as **karst**, which in Britain is seen most clearly in the Peak District and Yorkshire Dales National Parks.

Magnesian limestone This is distinctive because it contains a higher proportion of magnesium carbonate. In Britain, it extends in a belt from the mouth of the River Tyne to Nottingham. In the Alps, it is known as **dolomite**.

Jurassic (oolitic) limestone This forms a narrow band extending southwards from the North Yorkshire Moors to the Dorset coast. Its scenery is similar to that typical of chalk.

Cretaceous chalk This is a pure, soft, well-jointed limestone. Stretching from Flamborough Head in Yorkshire (Figure 6.19), it forms the escarpment of the Lincoln Wolds, the East Anglian Heights and the North and South Downs, before ending up as the 'White Cliffs' at Dover and at Beachy Head, the Needles and Swanage. Cretaceous chalk is assumed to be the remains of small marine organisms which lived in clear, shallow seas.

Figure 8.3

A stream disappearing down a swallow hole near Hunt Pot, Pen-y-Ghent, Yorkshire Dales National Park

The most distinctive of the limestone landforms are found in Carboniferous limestone and chalk.

Carboniferous limestone

This rock develops its own particular type of scenery primarily because of three characteristics. First, it is found in thick beds separated by almost horizontal bedding planes and with joints at right-angles (Figure 8.1). Second, it is pervious but not porous, meaning that water ca pass along the bedding planes and down joints but not through the rock itself. Third, calcium carbonate is soluble. Carbonic acid in rainwater together with humic acid from moorland plants dissolve the limestone and widen any weakness in the rock, i.e. the bedding planes and joints. Acid rain also speeds up carbonation and solutio (page 43). As there is minimum surface drainage and little breakdown of bedrock to form soil, the vegetation cover tends to be thin or absent. In winter, this allows frost shattering to produce scree at the foot of steep cliffs.

It is possible to classify Carboniferous limestone landforms into four types:

1 **Surface features caused by solution** **Limestone pavements** are flat areas of exposed rock. They are flat because they represent the base of a dissolved bedding plane, and exposed because the surface soil may ha been removed by glacial activity and never replaced. Where joints reach the surface, the may be widened by the acid rainwater (carbonation, page 43) to leave deep gashes called **grikes**. Some grikes at Malham in nort west Yorkshire are 0.5 m wide and up to 2 m deep. Between the grikes are flat-topped yet dissected blocks referred to as **clints** (Figure 2.8). In time, the grikes widen and the clints are weathered down until a lower bedding plane is exposed and the process of solution-carbonation is repeated.

2 **Drainage features** Rivers which have their source on surrounding impermeable rocks, such as the shales and grits of northern England, may disappear down **swallow holes** or **sinks** as soon as they reach the limestone (Figure 8.3). The streams flow underground finding a pathway down enlarged joints, forming **potholes**, and along bedding planes. Where solution is more active, underground **caves** may form. While most caves develop above the water table (**vadose caves**, Figure 8.8), some may form beneath it (**phreatic caves**).

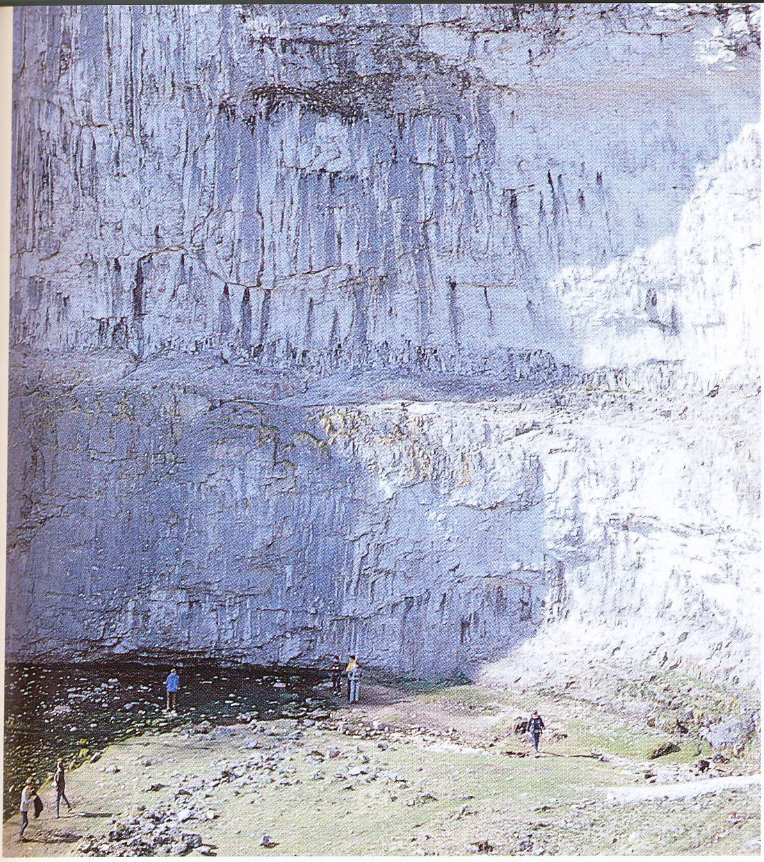


Figure 8.4

The resurgence at the foot of Malham Cove, Yorkshire Dales

Corrosion often widens the caverns until parts of the roof collapse, providing the river with angular material ideal for corrasion. Heavy rainfall very quickly infiltrates downwards, so caverns and linking passages may become water-filled within minutes. The resultant turbulent flow can transport large stones and the floodwater may prove fatal to cavers and potholers. Rivers make their way downwards, often leaving caverns abandoned as the water finds a lower level, until they reach underlying impermeable rock. A **resurgence** occurs where the river reappears on the surface, often at the junction of permeable and impermeable rocks (Figure 8.4).

3 **Surface features resulting from underground drainage** Steep-sided valleys are likely to have been formed as rivers flowed over the surface of the limestone, probably

Figure 8.6

Stalactites, stalagmites and pillars, Carlsbad Caverns, New Mexico, USA

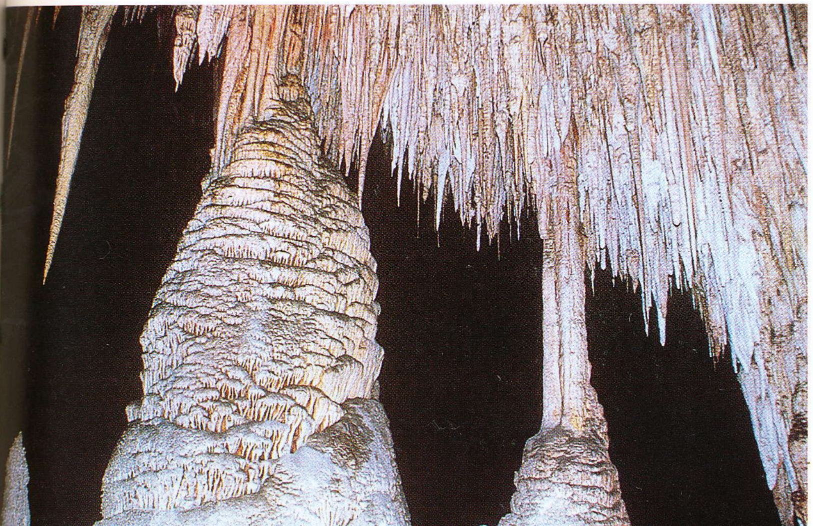


Figure 8.5

The Watlowes dry valley above Malham Cove

during periglacial times when permafrost acted as an impermeable layer. When the rivers were able to revert to their subterranean passages, the surface valleys were left dry (Figure 8.5). Many dry valley sides are steep and gorge-like, e.g. Cheddar Gorge. If the area above an individual cave collapses, a small surface depression called a **doline** is formed. **Shakeholes** are smaller doline-like features found in the northern Pennines where glacial material has subsided into underground cavities (Figure 8.8). In the former Yugoslavia, where the term 'karst' originated, huge depressions called **poljes** may have formed in a similar way. Poljes may be up to 400 km^2 in area. In the tropics, the landscape may be composed of either cone-shaped hills and polygonal depressions known as 'cockpit country' (e.g. Jamaica) or tall isolated 'towers' rising from wide plains (e.g. near Guilin, China – Places 26).

4 **Underground depositional features** Groundwater may become saturated with calcium bicarbonate, which is formed by the chemical reaction between carbonic acid in rainwater and calcium carbonate in the rock. However, when this 'hard' water reaches a cave, much of the carbon dioxide bubbles out of solution back into the air – i.e. the process of carbonation in reverse. Aided by the loss of some moisture by evaporation, calcium carbonate (calcite) crystals are subsequently precipitated. Water dripping from the ceiling of the cave initially forms pendant soda straws which, over a very long period of time, may grow into icicle-shaped **stalactites** (Figure 8.6). Experiments in Yorkshire caves suggest that stalactites grow at about 7.5 mm per year. As water drips onto the floor, further deposits of calcium carbonate form the more rounded, cone-shaped **stalagmites** which may, in time, join the stalactites to give **pillars**.

Places 26 Li valley, south China: karst scenery

Figure 8.7

The karst towers of Guilin, south China

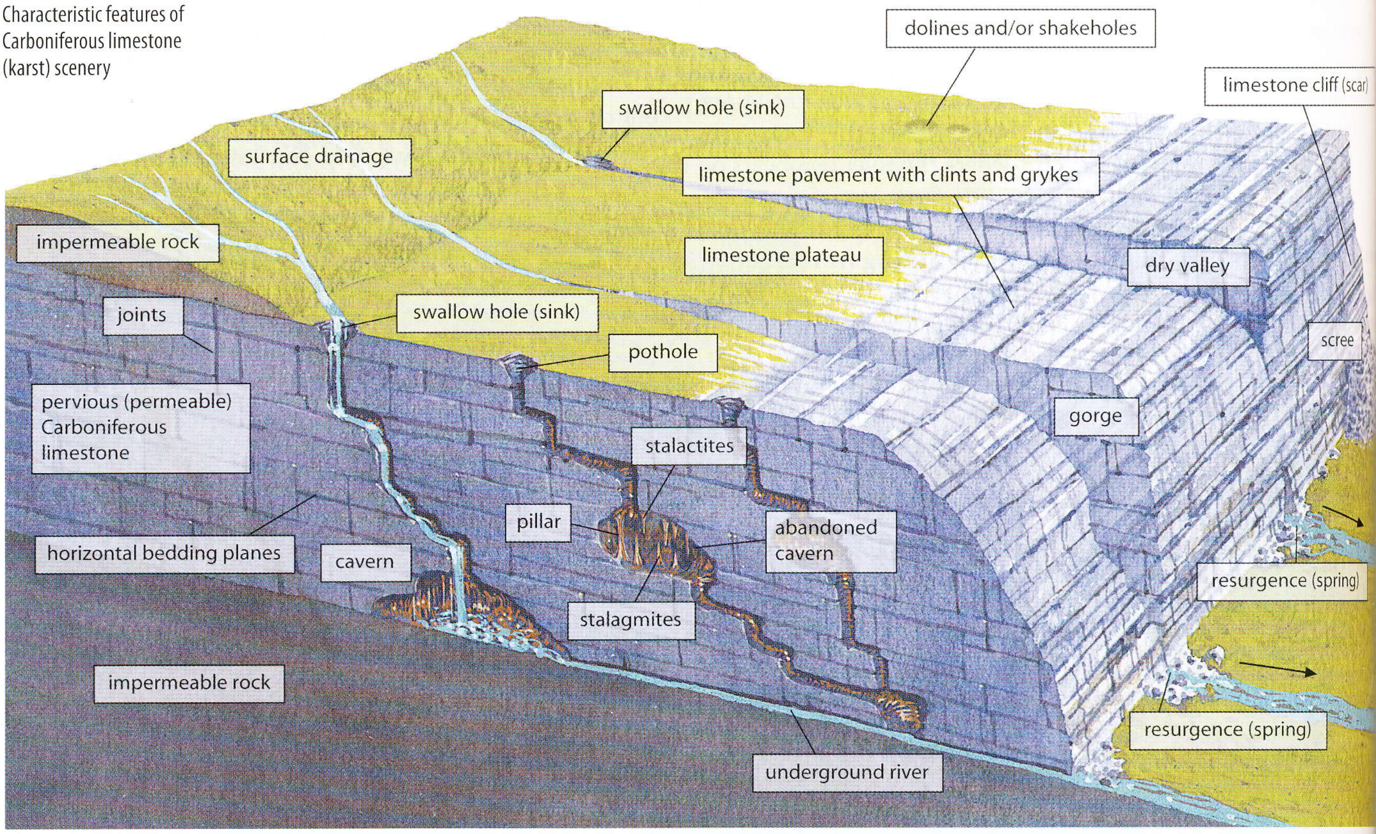
Limestone covers some 300 000 km^2 of China – an area larger than that of the UK. Its scenery is seen at its most spectacular in the Three Gorges section of the Yangtze River and where it forms the karst towers in the Guilin region of Guangxi Province.

The limestones that outcrop near Guilin have formed a unique karst landscape. The massively bedded, crystalline rock, which in places is 300 m thick, has been slowly pushed upwards from its seabed origin by the same tectonic movements that formed the Himalayas and the Tibetan Plateau far to the west. The heavy summer monsoon rain, sometimes exceeding 2000 mm, has led to rapid fluvial erosion by such rivers as the Li Jiang (Li River). The availability of water together with the high sub-tropical temperatures (Guilin is at 25°N) encourage highly active chemical weathering (solution–carbonation, page 43).

The result has been the formation of a landscape which for centuries has inspired Chinese artists and, recently, has attracted growing numbers of tourists. To either side of the river are natural domes and towers, some of which rise almost vertically 150 m from surrounding paddy fields (Figure 8.7), giving the valley its gorge-like profile. Caves, visible on the sides of the towers, were formed by underground tributaries to the Li Jiang when the main river was flowing at levels considerably higher than those of today.

Figure 8.8

Characteristic features of Carboniferous limestone (karst) scenery



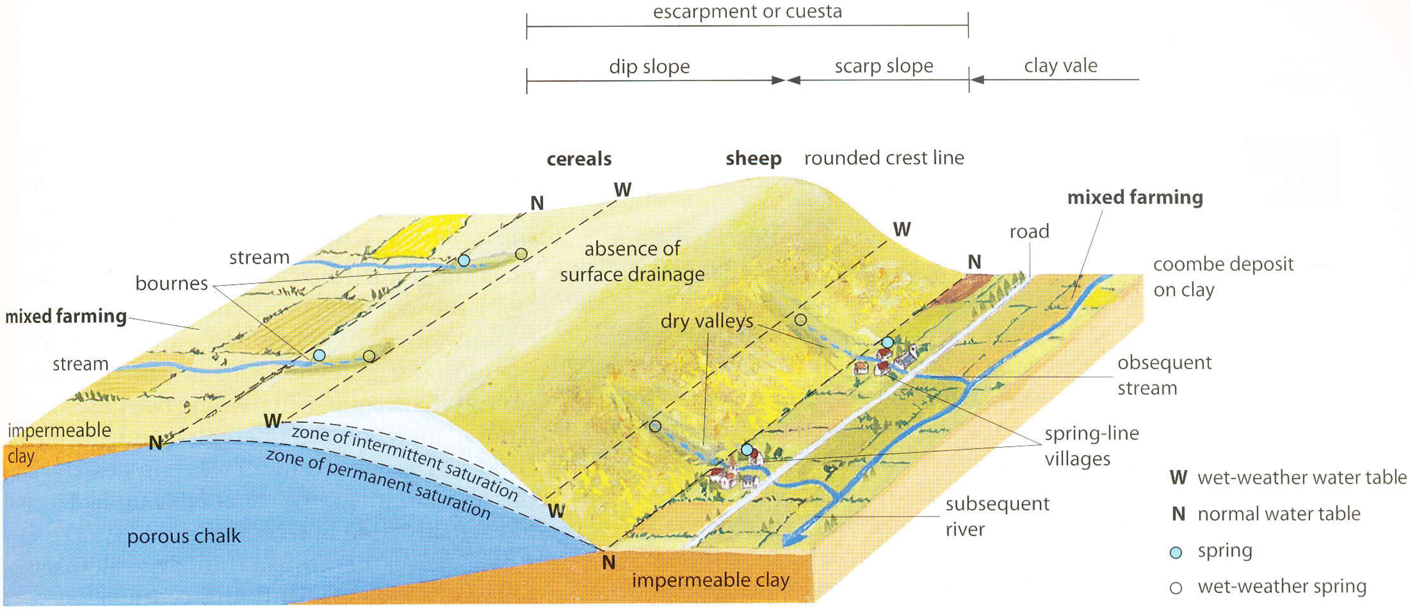


Figure 8.9

Scarp and vale scenery: an idealised section through a chalk escarpment in south-east England

Economic value of Carboniferous limestone

Human settlement on this type of rock is usually limited and dispersed (page 397) due to limited natural resources, especially the lack of water and good soil. Villages such as Castleton (Derbyshire) and Malham (Yorkshire) have grown up near to a resurgence.

Limestone is often quarried as a raw material for the cement and steel industries or as ornamental stone, but the resultant scars have led to considerable controversy (Case Study 8). The conflict is between the economic advantages of extracting a valuable raw material and providing local jobs, versus the visual eyesore, noise, dust and extra traffic resulting from the operations, e.g. the Hope valley, Derbyshire.

Farming is hindered by the dry, thin, poorly developed soils for, although most upland limestone areas of Britain receive high rainfall totals, water soon flows underground. The rock does not readily weather into soil-forming particles, such as clay or sand, but is dissolved and the residue is then leached (page 261). On hard limestones, rendzina soils may develop (page 274). These soils are unsuitable for ploughing and their covering of short, coarse, springy grasses favours only sheep grazing. In the absence of hedges and trees, drystone walls were commonly built as field boundaries. The scenery attracts walkers and school parties, while underground features lure cavers, potholers and **speleologists** (scientists who study caves).

Chalk

Chalk, in contrast to Carboniferous limestone scenery, consists of gently rolling hills with rounded crest lines. Typically, chalk has steep, rather than gorge-like, dry valleys and is rarely exposed on the surface (Figure 8.9).

The most distinctive feature of chalk is probably the **escarpment**, or **cuesta**, e.g. the North Downs and South Downs (Figures 8.10 and 14.4). Here the chalk, a pure form of limestone, was gently tilted by the earth movements associated with the collision of the African and Eurasian Plates. Subsequent erosion has left a steep scarp slope and a gentle dip slope. In south-east England, clay vales are found at the foot of the escarpment (Figure 3.51b).

Although chalk – like Carboniferous limestone – has little surface drainage, apart from rivers like the Test and Itchen, its surface is covered in numerous dry valleys (Figure 8.11). Given that chalk can absorb and allow rainwater to percolate through it, how could these valleys have formed?

Figure 8.10

South Downs chalk escarpment, Poynings, Sussex

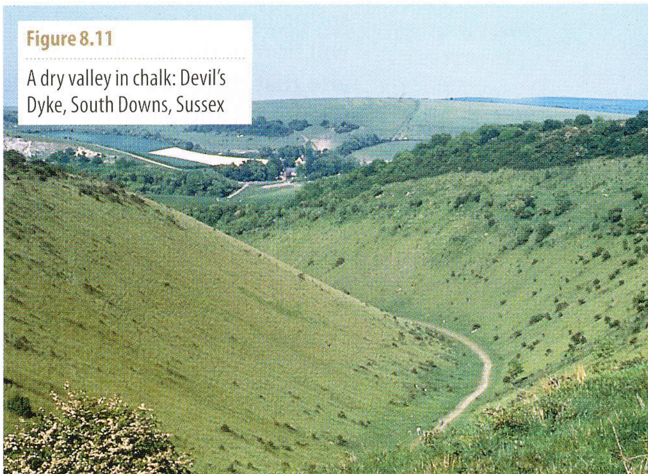


Figure 8.11

A dry valley in chalk: Devil's Dyke, South Downs, Sussex

Goudie lists 16 different hypotheses that have been put forward regarding the origins of dry valleys. These he has grouped into three categories:

1 **Uniformitarian** These hypotheses assume that there have been no major changes in climate or sea-level and that 'normal' – i.e. fluvial – processes of erosion have operated without interruption. A typical scenario would be that the drainage system developed on impermeable rock overlying the chalk, and subsequently became superimposed upon it (page 85).
2 **Marine** These hypotheses are related to relative changes in sea-level or base level (page 81). One, which has a measure of support, suggests that when sea-levels rose eustatically at the end of the last ice age (page 123), water tables and springs would also have risen. Later, when the base level fell, so too did the water table and spring line, causing valleys to become dry.
3 **Palaeoclimatic** This group of hypotheses, based on climatic changes during and since the ice age, is the most widely accepted. One hypothesis claims that under periglacial conditions any water in the pore spaces would have been frozen, causing the chalk to behave as an impermeable rock (page 135). As temperatures were low, most precipitation would fall as snow. Any meltwater would have to flow over the surface, forming valleys that are now relict landforms (Figure 8.11).

An alternative hypothesis stems from occasions when places receive excessive amounts of rainfall and streams temporarily reappear in dry valleys. Climatologists have shown that there have been times since the ice age when rainfall was considerably greater than it is today. Figure 8.9 shows the normal water table with its associated spring line. If there is a wetter than average winter, or longer period, when moisture loss through evaporation is at its minimum, then the level of permanent saturation will rise. Notice that the wet-weather water table causes a rise in the spring line and so seasonal rivers, or **bournes**, will flow in the normally dry valleys. Remember also that there will be a considerable lag time (Figure 3.5 and page 61) between the peak rainfall and the time when the bournes will begin to flow (throughflow rather than surface runoff on chalk). The springs are the source of obsequent streams (page 84).

The presence of coombe deposits, resulting from solifluction (pages 47 and 135), also links chalk landforms with periglacial conditions.

Economic value of chalk

The main commercial use of chalk is in the production of cement, but there are objections on environmental grounds to both quarries and the processing works. Settlement tends to be in the form of nucleated villages strung out in lines along the foot of an escarpment, originally to take advantage of the assured water supply from the springs (Figures 8.9, 8.10 and 14.4). Water-storing chalk aquifers have long been used as a natural, underground reservoir by inhabitants of London. Despite recent increases in demand for this artesian water, the water table under London has actually risen in recent decades.

Chalk weathers into a thin, dry, calcareous soil with a high pH. Until this century, the springy turf of the Downs was mainly used to graze sheep and to train race horses. Horse racing is still important locally, as at Epsom and Newmarket, but much of the land has been ploughed and converted to the growing of wheat and barley. In places, the chalk is covered by a residual deposit of **clay-with-flints** which may have been an insoluble component of the chalk or may have been left from a former overlying rock. This soil is less porous and more acidic than the calcareous soil and several such areas are covered by beech trees – or were, before the violent storm of October 1987 (Places 29, page 232). Flint has been used as a building material and was the major source for Stone Age tools and weapons.

Figure 8.12
Bedding planes in Old Red Sandstone, Old Man of Hoy, Orkney

Sandstone

Sandstone is the most common rock in Britain. It is a sedimentary rock composed mainly of grains of quartz, and occasionally feldspar and even mica, which have been compacted by pressure and cemented by minerals such as calcite and silica. This makes it a more coherent and resistant, but less porous, rock than sands. The sands, before compaction, may have been deposited in either **a** shallow seas, **b** estuaries and deltas, or **c** hot deserts. The presence of bedding planes (Figure 8.12) indicates the laying down of successive layers of sediment. Sandstone can vary in colour from dark brown or red through to yellow, grey and white (Figure 6.52), depending on the degree of oxidation or hydration (page 42). Like limestone (page 196), sandstone has formed in several geological periods (Figure 8.13), of which perhaps the most significant have been the following:

- The **Devonian**, or **Old Red Sandstone** (Figure 1.1), when sand was deposited in a shallow sea which covered present-day south-west England, South Wales and Herefordshire. These deposits, which were often massively bedded, were contorted and uplifted by subsequent earth movements. Landforms, indicative of an often resistant rock, vary from spectacular coastal cliffs to the plateau-like Exmoor, the north-facing scarp slope of the Brecon Beacons and the flatter lowlands of Herefordshire.
- The **Carboniferous** period, during part of which **Millstone Grit** was formed under river delta conditions. This is a darker, coarser and more resistant rock interbedded with shales. In the southern Pennines it can form either a plateau (Kinder Scout) or steep escarpments (Stanage Edge).
- The **Permian**, or **New Red Sandstone**, when sand was deposited under hot desert conditions, often in shallow water (i.e. when Britain lay in the latitude of the present-day Sahara). The rock is red, due to oxidation, and, being less resistant than the Old Red Sandstone, tends to form valleys (Exe and Eden) or low-lying hills (English Midlands).

Economic value of sandstone

Sandstone is the most common building material in Britain. In the past it was often used as stone for castles and cathedrals and, later, converted into brick for housing. Much of the New Red Sandstone has weathered into a warm, red, light and easily worked soil of high agricultural value, in contrast to the Old Red Sandstone which, being

Figure 8.13

Geological periods of various British sandstones

Geological period/ epoch	Type of sandstone	Examples: location in the UK
Post-Eocene	See Figure 1.1	
Eocene		London and Hampshire basins
Cretaceous	Greensand	The Weald (south-east England)
Jurassic		
Triassic	Bunter and Keuper sandstone	English Midlands, Cheshire
Permian	New Red Sandstone	Exe and Eden valleys, south Arran
Carboniferous	Millstone Grit	Southern Pennines
Devonian	Old Red Sandstone	South-west England, South Wales, Herefordshire, central and north-east Scotland
Silurian, Ordovician and Cambrian		
Pre-Cambrian	Torridon	Wester Ross, Scotland

more resistant, weathers to form uplands that have largely been left as moorland. Millstone Grit areas provided grindstones for Sheffield's cutlery industry in the past, and today these areas are popular for walking, rock-climbing, grouse moors and reservoirs.

Granite

Granite was formed when magma was intruded into the Earth's crust. Initially, as on Dartmoor and in northern Arran, the magma created deep-seated, dome-shaped batholiths (page 29). Since then the rock has been exposed by various processes of weathering and erosion. Having been formed at a depth and under pressure, the rate of cooling was slow and this enabled large crystals of quartz, mica and feldspar to form. As the granite continued to cool, it contracted and a series of cracks were created vertically and horizontally, at irregular intervals. These cracks may have been further enlarged, millions of years later, by pressure release as overlying rocks were removed (Figure 8.14).

The coarse-grained crystals render the rock non-porous but, although many texts quote granite as an example of an impermeable rock, water can find its way along the many cracks making some areas permeable. Despite this, most granite areas usually have a high drainage density and, as they occur in upland parts of Britain which have a high rainfall, they are often covered by marshy terrain.

Although a hard rock, granite is susceptible to both physical and chemical weathering. The joints, which can hold water, are widened by frost shattering (page 40), while the different rates of expansion and cooling of the various minerals within the rock cause granular disintegration (page 41). The feldspar and, to a lesser extent, mica can be changed chemically by hydrolysis (page 42). This means that calcium, potassium, sodium, magnesium and, if the pH is less than 5.0, iron and aluminium, are released from the chemical structure. Where the feldspar is changed near to the surface it forms a whitish clay called **kaolinite**. Where the change occurs at a greater depth (perhaps due to hydrothermal action), it produces **kaolin**. Quartz, which is not affected by chemical weathering, remains as loose crystals (Figure 2.7).

Figure 8.14

Hound Tor, Dartmoor

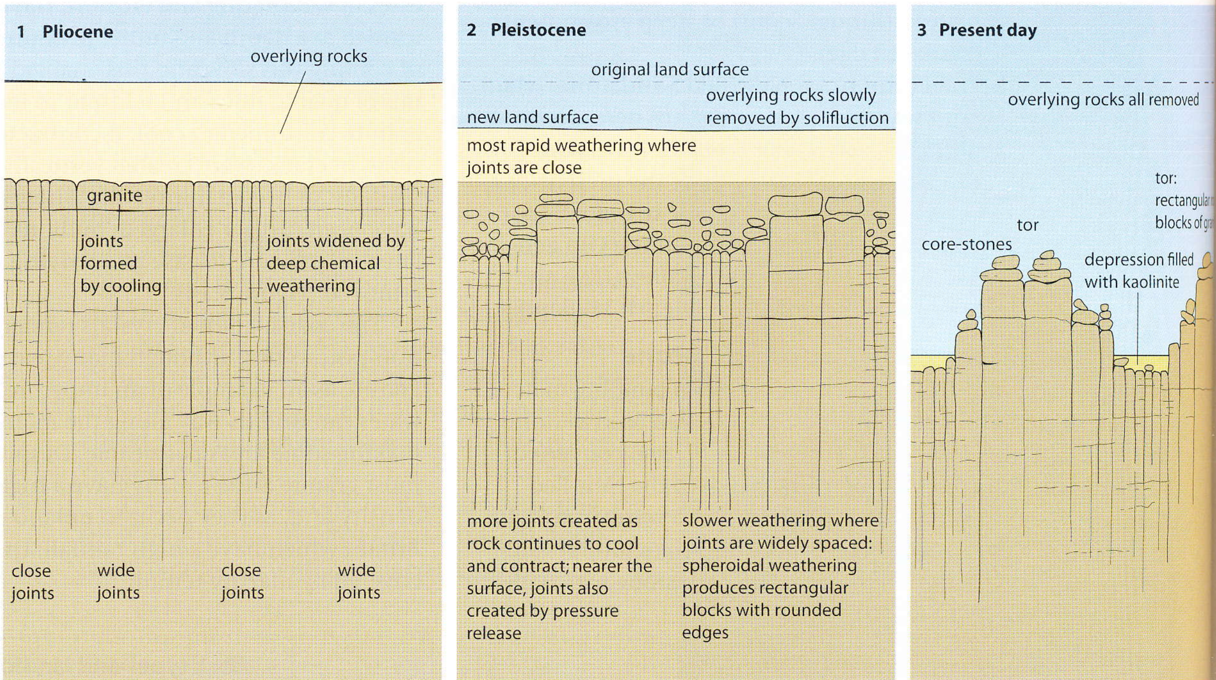
The most distinctive granite landform in temperate countries is the **tor** (Figure 8.14) and, in tropical regions, the **inselberg** (Figures 2.3 and 7.6). There are two major theories concerning their formation, based on physical and chemical weathering respectively. Both, however, suggest the removal of material by solifluction and hence lead to the opinion that tors and inselbergs are relict features.

The first hypothesis suggests that blocks of exposed granite were broken up, subaerially, by frost shattering during periglacial times. The weathered material was then moved downhill by solifluction to leave the more resistant rock upstanding on hill summits and valley sides.

The second, proposed by D.L. Linton, suggests that joints in the granite were widened by sub-surface chemical weathering (Figure 8.15). He suggested that deep weathering occurred during the warm Pliocene period (Figure 1.1) when rainwater penetrated the still-unexposed granite. As the joints widened, roughly rectangular blocks or core-stones were formed. The weathered rock is believed to have been removed by solifluction during periglacial times to leave outcrops of granite tors, separated by shallow depressions. The spacing of the joints is believed to be critical in tor formation: large, resistant core-stones have been left where joints were spaced far apart; where they were closely packed and weathering was more active, clay-filled depressions have developed. The rounded nature of the core-stones (Figure 8.15), especially in tropical regions, is caused by **spheroidal weathering**, a form of exfoliation (page 41).

Figure 8.15

The formation of tors (*after* D.L. Linton)



Economic value of granite

As a raw material, granite can be used for building purposes; Aberdeen, for example, is known as 'the granite city'. Kaolin, or china clay, is used in the manufacture of pottery. Peat, which overlies large areas of granite bedrock, is an acidic soil which is often severely gleyed (page 275) and saturated with water, forming blanket bogs. The resultant heather-covered moorland is often unsuitable for farming but provides ideal terrain for grouse, and for army training. With so much surface water and heavy rainfall, granite areas provide ideal sites for reservoirs. Tors, such as Hound Tor on Dartmoor (Figure 8.14), may become tourist attractions, but granite environments tend to be inhospitable for settlement.

Basalt

Unlike granite, basalt formed on the Earth's surface, usually at constructive plate margins. The basic lava, on exposure to the air, cooled and solidified very rapidly. The rapid cooling produced small, fine-grained crystals and large cooling cracks which, at places like the Giant's Causeway in Northern Ireland (Figure 1.27) and Fingal's Cave on the Isle of Staffa, are characterised by perfectly shaped hexagonal, columnar jointing. Basalt can be extruded from either fissures or a central vent (page 25). When extruded from fissures, the lava often covers large areas of land – hence the term flood basalts – to produce flat plateaus such as the Deccan Plateau in India and the Drakensbergs in South Africa. Successive eruptions often build upwards to give, sometimes aided by later erosion, stepped hillsides beneath flat, tabular summits (e.g. the Drakensbergs, Lanzarote and Antrim). When extruded from a central vent, the viscous lava produces gently sloping shield volcanoes (Figure 1.22b). Shield volcanoes can reach considerable heights – Mauna Loa (Hawaii) rises over 9000 m from the Pacific seabed making it, from base to summit, the highest mountain on Earth.

Economic value of basalt

Basaltic landforms can sometimes be monotonous, such as places covered in flood basalts, and sometimes scenic and spectacular, as the Giant's Causeway, the Hawaiian volcanoes and the Iguaçu Falls in Brazil (Places 11, page 76). Basaltic lava can weather relatively quickly into a deep, fertile soil as on the Deccan in India and in the coffee-growing region of south-east Brazil. It can also be used for road foundations.

Quarrying in northern India

Case Study 8

The 1960s

Dehra Dun, the main town in the Dun Valley with a population exceeding 400 000, is situated in the foothills of the Himalayas some 200 km north of Delhi (Figure 8.16). Until the 1960s, the rich soil of the valley allowed farmers to produce high-quality basmati rice, and the lush green forest surrounding the town had been used sustainably by local people for centuries. That changed in the 1960s when several large quarries were allowed to open up in the valley without any regard for either the inhabitants of the area or the environment.

As India's economy grew, there was increasing conflict between development and the environment. The extraction of rocks and minerals was necessary to provide the new manufacturing industries with raw materials and to provide people with jobs, but mining and quarrying can be very damaging to the environment and to fragile ecosystems. The limestone that was quarried in the Dun Valley was either crushed and used in India's steel industry or used for road building, concrete and whitewash.

Figure 8.16

Location of Dehra Dun

Quarrying in northern India

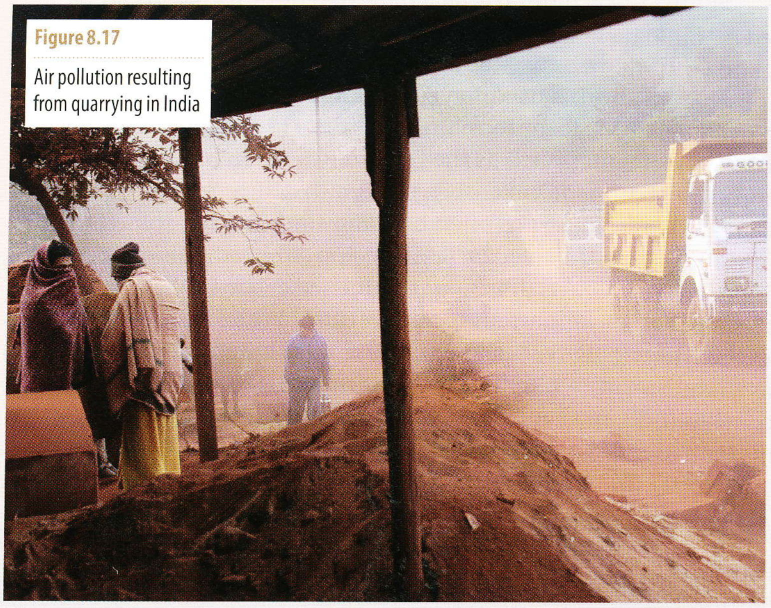


Figure 8.17
Air pollution resulting from quarrying in India

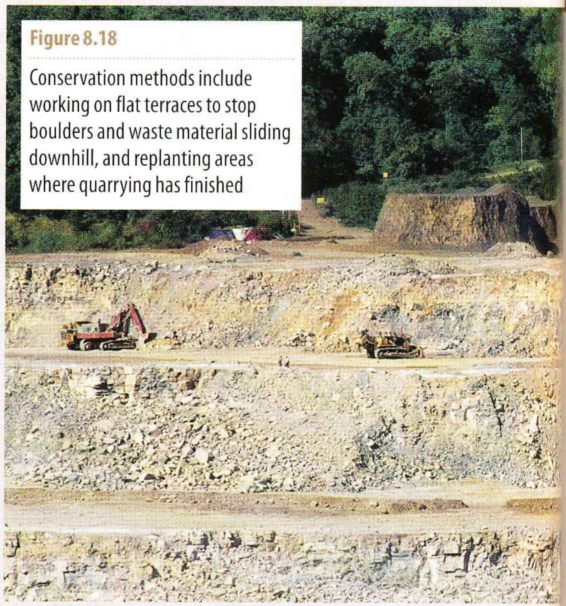


Figure 8.18
Conservation methods include working on flat terraces to stop boulders and waste material sliding downhill, and replanting areas where quarrying has finished

The effects

- As new quarries developed, many of the trees growing on the hillsides were removed. Steep hillsides and deforestation in an area with a monsoon climate (page 239) meant that when the heavy summer rains fell, the soil was seriously eroded. Surface runoff led to the fertile soils being covered in debris and caused landslides, especially where unstable quarry waste had been dumped. Deforestation also meant there was less fuelwood for people living in nearby villages.
- Material carried downhill often ended up in rivers, where it not only polluted water supplies but also blocked the river with boulders and waste. Before quarrying began, one bridge had an arch nearly 20 m above the river, but after quarrying it was reduced to less than 5 m.
- Before quarrying, settlements in the area had an all-year supply of clean water obtained from springs and resurgences formed when underground rivers in the limestone hills re-appeared at the surface (page 197). The increase in surface runoff due to quarrying and deforestation caused the water table to fall by 5 m in seven years. This meant that Dehra Dun often received water for only a few hours a day. Without enough water to irrigate their fields, local farmers were unable to provide enough food for their families.
- The blasting of rock created noise and air pollution and caused nearby buildings to vibrate.
- The trucks and lorries – many old and badly maintained – that transported the limestone down the steep, narrow roads caused the road surface to break up, released poisonous fumes and created more dust (Figure 8.17).
- The kilns that processed the limestone also added to the air pollution.

Local protests

In the 1980s, many local people grouped together to form the 'Friends of Dun'. The group, led mainly by wealthy and influential business and retired people, submitted a petition to the Supreme Court which led, in 1988, to all the quarries (with one exception) being closed down. By the end of the 20th century, trees planted by school children and local people had begun to mature into forest, although farmers still found much of their soil unusable.

Should the one quarry remain open?

The Supreme Court allowed one quarry to operate until its lease ran out. This was partly because the quarry provided hundreds of jobs for local people, although they were poorly paid, and partly because the quarry owners attempted to implement conservation techniques, such as working on flat terraces to stop boulders and waste material sliding downhill (Figure 8.18) and replanting areas where quarrying had finished. The argument now appears to be between the wealthy conservation group who want to protect and restore the Dun Valley and the poorer workers who, without the quarry and with few alternative jobs available, would have no income if it closed.

Further reference

Goudie, A.S. (2001) *The Nature of the Environment*, WileyBlackwell.

Michigan Karst Conservancy Group: www.caves.org/conservancy/mkc/michigan_karst_conservancy.htm

Pretoria Portland Cement Co. Ltd: www.ppc.co.za

Questions & Activities

Activities

1 **a** Describe the characteristics of each of the following rock types in terms of chemical composition, rock structure and origin: Carboniferous limestone; chalk; granite; basalt. *(12 marks)*

b Choose **one** of the rock types in **a** and draw an annotated diagram to identify the characteristic landscape features associated with it. *(9 marks)*

c For **each** of the rock types identified in **a**, suggest one reason why it may be of value as a resource for human use. *(4 marks)*

2 Study the OS map extract of the area around Malham in Figure 8.19.

a **i** How high above sea-level is the minor road at GR 907649? *(1 mark)*

ii What is the feature at GR 906655? *(1 mark)*

b Identify and give grid references for **two** pieces of evidence that large parts of this area have limestone rock outcropping at the surface.

Justify **each** of your choices. *(6 marks)*

c Explain, using one or more diagrams, why there are large areas of bare flat rock in the area shown on the map extract. *(6 marks)*

d A stream flows from the edge of the map at 893661 to 894657. South of this point is a dry valley. Suggest why this dry valley is here. *(6 marks)*

e Farming in this area has been described as 'marginal; it could not exist without subsidies'.

Suggest why the physical geography makes farming so difficult. *(5 marks)*

3 **a** Making good use of annotated diagrams, describe the surface features of a chalk cuesta. *(6 marks)*

b Describe and explain the location of the water table within an area of chalk hills. *(6 marks)*

c Describe and suggest reasons for the location of settlements close to the foot of a chalk cuesta. *(4 marks)*

d Suggest two reasons why some chalk downs have prehistoric carved figures on them. *(4 marks)*

e Chalk escarpments may have 'hangers' (areas of beech woodland on the brow of the scarp). Suggest why these woodlands are found here. *(5 marks)*

Exam practice: structured questions

4 Study the OS map extract of the area around Malham in Figure 8.19.

a Identify and locate two pieces of evidence to suggest that this area is limestone rock. For **each** explain how the evidence shows it to be limestone. *(10 marks)*

b Why is there so much settlement and other ancient remains visible in an area such as this? *(7 marks)*

c This area is both a tourist area and a working farming area. Identify **one** way these two land uses are in conflict and explain the reasons for this conflict. *(8 marks)*

5 **a** **i** Explain how areas of granite rock, such as Dartmoor, were formed. *(6 marks)*

ii Describe the processes of weathering in granite. *(6 marks)*

b 'Granite tors form as a result of the nature and structure of the rock and the nature of the weathering processes.'

Describe a typical granite tor and explain its formation. *(13 marks)*

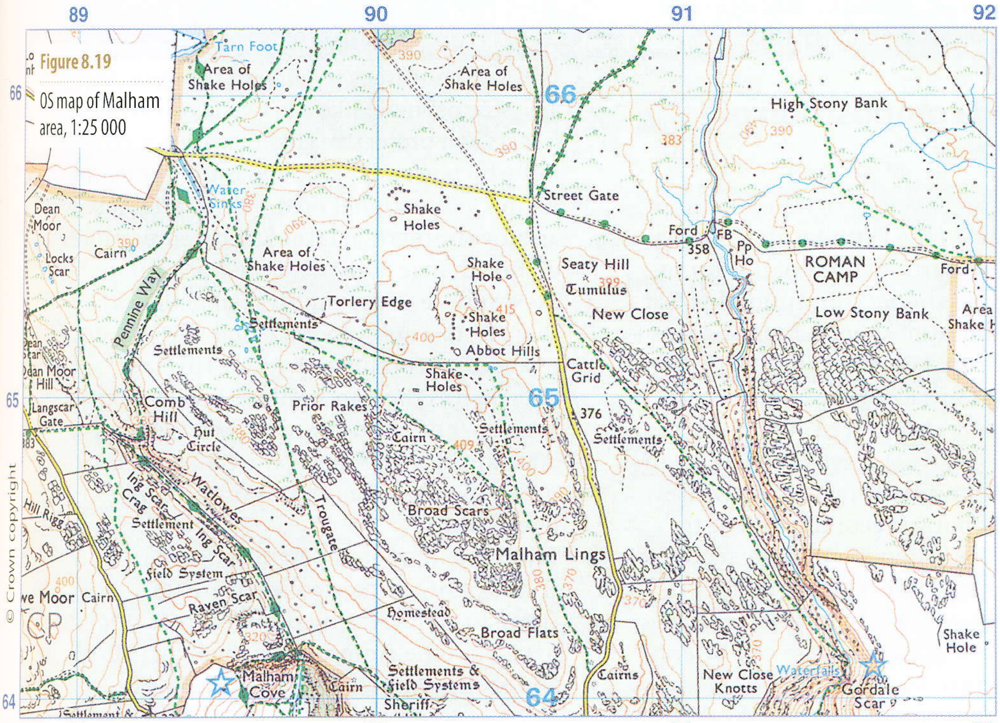


Figure 8.19 OS map of Malham area, 1:25 000

Exam practice: essay

6 Should the quarry in the Dun valley be allowed to remain open?

Present the arguments for **two** groups that think the quarry should continue and for **two** groups that think it should be closed.

Then present a conclusion taking the arguments of both sides into consideration. *(25 marks)*