Chapter 4 Weathering, Mass Movement and Groundwater

The earth's crust is constantly undergoing geological changes caused by internal forces, which create new relief features. Orogenesis build new mountain ranges, uplift or depression of particular areas is caused by folding or faulting, and volcanic disturbances also modify the landscape. Meanwhile external forces are working vigorously to wear away the surface, and the interaction of these constructive and destructive forces gives rise to the great diversity of present-day landforms. The process of wearing away the earth causes a general lowering and levelling out of the surface. It is known as denudation and is carried out in four phases.

i. *Weathering:* the gradual disintegration of rocks by atmospheric or weather forces;
ii. *Erosion:* the active wearing away of the earth's surface by moving agents like running water, wind, ice and waves;
iii. *Transportation:* the removal of the eroded debris to new positions;
iv. *Deposition:* the dumping of the debris in certain parts of the earth, where it may accumulate to form new rocks.

All four phases of the denudation process are taking place simultaneously in different parts of the world at different rates, much depending on the nature of the relief, the structure of the rocks, the local climate and interference by man.

This chapter describes the work of weathering and the features it produces, while Chapters 5 to 10 deal with erosion, transportation and deposition by water, wind, ice and waves.

Weathering

The work of weathering in breaking up the rocks is of two kinds, namely chemical, and physical or mechanical weathering, but the processes involved in each are closely interrelated.

1. Chemical weathering

Chemical weathering is the basic process by which denudation proceeds. It is the extremely slow and gradual decomposition of rocks due to exposure to air and water. Air and water contain chemical elements, which though they may be in small quantities, are sufficient to set up chemical reactions in the surface layers of exposed rocks. Such reactions may weaken or entirely dissolve certain constituents of the rock, thus loosening the other crystals and weakening the whole surface. For example, in Malaysia, the surface of granite which has been exposed to the weather is found to be pitted and rough. This is because the granite is made of three main minerals: quartz, felspar and mica. The felspar is more quickly weathered than the quartz and thus the felspar crystals are worn away. The quartz crystals are eventually loosened in this way and form a coarse sandy residue.

When the surface of a rock is weathered some of the material which is loosened is removed by erosive agents such as wind or running water thus exposing a fresh surface to weathering, but much of the weathered material or *regolith* (remains of the rock) may stay in position forming the basis of soil. Regolith is simply the mineral remains of decomposed rocks, but soil contains organic materials, such as the roots of plants, fallen leaves, small animals such as worms, bacteria and so on. It is the organic content of soil which makes it fertile and allows crops to be grown.

When a soil cover exists, chemical weathering of the underlying rocks does not cease; on the contrary it is usually enhanced. This is because the soil absorbs rain-water and keeps the underlying rocks in contact with this moisture. The rain-water absorbs organic acids from the soil and thus becomes a stronger weathering agent than pure rain-water acting on bare rock.

There are three major chemical weathering processes.

(a) Solution. Many minerals are dissolved by water, especially when, as with rain-water, it contains enough carbon dioxide to make it a weak acid. Solution is the most potent weathering process in limestone regions because the rain-water attacks and dissolves the calcium carbonate of which the rock is chiefly formed. The dissolved calcium carbonate is carried away by the water, joints and cracks in the rock are quickly widened and whole systems of caves and passages are worn out (see Chapter 8). Limestone, however, is by no means the only rock to suffer from solution. All rocks are subject to solution to some extent, though the process is much slower than with limestone. The rate at which solution takes place is affected not only by the mineral composition of the rock but also by its structure. Sedimentary rocks often have pore-spaces between the grains in which air and water can lodge and thus attack the rock. The

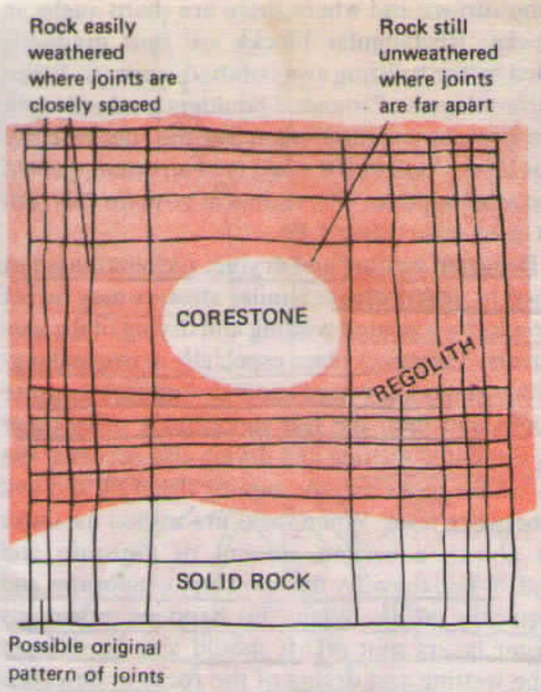


Fig. 4.1 Differential weathering in a rock such as granite where unevenly spaced joints may give rise to corestones and certain blocks remain unweathered. In jointed rocks, temperature change cracks up rectangular blocks.

density of joints or cracks in the rock is also crucial to the speed of weathering. This factor is very clearly seen in Malaysia in the weathering of granite. In tropical countries, where the heavy rainfall and warm climate both promote rapid chemical reactions, weathering often proceeds very rapidly. This produces the very deep regoliths or soils overlying the solid rocks. Often these regoliths contain core-stones. These are pieces of solid rock which have resisted weathering while a'' the surrounding rock has been weathered. They are more resistant because they have fewer joints or cracks to harbour moisture and are thus more slowly weathered by solution processes (Fig. 4.1 and Plate 4.A).

Rates of weathering are also affected by climate. Warm wet climates promote rapid chemical weathering, while dry climates inhibit chemical weathering. Dry climates, however, provide good conditions for physical or mechanical weathering.

(b) Oxidation. Oxidation is the reaction of oxygen in air or water with minerals in the rock. For example, most rocks contain a certain amount of iron, which when it comes in contact with air is changed to iron oxide, familiar brownish crust or rust. Iron oxide crumbles easily and is fat more easily eroded than the original iron. It is thus removed, loosening the overall structure of the rocks and weakening them.

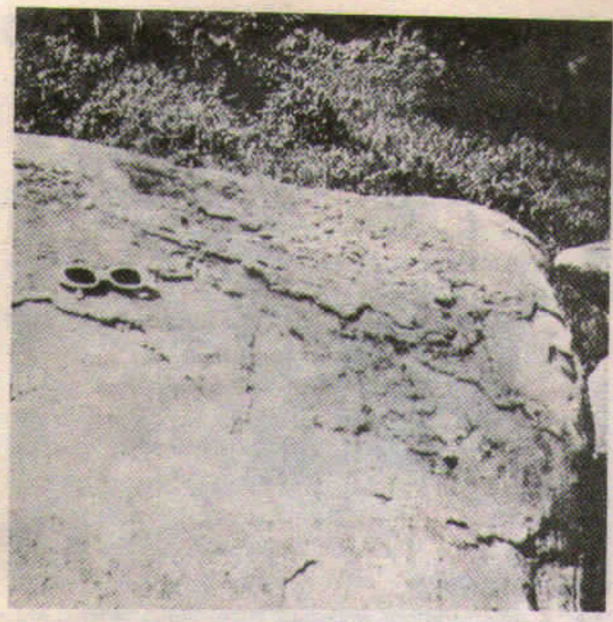
4.A A solid corestone embedded in weathered material which has been exposed in a road cutting near Tampin, Negri Sembilan *G.C. Morgan*

(c) Decomposition by organic acids. Within the soil which covers most rocks are bacteria whch thrive on decaying plant or animal material. These bacteria produce acids which, when dissolved in water, help to speed up the weathering of the underlying rocks. In some cases micro-organisms and plants like mosses or lichens can live on bare rock, so long as the surface is damp. These absorb chemical elements from the rocks as food and also produce organic acids. They are thus agents of both chemical and mechanical weathering.

2. Physical or Mechanical weathering

Mechanical weathering is the physical disintegration of a rock by the actual prising apart of separate particles. This can happen even with completely fresh rock but the processes of physical weathering are able to work much more easily when the surface of the rock has already been weakened by the action of chemical weathering. Mechanical weathering takes place in several ways.

(a) Repeated temperature changes. In deserts, rocks are exposed to the blazing sun during the day and are intensely heated. The outer layers expand much faster than the cooler interior of the rocks and tend to pull away from the rest. At nightfall the temperature drops rapidly and the outer layers contract more rapidly than the interior, setting up internal stresses. Such stresses, repeated every day for months



4.B When corestones are exposed to tropical weather conditions they are subject to repeated wetting and drying which cause the outer layers to peel off. This sandstone boulder shows several layers have split off in some areas. *G.C. Morgan*

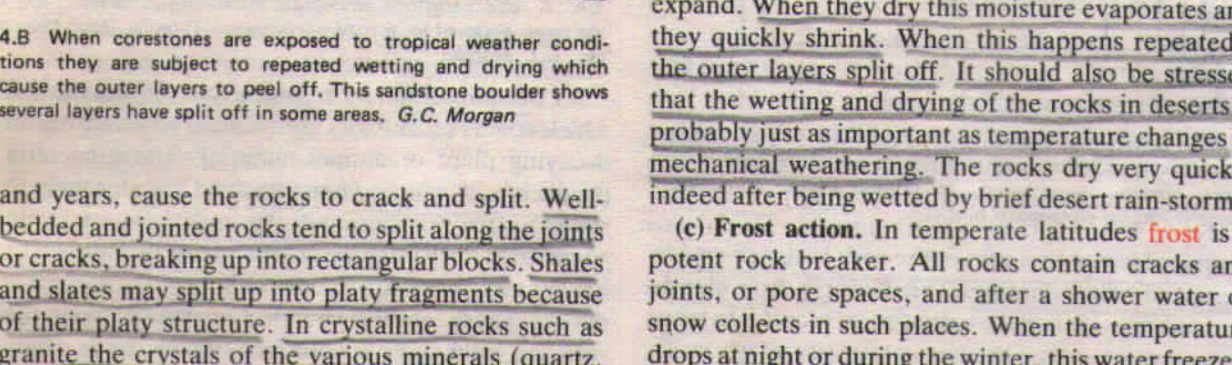
and years, cause the rocks to crack and split. Well-bedded and jointed rocks tend to split along the joints or cracks, breaking up into rectangular blocks. Shales and slates may split up into platy fragments because of their platy structure. In crystalline rocks such as granite the crystals of the various minerals (quartz, mica, felspar) will expand and contract at different rates, enhancing the stresses and accelerating the disintegration of the rocks. Fragments broken from large rock outcrops fall by gravity to the foot of the slope. They may form screes or may form a litter of angular chips and small boulders on the flatter ground.

Stresses and pressures will naturally be greatest near the surface and where there are sharp angles in the rocks. Rectangular blocks are thus gradually rounded by the splitting away of sharp corners. When the surface layers of rounded boulders gradually split off the process is called *onion peeling*, because the various layers look like the layers of an onion, peeled off one after another. The technical term for this process is *exfoliation* (Plate 4.B).

(b) Repeated wetting and drying. Exfoliation is not confined to desert areas. Similar stresses may be set up in rocks by repeated wetting and drying of the surface layers. This takes place especially in tropical regions, like Malaysia, where short downpours saturate the rocks and then the hot sun quickly dries them again. Repeated wetting and drying also occurs at the coast, where rocks may be rapidly dried by sun and wind between tides. When rocks are wetted the outer layers absorb a certain amount of moisture and expand. When they dry this moisture evaporates and they quickly shrink. When this happens repeatedly the outer layers split off. It should also be stressed that the wetting and drying of the rocks in deserts is probably just as important as temperature changes in mechanical weathering. The rocks dry very quickly indeed after being wetted by brief desert rain-storms.

(c) Frost action. In temperate latitudes frost is a potent rock breaker. All rocks contain cracks and joints, or pore spaces, and after a shower water or snow collects in such places. When the temperature drops at night or during the winter, this water freezes. When water freezes it expands by one-tenth -its volume and exerts a bursting pressure of almost 140 kg per square cm (2,000 lb. to the square inch). Repeated freezing of this kind will deepen and widen the original cracks and crevices and break the rock into angular fragments (Fig. 4.2). On mountain peaks this process creates sharp pinnacles and angular outlines. Such peaks are described as *frost-shattered*

Fig. 4.2 Frost action as an agent of mechanical weathering



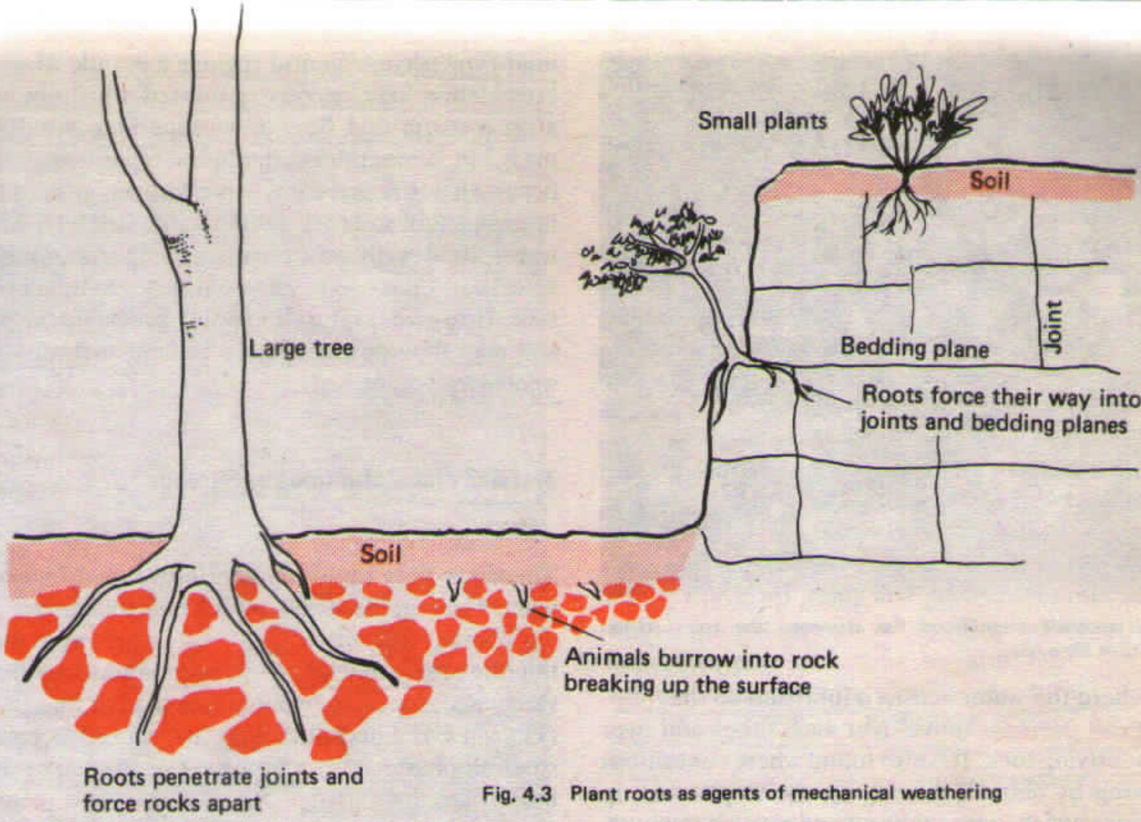


Fig. 4.3 Plant roots as agents of mechanical weathering

peaks. Angular fragments of rock are prised from mountain-sides or cliff faces and fall to the foot of the slope where they accumulate to form screes.

(d) Biotic factors. Small fragments of rock loosened by either chemical or mechanical weathering lodge in cracks and crevices in the rock and plants may sprout in such crevices. As they grow their roots penetrate the rocks below, usually along joints and other lines of weakness, prising them apart. You have often come across large trees growing near roads or the courtyards of houses that finally prise open the concrete or paving stones above their roots. The process is just the same on a smaller scale in a natural setting (Fig. 4.3).

Men, in the course of mining, road construction and farming, also contribute to mechanical weathering by excavating the rocks and rendering them more vulnerable to the agents of denudation.

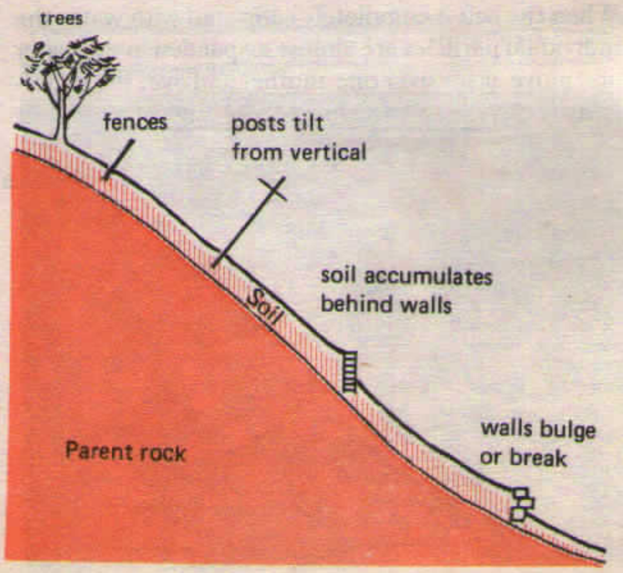
Mass Movement

Mass movement is the movement of weathered materials down a slope due to *gravitational forces*. The movement may be gradual or sudden, depending on the gradient of the slope, the weight of the weathered debris and whether there is any lubricating moisture supplied by rain-water. Several kinds of mass movement are distinguished.

1. Soil Creep

This is a slow, *gradual* but more or less continuous movement of soil down hillslopes. The movement is not very noticeable, especially when the slope is fairly gentle or when the soil is well-covered with grass or other vegetation. Soil creep is most common in damp

Fig. 4.4 Evidences of soil creep



4.C A landslide after flood has damaged the road *Jabatan Penerangan Malaysia*

soils where the water acts as a lubricant so that individual soil particles move over each other and over the underlying rock. It is also found where continuous trampling by animals grazing on the slopes sets up vibrations which loosen the soil and cause it to move. Though the movement is slow and cannot readily be seen in action, the gradual movement tilts trees, fences, posts and so on which are rooted in the soil. The soil is also seen to accumulate at the foot of slope or behind obstacles such as walls, which may eventually be burst by the weight of soil above (Fig. 4.4).

2. Soil Flow (Solifluction)

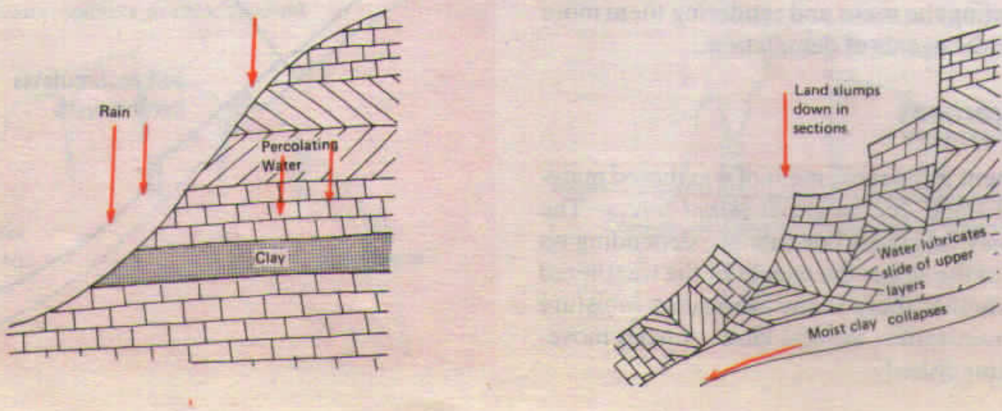
When the soil is completely saturated with water the individual particles are almost suspended in the water and move easily over one another and over the underlying rock. The soil acts like a liquid and a *soil-flow* or *mud-flow* occurs. In arid regions a mantle of weathered debris may become saturated with rain-water after a storm and flow downslope as a semi-liquid mass. In temperate and tundra regions soil flows occur when the surface layers of frozen ground thaw in spring. Soil and rock debris, lubricated by the melt-water, flow easily over the underlying frozen subsoil. In areas of peat soils, the peat absorbs much moisture. However if saturation point is reached the peaty soil may flow downslope. In Ireland such flows are known as *'bog-bursts'*.

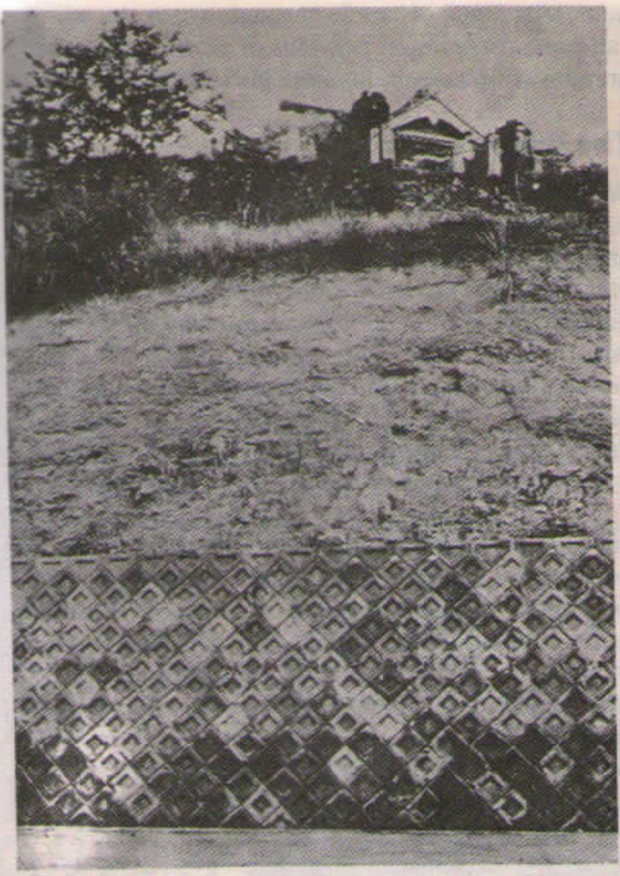
3. Landslides (Slumping or Sliding)

These are very rapid kinds of movement and occur when a large mass of soil or rock falls suddenly. Landslides usually occur on steep slopes such as in mountainous areas, on cliffs or where man has artificially steepened slopes, for example, in road or rail cuttings (Plate 4.C). Landslides may be caused because a steep slope is undercut by a river or the sea so that it falls by gravity. Earthquakes or volcanic disturbances may loosen rocks and start off a landslide. Man-made steepening both undercuts the slope and sets up vibrations which may loosen rocks or soil. But often landslides are caused by the lubricating action of rain-water. Water may collect in joints or bedding planes in rocks so that one layer slides over another, especially in areas of tilted strata. *Slumping* is particularly common where permeable debris or rock layers overlie impermeable strata such as clay. Water sinking through the permeable material is halted by the clay. The damp clay provides a smooth slippery surface over which the upper layers easily slide (Fig. 4.5).

Water may collect at the base of the regolith because it sinks readily into the weathered material

Fig. 4.5 Landslide





4.D An effective way of preventing landslide by building a concrete wall—Taiwan *Goh Cheng Leong*

but more slowly into the solid rock beneath. The water may allow the regolith to slide away from the underlying rock.

Man often enhances the possibility of landslides by clearing natural vegetation for agriculture or housing. Removal of the plant cover allows more water to penetrate the soil and rocks. In areas such as the Cameron Highlands, where steep slopes have been cleared, there is much evidence of minor slumps and slides, the old scars showing up clearly in the tea gardens. Extensive landslides, whether natural or man-induced, can have disastrous consequences, burying villages, railway lines or people. Spectacular landslides have taken place in many parts of the world, including South Wales, British Columbia, Hong Kong and the Cameron Highlands where the village of Ringlet was partially buried in 1961 and several houses were ruined.

Groundwater

The whole process of the circulation of water between the land, sea and atmosphere is known as the *hydrological cycle*. The movement of the water in the atmosphere and its effect on climate are dealt with in Chapters 13 and 14. The seas and oceans are discussed in Chapter 12. The effect of water on the land as an agent of weathering, erosion, transport and deposition is dealt with in this and the following chapters, especially Chapter 5.

When rain falls on the earth it is distributed in various ways. Some is immediately evaporated and thus returns to the atmosphere as water vapour. Some is absorbed by plants and only gradually returned to the atmosphere by *transpiration* from the leaves of plants. Much of it flows directly off slopes to join streams and rivers, eventually reaching the seas and oceans. This is known as run-off A considerable proportion of the water received from rain or snow, however, percolates downwards into the soil and rocks, filling up joints and pore-spaces and forming what is known as goundwater Groundwater plays an important part in weathering and mass movement and is also important as a means of natural water storage. It re-enters the hydrological cycle by way of springs.

The amount of water available to form groundwater depends to some extent on climate In dry climates much precipitation may be quickly evaporated into the dry atmosphere and little moisture may percolate into the ground. In very humid conditions, where the surface of the ground may already be moist, much water may be moved as run-off. In moderately humid areas water both runs off and sinks into the ground. The proportion of the rainfall absorbed as groundwater may depend on the season of the year.

More important, however, is the nature of the

4.E A severe flood in Kuala Kangsar (Malaysia) in 1967—the main street of the town was under 4-6 m (15-20 feet) of water *Jabatan Penerangan Malaysia*

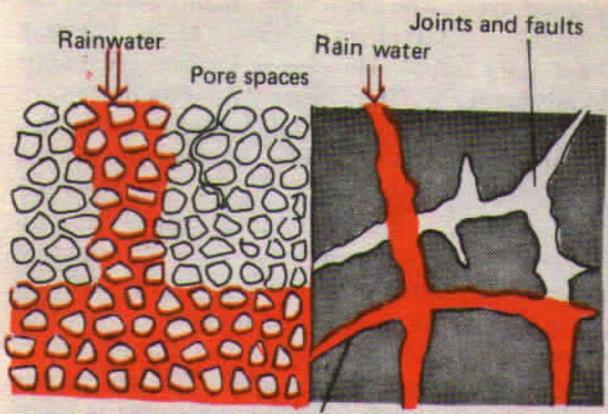


Fig. 4.6 Porosity and permeability of rocks

rocks and how easily they absorb and retain water. Various rocks and soils differ greatly in their porosity and permeability; the amount of groundwater present and the depth at which it lies are governed by these characteristics. Porous rocks are those, like sandstone, which have many pore-spaces between the grains. Water is easily absorbed by such rocks and may be stored in the pore-spaces. Permeable or pervious rocks are those which allow water to pass through them easily (Fig. 4.6). Thus most porous rocks are also permeable. However some rocks are porous but impermeable. Clay, for example, is highly porous since it is made up of innumerable very fine particles with pore-spaces between them. It thus absorbs a great deal of water. However, the pore-spaces are so small that the water does not move easily through the rock, which is thus impermeable. On the other hand, granite which is a crystalline rock and consequently non-porous is often pervious. Its individual crystals absorb little or no water but the rock may have numerous *joints or cracks* through which the water can pass, rendering it pervious or permeable. Some granites are, however, far more pervious than others.

The Water-Table

Water which seeps through the ground moves downward under the force of gravity until it reaches an impermeable layer of rock through which it cannot pass. If there is no ready outlet for the groundwater in the form of a spring, the water accumulates above the impermeable layer and saturates the rock. The permeable rock in which the water is stored is known as the aquifer (Fig. 4.7). The surface of the saturated area is called the *water-table*. The depth of the *water-table* varies greatly according to relief and to the type of rocks. The water-table is far below the surface of hill-tops but is close to the surface in valleys and flat low-lying areas where it may cause *waterlogging* and swampy conditions. The depth of the water-table also varies greatly with the seasons. When plenty of rain is available to augment groundwater supplies the water-table may rise, but in dry periods, no new supplies are available, and the water-table is lowered as groundwater is lost through seepages and springs (Fig. 4.7).

Fig. 4.8(a) Spring seeps from edge of pervious rock lying above an inclined impervious strata

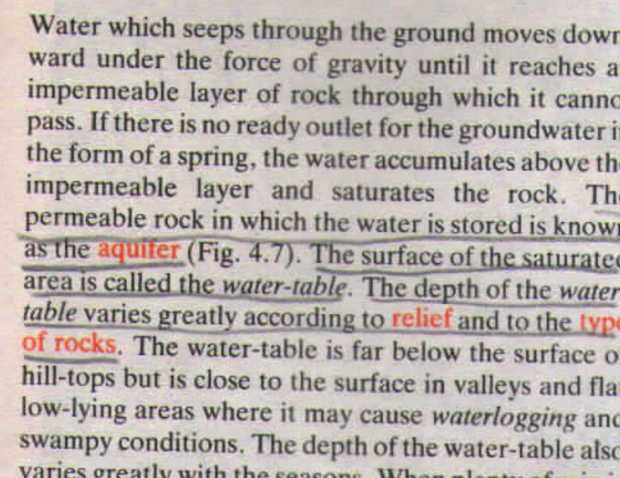
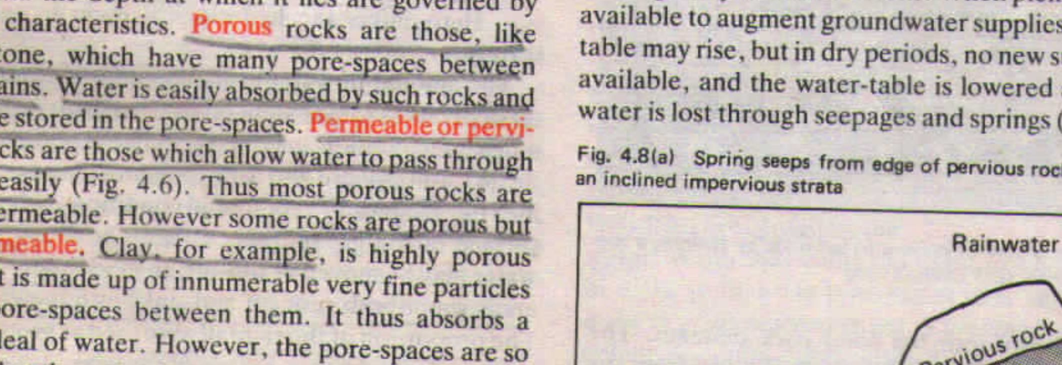


Fig. 4.7 Groundwater table and its relationship to the curvature of the land



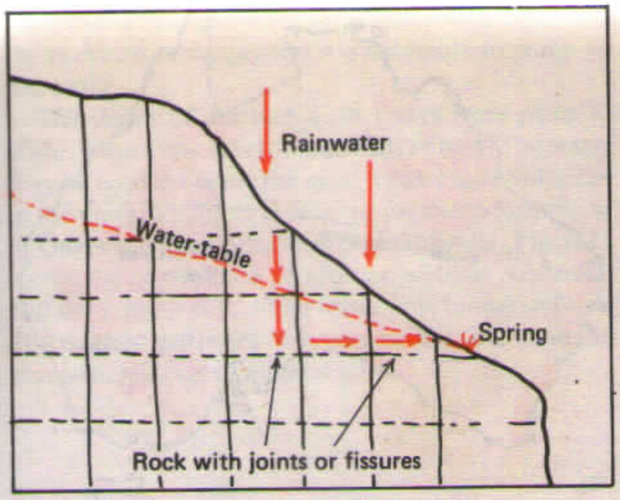


Fig. 4.8(b) Spring emerges from rocks with joints

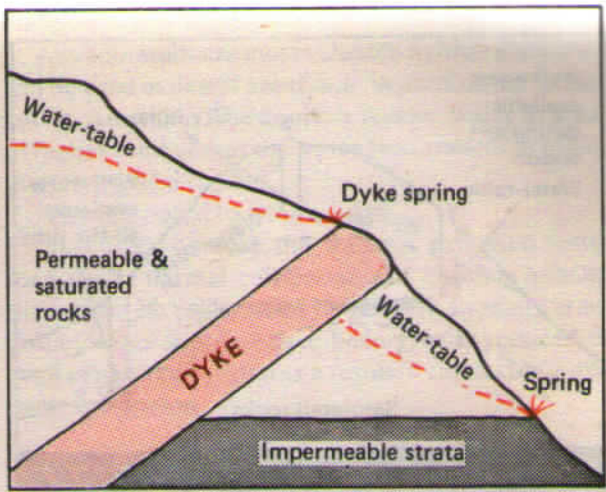


Fig. 4.8(c) A dyke spring

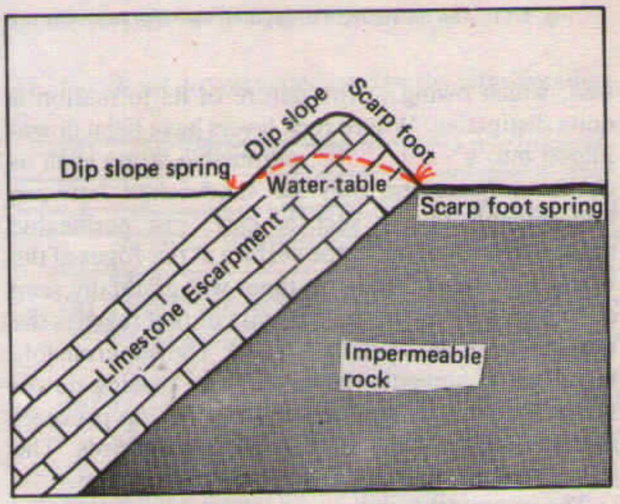


Fig. 4.8(d) Scarp-foot spring and dip-slope spring

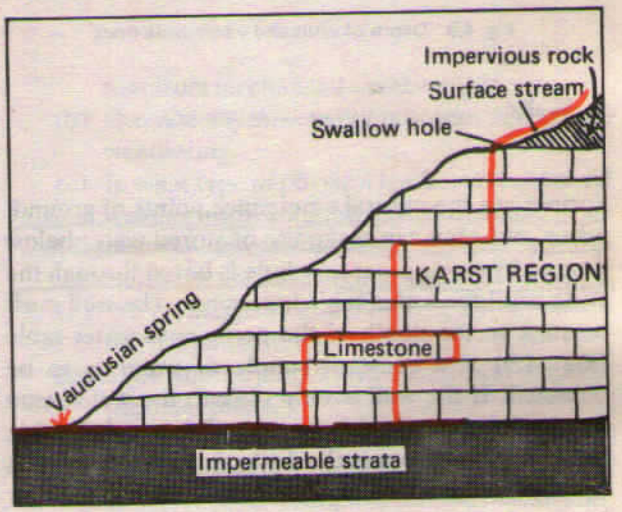


Fig. 4.8(e) Vauclusian spring in karst regions

Springs and Wells

1. Springs

The groundwater stored in the rock is released onto the surface at points where the water-table reaches the surface. A spring is simply an outlet for such water. The water may seep gradually out of the rock or may gush out as a fountain. Springs are of several kinds due to the nature of the rocks and the position of the water-table. The main types are described below.

(a) In areas of *tilted strata*, where permeable and impermeable rocks alternate, water emerges at the base of the permeable layers (Fig.4.8a).

(b) In *well-jointed rocks* water may percolate downwards until it reaches a joint which emerges at the surface. The water may come to the surface through the joint (Fig. 4.8b).

(c) Where a dyke or sill of impermeable rock is intruded through permeable rocks, it causes the water-table to reach the surface and the water issues as a spring (Fig. 4.8c).

(d) In limestone or chalk escarpments, where the permeable rock lies between impermeable strata, water issues at the foot of the scarp as a *scarp-foot spring*, or near the foot of the dip-slope as a *dip-slope spring*, as illustrated in Fig. 4.8d.

(e) In karst regions rivers often disappear underground. They then flow through passages worn in the rock by solution, and may re-emerge when limestone gives place to some impermeable rock. This kind of spring is sometimes called a *vauclusian spring* but is better referred to as a *resurgence* (Fig. 4.8e; see also Chapter 8).

Some other types of springs, e.g. hot springs, mineral springs and geysers are described in Chapter 3.

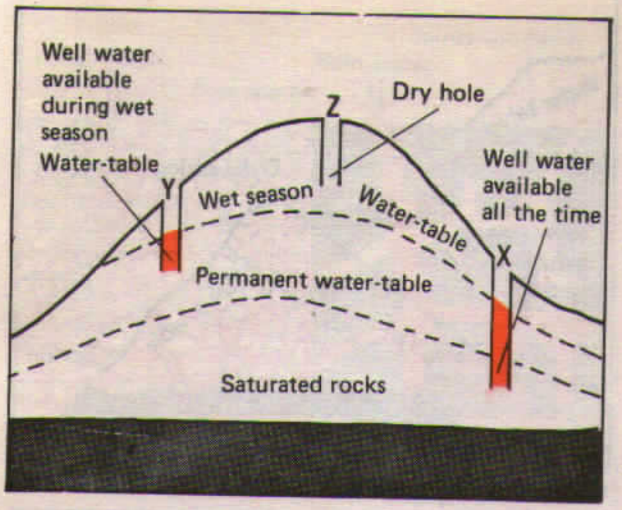


Fig. 4.9 Depth of wells and water-table mark

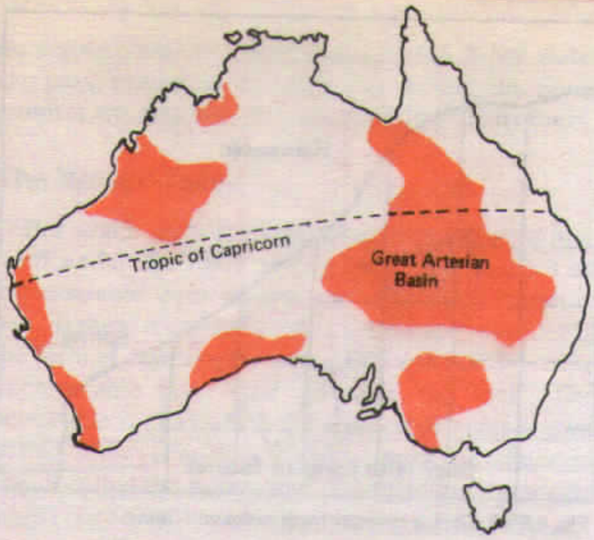


Fig. 4.11 The distribution of artesian basins in Australia

2. Wells

Springs are the natural emergence points of ground water, but Man can make use of stored water below ground by sinking wells. A hole is bored through the earth until the water-table is reached. The well must be sunk to the depth of the permanent water-table (Fig. 4.9) if a constant supply of water is to be obtained. If the well is only sunk to the wet-season depth of the water-table, water will be unobtainable when the level drops in the dry season. When a well is bored, the water usually has to be raised by hand or by mechanical pumping. Wells are particularly important in arid areas where there is little surface water but where the underlying rocks contain groundwater.

A particularly important type of well is the *artesian well*, which owing to the nature of its formation is quite distinctive. Where rock layers have been downfolded into a basin shape, permeable strata such as chalk or limestone may be sandwiched between impermeable layers, such as clay. The permeable rocks may only come to the surface at the edges of the basin, but water falling on them will gradually seep downwards by the force of gravity until it reaches the lowest part of the basin (Fig. 4.10). The impermeable layer below prevents the water from passing downwards while the impermeable layer on top prevents any possibility of the water escaping upwards. The aquifer is thus saturated to the brim of the basin.

The water is thus trapped in the aquifer under great pressure and when a well is bored, the pressure of water downwards from all around the basin is sufficient to force the water up the bore-hole so that it gushes onto the surface like a fountain. After a time

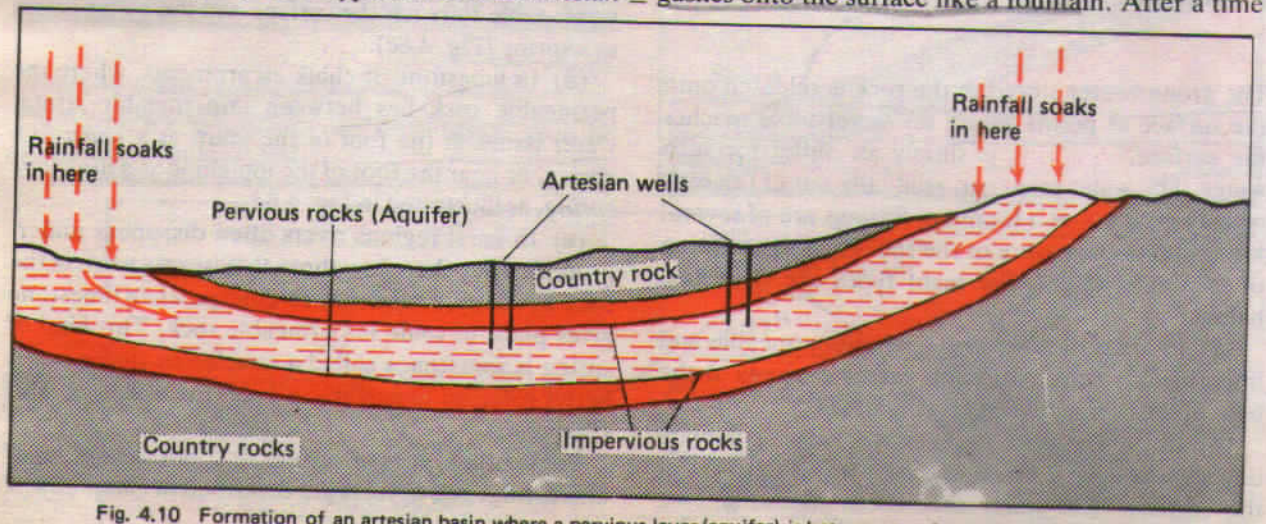


Fig. 4.10 Formation of an artesian basin where a pervious layer (aquifer) is between two impervious strata of rocks

the pressure decreases and it is necessary to pump up the water.

The depth of artesian wells varies from place to place, from a few feet to thousands of feet. The water may be used to supply the needs of an entire village as in the Great Plains of U.S.A. or for sheep farming as in Queensland and other parts of Australia. Fig. 4.11 shows the distribution of artesian wells in Australia. But the water is sometimes unsuitable for agricultural or irrigation purposes as it may be hot or contain an excessive amount of mineral salts.

Artesian wells are most valuable to Man when they can be used in desert areas, e.g. in parts of the Sahara and in Australia. The aquifers receive water in areas of higher rainfall, but the water accumulates in basins underlying arid regions.

All wells bored by Man tend to deplete groundwater resources because the water is extracted faster than under natural conditions and also much faster than it can be replenished by rainfall. In many areas groundwater supplies have been greatly reduced or even exhausted by Man as a result of carelessness and overexploitation.

QUESTIONS AND EXERCISES

1. (a) What do you understand by the term 'weathering'?
   (b) Name 4 natural forces that play a role in weathering.
   (c) Differentiate mechanical weathering from chemical weathering and give examples of each.
2. (a) Describe how gravitational forces and rainwater assist in the mass movement of weathered materials on hill slopes.
   (b) Distinguish soil creep from landslides, and locate places where such occurrences have taken place.
3. (a) What is meant by the following:
   i. hydrological cycle
   ii. water-table
   iii. acquifer.
   (b) For any *two* of the above, discuss their relationship with groundwater.
4. 'While the earth's crust is undergoing constructive changes to create new relief, external forces of nature are working vigorously to level this down.' Discuss.
5. Elaborate on any *three* of the following:
   (a) Exfoliation is the result of temperature changes in deserts.
   (b) Screes accumulate at the foot of steep mountains in temperate lands.
   (c) There are many ways in which springs can be formed.
   (d) Artesian wells have a distinct formation.
6. (a) In what ways are chemical weathering different from mechanical weathering?
   (b) Describe any *three* major processes of chemical weathering.
   (c) In what type of physical landform is chemical weathering by solution most dominant?
   (d) Name a few well-known physical features caused by solution in chemical weathering.
7. (a) Why is mechanical weathering also known as physical weathering?
   (b) State *four* ways by which mechanical weathering takes place.
   (c) In what climatic regions is mechanical weathering by frost action most potent?
8. With reference to examples, carefully distinguish betweeen:
   (a) 'weather' and 'erosion'
   (b) 'porous rocks' and 'pervious rocks'
   (c) 'a spring' and 'a well'
   (d) 'screes' and 'pebbles'.
9. Describe and explain the manner in which a land surface may be changed by
   i. rain;
   ii. frost;
   iii. wind.

   Illustrate your answer with annotated diagrams and specific examples.
10. (a) Explain what happens to precipitation when it falls on the land surface.
    (b) What factors determine the amount of water entering the ground in a particular place?
    (c) Why is the 'underground scenery' better developen in karst regions?