Landforms Associated with Vulcanic Activities

Vulcanic activities have a profound influence on the earth's landforms. Solid, liquid or gaseous materials may find their way to the surface from some deep-seated reservoir beneath. Molten magma is mobile rock that forces its way into the planes of weakness of the crust to escape quietly or explosively to the surface. The resultant landforms depend on the strength and fluidity of the magma, the types of cracks, faults and joints that it penetrates, and the manner in which it escapes to the surface. Magma while thrusting its way up to the surface may cool and solidify within the crust as plutonic rocks resulting in intrusive landforms. Magmas that reach the surface and solidify, form extrusive landforms. Rocks formed by either plutonic or volcanic activity are called igneous rocks.

Landforms of Igneous Intrusions

Perhaps the commonest intrusive landforms are *sills* and *dykes*. When an intrusion of molten magma is made horizontally along the bedding planes of sedimentary rocks, the resultant intrusion is called a sill. Denudation of the overlying sedimentary strata will expose the intrusion which will resemble a lava flow, or form a bold escarpment like the Great Whin Sill of N.E. England. Similar intrusions when injected vertically as narrow walls of igneous rocks within the sedimentary layers are termed as dykes. Because of their narrowness, dykes seldom dominate the landscape. When exposed to denudation they may appear as upstanding walls or shallow trenches, depending on whether they are more or less resistant than the rocks in which they are emplaced. Examples of dykes are the Cleveland Dyke of Yorkshire, England and hundreds of others in the Isles of Mull and Arran in Scotland. A large, very resistant dyke of quartzite forms a long ridge to the north of Kuala Lumpur.

Igneous intrusions on a larger scale are the various types of '–liths': *laccoliths, lopoliths, phacoliths* and *batholiths* (Fig. 26). The names may sound difficult; they are, in fact, all variations of igneous intrusions placed differently in the earth's crust, and soldifying within the upper layers of the crust. A laccolith is a large blister or igneous mound with a *dome-shaped* upper surface and a level base fed by a pipe-like conduit from below. It arches up the overlying strata of sedimentary rocks, e.g. the laccoliths of the Henry Mountains, in Utah U.S.A.

A lopolith is another variety of igneous intrusion with a *saucer shape*. A shallow basin is formed in the midst of the country rocks. The Bushveld lopoliths of Transvaal, South Africa are good examples.

A phacolith is a lens-shaped mass of igneous rocks occupying the crest of an *anticline* or the

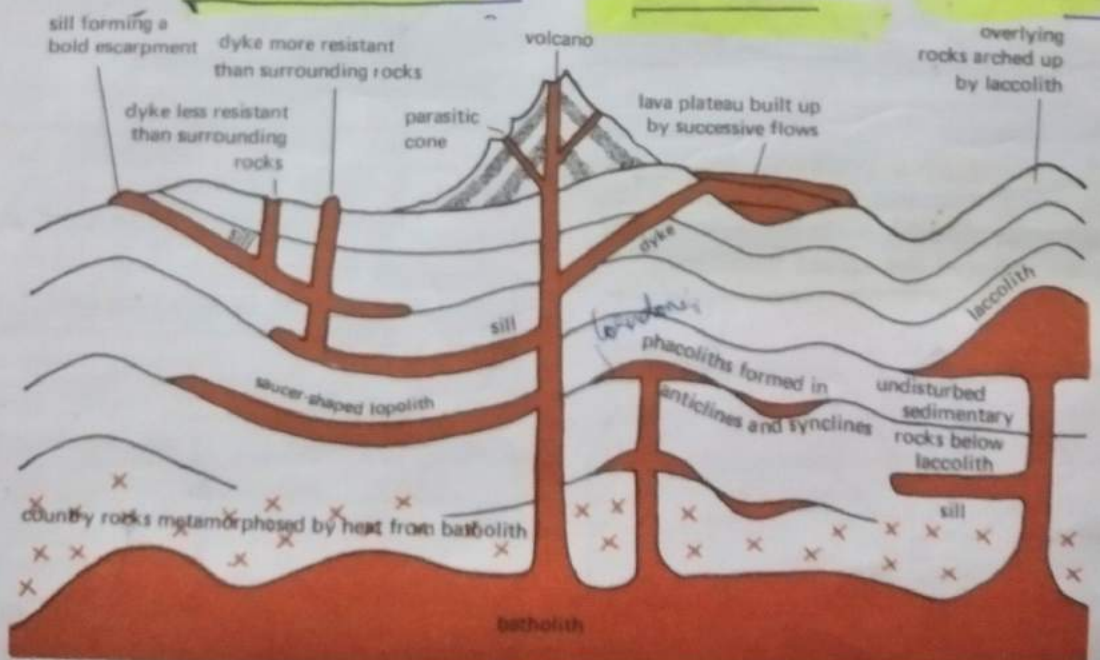

Fig. 26 Intrusive landforms of igneous intrusions in volcanic regions (showing sill, dyke, laccolith, lopolith phacolith and batholith)

bottom of a *syncline* and being fed by a conduit from beneath. An example of a phacolith is Corndon Hill in Shropshire, England.

A batholith is a huge mass of igneous rocks, usually *granite*, which after removal of the overlying rocks forms a massive and resistant upland region such as the Wicklow Mountains of Ireland, the uplands of Britanny, France and the Main Range of West Malaysia. Their precise mode of origin is still a matter of controversy. It is generally believed that large masses of magma rising upwards *metamorphosed* the country rocks with which they came into contact. These metamorphosed rocks together with the solidified magma give rise to extensive batholiths, sometimes hundreds of miles in extent. They are the most spectacular of the intrusive landforms.

The Origin of Volcanoes

The ancient Greeks believed that volcanic eruptions occurred when Vulcan, the God of the Underw stoked his subterranean furnace beneath Vulca small volcanic island off Sicily, from which the present word volcano is derived. Of course, we no longer believe this is true. Geologists and vulcanologists have ascertained that volcanic activity is closely connected with *crustal disturbances*, particularly where there are zones of weakness due to deep faulting or mountain folding. As temperature increases with increasing depth below the earth's crust, at an average rate of about 1°F. for every 65 feet of descent, the interior of the earth can be expected to be in a semi-molten state, comprising solid, liquid and gaseous materials, collectively termed *magma*.

The magma is heavily charged with gases such as carbon dioxide, sulphurated hydrogen, and small proportions of nitrogen, chlorine and other volatile substances. The gases and vapour increase the mobility and explosiveness of the *lavas* which are emitted through the orifice or vent of a volcano during a volcanic eruption. There are two main types of *lavas*.

1. **Basic lavas.** These are the hottest lavas, about 1,000°C. (1,830°F.) and are highly fluid. They are dark coloured like *basalt*, rich in iron and magnesium but poor in silica. As they are poured out of the volcano, they flow *quietly* and are not very explosive. Due to their high fluidity, they *flow readily* with a speed of 10 to 30 miles per hour. They affect extensive areas, spreading out as *thin sheets* over great distances before they solidify. The resultant *volcano* is gently sloping with a wide diameter and forms a flattene shield or dome (Fig. 27).

Mt. Mayon, Philippines, in eruption

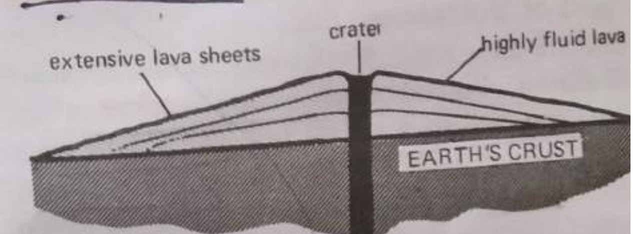

Fig. 27 Lava dome or shield volcano

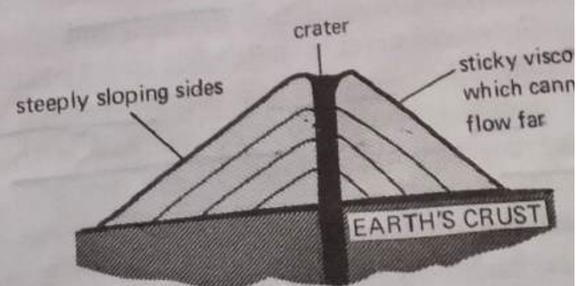

Fig. 28 Acid lava cone

2. **Acid lavas.** These lavas are highly viscous with a high melting point. They are *light-coloured*, of low density, and have a high percentage of silica. They *flow slowly* and seldom travel far before solidifying. The resultant cone is therefore steep-sided. The rapid congealing of lava in the vent obstructs the flow of the out-pouring lava, resulting in loud explosions, throwing out many *volcanic bombs* or *pyroclasts* (Fig. 28). Sometimes the lavas are so viscous that they form a spine or plug at the crater like that of Mt. Pelee in Martinique (Fig. 29). Some spines are very resistant and while most of the material of very old volcanoes is removed by erosion the spine may remain, e.g. Puy de Dome, France.

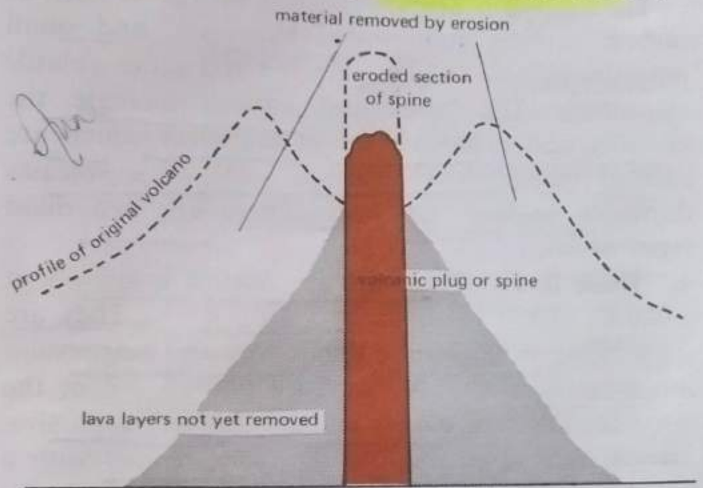

Fig. 29 A volcanic plug or spine after prolonged exposure to erosion. The plug is more resistant and remains after most of the volcanic materials have been worn away.

Types of Volcanoes

There are three types of volcanoes: *active, dormant* and *extinct*. Volcanoes are said to be active when they frequently erupt or at least when they have erupted within recent time. Those that have been known to erupt and show signs of possible eruption in the future are described as dormant. Volcanoes that have not erupted at all in historic times but retain the features of volcanoes are termed extinct. All volcanoes pass through active, dormant and extinct stages but we can never be thoroughly sure when they are extinct. Mt. Vesuvius and Mt. Krakatau were once thought by people to be extinct and yet both erupted most violently.

Extrusive Landforms

Extrusive landforms are determined by the nature and composition of the lava and other ejected materials that reach the surface of the earth. The fluid *basic lava*, flowing for long distances produces extensive lava plains and basalt plateaux, such as the great lava plains of the Snake Basin, U.S.A. The basalt plateaux are found in many continents, e.g. the north-western part of the Deccan Plateau and in Iceland.

Volcanic cones are most typical of the extrusive features. The highly fluid lavas build up lava domes or shield volcanoes with gently rising slopes and broad, flattened tops. The volcanoes of Hawaii have the best developed lava domes. The spectacular Mauna Loa and Kilauea are so accessible that they have been closely studied. Kilauea has a very steep-walled caldera into which the active vent pours red hot lava forming the *lava-pit* of Halemaumau. Thousands of lava fountains rise and fall in the dazzling pit.

The less fluid lavas that explode more violently form ash and cinder cones with large central craters and steep slopes. They are typical of small volcanoes, occurring in groups and seldom exceeding 1,000 feet in height, such as Mt. Nuovo, near Naples and Mt. Paricutin in Mexico. The lava flows are so viscous that they solidify after a short distance. When they are confined in valleys, they form lava tongues and *lava-dammed lakes* when they dam a river valley. Other minor features that may be associated with lava obstructions include lava bridges and lava tunnels.

A volcanic region may be strewn with solid materials that were hurled from the vent of the volcano. The very fine particles are the volcanic dust which may be shot so high into the sky that it travels round the world several times before it eventually comes to rest. The dust or ash falls as 'black snow' and can bury houses and people. The coarser fragmental rocks are collectively called pyroclasts and include cinders or *lapilli, scoria, pumice* and *volcanic bombs*.

The highest and most common volcanoes have composite cones. They are often called strato-volcanoes. The cones are built up by several eruptions of lava, ashes and other volcanic materials from the main conduit which leads down a reservoir of magma. Each new eruption adds new layers of ashes or lava to the sides of the volcano, which grows steadily in height. From the main conduit, subsidiary dykes or pipes may reach the surface as feeders to parasitic cones. Lava escapes through them to the sides of the main cones (Fig. 30). Mt. Etna in Sicily has hundreds of such parasitic cones. Another interesting composite volcano is Mt. Stromboli whose frequent eruptions that make the summit

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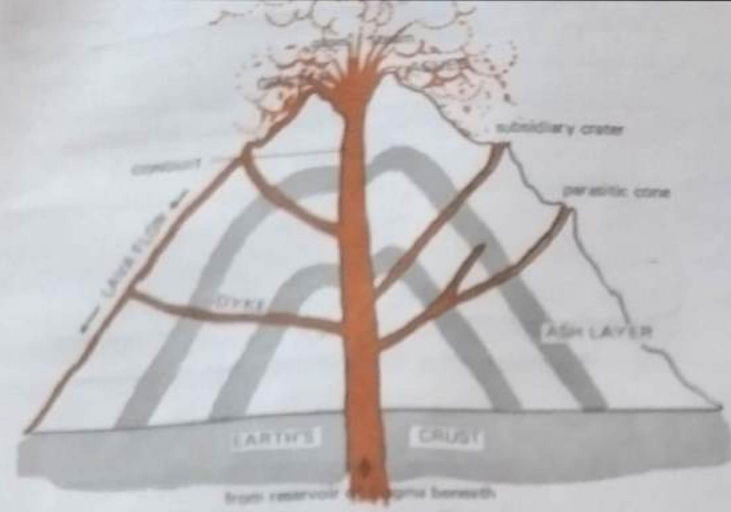

Fig. 30 A composite cone

glow have earned for it the name *'Lighthouse of the Mediterranean'*. Other well known composite volcanoes include Mt. Vesuvius, Mt. Fuji, Mt. Popacatapetl and Mt. Chimborazo.

During an eruption material from the top of the cone is blown off or collapses into the vent widening the orifice into a large crater. Some volcanoes may have greatly enlarged depressions called calderas, which may be several miles across. These are the result of violent eruptions accompanied by the subsidence of much of the volcano into the magma beneath (Fig. 31). Water may collect in the crater or the caldera forming crater or caldera lakes, e.g. Lake Toba in Sumatra.

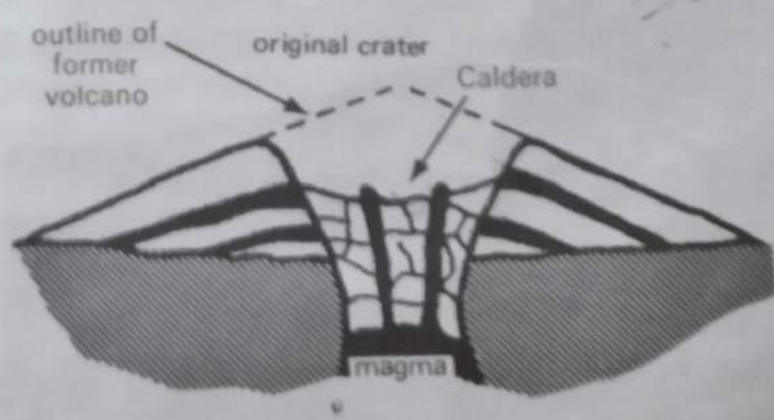

Fig. 31 A caldera. A violent eruption weakens the structure of the volcano and after eruption has ceased much of the volcano subsides into the magma reservoir beneath. The depression may later be filled with water to form a lake.

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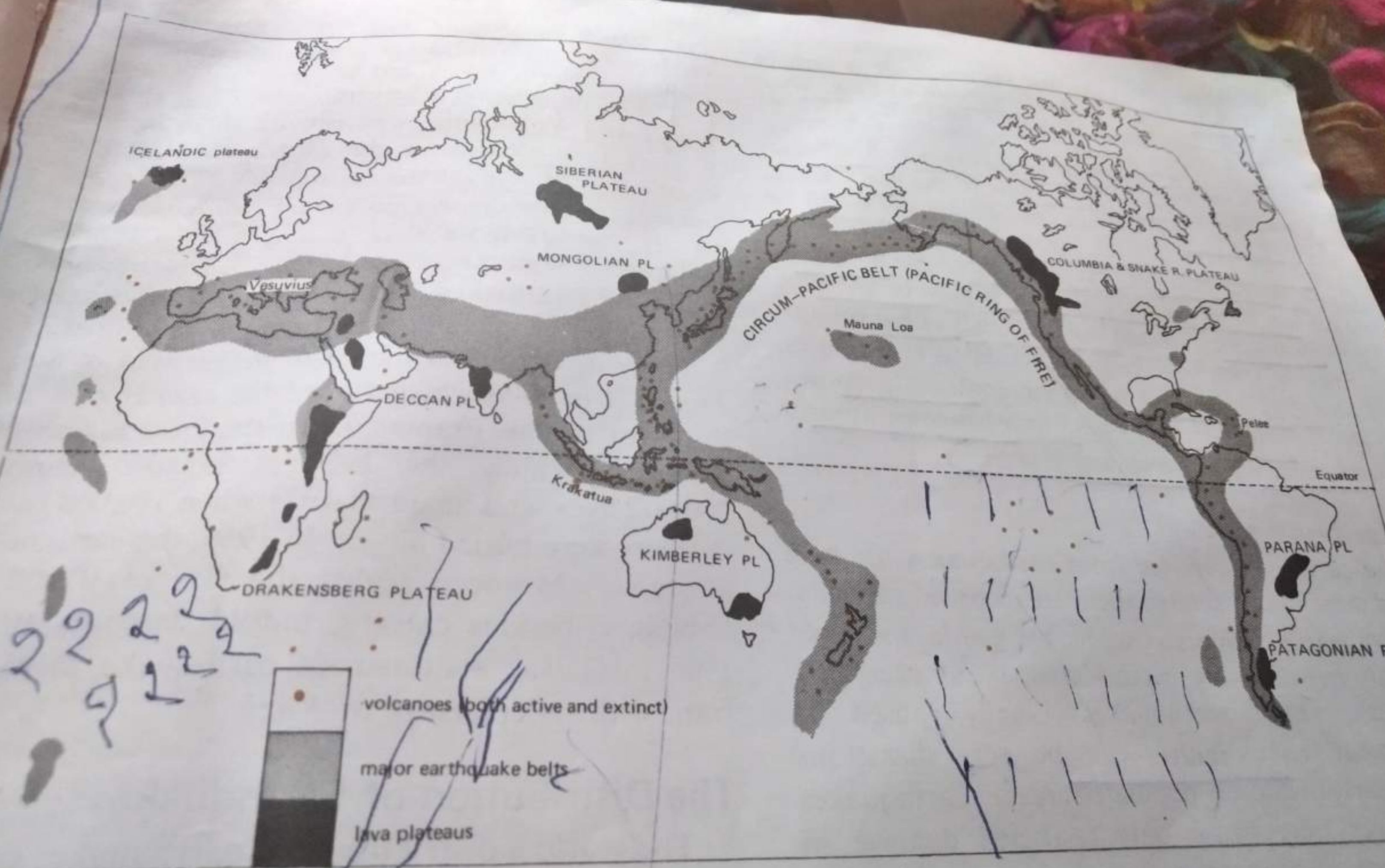

World distribution of volcanoes, lava plateaux and earthquakes

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

Chapter 4 Weathering, Mass Movement and Groundwater

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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 all 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 da[y] and are intensely heated. The outer layers expan[d] much faster than the cooler interior of the rocks a[nd] tend to pull away from the rest. At nightfall the tem[p]erature drops rapidly and the outer layers contr[act] more rapidly than the interior, setting up inte[rnal] stresses. Such stresses, repeated every day for mo

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*

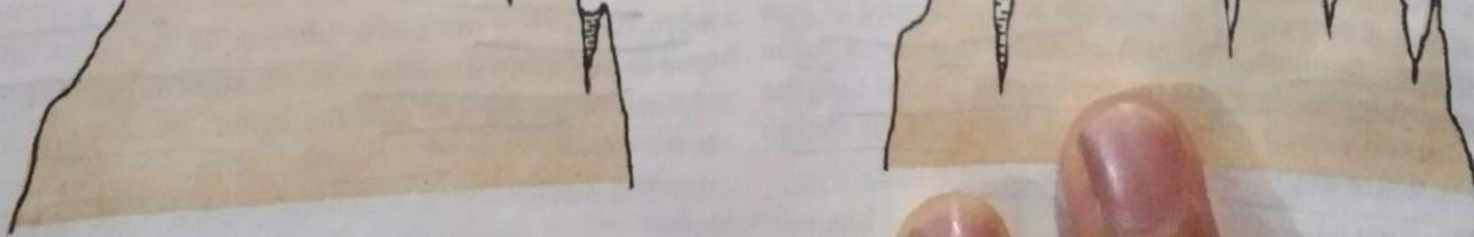
and years, cause the rocks to crack and split. Well-bedded and jointed rocks tend to split along the joints or cracks, breaking up into rectangular blocks. Shales and slates may split up into platy fragments because of their platy structure. In crystalline rocks such as granite the crystals of the various 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



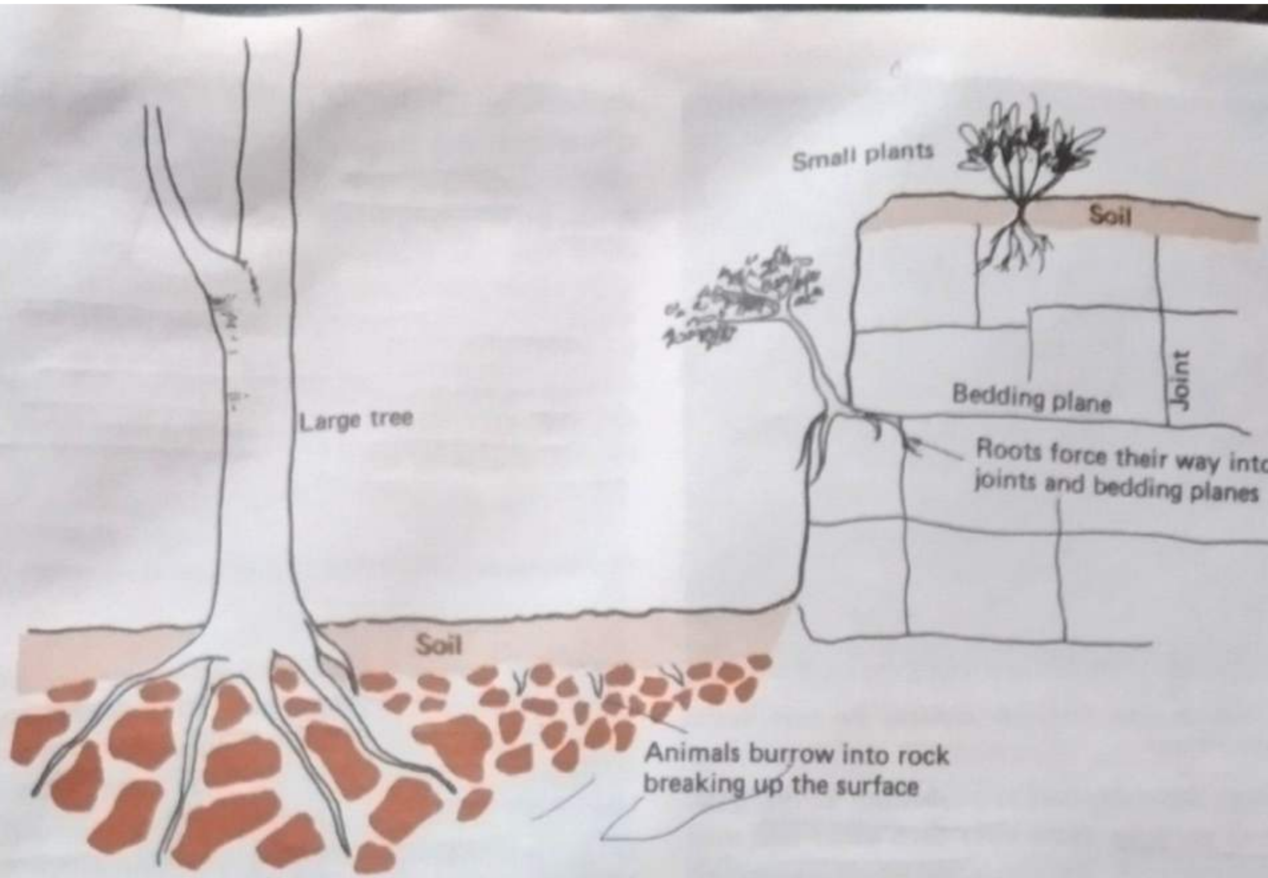


Fig. 4.3 Plant roots as agents of mechanical weathering

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).

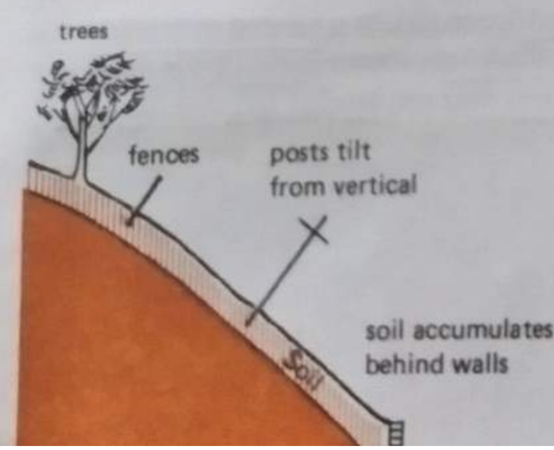
Men, in the course of mining, road construction and farming, also contribute to mechanical weathering by excavating the rocks and rendering them more vulnerable to the agents of denudation.

Mass Movement

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



force rocks apart

Fig. 4.3 Plant

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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 [s]upplied by rain-water. Several kinds of mass move-

4.C A landslide after flood has damaged the road *Jabatai 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 wea[thered] debris may become saturated with rain-wa[ter] after a storm and flow downslope as a semi-liq[uid] mass. In temperate and tundra regions soil flo[ws] occur when the surface layers of frozen ground tha[w] in spring. Soil and rock debris, lubricated by the mel[t] water, flow easily over the underlying frozen subsoil. In areas of peat soils, the peat absorbs much mois[]ture. However if saturation point is reached the pea[ty] soil may flow downslope. In Ireland such flows a[re] 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 rainwater. 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 sur[]face over which the upper layers easily slide (Fig 4.5).

Water may collect at the base of the regolit[h] because it sinks readily into the weathered materi[al]

Fig. 4.5 Landslide