Chapter 3 Vulcanism and Earthquakes

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

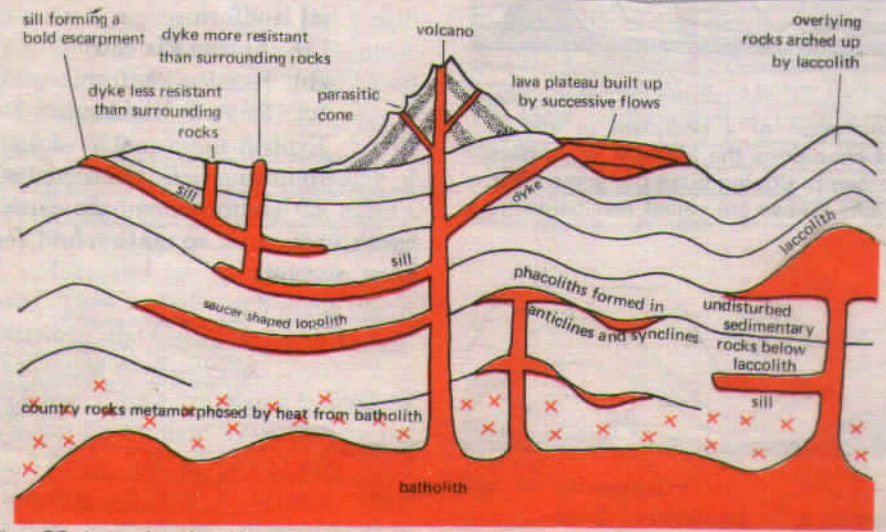

Fig. 26 Intrusive landforms of igneous intrusions in volcanic regions (showing sill, dyke, laccolith, lopolith phacolith and batholith)

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 Underworld, stoked his subterranean furnace beneath Vulcano, a 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*.

Mt. Mayon, Philippines, in eruption

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 flattened shield or dome (Fig. 27).

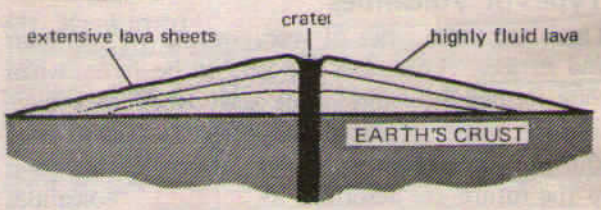

Fig. 27 Lava dome or shield volcano

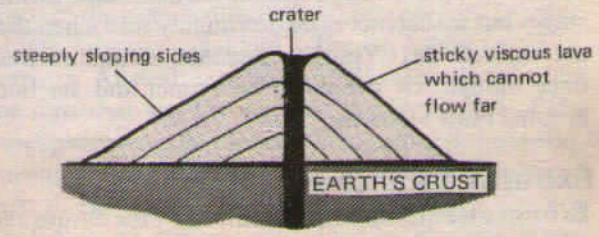

Fig. 28 Acid lava cone

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.

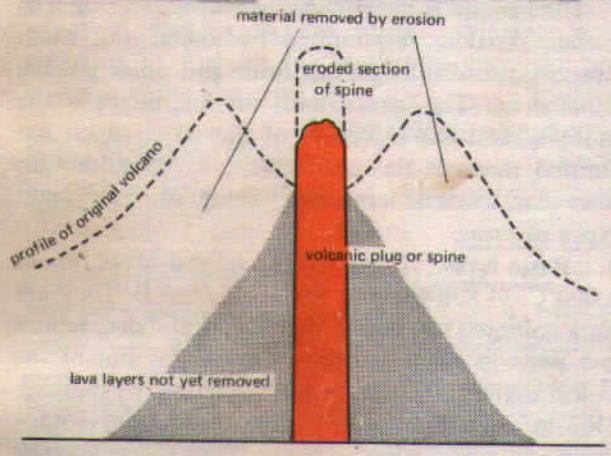

Fig. 29 A volcanic plug or spine after prolonged exposure to erosion. The plug is more resistant and remains after most of the volcanic materials have been worn away.

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

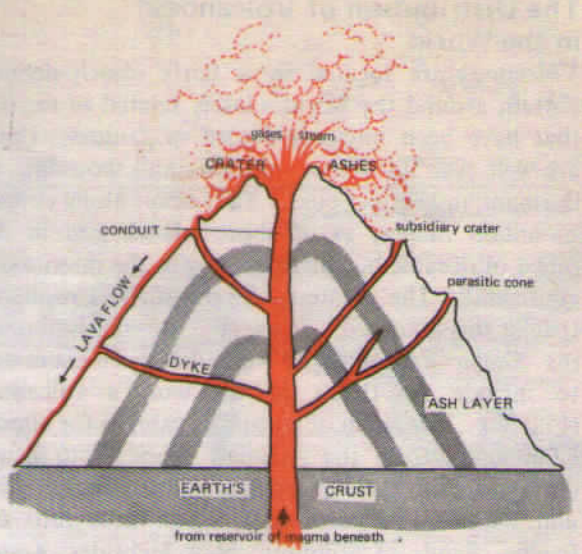

Fig. 30 A composite cone

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.

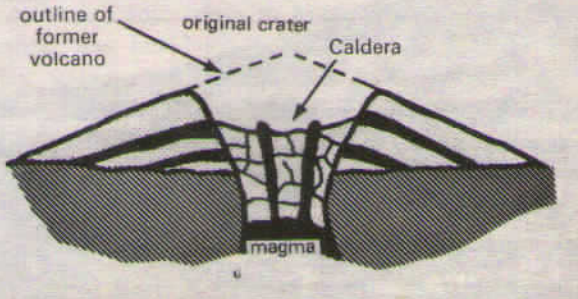

Fig. 31 A caldera. A violent eruption weakens the structure of the volcano and after eruption has ceased much of the volcano subsides into the magma reservoir beneath. The depression may later be filled with water to form a lake.

Some Volcanic Eruptions

In the history of mankind perhaps the most disastrous eruptions were those of Mt. Vesuvius, Mt. Krakatau and Mt. Pelee.

Mt. Vesuvius

Mt. Vesuvius, standing 4,000 feet above the Bay of Naples, erupted violently on 24 August A.D. 79 taking the people who lived around it by complete surprise. White-hot lava flowed from parasitic cones. In the midst of a thundering explosion, the highly gaseous magma escaped as gigantic luminous clouds in cauliflower form and shot up to great heights before it fell to earth as pyroclasts and ashes. The city of Pompeii, located to the south-west, was buried beneath twenty feet of volcanic ashes which were later cemented by the torrential downpours of heavy rain that accompanied the violent eruption. In a similar way, the city of Herculaneum on the west was completely overwhelmed by a mudflow of ashes and cinders almost 50 feet thick, washed down by torrential rain from the slopes of Vesuvius. Almost the entire population of the two cities was buried alive.

After this, minor eruptions occurred from time to time but the fertility of the solidified Volcanic ashes tempted many farmers to begin anew on the slopes of Vesuvius. Then came the catastrophic eruption of December 1631 when an avalanche comprising red hot volcanic debris, pasty lava and highly energized gases ruined fifteen towns and killed 4,000 inhabitants. The ashes that descended on Naples were estimated to be a foot thick.

Mt. Krakatau

The greatest volcanic explosion known to men is perhaps that of Mt. Krakatau in August 1883. Krakatau is a small volcanic island in the Sunda Straits, midway between Java and Sumatra. Dense black clouds of ashes shot 20 to 50 miles high, and were brought down as mud by the torrential rain which fell over the adjacent islands. So much magma was ejected from the underlying reservoir that two-thirds of the island collapsed and disappeared forming a huge submarine caldera. The explosion could be heard in Australia, almost 3,000 miles away. The fine dust that was thrown into the upper part of the atmosphere travelled several times around the world, causing brilliant sunsets and glowing sky in many parts of the globe. Though Krakatau itself was not inhabited and nobody was killed by the lava flows, the vibration set up enormous waves over 100 feet

high which drowned 36,000 people in the coastal districts of Indonesia.

After remaining dormant for almost half a century, an eruption in 1927 pushed up a cinder cone from the submarine floor, culminating in a summit of 220 feet above sea level by 1952. This new volcanic island was named Anak Krakatau, meaning 'the child of Mt. Krakatau'.

Mt. Pelee

The eruption of Mt. Pelee of the West Indies in May 1902 was the most catastrophic of modern times. The volcano erupted white-hot lava and super-heated steam which swept down the slope at an amazing speed as a *nuee ardente* (glowing avalanche). St. Pierre, the capital of Martinique, lying on the path of the lava, was completely destroyed within minutes. Its entire population of 30,000, except two of them, was killed almost instantly. Even the sea was boiling and all the ships in the harbour were wrecked.

The ejection of volcanic materials continued for several months until a vertical spine rose from the crater, almost a thousand feet high by the middle of 1903. The spine was formed by the pasty lava, partially solidified in the neck of the volcano. Part of the spine, however, crumbled under continual weathering as well as internal forces.

The Distribution of Volcanoes in the World

Volcanoes are located in a fairly clearly-defined pattern around the world, closely related to regions that have been intensely folded or faulted. There are well over 500 active volcanoes and thousands of dormant and extinct ones. They occur along coastal mountain ranges, as off-shore islands and in the midst of oceans, but there are few in the interiors of continents. The greatest concentration is probably that in the Circum-Pacific region, popularly termed the *'Pacific Ring of Fire'*, which has been estimated to include two-thirds of the world's volcanoes (Fig. 32). The chain of volcanoes extends for almost 2,000 miles from the Aleutian Islands into Kamchatka, Japan, the Philippines, and Indonesia (Java and Sumatra in particular), southwards into the Pacific islands of Solomon, New Hebrides, Tonga and North Island, New Zealand. On the other side of the Pacific, the chain continues from the Andes to Central America (particularly Guatemala, Costa Rica and Nicaragua), Mexico and right up to Alaska. It is said that there are almost 100 active volcanoes in the Philippines, 40 in the Andes, 35 in Japan, and more than 70 in Indonesia.

In contrast, the *Atlantic coasts* have comparatively few active volcanoes but many dormant or extinct volcanoes, e.g. Madeira, Ascension, St. Helena, Cape

Mt. Mayon seen from the town of Legaspi, southern Luzon. *Philippine Tourist and Travel Association*

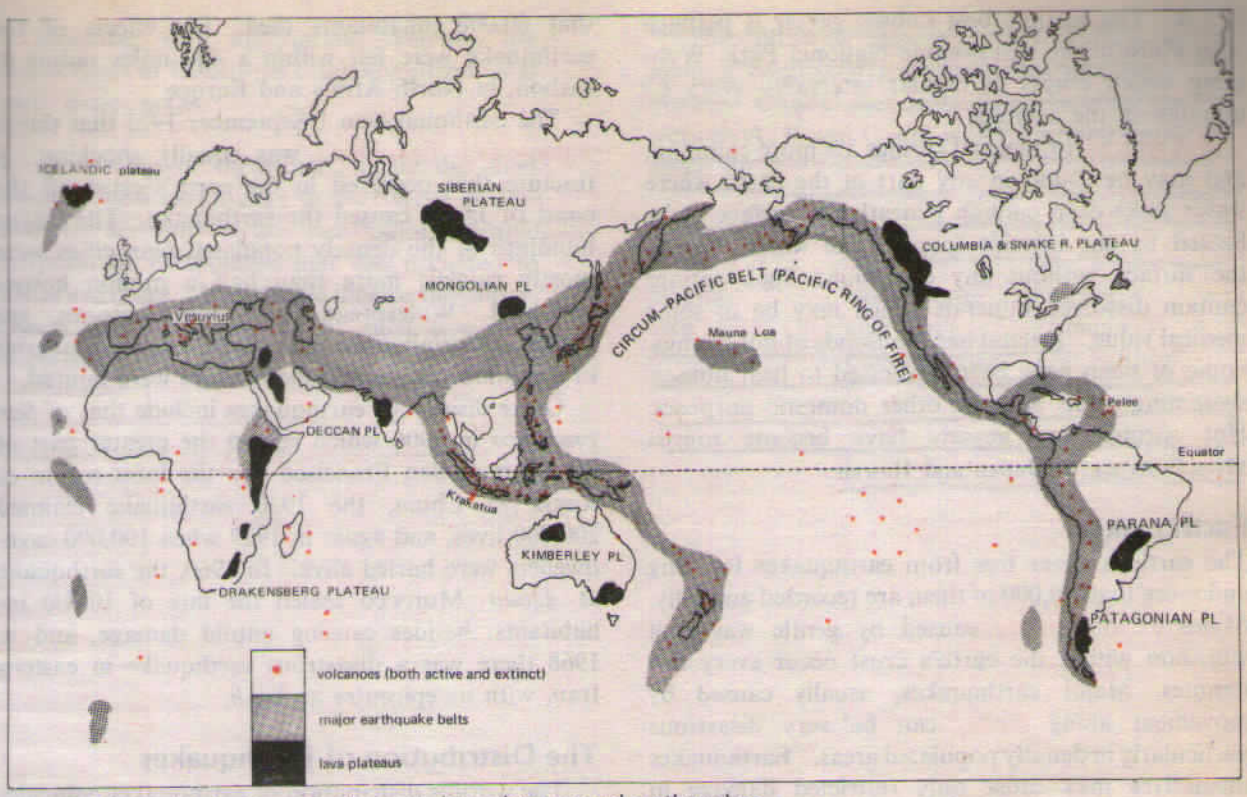

Fig. 32 World distribution of volcanoes, lava plateaux and earthquakes

Verde Islands and Canary Islands, but those of Iceland and the Azores are active. Volcanoes of the Mediterranean region are mainly associated with the Alpine folds, e.g. Vesuvius, Etna, Stromboli, Vulcano and those of the Aegean islands. A few continue into Asia Minor (Mt. Ararat, Mt. Elbruz). The Himalayas have, surprisingly, no active volcano at all.

In *Africa* some volcanoes are found along the East African Rift Valley, e.g. Mt. Kilimanjaro and Mt. Kenya, both probably extinct. The only active volcano of West Africa is Mt. Cameroon. There are some volcanic cones in Madagascar, but active eruption has not been known so far. The *West Indian islands* have experienced some violent explosions in recent times, e.g. Mt. Pelee in Martinique, and in St. Vincent further south. The Lesser Antilles are made up mainly of volcanic islands and some of them still bear signs of volcanic liveliness. Elsewhere in the interiors of continents—Asia, North America, Europe and Australia, active volcanoes are rare.

Geysers and Hot Springs

Geysers are fountains of hot water and superheated steam that may spout up to a height of 150 feet from the earth beneath. The phenomena are associated with a thermal or volcanic region in which the water below is being heated beyond boiling-point (100°C. or 212°F.). The jet of water is usually emitted with an explosion, and is often triggered off by gases seeping out of the heated rocks (Fig. 33). Almost all the world's geysers are confined to three major areas: Iceland, the Rotorua district of North Island, New Zealand and Yellowstone Park of

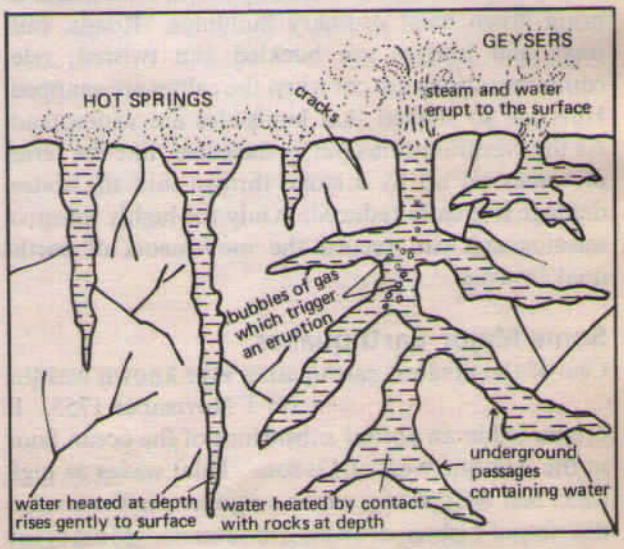

Fig. 33 Hot springs and geysers

U.S.A. The world's best known geyser is perhaps 'Old Faithful' in Yellowstone National Park, Wyoming which erupts at regular intervals—every 63 minutes on the average.

Hot springs or thermal springs are more common, and may be found in any part of the earth where water sinks deep enough beneath the surface to be heated by the interior forces. The water rises to the surface without any explosion. Such springs contain dissolved minerals which may be of some medical value. Iceland has thousands of hot springs. Some of them have been harnessed to heat houses, swimming pools and for other domestic purposes. Hot springs and geysers have become tourist attractions e.g. in Japan and Hawaii.

Earthquakes

The earth is never free from earthquakes for long and more than 50,000 of them are recorded annually. Minor earth tremors caused by gentle waves of vibration within the earth's crust occur every few minutes. Major earthquakes, usually caused by movement along faults, can be very disastrous particularly in densely populated areas. Earthquakes themselves may cause only restricted damage in the regions of occurrence, but their after-effects can be very catastrophic. They produce gigantic tidal waves, called tsunamis by the Japanese, which flood towns and drown thousands of people. Fires break out beyond control as gas mains are shattered and buildings collapse. In severe earthquakes, fissures gape open, and the ground writhes and undulates in the passage of the 'surface waves'. A wave height of a quarter of an inch in the upheaval is sufficient to bring down most ordinary buildings. Roads, railways and bridges are buckled and twisted; telecommunications are cut when the cables are snapped. Hills are so shaken that landslides are widespread. As the vibration thins out at the edges, like the series of waves set up by a stone thrown into the water, damage is greatly reduced. Only the highly sensitive seismograph can record the movements of earthquake waves.

Some Major Earthquakes

One of the greatest earthquakes ever known was the Great Lisbon Earthquake on 1 November 1755. It originated in an abrupt subsidence of the ocean floor in the Atlantic west of Lisbon. Tidal waves as high as 35 feet were set up which swept across the coastal districts of Lisbon, drowning thousands. Most of the buildings collapsed completely and it was estimated that 60,000 inhabitants died. The effects of the earthquake were felt within a 400 miles radius of Lisbon, in North Africa and Europe.

The earthquake on 1 September 1923 that shook Tokyo and Yokohama was equally shocking. A fracture that occurred in the earth's crust off the coast of Japan caused the earthquake. The fragile buildings of the densely populated twin cities were mostly ruined; more than half a million houses collapsed. Widespread fires from factories, gas mains, oil installations and kitchens killed a quarter of a million people and many more were injured.

Other disastrous earthquakes include that of *San Francisco* in 1906 which ruined the greater part of the heart of San Francisco. In the loess region of *Kansu* in China, the 1920 earthquake claimed 200,000 lives, and again in 1927 when 100,000 cave-dwellers were buried alive. In 1960, the earthquake at *Agadir*, Morocco sealed the fate of 10,000 inhabitants, besides causing untold damage, and in 1968 there was a disastrous earthquake in eastern Iran, with its epicentre at *Kakh*.

The Distribution of Earthquakes

The world's distribution of earthquakes coincides very closely with that of volcanoes. Regions of greatest seismicity are Circum-Pacific areas, with the epicentres and the most frequent occurrences along the *'Pacific Ring of Fire'*. It is said that as many as 70 per cent of earthquakes occur in the Circum-Pacific belt. Another 20 per cent of earthquakes take place in the *Mediterranean-Himalayan belt* including Asia Minor, the Himalayas and parts of north-west China. Elsewhere, the earth's crust is relatively stable and is less prone to earthquakes, though nowhere can be said to be immune to earth tremors.

QUESTIONS AND EXERCISES

1. With the aid of annotated diagrams, write a comparative account of landforms resulting from intrusive and extrusive igneous activities.

2. Distinguish the difference in appearance and origin of any *three* of the following pairs of terms associated with vulcanicity.
   (a) sills and dykes
   (b) cinder cones and lava domes
   (c) geysers and hot springs
   (d) crater and caldera
   (e) laccolith and lopolith

3. Describe, with appropriate sketches, the major types of landforms originating from acid and basic lavas.

4. On a map of the world, locate the chief volcanic and earthquake areas. Write a descriptive account of any *one* major volcanic eruption or earthquake that has occurred in historical times. You should include the causes, effects and consequences of such a named occurrence.

5. The following terms are in one way or another connected with volcanoes and earthquakes. Choose *one* term from each of the sections A, B and C and write what you know about them:

Section A	*Section B*	*Section C*
magma	basalt plateau	Vulcano
lava	lava plain	Tsunami
pyroclasts	parasitic cones	'Old Faithful'