Chapter Two

Geomorphology

Chapter Concepts

- Earth's Four Spheres
- Geomorphology
- The Interior of the Earth
- Rocks
- Continental Drift
- Plate Tectonics
- Continental Relief
- Volcano
- Earthquakes
- Denudation

Earth's Four Spheres

Earth's surface is where four open systems interface and interact **(Fig. 2.1)**. It may be seen from Figure 2.1 that the three abiotic (non-living) systems are overlapping to form the realm of biotic (living) system. The abiotic spheres are the *atmosphere, hydrosphere* and *lithosphere*. The biotic sphere is called the *biosphere*. Because these four spheres are not independent units in nature, their boundaries must be understood as transitional rather than sharp delimitations.

Atmosphere

The atmosphere is a thin, gaseous envelop surrounding the Earth, held by the force of gravity. Formed by gases arising from within the Earth's crust and interior, and the exhalations of all life over time, the lower atmosphere is unique in the solar system. It is a combination of nitrogen, oxygen, argon, carbon dioxide, water vapour, and small amount of trace gases.

Hydrosphere

Earth's water exists in the atmosphere, on the surface and in the crust near the surface, in liquid, solid, and gaseous states. Water occurs in two forms, fresh and saline (salty), and exhibits important heat properties as well as plying its extraordinary roles as a solvent. Among the planets in the solar system, only the Earth possesses sufficient water in quantity.

Lithosphere

Earth's crust and a portion of the upper mantle directly below the crust form the lithosphere. The crust is quite brittle compared to the layers beneath it, which are in motion in response to an uneven distribution of heat and pressure. In broad sense, the term lithosphere sometimes refers to entire solid planet.

Biosphere

The intricate, interconnected web that links all organisms with their physical environment is the biosphere. Sometimes called the *ecosphere*, the biosphere extends from the seafloor to about 8 km (5 miles) into the atmosphere. Biosphere is that area where the atmosphere, lithosphere, and hydrosphere function together to form the context within which life exists; an intricate web that connects all organisms with their physical environment. Life is sustainable within these natural limits. In turn, life processes have powerfully shaped the other three spheres through various interactive processes. The biosphere has evolved, reorganised itself at times, faced extinction, gained new vitality, and managed to flourish overall. Earth's biosphere is the only one known in the solar system; thus, life as we know is unique to the Earth.

Today, over six hundred million humans, approximately one million animal species and 355,000 known plant species depend on the air, water and land of the planet Earth.

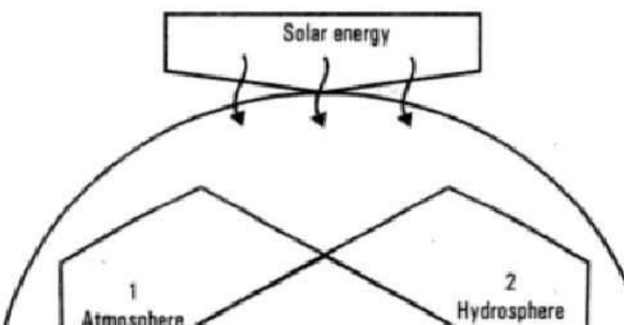


Fig. 2.1 – Four spheres of the Earth

Geomorphology

The science that analyse and describe the origin, evolution, form, classification, and spatial distribution of landforms is known as geomorphology. The term that arose in the Geological Survey in the USA in the 1880s, possibly coined by J.W. Powell and W.J. McGee. He regarded geomorphology as being that part of geology which enabled the geomorphologists to construct earth history by looking at the evidence for past erosion. In recent years there has been a tendency for geomorphologists to become more deeply involved with understanding the processes of erosion, weathering, transport and deposition, with measuring the rates at which such processes operate, and with quantitative analysis of the forms of the ground surface (morphometry) and of the materials of which they are composed. Geomorphology now has many component branches, e.g. Anthropogeomorphology; Applied Geomorphology.

The Interior of the Earth

The interior of the Earth and its constitution has always been a matter of great controversy among the geologists and geomorphologists. In the absence of direct evidence, the interior of the Earth was estimated with the help of change in temperature, pressure and density with depth. A reliable picture of the physical constitution of the Earth was however, ascertained with the help of seismic waves.

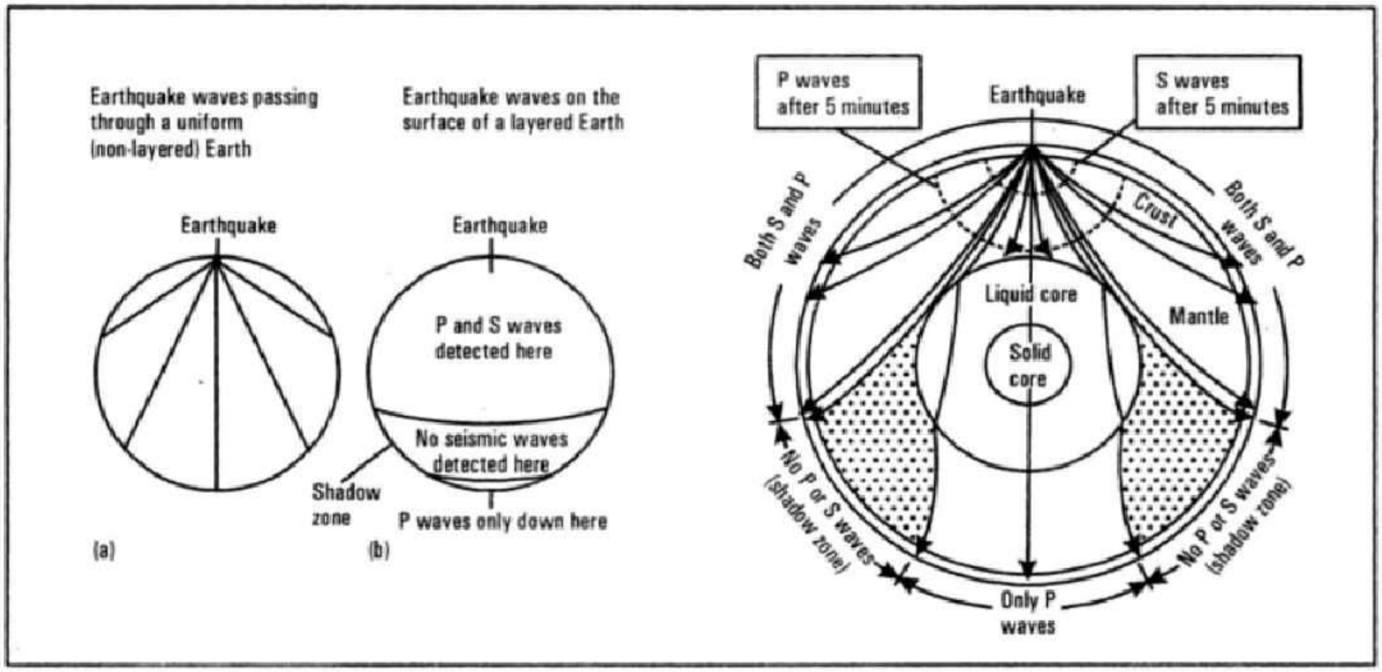
Earthquake Waves and Interior of the Earth

The behaviour of the earthquake waves in the different layers of the Earth provides the most authentic evidence about the composition and structure of the Earth. For example, when an earthquake or underground nuclear test sends shock waves through the Earth, the cooler areas, which generally are rigid, transmit these waves at a higher velocity than the hotter areas.

The different types of waves generated during the occurrence of an earthquake are generally divided into three broad categories: (i) Primary waves, (ii) Secondary waves, and (iii) Surface waves. The behaviour of different types of earthquake waves in the different mediums (solid, liquid and gaseous) has been described as under:

Primary Waves

These are also called as the longitudinal or compressional waves. In this type of wave motion, particles of the medium vibrate along the direction of propagation of the wave. These are the high frequency, short wave length, longitudinal waves. These waves travel not only through the solid part of the earth but also through the liquid part of the core. A primary wave travels with fastest speed through solid and more dense materials, and under certain circumstances, it changes into a secondary wave on refraction, or vice versa. In the liquid materials, their speed is slowed down. These waves are analogous to sound waves wherein particles move to and fro in the line of propagation of the ray **(Fig. 2.2).**



Seismic Wave model: How earthquakes contributed to our model of the layered earth.

(a) If the earth were homogeneous throughout, seismic waves would travel in straight-line paths at constant speed.

(b) Actually, the earth has a dense core, producing a shadow zone in which no seismic waves are detected.

(c) The patterns of reflected and refracted waves helped geophysicists deduce the structure of the earth's layers (after T. Garrison).

Fig. 2.2 – Seismic waves inside the Earth

Secondary Waves

These are also called as transverse or distortional waves. Secondary waves are analogous to water ripples or light waves, wherein the particles move at right angles to the rays **(Fig. 2.2)**. A secondary wave cannot pass through liquid materials. These are the high frequency, short wave-length waves which are propagated in all directions from the focus and travel at varying velocities (proportional to density) through the solid part of the Earth's crust, mantle and core. The shallow zone of 'S' waves extends almost halfway around the globe from the earthquake's focus. This can be explained if the outer core of the Earth is liquid. Since S waves cannot travel through liquid, they do not pass through the core.

Surface Waves

Surface waves are called long period waves. These waves generally affect the surface of the Earth only and die out at smaller depth. The surface waves are characterised with low frequency, long wavelength, and transverse vibration which develop in the immediate neighbourhood of the epicenter. These waves are responsible for most the destructive force of earthquake. They cover the longest distance of all the seismic waves and recoded in the last at the seismograph.

Seismic Waves as Probes of Earth's Interior

Seismic waves passing through the earth are refracted in ways that show distinct discontinuities within the Earth's interior and provide the basis for the belief that the Earth has: (i) a solid inner core, (ii) a liquid outer core, (iii) a soft asthenosphere, and (iv) a rigid lithosphere.

If the Earth were a homogeneous solid, seismic waves would travel through it at a constant speed. A seismic ray (a line perpendicular to the wave front) would then be a straight line as shown in **Fig. 2.2**. Early investigations, however, found that seismic waves arrive correspondingly sooner than was expected at stations progressively farther from an earthquake's course. The rays arriving at a distant station travel deeper through the Earth than those reaching stations closer to the epicenter. Obviously, then, if travel times of long-distance waves are progressively shortened as they go deeper into the Earth, they must travel more rapidly at depth then they do near the surface. The significant conclusion drawn from these facts is that the Earth is not a homogeneous, uniform mass, but has physical properties that change with depth. As a result seismic rays are believed to follow curved paths through the Earth **(Fig. 2.2)**.

Seismic Discontinuities

Seismologists have located two major layers which separate zones within the Earth having markedly different properties. The outer one – Mohorovicic Discontinuity (Moho) – separates the crust from the mantle, its average depth being about 35 km. The second discontinuity lies between the mantle and the outer core known as Gutenberg Discontinuity which is about 2900 km.

Thus, the Earth is a differentiated planet, that is, its constituent materials are separated and segregated into layers according to density. The denser materials are concentrated near the centre, the less dense near the surface. The internal layers are recognised on the basis of composition, and physical properties. The chemical compositional layers are: (1) crust, (2) mantle, and (3) core. Layers based on physical properties are: (i) lithosphere, (ii) asthenosphere, (iii) mesosphere, (iv) outer core, and (v) inner core.

The Crust

The outermost layer, or shell, of the Earth is known as crust. The Earth's crust is generally defined as the part of the Earth above the Mohorovicic (Moho) discontinuity. It is rigid and represents less than 1% of the Earth's total volume **(Figs. 2.3 & 2.4)**.

Mantle

The zone of Earth's interior between the base of crust (the Moho-Discontinuity) and the core. The depth of mantle varies between 35 km and 2900 km. The density ranges from 3.3 to 5.7 in the lower part. The density varies between 2.9 and 3.3. It is composed of solid rock and magma **(Figs. 2.3 & 2.4)**.

Core

The central part of the Earth below a depth of 2900 km is known as core. It consists of a dense nickel-iron alloy (*nife*) with a temperature estimated at about 2700°C. The outer core is liquid while the inner core is solid. The 'S' waves, which can pass only through solid subjects, suddenly disappear at the depth of 2900 km **(Figs. 2.3 & 2.4)**.

To conclude, the velocities of P waves and S waves through the Earth indicate that the Earth has a solid inner core, a liquid outer-core, a thick mantle, a soft asthenosphere, and a rigid lithosphere **(Figs. 2.2 & 2.4)**

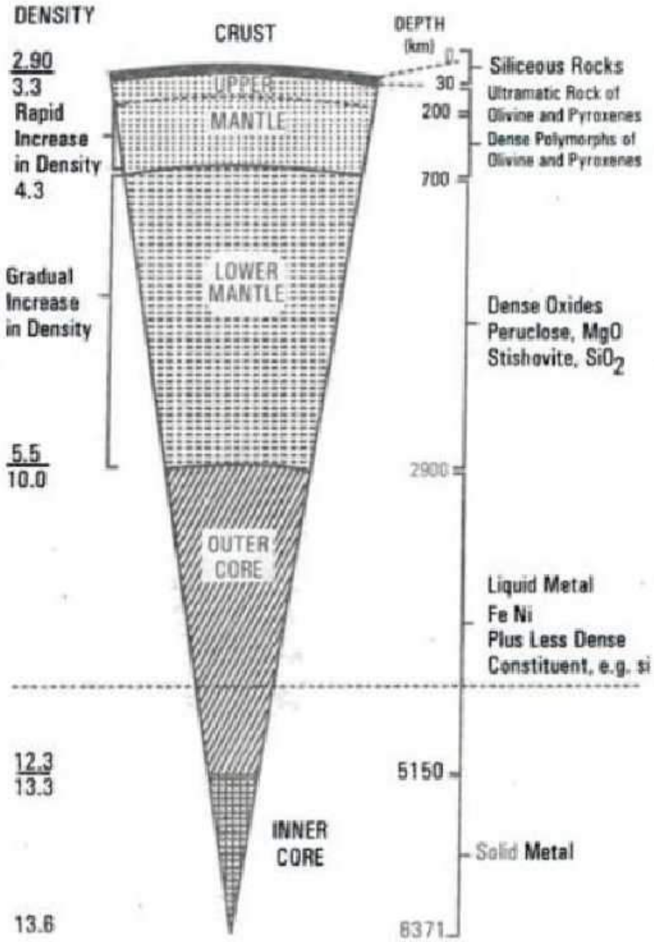


Fig. 2.3 – A Schematic section of the Earth

Rocks

Rock is an aggregate of minerals that forms an appreciable part of the lithosphere. The most important rock forming minerals are feldspars, micas, amphiboles, pyroxenes, olivine, quartz, calcite, dolomite, clays, and gypsum. On the basis of origin, and mode of formation, rocks may be classified into: (i) igneous, (ii) sedimentary, and (iii) metamorphic.

Igneous Rocks

Rocks formed by the cooling and solidification of molten silicate minerals (magma). Igneous rocks include volcanic and plutonic rocks. Igneous rocks are classified on the basis of texture and composition. The major kinds of igneous rocks are basalt, gabbro, andesite, diorite, rhyolite, and granite. Igneous rocks may also be classified under intrusive and extrusive rocks:

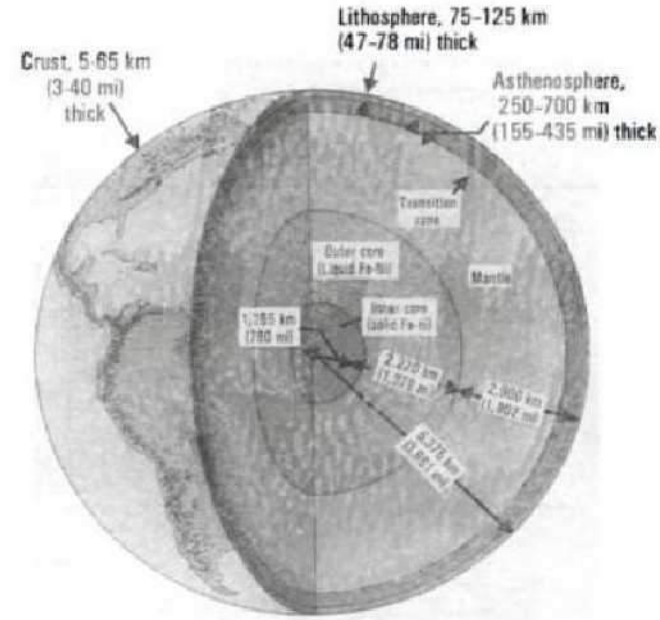


Fig. 2.4 – Major of Earth's interior after Conte Thompson, Moses, Earth Science, 1977, p.35.

Intrusive Rocks

These are the igneous rocks that, penetrated into or between other rocks in their fluid state and solidified. It can later be exposed at the Earth's surface after erosion of the overlying rock. A section of the intrusive rocks has been shown in **Fig. 2.5**.

Batholith

The term is applied to any large intrusive mass of igneous rock (almost always granite) in which there is no observable bottom of the structure. A batholith usually exposed over an area of at least 100 sq km **(Fig. 2.5)**.

Laccolith

Laccolith is an intrusive, dome-like mass of igneous rock which arches the overlying sediment and has more or less flat floor **(Fig. 2.5)**.

Sill

A tabular body of intrusive rock injected between layers of the enclosing rocks **(Fig. 2.6)**.

Dike (Dyke)

Dike a tabular intrusive rock that occurs across strata or other structural features of the surrounding rock **(Fig. 2.6)**.

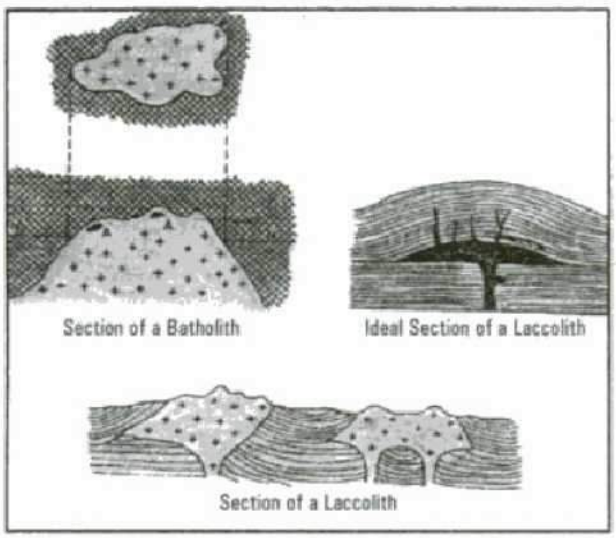


Fig. 2.5 – Section of Intrusive Rocks.

Phacolith

A concave-convex body of igneous rock which is inclinal in form, i.e. the concave surface is downward. Occasionally gold-quartz veins, occur in this form and are called saddle reefs.

Stock

A small, roughly circular intrusive body, usually less than 100 sq km in surface exposure

Zeolites

Zeolite is a large group of tekto (silicates) which contain true water of crystallisation. Zeolites occur in cavities in basic volcanic rocks and are thought to be product of hydrothermal activity.

Extrusive Igneous Rocks

Rocks formed by solidification of magma above the Earth's surface are known as extrusive igneous rocks.

(i) Explosive Rocks

These igneous rocks are the results of volcanic materials in which bombs, lapilli, dust and ash are deposited.

(ii) Quite Types

Lava comes out through minor cracks and fissures. After being cooled, the lava acquires the shape of basaltic igneous rocks. Most of the lava plateaus of the world are the results of fissure eruptions of lava **(Fig. 2.7)**.

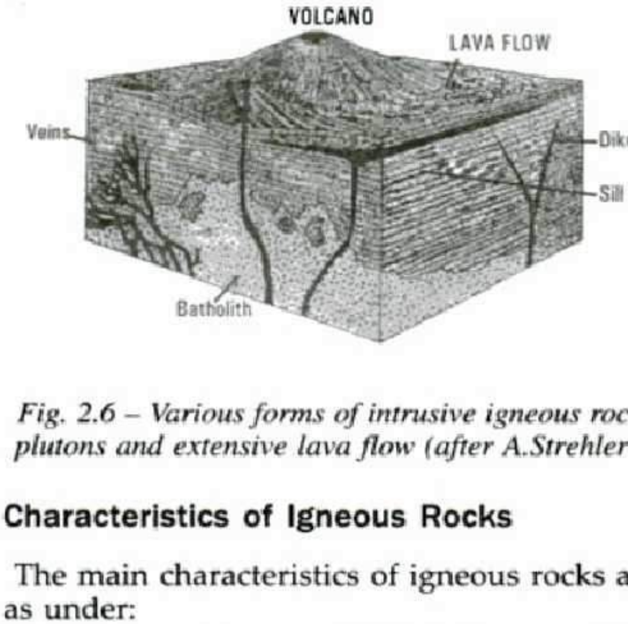


Fig. 2.6 – Various forms of intrusive igneous rock plutons and extensive lava flow (after A.Strehler)

Characteristics of Igneous Rocks

The main characteristics of igneous rocks are as under:

1. These rocks are solidified from molten magma.
2. They usually do not occur in distinct beds or strata.
3. Igneous rocks are generally not fossiliferous.
4. They are generally hard and water percolates in them with great difficulty along the joints.
5. Igneous rocks are granular and crystalline. The size of crystals, however, differs from one rock to another.

6. These rocks are generally weathered by mechanical (physical) weathering.
8. Igneous rocks are mostly associated with the volcanic activity.
9. Most igneous rocks consist of silicate minerals.
10. The valuable minerals like iron-ore, copper, gold, silver, zinc, lead, manganese, mica, etc. are generally found in the igneous rocks.

Sedimentary Rocks

Rocks formed by the accumulation and consolidation of sediment are known as sedimentary rocks. Sedimentary rocks may be of the following types:

Argillacous (Aquueous Rocks)

A group of detrital sedimentary rocks deposited in water. They are commonly, clay, shale, mudstones, siltstones, and marl.

Argillaceous sedimentary rocks are further subdivided into:

(i) Marine argillaceous sedimentary rocks,
(b) Lacustrine argillaceous sedimentary rocks,
(iii) Riverine argillaceous sedimentary rocks.

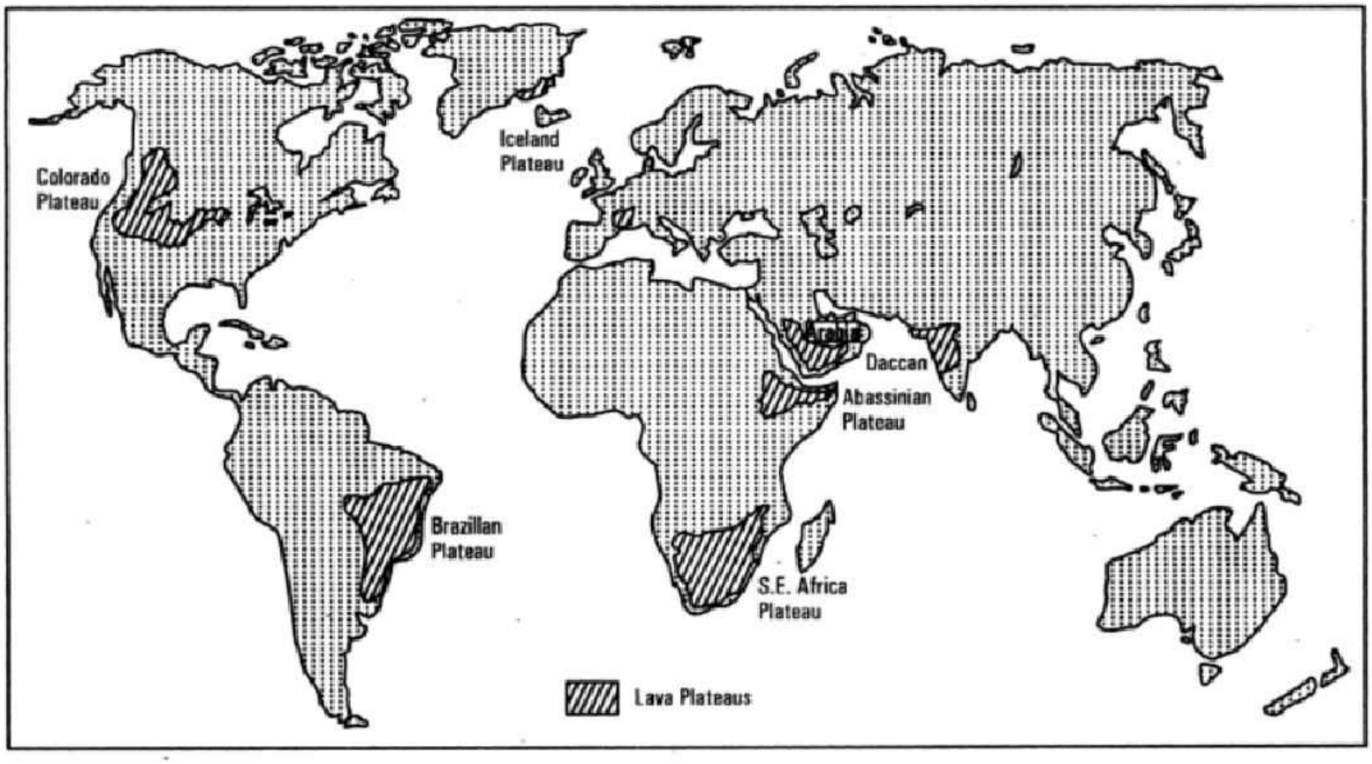


Fig. 2.7 – Main lava plateaus of the world

Aeolian

Sediments deposited after transported by wind are known as aeolian deposits. Loess is one of the most important aeolian deposits. The loess deposits are found away from the source region and outside the desert. The dust particles of loess are so small that they hold together even when dry and once deposited cannot be easily lifted by the wind. Loess is coherent (bound together) but not cemented and hence is permeable. Lack of stratification is a clear proof of its Aeolian origin. The equatorial tropics are free from loess because it is washed away by heavy rainfall as soon as it is deposited. The most extensive loess deposits in the world are in North China **(Fig. 2.8)**.

There caves and houses are carved out of the thick deposits. Loess deposits are also found in North European Plain, the Asiatic Steppe, Central North America and Argentina.

Glacial

The sediments deposited by glaciers are called glacial sedimentary rocks. These deposits are also known as moraines.

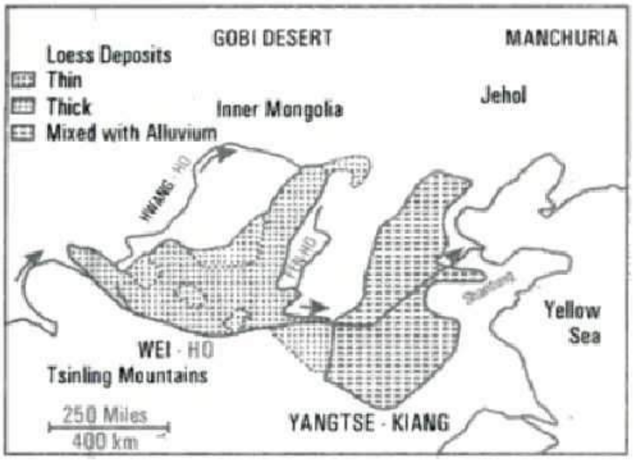


Fig. 2.8 – Loess deposits in northern China

Characteristics of sedimentary rocks

The main characteristics of sedimentary rocks are as under:

1. The material of sedimentary rocks is derived from the pre-existing rock of any of the three rock classes as well as from newly formed organic matter. However, igneous rock is the most important original source of the inorganic mineral matter that forms sedimentary rock.
2. The sedimentary rocks contain layers or strata. They are, therefore, often called stratified rocks.
3. The layers of the sedimentary rocks are sometimes horizontal, and sometimes tilted due to lateral compressive and tensile forces.
4. Sedimentary rocks are deposited in seas and oceans in a sequential order.
5. Sedimentary rocks are characterised by joints of different sizes.
6. Most of the sedimentary rocks are permeable and porous.
7. Sedimentary rocks contain fossils.
8. Sedimentary rocks may be well consolidated, poorly consolidated and even unconsolidated.
9. The riverine sedimentary rocks develop cracks when exposed to the Sun. These cracks are generally of polygonal shape.

Metamorphic Rock

These rocks are formed from pre-existing rocks within the Earth's crust due to changes in temperature, pressure and chemical action of fluid. The main examples of metamorphic rocks are slate, marble, quartzite, schist, and gneiss **(Fig. 2.9)**.

Gneiss

Gneiss is a coarse-grained, banded, crystalline rock resulting from high grade regional metamorphism.

Marble

Limestone, after undergoing metamorphism becomes marble. Marble is produced under conditions of thermal metamorphism.

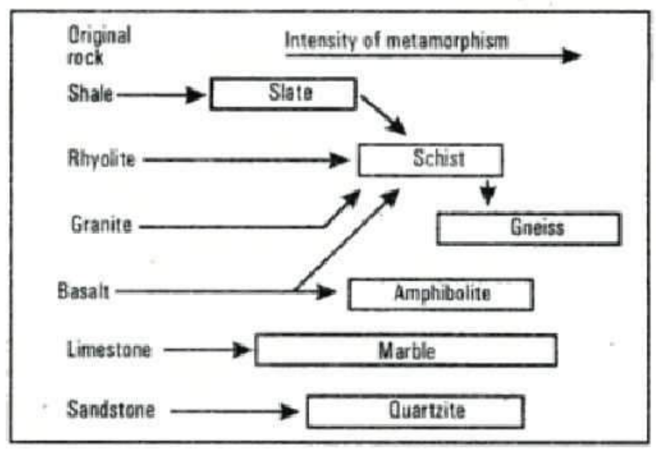


Fig. 2.9 – The origin of common metamorphic rocks is complex. In some cases, such as quartzite, marble, and metaconglomerate (not shown in diagram), the nature of the original rocks is easily determined. In other cases, such as schist and gneiss, it is difficult and sometimes impossible to determine the type of source rock. This diagram is a simplified flowchart showing the origin of some of the common metamorphic rocks.

Phyllite

Phyllite is a cleaved metamorphic rock having affinities with both slate and mica-schist.

Quartzite

Quartzite is a metamorphosed arenaceous rock. Quartzite is a metamorphic equivalent of conglomerate, sandstone and silt-stone, which is formed by the addition of silica to fill completely the open spaces between grains.

Schist

Schist is a well foliated, medium to coarse-grained metamorphic rock created by the effect of regional metamorphism.

Slate

Slate is a very fine-grained metamorphic rock, generally produced by the low-grade metamorphism of shale. It is characterised by excellent foliation, known as slaty cleavage.

Characteristics of metamorphic rocks

The main characteristics of metamorphic rocks are as under:

1. Metamorphic rocks are formed due to change in texture and mineral composition of the pre-existing rocks.
2. Some rocks after metamorphism become more hard than their original form. For example, marble from limestone, quartzite from sandstone, and diamond from carbon.
3. The fossils of the original sedimentary rocks are destroyed and, therefore, they do not contain fossils.
4. The coarse-grained metamorphic rocks are imperfectly foliated, e.g. gneisses, from granites, while the fine–grained metamorphic rocks are perfectly foliated, e.g. schist from shale.
5. Many of the metamorphic rocks are impervious (marble and slate), and some of them are pervious, e.g. gneiss.
6. Many of the metamorphic rocks may split along the bedding planes, e, g., micaschist.
7. Most gneissic metamorphic rocks comprise bands of granular quartz and feldspar.

Continental Drift

The movement of continents relative to each other across the Earth's surface is known as continental drift. Although it was a subject of speculation by numerous early workers, the first comprehensive case of continental drift was presented by the German meteorologist, polar explorer, astronomer, and geologist, Alfred Wegener in 1914. Wegener suggested that all the Earth's land had once been joined into a single supercontinent, surrounded by an ocean.

He called the land mass Pangaea (Pan = all + gaea = Earth) and the surrounding ocean Panthalassa (Pan = all + Thalassa = ocean). Wagener thought Pangaea had broken into pieces during the Carboniferous period. Since then, the pieces had moved to their present positions and are still moving **(Fig. 2.10)**.

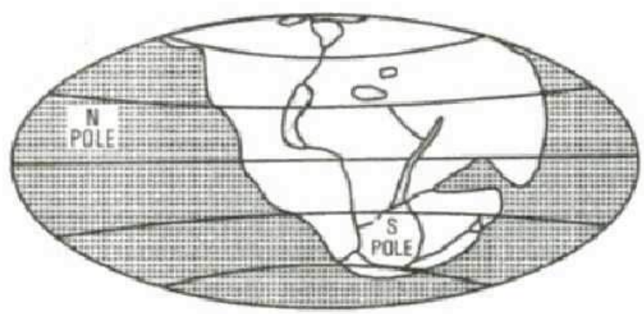


Fig. 2.10 – Pangaea

Wegener cited various evidence in support of his theory of super continent (Pangaea) which gradually separated into Northern (Laurasia) and the Southern (Gondwanaland) landmass before finally splitting into continents of the present day.

Wegener's evidence included the apparent shore fit of continents across the North and South Atlantic. The evidence included the matching configuration of opposing continental coastlines, the similarity of geological structures on separate continental masses, the anomalous location of ancient deposits, indicating specific climatic conditions, and distribution of fossil species through time **(Figs. 2.11 and 2.12)**.

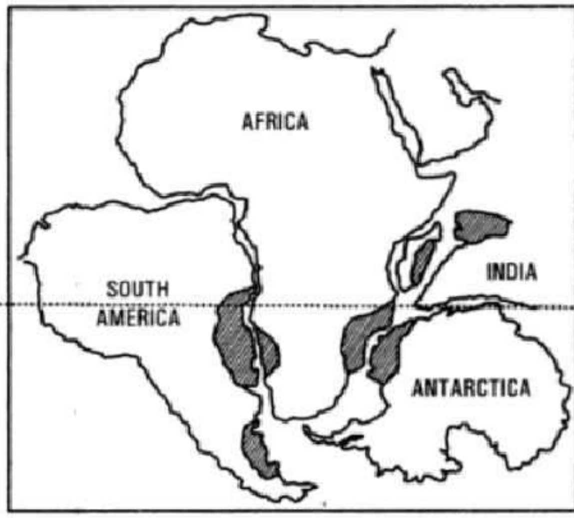


Fig. 2.11 – Jig-saw fit of continents and major basalt plateaus

He believed that the continents were slung towards the equator on the spinning Earth by a centrifugal effect, while the westward movement of the continents was due to the tidal force of the Moon and the Sun. The theory was rejected first by most geologists and geophysicists, largely because of a lack of viable mechanism. Wegener was dismissed as a crank. His critiques claimed, with some justification, that he had carefully selected those evidence, supporting his hypothesis, ignoring contrary evidence. Where, for instance, were the 'wakes' or 'tracks' through old seabed that the migrant continents would leave? But a few geologists sided with Wegener. Further support for continental drift was provided during the 1950s and 1960s through evidence from Palaeomagnetism. In 1967 the idea was incorporated into the theory of Plate Tectonics.

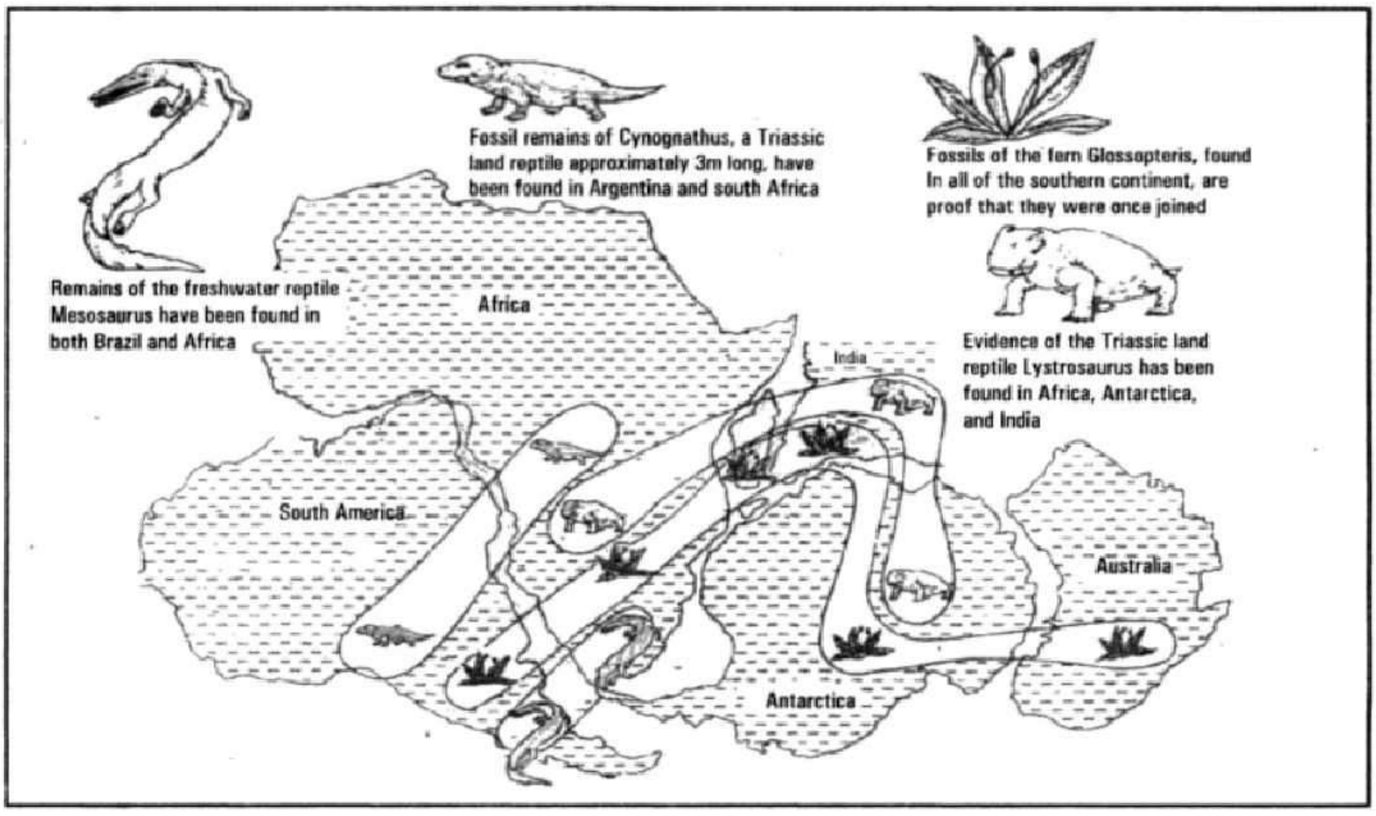


Fig. 2.12 – Paleontological evidence of Continental Drigt (after Hamblin, 1995)

Plate Tectonics

The Earth's crust is made up of seven major and several minor rigid continental and oceanic tectonic plates, which fit closely together. These plates are constantly moving relative to one another **(Fig. 2.13)**. The type of movement between plates affects the way in which they alter the structure of the Earth. The oldest parts of the plates, known as shields, are the most stable parts of the Earth and little tectonic activity occurs here.

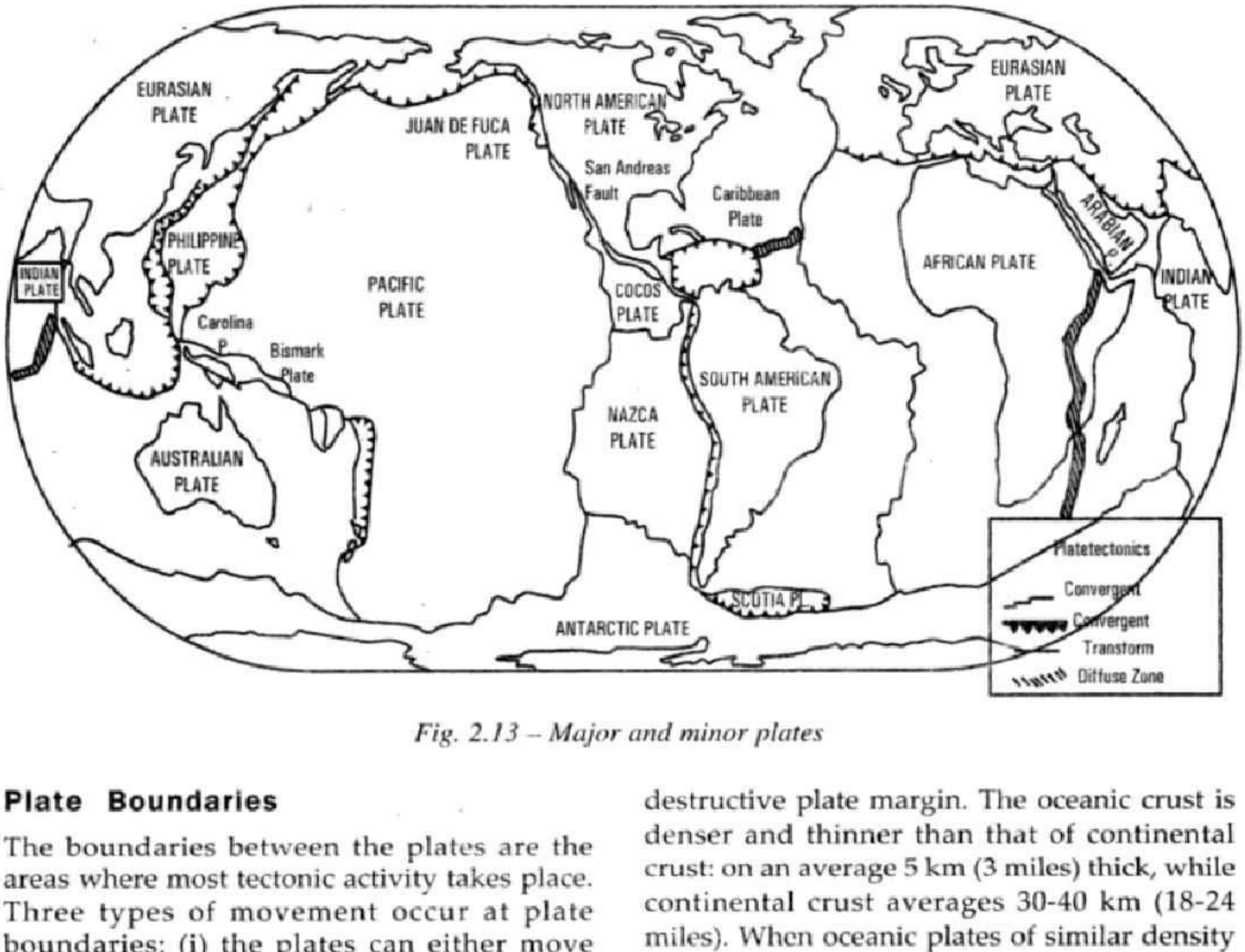


Fig. 2.13 – Major and minor plates

Plate Boundaries

The boundaries between the plates are the areas where most tectonic activity takes place. Three types of movement occur at plate boundaries: (i) the plates can either move toward each other,(ii) move apart, and (iii) slide past each other. The effect of this movement on the earth's structure depends on whether the margin is between two continental plates, two oceanic plates, or an oceanic and continental plates.

(i) Convergent or destructive plate margin (subduction)

When the plates move towards each other **(Fig. 2.14)**, such margins are called convergent or destructive plate margin. The oceanic crust is denser and thinner than that of continental crust: on an average 5 km (3 miles) thick, while continental crust averages 30-40 km (18-24 miles). When oceanic plates of similar density meet, the crust is contorted and one plate overrides the other, forming deep sea trenches and volcanic island arcs above sea level. The Andes mountains is a typical result of the impact of convergent.

The Alps were formed when the African plate collided with the Eurasian plate about 65 million years ago. Similarly, the Himalayas are the results of the colliding of the Indian plate with the Eurasian plate.

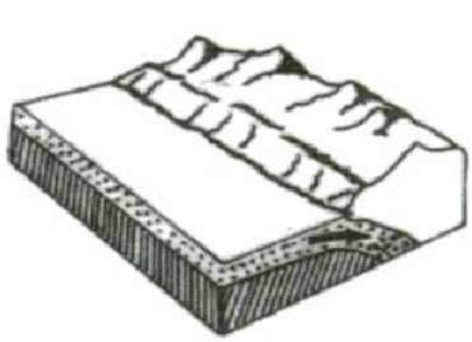


Fig. 2.14 – Convergent plate boundaries

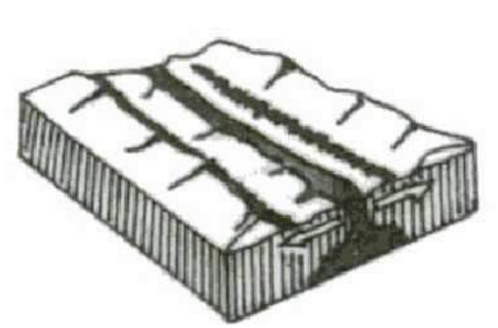


Fig. 2.15 – Divergent plate boundaries

(ii) Divergent or constructive plate margins

When the plates move away (apart) from each other, such margins are called divergent of constructive margins **(Fig. 2.15)**. The divergence of plates allows magma to force its way up to surface. The oceanic ridges are constructed because of the divergence of plates.

Vast amounts of volcanic materials are discharged at the mid-oceanic ridges which can reach heights of 3000 m (about10,000 feet).

The Mid-Atlantic ridge rises above sea level in Iceland, producing geysers and volcanoes.

The Eyjafjoell volcano of Iceland, erupted on 17.4.2010 was on the divergent plate of the Atlantic ocean.

(iii) Shearing or neutral plate margins

When the plates slide past each other, they neither construct the earth-crust nor destroy it. When two plates slide, past each other, friction is caused along the fault line which divides them.

The plates do not move smoothly, and the uneven movement causes earthquakes. The deep fracture caused by the sliding plates of San Andreas Fault (California-USA) is one of such examples **(Fig. 2.16)**.

Ring of Fire

The concept of 'Ring of Fire' was given by Hugo Benioff (a seismologist) in 1940. He plotted the locations of deep earthquakes at the edges of the Pacific Ocean. His maps revealed the true extent of 'Ring of Fire'- a circle of violent volcanic activity surrounding much of the Pacific ocean **(Fig. 2.17)**. According to Benioff, Wadati, Japanese seismologist, deep earthquakes did not occur randomly over the Earth's surface but were concentrated in zones that extended in lines along the earth's crust. Benioff and others wondered what could cause such an orderly pattern of deep earthquakes. Many of the lines corresponded with a worldwide system of oceanic ridges, (plotted for the first time in 1928 by Meteor oceanographers) while working in the Middle Atlantic. The concept of 'Ring of Fire' helped in the development of new concepts of 'Seafloor Spreading' and 'Plate Tectonic'.

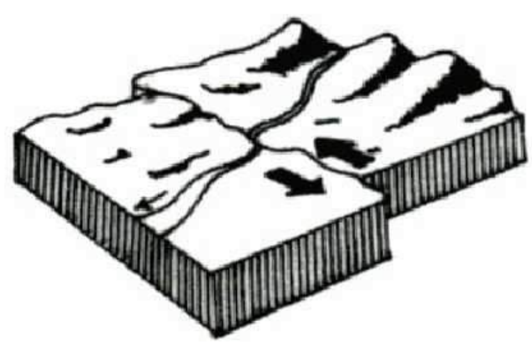


Fig. 2.16 – Transform plate boundaries

Fig. 2.17 – Ring of Fire

Seafloor Spreading

The concept of seafloor spreading was put forward by Professor H. Harry Hess of Princeton University in 1960. He suggested that new seafloor forms at the Mid-Atlantic Ridge (and the other newly discovered ocean ridges) and spreads outward from this line of origin. Continents would be pushed aside by the same forces that cause the ocean to grow. This motion could be powered by convection currents, slow-flowing circuits of material within the asthenosphere **(Fig. 2.18).**

The theory of seafloor spreading solved many of the unsolved problems. It solved the problem of the younger age of the crust at the mid-oceanic ridges and older rocks as one moves away from the middle parts of the ridges. It also resolved why the sediments at the central parts of the oceanic ridges are relatively thin. Finally, the concept of seafloor spreading proved the drift of the continents as propounded by Wegener and helped in the development of the theory of Plate Tectonic.

Continental Relief

All the continents are characterised by shields, platforms, mountains, plateaus, plains, volcanoes, etc.

Continental Shield

The centres of the Earth's continents, known as shields, were established during the Pre-Cambrian Period (over 570 million years ago), some of them like the Canadian Shield contain rocks over three billion years old. They were formed by a series of turbulent events; plates movements, earthquakes, and volcanic eruptions. They have experienced little tectonic activity, and today, their flat, low-lying slabs of solidified molten rock form the stable centres of the continents. They are bounded or covered by successive belts of younger sedimentary rocks.The major continental shields have been given in **Fig. 2.19**.

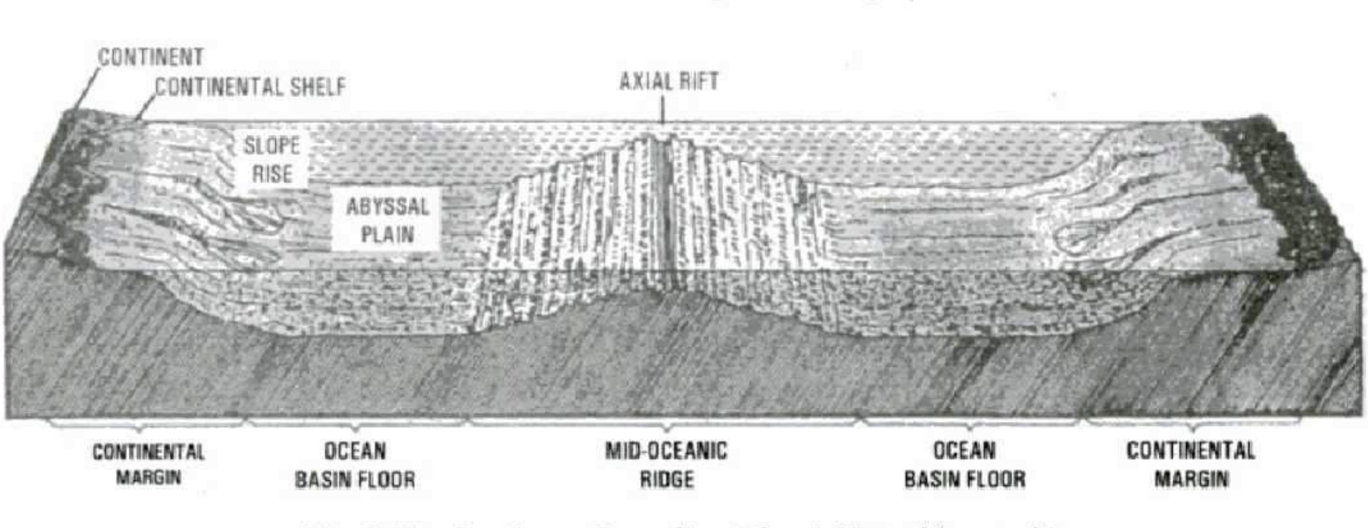


Fig. 2.18 – Sea floor - Spreading (after A.H. strahler et. al.)

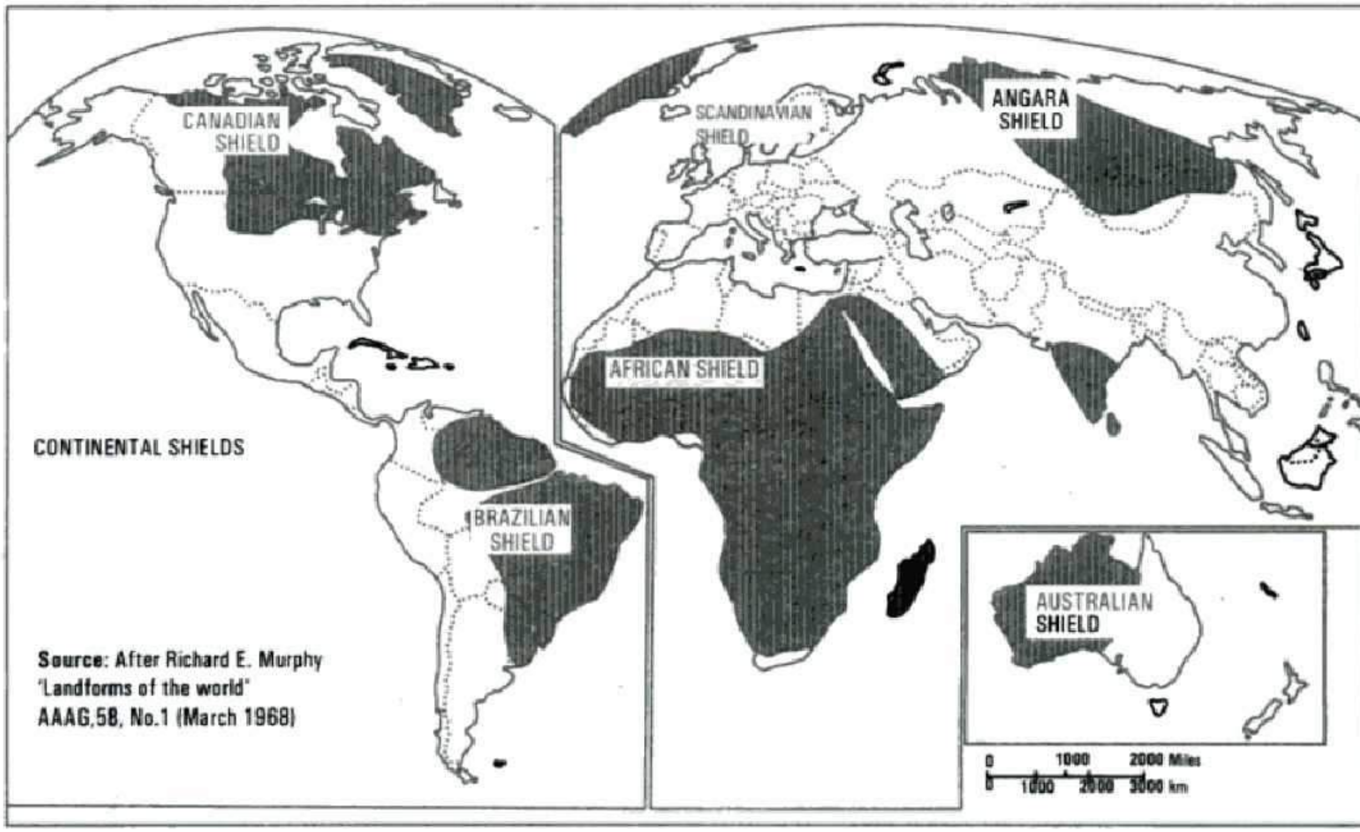


Fig. 2.19 – Major continental shields of the world

Mountain

Mountain can be single peak or part of a range. The summit of Mt. Everest is 8848 meters, the highest mountain range in the world is a part of the Himalayas. On the basis of their origin, the mountains may be classified into: (A) Folded, (B) Volcanic, (C) Fault Black, and (D) Dome-uparched of beds **(Fig. 2.20)**.

Plateau

Plateaus are vast areas of relatively flat land at high elevations. The Plateau of Tibet, located in China, is the highest plateau of the world.

Plain

Plains are broad stretches of nearly level land, usually found at low elevations. The fertile lowlands of North China plain and the Indo-Gangetic plains have the highly productive agricultural lands in the world. China plain ranges from 0 to 150 meters, while the Indo-Gangetic plain ranges from 0 to 300 metres above the sea level.

Elevation

Elevation is the measure of land's height or depth above or below the sea level.

Landforms

Landforms are the physical features of the landscape. Most extensive landforms have patterns of high, low, or changing elevation.

Relief

Relief is the difference between the highest and the lowest elevation of a landform, feature or a region.

Basin

Basins are low areas surrounded by higher grounds.

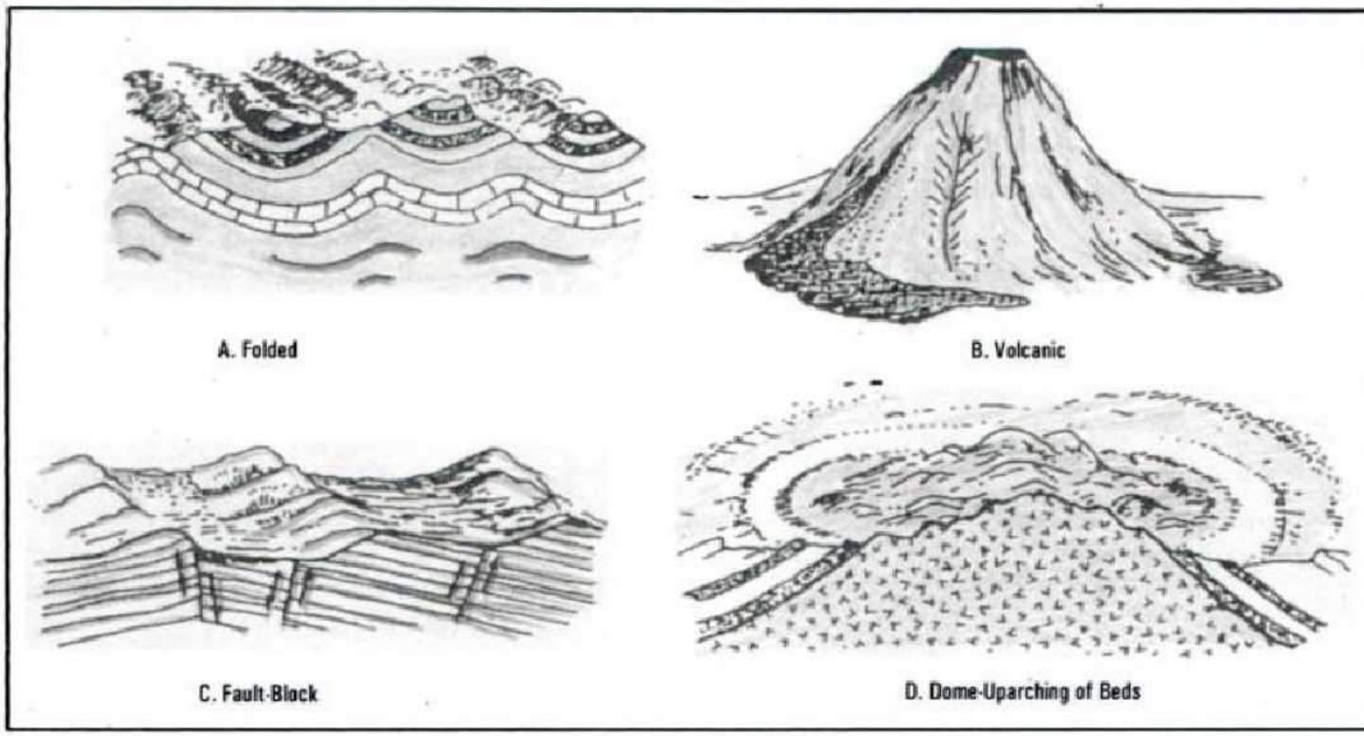


Fig. 2.20 – Classification of mountains

Volcano

Volcano is a landform at the end of a conduit or pipe which rises from below the crust and vent to the surface of the Earth. Magma rises and collects in a magma chamber deep below resulting in eruption that are effusive or explosive forming the mountain. An idealised cross section of a volcano has been given in **Fig. 2.21**.

The magma that actually issues from the volcano is termed lava (molten rock). Lava gases and tephra (pulverised rock and clastic materials ejected violently during eruption) pass through the vent to the surface and build a volcanic landform.

A cinder cone is a small cone-shaped hill usually less than 450 m (1500 ft) with a truncated top formed from cinders that accumulate during moderately explosive eruptions. Cinder cones are made of tephra and scoria. Another distinctive landform is a large basin shaped depression called caldera (Spanish from 'kettle'). It forms when summit material on a volcanic mountain collapses inward after an eruption or other loss of magma, forming a caldera that may fill with rainwater such as crater lake.

Composite Volcanoes

Composite volcanoes are built up of alternating layers of ash and lava flows, which characteristically form high, steep-sided cones **(Fig. 2.21)**.

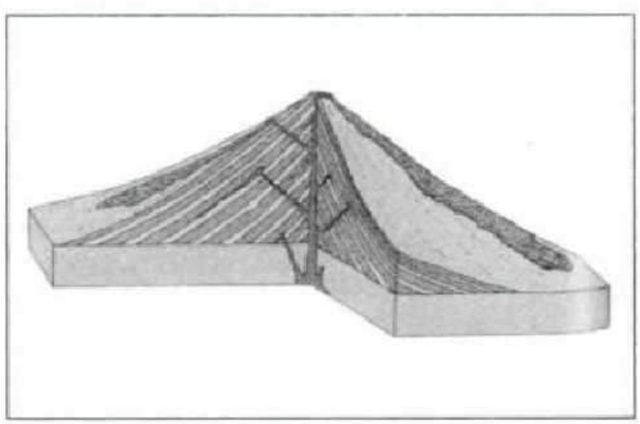


Fig. 2.21 – Composite volcanoes

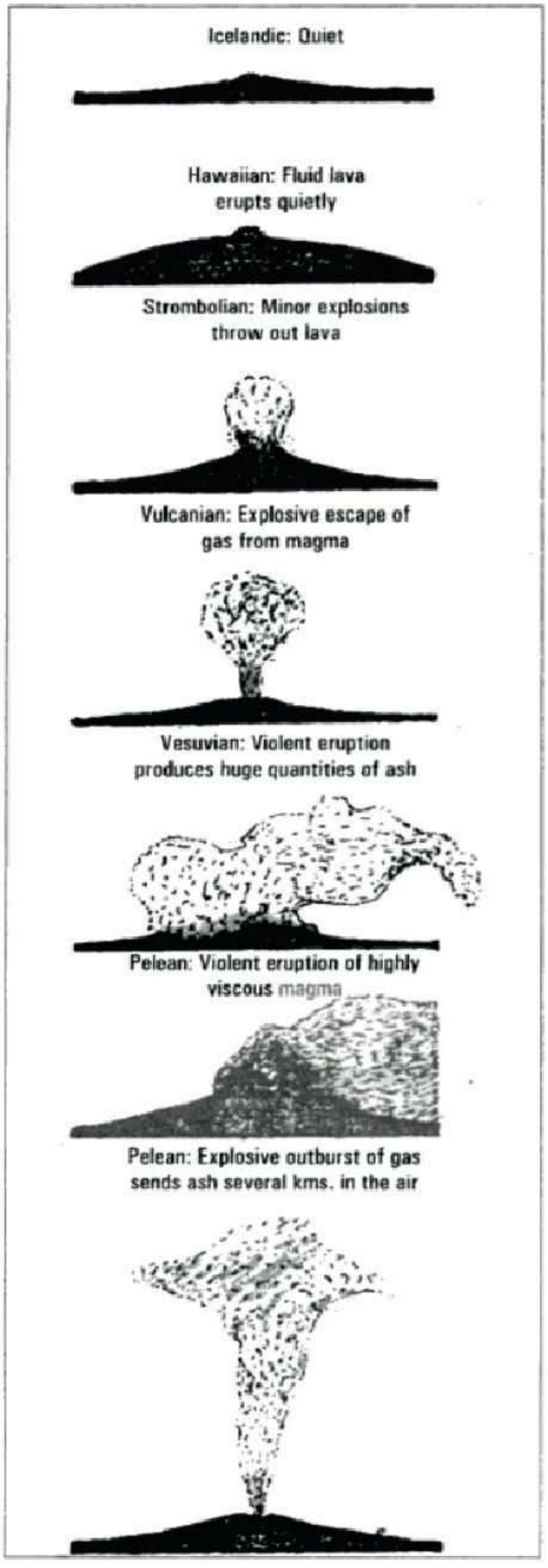


Fig. 2.22 – Types of vocanic eruptions

Types of Volcanic Eruptions

On the basis of mode of eruptions, numerous classifications of volcanoes have been given. The most commonly used classification of volcanic eruptions was given by Lacroix in 1908. According to Lacroix, there are four principal types of eruptions: (i) Hawaiian, (ii) Strombolian, (iii) Vulcanian, and (iv) Pelean **(Fig. 2.22)**.

(i) Hawaiian Eruption

It is an eruption in which large quantities of extremely fluid basic lava flow out from a fissure or a central vent to form a typical shield. In this type of volcano, explosive activity is almost absent **(Fig. 2.22)**.

(ii) Strombolian Eruption

In this type of volcanic eruption, the basic lave (basaltic) is less fluid than that of Hawaiian type. Consequently, explosions are more common and more gragmental material is ejected. It is named after the volcano on the island of Stromboli off north Sicily **(Fig. 2.22)**.

(iii) Vulcanian

In this type of eruption, the lava surface solidifies rapidly because of its high viscosity. The solidification results in building up of pressure beneath the lava crust and continuous series of violent explosions during which large quantities of pyroclastic materials are ejected violently from the vent. The ash coming out of the volcano may be distributed widely by the wind **(Fig. 2.22)**.

(iv) Pelean Eruption

In Pelean the lava is extremely viscous. It erupts generally in violent forms. One of its salient feature is the formation of *nuee ardentes* (glowing clouds). This type of volcanic eruption is named after Mt. Pelee (West Indies) where extremely violent eruptions have occurred including that of 1902 **(Fig. 2.22)**.

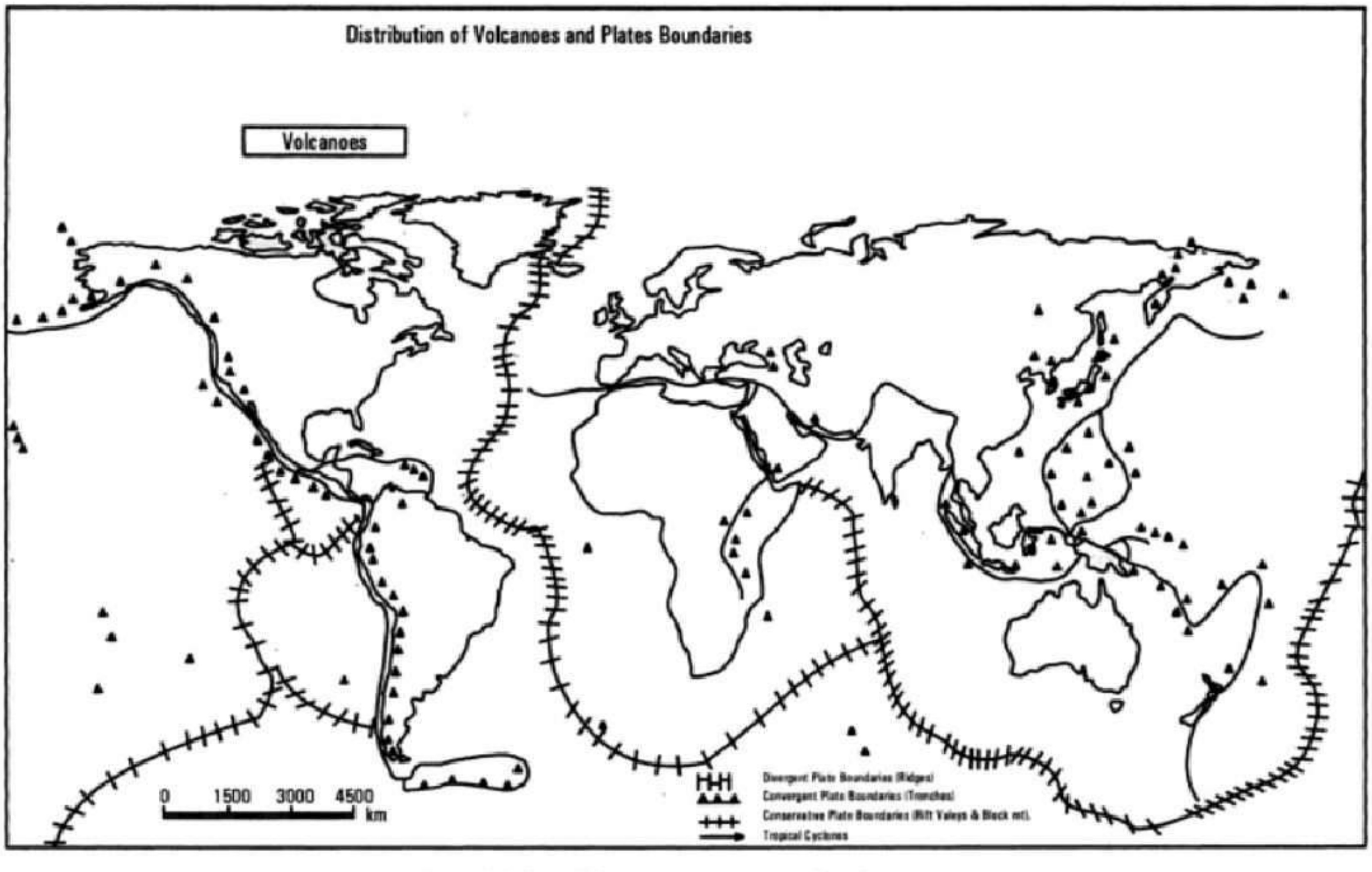


Fig. 2.23 – Plates margins and volcanoes

Distribution of Volcanoes in the World

There is a close relationship between the plates margin and the distribution of volcanoes in the world. In fact, the volcanoes are closely concentrated along the plates margin. The main concentration of the volcanoes lies in the following regions **(Fig. 2.23)**.

1. Along subduction boundaries at continental plate-oceanic plate convergence (Mount Saint Helens) or oceanic plate-oceanic plate convergence (Philippines and Japan).
2. Along seafloor spreading centres on ocean floor (Iceland) and areas of rifting on continental plates (the Rift Valley in East Africa).
3. At hot spots, where individual plumes of magma rise the crust (Hawaii Islands).

On the basis of periodicity, the volcanoes may be divided into the following three categories:

(i) Active volcanoes, (ii) Dormant volcanoes, and (iii) Extinct volcanoes

(i) Active Volcanoes

Volcanoes which constantly eject lava, gases, ashes, cinder, pumice, etc. are known as active volcanoes. At present, there are about 600 active volcanoes in the world, most of which are located in the Pacific ocean.

(ii) Dormant Volcanoes

A volcano which, although not extinct, has not been known to erupt within the historic time. The Vesuvius volcano (Italy) is one of the best examples of dormant volcano which erupted first in 79 A.D. It remained dormant for over 1550 years and then suddenly erupted with great force in 1631 A.D. The subsequent eruptions occurred in 1803, 1872, 1906, 1927, 1928, 1929. Kilimanjaro (Tanzania) is also an example of dormant volcano.

(iii) Extinct Volcanoes

A volcano that was active in distinct geological past and the remains of which occur in an area where there is no longer any volcanic activity is known as an extinct volcano. The crater is filled up with water converting it into a lake. The Arthur's seat (Edinbourg- capital of Scotland), Aconcagua (Andes), Sulaiman and Demavand in Elburz (Iran) are some of the examples of the extinct volcanoes **(Fig. 2.24)**.

Volcanoes and Society

Volcanic eruptions are the most popular spectacular of all the geographic phenomena. For centuries, they have caused dismay and terror for people who live in the volcanic belts.

Throughout the history of mankind, volcanoes have been a source of terrible destruction. They however, yielded life sustaining valuable mineral resources. Among the resources provided by volcanoes are rich volcanic soils, geothermal heat, metallic óres (including gold, silver, copper, molybdenum, beryllium, iron, lead, zinc, etc.), and the very air we breath and the water we drink. Industrial materials like building stones, sulfur, pumice, slate, dykes are the results of volcanic activity. Precious stones like diamond, gems have volcanic origin. The scenery of some of our most spectacular landscapes such as Laki, Eyjafjoell and Katla (Iceland), Kilimanjaro (Tanzania), Mt.Fuji (Japan), Lake Titicaca (Bolivia-Peru border) Pacific islands, Yellowstone Park (USA), etc. are the gifts of volcanoes. The eruption of volcano also bring climatic change.

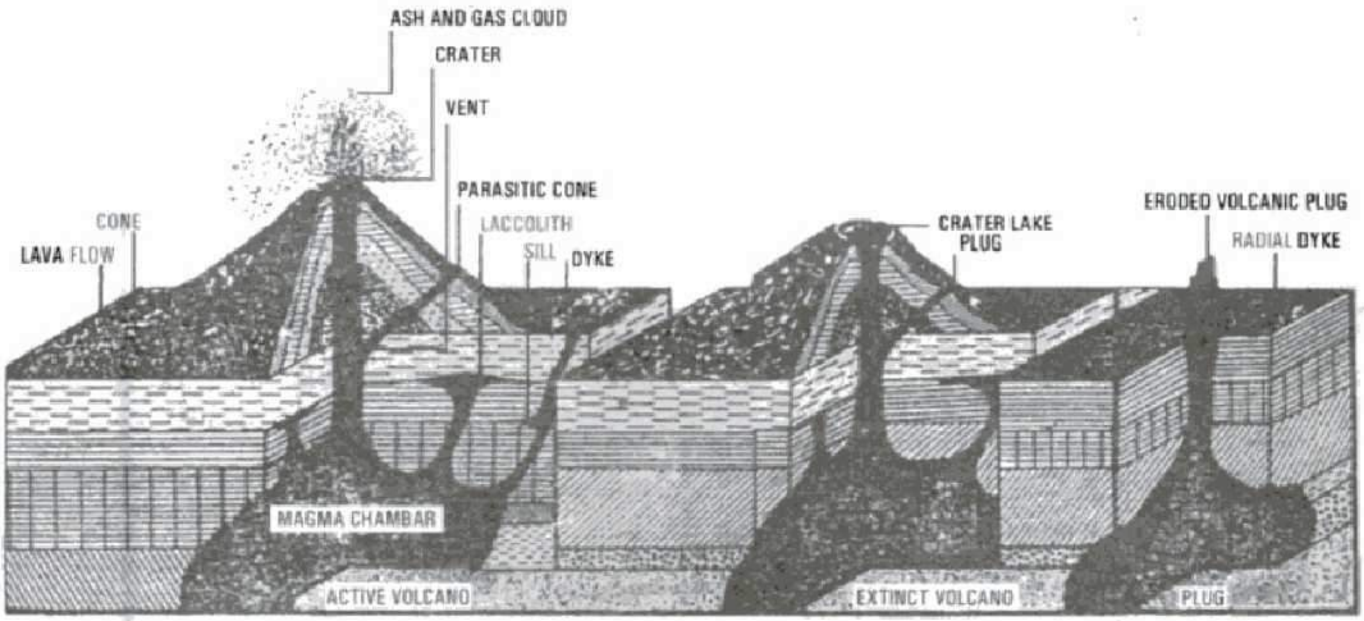


Fig. 2.24 – Active and extinct volcanoes and their main features (after The Encyclopedia of Earth's Resources, Exeter Books N.Y.)

Table 2.1: *Main active volcanoes of the world.*

	Volcano meters	*Height in*	*Location*	*Country*	*Date of last eruption*
1.	Ojos del Salado	6885	Andes	Argentina-Chile	1981
2.	Guallatiri	6060	Andes	Chile	1960
3.	Cotopaxi	5897	Andes	Ecuador	1975
4.	Tupungatiti	5640	Andes	Chile	1964

5.	Lascar	5641	Andes	Chile	1968
6.	Popocatepeti	5451	Altiplano de Mexico	Mexico	1920
7.	Navado del Ruiz	5400	Andes	Colombia	1985
8.	Sangay	5230	Andes	Ecuador	1976
9.	Klyuchevskaya	4850	Sredinny Khrebet	USSR	1974
10.	Purace	4590	Andes	Colombia	1977
11.	Mauna Loa	4170	Hawaii	USA	1978
12.	Mt.Cameroon	278	Monarch	Cameroon	1959
13.	Fuego	3836	Sierra Madre	Guatemala	1962
14.	Frebus	3795	Ross Island	Antarctica	1975
15.	Semru	3676	Java	Indonesia	1976
16.	Nyiragongo	3470	Virunga	Zaire	1977
17.	Mt. Etna	3308	Sicily	Italy	1979
18.	Agung	3142	Bali	Indonesia	1964
19.	Surtsey	173	S.E. Iceland	Iceland	1963
20.	Ana	155	Karakotoa	Indonesia	1929
21.	Mt. Unzen	-	Honshu	Japan	1991
22.	Mt. Mayon	-	Philipines	Philipines	1991, 1993
23.	Mt.Eyjafjoell tavel standstill in Europe	Brought air	Iceland	Iceland	17.04.2010

Earthquakes

Earthquakes are vibrations of the Earth, caused by the rupture and sudden movement of rocks that have been strained beyond their elastic limits. In other words, earthquake is a series of shocks and tremors resulting from the sudden release of pressure along active faults and in areas of volcanic activity. Earthquake magnitude is estimated by the Richter Scale, while intensity of the earthquake is described by the Mercalli Scale. The Richter Scale is open ended and logarithmic, i.e. each whole number on the scale represents a 10-fold increase in the measured wave amplitude. Translated into energy, each whole number demonstrates a 31.5-fold increase in the amount of energy released. The waves of the earthquakes are measured on ***seismograph***. About 507,150 earthquakes are recorded annually out of which 50,000 are felt and one leads to total destruction.

Focus

The point of origin of an earthquake is known as focus.

Epicenter

The point of the Earth's surface which is directly above the focus of an earthquake is known as epicenter.

Causes of Earthquakes

The main causes of earthquakes are as under:

(i) Plate Tectonics

The Earth's crust is made up of seven major and several minor plates, which fit closely together. The positions of the plates are not static. They are constantly moving relative to one another. The type of movement between plates affects the way in which they alter the structure of the Earth. The oldest parts of the plate, known as shields are the least susceptible to earthquakes. Most of the earthquakes occur along the boundaries of the major and minor plates.

(ii) Volcanic Eruption

Volcanic eruption is one of the main causes of earthquakes. Volcanic earthquakes are caused by plates movements, gas explosion, the up-doming, fracture of rocks and fissuring of volcanic structures. Such earthquakes occur either simultaneously with eruption or more commonly in the period preceding an eruption.

(iii) Folding and Faulting (compression and fracture of rocks)

Folding of rocks due to compressional forces lead to earthquakes. Fault is the fractured surface in the Earth's crust along which rocks have travelled relative to each other. It is a surface along which a rock body has broken and been displaced. Earthquakes occur when movement of Earth takes place along a line of fracture called a fault. The San Andreas Fault of California is a typical example which led to earthquakes at Los Angles in 1906. The massive earthquakes of March 11, 2011 in Japan was the result of subduction of the Pacific plate underneath Japan (N. Honshu) at Japan Trench and dips to the west beneath the Eurasian plate. According to Italy's Institute of Geophysics and Volcanology, the earthquake shifted the Earth's axis by 25 cm which would have led to a shortening of the 24-hour day by 1.8 microseconds.

(iv) Anthropogenic

Human over-interaction with nature is also one of the main causes of earthquakes. The extraction of minerals, deep underground mining, blasting of rocks by dynamites for construction of roads, dams and reservoirs, nuclear explosions, etc. lead to the occurrence of earthquakes of various intensity and magnitude. The Koyna earthquake of 1967 in Satara district of Maharashtra was mainly due to Koyna Reservoir constructed in 1962. There have been earthquakes due to the construction of Hoover Dam (1935), Mangla Dam (Pakistan), Kariba Dam (Zambia), Manuic Dam (Canada), Kurobe Dam (Japan), Nourek Dam (Russia) and Marathon Dam earthquake-1931 (Greece). Some of the largest killer earthquakes have been plotted in **Fig. 2.25**.

Table 2.2: *Some of the important earthquakes of the world.*

Year	*Date*	*Location*	*Deaths*	*Magnitude*
1556	Jan.23	Shenshi, China	830,000	-
1737	Oct.11	Kolkata, India	300,000	-
1923	Sept.1	Kwanto, Japan	143,000	8.2
1939	Dec.27	Erzican, Turkey	40,000	8.6
1970	May 31	Northern Peru	66,000	7.8
1976	July 288	Tangshan, China	250,000	7.6
1978	Sept. 16	Iran	25,000	7.7
2004	Jan.26	Banda Aceh, Sumatra, Indonesia	> 200,000	8.5
2011	March, 11	Tohoku, Japan	>25,000	9.0

Source: 1. *Christopherson, R.W., 1995,* **Elemental Geosystem – A Foundation in Physical Geography,** *Prentice Hall, Englewood Cliffs, New Jersey-07632, p. 298.*

2. *Frontline, Vol-28, N.7, March 26, 2011, pp.8-14.*

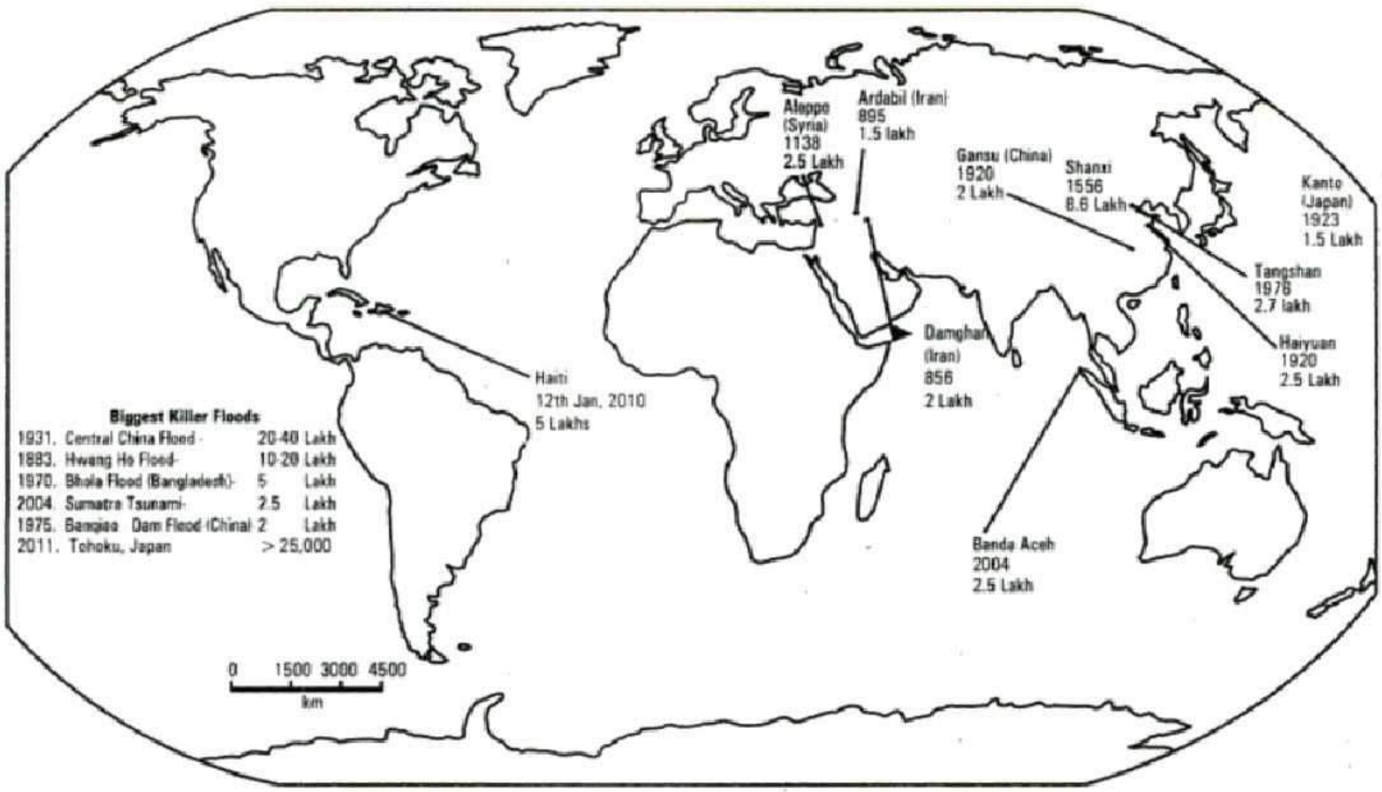


Fig. 2.25 – Largest killer earthquakes (Epicentres, Years and Casualties)

Earthquake Zones of India

In India, most of the earthquakes occur in the Himalayan belt. The young folded Himalayan belt is a marked region of instability which is characterised with several thrust planes. The Indo-Gangetic alluvial track, the Rann of Kachchh are also highly vulnerable to earthquakes. The peninsular part is considered to be a more stable block. Occasionally, some earthquakes are felt along the margins. The Koyna earthquake of 1967 and the Latur earthquake of 1993 show that the peninsular India is also not a earthquake free zone of the country. The earthquake zones of India have been shown in **Fig. 2.26**.

Consequences of Earthquakes

Throughout the human history, earthquakes have done great damage to human lives and property. The major consequences of earthquakes are: (i) deformation of ground surface, (ii) loss of human life and livestock, (iii) damage and destruction of human establishments, structures, buildings, railway-lines, roads, bridges, dams, villages, towns and cities, (iv) tsunamis (seismic sea-waves), (v) rise and subsidence of ground surface, (vi) devastating fires, flash-floods, landslides, changes in the underground water level, and 'meltdown' of civil nuclear reactors like the Fukushima Daiichi plant in Japan, (March, 2011). This earthquake shifted the Honshu island by 2.4 metres.

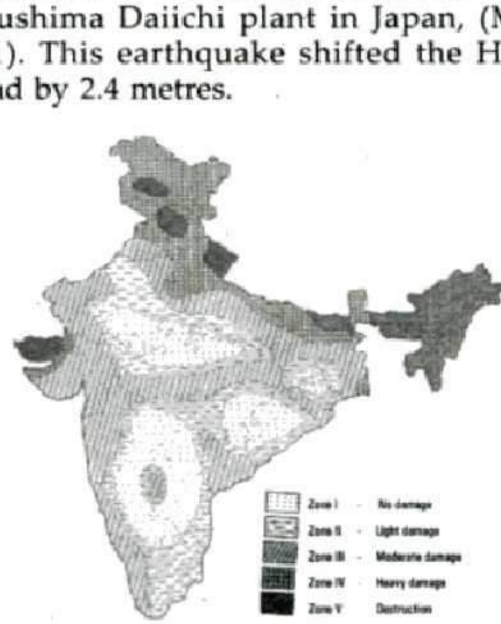


Fig. 2.26 – India – Earthquake prone zones

Earthquake Forecasting

Till date scientific prediction about earthquakes has not been possible. Therefore, implementation of an action plan to reduce deaths, injuries, and property damage from earthquakes is very difficult. The political environment adds complexity; sadly, the impact of an accurate earthquake prediction may be viewed as a negative threat to a region's economy. For example, if the seismologists examine the potential socio-economic impact of earthquake prediction on an urban community, it is difficult to imagine a chamber of commerce, bank, real-estate agent, tax assessor, or politician who would privately welcome such prediction.

The Chinese, on the basis of seismographic studies on animal behaviour, made fairly accurate predictions about the Haicheng (China) earthquake in 1975. The Chinese seismologists provided a list of indicatives of animal behaviour. Before the earthquake of Haicheng e.g. cattle refusing to enter houses, corals and ducks refusing to enter water, snakes coming out of hibernation and fish jumping out of water. Chicken, mules, goldfish, mice, all showed unusual behaviour just before the earthquake. The water of the wells rose by more than one meter, the dogs started barking and running for shelter inside the house, while, the livestock was restless. On the basis of these indicators, a reliable prediction was made and thus, lives of thousands of people was saved. The very next year in1976, the Tangshan earthquake could not be predicted in which more than 2.5 lakh people lost their lives. Despite animals behaviour, precise, scientific predictions about earthquakes is still a remote possibility.

Denudation

The combined action of all of the processes that cause the wearing away and lowering of the land, including weathering, mass wasting, and work of agents of erosion (running water, wind, glaciers, sea-waves and underground water) is known as denudation.

Weathering

The processes by which rocks are chemically decomposed or physically disintegrated into fragments as a result of exposure to atmospheric agents and the pressures and temperatures at or near the Earth's surface, with little or no transportation of the loosened or altered materials. Weathering is a process that affects rocks *in-situ* in which no transportation is involved. Thus, weathering is essentially the break-down of rocks due to physical (mechanical) and chemical processes at their places.

Weathering is a critical base to our ecology, and our existence depends on it. Weathering produces soil on which agriculture depends. Sand gravel, and clay deposits are produced by weathering. Practically all aluminium ore, tin, and some copper ore are formed and concentrated by weathering.

The weathering of a rock is influenced by a number of factors, such as: (i) rock structure and hardness, (ii) climate, (iii) topography and slope, (iv) type of natural vegetation, (v) time, and (vi) land use by man **(Fig. 2.27)**.

Weathering may be classified under the following three categories:

(i) Physical or mechanical weathering
(ii) Chemical weathering, and
(iii) Biological or organic weathering

(i) Physical Weathering

Physical weathering is also known as mechanical weathering. When rock is broken *in-situ* and disintegrated without any chemical change, the process is called as physical weathering. For example, the break up of massive rock (bed-rock) into small particles through the action of frost or /and change in temperature – leading to expansion and contraction of rocks, salt crystals, crystallisation, hydration, and the action of plant roots penetration into cracks in rocks. The physical weathering is mainly found in the higher latitudes and higher altitudes **(Fig. 2.28)**.

Frost action

Water expands as much as 9 % of its volume as it freezes. This expansion creates a powerful mechanical force called frost action or freeze-thaw action. Frost actions are important in humid micro-thermal climates, and in sub-arctic, polar and high altitudinal climates.

Crystallisation

Crystallisation is a phenomenon in the arid and semi-arid climates. Dry weather draws moisture to the surface of rocks. As the water evaporates, crystals form from dissolved minerals. As the process continues over time and the crystal grow and enlarge, they exert a force great enough to spread part individual mineral grains and begin breaking up the rock.

Hydration

This is a physical weathering process. Hydration is a process involving water, although not involving any chemical change; water is added to a mineral, which initiates swelling and stress within the rock, mechanically forcing grains apart as the constituents expand.

Exfoliation

Exfoliation is a physical weathering process by which concentric shells, slabs, sheets, or flakes are successively broken loose and stripped away from a rock mass. This is also known as *onion weathering*. Exfoliation process creates arch-shaped and dome-shaped features on the exposed landscape, forming an exfoliation dome **(Fig. 2.28)**.

(ii) Chemical weathering

Chemical weathering is brought about by the action of substances dissolved in rain-water. They are usually acidic in character and leach rock quite actively. In general chemical weathering is more important than physical weathering. This is particularly so in the hot and humid climates of the equatorial, monsoon and other sub-tropical wet regions. The chemical weathering is more pronounced in the regions of *karst* topography and limestone regions. The main processes of chemical weathering are: oxidation, carbonation, solution, and hydrolysis.

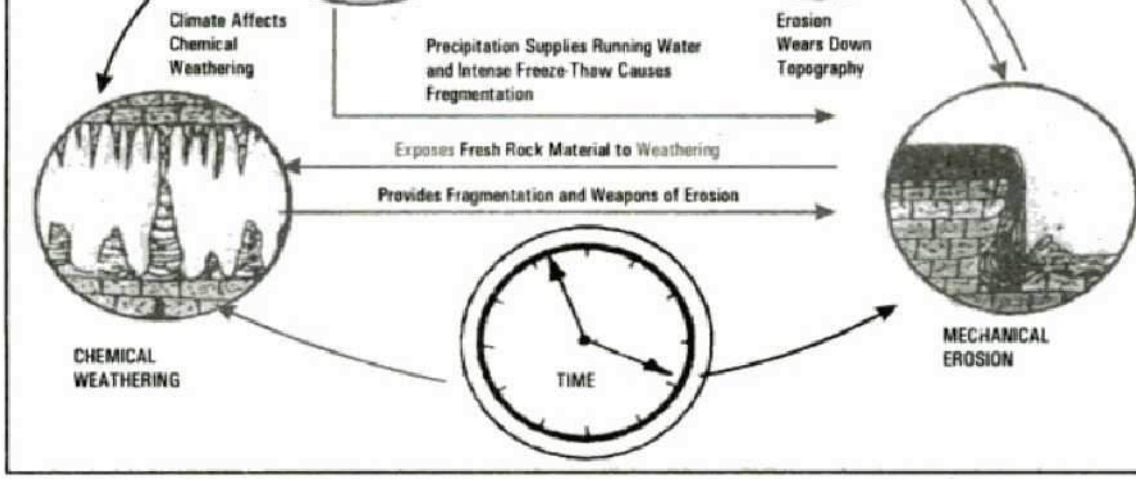


Fig. 2.27 – Major determinants of Weathering (after A.H.Strahler)

Oxidation

Chemical combination of oxygen with another substance is known as oxidation. The most familiar is the *'rusting'* of iron-ore in rocks or soil that produces a reddish-brown stain of oxide. Thus, the iron bearing rocks become weak by the process of oxidation.

Carbonation

This is a process of chemical weathering by a weak carbonic acid (water and carbon dioxide) that reacts with many minerals, especially limestone containing calcium, magnesium, potassium, and sodium transforming them into carbonates.

Hydrolysis

When minerals chemically combine with water, the process is called hydrolysis.

Solution

The change of limestone from the solid state to the liquid state by combination with water is known as solution.

Biological or Organic Weathering

It is the disintegration or destruction of a rock by living organisms or organic processes. It is a much neglected cause of weathering. For example, algae, mosses, lichen and other vegetations retain water on the surface of the rock, and various organic acids help to decay the rock beneath, so that a tuft of moss may lie in a small and growing hollow in the rock. The presence of vegetation increases the acid content of the soil water, which helps in the chemical disintegration of calcarious rocks. The water containing bacteria can help the composition of some rocks, particularly limestone. The mechanical disintegration effect of vegetation is mainly due to the penetrating and expanding of roots.

Various forms of life, such as worms, rabbits and moles also disintegrate rocks. Worms bring large quantities of fine material to the surface in the form of casts, while borrowing animals help to loosen the surface material.

Erosion

Denudation by running water, wind, ice (glacier), underground water and sea-waves is known as erosion. In other words, the processes that loosen sediment and move it from one place to another on the Earth's surface is known as erosion. Running water, as stated above, is the most powerful land forming agent. The action of running water known as fluvial action can be observed everywhere on the Earth's surface.

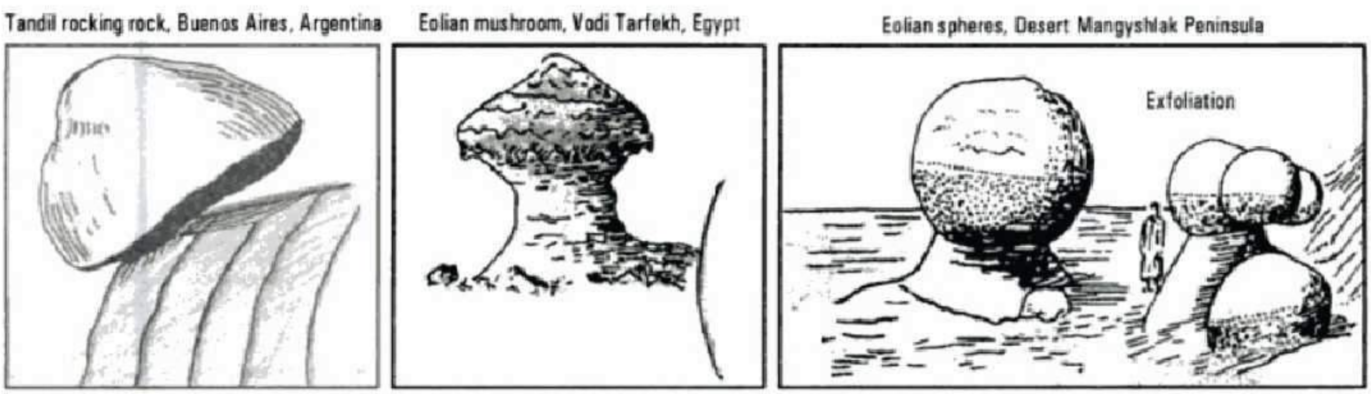


Fig. 2.28 – Physical weathering

Fluvial Processes (Rivers and Related Landform)

Rivers have often been described as the life blood of the Earth. They redistribute mineral nutrients which are important for soil formation and plant growth and serve society in many ways. Rivers provide essential water supplies for domestic, agricultural, industrial use and transport. Rivers have been of fundamental importance throughout human history. A brief account of the river action and the consequent landforms have been given in the following.

Running water (river) by far is the most important agent of erosion. Other agents of erosion such as glaciers, wind, underground-water and sea-waves are locally dominant which affect limited parts of the Earth's surface.

River System

A river system is a network of connecting channels through which water of rainfall is collected and carried to the ocean **(Fig. 2.29).** A river system may be divided into three parts: (i) collection system, (ii) transport system, and (iii) depositional or dispersing system **(Fig. 2.30).**

The erosion capacity of a river depends on (a) discharge, (b) velocity, (c) gradient slope, (d) sediment load, and (e) base level.

The main functions of a river are: (i) removing of regolith (weathered material), (ii) down cutting, (iii) headward cutting (erosion), and (iv) deposition.

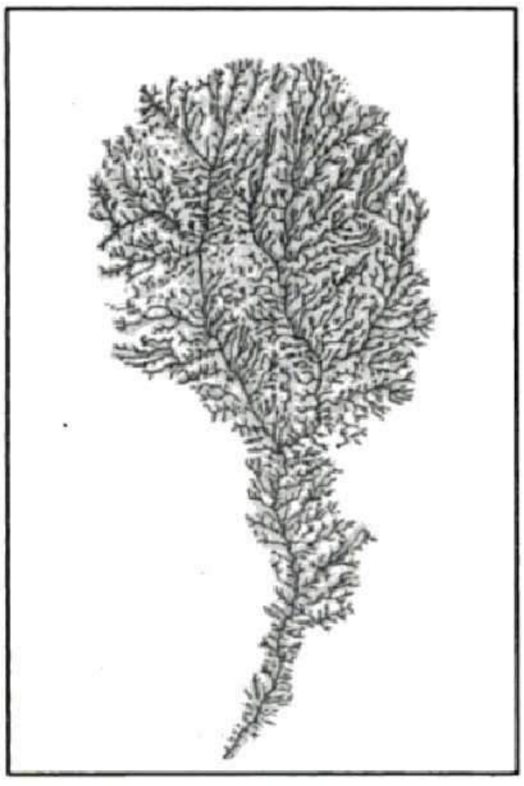


Fig. 2.29. – A river system is highly complex (after W.K. Hamblin *et. al.*)

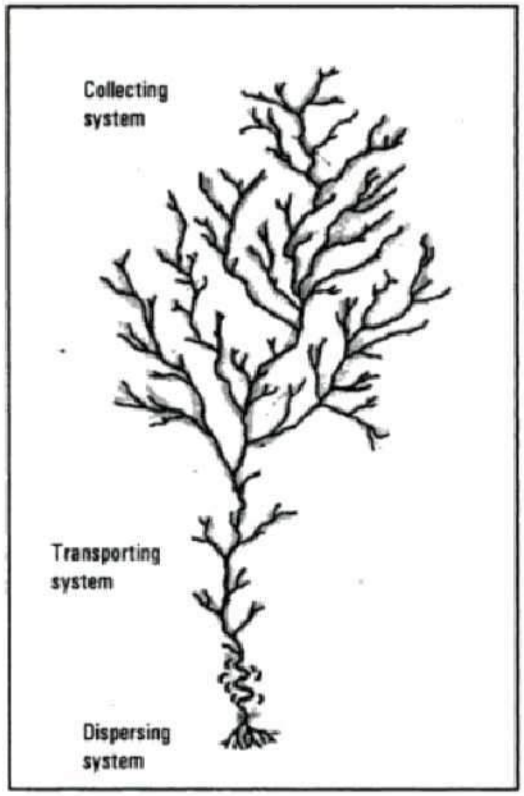


Fig. 2.30 – Major parts of a river system (after W.K.Hamblin, *et.al.*)

Erosion by Running Water

Running water erodes the rocks either by chemical or mechanical method. Some of the rocks (limestone, gypsum, etc.) over which the water flows, are dissolved in water. This process of dissolution is known as *chemical erosion*. The mechanical erosion is caused by loose solid material carried down by river, in wearing away fragments from its beds and banks. Corrosion of the bed, thereby causing a deepening of the channel is called *vertical erosion*, while corrosion of banks is known as *lateral erosion* **(Fig. 2.31).** Most of the corrosion by a river, however, is due to pebbles, gravels and sand that drives along its banks. Thus in a fluvial process, mechanical erosion is more important than chemical erosion. The rock fragments also collide against one another and in the process get disintegrated into small, smooth, rounded pieces of rock and ultimately into sand and silt. The process by which there is a progressive downstream reduction in size of the materials (load of a river by constant collision) is known as *attrition*.

Stream Transportation

The solid material carried by a stream is the stream load. The running water and all streams carry some dissolved material. Sand, gravel, pebbles, shingles and boulders are carried as the bed-load close to the channel floor by rolling or sliding. Clay and silt are carried by suspension. Some soft rocks are dissolved in water and they are carried in solution. In almost all the streams, *the suspended load is the maximum*. In general, more the velocity of a river, more the load it can transport.

Stream Deposition

Stream deposition is the accumulation of transported particles on the stream bed and flood plains, or on the floor of lake or sea into which the stream empties. As the velocity of a river decreases, it begins to deposit its load of rock fragments, sand and silt. At the time of flood, the river inundates its adjacent areas and deposits sand and silt outside the confines of channel. The maximum deposition takes place in the delta region when the river enters the sea or lake.

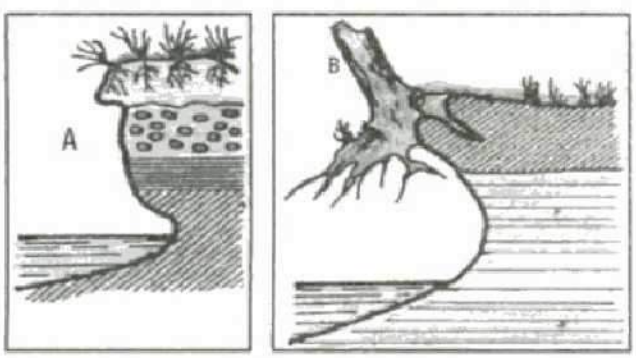


Fig. 2.31 – A. River bank eroded by current. B – Eroded - bank with tree stump and roots

Longitudinal Profile (Long Profile of a River)

The graph representing the relation between altitude and distance along the course of the river known as longitudinal profile. The profile is usually concave upwards, which is graded to the local or regional base level, and may be punctuated by knick-points where the river cuts through former valley floors or river terraces **(Fig. 2.32)**.

Cross Profile (River Channel)

A profile may be surveyed at right-angles to the river flow direction across a river channel or across the valley in which the river channel occurs. Information from contours or topographic maps is often sufficiently detailed to draw valley cross-profile **(Fig. 2.33)**.

Base Level

The lower limit to the operation of sub-aerial erosion processes, usually defined with reference to the role of running water. The level of the sea surface at any moment acts as a general base level for the continents, although there can be a wide range of local base levels, some above and some below sea level. The term was first used by J.W. Powell (1875) who defined it in a very broad fashion to include: first, the concept of the sea as 'a grand base-level, below which the dry lands cannot be eroded'; secondly, the existence of local or temporary base levels 'which are the levels of the beds of the principal streams which carry away the products of erosion; and, finally, as 'an imaginary surface, inclining slightly in all its parts towards the lower end of the principal stream draining the area'. W.M. Davis 1899/1902 considered that the breadth of Powell's definition had led to a variety of practices and confusion. He, therefore, proposed that base level be restricted to 'simply .... the level base with respect to which normal sub-aerial erosion proceeds' **(Fig. 2.34)**.

Base levels can be identified on a number of different scales. A stream channel acts as the base level for processes on the adjacent slope. A major stream is the base level for the courses of its tributaries. A lake or a reservoir or a waterfall is the base level for the entire basin upstream. Clearly, these base levels can and will alter over the time with implications for the operation of sub-aerial erosional processes. By and large, a fall in base level creates an increase in potential energy by increasing the total relief, and may result in an acceleration of rates of erosion and down cutting. A rise in base level, on the other hand, reduces relief and potential energy and its frequency marked by aggradation.

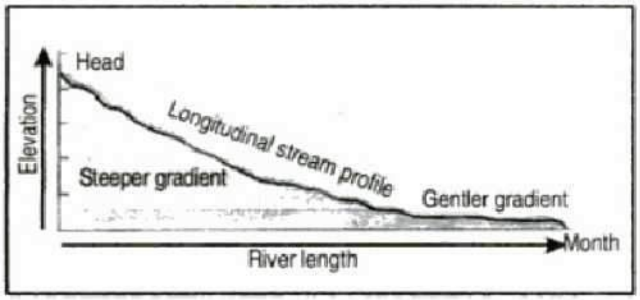


Fig. 2.32 – Iealilsed cross-section of the longitudinal profile of a stream showing its gradient. Upstream segments have a steeper gradient, whereas downstrean the gradient is more gentle

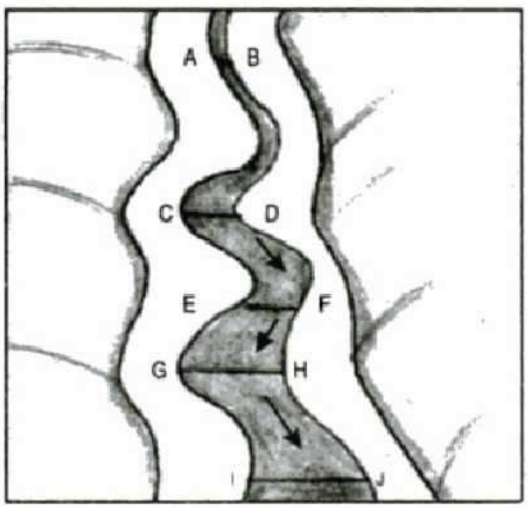


Fig. 2.33 – Cross or transverse profiles

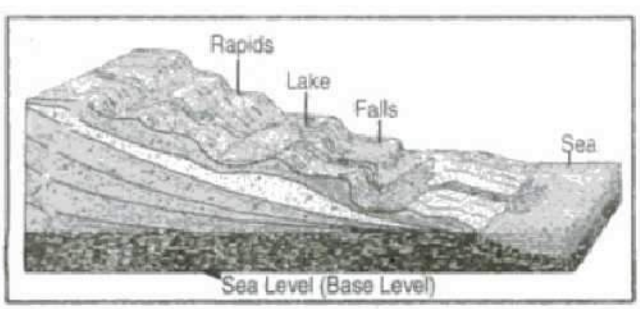


Fig. 2.34 – Base level (after W.M.Davis)

Landforms of Streams

Landforms in the Upper Course

Landforms in the upper coursa include waterfalls, cataracts, rapids, nickpoints, gorges, canyons, convex and concave slopes, river terraces, alluvial-fans (alluvial cones).

Gorge (Canyon)

It is a a deep and narrow section of river valley usually with near vertical rock walls more generally a narrow valley between hills or mountains **(Fig. 2.35)**. The Grand Canyon of the Colorado river in USA is the largest (277 km), widest (18km), and deepest (over one km) gorge in the world.

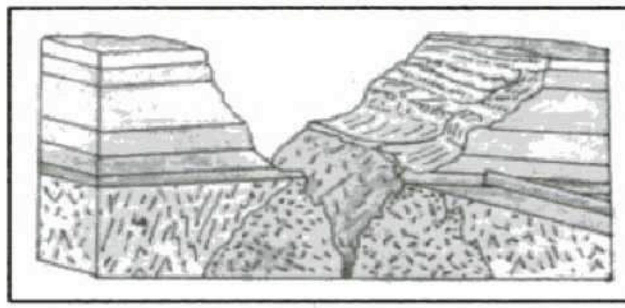


Fig. 2.35 – Gorge (canyon)

Rapids

A steep section in a river channel where the velocity of flow increases and there is extreme turbulence **(Fig. 2.36)**.

River Terrace

It is a nearly a flat area formed at river.level, but now above the river, separated at least by an eroded slope. Such a landform implies that production of a valley floor or alluvial plain, by a phase of deposition or lateral erosion by the river, was followed by a phase of down-cutting. Terraces may be rock-floored or alluvial. The simple alluvial terraces consist of deposits from one phase, but often there are patches of older deposits: just as a terrace may be cut into rock, it may be cut into any previous deposit, fluvial or otherwise. Thus, the age of terrace materials must not be confused with the age of the landform **(Fig. 2.37)**.

Waterfall

It is a stream that falls from a height. Waterfalls are often the sites of greatest concentration of energy dissipation along the course of a stream and have generally been regarded as forming where a soft rock is eroded from beneath a harder rock **(Figs. 2.36 and 2.38)**.

However, in reality, waterfalls have more diverse forms than this simple model would suggest. It is likely that it is applicable only in areas with gently dipping strata. In addition to such structural control, waterfalls depend for their development on such factors as glacial over-deepening, tectonic changes and base-level changes.

Alluvial-fan

A fan-shaped deposit of sediment built by a stream where it merges into a broad valley or plain. Alluvial fans are common in the hilly areas, especially in the arid and semi-arid climates, but are not restricted to them **(Fig. 2.39)**.

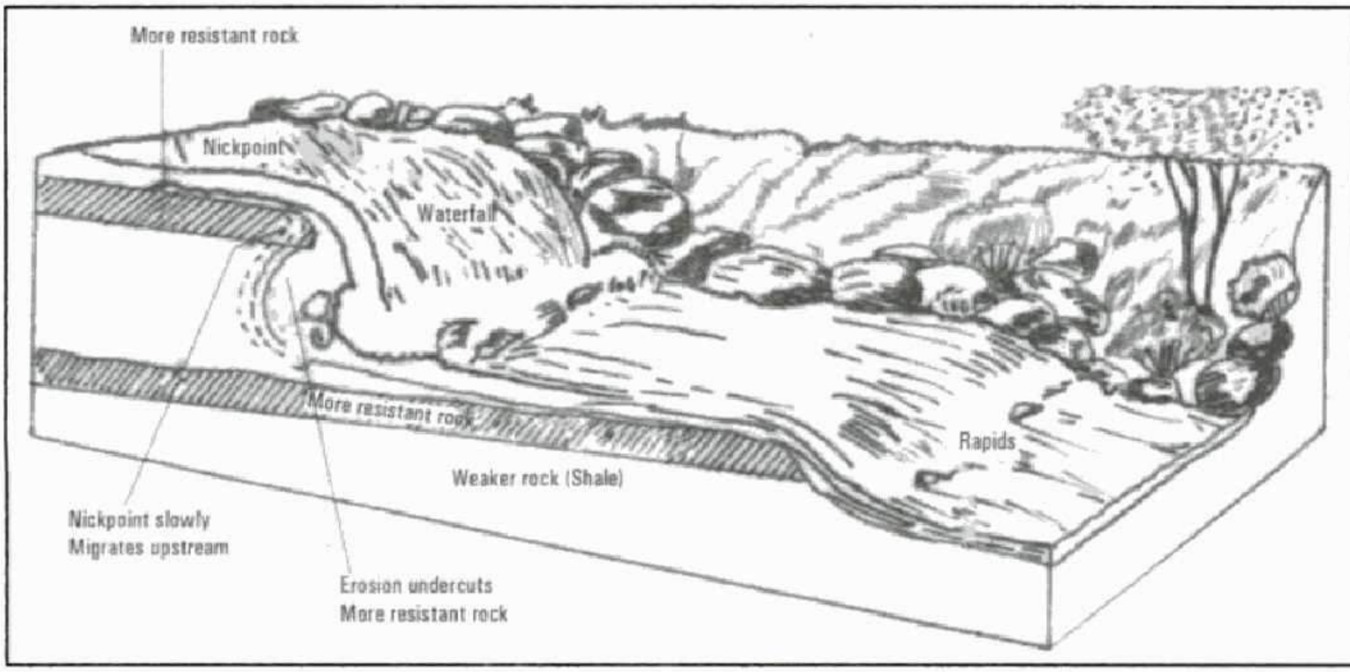


Fig. 2.36 – Rapids and waterfalls

River Capture

River capture or river-piracy occurs where a tributary with a high gradient rapidly erodes headward and captures the tributary of another river **(Fig. 2.40)**.

Landforms of Middle Course

Landforms of middle course include meanders, oxbow-lakes (bill-bong, mort-lake or bayou), natural levees, alluvial fans or alluvial cones, back-swamps, river-terraces *yazoo*-river.

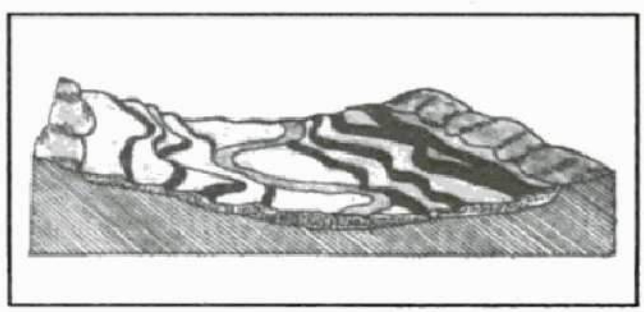


Fig. 2.37 – River terraces (after R.W.Chriastopherson)

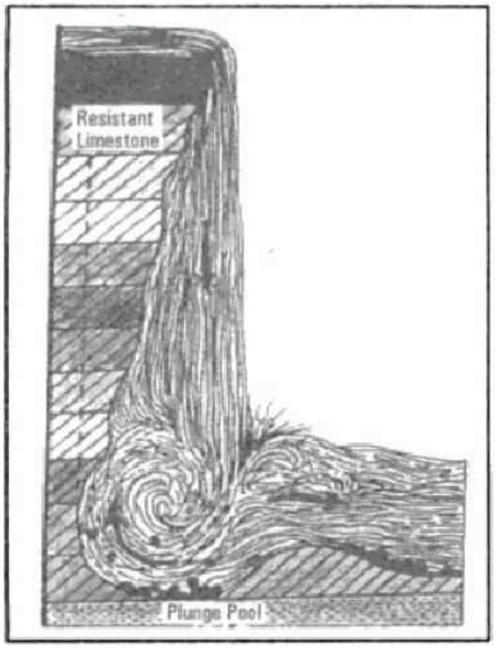


Fig. 2.38 – The Niagra fall

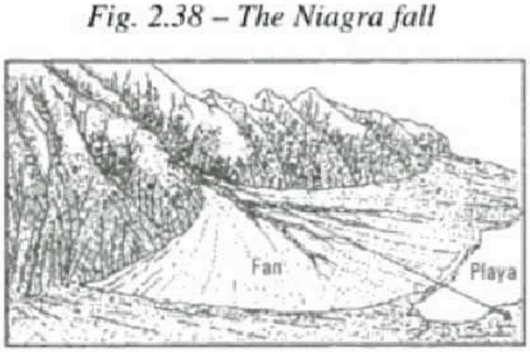


Fig. 2.39 – Alluvial. fan

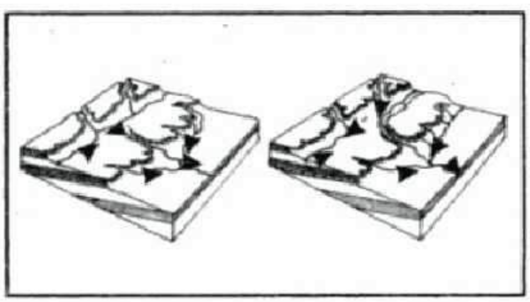


Fig. 2.40 - River capture

Flood Plain

Flood-plain is a geomorphological term for a relatively flat alluvial landform, constructed largely by the flow regime of present river and subject to flooding. Commonly plains flank a clearly defined river channel, but some occur in valleys without channels, while others form downstream of channels **(Fig. 2.41)**.

Levee

A broad, long-crested ridge running alongside a flood-plain stream or intertidal inlet, composed generally of coarse sand and silt grade suspended sediment deposited by flood waters as they overtop channel banks. The levee may slope gently away from the river and consist of progressively finer sediment as distance from the channel increases. Levees may also be artificially created or raised for flood protection **(Fig. 2.41)**.

Meander

The sinuous winding of a river, as in the *River Meanders* in south-west Turkey. A broad, looping bend in a river **(Fig. 2.42)**.

Ox-bow lake

It is a lake usually curved in plan, occupying a *cut-off* channel reach that has been abandoned. The term may be applied also to an extremely curved active channel meander with only a narrow neck between adjacent reaches or even to the land within such a reach. The term derives from the U-shaped piece of wood fitted around the neck of a harnessed ox. Lakes of this type may become plugged with sediment where they adjoin the channel and then progressively fill in **(Figs. 2.42)**

Landforms of the Lower Valley

Landforms of the lower valley include braided channel, delta, estuary and alluvial deposits.

Braided Channel (Braided River)

A river whose flow passes through a number of interlaced branches that divide and rejoin. The term has been applied both to short reaches where a river splits around an island and to very extensive river networks on valley bottoms or alluvial plains, the whole of which may be criss-crossed by rapidly shifting channels with freshly deposited sediment between them **(Fig. 2.43)**.

Delta

A large roughly triangular body of sediment deposited at the mouth of a river. The different types of deltas have been given in **Fig. 2.44**.

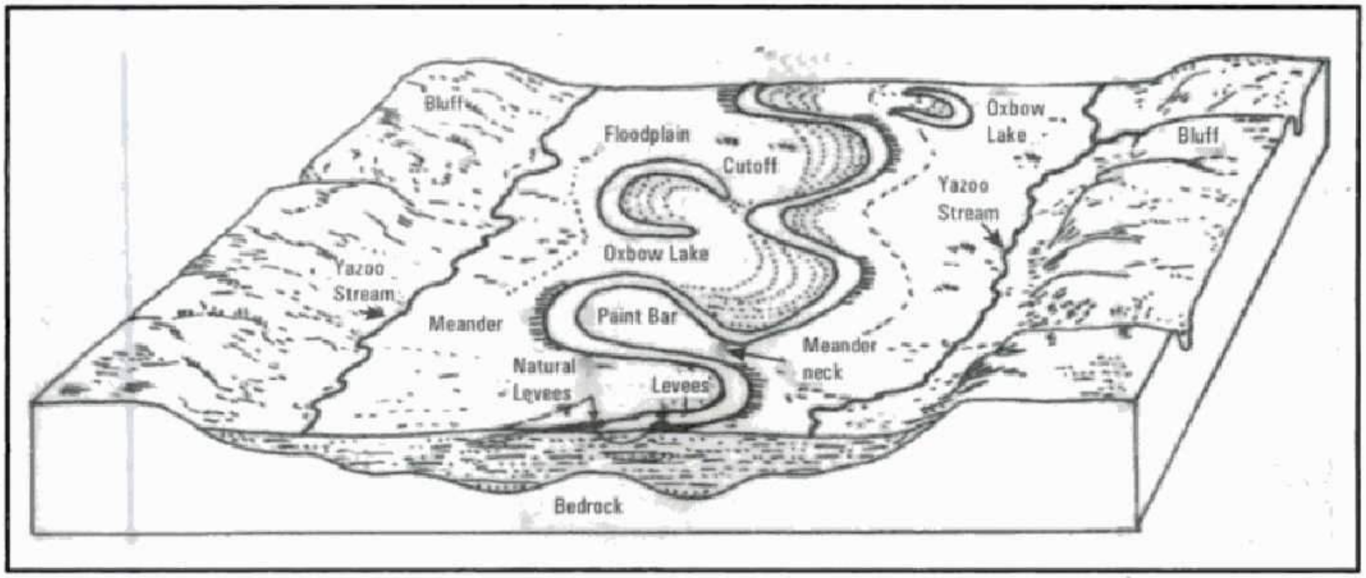


Fig. 2.41 – Major features of floodplain – Meanders, point-bars, ox-bow lakes, natural levees, stream-channels and Yazoo-stream

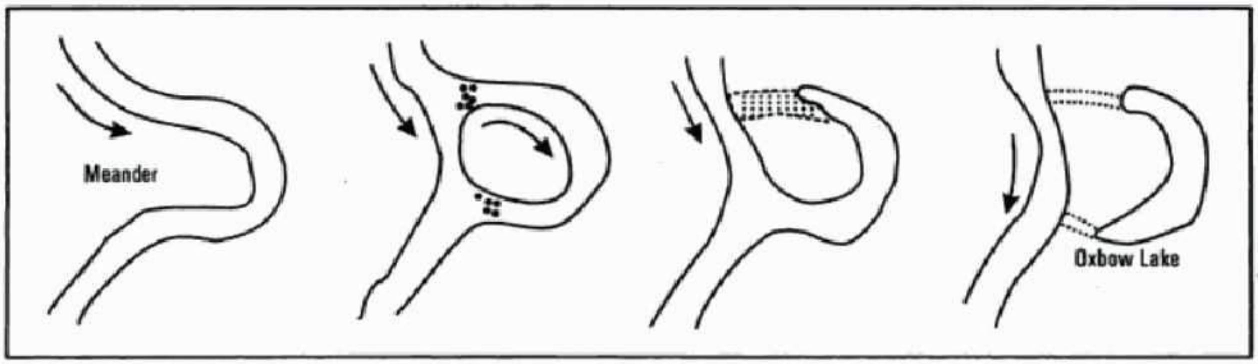


Fig. 2.42 – Transformation of Meander into Ox-bow lake

Estuary

The point at which the mouth of a river enters the sea and seawater are mixed, a place where tides ebb and flow **(Fig. 2.45)**. The Narmada and Tapti rivers make estuaries in the Gulf of Khambat.

Alluvial Deposits

The various types of alluvial deposits are: Colluvial deposits, vertical accretion deposits, lateral accretion deposits, filled channels, alluvial fans, etc. **(Fig. 2.46)**.

(ii) Glaciers and Glacial Landforms

A mass of ice formed from compacted, recrystallised snow that is thick enough to flow plastically is known as a glacier. Glaciers at present cover about 15 million sq km or about 10 per cent of the land area of the Earth. Over 96 per cent of the glacier ice, however, occurs in Antarctica and Greenland in the form of thick masses of ice-sheet. The greatest thickness of ice measured is 4270 metres (Antarctica).

Glaciers are formed due to accumulation of ice above snow-line. The altitude which delimits the lower level of permanent snow is known as snow-line. The snowline varies according to latitudes, altitudes and the degree continentality. A glacial system has been shown in **Fig. 2.47**, while **Fig. 2.48** represents the longitudinal profile of a valley glacier.

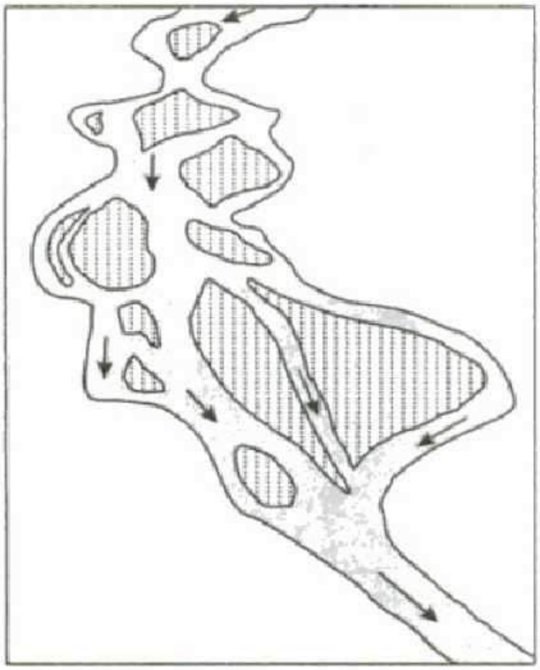


Fig. 2.43. – A braided stream

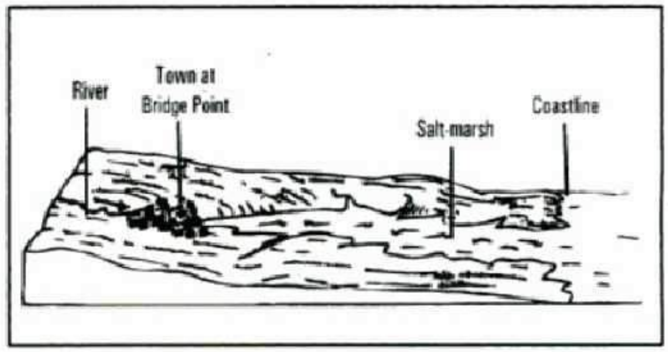


Fig. 2.45 – Estuary

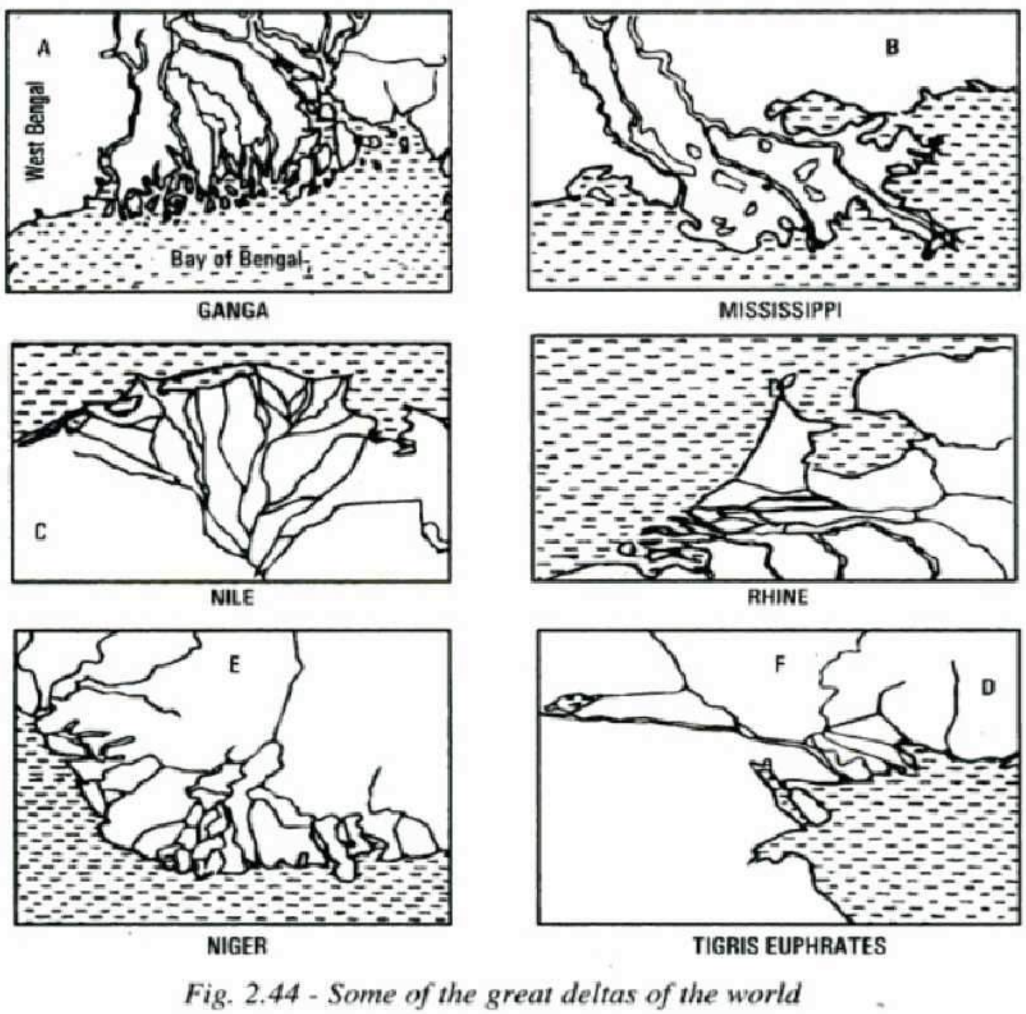


Fig. 2.44 - Some of the great deltas of the world

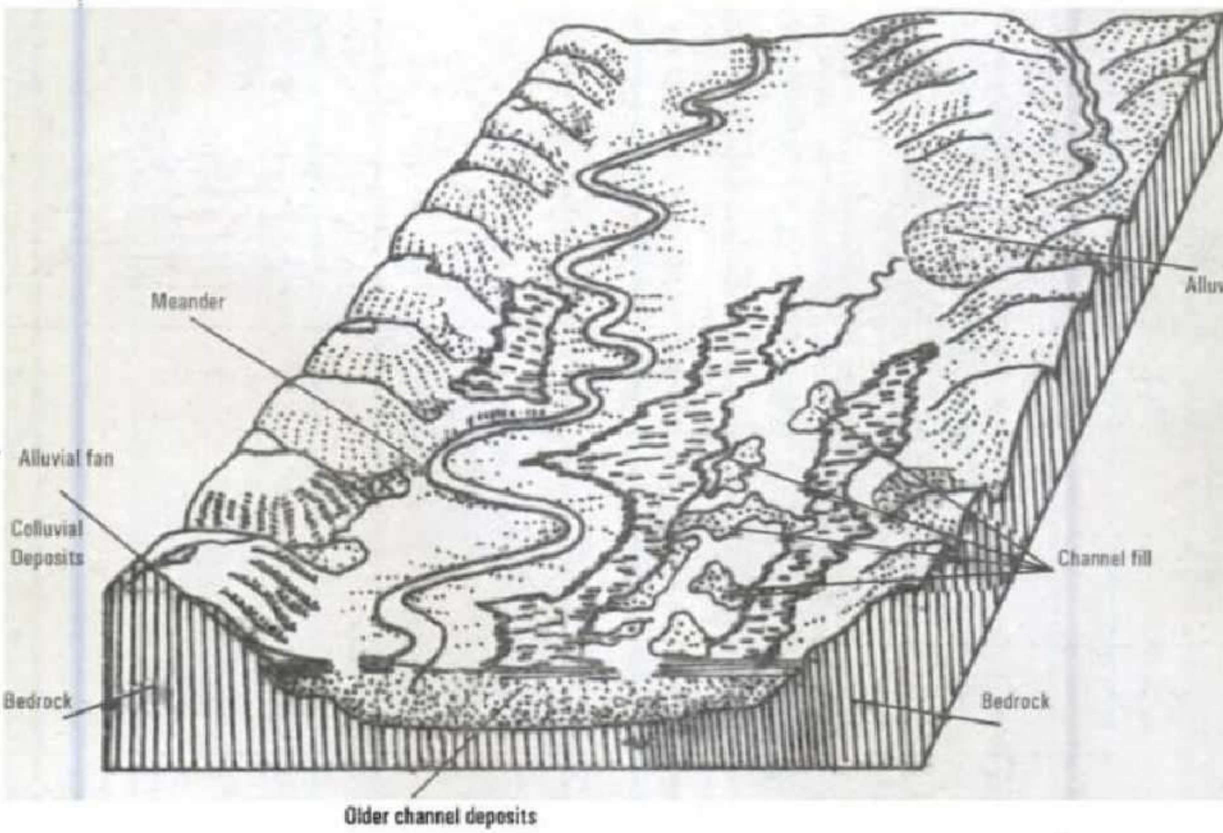


Fig. 2.46 – Types of alluvial deposits

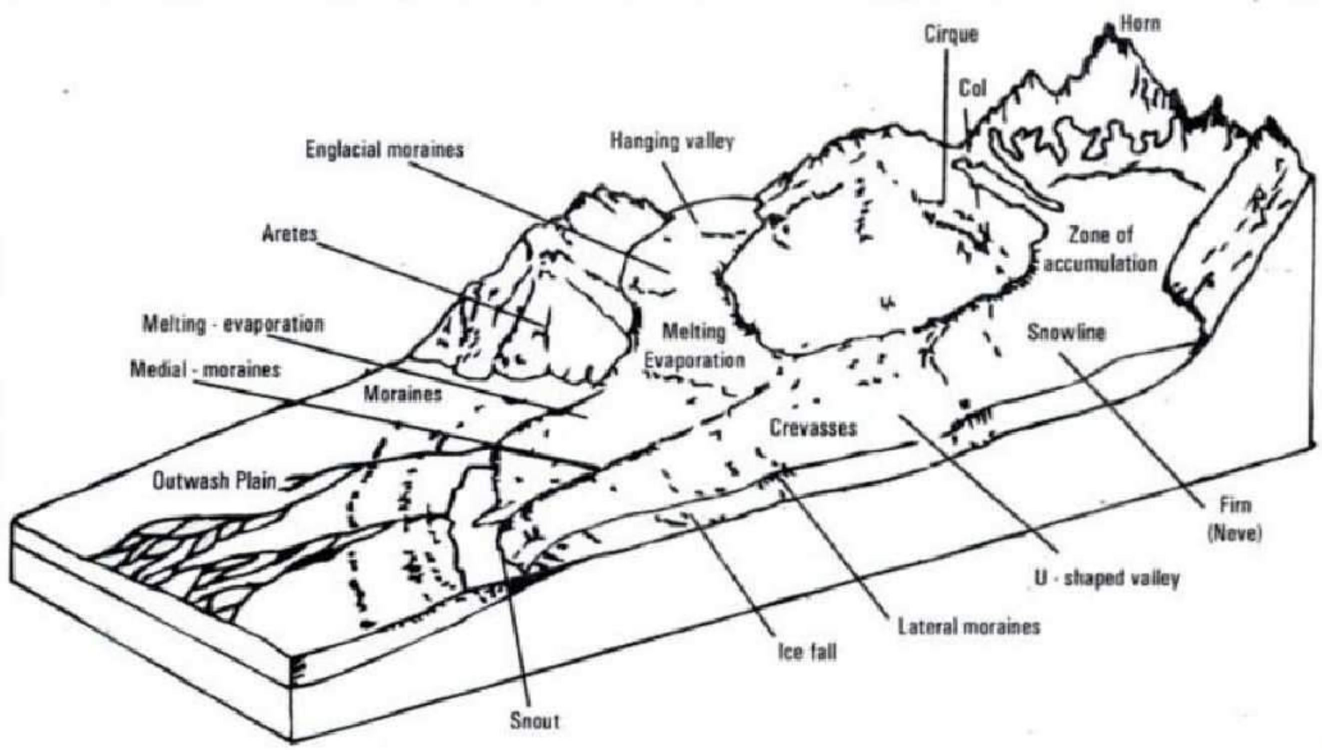


Fig. 2.47 – A glacial system

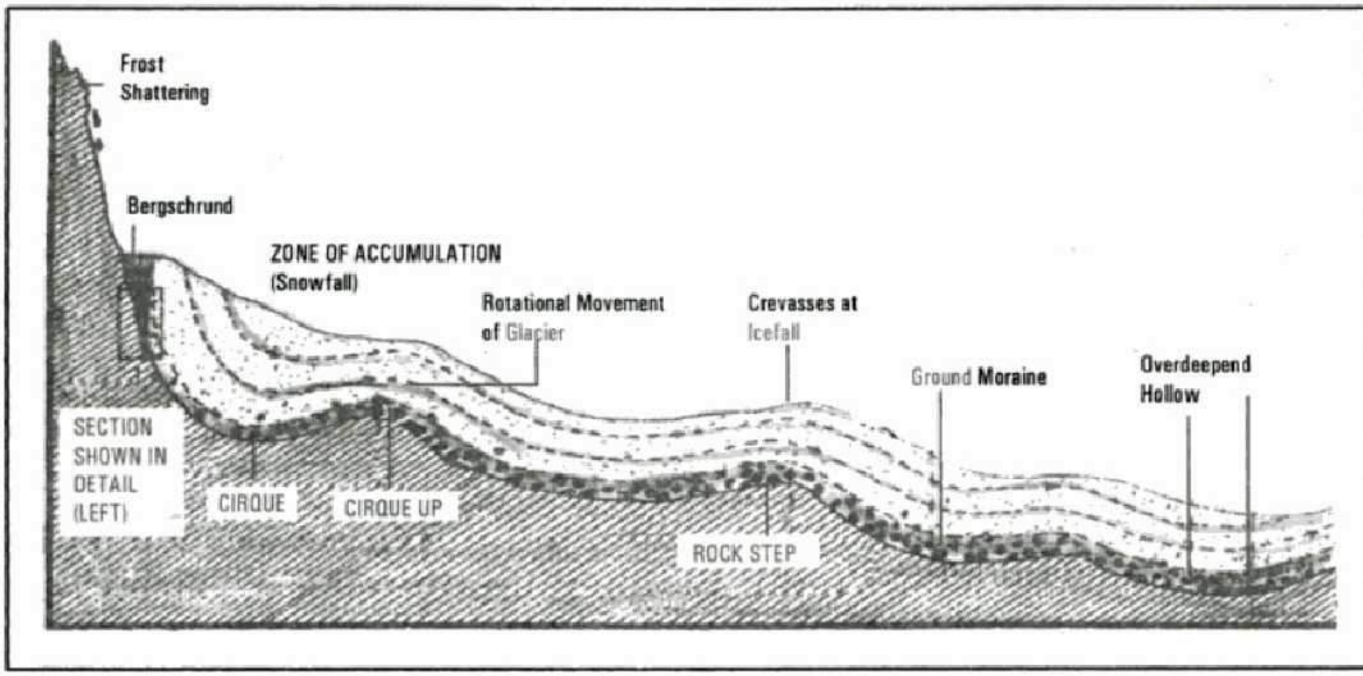


Fig. 2.48 – Longitudinal profile of a glacier

Types of Glaciers

Glaciers, in general, are two types:

Continental glaciers

Ice-sheet is a large continuous layer of land ice of considerable thickness. The average thickness of Antarctic ice-sheet is 2000 m which covers an area of 8 million sq km. The Greenland continental glacier has a thickness of 3000 m at its central dome and sprawls over an area of 1.3 million sq km.

Valley or Mountain Glaciers

Valley glaciers are the characteristic features of the greater mountain ranges of the world. The valley glaciers are mostly confined in the young folded mountains, like the Himalayas, Rockies, Andes, Alps, etc. Some of the important landforms created by the erosion and deposition processes of glaciers are as under:

Erosional Landforms

Cirque (Cwm, Welsh), arêtes, bergschrund, Col, Crag and tail, Fiord, Hanging Valley, Horn, Icefall, Neve, Niche, Nunataks, Pinnacle (Serac), Rochess Moutonnees, U-shaped valley.

- ***Arteries***

  A sharp ridge that separates two adjacent glacial valleys. Arete means'fish-bone' in French. Aretes form sawtooth and serrated ridges in glaciated mountains **(Fig. 2.47)**.

- ***Bergschrund***

  A deep, tensional crevasse formed around the head of a cirque glacier. The crevasse forms as ice falls away downslope. Often a sequence of bergschrunds form **(Fig. 2.48)**.

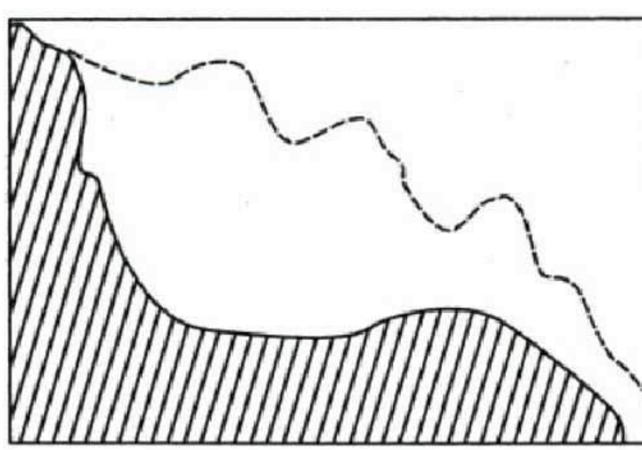


Fig. 2.49 – Longitudinal section of a cirque (corrie)

- ***Cirque (Cwm)***

  An amphitheatre-shaped depression at the head of a glacial valley, excavated mainly by ice-plucking and frost wedging **(Figs. 2.49)**.

- ***Col (Saddle)***

  A pass or saddle between two mountain peaks.

- ***Crag and Tail***

  Landform consisting of a small rock hill and tapering ridge which is produced by selective erosion and deposition beneath an ice-sheet. They range in scale from tens of metres to kilometers in length, with the tail pointing in the down-ice direction. The hill, or crag, is usually of strong rock that has resisted glacial erosion and forms an obstruction to the ice-producing a 'pressure shadow' in its lee **(Fig. 2.50)**.

- ***Firn***

  The term generally applied to snow which has survived a summer melt season and which has not yet become glacier ice.

- ***Fiord or fjord***

  A long, narrow arm of the sea which is the result of the 'drowning' of a glaciated valley. Most fiords, including the fiord coastline of Norway, are located on the west coast of continental masses, and it is thought that this is connected with the westerly winds which prevail in these locations. Fiords are distinctive both because of their great depth, and because of over-deepening of their middle section which are deeper than the water at the mouth **(Fig. 2.51)**.

- ***Hanging Valley***

  A tributary valley whose floor is discordant with the floor of the main valley. Hanging valleys are a hallmark of glacial erosion in mountains.

- ***Horn-glacial***

  A pyramidal peak with three or more distinct faces steepened by glacial undercutting. The classic situation occurs when cirque glaciers encroach on a mountain from all sides.

- ***Icefall***

  A heavily crevassed area of a glacier associated with flow down a steep rock slope. The zone is one of extending flow and is marked by arcuate rotational slumps.

- ***Neve***

  A less widely used term for firn.

- ***Nunataks***

  An inuit-derived word describing a mountain/peak completely surrounded by glacier ice, normally an ice-cap or ice-sheet. In other words, a mountain peak which projects above an ice-sheet. Nunataks are generally angular and jagged due to freeze –thaw and, after the ice has retreated. Contrast with the rounded contours of the glaciated landscape below **(Fig. 2.52)**.

- ***Roche Moutonnee***

  An asymmetric rock bump with one side ice-muddled and the other side steepened and often cliffed, generally recognised as the hall mark of glacial erosion.

- ***Snout (Tung)***

  The terminus of a glacier **(Fig. 2.53)**.

- ***Tarn***

  A small mountain lake created by glacial action.

- ***U-Shaped Valley***

  A glacial valley.

Depositional Landforms

Moraines, terminal moraines, lateral moraines, ground moraines, medial moraines, englacial, drumlins, eskers, kame, outwash plain (*sandar, sandur*) **(Fig. 2.54)**.

- ***Drumlins***

  An oval-shaped mound, largely composed of glacial drift, formed beneath a glacier or

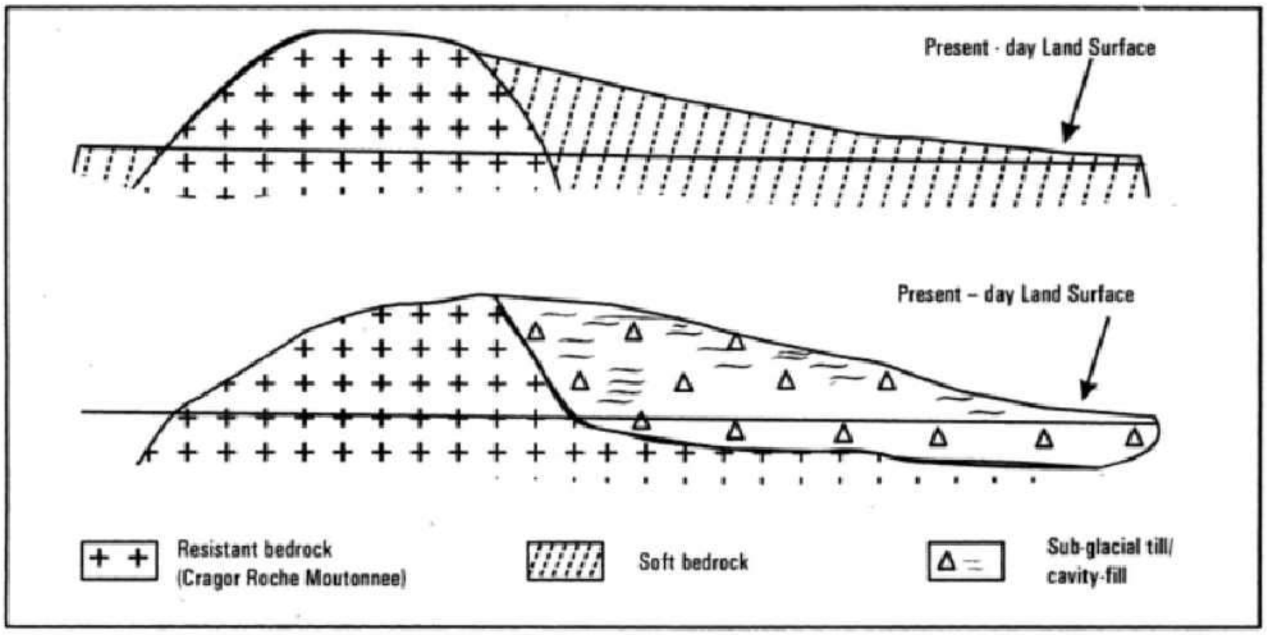


Fig. 2.50 – Crag and tail (Source: Born and Evans 1998)

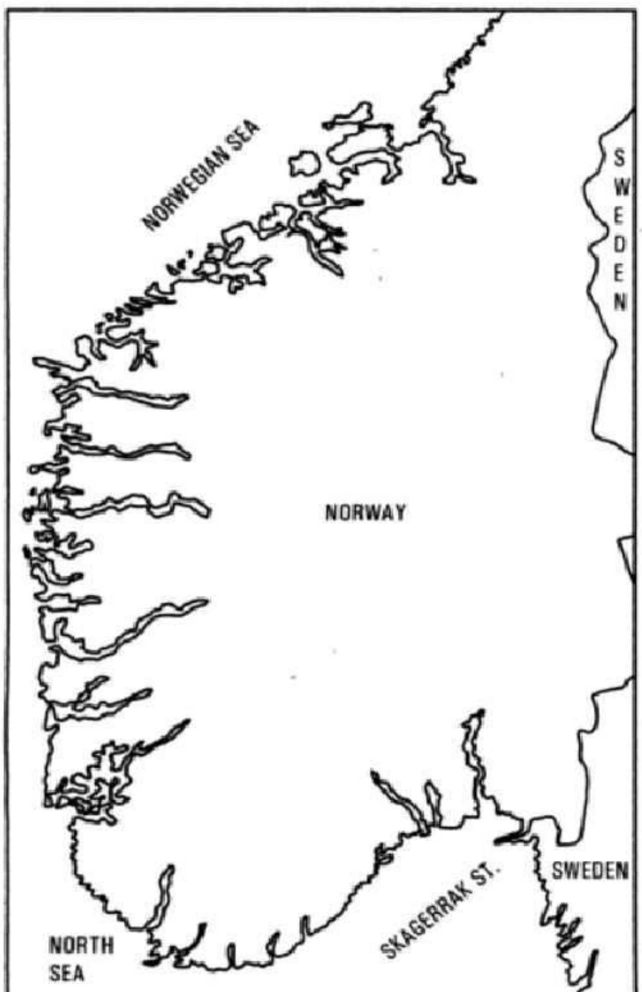


Fig. 2.51 – Fiord/Fjord

ice-sheet and aligned in the direction of ice flow. There are no strict definitions relating to their size but they tend to be up to a kilometer long and 50 metre in relief. They are widespread in Canada, Ireland, Sweden, Norway and Finland **(Fig. 2.54)**.

- ***Esker***

  A sinuous ridge of coarse gravel representing the deposits of a meltwater stream normally flowing subglacially. Eskers may be hundreds of kilometers in length and 100 m in height. Most eskers are the channel deposits of subglacial meltwater rivers and their orientation is usually parallel to that of overall ice flow **(Fig. 2.54)**.

- ***Kame***

  An irregular mound of stratified sediment associated with glaciofluvial activity during ice-stagnation. It is Scottish term for a landform much prized for the variety it adds to golf courses **(Fig. 2.54)**.

- ***Moraines***

  Any landform directly deposited by a glacier or ice sheet. The material which makes up moraines is often partly

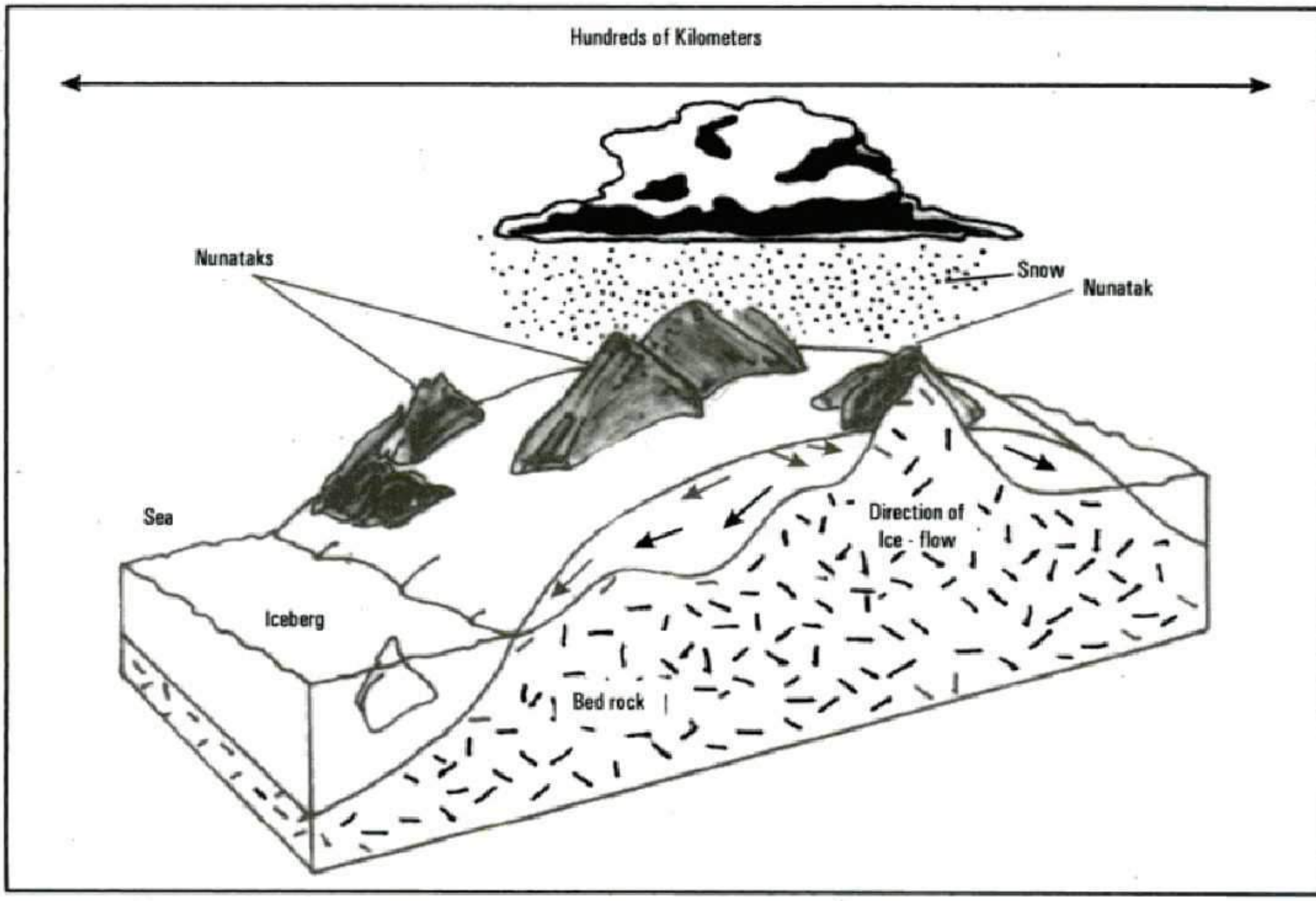


Fig. 2.52 – Ice movement in valley and continental glaciers

stratified, since some may have been formed under water. Moraines may be englacial moraines, ground-moraines, lateral moraines, or terminal moraines.

- ***Outwash Plain***

  It is a glacial plain deposited at or beyond the ice margin. Outwash usually forms fan, valley bottom or plain (*sandur*) deposits, often hundreds of metres thick, built up by aggrading braided melt water channels which migrate laterally across the outwash surface **(Fig. 2.54)**.

- ***Sandur (Sandar or Sandur)***

  An extensive plain of glaciofluvial sands and gravels deposited in front of an ice margin by a system of braided meltwater stream which migrate across the sandur surface.

- ***Till***

  A Scottish word, popularly used to describe a coarse, bouldry soil. It is a sedimentary material deposited directly by the action of a glacier **(Fig. 2.54)**.

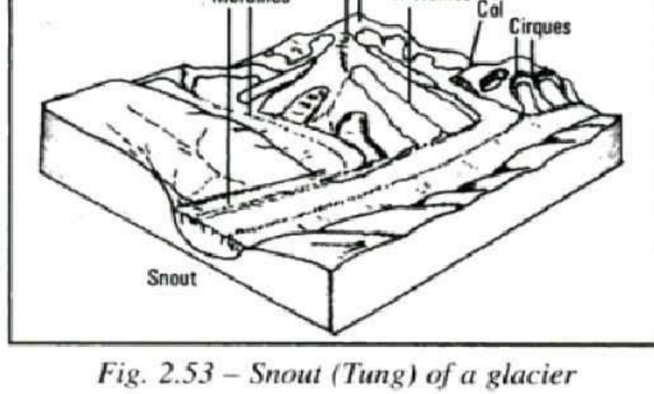


Fig. 2.53 – Snout (Tung) of a glacier

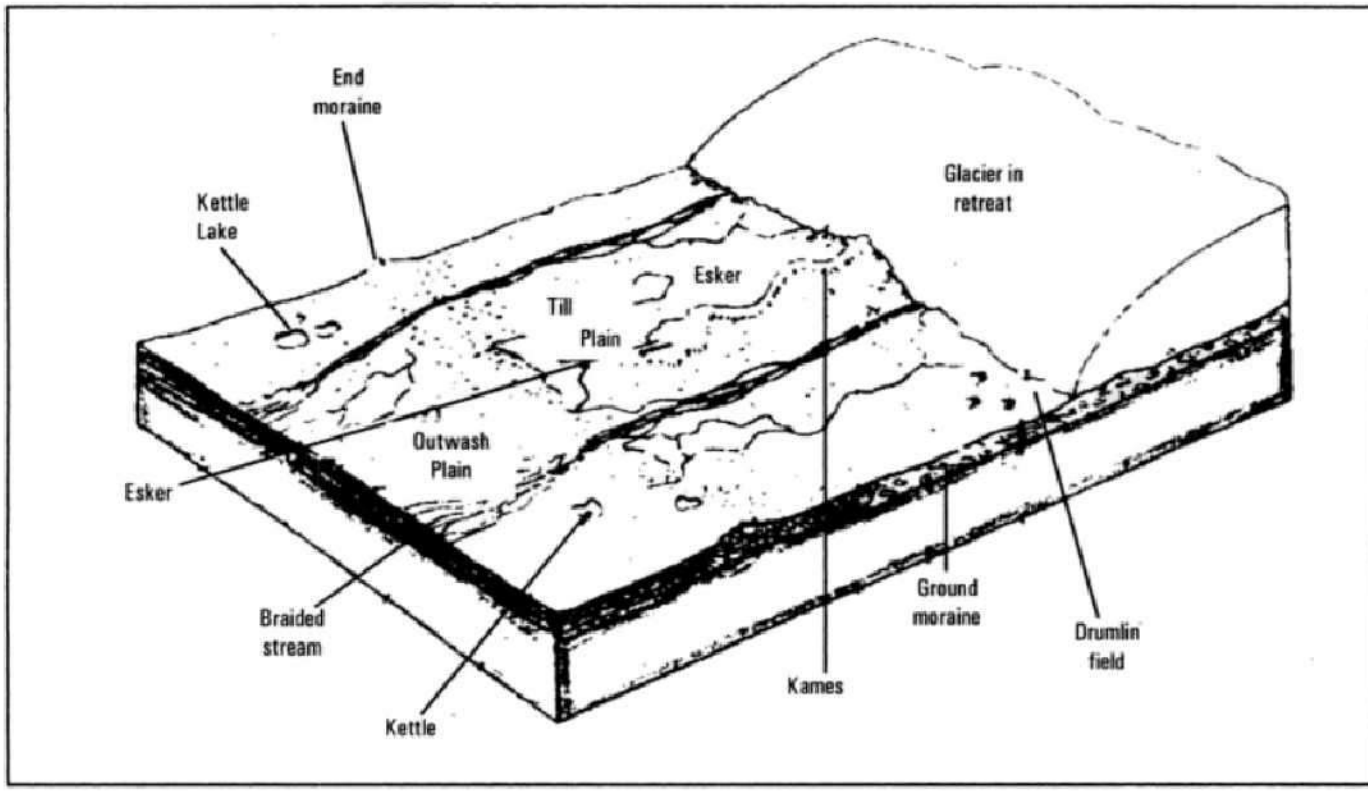


Fig. 2.54 – Glaciers depositional landforms (after Christopherson, R.W., Geogsytems, 1996, p.435)

(iii) Aeolian Landforms (Wind Action)

Aeolian is a term pertaining to the wind; hence wind-borne, wind-blown or wind deposited materials are often referred to as aeolian landforms. Wind as an effective agent in eroding, the landscape, but it can transport loose, unconsolidated fragments of sand and dust. Winds vary considerably in strength from one moment in time to the next and are thus able to lift and transport rock debris for only short period.

Thus, wind is a significant erosion and deposition agent. It is responsible for the formation of great *'seas of sand'* in Arabia, Sahara, Australia, Namibia, Arizona, Patagonia, Kalahari, Thar, Gobi, etc. **(Fig. 2.55).** According to one estimate wind blown dust covers about one-tenth of the land surface. This fact is important because soils from these deposits constitute some of the richest soils of the Earth.

Deserts are among the most inhospitable places on the Earth. Some deserts are scorching hot, others are freezing cold, but they have one thing in common – they are all dry. Very few plant and animal species can survive in these harsh conditions. The world's coldest and driest continent, Antarctica, is a cold desert.

Wind action is quite pronounced in the arid and semi-arid areas of the world where the absence of vegetation cover and presence of extensive desolate rocks help in the erosion, transportation and depositional processes. Apart from the deserts, arid regions, wind action is also quite significant on sandy coasts, outwash plains of glacial areas.

Erosion by Wind

Wind performs erosion through the processes of: (i) attrition, (ii) deflation, and (iii) abrasion.

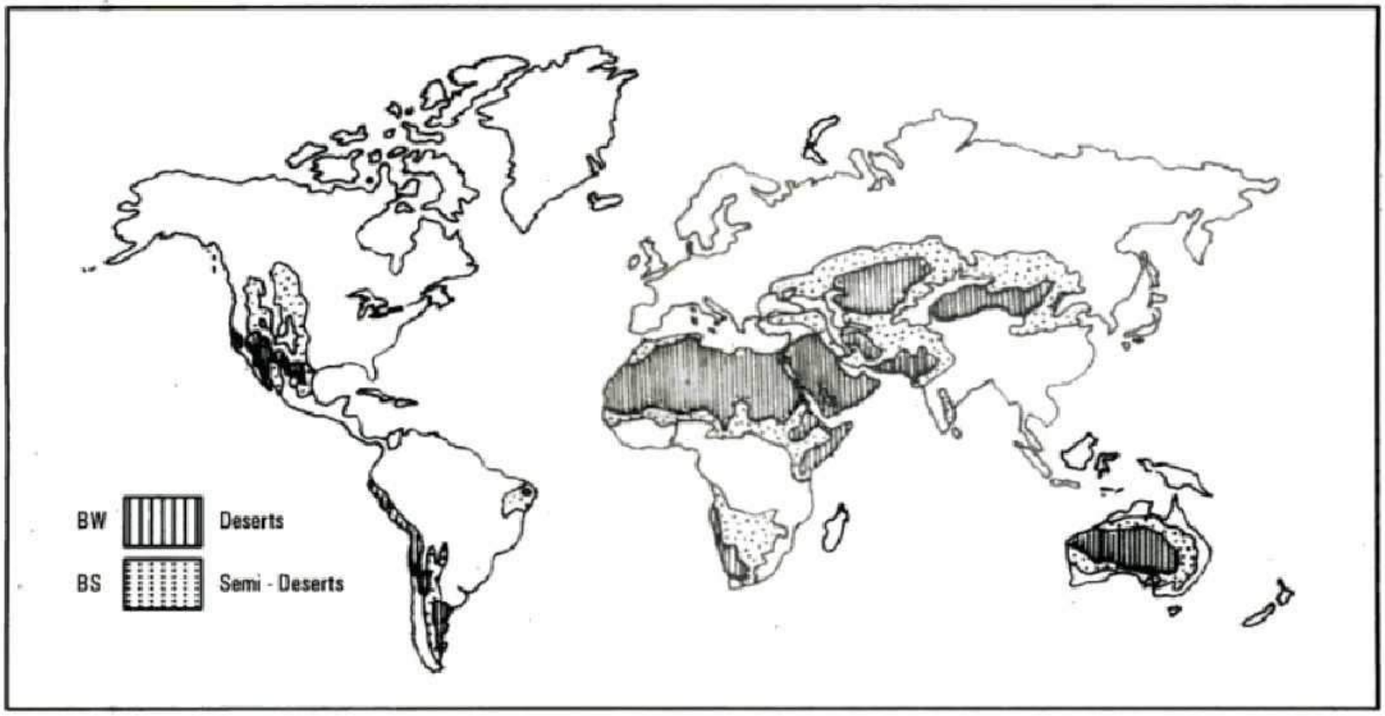


Fig. 2.55 – Deserts and semi-desert regions of the world

(i) Attrition

The mechanism by which the particles size of any material is reduced by friction during transport by an agent of erosion (running water, wind, sea-waves, etc.) is known as attrition.

(ii) Deflation

The process whereby the wind removes fine material from the surface of a beach or a desert. It is a process which contributes to the development of loess, dust storms and some stone pavements.

(iii) Abrasion or Corrasion

The process of wearing down or wearing away by friction as by windborne sand or material frozen into glacial ice.

Transportation by Wind

Wind transports dust, sand and pebbles, etc. in several ways. The fine, light materials are picked up, suspended in the air and carried away. Heavy of large sand-grains are dragged along the surface of the ground. In other words, wind transports sand by the process of saltation and surface creep. Most of the load is carried by wind in suspension. The quantity of material transported by the wind depends upon the size and amount of particles and the velocity of wind. The dust-storms carrying dust at long distances are known as *Haboobs* in Arabic language, especially in Sudan, Egypt. Saudi Arabia and Yemen.

Erosional Landforms by Wind Action

The main erosional features of wind action are : blowouts of deflation basins, bowls and caves, demoiselles, and desert pavements, dreikanter, inselberg, ventifacts, wind-bridges, yardangs, zeugen (mushroom-rock).

Demoiselles

A pillar of Earth or other unconsolidated material that is protected from erosion by a capping boulder **(Fig. 2.56)**.

Desert Pavements

The mountain wash containing pebbles, gravels and sand is exposed to wind. So, the fine material is soon removed, leaving a mosaic of pebbles which has been fittingly called desert pavement.

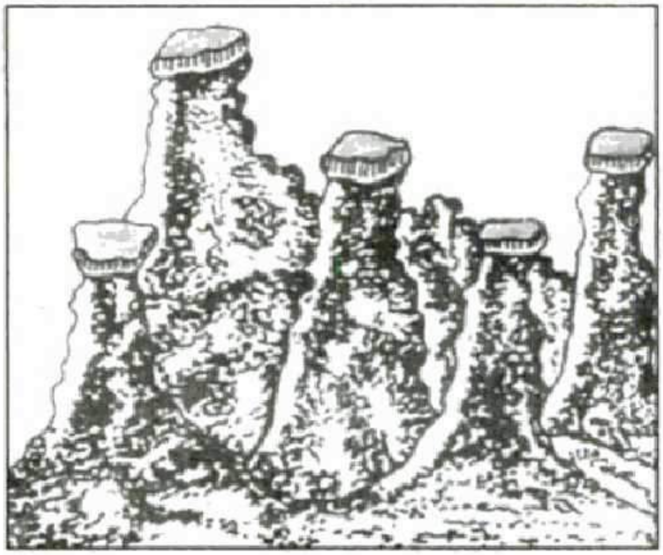


Fig. 2.56 – Demoiselles

Bowls and Caves

Depressions and caves are formed through the combined work of chemical weathering and wind. Usually, they are formed in massive sandstones whose cementing material is calcium carbonate.

Dreikanter

A pebble found on the surface in desert regions; it has three distinct facets on its upper surface as a result of wind abrasion.

Inselbergs

'Inselberg' is a German word (literally, island mountain) that has been widely adopted to describe a prominent steep-sided hill or solid rock, rising abruptly from a plain of low relief. Inselberg in arid regions are also called as '*hornhardts*' The Ulluru (Ayers Rock) in the Northern Territory of Australia is one of the highest inselbergs in the world **(Fig. 2.57)**.

Ventifacts

A stone that has been shaped by the wind, especially in arid areas. Abrasion is achieved by sand, dust and snow, and the stone becomes shaped and have surface textures that may be polished, pitted or fluted. They have some utility for estimating past and present wind directions.

Wind Bridge

The continuous abrasion of a rock by powerful wind results into the formation of holes in the rock which are gradually widened. Such holes are called as wind windows. The wholes are further widened and enlarged through the process of abrasion and deflation in such a way that an arch-like feature having intact roof is formed.

Yardang

Stream-lined wind erosion forms with their long axes parallel to the wind. They are often described as resembling an inverted ship's hull, although in many cases they are flat topped. Length to width ratios are commonly 3:1 or greater. Height varies from few metres to 200

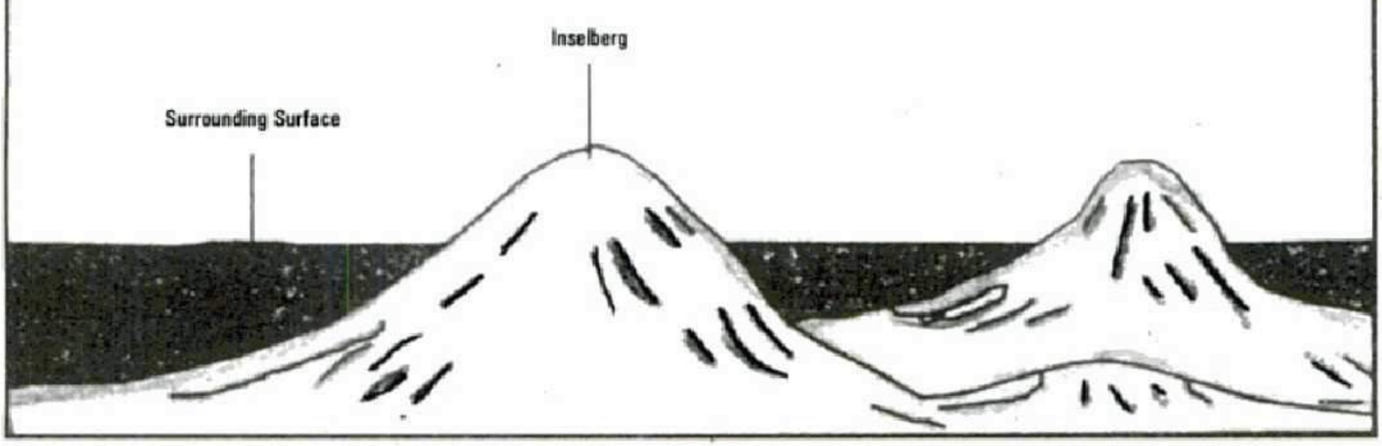


Fig. 2.57 – Inselberg

Fig. 2.58 – Yardangs

Fig. 2.59 – Zeugens (Rock Mushroom)

metres. Yardangs parallel to one another and are separated by either U-shaped of flat-bottomed troughs **(Fig. 2.58)**.

Zeugens (Rock Mushrooms)

It is the tabular mass of rock perched on a pinnacle of a softer rock as a result of erosion, usually by the wind **(Fig. 2.59)**.

Depositional Landforms by Wind

Bahada (Bajada)

'*Bahada*' is a term derived from the Spanish language. It is used to describe the gentle, sloping surface leading down from a mountain front to inland basins in an arid region. It is composed of unconsolidated materials, such as sand, gravel, and angular scree, which together mantle the underlying rock-cut /pediment **(Fig. 2.60)**.

Barchan

A crescent-shaped sand dune in which the horns point down wind in the wind direction of dune migration. Barchans are a type of transverse dune that tends to form where either sand transport rates are high and/or sand supply is limited, Thus, they frequently occur on the margins of sand seas and migrate over non-sandy surfaces **(Fig. 2.61)**.

Dunes

A dune is a subaerial accumulation of sediment. Dunes are formed by the wind in desert and semi-desert environment. Dunes may vary in size from less than a metre to over 200 m high, they may be longitudinal (*Seif-dune*), transverse, parabolic and star-shaped **(Fig. 2.62)**.

Loess (Loss)

Originally referring to a loose, fine and sharp-grained soil occurring in the Rhine Valley, this term has been extended to refer to any unconsolidated, non-stratified soil composed primarily of silt-sized particles. It is very fertile agricultural soil. Loess deposits are found in Hawang-Ho basion, Mississippi valley, Patagonia, New Zealand, Tunisia, Negev, Central Europe, Central Asia, China and Pakistan **(Fig. 2.63)**.

Pediment

A term applied by G.K. Gilbert (1880) to alluvial fans flanking the mountains in Utah (USA). It is a low-angled plain found at the foot of mountain, especially in semi-arid regions.

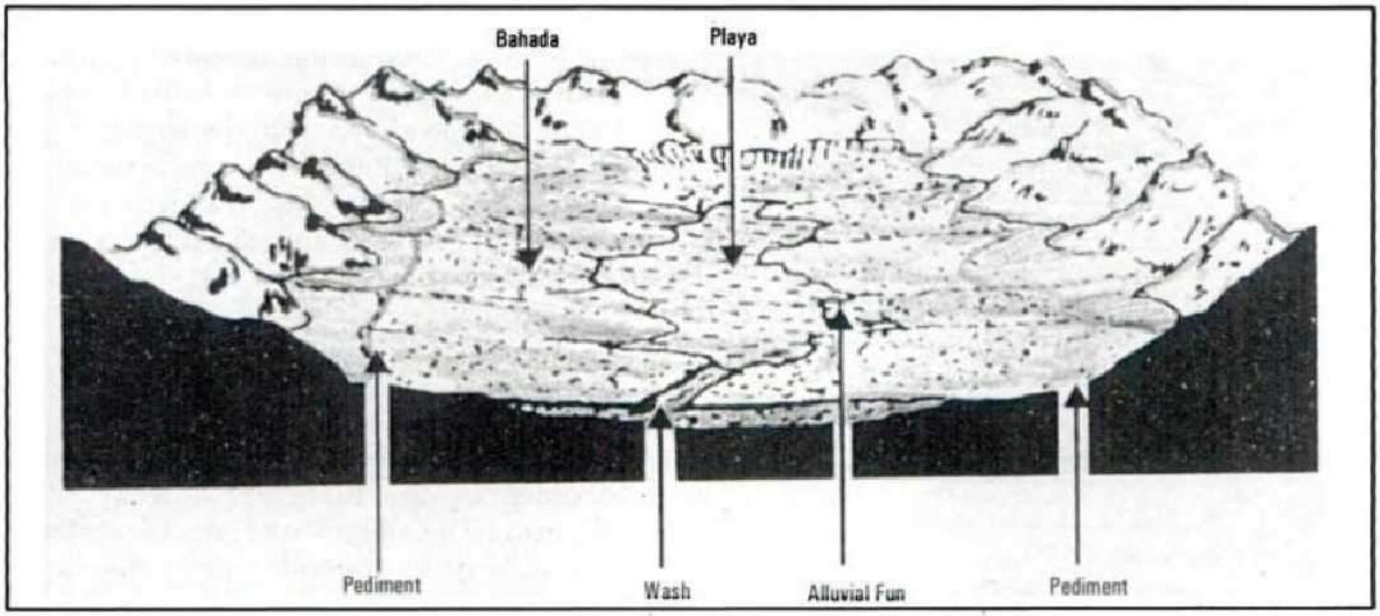


Fig. 2.60 – Bahada and Playa

Ripple

Ripples are small waves produced on a surface of sand or mud by the drag of wind or water moving over it. Ripples are more pronounced in the desert and develop when the wind blows at a gentle pace.

Sand Seas

The hot deserts in several continents are covered with wind-blown sand. These areas are referred to as *sand seas* or *ergs*. The largest sand seas are found in Saudi Arabia (Rab-al-Khali).

(iv) Erosional Processes by Ground Water

Water that occupies pores, cavities, cracks and other spaces in the rocks of the crust is known as ground water, sub-surface water or underground water. The ground water is distributed everywhere beneath the surface of the Earth. It occurs not only in humid areas, but also beneath desert regions. In many areas, the amount of water seeping into the ground equals or exceeds the surface runoff. Here, a brief description of the underground water, especially in the *karst* (limestone) topography has been given.

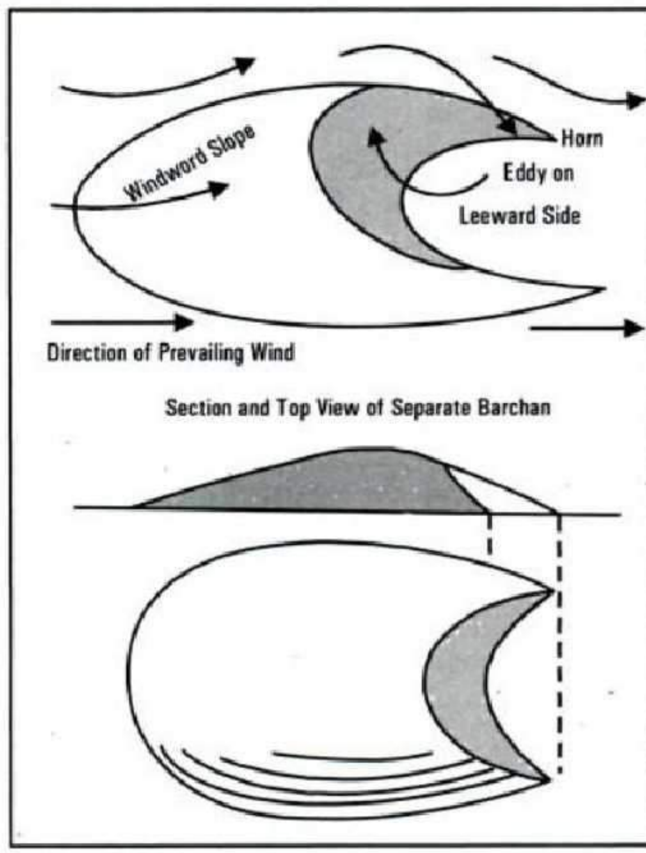


Fig. 2.61 – Barchans

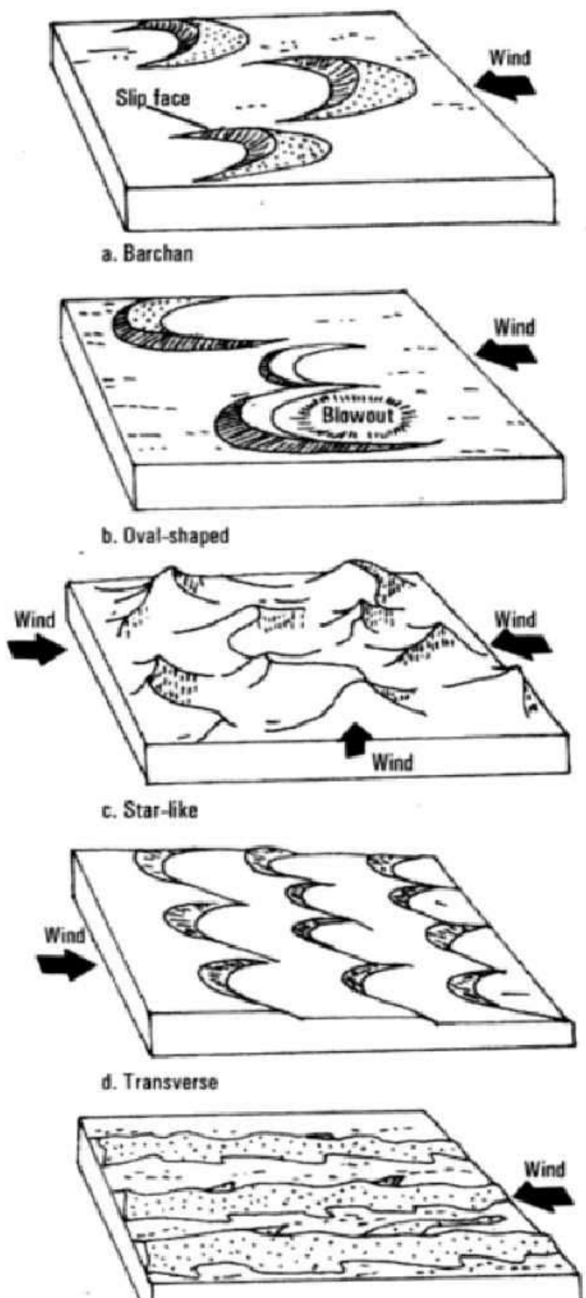


Fig. 2.62 – Types of sand-dunes

Karst

Karst is a distinctive topography formed in a region of chemically weathered limestone with poorly developed surface drainage and drainage features that appear pitted and bumpy; originally named after the *Krs Plateau* of Yugoslavia **(Fig. 2.64).**

Karst regions are typified by the dominant erosional process of solution, the lack of surface water and the development of stream sinks (dolines) cave systems and resurgences or springs. All the resultant landforms associated with karst scenery depend upon the phenomenon of stream sinking. Karst topography however, lacks a well-integrated drainage system.

Conditions for the Development of Karst Topography

The conditions that contribute to the maximum development of karst topography are:

1. There must be present at or near the surface a soluble rock, preferably limestone. The limestone must be massive, thickly bedded, hard, tenacious and well cemented.
2. The soluble rock should be dense, highly jointed, and preferably thinly bedded.
3. Existence of entrenched valley below uplands underlain by soluble and well-jointed rocks.
4. The climate should be humid-temperate. Karst topography does not develop in desert areas.
5. The region must receive moderate rainfall.

Aven

It is a French term for shaft-like hole in limestone terrain leading down into extensive cave system.

Carren (Lapies)

Karren is a German term initially used to describe minor and major solution furrows or funnels cut by ground water into karst topography. Now the term is used for highly corrugated and rough surface of lime stone lithology characterized by low ridges and pinnacles, narrow clefts, and numerous solution holes **(Fig. 2.65).**

Cave

A cave is a naturally formed subterranean open area, chamber or series of chambers commonly produced in limestone by solution activity **(Fig. 2.66)**.

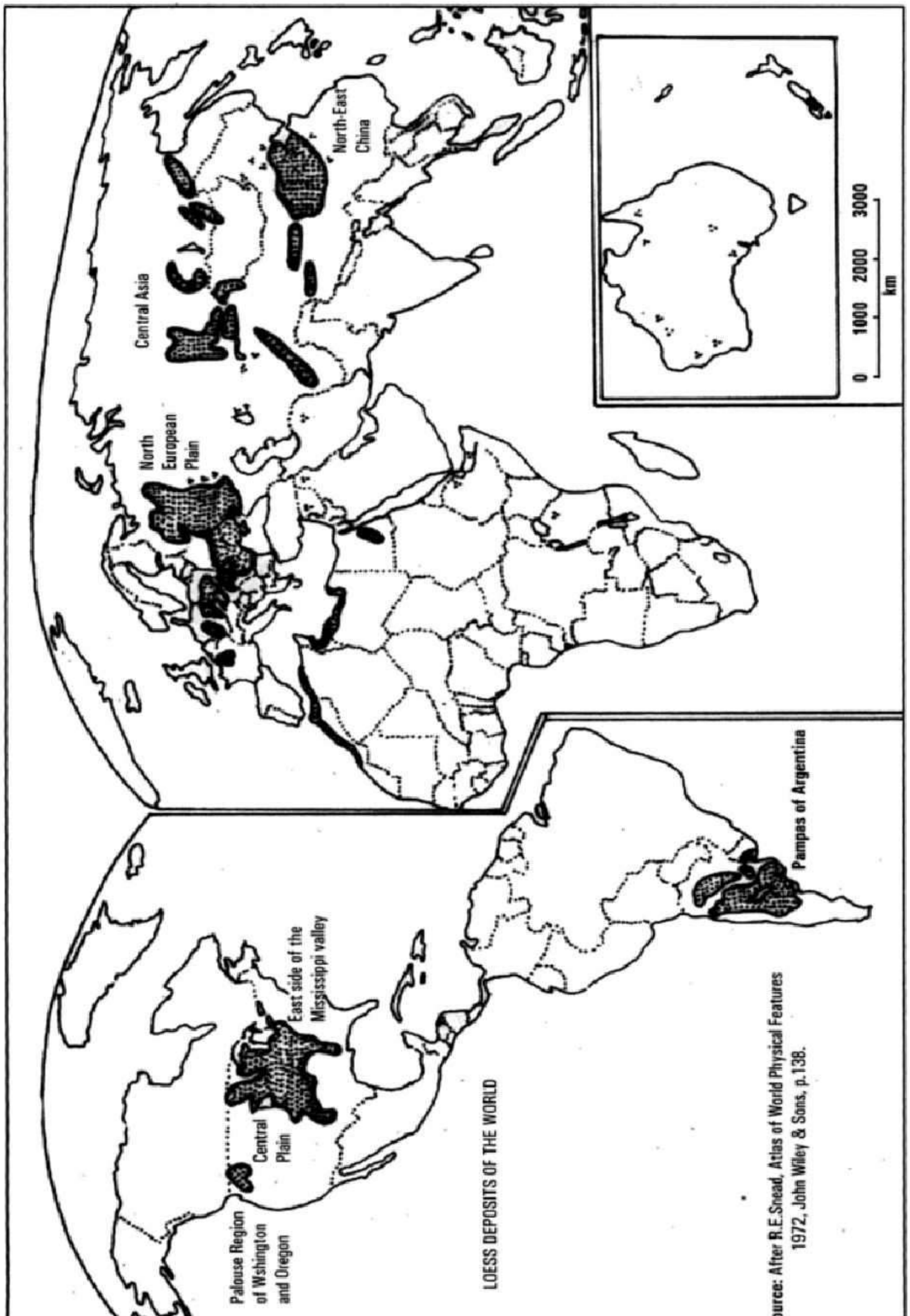


Fig. 2.63 – Worldwide loess deposits

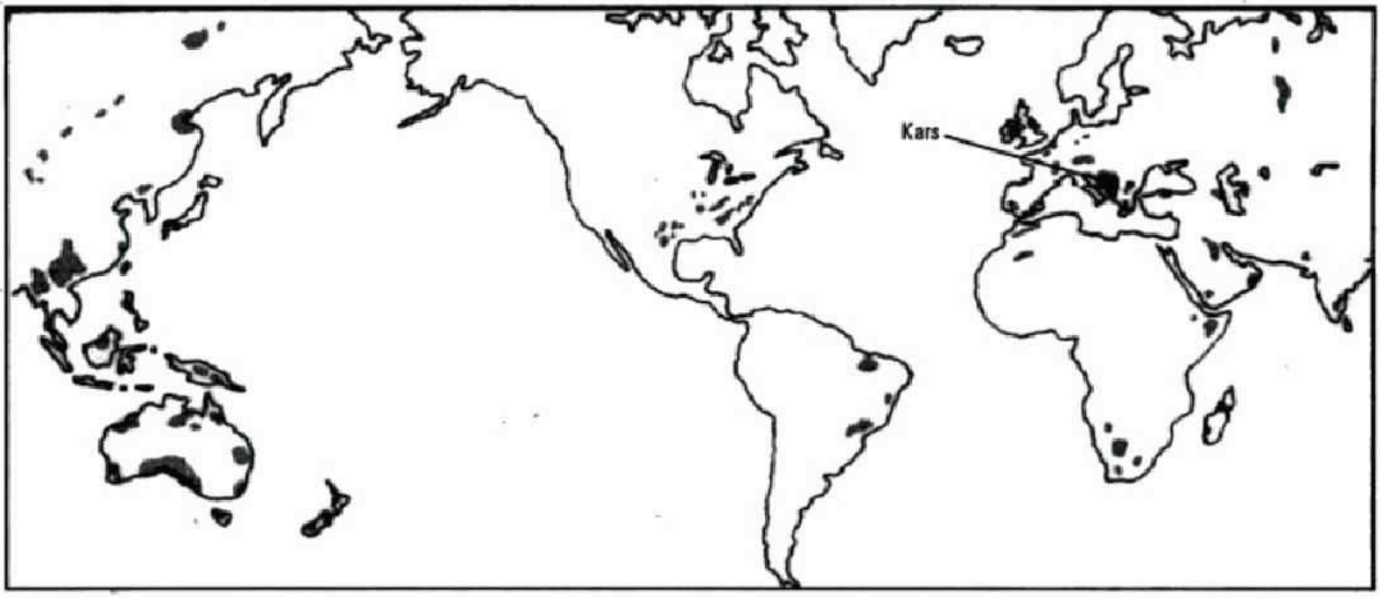


Fig. 2.64 – Major areas of Karst topography of the world

Erosional Landforms

Generally karst topography is characterized by: caves, karren, dolines, sink-holes, ponores, uvala, polje, Aven, natural bridge, springs, blind-valleys, etc **(Fig. 2.65 & 2.66)**.

Lapies

It is a French term for karren.

Natural Bridge

It is an erosional feature in karst topography. It is formed either due to the collapse of the roof of caves or due to the disappearance of surface streams as subterranean streams.

Polje

Polje is a large depression in a karst region with steep sides and flat valley floor **(Fig. 2.66)**.

Ponores

A vertical pipe-like passage that connects the caves and the shallow holes **(Fig. 2.66)**.

Sinkhole

A sinkhole is a depression formed by the collapse of a cavern roof **(Fig. 2.66)**.

Uvala

Uvala is a depression formed when two or more dolines coalese. The size of the hollow is not important in the recognition of uvala.

Depositional Landforms

The main depositional landforms in a limestone topography are given below:

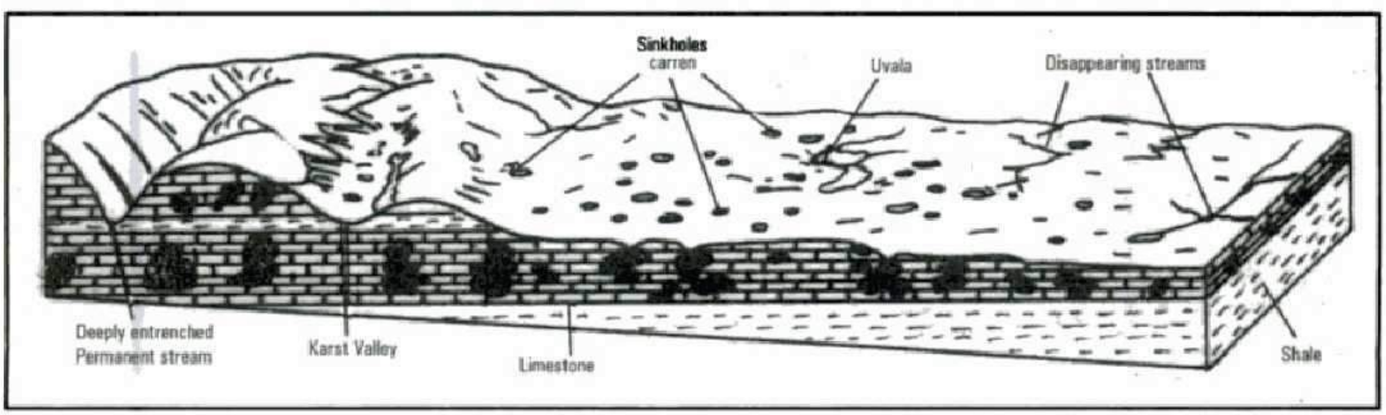


Fig. 2.65 – Salient features of karst topography

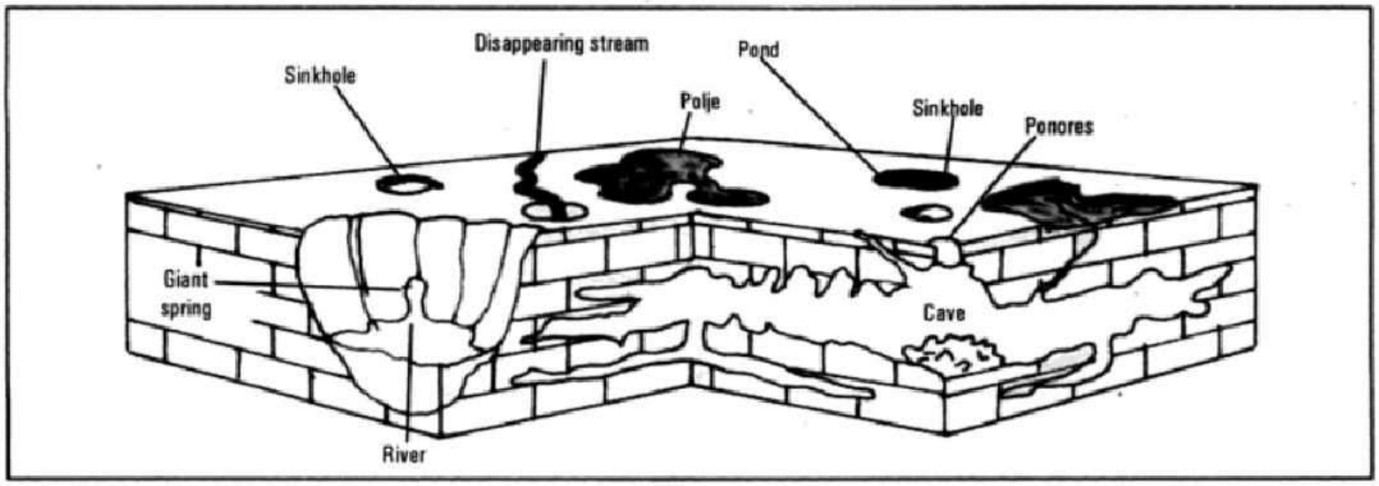


Fig. 2.66 – Karst topography

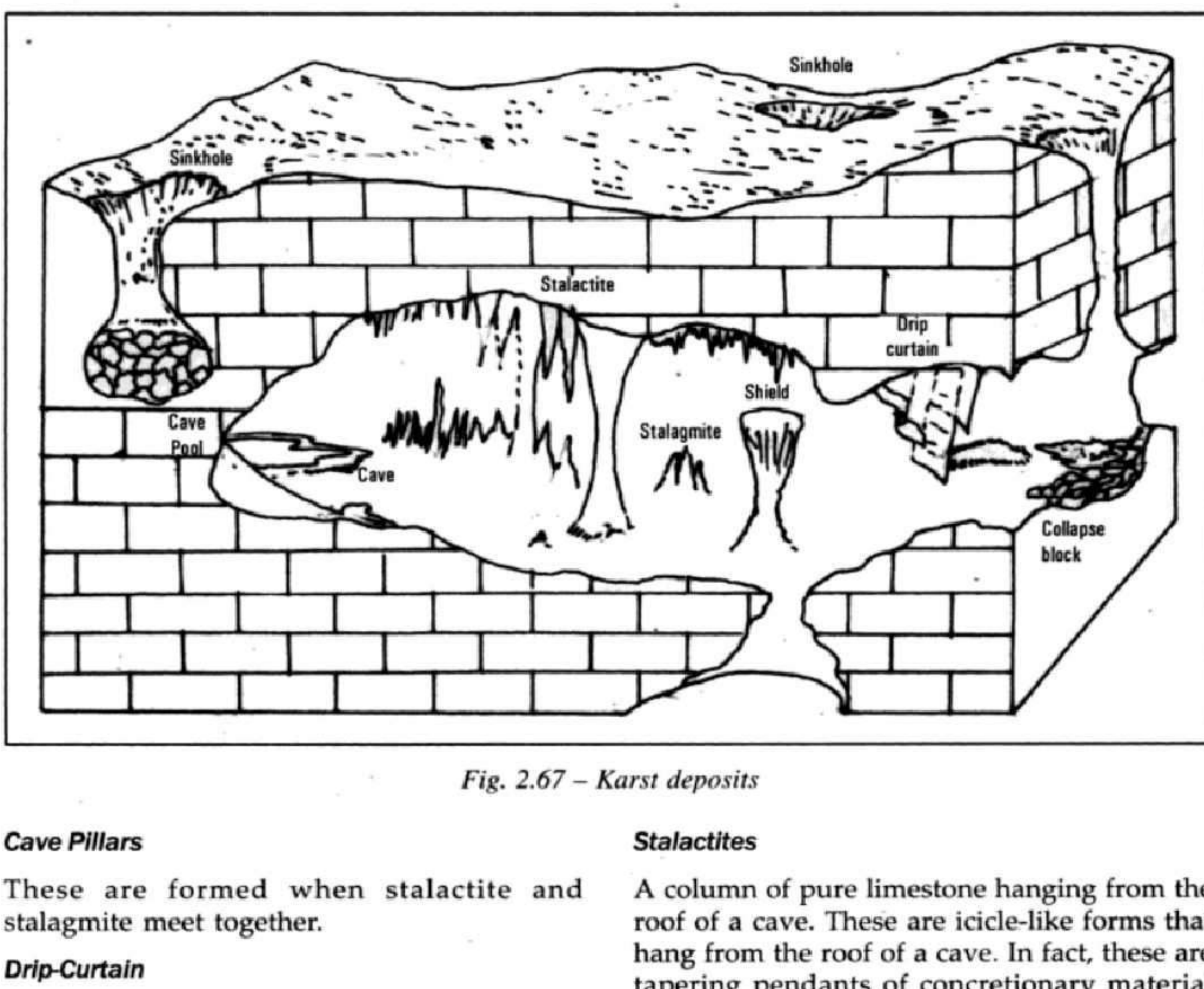


Fig. 2.67 – Karst deposits

Cave Pillars

These are formed when stalactite and stalagmite meet together.

Drip-Curtain

Numerous needle-shaped dripstones hanging from the cave ceiling are called as drip curtains or drapers **(Fig. 2.67)**.

Stalactites

A column of pure limestone hanging from the roof of a cave. These are icicle-like forms that hang from the roof of a cave. In fact, these are tapering pendants of concretionary material descending from a cave ceiling, created by the precipitation of carbonate in calcite from percolating groundwater **(Fig. 2.67)**.

Stalagmite

These are columns of pure limestone formed on the floor of a cave when dissolved calcium carbonate in the underground water is deposited and water evaporates as it splashes onto the cave floor **(Fig. 2.67)**.

Terra-Rossa

Terra-Rossa is a red intra-zonal soil developed in the karst regions by the weathering of limestone. The red condition comes from the dissolution of clay to form iron-oxide.

(v) Coastal Processes (Marine Erosion) and Landforms

The processes of erosion and deposition and the resultant landforms along the coasts have been briefly described in the following:

Erosional Landforms

Arch (Sea-arch)

In coastal geomorphology an arch is made when two caves occurring on either side of a headland are cut until they meet. Roof falls cut-off the seaward end of the arch which is then left as a stack **(Fig. 2.68)**.

Beach

Thick wedge-shaped accumulation of sand, gravel or cobbles in the zone of breaking waves

Cliff

Marine cliff: It is rock cliff shaped and maintained by the undermining action of breaking waves. In general, it is a sheer, near vertical rock wall formed from flat-lying resistant layered rocks, usually sandstone, limestone, or lava, may refer to any near vertical rock wall **(Fig. 2.68)**.

Sea-cave

A sea-cave is a large natural hollow in the cliff along the coast with horizontal opening **(Fig. 2.68)**.

Stack (Sea-stack, Needles, Columns, Pillars, Skerries)

A stack is an isolated columnar mass of bed-rock left standing in front of a retreating marine cliff **(Fig. 2.68)**.

Wave-cut Platform

A very gently slopping platform extending seaward from the base of the cliff. Platforms widen as the cliffs retreat. They are subject to

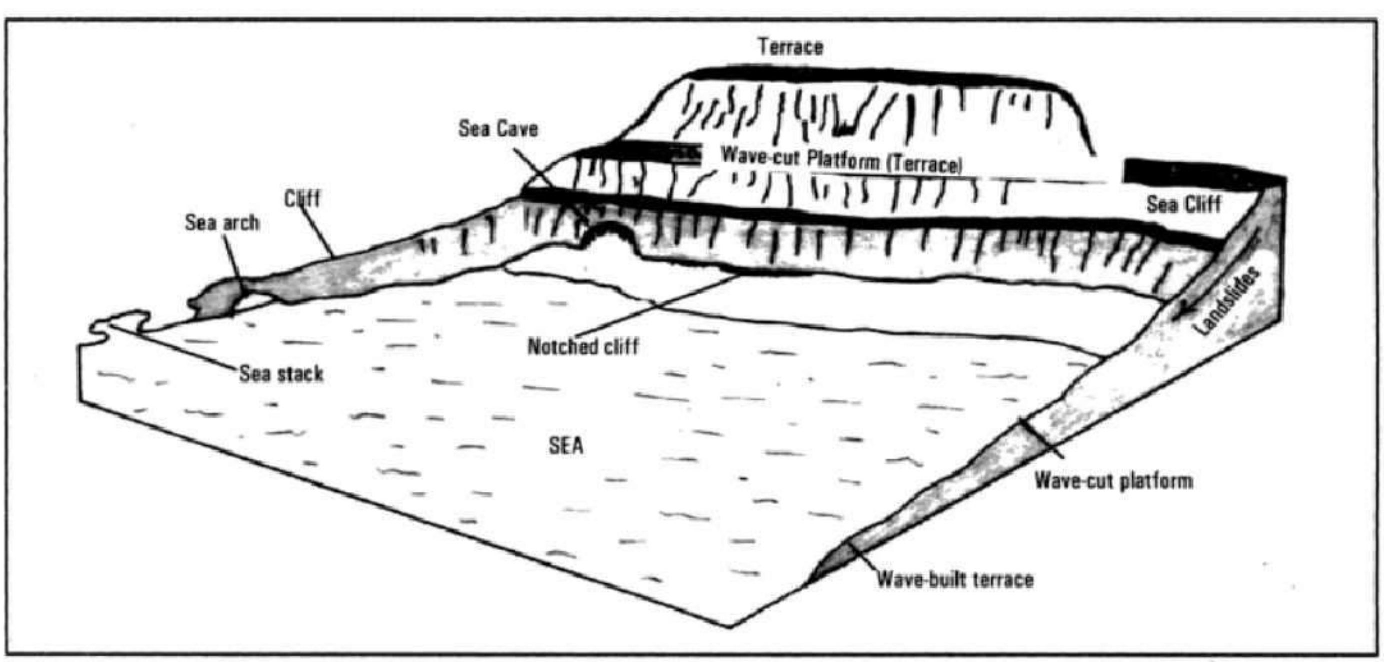


Fig. 2.68 – Coastal erosional land forms

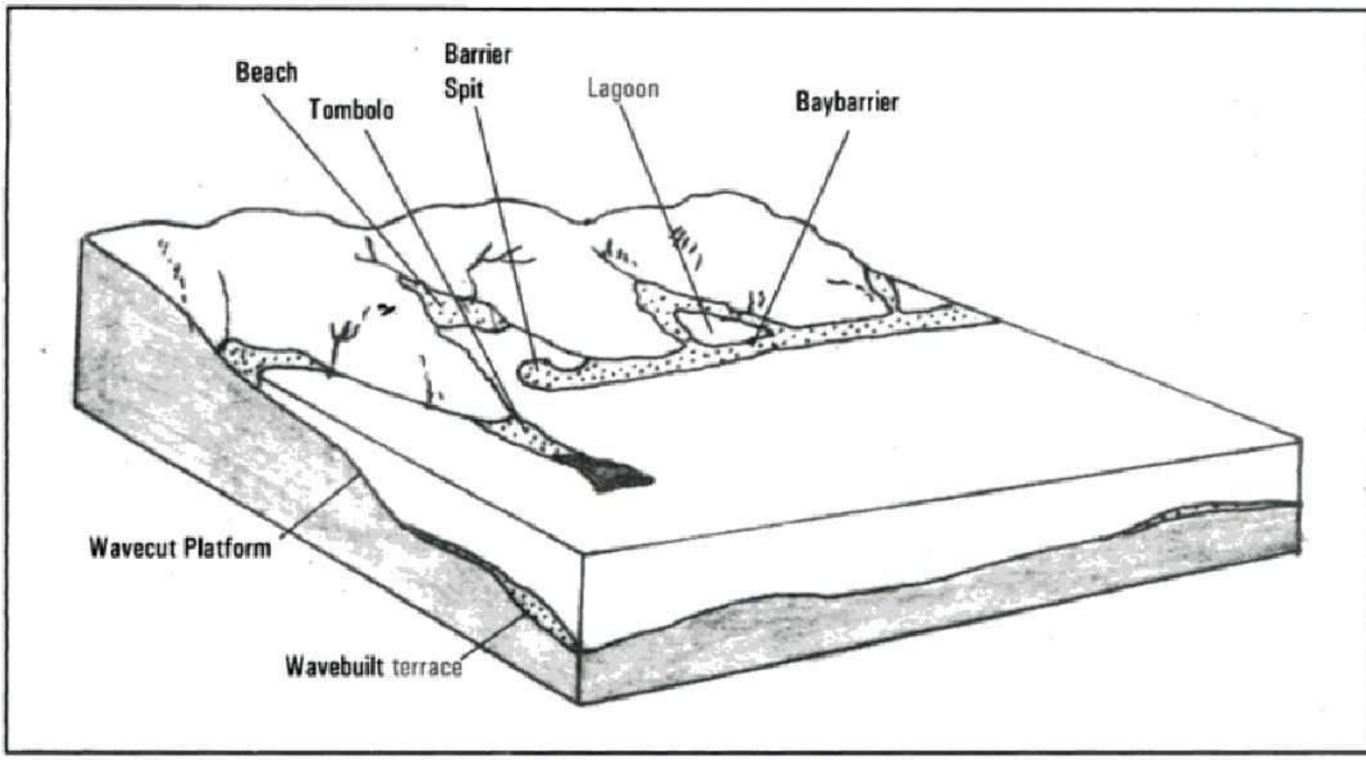


Fig. 2.69 – Coastal depositional landform

salt weathering, alternate wetting and drying and processes of erosion such as quarrying, hydraulic action and abrasion **(Fig. 2.68)**.

Depositional Landforms:

Bars

A low ridge of sand built above water level across the mouth of a bay or in shallow water paralleling the shoreline **(Fig. 2.69)**.

Spit (Sand-spit)

A narrow, fingerlike embankment of sand constructed by littoral drift into the open water of a bay **(Fig. 2.69)**.

Tombolo

A bar or spit connecting an island to the mainland or to another island **(Fig. 2.69)**.

Coasts Types

A coast is a zone in which coastal processes operate or have strong influence. Some of the important types of coasts have been defined in the following:

Dalmatian (Pacific/Concordant) Coast

This is a drowned seashore with the main relied trends running more or less parallel with the coastline, named after the Adriatic Coast **(Fig. 2.70)**.

Fiord (Fjord) Coast

Deeply embayed, rugged coast formed by partial submergence of glacial trough.

Ria Coast

The seaward end of a river valley which has been flooded as a result of rise in sea level. The name is from the Spanish language. The Cork harbor in Ireland is a ria coast **(Fig. 2.71)**.

Slopes or Hill-slopes

Slopes are curved, inclined surfaces essential slope forms that may vary with conditions of rock structure and climate. Slopes generally feature an upper *waxing slope* near the top ('waxing' here means increasing). This convex surface below. The presence of a free face indicates an outcrop of resistant rock that

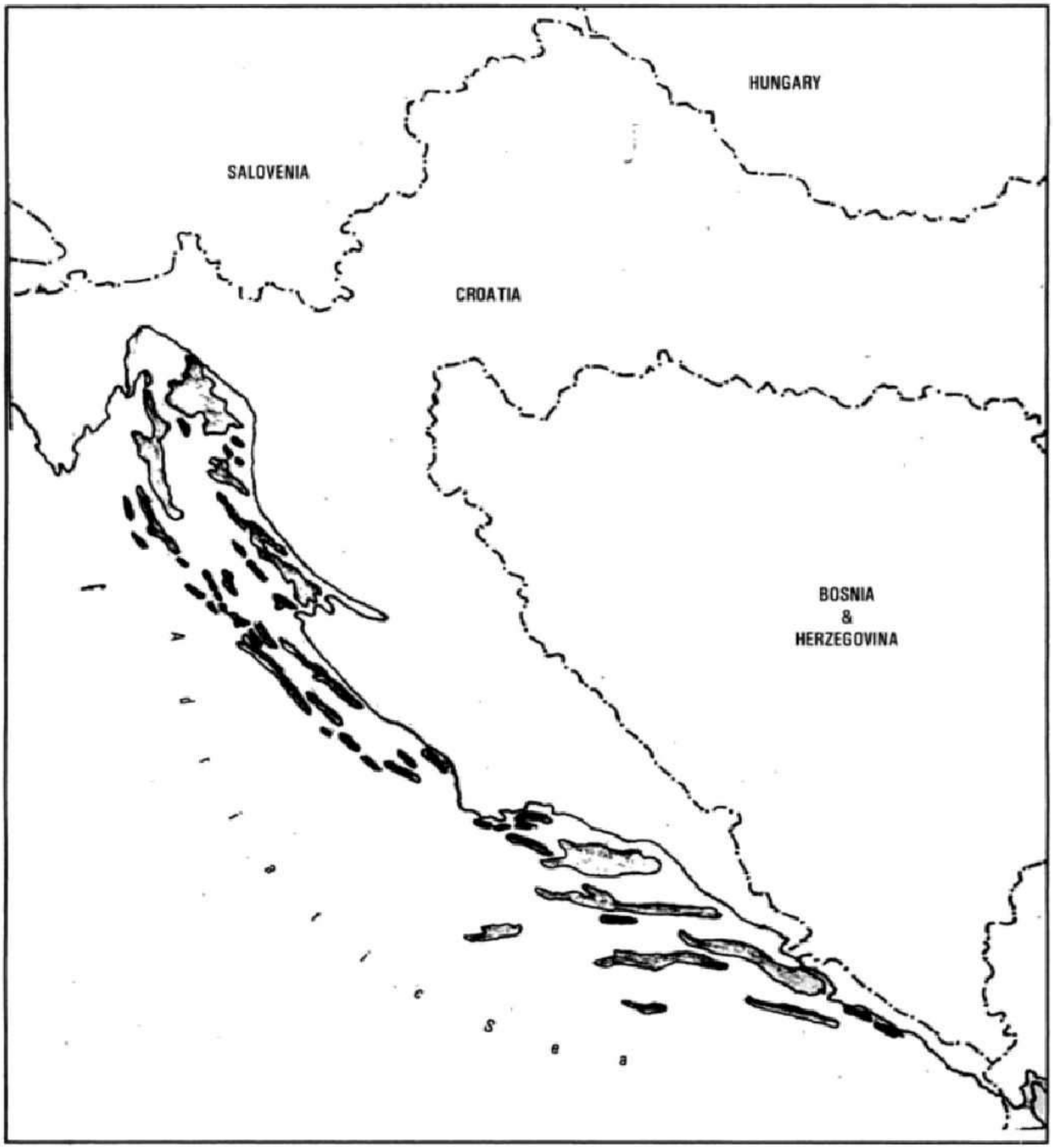


Fig. 2.70 – Dalmatian coast

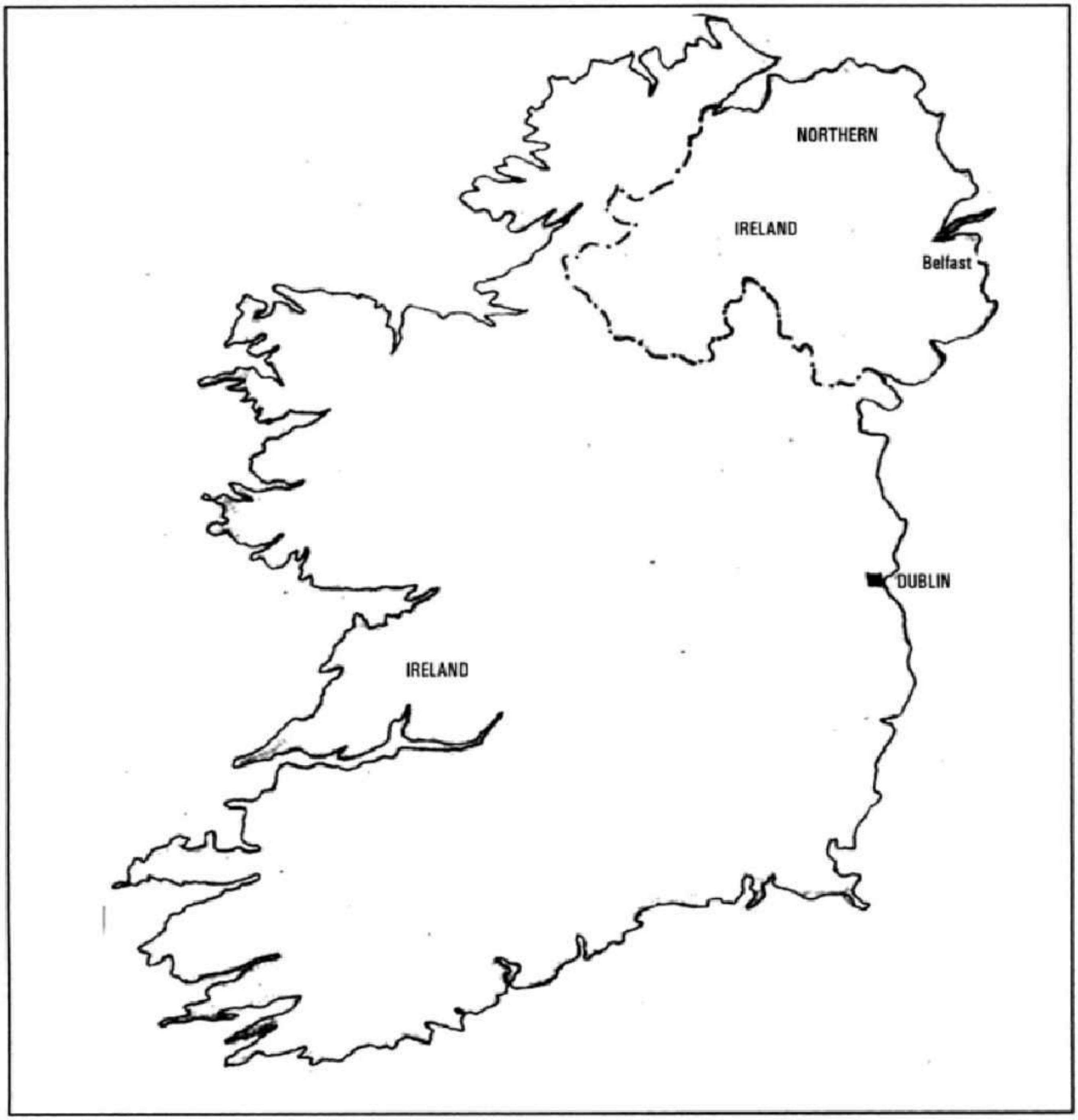


Fig. 2.71 – Ria-coast

forms a steep scarp of cliff. Down-slope from the free face is a debris slope that receives rock fragments and materials from above.

In humid climates constantly moving water carries away material as it arrives, whereas in arid climates, graded debris slopes persist and accumulate a debris slope grades into a waning slope, a concave surface along the base of the slope that forms a pediment, or broad, gently sloping erosion surface.

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