Module II: Physical Geography

1. Concepts in Geomorphology

- Geomorphology is the **study of landforms, their processes**, form and sediments at the surface of the Earth (and sometimes on other planets).
- Study includes looking at landscapes to work out how the earth surface processes, such as air, water and ice, can mold the landscape.
- Landforms are produced by **erosion or deposition**, **as rock and sediment is worn away by these earth-surface processes and transported and deposited to different localities.**
- The different climatic environments produce different suites of landforms.
- The basic or fundamental concepts of geomorphology are as follows
  - ❖ The same physical processes and laws that operate today operated throughout geologic time, although not necessarily with the same intensity as now
    - ➢ This is the important principle of geology and is known as the principle of **uniformitarianism.**
    - ➢ It was first enunciated by **Hutton in 1785.**
    - ➢ According to Hutton **"the present is the key to the past"**.
    - ➢ But he applied this principle somewhat too rigidly and argued that geologic processes operated throughout geologic time with the same intensity as now
    - ➢ Glaciers were much more significant during the **Pleistocene** and during other periods of geologic time than now; world climates have not always been distributed as they are now, and, thus, regions that are now humid have been desert and areas now desert have been humid.
  - ❖ Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them
    - ➢ The major controlling factor in landform development is structure and process.

- Here the term structure includes not only the folds, faults etc. but all those ways in which the earth materials out of which landforms are carved differ from one another in their physical and chemical attributes.
- it includes such as rock attitudes; presence or absence of joints, bedding planes, faults, and folds; rock massiveness; hardness of constituent minerals; the susceptibility of the mineral constituents to chemical alteration; permeability and impermeability of rocks; and various other ways by which the rocks of the earth crust differ from one another
- In general the structures are much older than the geomorphic forms developed upon them.
- Such major structural features as folds and faults may go back to far distant periods of **diastrophism**

- To a large degree the earth's surface possesses relief because the geomorphic processes operate at different rates.
  - The rocks of the earth's crust vary in their lithology and structure and hence offer varying degrees of resistance to the gradational processes.
  - Differences in rock composition and structures are reflected not only in regional geomorphic variability but in the local topography as well.
  - The local intensity of particular processes may change notably in response to differences in such factors as **temperature, moisture, altitude, exposure, topographic configuration, and the amount and type of vegetal cover.**
  - The microclimatic conditions may vary markedly between a valley floor and a hilltop, between a northern and a southern exposure, and between bare ground and that with a heavy vegetal cover

ENTRI

- Geomorphic processes leave their distinctive imprint upon landforms, and each geomorphic process develops its own characteristic assemblage of land forms.
    - The term process applies to the many physical and chemical ways by which the earth's surface undergoes modification.
    - In general **endogenic processes** (originate from forces within the earth crust such as diastrophism and volcanism) tend to build up or restore areas which have been worn down by the exogenetic processes (results from external forces like weathering, mass wasting, erosion); otherwise the earth's surface would finally become largely featureless.
- As the different erosional agents act upon the earth's surface there is produced an orderly sequence of landforms
    - The land forms possess distinctive characteristics depending upon the stage of their development
    - This idea was most stressed by **W. M. Davis** and out of this idea grew his concept of geomorphic cycle and its concomitant stages of **youth, maturity, and old age** culminating in a topographic surface of low relief called peneplain.
    - Use of the term **geomorphic cycle** will carry with it implication of orderly and sequential development but there will be no implication that designation of the topography to a certain area as **youthful, mature or old** means that the topography of another region in the same stage of development has fully comparable characteristics
    - Partial cycles are more likely to occur than completed ones, for much of the earth's crust is restive and subject to intermittent and differential uplifts.
- Complexity of geomorphic evolution is more common than simplicity.

- ➢ Usually most of the topographic details have been produced during the current cycle of erosion, but there may exist within as area remnants of features produced during prior cycles.
- ➢ **Horberg (1952)** divided the landscapes into five major categories:
  - ➔ Simple
    - ★ Simple landscapes are those which are the p**roduct of a single dominant geomorphic process.**
  - ➔ Compound
    - ★ compound landscapes are those in which **more than one geomorphic processes** have played major role in the development of existing topography
  - ➔ Monocyclic
    - ★ Monocyclic landscapes are those that bear the imprint of **only one cycle of erosion**
  - ➔ Multicyclic
    - ★ multicyclic landscapes have been produced during **more than one cycle of erosion.**
  - ➔ Exhumed
    - ★ **Exhumed or resurrected landscapes** are those which were formed during some past period of geological time, then buried beneath a cover mass of igneous or sedimentary origin, then still later exposed through removal of the cover.

❖ Little of the earth's topography is older than tertiary and most of it no older than the Pleistocene.

- ➢ Most of the details of our present topography probably do not date back to the Pleistocene, and certainly little of it existed as surface topography back of the tertiary.
- ➢ **Himalayas** were probably first folded in the **Cretaceous** and later in the **Eocene and Miocene** but their present elevation was

not attained until the **Pleistocene** and most of the **topographic details in Pleistocene or later in age.**

- Proper interpretation of present-day landscape is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene.
  - The Pleistocene have had far-reaching effects upon present-day topography.
  - Glaciation directly affected many million square miles, perhaps as much as **10,000,000** square miles, but its effects extended far beyond the areas actually glaciated
  - **Glacial outwash and windblown** materials of glacial origin extended into areas not glaciated, and climatic effects were probably worldwide in extent.
  - Although **glaciation** was probably the most significant event of the **Pleistocene**, we should not lose sight of the fact that in many areas the diastrophism which started during the Pliocene continued into the **Pleistocene** and even into the **Recent.**
  - Around the **Pacific Ocean,** Pleistocene diastrophism has played a most significant role in shaping of present day landscapes
- An appreciation of world climate is necessary to a proper understanding of the varying importance of the different geomorphic processes.
  - Climatic variations may affect the operation of geomorphic processes either indirectly or directly
  - The indirect influences are largely related to how climate affects the amount, kind, and distribution of the vegetal cover.
  - The direct controls are such as the amount and kind of precipitation, its intensity, the relation between precipitation and evaporation and daily range of temperature, whether and how frequently the temperature falls below.

- ➢ Topographic features transverse to the moisture-bearing winds, and the rapid changes in climatic conditions with increase in altitude.

- ❖ Geomorphology, although concerned primarily with present day landscapes, attains its maximum usefulness by historical extension.
  - ➢ Geomorphology concerns itself primarily with the origins of the present landscape but in most landscapes there are present forms that date back to previous geological epochs or periods.
  - ➢ A geomorphologist is thus forced to adopt an historical approach if he is to interpret properly the geomorphic history of a region.
  - ➢ The paleo-geomorphology covers the identification of ancient erosion surfaces and study of ancient topographies.

- <u>Structure of the earth</u>
  - ❖ The Earth can be divided into one of two ways: **mechanically or chemically.**
  - ❖ Mechanically (or **rheologically**) meaning the **study of liquid states** – it can be divided into the **lithosphere, asthenosphere, mesospheric mantle, outer core, and the inner core**.
  - ❖ Chemically or by composition, which is the more popular of the two, it can be divided into the **crust, the mantle (which can be subdivided into the upper and lower mantle), and the core** – which can also be subdivided into the **outer core, and inner core**.
  - ❖ Sources to study the earth's interior
    - ➢ The sources which provide knowledge about the interior of the earth may be classified into 2 sources
    - ➢ **<u>Direct sources</u>**
      - ➔ Surface rock
        - ★ Surface rock is readily available at the **surface of the earth.**

- ★ By observing these rocks, we can know the form of material that can be found up to a certain depth.
- ➔ Volcanos
  - ★ Volcanic material that gets out after an eruption is readily available to us for observation.
  - ★ Since these materials come up from great depth, therefore, the quality of this material at great depth can be analyzed directly.
  - ★ However, the accurate depth of material can’t be ascertained.
- ➔ Material obtained from Mining and Drilling areas
  - ★ From Mining and Drilling areas, many materials can be sourced for analysis.
  - ★ These materials reveal the nature of material available at a certain depth.
  - ★ From mining, it is easy to deduce that pressure and temperature increase from the surface towards the interior deeper depth.
  - ★ Also, the Density of the material increases from the top surface to the interior bottom.

➢ **Indirect sources**

- ➔ Temperature and pressure variation
- ➔ Seismic activities
  - ★ It provides information about the state of the interior of the earth.
  - ★ Whether it’s solid, liquid, or in gaseous form.
  - ★ The technology revealed that the mantle is liquid, the outer core is liquid but the inner core is solid.
- ➔ Meteorites

- ★ Meteorites are found in space and seldom reach the earth. When it reaches the earth, It is available for analysis.
- ★ Meteorites are not from the interior of the earth; therefore, it has an indirect source to acquire the interior of the earth because scientists assume that Meteorites were once part of the planet, therefore, their structure and material is similar to the earth.

➔ Gravitation

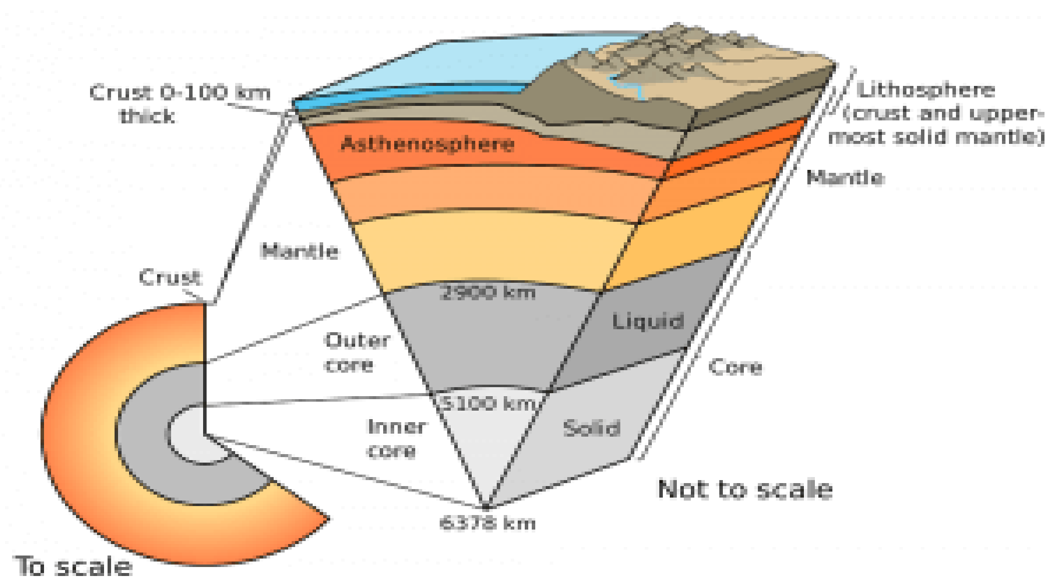
- ★ Gravitational value is not the same across all the latitudes. The differences in gravitational value show the uneven distribution of mass of material within the earth.

➔ Magnetic field

- ★ Magnetic survey of the earth reveals the distribution of magnetic materials available in different parts of the earth.

❖ Structure of the Earth's interior

➢ The structure of the earth's interior is made up of several concentric layers. Structure of Interior Of The Earth is divided into **three layers**



➢ **Crust**

- The crust is the outermost solid part and a thin layer of the earth with a total thickness normally between **30-50 km.**
- The thickness of the crust varies under the oceanic and continental areas.
- **Oceanic crust** is thinner **(5-30 km thick)** as compared to the **continental crust(50-70 km thick)**.
- The continental crust is thicker in the areas of major mountain systems.
- It is as much as **70 -100 km** thick in the Himalayan region.
- It is **0.5-1.0** percent of its volume and less than **1%** of its mass.
- The temperature of the crust increases with depth, reaching levels of around **200 °C to 400 °C** near the mantle-crust boundary.
- In the higher region of the crust, the temperature rises by up to **30 degrees** Celsius for every kilometer.
- The crust's outer layer is made up of sedimentary material, and beneath it are acidic crystalline, igneous, and metamorphic rocks.
- Basaltic and ultrabasic rocks make up the crust's lowest layer.
- The temperature of the crust rises with depth, reaching levels of around **200°C to 400°C** near the mantle-crust boundary.
- In the higher region of the crust, the temperature rises by up to **30 degrees** Celsius for every kilometer.
- The crust's outer layer is made up of sedimentary material, and beneath it are acidic crystalline, igneous, and metamorphic rocks.
- The lighter silicates — **silica + aluminum** (also known as **sial**) — make up the continents, while the heavier silicates — **silica + magnesium** (also known as **sima**) — make up the

oceans [Suess,1831–1914, this categorization is now obsolete (out of date)].

- ➔ Lighter (felsic) sodium potassium aluminum silicate rocks, such as granite, make up the continental crust.
- ➔ On the other hand, the oceanic crust is made up of thick (mafic) iron magnesium silicate igneous rocks like basalt.
- ➔ **Mohorovicic (Moho)** discontinuity forms between lower crust and upper mantle.
- ➔ The most abundant elements of the Earth's Crust

Element	Approximate % by weight
Oxygen (O)	46.6
Silicon (Si)	27.7
Aluminum (Al)	8.1
Iron (Fe)	5.0
Calcium (Ca)	3.6
Sodium (Na)	2.8
Potassium (K)	2.6
Magnesium (Mg)	1.5

1. Lithosphere
   - ★ The lithosphere is the earth's rigid outer layer, with a thickness ranging from **10 to 200 kilometers.**
   - ★ It consists of the crust as well as the upper part of the mantle.
   - ★ The lithosphere is divided into tectonic plates (lithospheric plates), which move and create large-scale

changes in the earth's geological structure (folding, faulting).

- ★ The primordial heat left over from the planet's birth, as well as the radioactive decay of **uranium, thorium, and potassium in Earth's crust and mantle,** are the sources of heat that drive plate tectonics.

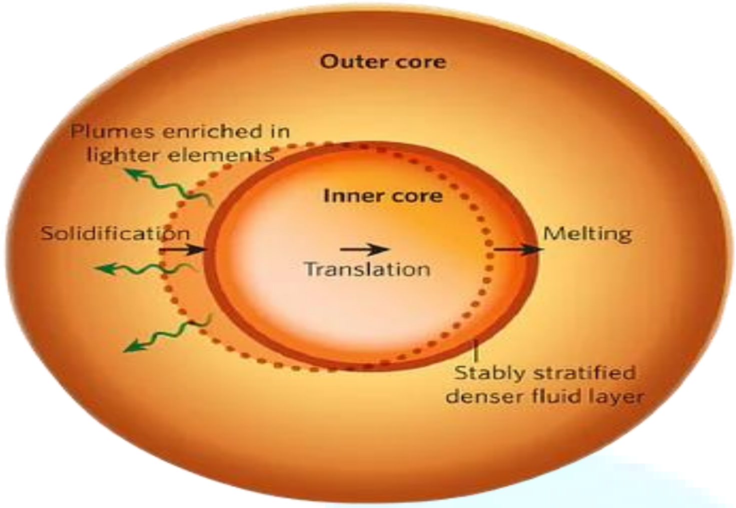
2. Asthenosphere
   - ★ It lies below the lithosphere extending up to **80-200 km.**
   - ★ The rigid lithosphere can easily move over it because the asthenosphere is soft and plastic.
   - ★ It's vicious, brittle, and ductile, and its density is higher than the crust.
   - ★ **During volcanic eruptions, it is the primary source of magma that rises to the surface.**
   - ★ The lithospheric shell is divided into large pieces called lithospheric plates. These plates can separate from one another at one location, while elsewhere they may collide in crushing impacts that raise great ridges.

➢ **Mantle**

- ➔ The portion of the interior beyond the crust is called the mantle.
- ➔ The mantle extends from **Moho's discontinuity(35 km)** to a depth of **2,900 km**.
- ➔ It equates to roughly **83 percent** of the earth's volume and **67 percent of its mass.**
- ➔ The upper portion of the mantle is called the asthenosphere.
- ➔ The asthenosphere reaches beyond the lower mantle. It is completely solid.
- ➔ The crust and the uppermost part of the mantle are called the lithosphere. Its thickness ranges from **10-200 km**.

- ➔ The lower mantle extends beyond the **asthenosphere**. It is in a solid-state.
- ➔ The density of the mantle is higher than the crust and varies from **3.3 to 5.5.**
- ➔ The upper mantle's density ranges from **2.9 to 3.3** grams per cubic meter.
- ➔ In the lower mantle, density ranges from **3.3 g/cm3 to 5.7 g/cm3.**
- ➔ It contains **83 percent** of the total volume and **68 percent** of the total mass of the earth.
- ➔ The mantle has been formed largely of silicate minerals rich in iron and magnesium.
- ➔ The mantle is made up of **45 percent oxygen, 21 percent silicon, and 23 percent magnesium as basic elements (OSM)**.
- ➔ Temperatures in the mantle range from around **200 °C** at the upper crustal border to almost **4,000 °C** at the core-mantle boundary.
- ➔ A convective material circulation occurs in the mantle as a result of the temperature differential (although solid, the high temperatures within the mantle cause the silicate material to be sufficiently ductile).
- ➔ The motions of tectonic plates represent the mantle's convection at the surface.
- ➔ Seismicity in the mantle should be inhibited by high-pressure circumstances. However, earthquakes have been detected in subduction zones as far as **670 kilometers below the surface (420 mi).**

➢ **Core**



- The core is made up of very heavy material mostly composed of nickel and iron.
- It is sometimes referred to as the **NIFE layer [nickel and iron].**
- The core-mantle boundary is located at the depth of 2900 km.
- Core lies between **2900 km and 6400 km** below the earth's surface.
- The outer core is liquid while the inner core is solid.
- The density of the core is higher than the mantle and varies from **5.5 to 13.6 g/cm3**
- Volume and mass of the core are **16% and 32%** of the total volume and mass of the earth respectively.
- The core-mantle boundary is located at the depth of **2900 km**. At this boundary, called the **Gutenberg discontinuity,** there is a sudden change from **5.5 gm/cm3** of the mantle to **10 gm/cm3.**
- The core is divided into two parts: the outer core and the inner core.
- **<u>Outer Core</u>**

- ★ The outer core, which surrounds the inner core, is located between **2900 and 5100 kilometers** beneath the surface of the planet.
- ★ **Iron with nickel** and trace amounts of lighter metals make up the outer core.
- ★ The outer core is liquid because it is not under enough pressure to solidify, despite having a comparable composition to the inner core.
- ★ According to dynamo theory, Earth's magnetic field is created by convection in the outer core mixed with the Coriolis effect.

➔ **<u>Inner Core</u>**

- ★ The inner core stretches from the earth's center to **5100 kilometers** below the surface.
- ★ This layer is solid because it can transmit shear waves (transverse seismic waves). (When **P-waves collide with the outer core – inner core border, S-waves result**.)
- ★ The rotation of the Earth's inner core is slightly quicker than the rotation of the surface.
- ★ A persistent magnetic field cannot be maintained in the solid inner core because it is too hot.
- ★ The core (inner core and outer core) makes up only around **16%** of the **earth's volume** but accounts for **33% of its mass.**

➢ Earth's Layers- Seismic Discontinuities

➔ Discontinuity refers to a **sharp boundary between layers in the earth's internal structure.**

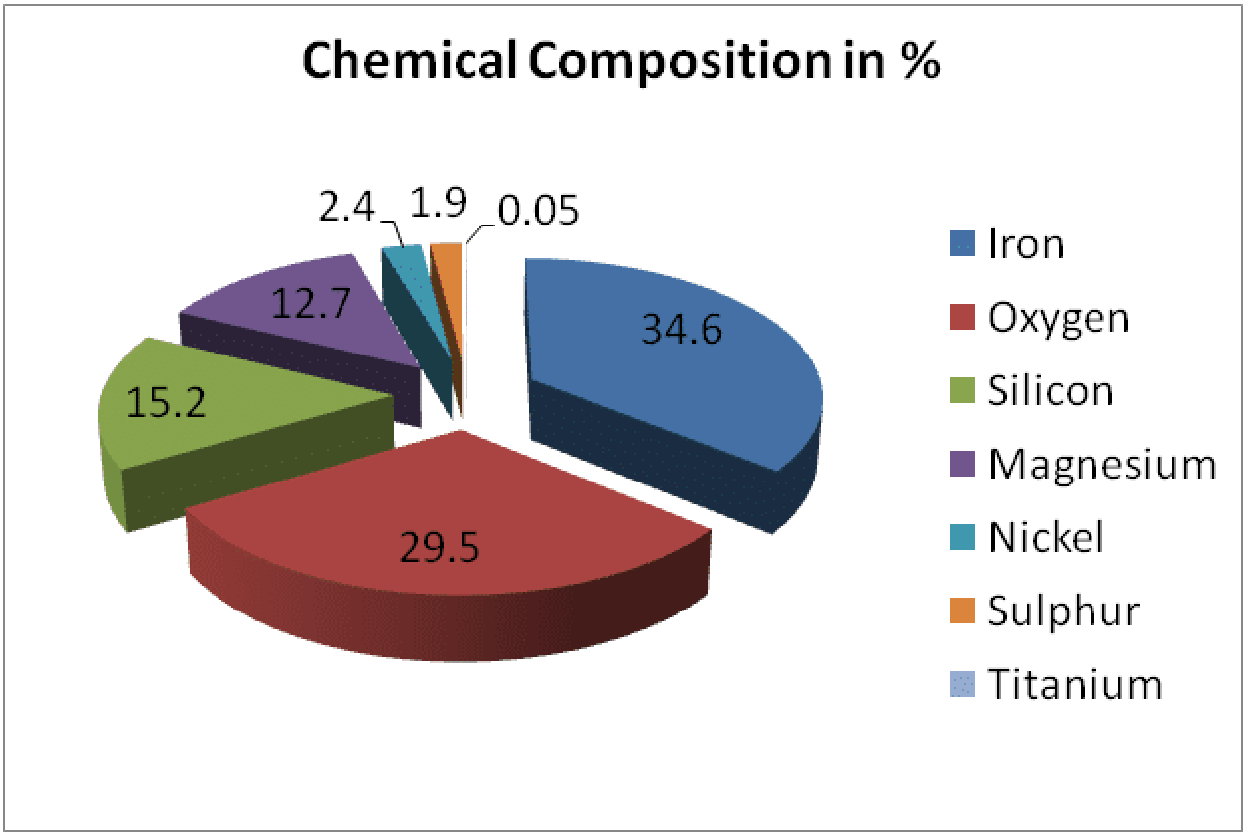
➔ Across these boundaries, seismic waves undergo significant changes in terms of their direction and speed.

1. **Conorod Discontinuity:** between **upper and lower crust**

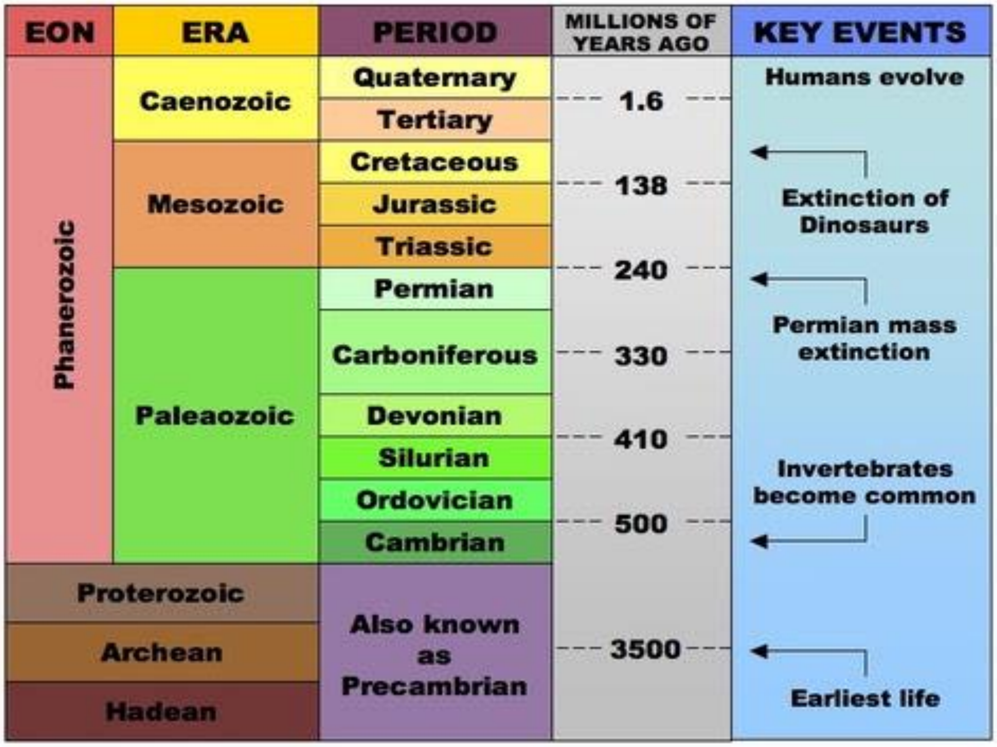
2. **Mohorovicic Discontinuity (Moho):** Separates the crust from the mantle, its average depth being about **35 km**.
3. **Repiti Discontinuity:** between the **upper and lower mantle**
4. **Gutenberg Discontinuity:** lies between the mantle and the outer core. Below 2900 km from earth's surface.
5. **Lehman Discontinuity:** between **inner and outer core.**

➢ **Earth's Chemical Composition**

- ➔ Earth's mass is approximately **5.97×1024 kg (5,970 Yg).**
- ➔ It is composed mostly of
  1. iron (32.1%),
  2. oxygen (30.1%),
  3. silicon (15.1%),
  4. magnesium (13.9%),
  5. sulfur (2.9%),
  6. nickel (1.8%),
  7. calcium (1.5%),
  8. aluminum (1.4%),
- ➔ with the remaining **1.2%** consisting of trace amounts of other elements.



- <u>Geologic time scale</u>
  - ❖ The geological time scale **(GTS)** is a system of chronological measurement that describes the **timing and relationships between events that have occurred throughout Earth's history.**
  - ❖ **<u>Applications</u>**
    - ➢ **Illustrate the vast diversity of life that has been present on Earth over time.**
    - ➢ Summarize how scientists study Earth's past environment and diverse life-forms by examining different types of fossils
    - ➢ Explains how Earth's history has been influenced by catastrophes that have affected the conditions on Earth and the diversity of its life-forms.
  - ❖ Divisions of Geologic Time



➢ Geological time begins with **Precambrian Time**.

1. **<u>PRE-CAMBRIAN</u>**
    - ➔ Started **700 million years before present**.
    - ➔ Earth changed from **gaseous to a liquid state.**
    - ➔ **Marine grasses evolved**
    - ➔ Soft-bodied invertebrate animals evolved in warm seas but land areas devoid of animals.
2. **<u>Paleozoic (ancient life)</u>**
    - ➔ The **Cambrian period** is the 1 st period of the Paleozoic Era.
    - ➔ The explosion of life in the oceans began during this era.
    - ➔ Most of the continents were covered in **warm, shallow seas.**
    - ➔ Invertebrates were dominate
    - ➔ Fish emerged during this time
    - ➔ Fish led to the arrival of amphibians

- ➔ The end of the Paleozoic era is called the "Age of Amphibians"
- ➔ Early land plants include mosses, ferns, and cone-bearing plants.
- ➔ The early coal forming forests were also formed during this time.
- ➔ Paleozoic Era
  - ★ The **Cambrian (beginning)** opened with the breakup of the world-continent **Rodinia** and closed with the formation of **Pangaea**, as the Earth's continents came together once again
  - ★ This event is thought to have caused the climate changes that led to the mass extinction events.
  - ★ The **Appalachian mountains** were formed during this time.
  - ★ At the end of the **Paleozoic, the largest mass extinction** in history wiped out approximately 90% of all marine animal species and **70% of land animals.**

3. <u>Mesozoic (middle life)</u>

- ➔ At the beginning of this era, the continents were joined as **Pangaea**.
- ➔ Pangaea broke up around the middle of this era.
- ➔ Reptiles became the most abundant animals because of their ability to adapt to the drier climate of the Mesozoic Era.
- ➔ **Dinosaurs** were also very active in this era.
- ➔ Small mammals and birds also appeared during this era.
- ➔ The main plant life of this time were **Gymnosperms or plants that produce seeds, but no flowers.**
- ➔ Flowering plants appeared during the END of this era.

- ➔ This era ended with a mass extinction event about 65 million years ago
- ➔ Many scientists believe that this event was caused by a comet or asteroid colliding with the Earth.
- ➔ Mesozoic Era – Mass Extinction Event
  - ★ Asteroid or Comet collides with Earth
    1. **Huge cloud of smoke and dust fills the air**
    2. **Blocks out sunlight**
    3. **Plants die**
    4. **Animals that eat plants die**
    5. **Animals that eat plant-eaters die.**
  - ★ However, not all forms of life died during this event. Many animals that you see today are descendants from the survivors of this extinction event.

4. **Cenozoic (recent life)**
   - ➔ Began about **65 million** years ago and continues today.
   - ➔ Mammals began to increase and evolve adaptations that allowed them to live in many different environments – land, air, and the sea.
   - ➔ Grasses increased and provided a food source for grazing animals
   - ➔ Many mountain ranges formed during the Cenozoic Era
   - ➔ The growth of these mountains may have helped to cool down the climate
   - ➔ As the climate changed, the animals had to adapt to the rise and fall of the oceans caused by melting glaciers.
   - ➔ This era is sometimes called the **“Age of Mammals”**

- Tectonics
  - ❖ The term **plate tectonics was first used by Tuzo Wilson**, of the University of Toronto

- **Plate Tectonics theory** was first published by **W.J Morgan** of Princeton University in **1962.**
- Plate tectonics is a scientific theory describing the large-scale motion of 7 large plates and the movements of a larger number of smaller plates of the Earth‘s lithosphere, over the last hundreds of millions of years.
- **<u>Plate Tectonics Theory</u>**
  - The comprehensive theory which tries to explain most of the dynamism of earth crust and features of the **endogenetic forces.**
  - The development towards the theory began in the **1960s** with extensive seafloor mapping
  - This theory is based on the 2 principle hypothesis – **Arthur Holmes** convection current hypothesis, and the concept of seafloor spreading' advocated by **Hess.**
  - It is an **improvement over Wegener's continental drift theory** and has been considered as the most sophisticated and comprehensive theory about the drift of continents and the expansion of sea floors.
  - The **lithosphere,** which is the rigid outermost shell of a planet (the crust and upper mantle), is broken up into tectonic plates. **The Earth's lithosphere is composed of seven or eight major plates (depending on how they are defined) and many minor plates.**
  - Where the plates meet, their relative motion determines the type of boundary: **convergent, divergent, or transform.**
  - Earthquakes, volcanic activity, mountain-building, and oceanic trench formation occur along these plate boundaries. The relative movement of the plates typically ranges from **zero to 100 mm annually.**
- **<u>According to Plate tectonics theory</u>**

- The lithosphere is believed to have been broken into fragments that are floating on a ductile layer called **asthenosphere (upper part of the mantle).**
- The movement of these plates is attributed to the convection currents being generated in the upper mantle.
- **Plates move horizontally over the asthenosphere as rigid units.**
- The lithosphere includes the crust and top mantle with its thickness range varying between **5-100 km** in oceanic parts and about **200 km** in the continental areas.
- The oceanic plates contain mainly the Simatic crust and are relatively thinner, while the continental plates contain Sialic material and are relatively thicker.
- Lithospheric plates **(tectonic plates)** vary from minor plates to major plates, continental plates **(Arabian plate)** to oceanic plates **(Pacific plate),** sometimes a combination of both continental and oceanic plates **(Indo-Australian plate).**
- The movement of these crustal plates **(due to convection currents in the mantle)** causes the formation of various landforms and is the principal cause of all earth movements.
- The margins of the plates are the sites of considerable geologic activity such as seafloor **spreading, volcanic eruptions, crustal deformation, mountain building, and continental drift.**

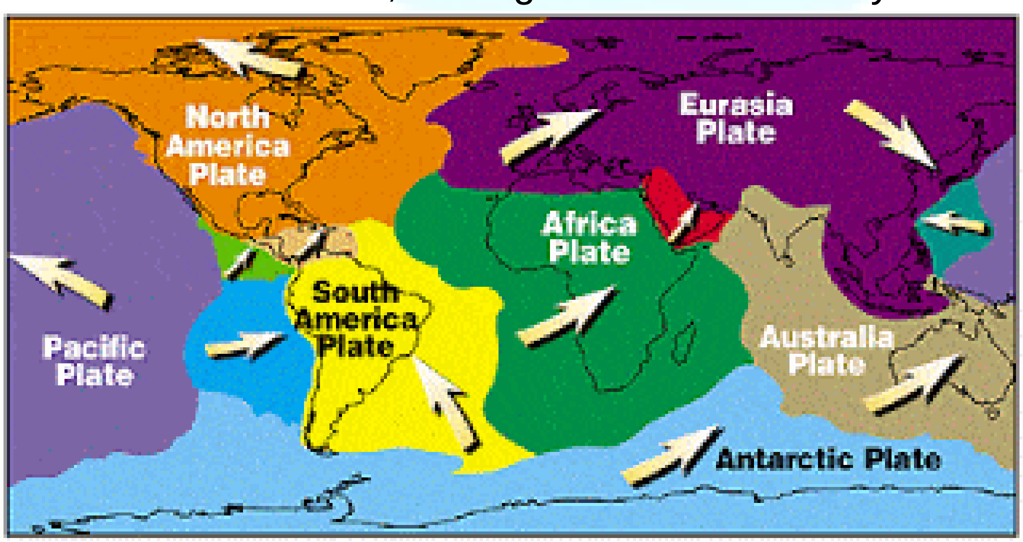
❖ Postulates of Plate tectonics theory

- The earth's interiors according to mechanical rigidity can be classified into
    1. Lithosphere
    2. Asthenosphere
    3. Mesosphere
- The theory rejects the ideas of SIAL, SIMA based classification.

- ➢ **Lithosphere –** The crust and part of the upper mantle = lithosphere (100 km thick, and less dense than the material below it so it "floats").
- ➢ **Asthenosphere –** The plastic layer below the lithosphere = asthenosphere (The plates of the lithosphere float on the asthenosphere)

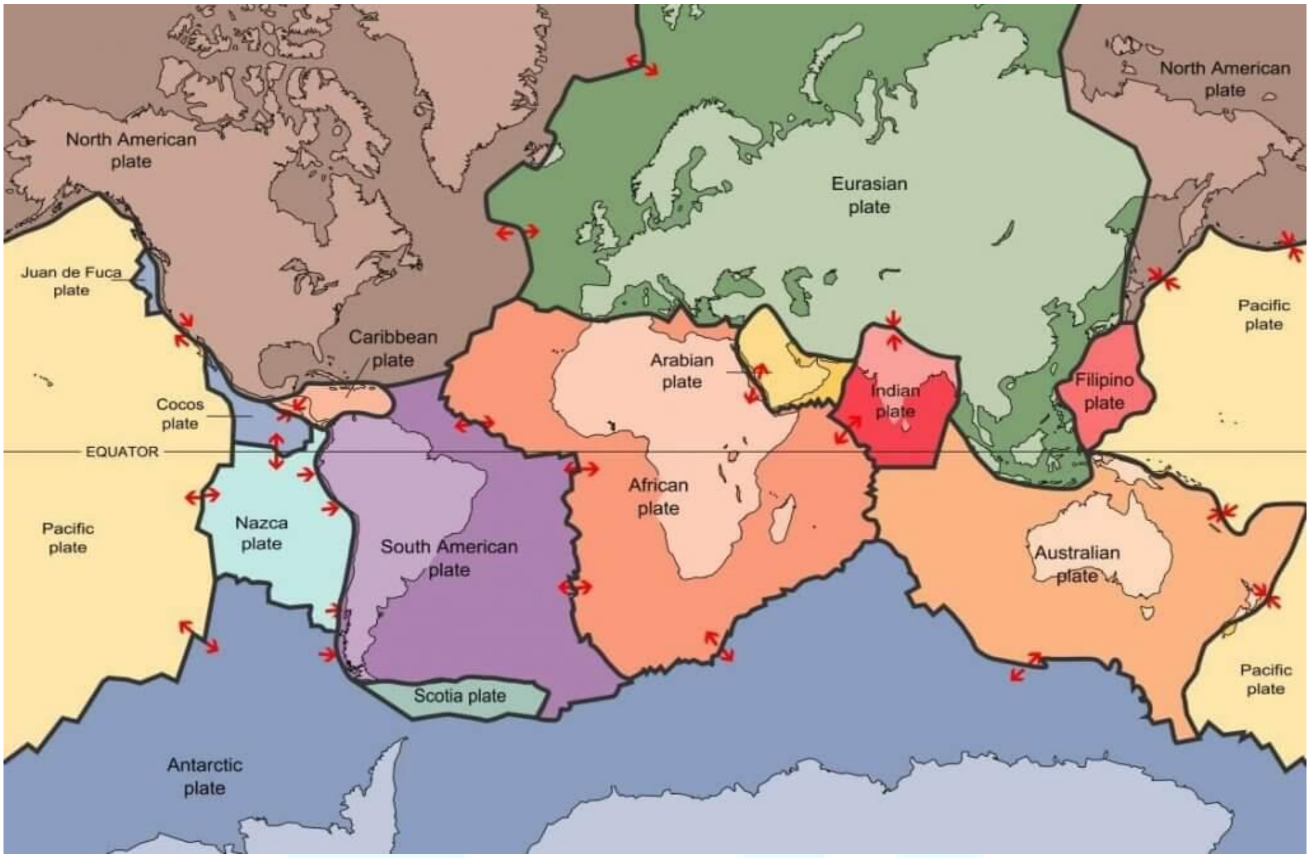
❖ **<u>Major tectonic plates</u>**

- ➢ **La Pichon** divided the earth into **seven major** and **nine minor plates.**
  1. **Antarctica and the surrounding oceanic plate** – (Surrounded by divergent boundaries.)
  2. **North American plate** – (shifting westwards, velocity 4-5 cm/year. It is half oceanic—half continental)
  3. **South American plate** – (shifting westwards, Half continental — half oceanic. 3-4 cm/year)
  4. **Pacific plate** – (Truly oceanic plate. Shifting NW 2-3cm/year)
  5. **India-Australia-New Zealand plate**
  6. **Africa with the eastern Atlantic floor plate**
  7. **Eurasia and the adjacent oceanic plate** – (mostly continental, shifting eastwards. Velocity -2-3cm/year)



❖ **<u>Minor tectonic plates</u>**

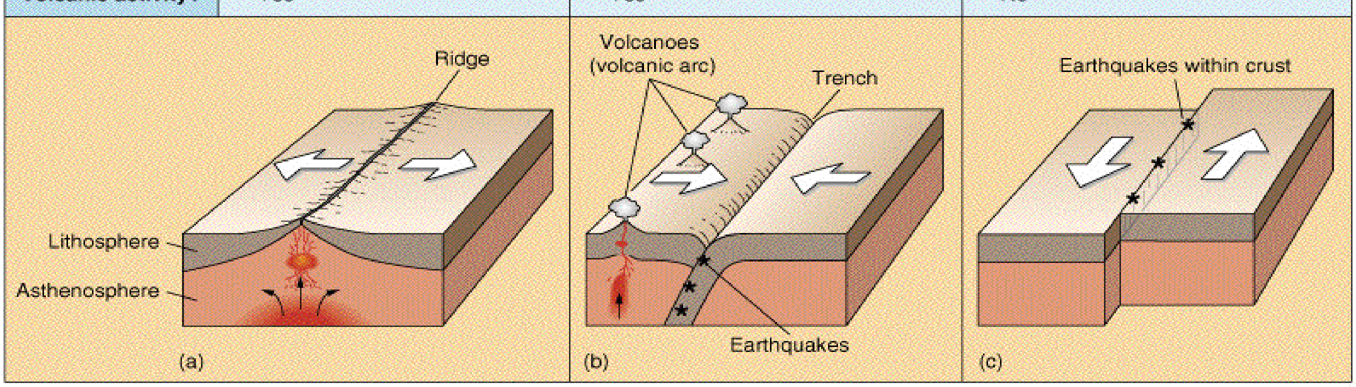
1. **Arabian plate:** Mostly the Saudi Arabian landmass
2. **Bismark plate** (North Bismarck Plate & South Bismarck Plate)
3. **Caribbean plate**
4. **Carolina plate** [straddles the Equator in the eastern hemisphere located north of New Guinea]
5. **Cocos Plate**
6. **Juan de Fuca Plate** (between Pacific and North American plates)
7. **Nazca plate**
8. **Philippine plate**: Between the Asiatic and Pacific plate
9. **Persian Plate**
10. **Anatolian Plate** [or the Turkish Plate is a continental tectonic plate comprising most of the Anatolia (Asia Minor) peninsula (and the country of Turkey)]
11. **China plate**
12. **Fiji plate [located b/w the Pacific Plate and the Indo-Australian Plate]**



❖ Three types of motion are possible between the plates

1. **Separation** or **divergent** or **constructive** plate margins
2. **Closing together** or **convergent** or **destructive** plate margins
3. **Transform** or **conservative** plate margin

Type of Margin	Divergent	Convergent	Transform
Motion	Spreading	Subduction	Lateral sliding
Effect	Constructive (oceanic lithosphere created)	Destructive (oceanic lithosphere destroyed)	Conservative (lithosphere neither created or destroyed)
Topography	Ridge/Rift	Trench	No major effect
Volcanic activity?	Yes	Yes	No



➢ **Divergent Boundaries**

➔ A divergent boundary occurs when **two tectonic plates move away from each other.**

➔ Along these boundaries, lava spews from long fissures and geysers spurt superheated water.

➔ **Frequent earthquakes strike along the rift.** Beneath the **rift, magma—molten rock—rises from the mantle.**

➔ It oozes up into the gap and hardens into solid rock, forming a new crust on the torn edges of the plates.

➔ Magma from the mantle solidifies into **basalt, a dark, dense rock that underlies the ocean floor.**

➔ Thus at divergent boundaries, oceanic crust, made of basalt, is created.

➔ Features of Divergent Boundaries

1. Mid-ocean ridges
   - ★ A mid-oceanic ridge is composed of **two chains of mountains separated by a large depression**. [Divergent Boundary]
   - ★ These oceanic ridge systems are of tectonic origin and provide evidence in support of the **theory of Plate Tectonics.**
   - ★ **Iceland,** a part of the mid-Atlantic Ridge, is an example.
2. Rift valleys
   - ★ Faulting due to divergence creates an extensive rift system (fault zones, rift valleys).
   - ★ Rifts are the **initial stage** of a continental break-up and, if successful, can lead to the formation of a new ocean basin.
   - ★ An example of a place on Earth where this has happened is the **South Atlantic Ocean,** which resulted

from the breakup of **South America and Africa** around 138m years ago.

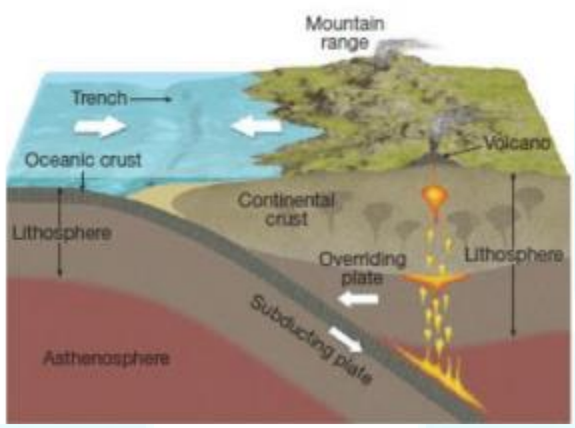
3. fissure volcanoes
   - ★ A fissure vent **(volcanic fissure)** is a narrow, linear volcanic vent through which lava erupts, usually without any explosive activity.
   - ★ The vent is often a few meters wide and may be many kilometers long.
   - ★ Fissure vents are common in **basaltic volcanism** (shield type volcanoes).

➢ **Convergent Boundaries**

- ➔ When **two plates come together**, it is known as a convergent boundary.
- ➔ The impact of the two colliding plates buckles the edge of one or both plates up into a rugged **mountain range**, and sometimes **bends the other down into a deep seafloor trench.**
- ➔ A chain of volcanoes often forms parallel to the boundary, to the mountain range, and to the trench.
- ➔ **Powerful earthquakes shake** a wide area on both sides of the boundary.
- ➔ If one of the colliding plates is topped with oceanic crust, it is forced down into the mantle where it begins to melt.
- ➔ Magma rises into and through the other plate, solidifying into a new crust. Magma formed from melting plates solidifies into granite, a light colored, low-density rock that makes up the continents.
- ➔ Thus at **convergent boundaries, continental crust, made of granite, is created, and oceanic crust is destroyed.**
- ➔ The three types of convergent boundaries are
  1. Oceanic–continental convergence,

★ **Oceanic crust may collide with a continent.** The **oceanic plate is denser**, so **it undergoes subduction.** This means that the oceanic plate sinks beneath the continent.

★ The dense oceanic plate slowly and inexorably sinks into the asthenosphere in the process of subduction. The subducting slab pulls on the rest of the plate—such "slab pull" is probably the main cause of most plate movement, pulling the rest of the plate in after itself, as it were.



2. Oceanic–oceanic convergence,

★ in collisions between two oceanic plates, the cooler, **denser oceanic lithosphere sinks beneath the warmer, less dense oceanic lithosphere.** As the slab sinks deeper into the mantle, it releases water from dehydration of hydrous minerals in the oceanic crust.

★ As one of the oceanic plates subducts beneath the other, an oceanic trench is formed, shallow and deep-focus earthquakes occur and volcanic activity is initiated with volcanoes forming on the ocean floor.

★ With time, a volcanic island arc (such as the **Aleutian Islands and the Mariana Islands**) develops; such an arc may eventually become a more mature island arc system (such as **Japan and the islands of Sumatra and Java in Indonesia are today).**

3. Continental–continental convergence.

★ Continent-Continent (C-C) convergence is formed between **two continental plates**. When the plates converge, oceanic sediments are squeezed and upthrust between the plates and these squeezed sediments appear as fold mountains along the plate margins.

★ **The Himalayan** Mountains are an example of this type of convergent plate boundary.

➢ **Transform Boundaries**

➔ A transform boundary is formed as tectonic plates slide horizontally past each other but parts of these plates get stuck at the places where they touch.

➔ These boundaries are conservative because plate interaction occurs without **creating or destroying crust**.

➔ **The San Andreas Fault in California** is an example of a transform boundary.

- Isostasy

❖ The word Isostasy is derived from the Greek word **'iso-stasios'** which means **'equal standing'** (in equipoise).

❖ The term isostasy was first proposed by an American geologist **Clarence Dutton in 1889** to indicate the state of balance which exists between large upstanding areas of the Earth's surface, mountain ranges and plateaus.

❖ The theory says that the less dense materials of the Earth's surface **(sial)** must float over the denser **magma (sima)** of the Earth's interior.

❖ Similarly, as we go deep into the Earth's interior, we see that there are several concentric layers.

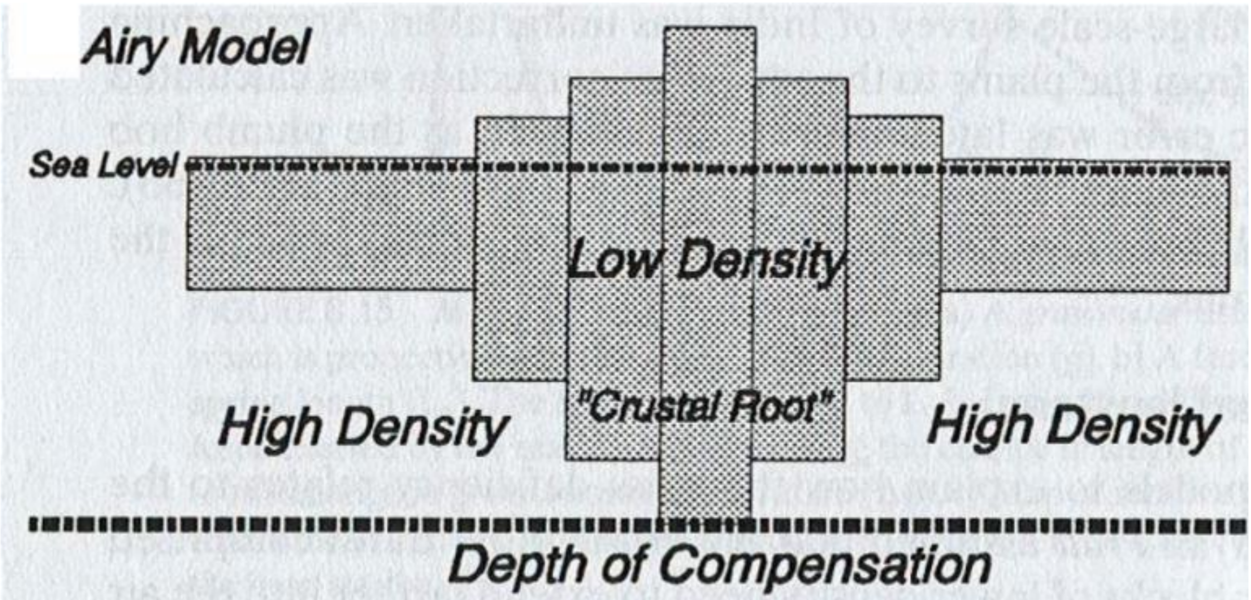
❖ **The densest material forms the core** whereas the **Earth's surface is composed of the lightest material.**

❖ **Development of the Isostasy Concept**

➢ The concept of isostasy came in the mind of geologists but the concept grew out of the attraction of giant mountainous masses.

➢ The following points highlight the top theories of isostasy

1. **Concept of Sir George Airy**



➔ According to Airy, the inner part of the mountains cannot be hollow; rather the excess weight of the mountains is compensated (balanced) by lighter materials below.

➔ According to him the crust of relatively **lighter material** is floating in the substratum of denser material. In other words, 'sial' is floating over **'sima'**.

➔ In other words, the **Himalayas** are floating in the denser magma with their maximum portion sunk in the magma in the same way as a boat floats in water with its maximum part sunk in the water. This concept in fact involves the principle of floatation.

➔ According to Airy, the density of different columns of the land (e.g. mountains, plateaux, plains etc.) remains the same. In other words, density does not change with depth, that is, 'uniform density with varying thickness'.

- ➔ This means that the continents are made of rocks having uniform density but their thickness or length varies from place to place.
- ➔ In order to prove this concept Airy took several pieces of iron of varying lengths and put them in a basin full of mercury.
- ➔ These pieces of iron sunk up to varying depths depending on their lengths.
- ➔ The same pattern may be demonstrated by taking wooden pieces of varying lengths. If we put them into the basin of water these would sink in the water according to their lengths
- ➔ Though the concept of Sir George Airy commands great respect among the scientific community, it also suffers from certain defects and errors.
- ➔ If we accept the **Airy's** views of isostasy, then every upstanding part must have a root below in accordance with its height.

2. Concept of Archdeacon Pratt

- ➔

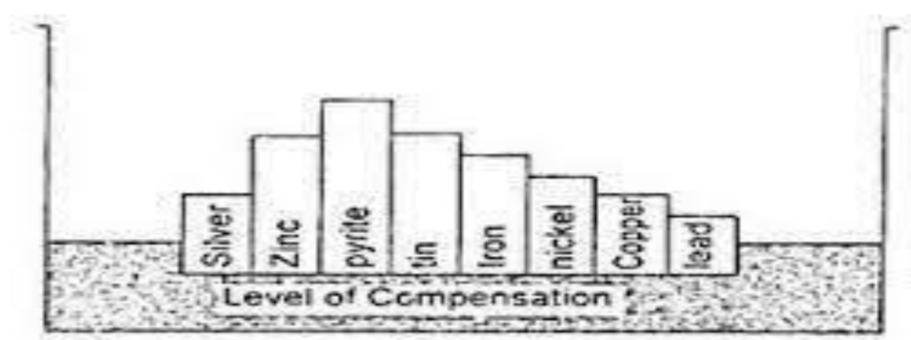


Fig. 6.3 : Explanation of the concept of Pratt on isostasy.

- ➔ Archdeacon Pratt calculated the gravitational force of the Himalayas after taking the average **density of the**

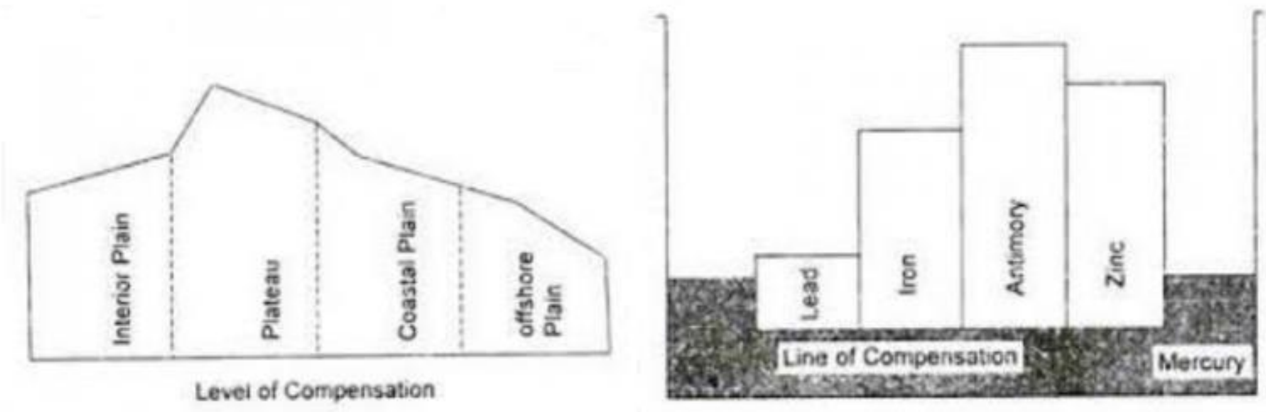
Himalaya as **2.75** and came to know that the difference should have been **15.885 seconds.**

- Pratt said that "In order to measure the angle to a star a surveyor must determine the horizontal plane if the horizontal plane between two sites were askew so must be the vertical direction".
- He then studied the rocks (and their densities) of the Himalayas and neighboring plains and found that the density of each higher part is less than a lower part. In other words, the density of mountains is less than the density of plateau, that of the plateau is less than the density of plain and the density of plain is less than the density of oceanic floor, and so on.
- This means that there is an inverse relationship between the **height of the reliefs and density.**
- **According to Pratt,** there is a **level of compensation above which there is variation in the density of different columns of the land but there is no change in density below this level.** Density does not change within one column but it changes from one column to other columns above the level of compensation.
- Thus, the central theme of the concept of Pratt on isostasy may be expressed as **'uniform depth with varying density.** According to Pratt equal surface area must underlie equal mass along the line of compensation.
- Thus, Pratt's concept of the inverse relationship between the height of different columns and their respective densities may be expressed in the following manner- **'bigger the column lesser the density and smaller the column, greater the density.'** According to Pratt

density varies only in the lithosphere and not in the pyrosphere and barysphere.

➔ Pratt's concept of isostasy was related to the **'law of compensation and not to 'the law of floatation.'**

3. Concept of Hayford and Bowie



➔ Hayford and Bowie have propounded their concepts of isostasy almost similar to the concept of Pratt. According to them there is a plane where there is complete compensation of the crustal parts. **Densities vary with elevations of columns of crustal parts above this plane of compensation.**

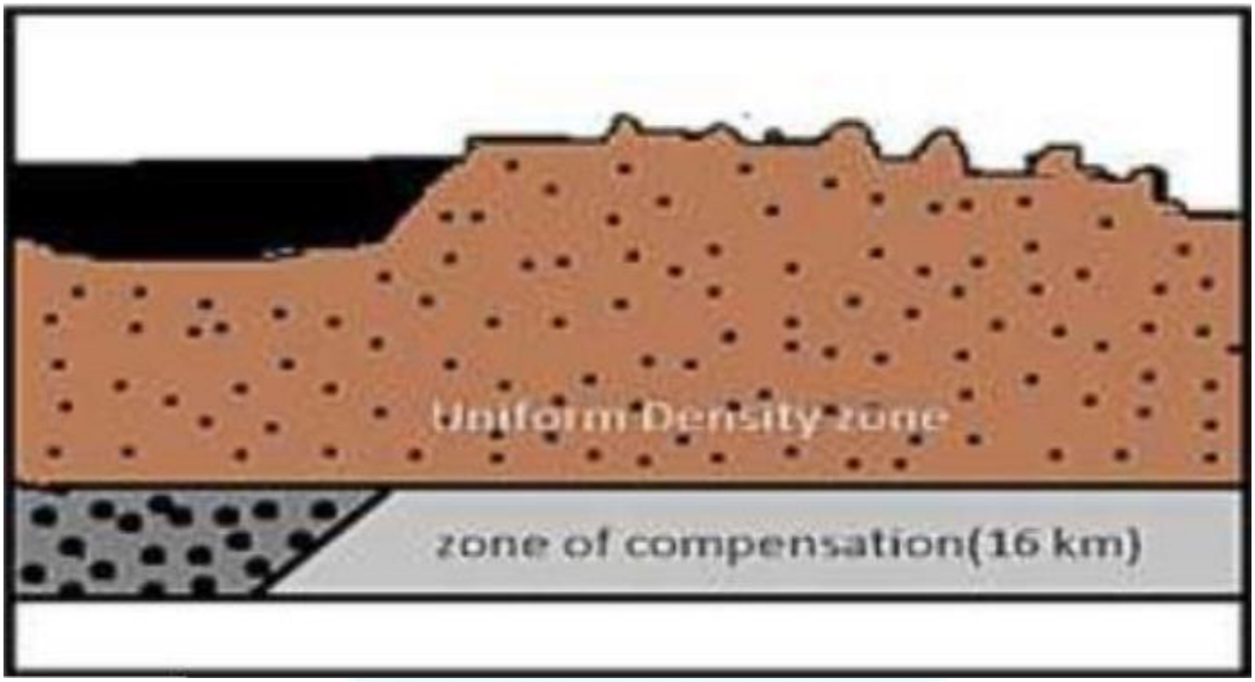
➔ **The density of the mountains is less than the ocean floor.** In other words, the crust is composed of lighter material under the mountains than under the floor of the oceans. There is such a zone below the plane of compensation where density is uniform in lateral direction.

➔ There are four imaginary columns (interior plain, plateau, coastal plain, and offshore region) which reach the level of compensation. Their height varies but they are balanced by their varying densities. **'The assumption is that the varying volume of matter in the several columns is compensated by their density, in such a fashion that they exert equal downward pressure at**

the level of compensation and thus balance one another'.

- The concept of Hayford and Bowie, that the **crustal parts (various reliefs) are in the form of vertical columns, is not tenable because the crustal features are found in the form of horizontal layers.**

4. **Concept of Jolly**



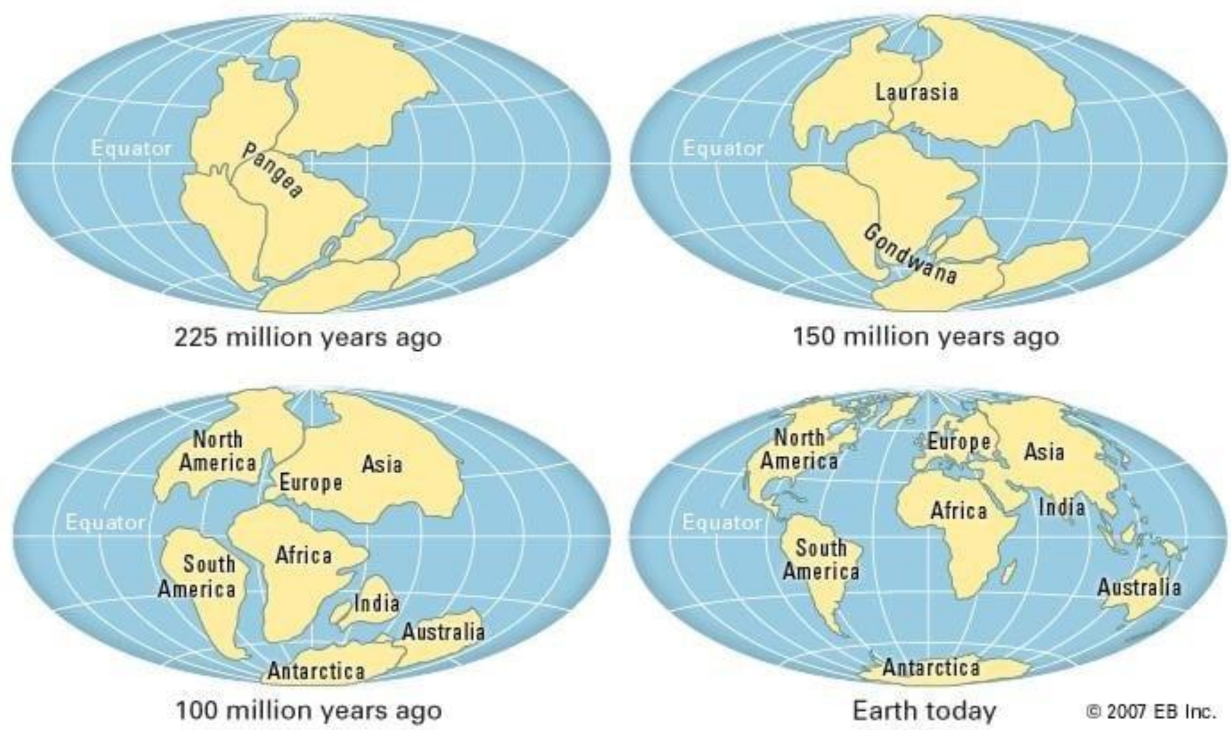
- Joly presented his views on isostasy in **1925**. He disapproved the view of **Hayford and Bowie** about the existence of a level of compensation at the depth of about 100 km on the ground that the temperature at this depth would be so high that it would cause complete liquefaction and thus level of compensation would not be possible.
- According to **Joly, there exists a layer of 10-mile (16 km) thickness below a shell of uniform density. The density varies in this zone of 10-mile thickness. It, thus, Joly assumed the level of compensation as not a linear phenomenon but a zonal phenomenon. In**

other words, he did not believe in a 'line (level) of compensation' rather he believed in a 'zone of compensation' (of 10-mile thickness).

- Continental Drift
  - Continental Drift theory was put forth by **Alfred Wegener,** a German meteorologist, polar explorer, astronomer, and geologist. **He is in fact known as the father of continental drift.**
  - In **1912, Wegener** proposed a startling theory of **'continental drift'**.
  - The movement of continents across the ocean bed is known as continental drift. This drifting takes millions of years to complete this process.
  - According to Wegener, all the continents formed a **single continental** mass which is called **"Pangaea"** which means all earth. This supercontinent was surrounded by a **mega ocean** called **"Panthalassa** " meaning all water.
  - Subsequently, **Laurasia and Gondwanaland** continued to break into various smaller continents that exist today.
  - **Various Stages of Continental Drift Theory**
    - The first stage occurred during the **Carboniferous period,** when **Pangea, a supercontinent, was encircled by Panthalassa, a mega-ocean.**
    - In the second stages around **200 million years ago** in the **Jurassic period,** the supercontinent, **Pangaea, began to split.** Pangaea first broke into large continental masses as **Laurasia** and **Gondwanaland** forming the northern and southern components respectively.
    - In the third stages, the **Tethys Sea** progressively filled the area between **Laurasia and Gondwanaland during the Mesozoic epoch,** and it gradually broadened.
    - In the fourth stage around **100 million years ago** when North and South America drifted westward, resulting in the emergence

of the Atlantic Ocean. The **Rockies and Andes** were formed by the westward drift of North and South America.

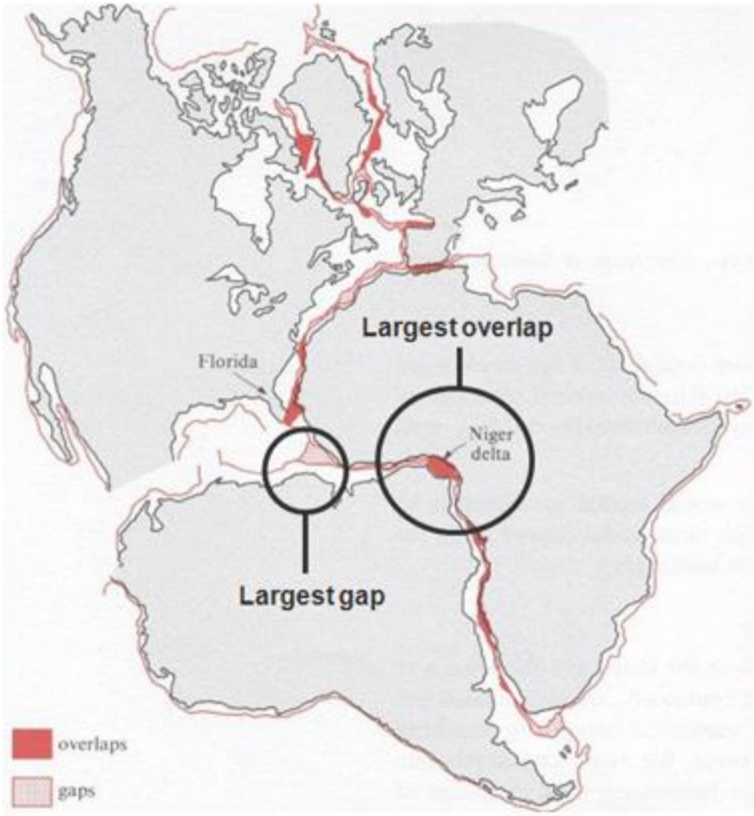
➢ The **Orogenetic Stage** in which **mountain-building activity** took place is the fifth stage.



❖ **<u>Evidence in support of the Continental Drift Theory</u>**

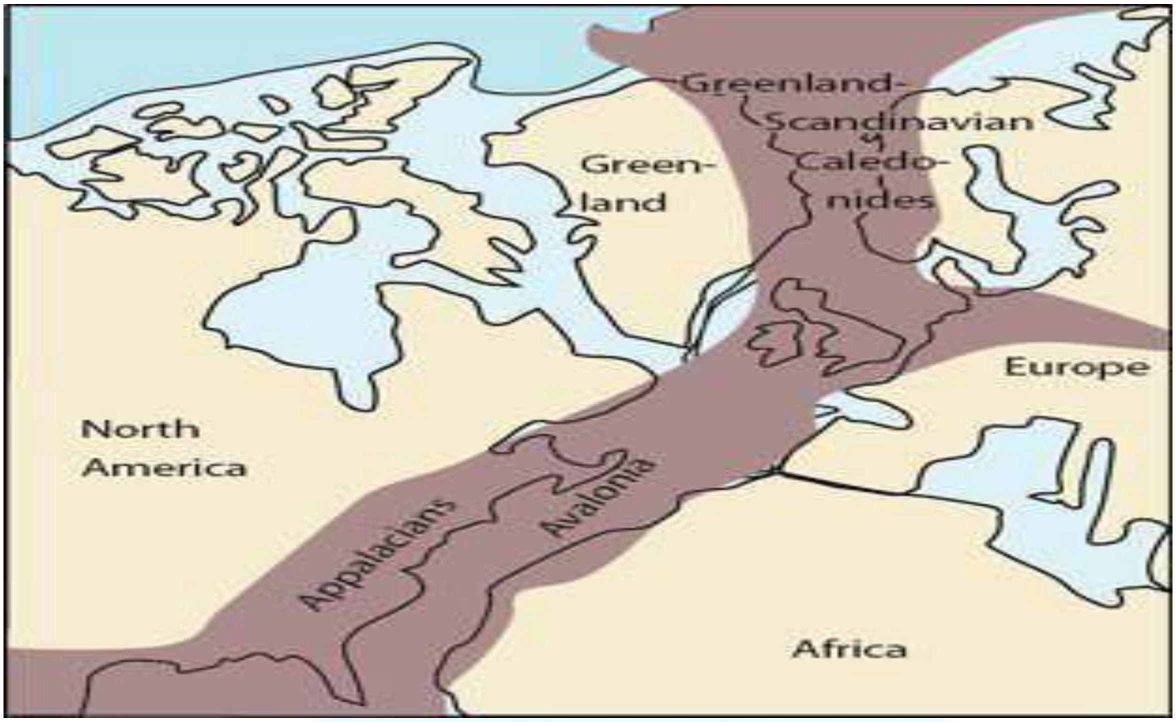
➢ **The Matching of Continents (Jig-Saw-Fit):**

➔ When facing one another, the shorelines of **South America** and **Africa** form a similarity. Similarly, when matched, Africa, Madagascar, and India's east coast all fit together.

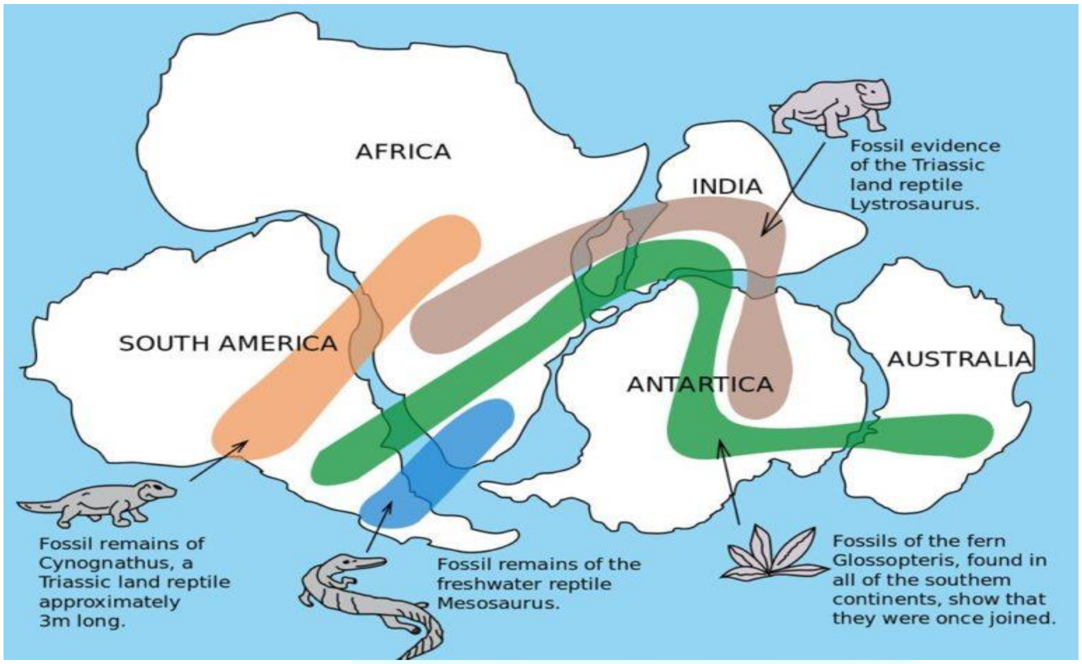


➢ **Geological structure**

- There is a remarkable similarity in geological structure along the two coasts of the Atlantic.
- The best example is provided by the **Appalachian mountains** of North America which come right up to the coast and continue their trend across the ocean in the old Hercynian Mountains of southwest Ireland, Wales, and central Europe. The opposite coasts of Africa and Brazil display even greater resemblance in their structure and rocks.



- **<u>Permo-carboniferous glaciations</u>**
  - It presents strong proof that at one point in time these landmasses were assembled together since the evidence of this glaciation is found in Brazil, Falkland island, South Africa, the Indian peninsula as well as Australia. It is difficult to explain these extensive glaciations on the basis of the existing distribution of landmass and water.
  - According to Wegener at the time of **Pangaea**, the South Pole was situated near **Durban** off the present coast of South Africa.
- **<u>Distribution of Fossils</u>**
  - **Identical species and animals were found on both sides of the marine barrier**.
  - For example, Mesosaurus, a freshwater crocodile-like reptile that lived between 286 and 258 million years ago, is only found in Southern Africa and Eastern South America.



- ➢ <u>**Paleoclimatic evidence**</u>
  - ➔ Coal deposits have been found in temperate and polar regions; however, coal is formed in tropical regions.
- ➢ <u>**Biological evidence**</u>
  - The migratory pattern of some animal species also hints towards the joined landmass.
  - For example, the entire lemming (a rodent) population crosses North America and falls in the Atlantic. It is estimated that they have not forgotten their route when the landmasses were joined, they might have traveled to Europe and Central Asia.

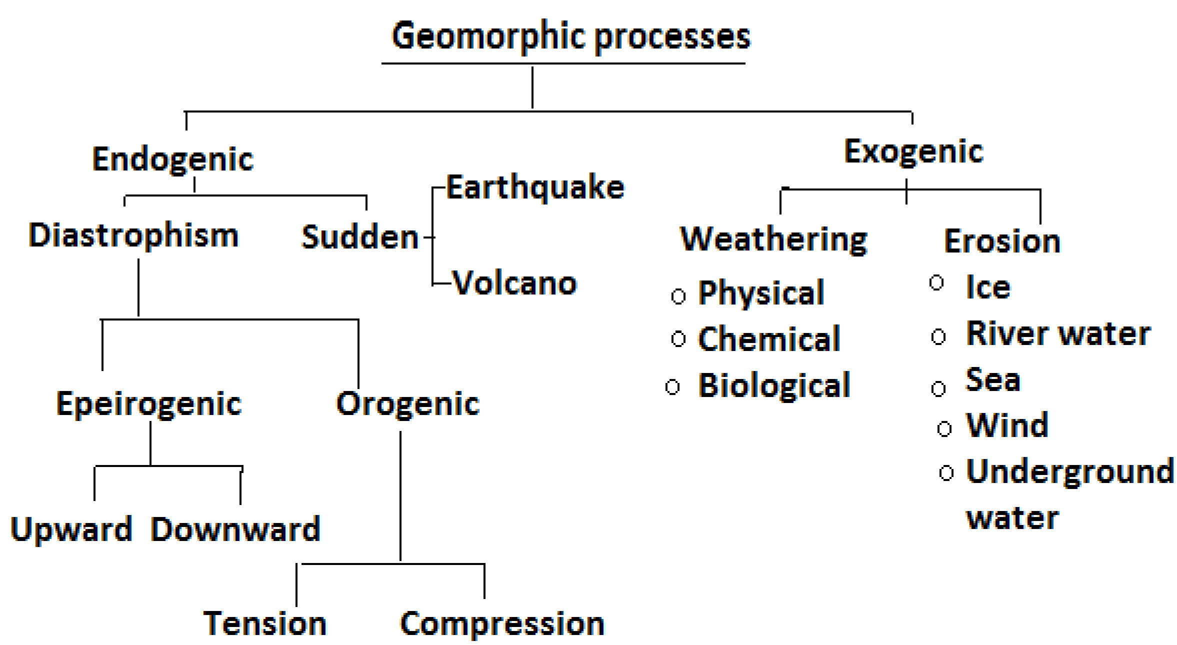
❖ <u>**Criticism of Continental Drift Theory**</u>

- ➢ The continental drift theory was undeniably convincing. But so much of the theory was based on **speculation and inadequate evidence**. **It provoked a lot of criticism and controversy.**
- ➢ The greatest criticism of this theory was due to the **controversial forces which were stated to have caused the drift.**
- ➢ According to experts, if the **gravitational force of the moon or sun was so strong to cause the landmass to break**, then it

would have stopped the rotations of the earth and made it stationary.

- ➢ Also in order to cause a drift in a landmass, the rotations required should be at such a high speed that it would have thrown the atmosphere (the gasses) and everything else in outer space away from the earth's gravitational pull.
- ➢ **Pre Carboniferous** history not known
- ➢ Why only northward and westward drift
- ➢ **Sial floating over Sima** – in reality, the lithosphere is floating on asthenosphere
- ➢ The formation of mountains **(Rockies and Andes)** due to friction by Sima is self-contradictory
- ➢ Did not explain the formation of oceanic ridges and Island arcs.

- Weathering erosion



❖ Exogenic (Exogenetic) Processes

- ➢ **Exogenic forces or external forces** are forces that draw their power from the earth's exterior or arise within the earth's atmosphere.

- ➢ The action of exogenic forces results in **wearing down** and hence they are considered as land wearing forces.
- ➢ Exogenic (Exogenetic) processes are a **direct result of** stress-induced in earth materials due to various forces that come into existence due to the sun's heat.
- ➢ Force applied per unit area is **called stress.** Stress is produced in a solid by pushing or pulling.
- ➢ The basic reason that leads to weathering, erosion, and deposition in the development of stresses in the body of the earth's materials.
- ➢ Temperature and precipitation are the two important climatic elements that control various processes by inducing stress in earth materials.

❖ **Denudation**

- ➢ All the exogenic geomorphic processes are covered under a **general term, denudation.**
- ➢ The word **'denude'** means to **strip off or to uncover.**
- ➢ **Weathering, mass wasting/movements, erosion, and transportation** are included in denudation.
- ➢ Denudation mainly depends on rock type and its structure that includes folds, faults, orientation and inclination of beds, presence or absence of joints, bedding planes, hardness or softness of constituent minerals, chemical susceptibility of mineral constituents; permeability, or impermeability, etc.
- ➢ The effects of most of the exogenic geomorphic processes are small and slow but will, in the long run, affect the rocks severely due to continued fatigue.
- ➢ Denudation:- 4 Phases

1. **Weathering**
   - ➔ Weathering is the **disintegration of rocks, soil, and minerals under the influence of physical (heat,**

pressure) and chemical (leaching, oxidation and reduction, hydration) agents.

➔ As very little or no motion of materials takes place in weathering. It is an **Insitu disintegration or breakdown of rock material.**

➔ The weathered material is carried farther away by erosion.

➔ There are **three major groups** of weathering processes

A. Mechanical Weathering

★ Physical weathering involves **mechanical disintegration of rocks due to temperature changes, freeze-thaw cycles, wet-dry cycles, crystallization of salts, animal and plant activity, etc..**

<u>Exfoliation due to pressure release or unloading</u>

★ intrusive igneous rocks formed deep beneath the Earth's surface are under tremendous pressure due to overlying load.

★ Removal of the overlying load because of continued erosion causes vertical pressure release with the result that the upper layers of the rock expand and fracture parallel to the surface.

★ Over time, sheets of rock break away from the exposed rocks along the fractures, a process known as exfoliation.

★ Exfoliation due to pressure release is also known as **"sheeting".**

<u>Exfoliation due to thermal stress weathering</u>

★ Thermal stress weathering results from the subsequent expansion and contraction of rocks caused by diurnal and seasonal variations in the temperatures.

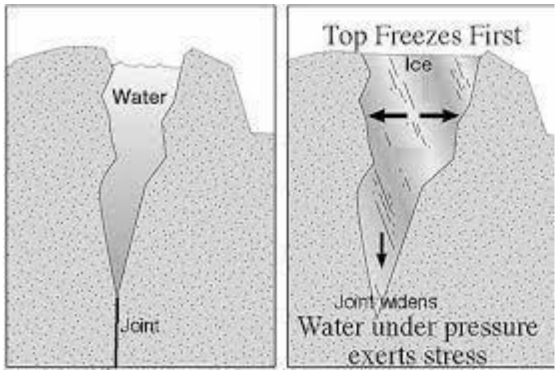
- ★ The surface layers of the rocks tend to expand more than the rock at depth, and this leads to peeling off of the surface layers (exfoliation).
- ★ This process is most effective in dry climates and high elevations where diurnal temperature changes are drastic.
- ★ Although temperature changes are the principal driver, moisture can enhance thermal expansion in rock.

Granular Disintegration

- ★ Granular disintegration happens in rocks composed of different types of **coarse-grained minerals.**
- ★ **Dark-colored minerals absorb more heat than light-colored minerals**.
- ★ This leads to differential expansion and contraction of mineral grains resulting in grain by grain separation from the rock.

Frost weathering

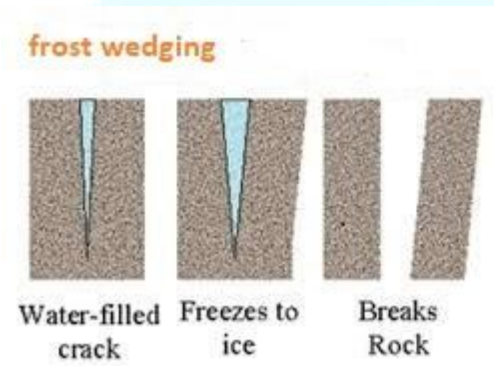
- ★ During the **warm season, the water penetrates the pore spaces or fractures in rocks.**
- ★ During the cold season, the water freezes into ice, and its volume expands as a result, this exerts tremendous pressure on rock walls to tear apart even where the rocks are massive.
- ★ Frost weathering occurs due to the growth of ice within pores and cracks of rocks during repeated cycles of freezing and melting.
- ★ Frost weathering is the collective name for several processes where ice is present.
- ★ These processes include frost **shattering, frost-wedging, and freeze-thaw weathering.**



Frost wedging

★ Freeze wedging is caused by the repeated freeze-thaw cycle.

★ Cracks filled with water are forced further apart with subsequent freezing and thawing.



Shattering

★ Severe frost can disintegrate rocks along weak zones to produce highly angular pieces with sharp corners and edges through the process of shattering.

★ Shattering piles up rock fragments called scree at the foot of mountain areas or along slopes

Block Separation (freeze-thaw weathering)

- ★ Repeated freeze-thaw cycles weaken the rocks which, over time, break up along the joints into angular pieces.
- ★ The splitting of rocks along the joints into blocks is called block disintegration.

Salt Weathering

- ★ Salt weathering occurs when saline solutions seep into cracks and joints in the **rocks and evaporate, leaving salt crystals behind.**
- ★ Salt crystals expand during the crystallization process and also when they are subjected to above normal temperatures.
- ★ The expansion in near-surface pores causes splitting of individual grains within rocks, which eventually fall off (granular disintegration or granular foliation).
- ★ Salt weathering is normally associated with arid climates where strong heating causes strong evaporation and crystallization.

➔ **Role of Physical Weathering**

- ★ Reduces rock material to smaller fragments that are easier to transport

★ Increases the exposed surface area of rock, making it more vulnerable to further physical and chemical weathering

B. Chemical Weathering

★ Chemical weathering involves chemical decomposition of rocks and soil.

★ Chemical weathering processes include **dissolution, solution, carbonation, hydration, oxidation, and reduction that act on the rocks to decompose, dissolve or reduce them to a fine state.**

★ These weathering processes are interrelated and go hand in hand and hasten the weathering process.

★ Acids produced by microbial and plant-root metabolism, water and air **(oxygen and carbon dioxide)** along with heat speed up all chemical reactions.

★ **Water** is the main operator

Dissolution

1. Many ionic and organic compounds dissolve in water
2. **Silica, K, Na, Mg, Ca, Cl, CO3, SO4**
3. **H_2O + CO_2 + $CaCO_3$** –> Ca^{+2} + $2HCO_3^-$
4. water + carbon dioxide + calcite dissolves into calcium ions and bicarbonate ions.

Acid Reactions

1. Water + carbon dioxide <—> carbonic acid
2. Water + sulfur <—> sulfuric acid
3. H^+ effective at breaking down minerals

Hydrolysis and oxidation

1) Hydrolysis is the most important process in chemical weathering. It is due to the dissociation of H_2O into H^+ and OH^- ions which chemically combine with minerals and bring about changes, such as exchange, decomposition of crystalline structure and formation of new compounds. Water acts as a weak acid on silicate minerals.

2) Oxidation is the reaction of a substance with Oxygen

Acid Action

1) Chemical weathering is also produced by acid action, most commonly Carbonic Acid. Carbon dioxide gets dissolved in water to form a weak acid. Now a day since the concentration of Sulphur oxides and Nitrogen oxides is increasing in the atmosphere because of the burning of fossil fuels, the acidity of the rain has also increased. Carbonate sedimentary rocks, especially limestone and marble are highly susceptible to this type of weathering.
2) Acid rain is also harmful to architectural structures, especially made of marble.

C. Biological Weathering

★ Biological weathering is the weakening and subsequent disintegration of rock by plants, animals, and microbes. It can occur due to physical stress like in case of penetration of plant’s roots, the physical impact of the hooves of the animal, etc., or due to chemical changes caused by them like the action of **worms, lichens, etc.**

2. Erosion

- ➔ Erosion is the act in which the earth is **worn away, often by water, wind, or ice.** It is an **ex-situ process** where an **external agent is involved**.
- ➔ The fragments break because of external impact i.e. kinetic energy. Unlike weathering where only gravity is involved.
- ➔ The rocks are broken at one place and the broken particles are carried by the agents to far distances and are deposited.
- ➔ It is the most destructive process shaping the tertiary reliefs
- ➔ Agents of Erosion
  - ★ **Running surface water** – The landforms made by surface streams are called fluvial landforms.
  - ★ **Wind** – these landforms are formed in arid and semi-arid regions where the action of the wind is dominating. These landforms are called Aeolian.
  - ★ **Glaciers** – These landforms are carved by Glaciers in high alpine mountains.
  - ★ **Waves** – They are formed by the action of waves on the edge of the continent.
  - ★ **Karst** – These landforms are formed by the action of underground water on the Karst or Limestone region.

3. Transportation

- ★ Transportation of material in a river begins when friction is overcome.
- ★ Material that has been loosened by erosion may be then transported along the river.
- ★ There are four main processes of transportation
  1. suspension / suspended load
  2. solution / solution load
  3. saltation
  4. Traction.

4. Deposition

- ★ Erosion is the acquisition and transportation of rock debris by geomorphic agents like running water, the wind, waves etc.
- ★ Though weathering aids erosion, it is not a precondition for erosion to take place. (i.e., erosion can take place in unweathered conditions also)
- ★ The **deposition is a consequence of erosion.** The erosional agents lose their velocity and energy on gentle slopes and materials carried by them start to settle themselves.
- ★ Deposition is **not the work of any agents**. **It is just the end result of erosion.**

- Erosional and depositional landforms

❖ **Fluvial Landforms: Erosional and Depositional**

- ➢ Fluvial landforms are those **generated by running water, mainly rivers. The term fluvial derives from the Latin word ‘fluvius’ that means river.**
- ➢ Fluvial landforms cover an enormous range of dimensions, from small features like rills to major continental-scale morpho-hydrological units like large rivers and their drainage basins.

- Rivers flowing to the oceans drain about **68 % of the Earth's land surface.**
- The source of the river is generally found in an upland region with a slope down for the run-offs.
- Hence, the uplands form the catchment areas of the rivers & the crest of mountains becomes the divide or watershed from which the streams flow down the slope.
- The initial stream that exists as a consequence of the slope is called the consequent stream
- As the consequent stream wears down the surface, it is joined by several tributaries from either side.
- The drainage basin or watershed is a fundamental landscape unit in fluvial geomorphology. A drainage basin contains a primary, or trunk, river and its tributaries
- Various aspects of fluvial erosive action include
  - **Hydration:** the force of running water wearing down rocks.
  - **Corrosion/Solution:** chemical action that leads to weathering.
  - **Attrition:** It involves wear & tear of transported material among them when they roll and collide into one another.
  - **Corrosion or abrasion:** solid river load striking against rocks and wearing them down.
  - **Downcutting (vertical erosion):** the erosion of the base of a stream (downcutting leads to valley deepening).
  - **Lateral erosion:** the erosion of the walls of a stream (leads to valley widening).
  - **Headward erosion:** erosion at the origin of a stream channel, which causes the origin to move back away from the direction of the stream flow, and so causes the stream channel to lengthen.

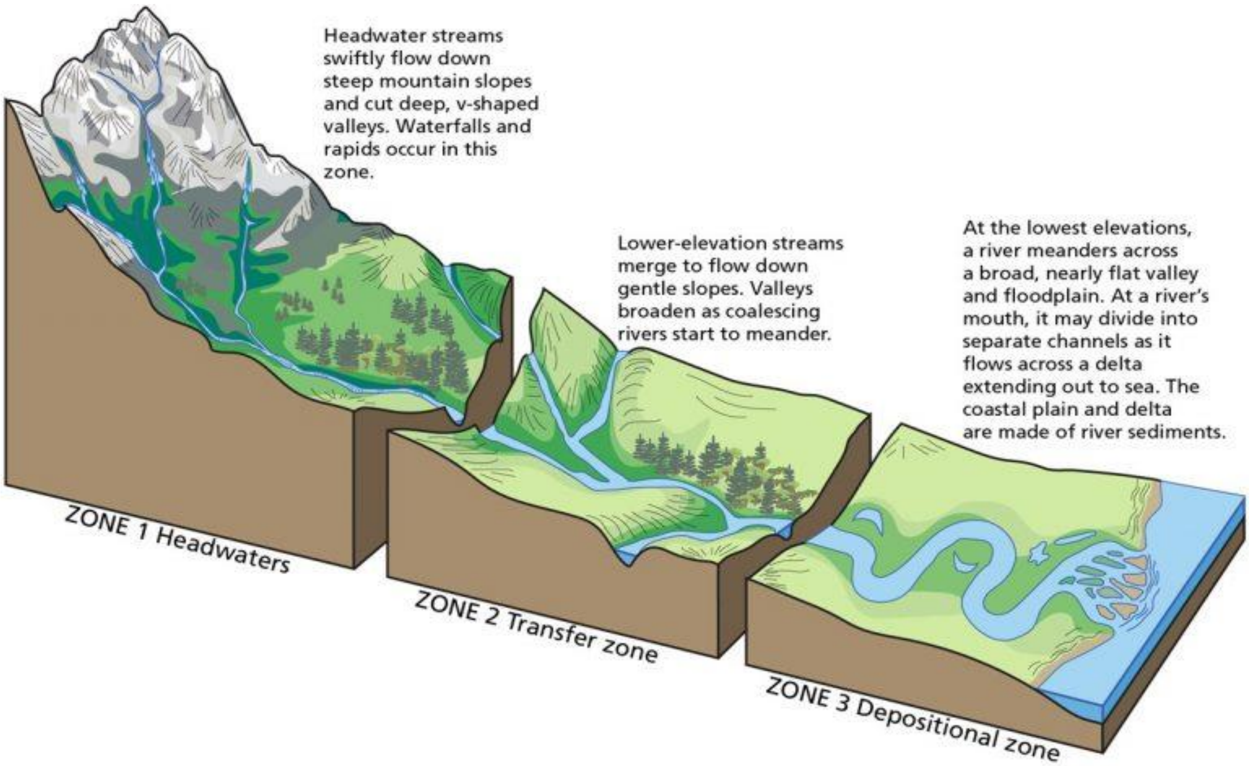
- **Hydraulic Action:** It involves Mechanical loosening & sweeping away of materials by river water. It occurs mainly by surging into the crevices & cracks of rocks & disintegrating them.
- **Braiding:** the main water channel splitting into multiple, narrower channels. A braided river, or braided channel, consists of a network of river channels separated by small, and often temporary, islands called braid bars. Braided streams occur in rivers with low slope and/or large sediment load.

- River course
  - **Youth**
    - Streams are few during this stage with **poor integration and flow over original slopes**
    - The valley developed is thus deep, narrow and distinctly **V-shaped with no floodplains or with very narrow floodplains.**
    - Downcutting predominates over lateral corrasion
    - Streams divide are broad and flat with marshes, swamp and lakes.
    - Some of the outstanding features which are developed in this stage are **gorges, canyons, waterfalls, rapids and river capture etc.**
  - **Mature**
    - During this stage, streams are plenty with good integration.
    - Lateral corrasion tends to replace vertical corrasion
    - The valleys are still V-shaped but wide and deep due to an active erosion of the banks;
    - Trunk streams are broad enough to have wider floodplains within which streams may flow in meanders confined within the valley.

- ★ Swamps and marshes of the youth stage, as well as flat and broad inter-stream areas, disappear. The stream divides and turns sharp.
- ★ **Waterfalls and rapids disappear.**
- ★ **Meander and slip off slopes are the characteristic features of this stage**

➔ **Old**

- ★ The river moving downstream across a broad level plain is heavy with sediments.
- ★ Vertical corrasion almost ceases in this stage though lateral corrasion still goes on to erode its banks further
- ★ **Smaller tributaries during old age are few with gentle gradients**.
- ★ Streams meander freely over vast floodplains. Divides are broad and flat with lakes, swamps and marshes.
- ★ **Depositional features predominate in this stage**
- ★ Most of the landscape is at or slightly above sea level
- ★ Characteristic features of this stage are **floodplains, oxbow lakes, natural levees and Delta etc.**



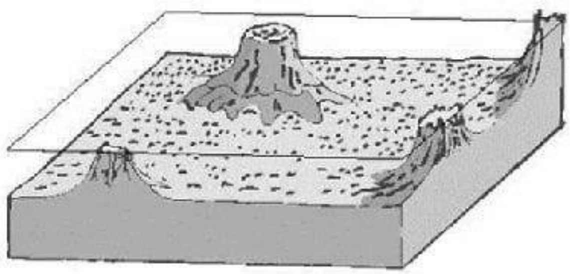
➢ **<u>Fluvial Landforms – Erosional</u>**

- ➔ Splash Erosion
  - ★ Splash erosion or rain drop impact represents the first stage in the erosion process. Splash erosion results from the bombardment of the soil surface by rain drops.
  - ★ Rain drops behave as little bombs when falling on exposed or bare soil, displacing soil particles and destroying soil structure.

- ➔ Sheet Erosion

★ Sheet erosion occurs as a shallow 'sheet' of water flowing over the ground surface, resulting in the removal of a uniform layer of soil from the soil surface.

★ Water moving fairly uniformly with a similar thickness over a surface is called sheet flow, and is the cause of sheet erosion.

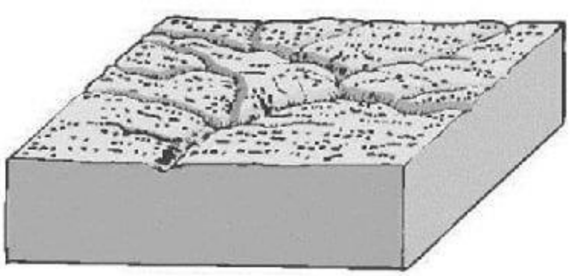


(a) Sheet erosion

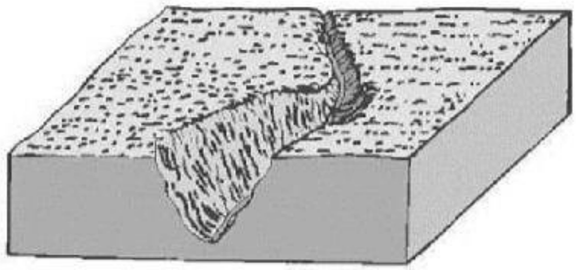
➔ Rills, and Gully

★ A rill is a shallow channel in some soil, created by the erosion of flowing water. Rills can generally be easily removed by tilling the soil.

★ When rills get large enough that they cannot easily be removed, they're known as **gullies**.



(b) Rill erosion

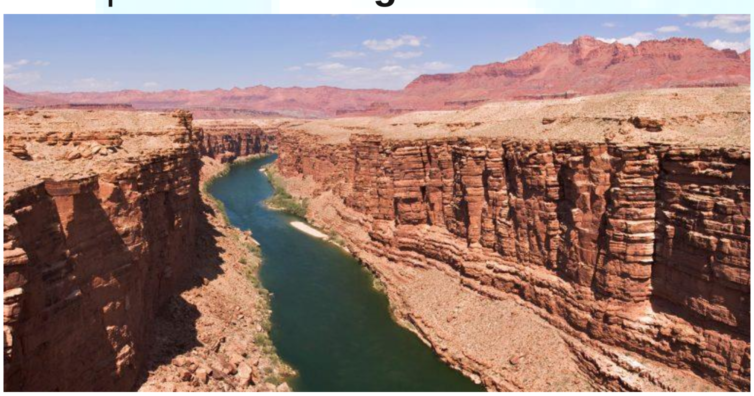


(c) Gully erosion

- ➔ Nala or Rivulet
  - ★ A rivulet is a small stream.
- ➔ Ravine
  - ★ A ravine is a landform that is narrower than a canyon and is often the product of streambank erosion.
  - ★ Ravines are typically classified as larger in scale than gullies, although smaller than valleys.
- ➔ River Valleys
  - ★ The extended depression on the ground through which a stream flows throughout its course is called a river valley.
  - ★ At different stages of the erosional cycle, the valley acquires different profiles
  - ★ **Valleys start as small and narrow rolls**
  - ★ The rills will gradually develop into long and wide gullies
  - ★ The gullies will further deepen, widen and lengthen to give rise to valleys.
  - ★ Depending upon dimensions, shape, types and structure of rocks in which they are formed, many types of valleys like the V-shaped valley, gorge, canyon, etc. can be recognised.

➔ I-shaped valley/Gorge

- ★ When the sides of the valley are almost parallel to each other, they form an **'I' shape and hence, these valleys are known as I-shaped valleys.**
- ★ A gorge is a deep and narrow valley with very steep to straight sides
- ★ A gorge is almost equal in width at its top as well as its bottom.
- ★ Gorges are formed in **hard rocks.**
- ★ Example- **Indus Gorge in Kashmir**



➔ Canyon

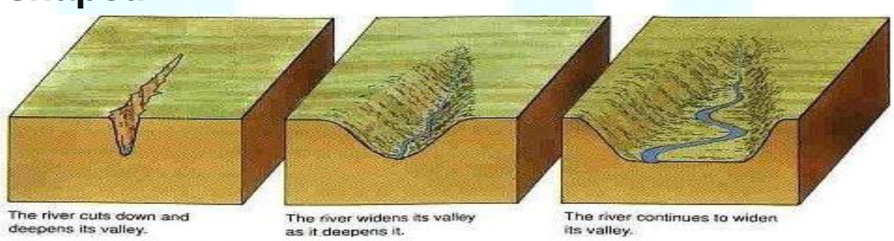
- ★ A canyon is a **variant of the gorge.**
- ★ Unlike Gorge, a **canyon is wider at its top than at its bottom.**
- ★ A canyon is characterized by **steep step-like side slopes**
- ★ Canyons commonly form in **horizontal bedded sedimentary rocks**

★ Example Grand Canyon carved by **Colorado River, USA**

➔ V-shaped valley

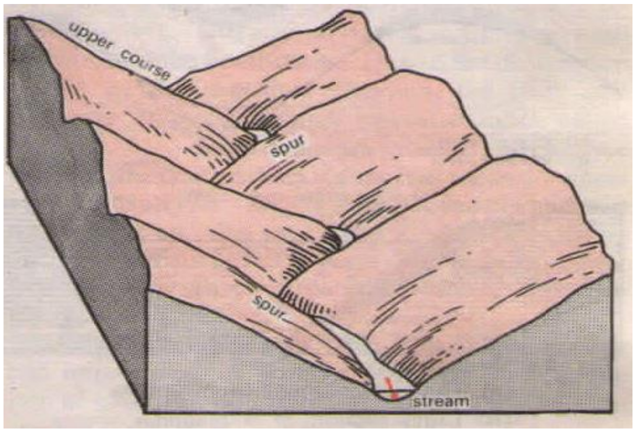
★ The river is very swift as it descends the **steep slope, and the predominant action of the river is vertical corrasion**

★ The valley developed is thus **deep, narrow and distinctly V-shaped**

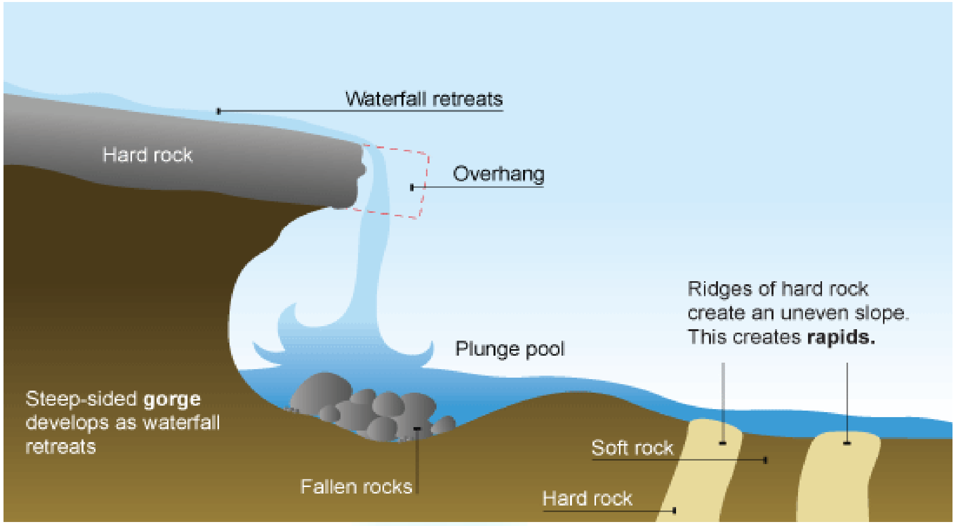


➔ Interlocking spurs

★ Interlocking spurs are projections of high land that alternate from either side of a V-shaped valley.

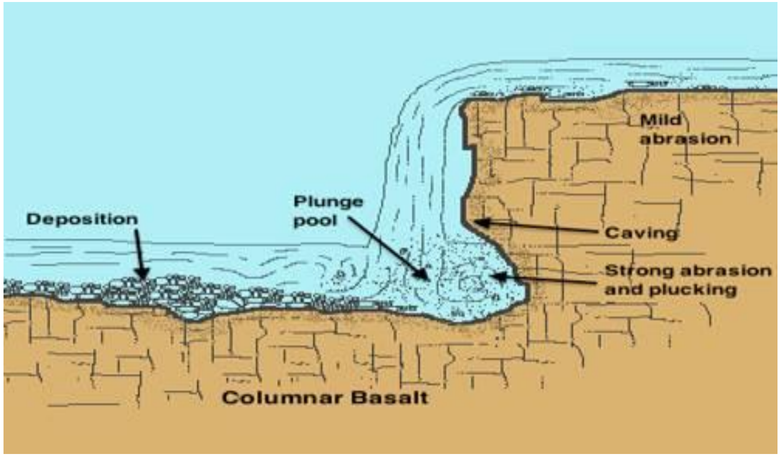


- Waterfalls & Rapid
  - When rivers plunge down in a sudden fall of some **height, they are called waterfalls**
  - Their great force usually wears out a plunge pool beneath
  - Waterfalls are formed because of several factors like the relative **resistance of rocks lying across the river, the relative difference in topographic reliefs e.g. in Plateau etc.**
  - A rapid is similarly formed due to an abrupt change in gradient of a river due to variation in resistance of hard and soft rocks traversed by a river
  - Waterfalls are also transitory like any other landform and will recede gradually and bring the floor of the valley above waterfalls to the level below



➔ Potholes & Plunge Pool

- ★ Potholes are more or less circular depressions formed over the rocky beds of hill-streams, because of stream erosion aided by the abrasion of rock fragments.
- ★ **Once a small and shallow depression forms**, **pebbles and boulders** get collected in those depressions and get rotated by flowing water and consequently the depressions grow in dimensions.
- ★ Eventually, such depressions are joined, leading to deepening of the stream valley.
- ★ At the foot of waterfalls also, large potholes, quite deep and wide, form because of the sheer impact of water and rotation of boulders. These deep and large holes at the base of waterfalls are referred to as plunge pools.
- ★ These pools also help in the deepening of valleys

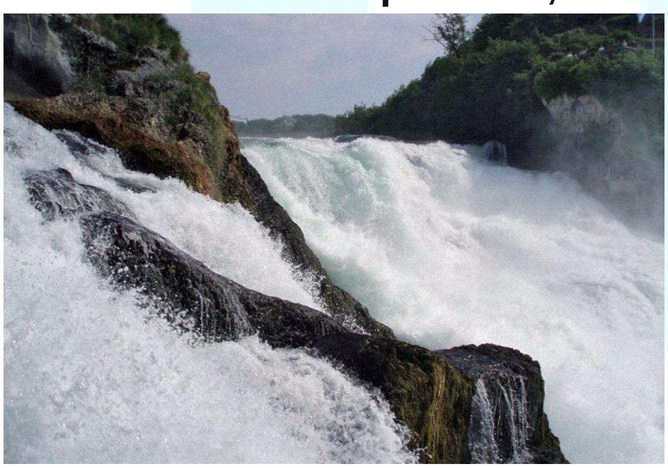


➔ Cataract

★ Cataracts are **waterfalls on very large rivers.**

★ The term cataract is usually applied to that section of a rapidly flowing river where the running water falls suddenly in a sheer drop. When the drop is less steep, the fall is known as a cascade.

★ A **cataract is a powerful, even dangerous, waterfall.**



➔ Ait/Eyot

★ An ait or eyot is a **small island.**

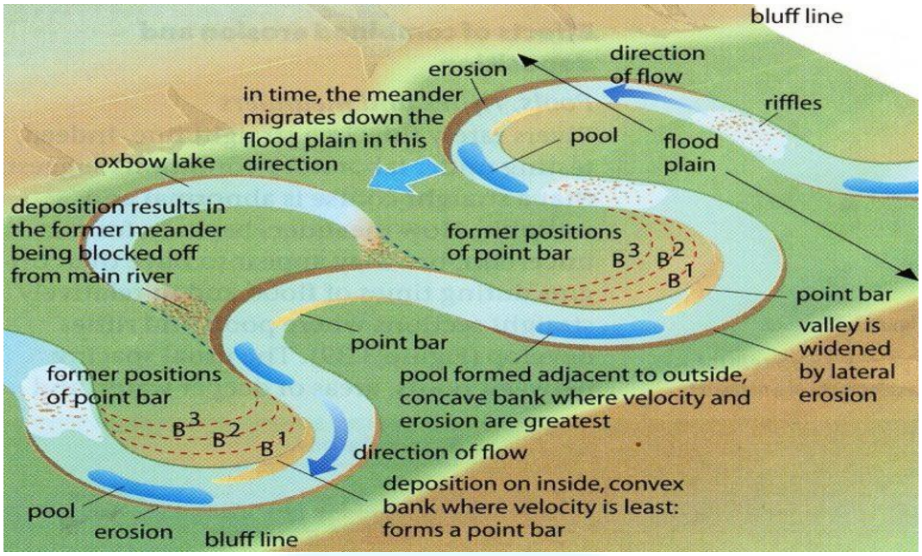
★ It is especially used to refer to river islands found on the **River Thames and its tributaries in England.**

★ Aits are typically formed by the deposit of sediment in the water, which accumulates over a period of time.

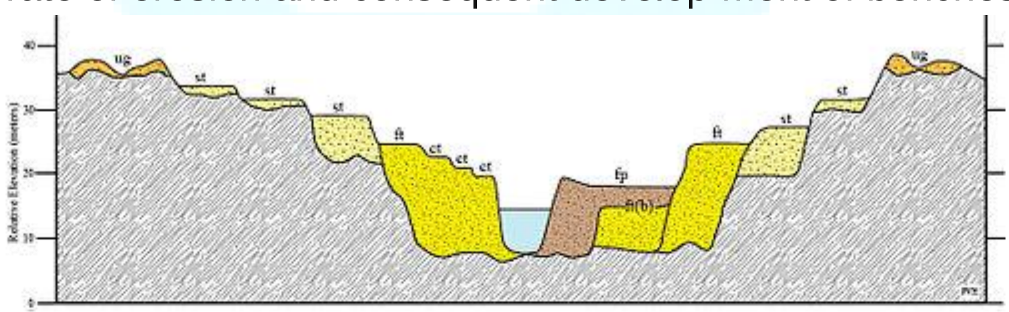
- ★ An ait is characteristically **long and narrow**, and may become a permanent island should it become secured and protected by growing vegetation.
- ★ However, aits may also be eroded: the resulting sediment is deposited further downstream and could result in another ait.
- ★ A channel with numerous **aits is called a braided channel.**

➔ Incised or Entrenched Meanders

- ★ Incised or entrenched meanders are found cut in hard rocks. **They are very deep and wide**.
- ★ In streams that flow rapidly over steep gradients, normally erosion is concentrated on the bottom of the stream channel.
- ★ Entrenched meander normally occurs where there is a rapid cutting of the river bed such that the river does not erode the lateral sides.
- ★ Meander loops are developed over original gentle surfaces in the initial stages of development of streams and the same loops get entrenched into the rocks normally due to erosion or gradual uplift of the land over which they started.
- ★ They are widened and deepened over a long period of time and can be found as deep gorges and canyons in the areas where hard rocks are found.
- ★ They give an indication of the status of **original land surfaces over which streams have developed**.
- ★ **Incised meanders are said to be an impact of river rejuvenation.**



- ➔ Structural Benches
  - ★ Step like sequence of **geomorphic surfaces**
  - ★ Differential erosion of alternately arranged hard and soft rocks forming step-like valleys known as structural benches
  - ★ The benches formed due to differential erosion of alternate bands of hard and soft rock beds are called structural benches or terraces because of lithological control in the rate of erosion and consequent develop-ment of benches.

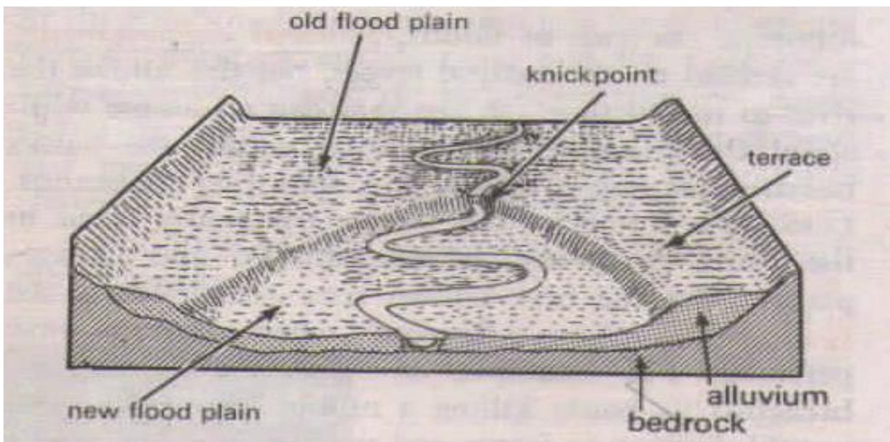


- ➔ River Terraces
  - ★ **River terraces refer to surfaces relating to old valley floor or floodplain levels.**
  - ★ They may be bedrock surfaces without any alluvial cover or alluvial terraces consisting of stream deposits.

★ **River terraces are basically products of erosion** as they result due to vertical erosion by the stream into its own depositional floodplain.

★ **There can be a number of such terraces**. They are found at different heights indicating former **river bed levels**.

★ The river terraces may occur at the same elevation on either side of the rivers in which case they are called paired terraces



➔ Peneplain

★ A peneplain (an almost plain) is a **low-relief plain** which is formed as a result of **stream erosion**

★ The peneplain is meant to imply the representation of a near-final **(or penultimate)** stage of fluvial erosion during times of extended tectonic stability

➔ Drainage Basin

★ Other terms that are used to describe drainage basins are **catchment, catchment area, catchment basin, drainage area, river basin, and water basin.**

★ The drainage basin includes both the streams and rivers and the land surface.

★ The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channeling it to a single point.

- ★ In closed (endorheic) drainage basins the water converges to a single point inside the basin, known as a sink, which may be a permanent lake (e.g. **Lake Aral, also known as Aral Sea, Dead Sea)**, dry lake (some desert lakes like **Lake Chad, Africa**), or a point where surface water is lost underground (**sinkholes in Karst landforms**).

➔ Drainage Divide

- ★ Adjacent drainage basins are separated from one another by a drainage divide.
- ★ **Drainage divide is usually a ridge or a high platform.**
- ★ Drainage divide is conspicuous in case of youthful topography (Himalayas), and it is not well marked in plains and senile topography.

➢ **<u>Fluvial Landforms – Depositional</u>**

➔ Fluvial Depositional landforms are made by river sediments brought down by extensive erosion in the upper course of the rivers.

➔ Rocks and cliffs are continually weathered and eroded in the youth stage or upper course of the river.

➔ The river moving downstream on a level plain brings down a heavy load of sediments from the upper course.

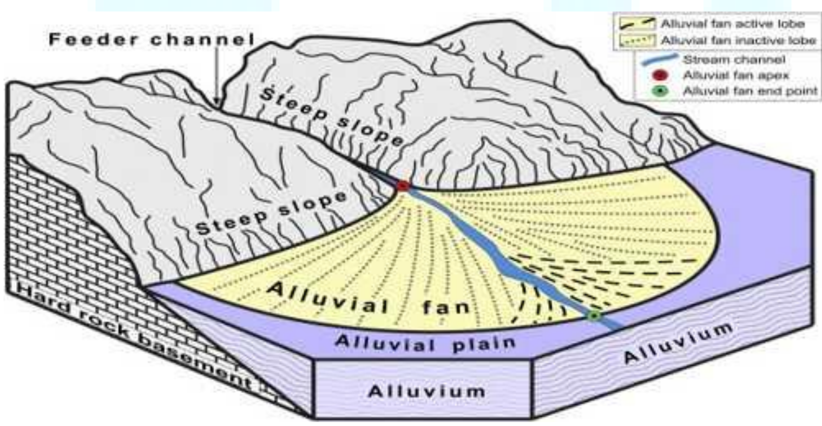
➔ The decrease in stream velocity in the lower course of the river reduces the transporting power of the streams which leads to deposition of this sediment load.

➔ **Coarser materials are dropped first and finer silt is carried down towards the mouth of the river**

➔ This depositional process leads to the formation of various depositional landforms through fluvial action such as **Delta, Levees and FloodPlain etc.**

➔ Various landforms resulting from fluvial deposition are as follows:

1. **Alluvial Fans and Cones**
   - ★ An alluvial fan is a **cone-shaped** depositional landform built up by **streams, heavy with sediment load.**
   - ★ Alluvial fans are formed when streams flowing from mountains break into foot slope plains of low gradient.
   - ★ Normally a very coarse load is carried by streams flowing over mountain slopes. This load gets dumped as it becomes too heavy to be carried over gentler gradients by the streams
   - ★ Furthermore, this load spreads as a broad low to a high cone-shaped deposit called an alluvial fan that appears as a series of continuous fans.
   - ★ Alluvial fans in humid areas show normally low cones with a gentle slope from head to toe and they appear as high cones with a steep slope in arid and semi-arid climates.



2. **Floodplains**
   - ★ Floodplain is a **major landform of river deposition.**
   - ★ Deposition develops a floodplain just as erosion makes valleys.
   - ★ Rivers in the **lower course carry large quantities of sediments**

★ Large sized materials are deposited first when the stream channel breaks into a gentle slope.

★ Sand, silt and clay and other fine sized sediments are carried over gentler channels by relatively slow-moving waters

★ During annual or sporadic floods, these materials are spread over the low lying adjacent areas. A layer of sediments is thus deposited during each flood, gradually building up a floodplain

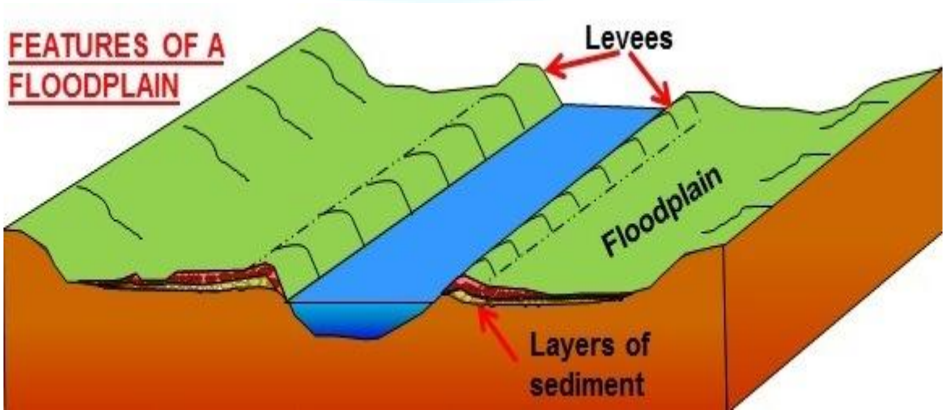
★ In plains, channels shift laterally and change their courses occasionally leaving cut-off courses which get filled up gradually by relatively coarse deposits.

★ The flood deposits of spilt waters carry relatively finer materials like silt and clay.

★ **Active Floodplain** – A riverbed made of river deposits is the active floodplain.

★ **Inactive Floodplain** – The floodplain above the bank is an inactive floodplain. Inactive floodplain above the banks basically contains two types of deposits: flood deposits and channel deposits.

★ **Delta plains – The floodplains in a delta are called delta plains**

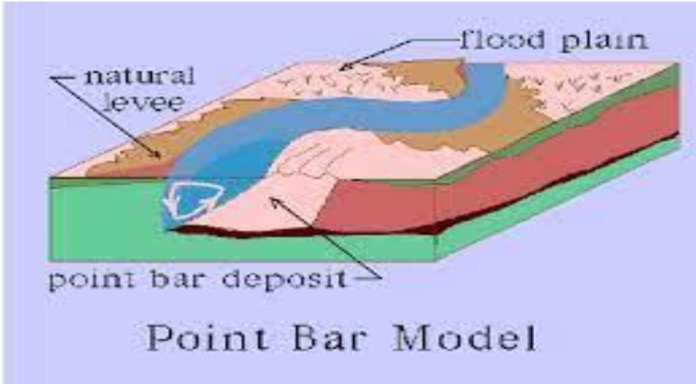


3. Doab

- ★ **Doab is the tract of land between two converging rivers.**
- ★ Doab is a term used in South Asia particularly in India and Pakistan to refer to **” tongue”** or tract of land lying between two converging rivers.

4. **Natural Levees**

- ★ **This is an important landform associated with floodplains.**
- ★ They are found along the **banks of large rivers.**
- ★ They are **low, linear and parallel ridges of coarse deposits along the banks of rivers on both sides** due to **deposition action of the stream, appearing as natural embankments.**
- ★ At the time of flooding, the water is spilt over the bank. As the speed of flow of the water comes down, large sized sediments with high specific gravity are dumped along the bank as ridges.
- ★ **They are high nearer the banks** and **slope gently away from the river.**
- ★ Generally, the **levee deposits are coarser**
- ★ When rivers shift laterally, a series of natural levees can form.
- ★ Artificial embankments are formed on the levees to minimize the risk of the floods.
- ★ But sudden bursts in the banks due to the pressure of water can cause disastrous floods.
- ★ An example of such a flood can be seen in **Hwang Ho** river which is also called **China's sorrow .**



5. **Point Bars & Cut Banks**
    - ★ Point Bar is also associated with **floodplain**
    - ★ Point bars are also known as **meander bars**.
    - ★ A point bar is a depositional feature
    - ★ It is formed by alluvium that accumulates in a linear fashion on the inside bends of streams and rivers below the slip-off slope.
    - ★ They are found on the convex side of meanders of large rivers.
    - ★ They are almost **uniform in profile and in width and contain mixed sizes of sediments.**
    - ★ Long and narrow depressions can be found in between the point bars where there is more than one ridge
    - ★ Rivers build a series of them depending upon the water flow and supply of sediment.
    - ★ As the point bars are built by the rivers on the convex side, erosion takes place on the concave side of the bank.
    - ★ Cut banks are found on the outside of a bend in a river. Cut banks are caused by the moving water of the river wearing away the earth.
6. **Meanders**

★ In large flood and delta plains, rivers rarely flow in straight courses. Loop-like channel patterns called meanders develop over flood and delta plains

★ Normally, in meanders of large rivers, there is active deposition along the convex bank and undercutting along the concave bank.

★ If there is no deposition and no erosion or undercutting, the tendency to meander is reduced.

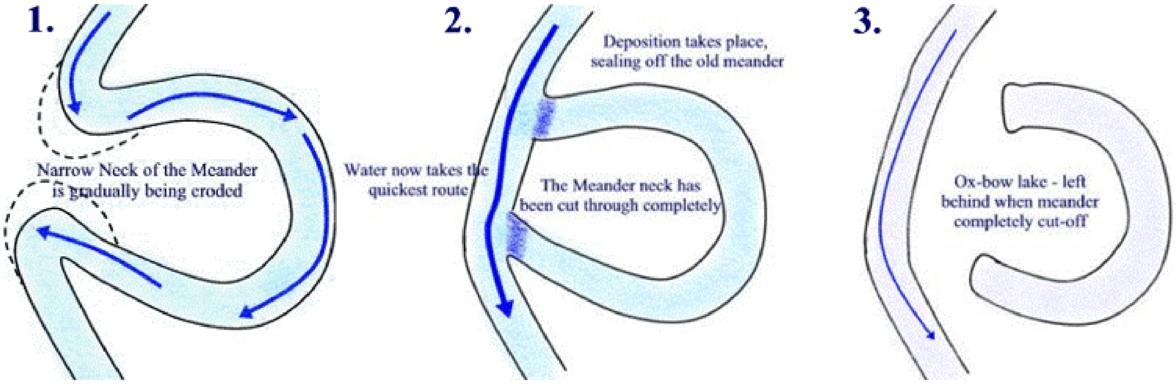
★ The concave bank is known as a cut-off bank which shows up as a steep scarp and the convex bank presents a long, gentle profile and is known as the slip-off bank

7. **Oxbow Lake**

★ In the lower course of a **river, meanders become very much more pronounced**

★ As meanders grow into deep loops, the same may get **cut-off due to erosion at the inflexion points and are left as independent water bodies**, known as **ox-bow lakes.**

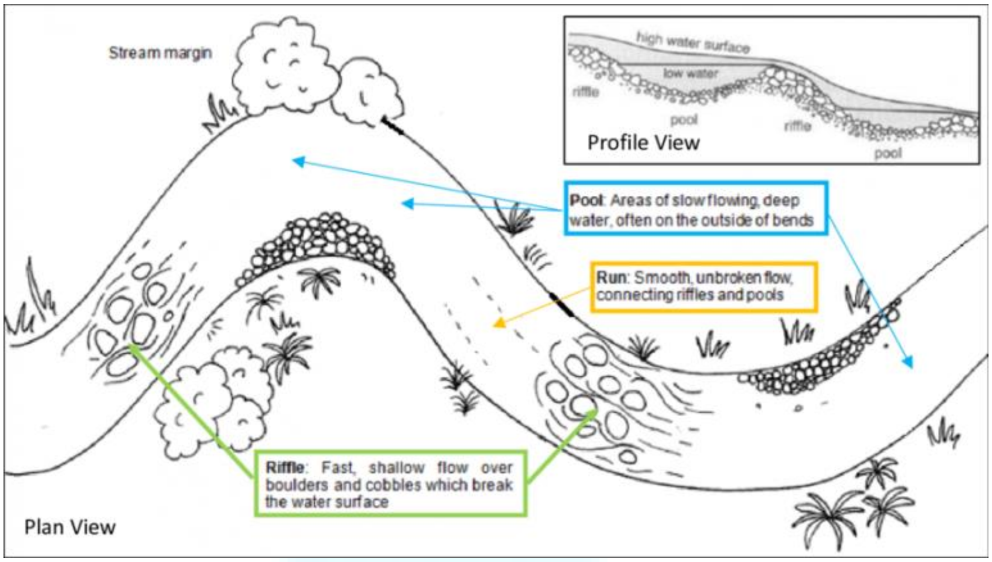
★ Through subsequent floods that may silt up the lake, oxbow lakes are converted into swamps in due course of time. It becomes marshy and eventually dries up



8. **Riffle and Pool**

★ **Pools:** An area of the stream characterized by **deep depths and slow current.** Pools are typically created by the vertical force of water falling down over logs or boulders. The movement of the water carves a deeper indentation in the stream bed. Pools are important because they can provide depth and still water.

★ **Riffles:** An area of stream characterized by **shallow depths with fast, turbulent water.** The rifles are short segments of the stream where water flow is agitated by rocks. The rocky bottom provides protection from predators, food deposition, and shelter. Riffle depths vary depending upon stream size but can be as shallow as 1 inch or deep as 1 meter. The turbulence and streamflow result in high dissolved oxygen concentration



9. **Bluff**
   - ★ A bluff is a small, rounded cliff that **usually overlooks a body of water, or where a body of water once stood.**
   - ★ Bluff is a ridge of land that extends into the air.

10. **Braided Channels**
   - ★ A braided channel consists of a network of river channels divided into multiple threads and separated by **small and often temporary islands called eyots .**
   - ★ Braided channels are commonly found where water velocity is low and the river is heavy with sediment load
   - ★ **Deposition and lateral erosion of banks are essential for the formation of the braided pattern.**
   - ★ There is the formation of central bars due to selective deposition of coarser material which diverts the flow towards the banks causing extensive lateral erosion
   - ★ As the valley widens due to continuous lateral erosion, the water column is reduced and more and more materials get deposited as islands and lateral bars developing a number of separate channels of water flow.

11. **Delta**

- ★ Deltas are **fan-shaped alluvial areas, resembling an alluvial fan**
- ★ This alluvial tract is, in fact, a seaward extension of the floodplain
- ★ The load carried by the rivers is dumped and spread into the mouth of the river at sea. Further, this load spreads and piles up as a low cone
- ★ Unlike in alluvial fans, the deposits making up deltas are very well sorted with clear stratification. The coarsest sediments are deposited first and the finer sediments are carried out further, into the sea.
- ★ **Deltas extend sideways and seaward at an amazing rate**
- ★ As the delta grows, the river distributaries continue to increase in length and Delta continues to build up into the sea.
- ★ **Some deltas are extremely large**. For example, the **Ganges delta** is as big as the whole west of **Malaysia**
- ★ Types of Deltas

  A. Bird's foot delta

  - ★ It's A kind of delta featuring long, stretching distributary channels, which branch outwards resembling the foot of a bird.
  - ★ Deltas that are less subjected to wave or tidal action culminate to a bird's foot delta. Example the **Mississippi River has a bird's foot delta extending into the Gulf of Mexico**

  B. Arcuate delta

  - ★ Arcuate is the most common type of delta. This is a **fan-shaped delta.** It's A curved or bowed delta with a convex margin facing the sea.

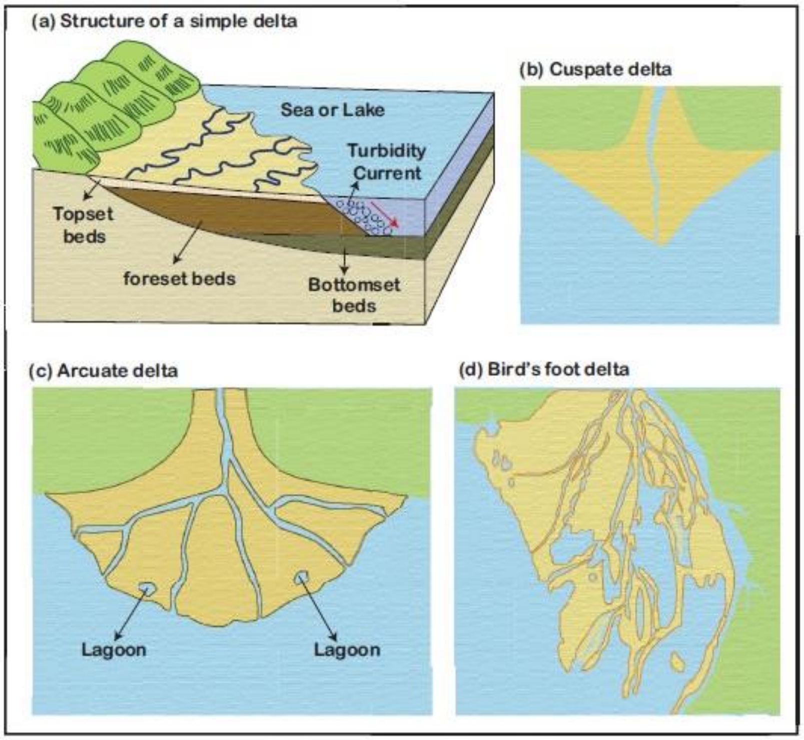
- ★ Arcuate deltas have a smooth coastline due to the action of the waves and the way they are formed. Examples – **The Nile, Ganges, and Mekong river deltas**

C. Cuspate delta

- ★ A few rivers have tooth-like projections at their mouth, known as the **cuspate delta.**
- ★ Cuspate deltas are formed where the river flows into a stable water body (sea or ocean). The sediments brought down by the rivers collide with the waves.
- ★ As a result, Sediments are spread evenly on either side of its channel. Example **Ebro river delta in Spain**

D. Estuarine delta

- ★ Some rivers have their deltas partly submerged in the coastal waters to form an estuarine delta.
- ★ This may be due to a drowned valley because of a rise in sea level. Example **Amazon river delta**



Types of Delta

➢ **Glacial Landforms: Erosional and Depositional**

Glaciers

- ➔ A glacier is a **huge mass of ice that moves slowly over land.** The term **"glacier"** comes from the **French word glace** (glah-SAY), which means **ice**. Glaciers are often called **"rivers of ice."**
- ➔ Glaciers normally assume the shape of a tongue, broadest at the source & becoming narrower downhill.
- ➔ Though the glacier is not liquid, **it moves gradually under the continual pressure from the snow accumulated above.**
- ➔ Glacial Landforms can be found in locations that currently have **no active glaciers or glaciation processes**
- ➔ Glaciers fall into two groups: **alpine glaciers and ice sheets**
- ➔ **Alpine glaciers**

- ★ **Alpine glaciers form on mountainsides and move downward through valleys**.
- ★ Sometimes, alpine glaciers create or deepen valleys by pushing dirt, soil, and other materials out of their way.
- ★ Alpine glaciers are found in high mountains of every continent except Australia (although there are many in New Zealand).
- ★ The **Gorner Glacier in Switzerland and the Furtwangler Glacier in Tanzania are both typical alpine glaciers**.
- ★ Alpine glaciers are also called **valley glaciers or mountain glaciers.**

➔ **Ice sheets**

- ★ Ice sheets, unlike **alpine glaciers,** are not limited to mountainous areas. They form broad domes and spread out from their centers in all directions.
- ★ As **ice sheets** spread, they cover everything around them with a thick blanket of **ice, including valleys, plains, and even entire mountains.**
- ★ **The largest ice sheets, called continental glaciers, spread over vast areas**. Today, continental glaciers cover most of **Antarctica and the island of Greenland**.
- ★ Massive ice sheets covered much of North America and Europe during the Pleistocene time period. This was the last glacial period, also known as the Ice Age. Ice sheets reached their greatest size about **18,000 years ago**. As the ancient glaciers spread, they carved and changed the Earth's surface, creating many of the landscapes that exist today.
- ★ During the **Pleistocene Ice Age, nearly one-third of the Earth's land was covered by glaciers.** Today, about **one-tenth of the Earth's land is covered by glacial ice**.

➔ **Glacial Cycle of Erosion**

1. **Youth**
   - ★ The stage is marked by the inward cutting activity of ice in a cirque.
   - ★ Aretes and horns are emerging**. The hanging valleys are not prominent at this stage.**
2. **Maturity**
   - ★ The valley glacier gets transformed into a trunk glacier and hanging valleys start emerging.
   - ★ The opposite cirques come closer and the glacial trough acquires a stepped profile that is regular and graded
3. **Old Age**
   - ★ The emergence of a **'U'-shaped valley** marks the beginning of old age. An outwash plain with features such as eskers, kame terraces, drumlins, kettle holes, etc. is a prominent development.
   - ★ The opposite cirques coalesce and the summit heights are greatly reduced. **Mountain tops become rounded.**

➢ **Glacial Landforms – Erosional**

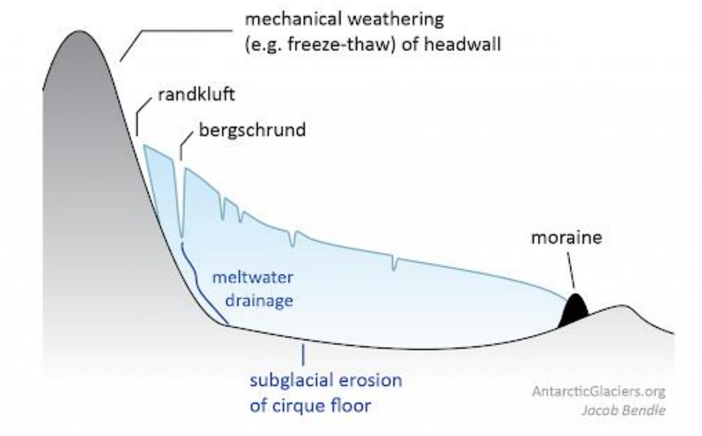
➔ **Snout or Glacier terminus**

- ★ A glacier terminus, toe, or snout, is the end of a glacier at any given point in time.
- ★ The terminus is usually the lowest end of the glacier.

➔ **Corrie, Cirque or cwm**

- ★ The downslope movement of a glacier from its snow-covered valley head & the intensive shattering of the upland slopes, tend to produce a depression where it never or firmly accumulates.
- ★ **Plucking & abrasion** further deepen the depression into a steep horse shoe-shaped basin called **Cirque (in French), cwm (in wales) & Corrie (in Scotland)**

★ There is a rocky ridge at the exit of the corrie & when the ice eventually melts, water collect behind this barrier known as **Corrie Lake or tarn**



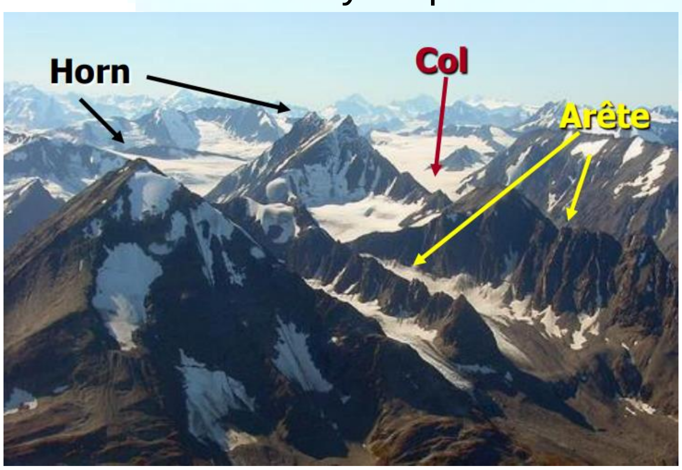
➔ Cols

★ Cols form when **two cirque basins** on opposite sides of the mountain erode the arête dividing them.

★ **Cols create saddles or passes over the mountain.**

➔ Horns

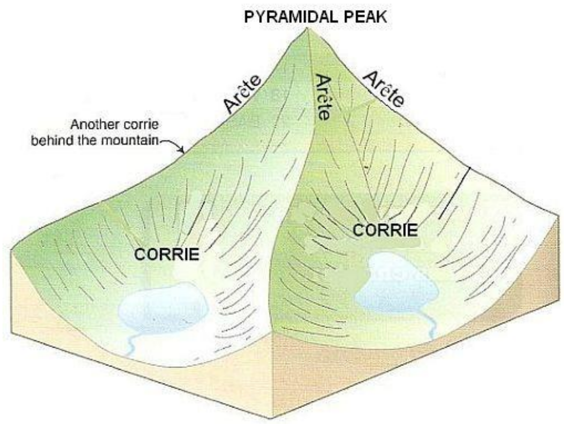
★ Horns are a single **pyramidal peak** formed when the summit is eroded by cirque basins on all sides



➔ Aretes and Pyramidal Peaks

★ When **two corries** cut back on opposite sides of the mountain, knife edged ridges are formed called **arêtes**

★ When **three or more cirques** cut back together, recession will form an angular horn or pyramidal peak.



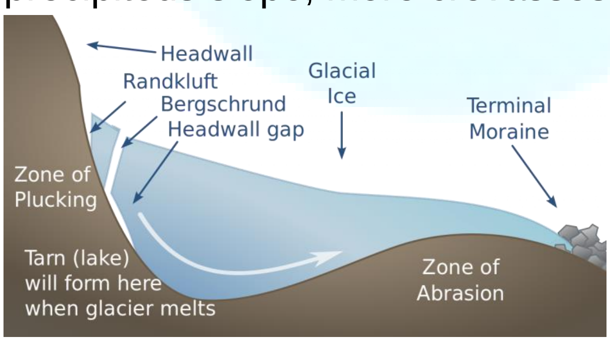
➔ Bergschrund

★ At the head of a glacier, where it begins to leave the snowfield of a corrie, a deep vertical crack opens up called a **Bergschrund or Rimaye**

★ This happens in summer when although the ice continues to move out of the corrie, there is no new snow to replace it

★ In some cases, not one but several such cracks occur which present a major obstacle to climbers

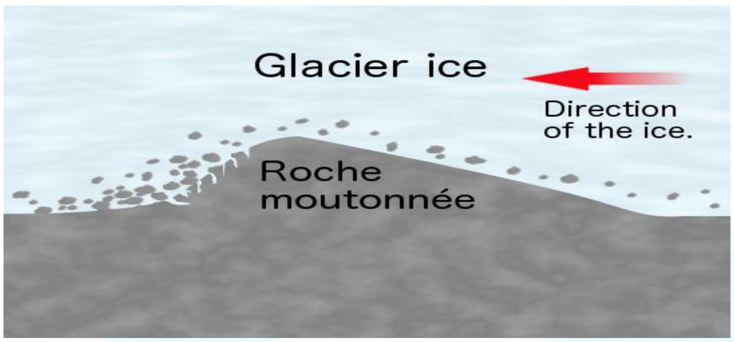
★ Further down, where the glacier negotiates a bend or a precipitous slope, more crevasses or cracks are formed



➔ Roche moutonnée

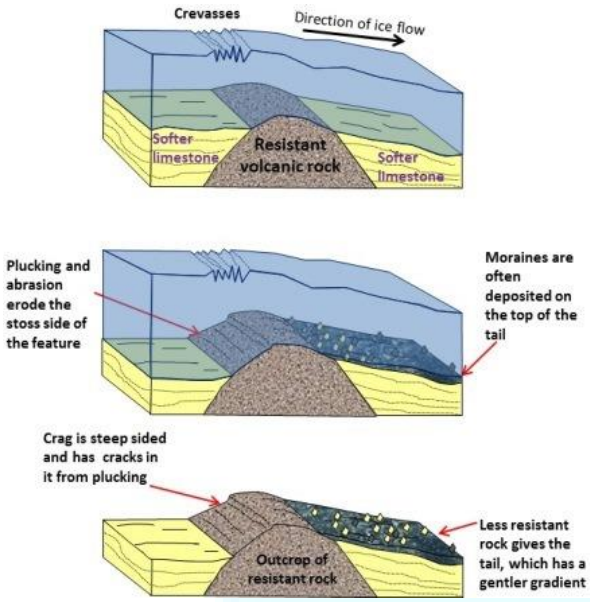
★ Basically, a resistant residual rock hummock or mound, striated by the ice movement.

★ Its upstream or stoss side is smoothed by abrasion & its downward or leeward side is roughened by plucking & is much steeper.
★ It is believed that plucking may have occurred on the leeward side due to a reduction in pressure of the glacier moving over the stoss slope
★ Therefore providing the opportunity for water to refreeze on the lee side and pluck the rock away.



➔ Crag and tail

★ A crag and tail is a larger rock mass than a **Roche moutonnee**
★ Like a Roche moutonnee, it is formed from a section of rock that was more resistant than its surroundings.
★ Crag is a **mass of hard rock with a steep slope** on the upward side, which protects the softer leeward slope from being completely worn down by the oncoming ice.
★ It therefore has a gentle tail strewn with the eroded rock debris



➔ **Nunatak**

★ A nunatak is the summit or ridge of a mountain that protrudes from an ice field or glacier that otherwise covers most of the mountain or ridge. They are also called **glacial islands.**

★ **Nunatak is a mountain peak or other rock formation that is exposed above a glacier or ice sheet**

➔ **Paternoster Lakes**

★ A paternoster lake is one of a series of glacial lakes connected by a single stream or a braided stream system.

★ **Paternoster lakes are formed in the low depression of a U-shaped valley.**

★ Paternoster lakes are created by recessional moraines, or rock dams, that are formed by the advance and subsequent upstream retreat and melting of the ice.

➔ **U shaped glacial Troughs & Ribbon lakes**

★ Glaciers on their downward journey are fed by several corries scratches & grind the bedrock with straightening out any protruding spurs.

★ The interlocking spurs are thus blunted to form truncated spurs with the floor of the valley deepened.

★ Hence, the valley which has been glaciated takes the characteristic of **U shape,** with **a wide flat floor & very steep sides.**

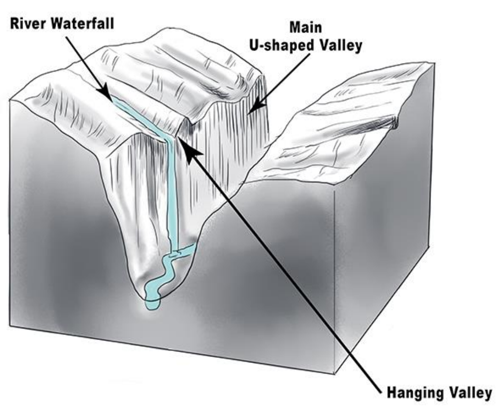
★ After the disappearance of the ice, the deep sections of these long, narrow glacial troughs may be filled with water forming **Ribbon lakes also known as Trough lakes or Finger Lakes.**

➔ **Hanging Valleys**

★ The main valley is eroded much more than the tributary valley as it contains a much larger glacier.

★ After the ice has been melted, a tributary valley hangs above the main valley & plunges down as a waterfall. Such Tributary valleys are termed as hanging valleys.

★ **Hanging valleys may form a natural head of water for generating hydroelectric power**



➔ **Rock Basins and Rock Steps**

★ **A glacier erodes & excavates the bedrock in an irregular manner**.

★ The unequal excavation gives rise to many rock basins later filled by lakes in valley trough.

★ Where a tributary valley joins a main valley, the additional weight of ice in the main valley cuts deeper into the valley floor & deepest at the point of convergence forming rock steps.

★ A series of such rock steps may also be formed due to different degrees of resistance to glacial erosion of the bedrocks

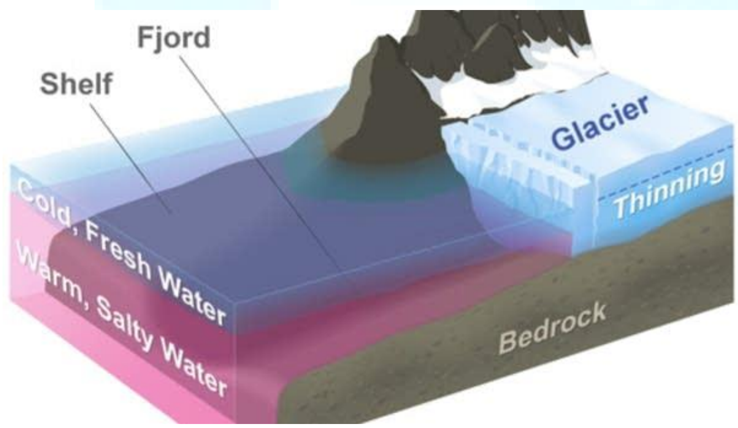
➔ **Fjord**

★ if the glacier flows right down to the sea, it drops its load of moraine in the sea.

★ If sections break off as icebergs, **moraine material will only be dropped when they melt**

★ Where the lower end of the trough is drowned by the sea, it forms a deep, steep side inlet called a **Fjord**, a typical of Norway & Chilean coast.

★ **Fjords are common in Norway, Greenland and New Zealand**



➢ **<u>Glacial Landforms – Depositional</u>**

➔ **Boulder clay or Glacial till**

★ This is an unsorted glacial deposit comprising a range of eroded materials such as **boulders, sticky clays & fine rock flour.**

★ It is spread out in sheets, not mounds, & forms gently undulating till or drift plains with monotonous landforms.

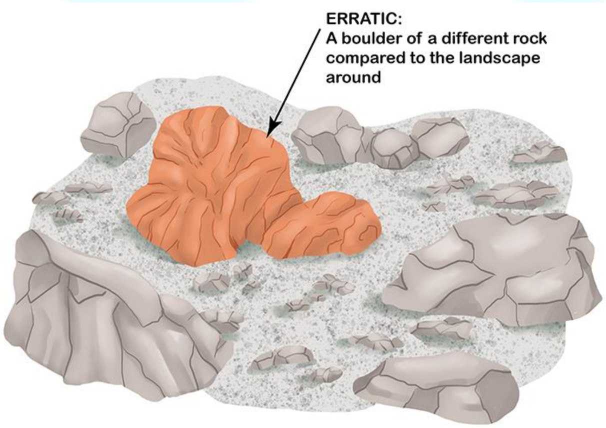
★ The degree of fertility of such glacial plains depends very much on the composition of the depositional materials.

➔ Erratics

★ Boulders of varying sizes are transported by ice & left stranded in the regions of deposition when the ice melted, called erratics because they are composed of materials entirely different from those of the regions in which they have been transported.

★ Useful in tracing the source & direction of ice movements but their presence in large numbers causes hindrance in farming.

★ **Also known as perched blocks as sometimes they are found perched in precarious positions as the ice dropped them**



➔ Moraines

★ Moraines are made up of pieces of rock that are shattered by frost action, embedded in the glaciers & brought down the valley.

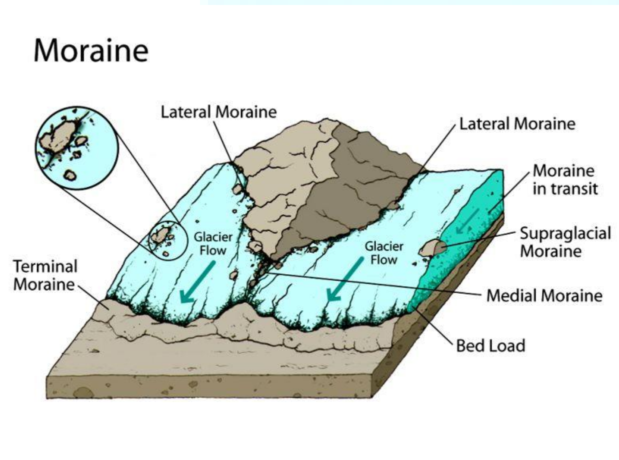
★ Those that fall on the sides of the glacier form lateral moraines.

★ When two glaciers converge, their inside lateral moraines unite to form a medial moraine.

★ The rock fragments which are dragged along, beneath the frozen ice, are dropped when the glacier melts & spread across the floor of the valley as ground moraine.

★ The glacier eventually melts on reaching the foot of the valley & the pile of transported materials left behind at the snout is terminal moraine or end moraine.

★ **The deposition of end moraines may be in several succeeding waves, as the ice may melt back by stages so that a series of recessional moraines are formed**



➔ Drumlins

★ Drumlins are oval-shaped hills, largely composed of glacial drift, formed beneath a glacier or ice sheet and aligned in the direction of ice flow.

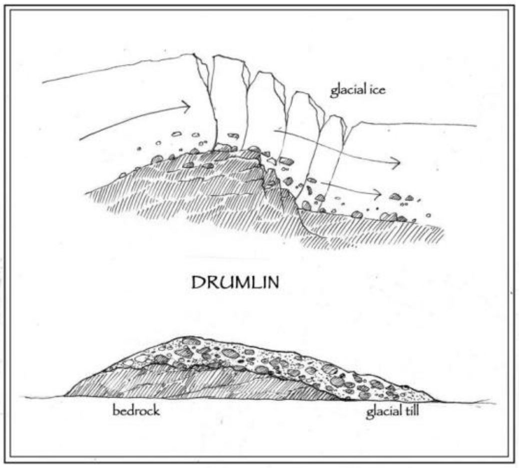
★ They are widespread in formerly glaciated areas and are especially numerous in **Canada, Ireland, Sweden, and Finland.**

★ They are low hills up to 1.5 km long and 60 mm tall & appear steeper on the onset side & taper off at the leeward side.

★ They are arranged diagonally & commonly referred to as a basket of eggs topography.

★ **'Basket of egg topography'** is the topography of drumlins, which are generally found in clusters.

★ **Drumlin fields are areas with numerous drumlins.**



➔ Eskers

★ Eskers are the sinuous ridges composed of glacial material mainly sands & gravel deposited by meltwater currents in glacial tunnels

★ Glacial tunnels mark the former sites of subglacial meltwater streams

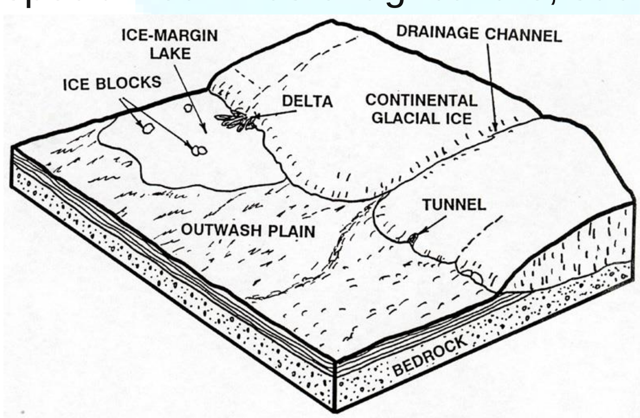
★ **Their orientation is generally parallel to the direction of glacial flow, and they sometimes exceed 100 kilometers in length**.

➔ Outwash Plains

★ Made up of fluvio glacial deposits washed out from the terminal moraines by the streams of stagnant ice mass.

★ The melt waters sort & redeposit the material mainly consisting of layers of sand and other fine sediments.

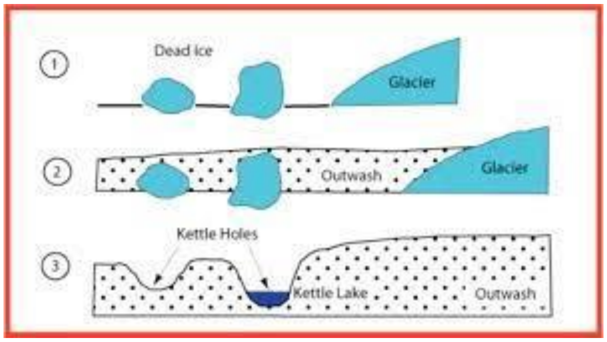
★ Such plains with their sandy soils are often used for specialized kinds of agriculture, such as the potato.



➔ Kettle lake

★ Depressions are formed when the deposition takes place in the form of alternating ridges.

- ★ Shallow, sediment-filled bodies of water formed by retreating glaciers.



➔ **Kames**

- ★ Small rounded hillocks of sand & gravel which cover part of the plain.
- ★ Kames are often associated with kettles, and this is referred to as kame & kettle topography.
- ★ **Kame is also called Hummocks**.

➢ **Marine Landforms: Erosional and Depositional**

➔ The most powerful agents of marine erosion are waves which originate due to the sweeping of winds over the water surface, setting up a series of undulating swells surging forward.

➔ On approaching shallow water near the shores, their speed is reduced and the waves are curved and refracted against the alignment of the coast.

➔ The shallow water when it is less than the height of the waves, checks their forward movement, the wave crest curls over and breaks into shore.

➔ Water that finally rushes up the beach and hurls rock debris against the land is called swash, with the water that retreats or is sucked back is called backwash.

➔ Another element in offshore drift is an undertow, which flows near the bottom away from the shore.

➔ This current exerts the pulling effect which can be dangerous for sea bathers.

Marine Landforms – Erosional

➔ **Headlands and Bays**

★ **Cliffs along the coastline do not erode at the same pace.** When a stretch of coastline is formed from different types of **rock, headlands and bays can form.**

★ Bands of soft rock such as clay and sand are weaker therefore they can be eroded quickly. This process forms bays. A bay is an inlet of the sea where the land curves inwards, usually with a beach. **Hard rock such as chalk is more resistant to the processes of erosion**. When the softer rock is eroded inwards, the hard rock sticks out into the sea, forming a headland.

★ Erosional features such as wave-cut platforms and cliffs can be found on headlands since they are more open to the waves. **Bays are more sheltered with constructive waves which deposit sediment to form a beach.**

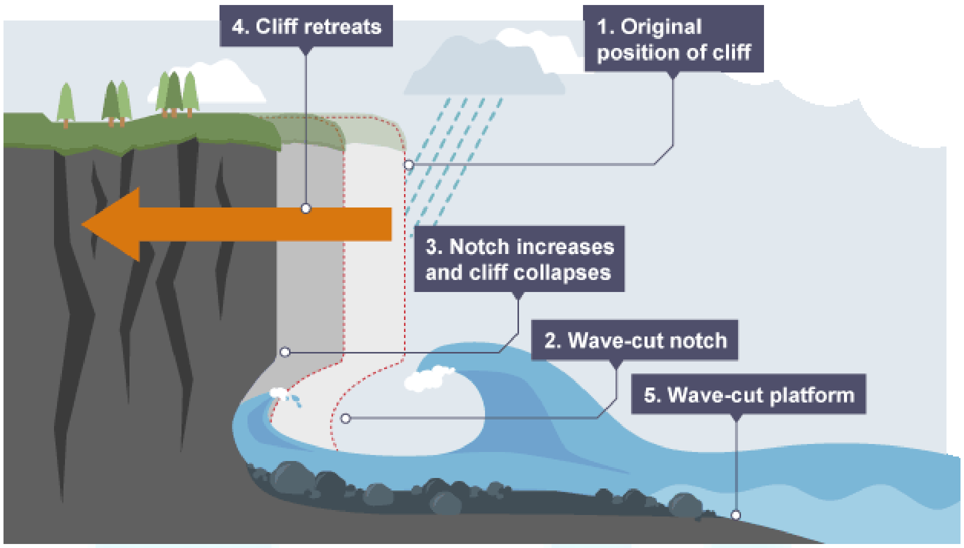
➔ **Cliffs and Wave-Cut platforms**

★ Cliffs are shaped through erosion and weathering. Soft rock erodes quickly and forms gentle sloping cliffs, whereas hard rock is more resistant and forms steep cliffs. A wave cut platform is a wide gently sloping surface found at the foot of a cliff.

★ A wave-cut platform is formed when the following occurs:

1. The sea attacks the base of the cliff between the high and low water mark.
2. A wave-cut notch is formed by erosional processes such as abrasion and hydraulic action – this is a dent in the cliff usually at the level of high tide.

3. As the notch increases in size, the cliff becomes unstable and collapses, leading to the retreat of the cliff face.
4. The backwash carries away the eroded **material, leaving a wave-cut platform.**
5. The process repeats. **The cliff continues to retreat**



➔ Caves, Arches, Stacks, and Stumps

★ **Caves, arches, stacks and stumps are erosional features that are commonly found on a headland.**

★ Cracks are widened in the headland through the erosional processes of hydraulic action and abrasion.

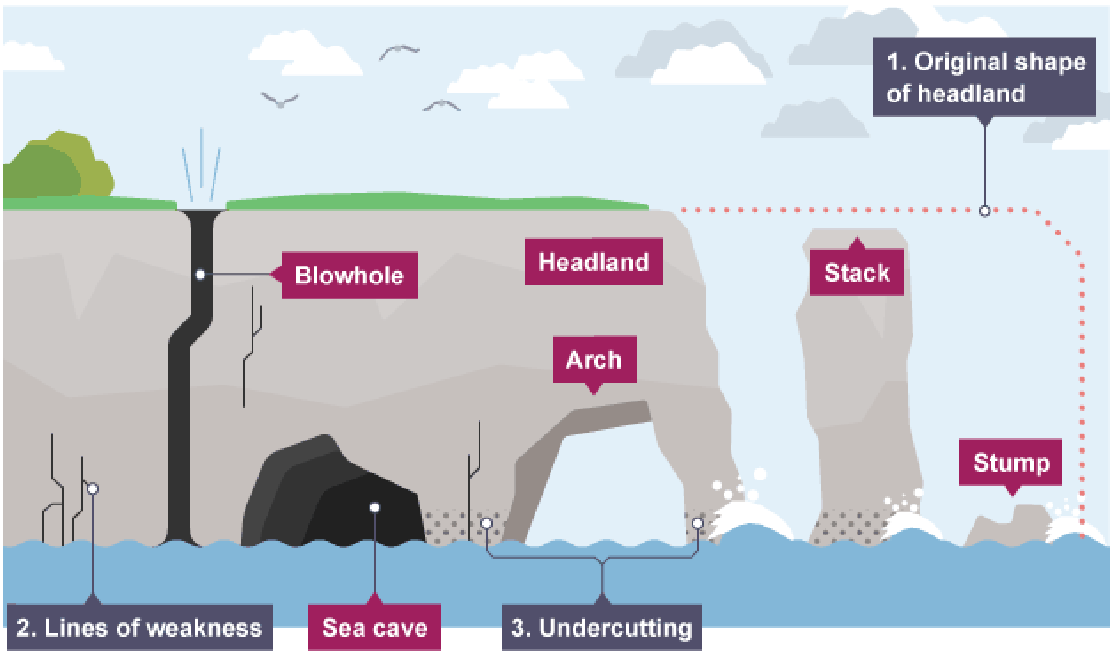
★ As the waves continue to grind away at the crack, it begins to open up to form a cave.

★ The cave becomes larger and eventually breaks through the headland to form an arch.

★ The base of the arch continually becomes wider through further erosion, until its roof becomes too heavy and collapses into the sea. This leaves a stack (an isolated column of rock).

★ When a portion of the sea arch collapses, the remaining column-like structure is called a stack, skarry or chimney rock.

★ The stack is undercut at the base until it collapses to form a stump.



➔ Ria, and Cove

★ A ria is a coastal inlet formed by the partial submergence of an unglaciated river valley. It is a drowned river valley that remains open to the sea.

★ A cove is a small bay or inlet with a sheltered or restricted entrance. It can also be the entrance to a creek or other small body of water.

★ Coves are usually formed by the erosion of soft rock formation, leaving hard rock that can form a circular or oval bay with a small entrance.

★ A cove is generally **less than 1000 feet** across and can be much smaller, sometimes **less than 100 feet** in diameter.

➔ **Geos and Gloups (blowholes or marine geyser)**

★ The occasional splashing of the waves against the roof of a cave may enlarge the joints when air is compressed & released repeatedly inside them.

★ A natural shaft is thus formed which may eventually pierce through the surface.

★ Waves breaking into the cave may force water or air out of this hole. Such a shaft is termed as Gloup or blow hole.

★ The enlargement of blow-holes & continual action of waves weakens the cave roof.

★ When the cave roof collapses, a long, narrow creek may develop known as **Geos.**

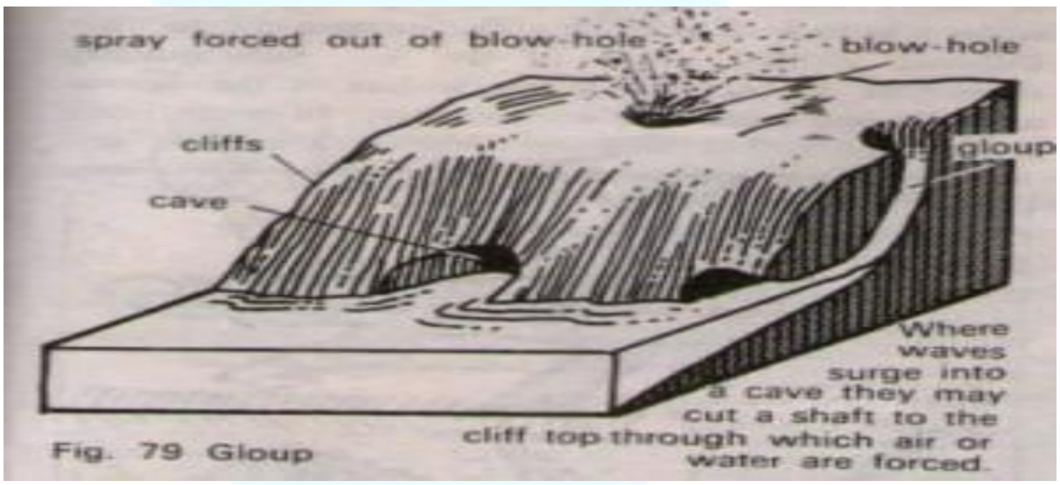


Fig. 79 Gloup

➔ **Chasms**

★ These are narrow, deep indentations **(a deep recess or notch on the edge or surface of something)** carved due to headward erosion **(downcutting)** through vertical planes of weakness in the rocks by wave action.

★ With time, further headward erosion is hindered by lateral erosion of the chasm **mouth, which itself keeps widening till a bay is formed.**

➔ **Creek, and Inlet**

- ★ **Creek:** natural stream of water normally smaller than and often tributary to a river. A creek is a narrow, sheltered waterway, especially an inlet in a shoreline or channel in a marsh.
- ★ **Inlet:** An inlet is an indentation of a shoreline, usually long and narrow, such as a small bay or arm, that often leads to an enclosed body of salt water, such as a sound, bay, lagoon, or marsh

➢ **Marine Landforms – Depositional**

- ➔ When water loses its energy, any sediment it is carrying is deposited. **The build-up of deposited sediment can form different features along the coast.**
- ➔ **Beaches**
  - ★ Beaches are made up of eroded material that has been transported from elsewhere and then **deposited by the sea.** For this to occur, waves must have limited energy, so beaches often form in sheltered areas like bays. Constructive waves build up beaches as they have a strong swash and a weak backwash.
  - ★ Sandy beaches are usually found in **bays where the water is shallow and the waves have less energy**. **Pebble beaches often form where cliffs are being eroded, and where there are higher energy waves.**
  - ★ A cross-profile of a beach is called the beach profile. The beach profile has lots of ridges called berms. They show the lines of the high tide and the storm tides. A sandy beach typically has a gently sloping profile, whereas a shingle beach can be much steeper.
  - ★ The size of the material is larger at the top of the beach, due to the high-energy storm waves carrying large sediment.

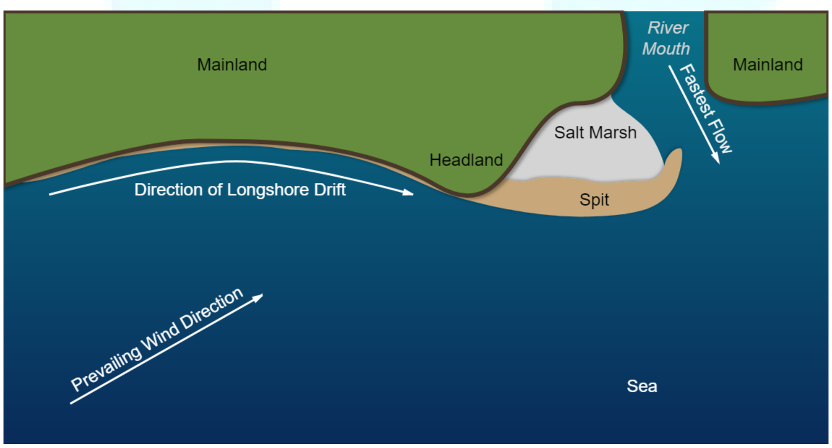
★ The smallest material is found nearest the water as the waves break here and break down the rock through attrition.

➔ Spits and Hook

★ A spit is an extended stretch of sand or shingle jutting out into the sea from the land. Spits occur when there is a change in the shape of the landscape or there is a river mouth.

★ This is how spits are formed:

1. Sediment is carried by **longshore drift.**
2. When there is a change in the shape of the coastline, deposition occurs. A long thin ridge of material is deposited. This is the spit.
3. A hooked end can form if there is a **change in wind direction.**
4. Waves cannot get past a spit, therefore the water behind a spit is very sheltered. Silts are deposited here to form salt marshes or mudflats.



➔ Bars, Lagoons, and Barrier

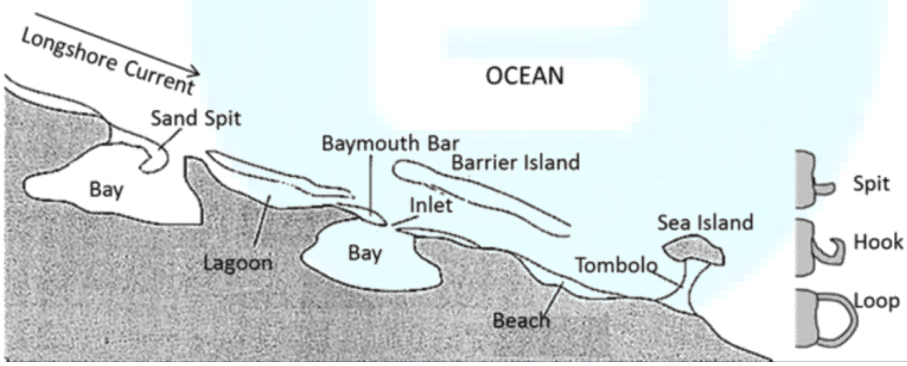
★ Sometimes a spit can grow across a bay and join two headlands together. This landform is known as a bar. They can trap shallow lakes behind the bar, these are known as lagoons. **Lagoons do not last forever and may be filled up with sediment**.

★ **Barrier: It is the overwater counterpart of a bar.**

➔ Tombolos & Dumb Ball

★ A tombolo is a sandy isthmus. Sometimes, islands are connected with the mainland by a bar called **tombolo.**

★ If two islands are connected to each other by a bar is called **Dumb Ball.**

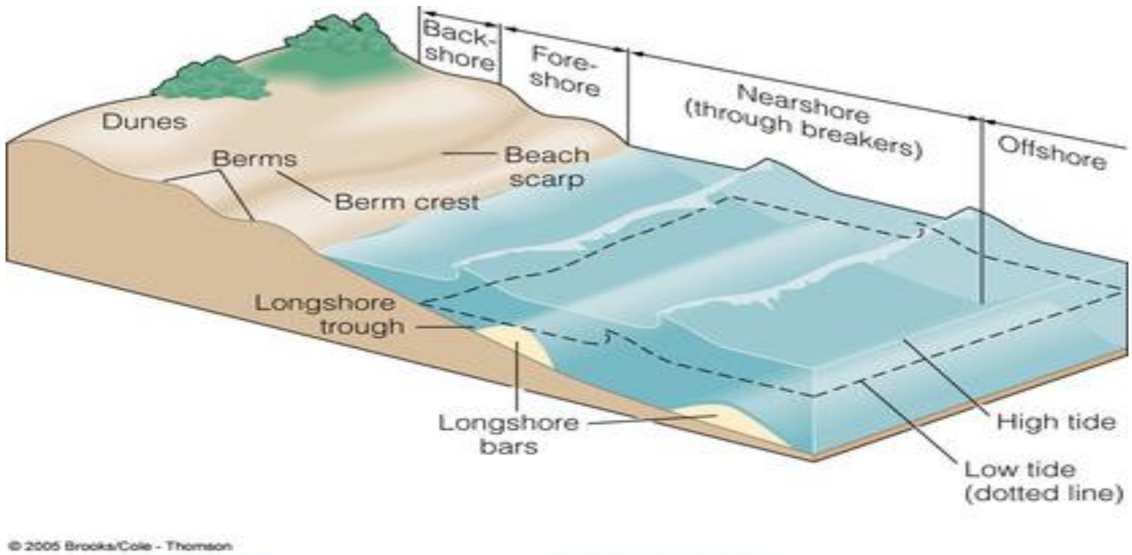


➔ Marine Dunes & Dune Belts

★ With the force of on-shore winds, a large amount of coastal sand is driven landwards forming extensive marine dunes that stretch into dune belts

★ Their advance inland may engulf farms, roads & even the entire villages;

★ Hence to arrest the migration of dunes, sand binding species of grass & shrubs, such as marram grass & pines are planted



➢ **Desert Landforms: Erosional and Depositional Desert**

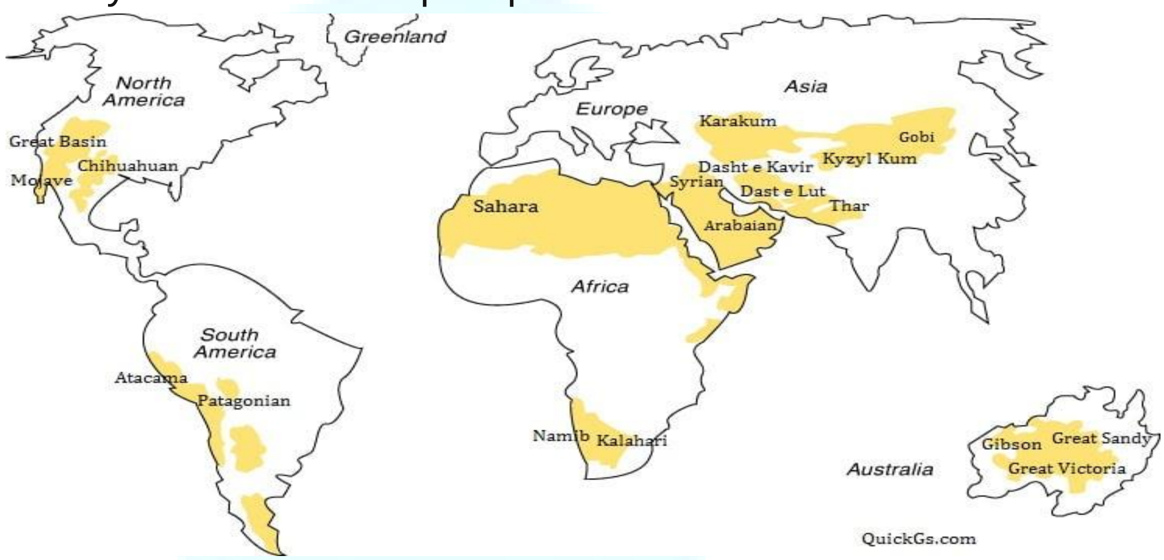
➔ A desert is a **barren area of landscape** where **little precipitation occurs** and, **consequently, living conditions are hostile for plant and animal life. The lack of vegetation** exposes the unprotected surface of the ground to the processes of denudation. About one-third of the land surface of the world is arid or semi-arid.

➔ This includes much of the Polar Regions, where little precipitation occurs, and which are sometimes called polar deserts or **"cold deserts"**. Deserts can be classified by the amount of precipitation that falls, by the temperature that prevails, by the causes of desertification, or by their geographical location.

➔ About **1/5 of the world's land is made up of deserts.**

➔ Desserts that are absolutely barren, where nothing grows are known as true deserts.

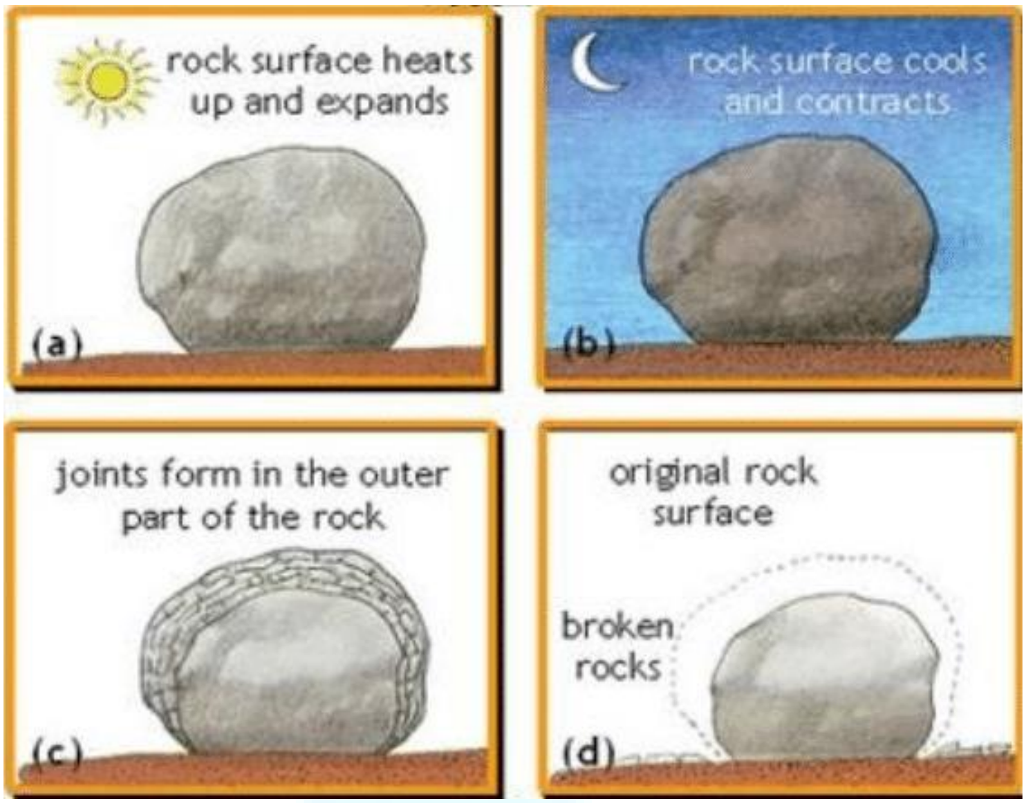
- ➔ Insufficient & irregular rainfall, high temperature & rapid rate of evaporation are the main causes of the desert's aridity.
- ➔ Almost all the deserts are confined within **15 degree – 30 degree** parallels to **N-S** of the equator known as trade wind deserts or tropical deserts.
- ➔ **They lie in the trade wind belt on the western parts of the continents**.
- ➔ Offshore trade winds are often bathed in cold currents which produces a desiccating (dehydrating) effect, hence moisture is not easily condensed into precipitation



➢ <u>**Mechanism of Desert/Arid Erosion**</u>

- ➔ Weathering
  - ★ **Most potent factor in reducing rocks to sand in arid regions.**
  - ★ Even though the amount of rain that falls in a desert is small, it manages to penetrate into rocks & sets up chemical reactions in various minerals it contains.
  - ★ Intense heating during the day & rapid cooling during the night by radiations, set up stresses in already weakened rocks, hence they eventually crack.

★ When water gets into cracks of a rock, it freezes at night as the temperature drops below the freezing point & expands by **10 %** of its volume.
★ Successive freezing will price fragments of rocks which get accumulated as screes.
★ As heat penetrates rock, its outer surface gets heated & expands, leaving its inner surface comparatively cool.

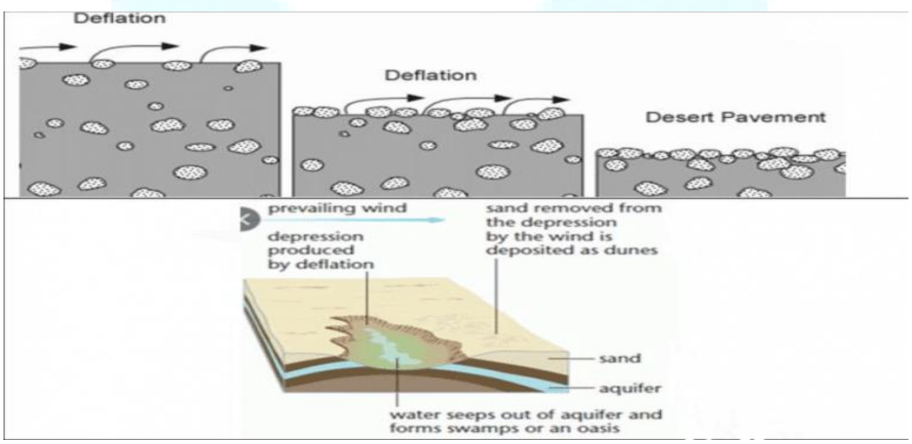


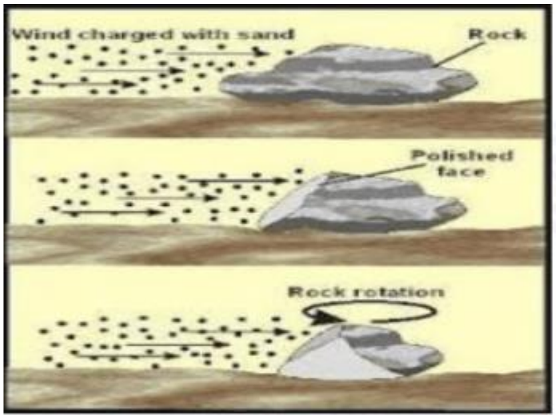
➔ Action of Wind

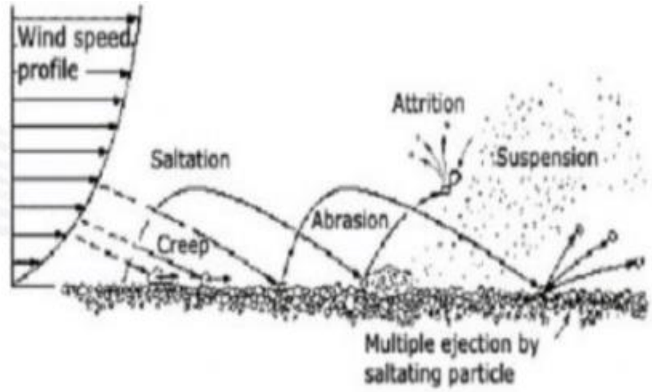
1. **Deflation**
   ★ **Involves lifting & blowing away of loose materials from the ground**
   ★ Blowing capacity depending largely on the size of the material lifted from the surface
   ★ Finer dust & sands may be removed miles away from their place of origin & may get deposited even outside the desert margins.

* **Deflation results in the lowering of the land surface to form large depressions called Deflation hollows**.

2. **Abrasion**
    * Sandblasting of rock surfaces by the wind when they hurl sand particles against them
    * This results in rock surfaces being scratched, polished & worn away
    * Abrasion is most effective near the base of the rocks, where the amount of material the wind is able to carry is greatest.
    * This explains why telegraphic poles in the deserts are protected by covering of metal for a foot or two above the ground.
3. **Attrition**
    * When wind-borne particles roll against one another in the collision, they wear each other away
    * **Hence their sizes are greatly reduced & grains are rounded into millet seed sand.**







➢ <u>**Desert Landforms by Wind Erosion**</u>

➔ **Rock pedestals/Mushroom rocks**

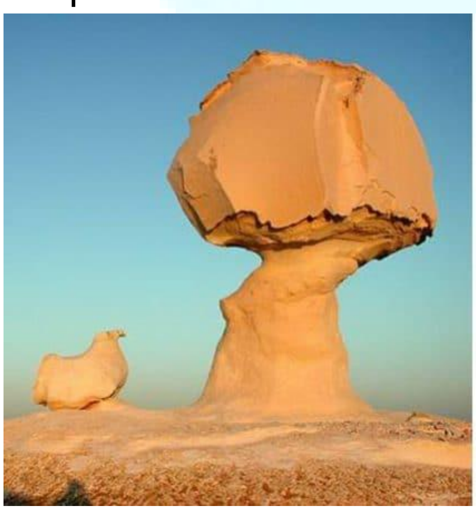
★ **Formed by the sandblasting effect of winds against any projecting rock masses**

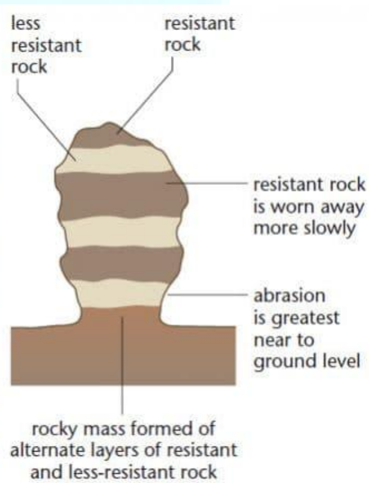
★ It wears down the softer layer leading to the formation of irregular edges on alternate bands of softer & harder rocks.

★ **Grooves & hollows** cut in the rock surfaces, carve them into grotesque-looking pillars known as rock pedestals.

★ Such rock pillars will be further eroded near their bases where friction is greatest.

★ This process of undercutting produces rocks of mushroom shape called **mushroom rocks.**





➔ **Messa and Butte**

- ★ Mesa is a Spanish word meaning **'table'.** It is a **flat**, **table-like landmass with a very resistant horizontal top layer and very steep sides**. The hard stratum on the surface resists denudation by both wind and water, and thus protects the underlying layers of rocks from being eroded away.
- ★ Mesas may be formed in canyon regions e.g. Arizona, or on fault blocks **e.g. the Table Mountain of Cape Town, South Africa**.
- ★ Continued denudation through the ages may reduce mesas in the area so that they become isolated flat-topped hills called buttes.

➔ Zeugen

- ★ Tabular masses which have a layer of soft rocks lying beneath a surface layer of more resistant rocks
- ★ Difference in the erosional effect of the wind on soft & resistant rock surfaces, carve them into weird looking ridge & furrow landscape
- ★ Mechanical weathering initiates their formation by opening up joints of the surface rocks
- ★ Wind abrasion further eats into the underlying softer layer so that deep furrows are developed

★ The hard rock then stand above the furrows as **ridges or Zeugen**

★ Zeugen may stand **10 to 100 feet above the sunken** furrows

★ Continuous abrasion by winds gradually lowers the **Zeugen & widens the furrow.**

➔ Yardangs

★ Yardangs looks quite similar to Zeugen but instead of lying in horizontal strata upon one another, the hard & soft rocks of Yardangs are vertical bands

★ **Rocks are aligned in the direction of prevailing winds.**

★ Wind's abrasion excavates the bands of softer rocks into long, narrow corridors, separating the steep-sided overhand ridges of hard rock called **Yardangs.**

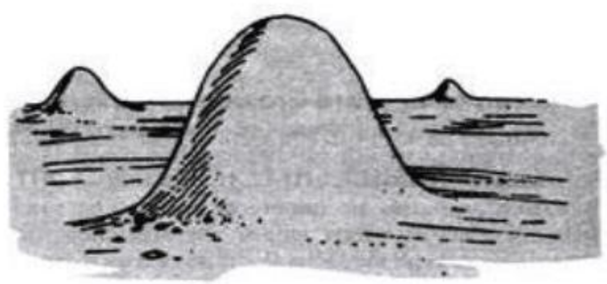
➔ Isenberg (Island Mountain)

★ They are basically isolated residual hills rising abruptly from the ground level

★ Characterized by very **steep slopes & rather rounded tops**

★ They are often composed of granite or gneiss

★ Are probably relics of an original plateau, which has been almost entirely eroded away



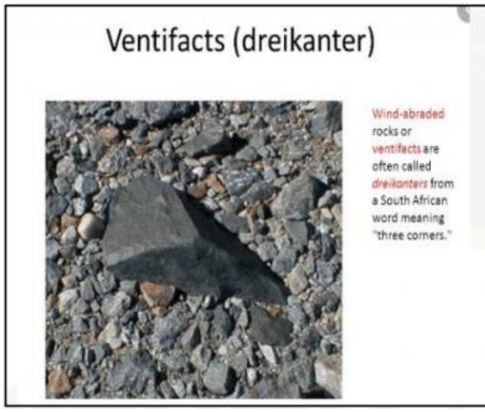
Round-topped, steep-sided inselbergs

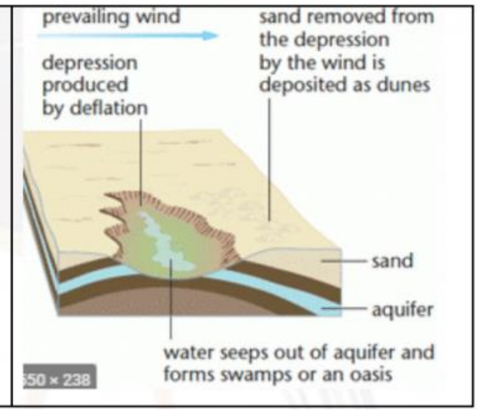
➔ Ventifacts & Dreikanter

★ These are pebbles faceted by **sand-blasting.** They are shaped and thoroughly polished by wind abrasion to shapes resembling **Brazil nuts**. Rock fragments, mechanically weathered from mountains and upstanding rocks, are moved by wind and smoothed on the windward side.

★ If the wind direction changes another facet is developed. Such rocks have characteristic flat facets with sharp edges.

★ Amongst the ventifacts those with three wind-faceted surfaces are called dreikanter. **These wind-faceted pebbles from the desert pavement a smooth, mosaic-like region, closely covered by the numerous rock fragments and pebbles.**





➔ **Deflation Hollows**

★ Winds lower the ground by blowing away the unconsolidated materials, and small depressions may form. Similarly, minor faulting can also initiate depressions and the eddying action of on-coming winds will wear off the weaker rocks until the water table is reached.

★ Water then seeps out forming oasis or swamps, in the deflation hollows or depressions.

★ Large areas in the western **U.S.A.,** stripped of their natural vegetation for farming, were completely deflated when strong winds moved materials as dust storms, laying waste crops and creating what is now known as the **Great Dust Bowl.**

➢ **<u>Deserts Landforms by wind deposition</u>**

➔ Materials eroded & transported by winds must come to rest somewhere.

- ➔ The finest dust travels enormous distances in the air sometimes as long as **2300 miles** before they settle down.
- ➔ The dust from the Sahara desert is sometimes blown across the Mediterranean to fall as blood rains in Italy or on the glaciers of Switzerland.
- ➔ Dust that settles in **Hwang Ho basin** (**also known as Hwangtu – the yellow earth**) from the Gobi desert has been accumulated over past centuries to a depth of several hundred feet
- ➔ As wind borne materials are shifted according to their coarseness, it can be expected that the coarser sands will be too heavy to be blown out of desert limits.
- ➔ They remain as dunes or other depositional landforms within the desert themselves.
- ➔ **Dunes**
  - ★ **Dunes are, in fact, hills of sand formed by the accumulation of sand and shaped by the movement of winds.**
  - ★ They may be active or live dunes, constantly on the move, or inactive fixed dunes, rooted with vegetation.
  - ★ Dunes are most well represented in the erg desert where a sea of sand is being continuously moved, reshaped, and re-deposited into a variety of features.
  - ★ Two most common types of dunes are **Barchan & Seifs.**

    1. **Barchan**
       - ★ These are crescentic or moon-shaped dunes that occur individually or in groups. They are live dunes that advance steadily before winds that come from a particular prevailing direction. They are most prevalent in the deserts of Turkestan and in the Sahara.

★ Barchans are initiated probably by a chance accumulation of sand at an obstacle, such as a patch of grass or a heap of rocks. They occur transversely to the wind, so that their horns thin out and become lower in the direction of the wind due to the reduced frictional retardation of the winds around the edges.

★ The windward side is convex and gently sloping while the leeward side, being sheltered, is concave and steep (the slip-face).

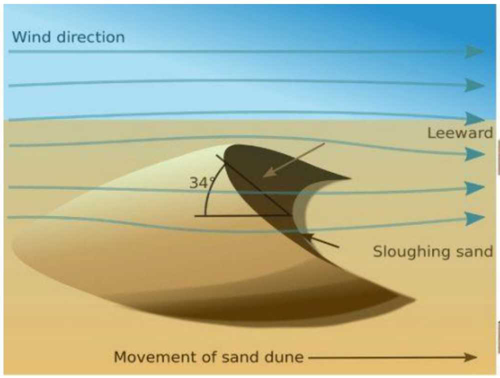
★ The crest of the sand dune moves forward as more sand is accumulated by the prevailing wind.

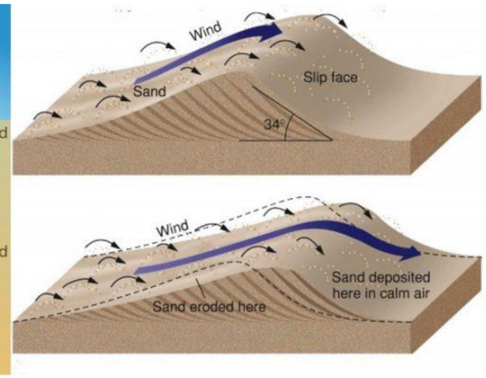
★ The sand is driven up the windward side and, on reaching the crest, slips down the leeward side so that the dune advances.

★ The migration of the barchans may be a threat to desert life for they may encroach on an oasis burying palm trees or houses.

★ Long-rooted sand-holding trees and grasses are therefore planted to halt the advance of the dunes thus preventing areas of fertile land from being devastated.

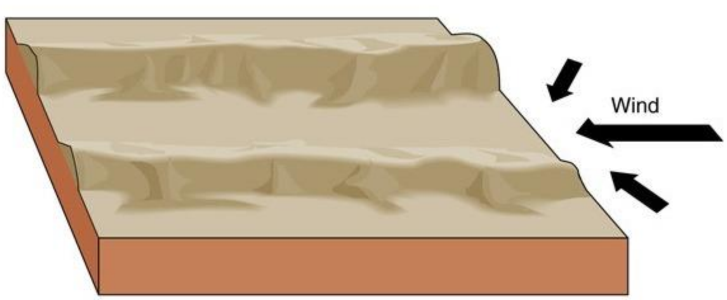
★ Under the action of winds, barchans take a chaotic changing pattern. Several barchans may coalesce into a line of irregular ridges, ever-changing with the direction of the winds. Ergs or sandy deserts are thus most difficult to cross.





2. <u>Seifs</u>

- ★ They are long, narrow ridges of sand, often over a hundred miles long lying parallel to the direction of the prevailing winds. **The Crestline of the seif rises and falls in alternate peaks and saddles in regular** successions like the teeth of a monstrous saw.
- ★ The dominant winds blow straight along the corridor between the lines of dunes so that they are swept clear of sand and remain smooth. The eddies that are set up blow towards the sides of the corridor, and, having less power, drop the sand to form the dunes.
- ★ In this manner, the prevailing winds increase the length of the dunes into tapering linear ridges while the occasional crosswinds tend to increase their height and width**. Extensive seif dunes are found in the Sahara Desert, south of the Qattara Depression;** e.g. the **Thar Desert and the West Australian Desert.**



D Longitudinal dunes (seifs)

➔ **Loess**

★ The fine dust blown beyond the desert limits is deposited on neighboring lands as loess. It is a yellow, friable material and is usually very fertile. Loess is in fact, fine loam, rich in lime, very coherent, and extremely porous. Water sinks readily so that the surface is always dry.

★ Streams have cut deep valleys through the thick mantle of soft loess and badland topography may develop. It is so soft that roads constructed through a loess region soon sink and their walls rise steeply. The most extensive deposit of loess is found in northwest China in the loess plateau of the Hwang- Ho basin.

★ It is estimated to cover an area of **250,000 square miles**, and the deposits have accumulated to a depth of **200 to 500 feet!** In **China,** such yellowish wind-borne dust from the Gobi Desert is called **'Hwangtu'** — the yellow earth! But the original tern loess actually comes from a village in **Alsace, France bearing that name, where such deposits occurred.**

★ Similar deposits also occur in some parts of **Germany, France and Belgium** and are locally called **Limon** They are also wind-borne but were blown from material deposited at the edge of ice sheets during the Ice Ages. In parts of the **Midwest, U.S.A.** loess was derived from the ice sheets which covered northern **North America and is termed adobe.**

➢ **Landform of water actions in desert**

➔ **Temporary lakes(Playas):**

★ Also known as **Playas, Salina or Salars**

★ Formed in arid or semi-arid areas by intermittent streams flowing into depressions

★ Contain a **high percentage of salts due to high evaporation & lower precipitation**.

★ The **playa plain covered up by salts is called alkali flats.**

➔ **Bajada & Pediment**

<u>Bajada</u>

★ **Depositional features made up of alluvial material lay down by intermittent streams.**

★ Bajada is formed by the coalescence of alluvial fans

★ These fan-shaped deposits form from the deposition of sediment by a stream from upland region onto flat land at the base of a mountain

★ Bajadas are common in arid areas where a large quantity of sediment is deposited by flash floods

★ **Bajadas frequently contain playa lakes**

<u>Pediment</u>

★ An erosional plain formed at the base of the **surrounding mountain scarps -steep slope.**

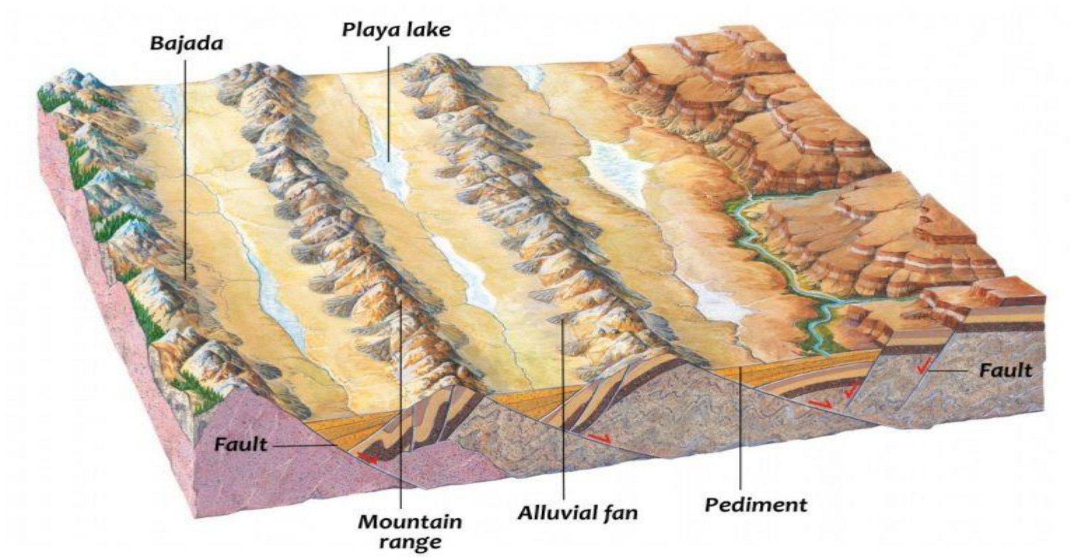
★ They are gently inclined rocky floors close to the mountains at their foot with or without a thin cover of debris.

★ They form through the erosion of the mountain front through a combination of lateral erosion by streams and sheet flooding.

★ Through parallel retreat of slopes, the pediments extend backwards at the expense of mountain front

★ Gradually, the mountain gets reduced leaving an inselberg which is a remnant of the mountain.

★ **That's how the high relief in desert areas is reduced to low featureless plains called pediplains**.



➔ Alluvial fans

★ **Alluvial fans are cone shaped heaps of sand that are deposited on the exit of a wadi or valley**.

★ A wadi is a narrow dry valley with ephemeral water flow (water that flows during heavy rains only). The valley is dry and baked most of the time, but during heavy downpours they can fill up with water and transport all the alluvium from the upslope as sheet wash.

★ This alluvium is deposited as the wadi terminates into an open space. **Energy is dissipated in the open space and material spreads apart into a fan shape**.

➔ Canyons/Gorges

★ **Gorges (canyons in America)** are **deep narrow valleys that are excavated and eroded vertically by rivers that flow along deserts.**

★ The **Grand Canyon in Arizona USA** was formed by vertical erosion of sedimentary strata by the Colorado River for millions of years.

➢ <u>**Karst Landforms: Erosional and Depositional**</u>

- ➔ Karst is a topography formed from the **dissolution of soluble rocks such as limestone, dolomite, and gypsum**. It is characterized by underground drainage systems with sinkholes and caves.
- ➔ Karst is most strongly developed in dense carbonate rock, such as limestone, that is thinly bedded and highly fractured.
- ➔ Karst is not typically well developed in chalk, because chalk is highly porous rather than dense, so the flow of groundwater is not concentrated along with fractures.
- ➔ Karst is also most strongly developed where the water table is relatively low, such as in uplands with entrenched valleys, and where rainfall is moderate to heavy. This contributes to the rapid downward movement of groundwater, which promotes the dissolution of the bedrock, whereas standing groundwater becomes saturated with carbonate minerals and ceases to dissolve the bedrock.
- ➔ In **India karst topography** is present in the Vindhya region (mainly southwestern Bihar), the Himalayas (parts of **Jammu & Kashmir, Robert Cave, Sahastradhara, the eastern Himalayas, areas near Dehradun**), **Pachmarhi in Madhya Pradesh, Gupt Godavari Cave in Chitrakoot (U.P.), the surrounding coast near Visakhapatnam(Borra Caves), and Bastar in Chhattisgarh.**
- ➔ **Characteristics of Karst Landforms**
  - ★ Generally, Karst regions have a **bleak landscape, occasionally broken by precipitous slopes.**
  - ★ General absence of surface drainage as most of the surface water percolates underground, hence surface valleys are generally dry.
  - ★ Streams generally cut their way along the joints & fissures of the rock wearing out a system of underground channels.

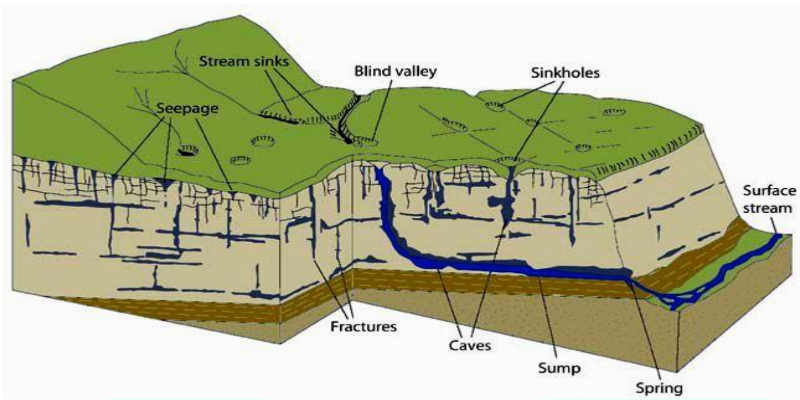
- ★ When the water penetrates to the base of the limestone & meets the non-porous rocks, it reemerges onto the surfaces as a spring or resurgence.
- ★ **Limestones** are well joined & it is through these joints & cracks that rain water finds its way into the underlying rock.
- ★ Progressive widening by the solution enlarges these cracks into trenches & a most intriguing feature called limestone pavement is developed.
- ★ The enlarged joints are called Grikes & the isolated, rectangular blocks are termed as clints.
- ★ On the surface of limestone are numerous swallow holes, which are small depressions carved out by solution where rainwater sinks into limestone at the point of weakness, also known as **sinkholes**. Once water has sunk into limestone, it etches out caverns & passages along joints.
- ★ When a number of swallow holes coalesce, a larger hollow is formed & is called a **Doline.**
- ★ Several dolines may merge as a result of subsidence (gradual caving) to form an even larger depression called an **Uvala**
- ★ In **Yugoslavia,** some very large depressions called Polje, may be as large as **100 square miles**, but produced partly due to faulting.
- ★ Subterranean streams which descend through swallow holes to the underground passes leads to the formation of caves & caverns which may contain ponds or lakes.
- ★ The most spectacular underground features that adorn the limestone caves are
    1. **Stalactites**
    2. **Stalagmites**
    3. **Calcite pillars**

➢ **Erosional landforms of Karst topography**

➔ **Blind Valley**

★ **A steephead valley**, steephead or blind valley is a deep, narrow, flat bottomed valley with an abrupt ending.

★ **Karst valley abruptly terminated by the passage** underground of the watercourse which has hitherto resisted the karst processes and remained at the surface



➔ **Swallow Hole/Sinkholes/Doline**

★ **A sinkhole,** also known as a **cenote**, **sink, sink-hole, swallet, swallow hole, or doline** (the different terms for sinkholes are often used interchangeably), **is a depression or hole in the ground caused by some form of collapse of the surface layer.**

★ Most are caused by **karst processes** – for example, the **chemical dissolution of carbonate rocks or suffosion processes**

★ The surface streams which sink disappear underground through swallow holes.

Local names:

★ Black hole – Sea water

★ Blue hole- deep under water

★ Cenotes- Belize (British Honduras)

★ Sotanos- Mexico

- ★ Tomo- New Zealand

➔ **Clift**

- ★ When the Solution hole is dippen over a period of time then the dipped part is called Clift.

➔ **Pinnacles**

- ★ Vertical rock blades fretted sharped by dissolution.

➔ **Lapies/Karren**

- ★ It is formed due to differential solution activity along parallel to sub-parallel joints. They are also called **grooved, fluted and ridge-like features in an open limestone field.**
- ★ The most widespread surface karst landforms are small solution pits, grooves and runnels, collectively called **Karren.**

➔ **Limestone Pavements**

- ★ It is a smoother form of lapies.

➔ **Sinking Creeks/Bogas**

- ★ In a valley, the water often gets lost through cracks and fissures in the bed.

- ★ These are called sinking creeks, and if their tops are open, they are called **bogas.**

➔ **Karst Window/Fenster**

- ★ **Karst fenster** is a geomorphic feature formed from the dissolution of carbonate bedrock.
- ★ In this feature, a spring emerges, then the discharge abruptly disappears into a sinkhole.
- ★ A **karst fenster** is caused by a caving in portions of the roof of a subterranean stream, thus making some of the underground stream visible from the surface.
- ★ When a number of adjoining **sinkholes** collapse, they form an open, broad area called a karst window.

➔ **Uvalas**

- ★ Karst depressions that are much larger than sinkholes and that display gentler slopes and more complex three-dimensional shapes are known as uvalas.
- ★ **Uvalas is a collection of multiple smaller individual sinkholes that coalesce into a compound sinkhole.**
- ★ A single uvala typically contains numerous sinkholes within it

➔ **Polje**

- ★ A polje, also karst polje or karst field, is a large flat plain found in karstic geological regions of the world, with areas usually **5 to 400 km².**

➔ **Pools**

- ★ An opening at the top with water collected in the void of the surface with varying depth

➔ **Caves/Cavern**

- ★ This is an underground cave formed by water action by various methods in a limestone or chalk area.

- ★ Cave formation is prominent in areas where there are alternating beds of rocks (shales, sandstones, quartzites) with limestones or dolomites in between or in areas where limestones are dense, massive and occurring as thick beds

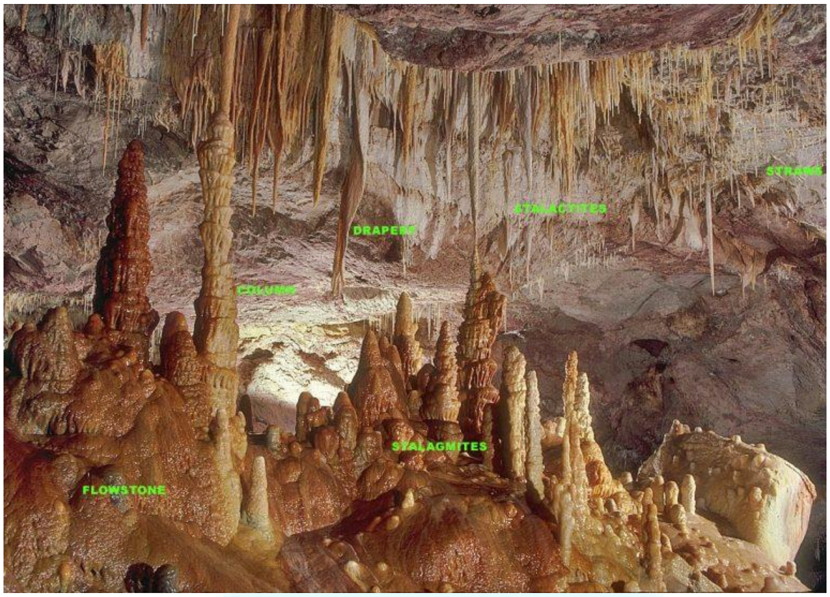
➔ **Karst Lake**

- ★ Karst lakes are formed as the result of a collapse of subterranean caves, especially in water soluble rocks
- ★ such as limestone, gypsum, and dolomite.
- ★ This process is known as karstification. They can cover areas of several 100 square kilometers.
- ★ Their shallow lakebed is usually an insoluble layer of sediment so that water is impounded, leading to the formation of lakes. Many karst lakes only exist periodically but return regularly after heavy rainfall

➢ **Depositional landforms of Karst topography**

➔ **Stalactites & Helictite**

- ★ The water containing limestone in solution, seeps through the roof in the form of a continuous chain of drops.
- ★ A portion of the roof hangs on the roof and on evaporation of water, a small deposit of limestone is left behind contributing to the formation of a stalactite, growing downwards from the roof.
- ★ Usually, the **base is broader than the free end of the hanging stalactites**.
- ★ The ones that descend vertically are known as stalactites, whereas the ones that extend **horizontally or diagonally are known as helictites**

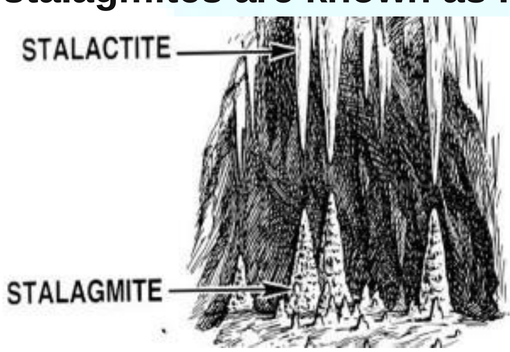


➔ **Stalagmites & Halagmite**

★ A stalagmite is a type of **rock formation that rises from the floor of a cave due to the accumulation of material deposited on the floor from the ceiling drippings.**

★ It is an upward-growing mound of mineral deposits that have precipitated from water dripping onto the floor of a cave.

★ Ones that extend **horizontally or diagonally from stalagmites are known as Halagmite.**



➔ **Cave Pillars**

★ The combination or fusion of stalactites and stalagmites form the pillars

★ The diameters of pillars vary

➔ **Drapes/Curtain**

- ★ Numerous needle-shaped dripstones hanging from the cave ceiling are called Drapes or Curtains.

➔ **Tufa**

- ★ Tufa is a variety of limestone formed when carbonate minerals precipitate out of ambient temperature water.
- ★ **Geothermally** heated hot springs sometimes produce similar (but less porous) carbonate deposits, which are known as **travertine.**

➔ **Travertine**

- ★ Travertine is a sedimentary rock formed by the chemical precipitation of calcium carbonate minerals from freshwater, typically in springs, rivers, and lakes that is, from surface and ground waters.
- ★ Developed form of **Tufa is Travertine**

➔ **Drip Stone**

- ★ Calcium carbonate rock deposited in caves by the precipitation of calcite from water as excess dissolved carbon dioxide is diffused into the atmosphere.
- ★ Dripstone takes various forms, including stalactites, helictites (having spiral form), curtains, ribbons, and stalagmites.

➔ **Terra Rossa**

- ★ Terra Rossa is a well-drained, reddish, clayey to silty clayey soil with neutral pH conditions.

➢ **<u>Periglacial Landforms</u>**

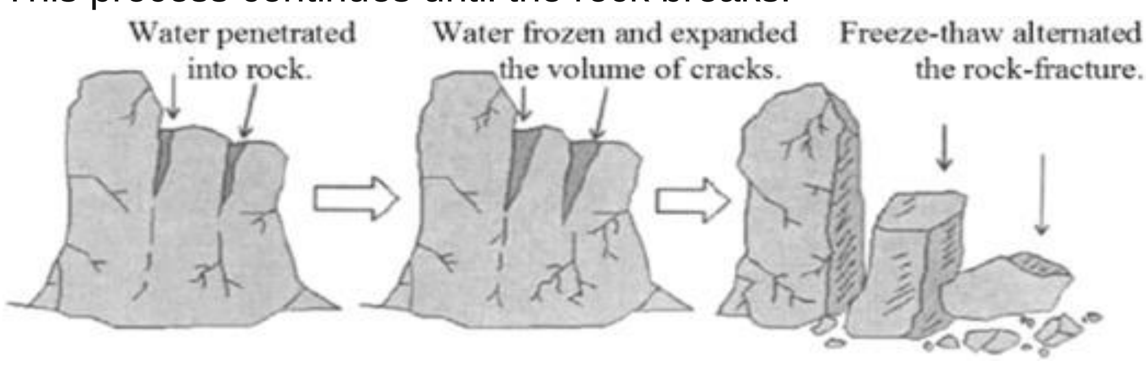
➔ The term periglacial **(near-glacial)** literally means **around the ice or peripheral to the margins of the glaciers but now this term is used for both 'periglacial landscape' and 'periglacial climate'.**

- ➔ Periglacial areas are those which are in **permanently (perennially) frozen condition but without permanent ice cover on the ground surface**
- ➔ The periglacial climate is characterized by mean an-nual temperature ranging between **1°C and – 15°C** and mean annual precipitation of **120 mm to 1400 mm** (**mostly in solid form).**
- ➔ Periglacial landform is a feature resulting from the action of **intense frost**, often combined with the presence of permafrost. **Periglacial landforms are restricted to areas that experience cold but essentially non glacial climates**

➢ **Periglacial Landforms – Erosional**

➔ Freeze-Thaw Cycle

- ★ Freeze-thaw weathering is a process of erosion that happens in **cold areas where ice forms. A crack in a rock can fill with water which then freezes as the temperature drops.**
- ★ As the ice expands, it pushes the crack apart, making it larger. When the temperature rises again, the ice melts, and the water fills the newer parts of the crack.
- ★ The water freezes again as the temperature falls, and the expansion of the ice causes further expansion to the crack. This process continues until the rock breaks.



➔ Nivation Hollow

★ Hollows produced by snow-patch erosion or nivation are called nivation hollows which are generally found along the hillsides in vari-ous forms. **They extend from a few meters to 1.5 kilometers.**

★ In time, these hollows may trap more snow and may deepen further with more nivation so that cirques or thermo cirques are formed.

★ They are classified on the basis of shape into: **(i) Transverse hollows (ii) Longitudinal hollows.**

➔ **Asymmetrical Valley**

★ **An asymmetric valley is a valley that has steeper slopes on one side**. Valley has one side steeper than the other, the opposing slopes having significantly contrasting angles.

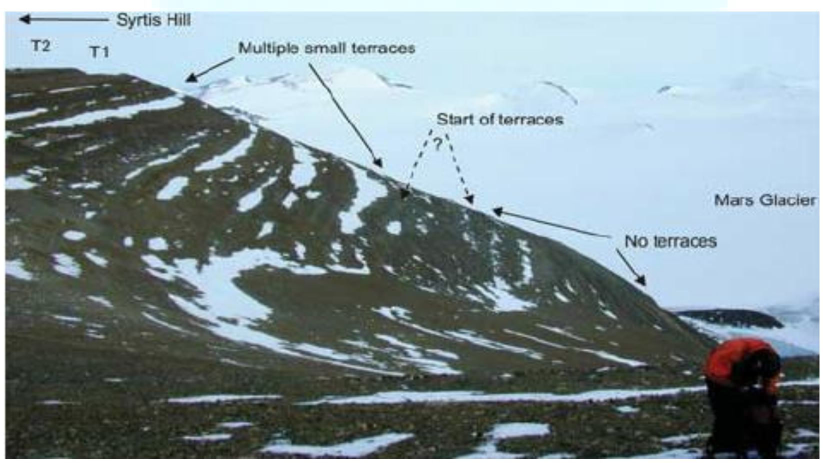
★ This contrast may be caused by geologic structure or variation in the nature and intensity of erosional (**e.g. periglacial)** processes and there may be contrasts in the vegetation on the opposing slopes.

★ Such valleys are common in past and present periglacial environments, where aspect has a significant effect on the nature of frost-based processes and on the depth of the active layer.

➔ Cryoplanation Terraces or Goletz Terraces

★ **Cryoplanation terraces** (**also known as altiplanation or goletz terraces and by several other terms**) are periglacial landforms consisting of nearly horizontal bedrock surfaces or benches backed by frost-weathered bedrock cliffs.

★ **Cryoplanation Terraces (CTs)** are erosional landforms reminiscent of giant staircases, with alternating shallow sloping treads and steep scarps leading to extensive flat summits.

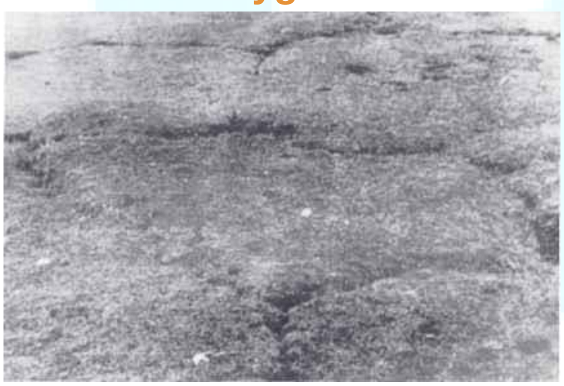


➔ Patterned Ground

★ When Ice from below makes upward pressure the overlying sedimentary flat rocks are being weathered and cracks are developed, these cracks it seems are having some pattern on ground.

★ **A process called frost heaving is responsible for these features**.

➔ **Frost Crack Polygon**



➔ **Stone Strips**

★ **A stone stripe is an elongated concentration of mostly talus-like basalt rock found along a hillside or the base of a cliff.** Many stone stripes occur without cliffs.

★ Stone stripes are thought to have been originally created by periglacial conditions of the **Quaternary period** during an **Ice age.** It is likely their formation originates from multiple processes including **frost action, surface**

erosion, eluviation, and mass wasting. However, it is likely that intense freeze and thaw cycles account for the natural sorting of the rock debris within a stone stripe, and also accounts for the shallow depth of the stripes, since frost penetration is thought to not penetrate deeper than **1 meter in the region.**

★ A stone stripe is identified by its lack of vegetative cover.

➔ Pingo

★ Pingo is an Eskimo word that means isolated dome-like low mounds or hills found in per-mafrost areas. This word was first used by **A.E. Porsild in the year 1938.** They are found in continuous as well as discontinuous permafrost areas.

★ They are abun-dantly found in the arctic areas **(65° N)** of Canada, Alaska, Greenland and Siberia.

★ They range in height from a few meters to **60 meters** (sometimes they are as high as **100 meters)** and from a few meters to **300 meters in diameter. Small pingos** have closed tops whereas big pingos have open tops.

➔ Hummocks

★ **Small upstanding wrinkles on the surface of permafrost are called hummocks.** These are formed due to squeezing of the ground surface because of lateral pressure exerted by freezing of the active layer.

➔ Palsa

★ A special category of hummock found in swampy areas and composed of peats having thin ice layers inside is called palsa which is about 10m in height and 10 to 20 m in diameter and is mostly found in the periglacial environment of arctic and subarctic areas.

★ **Palsa may be destroyed by rise in water table in the nearby swamps or by fracture in its upper surface.**

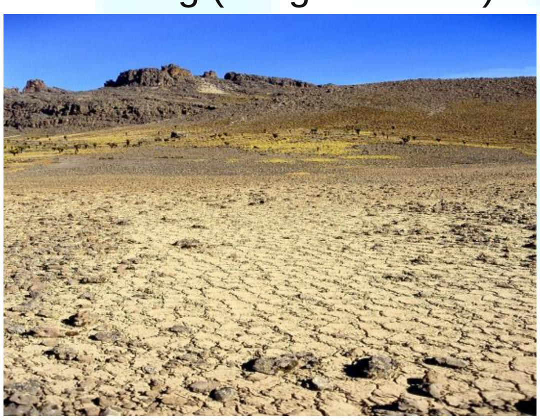
★ **It is formed by frost heaving under the influence of ice segregation.**

➢ <u>Periglacial Landforms – Depositional</u>

➔ BlockFields or Felsenmeer

★ Blockfields are areas covered by large angular blocks, traditionally believed to have been created by freeze-thaw action.

★ Block field refers to the natural collection of large stone blocks at the flat surface of the hill tops in the periglacial areas. **These block fields are also called blockmeer and felsenmeer.** The stone blocks are formed due to frost weathering (congelifraction).



➔ Patterned Ground

★ Blockfields sometimes take some geometrical shapes (like circles, polygons, nets, stripes and garlands) and are so sys-tematically arranged are called **Patterned Ground.**

★ **Patterned Ground is erosional as well as depositional landforms in periglacial.**

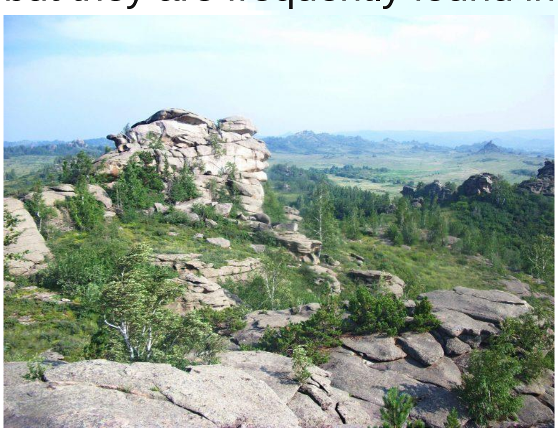
➔ Tors

★ Tors, one of the most controversial landforms, are piles of broken and exposed masses of hard rocks having a crown of rock blocks of different sizes on the top and clitters (trains of blocks) on the sides.

★ The rock blocks, main components of tors, may be **cuboidal, rounded, angular, elongated etc. in shape**.

★ They may be seated at the top of the hills, on the flanks of the hills or on flat basal platforms ranging from **6 m to 30 m** in height. They are found in different climates varying from cold to hot and dry to humid.

★ Though tors have developed over almost all types of rocks but they are frequently found in the regions of granites.



➔ Boulder Fields

★ Boulder Field is a **periglacial feature that formed as a direct result of its proximity to the end moraine**. Accumulations of rock debris in the valley floors are called stone streams or boulder fields.

★ **The stone is well sorting of rock debris in the stone streams**. The upper layer consists of large and coarse debris while the lower layer is dominated by fine materials. Water channel is developed between the valley walls and the stone stream. Sorting of rock debris occurs through the process of frost Heaving. **Stone streams move downslope due to the force of gravity, frost heaving and solifluction.**