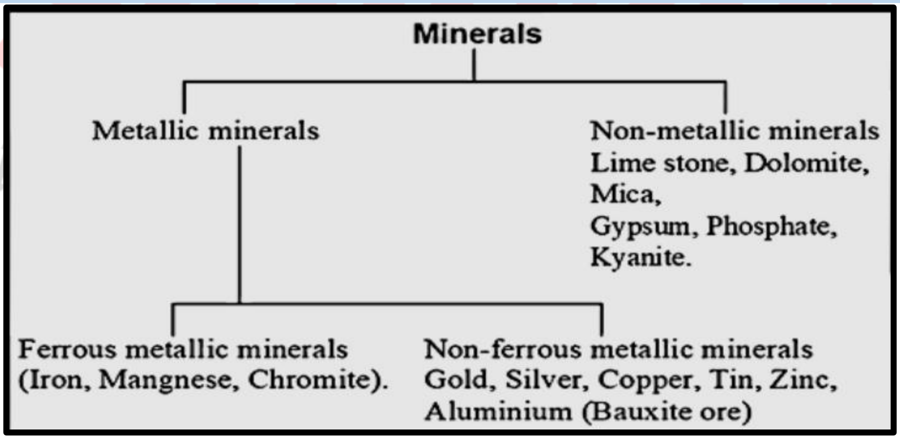
LECTURE 2 – GEOMORPHOLOGY

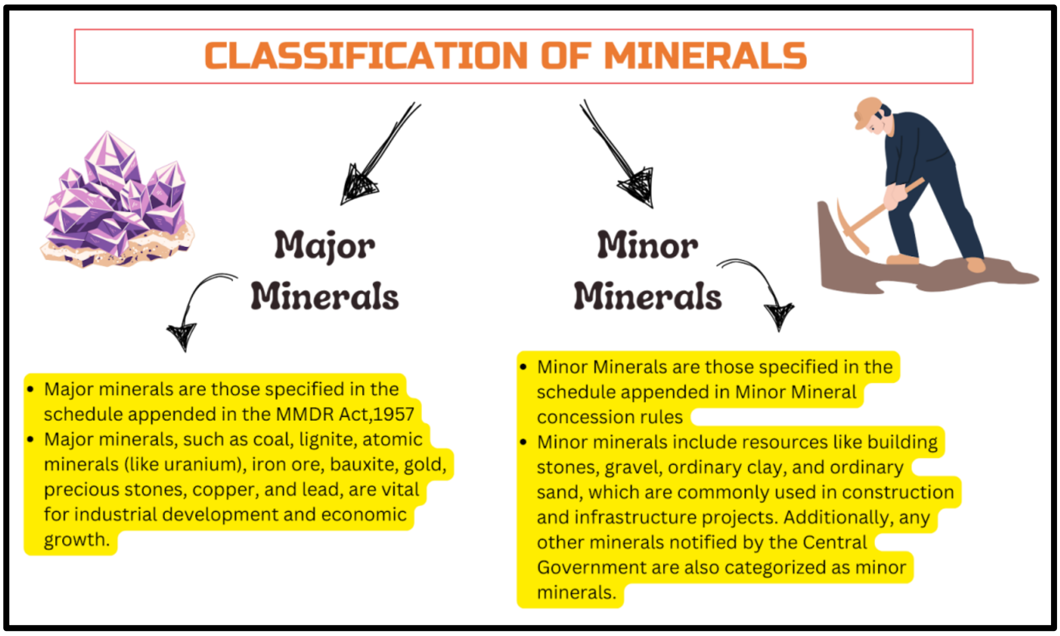
ELEMENTS/MINERALS/ROCKS

ELEMENTS	MINERALS	ROCKS
Substances which cannot be decomposed into simple forms via chemical processes.	Naturally occurring chemical compounds in which atoms are arranged in 3-D patterns. Formed due to cooling of magma	Aggregate or composition of one or more Minerals.
Rarely found exclusive Most abundant element in the Earth's Crust - Oxygen	Composed of two or more elements. Sometimes single element minerals are also found – Silver, Gold, Sulphur	Petrology – Study of Rocks

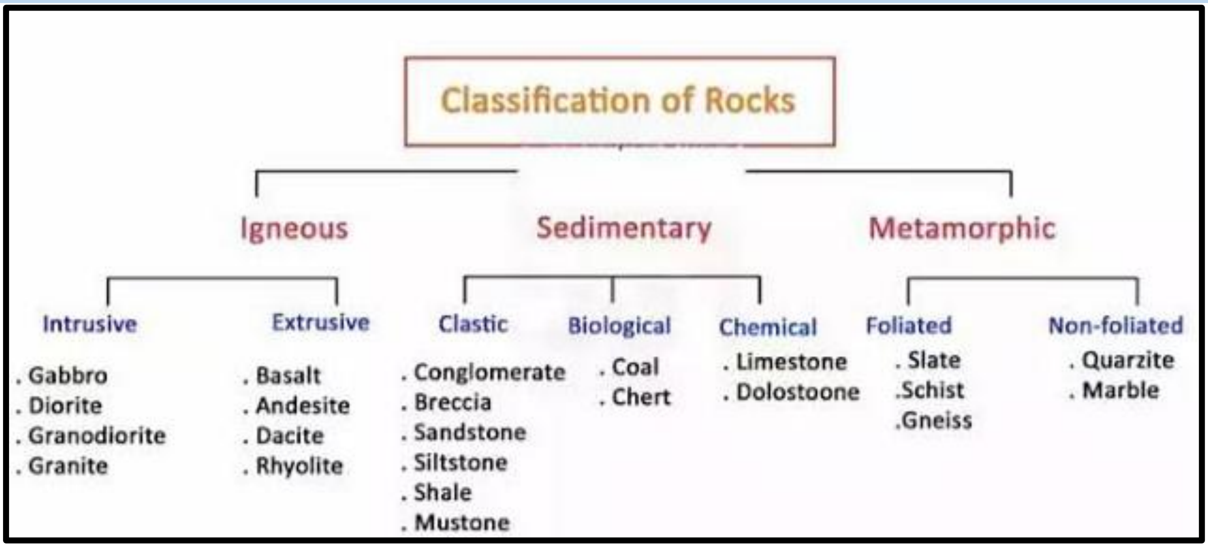
MINERALS

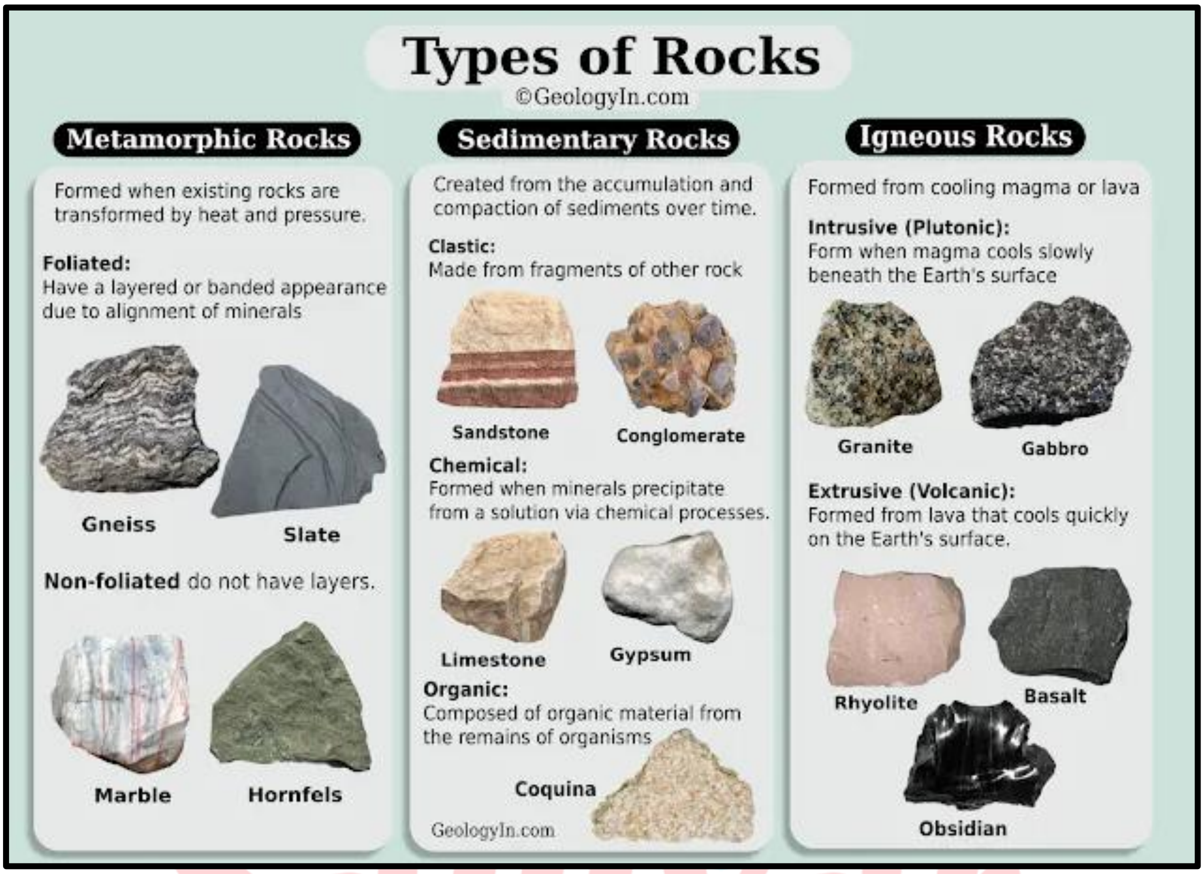


Major Minerals	Composition	Characteristics
Feldspar	Silicon and Oxygen	• Half of Earth's Crust is composed of Feldspar • Used in Ceramics and Glass making
Quartz	Silica	• Component of Sand and Granite • Used in Radio and RADAR • Virtually insoluble in water
Pyroxene	Calcium, Aluminium, Silica	Commonly found in Meteorites
Amphibole	Aluminium, Iron, Magnesium, Silica	Used in Asbestos industry
Mica	Potassium, Aluminium, Magnesium	Used in Electrical instruments
Olivine	Magnesium, Iron, Silica	Used in Jewellery



CLASSIFICATION OF ROCKS



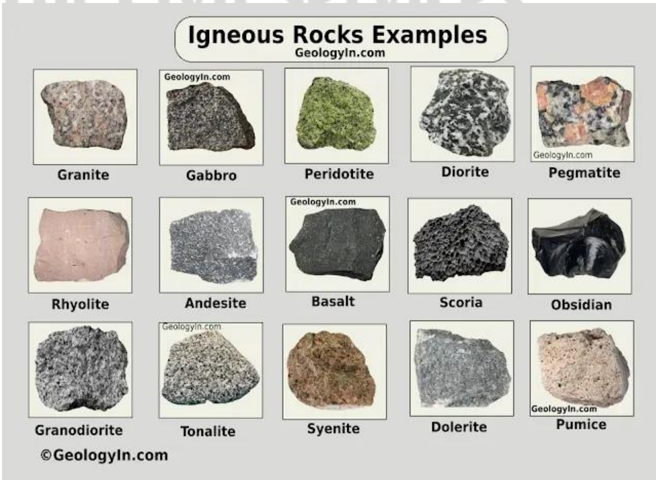


IGNEOUS ROCKS (PRIMARY ROCKS)

Igneous rocks are the first to form on Earth, originating from the solidification of magma (molten rock beneath the surface) and lava (molten rock above the surface). These rocks have a high temperature origin, making them unfossiliferous.

Some common examples of igneous rocks include **granite**, **gabbro**, and **basalt**.

Igneous rocks are classified into three types based on their formation:



1. **Intrusive Igneous Rocks (Plutonic Rocks):** These rocks form when magma cools slowly at great depths, resulting in large mineral grains. Examples include **granite**. These rocks appear on the surface after uplift and denudation.
2. **Extrusive Igneous Rocks (Volcanic Rocks):** These rocks form from the rapid cooling of magma just below the surface or lava above it. The cooling prevents crystallization, making these rocks fine-grained. An example is **basalt**, which is the origin of the **Deccan Traps** in India.
3. **Hypabyssal or Dyke Rocks (Intermediate Rocks):** These rocks form at intermediate depths and are semi-crystalline in structure.

Igneous rocks can also be categorized as **acidic rocks** or **basic rocks** based on their silica content. **Acidic rocks**, like **granite**, have high silica content, are lighter in color, and form high mountains. **Basic rocks**, like **basalt**, have low silica content, are darker in color, and are denser.

SEDIMENTARY ROCKS (DETRITAL ROCKS)

Sedimentary rocks form through the lithification (compaction and consolidation) of sediments, which result from the weathering and erosion of all types of rocks. These rocks are typically layered and make up 75% of the Earth's crust but only occupy 5% by volume. Some common types of sedimentary rocks include **sandstone**, **shale**, and **limestone**.

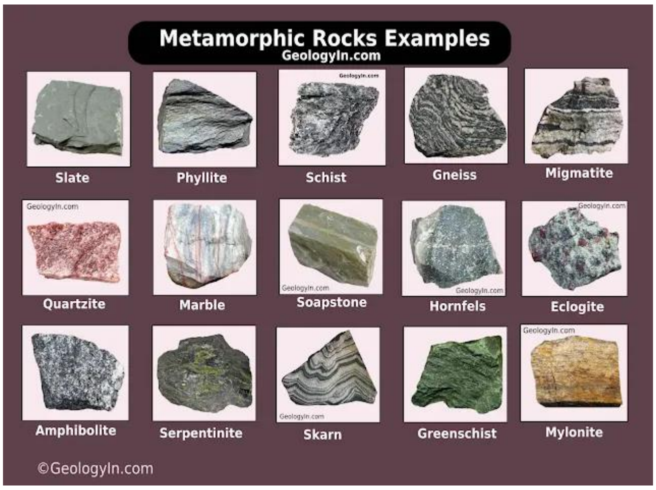
Sedimentary rocks are classified into three types based on their formation:

1. **Mechanically Formed Rocks:** Formed by mechanical agents like wind, water, or ice. Examples include **sandstone** (from sand) and **shale** (from clay).
2. **Organically Formed Rocks:** Formed from the remains of plants and animals, such as **coal** and **limestone**.
3. **Chemically Formed Rocks:** Formed by the evaporation of water containing minerals, such as **limestone** and **halite**.

Sedimentary rocks are important for their fossil content and permeability, which makes them useful as reservoirs for groundwater and petroleum.

METAMORPHIC ROCKS

Metamorphism refers to the process of rock transformation under high pressure and temperature. This transformation can result in the rearrangement or recrystallization of minerals within the rock. Common examples of metamorphic rocks include **gneiss**, **slate**, **schist**, **marble**, and **quartzite**.



Metamorphic rocks can be categorized into two types:

1. **Thermal Metamorphism:** Occurs when rocks are exposed to high temperatures, often due to proximity to magma. An example is the transformation of **limestone** into **marble**.
2. **Dynamic Metamorphism:** Occurs due to high pressure, often associated with tectonic movements. An example is the transformation of **shale** into **schist**.

Metamorphic rocks are often foliated (with layered or aligned minerals) or banded (with alternating layers of minerals).

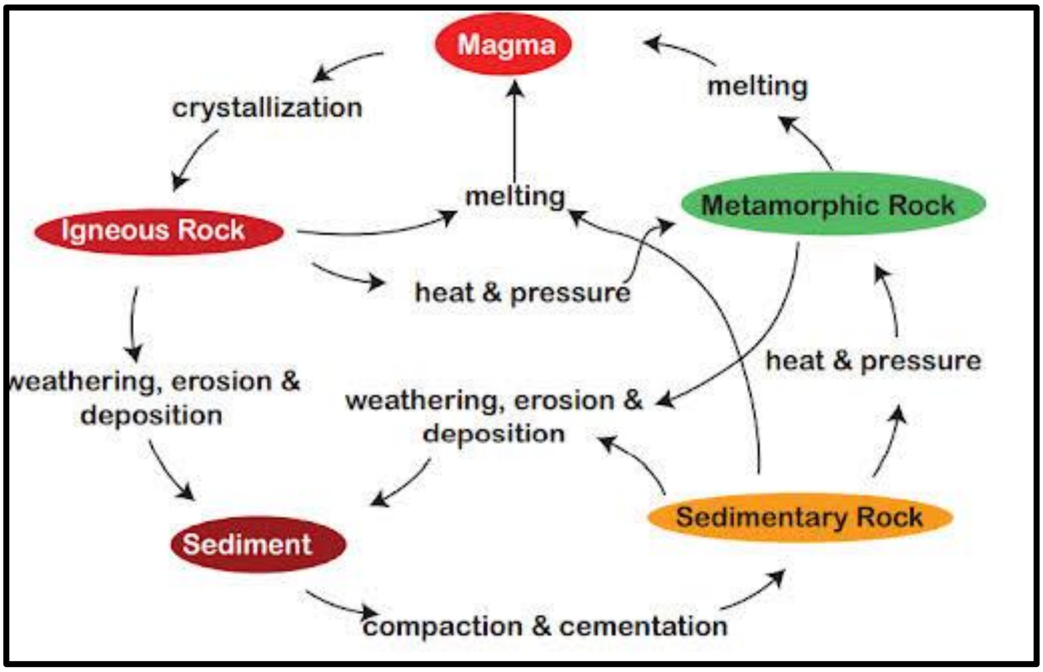
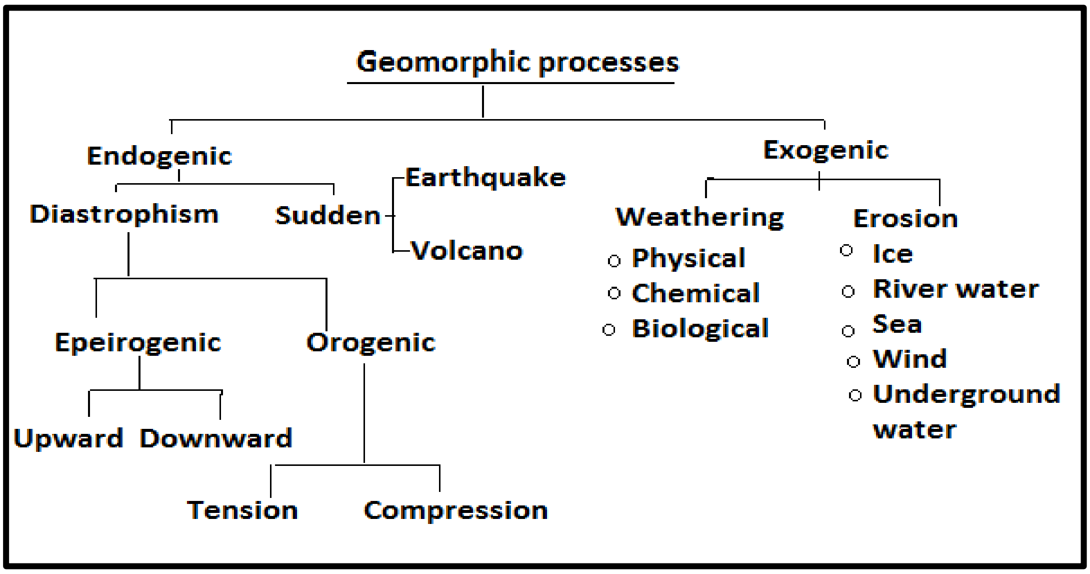


Figure 1 Rock Cycles

GEOMORPHIC PROCESSES AND EARTH'S MOVEMENT

- The Earth's crust and surface undergo continuous changes due to forces that act from both below (endogenic forces) and above the surface (exogenic forces).
- These forces result in physical and chemical changes to the geomorphic structure, which can be gradual or sudden.
- Geomorphic processes such as weathering, erosion, and folding occur at different rates, with some changes being imperceptibly slow, others gradual, and a few occurring suddenly, such as earthquakes and volcanic eruptions
- Endogenic forces come from deep within the Earth, driving movements like earthquakes and volcanic eruptions.
- Exogenic forces act on the Earth's surface, causing processes like weathering and erosion.

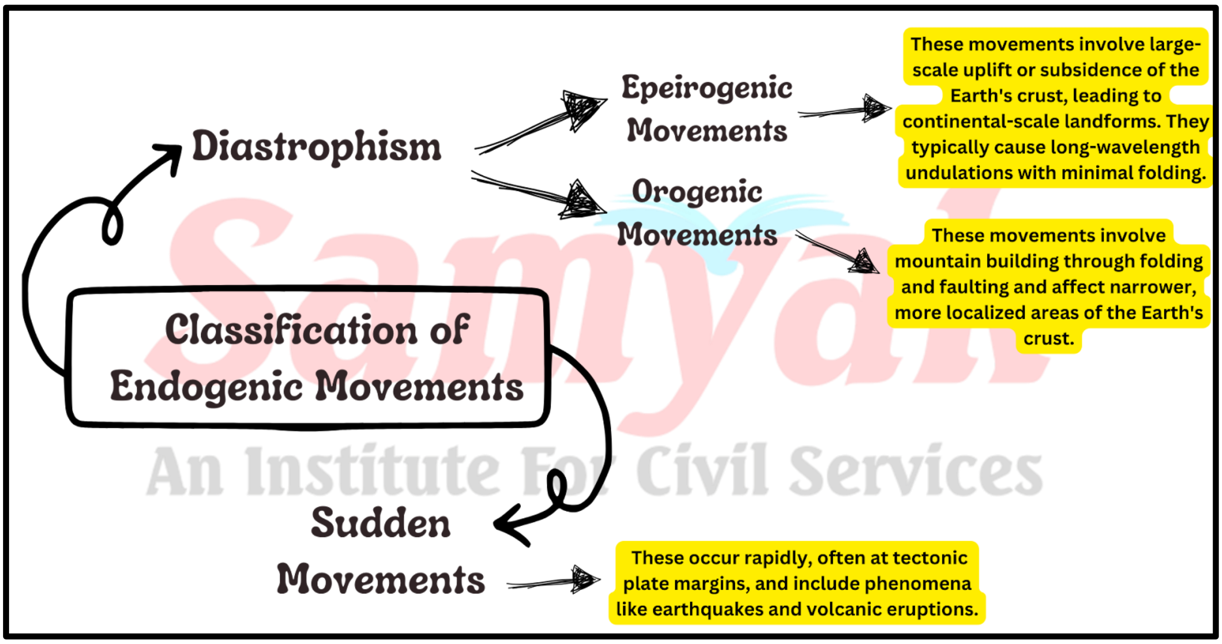


ENDOGENETIC FORCES

- Endogenic movements refer to large-scale changes in the earth's crust caused by forces originating deep within the Earth.
- These movements are driven by the planet's internal heat, primarily from radioactive decay and gravitational pressure, which result in temperature and pressure gradients.
- These gradients cause density differences, leading to convection currents in the mantle, which in turn drive the movement of lithospheric plates.
- The Earth's rotation (Coriolis effect) also influences the direction of these convection currents, determining the nature and location of endogenic movements.

CLASSIFICATION OF ENDOGENIC MOVEMENTS

Endogenic movements are classified into **diastrophic movements** (gradual) and **sudden movements** (rapid).



DIASTROPHISM

Diastrophism refers to the deformation of the Earth's crust through processes like folding, faulting, and warping. These movements occur over long periods and include:

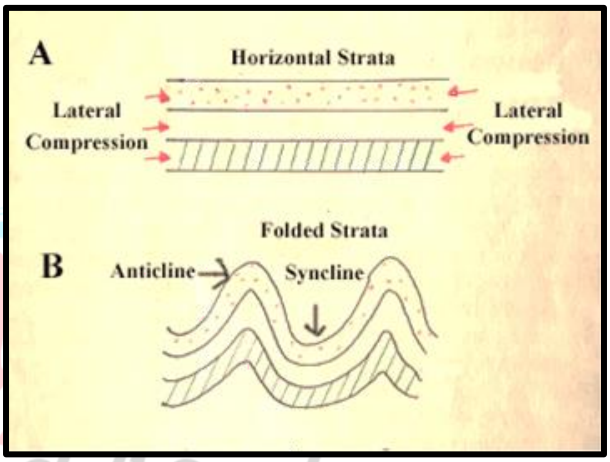
- **Orogenic Processes:** Associated with mountain building through intense folding and faulting, affecting long and narrow crustal belts.
- **Epeirogenic Processes:** Involve uplift or subsidence of large areas of the Earth's crust, resulting in broad, shallow deformations.
- **Earthquakes and Volcanism:** Localized, often rapid movements that are part of diastrophic processes.
- **Plate Tectonics:** Horizontal movements of the Earth's crustal plates are central to both orogenic and epeirogenic processes.

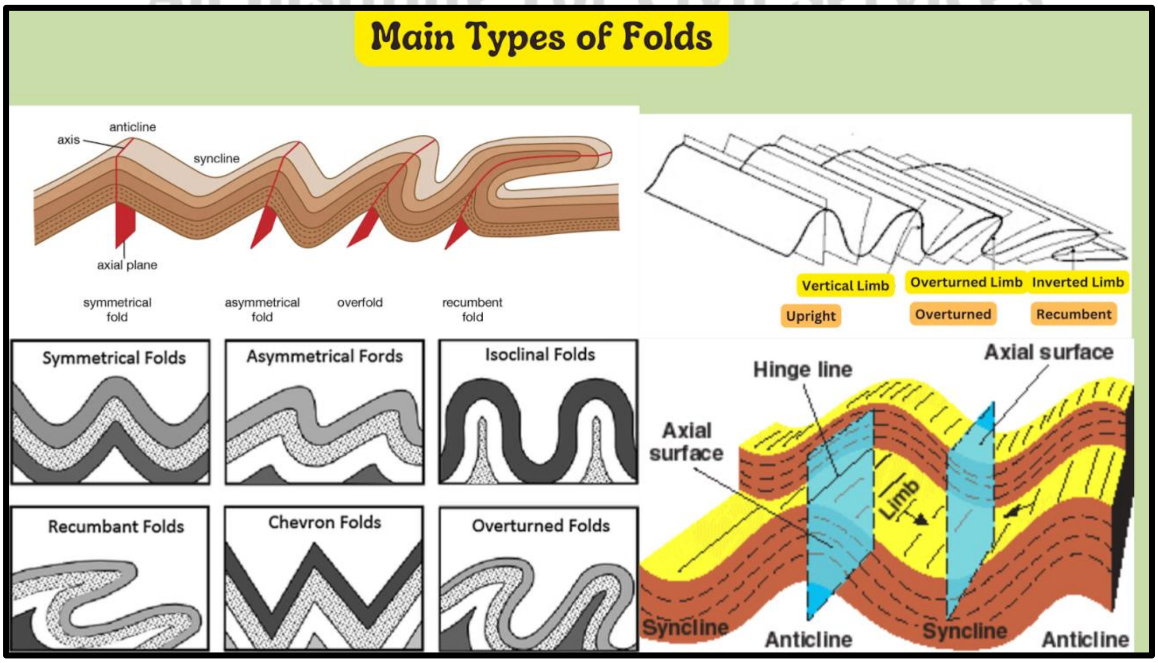
EPEIROGENIC OR CONTINENT-FORMING MOVEMENTS

- Epeirogenic movements are characterized by radial deformations of the Earth's crust, which may lead to either uplift or subsidence. These movements typically cause subtle undulations in the land. Evidence of uplift includes raised beaches, elevated wave-cut terraces, and fossiliferous beds above sea level. In India, regions like Kathiawar, Nellore, and Tirunelveli show evidence of upliftment, where areas that were once coastal are now several miles inland.
- Conversely, **subsidence** refers to the sinking or lowering of land. Examples include submerged forests and valleys, such as those in the Sundarbans and Tirunelveli. The 1819 earthquake in the Rann of Kachchh caused a significant subsidence event, as did other regions like the Gulf of Mannar and Palk Strait.

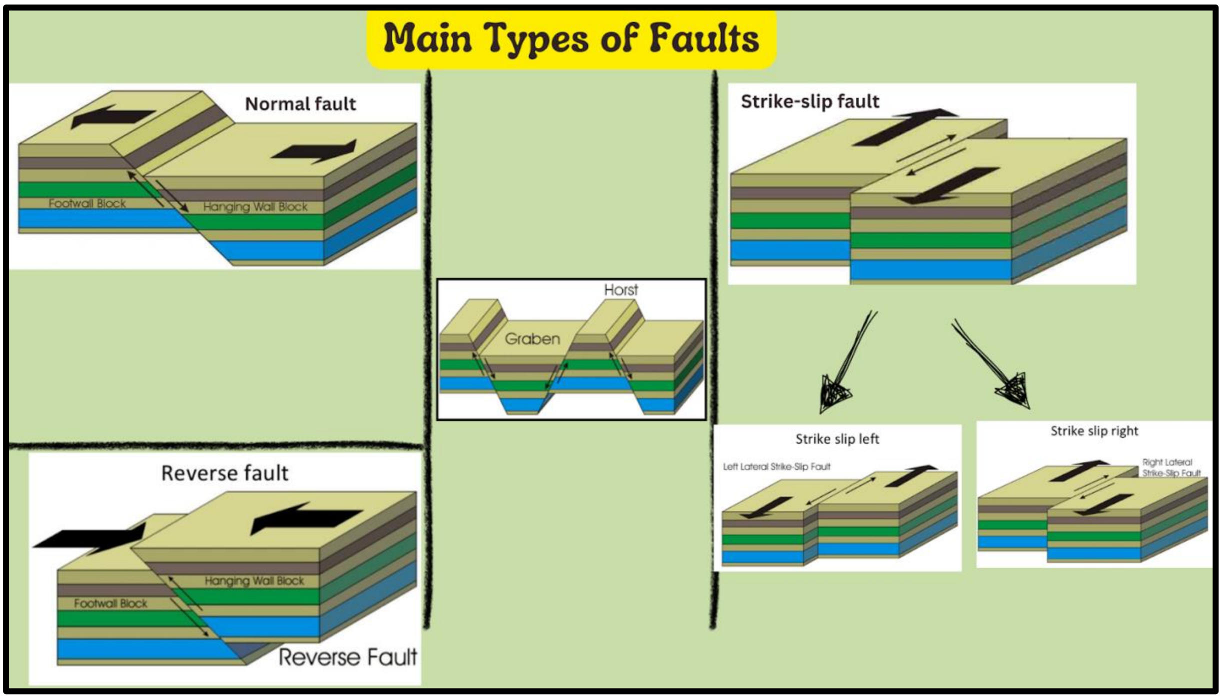
OROGENIC OR MOUNTAIN-FORMING MOVEMENTS

- In contrast to epeirogenic movements, orogenic movements involve the more complex deformation of the Earth's crust through the convergence of tectonic plates. These movements lead to the formation of mountain ranges and are characterized by the folding, faulting, and volcanic activity. Orogenic movements are typically associated with horizontal compressional forces, which cause the crust to thicken and create mountain ranges.
- **Compressional Forces -** type of force acts towards a point from two or more directions). It produces Folds.



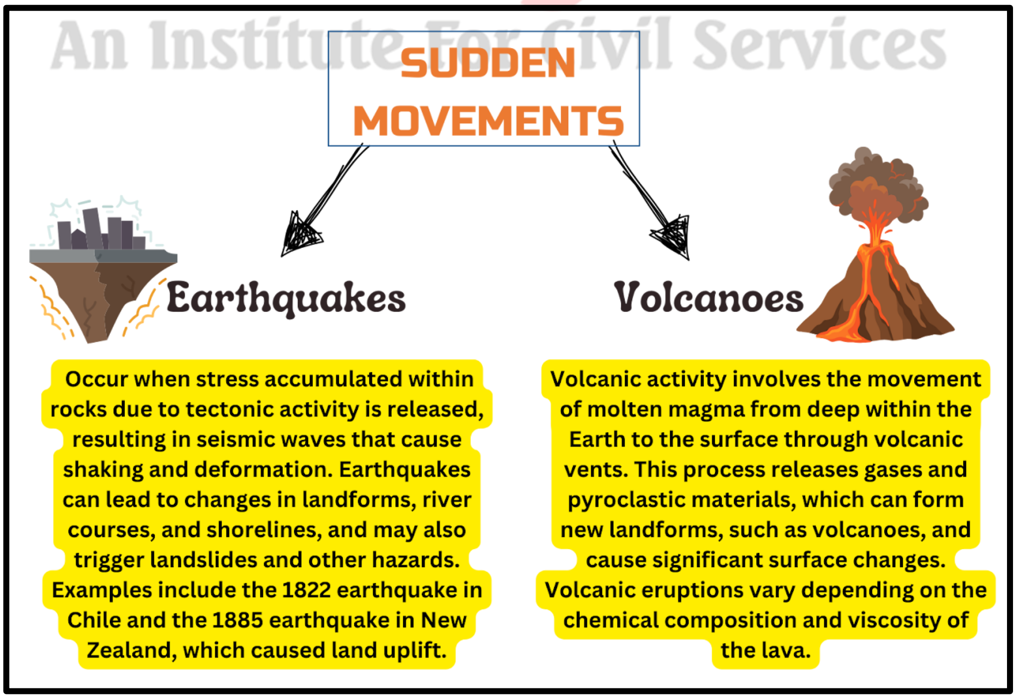


- **Tensional Forces -** type of force acts away from a point in two directions. It **produces Faults**



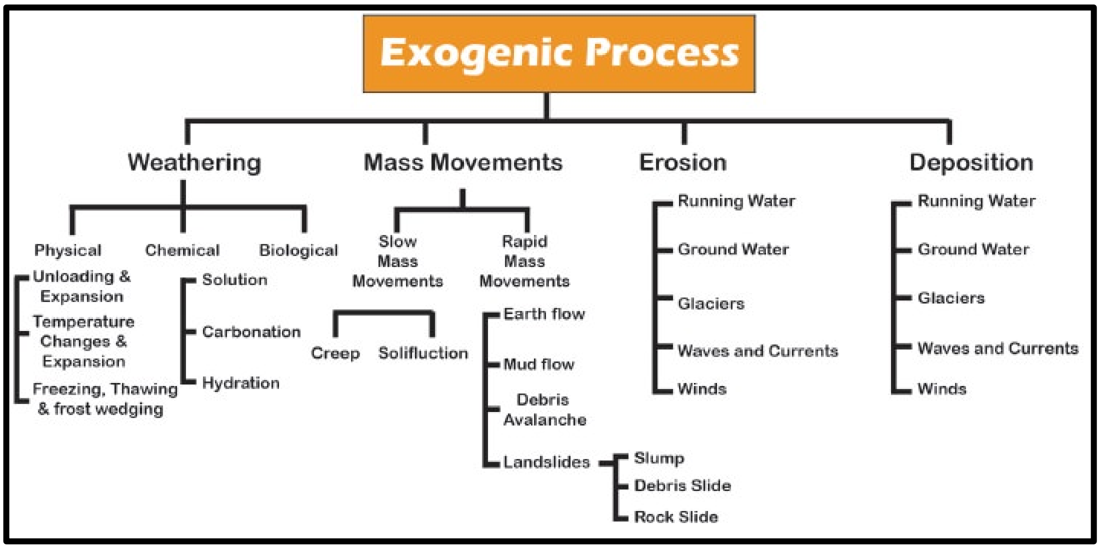
SUDDEN MOVEMENTS

- Sudden geomorphic movements, such as earthquakes and volcanic eruptions, are usually confined to tectonic plate margins, where the Earth's crust is under significant stress. These movements can cause substantial deformations in a short period.



EXOGENIC FORCES

- **Meaning** - Forces which originate from the Earth's Exterior or **within the Earth's Atmosphere.** These are **Land Wearing Forces**
- **FORCES BEHIND EXOGENIC MOVEMENTS**
  - **Sun's Energy:** Weather patterns like winds and precipitation result from solar heat, causing molecular stresses in earth materials.
  - **Stress-Induced Movements:** As temperature changes cause chemical reactions, stress is created in solid materials leading to exogenic processes.
- **Denudation** refers to the stripping away of materials, involving both weathering and erosion.
  - It depends on both physical (rock properties like hardness and permeability) and chemical factors (rock susceptibility to corrosion).
  - **Weathering:** The disintegration of rocks and soil occurs due to physical, chemical, and biological agents. It happens in situ, with materials being transported away later through erosion.

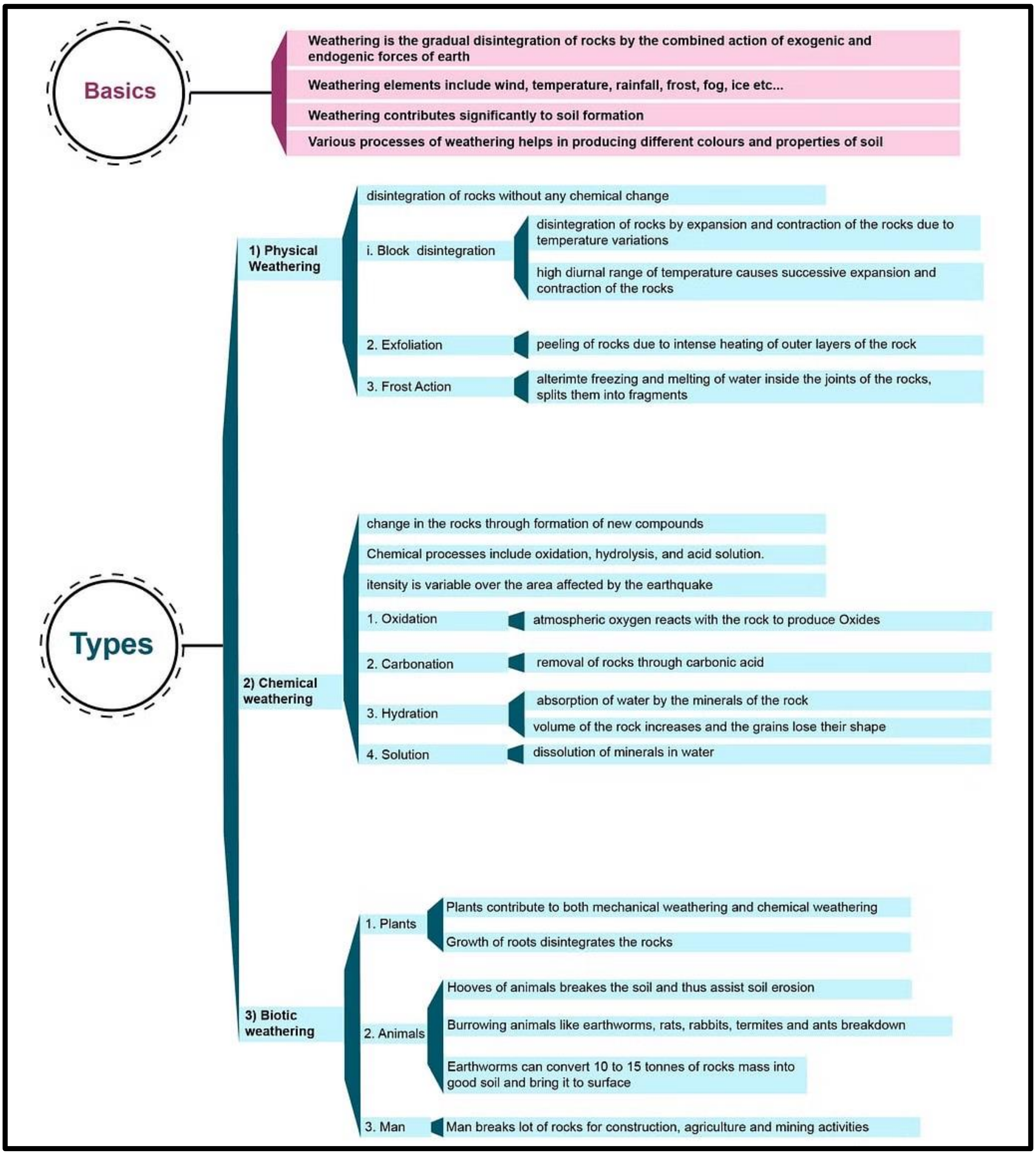


WEATHERING

- **In-situ** mechanical disintegration and chemical decomposition of rocks through the actions of various elements of weather and Climate.
- **Types of Weathering:**
  - **Physical Weathering**
    1. **Exfoliation (Pressure Release):** When overlying rock is removed, rocks beneath expand and fracture. This can cause sheets of rock to break off.
    2. **Thermal Stress Weathering:** Diurnal and seasonal temperature changes cause rock surfaces to expand and contract, leading to exfoliation.
    3. **Granular Disintegration:** Differential heating causes mineral grains within rocks to expand and separate.
    4. **Frost Weathering:** Freeze-thaw cycles cause ice to expand in rock cracks, fracturing the rock over time.
    5. **Salt Weathering:** Evaporation of saline solutions causes salt crystals to expand, breaking apart rocks.
  - **Chemical Weathering**
    1. **Dissolution and Solution Weathering:** Water dissolves minerals like nitrates or sulphates.

2. **Carbonation:** Carbon dioxide reacts with minerals like limestone, forming soluble compounds like calcium bicarbonate.
3. **Hydration:** Water added to minerals causes volume expansion and mechanical stress, aiding disintegration.
4. **Oxidation and Reduction:** Oxidation of minerals like iron creates rust, whereas in the absence of oxygen, reduction takes place.

- **Biological Weathering**
    1. Plants, animals, and microbes contribute to both mechanical (e.g., roots breaking rocks) and chemical weathering (e.g., decaying matter producing acids).



MASS MOVEMENT

- Mass movement is the **movement of weathered material** down a slope **due to gravitational forces.**
- The **movement may be gradual or sudden**, depending on the gradient of the slope, the weight of weathered debris, the presence of lubricating moisture.

Types of Mass Movements	Meaning
Creep	➢ a **slow and continuous movement of soil down the hill slopes**
Solifluction	➢ Movement of soil which is completely saturated with water
Earthflow	➢ **Downslope movement of water-saturated clay or silt** along a hill.
Mudflow	➢ **When thick layers of weathered materials become saturated with water** and flow down along definite pathways in the absence of vegetation and cover.
Landslides	➢ When a **large mass of soil or rock falls suddenly**. ➢ Occurs generally on **steep slope**
Slump	➢ A form of landslide in which many units of **rock debris slide backward in relation to the slope** over which the movement occurs.
Rockslide	➢ Movement of **individual rock masses**.

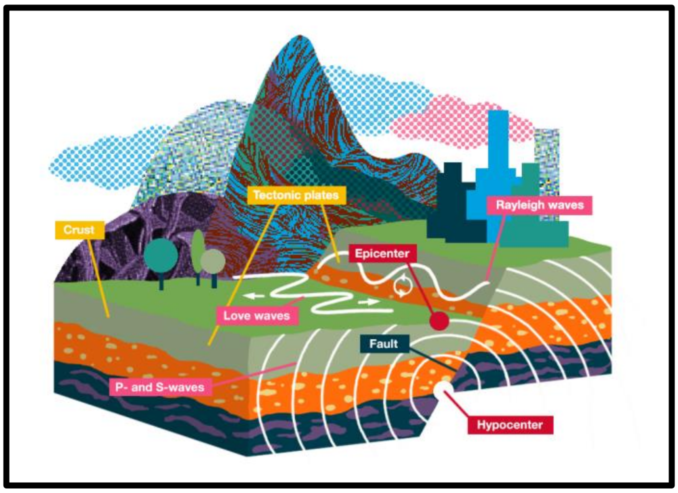
EARTHQUAKES

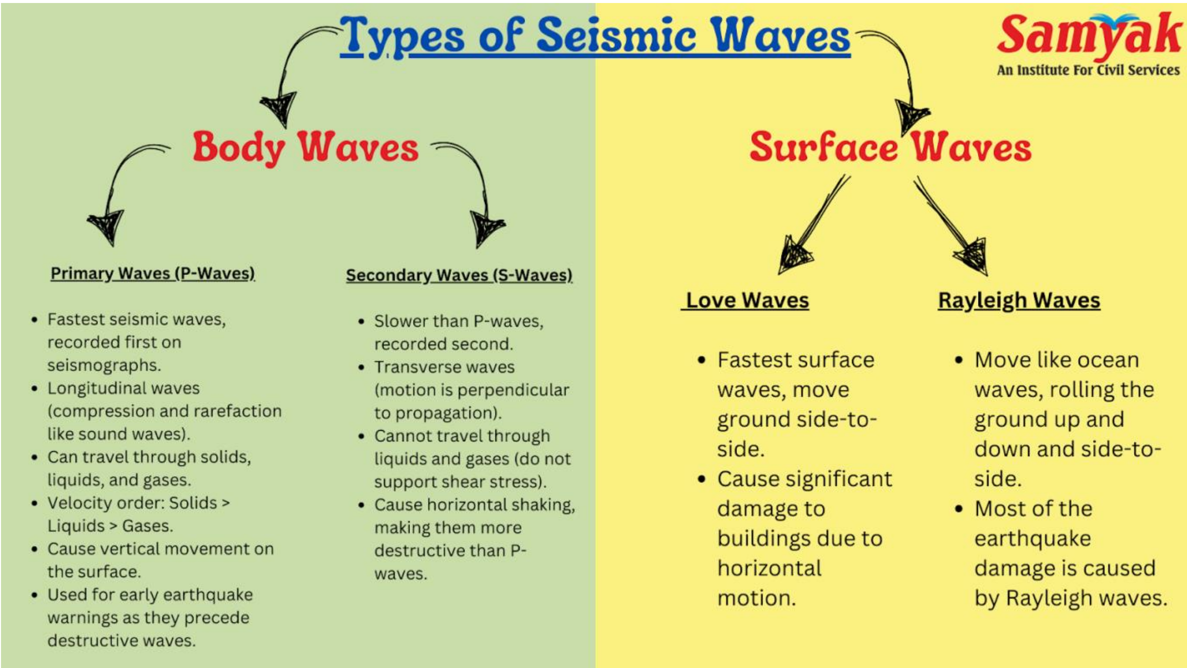
- An earthquake is the shaking or trembling of the Earth's surface, caused by the release of energy in the Earth's crust or upper mantle. This energy, which is released during sudden movements, creates seismic or earthquake waves that cause the surface to shake. Earthquakes can range from mild tremors to massive, destructive events.
- Seismic waves are waves of energy that travel through the Earth's layers and are caused by events such as earthquakes, volcanic eruptions, magma movement, large landslides, or significant human-made explosions. These waves provide insights into the Earth's interior structure when analyzed through seismic instruments like seismographs. The terms "seismic waves" and "earthquake waves" are often used interchangeably.

HOW ARE EARTHQUAKE WAVES PRODUCED?

- Earthquake waves are produced when energy is abruptly released along a fault, which is a sharp break in the Earth's crust. Rock layers along the fault move in opposite directions due to forces exerted on them but are initially held in place by friction. Over time, pressure builds up and overcomes this friction, causing a sudden movement that generates shockwaves (seismic waves).

- These shockwaves travel in all directions from the point where the energy is released, known as the **focus** or **hypocenter**. The point on the Earth's surface directly above the focus is called the **epicenter**. A **seismograph** is used to record these waves as they reach the Earth's surface.



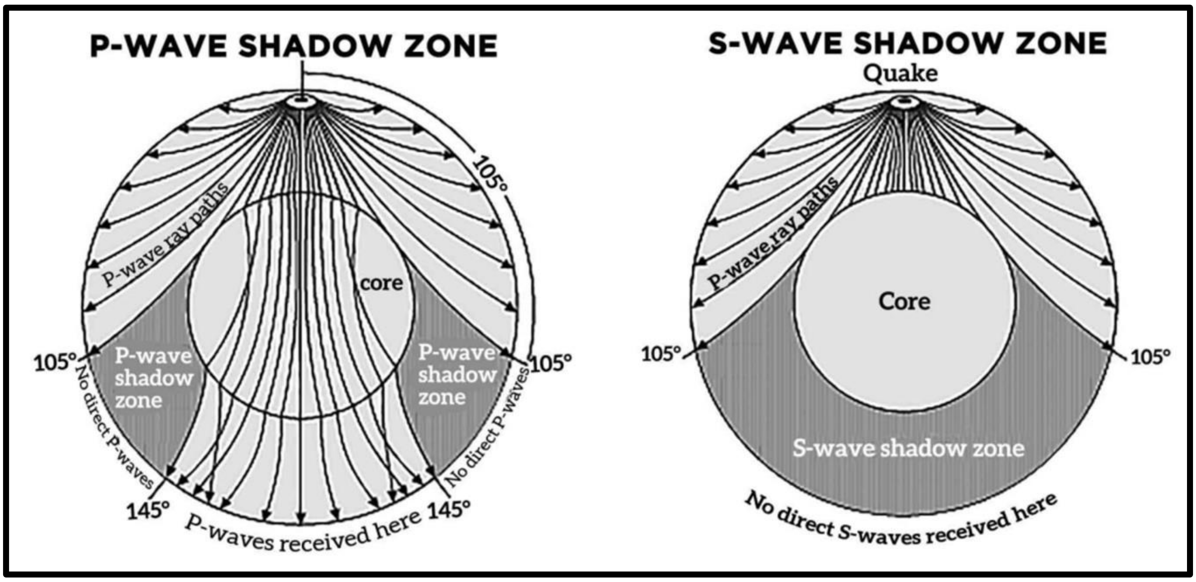


HOW SEISMIC WAVES HELP IN UNDERSTANDING THE EARTH'S INTERIOR

Seismic waves are instrumental in studying the Earth's interior. By observing the differences in arrival times and the refraction or reflection of seismic waves, scientists can deduce the Earth's internal structure. Key observations include:

- **Shadow Zones**: The **shadow zone** refers to areas where seismic waves are not detected, helping scientists infer the composition of the Earth's layers. For example:
  - S-waves do not pass through liquids, creating a shadow zone beyond 103° from the epicenter. This discovery led to the identification of the Earth's liquid outer core.
  - P-waves are refracted when they pass through the outer core, creating a shadow zone between 103° and 142° from the epicenter. However, they are detected beyond 142°, which suggests the presence of a solid inner core.

- **Discontinuities in Wave Motion**: Seismic waves change their velocity as they pass through different layers of the Earth, indicating changes in density and composition. These discontinuities also provide clues about phase changes in the Earth's materials.



Why Do P-Waves Travel Faster Than S-Waves?

- P-waves are faster because they are **compression waves,** which transmit energy more easily through the medium. In contrast, S-waves are shear waves, and their motion is perpendicular to the direction of propagation, making them harder to transmit.

The Shadow Zones of Seismic Waves

P-Wave Shadow Zone

- The P-wave shadow zone spans between 103° and 142° from the epicenter. P-waves are refracted when passing through the liquid outer core, and their behavior in this zone reveals the Earth's interior structure.

S-Wave Shadow Zone

- The S-wave shadow zone spans beyond 103° from the epicenter, as S-waves do not travel through liquids. This phenomenon also points to the existence of a liquid outer core.

KEY TERMS RELATED TO EARTHQUAKES

Term	Definition
Focus (Hypocentre)	The point within the Earth where the energy is released during an earthquake.
Epicentre	The point on the Earth's surface directly above the focus, where the earthquake waves first reach.
Isoseismal Lines	A line connecting points on the Earth's surface where earthquake intensity is the same.
Seismic Waves	Energy waves released during an earthquake.

Seismograph	An instrument used to detect and record seismic waves.
Foreshocks	Mild earthquakes that precede the violent shaking movement of a major earthquake.
Aftershocks	Smaller earthquakes that follow a major earthquake, often continuing for days or weeks.
Swarms	Large numbers of small earthquakes that can occur over months in a region without a major earthquake.
Shallow Earthquakes	Earthquakes occurring at depths of 0–70 km; usually of low magnitude but can cause greater surface damage due to energy concentration.
Deep Earthquakes	Earthquakes occurring at depths of 300–700 km; often of larger magnitude, but may not cause significant destruction due to energy dissipation.
Subduction Zones	Areas where one tectonic plate is forced beneath another, often associated with deep earthquakes.

EARTHQUAKE SWARM

What is it?

An earthquake swarm is a series of multiple seismic events of comparable intensity that occur in a relatively small area over a short period. Unlike a major earthquake followed by aftershocks, an earthquake swarm does not have a discernible main shock. These swarms often involve many (sometimes thousands) low-intensity earthquakes and can last for weeks, particularly in active geothermal or volcanic areas.

Causes of Earthquake Swarms

- Fluid Movement In volcanic environments, fluid movement from deeper magma or circulating fluids within active geothermal zones can trigger earthquakes. When seismic energy accumulates and is released through cracks or faults, this can lead to a series of small tremors. A notable example is the Taupō Volcanic Zone.
- Active Volcanism Magma movement can drive earthquake swarms, particularly when cracks filled with magma push their way through the Earth's crust. The earthquakes typically occur near the crack tip, where the crack is beginning to open, or along the sides of the crack.
- Slow-Slip Events Slow-slip events involve gradual movement along a fault over an extended period (weeks to years), often in the range of a few centimeters to tens of centimeters. These events can be considered "earthquakes in slow motion" and are typically observed at subduction zones like the Hikurangi subduction zone, where one or two slow-slip events occur annually.

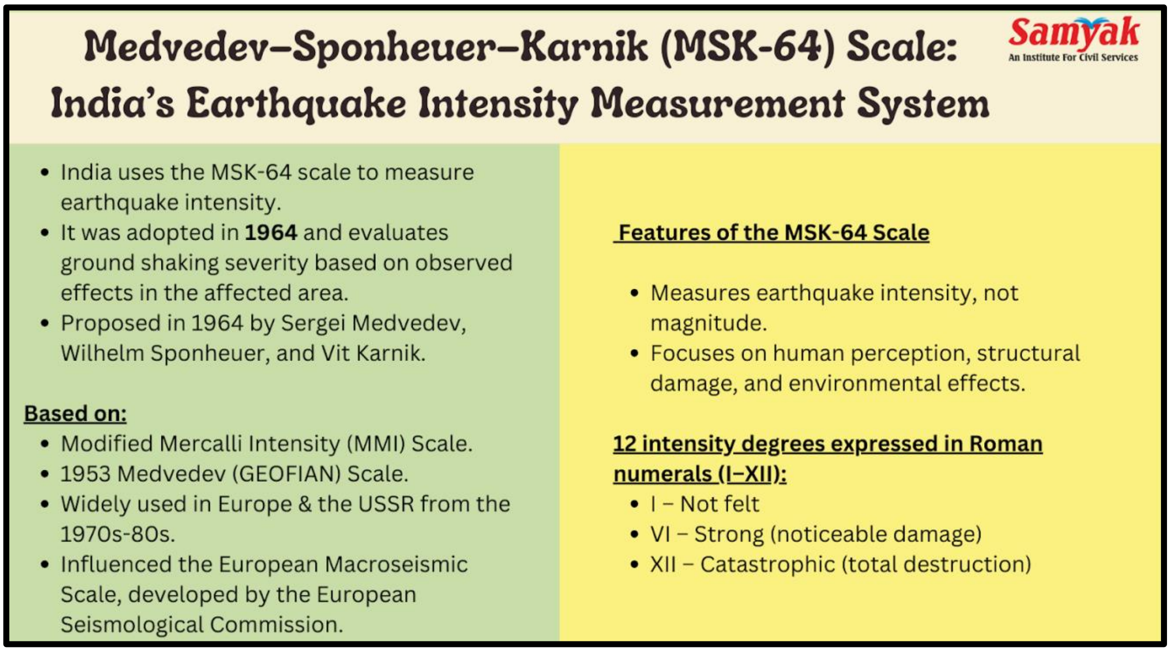
CAUSES OF EARTHQUAKES

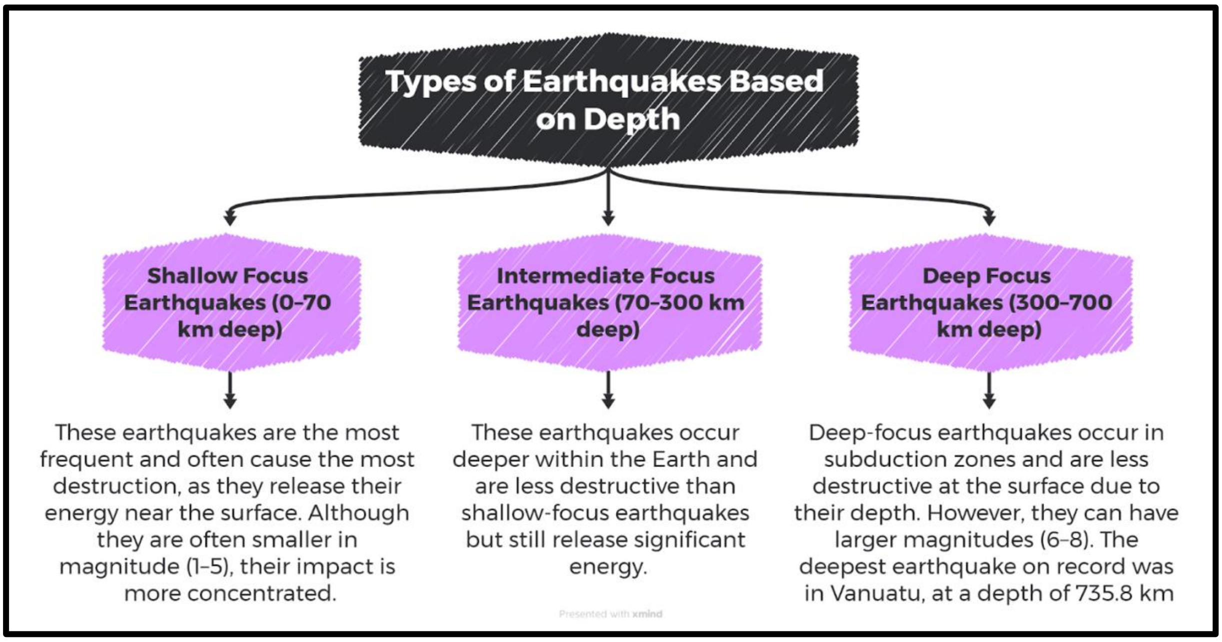
1. **Fault Zones**: Most earthquakes are caused by the sudden release of stress along faults, or fractures in the Earth's crust. The intensity of the earthquake depends on the length and width of the fault.
2. **Plate Tectonics**
   Earthquakes occur along plate boundaries due to the movement of tectonic plates:
   - **Convergent Boundaries (Reverse Faults)**: Plates collide, creating the most powerful earthquakes, including megathrust earthquakes like the 2004 Indian Ocean earthquake.
   - **Transform Boundaries (Strike-Slip Faults)**: Plates slide horizontally past one another, as seen along the San Andreas Fault.
   - **Divergent Boundaries (Normal Faults)**: Plates pull apart, usually resulting in smaller earthquakes.
3. **Volcanic Activity**
   Earthquakes in volcanic regions are caused by the movement of magma beneath the surface. While less severe, these earthquakes can serve as early warnings of volcanic eruptions, like the 1980 eruption of Mount St. Helens.

4. **Human-Induced Earthquakes**
   Human activities such as mining, petroleum extraction, nuclear testing, and the creation of artificial lakes can induce earthquakes. For example:
   - **Reservoir-Induced Seismicity**: The pressure of water in a reservoir can alter stresses along faults, leading to earthquakes. Notable examples include the 1967 Koynanagar earthquake in India and the 2008 Sichuan earthquake in China.

MEASUREMENT OF AN EARTHQUAKE

Richter Scale	Mercalli Scale
➢ **Measures Magnitude** – Energy released during an Earthquake	➢ **Measures Intensity** – Visible damage caused
➢ Scale is **Open-Ended and logarithmic** based on 10. ➢ Range – **0 to 10**	➢ **Closed-ended linear Scale** ➢ Range – **1 to 12**

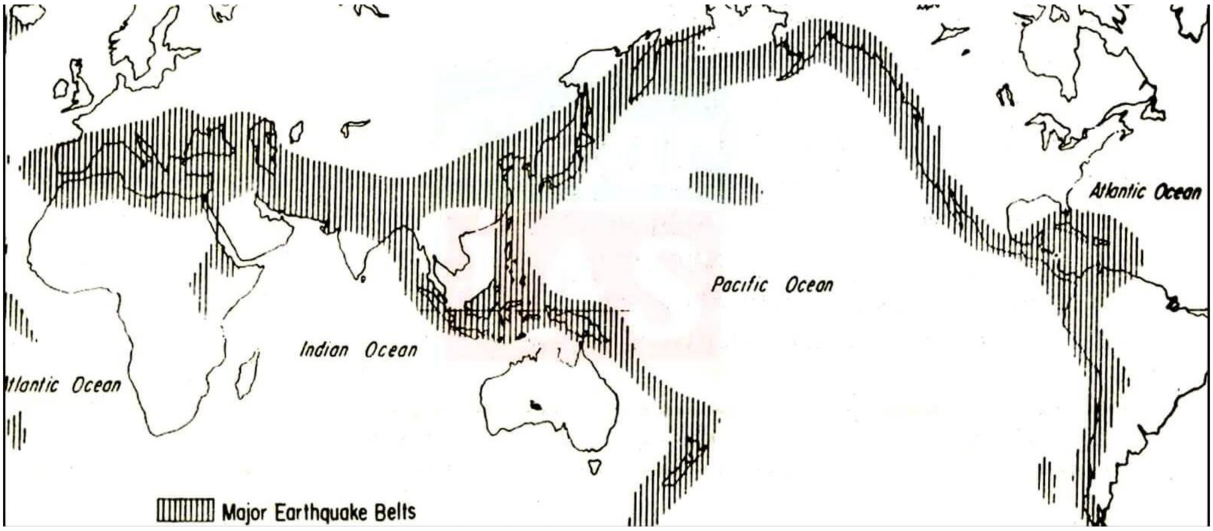




DISTRIBUTION OF EARTHQUAKES

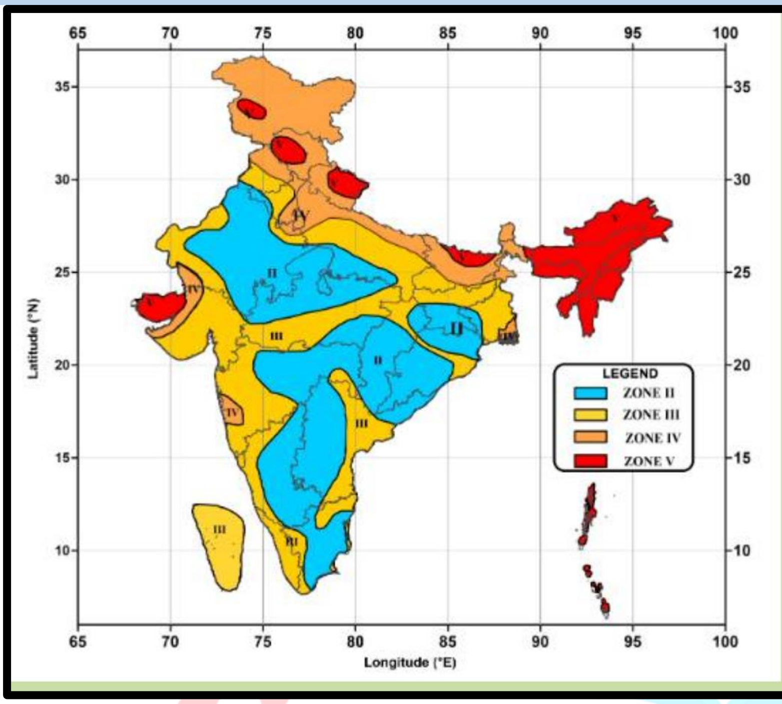
The majority of the world's earthquakes occur along the edges of tectonic plates, particularly in the following regions:

1. **Circum-Pacific Belt (Ring of Fire)**: This region is known for its high seismic activity and is home to approximately 68% of the world's earthquakes. It includes areas like New Zealand, Japan, the Aleutian Islands, and the coasts of North and South America.
2. **Alpine Belt**: Stretching from the Himalayas to the Alps, this belt contributes about 15% of the world's seismic activity. It is associated with mountain-building processes.
3. **Oceanic Ridges and Rift Valleys**: Earthquakes are also common along oceanic ridges, including in the Atlantic and Arctic Oceans, and the rift valleys of East Africa.



The Wadati–Benioff Zone: The Wadati–Benioff zone is a subduction zone where earthquakes occur due to differential motion along faults. This zone produces some of the most powerful earthquakes and can extend to depths of 700 km.

EARTHQUAKE HAZARD ZONING IN INDIA

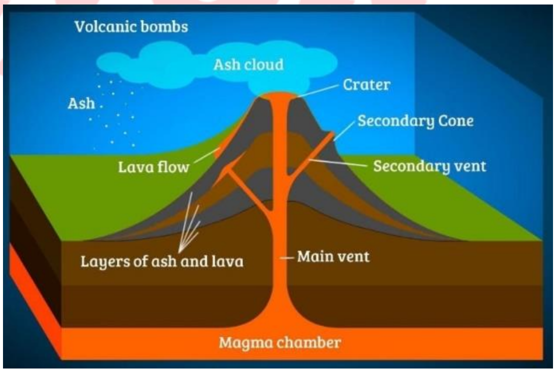


Seismic zoning classification by the Bureau of Indian Standards (BIS)

- **Zone II (Low Risk):** Standard construction practices are generally sufficient.
- **Zone III (Moderate Risk):** Buildings must be designed to withstand moderate shaking.
- **Zone IV (High Risk):** Special earthquake-resistant techniques are mandatory for buildings, bridges, and critical infrastructure.
- **Zone V (Very High Risk):** Strictest construction regulations apply. Use of seismic dampers, base isolators, and reinforced structures is essential.

VOLCANISM

- A volcano is a vent or fissure in the Earth's crust through which molten rock (lava), ash, gases, and rock fragments erupt from a magma chamber beneath the surface. The process of volcanic eruptions and associated activities is known as volcanism.

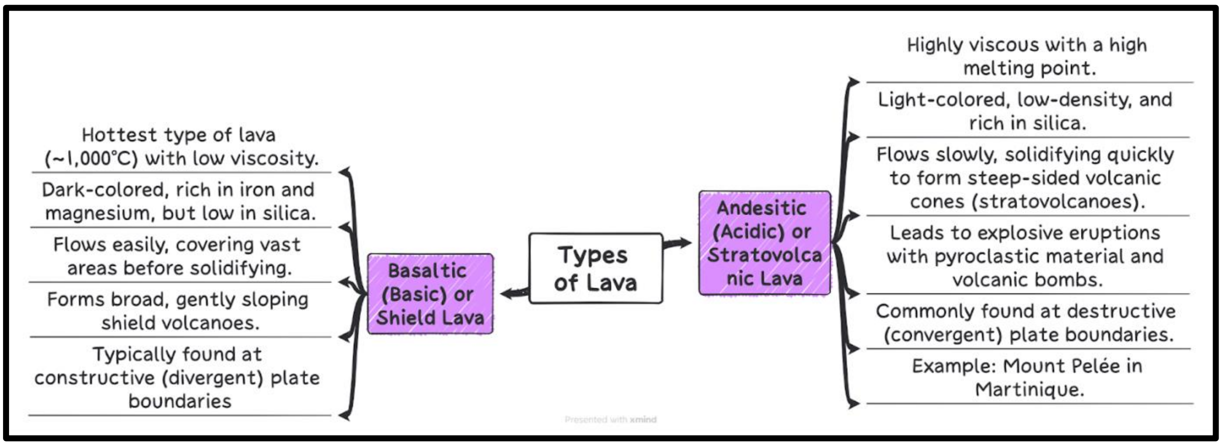


CAUSES OF VOLCANISM

Volcanism occurs due to the movement of molten material from the Earth's interior to its surface. The primary causes include:

1. **Temperature Difference:** The Earth's inner layers have significantly higher temperatures than the outer layers due to differences in radioactivity.
2. **Convection Currents in the Mantle:** The temperature difference generates convection currents in the mantle, leading to the formation of weak zones at convergent and divergent plate boundaries.
3. **Divergent Boundaries:** At these locations, molten and semi-molten material rises through the crust, often leading to fissure-type volcanic eruptions.
4. **Convergent Boundaries:** When one tectonic plate subducts beneath another, intense pressure causes magma to form and escape to the surface in violent eruptions.

5. **Earthquakes and Fault Zones:** Seismic activity may create fractures in the Earth's crust, allowing magma to escape and form volcanic features.



GLOBAL DISTRIBUTION OF EARTHQUAKES AND VOLCANOES

Volcanic activity is concentrated along tectonic plate boundaries. The most active regions include:

1. **Circum-Pacific Belt (Pacific Ring of Fire):**
    - Accounts for ~70% of global earthquakes.
    - Major active volcanic regions include:
        - Aleutian Islands (Alaska)
        - Kamchatka Peninsula (Russia)
        - Japan, the Philippines, and Indonesia
        - Solomon Islands, New Hebrides, Tonga
        - Andes region, Central America, and Mexico
2. **Mediterranean-Himalayan Belt:**
    - Represents ~20% of the world's earthquakes.
    - Extends across Asia Minor, the Himalayas, and parts of northwest China.
3. **Other Notable Volcanic Regions:**
    - **Atlantic Region:** Fewer active volcanoes but many dormant ones (e.g., St. Helena, Cape Verde, Canary Islands).
    - **East African Rift Valley:** Home to volcanic mountains like Mount Kilimanjaro and Mount Kenya.
    - **West Indian Islands (Lesser Antilles):** Includes volcanic islands with ongoing activity.
    - **Mediterranean Region:** Volcanism is associated with the Alpine fold belt (e.g., Mount Vesuvius, Stromboli, and the Aegean islands).

VOLCANISM IN INDIA

1. **Active Volcano:** Barren Island (Andaman & Nicobar Islands) has been active since the 1990s, with eruptions recorded in 2017.
2. **Dormant Volcano:** Narcondam Island, located ~150 km northeast of Barren Island, is considered extinct.
3. **Himalayan and Peninsular India:** No active volcanic activity.

TYPES OF VOLCANOES BASED ON ACTIVITY

1. **Active Volcanoes:** Frequently erupting (e.g., Barren Island, Anak Krakatoa).
2. **Dormant Volcanoes:** Temporarily inactive but may erupt in the future (e.g., Mount Kilimanjaro).
3. **Extinct Volcanoes:** No recorded activity and unlikely to erupt again (e.g., Mount Kenya).

An active volcano	A dormant volcano	An extinct volcano
An active volcano is one that has erupted in the Holocene epoch (the last 11,650 years) or shows signs of potential future eruptions, such as magma movement, seismic activity, or ground deformation.	A dormant volcano is an active volcano that is not currently erupting but has the potential to do so in the future. It may show occasional seismic activity or gas emissions, indicating an active magma chamber beneath the surface.	An extinct volcano is one that is not expected to erupt again because it no longer has a magmatic source. This conclusion is based on geological evidence, such as long-term erosion and lack of subsurface magma activity.
Example: Mauna Loa (Hawaiʻi), Kīlauea (Hawaiʻi), Stromboli (Italy), Erebus (Antarctica)	Example: Mount Hood (USA), Yellowstone Caldera (USA), Valles Caldera (USA)	Example: Mount Thielsen (Oregon, USA), Kilimanjaro (Tanzania), Ben Nevis (Scotland)

CLASSIFICATION ON THE BASIS OF TYPE OF ERUPTION

1. **Central-Type Eruption**
    - Occurs through a single vent or opening.
    - Eruptions are explosive in nature.
    - Forms stratovolcanoes or composite volcanoes.
    - Example: Mount Vesuvius, Mount St. Helens
2. **Fissure-Type Eruption**
    - Magma escapes through long, deep cracks in the Earth's crust.
    - Lava spreads over large areas, forming horizontal sheets.
    - Leads to the formation of lava plateaus and flood basalts.
    - Example: Deccan Traps (India), Columbia River Basalt Group (USA).

DESTRUCTIVE EFFECTS OF VOLCANISM

- **Loss of Life and Property:** Explosions and lava flows can cause widespread destruction (e.g., Mount Vesuvius eruption in 79 AD).
- **Tsunamis:** Underwater volcanic eruptions can trigger massive waves (e.g., 1883 Krakatoa eruption, 2018 Sunda Strait tsunami).
- **Climate Impact:** Volcanic ash can lower global temperatures, leading to famine (e.g., 1815 Mount Tambora eruption).
- **Lava Rivers:** Fast-moving lava can engulf entire cities.
- **Lahars:** Volcanic mudflows can bury towns within minutes (e.g., 1985 Nevado del Ruiz eruption).
- **Air Travel Disruptions:** Volcanic ash plumes can ground flights (e.g., 2010 Iceland eruption).
- **Supervolcanic Eruptions:** Large-scale eruptions can lead to extinction events (e.g., Toba eruption ~74,000 years ago).

PROCESS OF VOLCANISM

ALONG THE PLATE BOUNDARIES

- **Decay of Radioactive substances** within the Earth's interior generates heat.
- This lead to **temperature difference between the inner lavers and the outer layers** of the earth due to differential amount of radioactivity.
- It gives **rise to Convection Currents in the Mantle**
- The convectional currents in the mantle create convergent and divergent boundaries.
- **At the divergent boundary**
  - ✓ magma and other such substances rise in form of **Fissure eruptions**
- **At the convergent boundary**
  - ✓ the subduction of denser plate creates magma at high pressure which will escape to the surface. **(Central Type of Eruptions)**
  - ✓ Because of high pressure and volatile gases, the magma and gases escape with great velocity as the pressure is released through eruptions.

ALONG THE HOTSPOTS / HOTSPOT VOLCANISM

✓ In this situation, a zone of magmatic activity **occurs at the HOTSPOTS knows as MANTLE PLUMES in the middle of a tectonic plate**

VOLCANIC LANDFORMS

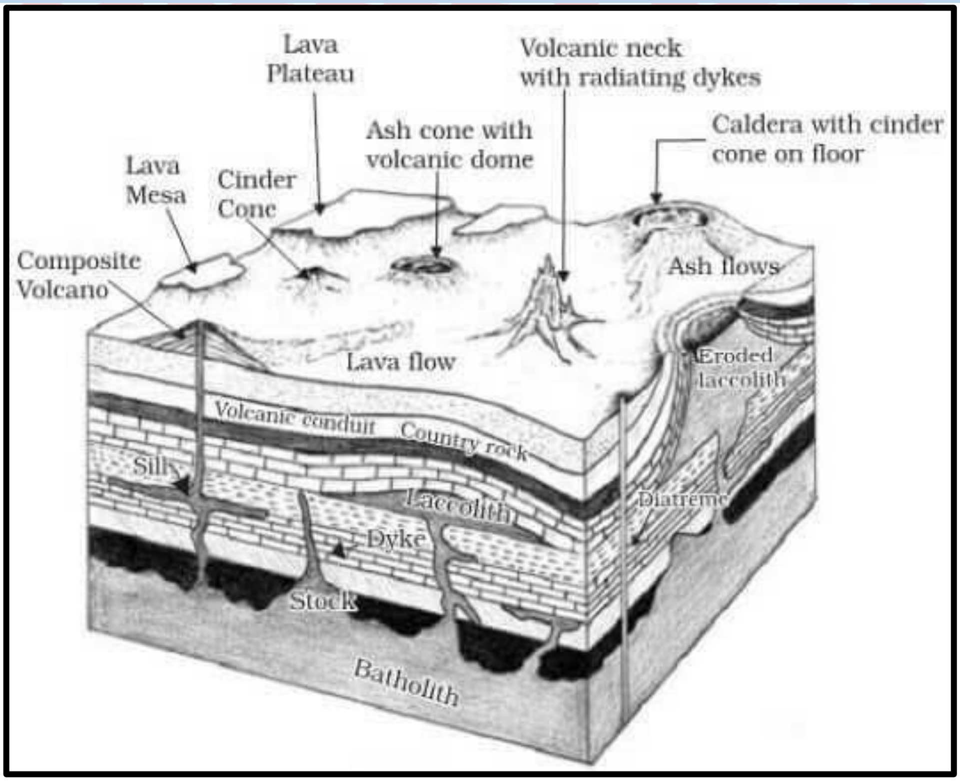


Figure 2 Extrusive and Intrusive Landforms

Extrusive Landforms	Intrusive Landforms
Cinder Cone – Ash Cone ➢ Formed due to **accumulation of loose pyroclastic fragments** ➢ **steep circular or oval-shaped**	**Batholiths** ➢ **large granitic dome shaped** rock bodies formed due to solidification of hot magma **inside the earth**. ➢ They **appear on the surface only after the denudation** processes remove the overlying materials.
Composite Cone ➢ Have **alternate layers of lava and fragmented materials**	**Laccoliths** ➢ Large **mushroom or dome-shaped** intrusive bodies connected by a pipe-like conduit from below.
Shield Volcano ➢ **Low slope** but extend far and wider ➢ Are of low explosive in general, but if somehow water gets into the vent they may turn explosive	**Lapolith** ➢ When magma solidifies in form of **saucer shape, concave to the sky body**
Flood Basalt ➢ Volcano outpour highly fluid lava that flows for long distances.	**Phacolith** ➢ **wavy** mass of intrusive rocks ➢ Intrusion of magma along the anticlines and synclines
Crater ➢ Inverted cone-shaped **or funnel shaped vent** through which the magma flows out.	**Sills** ➢ When magma solidifies in form of **thick horizontal bodies** **Sheets** ➢ The thinner ones are called sheets.
Caldera ➢ Such Volcanoes are so explosive that when they erupt they tend to collapse on themselves. ➢ The **collapsed depressions** are called calderas. **Caldera Lakes** – ➢ Water from rain or melted snow gets accumulated in the caldera	**Dykes** ➢ When magma solidifies **almost perpendicular to the ground.**

WHY AREN'T THE HIMALAYAS VOLCANIC?

- Mountains and volcanoes are often associated with each other, but not all mountain ranges have volcanic activity. The Himalayas, the tallest mountains on Earth, lack volcanoes, whereas the Andes are full of them. This difference arises due to variations in **tectonic interactions**.

TYPES OF TECTONIC PLATE INTERACTIONS AND THEIR IMPACT

- Tectonic plates interact in different ways, leading to varied geological formations. Two key types of convergent boundaries help explain why some mountains have volcanoes while others do not:
- **Continental Collision (Himalayas)**
  - Occurs when two **continental plates** collide.

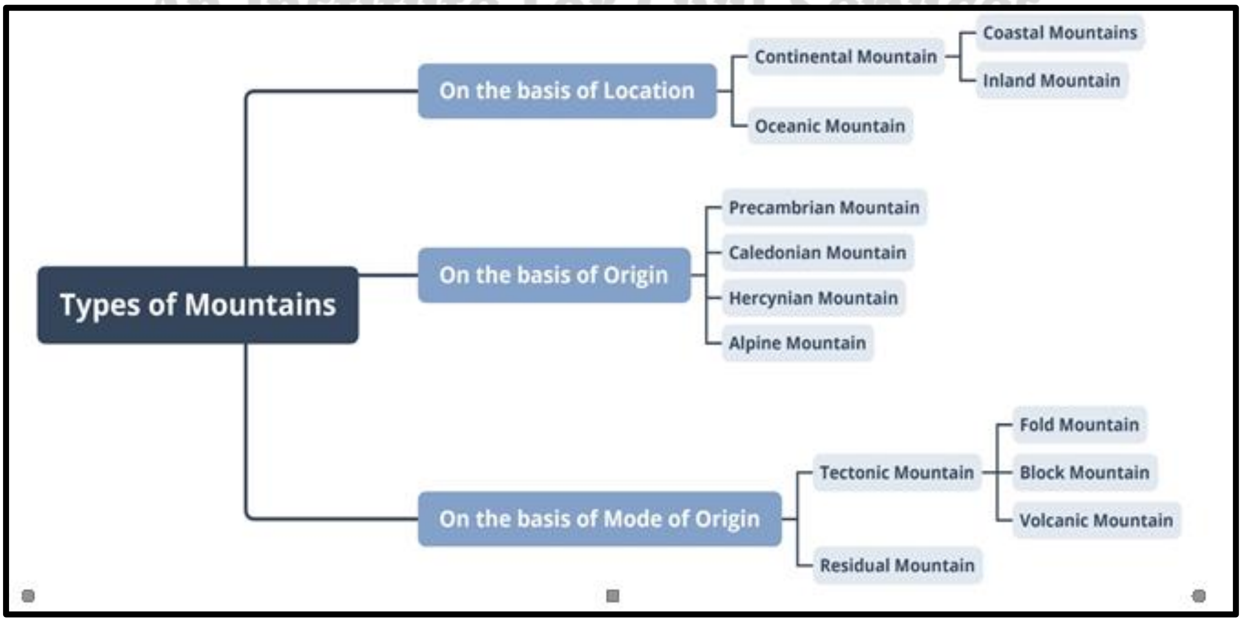
- Both plates are made of **low-density, thick rocks** (granite, sandstone).
- Neither plate subducts; instead, they **crumple and stack**, pushing the land upward.
- This process creates **massive mountain ranges** but does **not** generate significant magma formation, hence **no volcanoes**.
- **Example: The Himalayas**
  - Formed due to the collision of the **Indian Plate** and the **Eurasian Plate** millions of years ago.
  - The plates continue to push against each other, causing **continuous uplift**.
  - Despite immense tectonic activity, **no volcanic eruptions occur** because there is no subduction to trigger melting.

➢ **Subduction Zone Collision (Andes)**
- Occurs when an **oceanic plate** collides with a **continental plate**.
- The denser **oceanic plate subducts** (sinks) beneath the less dense continental plate.
- As the oceanic plate sinks into the mantle, it **releases water**, lowering the melting point of rocks.
- This process generates **magma**, leading to **volcanic activity**.
- **Example: The Andes**
  - Formed by the subduction of the **Nazca Plate** beneath the **South American Plate**.
  - The oceanic plate melts, creating a chain of **volcanoes** along the mountain range.
  - The Andes stretch **5,500 miles** along the western coast of South America.

MOUNTAIN BUILDING

➢ A Mountain can be defined as an area of land that rises abruptly from the surrounding region and higher than the hill.

➢ **Types of Mountains**



MOUNTAINS ON THE BASIS OF LOCATION

Mountains	Characteristics	Examples
Inland Mountains	➢ Located in the interiors of the Continent	➢ Vosges and the black forest (Europe), ➢ Kunlun, Tianshan and Altai mountains of Asia, ➢ Urals of Russia ➢ Himalayas, Satpura and Maikal Hills of India
Coastal Mountains	➢ Located at the **coastline** of the Continent.	➢ Rockies, Appalachians, Alpine mountain chains, Western Ghats and Eastern Ghats
Oceanic Mountains	➢ Oceanic Mountains are found on **continental shelves and ocean floors.**	➢ Mt. Mauna Kea (9140 meters; highest mountain if height is considered from the ocean floor).

MOUNTAIN ON THE BASIS OF THE PERIOD OF ORIGIN

Mountains	Characteristics	Examples
Precambrian	➢ Belong to the **Precambrian period**	➢ Laurentian mountains, Algoma mountains
Caledonian	➢ Originated during the **late Silurian and early Devonian periods due to Tectonic activity.**	➢ Appalachians, Aravalli and Mahadeo Hills
Hercynian	➢ Mountains originated during the **Upper Carboniferous to Permian period**.	➢ Vosges and black forest, Altai, Tianshan Mountains of Asia, Ural Mountains
Alpine	➢ Origin in the **tertiary period** ➢ About 65 million years to 7 million years ago.	➢ Rockies of North America, Alpine mountains of Europe, ➢ Atlas Mountains of North Western Africa, ➢ Himalayas

CLASSIFICATION BASED ON MODE OF ORIGIN

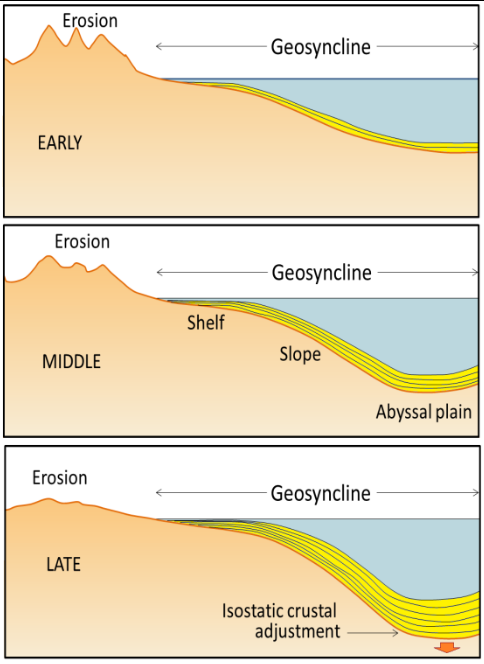
TECTONIC MOUNTAINS (ORIGINAL MOUNTAINS)

Formed due to **tectonic forces**, these mountains can be further divided into:

FOLD MOUNTAINS

- Formed by the **compression and folding of rock layers** due to tectonic movements. Examples: **Himalayas, Rockies, Andes**.

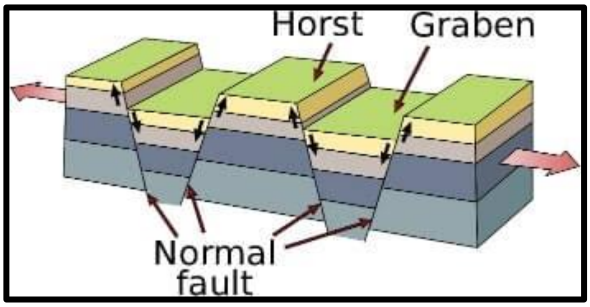
CHARACTERISTICS OF FOLD MOUNTAINS

Features	
➢ **Youngest mountains of the earth**. ➢ The presence of fossils suggests that the **sedimentary rocks** of these folded mountains were formed after accumulation and consolidation of silts and sediments in a marine environment. ➢ Extend for **great lengths** whereas their **width is considerably small**. ➢ Generally, have a **concave slope on one side and a convex slope on the other**. ➢ **Mostly found along continental margins** facing oceans (C-O Convergence).	

TYPES OF FOLD MOUNTAINS

Types	Features	Examples
Old Fold Mountains	➢ Origin before Tertiary period ➢ Slightly rounded features	➢ **Aravalli Range** in India are the oldest fold mountain systems in India ➢ **Appalachians** in North America and the **Ural Mountains** in Russia
Young Fold Mountains	➢ Origin during Tertiary period ➢ Rugged relief ➢ Imposing height (lofty). ➢ High conical peaks	➢ **Rockies, the Andes, the Alps, the Himalayas**,

BLOCK MOUNTAINS



- ➢ These Mountains are created when large areas or blocks of earth are broken and displaced vertically because of Faulting due to tensile and compressive forces.
- ➢ The uplifted blocks are termed as horst and the lowered blocks are called graben
- ➢ have flat tops or slightly sloping surfaces.
- ➢ They have steep sides and they are associated with rift valleys.
- ➢ Examples: **Vosges (France), Black Forest (Germany), Vindhya and Satpura Ranges (India)**.

VOLCANIC MOUNTAINS

- Formed due to **volcanic activity**, where lava and ash accumulate around volcanic vents.
- Examples: **Cascade Range (USA), Mount Kenya, Mount Kilimanjaro, Mount Fujiyama (Japan), Mauna Kea (Hawaii)**.

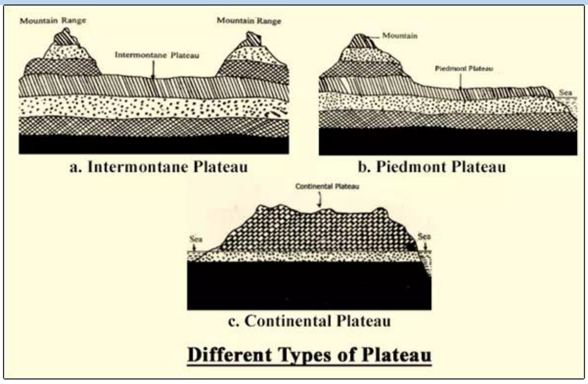
PLATEAUS

A plateau is a flat-topped elevated landform that rises sharply above the surrounding area. It is one of the four major landforms, alongside mountains, plains, and hills. Plateaus are present on every continent and occupy nearly one-third of the Earth's land surface.

FORMATION

Causes	Explanation	Examples
Tectonic Plateaus/Volcanic Flood Basalts	➢ From processes that create mountain ranges ➢ Associated with **Volcanic activities**	➢ **Deccan Traps** ➢ **Columbia Plateau** in the USA ➢ **Laurentian plateau or The Canadian Shield** ➢ **Siberian Traps of Russia**.
Crustal Shortening	➢ Thrusting of one block over another	➢ **Tibetan Plateau**
Thermal Expansion	➢ **Lithosphere underlying a broad area is heated rapidly** by an upwelling of hot material in the underlying asthenosphere ➢ This **cause consequent warming and thermal expansion** of the uppermost mantle causing an **uplift of the overlying surface**	➢ **Ethiopian Highlands** ➢ **Yellowstone Plateau** in the United States ➢ **Massif Central** in France

TYPES OF PLATEAUS



Different Types of Plateau

Types	Features
Intermontane Plateaus	➢ plateaus which are bordering the mountain ranges or are **partly or fully enclosed within mountains**

	➢ Example – **Tibetan Plateaus**
Piedmont plateaus/Plateau of Denudation	➢ Situated **at the foot of a mountain** and is **locked on the other side by a plain or a sea/ ocean** ➢ Example – **Malwa Plateau**
Continental plateaus/Plateaus of Accumulation	➢ Formed either by an **extensive continental upliftment or by the spread of horizontal basic lava** (less viscous) sheets ➢ Example – **Plateau of Maharastra**
Volcanic plateaus	➢ Plateau produced by **volcanic activity.** ➢ Example – **Columbia Plateau, Deccan Traps**
Dissected plateaus	➢ A plateau area that has been **severely eroded so that the relief is sharp**. Such an area may appear as mountainous.

MAJOR PLATEAUS OF THE WORLD

Plateau	Location	Key Features
Tibetan Plateau	China, India	Largest and highest plateau; influences monsoon patterns.
Colorado Plateau	USA	Home to the Grand Canyon; has artesian wells.
Deccan Plateau	India	Rich in minerals; covered by Deccan Traps.
Columbia Plateau	USA	Formed by extensive lava flows.
Laurentian Plateau	Canada	Part of the Canadian Shield; rich in iron ore.
Kimberley Plateau	Australia	Noted for diamond and mineral deposits.
Katanga Plateau	Congo	Major copper mining region.
Massif Central	France	Known for grape cultivation.
Anatolian Plateau	Turkey	Located between Pontic and Taurus mountain ranges.
Mexican Plateau	Mexico	Known as the "Mineral Store" for silver and copper.

PLAINS

➢ It is a relatively level area of the Earth's surface exhibiting gentle slopes and small local relief.

TYPES OF PLAINS

Types	Features
Structural Plains	➢ Mainly formed by the **upliftment of a part of the sea floor or continental shelf.** ➢ May also be formed by **the subsidence of areas.**
Erosional Plains	➢ Formed by the **continuous and longtime erosion of uplands**. ➢ The surface of such plains is hardly smooth and hence, they are also called as **Peneplains**, which means almost plain.
Depositional Plains	➢ Formed by the depositional activity of various geomorphic agents. ➢ **Loess Plains -** When plains are formed by wind deposits ➢ **Alluvial Plains -** When plains are formed by the river deposits ➢ **Lacustrine Plains -** The depositions of sediments in a lake. Example - The **Valley of Kashmir** ➢ **Glacial Plains -** When plains are formed by glacial deposits • **Outwash Plains/Sandur** – When a glacier deposits sediments at its terminus

	• **Till Plains -** deposition of glacial till (unsorted glacial sediment) ➢ **Lava Field** – Accumulation of layers of lava
Scroll Plains	➢ Formed in areas where a **river meanders across a low gradient**
Abyssal Plains	➢ Located at great depths on the **floor of the ocean** ➢ Abyssal plains comprise about 50% of the surface of our planet.

LANDFORMS

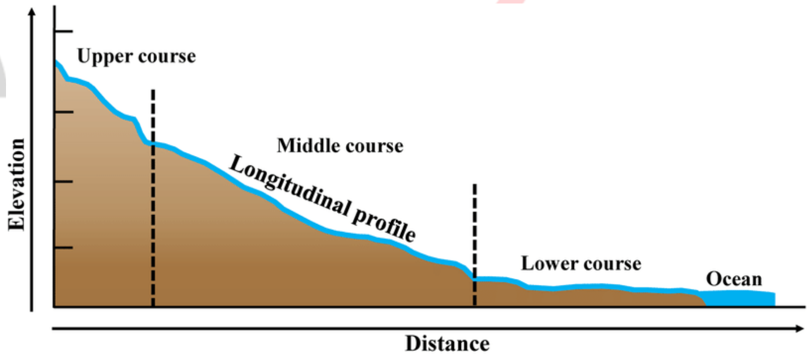
➢ Landforms of the earth are the result of two processes and they are:
1. **Internal process-** The Internal Process leads to the upliftment and sinking of the earth's surface.
2. **External process-** It is the continuous wearing down and rebuilding of the land surface and includes two processes namely:
   A. **Erosion**– It is the wearing away of the earth's surface.
   B. **Deposition**– It is the rebuilding of a lowered surface (occurred due to erosion).

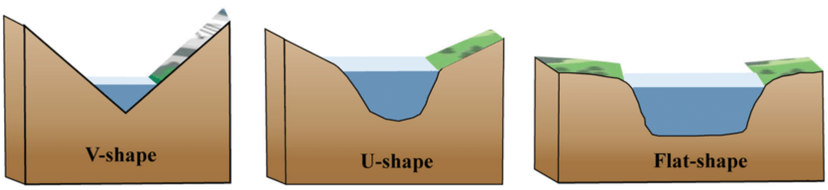
FLUVIAL LANDFORMS

➢ **Meaning -** Landforms created by erosional and depositional activities of a river.

COURSES OF A RIVER

➢ A river can be divided into three, on the basis of its course – upper course, middle course and lower course

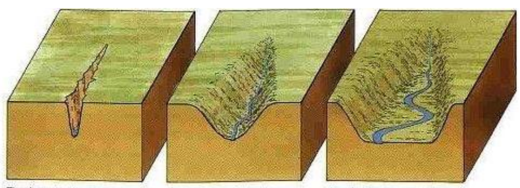
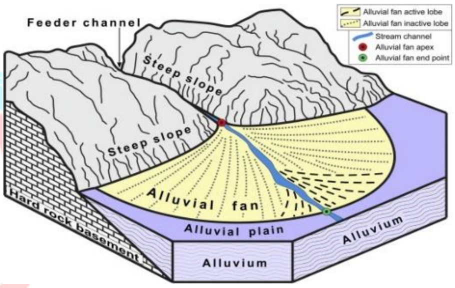


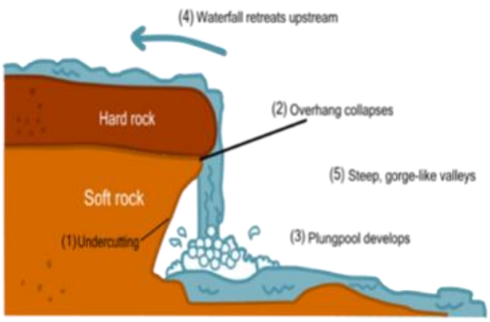


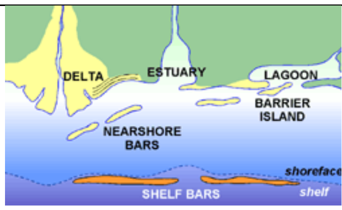
Features	**Upper Course**	**Middle Course**	**Lower Course**
Stage	Youthful	Mature	Old
Dominating Exogenic Process	Erosion dominates	Transportation dominates	Deposition dominates
Valleys	**V- Shaped Valleys** Rivers follow steep	**U-shaped Valleys** Low Slope ➔ Lateral	**Flat shape Valleys** Lateral erosion still

	slope ➔ High velocity and erosion power ➔ Vertical Erosion / downward cutting	Erosion (side by side) becomes more prominent than Vertical Erosion	happens but vertical erosion is almost negligible.
Landforms	Waterfalls and Rapids Gorges and Canyons Interlocking Spurs	Alluvial fans Alluvial plains, Meanders Oxbow Lake	braided channels, floodplains, levees, meanders, oxbow lakes, deltas

MAJOR FLUVIAL LANDFORMS

Erosional	**Depositional**
Valleys ➢ Rills ➔ Gullies ➔ Valleys **TYPES OF VALLEYS:** **Gorge (I-shaped Valleys)** ➢ A deep valley with very steep to straight sides. ➢ A gorge is almost equal in width at its top as well as its bottom.  **Canyon:** ➢ Has steep step-like side slopes ➢ A canyon is wider at its top than at its bottom.  **V-shaped Valleys** ➢ Due to Vertical erosion in youthful stage  	**Alluvial Fans:** ➢ When streams flowing from higher levels enters into the region of Plains with low gradient they deposit sediments forming Alluvial Fans and Cones 
Potholes and Plunge Pools: ➢ Potholes are more or less circular depressions ➢ **Plunge pools** are large potholes.	**Deltas:** ➢ The load carried by the rivers is dumped and spread into the sea.





Incised or Entrenched Meanders:

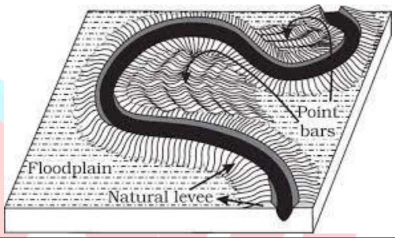
- Incised or Entrenched Meanders are very deep and wide meanders that can be found cut in hard rocks.

Peneplains

- This refers to an undulating featureless plain punctuated with low-lying residual hills of resistant rocks.
- It is considered to be an end product of an erosional cycle.

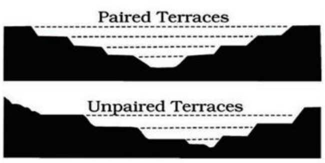
Floodplains:

- A floodplain (or floodplain) is a generally flat area of land next to a river or stream.
- It stretches from the banks of the river to the outer edges of the valley.
- The floodplains in a delta are called **delta plains.**



River Terraces:

- River terraces are surfaces marking old valley floor or floodplain levels.
- **Paired Terraces -** The river terraces may occur at the same elevation on either side of the rivers.
- **Unpaired Terraces -** When the terraces are seen only on one side with none on the other or one at quite a different elevation on the other side.



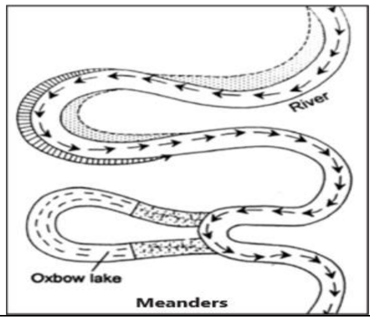
Others

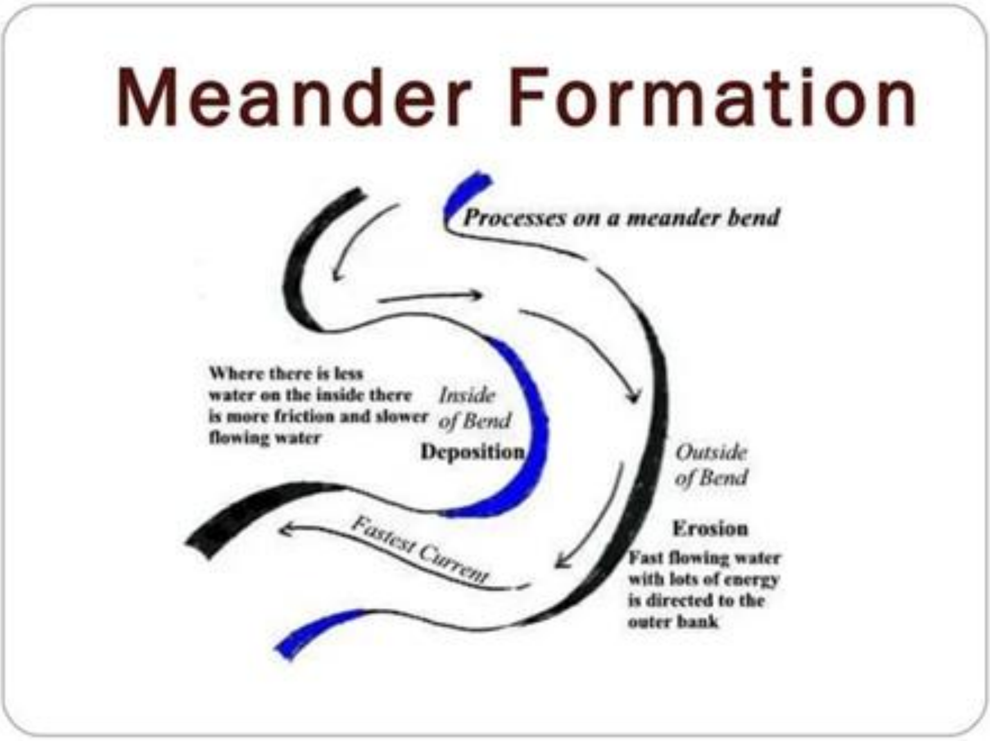
- **Interlocking Spurs, waterfalls, Rapids, Cataract**

Meanders:

- A pronounced curve or loop in the course of a river channel.
- **Cliff-slope side -** The outer bend of the loop is characterized by intensive erosion and Concave Slope.
- **slip-off side -** The inner side of the loop is characterized by deposition, a gentle convex slope

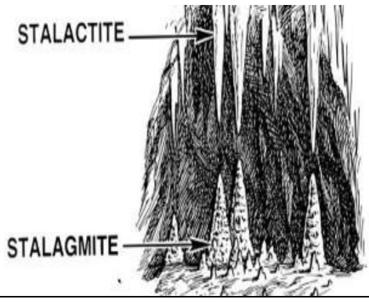
An oxbow lake - is a meander that is no longer attached to the river.

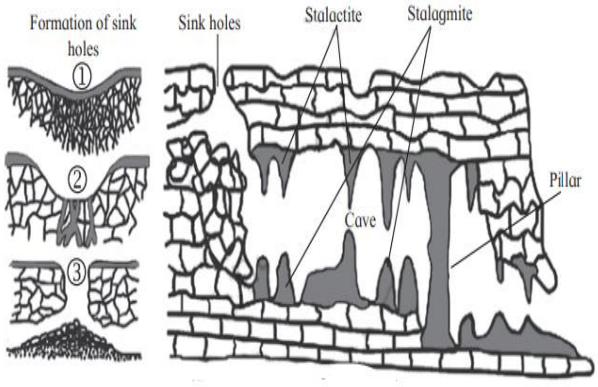


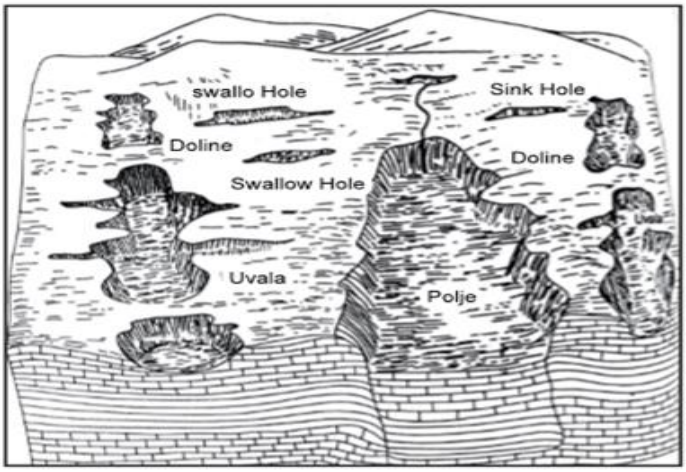


KARST Topography (Groundwater)

- **Rainwater absorbs carbon dioxide (CO_2) ------> form carbonic acid**
- Carbonic acid is especially good at dissolving the rock limestone in **limestone or dolomitic region resulting into Karst topography.**

Erosional Landforms	Depositional Landforms
Swallow Holes: ➢ Small to medium sized round to sub-rounded shallow depressions	**Stalactites:** ➢ an icicle-shaped formation that hangs from the ceiling of a cave
Sinkholes: ➢ An opening more or less circular at the top and funnel-shaped towards the bottom **Doline** ➢ When a number of swallow holes coalesce, a larger hollow is formed **Uvalas** ➢ Karst depressions that are much larger than sinkholes. (Several dolines may merge as a result of subsidence (gradual caving) to Uvala) **Polje** ➢ A large flat plain	**Stalagmites:** ➢ Stalagmites rise up from the floor of the caves. ➢ They form due to dripping water from the surface. **Speleothems** ➢ All types of deposits in the caverns are collectively called 'speleothems'. 
Lapies: ➢ Uneven grooves and ridges that form	**Pillars:** ➢ The stalagmite and stalactites eventually

when the majority of the limestone's surface is removed by the solution process.	fuse to give rise to columns and pillars of different diameters. **Other landforms** ➢ **Tufa, Travertine, Terra Rossa, Drapes/Curtain**
Caves: ➢ 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, cave formation is prominent.	



AEOLIAN LANDFORMS (BY WIND)

➢ More active in arid regions with fine-textured soils and sediments and little or no vegetation.

Erosional Landforms	Depositional Landforms
Deflation Hollows: ➢ Deflation basins, called blowouts, are hollows formed by the removal of particles by wind.	**Ripples:** ➢ They are regular, wavelike undulations lying at right-angles to the prevailing wind direction

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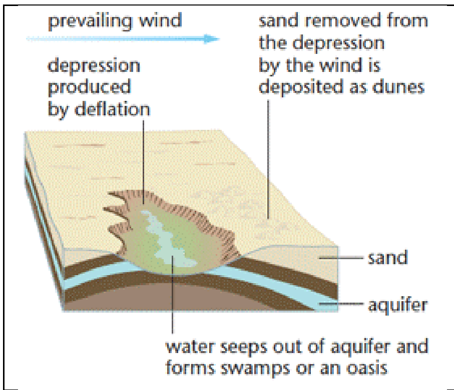

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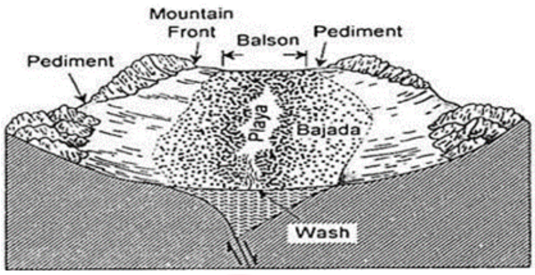
Playas

➢ Playa is a flat-bottom depression periodically covered by water.



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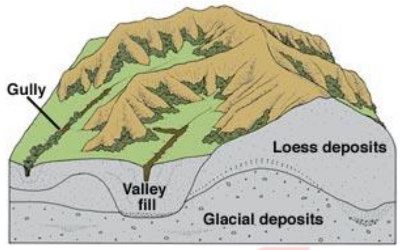
Loess:

➢ Loess is terrestrial sediment composed largely of windblown silt particles made of quartz.



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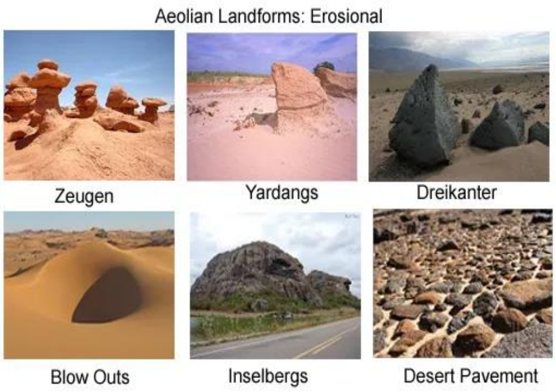
Yardangs:

➢ Yardangs are parallel troughs cut into softer rock running in the direction of the wind, separated by ridges.



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Dunes:

➢ Dunes are collections of loose sand built piecemeal by the wind.

Barchans:

➢ Barchans have crescent-shaped points or wings that face away from the wind, or downwind,


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Zeugen:

➢ When soft rocks covered by hard rocks are eroded by winds, hard rocks left behind looks like table


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Seif/Linear Dunes

➢ Similar to barchans with a small difference as it has only one wing or point.
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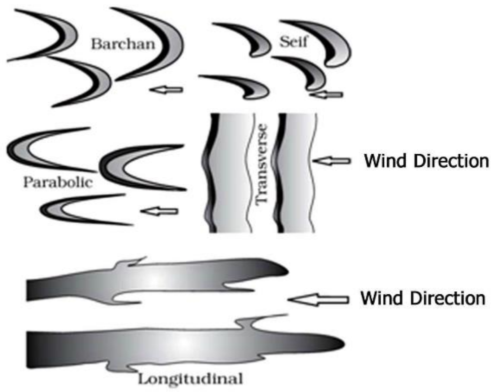
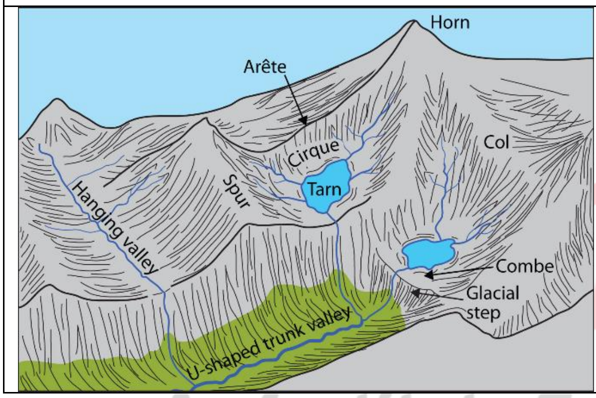
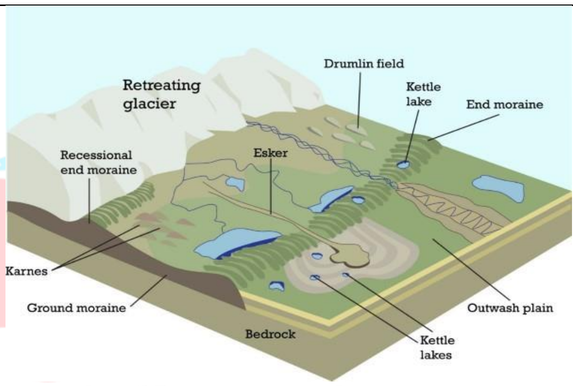
	
Messas – ➢ flat, table-like landmass with a very resistant horizontal top layer and very steep sides. **Buttes –** ➢ Continued denudation through the ages may reduce mesas in the area so that they become isolated flat-topped hills **Inselberg (Island Mountain)** ➢ They are basically isolated residual hills rising abruptly from the ground level ➢ Characterized by very steep slopes & rather rounded tops **Pediplains** ➢ are formed when high relief features in deserts are lowered to low featureless plains due to wind activity.	

GLACIAL LANDFORMS

Erosional Landforms	**Depositional Landforms**
Glacial Valleys/Troughs: ➢ These valleys are trough-like and U-shaped with broad floors and relatively smooth, and steep sides. **Fjords** ➢ Very deep glacial troughs filled with sea water and making up shorelines. (in high latitudes)	**Glacial Till:** ➢ The unassorted coarse and fine debris dropped by the melting glaciers is called glacial till
Cirques: ➢ They are deep, long and wide troughs or basins with very steep concave to vertically dropping high walls at its head as well as sides.	**Moraines:** ➢ They are long ridges of deposits of glacial till. **Terminal moraines** ➢ are long ridges of debris deposited at

Tarn Lake/Cirque Lake ➢ A lake of water can be seen quite often within the cirques after the glacier disappears	the end (toe) of the glaciers. **Lateral moraines** ➢ form along the sides parallel to the glacial valleys.
Horns and Serrated: ➢ Ridge that acquires a 'horn' shape when the glacial activity cuts it from more than two sides.	**Drumlins:** ➢ They are smooth oval shaped ridge-like features composed mainly of glacial till with some masses of gravel and sand.
Arete ➢ Steep-sided, sharp-tipped summit	**Outwash Plains** ➢ When the glacier reaches its lowest point and melts, it leaves behind a stratified deposition material, consisting of rock debris, clay, sand, gravel etc. **Eskers** ➢ resemble the features of an embankment





COASTAL LANDFORMS

Erosional Landforms	Depositional Landforms
Cliffs: ➢ A sea cliff is a vertical precipice created by waves crashing directly on a steeply inclined slope.	**Beaches:** ➢ Beaches are deposits of loose sediment adjacent to a body of water.
Sea Caves: ➢ Sea caves form along lines of weakness in cohesive but well-jointed bedrock. ➢ Sea caves are prominent headlands where wave refraction attacks the shore.	**Spits:** ➢ A sand spit is a linear accumulation of sediment that is attached to land at one end. ➢ The spit follows the longshore direction of the updrift coast.
Sea Stacks: ➢ A sea arch forms when sea caves merge from opposite sides of a headland. If the arch collapses, a pillar of rock remains behind as a sea stack.	**Bars:** ➢ Sandbar, also known as Offshore Bar, is a ridge built by waves offshore from the beach, usually submerged or partially exposed.

Sea Terraces:

- It is a rock terrace formed where a sea cliff, with a wave-cut platform before it, is raised above sea level.