2 CHAPTER LITHOSPERE

The **lithosphere** is the **outermost rigid layer** of the Earth encompassing the **crust** and the **uppermost solid portion of the mantle**. It plays a crucial role in shaping the Earth's surface and acts as the foundation for all terrestrial life and geologic processes.

- The term **"lithosphere"** originates from the **Greek words** *lithos* **(rock) and** *sphaira* **(sphere).**
- Introduced by **Joseph Barrell**, an American geologist, the concept of the lithosphere marked a foundational shift in understanding Earth's structural mechanics.

Note: The **lithosphere ≠ crust**. While the crust is a component of the lithosphere, the lithosphere also includes the rigid part of the upper mantle, differentiated based on mechanical properties.

- All **terrestrial planets** (e.g., Mercury, Venus, Mars) possess lithospheres. However, their lithospheres are significantly **thicker and more rigid** compared to Earth's due to different internal heat regimes and tectonic inactivity.

2.1 INTERIOR OF THE EARTH

Understanding the **internal structure of the Earth** is vital to decipher the dynamics of earthquakes, volcanic activity, and plate tectonics—all of which significantly influence the Earth's surface morphology and habitability.

Layered Structure of the Earth:

- **Crust**
- **Mantle** – Upper and Lower
- **Core** – Outer (liquid) and Inner (solid)

The Earth's internal heat and density variation result in **convection currents** in the mantle, driving **plate tectonic processes**. The **temperature gradient** averages **1°C per 32 metres** as we go deeper, though this varies in different layers.

2.1.1 The Crust: The Earth's Outermost Skin

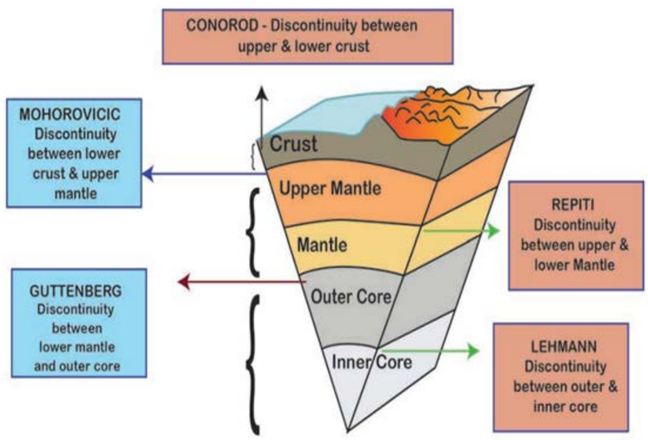
The **crust** is the **thinnest** and **outermost** layer of the Earth's structure, forming the interface between the solid earth and the atmosphere/hydrosphere.

Classification:

- **Continental Crust**: Averages **30–50 km** in thickness; composed primarily of **granitic rocks** (SIAL: Silica + Aluminium).
- **Oceanic Crust**: Averages **5–10 km**; primarily **basaltic** in composition (SIMA: Silica + Magnesium).

Key Features:

- The crust forms only about **1% of Earth's volume.**
- **Density**: Continental crust ~2.7 g/cm^3; Oceanic crust is denser.
- The **Conrad Discontinuity** separates the upper and lower crust.
- The crust is crucial for **life support systems**, as it hosts **soil, minerals,** and **fossil fuels.**



2.1.2 The Mantle: The Earth's Volatile Engine

The **mantle**, extending up to **2,900 km** below the surface, constitutes about **84% of Earth's volume**.

Composition:

- Rich in **silicates of magnesium and iron**.
- Predominantly **solid**, though it behaves plastically over long time periods.

Sub-layers:

- **Upper Mantle:** Includes the **asthenosphere**, a semi-molten zone critical to **magma generation** and **plate tectonic movement.**
  - ✧ Greek origin: *Asthenos* = weak.
  - ✧ Located between ~100 km to 400 km depth.
- **Lower Mantle**: More rigid due to high pressure, despite high temperature.

Boundaries:

- **Mohorovičić Discontinuity (Moho)**: Boundary between crust and mantle.
- **Density**: Ranges between **3.3 to 5.5 g/cm^3** in the mantle.

Importance:

The mantle is geodynamically active and drives **mantle convection**, influencing the formation of **mid-ocean ridges, subduction zones,** and **volcanoes**.

2.1.3 The Core: Earth's Energy Dynamo

The **core**, lying beneath the mantle, extends from **2,900 km to 6,370 km** in depth and is the **densest** region of the Earth.

Composition:

- Composed primarily of **Nickel (Ni)** and **Iron (Fe)**—hence the term **NIFE**.
- Known as the **barysphere** due to its extreme density.

Subdivisions:

- **Outer Core**: **Liquid**, responsible for generating the **Earth's magnetic field** through convective flow.
- **Inner Core**: **Solid**, due to immense pressure overriding the melting point of iron.

Boundaries:

- **Gutenberg Discontinuity**: Between mantle and outer core.
- **Lehmann Discontinuity**: Between outer and inner core.

Properties:

- **Density**: ~13.0 g/cm^3
- **Temperature**: Ranges from **5000°C to 6000°C**
- The outer core's motion is essential for **geomagnetic dynamo action**, which protects the Earth from harmful **solar and cosmic radiation**.

2.2 CONTINENTAL DRIFT THEORY

The theory of **Continental Drift**, proposed by **Alfred Wegener** in **1912**, revolutionized the understanding of Earth's geological history. Wegener, a German meteorologist and geophysicist, postulated that the continents were not stationary but rather have **drifted over geological time**.

Key Postulate:

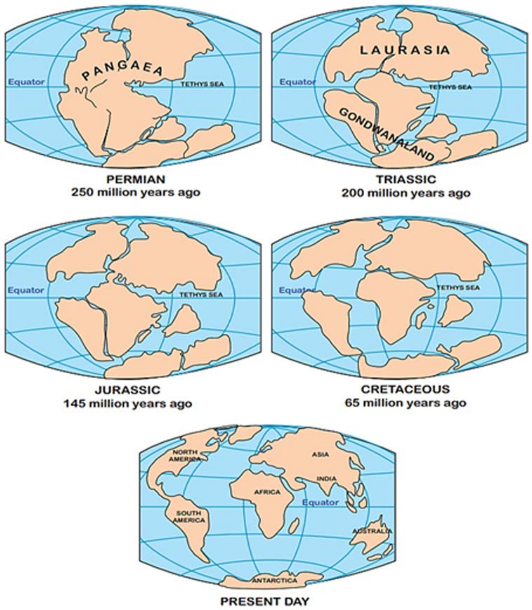
Wegener suggested that around **250 million years ago**, all present-day continents were once joined together in a **supercontinent called Pangaea** (Greek for "All Earth"), surrounded by a vast ocean named **Panthalassa**.

- Around **200–220 million years ago,** Pangaea began to **break apart** due to internal forces.
- It split into two major landmasses:
  - ✧ **Laurasia** (Northern Hemisphere)
  - ✧ **Gondwanaland** (Southern Hemisphere)

These supercontinents further fragmented to form the present continents:

- **Laurasia → North America and Eurasia**
- **Gondwanaland → South America, Africa, Antarctica, Australia, and the Indian subcontinent**

This idea laid the foundation for the development of **modern Plate Tectonics**, though Wegener's theory lacked a plausible mechanism at the time (such as mantle convection), leading to skepticism in the scientific community.



2.2.1 Evidences Supporting Continental Drift Theory

Wegener's theory was supported by a range of geological, biological, and paleontological evidences. These are now regarded as **classical proofs** for continental mobility:

1. Fossil Evidence (Paleontological)

- Fossils of **identical species** found on continents separated by vast oceans today.
  - ✧ Example: **Mesosaurus**, a small freshwater reptile from the **Permian period**, has been discovered in both **Brazil** (South America) and **Namibia** (Africa), indicating that these continents were once connected.
- Fossils of the ancient fern **Glossopteris**, around **360 million years old**, are found in **India, Antarctica, Africa, and South America** — supporting the idea of a common landmass (Gondwana).

2. Geological Evidence

- Rocks of **similar age, type, and formation** have been found across different continents:
  - ✧ For instance, geological formations in **Africa and Brazil** exhibit striking similarities in **cratonic structure and rock types**.
- The **Appalachian Mountains** in eastern North America align geologically with the **Caledonian Mountains** of **Scotland, Ireland, and Scandinavia**.
- Structures in **Newfoundland (Canada)** match those in **Northwest Europe**, supporting the idea of a prior connection.

3. Jigsaw Fit of the Continents

- The **coastlines** of various continents appear to fit together **like puzzle pieces**.
  - ✧ The **western coastline of Africa** matches closely with the **eastern coastline of South America**.
- The fit is particularly accurate when the **continental shelves** (rather than shorelines) are considered.

4. Paleoclimatic Evidence

(You may add this as an extension if needed for Mains)

- **Glacial deposits** of the same age have been found in now tropical regions like **India, South Africa, and Australia,** suggesting they were once located closer to the **South Pole**.
- Conversely, **coal deposits** in cold regions like **Antarctica** indicate a warmer, tropical past.

Relevance of Wegener's Theory

While Alfred Wegener's theory was initially criticized due to lack of a credible **driving mechanism**, it later found support with the advent of **Seafloor Spreading** and **Plate Tectonic Theory** in the mid-20th century. Today, his ideas are seen as **foundational** to our understanding of **earth dynamics, continental configuration, and the evolution of life**.

2.3 PLATE TECTONICS THEORY

The **Plate Tectonics Theory** is a unifying scientific model that explains the movement of Earth's lithosphere, which is fragmented into rigid plates floating over the more ductile asthenosphere. It was developed in the **1960s and 70s**, integrating insights from **continental drift (Wegener, 1912)** and **seafloor spreading (Hess, 1960)**.

What Is Plate Tectonics?

- The Earth's **lithosphere** (crust + uppermost mantle) is broken into about **7 major** and **numerous minor tectonic plates**.
- These plates move slowly (a few cm/year) over the **semi-molten asthenosphere**, driven by **mantle convection**, **gravity**, and **ridge push/ slab pull** mechanisms.
- The term "**tectonic**" derives from the Greek word *tekton*, meaning "builder."
- Plate tectonics explains both the **movement** and **distribution** of these plates.

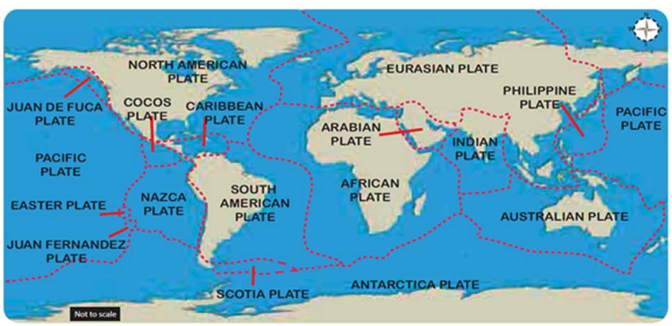
Major Tectonic Plates

- Pacific Plate
- North American Plate
- South American Plate
- African Plate
- Eurasian Plate
- Antarctic Plate
- Indo-Australian Plate

Minor Plates:

- Arabian Plate
- Caribbean Plate
- Cocos Plate
- Scotia Plate
- Philippine Plate, etc.

These plates interact at their boundaries, causing various **geological phenomena** such as earthquakes, volcanic eruptions, mountain building, and ocean trench formation.



Distribution of tectonic plates

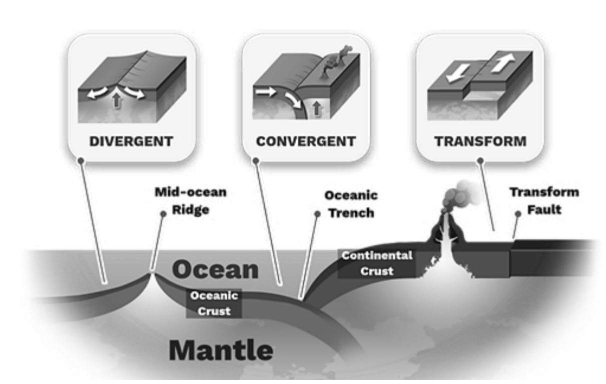
2.3.1 Plate Boundaries

Plate boundaries are **dynamic interfaces** where two or more lithospheric plates interact. The Earth's lithosphere is divided into rigid plates (also called **crustal** or **tectonic plates**) that **float over the asthenosphere** and move due to forces originating from the Earth's interior.

- Plate tectonics explains both the **movement** and **distribution** of these plates.
- The average rate of plate movement ranges from **2–3 cm per year**, though it can vary.

General Characteristics of Plate Boundaries

- Plates may consist of **continental crust, oceanic crust, or both**.
- Most tectonic activity (earthquakes, volcanoes, mountain building) occurs along plate margins.
- Plate movement is driven by **mantle convection**, **ridge push**, and **slab pull**.
- Subduction of **denser oceanic plates beneath lighter continental plates** leads to intense seismic and volcanic activity.
- Plate boundaries are key to understanding the origin of major **physiographic features** like **trenches, ridges, mountain ranges**, and **rift valleys**.



2.3.2 Types of Plate Boundaries

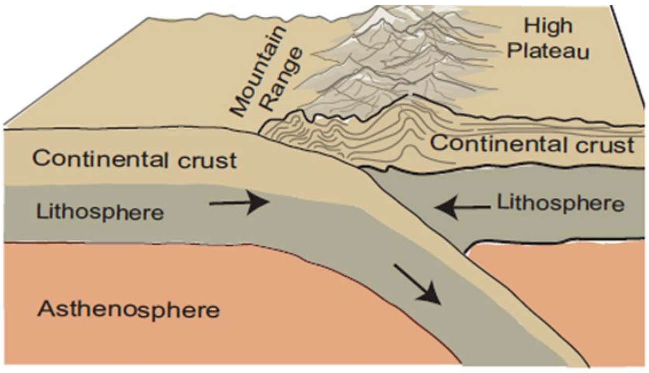
1. Divergent Plate Boundaries (Constructive Margins)

- Occur where two plates **move away** from each other.
- **New lithosphere** is formed due to magma upwelling from the mantle.

- Typically found along **mid-oceanic ridges** or **continental rift zones**.

Key Features:

- **Oceanic ridges** (e.g., Mid-Atlantic Ridge – the world's longest mountain range)
- **Rift valleys** on continents (e.g., East African Rift Valley)
- Narrow oceans suggest **young divergence**; wider ones indicate **mature basins** (e.g., Atlantic Ocean)



Convergent plate boundaries

Terminology:

- Also known as **accreting plate boundaries.**
- Called **constructive** because new crust is continuously formed.

2. Convergent Plate Boundaries (Destructive Margins)

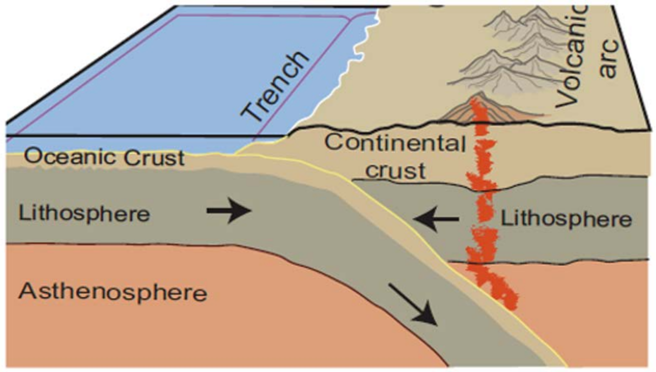
- Formed where two plates **collide**.
- One of the plates, usually oceanic, **subducts beneath** the other due to higher density.

Types of Convergence:

- **Oceanic–Continental:** Andes Mountains (Nazca Plate subducting beneath South American Plate)
- **Oceanic–Oceanic:** Island arcs like Japan, Philippines
- **Continental–Continental:** Himalayas (Indian Plate colliding with Eurasian Plate)

Key Features:

- **Deep oceanic trenches** (e.g., Mariana Trench)
- **Fold mountains** (e.g., Himalayas, Andes)
- **Volcanic arcs**, **earthquakes**, and **metamorphic activity**



Divergent margin

Terminology:

- **Subduction Zone**: Area where one plate sinks beneath another
- **Wadati–Benioff Zone**: Seismic zone within the subducting slab where intense earthquakes occur

3. Transform Plate Boundaries (Conservative Margins)

- Plates **slide past** each other laterally.
- No new crust is formed or destroyed.
- Lithosphere remains constant.

Key Features:

- Characterized by strike-slip faults and shear zones
- Associated with frequent shallow-focus earthquakes
- No volcanic activity due to lack of subduction or divergence

Example:

- **San Andreas Fault**, California (boundary between Pacific Plate and North American Plate)

Mechanisms Driving Plate Movement

Mantle Convection Currents

- Heat from the Earth's interior causes **convection currents** in the mantle that drag the plates along.

Ridge Push

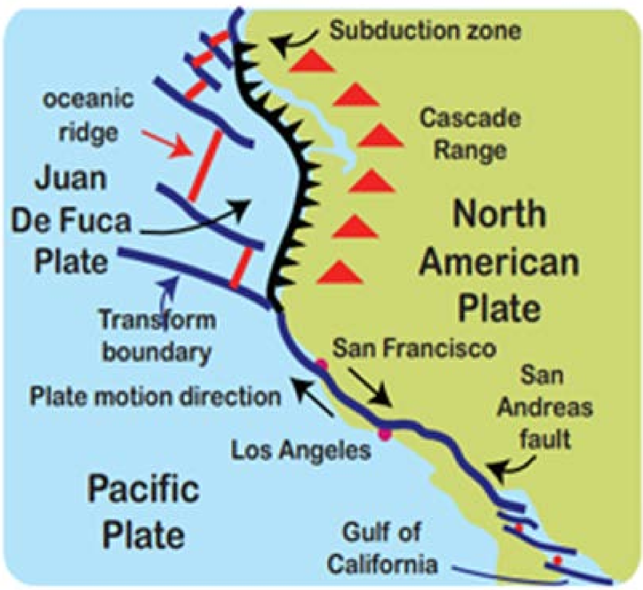
- At mid-ocean ridges, new material pushes older material away, driving plate motion.

Slab Pull

- The **subducting plate** pulls the rest of the plate behind it due to gravity.

Importance of Plate Boundaries:

- **Earthquake-prone zones**: Understanding of plate boundaries helps in seismic zonation and disaster risk mitigation.
- **Volcanic hazards**: Many active volcanoes are located along convergent and divergent margins (e.g., Pacific Ring of Fire).
- **Orogenesis and landscape evolution**: Fold mountains and rift valleys emerge from plate interactions.
- **Resource localization**: Mineral deposits and geothermal energy are often linked to plate boundaries.



Significance of Plate Tectonics in Earth Sciences

- **Explains global distribution** of earthquakes, volcanoes, and mountain ranges.
- Helps understand **continental drift**, **paleogeography**, and **earth's evolutionary history**.
- Crucial for **disaster risk assessment** (seismic zonation, volcanic hazards).
- Offers insights into **mineral and hydrocarbon exploration** (e.g., plate margins are rich in resources).
- Facilitates understanding of **climate change and ocean circulation** (via changing landmass positions).

Geological Features Formed by Plate Tectonics

Feature	Caused by	Example
Fold Mountains	Continental-continental convergence	Himalayas
Volcanic Arcs	Oceanic-continental convergence	Andes
Ocean Trenches	Subduction zones	Mariana Trench
Rift Valleys	Divergent boundaries	East African Rift
Earthquakes	Transform boundaries	San Andreas Fault
Island Arcs	Oceanic-oceanic convergence	Japan, Philippines

2.4 CONVECTION CELLS AND PLATE DYNAMICS

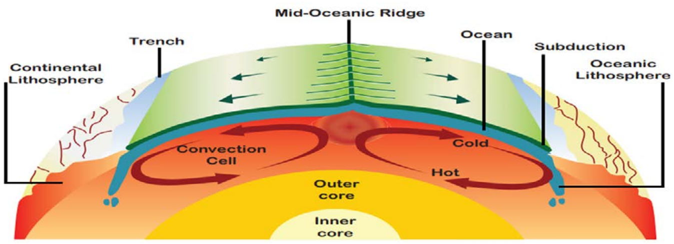
What are Convection Cells?

- **Convection cells** are **circular currents** of molten rock (magma) in the mantle, driven by **thermal energy** from the Earth's core.
- These currents act as the **engine of plate tectonics**, generating **force** that drives lithospheric plate movement.

Concept of Convection Currents:

- The Earth’s **mantle** behaves like a viscous fluid over geological time scales. It experiences **thermal convection** due to differential heating.
- **Heat from the core** (radiogenic + primordial heat) generates **thermal gradients** in the mantle.

- **Hot, less dense magma rises**, while **cooler, denser material sinks**, creating **convection cells** (or loops).



2.4.1 Convection and Plate Movement:

Convection Current	Plate Movement	Associated Boundary	Resulting Landforms
Rising	Divergence	Divergent Boundary	Mid-ocean ridges, rift valleys
Sinking	Convergence	Convergent Boundary	Subduction zones, trenches
Lateral	Shearing	Transform Boundary	Fault zones, lateral earthquakes

Relevance to Geohazards:

- Regions above active convection cells like the **Pacific Ring of Fire** experience high seismicity and volcanism.
- Understanding convection helps in **predicting tectonic activity,** useful in disaster preparedness.

2.4.2 Internal (Endogenic) Tectonic Forces

- Originating **within the Earth's interior,** these forces are responsible for **crustal deformation.**
- Occurs along plate boundaries.
- Divided into:
  - ✧ **Diastrophic Forces** (slow and large-scale) → folding and faulting
  - ✧ **Sudden Forces** → earthquakes and volcanoes

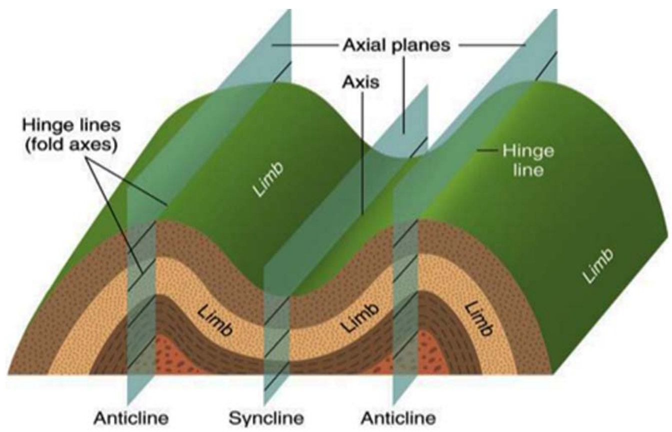
Folding: Mechanics of Compression

What is Folding?

- Folding is the **bending of rock strata under compressive stress,** typically in sedimentary rocks due to their layered structure and ductile nature.
- It occurs **away from plate margins** (continental interiors) as well as **along convergent boundaries.**
- Horizontal movements are produced by forces of compression and tension.
- **Folding reflects the long-term plastic deformation of rocks,** unlike faulting which is brittle.

Parts of a Fold

Part	Description
Anticline	Upward arch of folded rock layers
Syncline	Downward trough of folded rock
Limb	Sloping side of a fold
Crest	Highest point of an anticline
Axial Plane	Imaginary plane dividing the fold symmetrically



Types of Folds with Examples

Fold Type	Characteristics	Example
Symmetrical Fold	Equal compression from both sides	Appalachian Mountains (USA)
Asymmetrical Fold	Unequal compression	Andes (South America)
Isoclinal Fold	Limbs parallel and inclined equally	Scottish Highlands
Overturned Fold	One limb pushed over the other	Central Alps
Recumbent Fold	Horizontal compression so intense the fold lays flat	Himalayas (e.g., Zanskar Range)

Fold Mountains:

- **Formed at convergent plate boundaries**, especially **continental-continental collisions**.
- Examples:
  - ✧ **Himalayas** – India-Eurasia collision
  - ✧ **Alps** – African and Eurasian plate convergence
  - ✧ **Rockies** – North American plate with Pacific microplates

Faulting: Response to Tension and Shear

What is Faulting?

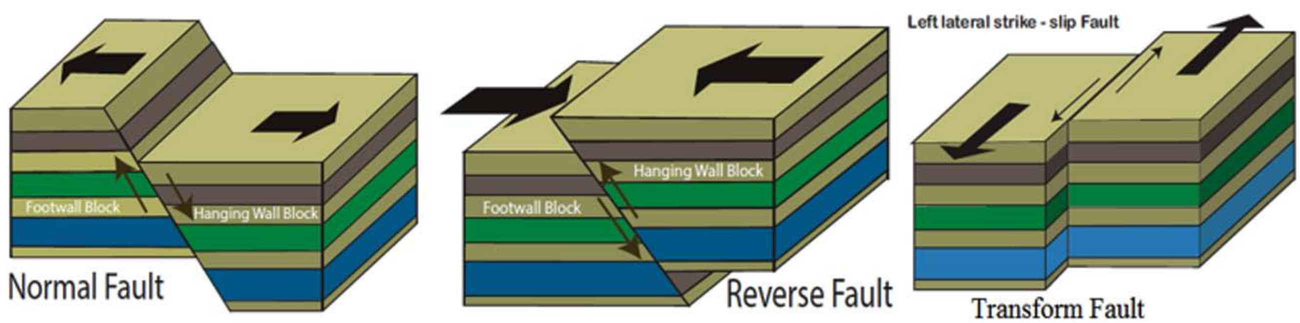
- A **fault** is a **fracture in the Earth's crust** along which displacement has occurred.
- Faults result from **tectonic stress exceeding the rock strength**, leading to **sudden brittle failure**.
- Faulting is the **primary mechanism behind most earthquakes**.

Fault Terminology:

Term	Meaning
Fault Plane	Surface along which movement occurs
Fault Dip	Angle between the fault plane and a horizontal plane
Hanging Wall	Rock mass **above** the fault plane
Foot Wall	Rock mass **below** the fault plane
Fault Scarp	Steep slope or cliff formed by vertical displacement

Classification of Faults:

Fault Type	Force	Movement	Example
Normal Fault	Tension	Hanging wall moves down	East African Rift
Reverse Fault	Compression	Hanging wall moves up	Himalayan Main Frontal Thrust
Strike-slip Fault	Shear	Horizontal movement	San Andreas Fault, USA



Associated Landforms:

1. Rift Valley / Graben:

- Caused by **normal faults.**
- Examples:
  - ✧ **East African Rift** (Kenya to Ethiopia to Mozambique)
  - ✧ **Narmada and Tapi Rifts**, India

2. Block Mountain / Horst:

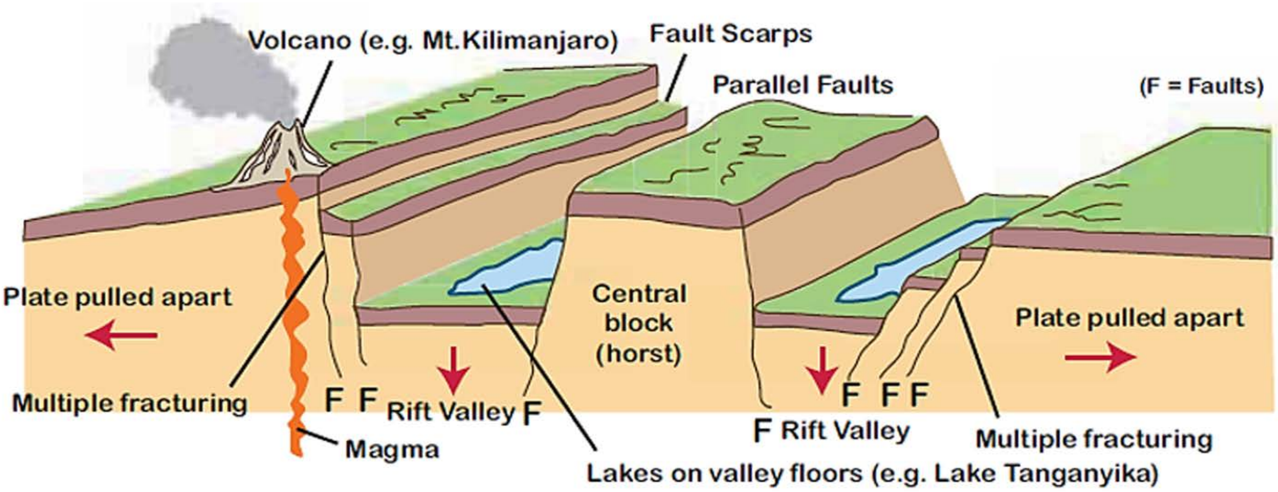
- Elevated block between two faults.
- Example: **Vindhya and Satpura Ranges**

3. Fault Scarp:

- A steep slope or cliff created due to fault movement.

4. Earthquake Epicenters:

- Most earthquakes originate along active faults in **subduction zones** or **transform boundaries**.



Rift valley and Block Mountain

Case Studies:

- **Nepal Earthquake (2015)**: Occurred along the **Main Himalayan Thrust**, a major reverse fault.
- **East African Rift System**: Ongoing continental rifting, visible on satellite, may lead to **new ocean formation**.
- **San Andreas Fault**: One of the best-studied transform faults; causes frequent quakes in California.

Interlinking Concept:

Process	Stress Type	Plate Boundary	Resulting Landform
Folding	Compression	Convergent	Fold Mountains (Himalayas)
Normal Faulting	Tension	Divergent	Rift Valleys (East Africa)
Reverse Faulting	Compression	Convergent	Fault Scarps, Quakes
Shear Faulting	Shearing	Transform	Lateral displacement zones

2.5 EARTHQUAKES

What is an Earthquake?

An **earthquake** is the **sudden shaking or vibration of the Earth's surface**, resulting from the **sudden release of energy** accumulated in the Earth's crust. This energy propagates as **seismic waves**, causing ground motion and structural damage.

Key Terms:

- **Focus (Hypocenter):** The point **within the Earth's crust** where the energy is released.
- **Epicenter:** The point **on the Earth's surface** directly above the focus.
- **Seismic Waves:** Waves of energy generated by the sudden rupture and movement.

Causes of Earthquakes

Natural Causes	Man-made (Anthropogenic) Causes
1. Plate Tectonic Movements (most common): Convergent, divergent and transform boundaries. e.g., Indo-Eurasian Plate collision	**1. Large Dam Construction:** Load-induced stress in reservoir region (e.g., **Koyna Dam**, Maharashtra)
2. Volcanic Eruptions: Sudden release of magma can trigger seismic activity.	2. Nuclear Testing/Blasts: Releases artificial seismic energy.
3. Faulting/Crustal Fracturing	**3. Mining and Drilling Operations:** Sudden subsidence or collapse.
4. Collapse of underground caves or Karst systems	—

2.5.1 *Seismic Waves*: Types and Characteristics

Seismic waves are categorized into **Body Waves** and **Surface Waves**.

A. Body Waves (Travel through Earth's interior)

Type	Speed	Motion	Medium	Damage Potential
P-Waves (Primary/ Compressional)	Fastest (~6 km/s)	Push-pull, longitudinal	Solids, liquids, gases (All medium)	Least damaging
S-Waves (Secondary/ Shear)	Slower (~3.5 km/s)	Side-to-side, transverse	Only solids	More damaging than P-waves

B. Surface Waves (Travel along the surface)

Type	Motion	Damage
Love Waves	Horizontal shearing motion	High surface damage
Rayleigh Waves	Rolling motion (like ocean waves)	Highly destructive

Note: Surface waves are responsible for the **most visible destruction** during large earthquakes, slower than body waves.

Measuring Earthquakes

Instrument / Scale	Description
Seismograph	Detects and records seismic wave activity.
Richter Scale	Measures **magnitude** (energy released); logarithmic scale (1 to 10).
Modified Mercalli Intensity (MMI) Scale	Measures **intensity** (effects felt by people and structures); ranges from I to XII.
A Richter magnitude increase by 1 unit represents **~32 times** more energy release.	

2.5.2 Effects of Earthquakes

Sector	Impacts
Infrastructure	Collapse of buildings, roads, bridges, railways, dams
Environment	Landslides, forest fires, ground ruptures, liquefaction
Hydrology	Flash floods due to dam failures, spring changes
Tsunamis	Submarine quakes (≥7 on Richter scale) displace large ocean volumes, causing devastating sea waves (e.g., **2004 Indian Ocean Tsunami,** >1.5 lakh deaths)
Society & Economy	Loss of life, Displacement, trauma, economic disruption, loss of heritage structures (e.g., Bhuj earthquake, 2001)

2.5.3 Global Distribution of Earthquakes

Earthquakes are unevenly distributed and primarily associated with **plate boundaries.**

1. Circum-Pacific Belt (Ring of Fire)

- **68%** of global earthquakes
- Extends along **coasts of North & South America, Japan, Philippines, Indonesia, New Zealand**
- Associated with **subduction zones and island arcs**

2. Mediterranean-Himalayan Belt

- **31%** of global earthquakes
- From **Alps** → **Turkey** → **Iran** → **Himalayas** → **Tibet** → **China**
- Caused by **continental collision and crustal compression**

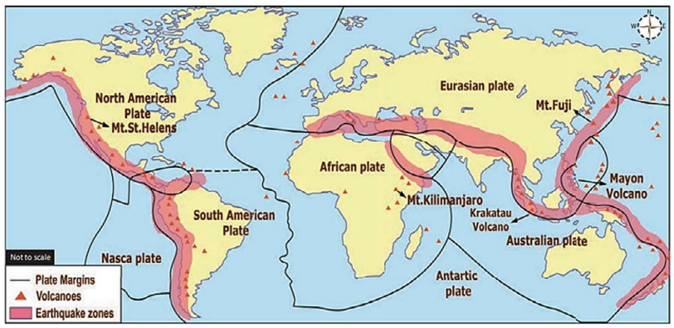
3. Other Seismic Zones

- **East African Rift System** – intraplate rifting
- **Red Sea & Dead Sea Transform Fault**
- **Stable continental regions** – e.g., Peninsular India (Koyna, Latur), Central USA (New Madrid fault)

Note: Though Peninsular India lies in a stable continental block, it still experiences earthquakes due to **intraplate stresses and reactivation of ancient faults.**

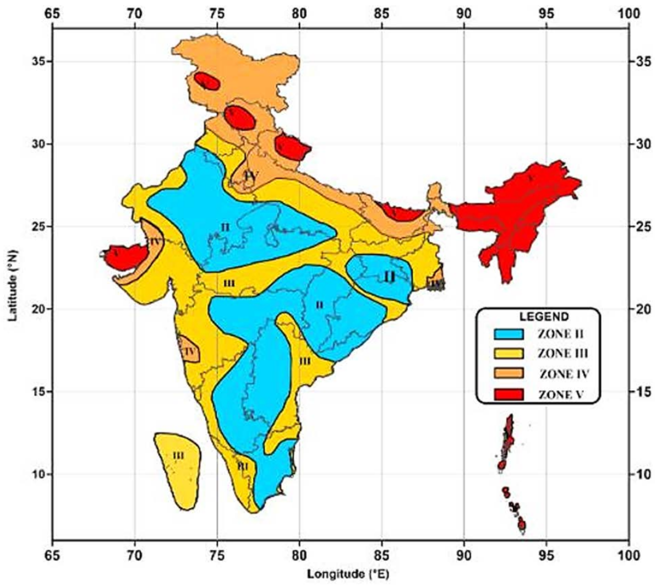
Case Studies

- **Bhuj Earthquake (2001):** Magnitude 7.7, killed ~20,000 people; caused by reactivation of faults in Peninsular India.
- **Nepal Earthquake (2015):** Magnitude 7.8; caused major destruction in the Himalayan belt.
- **Sumatra Tsunami (2004):** Magnitude 9.1; tectonic slip along the Sunda trench.



2.5.4 India's Seismic Exposure: A Snapshot

India is **highly prone to earthquakes**, with nearly **59% of its landmass vulnerable to moderate to severe seismic activity**, often exceeding **MSK Intensity VII**. These vulnerabilities are shaped by both **interplate tectonics** (e.g., Himalayan region) and **intraplate disturbances** (e.g., Peninsular India).



Major Tectonic Regions in India

1. Himalayan and Sub-Himalayan Region – Interplate Seismic Zone

- The **Himalayas are a young fold mountain system,** formed due to the ongoing collision **between the Indian and Eurasian plates.**
- This convergence zone is **highly seismically active,** often producing **megathrust earthquakes.**
- Earthquakes in this region often exceed magnitude 8.0 and have **short recurrence intervals** compared to other tectonic settings.

Historical Earthquakes:

- Shillong (1897) – M 8.7
- Kangra (1905) – M 8.0
- Bihar-Nepal (1934) – M 8.3
- Assam-Tibet (1950) – M 8.6

Seismic Gaps:

Geologists have identified **seismic gaps**—areas along the Himalayan arc that have not experienced recent large earthquakes. Notably, the **Central Himalayas,** due to prolonged tectonic stress accumulation, are considered potential sites for future high-magnitude quakes.

2. Indo-Gangetic and Brahmaputra Plains – Alluvium Amplification Zones

- Though these plains appear stable on the surface, the **subsurface geology comprises extensions of the Himalayan rock systems**, increasing seismic risk.
- The **soft alluvial soil layers** in these plains **amplify seismic waves**, making even moderate earthquakes more destructive.
- High population density in cities like Delhi, Patna, and Guwahati makes these areas **particularly vulnerable to high fatalities and economic loss**.

3. Peninsular India – Intraplate Seismicity

- The Peninsular region was traditionally considered seismically stable, but **intraplate earthquakes** have demonstrated latent seismic risks.
- Earthquakes here result from the **re-activation of ancient fault lines** and paleo-rift zones due to stress accumulation or isostatic adjustments.

Key Seismic Zones in Peninsular India:

- **Kachchh Rift Basin** – Site of the **2001 Bhuj Earthquake** (M 7.7)
- **Narmada–Son Lineament**
- **Godavari Graben**
- **Aravalli–Delhi Fold Belt**

Notable Intraplate Earthquakes:

- **Latur (1993)** – M 6.4
- **Broach (1970)** – M 5.4
- **Bhadrachalam (1969)** – M 5.7

These events highlight the **dynamic nature of the Indian plate interior**, which may no longer be considered fully "stable."

Anthropogenic Factors Aggravating Seismic Risk

Factor	Impact
Rapid Urbanisation	Construction in high-risk zones without adherence to seismic codes increases vulnerability.
Dams and Reservoirs	Large dams can trigger **reservoir-induced seismicity (RIS). E.g., Koyna Dam,** Maharashtra.
Mining and Quarrying	Blasting and excavation activities destabilize subsurface strata.
Poor Urban Planning	Unregulated development, slum proliferation, and vertical expansion worsen damage potential.
Climate Change Interactions	Glacier melting and hydrological imbalances may affect crustal load and stress.

Earthquake Zoning in India (As per BIS 2002)

The **Bureau of Indian Standards (IS 1893:2002)** classifies India into **four seismic zones (Zone II to Zone V)** based on expected ground motion and seismic hazard.

Zone V – Very High Seismic Risk

- Corresponds to **MSK Intensity IX and above**.
- Includes: **Northeast India**, parts of **Jammu & Kashmir**, **Northern Bihar**, **Rann of Kutch**, and **Andaman & Nicobar Islands**.
- Frequent and strong seismic activity with potential for catastrophic damage.

Zone IV – High Seismic Risk

- Corresponds to **MSK VIII**.
- Includes: **Delhi NCR**, parts of **Himachal Pradesh**, **Uttarakhand**, **Sikkim**, **Punjab**, **Haryana**, and parts of **Gujarat** and **Maharashtra**.

Zone III – Moderate Seismic Risk

- Corresponds to **MSK VII**.
- Covers areas in **Kerala**, **Goa**, **Lakshadweep**, **West Bengal**, **Odisha**, **Andhra Pradesh**, **Madhya Pradesh**, **Chhattisgarh**, and parts of **Karnataka**, **Telangana**, and **Tamil Nadu**.

Zone II – Low Seismic Risk

- Corresponds to **MSK VI or below**.
- Includes: The rest of P**eninsular India, Western Rajasthan, Central Madhya Pradesh,** and parts of **Odisha, Telangana, and Tamil Nadu.**

Note: The older "Zone I" has been merged with Zone II in the current classification.

India’s Earthquake Preparedness and Mitigation Strategy

Institutional and Strategic Measures

National Centre for Seismology (NCS)

- Functions under the **Ministry of Earth Sciences (MoES)**.
- Operates a robust seismic monitoring system with **115 observatories** across the country.
- Responsible for **real-time earthquake detection,** data analysis, and immediate dissemination to central and state disaster response agencies.

National Earthquake Risk Mitigation Project (NERMP)

- A **centrally sponsored scheme** under the **National Disaster Management Authority (NDMA)**.
- Focuses on the most vulnerable areas, especially **Seismic Zones IV and V**.
- Key components:
    - Development and enforcement of a **Techno-legal regime**.
    - **Institutional strengthening** for better disaster response.
    - **Public education and awareness** on seismic risks.

Seismic Microzonation of Urban Areas

- Led by the **National Centre for Seismology**.
- Target: All Indian cities with **a population of over 5 lakh**.

- Purpose: To map cities at a **fine spatial resolution** to guide:
  - Earthquake-resilient building codes.
  - Urban planning and land use strategies.
  - Emergency evacuation and disaster preparedness plans.

NDMA Awareness Campaigns

- NDMA conducts periodic **nationwide campaigns** to raise public awareness.
- Utilizes **print, electronic, and social media**.
- Promotes earthquake safety measures, **structural retrofitting**, and preparedness drills, especially in schools and public institutions.

Implementation of Seismic Building Codes

- India enforces earthquake-resistant construction through codes developed by:
  - **Bureau of Indian Standards (BIS)**
  - **Building Materials & Technology Promotion Council (BMTPC)**
  - **Housing and Urban Development Corporation (HUDCO)**
- These codes are circulated to **urban local bodies**, engineers, and construction agencies for implementation.

Earthquake Disaster Risk Index (EDRI)

- An initiative by the **NDMA** to evaluate the vulnerability of cities located in **Seismic Zones IV and V**.
- Quantifies risks by combining exposure, fragility, and hazard data.
- Assists government agencies in **prioritising mitigation efforts** and allocating resources effectively.

Challenges in Earthquake Risk Management

1. High Tectonic Vulnerability

- India's location near the **Indian-Eurasian Plate boundary** leads to frequent high-magnitude earthquakes.
- Retrofitting large, aged infrastructure and strengthening new construction is **resource-intensive and complex**.

2. Rapid and Unplanned Urbanisation

- Cities are expanding **without adherence to seismic zoning or building codes.**
- Example: In Delhi, **multi-storeyed buildings along the Yamuna and Hindon floodplains** are located in high-risk seismic zones, increasing vulnerability.

3. Rise in Tourism in Hazard Zones

- The surge in domestic tourism, including to the **Himalayan and Northeastern regions**, leads to **overdevelopment** in seismically sensitive areas.
- Increased human presence and infrastructure pressure **heighten the risk** during seismic events.

4. Non-compliance with Building Regulations

- Widespread **violations of construction norms** significantly compromise structural safety.
- According to the **Centre for Science and Environment**, nearly **80% of buildings in Delhi** do not comply with building codes.
- Retrofitting existing structures remains a major challenge.

5. Lack of Awareness and Preparedness

- Public understanding of earthquake safety remains **inadequate**, especially in rural and semi-urban areas.
- Mass awareness programs, **school drills**, and community-based training are needed to build a **culture of safety**.

6. Financial Constraints

- Seismic mitigation projects require **substantial long-term investment**.
- Limitations in funding affect:
  - Retrofitting and infrastructure upgrades.
  - Research and monitoring advancements.
  - Disaster response capabilities.
- There is a need for **innovative financing models**, including **public-private partnerships** and **disaster insurance schemes**.

Ways to reduce impacts and some recommendations

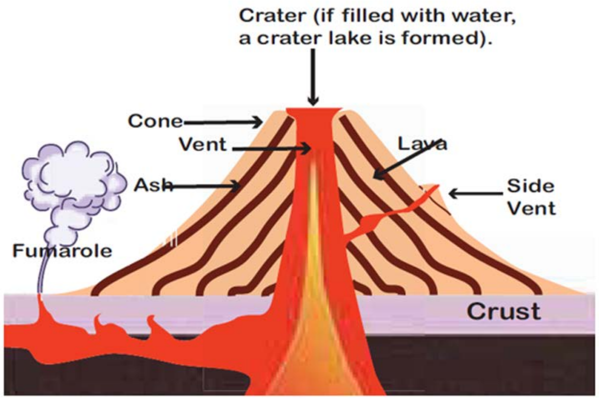
Focus Area	Actionable Steps
Strengthen Enforcement	Ensure strict implementation of **seismic building codes,** especially in high-risk zones.
Enhance Monitoring	Expand and modernize **seismic observatories** and **real-time data sharing systems.**
Promote Risk Zoning	Complete **microzonation of all Tier 1 and Tier 2 cities** and integrate into urban planning.
Public Education	Launch nationwide campaigns and include **disaster preparedness in school curricula.**
Encourage Retrofitting	Provide **financial incentives** and technical support to retrofit old buildings and critical infrastructure.
Policy Coordination	Foster **inter-agency coordination** between NDMA, MoES, Urban Development, and state governments.
Leverage Technology	Use **AI, GIS, and remote sensing** for risk prediction, damage assessment, and rapid response planning.

2.6 VOLCANOES

A **volcano** is a rupture or opening in the Earth's crust through which **magma**, **volcanic gases**, and **ash** escape to the surface. Once magma exits the Earth and flows outward, it is called **lava**.

Key Terminology

- **Magma**: Molten rock material located beneath the Earth's surface.
- **Lava**: Magma that reaches the Earth's surface during an eruption.
- **Vent**: The main opening or outlet of a volcano through which lava, gases, and ash are expelled.
- **Crater**: A bowl-shaped depression at the summit of a volcano; when expanded significantly, it becomes a **caldera**.
- **Fumaroles**: Openings near the vent that emit steam and volcanic gases.
- **Volcanic ash**: Fine fragments of rock, minerals, and volcanic glass formed during explosive eruptions.
- **Pumice**: A light, porous volcanic rock formed when lava high in water and gases cools rapidly.



Causes of Volcanic Eruptions

Volcanic eruptions are typically triggered by the following geophysical processes:

1. Tectonic Plate Interactions

- Eruptions often occur at **weak zones** in the Earth's crust, especially along **divergent** (plates moving apart) and **convergent** (plates colliding) boundaries.
- Example: Interaction between the **African and Eurasian plates**.

2. Gas-Rich Magma

- Magma deep within the Earth is often saturated with **volatile gases** like carbon dioxide and hydrogen sulfide.
- The pressure from these gases, combined with water vapor, creates explosive conditions, forcing magma to the surface as **lava**.

2.6.1 Types of Volcanoes

A. Based on Eruption Frequency:

Active Volcanoes

- Frequently erupting and have open vents.
- Example: *Mount Etna* (Italy), *Cotopaxi* (Ecuador – highest active volcano).

Dormant Volcanoes

- Have not erupted recently but may erupt again.
- Emit occasional gas or steam.
- Example: *Mount Vesuvius* (Italy), *Mount Fujiyama* (Japan).

Extinct Volcanoes

- Have not erupted in recorded history and are unlikely to erupt again.
- Vents are closed and often vegetated or filled with water forming crater lakes.
- Example: *Popa* (Myanmar), *Mount Kenya* (Kenya).

B. Based on Eruption Style and Shape:

Shield Volcanoes

- Broad, gently sloping landforms.
- Formed by low-viscosity, basaltic lava that flows easily.
- Can become explosive if water enters the vent.
- Example: *Hawaiian volcanoes.*

Composite or Stratovolcanoes

- Cone-shaped and made of alternating layers of lava, ash, and rock.
- Known for explosive eruptions.
- Example: *Mount St. Helens* (USA), *Mount Vesuvius* (Italy).

Cinder Cone Volcanoes

- Small, steep-sided cones formed from cooled lava fragments like ash and cinders.
- Less explosive than composite volcanoes.

Lava Domes

- Smaller, rounded volcanoes formed from highly viscous lava.
- Lava doesn't travel far and piles up near the vent.
- As the dome grows, internal pressure can cause the hardened surface to shatter and collapse.

Effects of Volcanic Activity

Negative Impacts

- Lava flows, ash showers, and pyroclastic materials can cause **loss of life**, **property destruction**, and **air traffic disruptions**.
- **Toxic gases** like sulfur dioxide can cause **air pollution** and **acid rain**, harming health, agriculture, and ecosystems.
- Volcanic ash can collapse roofs, clog machinery, and reduce visibility.

Positive Impacts

- Formation of **new landforms** (islands, mountains).
- **Fertile soil** from weathered volcanic material boosts agriculture (e.g., coffee in Java).
- **Mineral wealth**: Volcanoes bring valuable minerals to the surface (e.g., diamonds from kimberlite pipes).
- **Geothermal energy**: Heat from magma sources generates electricity.
  - ✧ Examples in India: *Puga Valley* (Ladakh), *Manikaran* (Himachal Pradesh).

2.6.2 Global Distribution of Volcanoes

Volcanic activity is concentrated along **tectonic plate boundaries** and **mid-oceanic ridges**. Major volcanic regions include:

1. Pacific Ring of Fire

- Encircles the Pacific Ocean basin.
- Contains over **two-thirds** of Earth's active volcanoes.
- Example: *Mt. Fuji*, *Mt. St. Helens*, *Mt. Krakatau*.

2. Mid-Atlantic Region

- Features both active and extinct volcanoes.
- Example: *Iceland*, *Azores*, *Canary Islands*.

3. East African Rift Valley

- Home to both extinct and active volcanoes.
- Examples: *Mt. Kilimanjaro* (extinct), *Mt. Cameroon* (active).

4. Mediterranean Region

- Linked to **Alpine Fold Mountains**.
- Example: *Mt. Stromboli*, *Mt. Vesuvius* (Italy).

5. Other Regions

- Isolated volcanic activity exists in parts of Asia, North America, and Europe.
- **Australia** has **no active volcanoes**.

Volcanoes in India

India experiences limited volcanic activity due to its position away from major tectonic boundaries. Key locations include:

- **Barren Island (Andaman and Nicobar Islands)**
  - Only active volcano in India.
  - Last erupted in 1991 and 1995.
- **Narcondam Island (Andaman region)**
  - Extinct volcanic island; crater wall has collapsed.

2.7 ROCKS AND THEIR TYPES

Definition:

- A **rock** is a naturally occurring solid mass composed of one or more minerals, mineraloids, or organic materials. Rocks form the Earth's crust and can vary in composition, texture, and origin.
- The scientific study of rocks is known as **Petrology**.
- The **age of rocks** is typically determined using **radiometric dating methods**, such as **Carbon-14** dating (for recent organic remains) and **Uranium-Lead** or **Potassium-Argon dating** (for older rocks).

2.7.1 Classification of Rocks by Origin

Rocks are classified into **three major types** based on their formation process:

1. Igneous Rocks (Primary Rocks)

- Formed from the **cooling and solidification of magma or lava**.
- These are the **oldest types of rocks** on Earth and form the foundation of the crust.
- **Texture** depends on cooling rate:
  - **Slow cooling (deep underground)** → large crystals (e.g., granite).
  - **Rapid cooling (on surface)** → Fine crystals (e.g., basalt).

Types of Igneous Rocks

- **Intrusive (Plutonic)**: Formed below the surface (e.g., granite).
- **Extrusive (Volcanic)**: Formed on the surface after lava eruption (e.g., basalt, andesite).

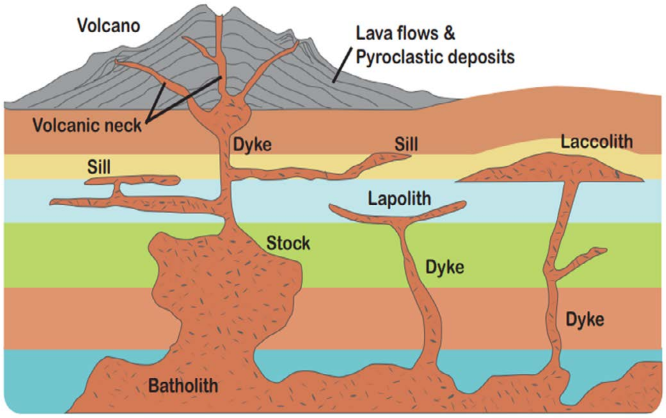
Examples:

- **Granite** (intrusive, coarse-grained, light-colored)
- **Basalt** (extrusive, fine-grained, dark-colored; forms the **Deccan Traps**)

Intrusive Igneous Rock Forms

When magma solidifies beneath the Earth's surface, it creates various **intrusive geological formations**:

Form	Description	Example/Note
Batholith	Massive, irregularly shaped deep-seated intrusion; granitic in composition	Found in Himalayan and Peninsular regions
Laccolith	Dome-shaped intrusion with a pipe-like feeder	Granite domes in Karnataka Plateau
Lapolith	Saucer-shaped, concave-downward intrusion	Less common; found in layered igneous complexes
Sill	Horizontal sheet of cooled magma between rock layers	Thicker deposits are called sills
Dyke	Vertical wall-like intrusion cutting across layers	Common in **Maharashtra**, feeders of Deccan Traps



2. Sedimentary Rocks (Secondary Rocks)

- Formed by the **accumulation, compaction, and cementation** of sediments derived from other rocks or biological sources.
- Often **layered** or **stratified**, with fossils sometimes embedded.
- Occupy **only 5%** of Earth's crust by volume, but cover **75%** of land surface.
- **Examples**: Sandstone, shale, limestone, coal.

Types of Sedimentary Rocks

- **Mechanically Formed** (by physical deposition): E.g., sandstone, shale, conglomerate, loess.
- **Organically Formed** (from biological remains): E.g., coal, chalk, limestone, geyserite.
- **Chemically Formed** (from solution precipitation): E.g., halite (rock salt), potash, gypsum.

Special Sedimentary Deposits

- **Till**: Ice-deposited sediments.
- **Loess**: Wind-blown fine silt and clay, fertile but erosion-prone.

3. Metamorphic Rocks (Changed Rocks)

- Formed when **existing igneous or sedimentary rocks** undergo **recrystallization** due to intense **heat, pressure, and chemically active fluids**—without melting.
- This process is called **Metamorphism**.
- Results in denser, more compact, and often crystalline structures.

Examples:

- **Slate** (from shale)
- **Marble** (from limestone)
- **Gneiss** (from granite)
- **Schist** (from mudstone/shale)
- **Quartzite** (from sandstone)
- **Diamond** (from carbon under pressure)

Note: Igneous and metamorphic rocks together form **95% of the Earth's crust by volume**.

Types of Rocks

Type	Formation Process	Examples	Key Features
Igneous	Cooling of magma/lava	Granite, Basalt	Oldest rocks, crystalline
Sedimentary	Compaction of sediments	Sandstone, Shale, Coal	Layered, may contain fossils
Metamorphic	Alteration of existing rocks	Marble, Slate, Gneiss	Hard, dense, changed structure

2.7.2 Rock Cycle

The **rock cycle** is a **natural, continuous, and dynamic process** through which rocks of one type are transformed into another over geological time.

It illustrates how **igneous, sedimentary, and metamorphic rocks** are interconnected and how Earth materials are recycled over time.

Process of the Rock Cycle

- **Formation of Igneous Rocks**
  - ✧ When **magma cools and solidifies**, it forms **igneous rocks** (e.g., granite, basalt).
  - ✧ This can occur **beneath the surface** (intrusive) or **on the surface** (extrusive).

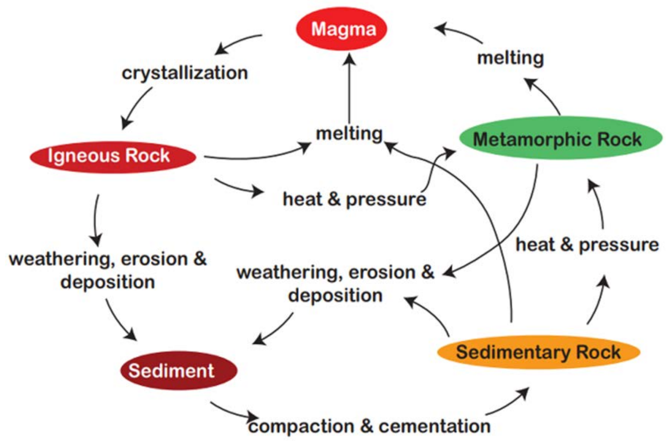
- **Weathering and Erosion**
  - ✧ Igneous rocks are broken down into smaller fragments by **weathering** and **erosion**.
  - ✧ These fragments are transported and deposited by wind, water, or ice.
- **Formation of Sedimentary Rocks**
  - ✧ The accumulated sediments undergo **compaction and cementation** to form **sedimentary rocks** (e.g., sandstone, limestone).
- **Formation of Metamorphic Rocks**
  - ✧ When **igneous or sedimentary rocks** are subjected to **intense heat, pressure, and chemical activity**, they transform into **metamorphic rocks** (e.g., marble, gneiss).
- **Melting into Magma**
  - ✧ Any rock type (igneous, sedimentary, or metamorphic) may be **subducted into the mantle**.
  - ✧ Under extreme heat, they **melt to form magma**, completing the cycle.

Key Rock Transformations

From	To
Igneous → Sedimentary	Weathering, erosion, deposition
Igneous → Metamorphic	Heat and pressure
Sedimentary → Metamorphic	Heat and pressure
Metamorphic → Magma	Melting (subduction)
Magma → Igneous	Cooling and solidification
Sedimentary → Magma	Deep burial and melting

Why Is the Rock Cycle Important?

- It **recycles Earth's materials** and maintains a balance in the Earth's crust.
- It explains the **formation of different types of rocks** and the **landforms** we see today.
- It contributes to the formation of **mineral resources** and **fossil fuels.**



The **rock cycle** is an endless loop through which rocks change from one form to another: **Igneous → Sedimentary → Metamorphic → Magma → Igneous again**, driven by Earth's **internal heat**, **tectonic movements**, and **surface processes** like erosion.

2.8 EXOGENIC PROCESSES

Exogenic processes are the natural processes that occur **on the Earth's surface** due to **external forces** such as **solar radiation** and **gravity**.

- These processes shape the Earth's landscape by **breaking down rocks** and **redistributing materials**.
- Major exogenic processes include:
  - ✧ **Weathering**
  - ✧ **Mass wasting**
  - ✧ **Erosion**
  - ✧ **Denudation**
- The agents responsible for these processes (like wind, water, ice, etc.) are known as **gradational agents**.

2.8.1 Weathering

Weathering is the **disintegration and decomposition** of rocks at or near the Earth's surface due to the action of:

- **Climate** (temperature, moisture)
- **Living organisms** (plants, animals, microbes)

There are three major types of weathering:

- Physical (Mechanical) Weathering
- Chemical Weathering
- Biological Weathering

Physical Weathering

This involves the **breaking down of rocks without any chemical change**. It mainly occurs in areas with **extreme temperature fluctuations**, **low rainfall**, or **high-altitude regions**.

Types of Physical Weathering

1. Thermal Weathering

- Occurs in **hot arid/semi-arid areas**.
- Rocks expand during the day and contract at night.
- Repeated expansion-contraction causes the rock to break apart.
- There are two forms:
  - ✧ **Granular Disintegration**: Individual mineral grains dislodge due to varying expansion rates.
  - ✧ **Block Disintegration**: Large blocks split off along joints (common in granite).

2. Frost Wedging

- Water enters rock cracks → freezes → expands → cracks widen.
- Common in **cold regions** with freeze-thaw cycles.

3. Exfoliation (Onion Weathering)

- Surface rock layers peel off due to **thermal expansion and contraction**.
- Results in **dome-shaped structures**.
- Common in **arid areas**.

Chemical Weathering

This involves the **chemical alteration or decomposition** of rock minerals when exposed to **air and water**.

Types of Chemical Weathering

Type	Description	Example
Solution	Soluble minerals dissolve in water	Limestone caves
Oxidation	Oxygen reacts with minerals, especially iron	Rusting of iron in rocks
Hydrolysis	Water reacts with minerals forming new substances	Feldspar → Kaolinite (clay)
Carbonation	CO_2 + Water = Carbonic Acid → reacts with rocks	Cave formation in limestone
Hydration	Water is absorbed into minerals causing swelling	Anhydrite → Gypsum

Biological Weathering

This is the **breakdown of rocks by living organisms** such as:

- **Plants**: Roots grow into cracks, exert pressure and split rocks.
- **Animals**: Burrowing by earthworms, termites, rodents exposes rock to air and water.
- **Humans**: Deforestation, farming, construction accelerate weathering by exposing rock surfaces.

2.8.2 Mass Wasting (Mass Movement)

Mass wasting refers to the **downhill movement** of rock, soil, and debris under the **influence of gravity**.

It is also called:

- **Slope movement**
- **Mass movement**

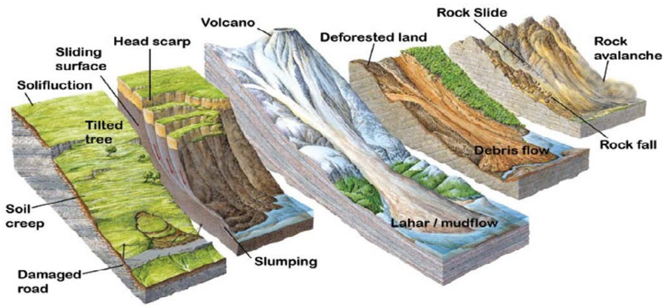
It may occur:

- **Suddenly** (rapid movement like landslides)
- **Slowly** (like soil creep)

Classification of Mass Wasting

Mass wasting is classified based on:

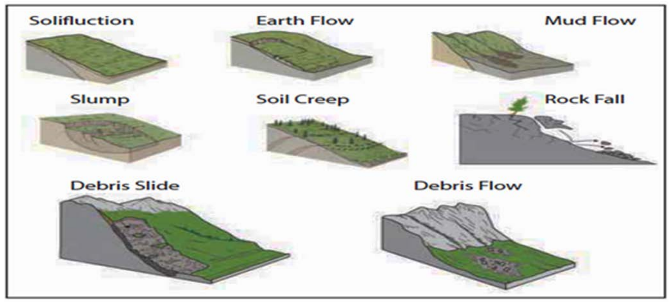
- **Material involved**: mud, soil, rock
- **Type of motion**:
  - ✧ **Fall**: Free-falling material
  - ✧ **Slide**: Movement along a slope
  - ✧ **Flow**: Material mixed with water



Types of Mass Wasting

Type	Description	Key Features
Rockfall	Pieces of rock **break from a cliff** and fall freely	Often caused by **frost wedging**; accumulation forms **talus** at the base
Rockslide	Large rock mass slides along a zone of **weakness**	May break into rubble while moving
Landslide	Sudden downhill movement of **large rock/soil mass**	Often triggered by **earthquakes or heavy rain**
Slump	**Rotational movement** of rock/soil from a high cliff	Caused by **erosion** at the base, leading to loss of support
Debris Slide	Involves **mixture of soil & rock,** dry movement	Larger in scale than slump, **little water** involved
Debris Flow	Rock/soil mass becomes **saturated and turbulent**	Behaves like liquid mud, often **carries large boulders**
Earth Flow	**Clay-rich soil** becomes saturated and flows downhill	Common in **humid areas** with thick soil
Mudflow	**Liquid mass** of soil, debris & water flows rapidly	Occurs in **semi-arid mountains**; volcanic version = **Lahar**
Debris Avalanche	**Fastest & deadliest** mass wasting type	Mixture of debris, water, air; air cushion boosts speed
Creep	**Slow, continuous movement** of soil downhill	Caused by **freeze-thaw cycles;** seen in tilted fences, poles

Mass Movement



2.8.3 Gradational Processes

Gradation refers to the **natural leveling** of the Earth's surface. It consists of two opposing processes:

- **Degradation**: Wearing down of elevated surfaces (erosion)
- **Aggradation**: Filling up of low-lying areas (deposition)
- **Goal of Gradation**: Achieve a more **even landscape** over time.

Gradational Agents

These are **natural forces** that bring about erosion and deposition.

Agent	Mode of Action
Running Water (Rivers)	Erodes land, transports sediment, deposits it in plains or deltas
Waves (Marine)	Erodes coastlines and builds beaches, spits, bars
Wind (Aeolian)	Erodes and deposits fine particles in arid regions, forming dunes
Ice (Glaciers)	Carves valleys and deposits moraines
Gravity	Drives all mass movements downhill

2.8.4 The River

Rivers are dynamic agents of erosion, transportation, and deposition. Over time, they carve landscapes, transport sediment, and reshape landforms. Their activity is driven by the **volume of water**, **velocity of flow**, and **gradient**.

Work of a River

1. Erosion

Erosion is the mechanical and chemical breakdown of rocks by flowing water along a river's course.

Types of River Erosion:

Type	Description
Hydraulic Action	The sheer force of moving water dislodges and breaks rock particles.
Corrasion (Abrasion)	Rock fragments carried by the river grind and wear down the riverbed and banks.
Corrosion (Solution)	Soluble minerals dissolve in river water through chemical reactions.
Attrition	Rock fragments carried by the river collide with each other and break into smaller pieces.

2. Transportation

Transportation is the process of moving eroded material downstream.

Modes of River Transport:

Type	Description
Traction	Large and heavy materials like boulders roll or slide along the riverbed.
Saltation	Small pebbles bounce along the bed in a hopping motion.
Suspension	Fine particles like silt and clay are carried within the water column.
Solution	Dissolved minerals are carried in the water itself.

3. Deposition

Deposition occurs when a river loses velocity and can no longer carry its load. Heavier materials are dropped first, followed by finer sediments. The river starts depositing larger materials first and smaller and finer materials are carried further down to the mouth of the river.

Stages of a River

1. Upper Course (Youthful Stage)

- **Location**: Mountainous, steep slopes
- **Main Work**: **Vertical erosion**
- **Landforms**: V-shaped valleys, interlocking spurs, waterfalls, rapids

Key Terms:

- ✧ **Source**: Beginning of a river
- ✧ **Tributaries**: Smaller streams joining the main river
- ✧ **Confluence**: Point where two rivers meet
- ✧ **Water Divide**: Ridge separating river systems

2. Middle Course (Mature Stage)

- **Location**: Rolling plains
- **Main Work**: **Lateral erosion**
- **Features**: Wider valleys, meanders, river terraces
- **Characteristics**: Moderate gradient, increased discharge, deep channel

3. Lower Course (Old Stage)

- **Location**: Near the river mouth
- **Main Work: Deposition**
- **Landforms**: Floodplains, deltas, levees, oxbow lakes
- **Features**: Gentle slope, broad valleys, distributaries
- **Mouth**: Where the river enters the sea, lake, or another river

Landforms Created by Erosion

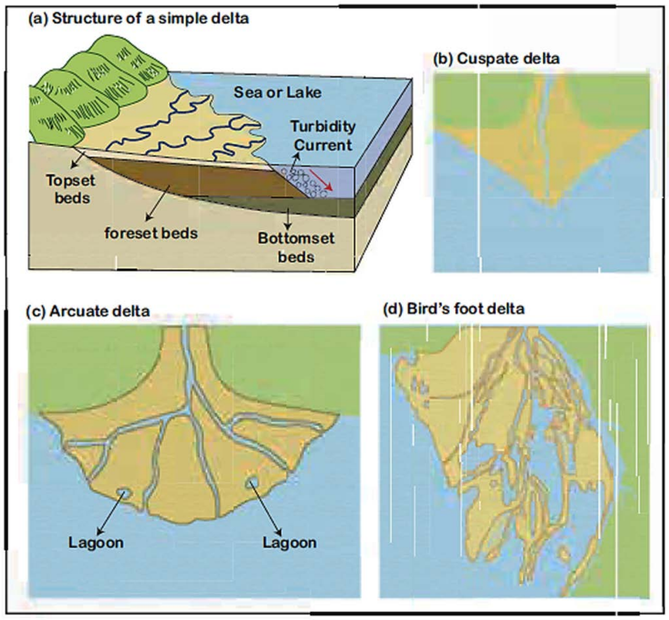
Landform	Description
V-Shaped Valley	Narrow, deep valley formed by vertical erosion in the upper course.
Gorge	Deep, narrow valley with steep sides formed by rapid down-cutting.
Canyon	Extended form of a gorge; deeper and longer (e.g., Grand Canyon).
Waterfall	Vertical drop in a river, often over resistant rock layers.
Rapids	Sections with turbulent flow due to hard rocks or uneven bed.
Cascade	Series of small waterfalls close together.
Plunge Pool	Deep basin at the base of a waterfall formed by falling water.
Grooves	Long, narrow channels eroded at waterfall bases.
Eddying	Swirling motion of water in plunge pools.
Interlocking Spurs	Alternating ridges formed where river winds around resistant rock.
Potholes	Round, bowl-shaped holes in the riverbed caused by swirling pebbles.
River Terraces	Step-like flat surfaces along valley sides representing previous riverbeds.

Landforms Created by Deposition

Landform	Description
Alluvial Fan	Fan-shaped deposit formed at the base of mountain slopes in arid regions.
Peneplain	Low, almost level land formed by prolonged erosion during the river's final stage.
Meander	Winding curve in a river's course formed by lateral erosion and deposition.
Oxbow Lake	U-shaped lake formed when a meander is cut off from the main channel.
Levees	Raised banks formed by repeated flooding and sediment deposition.
Floodplain	Flat land adjacent to a river, submerged during floods, rich in alluvium.
Estuary	Wide river mouth where freshwater mixes with seawater (e.g., Narmada estuary).
Delta	Fan-shaped alluvial landform at the river's mouth, formed by heavy deposition.

Types of Deltas

Type	Description	Example
Arcuate Delta	Bow-shaped with convex edge facing the sea	Nile Delta, Ganga Delta
Estuarine Delta	Formed in submerged river mouths	Seine Delta, France
Bird's Foot Delta	Narrow extensions resembling bird's claws	Mississippi River Delta, USA
Lacustrine Delta	Formed where river meets a lake	Lough Leanne Delta, Ireland
Truncated Delta	Modified or destroyed by sea waves	Parts of East Coast of India
Abandoned Delta	Left behind after river changes its course	Yellow River Delta, China
Cuspate Delta	Tooth-shaped, formed by single distributary	Tiber River Delta, Italy



Special Feature: The Grand Canyon of India — Gandikota

- **Location**: Kadapa district, Andhra Pradesh
- **River**: Pennar River
- **Features**:
  - ✧ Spectacular gorge through Erramala Hills
  - ✧ Adjacent to Gandikota Fort and Belum Caves (India's 2nd largest cave system).
  - ✧ Rich in quartz and stalactite/stalagmite formations.

Importance of Rivers

Environmental

- Form and nourish **ecosystems**
- Replenish **wetlands**, deltas, and mangroves
- Support **biodiversity**

Agricultural

- Provide **irrigation** for agriculture
- Build **fertile alluvial plains**

Economic

- Enable **hydropower generation**
- Aid **navigation** and **transport**
- Support **fishing** and **aquaculture**

Cultural and Civilizational

- Cradle of ancient civilizations (e.g., Indus, Nile, Mesopotamia)
- Have spiritual, religious, and cultural significance (e.g., Ganga)

River as a Sculptor of the Earth

Rivers are powerful agents of landscape transformation. Over time, they:

- Carve out valleys and canyons
- Build floodplains and deltas
- Create waterfalls and oxbow lakes
- Transport sediments across great distances

Their work is continuous, intricate, and deeply impactful in shaping the Earth's surface.

2.8.5 Glacier

A **glacier** is a massive, slow-moving body of ice that forms in regions where snow accumulation exceeds its melting (ablation) over many years. Derived from the French word *"glace"* meaning ice, glaciers are often referred to as **"rivers of ice"** due to their powerful yet gradual movement along mountain slopes or across polar landscapes.

Formation and Structure of Glaciers

- **Snowfields**: Regions where snow persists year-round. Over time, compacted snow transforms into firn and eventually glacial ice.
- **Snow Line**: The lowest elevation where snow remains throughout the year. It varies with:
  - ✧ Latitude (lower at poles, higher in tropics)
  - ✧ Altitude
  - ✧ Wind direction
  - ✧ Precipitation and local climate
- **Movement**: Under pressure, the lower snow layers begin to melt and move downslope under gravity.
- **Speed**: Average glacial movement is about **1 meter/day**, but it can vary based on slope, temperature, and ice thickness.

> **Fact**: Over **96% of the world's glaciers** are found in **Antarctica and Greenland**.

World's Largest Glacier:

- **Name**: Lambert Glacier, Antarctica
- **Dimensions**:
  - Length: **435 km**
  - Width: **96 km**
  - Depth: **2,500 meters**

Types of Glaciers

Glaciers are broadly classified based on their **location**, **formation**, and **extent**:

1. Continental Glaciers (Ice Sheets)

- Found in **polar regions** (Antarctica and Greenland)
- Cover entire land masses with thick, extensive ice
- Formed from continuous snowfall accumulation
- **Example**: Greenland Ice Sheet (3,400 m thick), Antarctic Ice Sheet (4,776 m thick)
- Ice projecting into seas can break into **icebergs**

2. Ice Caps

- Dome-shaped masses of glacial ice smaller than continental glaciers
- Cover high-latitude land areas
- **Example**: Svartisen Ice Cap, Norway

3. Mountain and Valley Glaciers (Alpine Glaciers)

- Flow from mountain snowfields into valleys
- Confined within valley walls
- Include **piedmont glaciers**, **cirque glaciers**, and **valley glaciers**
- Common in **Himalayas**, **Andes**, **Alps**, and **Rockies**

Characteristics of Glaciers

Feature	Description
Movement	Slow, plastic flow under gravity
Speed	Varies with slope and ice thickness
Crevasses	Deep cracks or fissures on glacial surfaces, hazardous to climbers
Plastic Flow	Ice flows like a viscous fluid under pressure
Zone of Accumulation	Region where snowfall adds to glacier mass
Zone of Ablation	Region where ice melts faster than accumulation

Actions of Glaciers

Glaciers shape the Earth through **three main processes**:

1. Erosion

Glaciers erode bedrock by:

- **Plucking**: Ice freezes around loose rocks, pulling them away as it moves.
- **Abrasion**: Embedded debris scrapes and grinds the valley floor like sandpaper.

2. Transportation

- Glaciers carry **rock debris**, soil, and sediment over great distances.
- Material is carried **on**, **in**, and **beneath** the glacier.

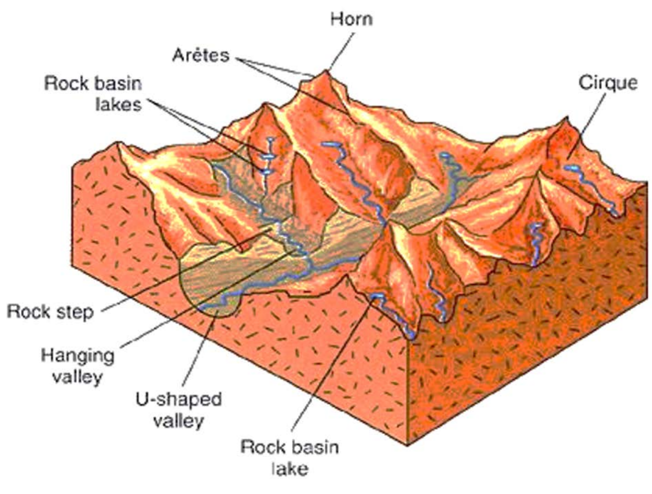
3. Deposition

- When glaciers melt, they deposit the debris they've transported, forming distinct **landforms**.

Erosional Landforms Created by Glaciers

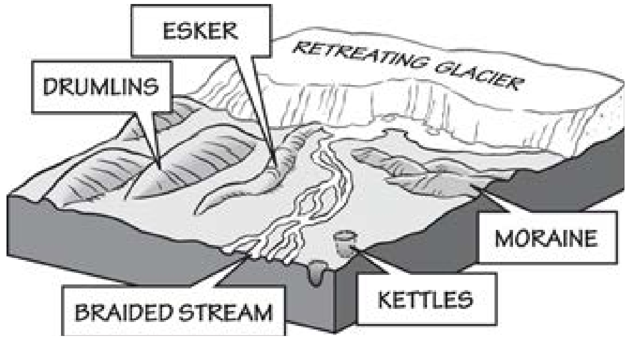
Glacial erosion carves striking landforms, especially in **mountainous regions**:

Landform	Description
U-Shaped Valley	Broad, flat valley with steep sides; formed by glacial abrasion replacing river-carved V-shaped valleys.
Hanging Valley	Tributary valley suspended above the main valley; forms waterfalls after glacier retreat.
Cirque/ Corrie	Bowl-shaped hollow with steep walls and a flat base, often containing a Tarn (small lake).
Aretes	Sharp, narrow ridges formed between adjacent cirques.
Horn	Pyramidal peak created when multiple aretes converge (e.g., Matterhorn, Switzerland).
Roche Moutonnée	Asymmetrical rock hill: smooth upstream (abrasion) and jagged downstream (plucking).
Nunatak	Rock outcrop projecting through ice, like an island in a sea of ice.
Fjord	Deep, narrow coastal valley submerged by the sea after glacial retreat. Common in Norway and New Zealand.



Depositional Landforms of Glaciers

When glaciers melt or retreat, they deposit unsorted material known as **glacial till**. This results in several distinctive landforms:



1. Moraines – Ridges of glacial debris (rocks, clay, gravel)

Type	Location	Description
Lateral Moraine	Sides	Debris from valley walls along glacier margins
Medial Moraine	Center	Formed where two glaciers merge; debris from both lateral moraines
Ground Moraine	Beneath glacier	Uneven layer of till deposited beneath glacier
Terminal Moraine	End of glacier	Forms a ridge marking glacier's farthest advance
Recessional Moraine	Behind terminal	Formed during temporary halts in glacial retreat

2. Outwash Plain

- Flat area of sorted sediments (sand, gravel) laid by meltwater beyond glacier's terminal moraine

3. Eskers

- Long, winding ridges formed by sub-glacial meltwater streams depositing sediments

4. Drumlins

- Elongated, egg-shaped hills made of till; steep end faces direction glacier came from

5. Kames

- Irregular hills or ridges of sand and gravel formed at glacier margins

2.8.6 Groundwater: Karst Topography

Karst Topography refers to distinctive landforms created by the **chemical action of groundwater** (particularly the process of *solution* and *deposition*) on **soluble rocks** like limestone, dolomite, or gypsum.

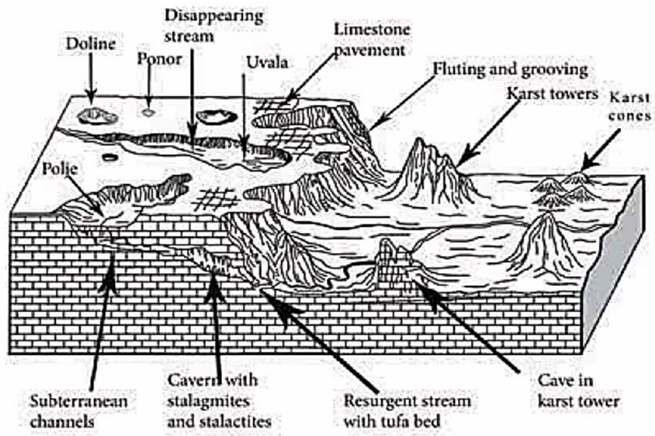
- The term "**Karst**" originates from the **Kras region** in **Slovenia and Croatia** (former Yugoslavia).
- The word is derived from the **Slavic word** "**Kras**", meaning *"rocky terrain"*.

Erosional Landforms by Groundwater

Groundwater dissolves soluble rocks over time, producing the following **erosional landforms**:

Landform	Description
1. Sinkhole	Circular depression at the surface, funnel-shaped below. If formed solely by solution, it is called a **solution sink.**
2. Doline	A closed, bowl-shaped depression that drains water underground. Size varies from a few meters to hundreds of meters.
3. Lappies	Small-scale grooves or ridges formed when rainwater dissolves exposed limestone surfaces.
4. Uvala	A large, irregular depression formed by the merging of multiple sinkholes.
5. Polje	Large flat-floored depression formed by coalescence of sinkholes, often with disappearing streams. Enclosed by steep walls, it may span up to 250 km².
6. Cave	Underground passage formed by the dissolution of limestone. If it has openings at both ends, it is called a **tunnel**.

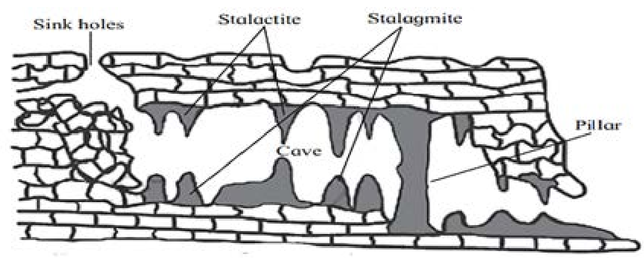
Fact: Caves in karst regions may contain underground rivers and are often tourist attractions due to their stunning formations.



Depositional Landforms by Groundwater

When water containing **calcium carbonate ($CaCO_3$)** loses CO_2 inside caves, it deposits minerals, forming **speleothems** or cave features:

Landform	Description
1. Curtains	Thin, sheet-like calcite formations resembling drapes or curtains. Formed by water seeping through long cracks.
2. Stalactite	Icicle-like calcium carbonate deposits **hanging from the ceiling** of caves. Formed by dripping water.
3. Stalagmite	Mound-shaped deposits **growing upward from the cave floor** beneath stalactites.
4. Helactite	Twisted, sideways-growing extensions of stalactites. Formed when capillary forces deflect water.
5. Pillar (Column)	When stalactites and stalagmites **join together,** they form a **pillar** or **column**.
Tip:"**Stalactite** holds *tight* to the ceiling." "**Stalagmite** *might* reach the roof.	



2.8.7 Wind: Aeolian Landforms

Wind is a powerful geomorphic agent in **arid and semi-arid** regions. The landforms shaped by **wind erosion and deposition** are called **Aeolian Landforms**.

Modes of Wind Action

1. **Deflation**: Lifting and removal of loose particles like sand and dust.
2. **Abrasion**: Mechanical scraping of surfaces by wind-blown sand (like sandblasting).
3. **Attrition**: Collision of particles carried by wind, breaking them into finer pieces.

Erosional Landforms of Wind

Landform	Description
Deflation Hollows	Shallow depressions caused by persistent wind removing loose particles. If water accumulates, it may form an Oasis.
Mushroom Rock	Rock pedestal with narrow base and wide top. Formed due to more erosion at the base by sand-laden wind.
Yardang	Streamlined ridges aligned with the wind direction. Formed by differential erosion in soft and hard rocks. Size: 1–10 meters high.
Zeugen	Table-like landforms created by wind abrasion on horizontal rock layers. Alternating soft and hard rock layers are eroded unevenly.

Example: Yardangs are found in the **Sahara Desert** and near **Lake Aswan**, Egypt.

Depositional Landforms of Wind

Wind deposits materials when it loses speed. Major landforms include:

1. Sand Dunes

Formed by the accumulation of sand. Classified by shape and wind direction:

Type	Description
Barchan	Crescent-shaped dunes with horns pointing **leeward**. Formed in areas with **unidirectional winds.**
Seif Dunes	Long, narrow ridges parallel to prevailing winds. Separated by wind-eroded corridors.

Barchans can reach up to **27 meters** in height.

2. Loess

- Wind-blown **silt and fine dust** deposited over vast areas.
- Often found in **China**, **Central Asia**, **Europe**, and the **Midwestern USA**.
- Fertile but highly erodible.

3. Pediplains

- Large, **flat desert surfaces** formed after long-term wind erosion levels highlands.
- Represents **end stage** of arid landscape development.

2.8.8 Waves and Coastal Landforms

Waves are **horizontal movements of seawater** primarily caused by **wind**, the **Earth's rotation**, gravitational forces of the **moon and sun** (tides), and

underwater disturbances like earthquakes (tsunamis). Waves play a significant role in **shaping coastal landscapes** through processes of **erosion**, **transportation**, and **deposition**.

How Do Waves Erode the Coast?

Waves erode coastlines using four main mechanisms:

Erosive Process	Explanation
Abrasion (Corrasion)	Occurs when **sand, pebbles, and boulders** carried by waves strike against the coastline, grinding and wearing it away like sandpaper.
Hydraulic Action	The force of waves compresses **air and water** into cracks in rocks. As the wave retreats, compressed air expands explosively, weakening and eventually breaking the rock.
Corrosion (Solution)	The **chemical action** of seawater **dissolves soluble rocks,** particularly limestone, chalk, and dolomite.
Attrition	Rock fragments carried by waves collide, breaking into smaller and smoother particles. Over time, sharp rocks become sand or silt.

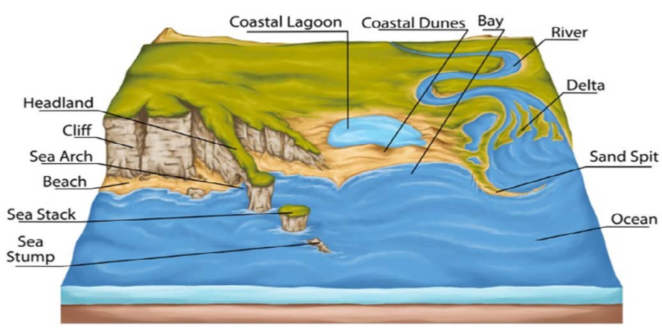
Key Coastal Terminology

Term	Description
Sea Shore	Zone between the **high tide and low tide** marks
Shoreline	The **boundary** between land and water
Backshore	Beach zone above normal high tide, affected by **storm waves**
Foreshore	Beach area between **high tide and low tide** affected during normal conditions
Offshore	Shallow sea area extending to the **continental shelf**
Coastline	Where **land meets the sea**
Swash	Water that **washes up the beach** after a wave breaks

Landforms Created by Wave Erosion

Wave erosion primarily shapes **rocky coasts**, though these features can also occur near depositional zones.

Landform	Description
Sea Cliff	A **steep vertical rock face** formed by persistent wave erosion at the base of a rock mass.
Wave-Cut Platform	A **flat, gently sloping surface** formed as the cliff retreats. May be exposed at low tide. Sometimes formed after **blowhole collapse.**
Sea Cave	A **hollow tunnel** eroded into a cliff, often along lines of weakness (faults, joints). Entrance is usually smaller than depth.
Blowhole	A vertical shaft formed in the roof of a sea cave. **Water and spray shoot upwards** during wave impact. May later collapse.
Sea Arch (Tunnel)	Formed when waves **erode through a headland**, connecting two caves. If long, it's termed a **sea tunnel.**
Sea Stack	A **pillar of rock** left behind after a sea arch collapses. Known by names like **chimney rock, needle, skerry, etc.**
Stump	A **worn-down remnant** of a sea stack, often visible at low tide.



Examples:

- **Durdle Door**, UK – Sea Arch
- **Twelve Apostles**, Australia – Sea Stacks
- **Matainaka Cave**, New Zealand – World's longest sea cave (1.5 km)

Transportation by Waves

Waves transport eroded materials such as **silt, sand, gravel, cobble, pebble**, and **boulders** via:

- **Longshore drift**: Movement of materials **parallel to the shore** due to oblique wave action.
- **Saltation and suspension**: Lighter materials are bounced or carried in suspension.
- **Traction**: Heavier materials are rolled along the seabed.

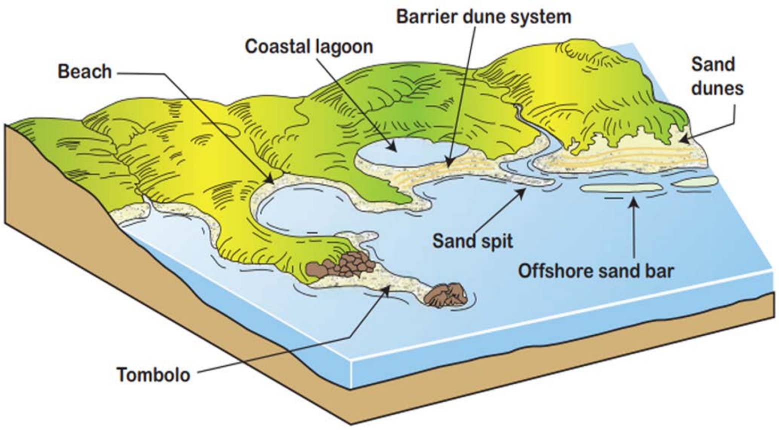
Landforms Created by Wave Deposition

When the **energy of sea waves reduces**, they lose the ability to carry sediments, leading to **deposition** along the coast. Over time, this results in the formation of various **coastal depositional landforms**.

Key Depositional Landforms by Waves

Landform	Description	Example
1. Beach	A **gently sloping accumulation** of sand, pebbles, or shingle deposited along the shoreline by wave action. Beaches act as buffers, absorbing wave energy. Types include: - **Sandy Beaches** – Fine grains; popular in tropical zones - **Pebble/Shingle Beaches** – Found in areas with higher wave energy	- **Praia do Cassino,** Brazil – World's longest beach (200 km) - **Marina Beach**, Chennai – Second longest urban beach in the world
2. Bar	A **ridge or narrow belt** of sand or sediment deposited **offshore**, often **parallel** to the coastline. Bars form where wave action reduces velocity. If the bar becomes extensive, it may become a **barrier island.**	Found along **low-gradient coastlines** around river mouths
3. Lagoon	A **shallow body of water** partially or completely separated from the ocean by a bar, spit, or barrier island. It is typically enclosed seawater.	- **Pulicat Lake** (Tamil Nadu & Andhra Pradesh) - **Chilika Lake** (Odisha)
4. Spit	A **long**, **narrow deposit** of sand or gravel that extends from the coast into the sea. Formed by **longshore drift**, it is attached to the land at one end, and may curve due to wind/currents.	- **Rameswaram Spit,** Tamil Nadu
5. Tombolo	A **sandbar or spit** that connects an **island to the mainland.** Formed when **wave refraction** and **deposition** link the two landmasses.	- **Chesil Beach**, UK – connects the **Isle of Portland** to mainland England

Fun Fact: A **tombolo** is often mistaken for a spit. The difference lies in **both ends being connected** to land in a tombolo.



Quick Comparison Table

Process	Erosional Landforms	Depositional Landforms
Waves	Sea Cliff, Wave-Cut Platform, Sea Cave, Blowhole, Arch, Stack, Stump	Beach, Bar, Lagoon, Spit, Tombolo, Barrier Island

Key Concepts

- **Hydraulic Action:** Compression of air + water into cracks.
- **Abrasion**: Sandblasting by rock fragments.
- **Attrition**: Collision and breaking of sediments.
- **Longshore Drift:** Movement of materials along coast due to angled waves.
- **Spit vs Tombolo:**
  - ✧ Spit = only one end connected to land
  - ✧ Tombolo = both ends connect land/island