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Pocket Notes

PHYSICAL GEOGRAPHY

For OPSC, OSSC & Other State Level Exams.
Last Minute Revise

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Origin & Evolution of Earth

Origin of the Universe

A. Big Bang Theory (Most accepted)

- Proposed by Georges Lemaître (1927), supported by Edwin Hubble (1929).
- Around 13.8 billion years ago, a massive explosion (Big Bang) occurred from a singular point (high density + temperature).
- Universe started expanding → galaxies, stars, and planets formed.
- Evidence:
    - Red shift in light from galaxies (Hubble's law → universe expanding).
    - Cosmic Microwave Background Radiation (CMBR) – thermal echo of Big Bang.
    - Abundance of light elements (Hydrogen, Helium).

B. Steady State Theory (Hoyle, 1948)

- Universe has no beginning or end — new matter continuously created.
- Rejected after discovery of CMBR.

C. Oscillating / Pulsating Universe Theory

- Universe expands → contraction → collapse → Big Crunch → new Big Bang.
- Cyclical model, gaining attention in modern cosmology.

Star Formation

- Stars form from large clouds of hydrogen gas and dust → called Nebulae.
- Due to gravity → cloud contracts → forms dense core → temperature and pressure rise → nuclear fusion begins → star is born.
- Lifecycle:

- Nebula → Protostar → Main Sequence Star → Red Giant → White Dwarf / Neutron Star / Black Hole (depending on mass).
- Our Sun is a medium-sized main sequence star (age: ~4.6 billion years).

Formation of Planets – Nebular Hypothesis

Proposed by: Immanuel Kant (1755) & Laplace (1796).
Modified by: Chamberlain & Moulton (Planetesimal Hypothesis, 1900s) and later by Otto Schmidt (1944).

Stages of Planet Formation:

1. Nebula Stage:
   - Solar system began as a rotating gas-dust cloud (solar nebula).
2. Proto-Sun Formation:
   - Central mass condensed → formed Sun.
   - Outer matter flattened into a rotating disc.
3. Planetesimal Stage:
   - Dust and gas particles collided → formed small bodies called planetesimals.
4. Protoplanet Stage:
   - Planetesimals combined through gravitational attraction → protoplanets.
5. Planet Stage:
   - Protoplanets condensed into planets, satellites, and asteroids.
   - Solar wind from young Sun blew away lighter gases from inner planets → formed rocky planets (Mercury to Mars).
   - Outer planets retained gases → gas giants (Jupiter to Neptune).

Solar System

- Age: ~4.6 billion years.
- Structure: Sun + 8 planets + dwarf planets + moons + asteroids + comets + meteoroids.

Components

1. Sun:
    - Central body (~99.86% of solar mass).
    - Source of light and heat.
2. Inner Planets (Terrestrial):
    - Mercury, Venus, Earth, Mars.
    - Small, rocky, dense, few/no moons.
3. Outer Planets (Jovian):
    - Jupiter, Saturn, Uranus, Neptune.
    - Large, gaseous, many moons, ring systems.
4. Dwarf Planets:
    - Pluto, Ceres, Eris, Haumea, Makemake.
    - Smaller than planets, don't clear orbital path.
5. Asteroids:
    - Rocky fragments between Mars & Jupiter (Asteroid Belt).
6. Comets:
    - Ice + dust bodies from outer solar system.
    - Eg: Halley's Comet (returns every 76 years).
7. Meteoroids / Meteor / Meteorite:
    - Small rocky fragments → burn in atmosphere (shooting star).
    - If reach Earth's surface → meteorite.

Geological Time Scale

What is Geological Time Scale (GTS)?

- The chronological framework of Earth's history based on major geological and biological events.
- It divides 4.6 billion years of Earth's history into hierarchical units: Eon → Era → Period → Epoch → Age.
- Built mainly from fossil records, rock strata, and radiometric dating.

Major Eons

Eon	Duration (approx.)	Key Features
Hadean	4.6 – 4.0 billion years ago	Earth's crust formed, molten surface, no life, formation of Moon.
Archean	4.0 – 2.5 billion years ago	First stable continental crusts, first life (unicellular bacteria, cyanobacteria).
Proterozoic	2.5 billion – 541 million years ago	Oxygen buildup (Great Oxidation), multicellular life begins.
Phanerozoic	541 million years ago – Present	Explosion of life, appearance of plants, animals, humans.

Phanerozoic Eon in Detail

(A) Paleozoic Era (541 – 252 million years ago)

Meaning: "Ancient Life"

- Life shifted from seas → land.
- Pangaea supercontinent formed.
- Ended with Permian mass extinction (largest ever).

Major Periods:

1. Cambrian: Explosion of marine life.
2. Ordovician: First vertebrates.
3. Silurian: Early land plants.
4. Devonian: Age of fishes.
5. Carboniferous: Coal forests, amphibians dominant.
6. Permian: Reptiles evolved; ends with extinction.

(B) Mesozoic Era (252 – 66 million years ago)

Meaning: "Middle Life"

- Age of Reptiles / Dinosaurs.
- Pangaea broke into continents.
- Warm climate, first birds and mammals.
- Ends with Cretaceous–Paleogene extinction (asteroid impact).

Major Periods:

1. Triassic: First dinosaurs & mammals.
2. Jurassic: Large dinosaurs, first birds.
3. Cretaceous: Flowering plants; dinosaurs extinct.

(C) Cenozoic Era (66 million years ago – Present)

Meaning: "Recent Life"

- Age of Mammals & Humans.
- Continents took modern shape.
- Himalayas formed (~50 mya).
- Ice Ages & human evolution.

Major Periods & Epochs:

1. Paleogene: Mammals diversify.
    - *Epochs:* Paleocene, Eocene, Oligocene.
2. Neogene: Early humans appear.
    - *Epochs:* Miocene, Pliocene.
3. Quaternary: Modern humans & Ice Ages.

- *Epochs:* Pleistocene (Ice Age), Holocene (current).

Biological Milestones

Event	Geological Period / Era
Origin of life	Archean
Photosynthesis & oxygen rise	Proterozoic
Cambrian explosion (marine life boom)	Cambrian
Fish dominant	Devonian
First reptiles	Carboniferous
Dinosaurs appear	Triassic
Mammals emerge	Jurassic
Flowering plants appear	Cretaceous
Mammals dominate	Cenozoic
Humans appear	Quaternary (Pleistocene)

Interior of the Earth

Lithosphere

- The outermost solid shell of the Earth — includes the crust + uppermost mantle.
  It is the "rocky skin" on which continents and ocean basins rest.
- Thickness:
  - Average: 100 km (varies from 10 km under oceans to 200 km under continents).
- Composition:
  - Made of rocks & minerals (mainly oxygen, silicon, aluminium, iron).
  - Divided into tectonic plates — 7 major + several minor plates.
  - Plates float over the asthenosphere (semi-molten upper mantle layer).
- Crustal Composition:
  - Continental crust: Granite (Si + Al → "Sial").
  - Oceanic crust: Basalt (Si + Mg → "Sima").
  - Average density: Continental (2.7 g/cm³), Oceanic (3.0 g/cm³).
- Importance:
  - Supports life (landforms, soil, minerals).
  - Controls earthquakes, volcanoes, and mountain building.

Atmosphere

- The gaseous envelope surrounding the Earth, held by gravity.
  Extends up to ~10,000 km but ~99% mass lies within 30 km.
- Composition (by volume):
  - Nitrogen (78%)
  - Oxygen (21%)
  - Argon (0.93%)
  - CO_2 (0.04%)
  - Other gases (neon, helium, ozone, methane, hydrogen).
- Layers of Atmosphere:
  1. Troposphere (0–12 km):

- Weather phenomena occur here.
- Temperature decreases with height (6.5°C/km).
- Boundary: Tropopause.

2. Stratosphere (12–50 km):
   - Contains ozone layer → absorbs UV rays.
   - Temperature increases with height.
3. Mesosphere (50–80 km):
   - Coldest layer; meteors burn here.
4. Thermosphere (80–700 km):
   - Ionized gases; auroras occur.
   - Space shuttles orbit here.
5. Exosphere (700+ km):
   - Outermost; merges with space.

- Functions:
  - Regulates temperature.
  - Protects from harmful solar radiation.
  - Supports life via oxygen & water cycle.

3. Hydrosphere

- All water bodies on, under, and above the Earth's surface.
- Distribution:
  - Oceans: ~97.5% (saline water).
  - Freshwater: ~2.5% (glaciers, groundwater, lakes, rivers, atmosphere).
- Components:
  - Oceans & Seas: Regulate climate, store heat.
  - Rivers & Lakes: Freshwater sources.
  - Groundwater & Ice Caps: Long-term reservoirs.
  - Atmospheric Moisture: Part of water cycle.
- Functions:
  - Controls Earth's energy balance & weather.
  - Medium for nutrient transport & aquatic life.
  - Key in erosion, sedimentation, and shaping landforms.

Structure of the Earth

The Earth's internal structure is divided based on composition and mechanical properties.
It has three main layers — Crust, Mantle, and Core, separated by discontinuities.

Crust

- Outermost layer — thinnest and lightest.
- Thickness:
  - Continental crust → 30–70 km (average ~40 km).
  - Oceanic crust → 5–10 km (thin but denser).
- Composition:
  - Continental crust: Granite-type (Silica + Aluminium → "SIAL").
  - Oceanic crust: Basaltic (Silica + Magnesium → "SIMA").
- Density:
  - Continental: 2.7 g/cm^3
  - Oceanic: 3.0 g/cm^3
- Major Elements: Oxygen, Silicon, Aluminium, Iron, Calcium, Sodium, Potassium, Magnesium.

Mantle

- Lies below the crust, extends up to ~2,900 km.
- Volume: ~83% of Earth's total volume.
- Composition:
  - Silicates of Iron and Magnesium (hence called SIMA).
  - Rich in olivine and pyroxene minerals.
- Density: 3.3 – 5.5 g/cm^3.
- Division:
  - Upper Mantle (up to 660 km): Includes Asthenosphere.
  - Lower Mantle (660–2,900 km): Denser, rigid zone.

Asthenosphere

- Located within upper mantle (80–200 km depth).
- Semi-molten, plastic-like layer → behaves as "lubricating zone" for tectonic plate movement.
- Made of partially molten rocks rich in silicates of iron and magnesium.
- Plays key role in plate tectonics and isostasy.

Core

- Innermost and densest layer of Earth.
- Extends from 2,900 km to 6,371 km (center).
- Composition: Nickel + Iron → "NIFE."
- Density: 9.5 – 13 g/cm³.
- Division:
    - Outer Core (2,900–5,150 km):
        - Liquid state (molten iron-nickel).
        - Generates Earth's magnetic field via convection currents.
    - Inner Core (5,150–6,371 km):
        - Solid state (due to immense pressure).

Important Discontinuities

Discontinuity	Between	Nature/Feature
Conrad Discontinuity	Upper & Lower Crust	Not always distinct; separates granitic & basaltic layers.
Mohorovičić (Moho) Discontinuity	Crust & Mantle	Sharp increase in velocity of seismic waves.
Repetti Discontinuity	Upper & Lower Mantle	Gradual density change (less distinct).
Gutenberg Discontinuity	Mantle & Core	Sharp drop in P-wave speed; S-waves disappear (liquid outer core).
Lehmann Discontinuity	Outer & Inner Core	P-wave speed increases → indicates solid inner core.

Density & Temperature Trend

- Density: Increases with depth (from 2.7 g/cm^3 in crust → ~13 g/cm^3 in core).
- Temperature: Rises with depth (~25–30°C/km in upper crust → ~5000°C at core).
- Pressure: Increases steadily → keeps lower layers solid despite high temperature.

Composition & Motion of the Earth

Composition of the Earth's Crust

- The crust is the outermost, thinnest, and solid layer of the Earth — forms continents & ocean floors.
- Average thickness:
  - Continental crust: ~35 km
  - Oceanic crust: ~5–10 km

Major Elements in Earth's Crust

Element	% by Weight
Oxygen (O)	46.6%
Silicon (Si)	27.7%
Aluminium (Al)	8.1%
Iron (Fe)	5.0%
Calcium (Ca)	3.6%
Sodium (Na)	2.8%
Potassium (K)	2.6%
Magnesium (Mg)	2.1%
Others (Ti, H, P, etc.)	1.5%

Rocks forming the crust:

- Granite (continental crust) → rich in silica + aluminium (SIAL).
- Basalt (oceanic crust) → rich in silica + magnesium (SIMA).

Chemical Composition of the Entire Earth

Layer	Dominant Elements	Key Points
Crust	O, Si, Al, Fe	Silicate-rich rocks
Mantle	Si, Mg, Fe	Denser, Fe-Mg silicates
Core	Fe, Ni	Heavy metals → "NIFE"

Approximate composition (by weight):

- Iron (Fe) → 35%
- Oxygen (O) → 30%
- Silicon (Si) → 15%
- Magnesium (Mg) → 13%
- Nickel, Sulphur, Calcium → small %

Motions of the Earth

Earth performs two main motions: Rotation and Revolution.

(A) Rotation

- Definition: Spinning of Earth on its axis from west to east.
- Duration: 23 hrs 56 min 4 sec (1 sidereal day).
- Speed: ~1670 km/hr at equator (decreases toward poles).

Consequences:

1. Day and Night formation.
2. Apparent movement of the Sun (east to west).
3. Time difference between longitudes (15° = 1 hr).
4. Coriolis Effect (deflection of winds & ocean currents).
5. Flattening of poles and bulging at equator.

(B) Revolution

- Definition: Movement of Earth around the Sun in an elliptical orbit.
- Duration: 365 days 5 hrs 48 min 45 sec (1 year).
- Average distance from Sun: 149.6 million km (1 Astronomical Unit).
- Speed: ~30 km/sec.
- Plane of orbit: Ecliptic plane (tilted 23.5° to Earth's axis).

Consequences:

1. Seasons (due to tilt + revolution).
2. Variation in day length.
3. Changes in solar altitude & apparent path of the Sun.
4. Leap Year (extra ¼ day each year → 1 day added every 4 years).

(C) Important Terms

Term	Explanation
Perihelion	Earth closest to Sun (Jan 3).
Aphelion	Earth farthest from Sun (July 4).
Equinox	Equal day & night (March 21, Sept 23).
Solstice	Longest/Shortest day (June 21, Dec 22).
Circle of Illumination	Line dividing day & night on Earth.

Seasons

Seasons

Earth's axis is tilted at 23.5° and it revolves around the Sun.

- The tilt causes different parts of Earth to receive varying sunlight throughout the year.
- One revolution = 365¼ days → 4 main seasons in mid-latitudes:
  - Spring, Summer, Autumn, Winter.
- In India (Northern Hemisphere):
  - Summer: March–June
  - Monsoon: June–Sept
  - Winter: Dec–Feb

Summer Solstice (June 21)

- Earth's North Pole tilted maximum toward the Sun.
- Sun's vertical rays fall on the Tropic of Cancer (23.5°N).
- Northern Hemisphere: Longest day, shortest night.
- Southern Hemisphere: Shortest day, longest night.
- Arctic Circle (66.5°N): 24-hour daylight ("Midnight Sun").

➢ In India: Around June 21, longest daylight occurs.

Winter Solstice (December 22)

- Earth's South Pole tilted toward the Sun.
- Sun's rays directly fall on the Tropic of Capricorn (23.5°S).
- Northern Hemisphere: Shortest day, longest night (Winter).
- Southern Hemisphere: Longest day, shortest night (Summer).
- Antarctic Circle: 24-hour daylight.

In India: Coldest months begin soon after this period.

Equinoxes (Equal Day & Night)

- Occurs when Sun's rays fall vertically on the Equator (0°).
- Day and night are equal (12 hours each) worldwide.

Date	Event	Hemisphere Season
March 21 (Vernal Equinox)	Sun crosses Equator northward	Spring (N), Autumn (S)
September 23 (Autumnal Equinox)	Sun crosses Equator southward	Autumn (N), Spring (S)

Latitude and Longitude

Latitude

- Imaginary horizontal lines parallel to the Equator.
- Measure angular distance north or south of Equator (0° to 90°).
- Key Latitudes:
  - Equator (0°)
  - Tropic of Cancer (23.5°N)
  - Tropic of Capricorn (23.5°S)
  - Arctic Circle (66.5°N)
  - Antarctic Circle (66.5°S)
  - Poles (90°N & 90°S)
- 1° latitude ≈ 111 km everywhere (constant distance).

Longitude

- Imaginary vertical lines joining poles.
- Measure angular distance east or west of the Prime Meridian (0° Greenwich, London).
- 1° longitude = 4 minutes of time difference.
- Total = 360 longitudes → 180° East + 180° West.

Greenwich Mean Time (GMT)

- Time at Prime Meridian (0° longitude) passing through Greenwich Observatory, London.
- Reference for all world time zones.
- Earth rotates 360° in 24 hours → 15° per hour.
    - Moving east → add time,
    - Moving west → subtract time.

Indian Standard Time (IST)

- India lies between 68°7'E – 97°25'E longitudes.
- To avoid confusion of local times, one standard meridian = 82°30'E is chosen.
- Time difference from GMT = +5 hours 30 minutes.
  (IST = GMT + 5:30)
- Passes through Mirzapur (U.P.) near Allahabad.
- India has single time zone, though longitudinal spread ≈ 30°.

Rock Cycle & Classification of Rocks

- A natural solid aggregate of minerals that makes up the Earth's crust.
- Rocks are of three main types based on their origin and formation process.

The Rock Cycle

- The rock cycle explains how the three types of rocks — Igneous, Sedimentary, and Metamorphic — transform from one form to another continuously under natural processes.

Sequence:

1. Magma (molten material below surface) → cools → forms Igneous rock.
2. Igneous rocks → weathered & eroded → sediments.
3. Sediments → compacted → Sedimentary rock.
4. Sedimentary or Igneous rocks → subjected to heat & pressure → Metamorphic rock.
5. Metamorphic rocks → melt → magma → cycle restarts.

Classification of Rocks

(A) Igneous Rocks — "Primary or Parent Rocks"

- Formed by: Cooling & solidification of molten magma or lava.
- Examples: Basalt, Granite, Gabbro, Diorite.

Types:

1. Intrusive (Plutonic):
   - Formed when magma cools slowly beneath Earth's surface.
   - Large crystals, coarse texture.

- Eg: Granite, Diorite, Gabbro.

2. Extrusive (Volcanic):
   - Formed when lava cools quickly on the surface.
   - Small crystals, fine texture.
   - Eg: Basalt, Andesite, Rhyolite.

Characteristics:

- Hard, dense, crystalline.
- Do not contain fossils.
- Forms base for other rocks.

Example (India): Deccan Traps (Basaltic lava flows).

(B) Sedimentary Rocks — "Secondary Rocks"

- Formed by: Deposition, compaction, and cementation of sediments (weathered particles).
- Can also form from precipitation of minerals or remains of organisms.

Types:

1. Clastic (Mechanically formed):
   - From rock fragments. Eg: Sandstone, Shale, Conglomerate.
2. Chemical (Precipitated from solution):
   - Eg: Limestone, Gypsum, Rock Salt.
3. Organic (Biological origin):
   - From remains of plants/animals. Eg: Coal, Chalk.

Characteristics:

- Often layered (stratified).
- Contain fossils.
- Soft and easily eroded.

Example (India): Vindhyan ranges (sandstone, limestone).

(C) Metamorphic Rocks — “Changed Rocks”

- Formed by: Alteration of pre-existing rocks (igneous or sedimentary) under heat, pressure, or chemical activity.
- Process called Metamorphism (Greek: “meta” = change, “morph” = form).

Types of Metamorphism:

1. Contact Metamorphism: Due to heat from magma.
2. Regional Metamorphism: Due to pressure over large areas (mountain building).

Examples:

Original Rock	Metamorphic Rock
Limestone	Marble
Shale	Slate
Sandstone	Quartzite
Granite	Gneiss
Coal	Graphite

Characteristics:

- Crystalline, hard.
- Fossils destroyed due to heat/pressure.

Example (India): Marble of Makrana (Rajasthan), Slate of Himachal Pradesh.

Geomorphology

- Geomorphology is the scientific study of landforms, their origin, evolution, and present shape, and the processes that act upon the Earth's surface.

Classification of Geomorphic Processes

Geomorphic processes are broadly classified into Endogenetic (internal) and Exogenetic (external) movements:

Type	Source of Energy	Nature	Examples
Endogenetic	Internal heat & pressure from Earth's interior	Constructive (creates relief)	Earthquakes, volcanism, folding, faulting
Exogenetic	External forces like atmosphere, water, ice, wind	Destructive (wears down relief)	Weathering, erosion, transportation, deposition

Endogenetic Movements

- Originate inside the Earth due to radioactive decay, heat flow, and pressure differences.
- Responsible for creating relief features (mountains, plateaus, rift valleys, basins).

Types of Endogenetic Movements

(A) Sudden Movements

- Occur abruptly; cause large-scale destruction.
- Examples:
  - Earthquakes → due to sudden release of energy along faults.
  - Volcanic Eruptions → magma expulsion from Earth's interior.

(B) Slow Movements (Diastrophic Movements)

- Act over long geological time periods.
- Cause uplift, subsidence, folding, and faulting of Earth's crust.
- Eg: Formation of Himalayas, Great Rift Valley.

Diastrophism

Diastrophism refers to all large-scale Earth movements produced by internal forces that deform the crust — includes both folding and faulting.

(A) Folding

- Bending of rock strata due to horizontal compressional forces.
- Produces mountain ranges and anticlines (upfolds) & synclines (downfolds).
- Eg: Himalayas, Alps, Rockies.

(B) Faulting

- Breaking and displacement of rock strata due to tensional or compressional forces.
- Creates fault lines, rift valleys, block mountains.
- Eg: Great African Rift Valley, Vindhyan Faults (India).

Exogenetic Movements

- Operate on Earth's surface.
- Driven by sun's energy, gravity, and atmospheric processes.
- Erosional, depositional, and weathering activities shape landforms.

Major Exogenetic Agents:

- Running Water (Fluvial): Rivers — valleys, deltas, floodplains.
- Glacial (Ice): Glaciers — U-shaped valleys, moraines.
- Aeolian (Wind): Deserts — dunes, loess plains.
- Marine (Waves): Coastal landforms — cliffs, beaches, arches.

- Weathering: Breaking down of rocks in situ (chemical, mechanical, biological).

Mountain Building & Vertical Movements

Mountain-Building Movements (Orogeny)

- Orogeny (Greek: *Oros* = mountain, *Geny* = birth) refers to processes of mountain formation caused by endogenetic forces (internal forces of the Earth).
- These movements involve crustal deformation under compression and tension leading to folds, faults, uplift, and subsidence.

Forces Involved in Crustal Movements

The Earth's crust is continuously subjected to horizontal and vertical forces due to internal energy, mainly from radioactive decay and mantle convection.

(A) Horizontal Forces — cause Folding & Faulting

1. Force of Compression
    - Acts toward each other (converging direction).
    - Rocks are squeezed, bent, and folded.
    - Produces Fold Mountains — long, parallel ridges & valleys.
    - Examples:
        - Himalayas, Alps, Andes, Rockies.
    - Structure formed:
        - Anticline (upfold) and Syncline (downfold).
2. Force of Tension
    - Acts away from each other (diverging direction).
    - Rocks are pulled apart, leading to fractures or faults.
    - Creates Rift Valleys (down-faulted blocks) and Block Mountains (uplifted blocks).
    - Examples:
        - East African Rift Valley, Rhine Valley, Vindhyan Faults, Satpura Block (India).

Result: Stretching and thinning of the crust → valley formation.

(B) Vertical Forces — cause Uplift & Subsidence

1. Uplift (Epeirogenic Movement)
    - Broad, gentle upward movement of large crustal areas.
    - Occurs very slowly over geological time.
    - Results in formation of plateaus, continental rises, or land emergence from sea.
    - Examples:
        - Deccan Plateau (India), Tibetan Plateau, Uplift of Himalayas (ongoing).
    - Caused by isostatic adjustment — when crust rises due to reduced weight (erosion, glacier melting).
2. Subsidence
    - Slow downward movement of Earth's crust.
    - Opposite of uplift; may be due to loading (sediment deposition), crustal compression, or cooling of lithosphere.
    - Leads to formation of basins, depressions, coastal submergence.
    - Examples:
        - Ganges–Brahmaputra delta subsidence, Maldives coral atolls (due to sinking crust).

Classification of Crustal Movements

Type	Nature	Resultant Feature	Example
Orogenic (Mountain-building)	Horizontal (compression/tension)	Folds, Faults, Mountains	Himalayas, Andes, Alps
Epeirogenic (Vertical movement)	Upward or downward	Plateaus, Basins, Uplifts, Subsidence	Deccan Plateau, North Sea Basin

Continental Drift Theory

- Proposed by Alfred Wegener (German Meteorologist, 1912) in his book *"The Origin of Continents and Oceans" (1915).*
- He suggested that continents are not stationary, but drifted apart from a single ancient landmass.

Idea of the Theory

- Around 200 million years ago (Mesozoic Era), all landmasses were joined together forming a supercontinent called "Pangaea" (Greek: "All Earth").
- Surrounded by a single global ocean called Panthalassa ("All Sea").
- Pangaea later broke into two parts:
  - Laurasia (Northern Hemisphere)
  - Gondwanaland (Southern Hemisphere)
- These two landmasses drifted apart horizontally, giving rise to the present continents.

Mechanism of Drift

- Wegener proposed that continents floated over denser oceanic crust made of "Sima" (Silica + Magnesium).
- He attributed drift to two forces:
  1. Pole-fleeing force (Centrifugal force) due to Earth's rotation.
  2. Tidal force caused by gravitational pull of the Sun and Moon.
- These forces supposedly pushed the continents toward the equator and westward.

☐ However — these forces were later found too weak to move continents.

Evidence Supporting Continental Drift Theory

(A) Jig-saw Fit of the Continents

- The east coast of South America and the west coast of Africa fit together like puzzle pieces.
- Best fit obtained at 1000 fathoms (1800 m depth) — continental shelf edges.

(B) Fossil Evidence

- Same species of fossils found on continents now far apart.
  - Glossopteris (plant) fossils in India, Africa, Australia, South America, Antarctica.
  - Mesosaurus (reptile) fossils in Brazil and South Africa — freshwater species, couldn't cross ocean.

(C) Rock and Mountain Similarity

- Similar rock formations and mountain ranges found on different continents.
  - Appalachians (North America) continue as Caledonides (Europe).
  - Gondwana rock system similar across India, Australia, South Africa.

(D) Paleoclimatic Evidence

- Coal found in cold regions (e.g., Antarctica) indicates past tropical climate.
- Glacial deposits (Tillites) in now tropical areas like India, South Africa, and Australia suggest these were once near poles.

(E) Paleomagnetism (Later Evidence)

- Magnetic minerals in rocks record Earth's magnetic orientation at the time of formation.

- Rocks of same age from different continents show different magnetic orientations, supporting movement.

Criticism of Wegener's Theory

Point	Criticism
Lack of Mechanism	Could not explain how massive continents moved through solid oceanic crust.
Weak Forces	Centrifugal & tidal forces are too small to cause drift.
Ocean Floor Studies (Later)	Showed ocean crust younger than continental crust; not compatible with Wegener's timeline.
No evidence of path of drift	Movement directions unclear in early models.

Convectional Current Theory & Sea-Floor Spreading

Convectional Current Theory

Proposed by

- Arthur Holmes (1928) — British geologist.
- His theory provided the mechanism missing in Wegener's Continental Drift Theory.

Idea:

- Movement of continents is caused by convection currents operating in the mantle due to internal heat.
- Heat generated from radioactive decay inside the Earth causes cyclic movement of molten material in the asthenosphere (upper mantle).

Process

1. Hot material from deeper mantle → rises toward the crust.
2. It spreads horizontally beneath the lithosphere, dragging plates along.
3. As it cools, it sinks back down, creating a continuous convection loop.

These convection cells cause:

- Divergence (spreading) → where currents move apart → new crust forms.
- Convergence (collision) → where currents sink → crust subducts.

Significance

- Explained driving force behind continental drift.
- Formed basis for Plate Tectonic Theory (1960s).

Sea-Floor Spreading Theory

Proposed by

- Harry H. Hess (1962) — American geologist & naval officer.
- He used ocean-floor mapping (from sonar studies) during WWII to explain movement of oceanic crust.

- New oceanic crust is created at mid-ocean ridges by upwelling magma,
  and old crust moves away and sinks into trenches (subduction zones).
- This continuous creation and destruction of crust causes the sea floor to spread — pushing continents apart.

Process

1. Upwelling of magma from the mantle at mid-ocean ridges (e.g., Mid-Atlantic Ridge).
2. Magma solidifies → forms new basaltic crust.
3. The newly formed crust moves laterally away from the ridge → old crust pushed farther.
4. At ocean trenches, the older crust subducts into the mantle, melts, and recycles.

Evidences Supporting Sea-Floor Spreading

(A) Magnetic Stripes on Ocean Floor

- Basalt rocks record Earth's magnetic polarity when they cool.
- Alternating normal and reversed magnetic stripes on both sides of ridges show symmetric spreading pattern.

(B) Age of Ocean Floor

- Ocean floor youngest near mid-ocean ridges, and oldest near continental margins.

  - Eg: Rocks near Mid-Atlantic Ridge are <10 million years old, while near trenches >180 million years.

(C) Heat Flow

- Highest near ridges → magma upwelling;
  lowest near trenches → subduction zones.

(D) Earthquake & Volcanic Zones

- Earthquakes concentrated along ridges and trenches, confirming active crustal movement.

Consequences

- Explains movement of continents without "drifting through" oceans.
- Supports creation–destruction cycle of crust → dynamic Earth surface.
- Provided foundation for Plate Tectonic Theory (1968).

Plate Tectonic Theory

- Developed during the 1960s, combining ideas from Wegener (drift theory), Holmes (mantle convection), and Hess (seafloor spreading).
- Key contributors: Tuzo Wilson, Vine & Matthews, McKenzie & Parker.

Concept

- The Earth's lithosphere is divided into several large and small plates (rigid slabs).
- These plates float on the semi-molten asthenosphere and move due to convection currents in the mantle.
- Plate movements cause earthquakes, volcanoes, mountains, and ocean trenches — the dynamic face of Earth.

Composition of Plates

Each plate includes:

- Continental crust + Oceanic crust + upper mantle (rigid lithosphere).
- Below lies the Asthenosphere — a plastic, partially molten layer that allows plates to move.

Major Plates:

1. Pacific Plate
2. North American Plate
3. South American Plate
4. African Plate
5. Eurasian Plate
6. Indo-Australian Plate
7. Antarctic Plate

Minor Plates: Nazca, Philippine, Cocos, Arabian, Caribbean, etc.

Rate of Plate Movement

- Average movement: 2–5 cm/year, similar to fingernail growth!
- Fastest: Pacific Plate (~11 cm/yr)
- Slowest: Eurasian Plate (~2–3 cm/yr)

Types of Plate Boundaries

Based on relative movement between two plates:

Type	Direction of Movement	Main Landform	Example
Divergent (Constructive)	Plates move away from each other	Mid-ocean ridges, rift valleys	Mid-Atlantic Ridge, East African Rift
Convergent (Destructive)	Plates move toward each other	Mountains, trenches, volcanoes	Andes, Himalayas, Japan trench
Transform (Conservative)	Plates slide past each other horizontally	Fault lines, earthquakes	San Andreas Fault (California)

Divergent Boundaries (Constructive Margins)

- New crust forms as magma rises from the mantle and cools.
- Common at mid-ocean ridges and continental rift zones.

Types:

1. Ocean–Ocean Divergence: Mid-Atlantic Ridge.
2. Continent–Continent Divergence: East African Rift Valley.

Features:

- Mid-oceanic ridges, fissure eruptions, shallow earthquakes, volcanic islands.

Example: Iceland (on Mid-Atlantic Ridge).

Convergent Boundaries (Destructive Margins)

- Two plates move toward each other; one subducts beneath the other → crust destroyed.

Types:

1. Ocean–Continent Convergence:
    - Denser oceanic plate subducts beneath lighter continental plate.
    - Forms volcanic mountain chains & trenches.
    - Eg: Andes (Nazca + South American Plate).
2. Ocean–Ocean Convergence:
    - One oceanic plate subducts under another.
    - Forms island arcs & deep ocean trenches.
    - Eg: Mariana Trench, Japan Islands.
3. Continent–Continent Convergence:
    - No subduction → crust folds and thickens → Fold Mountains.
    - Eg: Himalayas (Indian + Eurasian Plate).

Features: Volcanic arcs, earthquakes, trenches, mountain ranges.

Transform Boundaries (Conservative Margins)

- Plates slide horizontally past each other.
- Crust neither created nor destroyed.
- Movement causes faulting and shallow earthquakes.
- Eg: San Andreas Fault (N. America), North Anatolian Fault (Turkey).

Feature: Intense seismic activity but no volcanism.

Volcanism

- Volcanism refers to the eruption of molten material (magma) from the Earth's interior to its surface through vents or fissures.
- The process includes formation of volcanoes, lava flows, gases, and pyroclastic materials.

Terms:

- Magma: Molten rock beneath the surface.
- Lava: Magma that reaches the surface.
- Vent: Opening through which magma erupts.
- Crater: Bowl-shaped depression at volcano's summit.
- Caldera: Large depression formed after explosive eruption or collapse of summit.

Causes of Volcanism

- Generated mainly by endogenic forces due to internal heat and pressure.
- Common at:
  - Divergent boundaries: Magma rises through rifts (e.g., Mid-Atlantic Ridge).
  - Convergent boundaries: Subducted plate melts (e.g., Andes).
  - Hotspots: Fixed mantle plumes beneath plates (e.g., Hawaii).

Classification of Volcanoes

(A) Based on Frequency of Eruption

Type	Description	Example
Active Volcano	Erupts frequently or recently; shows signs of activity (lava, smoke, gases).	Mount Etna (Italy), Kilauea (Hawaii), Stromboli (Italy)
Dormant	Has not erupted in recent times but	Vesuvius (Italy), Fujiyama

Type	Description	Example
Volcano	may erupt again.	(Japan), Krakatoa (Indonesia)
Extinct Volcano	No eruption for thousands of years; magma chamber solidified.	Kilimanjaro (Tanzania), Aconcagua (Andes)

(B) Based on Mode & Nature of Eruption

Type	Nature of Eruption	Characteristics	Example
Central Eruption	Magma erupts through a single vent	Cone-shaped mountain with crater	Mount Fuji, Vesuvius
Fissure Eruption	Magma comes out through cracks/fissures	Broad plateau of basaltic lava	Deccan Traps (India), Columbia Plateau (USA)
Explosive Eruption	Violent, gaseous, ejects ash & pyroclasts	Steep-sided cone, caldera formation	Mount St. Helens, Krakatoa
Quiet (Effusive) Eruption	Gentle lava flow, less gas	Broad, shield-like structure	Mauna Loa (Hawaii)

Types of Lava

Type	Description	Characteristics	Example
Basaltic Lava (Mafic)	Low silica (45–55%), high iron & magnesium	Very fluid, travels long distances, forms shield volcanoes	Deccan Traps, Hawaii
Andesitic Lava (Intermediate)	Moderate silica (55–65%)	Medium viscosity, moderate explosion	Andes, Philippines
Rhyolitic Lava (Felsic)	High silica (>70%), low iron & magnesium	Very viscous, traps gases → violent eruptions	Mount St. Helens, Japan

Volcanic Materials

- Lava: Molten rock.
- Pyroclasts: Ash, lapilli, volcanic bombs.
- Volcanic gases: Steam, CO_2, SO_2, H_2S.

Types of Volcanoes (by Shape and Structure)

Type	Formation	Characteristic	Example
Shield Volcano	Gentle lava outflows of basaltic type	Broad, dome-shaped, gentle slopes	Mauna Loa (Hawaii)
Composite (Strato) Volcano	Alternating layers of lava & ash	Steep slopes, explosive	Mount Fuji (Japan), Mount Etna
Cinder Cone Volcano	Ejected ash and cinders around vent	Small, steep, short-lived	Parícutin (Mexico)
Fissure Volcano	Lava through cracks, not a cone	Forms basaltic plateaus	Deccan Traps (India)
Caldera Volcano	Collapse after huge explosion	Large depression filled with water	Krakatoa, Yellowstone

Intrusive & Extrusive Volcanic Features

(A) Extrusive (Surface) Forms

Formed when magma reaches the surface and cools rapidly.

- Lava Cones: Form mountains (shield, composite, cinder).
- Lava Domes: Dome-shaped due to viscous lava.
- Basalt Plateaus: Broad areas formed by fissure eruptions (Deccan Traps).
- Calderas: Huge circular depressions after violent eruptions.
- Lava Plains & Flows: Gentle lava spread over wide areas.

(B) Intrusive (Subsurface) Forms

Formed when magma solidifies below surface.

Type	Shape/Feature	Example
Batholith	Largest irregular intrusive mass; deep-seated	Sierra Nevada (USA), Nilgiri (India)
Laccolith	Dome-shaped intrusion between layers	Henry Mountains (USA)
Lopolith	Saucer-shaped, depressed intrusion	Bushveld (South Africa)
Sill	Horizontal sheet-like intrusion	Great Whin Sill (England)
Dyke	Vertical wall-like intrusion cutting across strata	Deccan region (India)
Phacolith	Lens-shaped intrusion in folded regions	European Alps

Distribution of Volcanoes (World)

- Pacific Ring of Fire: Most active — 70% of world's volcanoes (Japan, Indonesia, Andes, Alaska).
- Mid-Atlantic Ridge: Divergent boundary volcanoes (Iceland).
- Mediterranean Belt: Convergent zones (Italy, Greece, Turkey).
- Intraplate Volcanoes (Hotspots): Hawaii, Yellowstone.

Volcanic Landforms & Distribution

Intrusive Volcanic Landforms (Plutonic Forms)

These are formed when magma solidifies beneath the Earth's surface, cooling slowly to form crystalline igneous rocks.
They are later exposed due to erosion or uplift.

Feature	Description	Shape & Formation	Example
Batholith	Largest intrusive body, irregular in shape, deep-seated	Roots of major mountain systems; forms the core of fold mountains	Sierra Nevada (USA), Nilgiri Hills (India)
Laccolith	Dome-shaped intrusion between sedimentary layers	Magma pushes overlying strata upward like a blister	Henry Mountains (USA)
Lopolith	Saucer-shaped (concave upward) intrusion	Magma collects in a basin-shaped cavity	Bushveld Complex (South Africa)
Phacolith	Lens-shaped intrusion in folded mountain regions	Occupies crests of anticlines or troughs of synclines	Alps, Scotland
Sill	Flat, sheet-like layer between rock strata	Magma injected horizontally and solidifies	Great Whin Sill (England)
Dyke	Vertical or steeply inclined wall-like body cutting across layers	Magma forced upward through cracks	Deccan Region (India)

Composite Volcano (Strato Volcano)

- Formed by alternating eruptions of lava and ash/pyroclastic material.
- Steep-sided, conical mountains → made of layers (strata).
- Lava often andesitic or rhyolitic (viscous, gas-rich).

- Highly explosive due to trapped gases and high silica content.

Examples:

- Mount Fuji (Japan)
- Mount Etna & Vesuvius (Italy)
- Mount St. Helens (USA)

Features:

- Central vent + secondary cones.
- Alternating lava + ash layers.
- Violent eruptions, ash clouds, pyroclastic flows.

Distribution of Volcanoes (World)

Volcanoes are not randomly distributed — they align with plate boundaries.

(A) Pacific Ring of Fire

- Most active volcanic belt — accounts for ~70% of world's volcanoes.
- Due to subduction zones around Pacific Plate.
- Countries: Japan, Philippines, Indonesia, New Zealand, Chile, Alaska, Mexico, USA (West Coast).

(B) Mid-Atlantic Ridge (Divergent Zone)

- Magma upwells along ridge → forms fissure volcanoes & islands.
- Examples: Iceland, Azores, Ascension Island.

(C) Mediterranean Belt (Alpine Belt)

- Along convergent boundary between African & Eurasian Plates.
- Examples: Etna, Vesuvius (Italy), Santorini (Greece).

(D) Intraplate (Hotspot) Volcanoes

- Occur away from plate boundaries, over mantle plumes.
- Examples: Hawaii, Yellowstone (USA), Reunion (Indian Ocean).

Thermal Features Related to Volcanism

These are secondary volcanic phenomena, occurring in areas of residual subterranean heat.

(A) Hot Springs

- Groundwater seeps deep into the Earth, gets heated by hot rocks/magma, and rises back to surface through cracks.
- Water temperature often above 50°C.
- Dissolves minerals → forms colored deposits.

Examples:

- Manikaran (Himachal Pradesh), Taptapani (Odisha), Iceland, New Zealand.

Use: Medicinal baths, geothermal energy.

(B) Geysers

- A special type of hot spring that erupts intermittently, ejecting jets of steam and boiling water.
- Occurs where underground water is trapped in chambers over hot rocks → pressure builds → sudden release.

Mechanism:

1. Water heated below → builds steam pressure.
2. Steam forces water upward → eruption.
3. Repeats periodically.

Examples:

- Old Faithful (Yellowstone, USA)
- Iceland, New Zealand, Kamchatka (Russia)

Difference:

Feature	Hot Spring	Geyser
Flow	Continuous	Intermittent eruption
Pressure	Low	High
Example	Taptapani (India)	Yellowstone (USA)

Earthquake

- A sudden shaking or vibration of the Earth's surface caused by the release of energy from the Earth's crust.
- The energy is released in the form of seismic waves that travel in all directions.
- Usually caused by tectonic movements along fault lines, but can also occur due to volcanic activity, explosions, or collapse of underground cavities.

Terms

Term	Description
Focus (Hypocenter)	The point inside the Earth where energy is first released. Origin of earthquake waves.
Epicenter	The point directly above the focus on the Earth's surface. It experiences the maximum shaking.
Seismic Waves	Vibrations that travel outward from the focus through the Earth.
Isoseismal Line (Isoseismic Line)	Imaginary lines joining places that experience equal intensity of shaking or damage.
Seismograph / Seismometer	Instrument that records earthquake waves.
Seismogram	Graphical record of the seismic waves.

Measurement Scales

Scale	Measures	Points
Richter Scale (1935)	Magnitude (energy released)	1 to 10 scale; quantitative; instrument-based
Mercalli Scale (Modified)	Intensity (damage caused)	Based on observation; varies by location

Causes of Earthquake

1. Tectonic Movements → Most common; due to plate collision or subduction.
2. Volcanic Activity → Associated with eruptions.
3. Collapse Earthquakes → Due to underground cavity collapse (mining).
4. Human-induced → Reservoir filling, nuclear testing, etc.

Seismic Waves

Earthquake energy travels as seismic waves in all directions from the focus.

Types of Seismic Waves

1. Body Waves → Travel through the Earth's interior.
2. Surface Waves → Travel along the Earth's surface.

(A) Body Waves

Two types: P-waves (Primary) and S-waves (Secondary)

Type	Nature	Medium	Speed	Characteristics
P-Waves (Primary)	Longitudinal / Compressional	Travel through solids, liquids & gases	Fastest (~6–8 km/s)	Push-pull movement (like sound waves); first to arrive.
S-Waves (Secondary)	Transverse / Shear	Travel only through solids	Slower (~3–5 km/s)	Move perpendicular to direction of travel; cause more shaking.

Note:
S-waves do not pass through liquid outer core, confirming its fluid nature.

(B) Surface Waves

Generated when P and S waves reach the surface.
Most destructive → cause majority of damage.

Type	Movement	Effect	Speed
Love Waves	Side-to-side, horizontal	Cause severe shaking of ground and buildings	Slightly slower than S-waves
Rayleigh Waves	Rolling motion (like sea waves)	Cause vertical + horizontal displacement	Slowest of all

Order of Arrival:
P → S → Love → Rayleigh

Shadow Zones

- Certain areas on Earth's surface receive no direct seismic waves.
- Caused by refraction or blockage of waves as they pass through layers.

Wave Type	Shadow Zone	Reason
P-Waves	Between 103°–142° from epicenter	Refraction due to liquid outer core
S-Waves	Beyond 103°	Cannot pass through liquid outer core

Earthquake Zones in India

As per Bureau of Indian Standards (BIS, 2002):
India is divided into 4 Seismic Zones (Zone II–V).

Zone	Level of Risk	Examples
Zone V	Very High	Kashmir, Himachal, Northeast, Bihar-Nepal border, Andamans
Zone IV	High	Delhi, Haryana, Punjab, Uttarakhand, Gujarat
Zone III	Moderate	Kerala, Tamil Nadu, parts of Maharashtra, Rajasthan
Zone II	Low	Peninsular India, Deccan plateau

Denudation & Weathering

Denudation

- Denudation means the wearing down and leveling of the Earth's surface by natural agents.
- It includes four major processes:

Process	Description
Weathering	Disintegration and decomposition of rocks *in situ* (no movement).
Erosion	Wearing away and removal of rock particles by moving agents (water, wind, ice).
Transportation	Movement of eroded materials by these agents.
Deposition	Laying down of transported materials to form new landforms.

➢ Denudation = Weathering + Erosion + Transportation + Deposition.

Weathering

- Weathering is the breaking down of rocks at or near the Earth's surface by atmospheric or biological agents without transportation.
- It is a static (on-site) process — first step of denudation.

Types of Weathering

Broadly Classified into:

1. Physical (Mechanical) Weathering
2. Chemical Weathering
3. Biological Weathering

Chemical Weathering

- Involves chemical alteration of rock minerals due to reactions with water, oxygen, CO_2, and acids.
- Changes the composition of rocks → forms new minerals or soluble materials.
- Dominant in humid, hot climates.

Main Types of Chemical Weathering

Type	Process	Example / Effect
Solution	Water dissolves soluble minerals (e.g., rock salt, limestone).	Caves in limestone → *Karst Topography.*
Oxidation	Oxygen reacts with minerals (especially iron) forming oxides.	Iron → Rust (reddish-brown). Eg: Laterite soils.
Carbonation	CO_2 in rainwater forms weak carbonic acid → dissolves calcium carbonate.	Limestone caves, sinkholes.
Hydration	Minerals absorb water, swell and expand, causing disintegration.	Feldspar → Kaolin (clay).
Hydrolysis	Chemical reaction between minerals and water → new soft compounds.	Feldspar → Kaolinite (in granite).

Physical (Mechanical) Weathering

- The breakdown of rocks into smaller fragments without any chemical change.
- Caused by temperature changes, pressure release, frost, or crystal growth.
- Dominant in arid or cold climates with temperature extremes.

Main Types of Physical Weathering

Type	Process	Example / Effect
Block Disintegration	Rocks with joints crack due to temperature fluctuations or pressure release.	Common in granitic rocks of arid regions.
Exfoliation (Onion Peeling)	Outer rock layers peel off due to thermal expansion or pressure release.	Domes in granite (e.g., Mahabalipuram, India).
Frost Action (Freeze–Thaw)	Water enters cracks, freezes → expands (9%) → widens cracks.	Found in temperate & glacial regions.
Granular Disintegration	Different minerals expand/contract differently with heat → rock crumbles.	Common in coarse-grained rocks (granite).
Salt Weathering (Haloclasty)	Salt crystals grow in pores (due to evaporation), exert pressure → break rocks.	Arid & coastal regions.

Mass Movement, Groundwater & Coral Reefs

Mass Movement (Mass Wasting)

- The downward movement of weathered rock debris and soil under the influence of gravity, without the aid of any transporting agent (like water, wind, etc.).
- It acts as a link between weathering and erosion.
- Controlled by:
  - Slope angle
  - Gravity
  - Water content
  - Nature of material
  - Vegetation cover
  - Earthquake & human activity

Types of Mass Movement

Broadly divided into two types based on speed and moisture content:

Type	Nature	Description	Example
A. Slow Movements	Gradual, long-term	Occur imperceptibly; materials move slowly downslope.	Soil Creep, Solifluction
B. Rapid Movements	Sudden, short-term	Fast movement of material; often triggered by rain, quake.	Landslide, Rockfall, Mudflow, Debris flow

(A) Slow Movements

1. Soil Creep:
    - Very slow, imperceptible downslope movement of soil due to expansion-contraction from temperature, frost, or moisture.
    - Evident by tilted fences, bent trees, cracked roads.
    - Common in humid & temperate slopes.
2. Solifluction:
    - Occurs in periglacial regions (frozen subsoil).
    - Top soil thaws and moves slowly over frozen ground.

(B) Rapid Movements

1. Landslide:
    - Sudden slipping of large rock/soil masses down steep slopes.
    - Triggered by heavy rainfall, earthquakes, deforestation, or mining.
    - Common in Himalayas, Western Ghats, NE India.
2. Rockfall:
    - Free fall of rock blocks from cliffs due to gravity.
    - Common in steep, jointed mountain faces.
3. Debris Flow / Mudflow:
    - Rapid flow of water-saturated soil & debris.
    - Common during heavy rains on steep slopes.
4. Slump:
    - Downward & outward movement of rock mass along curved surface → rotational slip.

Groundwater

(A) Water Table

- The upper surface of the zone of saturation, below which all soil pores and rock spaces are filled with water.
- Lies between Zone of Aeration (unsaturated) and Zone of Saturation (saturated).
- Fluctuates with rainfall, topography, and human usage.
- Shallow in plains, deep in arid or hilly regions.

(B) Springs

- A natural outflow of groundwater to the surface when the water table meets the ground.
- Occurs where an impermeable layer forces groundwater to emerge along slopes, valleys, or faults.

Types of Springs:

Type	Description	Example
Gravity Spring	Water emerges due to gravity where water table intersects slope.	Himalayan foothills.
Artesian Spring	Under pressure between two impermeable layers; rises naturally.	Rajasthan, Great Artesian Basin (Australia).
Thermal Spring	Heated by geothermal activity; high temperature.	Manikaran (HP), Taptapani (Odisha).

☐ All hot springs & geysers are linked with volcanic/geothermal zones.

Coral Reefs

- Coral reefs are marine structures made by calcium carbonate skeletons secreted by tiny marine animals called coral polyps (Cnidarians).
- Found in shallow, warm, tropical seas (20°N–20°S).
- Thrive in clean, well-aerated saline water (20–27°C) and sunlight (for symbiotic algae "zooxanthellae").

Types of Coral Reefs (Darwin's Classification)

Type	Formation	Description	Example
Fringing Reef	Develops directly along coastlines	Attached to shore; separated by shallow lagoon	Gulf of Mannar (India), Red Sea
Barrier Reef	Parallel to coast, separated by deep	Outer edge grows faster → reef detaches	Great Barrier Reef (Australia), New

Type	Formation	Description	Example
	lagoon	from shore	Caledonia
Atoll	Circular reef enclosing lagoon	Formed over submerged volcanic island	Lakshadweep (India), Maldives, Marshall Islands

Ideal Conditions for Coral Growth

- Temperature: 20–27°C
- Depth: ≤ 50 m (shallow)
- Salinity: Normal (27–35‰)
- Sunlight: Needed for photosynthesis by algae
- Sediment-free, clean water

Landforms Created by Running Water (Fluvial Landforms)

Fluvial Processes

- "Fluvial" = related to rivers and streams.
- Running water shapes the Earth's surface through:
    1. Erosion → Wearing away of land.
    2. Transportation → Movement of sediments.
    3. Deposition → Laying down of sediments when velocity decreases.

These processes vary according to stage of river development — *Youth → Maturity → Old Age.*

Stages of River Landform Development

Stage	Dominant Process	Main Landforms	Example (India)
Youth Stage	Vertical erosion (downcutting)	V-shaped valleys, waterfalls, gorges	Upper Ganga, Brahmaputra
Mature Stage	Lateral erosion & deposition	Meanders, floodplains, oxbow lakes	Middle Ganga
Old Stage	Deposition dominant	Deltas, levees, braided channels	Lower Ganga, Mahanadi delta

Erosional Landforms by Rivers

Running water erodes by hydraulic action, abrasion, attrition, and corrosion (solution).

(A) V-Shaped Valley

- Formed by vertical erosion in youthful stage.

- Valley sides steep and narrow → resembles "V."
- Examples: Headstreams of Ganga, Yamuna, and Brahmaputra.

(B) Gorge

- Deep, narrow valley with steep vertical sides.
- Caused by rapid downcutting of river.
- Common in hard rocks or tectonic uplift zones.
- Example: Indus Gorge (Ladakh), Brahmaputra Gorge near Assam-Arunachal border.

(C) Canyon

- Similar to gorge but wider at the top due to weathering and side erosion.
- Found in arid regions.
- Example: Grand Canyon (USA).

(D) Waterfall

- Sudden fall of river water from a height due to change in gradient or hard–soft rock layers.
- Formed by differential erosion or faulting.
- Examples:
  - Jog Falls (Sharavathi River, Karnataka)
  - Hundru Falls (Subarnarekha, Jharkhand)
  - Niagara (Canada–USA).

(E) Rapids

- Series of small falls caused by uneven rock resistance along riverbed.
- Found in upper course (e.g., Himalayan Rivers).

(F) Potholes

- Circular depressions on riverbed formed by abrasion of pebbles in whirlpools.

- Common in rocky beds of youthful rivers.

(G) Plunge Pool

- Deep hollow formed at the base of waterfalls by falling water's impact and rock fragments.

Depositional Landforms by Rivers

When river velocity decreases (in gentle slopes or plains), sediment is deposited, forming depositional features.

(A) Alluvial Fan

- Cone-shaped deposit where a river descends from a mountain onto a plain.
- Example: Kosi River fans in North Bihar.

(B) Floodplain

- Flat valley floor formed by lateral erosion and deposition during floods.
- Composed of fine alluvium → fertile.
- Example: Indo-Gangetic plains.

(C) Natural Levee

- Raised embankment formed along riverbanks during floods as heavier sediments settle first.
- Protects surrounding land from minor flooding.

(D) Meander

- Curved or sinuous bends formed by lateral erosion on outer banks & deposition on inner banks.
- Common in middle course.
- Eventually leads to oxbow lake formation.

(E) Oxbow Lake

- Formed when a meander loop is cut off due to river erosion and deposition.
- Crescent-shaped water body remains separated.
- Example: Found along Ganga, Brahmaputra, Mahanadi plains.

(F) Braided Channel

- River splits into many channels separated by sand/gravel bars due to excess load.
- Common in Himalayan rivers (e.g., Brahmaputra).

(G) Delta

- Triangular depositional feature formed at river mouth where it meets a sea or lake.
- Formed due to sediment accumulation > removal rate by tides/currents.

Types of Deltas:

Type	Description	Example
Arcuate Delta	Fan-shaped, smooth coastline	Ganga–Brahmaputra
Bird’s Foot Delta	Finger-like projections	Mississippi River (USA)
Estuarine Delta	River enters sea through estuary	Narmada, Tapti
Cuspate Delta	Pointed/arc-shaped	Tiber (Italy)

(H) Point Bar (Meander Bar)

- Sandy deposits on inner bends of meanders due to slower current.

(I) Alluvial Terrace

- Step-like terraces formed along valley sides due to periodic changes in river level.

Landforms Created by Glaciers

- A glacier is a large mass of moving ice formed by the compaction and recrystallization of snow.
- Acts as a powerful agent of erosion, transportation, and deposition.

Types of Glaciers:

Type	Description	Example
Continental Glacier	Huge ice sheets covering large land areas	Antarctica, Greenland
Valley (Mountain) Glacier	Confined to mountain valleys	Gangotri (India), Alps, Himalayas
Piedmont Glacier	Where valley glaciers merge at foothills	Alaska
Cirque Glacier	Occupies a bowl-shaped hollow on mountains	Swiss Alps
Tidewater Glacier	Flows into the sea forming icebergs	Alaska, Greenland

Glacial Erosion Processes

Process	Description
Plucking (Quarrying)	Glacier freezes onto rock fragments and pulls them away during movement.
Abrasion	Rock debris embedded in ice grinds and polishes the underlying rock surface.
Frost Shattering	Freezing and expansion of water in cracks cause rock disintegration.
Subglacial Meltwater Erosion	Running water below glacier erodes channels and tunnels.

Erosional Landforms by Glaciers

(A) Cirque (Corrie or Cwm)

- Bowl-shaped hollow at the glacier's head formed by plucking and frost action.
- Often contains a small lake called a Tarn after glacier melts.
- Example: Kashmir Himalayas, Swiss Alps.

(B) Arête

- Sharp, narrow ridge between two cirques or glacial valleys.
- Formed when two glaciers erode parallel valleys.
- Example: Hornli Ridge (Matterhorn).

(C) Pyramidal Peak (Horn)

- Sharp-pointed mountain peak formed where three or more cirques erode towards each other.
- Example: Matterhorn (Alps), Trisul (Himalayas).

(D) U-Shaped Valley (Glacial Trough)

- Steep-sided, flat-floored valley formed by glacier deepening and widening a pre-existing river valley.
- Example: Alaknanda Valley (Himalayas), Rhine Valley (Europe).

(E) Hanging Valley

- Small tributary glacier valleys hanging above the main valley; form waterfalls when ice melts.
- Example: Yosemite National Park (USA).

(F) Roche Moutonnée

- Asymmetrical rock hill with smooth upstream (stoss) and rough downstream (lee) side due to plucking and abrasion.

- Example: Lake District (England).

(G) Truncated Spurs

- Interlocking spurs cut off by glacier erosion → steep triangular faces.

(H) Fiords (Fjords)

- Drowned U-shaped valleys formed where glaciers meet the sea.
- Common in Norway, Alaska, New Zealand.

Depositional Landforms by Glaciers

When glaciers melt, they deposit unsorted debris called glacial till or drift. Deposition occurs by ice itself or meltwater streams.

(A) Moraine

- Accumulation of unsorted rock debris (till) carried by glaciers.

Type	Description	Example
Lateral Moraine	Along glacier sides	Valley margins of Himalayas
Medial Moraine	Between two merging glaciers	Alps
Terminal Moraine	At the glacier's snout, marking its farthest advance	Alaska
Ground Moraine	Irregular layer beneath the glacier	Canadian Shield

(B) Drumlin

- Smooth, elongated hill of glacial till with steep stoss and gentle lee slope.
- Formed under moving ice → indicates glacier movement direction.

- Example: Ireland, Northern USA.

(C) Eskers

- Long, winding ridge of sand and gravel deposited by meltwater streams flowing beneath glaciers.
- Example: Finland, Canada.

(D) Kames

- Irregular mounds of sand and gravel deposited by meltwater in depressions on glacier surface.

(E) Outwash Plain (Sandur)

- Broad flat area formed by glacial meltwater depositing sorted materials beyond the glacier snout.
- Example: Iceland, Alaska.

(F) Erratics

- Large rock boulders transported and deposited far from their origin.
- Example: Canada, Northern Europe.

(G) Kettle Lake

- Depressions formed when detached ice blocks get buried in till and later melt.
- Found in glaciated plains (USA, Canada).

Desert (Aeolian) Landforms

Desert / Aeolian Processes

- Desert (Arid Region):
  Area with low rainfall (<25 cm), high temperature, strong winds, and scarce vegetation.
- Aeolian Process:
  All geomorphic processes and landforms produced by wind action in deserts.
- Main agents: Erosion, Transportation, and Deposition by wind.

Wind Erosion Processes

Process	Description
Deflation	Lifting and removal of loose sand, silt, and dust by wind. Creates hollows and depressions.
Abrasion (Corrasion)	Mechanical scraping of rock surfaces by wind-driven sand particles. Polishes and shapes rocks.
Attrition	Sand grains collide with each other → rounded, finer particles.

Erosional Landforms Created by Wind

Landform	Description	Example / Region
Deflation Hollow	Depression formed due to wind removing loose materials. If deep, can reach water table → Playa / Pan.	Qattara Depression (Egypt), Rajasthan.
Mushroom Rock (Rock Pedestal)	Rock shaped like a mushroom — narrow stem, broad top — formed by abrasion near base where sand impact is strongest.	Western Rajasthan, Sahara.
Yardang	Long, narrow ridges separated by	Egypt, Iran,

Landform	Description	Example / Region
	troughs formed by parallel wind erosion on soft & hard rock layers.	Ladakh Cold Desert.
Zeugen	Table-like ridges formed by horizontal abrasion of soft rock layers beneath hard strata.	Sahara Desert.
Ventifacts	Individual stones polished, grooved, or faceted by sandblasting wind.	Thar Desert, Sahara.
Inselberg	Isolated residual hill rising abruptly from plains due to prolonged wind erosion.	Mt. Uluru (Australia), Rajasthan.
Pediment & Bajada	Gently sloping rock surface at base of hills due to retreat of slopes; coalescing pediments form Bajada.	At foothills of Aravalli, USA deserts.

Depositional Landforms Created by Wind

When wind loses energy, it deposits sand and dust — forming dunes and loess plains.

Landform	Formation & Features	Example / Region
(A) Sand Dunes	Hills/ridges of sand formed by wind deposition. Shape & size depend on wind direction, sand supply, and obstacles.	Thar, Sahara, Kalahari
Barchan (Crescent-shaped)	Formed by unidirectional wind; horns point downwind; gentle windward slope, steep leeward slope.	Sahara, Thar.
Seif Dune (Longitudinal)	Long, narrow ridges parallel to prevailing wind; alternating ridges and troughs.	Sahara, Rajasthan.
Transverse Dune	Formed perpendicular to wind direction in areas with abundant sand.	Sahara.
Parabolic Dune	Crescentic but horns point upwind,	Coastal deserts

Landform	Formation & Features	Example / Region
	stabilized by vegetation.	(Namibia).
Star Dune	Pyramid-like dune formed by multi-directional winds.	Rub' al Khali (Arabia).
Dome Dune	Oval, gentle dome shape — rare, form in light wind conditions.	Sahara.

Landform	Formation	Example
Loess Deposits	Fine silt & dust carried by wind from deserts and deposited in thick blankets far away.	Northern China (Loess Plateau), Europe.
Dune Field / Erg	Vast area covered by sand dunes — typical desert landscape.	Sahara, Thar Desert.
Playa / Pan	Shallow depression where water evaporates leaving salt/silt crust.	Rann of Kachchh, Qattara (Egypt).

Coastal (Marine) Landforms

Marine Processes

- Main Agent: Sea waves — erode, transport, and deposit sediments along coasts.
- Secondary Agents: Tides, ocean currents, and wind.
- Major Processes:
  - Erosion: Wearing away of coast by hydraulic action, abrasion, corrosion, attrition.
  - Deposition: Sediment accumulation when wave energy decreases.

Coastal landforms depend on rock type, tide range, wave energy, and tectonic setting (emergent/submergent coast).

Erosional Landforms by Sea Waves

Landform	Formation Process	Features
Sea Cliff	Hydraulic action and abrasion at base of coastal rocks	Steep rock face rising almost vertically from sea; wave undercutting forms notches
Wave-Cut Platform	Continued cliff retreat leaves flat, gently sloping surface at sea level	Formed between high and low tide marks
Sea Cave	Differential erosion of weaker rocks at cliff base	Hollow cavity formed by waves
Sea Arch	Continued erosion of caves from both sides of a headland → meet to form an arch	Example of marine erosion through a headland
Sea Stack	Collapse of roof of sea arch → isolated pillar of rock remains	Further eroded into stumps
Blow Hole	Vertical shaft formed when roof of sea cave collapses;	“Marine geyser” effect

Landform	Formation Process	Features
	sprays water upward	
Headland & Bay	Alternate erosion of hard & soft rocks	Hard rock = headland (projects), soft rock = bay (recessed)

Depositional Landforms by Sea Waves

When wave energy decreases (in sheltered coasts or during low tide), sediments are deposited forming various depositional features.

Landform	Formation / Feature
(A) Beach	Accumulation of sand, pebbles, shells along coast; formed by longshore drift
(B) Spit	Narrow ridge of sand or shingle projecting into sea; formed by longshore currents
(C) Bar	Ridge of sand parallel to coast, sometimes enclosing a lagoon
(D) Tombolo	Sandbar connecting an island to mainland
(E) Lagoon	Shallow water body separated from sea by sandbar/spit
(F) Dune Coast / Beach Ridge	Wind-modified beach deposits forming sandy ridges
(G) Delta	Depositional feature at river mouth where sediment accumulates faster than removal

Types of Coasts (by Formation)

Type	Description	Example
Emergent Coast	Land uplifted or sea level falls → new land exposed	Raised beaches of Scotland, West coast of India
Submergent Coast	Land submerged or sea level rises → drowned valleys	Ria coasts (Konkans), Fjord coasts (Norway)

Marine Erosion Processes

Process	Description
Hydraulic Action	Force of wave pressure breaks rock.
Abrasion / Corrasion	Sand & pebbles grind rock surfaces.
Attrition	Particles collide & become rounded.
Corrosion / Solution	Seawater dissolves soluble rocks like limestone.

Karst Topography

- "Karst" = term derived from Kras plateau (Slovenia), where such features were first studied.
- Formed on soluble rocks — mainly limestone, sometimes dolomite or gypsum.
- Developed due to chemical weathering by carbonation and solution.

Conditions Required:

- Thick limestone bed ($CaCO_3$-rich).
- Presence of joints, cracks, and fissures for water movement.
- Humid climate with abundant rainfall.
- Subsurface drainage system (since limestone is permeable).

Agent of erosion: Carbonic acid in rainwater → dissolves $CaCO_3$ → forms cavities and underground drainage.

Surface (Erosional) Karst Landforms

Landform	Description	Example
Lapies (Lapiaz)	Small ridges and grooves on limestone surface due to solution along joints.	France, Slovenia
Sinkhole (Swallow Hole / Dolina)	Funnel-shaped depression formed by collapse of underground cavity or direct dissolution.	Found in Meghalaya, Bosnia, Florida
Doline	Broader version of sinkhole; circular depression where surface water disappears underground.	Yunnan (China), Slovenia
Uvala	Several dolines coalesce to form an elongated depression.	Dinaric Alps (Europe)
Polje (Karst Valley)	Large, flat-floored depression with steep sides formed by joining of several uvalas; often with seasonal	Livanjsko Polje (Bosnia), Croatia

Landform	Description	Example
	lakes.	
Swallow Hole / Ponor	Opening through which surface stream disappears underground.	Slovenia, Meghalaya
Karst Tower (Mogote / Cockpit Karst)	Residual limestone hills left standing due to differential solution.	Guilin (China), Ha Long Bay (Vietnam), Meghalaya (India)

Underground (Subsurface) Karst Landforms

Formed by continuous solution, erosion, and redeposition of calcium carbonate in caves.

Landform	Formation
Cave (Cavern)	Solution along joints enlarges underground passages → caves form.
Stalactite	Icicle-shaped deposit hanging from roof; formed by dripping calcium carbonate solution.
Stalagmite	Rises from cave floor, formed by deposition from water drops.
Column / Pillar	Formed when stalactite and stalagmite join.
Flowstone	Sheet-like $CaCO_3$ deposit on cave walls/floors from flowing water.

Karst Drainage Features

- Disappearing (Losing) Streams: Rivers that vanish into swallow holes.
- Resurgent (Reappearing) Streams: Re-emerge at lower elevation as springs.
- Blind Valleys: Valleys where river suddenly disappears underground.

Soil: Formation, Classification & Conservation

- The upper weathered layer of the Earth's crust that supports plant growth.
- Mixture of minerals, organic matter (humus), water, and air.
- Interface between lithosphere, atmosphere, hydrosphere, and biosphere.

Soil Formation (Pedogenesis)

Two Main Stages:

1. Weathering of rocks → produces mineral matter.
2. Addition of organic material → by plants, animals, microorganisms.

Factors Affecting Soil Formation (5 Classic Factors)

Factor	Role
Climate	Temperature & rainfall control weathering, leaching, and humus content.
Living Organisms	Plants add humus; microorganisms decompose matter.
Relief (Topography)	Slope affects drainage & erosion — flat = deep soil; steep = thin soil.
Parent Rock (Material)	Determines mineral composition, texture, color (e.g., basalt → black soil).
Time	More time → more mature soil with well-developed horizons.

Soil Profile (Layers of Soil)

☐ Typical vertical section of soil showing distinct layers:

Horizon	Description
O – Organic Horizon	Upper layer of organic matter (leaves, humus).
A – Topsoil	Rich in humus and minerals; supports most plant roots.
B – Subsoil	Accumulated minerals (iron, clay, salts) from above.
C – Parent Material	Weathered rock fragments.
R – Bedrock	Unweathered solid rock beneath.

Soil Classification in India

India has 8 major soil types (as per ICAR classification).

Soil Type	Formation / Region	Key Features	Crops
Alluvial Soil	Formed by rivers; Indo-Gangetic plains, deltas	Fertile, rich in potash & lime; low in N	Rice, wheat, sugarcane
Black Soil (Regur)	From basalt; Deccan plateau (MP, MH, Gujarat)	Clayey, moisture-retentive, rich in iron & lime; poor in P	Cotton (Black Cotton Soil), soybean
Red Soil	From crystalline rocks (granite, gneiss); Tamil Nadu, Odisha, Jharkhand	Rich in iron (reddish), poor in N, P, humus	Millets, pulses, groundnut
Laterite Soil	In high rainfall + temperature; Western Ghats, NE India	Leached, rich in iron/aluminium, poor in fertility	Tea, coffee, cashew (after manuring)
Arid (Desert) Soil	Rajasthan, Gujarat	Sandy, saline, poor in humus, alkaline	Barley, bajra (with irrigation)
Mountain Soil	Himalayan slopes	Thin, immature, varies with altitude	Tea, apples, spices

Soil Type	Formation / Region	Key Features	Crops
Peaty & Marshy Soil	Humid, waterlogged areas (Kerala, Sunderbans)	High humus & moisture; acidic	Paddy, jute
Saline & Alkaline Soil	Poor drainage areas (UP, Punjab, Gujarat)	Contains Na, Mg salts; infertility common	Can be reclaimed by gypsum or leaching

Soil Erosion

- Removal of topsoil by wind, water, or human activity.

Type	Cause	Example
Sheet Erosion	Uniform removal of thin topsoil layer	Ganga Plains
Rill Erosion	Formation of small channels by running water	Foothills
Gully Erosion	Deep cuts forming ravines	Chambal Valley
Wind Erosion	Removal of dry soil by wind	Thar Desert

Soil Conservation Measures

Method	Description
Contour Ploughing	Ploughing along contour lines → reduces runoff.
Terrace Farming	Step-like terraces on hills → slows water flow.
Strip Cropping	Alternating strips of crops reduce erosion by wind/water.
Afforestation	Planting trees → binds soil with roots.
Shelterbelts / Windbreaks	Rows of trees reduce wind speed in dry areas.
Check Dams & Bunding	Control gully/rill formation and store runoff.
Mulching	Covering soil with leaves/straw to retain moisture.

Important Terms

Term	Meaning
Leaching	Downward removal of soluble nutrients by rainwater.
Laterisation	Formation of laterite soil due to leaching of silica.
Podzolisation	Formation of acidic soils under cold, wet climates.
Salinisation	Salt accumulation on surface due to evaporation.
Soil Fertility	Ability of soil to supply nutrients for plant growth.

Oceanography

Relief of the Ocean Floor

The ocean floor has four major divisions, formed by tectonic and depositional processes.

Division	Description	Features / Example
Continental Shelf	Submerged extension of continent, gentle slope (avg. depth: 150–200 m)	Shallowest part of ocean; rich in oil, gas, fisheries; e.g., North Sea, Bay of Bengal Shelf
Continental Slope	Steep slope beyond shelf; connects continental crust to oceanic crust (depth: 200–3000 m)	Marked by submarine canyons; major sediment transport zone
Deep Sea Plain (Abyssal Plain)	Flat, deep ocean floor (avg. depth: 3000–6000 m)	Covered with fine sediments; flattest area on Earth
Oceanic Ridge / Rise	Submarine mountain chain formed by plate divergence	Mid-Atlantic Ridge, East Pacific Rise, Carlsberg Ridge (Indian Ocean)

Submarine Canyons

- Deep, narrow, V-shaped valleys cutting across continental shelf and slope.
- Formed by turbidity currents or ancient river valleys drowned by sea.
- Examples:
  - Hudson Canyon (Atlantic)
  - Indus & Ganga Canyons (Arabian Sea, Bay of Bengal)

Oceanic Ridges and Trenches

Feature	Description	Example
Mid-Oceanic Ridge	Long, continuous mountain system formed by divergence and magma upwelling	Mid-Atlantic Ridge, Indian Ocean Ridge
Ocean Trench	Deep, narrow depression formed at convergent plate boundaries (subduction zones)	Mariana (deepest, 11,034 m), Sunda, Peru–Chile

Ocean Deposits

Material accumulated on ocean floor by erosion, precipitation, and biological processes.

Types of Ocean Deposits:

Type	Composition
Terrigenous	Sand, silt, clay; from land erosion via rivers/wind
Pelagic	Fine-grained ooze from microscopic marine organisms
Biogenous	From remains of marine organisms ($CaCO_3$, silica)
Hydrogenous (Chemical)	Precipitated directly from seawater

Salinity of Ocean Water

- Salinity: Amount of dissolved salts (mainly NaCl) in seawater.
- Measured in parts per thousand (ppt or ‰).
- Average salinity: 35‰ (35 g salt per kg of seawater).

Distribution & Variation:

Region	Characteristic	Reason
Equator (34–35‰)	Slightly low	Heavy rainfall, river input, low evaporation
Subtropics (30°–35°)	Highest (37‰)	High evaporation, less rainfall
Polar regions (<30‰)	Low	Melting ice & low evaporation

Highest salinity: Red Sea, Persian Gulf.
Lowest salinity: Baltic Sea, Arctic Ocean.

Factors Affecting Salinity:

1. Evaporation → Increases salinity.
2. Precipitation → Decreases salinity.
3. River inflow → Lowers salinity near coasts.
4. Temperature & Ice melting → Affect density & salinity.
5. Ocean currents → Mix saline & fresh waters.

Temperature of Ocean Water

- Surface temperature varies with latitude, currents, and seasons.
- Average surface temperature: ~27°C at equator; ~0°C near poles.

Vertical Temperature Structure:

Layer	Depth	Feature
Surface layer	Up to 100 m	Warm, mixed by wind & currents
Thermocline	100–1000 m	Rapid temperature decrease with depth
Deep layer	Below 1000 m	Uniform cold water (~2°C–4°C)

Factors Affecting Temperature:

- Latitude (solar radiation)
- Ocean currents
- Cloud cover & winds
- Ice cover
- Vertical mixing

Warm currents → raise temp (e.g., Gulf Stream)
Cold currents → lower temp (e.g., Labrador Current)

Ocean Currents

- Large-scale, continuous movement of surface water in definite direction.
- Driven by wind, temperature, salinity, rotation (Coriolis effect).

Types of Currents:

Type	Direction / Feature	Example
Warm Currents	Flow from equator → poles	Gulf Stream, Kuroshio, Brazil Current
Cold Currents	Flow from poles → equator	Labrador, Humboldt, Canary, Oyashio

Major Ocean Current Systems

A. Atlantic Ocean

- Warm: Gulf Stream (N. Atlantic), Brazil Current (S. Atlantic)
- Cold: Canary (NE), Labrador (NW), Benguela (SW)
  Effect: Europe’s mild climate (by Gulf Stream).

B. Pacific Ocean

- Warm: Kuroshio (Japan), East Australian
- Cold: Oyashio, Peru (Humboldt)
  Effect: Peru Current causes Atacama Desert (dry west coast).

C. Indian Ocean

- Currents reverse seasonally with monsoon.
  - Summer: Clockwise (Northeast → Southwest Monsoon Current)
  - Winter: Anticlockwise
- Cold: West Australian Current.
- Warm: Agulhas, Somali Current (reverses seasonally).

Factors Affecting Ocean Currents

Factor	Effect
Wind (Trade & Westerlies)	Primary driving force for surface currents.
Coriolis Force (Earth's rotation)	Deflects currents — right in N. Hemisphere, left in S. Hemisphere.
Temperature Difference	Warm → rise, Cold → sink → circulation.
Salinity Difference	Dense saline water sinks, creating thermo haline circulation.
Continental Deflection	Landmasses redirect currents (e.g., Gulf Stream by N. America).
Monsoon Winds	Reverse Indian Ocean currents seasonally.

Effects of Ocean Currents

1. Regulate climate (warm currents = mild winters).
2. Influence marine life & fishing zones (mixing of cold & warm).
3. Aid navigation & trade routes.
4. Affect rainfall and temperature along coasts.

Ocean Currents

- Ocean current = large-scale, horizontal movement of seawater in definite direction and speed.
- Currents are generated by winds, Earth's rotation (Coriolis effect), temperature & salinity difference.

- Warm currents → flow from *equator to poles*.
- Cold currents → flow from *poles to equator*.

Together, they form gyres (circular systems) — clockwise in Northern Hemisphere, anticlockwise in Southern Hemisphere.

Warm and Cold Currents – Comparison

Basis	Warm Currents	Cold Currents
Direction	Equator → Poles	Poles → Equator
Temperature	Carry warm water	Carry cold water
Effect on Climate	Increase coastal temperature & humidity → warm & wet climate	Decrease temperature & humidity → cool & dry climate
Effect on Rainfall	Promote convectional rainfall	Suppress rainfall, cause aridity
Effect on Marine Life	Moderate productivity	Highly productive (mixing of nutrients)
Example	Gulf Stream, Kuroshio, Brazil, Agulhas	Labrador, Humboldt, Canary, Benguela, Oyashio

Major Ocean Current Systems (By Ocean)

Atlantic Ocean Currents

Region	Warm Current	Cold Current	Remarks
North Atlantic	Gulf Stream (off USA → Europe)	Labrador (Greenland → Newfoundland)	Mixing forms Grand Banks → world's richest fishing ground.
South Atlantic	Brazil Current (westward from equator)	Benguela (northward along SW Africa)	Benguela causes aridity → Namib Desert.
East Atlantic	North Equatorial → Canary (Cold)	—	Canary causes Sahara dryness.

- *Warm + Cold mixing → high fish productivity (nutrient upwelling).*

Pacific Ocean Currents

Region	Warm Current	Cold Current	Remarks
North Pacific	Kuroshio (Japan Current)	Oyashio (Kamchatka → Japan)	Their confluence → rich fisheries near Japan.
South Pacific	East Australian Current	Peru (Humboldt) Current	Humboldt → causes Atacama Desert dryness.
Central Pacific	North & South Equatorial (warm), Equatorial Countercurrent	—	Maintain Pacific circulation.

El Niño = Weakening/reversal of Humboldt Current → warm Pacific waters, global climate disruption.

Indian Ocean Currents

Season	Warm Currents	Cold Currents	Note
Summer (SW Monsoon)	Somali (warm), Agulhas (warm)	West Australian (cold)	Currents reverse due to monsoon winds.
Winter (NE Monsoon)	North Equatorial (warm)	—	Arabian Sea current changes direction seasonally.

Indian Ocean is unique — no permanent gyre system; currents reverse direction with monsoon winds.

Weather, Climate & Heat Balance

Weather vs. Climate

Basis	Weather	Climate
Meaning	Short-term atmospheric conditions (hours/days)	Long-term average (≥30 years)
Scope	Local, temporary	Regional or global, permanent
Elements	Temperature, humidity, rainfall, pressure, wind	Average of weather elements
Example	"It rained today in Bhubaneswar."	"Odisha has a tropical monsoon climate."

Clouds

- Clouds are visible masses of condensed water vapour or ice crystals suspended in the atmosphere.
- Formed by cooling and condensation of moist air when it rises and expands.

Classification (Based on Height & Appearance)

Level	Cloud Type	Features / Weather Indication
High Clouds (6–13 km)	Cirrus, Cirrostratus, Cirrocumulus	Ice-crystal clouds; thin, feathery; fair but cold weather; Cirrostratus → halo around sun/moon.
Middle Clouds (2–6 km)	Altostratus, Altocumulus	White or grey; may cause light rain/snow.
Low Clouds (Up to 2 km)	Stratus, Stratocumulus, Nimbostratus	Grey blanket-like; continuous drizzle or rain.
Vertical	Cumulus,	Puffy, tower-like; fair weather

Level	Cloud Type	Features / Weather Indication
Development	Cumulonimbus	(Cumulus) or thunderstorms (Cumulonimbus).

Smog

- Smog = Smoke + Fog, a form of air pollution when smoke and fog combine near surface.

Type	Composition
Classical (London) Smog	Sulphur dioxide + fog (cold, humid air)
Photochemical (Los Angeles) Smog	Nitrogen oxides + hydrocarbons + sunlight

Frost

- Frost: Ice crystals formed when water vapour directly condenses (sublimates) on cold surfaces below 0°C.
- Common on clear, calm nights with high radiation loss.
- Types:
  - Hoar frost (feathery ice on grass/leaves)
  - Rime (freezing fog on windward objects)

Insolation

- Incoming Solar Radiation received by Earth from the Sun.
- Measured in calories/cm²/minute or W/m² (solar constant ≈ 1367 W/m²).

Factors Affecting Insolation:

1. Angle of Sun’s rays (latitude) – direct rays → high insolation.
2. Duration of day – longer days → more energy.
3. Atmospheric transparency – dust, clouds reduce it.
4. Altitude – higher → more insolation.

5. Earth's distance from Sun – perihelion (Jan) > aphelion (July).

Earth's Heat Budget (Energy Balance)

- Earth receives solar energy (shortwave) and emits terrestrial radiation (longwave).
- Balance between incoming and outgoing energy maintains global temperature.

Distribution:

- Incoming solar radiation: 100 units
  - 19 absorbed by atmosphere
  - 51 absorbed by Earth's surface
  - 30 reflected back to space (planetary albedo = 30%)

Outgoing longwave: emitted back to space — keeps balance (no overheating).

Modes of Heat Transfer

Process	Description
Conduction	Heat transfer by direct contact between molecules; limited to surface
Convection	Heat transfer by vertical movement of air or fluid
Advection	Horizontal transfer of heat by wind
Radiation	Emission of energy as electromagnetic waves

Albedo (Reflectivity)

- Albedo: Percentage of incoming solar radiation reflected by a surface.
- Measured as a fraction or % (0–100).

Surface	Albedo
Fresh snow	80–90%
Cloud cover	40–70%
Forest / Cropland	10–20%
Ocean / Water	5–10%
Earth's average albedo	~30%

Higher albedo = more reflection, less absorption (cooler);
Lower albedo = more absorption (warmer).

Elements of Climate & Weather Disturbances

Elements of Climate

Climate = long-term average of atmospheric conditions.
Its elements determine regional variations in weather.

Element	Description / Importance
Temperature	Determines heat energy; affects air pressure, humidity, wind.
Pressure	Air weight on a surface; controls wind movement.
Wind	Horizontal movement of air from high → low pressure.
Humidity	Amount of water vapour in air; measured by hygrometer.
Precipitation	All forms of water falling from atmosphere — rain, snow, hail.
Cloud Cover	Regulates insolation & heat radiation.
Sunshine Duration	Duration of direct solar exposure; affects evapotranspiration.

Inversion of Temperature

- Normally, temperature decreases with altitude (~6.5°C per 1000 m).
- But under inversion, this pattern reverses → temperature increases with height in lower layers.

Causes of Inversion:

Type	Description	Example
Radiation Inversion	At night, rapid cooling of ground → cold air trapped below warm layer	Winter nights, valleys
Advection Inversion	Warm air passes over cold surface (land or sea)	Coastal regions
Frontal Inversion	Warm air overrides cold air at a weather front	Cyclonic zones
Subsidence Inversion	Descending air in high-pressure zone compresses & warms upper layer	Subtropical deserts

Effects:

- Traps pollutants → smog formation (common in winter cities).
- Creates stable weather conditions → fog, frost.
- Reduces vertical air mixing.

Precipitation

- Any form of water that falls from atmosphere to Earth's surface.
- Occurs when air becomes saturated and water vapour condenses to form droplets that coalesce and fall under gravity.

Types of Rainfall

(A) Convectional Rainfall

- Cause: Intense heating → warm moist air rises → cools → condensation → rain.
- Feature: Short duration, high intensity, localized (often with lightning).
- Region: Equatorial areas (Amazon, Congo, Indonesia) & Indian summer thunderstorms.

(B) Orographic (Relief) Rainfall

- Cause: Moist air forced to rise over a mountain barrier → cools → condenses → rain on windward side; leeward side becomes dry (*rain shadow*).
- Example:
  - Western Ghats (Mangalore = wet, Pune = dry)
  - Khasi Hills (Cherrapunji = highest rainfall).

Orographic = mountain-induced.

(C) Cyclonic (Frontal) Rainfall

- Cause: When two air masses (warm & cold) meet → warm air lifted → condensation & rain.
- Feature: Moderate to continuous rainfall over wide area.
- Region: Mid-latitude temperate regions; also in tropical cyclones (Bay of Bengal).

Polar Vortex

- Large-scale cyclonic circulation of extremely cold air around the Arctic & Antarctic poles in the stratosphere.
- Exists year-round but strengthens in winter.
- Occasionally weakens or splits → allows cold Arctic air to move southward (into N. America, Europe, Asia).
- Causes cold waves, snowstorms, and temperature drops.

Thunderstorm

- Localized storm produced by cumulonimbus clouds — with lightning, thunder, gusty winds, and rain/hail.
- Energy source: Rapid condensation of moist air → releases latent heat → strong updrafts.

- Typical in: Equatorial and tropical regions; common in pre-monsoon India.

Structure:

1. Cumulus stage: Updraft dominates (rising warm air).
2. Mature stage: Heavy rain, lightning, downdrafts form.
3. Dissipating stage: Cooling air cuts off updraft; rain weakens.

Lightning: Instant heating (30,000°C) → air expands → thunder sound.

Tornado

- Violently rotating column of air extending from a cumulonimbus cloud to the ground.
- Shape: Funnel or rope-like.
- Speed: 200–500 km/h (most destructive atmospheric phenomenon).
- Core pressure: Extremely low → vacuum effect.
- Duration: Short (few minutes) but intense damage to narrow path (~100–500 m wide).

Favourable Conditions:

- Intense heating, moisture, and wind shear.
- Common in central USA (Tornado Alley), also Bangladesh, India (NE).

Cyclone vs Tornado:

Basis	Cyclone	Tornado
Scale	Large (100–1000 km)	Small (few hundred meters)
Duration	Days	Minutes
Origin	Warm sea surface	Thunderstorm
Wind speed	120–250 km/h	Up to 500 km/h

Atmospheric Circulation & Pressure Belts

Atmospheric Circulation

- The unequal heating of the Earth's surface creates differences in air pressure, leading to movement of air (winds).
- This global system of winds that redistributes heat from equator → poles is called Atmospheric Circulation.

Components of Air Circulation

Component	Description	Example
Primary Circulation	Permanent planetary winds	Trade winds, Westerlies, Polar easterlies
Secondary Circulation	Periodic winds	Monsoon, land–sea breeze
Tertiary Circulation	Local winds	Loo, Chinook, Foehn, Mistral

General Circulation of the Atmosphere

- Describes large-scale wind patterns that encircle Earth, driven by solar heating & Earth's rotation.
- Divided into three cells per hemisphere (as per *Ferrel's Three-Cell Model*):

(A) Hadley Cell (0°–30° N/S)

- Warm equatorial air rises → forms low pressure (Equatorial Low / Doldrums).
- Air diverges aloft → moves poleward → cools → descends near 30° → forms Subtropical High (Horse Latitudes).

- Surface air returns toward equator → deflected by Coriolis → forms Trade Winds (NE in N. Hemisphere, SE in S. Hemisphere).

(B) Ferrel Cell (30°–60° N/S)

- Between Subtropical Highs and Subpolar Lows.
- Air at surface moves poleward → deflected → forms Westerlies.
- Aloft, air moves equatorward.
- Indirect cell driven by adjacent Hadley & Polar cells.

Effect: Variable weather (mid-latitude cyclones) in temperate regions.

(C) Polar Cell (60°–90° N/S)

- Cold dense air descends at poles → Polar High.
- Air flows equatorward at surface → deflected → Polar Easterlies.
- Meets westerlies at ~60° → Subpolar Low / Polar Front.

Resulting Pressure & Wind Belts (from Equator to Pole):

Latitude Zone	Pressure Belt	Wind System	Direction
0°–5°	Equatorial Low (Doldrums)	Calm, weak variable	—
5°–30°	Subtropical High (Horse Latitudes)	Trade Winds	NE (N. Hem), SE (S. Hem)
30°–60°	Subpolar Low	Westerlies	SW (N. Hem), NW (S. Hem)
60°–90°	Polar High	Polar Easterlies	E → W

Pressure Belts of the Earth

(A) Equatorial Low Pressure Belt (Doldrums)

- Region of intense solar heating → warm air rises → permanent low pressure zone.
- Location: Around equator (5°N–5°S).
- Features:
  - Light variable winds (calm zone)
  - Heavy convectional rainfall
  - Rising air → Hadley cell origin
  - "Doldrums" = sluggish winds

(B) Subtropical High Pressure Belt (Horse Latitudes)

- At ~30°N/S → descending air from Hadley cell → high pressure.
- Dry & stable weather → world's major deserts (Sahara, Thar, Atacama).
- Winds diverge outward:
  - Equatorward → Trade winds
  - Poleward → Westerlies

Called "Horse Latitudes" because sailing ships stalled here; sailors threw horses overboard historically.

(C) Subpolar Low Pressure Belt

- Around 60°N/S → warm westerlies meet cold polar easterlies → cyclonic activity.
- Unstable zone → frontal uplift → frequent storms.
- Example: Icelandic Low, Aleutian Low (North); Antarctic Low (South).

(D) Polar High Pressure Belt

- At poles → intense cold → air descends → high pressure zone.
- Surface air flows outward → forms Polar Easterlies.

Shifting of Pressure Belts

- Due to Earth's axial tilt, pressure belts shift north or south with the apparent movement of the Sun.
  - Summer (N. Hemisphere): Belts shift northward.
  - Winter (N. Hemisphere): Belts shift southward.
- Result:
  - Seasonal monsoons (Asia–Africa).
  - Alternating wet–dry seasons in tropics.

Example:
In June, ITCZ (Inter-Tropical Convergence Zone) shifts toward Tropic of Cancer → Southwest Monsoon in India.

Global Wind Patterns

Wind	Origin Zone	Direction	Nature
Trade Winds	Subtropical High → Equatorial Low	NE/SW or SE/NW	Steady, moisture-laden
Westerlies	Subtropical High → Subpolar Low	SW (N. Hem), NW (S. Hem)	Strong, variable
Polar Easterlies	Polar High → Subpolar Low	East → West	Cold, dry

Planetary & Local Winds

Planetary (Permanent) Winds

- These are long-term, large-scale winds that blow consistently in the same direction throughout the year across the globe.
- Cause:
  Due to unequal heating of Earth, formation of pressure belts, and the Coriolis force (Earth's rotation).
- Function:
  They maintain the global heat balance by transferring air masses between equator and poles.

Types of Planetary Winds

Wind Type	Pressure Belt	Hemisphere	Characteristics
Trade Winds	Subtropical High → Equatorial Low	Tropical Zone (0°–30°)	Steady, moist, cause heavy rain on east coasts of continents.
Westerlies	Subtropical High → Subpolar Low	Mid-latitudes (30°–60°)	Strong, variable, bring cyclones; stronger in Southern Hemisphere (no land obstruction).
Polar Easterlies	Polar High → Subpolar Low	High latitudes (60°–90°)	Cold, dry, and weak; move from poles toward lower latitudes.

Characteristics of Planetary Winds

- Controlled by pressure belts and Coriolis effect.
- Deflected to right in N. Hemisphere, left in S. Hemisphere.
- Trade winds converge near equator forming ITCZ (Inter-Tropical Convergence Zone) → rising air → rain → Doldrums.

- Westerlies dominate temperate regions, leading to mid-latitude cyclones.
- Polar easterlies help form polar fronts (meeting zone of warm & cold air).

Seasonal Shifts

- Planetary wind system shifts north or south with apparent movement of the Sun.
- Effect:
  - Monsoon formation (seasonal reversal of trades).
  - Wet and dry tropical seasons.

Example: In summer, ITCZ shifts north → SE trades appear as SW monsoon over India.

Local Winds

- Winds that develop in small areas due to local differences in temperature and pressure.
- Duration:
  Short-term, irregular, but significant for local climate and agriculture.

A. Local Winds Due to Differential Heating of Land & Sea

Type	Time	Direction	Effect
Land Breeze	Night	Land → Sea	Land cools faster; wind flows seaward; brings dry air.
Sea Breeze	Day	Sea → Land	Land heats faster; cool sea air moves inland; moderates coastal temperature.

B. Local Winds Due to Topography (Mountain–Valley)

Type	Time	Direction	Effect
Valley Breeze	Day	Valley → Mountain	Air on slopes warms, rises → draws air from valley → afternoon showers possible.
Mountain Breeze	Night	Mountain → Valley	Air cools rapidly → flows downslope → frost formation.

C. Hot Local Winds

Wind	Region	Nature / Effect
Loo	North India (pre-monsoon)	Hot, dry, dusty wind (~45°C); causes heatstrokes.
Sirocco	Sahara → Mediterranean	Hot, dry, carries red dust ("blood rain").
Khamsin	Egypt (spring)	Hot, sandy wind before Nile flood.
Santa Ana	California (USA)	Hot, dry wind from desert → forest fires.
Chinook	Rockies (N. America)	Warm, dry wind; "Snow eater" — melts snow rapidly, helps wheat farmers.
Foehn (Föhn)	Alps (Europe)	Warm, dry wind; improves pasture conditions.
Harmattan	Sahara → Gulf of Guinea	Dry, dust-laden; called "Doctor Wind" (clears humidity).

D. Cold Local Winds

Wind	Region	Nature
Mistral	France (Rhone Valley)	Cold, dry wind → clears skies.
Bora	Adriatic Coast (Europe)	Cold, gusty downslope wind.

Wind	Region	Nature
Pampero	Argentina (Pampas)	Cold, strong wind after thunderstorms.
Blizzard	Polar regions	Violent snow-bearing wind; near-zero visibility.

E. Dusty / Stormy Local Winds

Wind	Region	Feature
Haboob	Sudan, Egypt	Dust-laden violent storm before rain.
Typhoon / Hurricane	Tropical oceans	Large-scale local storms (not truly “local,” but region-specific).

Air Masses & Their Influence on Weather

- A large body of air with uniform temperature, humidity, and pressure characteristics across vast horizontal extent (hundreds to thousands of km).
- It behaves as a single unit and affects the weather of regions it moves over.

Origin

For an air mass to form, the source region must have:

1. Uniform surface (land or sea).
2. Stable weather conditions (little horizontal mixing).

Hence, ideal source regions are:

- Subtropical oceans → warm, moist air.
- Polar continental interiors → cold, dry air.

Classification of Air Masses (Bergeron's Scheme)

Based on moisture (surface type) & temperature (latitude):

Type	Source	Nature
Continental Polar	Land in high latitudes (Canada, Siberia)	Cold & Dry
Maritime Polar	Cold oceans (N. Atlantic, N. Pacific)	Cool & Moist
Continental Tropical	Hot deserts (Sahara, Arabian, Thar)	Hot & Dry
Maritime Tropical	Warm oceans (Caribbean, Indian Ocean)	Warm & Moist

Type	Source	Nature
Continental Arctic	Polar ice regions	Very Cold & Dry

Vertical Structure of Air Mass

- Lower layer: modified by Earth's surface (friction, heating).
- Upper layer: retains properties of source region.
- Boundary zone between two air masses = Front (forms cyclones & rain).

Modification of Air Masses

When air masses move from their source region, their properties change due to new surface conditions:

Modification Process	Example
Heating/Cooling	Polar air moving over warm sea → maritime modification.
Moisture Change	Continental air mass over ocean → becomes humid.
Mixing with other air masses	Causes instability → rainfall.

Major Air Masses Affecting India

Air Mass	Source Region	Nature	Influence
mT (Maritime Tropical)	Indian Ocean, Bay of Bengal, Arabian Sea	Warm, moist	Brings monsoon rains
cT (Continental Tropical)	NW India, Iran, Arabian Peninsula	Hot, dry	Causes pre-monsoon heat (Loo)
cP (Continental Polar)	Central Asia	Cold, dry	Responsible for Western Disturbances (rain in winter

Air Mass	Source Region	Nature	Influence
			over N. India)
mP (Maritime Polar)	S. Indian Ocean (rare influence)	Cool, moist	Occasional southern storms

Influence of Air Masses on Weather

(A) Temperature Changes

- Warm air mass over cold surface → inversion, fog.
- Cold air mass over warm surface → instability, convection & rain.

(B) Pressure Changes

- Warm, moist air → low pressure → rainfall & storms.
- Cold, dry air → high pressure → clear, dry weather.

(C) Rainfall Formation

- When contrasting air masses meet → fronts → uplift → frontal rainfall.

(D) Wind Patterns

- Air mass movements create prevailing winds (e.g., trade winds, westerlies).
- Jet streams flow along air mass boundaries (polar front).

(E) Cyclone Development

- Tropical cyclones form in mT air over warm seas.
- Temperate cyclones develop at polar front (mP vs. mT).

Fronts – Interface Between Air Masses

Type	Warm/Cool Air Relation	Result
Warm Front	Warm air overrides cold air	Gentle, prolonged rain
Cold Front	Cold air undercuts warm air	Sudden, heavy rain & thunderstorms
Occluded Front	Cold front overtakes warm front	Complex precipitation
Stationary Front	Both air masses balanced	Cloudy, steady weather

Jet Streams & Their Influence on Indian Monsoon

- Jet Streams are narrow belts of very high-speed westerly winds (200–400 km/h) that flow in the upper troposphere / lower stratosphere (8–14 km altitude).
- They move from west to east (westerlies) in both hemispheres.
- These are like "rivers of air" — controlling movement of pressure systems, cyclones, and monsoon circulation.

Formation of Jet Streams

- Formed along boundaries of contrasting air masses (warm tropical vs. cold polar).
- Strong pressure & temperature gradients → steep slope in upper air → fast wind flow.
- Coriolis force + temperature contrast sustain them.

Types of Jet Streams (Globally)

Jet Stream	Latitude	Height	Wind Speed	Feature
Polar Front Jet (PFJ)	50°–60°	9–12 km	250–400 km/h	Found along polar front; causes temperate cyclones.
Subtropical Westerly Jet (STWJ)	25°–35°	12–14 km	200–300 km/h	Dominant over India in winter.
Tropical Easterly Jet (TEJ)	10°–20°	12–16 km	150–250 km/h	Develops over Indian region in summer monsoon.
Polar Night Jet	Near poles	15–20 km	200 km/h	Exists in winter due to strong thermal contrast.

Jet Streams Over India

India experiences two main upper-level jets that influence monsoon & winter weather:

Season	Dominant Jet Stream	Direction	Effect
Winter (Dec–Feb)	Subtropical Westerly Jet (STWJ)	West → East	Brings Western Disturbances to N. India → winter rain in Punjab, Kashmir.
Summer (Jun–Sep)	Tropical Easterly Jet (TEJ)	East → West	Strengthens SW Monsoon, steers it south of Himalayas.

Subtropical Westerly Jet (STWJ) – *Winter Jet*

- Present over Himalayas at ~27°N, height ~12 km.
- Strong in winter when temperature gradient between Tibet (cold) & Indian Ocean (warm) is high.
- Its southern position keeps ITCZ southward → dry, cool winter in most of India.
- Occasionally dips south → carries Western Disturbances → causes rain/snow in N. India.

When STWJ is strong → monsoon is weak.

Tropical Easterly Jet (TEJ) – *Summer Jet*

- Develops at ~15°N during summer (May–Sept).
- Height: 12–16 km.
- Originates over Tibetan Plateau & East Africa, flows east → west.
- Strengthens due to heating of Tibetan Plateau and formation of upper-air high pressure over it.
- Associated with active Southwest Monsoon and good rainfall.

When TEJ is strong → monsoon is strong.

Jet Streams and the Indian Monsoon – Mechanism

A. Winter (Pre-Monsoon Stage)

- In January, Subtropical Westerly Jet (STWJ) lies south of Himalayas (~25°N).
- It prevents the northward movement of ITCZ → no monsoon (India remains dry).
- Brings Western Disturbances → winter rain in North India.

B. Summer (Onset of Monsoon – June)

- As Sun shifts northward:
  - Tibetan Plateau heats up → creates strong thermal low.
  - STWJ shifts north of Himalayas.
  - Tropical Easterly Jet (TEJ) sets in over peninsular India.
- These shifts allow ITCZ (monsoon trough) to move north → Southwest Monsoon sets in.

C. During Monsoon (June–September)

- Strong TEJ supports rising air over Indian subcontinent → maintains rainfall.
- Weak TEJ or delayed formation → delayed or weak monsoon.
- Upper-air divergence due to TEJ enhances rainfall intensity.

D. Withdrawal of Monsoon (October–November)

- As Tibetan Plateau cools, TEJ weakens and disappears.
- STWJ reappears south of Himalayas → ITCZ shifts south → withdrawal of monsoon.

Influence of Jet Streams on Indian Weather

Jet Stream	Season	Influence
STWJ	Winter	Brings Western Disturbances → light rain in Punjab, Haryana, Kashmir; suppresses monsoon.
TEJ	Summer	Promotes monsoon circulation & rainfall; enhances convection.
Jet Anomalies	—	Weak/late TEJ → weak monsoon; early strong TEJ → early monsoon onset.

Global Significance of Jet Streams

- Guide movement of cyclones, anticyclones, and air masses.
- Affect air travel — west → east flights faster due to tailwinds.
- Key in weather forecasting — shifts indicate storm or drought likelihood.

Cyclones & Anticyclones

Cyclone:

- A large low-pressure system in which air spirals inward toward the center.
- The air rises at the center → condensation → clouds → rain.
- Due to Earth's rotation (Coriolis force), air deflects:
    - Counter-clockwise in Northern Hemisphere,
    - Clockwise in Southern Hemisphere.

Cyclone = Low pressure + Inward spiral + Rising air + Cloud formation.

Anticyclone:

- A high-pressure system in which air descends and diverges outward at the surface.
- The descending air inhibits cloud formation → clear, dry, and stable weather.
- Air moves:
    - Clockwise in Northern Hemisphere,
    - Counter-clockwise in Southern Hemisphere.

Anticyclone = High pressure + Outward spiral + Descending air + Clear weather.

Types of Cyclones

Type	Location	Character	Example
Tropical Cyclones	5°–30° latitude	Warm-core, intense, circular	Bay of Bengal, Arabian Sea, Caribbean
Temperate (Extratropical) Cyclones	35°–65° latitude	Cold-core, frontal, elongated	North Atlantic (Icelandic Low), Mediterranean

Tropical Cyclones

- A rapidly rotating storm system over tropical oceans with low central pressure, strong winds (120–300 km/h), and heavy rainfall.

Conditions for Formation:

1. Sea surface temperature ≥ 27°C (up to 60 m depth).
2. High humidity in lower–middle troposphere.
3. Coriolis force (so not within 5° of Equator).
4. Low vertical wind shear (uniform wind speed with height).
5. Pre-existing low-pressure disturbance.

Hence, cyclones rarely form near the equator (no Coriolis).

Stages of Development:

1. Tropical Disturbance – weak low-pressure area.
2. Tropical Depression – wind speed 30–50 km/h.
3. Tropical Storm – organized system, 60–90 km/h.
4. Severe Cyclone / Hurricane / Typhoon – winds >118 km/h, clear "eye".

Structure of a Tropical Cyclone:

Part	Description
Eye	Calm, clear center (~10–50 km diameter), lowest pressure, subsiding air.
Eye Wall	Tall ring of cumulonimbus clouds; heaviest rain, strongest winds.
Rain Bands	Spiral clouds producing intermittent rain.

Movement:

- Initially westward under trade winds.
- Later poleward & eastward under westerlies.
- Dissipates over land due to friction and lack of moisture.

Regional Names:

Region	Name
Atlantic / Caribbean	Hurricane
Indian Ocean	Cyclone
Western Pacific	Typhoon
Australia	Willy-willy

Tropical Cyclones in India:

- Origin areas: Bay of Bengal & Arabian Sea.
- Seasons:
  - Pre-monsoon: April–May
  - Post-monsoon: Oct–Nov
- More frequent & severe in Bay of Bengal due to warmer waters & favorable winds.

Temperate (Extratropical) Cyclones

- Form between 35°–65° latitudes along polar fronts (boundary of cold polar and warm tropical air).
- Driven by jet streams and Coriolis force.
- Larger in size (1000–3000 km) but less intense than tropical ones.

Structure:

- Warm front: Warm air ascends gradually → light rain.
- Cold front: Cold air pushes under warm → heavy, short rain.
- Occluded front: Cold front overtakes warm front → complex weather.

Temperate cyclones = frontal depressions (rain belts of Europe & N. America).

Anticyclones

- Form under high-pressure zones where air descends and diverges at the surface.
- Associated with stable, dry, clear weather.
- Opposite circulation to cyclones:
  - Clockwise in N. Hemisphere, Counter-clockwise in S. Hemisphere.

Types:

Type	Location	Example
Cold Anticyclone	Over land in winter	Siberian High
Warm Anticyclone	Over oceans in subtropics	Azores High, Hawaiian High

Effects:

- Clear skies, calm winds, temperature inversion, and fog in winter.
- May cause droughts by blocking rain-bearing cyclones.

Anticyclones = "weather brakes" of the atmosphere.

El Niño, La Niña, Indian Ocean Dipole & Madden–Julian Oscillation

El Niño

El Niño (Spanish: "The Christ Child") is a periodic warming of sea surface temperatures (SSTs) in the central and eastern equatorial Pacific Ocean.

Normal (Non–El Niño) Conditions:

- Strong trade winds blow from east → west (South America → Indonesia).
- Warm water piles up near Australia & Indonesia (Western Pacific Warm Pool).
- Cold upwelling off Peru & Ecuador → rich fisheries.
- Results in high pressure in the east and low pressure in the west (Walker Circulation).

During El Niño:

- Trade winds weaken or reverse.
- Warm water moves eastward → central/eastern Pacific.
- Upwelling off Peru stops → warming of eastern Pacific.
- Pressure pattern reverses (Southern Oscillation).

Hence, El Niño = Warming in East Pacific + Weak monsoon in India.

Impacts of El Niño:

Region	Effect
India	Weak / delayed monsoon, droughts (e.g. 2002, 2015).
Peru	Collapse of fisheries, heavy rainfall & floods.
Australia / SE Asia	Drought, forest fires.
Global	Rise in global temperature (temporary), coral bleaching.

La Niña

La Niña ("The Girl") is the opposite phase of El Niño — characterized by abnormal cooling of SSTs in the central and eastern Pacific.

During La Niña:

- Trade winds strengthen.
- Warm water pushed further west → strong upwelling in East Pacific.
- Cold SSTs near Peru, warm SSTs near Indonesia.
- Enhanced Walker Circulation.

Impacts of La Niña:

Region	Effect
India	Stronger & wetter monsoon, floods (e.g. 2010, 2020).
Peru	Very dry conditions.
Australia / SE Asia	Heavy rainfall, cyclones.
Global	Cooler global average temperatures.

La Niña = Cooling in East Pacific + Strong Indian Monsoon.

Southern Oscillation (SO)

- Discovered by Sir Gilbert Walker.
- It's the alternating pattern of air pressure between the eastern (Tahiti) and western (Darwin, Australia) Pacific.
- Negative SOI (El Niño years): High pressure in west, low in east.
- Positive SOI (La Niña years): Low pressure in west, high in east.

SOI (Southern Oscillation Index) = Pressure at Tahiti – Pressure at Darwin → Positive = La Niña, Negative = El Niño.

- El Niño + SO = ENSO (El Niño–Southern Oscillation).

ENSO (El Niño–Southern Oscillation)

- The combined ocean–atmosphere phenomenon linking SST changes (El Niño/La Niña) and pressure variations (Southern Oscillation).
- Periodicity: Every 2–7 years.
- Control: Pacific Ocean, but impacts global rainfall, monsoon, and temperature patterns.

In India:

- El Niño → weak/delayed monsoon □
- La Niña → strong monsoon, floods ☔

Indian Ocean Dipole (IOD)

IOD is an irregular oscillation of SSTs between the western and eastern Indian Ocean — similar to ENSO, but specific to Indian Ocean.

Types:

Type	SST Pattern	Effect on India
Positive IOD	Western Indian Ocean (off Africa) → warmer than eastern (near Indonesia)	Enhances Indian Monsoon (even during El Niño)
Negative IOD	Western Indian Ocean → cooler than eastern	Weakens Indian Monsoon

Positive IOD can neutralize El Niño impact on monsoon.

Mechanism:

- In Positive IOD, west Indian Ocean warms → low pressure → draws moisture-laden winds toward India → more rainfall.
- In Negative IOD, east Indian Ocean warms → convection shifts toward Indonesia → monsoon weakens.

Madden–Julian Oscillation (MJO)

MJO is a moving system of clouds, rainfall, wind, and pressure that travels eastward around the equator every 30–60 days.

- Unlike ENSO or IOD (which are stationary), MJO is mobile.
- Moves eastward from Africa → Indian Ocean → Pacific → Americas.
- It's an intra-seasonal oscillation (short-term, within a season).

Phases of MJO:

1. Convective (Active) Phase:
   - Low pressure, rising air, heavy rainfall.
2. Suppressed Phase:
   - High pressure, sinking air, dry conditions.

When MJO is over the Indian Ocean, it enhances monsoon rainfall.
When it moves away (to Pacific), monsoon weakens.

Overall Impact on Indian Monsoon

Phenomenon	Effect on Monsoon
El Niño	Weak / delayed monsoon (deficient rainfall)
La Niña	Strong / early monsoon (floods)
Positive IOD	Enhances monsoon (can offset El Niño)
Negative IOD	Weakens monsoon
Active MJO	Short-term heavy rain / monsoon revival
Inactive MJO	Dry spell / monsoon break

Major World Climatic Regions

Hot, Wet Equatorial Climate (Tropical Rainforest Climate – Af)

Location:
0°–10° N/S — Amazon Basin, Congo Basin, Indonesia, Malaysia.

Features:

- High temperature (27°C avg) — small annual range.
- High rainfall (200–300 cm), well distributed all year.
- Daily convectional rainfall (“4 o’clock showers”).
- High humidity (80–90%).
- No dry season.

Vegetation:

- Dense evergreen forests, tall broad-leaved trees, multiple canopy layers.
- e.g. Mahogany, Ebony, Rosewood.

Life & Economy:

- Shifting cultivation, forest products (rubber, cocoa).
- Diseases like malaria common.

Tropical Monsoon Climate (Am)

Location:
10°–25° N/S — India, Bangladesh, Myanmar, Thailand, NE Australia.

Features:

- High temp (25–35°C).
- Distinct wet and dry seasons.
- Heavy summer rain (SW Monsoon) — 150–250 cm.

- Winter = dry (NE Monsoon).

Vegetation:

- Deciduous forests (teak, sal, bamboo).
- Grasses in dry season.

Life & Economy:

- Rice, jute, tea, cotton.
- Dependent on monsoon rains.

Tropical Marine Climate

Location:
10°–20° latitudes on east coasts — Caribbean Islands, Philippines, East Indies, Queensland (Australia).

Features:

- High temperature, small annual range.
- Rainfall all year (150–200 cm) — convectional & orographic.
- High humidity, uniform weather.

Vegetation:

- Tropical evergreen & mangroves.

Life & Economy:

- Fishing, sugarcane, banana, coconut.

Tropical Savanna or Sudan Climate (Aw)

Location:
5°–20° N/S — Africa (Sudan, Kenya, Tanzania), Brazil, Deccan Plateau (India).

Features:

- Distinct wet (summer) & dry (winter) seasons.
- Annual rainfall: 75–150 cm.
- High temperature (25–30°C).

Vegetation:

- Tall grass ("Elephant grass"), scattered trees (acacia, baobab).
- Transition between rainforest & desert.

Hot Desert Climate (BWh)

Location:
15°–30° N/S on western continental margins — Sahara, Thar, Arabian, Kalahari, Australian desert.

Features:

- Very high temp (day ~45°C), large diurnal range.
- Rainfall <25 cm (very low, irregular).
- Clear skies, dry air.

Vegetation:

- Xerophytes: cactus, thorny shrubs, date palm in oases.

Life & Economy:

- Sparse population; nomadic herding; oil fields in modern era.

Warm Temperate Western Mediterranean Climate (Csa / Cs)

Location:
30°–45° N/S on west coasts — Mediterranean Basin, California, Central Chile, SW Australia, Cape Town.

Features:

- Hot dry summer, mild wet winter (due to westerlies).
- Rainfall: 40–90 cm annually (mostly winter).
- Bright sunshine, low humidity.

Vegetation:

- Drought-resistant sclerophylls (olive, cork oak).
- Evergreen shrubs (maquis, chaparral).

Life & Economy:

- "Garden of the world" → fruits, olives, wine.
- Tourism, citrus farming.

Steppe Climate (BS / BSk)

Location:
Margins of deserts (continental interiors) — Central Asia (Kazakhstan, Mongolia), N. America (Prairies), Argentina (Pampas).

Features:

- Semi-arid: Rainfall 25–75 cm.
- Large temp range (summer hot, winter cold).
- Cold winters due to inland location.

Vegetation:

- Grasslands (treeless plains).
- Short grasses — ideal for grazing.

- “Breadbasket of the world.”

China Type / Warm Temperate Eastern Margin Climate (Cfa)

Location:
20°–40° N/S — SE China, SE USA, S. Japan, E. Australia.

Features:

- Hot, humid summer (monsoon influence).
- Cool, dry winter (continental air).
- Rainfall: 75–150 cm.

Vegetation:

- Mixed forests — evergreen + deciduous.

British Climate / Marine West Coast (Cfb)

Location:
40°–60° N/S on west coasts — UK, N. France, W. Norway, New Zealand.

Features:

- Mild winters, cool summers.
- Rainfall throughout year (50–150 cm).
- Frequent cyclones, cloudy skies.

Vegetation:

- Deciduous forests (oak, beech).

"No extreme weather, always green — that's the British climate."

Siberian Climate / Cool Temperate Continental (Dfc – Taiga Type)

Location:
50°–70° N — Siberia, Canada, Alaska, N. Scandinavia.

Features:

- Long, harsh winters; short, cool summers.
- Temp range: –40°C to 15°C.
- Rainfall low (25–50 cm), mainly summer.

Vegetation:

- Coniferous forests (pine, fir, spruce) — Taiga.

"Six months of winter, rest is cold."

Laurentian Climate (Dfb)

Location:
Eastern Canada, NE USA, N. Japan, Korea, Manchuria.

Features:

- Cold winter, warm summer.
- Rainfall throughout year (more in summer).
- Influence of westerlies & ocean currents.

Vegetation:

- Mixed forest (coniferous + deciduous).

Polar Climate (E-type)

Location:
66°–90° N/S — Greenland, Antarctica, Arctic Canada, Siberia.

Features:

- Very cold all year (below 0°C).
- Precipitation <25 cm (snow).
- 6 months day, 6 months night.

Vegetation:

- Tundra: Moss, lichen, short grass (ET).
- Ice Cap: No vegetation (EF).

Life & Economy:

- Nomadic herding (reindeer, Eskimos).

Köppen's Climatic Classification

- Developed by Wladimir Köppen (1918), a German climatologist.
- Based on temperature and rainfall patterns and natural vegetation.
- Climate types are represented by letters (A–E).
- First letter = Major climate group,
  second = precipitation pattern,
  third = temperature characteristics.

Major Climate Groups (Köppen's Classification)

A – Tropical Climates
• Temperature of all months > 18°C
• Found near the Equator.

B – Dry (Arid and Semi-Arid) Climates
• Evaporation > precipitation.

C – Temperate (Warm Temperate / Mesothermal)
• Mean temperature of coldest month between -3°C and 18°C.

D – Cold (Microthermal)
• Cold winters; mean temperature of coldest month < -3°C.

E – Polar Climates
• Mean temperature of warmest month < 10°C.

Subtypes of Tropical (A) Climate (important for India)

Af – Tropical Rainforest Climate

- "f" = no dry season.
- Hot and wet throughout the year.
- Heavy rainfall (>200 cm).
- Dense evergreen forests.
- Example: Equatorial regions (Amazon, Indonesia, Congo).
- In India → parts of Andaman & Nicobar Islands and Western Ghats (windward side).

- Characteristic: *Humid tropical climate.*

Am – Tropical Monsoon Climate

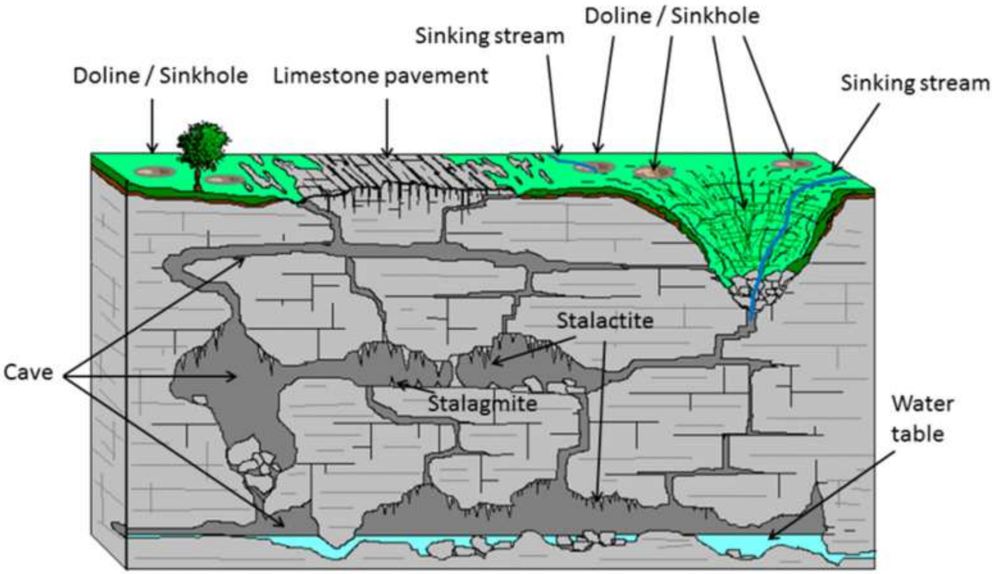
- "m" = monsoon influence.
- Distinct wet and dry seasons.
- Heavy rainfall in summer, short dry period.
- Example: India, Myanmar, Sri Lanka, Bangladesh.
- Characteristic: *Monsoon climate.*

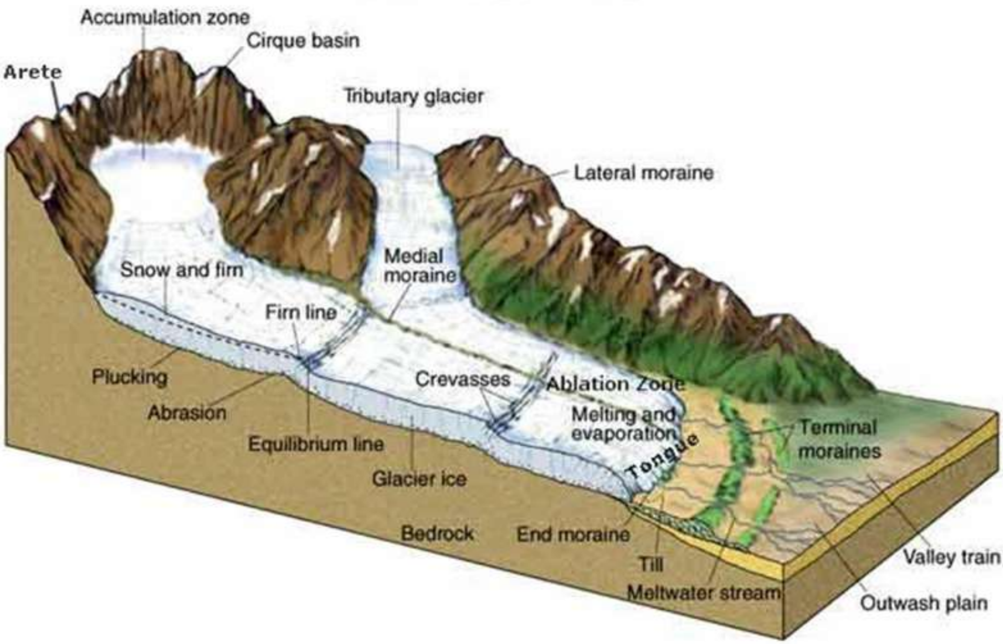
Aw / As – Tropical Wet and Dry (Savanna) Climate

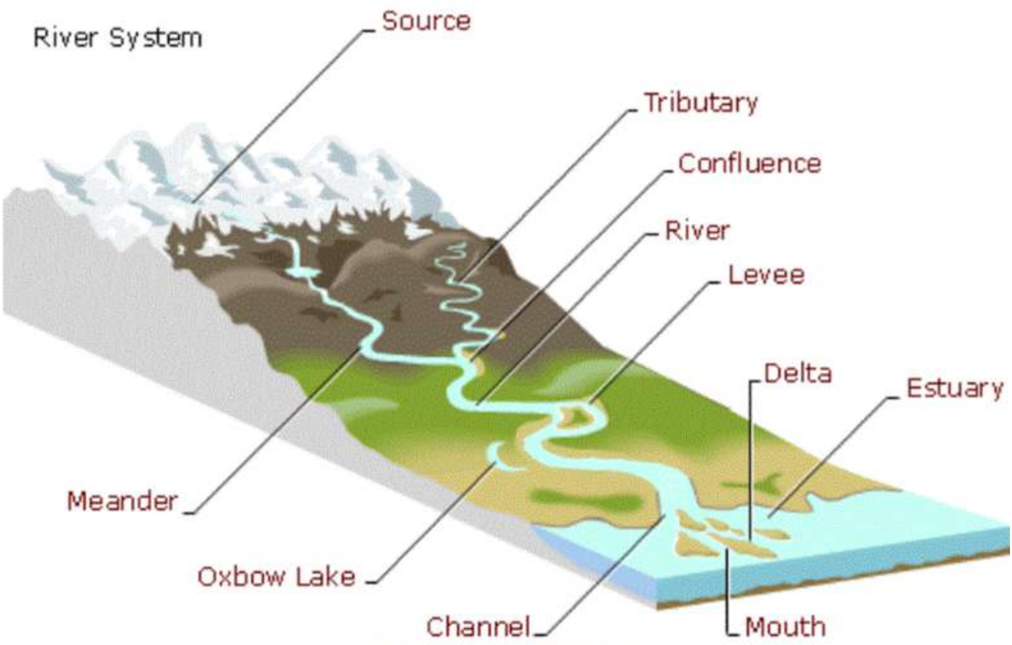
- "w" = dry winter; "s" = dry summer.
- Rainfall mainly in one season (summer monsoon).
- Dry season marked by drought conditions.
- Natural vegetation → Savanna grasslands and scattered trees.
- Example: Central India, Odisha, Tamil Nadu plateau, parts of Africa.
- Characteristic: *Tropical humid and dry climate.*

Köppen's Climatic Types in India

- Af: Western Ghats, Andaman & Nicobar Islands.
- Am: West Coast, Assam, Meghalaya, parts of NE India.
- Aw: Most of Peninsular India – Maharashtra, Chhattisgarh, Odisha, Jharkhand.
- BS / BW: Arid & Semi-Arid – Rajasthan, Gujarat.
- Cw: Humid subtropical – North India (UP, Bihar).
- ET: Polar type – upper Himalayas (Ladakh, Karakoram).


Doline / Sinkhole
Limestone pavement
Sinking stream
Doline / Sinkhole
Sinking stream
Cave
Stalactite
Stalagmite
Water
table


Accumulation zone
Cirque basin
Arete
Tributary glacier
Lateral moraine
Snow and firn
Medial
moraine
Firn line
Plucking
Abrasion
Crevasses
Ablation Zone
Melting and
evaporation
Tongue
Terminal
moraines
Equilibrium line
Glacier ice
Bedrock
End moraine
Till
Meltwater stream
Valley train
Outwash plain


River System
Source
Tributary
Confluence
River
Levee
Delta
Estuary
Meander
Oxbow Lake
Channel
Mouth

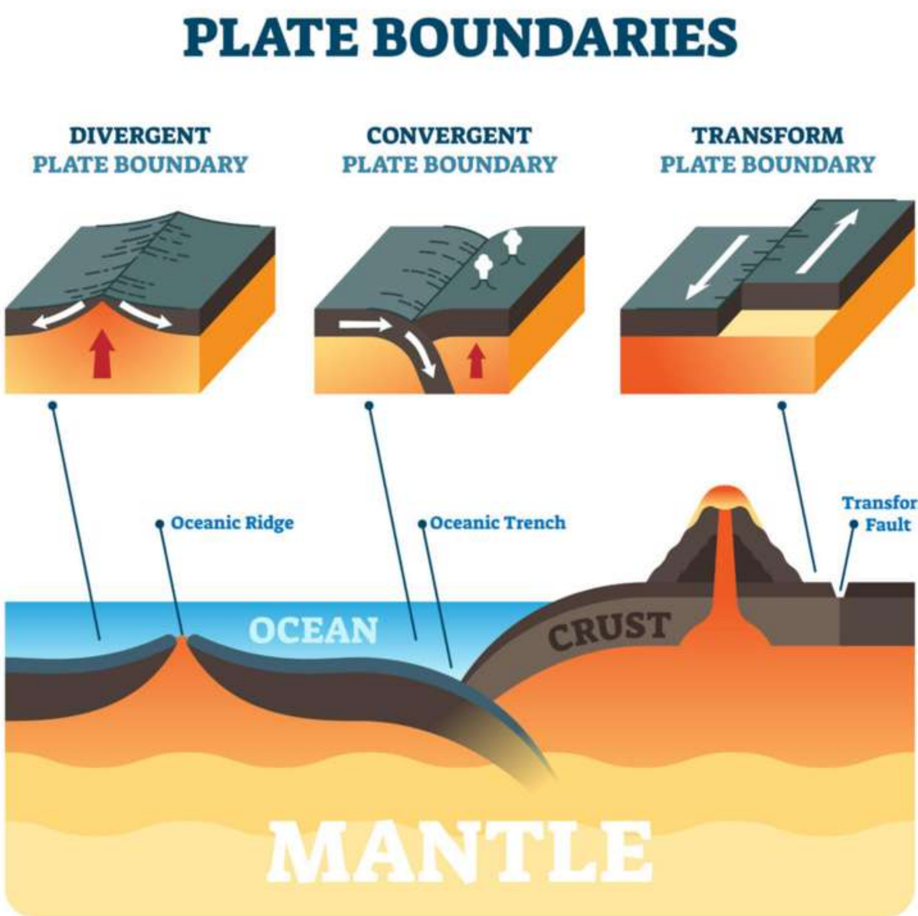
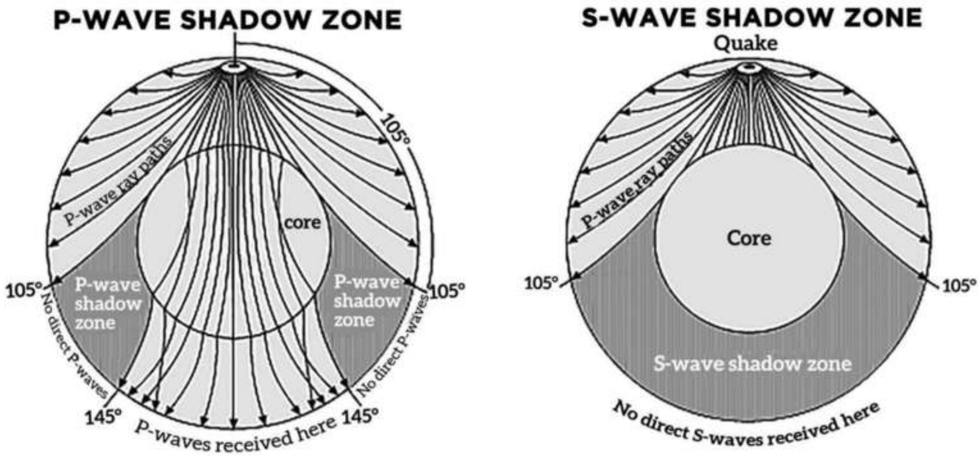
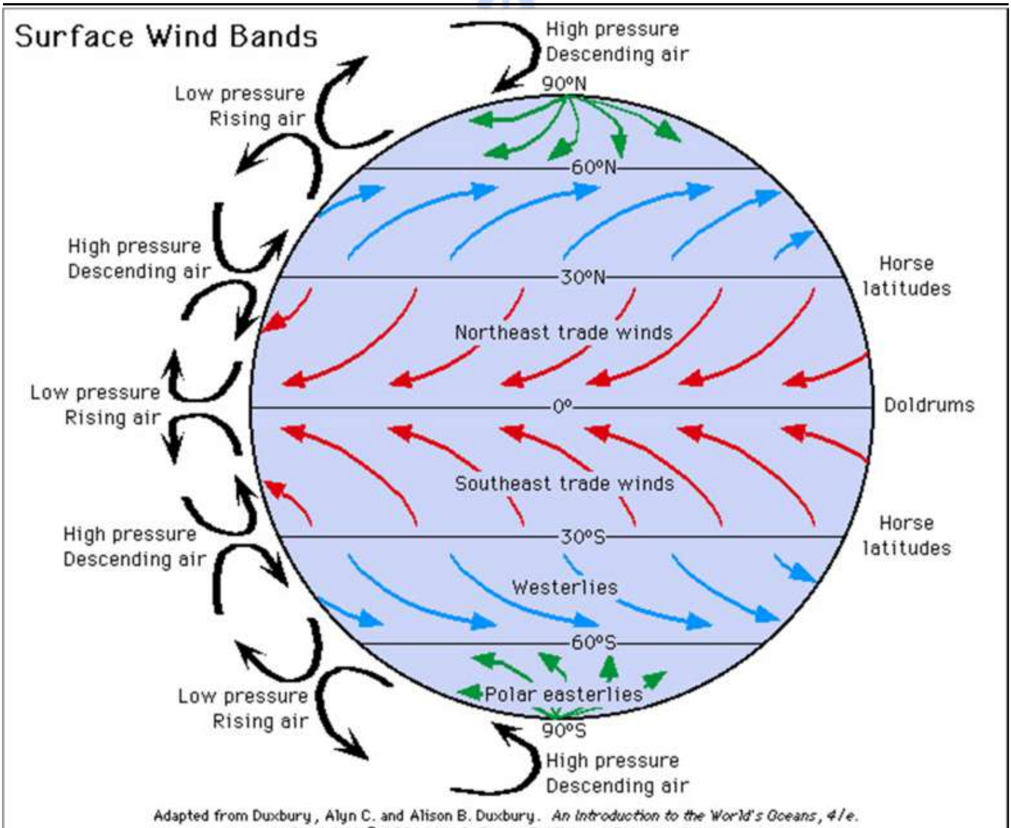
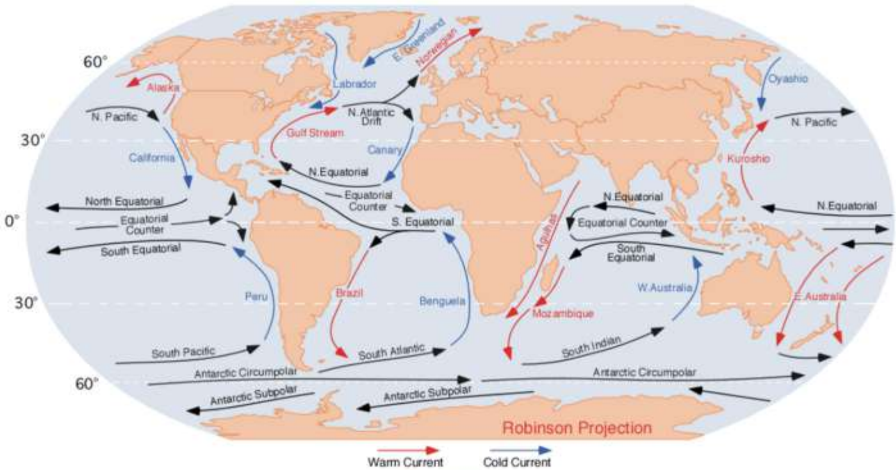


PLATE BOUNDARIES
DIVERGENT
PLATE BOUNDARY
CONVERGENT
PLATE BOUNDARY
TRANSFORM
PLATE BOUNDARY
Oceanic Ridge
Oceanic Trench
Transform
Fault
OCEAN
CRUST
MANTLE





Adapted from Duxbury, Alyn C. and Alison B. Duxbury. *An Introduction to the World's Oceans, 4/e.*


60°
30°
0°
30°
60°
Alaska
N. Pacific
California
North Equatorial
Equatorial Counter
South Equatorial
Peru
South Pacific
Antarctic Circumpolar
Antarctic Subpolar
Labrador
E.Greenland
Norwegian
N. Atlantic Drift
Gulf Stream
Canary
N.Equatorial
Equatorial Counter
S. Equatorial
Brazil
Benguela
South Atlantic
Agulhas
Mozambique
N.Equatorial
Equatorial Counter
South Equatorial
W.Australia
South Indian
Antarctic Circumpolar
Oyashio
N. Pacific
Kuroshio
N.Equatorial
E.Australia
Robinson Projection
Warm Current
Cold Current