Physical Geography

MPSC Mains

General Studies I

Class Notes

PRAYAAS

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MPSC MAINS

Physical Geography

GENERAL STUDIES - I
(Class Notes)

Year 2025-26

Features of Physical Geography Notes (Part-I)

1. Syllabus-Centric & Concept-First Structure

- Entire content aligned with **GS Paper-I (Physical Geography)** syllabus
- Logical progression from **Earth's Interior** → **Geomorphology** → **Volcanism** → **Earthquakes** → **Weathering & Erosion**
- Ideal foundation notes for beginners as well as revision material for advanced aspirants

2. Strong Conceptual Clarity with Definitions & Terminology

- Clear, exam-ready definitions of core concepts such as **Moho discontinuity, Asthenosphere, Geosyncline, Plate Boundaries, Palaeomagnetism, Shoaling effect**, etc.
- Technical terms explained in simple language without diluting scientific accuracy
- Helps in writing precise introductions and value-added explanations in answers

3. Diagram-Oriented Explanations

- Frequent use of **label-friendly diagrams** for seismic waves, Earth's interior, plate boundaries, volcano structure, rock cycle, geomagnetic field, etc.
- Diagrams directly usable in **Mains answer writing**

4. Point-Wise Topic Breakdown for Fast Recall

- All topics presented in **crisp bullet points** instead of bulky paragraphs
- Suitable for **last-minute revision, quick scanning, and answer structuring**
- Makes complex theories like **Continental Drift, Plate Tectonics, Geosyncline theory** easy to grasp

5. Static Core + Dynamic Linkages

- Strong coverage of **static geography**, which frequently overlaps with current affairs (earthquakes, volcanoes, tsunamis, hotspots, disasters)
- Helps in answering **disaster-related questions** in GS-I and GS-III
- Acts as a base for linking geography with environment, disaster management, and current events

6. Revision-Friendly & Exam-Ready Notes

- Structured in a way that **entire Part-I Physical Geography can be revised in limited hours**
- Easy to annotate and update with current examples

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Geomorphology

Oceanography

Climatology

1. Structure and Composition of the Earth's Interior

Introduction

- The Earth's interior is composed of distinct layers that differ in composition, density, and physical properties. Our knowledge about these layers comes from **artificial observations, theories of Earth's origin, and natural evidences like volcanic activity and seismology**.
- Earth is not a monolith, it is made up of various layers. The sources which provide the knowledge about the interior are classified into three groups :
  1. Artificial sources
  2. Evidences from the theories of the origin of the earth
  3. Natural sources like volcanic eruption, earthquakes and seismology

1.Artificial sources

- Numerous inferences can be drawn about the constitution of the interior of the Earth on the basis of density of rocks, pressure of superincumbent load and increasing trend of temperature with increasing depth inside the Earth.
- But these sources have certain limitations like,
  1. There is a crucial limit in each rock beyond which the density of the rock cannot be increased in spite of increasing pressure. This shows that very high density of the core of the earth is not because of very high-pressure prevailing there. The core must be composed of heavy metallic materials of high-density like mixture of iron and nickel.
  2. Temperature increases from the surface of the Earth downward at the rate of 20C to 30C per 100 m. It appears that the rate of increase of temperature downward decreases with increasing depth. This is because most part of the radioactive minerals are concentrated in the uppermost layer of the Earth.

2.Evidence from the theories of the origin of the Earth

- Various theories like planetesimal hypothesis, tidal hypothesis, nebular hypothesis tries to explain the origin of the Earth along with its interior. But they explain only two possibilities viz. either the core may be in solid or in a liquid state. It does not explain the detail picture of earth's interior.

3.Natural sources

- The problem faced by above two sources are properly dated by natural sources. They are further divided into direct sources and indirect sources.

(A) Direct Sources

1. **Deep ocean drilling project - Cola Peninsula near Arctic Ocean :** This project directly digs the hole inside the Earth and tries to look into the interior of the Earth. But at present we can reach only up to 27 km inside the Earth.
2. **Vulcanicity :** Volcanic eruption gives idea about the chemicals present in the interior of the Earth. It also shows that the layer below the Earth's surface is in liquid state.

(B) Indirect sources

1. Meteorites
2. Magnetic survey
3. Gravitational force study
4. Evidences of seismology
   - Out of all the sources, most correct picture of the interior of the earth is provided by the evidences of seismology.

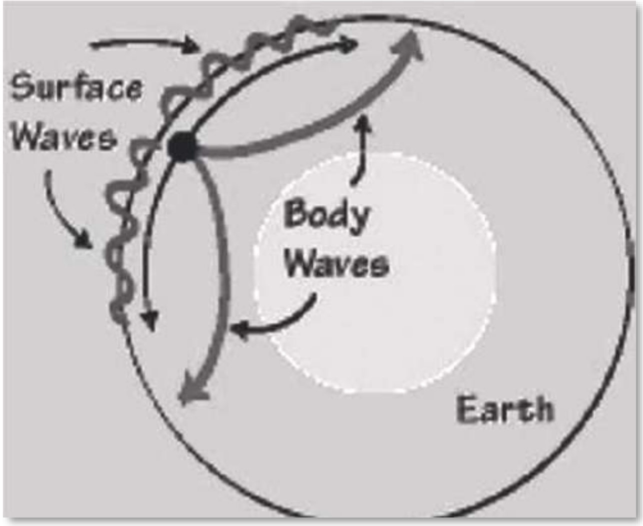
Evidences of seismology

- Seismology is the science which studies various aspects of seismic waves generated during the occurrence of earthquake. They are recorded on seismograph.

Seismic Waves

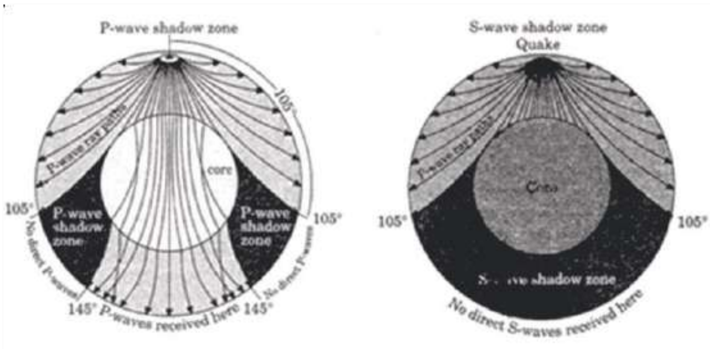
- Different types of tremors and waves generated during the occurrence of an earthquake are called seismic waves. They are generally divided into two broad categories,
  1. **Body waves :** They always travel below the surface of the Earth and are further divided into P waves (primary waves) and S waves (secondary waves).
  2. **Surface waves :** They travel along the surface of the Earth and are prominently recorded on seismograph. They are also called that Long Period waves (L-waves).

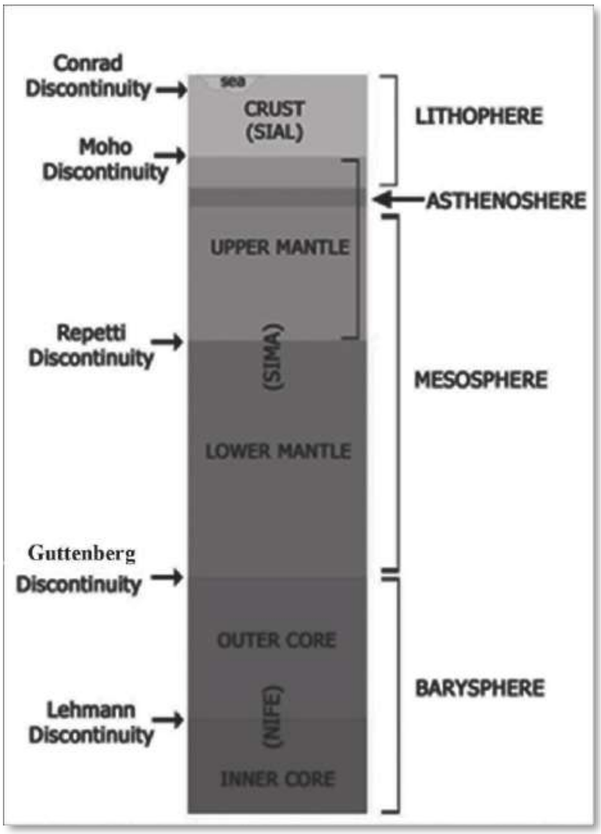
They cover the longest distances off on seismic waves. Their speed is much lesser than body waves. They are the most violent and destructive waves.



P waves	S waves
Travel inside the Earth.	Travel inside the Earth.
They are of longitudinal or compressional type.	They are of transverse or distortional type.
Similar to sound waves.	Similar to water ripples or light waves.
Faster than secondary waves.	Slower than primary waves but faster than surface waves.
Can pass through solid as well as liquid medium, but their speed gets reduced while travelling through liquids.	Cannot pass through liquid medium.

- Interior of the earth is studied with the help of velocity and travel paths of these waves. While passing through any medium, these waves are reflected and refracted. Generally, S waves disappear at an angular distance of 1200 from the epicentre (the place which experiences the seismic event first) and P waves are weakened there. Also, it is observed that S waves are totally absent in the core of the earth and P waves change their path while travelling through the core. S waves are completely absent between the angular distance of 1200 from the epicentre while P waves are absent between angular distance of 1030-1420 on either side. This absence of seismic waves is called as shadow zone of seismic waves.
- Based on the seismic waves, detailed interior of the earth can be shown as below :

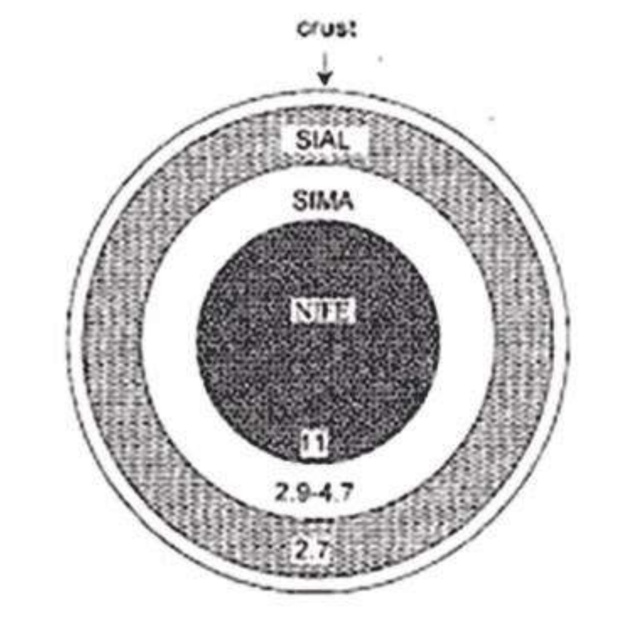




1. **Crust (Lithosphere) :** It has thickness of about hundred kilometres and is mostly composed of Granite. Silica and aluminium are dominant constituents. It's average density is 3gm/cm3. It is further divided into outer and lower crust which is separated by Conrad discontinuity.
2. **Mantle (Mesosphere/Pyrosphere) :** It has thickness of around 2800 km. The dominant rock is basalt. It has average density of 5.5 gm/cm3. It is further divided into upper mantle and lower mantle which is separated by Repetti discontinuity. Separating boundary between crust and mantle is known as Mohorovicic/Moho's discontinuity. Mantle is in solid state.
3. **Core (Barysphere) :** It is composed of iron and nickel. Its average density ranges between 8-11 gm/cm3. It stretches from 2800 km to the

nucleus of the core that is 6371 km. Outer core is in liquid state while inner core is in solid state and they are separated by Lehmann/ Transitional discontinuity. Outer core is separated from lower mantle by Weichert-Guttenberg discontinuity.

4. **Asthenosphere :** It is the ductile upper part of the mantle. It lies just below the lithosphere and is in semi solid state. Its depth may range up to 400 km. Plate movements are generally considered to be happening above this layer giving birth to plate tectonics.



Chemical Interior of the Earth

- Edward Suess has thrown light on the chemical interior of the earth's. He divided earth's interior chemically in following way:
  1. **Crust :** It is mostly covered by a thin layer of sedimentary rocks of very low density. The dominant minerals are felspar and Mica.
  2. **SIAL :** This layer is dominated by silica and aluminium (SI+AL=SIAL). Major component is Granite and average density is 2.9 gm/cm3 thickness ranging between 50 to 300 km. It is generally acidic in nature. Continents are supposed to be formed by this layer
  3. **SIMA :** This layer is dominated by silica and magnesium (SI+MA=SIMA). Component is bad salt and average density ranges between 3.3-5.4g/cm3 with thickness ranging between 1000 km to 2000 km. It is generally basic in nature. Ocean floors are supposed to be formed by this layer
  4. **NIFE :** This layer is dominated by nickel and iron (NI+FE=NIFE). It is composed of heavy metals and thus it has very high density. The diameter of the zone is 6880 km. This layer has given magnetic properties to the earth giving birth to geomagnetism.

2. Continental Drift, Plate Tectonics & Geomagnetism

Introduction

The dynamic nature of the Earth's crust is explained through theories like Continental Drift, Plate Tectonics, and Geomagnetism. Together, they describe the movement of continents, the interaction of lithospheric plates, and the role of Earth's magnetic field in shaping geological processes. These concepts form the foundation for understanding mountain building, volcanism, earthquakes, and oceanic evolution.

Continental Drift Theory Background

- The gradual movement of the continents across the earth's surface through geological time is called as continental drift. FB Taylor first postulated the concept of horizontal displacement of continents in 1908. It has various flaws. The improvisation to this theory was given by Alfred Wegener (Germany) in 1912.

Aim

- Theory aimed to explain the global climatic changes which are reported to have taken place during the past Earth history. If the continents remain stationary at their places throughout geological history of the earth, the climatic zones might have shifted from one region to another region and thus a particular region might have experienced varying climatic conditions from time to time. But climatic zones have remained stationary, this means that land masses might have been displaced and drifted.

Assumptions

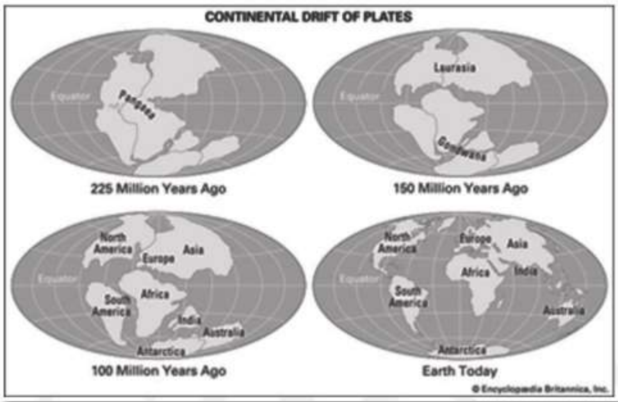
1. Taylor stated that movement of continents began in cretaceous times while Wegener stated that movement began much earlier in Carboniferous times.
2. SIAL is easily floating on SIMA without any resistance offered by SIMA.
3. Continents are made up of upper parts of SIAL while ocean beds are made up of upper parts of SIMA.
4. All landmasses were concentrated in the form of one landmass in Carboniferrous period near south pole. He named this huge land mass as Pangaea.
5. It was surrounded by a huge water body named as Panthalassa.
6. South pole was located near present Durban.

Forces Behind Continental Drift

1. **Force behind equator-ward movement :** Gravitational differential force and force of buoyancy
2. **Force behind westward movement :** Tidal force of the sun and the moon

Processes of the theory

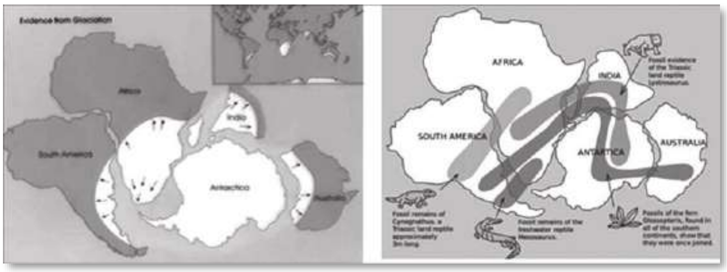
1. **Flight from the Poles :** Pangaea was broken into two parts due to differential gravitational force and the force of buoyancy. Northern part became Laurasia/Angaraland (consisting of present North America, Europe and Asia) while southern part called as Gondwanaland (consisting of present South America, Africa, Madagascar, Peninsular India, Australia and Antarctica). The intervening space between these two continental blocks was filled up with water and the resultant water body is called as Tethys sea. Thus, this phase is also known as opening of Tethys.
2. **Opening of Atlantic :** Due to tidal force of the sun and the moon, Gondwanaland and Angaraland were disrupted and the gap was filled by water known as Atlantic Ocean.
3. **Opening of Indian Ocean :** Indian Peninsula was broke away from Gondwanaland and started moving towards north. This process has buckled up the Tethys sea and closed it completely giving birth to Himalayas while water body formed at the south of Indian Peninsula is known as Indian Ocean. Thus, this process is also known as closing of Tethys.
4. The remaining portion of Panthalassa became Pacific ocean.



Evidences of Continental Drift Theory

1. **Mountain building :** During equatorward and westward movement of the continents, SIMA started creating obstacles to freely floating SIAL above it. Mountain belts represented the wrinkling of crust due to the drifting of continents. According to this hypothesis, the leading edges of moving continents first depressed the oceanic crust ahead to form a trough that then accumulated sediment. Further movement of the continents eventually caused upheaval of the strata to produce mountain ranges. Westward movement of North America and South America gave birth to Rockies and Andes, respectively while equatorward movement of Africa and Indian Peninsula gave birth to Alps and Himalayas, respectively.
2. **Origin of Island Arches :** During westward movement, eastern margin of these continents could not keep pace with the westward moving major landmasses, thus, they lagged behind and consequently ruptured from the main continents giving birth to Island arcs. For example, Japan, Philippines, Indonesia, West Indies etc.
3. **Paleontological fossils :** It is the geological similarities along both coasts of the Atlantic Ocean.
4. **Jig-Saw fit :** Opposing coasts of the Atlantic can be fitted together in the same way as 2 cut pieces of wood can be refitted.

5. Mountain systems of the western and eastern coastal areas of the Atlantic are similar and identical. For example, applications are compatible with mountain systems of Ireland and Wales.



6. Similarity in the fossils and vegetation remains along the eastern coast of South America and western coast of Africa.
7. Greenland is still drifting westward at the rate of 20 cm per year.
8. The lemmings of the northern part of Scandinavia have a tendency to run westward when their population is in danger.
9. Distribution of marsupial fauna in South Africa, India, Australia and Falkland islands.
10. Distribution of Glossopteris flora in India, South Africa, Australia, Antarctica and Falkland islands.
11. Evidences of Carboniferous glaciation of Brazil, Falkland, South Africa, Peninsular India, Australia and Antarctica.

Criticism of Continental Drift Theory

1. According to this theory, movement of continents started from Carboniferous period. It does not explain the situation before this period.
2. Views about SIAL & SIMA are contradictory.
3. For formation of Rockies, Andes, Himalaya and Alps, continental drift of 32 to 64 km is sufficient.
4. Force applied is not sufficient to cause drifting. For the movement of continents, tidal force of sun and the moon required is thousand times more than as postulated by Wegener. And if such forces existed, earth rotation would have been stopped within 24 hours.
5. Jig-saw fit is not completely validated due to seafloor reliefs.

Achievements

1. This theory was the first theory which gave answers to many questions of continental drift.
2. Though most of the arguments of Wegener's theory were rejected, its central theme of horizontal displacement was retained.
3. Continental drift phenomenon was accepted

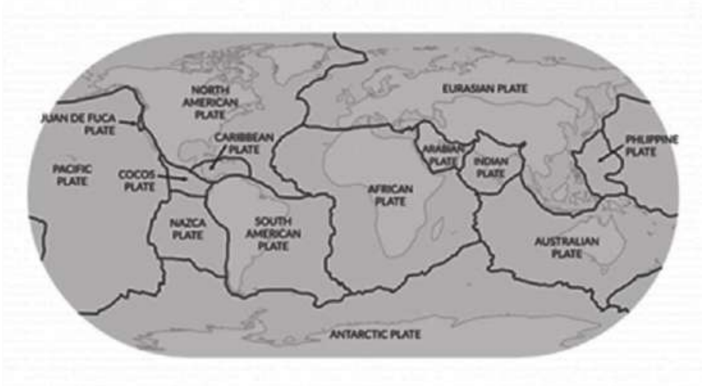
by plate tectonics theory.

Plate tectonics theory

- **Background :** The term plate was first used by Canadian geographer JT Wilson in 1963, McKenzie and Parker discussed in detail the mechanism of plate tectonics.
- **Aim :** To explain the movement of plates and formation of various landforms at various plate boundaries.

Assumptions

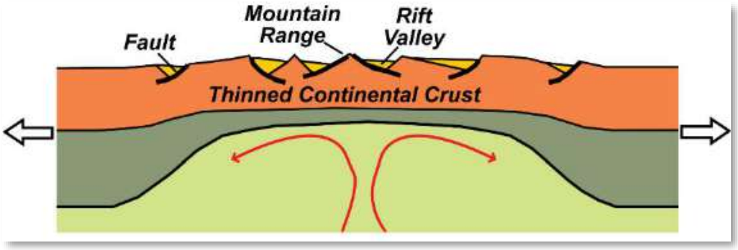
1. According to JT Wilson, plates are solid and rigid lithospheric slabs.
2. Plates are freely moving over weak asthenosphere.
3. Plate movement has begun from Precambrian era.
4. It is based on two major scientific concepts, that is, the concept of continental drift and the concept of seafloor spreading.
5. There are seven major (Eurasian, Indo-Australian, North American, Pacific, African, Antarctic and South American) and 20 minor plates (Philippine, Cocos, Nazca etc.).



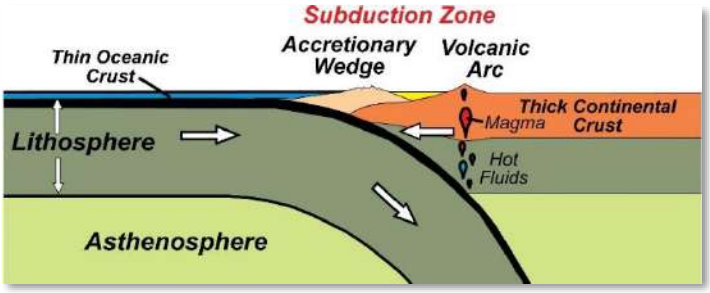
Processes

(A) Various plate boundaries : Plate boundaries or plate margins are most important because all tectonic activities occur along the plate margins.

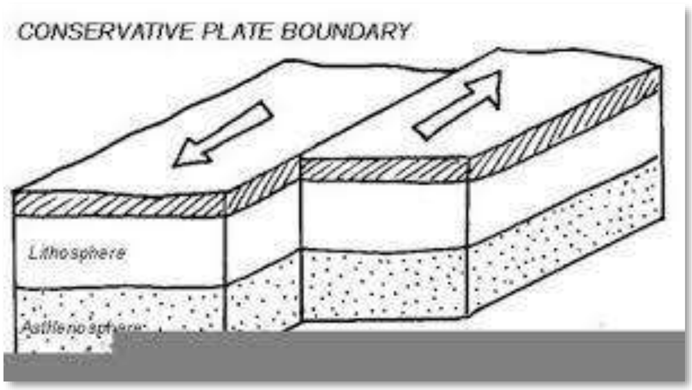
1. **Divergent plate margins :** Along this margin, boundary plates move away from each other and there is continuous upwelling of molten material. After solidification of this, molten material gives birth to plate material. Hence, this plate margin is also known as constructive or accreting plate margin. Generally, most of the oceanic plate boundaries are divergent in nature. E.g. Mid Atlantic Ridge

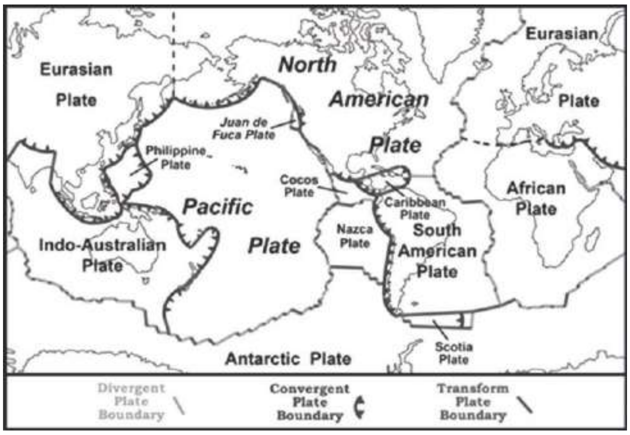


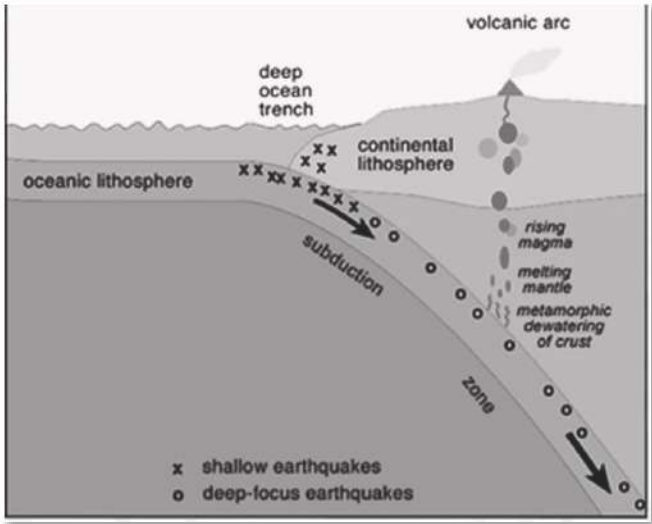
2. **Convergent plate margins :** Along this margin, boundary plates converge into one another and denser plates subduct below lighter plates. Oceanic plates being heavier generally subject below lighter continental plates. Subducting plate at greater depth (at Benioff zone-100km) melts and consequently gets destroyed; hence these plate margins are also called as destructive plate margins or consuming plate margins. E.g. Nazca plate subducting below South American plate.



3. **Conservative plate margins :** Along this margin, two plates slide past one another along transform faults and thus, crust is neither created nor destroyed. It is also known as shear plate margin or transform plate boundary.

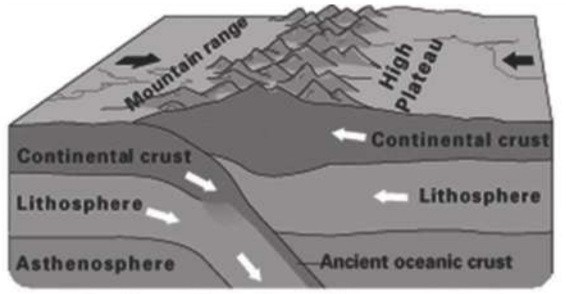






(B) **Landforms created at various plate boundaries :**

1. **Landforms created at divergent plate boundaries**
   - Lava plains
   - Lava plateaus
   - Mid oceanic ridges
   - Rift Valley. e.g. African Rift Valley
   - Fissure volcano
2. Landforms created at convergent plate boundaries
   - **(i) Ocean-Ocean convergence :** In this case, relatively denser plate subducts beneath the less dense plate. E.g. subduction of Pacific plate below Philippine plate. Landforms formed are:-
     - Trenches : Mariana trench is formed due to subduction of Pacific plate below Philippines plate.
     - Island arc and submarine volcanoes. E.g. Indonesian archipelago
   - **(ii) Ocean-Continent convergence :** In this case, denser oceanic crust slides below lighter continental crust. E.g. Nazca plate is subducting below South American plate. Landforms formed are :-
     - Volcanic eruption. e.g. Mount Fujiyama
     - Volcanic arc. E.g. Pacific ring of fire
     - Trenche
     - Fold mountains. E.g Andes Mountain
3. **Continent-Continent convergence :** In this case, collision zone is formed. Due to buckling of earth's crust near this coalition zone, fold mountains of high-intensity are formed. e.g. Formation of Himalayas due to collision of Indo Australian plate and Eurasian plate where Indo-Australian plate subducts below Eurasian plate.

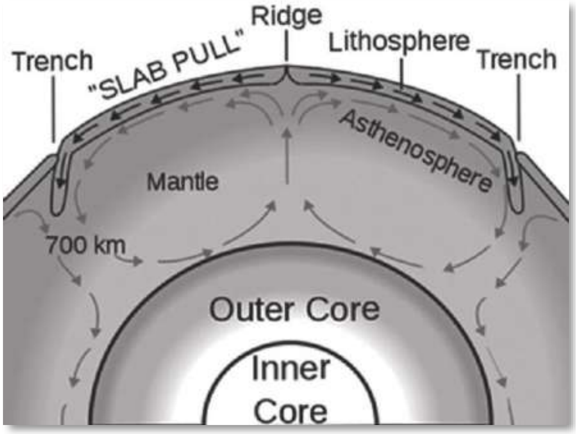


Continental-continental convergence

No landforms are created near transform plate boundaries.

(C) **Mechanism of the theory**

Near divergent plate boundaries, hot magma from the earth moves toward the surface and gets cooled. At the same time, plates near convergent plate boundaries subduct below and once they reach Benioff zone, which lies around hundred kilometres beneath the surface, they melt and gets destroyed. In this way, near convergent plate margins, there lies excess magma while near divergent plate margins, magma vacuum is created. To balance this, excess magma from convergent plate margin start travelling towards divergent plate margin beneath the surface giving birth to thermal convective currents. These are convection currents beneath the plates and complement the further plate movement. This phenomenon was postulated by Arthur Holmes.



Evidences of Plate Tectonics Theory

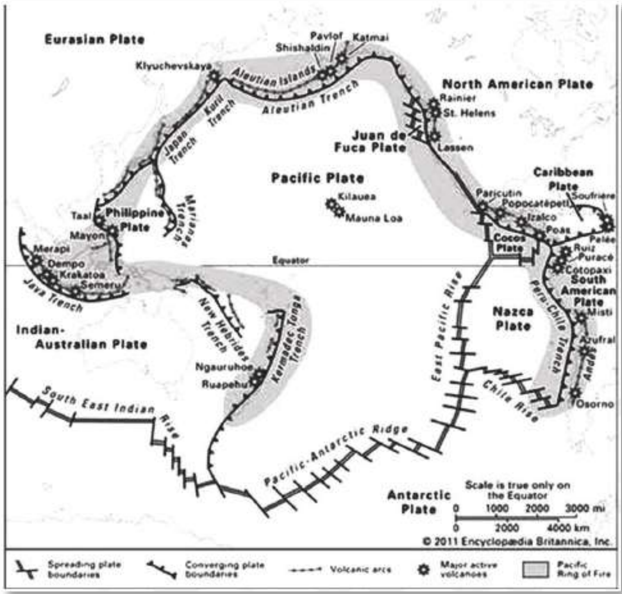
1. Occurrence of various landforms near various plate boundaries
2. Pacific ring of fire
3. Mountain ranges near plate boundaries
4. Volcanic activities near plate boundaries
5. Seafloor spreading
6. Palaeomagnetism (explained under seafloor spreading below)

Criticisms of Plate Tectonics Theory

1. Thermal convective currents are doubtful phenomenon.
2. This theory starts from Precambrian period and doesn't explain situation before it.
3. This theory fails to explain intra-plate volcanism which is associated with hotspots.
4. This theory fails to explain the varying rate of plate movement.

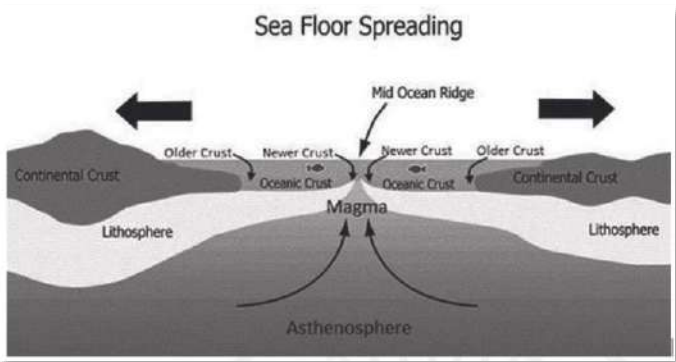
Achievements of Plate Tectonics Theory

1. It gives answers to almost all the questions raised by continental drift theory of Alfred Wegener.
2. As per previous theories, forces required for the movement of the continents were outside the earth, but plate tectonics theory successfully proves that forces within the earth are sufficient for movement of continents.



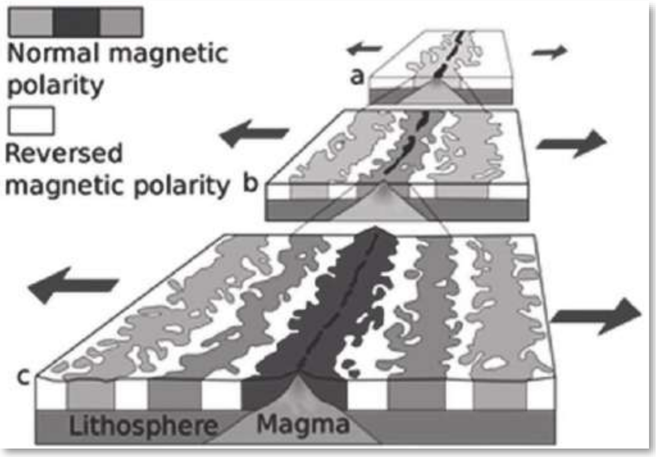
Pacific Ring of Fire

The Ring of Fire (also known as the Rim of Fire or the Circum-Pacific belt) is a major area in the basin of the Pacific Ocean where many earthquakes and volcanic eruptions occur. In a large 40,000 km horseshoe shape, it is associated with a nearly continuous series of oceanic trenches, volcanic arcs, volcanic belts and plate movements. It has 452 volcanoes (more than 75% of the world's active and dormant volcanoes). About 90% of the world's earthquakes occur along the Ring of Fire.The Ring of Fire is a direct result of plate tectonics: the movement and collisions of lithospheric plates, especially subduction of oceanic plates below surrounding continental plates.



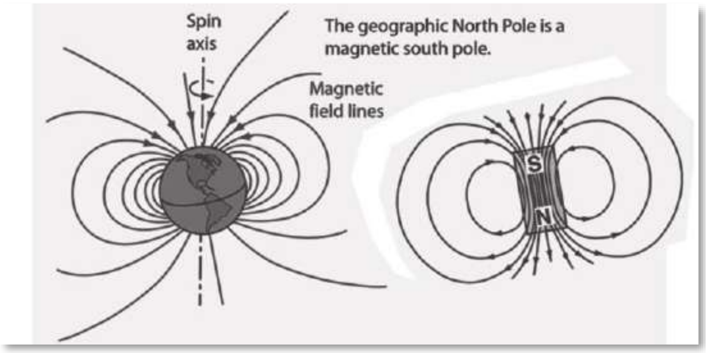
Concept of Sea Floor Spreading

The idea of seafloor spreading was first proposed by Harry Hess in 1960s. It is a process that occurs at mid oceanic ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. Due to divergence, tensional forces occur and lithosphere gets fractured and consequently magma rises up through these fractures. Solidification of this magma forms new sea floor. Due to divergence, older rocks are moved further away from the divergence zone while younger rocks are found nearer to the divergence zone. In this way, there is a continuous creation of new crust along mid oceanic ridges. This is called as seafloor spreading. During seafloor spreading, rising magma assumes the polarity of earth's geomagnetic field before solidification. Subsequently, parallel bands of rocks of similar magnetic polarity are observed on either side of the diverging margin. Continuation of this process over the long period of time for an alternate stripes of positive and negative magnetic anomalies on either side of the mid oceanic ridges results into the process of palaeomagnetism.

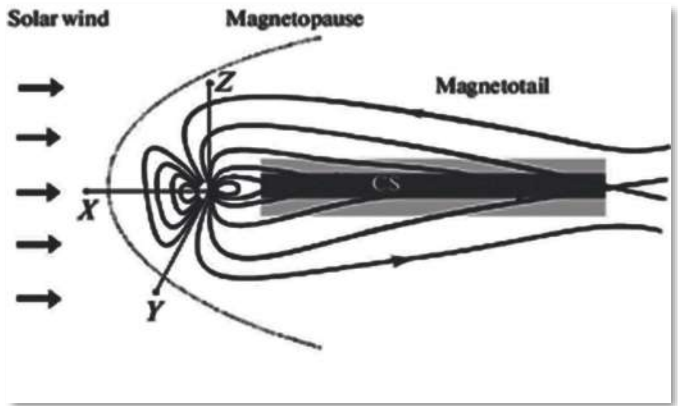


Geomagnetism

- Due to abundance of iron group elements in the core of the earth, especially Nickel and Iron, earth behaves like a giant magnet and this generates magnetic field around the earth. This phenomenon is known as geomagnetism. Magnetic South Pole lies near earth's geographic North Pole and magnetic North Pole lies near earth's geographic South Pole. Angular difference between magnetic and geographical axis is 11.30, this is known as declination of earth's magnetic field.
- The generation of this magnetic field is well explained by dynamo theory. According to this theory, rotating, convecting and electrically conducting fluid maintains magnetic field around the earth.



- Ideally, magnetic field of the earth should be like below
- Influence of sun on magnetosphere of the earth : Magnetic sphere is defined as the outer part of earth's magnetic field whose shape and behaviour is governed by the sun. Electrical particles coming from the sun in the form of solar winds flattens magnetosphere of the earth on the Sunward side (day side) and stretches it on the downward side (night side).



Importance of earth's magnetic field :

1. It protects the earth's atmosphere against charge particles from the solar wind. It protects the earth from extreme solar events like solar storms.
2. It is important for navigation tools like compass.
3. It is useful for radio communication.
4. Magnetosphere gives birth to Aurora lights on either poles.

Introduction

Rocks are the fundamental building blocks of the Earth's crust, formed through geological processes and classified into **igneous, sedimentary, and metamorphic types**. Their continuous transformation through the **rock cycle** reflects the dynamic nature of the Earth and its geomorphic processes.

Geological Classification of Rocks

1. Primary Rocks (Igneous Rocks)

- **Definition:** First-formed rocks of the Earth's crust, formed directly from cooling of magma.
- **Formation Process:**
  - Molten magma cooled and crystallized either inside (intrusive) or on the surface (extrusive).
- **Characteristics:**
  - Hard, crystalline structure.
  - Non-stratified (no layering).
  - Unfossiliferous (life had not developed when they formed).
  - Very resistant to weathering and erosion.
  - Form the base/foundation for other rock types.
  - Provide minerals and ores (e.g., granite with feldspar, basalt with iron & magnesium).
- **Examples:** Granite, Basalt, Diorite, Gabbro, Obsidian, Pumice.

2. Secondary Rocks (Sedimentary Rocks)

- **Definition:** Rocks formed by the **accumulation and compaction of sediments** derived from pre-existing rocks.
- **Formation Process:**
  - Weathering → Erosion → Transportation → Deposition → Compaction & Cementation.
- **Characteristics:**
  - Generally stratified/layered in appearance.
  - Softer and less resistant than igneous rocks.
  - May contain fossils (remains of plants/animals).
  - Color and texture vary depending on sediments.
  - Often porous and permeable (important for groundwater storage).
  - Important reservoirs for oil, natural gas, and coal.
- **Sub-Types:**
  - **Clastic:** Made of fragments of other rocks (sandstone, shale, conglomerate).
  - **Chemical:** Formed by precipitation of minerals (rock salt, gypsum, limestone).
  - **Organic:** From remains of living organisms (coal, chalk, fossiliferous limestone).
- **Examples:** Sandstone, Shale, Limestone, Conglomerate, Coal.

3. Tertiary Rocks (Metamorphic Rocks)

- **Definition:** Rocks formed when **primary (igneous) or secondary (sedimentary) rocks** are altered by **heat, pressure, or chemical processes**.
- **Formation Process:**
  - Metamorphism due to contact with magma (contact metamorphism).
  - Deep burial and tectonic forces (regional metamorphism).
- **Characteristics:**
  - Harder and more compact than their parent rocks.
  - May be foliated (layered) or non-foliated (massive).
  - Sometimes exhibit banding/lineation due to mineral reorientation.
  - New minerals may develop (e.g., mica, garnet).
  - Durable and resistant to weathering.
- **Examples:**
  - From Igneous: Granite → Gneiss; Basalt → Schist.
  - From Sedimentary: Limestone → Marble; Shale → Slate; Sandstone → Quartzite.

Based on mode of formation, rocks are divided into three categories:

1. Igneous rocks
2. Sedimentary rocks
3. Metamorphic rocks

Igneous Rocks

Igneous rocks are formed due to cooling, solidification and crystallisation of molten earth materials (generally known as magma and lava). E.g. Granite and Basalt

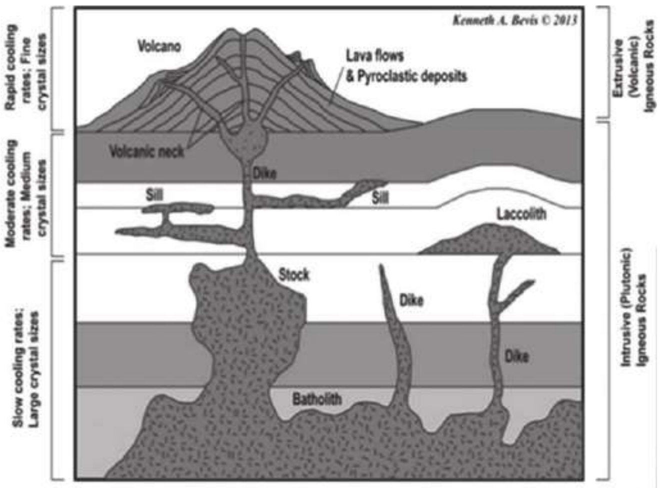
Characteristics of Igneous Rocks

1. As these are the first rocks to be formed on the earth, that's why they are also known as primary rocks or parent rocks.
2. Generally, they are hard and water percolates with great difficulty and that too along with joints and cracks.
3. Sometimes rocks become so soft due to their exposure to environmental conditions for longer duration that they can be easily dug out by spade. E.g. Basalt
4. These rocks are granular or crystalline which depends on the rate of cooling of magma or lava. If molten material is quickly solidified at the surface of the earth, then lesser and smaller crystals are formed. e.g. Basalt. On the other hand, if molten material gets sufficient time for solidification inside the earth, then more and larger crystals are formed. E.g. Granite.
5. They do not have strata like sedimentary rocks.
6. They are less affected by chemical weathering.
7. They do not contain fossils.
8. Number of joints increases upward in any igneous rocks mostly due to cooling, expansion and contraction, decrease in super incumbent load and earth's movements.
9. They are always associated with volcanic activities.
10. Valuable minerals like iron, nickel, cobalt are found in igneous rocks.
11. They are prone to faulting rather than folding.

Classification of igneous rocks (based on mode of occurrence)

1. **Intrusive igneous rocks :** They are formed due to cooling and solidification of magma below the surface of the earth. They get ample time for solidification and hence they have the largest crystals among all types of igneous rocks. They are further subdivided into -
   (a) **Plutonic igneous rocks :** They are the deepest igneous rocks. They possess the largest crystals among all. They are not helpful in soil formation. E.g. Granite
   (b) **Hypabyssal igneous rocks :** They are formed just below the surface of the earth and hence size of crystals is smaller than plutonic igneous rocks. They are further classified into batholith, laccolith, lopolith, phacolith, sill and dyke.

Extrusive Igneous Rocks : They are formed due to cooling and solidification of hot and molten lava on the earth's surface. They are generally formed during fissure eruption of volcanoes. They have smallest crystals among all. They are further classified into :
(a) Explosive type. e.g. volcanic cone
(b) Quiet type. E.g. Lava plains and lava plateaus.



Igneous rocks and associated landforms :

1. Hogback and Cuestas
2. Batholithic domes/patlands/exfoliation domes
3. Mesa and Butte
4. Volcanic messa and butte
5. Rectangular and hexagonal drainage pattern
6. Tors

Sedimentary Rocks

- Rocks formed due to aggregation and compaction of sediments are known as sedimentary rocks. E.g. Sandstone, limestone etc.
- Characteristics of sedimentary rocks :
  1. They are stratified or layered.
  2. They contain fossils of plants and animals.
  3. They cover the largest surface area of the earth that is around 75%.
  4. Component wise they form only 5% of the crust. Rest of the 95% is made up of igneous and metamorphic rocks.
  5. The size of sediments decreases from littoral margins to the centre of the sedimentary basins.

6. Crystals are not found in these rocks.
7. Batholiths, laccoliths, lopolith etc. are not found in these rocks.
8. Due to their porosity, groundwater is trapped in sedimentary rocks.
9. Sedimentary basins are potential ground for petroleum and natural gas reserves.
10. They do not undergo faulting; rather, they undergo folding and give birth to fold mountains.

Types of sedimentary rocks (based on transporting agent)

(1) Argillaceous sedimentary rocks/ aqueous sedimentary rocks
- (a) Marine sedimentary rocks
- (b) Riverine sedimentary rocks
- (c) Lacustrine sedimentary rocks (formed in Lake environment)

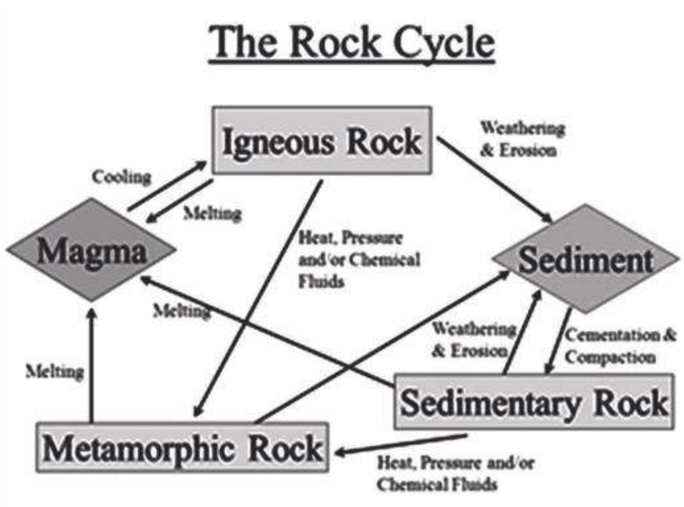
(2) Aeolian sedimentary rocks : They are formed due to deposition of sands brought down by the winds. They are generally found in hot and arid regions. Due to lack of consolidating agents, these are the weakest among all sedimentary rocks. E.g. Loess
- (a) Glacial sedimentary rocks
- (b) Lateral moraines
- (c) Medial moraines
- (d) Ground moraines
- (e) Terminal moraines

Metamorphic Rocks

- These are those rocks which have been changed either in form or composition without disintegration. These rocks can be formed from igneous, sedimentary or even metamorphic rocks. Examples of some metamorphic rocks are, Granite-Gneiss, Basalt-Slate, Limestone- Marble, Coal-Graphite-Diamond etc.
- Lava inflow, organic movement, geodynamic forces, plate tectonic activities, hydraulic pressure are some of major causes of metamorphism.
- Heat, pressure and chemical reactions (especially solution) are major agents of metamorphism. Based on these agents, metamorphic processes are further subdivided into thermal metamorphism, dynamic metamorphism, hydro metamorphism, hydrothermal metamorphism, contact metamorphism, regional metamorphism etc.

Rock Cycle

The rock cycle is a concept used to explain how the three basic rock types are related and how Earth processes, over geologic time, change a rock from one type into another. Plate tectonic activity, along with weathering and erosional processes, are responsible for the continued recycling of rocks.



Geomorphic Processes

Geomorphic processes are the processes responsible for the formation and alteration of the earth's surface. Geomorphic processes forms the landforms and other natural features of the earth surface through endogenic and exogenic forces.

Endogenic Process

These processes take place within the earth due to endogenic forces. These are constructive in nature giving birth to new landforms like mountains, plateaus and plains. They are further subdivided into following categories :

1. Diastrophic Processes : These processes take place due to tangential or horizontal movement of the earth's crust with gradual force.
   - (a) **Epeirogenic Processes :** These are continent forming processes.
   - (b) **Orogenic Process :** These are mountain building processes. Following two types of forces are necessary for orogeny -
     - (i) Tensile forces, working in opposite direction causing crustal fracture and faulting. Landforms associated with

faulting are, rift valley, graben and block mountain. Ex. Great Rift Valley of Africa, Black Forest mountain of Europe.

(ii) Compressive forces, working towards each other causing crustal bending and folding. Major landforms associated with folding is fold mountain. Ex. Himalayas, Alps, Rocky, Andes etc.

2. **Catastrophic processes :** These processes take place due to sudden intense force and cause considerable deformation over a short span of time -
   (a) Volcanic eruption
   (b) Earthquakes

Exogenic Processes

These processes take place due to exogenic forces which are generated from the atmosphere due to varying combinations of temperature and moisture. They are also known as denudation processes. These are destructive in nature. They are of three types.

1. Weathering processes
2. Erosional processes
3. Mass movement.

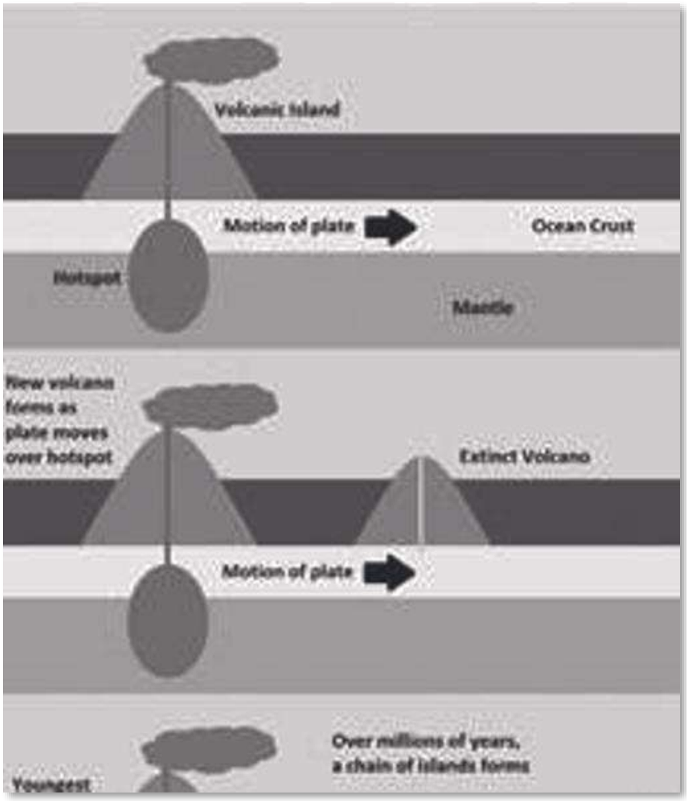
Introduction

Vulcanicity or volcanism covers all those processes and phenomena in which molten rock materials or magma rises into the crust or it is poured out on its surface. This means that vulcanicity can be of extrusive or of intrusive type. Vulcanicity is associated with following geophysical phenomena-

1. Volcano
2. Earthquake
3. Hot Springs
4. Geysers
5. Fumaroles
6. Mud volcano

Causes of Volcanism

1. Plate tectonics provide the most appropriate explanation of volcanism. Various plate boundaries are sites for active volcanism.
2. Hotspots : It is also known as intraplate volcanism. It includes a mantle plume which is a fixed source of magma in the asthenosphere. When magma reaches the lithosphere sending intrusions of magma upward into the plate, some of the magma erupts to form active volcanoes. Ex. Hawaii island, Reunion hotspot.

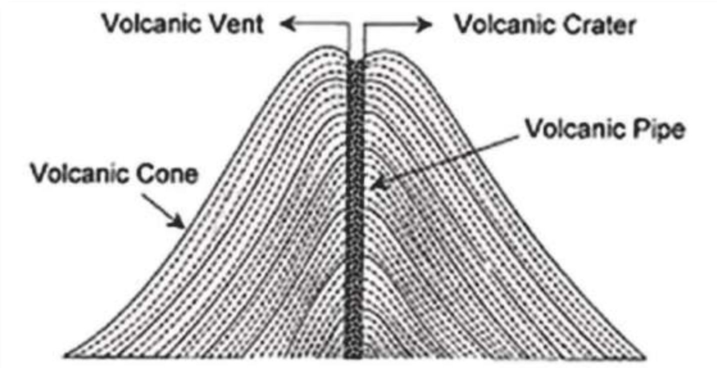


Volcano

A volcano is a vent or opening (usually circular or near circular) through which heated materials consisting of hot gases, water vapour, liquid lava and fragments of rocks are ejected from the highly heated interior to the surface of the earth.

Following are the components of volcano -

1. **Volcanic Cone :** It is accumulated volcanic material around the central volcanic vent.
2. **Volcanic vent/ Volcanic Opening/Volcanic mouth :** It is connected with the interior part of the earth by a narrow pipe and volcanic materials are ejected through this.
3. **Volcanic Pipe :** It transports hot molten materials from the interior of the earth to the volcanic vent.
4. **Volcanic crater/Caldera :** It is the enlarged form of volcanic vent.



Classification of volcanoes (on the basis of mode of eruption)

(A) Central eruption type or Explosive eruption type volcanoes
   1. Hawaiian type
   2. Strombolian type
   3. Vulcanian type
   4. Pelean type
   5. Vesuvius type

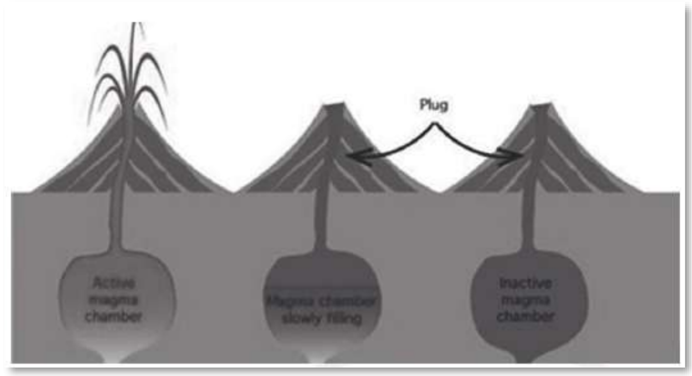
(B) Fissure eruption type or Quiet volcanoes or Effusive volcanoes
   1. Lava flood or lava flow
   2. Mudflow
   3. Fumaroles

(C) Subaqueous volcanoes (these are underwater marine volcanoes)

(D) Exhalative volcanoes (gases form the majority of volcanic material in these volcanoes)

Classification of volcanoes (on the basis of periodicity of eruptions)

1. **Active Volcano :** They constantly eject volcanic lava, gases, ashes and fragmented materials. They generally occur near divergent and convergent plate boundaries and near hotspots and mantle plumes. Ex. Mount Stromboli (Italy), Mount Etna (Sicily)
2. **Dormant Volcano :** These volcanoes become quiet after their eruptions for some time and there are no indications for future eruptions, but suddenly they erupt very violently and cause enormous damage to human health and wealth. Ex. Mount Fujiyama (Japan), Barren Island Volcano (Andaman and Nicobar)
3. **Extinct Volcano :** There are no indications of future eruptions. Volcanic crater is filled up with water and crater lakes are formed. Ex. Mount Kilimanjaro (Tanzania), Narcondam Island Volcano (India)

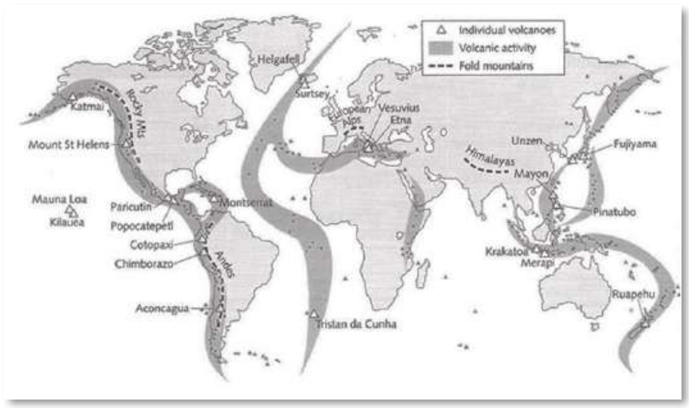


Volcanic Material

1. **Gaseous material :** It includes water vapour and various gases like carbon dioxide, nitrogen oxide, sulphur dioxide, hydrogen, carbon monoxide etc. Water vapour constitutes around 60 to 90% of the total gases discharged. Water vapours are further divided into phreatic and magmatic vapours.
2. **Liquid material :** It includes magma and lava. Molten rock materials below the earth surface are called as Magma while they are called Lava when they come at the earth's surface. Based on the amount of silica present in molten materials, they are further divided into acidic (amount of silica present is greater than 65%) and basic (amount of silica present is less than 65%). Basic lava is less viscous and more fluid; hence it covers large distances while acidic lava covers short distances.
3. **Solid material :** They are also known as fragmental or pyroclastic materials. With the ascending order of their size, they are categorised as volcanic dust, volcanic ash, lapilli and volcanic bombs.

Global distribution of volcanoes

Volcanoes are associated with the weaker zones of the earth's crust and thus their distribution pattern is zonal in character. They are closely associated with seismic events. Volcanoes also occur at the meeting zones of the continents and oceans that is along coastal margins. Volcanoes can be found near the zone of mountain building and fracturing. Plate tectonics provides the satisfactory explanation of origin of volcanoes as well as their global distribution. Around 15% of the world's active volcanoes are found along constructive plate boundaries while 80% of world's active volcanoes are associated with destructive plate boundaries. Remaining volcanoes are found in intraplate regions, that is, the region of hotspots and mantle plume.

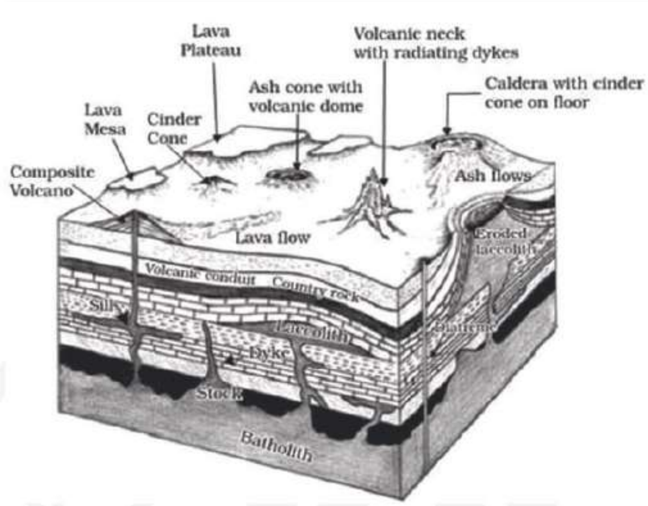


1. **Circum-Pacific belt :** It is also known as Pacific ring of fire or fire girdle of the Pacific. It includes significant volcanoes like Mount Fujiyama, Mount Cotopaxi, Mount Shasta, Mount Pinatubo, Mount Saint Helens.
2. **Mid continental belt :** It includes the volcanoes of Alps Mountain and the Mediterranean sea and the volcanoes of fault zone of eastern Africa. The famous volcanoes of this region are Mount Stromboli (due to its continuous eruption, it is also known as lighthouse of the Mediterranean) and Mount Etna. Generally made continental belt stretches towards Himalayas but volcano eruptions are not observed in Himalayas- mainly because of compact and thick crust formed due to intense folding activity there.

3. **Mid Atlantic belt :** This belt has volcanoes mainly because of fissure eruption at divergent plate boundaries. Volcanoes in this region are generally quiet in nature. Most active volcanic area is Iceland.
4. **Intraplate volcanoes :** The major reason behind these volcanoes are mantle plumes and hotspots. Ex. Hawaii and Reunion hotspots.

Landforms created by volcano

1. **Intrusive volcanic landforms :** They include batholith, laccolith, lopolith, phacolith, sill, dyke, volcanic plug and stack.
2. **Extrusive volcanic landforms**
   - **(A) From explosive type of eruptions**
     - **(i) Elevated land forms**
       - Cinder or Ash cone
       - Composite cone
       - Parasite cone/ lateral cone / adventive cone
       - Basic lava cone
       - Acid lava cone
       - Lava dome
       - Volcanic neck
     - **(ii) Depressed landforms**
       - Craters and crater lakes
       - Caldera and caldera lake
   - **(B) From fissure eruptions**
     - (i) Lava plateau
     - (ii) Lava plain

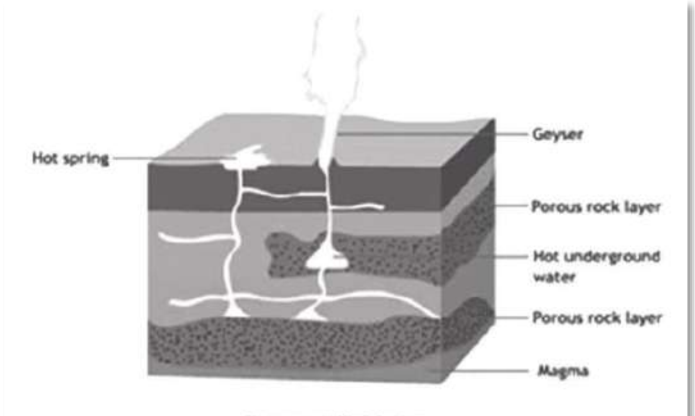


Hazardous effects of volcanic eruptions

1. Volcanic eruptions cause heavy damage to human lives and property through advancing hot lava and fall out of volcanic materials.
2. Volcanic eruptions destroy agricultural farms and pastures, plug rivers and lakes and can burn and destroy forests.
3. Fallout of immense quantity of volcanic materials specially pyroclastic materials destroy human structures. It can destroy vegetation and can disrupt and divert natural drainage systems.
4. Due to eruption of poisonous gases, it may create health hazard.
5. Emission of large quantity of sulphur and nitrogen gases may lead to acid rain.
6. Volcanic eruptions emit large amount of dust. This increases the availability of hygroscopic nuclei in the atmosphere which causes heavy rainfall mixed with falling volcanic dust and ash. This causes enormous mudflow.
7. Earthquakes and tsunamis
8. It changes the radiation balance of the earth and the atmosphere. Greater concentration of volcanic dust and ash in the sky reduces the amount of incoming insolation and traps outgoing long wave terrestrial radiation.
9. Volcanic ash and dust affects visibility and hampers navigation.

Hot spring and geysers

- Hot springs are geothermal heated ground water coming out from the earth's crust. Groundwater moves downwards and is heated by magma or hot rock, then hot water rises giving birth to hot spring. Iceland, Japan, Hawaii have good pools of hot springs.
- Geyser is a kind of hot spring characterised by intermittent discharge of water ejected turbulently and accompanied by steam. It occurs when groundwater is heated beyond its boiling point due to magma or hot rocks. Water comes out from a small and narrow vent which is connected to underground aquifer. New Zealand, Yellowstone National Park of USA, Iceland have numerous geysers.
- Hot spring and geysers form due to same cause, the only difference between them lies in the fact that there is continuous spouting of hot water from hot springs while there is intermittent spouting of water from geysers. Generally, temperature of water coming out of hot spring and geyser ranges between 750 to 900C.



Geysers and Hot Springs

Fumaroles

- Fumarole is a vent through which there is emission of gases and water vapour. Emission of gases and vapours begins after the emission of volcanic material is terminated in an active volcano. The fumarole show the signs of activeness of any volcano. The gases and vapours are generated due to cooling and contraction of magma after the termination of the eruption of volcano. e.g. Katmai volcano of Alaska, valley of Ten Thousand Smokes in Alaska.
- Temperature of vapour emitted from fumarole is around 6450C. This vapour mainly includes carbon dioxide, hydrochloric acid, hydrogen sulphide, nitrogen, some oxygen and ammonia. But water vapour constitutes almost 98 to 99% of total gases emitted. Sulphur is the most important mineral emitted with gases.

Hot springs, geysers and fumaroles are important for humans in following ways,

1. Minerals found near them have great medicinal value.
2. Minerals coming out nearby can be mined easily. For example, sulphur extraction at Yellowstone National Park.
3. The heat energy coming out of these can be used for warming purposes, like heating houses and swimming pools, providing steam to boilers. Iceland extracts around 80% of its heat from hot springs and geysers.
4. These are the ideal locations for extracting geothermal energy. Ex. Manikaran (Himachal Pradesh) and Puga valley (Ladakh).
5. Pleasing geographical features promote tourism in cold temperate regions.
6. Farming has become possible in Arctic countries as snow melts away because of the heat coming from hot springs, geysers and fumarole.

Mud Volcano

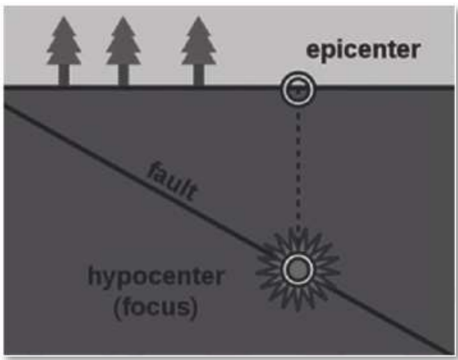
- **General Features**
  - A **mud volcano** is a geological formation where mud, water, and gases erupt onto the surface.
  - Unlike true volcanoes, they **do not produce lava or magma**.
  - Activity is driven by **pressurized gases** (methane, CO_2, nitrogen, hydrogen sulfide) and **subsurface fluids**.
  - They vary in size from **less than 1 meter** to **over 10 kilometers** in diameter.
- **Formation**
  - Occur in regions with **thick sedimentary deposits** (especially clay).
  - Often linked to **subduction zones, tectonic plate boundaries, and fault lines**.
  - Pressure builds up underground due to **hydrocarbon activity or tectonic compression**.
  - Escaping gas and fluid push sediments upward, creating a **cone or dome-shaped mound**.
- **Distribution**
  - Found worldwide; over 1,000 identified.
  - **Major concentrations in:**
    - **Azerbaijan (Caspian Sea region)** – known as the "land of mud volcanoes."
    - **Indonesia** (e.g., Sidoarjo "Lusi" mud eruption).
    - **Pakistan**, **Iran**, **Trinidad**, **Ukraine**, and **Italy**.
  - Also present **underwater** on continental margins.
- **Characteristics**
  - Can release cool mud or hot slurry (temperature varies with depth and gas pressure).
  - Mudflows can last for days to decades.
  - Some eruptions are explosive, throwing mud tens of meters high.
  - Frequently accompanied by fire flames if methane ignites.
  - Some mud volcanoes emit saltwater and mineral-rich fluids, leaving mud pools and

barren landscapes.

- **Environmental & Scientific Importance**
  - Provide clues to underground oil and gas deposits.
  - Important for studying seismic and tectonic activity.
  - Support unique microbial ecosystems that thrive on methane.
  - Sometimes considered natural hazards — eruptions can bury villages or farmland.
  - The Lusi mud volcano in Indonesia (2006) displaced tens of thousands of people.

Earthquakes

- Earthquake is the result of a sudden release of energy in the earth's crust that creates systematic waves. Earthquakes are caused mainly due to disequilibrium in any part of the crust of the earth. Such disequilibrium can be caused due to volcanic eruptions, faulting and folding, upwarping and downwarping, gaseous expansion and contraction inside the earth, hydrostatic pressure, plate movements or man-made activities.
- The place of origin of an earthquake is called focus or hypocentre. It is always located inside the earth but its depth varies from place to place. Depending on the depth of this focus, earthquakes are divided into shallow and deep earthquakes. The place on the ground surface which is perpendicular to the focus and where seismic waves are recorded for the first time is called epicentre.
- The waves generated by an earthquake are called seismic waves which are recorded on seismograph. (explained in interior of the earth) The magnitude, that is the energy released, of an earthquake is measured by Richter scale whereas the intensity, that is the damage caused, is measured by Mercalli scale.

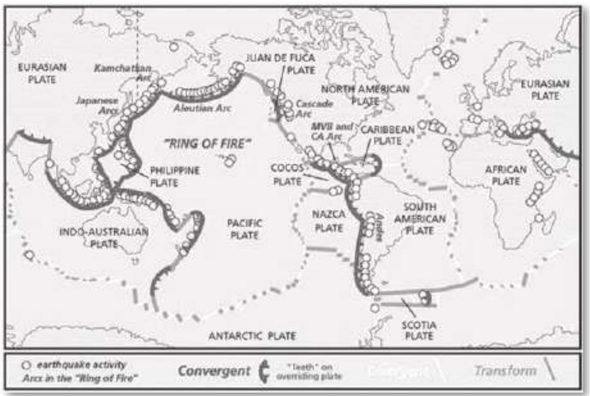


Causes of earthquake

1. **Vulcanicity :** The explosive oil and gas that is coming out during volcanic eruption push the crystal surface from below with great force and cause tremors.
2. **Faulting and Elastic Rebound Theory of Reid :** The horizontal and vertical movements caused by endogenic forces result in the formation of faults which causes isostatic disequilibrium and causes earthquakes.
3. **Hydrostatic Factors :** Pressure and anthropogenic activities like deep mining, pumping of groundwater and oil explosions, construction of water bodies like reservoirs and lakes (also known as reservoir induced seismicity), etc.
4. **Plate tectonics :** It provides the most logical information about the volcanoes and earthquakes. Earthquakes occur all along the three types of boundaries but with varying intensity.

Global distribution of earthquakes

- As stated above, earthquakes occur along plate boundaries but with varying intensity. Earthquakes occurring near convergent plate boundaries are of very high intensity earthquakes while earthquakes occurring near divergent plate boundaries are of moderate intensity.
- Like volcanoes, earthquakes are associated with the weaker and isostatically disturbed areas of the globe.
- Most of the world earthquakes occur in following zones,
  1. The zone of young fold mountains
  2. The zone of faulting and fracturing
  3. The zone representing the junction of continents and ocean
  4. The zone of active volcanoes
  5. The zone along different plate boundaries
     - Around 65% of all earthquakes occur in the circum-Pacific belt. 21% earthquakes occur in mid continental belt and remaining 5% occur in the interiors of plates.



Hazardous effects of earthquake

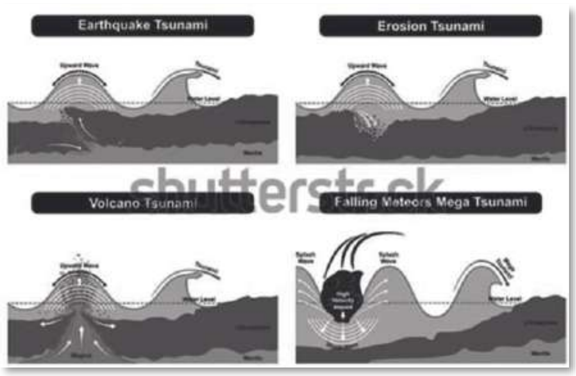
1. Loss of life and property
2. Slope instability, slope failure and landslide
3. Damage to town and cities infrastructure
4. Deformation of ground surface
5. Fires in houses, mines and factories because of overturning of cooking gas cylinders, contact of live electric wires, churning of blast furnaces and other appliances
6. Flash floods because of blocking of river flow
7. Tsunamis

Tsunami

Tsunami is a Japanese word which means harbour waves. A tsunami is a series of waves in a water body caused by the displacement of a large volume of water, generally in an ocean or in a large lake.

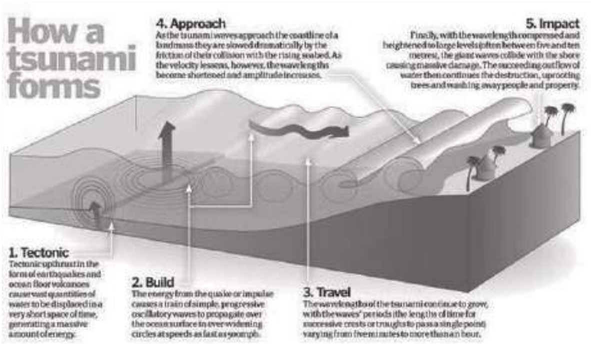
Causes of Tsunami

1. Underwater marine earthquake or near coast earthquake
2. Submarine landslides or near coast landslide
3. Submarine volcano or near coast volcanoes
4. Impact of extra terrestrial collision like meteorite
5. Anthropogenic activities like nuclear testing, massive explosion, seafloor blasting etc.



Characteristics of Tsunami

1. In deep oceans, tsunamis have hundreds of miles of length from crest to crest. Their amplitude is very less (2-4 meters).
2. They travel with great velocity in deep oceans sometimes exceeding 900 km/h.
3. Due to hundreds of miles of length and very less amplitude, tsunamis are very difficult to detect in deep oceans.
4. As tsunamis approach in shallow waters, velocity of waves decreases due to feeling of bottom effect and consequently wave height increases. This combined phenomenon is known as shoaling effect.
5. Due to shoaling effect, height of tsunamis can be reached above 30 m and their velocity is reduced to 30-50 km/h.
6. As tsunani travels towards the coast, its speed decrases. Consequently, as tsunamis's speed diminishes, its kinetic energy decreases and potential energy increases in the form of increasing height of waves.
7. The total height of a tsunami wave from its bottom is called as run-up.



Hazardous effects of tsunami

1. Loss of human life and property.
2. Flooding and contamination of drinking water which can cause waterborne diseases like malaria and dengue.
3. Physiographical changes. For example, many of the smaller islands near the coast of Sumatra have been disappeared during 2004 tsunami.
4. Impact of huge water mass in the form of tsunami makes the earth to wobble on its axis. This affects the motion of the earth. For example, in 2011 Japan tsunami has caused the planet to spin 3 microseconds faster.
5. Decline of soil fertility and agricultural production in coastal areas.
6. Adverse effect on marine life and corals.

5. Geosynclines and Theories of Mountain Building

Introduction

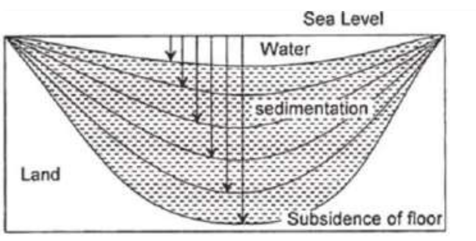
The geological history of the continents and ocean basins denotes that in the beginning the globe was characterised by two important features that is rigid masses and geosynclines. Rigid masses representing the ancient nuclei of the present continents have remained stable for considerably longer periods of time and they were surrounded by mobile zones of water characterised by extensive sedimentation. These mobile zones of water are known as geosynclines. Geosynclines have now been converted by compressive forces into fold mountain ranges.

Certain similarities between present fold mountains and geosynclines give support to this claim.

Following are some characteristics of fold mountains :

1. Fold mountains are the youngest mountains on the earth's surface.
2. Fold mountains are formed due to folding of sedimentary rocks by strong compressive forces and hence fossils are found in fold mountains.
3. Fossils found in fold mountains are of marine origin especially of those organisms which can survive only in shallow water or shallow sea.
4. Folded mountains extend for greater lengths but their widths are far smaller than their lengths. For example - length of Himalaya is around 2400 km while its maximum width is only 400 km.
5. Fold mountains are generally found in Alaska having one side concave slope and other side convex slope.
6. Fold mountains are found along the margins of the continents facing oceans.

After observing all these characteristics of fold mountains, it can be said that fold mountains have been found in long narrow and shallow seas.

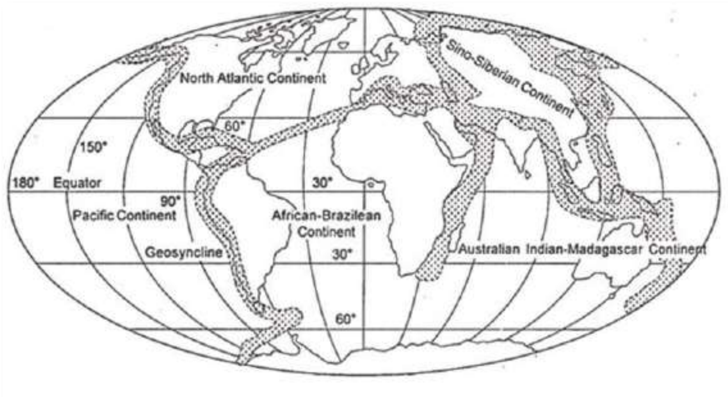


General characteristics of Geosynclines :

1. Geosynclines are long, narrow and shallow water depressions characterised by continuous sedimentation and subsidence.
2. Location, shape, dimension and extent of geosynclines have considerably changed due to earth movements and geological processes.
3. Geosynclines are mobile zones of water.
4. They are generally bordered by rigid masses which are called forelands

Hence by comparing the properties of fold mountains and geosynclines, it can be said that geosynclines have been cradles of mountains.

Hall and Dana are credited for the concept of geosynclines. While their global distribution is given by E. Haug, Haug's concept is slightly different than that of Hall and Dana. According to Haug, geosynclines are relatively deepwater areas and they are much longer than they are wide while according to Hall and Dana geosynclines are relatively shallow water depressions. Haug also drew the Paleogeographical map of the world and further postulated that the position of present-day mountains were previously occupied by long and relatively deeper geosynclines. He divided the world into five rigid masses and four geosynclines in following way -



Rigid masses

1. North Atlantic mass
2. Sino Siberian mass
3. Africa Brazilian mass
4. Australia-India-Madagascar mass
5. Pacific mass

Geosynclines

1. Rockies Geosynclines
2. Ural Geosynclines

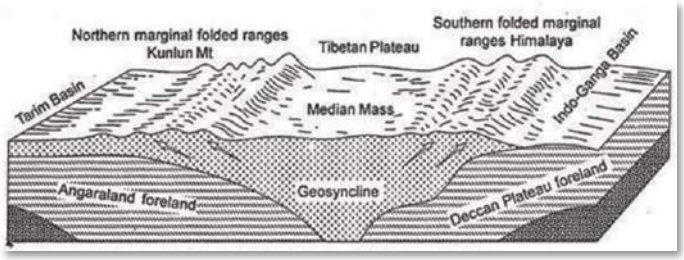
3. Tethys Geosynclines
4. Circum-pacific Geosynclines

Concept of Geosyncline was postulated by Hall and Dana, and further develop by Haug. But they never talked about process of mountain building from geosynclines. This theory was given by Kober. According to Kober, geosynclines have passed through three stages and has given birth to fold mountains of present times.

(i) **Lithogenesis :** This is the stage of formation of Geosynclines (orogen) and their subsequent sedimentation and subsidence.

(ii) **Orogenesis :** Both the rigid masses (kratogen/foreland) started moving towards each other giving birth to median mass (zwischengebirge) and parallel ranges (randketten).

(iii) **Gliptogenesis :** This is the stage of gradual rise of mountains and their subsequent denudation.



The process of disintegration and decomposition of rocks in situ is generally called weathering.

In weathering, transporting agent is not involved. This weathering is a static process. The major difference between weathering and erosion is the availability of transporting agent which is available in the process of erosion.

Controlling factors of weathering

1. **Composition and structure of rocks :** Mineral composition, joint patterns, layering system, faulting, folding etc. largely affect the nature and intensity of weathering. For example - carbonate rocks having more soluble minerals are easily affected by chemical weathering. Well jointed rocks are more subjected to mechanical disintegration. Rocks with horizontal beads are less susceptible to insolation weathering while rocks with vertical beds are more susceptible to insolation weathering.
2. **Nature of ground slope :** Ground slope affects mechanical disintegration. A steep slopes rate of mechanical disintegration is fast while on gentle slopes, rate of mechanical disintegration is slow.
3. **Climate :** It is the most dominant factor. For example - limestone is weathered easily in humid conditions, but it become resistant in hot and arid climate. Mechanical disintegration of rocks is more dominant in tropical and semi arid regions than temperate and polar regions. Seasonal change also affect weathering processes, for example, in monsoon regions during dry season, mechanical weathering is rampant while in rainy season chemical weathering is rampant.
4. **Floral effects :** Vegetation acts in two ways on weathering processes. Sometimes, vegetation bind the rocks together through their roots and protect them from weathering and erosion. But sometime penetration of roots weakens the rocks and breaks them into several blocks.

Agents of weathering

(A) Physical or mechanical weathering agents

1. Moisture and water
2. Frost
3. Insolation or temperature
4. Wind

(B) Chemical weathering agents

1. Oxygen
2. Hydrogen
3. Carbon dioxide

(C) Biological weathering agents

1. Flora
2. Fauna
3. Anthropogenic activities

Weathering processes

(A) **Physical or mechanical weathering :** It leads to fragmentation and breakdown of rock masses into big blocks and boulders.

1. **Block disintegration due to temperature change :** It generally takes place on crystalline igneous rocks which are more affected by temperature changes. Sedimentary rocks are least affected by temperature. This weathering takes place in hot and arid regions where daily temperature range is very high. Rock surfaces are heated during daytime due to which their outer layer expands. During nights the rocks are cold due to decrease in temperature which leads to contraction of the outer layer. The repeatation of expansion and contraction causes tension and stresses which creates cracks in the rocks. Rock boulders broke up along these cracks leading to weathering.
2. **Granular disintegration due to temperature change :** It is similar to block disintegration due to temperature change process. If the rocks are coarse grained and are of different colours, they absorb insolation differently. Thus, the different parts of the same rock gets expanded and contracted differentially. This causes stress within the rocks and they are disintegrated into smaller particles.
3. **Shattering due to rain shower and heat :** In this process, the outer heated shells of the rocks are shattered due to sudden rain showers in hot climatic regions specially in hot deserts.
4. **Block disintegration due to frost :** Rocks get disintegrated into boulders due to

freeze and thaw of water trapped between rock pores and crevices. Alternate freezing and thawing can change volume of water droplet by about 10%. This creates stress leading to disintegration of rocks. This process is also known as frost weathering or congelifraction.

5. **Exfoliation due to temperature and wind :** It includes peeling of concentric shells of rocks due to combined action of heat and wind in hot and semi arid regions and in monsoon lands. It is more common in crystalline rocks. It is also known as onion weathering.
6. **Exfoliation due to unloading :** Unloading or release of stress in a rock that produces expansion joints can cause exfolliation. Stress reduces when underlying rock is exposed due to pressure of overlying rocks. This process is also known as sheeting.

(B) Chemical weathering Exfoliation due to unloading

1. **Solution :** This is considered as the first step in the chemical weathering. Solution process depends on the nature of rocks and solubility of rocks. It also depends on temperature, carbon dioxide content of water and pH of the solution. Limestones are more susceptible to solution processes. When rainwater mixes with atmospheric carbon dioxide, it becomes active solvent and when it comes in contact with the limestone, it dissolves it. Solution process of limestone gives unique karst topography.
2. **Oxidation :** It is the reaction of atmospheric oxygen with metals to form oxides. For example, when water mixed with atmospheric oxygen comes in contact with iron bearing rocks; the iron oxidises to form ferrous oxides and further oxidation of ferrous oxides produce ferric oxide which is nothing but rust.
3. **Carbonation :** It is the reaction of carbonate or bicarbonate ions with minerals producing water soluble product.
4. **Hydration :** It is the process of addition of water to the minerals. After absorption of water, rocks undergo the process of expansion due to increase in volume. This creates stress and consequently disintegration of rocks. This process is also known as kaolinizaion.
5. **Hydrolysis :** This is the chemical reaction between mineral and water. Silicate minerals are most affected by this process.
6. **Chelation :** In this process, metallic cations are incorporated into hydrocarbon molecules.

(C) Biological weathering

1. **Faunal weathering :** Burrowing animals, worms and other organisms helps in gradual breakdown of rocks into smaller fragments. These organisms repeatedly mix up the soil materials and this always expose fresh materials to weathering agents.
2. **Floral weathering :** Cracks are widened by root penetration and consequent root pressure leading to rock disintegration.
3. **Anthropogenic weathering :** It includes activities like mining, blasting, quarrying, explosions etc
4. **Biochemical weathering :** Living organisms weathers rocks through physical as well as chemical ways by various processes like cation root exchange, solution, chelation, activities of chemotropic bacteria, etc. Burrowing organisms like earthworms not only mix various layers of the soils but through their excreta add various chemicals into the soil which leads to chemical weathering processes. Similarly, soil atmosphere is largely affected by root respiration you must contain increase moisture because of Foral presence.

Importance of weathering

1. It is the first step of soil formation and its enrichment.
2. Helps in the enrichment of soil by addition of various minerals through disintegration of rocks.
3. It leads to erosional processes.
4. Weathering lowers the surfaces and plays an important role in evolution of landforms and their modifications.

Erosion

Erosion is the process that breaks things down. Erosion is the breakdown of the continents and the landforms. The overall effect of breaking down and weathering the land is called denudation. Denudation is the process of erosion. In short, erosion is the geological process in which landform are worn away and transported by agents of erosion.

Factors controlling erosion

1. Gradient or slope
2. Volume of agent
3. Tools of erosion

Agents of erosion

1. Water including surface and ground water
2. Wind
3. Glaciers
4. Sea waves

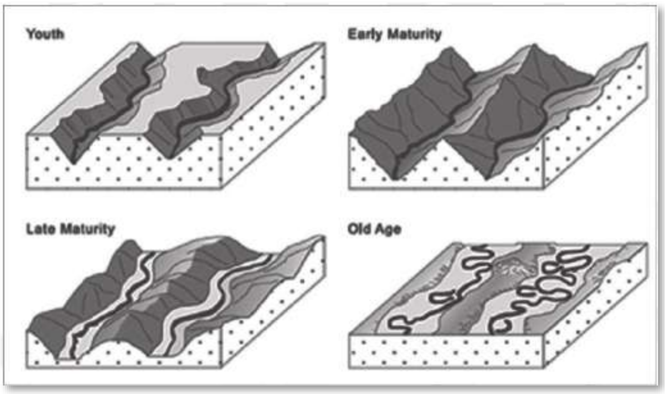
Types of erosion

1. Vertical erosion
2. Lateral erosion
3. Headward erosion

Limit for maximum vertical erosion by any agent beyond which it cannot degrade is known as base level of erosion. The sea level is known as grand base level of erosion. This means that below sea level there are no erosional processes taking place.

Cycle of erosion

- Endogenic forces create vertical irregularities and exogenic forces destroy them. This endless process of creation and destruction is going on throughout the geological time. Creation is followed by the destruction and destruction is followed by the creation. This process is known as cycle of erosion.
- Cycle of erosion is the period of time during which an uplifted landmass undergoes transformation by the denudational processes ending into low featureless plain and further upliftment of that plain. Cycle of erosion is evolved through three sequential periods (that is, youth followed by maturity and maturity is followed by old stage).
  (1) **Youth :** It is characterised by high rate of erosion and almost no deposition.



  (2) **Maturity :** It is characterised by decreasing rate of erosion and increasing rate of deposition.
  (3) **Old :** It is characterised by almost nil vertical erosion, small amount of lateral erosion and maximum rate of deposition.
- Due to rising sea level, there is a positive change in base level and this pushes cycle of erosion forward while due to fall in the sea level, there is a negative change in the base level and this pulls back cycle of erosion backward. Such a pulling back of cycle of erosion is known as rejuvenation.

Landforms associated with rejuvenation (negative change in base level)

1. Topographic discordance
2. Paired terraces
3. Valley in valley topography
4. Uplifted peneplains
5. Incised meanders
6. Knick points and knick point waterfalls

Landforms associated with positive change in base level

1. Formation of ria coasts and estuaries
2. Formation of buried valleys or channels
3. Formation of floodplains
4. Formation and development of sea islands near coasts

Agent	Erosional Landforms	Depositional Landforms	Cycle of Erosion			Processes involved in erosion
			Youth	Maturity	Old	
Surface Water (Fluvial Cycle of erosion / Normal Cycle of erosion given by W. M. Davis	V-shaped valley Gorge and Canyon Waterfall and rapids Potholes Structural benches/ river terraces Meanders Ox-bow lakes Peneplains and monadnocks	Alluvial fan and cones Natural levees River delta (Arcuate delta, bird - foot delta and estuarine delta 4. Flood plains	Abundance of consequent streams Prominent headward erosion Valley deepening through vertical erosion Dendritic drainage pattern Pothole drilling Maximum kinetic energy	Formation of alluvial fans and cones Prominent lateral erosion U-shaped valleys Meanders Natural levees Flood plains Ox-bow lakes	Erosion almost stops and maximum deposition happens Decreasing channel gradient Spreading of stream water over a large area Obstruction in channel flow Decrease in velocity of streams Formation of delta and delta lakes Formation of peneplains and monadnocks (in dry and arid regions)	1. Solution or corrosion (chemical erosion - similar to that of chemical weathering) Abrasion or corrasion (removal of loose materials of the rocks of valley walls and valley floors with the help of erosional tools) Attrition (mechanical wear and tear of erosional tools themselves) Hydraulic action (Break down due to impact of water)
			7. Convex valley slopes			
			8. V-shaped valleys			
			9. Canyons and gorges			
			10. Numerous waterfalls and rapids			
			11. River capturing phenomenon.			
			12. Interlocking spurs			

Agent	Erosional	Depositional	Cycle of Erosion			Processes involved in erosion
	Landforms	Landforms	Youth	Maturity	Old	
Groundwater (Karst cycle of erosion given by Cvijic and Beede)	Lapies Sink holes Swallow holes Dolines Uvala Polje Collapse Sinks Solution Pans Karst Lakes Karst Window	All types of deposits in the caves are collectively called as Speleothems Travertine Stalactites and stalagmites Cave pillars	Initiation of surface drainage Sinkholes and swallow holes Lapies Dolines Sinking creeks and blind valleys are formed	Total disappearance of surface drainage. Numerous sinking creeks Uvulas and poljes Numerous karst windows	1. Almost entire limestone is washed off. 2. Formation of featureless plain	Only solution process as groundwater is not an active erosional agent.
	11. Cockpits					
	12. Valleys (Sinking creek, blind valley, karst valley)					
	13. Caves or caverns					
	14. Ponors					
	15. Natural bridge					

Agent	Erosional Landforms	Depositional Landforms	Cycle of Erosion			Processes involved in erosion
			Youth	Maturity	Old	
Sea Waves (Marine cycle of erosion given by W.M.Davis)	Cliff Wave-cut platform Sea Caves Sea Arc Natural chimney or blow hole or gloup Stack or stump Cove	Beaches Sand bars or spits (offshore bars, longshore bars, hooked bar, looped bar, connecting bars, winged bars, tombolo) Coastal wetlands Sabkha Wave-built platform	Cliff Wave-cut platforms Sea Caves Blowholes Sea arc Stacks Spits Shoreline is irregular	Most of the features developed during youth stage are obliterated.	All the features developed during youth stage are obliterated and coastline becomes almost Street and there is formation of beaches	Hydraulic action Abrasion or corrasion Corrosion or solution Attrition Wave pressure.

Agent	Erosional Landforms	Depositional Landforms	Cycle of Erosion			Processes involved in erosion
			Youth	Maturity	Old	
Wind (Aeolian cycle of erosion or Arid cycle of erosion given by W.M.Davis)	Deflation basins and desert oasis Blow outs Mushroom rocks (Pedastal/ Pizlfelsen) Inselbergs and Bornhardts Demiselles	Ripple marks Sand dunes (Nebkha and lunette) Seif (longitudinal sand dune) Barchan dunes Star dunes Parabolic dunes Loess Bolson, Playa and Bajda	Wind as a tool of erosion does not passes through youth, maturity and old phases. Cycle of erosion in desert is mostly controlled by seasonal streams and it is similar to that of normal cycle of erosion. Also cycle of erosion is applicable only in the case of mountains deserts and not in the case of open deserts.			Deflation (process of removing, lifting and blowing away dry and loose particles of sand) Abrasion (also known as sand blasting because sand acts as a polishing tool) Attrition
	6. Zeugen					
	7. Yardang					
	8. Dreikanter and zweikanter					
	9. Stone lattice					
	10. Wind bridge and wind window					

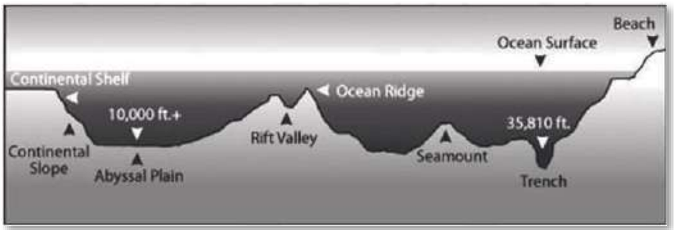
Agent	Erosional Landforms	Depositional Landforms	Cycle of Erosion			Processes involved in erosion
			Youth	Maturity	Old	
Glacier (Glacial cycle of erosion given by W.M.Davis	U-shaped valley Hanging Valley Cirque 4. Bergschrund Tarn Col, Arete and Horns Nunatak	Moraines (terminal, lateral, ground and medial moraines) Drumlins (Basket of eggs topography) Erratics/ Perched blocks Eskers Kames Kettles and Hummocks	1. Hanging valley 2. U-shaped valley Cirque Arete Glacial stairways and paternoster lakes No formation of moraines	1. Beginning of formation of lateral moraines 2. Beginning of formation of drumlins	Formation of terminal and ground moraine Outwash plains / cryoplain Formation of eskers and kames	Abrasion Polishing Plucking
	8. Crag and tail					
	9. Roches mountain					
	10. Glacial stairway (giant stairway/ cyclopean stairway) and paternoster lakes					
	11. Glacial grooves					
	12. Fiords					
	13. Outwash plain					

1. Oceanic Relief and Submarine Landforms

Reliefs of the ocean basins

About 71% of the globe is covered by oceans. There are four oceans around the globe which are Pacific Ocean, Atlantic Ocean, Indian Ocean and Arctic Ocean. Ocean relief features are divided into major and minor categories as follows :

1. **Major ocean relief features**
   - ¾ Continental shelf
   - ¾ Continental slope
   - ¾ Continental rise
   - ¾ Deep sea plains or abyssal plains
2. **Minor ocean relief features**
   1. Ridges
   2. Hills
   3. Seamounts
   4. Guyots
   5. Trenches
   6. Submarine canyon
   7. Island arcs
   8. Coral reefs
   9. fjord



Continental shelf

These are continental marginal areas submerged under oceanic water having average depth of 100 fathoms (1 fathom=6 feet) and gently sloping with sloping angle between 10 to 30. Continental shelves are narrow near high mountains while they are wider near wide coastal plains. For example- Pacific coast of North America has continental shelf of only 16 km while Atlantic coast of North America has a wide continental shelf of 96 to 120 km. Continental shelves represent 6% of the total area of the ocean. Due to availability of sunlight, continental shelves are nourishing grounds for phytoplanktons and marine life.

Continental slope

The zone of steep slope extending from the continental shelf to the deep sea planes are known as continental slopes. Their sloping angle varies from 50 to more than 600. There is a sudden drop in depth from 200 m to 2000 m. Due to the steep slope, marine deposits do not accumulate here. Continental slope represent submarine canyons and trenches which are generally transverse to the continental shelves. They occupy around 5% of the total area of the oceans.

Continental rise

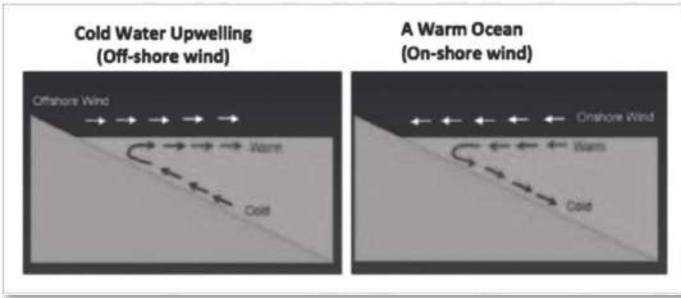
At the depth of around 2000 to 3000 m, continental slope gradually loses its stiffness and it is reduced to just 0.50 to 10. With increasing depth, slope becomes generally flat and it is known as continental rise.

Deep sea plain or abyssal plain

It is flat and rolling submarine area. Its depth ranges between 3000 m to 6000 m and it covers around 76% of the total area of the ocean. This is generally featureless but submarine ridges, seamounts, guyots (submarine plateau/flat topped mountains) are found there. This area receives highest marine deposits but due to lack of penetration of sunlight, it is of least biological activity.

Submarine Canyons

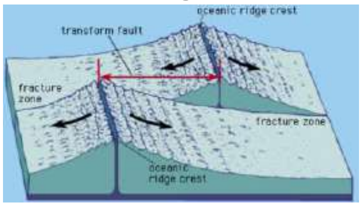
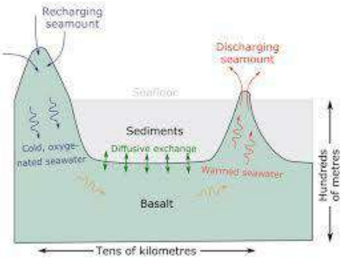
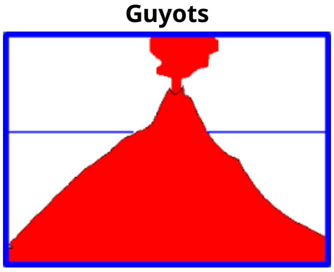
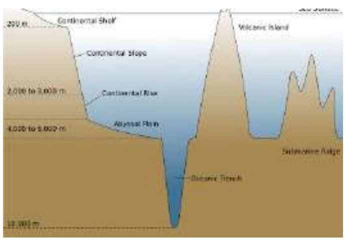
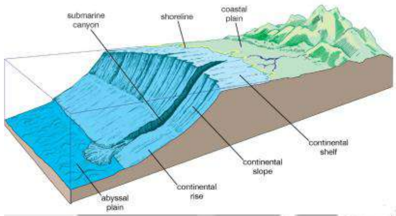
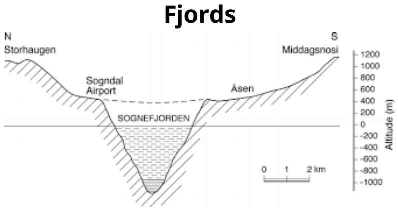
Long, narrow and very deep valleys located on the continental shelves and slopes with vertical walls resembling the continental canyons transverse to the coastline are known as submarine canyons. They are similar to the youthful river valleys. They are generally found in front of the mountains of major rivers. Canyons facing the river mouths are usually long but have a gentle slopes while canyons located near the islands are deep with steepest slope. Ex. Hudson canyon, Congo canyon etc.



Oceanic deeps and trenches

The trenches are steep sided narrow basin of oceans. They are of tectonic origin and are formed near convergent plate boundaries. Thus, they are associated with active volcanoes and earthquakes. Deeps are the deepest part of the oceans. The major difference between deeps and trenches is trenches are generally longer than deeps. Ex. Mariana trench and Challenger deep.

Minor ocean relief features

Feature	Explanation
Ridges 	• Long, narrow mountain chains on the ocean floor. • Formed due to tectonic plate divergence (seafloor spreading). • Example: Mid-Atlantic Ridge. • Often associated with volcanic activity and new crust formation.
Seamounts 	• Submarine volcanic mountains rising from the seafloor. • Do not reach the ocean surface (unlike islands). • Often form near tectonic plate boundaries or hotspots. • Rich in marine life due to nutrient upwelling.
Guyots 	• Flat-topped seamounts. • Once volcanic islands eroded by waves, then submerged. • Found mostly in Pacific Ocean. • Important for studying sea level changes.
Trenches 	• Deep, narrow depressions in the ocean floor. • Formed by subduction of one tectonic plate under another. • Example: Mariana Trench (deepest point on Earth). • Associated with strong earthquakes and volcanic activity.
Submarine Canyon 	• Deep valleys cut into continental slopes. • Formed by river erosion during low sea levels or turbidity currents. • Example: Hudson Canyon (off New York). • Serve as routes for sediments from land to deep sea.
Coral Reefs	• Structures formed by colonies of tiny marine organisms (corals). • Found in warm, shallow, sunlit waters. • Three main types: fringing reef, barrier reef, atoll. • Example: Great Barrier Reef (Australia).
Fjords 	• Narrow, deep, steep-sided inlets of the sea. • Formed by glacial erosion and later submerged by seawater. • Common in Norway, New Zealand, Canada. • Provide natural harbors but are limited to glaciated coasts.

Temperature of oceans

The major source of the temperature of the oceanic water is the sun. The amount of insolation to be received at the sea surface depends on the angle of sun's rays, length of day, distance of the earth from the sun and effects of the atmosphere. Also, penetration of sun rays in ocean water determines the vertical distribution of temperature in oceans.

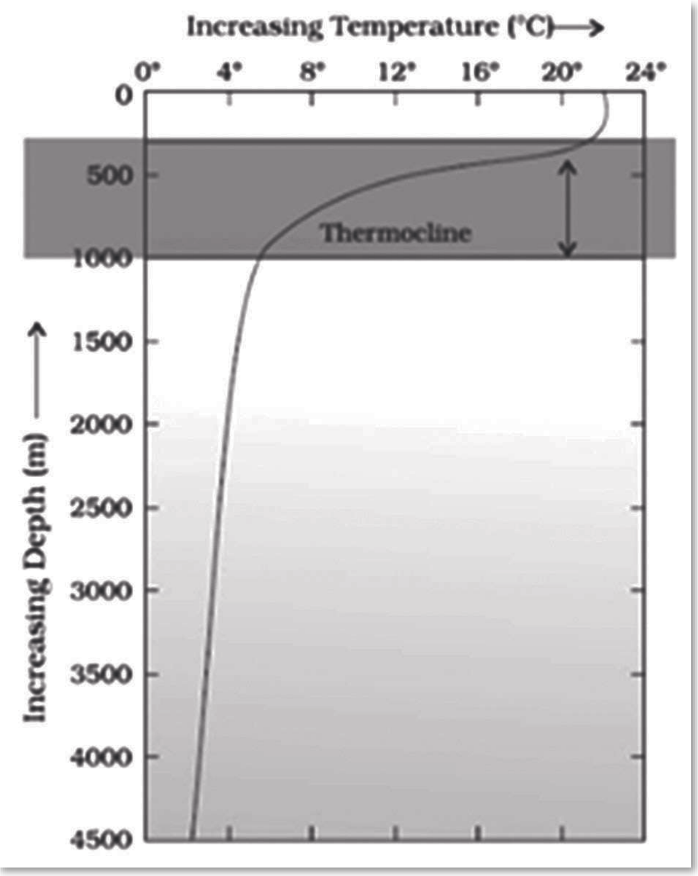
However, daily range of temperature is almost insignificant as it is around only 10C in oceans. The annual range of temperature is quite significant. In northern hemisphere, August and February represent maximum and minimum temperatures respectively with annual temperature range of 120C.

Factors affecting distribution of temperature in oceans

1. **Latitudes :** Insolation decreases from lower latitudes to higher latitudes; hence temperature of ocean surface water also decreases as one moves towards the poles from either sides of equator.
2. **Unequal distribution of land and water :** The oceans in the northern hemisphere receive more heat due to their contact with larger continental masses as compared to southern hemisphere. Thus, their average temperature is more as compared to Southern Oceans.
3. **Prevailing winds :** The winds blowing from the land towards the ocean drive warm surface water away from the coast resulting into upwelling of the cold bottom water from below. On the other hand, the onshore winds piles up warm water near the coast and rises the temperature there. For example - trade winds raise the temperature in the western margins of the ocean and reduce the temperature in eastern margins of oceans.
4. **Ocean currents :** Ocean currents drive away warm equatorial waters to cold polar regions and cold polar water to warm equatorial regions. For example - warm north Atlantic drift raises the temperature of north ocean by 40C.
5. Minor factors like submarine bridges, local weather conditions like storms, cyclones, hurricanes, fog, cloudiness, evaporation, condensation, location and shape of the sea also affect distribution of temperature in oceans.

Vertical distribution of temperature

Maximum temperature of the ocean is observed at the surface because of direct heating from sun rays. Sunrise effectively penetrate up to 200 m beyond which the rate of penetration decreases, so the temperature also decreases significantly. The temperature falls very rapidly up to the depth of 1000 m (this rapid fall of temperature is known as thermocline) and thereafter the rate of decrease of temperature is slowed down. The oceans are divided vertically into two major zones that is Photic/Euphotic zone (upto 1000m) and Aphotic zone (from 1000m to the bottom of the ocean). Though photic zone comprises barely 20% of on oceanic waters, around 90% of the marine life is concentrated there. The rate of decrease of temperature with increasing depth from equator towards the poll is not uniform. It is maximum near the equator and minimum near poles. Temperature at the ocean bottoms is uniform from the equator towards the pole.



Density of oceans

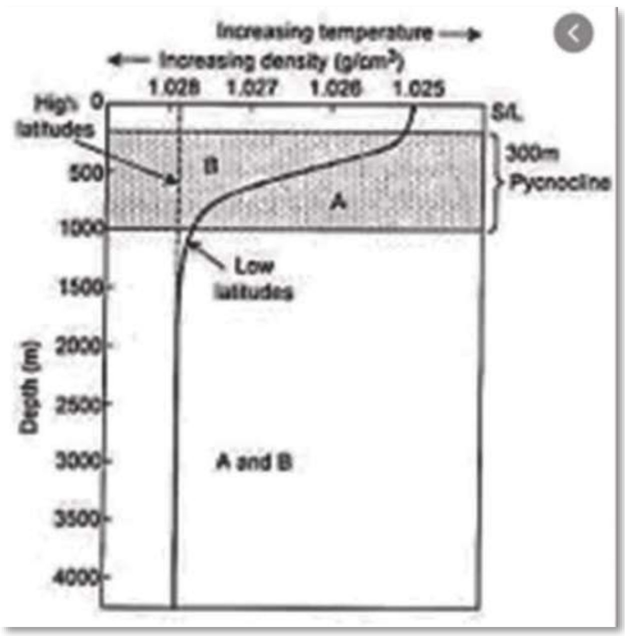
- Density of ocean water is the amount of mass per unit volume of a substance. It is usually measured in gram per cubic centimetres (g/cm3). Average density of seawater is 1.0278 g/cm3. It is 2 to 3% higher than the density of pure water.
- Density determines the dynamics of ocean water, i.e., it determines whether the sea water will sink and will there be any vertical and horizontal movement of water.

Factors affecting density of seawater

1. **Temperature :** Temperature and density are inversely related. Thus, density is highest at poles and lowest near equator.
2. **Salinity :** Salinity and density are directly related. But, most of the times temperature factor suppresses salinity factor. For example - polar waters are less saline and they should have less density, but due to low temperature prevailing there, the region has the highest density of ocean water.
3. **Pressure :** Pressure and density are directly related, i.e., increasing pressure increases density. But it has negligible control over seawater density.

Vertical distribution of density

As temperature factor plays dominant role over other factors; hence vertical distribution of salinity follows the trends of vertical distribution of temperature and can be shown in the graph below:



Salinity of oceans

The total amount of salt in grams contained in 1 kg of seawater is known as salinity of ocean. It is represented in parts per thousand (%0). Average sanity of oceans varies from 33 to 37 parts per thousand. The source of oceanic salinity is land. River water flowing into the ocean contain around 60% of calcium sulphate and around 2% of sodium chloride. Calcium brought by rivers is consumed by marine organisms while sodium chloride remains is not consumed and is bit modified giving birth to present day salinity.

Factors controlling salinity in oceans

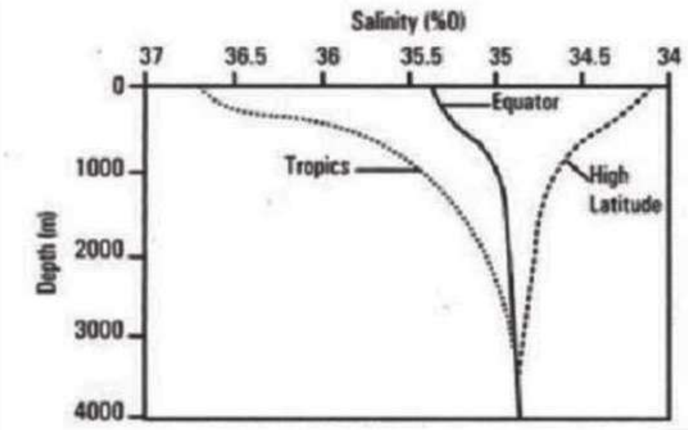
1. **Evaporation :** Evaporation and salinity are directly related i.e., greater the evaporation higher the salinity. Because of high evaporation at subtropical high-pressure belts, high salinity is recorded as compared to equatorial belt which often has cloudy skies.
2. **Precipitation :** Precipitation and salinity are inversely related. This is the reason behind low salinity patterns near equator.
3. **Influx of freshwater :** Freshwater, either supplied by rivers or melting of glaciers, is inversely related to salinity. Thus, salinity is less at river mouth and near at polar regions. For example salinity of Bay of Bengal is much lower as compared to salinity of Arabian Sea because Bay of Bengal receives more fresh water from rivers like Ganga, Brahmaputra, Godavari, Krishna, Kaveri.
4. **Wind direction :** Offshore and onshore winds drive away ocean waters and affect temperature distribution. This ultimately affects salinity distribution. Though located on the same latitudes, Gulf of Mexico and Gulf of California record different salinity patterns mostly due to onshore and offshore trade winds. Onshore trade winds increase the temperature near Gulf of Mexico and it records higher salinity to 37 parts per thousand; on the other hand, offshore trade winds reduce the temperature near Gulf of California and it records lower salinity of 34 parts per thousands.
5. **Atmospheric pressure and circulation :** Anti-cyclonic conditions create clear cloudless sky and low rainfall environment. This increases the temperature and ultimately increases the

salinity.

6. **Circulation of oceanic water :** Equatorial warm currents drive away salt water from the western coastal areas of the continents and accumulate them along the eastern coastal areas. Similarly, North Atlantic drift drives away saline water from north-eastern coast of North America and piles it up near the Norwegian coast.

Horizontal distribution of salinity in oceans

1. **Salinity distribution in open seas :** On an average, salinity decreases from equator towards the poles. However, the highest salinity is not recorded at the equator, it is recorded between 200 to 400 N and S. This is mainly because equator receives daily rainfall. Also, due to vertical wind shear there is always cloudy sky prevailing in the region effecting incoming installation. On the basis of latitudinal distribution of salinity, four zones of oceanic salinity are identified-
    1. Equatorial zones of low salinity due to excessive rainfall
    2. Tropical zone (between 200 to 300) of maximum salinity due to low rainfall and high evaporation
    3. Temperate zone of low salinity due to low evaporation
    4. Polar zones of minimum salinity due to low evaporation and melting of glaciers.
2. **Salinity distribution in inland or enclosed seas :** Marginal areas of enclosed seas have lower salinity than their central parts because of freshwater added through the rivers. There is no control of latitudes on the distribution of salinity. It solely depends on influx of freshwater. For example, though located on the same latitude, Baltic Sea records comparatively lower salinity than the North Sea because influx of freshwater is more in Baltic Sea. Northern part of Caspian Sea record low salinity of 14 parts per thousand because of addition of enormous volume of water brought by rivers like Volga and Ural; while in southern part, it becomes 170 parts per thousand due to lack of influx of freshwater.



Vertical distribution of salinity in oceans

Vertical distribution patterns are complicated and no definite trend can be spelt out. Salinity increases with increasing depth in high latitudes. In middle latitudes, salinity decreases with increasing depth. At equator, salinity is low at the surface due to high rainfall but higher salinity is noted below the water surface and it again becomes low at the bottom. There is a transition zone between surface waters and bottom waters. This transition zone represents sudden change in salinity and is known as Halocline. (from 200m to 1000m)

Significance of salinity

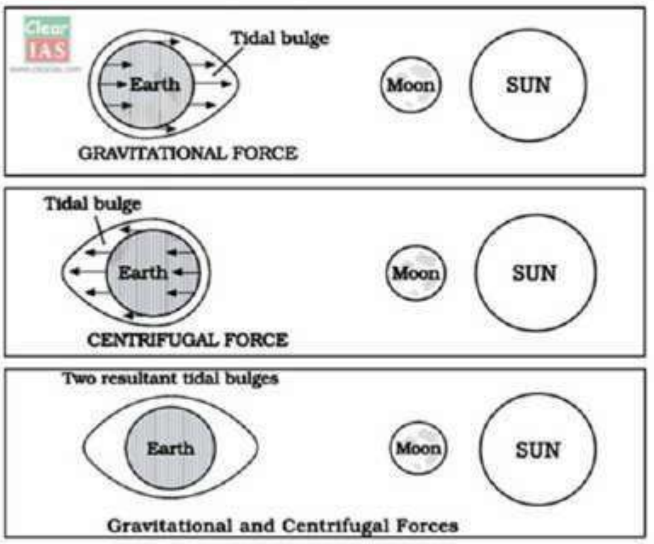
1. Affects marine organisms and plant community and plays important role in their biochemical cycles.
2. Affects the physical properties of the oceans like temperature, density, pressure, waves and currents.
3. It affects to the freezing and boiling point of ocean water. More saline water freezes slowly as compared to less saline water. Boiling point of saline water is higher than freshwater.
4. This changing of boiling and freezing point also changes the rate of evaporation.
5. Salinity impacts density of seawater.
6. It plays a very important role in the origin of ocean currents.

Ocean tides

The periodic rise and fall of seawater due to gravitational forces of the sun and the moon are called tides. The rise of sea water and its movement towards the coast is called tide and the resultant high water level is called high tide water. The fall of seawater and its movement towards the sea is called ebb and the resultant low water level is quite low tide water. The difference between high tide water and low tide water is called tidal range. This tidal range depends on depth of ocean water, configuration of seacoast and coastlines and openness or closeness of the sea.

Formation of tides

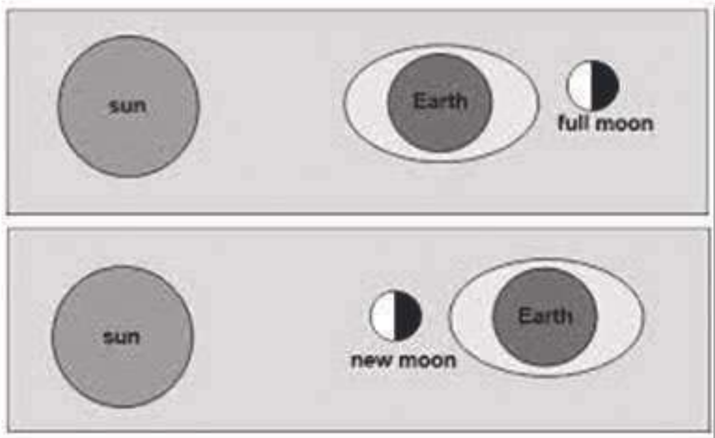
As per Sir Isaac Newton, tides are formed due to gravitational pull of the moon and the sun and centrifugal force of the rotating earth. This theory is known as equilibrium theory of origin of tide. According to this theory, the gravitational force of the moon will be maximum at the earth surface facing the moon while it will be minimum at the opposite side of the earth. Consequently, the water of the earth surface facing the moon is attracted and pulled and high tide occurs. To balance this shift in the centre of gravity, a bulge of water of equal magnitude originates on the earth surface, which is opposite to side facing moon, due to centrifugal force. In this way, tides occur on the earth surface which is facing the moon as well as on the earth surface which was opposite to the side facing the moon.



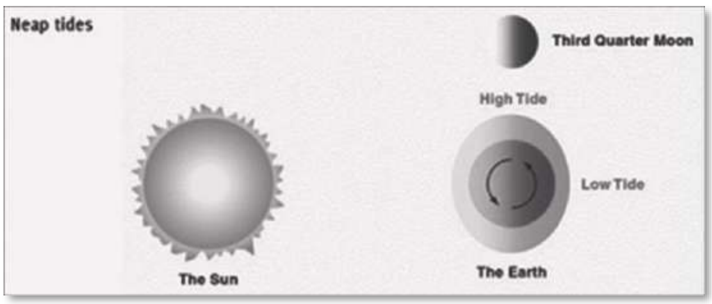
The time span between two successive tides occurring at the same place is of 12 hours 26 minutes.

Types of tides

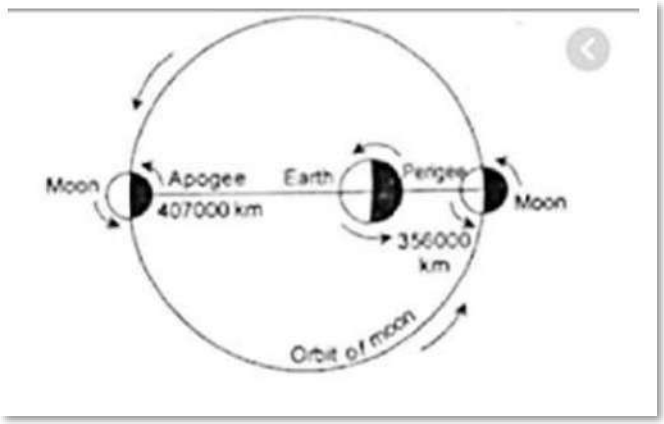
1. **Spring tide :** It occurs when the sun, the moon and the earth are positioned in a straight line. Such alignment is called as Syzygy. When the sun and the moon are on one side of the earth, the position is called conjunction (that is New moon day). When the position of the earth is in between the sun and the moon, this is called opposition (that is new moon day). Due to combined gravitational attraction of the sun and the moon, the tides coming on this day are very high tides. Generally, height of spring tide is 20% more than normal tide.



2. **Neap tide :** It occurs when the sun, the moon and the earth are at right angle to each other. Such alignment is called as quadrature. Such position is aligned on half moon day. Gravitational force of attraction of the sun and the moon work in opposite direction and both try to pull water towards their side. Though sun is larger in size, moon is nearer to the earth and hence tidal bulge occurs towards the moon. The height of neap tides is generally 20% lower than the normal tides.



3. **Apogean and Perigean tide :** Apogean and perigean tides occur on apogee and perigee position of the earth and the moon. The nearest position of the moon with the earth is called perigee; and farthest position of the moon and the earth is called apogee. Apogean tides are lesser than perigean tides.



Importance of tides

1. They are responsible for moving large amount of sediments perpendicular to the coast.
2. Tidal range determines the width of littoral zones.
3. Periodic rise and fall of water is helpful in harnessing wave energy and tidal energy.
4. Tides influence the distribution and morphology of coastal delta, tidal flats, barrier islands and spits.
5. It is important for fishing and navigation.
6. It influences coastal marine life.

Ocean currents

- The general moment of a mass of oceanic water in a definite direction is called as ocean currents.
- They are classified into warm and cold currents depending on their temperature. On the basis of their velocity and direction, they are further divided into -
  1. **Drifts :** It is the movement of ocean water under the influence of prevailing winds. e.g. North Atlantic drift
  2. **Currents :** It is the moment of oceanic water in a definite direction with greater velocity. Ex. North Equatorial Pacific current
  3. **Streams :** It is the movement of ocean water like big rivers of a continent, in definite direction with greater velocity. Ex. Gulf Stream.

Factors Behind the Origin of Ocean Currents

(A) Factors Related to the Rotation of the Earth

1. **Coriolis force :** Coriolis force deflect the general direction of ocean currents. It deflects ocean currents in northern hemisphere to their right side and those in southern hemisphere to their left side.
2. The rotational force of the earth causes movement of ocean water near the equator in opposite direction to the direction of rotation of the earth. This gives birth to equatorial current.
3. Rotation of the earth gives birth to counter equatorial current.

(B) Factors Related to the Oceans

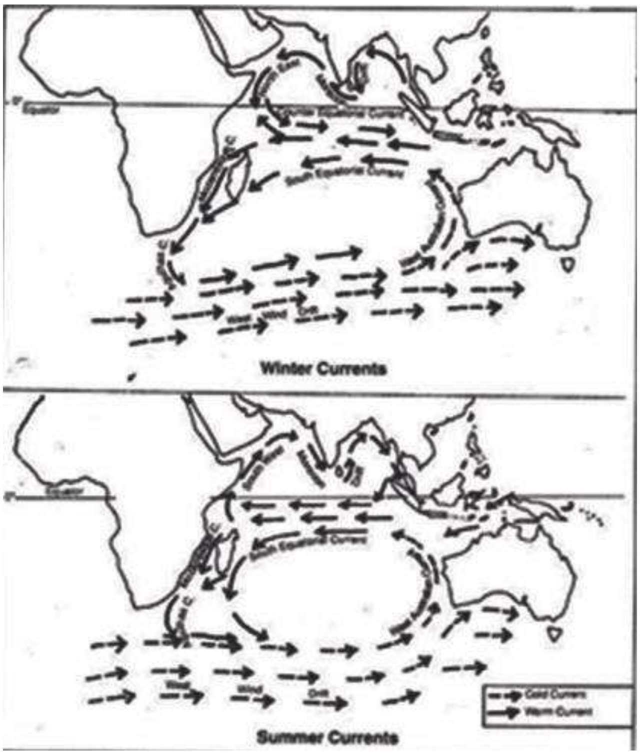
1. Temperature difference
2. Salinity difference
3. **Density difference :** The difference in the density of oceanic water is the main cause for the movement of oceanic water. Density determines whether the oceanic water will float or sink. It also determines the horizontal movement of ocean water. Density is closely associated with temperature and salinity. (see 'density of oceans' chapter). For example, current flowing from Atlantic Ocean to Mediterranean Sea via Gibraltar strait is caused mainly because of salinity and density difference.

(C) Factors related to the atmosphere

1. **Air Pressure and Wind :** Planetary winds blow in the same direction throughout the year. While blowing over the surface of the ocean water, water also moves in wind's direction due to its frictional force. For example - North Atlantic drift, Kuro Shio current. Also in North Indian Ocean, there is a seasonal reversal in the direction of winds due to monsoon. Accordingly, ocean currents also reverse their direction.

2. **Rainfall and Evaporation :** The sea water level becomes relatively higher in the areas of low air pressure and high rainfall than those areas which record low rainfall but higher evaporation. In this case, water flows from high sea water level to low

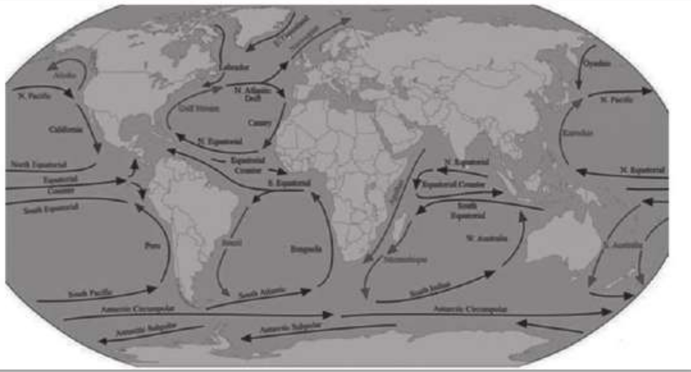
seawater level, but this phenomenon is restricted locally.



Factors Modifying Ocean Currents

1. **Direction, shape and configuration of coastlines :** If coastline lies perpendicular to the natural flow direction of the ocean currents, it obstructs them and consequently ocean currents get bifurcated and start flowing parallel to the coastline. For example - equatorial current is bifurcated into two branches, at the shoulder of the Brazilian coast, northern branch flows as Antilles current and merges into Gulf stream while southern branch continues to flow as a Brazilian current. Similarly, in South Indian Ocean south equatorial current gets bifurcated at Madagascar into Mozambique and Agulhas current.
2. **Bottom reliefs :** Generally, ocean currents while crossing over a submarine ridge are deflected to the right in the northern hemisphere and to the left in the southern hemisphere.
3. Seasonal variations as observed in Indian Ocean during monsoon.

Ocean Currents in Various Oceans



- Due to closed circulation pattern of current flows in the oceans, there is a formation of a circulation gyre or simply gyre in each ocean. Gyre formed are -
  1. In North Pacific - Subtropical North Pacific Gyre (SNPG)
  2. In South Pacific - Subtropical South Pacific Gyre(SSPG)
  3. In north Atlantic - Subtropical North Atlantic Gyre (SNAG)
  4. In South Atlantic - Subtropical South Atlantic Gyre (SSAG)
  5. In South Indian ocean - Subtropical South Indian Gyre
- Ocean currents in Indian Ocean seasonally change their direction; hence no such gyre formed in north Indian Ocean.
- Among all these gyres, sub tropical North Atlantic Gyre is very important in ecological point of view. It is also known as Sargasso Sea. It has following characteristics -
  1. It is the only sea without coastline.
  2. There is an anti-cyclonic circulation of ocean currents comprising of North Equatorial current (Southern boundary), Gulf stream (Western boundary), North Atlantic Drift (Northern boundary) and Canary current (Eastern boundary).
  3. Name of this sea is derived from Portuguese word Sargassum meaning thereby seaweeds. Sargassum is a rootless weed freely floating on the sea water.
  4. Water confined in this area is calm and motionless.
  5. Latitudinal extent is 200 north to 400 north and longitudinal extent is 350 west to 750 west.
  6. It has exceptional clarity of water.
  7. Confined water does not have any

connection with remaining waters of ocean.

8. It is located in the transitional zone of trade winds and westerlies.
9. This zone is characterised by the subsidence of the air from above giving birth to anticyclonic conditions and hence atmospheric stability.
10. Due to anti-cyclonic conditions, there is high temperature and rate of evaporation is also high. Ultimately, it has the highest salinity in Atlantic Ocean (37ppt).
11. This sea is the breeding ground of eel.
12. This sea is the feeding ground of loggerhead turtles.
13. Due to anthropogenic activities especially plastic pollution, huge garbage patches are developing fastly in this region. These garbage patches are creating serious threats to local unique ecosystem.

Significance of ocean currents

1. Moderating effect at coast : North Atlantic drift brings warmness to Norwegian coast while Canary current brings cooling effect to Spain and Portugal.
2. Cold currents have a direct effect on desert formations in the western regions of continents. For example - Atacama desert lies near Peru current, Mojave desert lies near cold California current.
3. Warm ocean currents bring rainfall to coastal regions. For example - warm ocean current brings rainfall in British type climate.
4. Ocean currents can bring extreme weather events. For example - Gulf stream raises the temperature of Atlantic coast and of the plains of USA during summer months and brings intensive heat waves.
5. Meeting grounds of warm and cold ocean currents form dense fogs.
6. Mixing of cold and warm ocean currents creates richest fishing grounds in the world. Ex. Grand bank around Newfoundland Canada, Dogger bank near England.
7. Mixing of warm and cold ocean currents helps to replenish the oxygen and favour the growth of phytoplankton which further helps in carbon dioxide absorption and have great potential of reducing global warming.
8. Ocean currents causes upwelling because of which nutrient rich water comes to the surface and rich fishing grounds are formed. For example - upwelling near Peruvian coast.
9. El-Nino is modified South Pacific ocean current system where warm counter equatorial current replaces cold Peruvian current affecting global climate including monsoon in Indian subcontinent.
10. Ocean currents have great impact on trade and navigation.
11. Ocean currents help marine animals in migration.

Sea Level Rise: Causes, Impacts and Way Forward

Introduction

- Sea level rise is one of the most visible consequences of global climate change. According to the Intergovernmental Panel on Climate Change (IPCC), the global mean sea level has risen by **about 20 cm since 1900**, with the rate of rise accelerating in recent decades. This phenomenon poses grave risks to coastal ecosystems, infrastructure, and livelihoods, making it a critical issue for sustainable development and climate resilience.

Causes of Sea Level Rise

- **Thermal Expansion of Oceans**
  - Oceans absorb ~90% of excess heat trapped by greenhouse gases.
  - Warmer water expands, contributing to rising sea levels.
- **Melting of Glaciers and Ice Sheets**
  - Greenland and Antarctic ice sheets are losing mass at unprecedented rates.
  - Himalayan glacier retreat also contributes regionally.
- **Melting of Polar Ice Caps & Sea Ice Decline**
  - Though sea ice melt does not directly add water, it reduces reflectivity (albedo), accelerating warming.
- **Anthropogenic Causes**
  - Groundwater extraction and reservoir depletion contribute indirectly.

Global Impacts

- **Coastal Flooding and Storm Surges**: Higher baseline sea levels amplify cyclones and hurricanes.

- **Displacement and Migration**: Low-lying islands (e.g., Maldives, Kiribati) and megacities (e.g., Jakarta, Miami, Dhaka) face existential threats.
- **Loss of Ecosystems**: Mangroves, wetlands, and coral reefs are at risk.
- **Economic Impacts**: Damage to ports, fisheries, and coastal infrastructure.

Indian Context

- **Vulnerability**: India has a **7,500 km coastline**, supporting over **170 million people**.
- **At-Risk Regions**: Sundarbans, Mumbai, Chennai, and Kochi are highly vulnerable.
- **Fisheries and Agriculture**: Saltwater intrusion threatens paddy fields and drinking water in states like West Bengal and Odisha.
- **Disaster Intensification**: Cyclones (e.g., Fani, Amphan) cause greater devastation due to higher sea levels.

International Frameworks

- **Paris Agreement (2015)**: Aims to limit global warming to well below 2°C, indirectly reducing sea-level rise risks.
- **Sendai Framework (2015–2030)**: Focus on disaster risk reduction, including coastal resilience.
- **UN Sustainable Development Goals (SDGs)**: Goals 13 (Climate Action) and 14 (Life Below Water) address ocean and climate resilience.

Mitigation and Adaptation Strategies

- **Mitigation**
  - Reducing greenhouse gas emissions.
  - Enhancing carbon sinks through afforestation and wetland conservation.
- **Adaptation**
  - **Coastal Protection**: Sea walls, dikes, mangrove restoration.
  - **Urban Planning**: Climate-resilient infrastructure and zoning laws.
  - **Early Warning Systems**: Improving disaster preparedness.
  - **Community-Based Adaptation**: Empowering local populations with knowledge and resources.
- **Technological Measures**
  - Satellite monitoring of sea-level trends.
  - Sustainable desalination and water management practices.

Way Forward

Sea level rise is a **slow-onset disaster** but with potentially irreversible consequences. A **multi-pronged approach** is required:

- Strengthening international climate commitments.
- Investing in resilient coastal infrastructure.
- Mainstreaming climate adaptation into developmental policies.
- Promoting regional cooperation in the Indian Ocean region for disaster risk reduction.

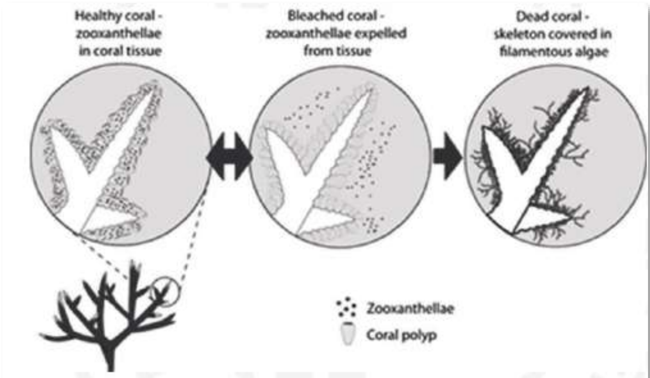
4. Coral Reefs: Types, Formation, and Distribution

Corals are the living organisms of the category of marine animals relating to jellyfish - also called as polyps.

Corals are responsible for building coral reefs. Coral reefs are the cemented, compact and rigid massive structures of numerous corals living as well as dead.

Coral polyps cannot survive above the water level and hence are always found either up to the sea level or below it. Coral polyps often exists with their symbiotic partner Zooxanthellae algae. This algae provides more than 60% of total food requirement of living corals and recycle the excreta and west of corals. In return, coral organisms provide them shelter in their bodies. This algae has different colours giving magnificent colours to coral reefs. Corals are also called as rainforests of the oceans as there exists more diversity than that of tropical rainforests.

Due to change in environmental conditions of corals, zooxanthellae leaves the symbiotic partnership or simply dies out. Death of algae results into loss of colours of corals and this phenomenon is known as coral bleaching.

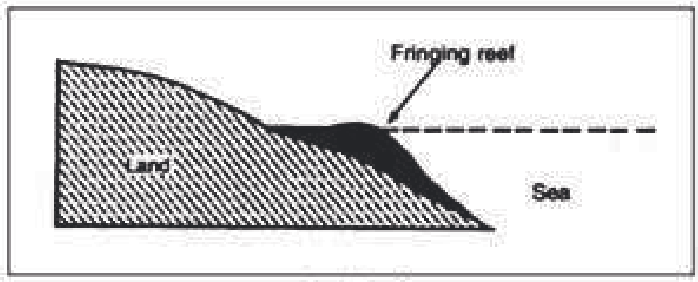


Conditions for the growth of coral polyps

1. They require mean annual temperature ranging between 200C to 210C. Hence coral polyps thrive in the tropical oceans confined between 250 north to 250 south latitudes.
2. Corals cannot live in deeper waters that is not more than 200 to 250 feet due to lack of sufficient amount of sunlight and oxygen.
3. Clean sediment free water is required because muddy water or turbid water clog the mouths of coral polyps resulting into their death.
4. Freshwater is also injurious for coral polyps that is why they live away from the areas of river mouths.
5. Very high proportion of oceanic salinity is also injurious because they require calcium carbonate as food rather than sodium. Ideal oceanic salinity required ranges between 27 to 30 parts per thousand.
6. Ocean currents and waves are favourable for coral because they bring necessary food supply and vital nutrients.
7. Extensive submarine platforms are thriving grounds for development of corals.
8. Minimum human activities, little or no pollution are favourable conditions for corals.

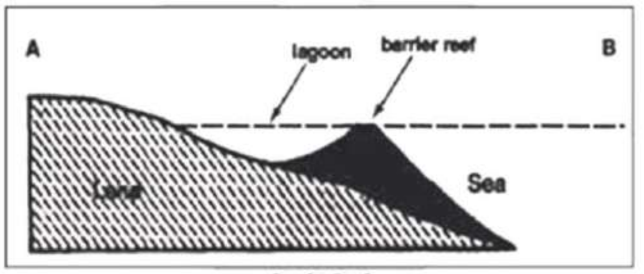
Types of coral reefs

1. **Fringing reefs :** They develop along the continental margins or along the islands. They are directly attached to coast line. Ex - Bahamas, Caribbean islands etc



Fringing Reef

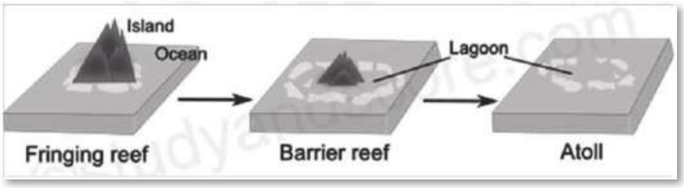
2. **Barrier reef :** They develop off the coastal platforms but parallel to coastline. There is gap between these corals and coastline and this gap is filled by water. It is known as Lagoon. Barrier reef's are seldom found as continuous. Sometimes, they are broken at many places where Lagoon are opened up into seas, what is known as both channel and they are formed through tidal inlets. Eg. Great Barrier Reef of Australia.



Barrier Reef

3. **Atoll :** Ring of narrow growing corals of horseshoe shape and crowned with palm trees is called atoll. It is generally found around an island (island atoll) or sometimes island is absent inside it (true atoll). Ex. Funafuti Atoll of

Ellice island, atolls of Maldives etc.



Coral bleaching

As stated above, coral bleaching is end of symbiotic partnership between coral polyps and zooxanthellae algae leading to decoloration of coral reefs and consequently, death of coral polyps.

Coral bleaching is categorised into four types based on its intensity

1. **Catastrophic bleaching :** Around 70-95% of shallow water corals are adversely affected. Ex. Bahrain, Maldives, Sri Lanka, Singapore and Tanzania.
2. **Severe bleaching :** Around 50 to 70% of shallow water corals are affected. Ex. Kenya, Seychelles, Japan, Thailand and Vietnam.
3. **Moderate bleaching :** Around 20 to 50% of shallow water corals are adversely affected. Quick recovery is possible in these types of corals.
4. **Insignificant bleaching or no bleaching :** Unfortunately such coral reefs does exist. All coral reefs are more or less adversely affected by anthropogenic activities.

Causes of coral bleaching

1. Increase in ocean temperature due to various reasons like global warming, industrial sewage, urban sewage, shipping, El-Nino events, etc.
2. Ocean acidification.
3. Increasing influx of freshwater due to melting of glaciers.
4. Increasing sea levels pushes corals into deeper waters where it is difficult for them to survive because of lack of availability of sunlight for the photosynthesis by algae.
5. Outbreak of coral diseases (epizootics).
6. Increase in siltation of sea due to increasing urbanisation, deforestation, pollution etc.
7. Increasing use of pesticides and herbicides in agricultural activities.
8. Cosmetics containing microbeads are washed away into the sea. Such microbeads clogs mouths of corals leading to their death.
9. Corals are mined heavily for gypsum.

Marine resources

(A) Biotic resources

1. Food resources:- includes fish, sea grass, algae, seaweed, etc
2. Non-food resources:- corals

(B) Abiotic resources

1. Mineral resources

(i) Metals

- **Polymetallic nodules :** They are in dissolved form in ocean water. eg. gold, zinc, uranium, thorium, etc.
- **Placer deposits :** They are deposited on continental shelf, continental slopes and ocean bottoms. They are generally carried via rivers flowing on continents. Ex. Zircon, monazite, magnetite, platinum, sulphur, etc.
- **Nonmetals :** They mostly include various salts and construction materials like gravel and sand.

2. Energy resources

(i) **Renewable energy sources :** They include tidal energy, ocean thermal energy and ocean wave energy. Offshore wind energy and floating nuclear plants are also under experiment.

(ii) **Non-renewable energy sources :** They include petroleum and natural gas.

1. Atmosphere - Composition & Structure

Atmosphere

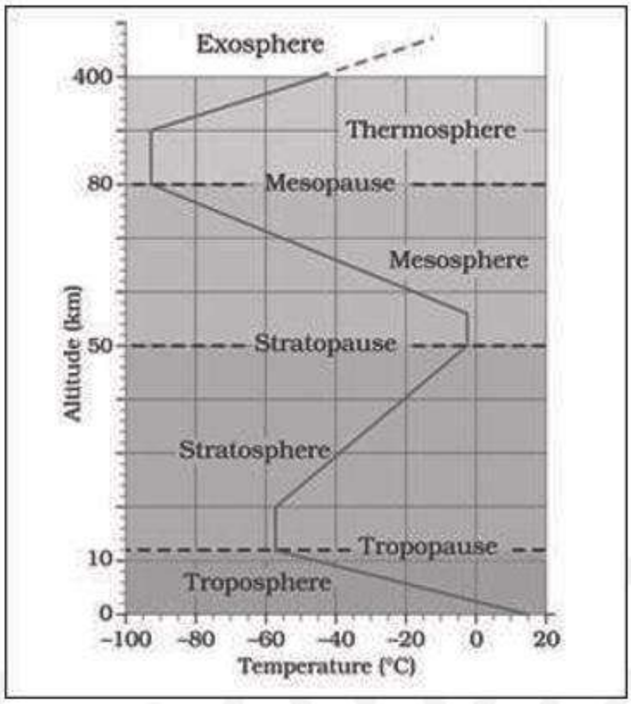
Composition of Atmosphere

The atmosphere is a thick gaseous envelope which surrounds the earth from all sides and is attached to earth surface by gravitational force. The height of atmosphere is estimated between 16 to 29,000 km from sea level. But 97% of the atmosphere is up to the height of 29 km. Atmosphere is composed of gases (78% of nitrogen, 21% of oxygen, 0.93% of Argon, 0.03% of carbon dioxide), water vapour (0-5% of total volume of atmosphere and 90% of it lies up to the height of 5 km associated with various weather phenomena) and particulates (include dust particles, salt particles, pollen grains, smoke, volcanic ash etc).

Structure of Atmosphere

On the basis of characteristics of temperature and air pressure, there are four layers of atmosphere -

1. **Troposphere**
   It is the lowermost layer of the atmosphere. Almost all of the weather phenomena (like fog, cloud, due, frost, rainfall, lightning etc) are associated with this layer. Here, temperature decreases with increasing height at the rate of 6.50C per 1000 m (known as normal lapse rate). Height of troposphere decreases from equator towards poles. Average height of the troposphere is about 16 km over the equator and around 6 to 8 km over the poles. During summer season its height increases while during winters its height decreases. The upper limit of the troposphere is called tropopause. Height of tropopause varies as per variations in troposphere.
2. **Stratosphere**
   This layer lies immediately above troposphere. Average upper limit of the stratosphere is 50 km. Here, temperature gradually rises upward due to presence of ozone. Ozone layer is present at the lower limits of stratosphere. Ozone layer absorbs harmful ultraviolet rays preventing them from reaching to the earth surface. In this process, ozone layer gets heated and ultimately stratosphere also gets heated. Stratosphere is devoid of major weather phenomena. But there is circulation of feeble winds and cirrus clouds in the lower stratosphere. Upper limit of stratosphere is known as stratopause.
3. **Mesosphere**
   It extends between 50 to 80 km. Air temperature again decreases with increasing height. Upper limit of mesosphere is known as mesopause.
4. **Thermosphere**
   This layer lies beyond the mesopause and forms the outer limit of the atmosphere. Here, temperature increases rapidly with increasing height. Gases become very light due to extremely low density and less gravitational pull, that is why warmth is not felt in thermosphere. It is divided into two layers -
   (a) **Ionosphere :** It extends from 80 to 640 km. There are a number of ionic layers in this atmospheric layer. Due to radiation from the sun, gases in this layer get ionised; hence this layer is called as Ionosphere. This layer plays very important role in satellite communication and radio communication.
   (b) **Exosphere :** It is the outermost layer of the atmosphere. The severity of gases become extremely low and temperature becomes very high.

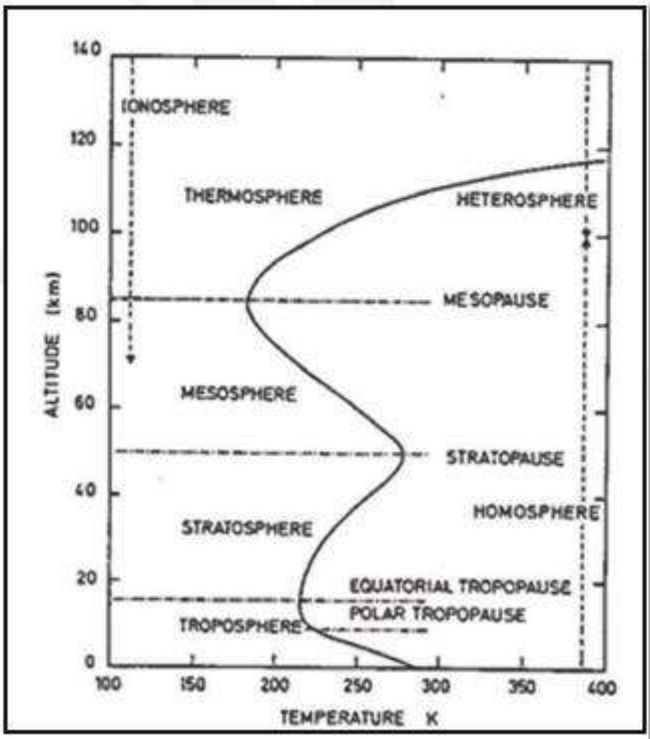


Chemical composition of the atmosphere

1. **Homosphere :** This is the lower portion of the atmosphere and extends up to the height of 90 km from the sea-level. This zone is called so

because of the homogeneity of the proportion of various gases, that is nitrogen 78% and oxygen 21%. Structurally, homosphere is divided into troposphere, stratosphere and mesosphere.

2. **Heterosphere :** It extends from 90 km to 10,000 km. It is further divided into various layers as per the dominance of particular gases and their physical properties. Those divisions are
   - **(i)** Molecular nitrogen layer from 90 to 200 km
   - **(ii)** Atomic oxygen layer from 200 to 1100 km
   - **(iii)** Helium layer from 1100 km to 3500 km
   - **(iv)** Atomic hydrogen layer from 3500 km to the uppermost limit of the atmosphere.



2. Solar Radiation, Insolation, and Heat Budget

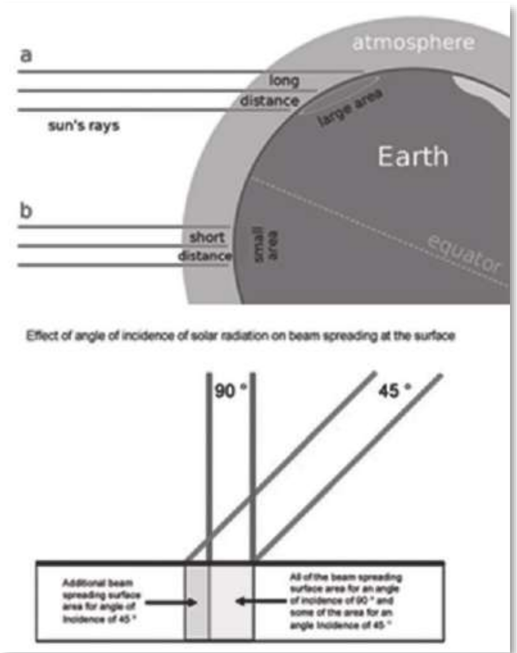
Earth receives heat energy from three basic sources that is solar radiation, gravity and endogenic forces coming from within the earth. Among these, solar radiation is the most significant source of terrestrial heat energy. The radiant energy received by the earth and its atmosphere from the sun is called insolation.

Solar energy received by the earth is not same at all places. Because of this differential reception of solar energy, earth surface gets heated differentially giving birth to various pressure belts and consequently, there is circulation of winds.

Distribution of insolation

Due to the shape of the earth, insolation received is not same at all places. The insolation received at the poles is hardly 40% of the insolation received at equator. The globe is divided into three zones on the basis of amount of insolation received.

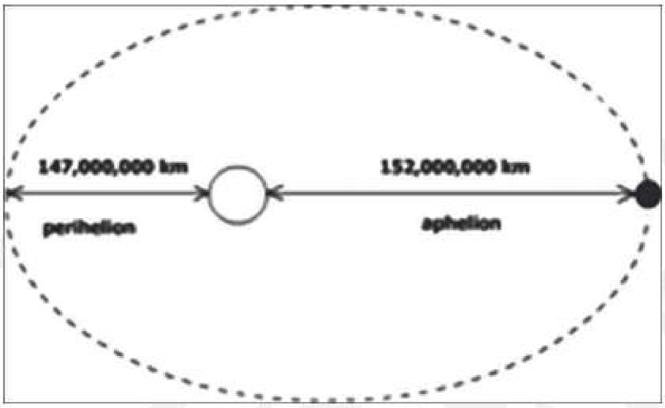
1. **Low latitude or a tropical zone :** It extends between the Tropic of Cancer and Tropic of Capricorn. All places experience overhead sun twice and every place receives maximum and minimum insolation twice a year.
2. **Middle latitude zone :** It extends between tropics and polar circles, that is between 250 to 660 latitudes in both hemispheres. This zone receives maximum and minimum insolation once a year. Insolation is never absent at any time of the year. No place experiences overhead sun.



3. **Polar Zone :** It extends between 660 to poles in both hemispheres. Every place receives maximum and minimum insolation once a year. No place experiences overhead sun. Sometimes, insolation becomes zero due to absence of direct solar rays.

Factors affecting the distribution of insolation

1. **Latitudes :** Latitude determines the angle of the sun's rays with the earth surface. Sun rays are more or less vertical near lower latitudes (equator) and the angle is right angle, while as the latitudes increase (as we move towards pole) the angle made by sun's rays with the surface of the earth start decreasing. Vertical rays are spread over minimum area of the earth surface and they heat the minimum possible area and thus, energy received per unit area increases. On the other hand, oblique rays are spread over larger area of the earth surface and hence the amount of energy received per unit area decreases. Also, oblique rays have to pass through thicker portion of the atmosphere than vertical rays. During this travel, the amount of solar energy is lost due to reflection, scattering and absorption.
2. **Length of the day :** Longer days make longer duration available for sunshine. In short, longer the day



greater the insolation received. In spite of increasing length of day from the equator towards the north pole during summer solstice and from the equator to the south pole during winter solstice, amount of insolation received at the ground surface decreases considerably poleward because of decrease in the angle of sun's rays.

3. **Distance between the earth and the sun :**

The position of aphelion (farthest distance between the sun and the earth) and perihelion (closest distance between the sun and the earth) determines the amount of insolation. This position can affect the amount of insolation up to 7%.

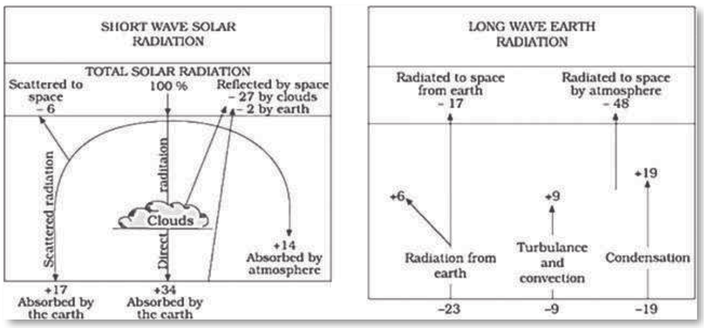
4. **Sun spots :** During sunspots, the energy radiated from the sun increases. Therefore, the amount of insolation received at the earth's surface also increases. During every 11th year, there is maximum number of sunspots.
5. **Effect of the atmosphere :** While passing through the atmosphere sun rays are absorbed, scattered and gets reflected due to atmospheric gases and dust particles affecting the total amount of insolation.

Heat budget of the earth and atmosphere

A heat budget is the perfect balance between incoming heat absorbed by earth in the form of short wave radiations and outgoing heat escaping it in the form of long wave radiation. If the balance is disturbed, then earth would get progressively warmer or cooler with each passing year.

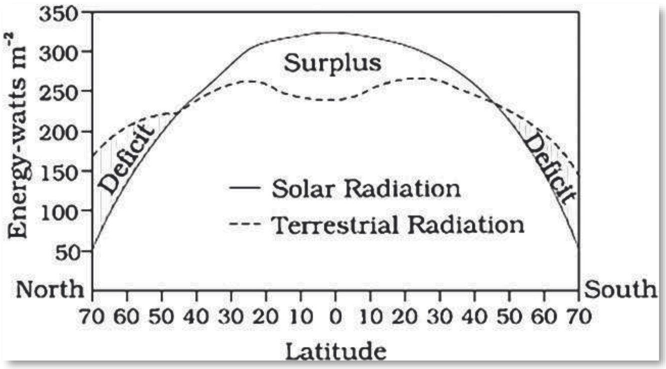
Comprehensive heat budget of the earth is divided into -

1. **Heat budget of the earth surface**
   - Incoming solar radiation : The earth receives most of its energy from the sun than the shorter solar radiation. Let us assume that 100 units of solar radiation radiated towards the earth's surface. Out of these 35 units are sent back to space through scattering by dust particle (6 units), reflection from the clouds (27 units) and reflection from the ground surface (2 units). Remaining 65 units become the effective radiation which hit earth and atmosphere. Out of these 65 units, 14 units are observed by the atmospheric gases. Hence earth surface receives remaining 51 units only and these two are divided into direct solar radiation (34 units) and diffuse daylight (17 units).
   - Outgoing terrestrial radiation : Outgoing terrestrial radiation is in the form of long wave radiations and is also called as effective radiation. It helps in hitting a lower portion of the atmosphere. Out of the total 51 units received by the earth surface, 23 units are lost through direct longwave outgoing terrestrial radiation, 9 units are spent on convection and turbulence and remaining 19 units are sent through evaporation. In this way, incoming radiations are balanced by outgoing radiations and heat balance of the earth surface is achieved.
2. **Heat budget of the atmosphere**
   - Energy received by atmosphere : Atmosphere receives energy through following ways -
     (i) 14 units through absorption of incoming solar radiation
     (ii) 19 units through evaporation
     (iii) 9 units through convection and turbulence
     (iv) Out of 23 units of longwave terrestrial radiations, 6 units are absorbed by atmosphere
   - In this way, atmosphere receives the total energy of 48 units. Atmosphere loses this entire 48 units of energy into the space through radiation.
   - In this way, energy gained is balanced by energy lost and heat balance of the atmosphere is achieved.
   - But anthropogenic activities are increasing the energy holding capacity of the atmosphere due to greenhouse gases. This makes energy received by atmosphere greater than energy lost by the atmosphere. This leads to the phenomenon of global warming.



Net radiation and latitudinal heat balance

The difference between all incoming solar energy and outgoing terrestrial energy is called net radiation. According to heat budget, theoretically, it is zero. But practically there are some places where the incoming solar energy is more than outgoing terrestrial energy (Energy surplus regions) and in some places incoming solar energy is less then outgoing terrestrial energy (Energy deficit regions).



The distribution of net radiation at the earth surface from equator towards the pole shows that,

1. There are large energy surplus areas between the zone of 200N and 200S.
2. Net radiation rapidly decreases from the energy surplus areas of low latitudes to mid-latitudes.
3. Net radiation becomes practically zero near 700 latitude in both hemispheres.
4. The polar areas are the zones of perennial energy deficit.

To achieve the heat balance, energy must be transported from heat surplus areas to heat deficit areas. This is known as meridional transport of heat. And it is achieved through ocean currents and wind circulation.

Urban Heat Island Effect: Causes, Impacts and Solutions

Introduction

- Urban Heat Island (UHI) refers to the phenomenon where urban areas experience higher temperatures than surrounding rural regions due to human activities and land-use changes. According to the IPCC, UHI can raise city temperatures by 1–3°C during the day and up to 12°C at night, worsening the impacts of climate change, especially in megacities.

Causes of UHI

- **Surface Modification**
  - Replacement of natural vegetation with asphalt, concrete, and buildings which absorb and retain heat.
- **Reduced Vegetation Cover**
  - Loss of tree canopy reduces shade and evapotranspiration cooling.
- **Anthropogenic Heat Release**
  - Heat from vehicles, industries, and air conditioners.
- **Air Pollution & Greenhouse Gases**
  - Smog and suspended particles trap outgoing long-wave radiation.
- **Urban Morphology**
  - Tall buildings and narrow streets create a “canyon effect,” limiting heat dissipation.

Impacts of UHI

Environmental

- Altered local climate and increased energy demand for cooling.
- Degradation of air quality due to temperature inversion.
- Reduced biodiversity in urban ecosystems.

Social

- Increased incidence of **heat-related illnesses** (heat strokes, cardiovascular issues).
- Exacerbates vulnerability of marginalized urban populations.

Economic

- Higher electricity bills due to air conditioning demand.
- Strain on urban water and power supply.

Indian Context

- **Delhi, Mumbai, Chennai, Bengaluru** record significant UHI intensity.
- **Example**: A 2021 study found Delhi’s central business districts up to **7°C hotter** than surrounding rural areas.
- Rising UHIs intensify **heat waves**, already a growing concern due to climate change.

Mitigation and Adaptation Strategies

- **Urban Greening**
  - Increasing green spaces, rooftop gardens, and tree cover.
  - Protection and rejuvenation of urban wetlands.
- **Cool and Reflective Surfaces**
  - Use of **cool roofs, reflective paints, and permeable pavements**.
- **Urban Planning and Design**

    - Wider roads, green belts, and climate-sensitive zoning.
    - Vertical gardens and sustainable building codes.
- **Technological Solutions**
    - Smart city designs with climate modeling.
    - Use of **GIS and remote sensing** to map UHI zones.
- **Policy Measures**
    - National Cooling Action Plan (2019) aims to reduce cooling demand and promote passive cooling.
    - Integration of UHI mitigation into **Smart Cities Mission and AMRUT**.

Generally, insolation determines the temperature distribution on earth's surface. However, insolation depicts the incoming solar radiation while temperature actually denotes the intensity of hotness or coldness. Temperature of the atmosphere is governed by following factors :

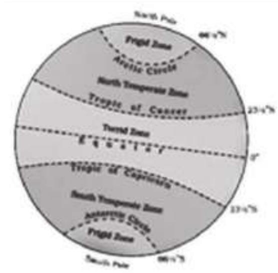
1. Heating of the atmosphere by direct insolation
2. Conduction
3. Terrestrial radiation
4. Convection

Factors controlling the horizontal distribution of temperature on earth's surface -

1. **Latitudes :** Latitudes directly determine the amount of insolation and temperature. That is why temperature at the equator is high and it decreases as one starts moving towards the poles.
2. **Altitude :** Temperature decreases with increasing height. Usually temperature falls by Celsius with the increase of height of 1000 m and this is known as normal lapse rate. For example - Quito (Capital of Ecuador) is located near the equator still it receives snowfall due to its altitude.
3. **Distance from the coast :** The marine environment moderates the weather conditions because there is mixing of temperature of the coastal areas and oceans through land and sea breeze. Hence, the daily range of temperature near the coastal environment is minimum, but as we move inside the continent, daily range of temperature increases. For example - Chennai and Bangalore lies almost on the same latitude but daily range of temperature is higher in Bangalore as compared to Chennai.
4. **Nature of land and water :** Land becomes warm and cold more quickly than the water even after receiving equal amount of insolation.
5. **Nature of ground slope :** Ground slopes facing the sun receives more insolation while sheltered slopes receive less insolation. For example - southern slopes of Himalaya record high temperature as compared to northern slopes because they receive more direct insolation.
6. **Nature of earth surface :** The nature of earth surface in terms of colour, vegetation and land use patterns determine its reflectivity. Reflectivity of solar radiation by ground surface is known as albedo. More the reflectivity less is the temperature. For example - snow-covered surfaces have more reflectivity as compared to forest lands.
7. **Prevailing winds :** Winds helps in the distribution of temperature and brings moderating effects of oceans to adjacent coastal areas (offshore and onshore winds). Winds blowing from low latitude toward high latitudes increase the temperatures of high latitudes.
8. **Ocean currents :** Temperature of the coastal area increases or decreases according to the nature of the ocean current. For example - temperature of Norwegian coast increases because of warm North Atlantic Drift.

Based on these factors the globe is divided into three temperature zones on the basis of latitudes -

1. **Tropical zone/torrid zone :** It extends between the Tropic of Cancer and Tropic of Capricorn. Sun rays are more or less vertical. Thus, it receives the highest amount of insolation and has high temperature throughout the year.
2. **Temperate zone :** It extends between 23. 50 to 660 in both hemispheres. Duration of day and night is longer in this region, but sun rays are never vertical; hence its temperature is less as compared to tropical zone.
3. **Frigid zone/Polar zone :** It extends beyond 660 till North and South pole. Sun rays are never vertical and the length of the day and night is more than 24 hours. This region receives the least amount of insolation and hence the temperature is the lowest in this zone.



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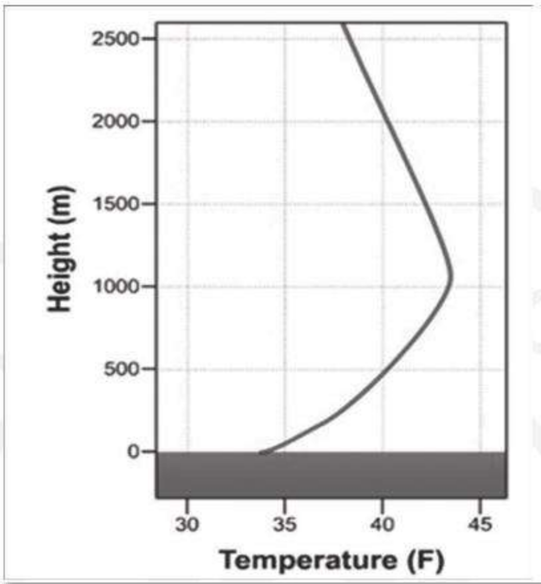
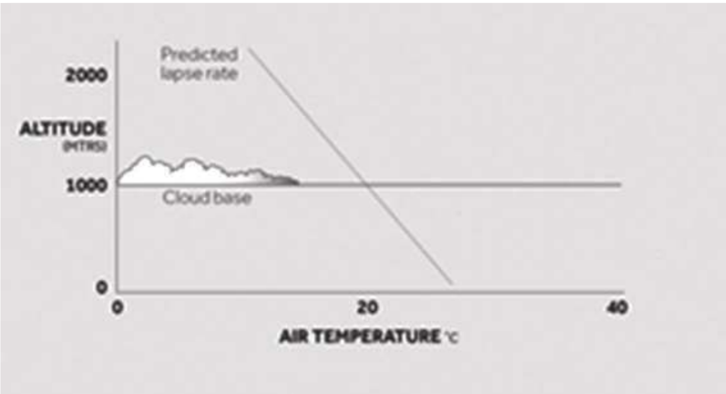
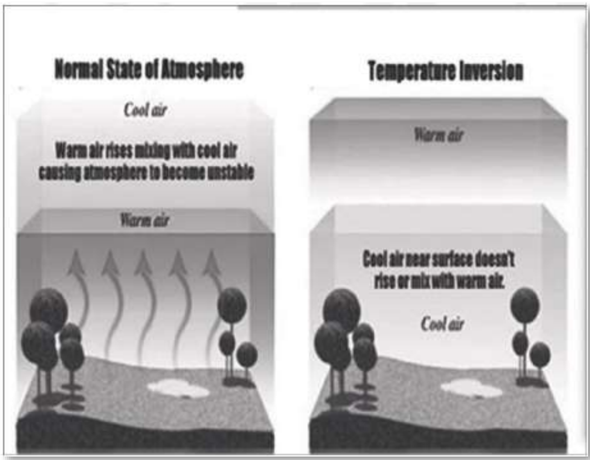
Vertical distribution of temperature

1. **Normal lapse rate :** The decrease of temperature with increasing altitude is known as normal lapse rate. It is generally 6.50C for 1000 m. Atmosphere gets heat from the earth surface through the process of conduction, radiation and convection. As the height increases, atmosphere becomes thinner because of which temperature decreases. In short, in thinner atmosphere, intensity of conduction, radiation and convection decreases; hence upper atmosphere records low-temperature with increasing height.
   In short, in the process of normal lapse rate, cold air lies above the warm air. Warm air being lighter tries to ascend while cold air being denser tries to descend. This creates atmospheric instability causing storms, rainfall, cloudy weather, etc.

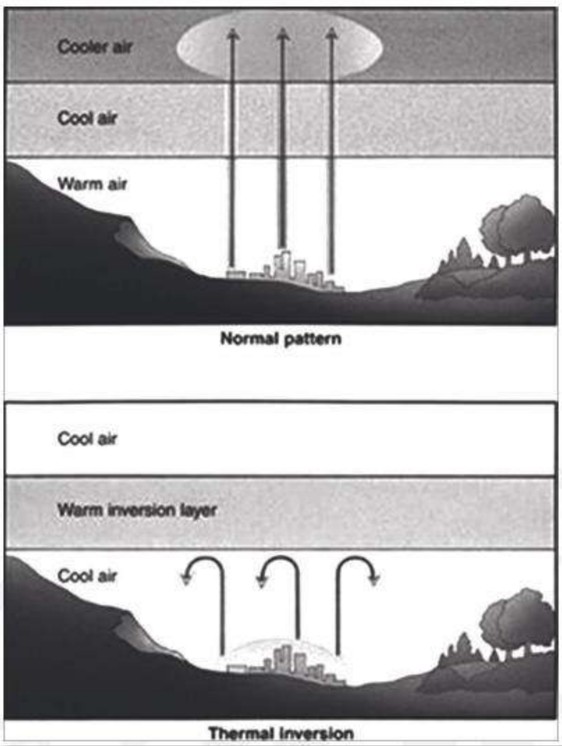




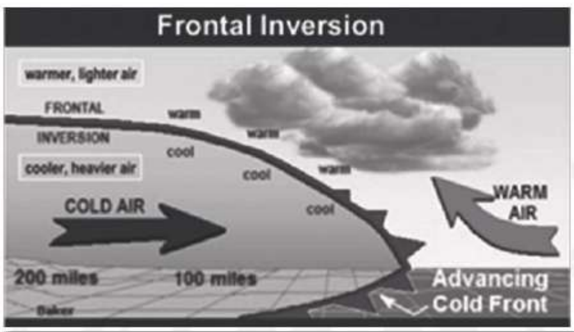


2. **Temperature inversion :** The increase of temperature with increasing height is known as temperature inversion. It is also known as negative lapse rate. Generally, it occurs near the earth surface or at greater height in the troposphere. Inversion of temperature near the earth surface is of very short duration because the radiation of heat from the earth surface during daytime warms up the cold air which soon disappears and temperature inversion also disappears. During temperature inversion process, warm air lies above the cold air. Warmer being lighter ascends and cold air being denser descends. This gives atmospheric stability and clear sky.

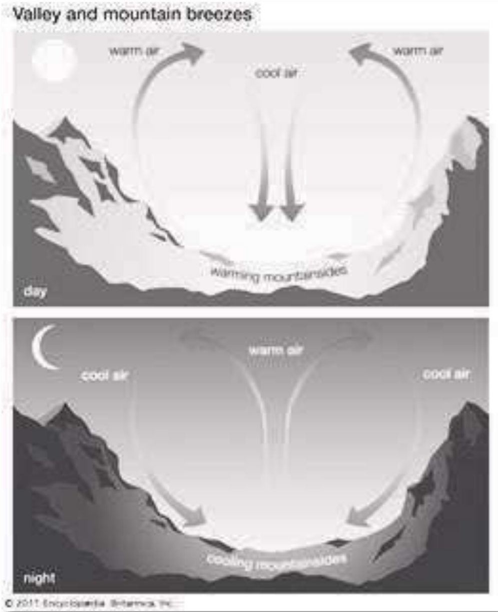
Types of temperature inversion



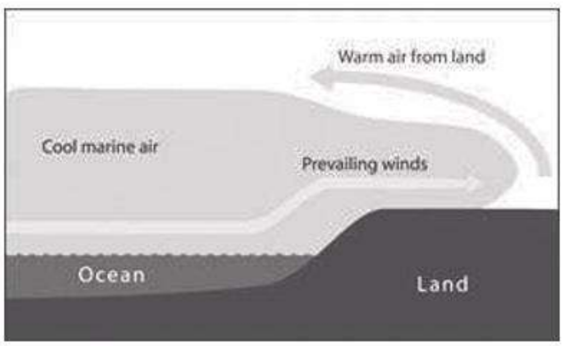
1. **Non-advectional inversion (due to static atmospheric conditions)**
   - **(A) Ground surface inversion/ radiation inversion :** It occurs during the long cold winter nights in the snow-covered regions of middle and high latitudes. It happens due to excessive cooling of the ground surface due to rapid loss of heat from ground through outgoing terrestrial radiation. Following conditions are necessary for ground surface inversion,
     - **(i)** Long winter nights so that amount of outgoing terrestrial radiation is greater than incoming solar radiation.
     - **(ii)** Cloudless and clear sky so that outgoing terrestrial radiation goes directly into the space without any obstacle. Also, there is no reradiation from the clouds.
     - **(iii)** Presence of dry air near the ground surface. Cooling of moist air will lead to precipitation.
     - **(iv)** Slow movement of air so that there is no transfer and mixing of heat between different layers of air.
     - **(v)** No covered ground surface.
   - **(B) Upper atmospheric inversion :** It is observed in upper layer of troposphere and stratosphere where because of presence of ozone, temperature increases with increasing height.
2. **Advectional inversion/ dynamic inversion (due to either horizontal or vertical movement of air)**
   - **(A) Frontal or cyclonic inversion :** It occurs in temperate region due to temperate cyclones. During the formation of temperate cyclones, warm air is pushed up by the cold polar air giving birth to temperature inversion conditions.



   - **(B) Valley inversion :** It occurs in the mountainous valleys due to radiation and vertical movement of air. During winter nights, temperature of the upper parts of the valley becomes very low because of rapid rate of loss of heat from the surface through terrestrial radiation. On the other hand, the temperature of the valley floor does not fall considerably because of comparatively low rate of loss of heat through terrestrial radiation and air remains warmer there. This warm air being lighter starts ascending towards the hilltops while the cold air of hilltops being denser starts descending towards valleys. This way warm air lies above the cold air giving birth to temperature inversion.



   - **(C) Surface inversion :** Surface temperature inversion occurs when warm air lies over the area of cold air or cold air moves into the area of warm air. Former being lighter is pushed upwards. Such inversion generally occurs near coastal areas and on islands.



Significance of temperature inversion

1. Due to position of warm air above the cold air, warm air is cooled from below and fog is formed.
2. Inversion of temperature causes frost when the condensation of warm air due to its cooling by cold air below occurs at temperature below freezing point.
3. Formation of frost is unfavourable for crops.
4. Fog is favourable for crops like coffee and wheat which prevent them from direct sunlight. Ex. Coffee plants in Yemen Hills of Arabia.
5. Valley inversion is responsible for severe frost in the valley floors causing great damage to fruit orchards, vegetables and agricultural crops; hence this area is not suitable for human settlements as well as agriculture.
6. Atmospheric stability formed due to temperature inversion discourages rainfall and favours dry conditions resulting into anti-cyclonic conditions. For example - temperature inversion occurs on the western part of the continents situated between 200 to 300 latitude. Due to anti- cyclonic conditions prevailing there, this region is dotted with tropical deserts.
7. Dense fog hampers navigation.
8. Temperature inversion prevents atmospheric escape of dust particles near the ground surface. This has created severe pollution problems in temperate cities like Delhi.
9. Fog created during temperature inversion when mixed with smoke generates harmful urban smog.

4. Atmospheric Pressure and Pressure Belts

Air pressure and atmospheric circulation

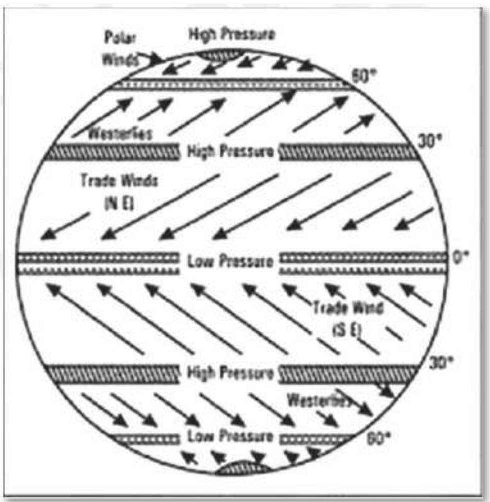
Air pressure is defined as total weight of mass of column of air above per unit area at sea level. As height increases density of air decreases, hence it is maximum at sea level. In short, as height increases air pressure decreases. The lines dividing the places of equal pressure at sea level are called isobars.

Horizontal distribution of air pressure and pressure belts

On the basis of mode of formation, pressure belts are divided into two categories -

(A) Thermally induced pressure belts (formed due to differential heating of the Earth's surface)

1. **Equatorial low-pressure belt :** It lies between 50 north and 50 south latitudes. No pressure belt is created near equator due to direct perpendicular insolation received from the sun throughout the year. Due to high temperature prevailing near equator, air becomes warm. This warm air expands, becomes light and consequently rises upward causing low pressure. This belt is the zone of convergence of North - East and South - East trade winds. This belt presents vertical movement of air; and there is very calm horizontal movement of air; hence this belt is also known as doldrums.
2. **Polar high-pressure belt :** This belt entirely lies near the poles. High pressure existed here because of prevalence of very low temperature throughout the year.

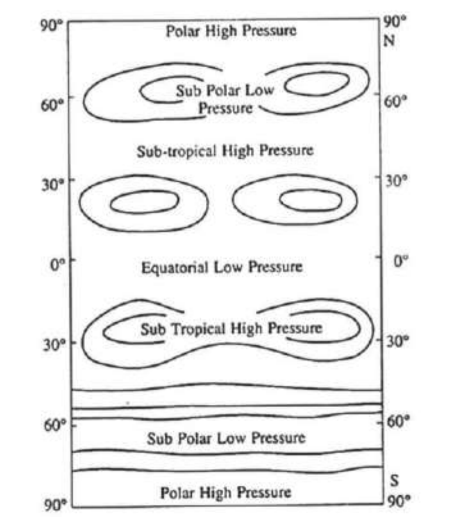


(B) Dynamically induced pressure belts (formed due to rotation of the earth and sinking of winds)

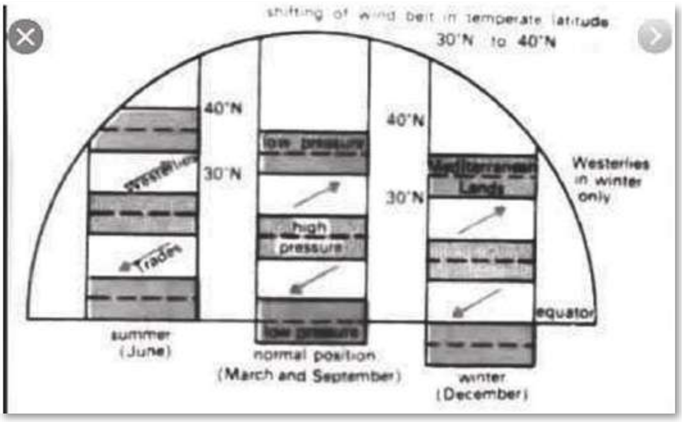
1. **Subtropical high-pressure belt :** This belt extends between 250 to 350 in both hemispheres. The conversion of links at higher altitude above this zone results in the subsidence of air from higher altitudes. This descend of wind causes high pressure. The zone is characterised by anti-cyclonic conditions which cause atmospheric stability and aridity. Hot deserts of the world lies in the region of subtropical high-pressure belt. This belt is also known as horse latitudes. Ideally, this belt should be continuous, but it is broken into number of high-pressure centres.
2. **Subpolar low-pressure belt :** It lies between 600 to 650 latitudes in both hemispheres. Due to rotation of the earth surface, area spreads outward from this zone creating low-pressure. This belt is regular in southern hemisphere, but it is broken in northern hemisphere because of overdominance of water in southern hemisphere.

Seasonal shifting of pressure belts

Due to the phenomena of summer and winter solstice, sun changes its apparent position throughout the year and thus, the position of all pressure belts except the polar high-pressure belt changes with the northward and southward migration of the sun. For example - during summer, equatorial low-pressure belt shifts to 100 to 200 towards north during Northern summers.

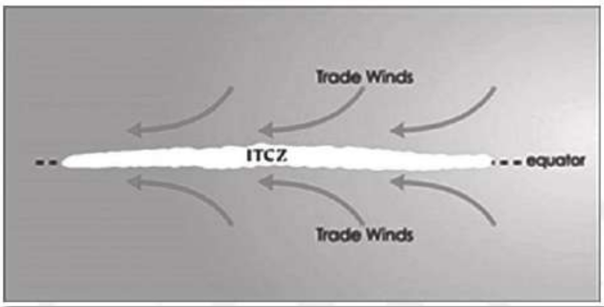


Seasonal shifting of pressure belts gives birth to unique Mediterranean climatic region. Mediterranean climatic region has unique characteristic of winter rainfall which is not observed in any climatic region over the globe. Mediterranean climatic region lies between 300 to 450 latitudes in both hemispheres. During summers in north, subtropical high-pressure belt shifts northward and lies exactly over Mediterranean climatic region. This creates anti cyclonic conditions and prevent summer rainfall in the region. During winters in North hemisphere, pressure belts shift southward. Consequently, anti-cyclonic conditions prevailing over Mediterranean climatic region also diminishes. During winter, westerlies start blowing towards Mediterranean region, while doing so, they carry moisture and give rainfall in the region.
Similarly, seasonal shifting of pressure belts affect shifting of ITCZ, which has greater impact on monsoon (explained separately).



Coriolis force and direction of wind

Winds blow from high-pressure areas to low-pressure areas. Difference of pressure between any two places is called as pressure gradient. Air movement follows this pressure gradient. While following the pressure gradient due to rotation of the earth, direction of winds changes which is determined by Coriolis force.



Coriolis force is also called as deflection force. It is based on Ferrell's law. Due to effect of Coriolis force, all the winds are deflected to the right in the northern hemisphere, while they are deflected to the left in the southern hemisphere. Following are the characteristic features of coriolis force :

1. Coriolis force is not a force itself rather it is just an effect of rotational movement of the earth.
2. Coriolis force affects only the objects which are in motion.
3. Coriolis force just affects the direction and not the speed.
4. Magnitude of Coriolis forces is determined by using formula 2mw(sin0), where 'm' is the mass of object in motion, 'w' is the velocity of an object, '0' the latitude.
5. Thus, it is clear that magnitude of Coriolis force is determined by wind speed i.e., higher the wind speed greater is the deflection.
6. Also the magnitude is determined by the latitude. Near equator, it is maximum (as sin0=0) while near pole it is zero (as sin90=0).

Classification of winds

Winds are classified into three broad categories -

(A) Permanent winds/ prevailing winds/ planetary winds/ invariable winds/ primary circulation (as they blow throughout the year without changing the direction).
  1. Trade winds
  2. Westerlies
  3. Easterlies or polar winds

(B) Secondary winds/Seasonal winds/ variable winds/ secondary circulation/ non-permanent wind (as they change their direction seasonally)
  1. Monsoon winds
  2. Air masses
  3. Cyclones
  4. Anticyclones

(C) Tertiary circulation/ local winds (they blow locally and only for few days)
  1. Land and sea breeze
  2. Mountain and valley breeze
  3. Chinook and Foehn
  4. Harmatten
  5. Sirocco
  6. Mistral
  7. Bora
  8. Blizzard

Permanent winds

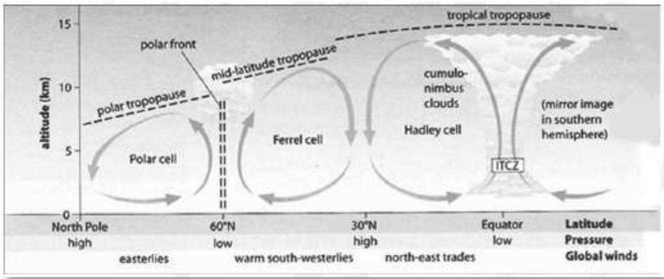
The direction of these winds remained more or less the same throughout the year. They are closely associated with pressure belts. They are further subdivided into -

1. **Winds in the tropics :** These winds lie between 300 North and 300 South latitudes. Here, winds blow from the subtropical high-pressure belt to the equatorial low-pressure belt. These winds meet near the equator creating belt of calm doldrum where only vertical movement of air takes place. Due to continuous vertical movement of air, weather is frequently interrupted by atmospheric disturbances like cyclones, hurricanes, convectional rainfall, etc. The meeting ground of North-East and South-East trade winds is also called as intertropical convergence zone (ITCZ) or intertropical fronts.
2. **Horse latitudes and westerlies :** Westerlies are the permanent winds blowing from subtropical high-pressure belt to subpolar low-pressure belt. The zone of origin of trade winds and westerlies is also called as horse latitudes which is nothing but subtropical high-pressure belt. Westerlies encounter with cold winds from the poles giving birth to polar front and temperate cyclones are originated there. The cyclones were along with the westerlies in easterly direction. Because of dominance of land in northern hemisphere, westerlies are less effective but in southern hemisphere their velocity increases because of absence of obstacle of land. They are called as roaring 40s, furious 50s and striking 60s in southern hemisphere near 400, 500 and 600 latitude respectively. In North, while crossing over any water body, westerlies pick up the moisture and give precipitation in easterly regions. Good example of westerlies are western disturbances observed in north and north-west India which gives snowfall and winter rainfall in the month of December, January.
3. Polar winds : These cold winds blow from polar high-pressure area to subpolar low- pressure area. They become more active during winters as high pressure intensifies over poles, they encounter with westerlies and give birth to temperate cyclones.

Tricellular Meridional circulation of the atmosphere

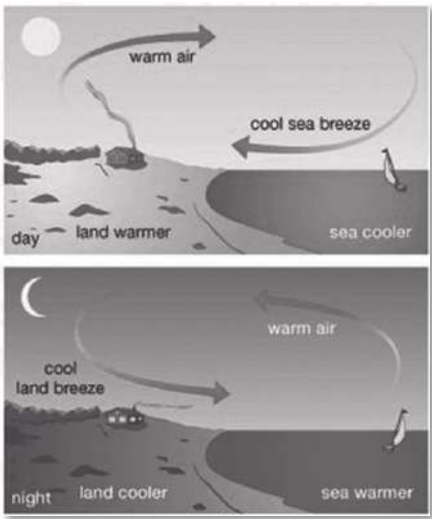
Tri-cellular model emphasises that there is cellular circulation of air at each longitude. In this model, surface winds blow from high-pressure areas to low-pressure areas but in the upper atmosphere, the direction of air circulation is opposite to the direction of surface wind. This model has three cells:

1. **Tropical cell/Hadley cell :** Due to high temperature at equator, air ascends upward. After reaching a height of 8 to 12 km in the troposphere over the equator, air diverges northward and southward (poleward). Surface wind starts blowing from subtropical high-pressure area to equatorial low-pressure area to fill the vacuum created by ascending air. These surface winds are called as trade winds. In the upper atmosphere while moving towards the pole (called as anti-trade), air loses its energy and starts descending above subtropical high-pressure area. In this way, one complete Meridional cell of air circulation is formed.
2. **Mid-latitude cell/ Ferrel cell :** Air rises near subpolar low-pressure belt due to rotation of the earth. After reaching the height of 5 to 8 km in the troposphere, it diverges northward and southward. To fill this vacuum, wind starts blowing from subtropical high-pressure area as well as from polar high-pressure area towards this south polar low-pressure area giving birth to westerlies and easterlies respectively. In this way, second cell of air circulation is formed.
3. **Polar cell :** The air ascending from subpolar low-pressure area starts moving towards the pole and it finally descends around the pole because of low temperature and high pressure. This descending air blows on the surface of the earth towards the subpolar low-pressure belt to fill the vacuum in the form of easterlies. In this way, third cell of air circulation is formed.

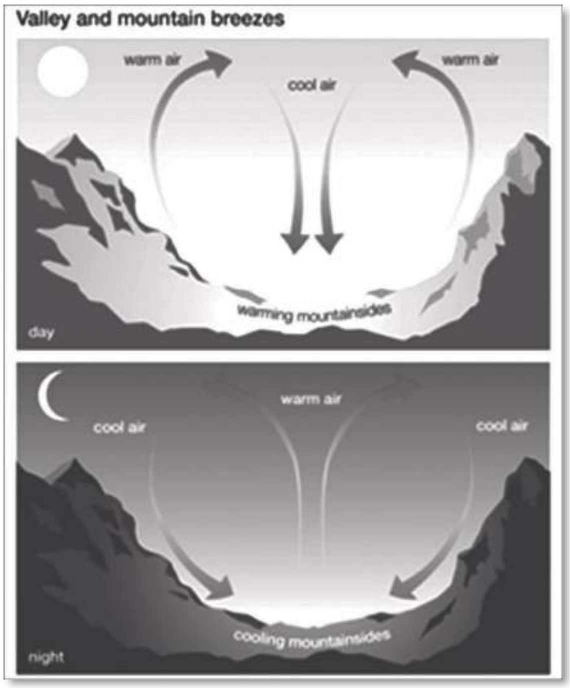


Local winds

1. **Land and sea breeze :** Land and sea breeze are diurnal winds completing their cycle in 24 hours period. They originate due to differential heating and cooling of land and water. As we know that land gets heated and gets cooled faster as compared to water, during daytime near coastal areas, land is warmer than water surface. This land area experiences low pressure while water surface experiences high-pressure. Consequently, wind starts blowing from high- pressure to low-pressure area i.e., from water bodies towards the coastal areas giving birth to sea breeze. At night time, this condition gets reversed as land cools faster than water bodies. Hence land surface has high pressure as compared to surrounding water body. In this case, wind starts blowing from land towards the water called as land breeze. Land and sea breeze brings moderating effect to the coastal areas by bringing down the temperature by 50C-100C. They can reach up to 50 to 65 km inland in tropical regions. They have great potential of bringing down the pollution near coastal areas. They carry pollutants along with them and redistribute in the inland regions. These winds are most active during summer season.

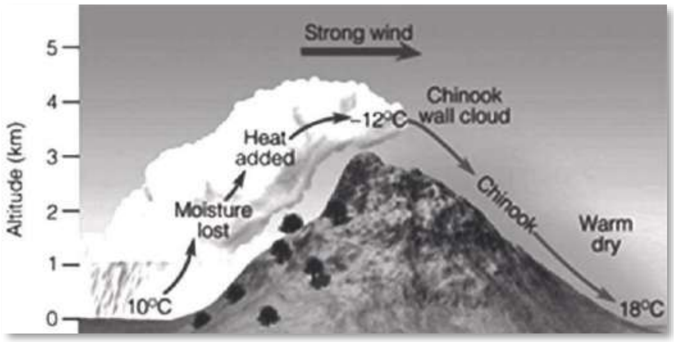


2. **Mountain (Katabatic) and Valley (Anabatic) breeze :** During daytime, mountain tops get heated quickly as they receive insolation earlier than valley bottoms. Thus, valley bottoms experience high pressure while mountain-tops experience low pressure. Consequently, wind starts blowing from valley bottom towards the mountain top and is known as valley breeze. During nighttime, mountain-tops radiate energy quickly as compared to valley bottoms and become cooler faster. This creates high pressure at mountain tops while valley bottom experience low pressure. Consequently, wind starts blowing from mountain tops towards valley bottoms which is called as mountain breeze. Day time breeze is also known as valley breeze and nighttime breeze is also known as down valley breeze.



3. **Chinook and Foehn :** Warm and dry local winds blowing on the leeward side of mountains are called as Chinook in USA and Foehn in Switzerland. In USA, the winds ascend through the western slopes of the Rockies and give rainfall along the western slopes of Rockies. After crossing over the Rockies, these wind descend through the eastern slopes. During this time, they become warm and dry. Similar process takes place in Swiss Alps where firstly wind ascends on southern slopes and then descends on northern slopes. These winds are more common during winter. Arrival of these winds increases temperature of the

region by around 440C. This melts away the snow present on the ground; hence they are also called as snow eaters. These winds open up green pastures and makes early sowing of wheat possible. This in longer run makes wheat available early in the market as compared to other competitors. These winds are also known as climatic oasis in Switzerland as it not only allows early sowing of spring wheat but it also helps in ripening of grapes and checks autumn frost.



4. **Harmattan :** The warm and dry winds blowing from Northeast and east to west in eastern parts of Sahara desert are called Harmattan. They are extremely dry winds and carry desert sands while blowing. Generally, western coast of Africa is warm and moist and hence weather is very unpleasant. High humidity prevailing in the western coast of Africa is injurious to human health. Arrival of hyperacid Harmattan makes weather suddenly dry and pleasant as they suck extra humidity. In short, arrival of this wind make life possible in the region; hence they are also called as DOCTOR in the Guinea. Sometimes, harmattan bring dust storms along with them. Similar warm, dry, very strong and dust laden winds are called brick fielder in Victoria province of Australia, blackroller in the Great Plains of USA, Norwester in New Zealand and Shamal in Persia.
5. **Sirocco :** It is a warm dry and dusty wind which blows in the only direction from Sahara desert. While crossing Mediterranean sea, it picks up moisture and gives precipitation along the southern slopes of Alps, especially in Italy and Spain. The rain associated with Sirocco is called blood showers because of fall out of red sands with falling rains which Sirocco has picked up while blowing over Sahara desert. This rainfall is very much injurious to agriculture and fruit crops. It is locally called as Khamsin in Egypt, Gibli in Libya, Chilli in Tunisia and Simoom in Arabian desert.
6. **Mistral :** This wind blows from north-west to south-east direction in France and Spain. They are most active during winter season. Because of their origin near Arctic circle, they are very cold and stormy in nature; adversely affecting air traffic frequently.
7. **Bora :** These are extremely cold and dry north - easterly winds blowing along the shores of Adriatic Sea. They can reach up to southern slopes of Alps that is North Italy. Though they are cold, they are relatively moist because they pick up moisture while coming from over the Adriatic Sea.
8. **Blizzard :** It is a violent, stormy, cold and polar wind which is laden with dry snow. It is prevalent in north and south polar regions. It blows for hundreds of kilometres in Siberia, Canada and Alaska. On the onset of these winds, visibility becomes remarkably low. Average velocity of blizzards is 80-96 km/h. They are also called as norther in Southern USA and Burran in Siberia.

Atlantic Meridional Overturning Circulation (AMOC): Significance, Risks, and Implications
Introduction

- The **Atlantic Meridional Overturning Circulation (AMOC)** is a large system of ocean currents that transports warm, salty water from the tropics to the North Atlantic and returns cold, deep water southwards. It is a crucial component of the **global thermohaline circulation** (the "ocean conveyor belt"), regulating Earth's climate.
- NASA calls AMOC the **"conveyor belt of the oceans"**, and the IPCC warns of its weakening under climate change.

How AMOC Works

- Warm surface water from the tropics moves northward via the **Gulf Stream**.
- On cooling, the water becomes denser, sinks near Greenland and Iceland, and flows south as deep cold currents.
- This overturning circulation redistributes **heat, carbon, and nutrients** globally.

Importance of AMOC

- **Climate Regulation**: Balances heat between tropics and higher latitudes, influencing the monsoon system.
- **Carbon Sequestration**: Stores atmospheric CO_2 in deep ocean layers.
- **Marine Productivity**: Supports nutrient circulation critical for fisheries.
- **Weather Patterns**: Stabilizes rainfall and storm activity in the North Atlantic and tropics.

Threats to AMOC

- **Global Warming**
  - Melting Greenland and Arctic ice adds freshwater, reducing salinity and density, weakening the sinking mechanism.
- **Increased Rainfall**
  - More freshwater input into the North Atlantic reduces water density.
- **Ocean Warming**
  - Warmer waters reduce stratification, slowing overturning circulation.

Consequences of AMOC Weakening/Collapse

- **Global**
  - More **extreme weather**: storms in North America, droughts in Africa and Asia.
  - **Sea Level Rise**: Slowing AMOC raises sea levels along the U.S. east coast.
  - Possible **shutdown** could destabilize global climate like during the last Ice Age.
- **For India**
  - **Monsoon Disruption**: Weaker AMOC may reduce rainfall over India and the Sahel region.
  - **More Heat Waves**: Altered circulation can intensify warming over South Asia.
  - **Cyclone Intensification**: Warmer Indian Ocean could strengthen tropical cyclones.

International Findings

- **IPCC AR6 (2021)**: High confidence that AMOC has weakened since mid-20th century.
- **Nature (2021) study**: AMOC at its weakest in over a **millennium**.
- **Projections**: While a complete collapse before 2100 is unlikely, continued warming may push AMOC past tipping points.

Way Forward

- **Mitigation**
  - Aggressive reduction in greenhouse gas emissions.
  - Protection of Arctic and Greenland ice sheets.
- **Adaptation**
  - Strengthening early-warning systems for extreme weather.
  - Building resilience in vulnerable regions like South Asia.
- **Research & Monitoring**
  - Expansion of ocean observation systems (e.g., **RAPID array at 26.5°N in Atlantic**).
  - International collaboration under **UN Decade of Ocean Science (2021–2030)**.

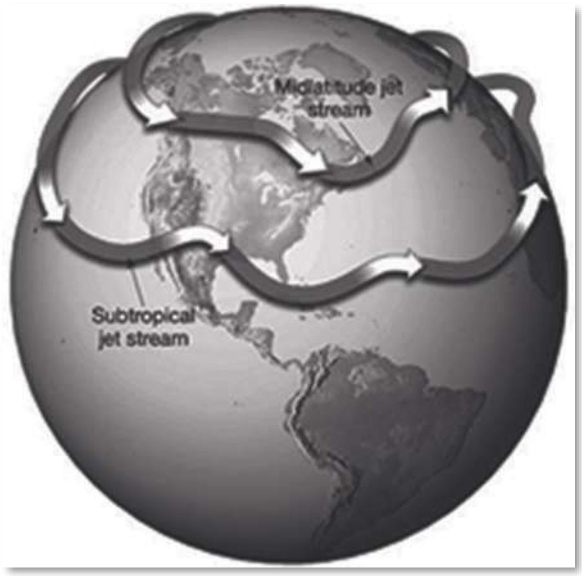
5. Jet Streams and Monsoonal Circulation

Jet Stream

The strong and rapidly moving circumpolar westerly air circulation in a narrow belt of a few hundred kilometres width in the upper limit of troposphere is called jet streams.

Properties of jet streams

1. They are confined between poles and 200 latitudes.
2. Their height from the ground surface is between 5 to 14 km.
3. Direction of their flow is from west to east.
4. They measure thousands of kilometres in length, few hundred kilometres in width and few kilometres in depth.
5. Minimum velocity of jet stream is 108 km/h. They become strong during winter season and reaches to their maximum velocity of 480 km/h.
6. They meander and develop crests and troughs called as Rossby waves. The period of transformation of straight path of the jet stream to wavy and meandering path is called as index cycle of jet stream.



7. Extent of jet streams narrows down with respect to seasonal shifting of pressure belts.

Types of jet streams

1. Polar front jet stream/ mid-altitude jet stream
2. Subtropical westerly jet stream
3. Tropical easterly jet stream
4. Polar night jet stream
5. Local jet stream

Significance of jet stream

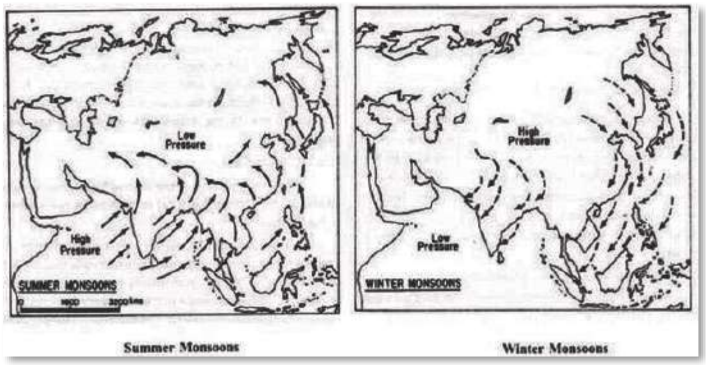
1. They are associated with temperate cyclones. Intensity of temperate cyclones is more or less determined by jet streams.
2. They fluctuate local weather conditions.
3. Subtropical westerly jet stream plays pivotal role in the formation of monsoon.
4. Polar vortex phenomenon is linked with index cycle of jet streams.
5. Jet streams play a major role in air travel.

Monsoon

y Monsoon is the seasonal reversal of wind direction. Differential heating of continents and ocean is the principal cause of its origin. Monsoon winds are divided into south-west monsoon and North-East monsoon.

Origin and mechanism of monsoon

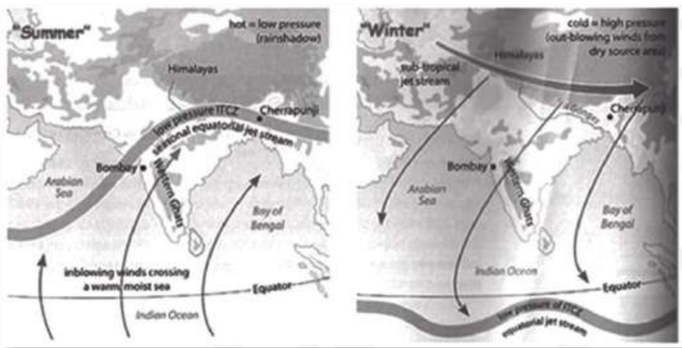
1. **Thermal heating theory**
   - This theory was presented by Halley in 1886. According to this theory, monsoon is caused because of differential heating of land and sea. During summers in northern hemisphere, temperature is very high on Indian subcontinent creating low-pressure area. At the same time, southern hemisphere experiences winter creating high pressure area. Due to pressure gradient, wind starts blowing from high-pressure to low-pressure. After crossing equator due to Coriolis force, they get deflected towards their right. This wind travels over peninsular India from Southwest direction and this is known as south-west monsoon.
   - This condition is reversed during winters in northern hemisphere creating high-pressure area on Indian subcontinent and creating low-pressure area in Southern hemisphere. Due to pressure gradient, wind starts blowing from high-pressure to low-pressure area. Because of Coriolis force, winds in northern hemisphere have north-easterly direction. This is called as North-East monsoon.



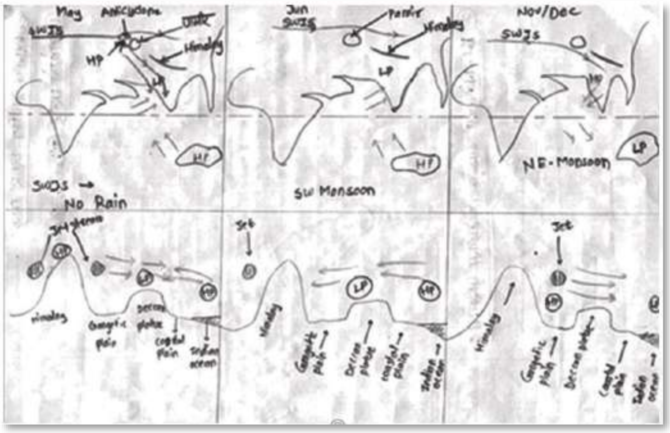
Summer Monsoons Winter Monsoons

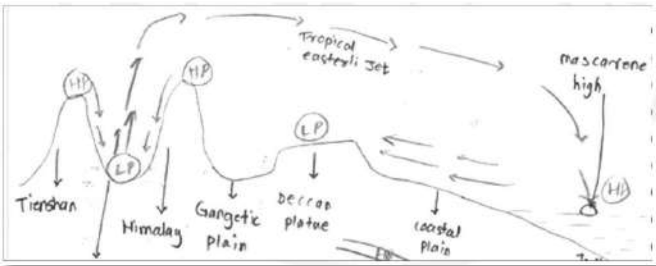
2. **Dynamic concept**
   - This concept is given by Flohn. According to this concept, Indian monsoon is a modification of trade winds. Due to seasonal shifting of pressure belts, ITCZ also gets shifted. During summer, ITCZ lies over northern Indian plains, thus, trade winds from south hemisphere need to cross equator to reach ITCZ. But after crossing equator, due to Coriolis force, they get deflected towards their right and this forms south-west monsoon. Similarly, during winter ITCZ shifts below equator and north easterly trade winds have to cross the equator. These north easterly trade winds are North East monsoon.
   - However, above two theories do not help to fully understand the mechanism of monsoon. Low-pressure area is prevalent on Indian peninsula in the month of May itself. So, ITCZ lies over peninsular India in the month of May. But monsoon starts in the first week of June. Only this anomaly was not explained by above two theories. Also, there is gradual development of low-pressure area and gradual shifting of ITCZ towards north. Hence monsoon should be developed gradually over Indian subcontinent. On the contrary, there is sudden burst of monsoon which is not explained by these theories. The explanation to this questions is given by jet stream theory.
3. **Jet streams theory**
   - The position of subtropical jet stream (STWJ) influences the mechanism of monsoon.
   - During winter, STWJ shifts southward. It gets bifurcated due to Himalayas and one branch blows over Gangetic plains i.e., south of Himalayas and another one blows over Tibet that is north of Himalayas. Due to winter, high pressure is prevalent over Indian subcontinent while southern hemisphere experiences low-pressure. Presence of STWJ over Gangetic plain further intensifies this high-pressure. Consequently, wind starts blowing from North- east direction towards southern hemisphere. This is North-East monsoon.
   - After winter solstice, sun starts moving towards Tropic of Cancer. Along with this, STWJ also starts moving towards north. This weakens southern branch of STWJ. In the month of May, sun lies exactly overhead at 15 to 200 latitudes. Though weakened, the branch of STWJ is not completely absent over Gangetic plain. This branch creates high-pressure belt in the upper troposphere and prevents upward movement of air from the surface. This prevents creation of low-pressure area on the surface; therefore, monsoon is not yet activated.
   - By the start of June, STWJ shifts completely to the north of Himalayas and upper troposphere once high-pressure is removed. This induces the rapid movement of wind from sea towards the land and this is called as sudden burst of monsoon.

Role of Tibetan Plateau in monsoon



- Tibetan Plateau plays very important role in determining the strength of monsoon. Tibet is surrounded by higher mountain ranges, Himalaya towards its south and Tienshan towards its north. Hence Tibetan Plateau experiences low-pressure as compared to surrounding mountain ranges. Tibetan Plateau acts as a heat source. Air above it is heated and becomes warmer as compared to surrounding mountain ranges. This warm air rises above and spreads southwardly. This air sinks over Indian Ocean at about 300S and 700E, known as Mascarene high. This movement of wind is called as tropical easterly jet. This jet pushes monsoonal rains towards Indian subcontinent and intensifies south-west monsoon.



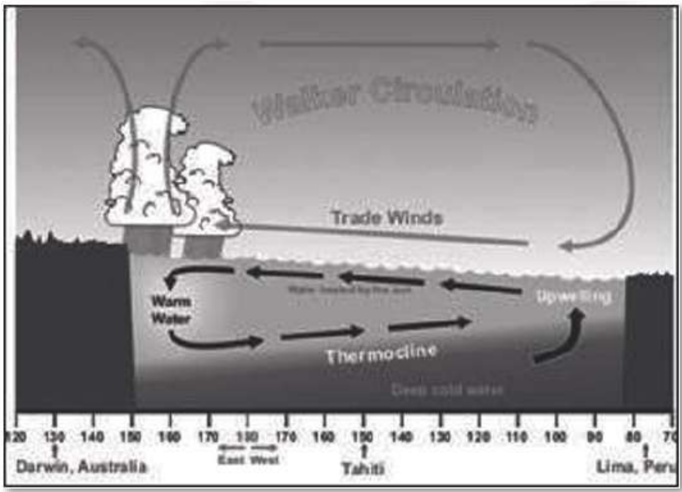


El Nino and its impact on monsoon

El-Nino is the extension of counter equatorial Pacific current towards Peruvian cost. In this event, warm counter equatorial Pacific current replaces cold Peruvian current/Humboldt current. This phenomenon typically occurred during Christmas. Hence it is also called as Christ child or baby Jesus. El-Nino occurs in a cycle of 3-7 years.

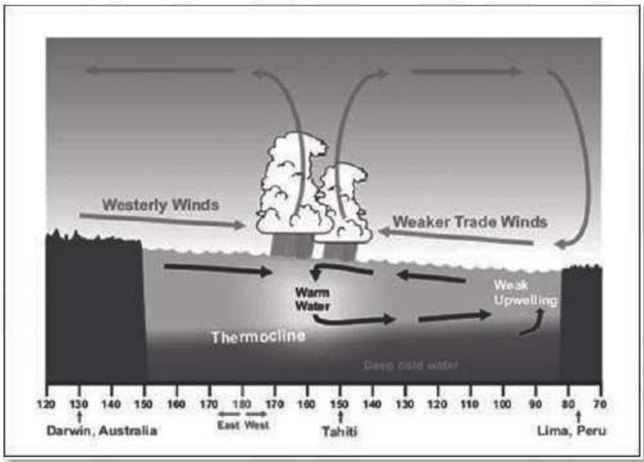
Normal conditions

Under normal conditions, easterly trade winds while blowing towards the equator pushes warm water towards the Australia and Indonesia from Peruvian coast. This piles up warm water near the Western Pacific coast and brings up cold water on the surface due to upwelling near Peruvian coast. Hence Western Pacific experiences low pressure as compared to eastern Pacific. This pressure gradient creates east to west circulation of tropical winds which is known as Walker circulation. Walker circulation is a convective cell of air circulation. Due to Walker circulation, high-pressure further gets intensified near equatorial East Pacific ocean due to subsidence of air from above. This Walker circulation further pushes monsoon winds in Indian Ocean.



El-Nino conditions

El-Nino conditions weakens the easterly trade winds and warms the Peruvian coast preventing upwelling. Pressure system gets reversed and so are Walker circulations. Such oscillation in pressure gradient and reversal of Walker circulations is called as Southern oscillation. Southern oscillations are always associated with El-Nino events. This combined phenomenon is known as ENSO effect. During this effect, Walker circulations are weakened due to development of equatorial westerlies on the sea surface which suck monsoon winds developed over Indian Ocean and subsequently leads to weakening the monsoon in Indian subcontinent.



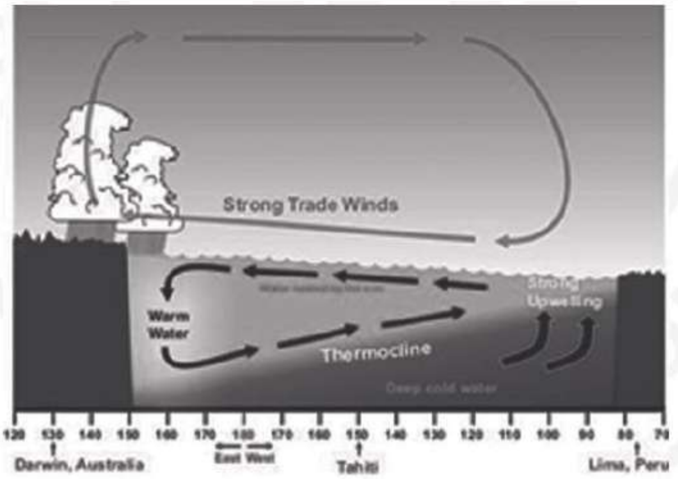
The main difficulty with the Southern oscillation is that its periodicity is not fixed and its period varies from 2 to 5 years. Different indices have been used to measure the intensity of the Southern oscillation but the most frequently used is the Southern Oscillation Index (SOI). It is the difference in pressure between Tahiti representing the Pacific ocean and Port Darwin representing the Indian Ocean. Positive Southern Oscillation Index means Tahiti pressure is greater than that of Port Darwin which brings good monsoon rain over India and Indian Ocean. Negative Southern Oscillation Index represents Port Darwin's pressure exceeding that of Tahiti and this brings low rainfall and poor monsoon over Indian subcontinent which represents arrival of El-Nino.

Significance of El-Nino

1. Under normal conditions, there is no rainfall on Peruvian coast due to subsidence of air and creating anticyclonic conditions. But El-Nino replaces the high-pressure with the low pressure bringing rainfall on the coast of Peru.
2. Under normal conditions, there is rainfall on western margins of Pacific due to ascendance of air. This condition is reversed because of reversal of Walker circulations and there is no rainfall along western margins of equatorial Pacific.
3. During El-Nino conditions, winds originating in Indian Ocean are sucked towards the Pacific, this weakens monsoon in Indian subcontinent.
4. Under normal conditions due to upwelling at Peruvian coast, good fishing grounds are developed. Lack of rainfall and good fishing grounds promote fisheries in this region. But during El-Nino upwelling stops affecting fish catch. At the same time, rainfall promotes agriculture in the region.
5. Heavy rainfall during El-Nino events cause frequent flash floods and malaria outbreaks along the western coast of south America.
    - It is believed that El Niño affects Indian monsoon resulting into droughts; but there is no general rule that whenever there is El-Nino, monsoon gets affected. The more research is needed to understand the complex link between these two phenomena.

La-Nina

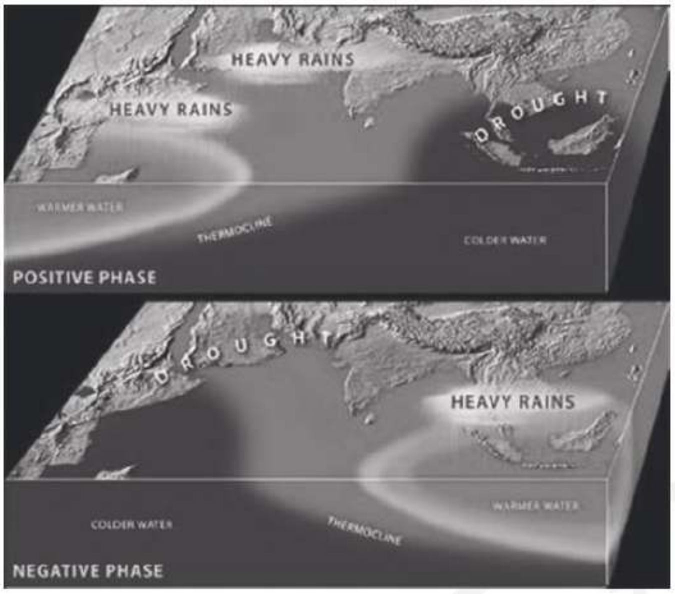
- La-Nina is the counterpart of El-Nino. It is characterised by cooler than normal surface sea temperatures at eastern equatorial Pacific. In short, it is the intensification of normal conditions. Generally, El-Nino events are followed by La-Nina which brings disturbed condition to normalcy. This condition has opposite effects of El-Nino conditions.



Indian Ocean Dipole/ Indian Nino

- Although ENSO was statistically effective in explaining several past droughts in India, in the recent decades the ENSO-Monsoon relationship seemed to weaken in the Indian subcontinent. For e.g. the 1997, strong ENSO failed to cause drought in India.
- However, it was later discovered that just like ENSO was an event in the Pacific Ocean, a similar seesaw ocean-atmosphere system in the Indian Ocean was also at play. It was discovered in 1999 and named the Indian Ocean Dipole (IOD).
- The Indian Ocean Dipole (IOD) is defined by the difference in sea surface temperature between two areas (or poles, hence a dipole) – a western pole in the Arabian Sea (western Indian Ocean) and an eastern pole in the eastern Indian Ocean south of Indonesia.
- IOD develops in the equatorial region of Indian Ocean from April to May peaking in October.
- With a positive IOD winds over the Indian Ocean blow from east to west (from Bay of Bengal towards Arabian Sea). This results in the Arabian Sea (western Indian Ocean near African Coast) being much warmer and eastern Indian Ocean around Indonesia becoming colder and dry.
- In the negative dipole year (negative IOD),

reverse happens making Indonesia much warmer and rainier.



- It was demonstrated that a positive IOD index often negated the effect of ENSO, resulting in increased Monsoon rains in several ENSO years like the 1983, 1994 and 1997.
- Further, it was shown that the two poles of the IOD – the eastern pole (around Indonesia) and the western pole (off the African coast) were independently and cumulatively affecting the quantity of rains for the Monsoon in the Indian subcontinent.
- Similar to ENSO, the atmospheric component of the IOD was later discovered and named as Equatorial Indian Ocean Oscillation [EQUINOO]. [Oscillation of warm water and atmospheric pressure between Bay of Bengal and Arabian Sea].
- Positive IOD (Arabian Sea warmer than Bay of Bengal) results in more cyclones than usual in Arabian Sea.
- Negative IOD results in stronger than usual cyclonogenesis (Formation of Tropical Cyclones) in Bay of Bengal. Cyclonogenesis in Arabian Sea is suppressed.

El Nino Modoki

- El Niño Modoki is a coupled ocean-atmosphere phenomenon in the tropical Pacific.
- It is different from another coupled phenomenon in the tropical Pacific namely, El Niño.
- Conventional El Niño is characterized by strong anomalous warming in the eastern equatorial Pacific.
- Whereas, El Niño Modoki is associated with strong anomalous warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific .
- The El Niño Modoki phenomenon is characterized by the anomalously warm central equatorial Pacific flanked by anomalously cool regions in both west and east.
- Such zonal gradients result in anomalous two-cell Walker Circulation over the tropical Pacific, with a wet region in the central Pacific.

6. Air Masses and Frontogenesis

Air mass is a large body of air whose physical properties especially temperature, moisture content and lapse rate are more or less uniform horizontally for hundreds of kilometres.

Characteristics of air masses

1. High isobaric pressure
2. Upper air continues to descend
3. No precipitation and rare presence of clouds
4. Relatively low humidity
5. Stable air
6. Spread over hundreds of kilometres
7. Small vertical and horizontal variation in air

Properties of air masses are determined by

1. Properties of the source area
2. Direction of the movement of air mass
3. Changes introduced during its journey away from the source
4. Age of the air mass

Essential conditions for the formation of air mass

1. Extensive homogeneous earth surface
2. Uniform temperature and moisture conditions
3. Regular topography either in the form of land surface or ocean surface
4. No convergence of air (divergence is needed)
5. Prevailing anti-cyclonic conditions
6. Stable atmospheric conditions for long period

Based on these essential conditions, following are major source regions of air masses -

1. Polar oceanic areas
2. Polar and Arctic continental areas
3. Tropical oceanic areas
4. Tropical continental areas
5. Equatorial regions
6. Monsoon lands

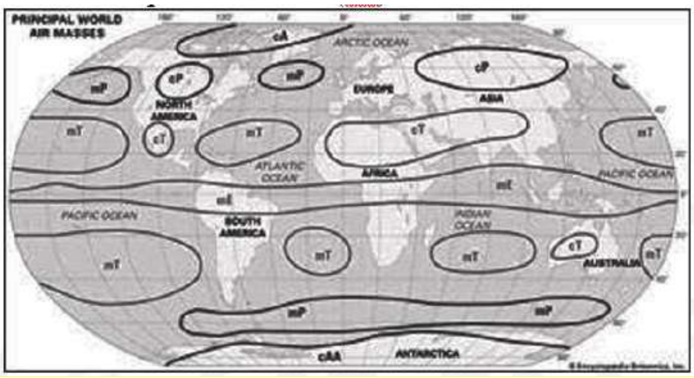
Classification of air masses

(A) Geographical classification : It is based on the characteristic features of the source regions. According to geographical locations of source region, they are further divided into -

1. Polar air mass (P)

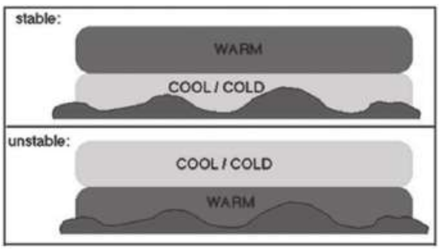
2. Tropical air mass (T)

- On the basis of nature of the surface of the source region they are further divided into,
  - **(i)** Continental air masses (c)
  - **(ii)** Maritime air masses (m)
- By combination of these factors air masses are classified into four principal types,
  - **(i)** Continental polar air mass (cP)
  - **(ii)** Maritime polar air mass (mP)
  - **(iii)** Continental tropical air mass (cT)
  - **(iv)** Maritime tropical air mass (mT)



(B) Thermodynamic modifications and classification : Thermodynamic modification involves heating or cooling of air mass from below while passing through different surfaces away from its source region. Such a modification depends on four factors,

1. Initial characteristics of air mass
2. Nature of land or water surface over which it moves
3. Path followed by air mass from the source region to destination
4. Taken by air mass to reach a particular destination
   - Based on thermodynamic modifications, air masses are divided into stable and unstable air masses. An air mass while moving over the surface whose temperature is greater than the air mass, is heated from below and becomes unstable (u). On the other hand, when air mass moves over the surface whose temperature is less than it, it cools from below and becomes stable.



- Also based on the destination region, air mass is divided into warm and cold air mass. A warm air mass (w) is that whose temperature is greater than the surface temperature of the destination while air mass is cold air mass (k) when its temperature is less than the surface temperature of the destination.

Influence of air masses on weather

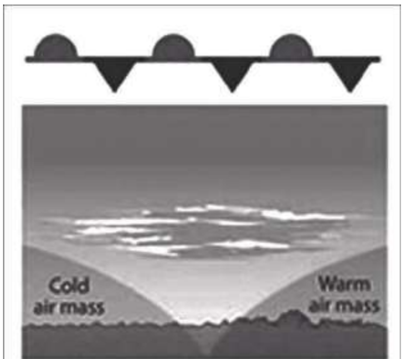
1. They carry atmospheric moisture from oceans to continents and cause precipitation over land masses.
2. Temperate cyclones originate at the contact zone between different air masses.
3. Near stable air masses, anti-cyclonic conditions are formed creating hot and dry weather.
4. Near unstable air masses, due to vertical share atmospheric disturbances are formed.

Fronts

Front is a three-dimensional sloping boundary zone where two different air masses with contrasting physical properties converge. The process of formation of new front for regeneration of dying front is known as frontogenesis. Dissipation of a front is known as frontolysis. In short, frontogenesis involves convergence of two distinct air masses while frontolysis involves overriding of one air mass by another.

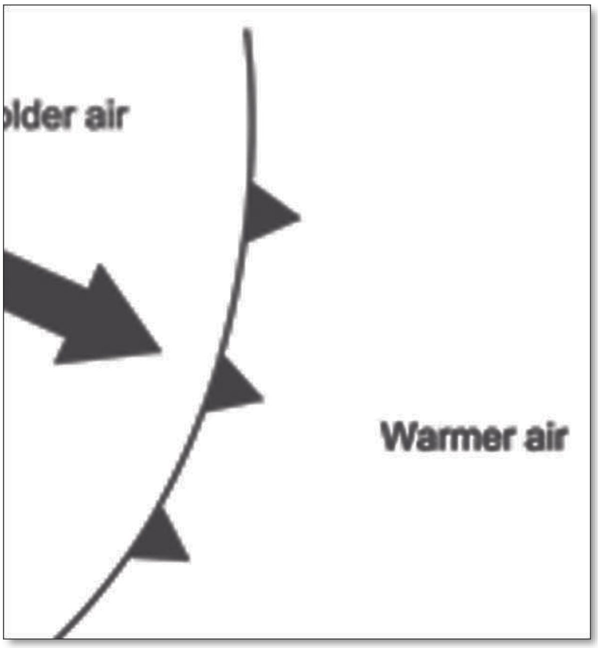
Types of fronts

1. **Stationary front :** It is characterised by no movement towards each other by two distinct air masses. This front is not moving. The wind motion on both sides of the front is parallel to the front.

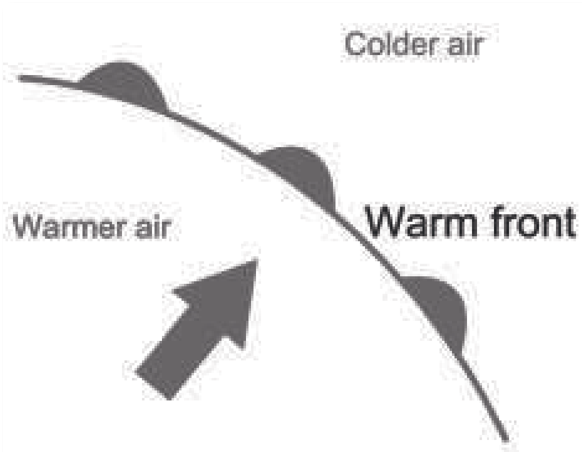


Stationary front

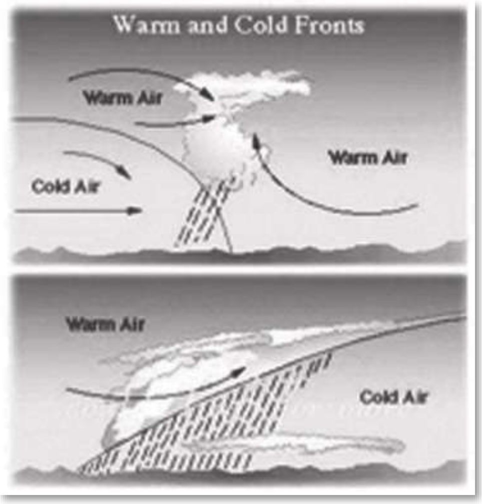
2. **Cold front :** Cold front is formed when a cold air mass replaces warm air mass by advancing into it or warm air mass retreats and cold air mass advances. In this case warm air is not active, thus, cold air violently pushes warm air upward creating steep sloped front. Symbolically, a cold front is represented by a solid line with blue triangles pointing towards the warmer air.
Due to violent ascendance of air, severe storms occur near cold front. It gives thunderous rainfall for a short period of time. Cold front spreads over less area; hence rainfall is concentrated in limited locality. It gives rise to cumulonimbus clouds.



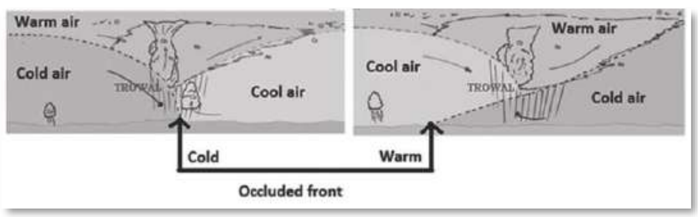
3. **Warm front :** Warm front is formed when warm air mass slides over cold air mass by advancing over it. Warm air mass being lighter and active, it smoothly slides over cold air mass creating gentle sloped front. Symbolically, warm front is represented by a solid line with red semi circle pointing towards the cold air.



Due to smooth ascendence of air, rainfall generally occurs in the form of drizzle. The rainfall is spread over larger area and it lasts for few days. Generally, cirrus, stratus and nimbostratus clouds are observed. Cumulonimbus clouds are absent. Cirrostratus clouds create halo around the sun.



4. **Occluded front :** In occluded front, warm air is pushed upward and cold air lies below. Occluded front is obtained at the end of either cold front or warm front. In that case, they are called as cold front occlusion and warm front occlusion respectively. Symbolically, it is represented by a solid line with alternating triangles and semi-circles pointing in the direction of front movement. It is drawn in purple colour. Weather along occluded front is complex. It shows a mixture of cold front type and warm front type weather.



7. Cyclones & Anti-cyclones

Cyclones

- Cyclones are centres of low-pressure surrounded by high-pressure and having closed air circulation from outside towards the central low-pressure. In northern hemisphere, air blows inward in anticlockwise direction and in southern hemisphere, air blows inward in clockwise direction. They are also known as atmospheric disturbances and secondary circulations. Their shape varies from circular to elliptical to V-shaped. On the basis of location of origin, cyclones are divided into two principal types - tropical cyclones and extratropical or temperate cyclones.
- The process of origin and development of cyclone is called cyclogenesis. Dissipation of developed cyclone is known as cyclolysis.

Temperate Cyclones

They are formed between 350 to 650 north and south of equator. They are also called as extratropical cyclones, wave cyclones, travelling depressions or cold-core cyclones. They are formed due to convergence of two contrasting air masses (warm, moist and light tropical air mass and cold and dense polar air mass). Polar front is created at the convergence of these two opposing air masses which is responsible for the origin and development of temperate cyclone. After their formation, they move in easterly direction under the influence of westerlies.

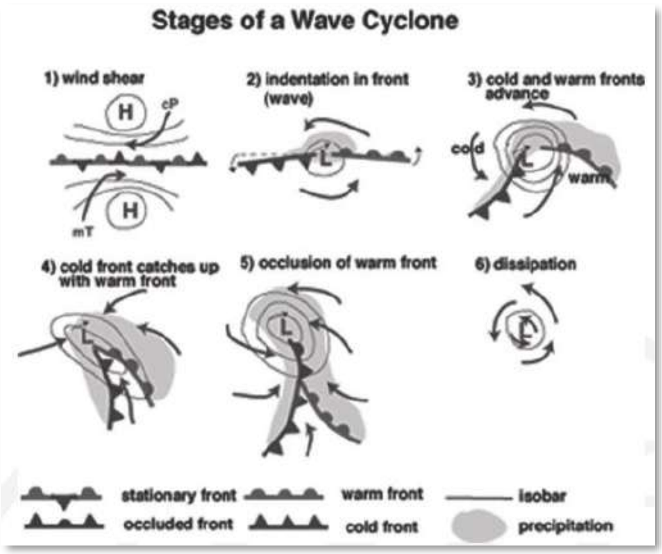
Stages of formation of temperate cyclone

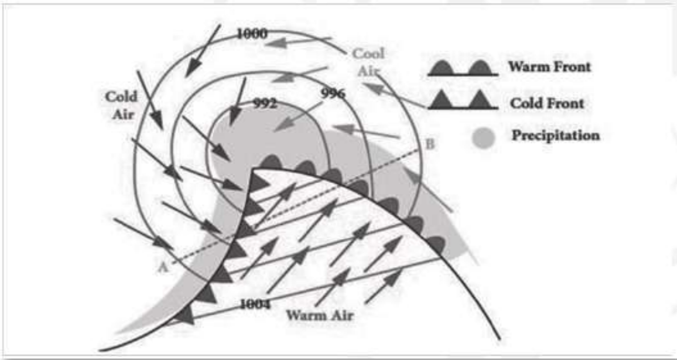
- The concept of origin of temperate cyclone is explained by polar front theory (also known as frontal theory or wave theory or Bergen theory) given by V. Bjerknes and J. Bjerknes in 1918.
    1. **1st Stage - Initial stage :** Cold air mass from poles and warm air mass from tropics are pushed closer to each other by easterlies and westerlies, respectively. But in first stage, there is no horizontal mixing of these contrasting air masses, as both air masses move parallel to each other. This generates stationary front.
    2. **2nd Stage - Juvenile stage / Incipient stage :** In this stage, polar easterlies become more forceful and cold front is created. Cold air pushes warm air and gradually starts lifting it. On the other hand, along the eastern section, westerlies become more effective and warm air becomes more active giving birth to warm front. In short, in this phase warm and cold air mass penetrates into the territories of each other and wave like front is formed.
    3. **3rd Stage - Mature stage :** In this stage, cyclone is fully developed and isobars become almost circular. Cold easterlies further push warm air above, bringing the cold and warm fronts close to each other.
    4. **4th Stage - Signs of occlusion :** Cold and warm friends almost become parallel to each other. Warm air has been completely lifted by cold air.
    5. **5th Stage - Beginning of cyclolysis :** With the occlusion of cyclone advancing cold front completely overtakes warm front and occluded front is formed.
    6. **6th Stage - Dissipation stage :** In this stage, warm sector completely disappears, occluded front is eliminated and cyclone dies out.

Characteristics of temperate cyclone

1. They have different shapes like circular, semi-circular, elliptical, elongated, etc.
2. Their diameter varies from 1000 km to 1900 km.
3. The vertical extent of an average cyclone is about 10 to 12 km.
4. They move eastward under the influence of westerlies with average velocity of 32-48 km/h.
5. They become more active in winters as cold polar wind becomes strong in winters.
6. There are variations in the nature and direction of winds in different parts of the cyclone.

A fully developed temperate cyclone looks like from the space as shown below.





Weather conditions associated with temperate cyclones

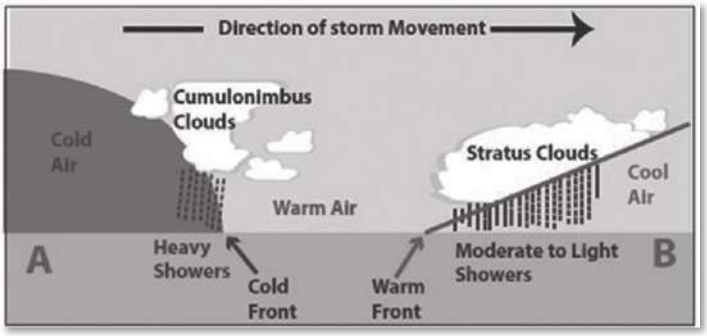
1. **Arrival of cyclone :** When cyclones start moving towards east under the influence of westerlies, its arrival is marked by slowing down of wind velocity, decrease in air pressure and encircling of the sun and the moon by halo. As the cyclone approaches, temperature starts increasing and wind direction also changes from easterly to south-easterly.
2. **Warm front arrival :** Upon arrival of warm front, cloud cover increases and sky becomes overcast with dark and thick nimbostratus clouds. When precipitations starts, it is slow and gradual in nature but lasts for longer duration.
3. **Arrival of warm sector :** There is sudden change in pre-existing weather conditions. Wind direction become southernly. Sky becomes cloudless and clear. Temperature rises and air pressure decreases remarkably.
4. **Cold front arrival :** There is a marked decrease in temperature. Cold air pushing the warm air and sky is covered with nimbostratus clouds. This gives heavy thunder of showers but lasts only for few hours.
5. **Arrival of Cold sector :** It is also called as the tail of the cyclone. Sky becomes cloudless and clear. There is sharp fall in air temperature and considerable rise in air pressure. Wind direction becomes westerly.

Tropical cyclones

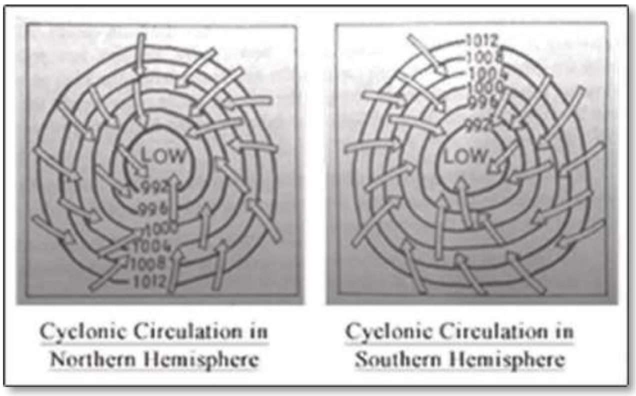
Tropical cyclones are generally developed between the region lying between Tropic of Capricorn and Tropic of Cancer.

Conditions required for origin of tropical cyclones

1. High sea surface temperature (generally greater than 270C).
2. Necessary Presence of Coriolis force : Coriolis force is generally absent between 50 north and 50 south latitudes. Hence despite having high sea surface temperature, cyclones are not developed there.



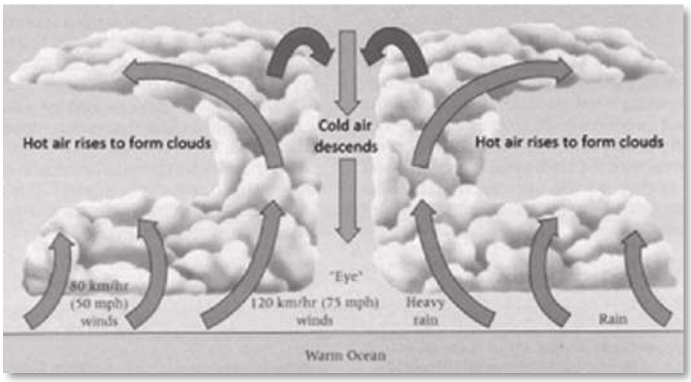
3. Continuous supply of abundant warm and moist air : That is why they are always formed over oceans and then they move towards the land.
4. Minimum vertical wind shear required.
5. Upper air and the cyclonic conditions needed to maintain low pressure over the ground.



6. Intense convection of air is required.
7. Pre-existing weak tropical disturbances intensify tropical cyclones.

Origin of tropical cyclones

Under the above mentioned conditions, moist air gets heated and rises upward forming a low pressure centre called as an eye of the cyclone. This low pressure centre draws air from surrounding areas. Due to Coriolis force, these winds get deflected which initiates anticlockwise circulation in North hemisphere around the low-pressure centre. Rising air from the centre cools and gets condensed. During this process, latent heat of condensation is released which further heats the condensed air and forces it to rise upward again. Ultimately rising air forms very high altitude clouds. In short, the released heat of condensation acts as an engine for the further growth of the cyclones. Hence cyclones are also known as heat engine of the earth. Once the cyclone is developed, it moves according to the direction of prevailing winds and passes over a nearby land. As soon as it passes over a land, supply of moist air is cut-off. This lowers the intensity of cyclone (known as landfall of cyclone) and finally leads to its dissipation.



Characteristics of tropical cyclone

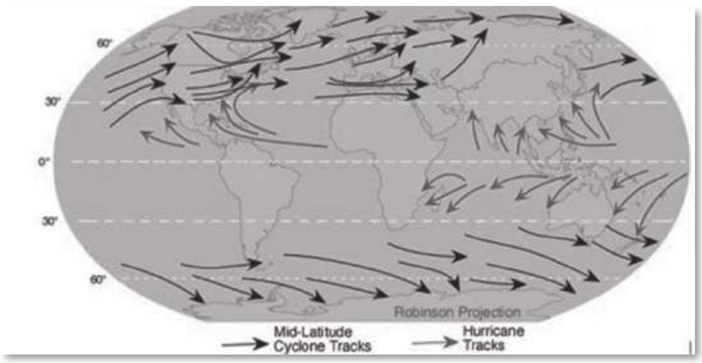
1. Average diameter of tropical cyclone ranges between 80 to 300 km.
2. They advance with varying velocity which ranges between 32 km/h to 180 km/h.
3. They move with high velocity over the oceans but become weak while moving over land areas. That is why they affect only coastal areas of the continents.
4. They are not characterised by temperature variations in their different parts because they do not have different fronts.
5. There are no different rainfall cells. Except eye, each part of the cyclone yields rainfall.
6. Sometimes, they become stationary over a particular place for several days giving heavy rainfall, causing flood and environmental disaster.
7. Generally, they move from east to west under the influence of trade winds.
8. They are confined to summer seasons only.
9. They become disastrous natural hazards because of high winds speed (ranging between 180- 400 km/h), high tidal surges (storm surges), high rainfall intensity, very low atmospheric pressure and presence for several days. High velocity winds of cyclone are known as Gale.

Weather conditions associated with tropical cyclones :

1. **Weather conditions associated with the Eye :** This is the central region of the cyclone with clear skies, warm temperature and low atmospheric pressure. This section does not receive any rainfall.
2. **The Eyewall :** It is the most dangerous and destructive part of a tropical cyclone. Here winds are the strongest, rainfall is the heaviest and convective air rises from earth surface to higher atmosphere (upto 15000m).
3. **Rainbands :** In addition to eyewall, there are often secondary cells arranged in bands around the centre. These bands are known as rain bands which spirals into the centre.

Tropical cyclones are called differently in different regions as below,

1. China - Typhoon
2. Indian ocean - Tropical cyclones
3. Caribbean sea - Hurricanes
4. North Australia - Will Willy
5. Philippines - Baguio
6. Japan – Taifu



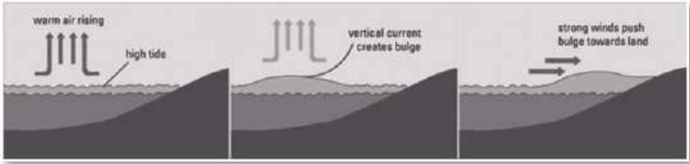
Global distribution of cyclones,

Comparison between tropical and temperate cyclone

	Tropical cyclone	Temperate cyclones
Geographical location	Between 100 to 300 N and S of equator	Between 350 to 650 N and S of equator
Origin surface	Forms over warm sea surface and dissipate when pass over the land	Form on both land and sea surface
Mechanism of origin	Thermal origin	Polar front theory
Size	80-300 km	1000 to 1900 km
Velocity	Generally, 32 to 180 km/h but can reach up to 400 km/h	32 to 48 km/h
Shape	Circular or elliptical	Circular, semi-circular, elliptical, elongated or V-shape
Rainfall	Heavy downpour associated with thunderstorm and lightning. No different rain cells.	Different rain cells associated with cold and warm fronts
Temperature	No temperature variation	Temperature variation with fronts
Centre of cyclone	Have central core of calm and light rains with no rainfall and clear sky. Called as Eye	Eye is absent.
Direction of movement	From east to west under the influence of trade winds	From west to east under the influence of westerlies
Season	Appear in summers	Year round phenomenon but more

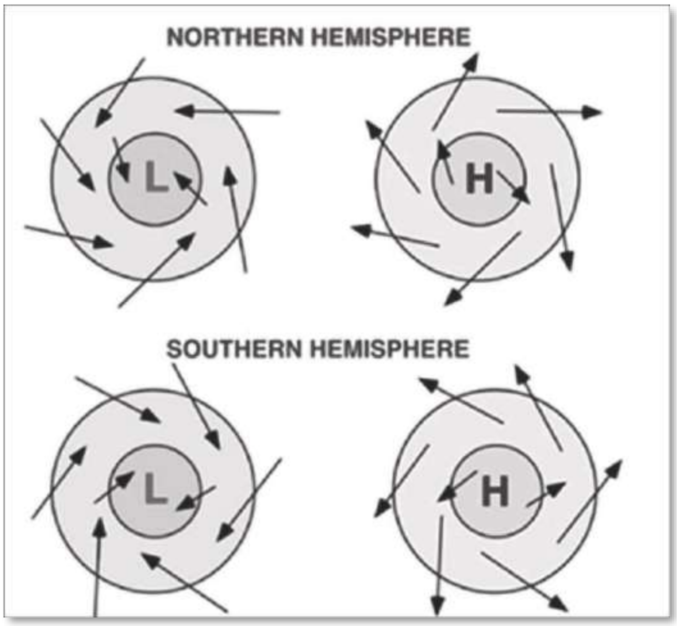
Storm Surge

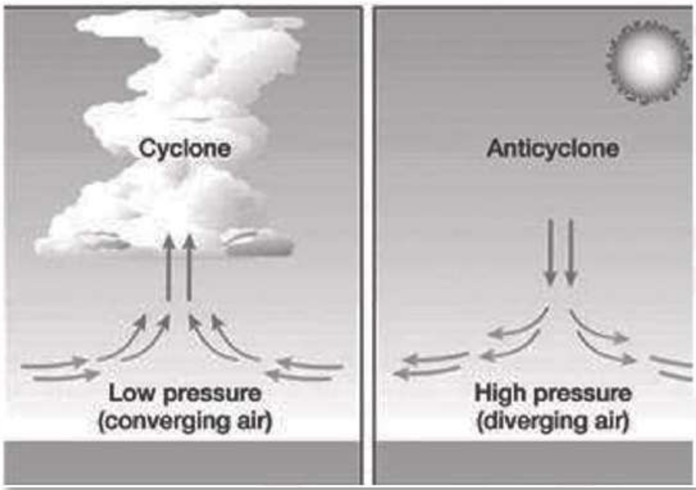
- A storm surge is a rise in sea level that occurs during tropical cyclones. The storms produce strong winds that push the water into shore, which can lead to flooding. This makes storm surges very dangerous for coastal regions. A storm surge is primarily caused by the relationship between the winds and the ocean's surface. The water level rises where the winds are strongest. In addition, water is pushed in the direction the winds are blowing. Another factor contributing to storm surge is atmospheric pressure. Atmospheric pressure is the force exerted by the weight of air in the Earth's atmosphere. The pressure is higher at the edges of a cyclone than it is at the center. This pushes down the water in the outer parts of the storm, causing the water to bulge at the eye and eye wall where the winds have helped to add the rise in sea level.
- The water level can reach as high as 10 meters (33 feet) if the storm surge happens at the same time as high tide. The slope of the land just off the coast also plays a part : Water will more easily flow in a shallow coast than a steep one. Tropical cyclones, and the storm surges they generate, are a serious hazard for coastal areas in tropical and subtropical regions of the world.



Anti-cyclones

Anti-cyclone is the air circulation having opposite conditions and characteristics of cyclones. They are characterised by circular isobars having highest pressure at the centre and lowest pressure at the outer margins. At the highest pressure centre, warm air sinks from above and diverges in all directions giving birth to cloudless, clear and dry weather. They have clockwise air circulation in northern hemisphere and anticlockwise air circulation in southern hemisphere.





Characteristics of anticyclones

1. They are usually circular in shape.
2. Their diameter is around 75% larger than temperate cyclones. Some temperate anticyclones can be so extensive that they can occupy half of the USA, their diameter can become 9000 km.
3. They are more common in the subtropical high-pressure belt and practically absent in equatorial regions.
4. They are associated with rain less fair weather. In fact, they are called as the weatherless phenomena.
5. They generally follow cyclones but their track is highly variable and unpredictable.
6. They move very sluggishly and sometimes become stationary over a particular place for few days. Average velocity of anticyclones is 30-50 km/h.
7. They cause atmospheric stability and give birth to various air masses.
8. They do not have fronts.
9. Due to weak pressure gradient, wind system is not fully developed in anti-cyclones.
10. They are further divided into warm (formed due to descending of warm tropical air mass) and cold (formed due to descending of cold polar air mass) anti-cyclones.
11. Prolonged presence of anti-cyclones lead to formation of deserts.
12. Due to feeble wind, they hamper navigation.

Important definitions related to humidity and precipitation

1. Latent heat : The heat energy spent during the evaporation of water and its conversion into water vapour is called the latent heat. It is the hidden amount of heat present in water vapour.
2. Latent heat of condensation : The release of heat energy after condensation of water vapour into liquid or solid form is called the latent heat of condensation.
3. Humidity : The content of water vapour present in the air in gaseous form at a particular time and place is called as humidity.
4. Humidity capacity : The moisture retaining capacity of the air is known as humidity capacity. It is positively related with temperature, that is with rising temperature humidity capacity also increases.
5. Absolute humidity : It is the total weight of moisture content per volume of air at definite temperature. Absolute humidity does not change with increase or decrease of temperature. It can be increased or decreased by direct addition of vapour through evaporation. As the rate of evaporation decreases, absolute humidity also decreases.
6. Specific humidity : It is defined as the mass of water vapour in grams containing in a kilogram of air. It represents the actual quantity of moisture present in definite air. It does not get affected by temperature and evaporation.
7. Relative humidity : It is the ratio of the amount of water vapour actually present in the air at definite volume and temperature to the maximum amount of humidity that air can hold. In short, it is the ratio of absolute humidity to humidity capacity. Possibility of precipitation depends on relative humidity. Air having 100% relative humidity is called as saturated air.
8. Saturated air : The air having moisture content equal to its humidity capacity is called saturated air. It has 100% relative humidity. Condensation begins only when the air is super saturated, that is when relative humidity exceeds 100%. Air can be saturated :
9. By adding extra moisture
10. By reducing the temperature of air.
11. Dew Point : The temperature at which an air become saturated is called dew point. If due point is above freezing point, condensation will occur in liquid form (dew, fog, rainfall etc.). But if due point is below freezing point, condensation occurs in solid form (frost ice, snow, hailstorm etc.)
12. Dew : When the temperature of air falls below the dew point, water vapour present in it starts condensing and gets accumulated on the leaves of plants and trees in the form of small water droplets, it is called as dew. The major difference between dew and other forms of condensation is that, dew is deposited in the form of water droplets on cooler surfaces of solid objects without hygroscopic nuclei.
13. Haze : It is an atmospheric phenomena on where dust, smoke and another dry particles obscure the clarity of the sky.

Fog

Fog is a special type of thin cloud consisting of microscopically small water droplets which are kept in suspension in the air near the ground surface. It reduces horizontal visibility to less than one kilometre. It is formed due to mixing of warm and cold air mass near the earth surface. When moist air is super saturated, water vapour gets condensed around hygroscopic nuclei (dust particles, smoke etc) and kept on suspended in the air. Light fog is called as mist (visibility upto two kilometres). Fogs are generally formed due to temperature inversion and they disappear as temperature inversion disappears. Fog when mixed with smoke generates smog (smoke+fog) which is harmful for environment.
(See temperature inversion for details)

Clouds

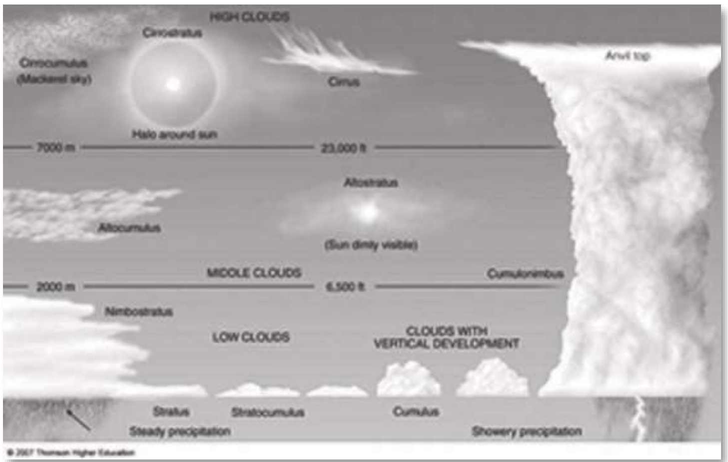
Clouds are aggregation of innumerable tiny water droplets, ice particles or mixture of both above the ground surface at certain altitude. They are formed when invisible water vapour in the air condenses into visible water droplets or ice crystals. Clouds are formed when the relative humidity is 100%, that is air is saturated. Clouds are not always associated with precipitation, but no precipitation is possible without clouds. Clouds play major role in the heat budget of the earth.

Types of clouds

(A) High altitude clouds (height between 6 to 20 km)
1. Cirrus clouds
2. Cirro-cumulus clouds
3. Cirro-stratus clouds

(B) Mid altitude clouds (height between 2.5 to 6 km)
1. Alto-stratus clouds
2. Alto-cumulus clouds
3. Nimbo-stratus clouds

(C) Low altitude clouds (between ground surface to 2.5 km)
1. Strato-cumulus clouds
2. Stratus clouds
3. Cumulus clouds
4. Cumulonimbus clouds



Depending on the dew point, precipitation is divided into various forms,
1. Rainfall (dew point is above freezing point)
2. Snowfall (dew point is below freezing point)
3. Sleet (mixture of rain and snow)
4. Hail (form of solid precipitation consisting large spheres of ice balls)

Rainfall
- Precipitation in the form of liquid water particles that fall from the atmosphere and reach the surface of the earth is called as rainfall. The presence of warm, moist and unstable air and sufficient number of hygroscopic nuclei are prerequisite conditions for rainfall. Warm and moist air after being lifted upward becomes saturated and clouds are formed. After air becoming super saturated, condensation occurs around larger hygroscopic nuclei. Such droplets are called as cloud droplets. The aggregation of large number of cloud droplets form clouds. Rainfall does not occur unless these cloud droplets become so large that the air becomes unable to hold them due to gravitational pull of earth. As these condensed water droplets start descending, their temperature rises. Sometimes, these droplets get evaporated before reaching the ground surface. This phenomenon is known as Virga.
- In artificial rainfall techniques, either there is an attempt to increase the number of hygroscopic nuclei through spraying aerosols and silver iodide particles or an attempt to increase the moisture content through spraying sea water.
- When the air ascends slowly, the process of condensation is also very slow and hence rainfall is in the form of drizzle. And if the air ascends hurriedly with greater speed, resultant rainfall is in the form of heavy downpour.

Types of rainfall

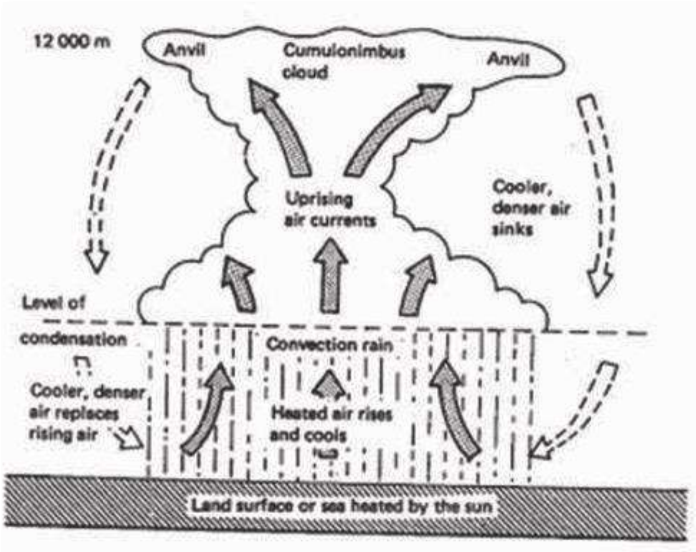
The upward movement of air is a prerequisite condition for cloud formation and rainfall. There are three ways in which air is forced to move upward. Based on these three ways, rainfall is categorised into three types -
1. Convectional rainfall
2. Orographic rainfall
3. Cyclonic or frontal rainfall

Convectional rainfall

During convection process, heating of ground surface leads to expansion of air and this expanded air rises upward in the form of convection currents. This process is also known as thermal convection. Rising air gets cooled at particular height and latent heat of condensation is released. This latent heat of condensation further heats the condensed water vapour making further rise of air column. When the ascending air reaches such a height where its temperature matches with the temperature of surrounding, cumulonimbus clouds are formed and there begins heavy downpour. Two conditions are necessary to cause convectional rainfall -
1. Abundant supply of moisture through evaporation to the air
2. Intense heating of ground surface.

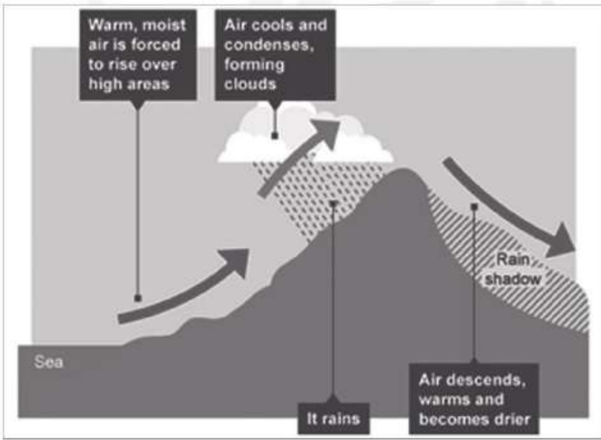
Characteristic features of convectional rainfall

1. It is a warm weather phenomenon and is associated with lightning and thunder clouds.
2. It mainly occurs at equatorial region. It generally takes place in the afternoon (between 2-4 PM).
3. It is of very short duration.
4. It occurs through thick, dark and extensive cumulonimbus clouds.
5. It is accompanied by clouds, thunder and lightning.
6. Much of the rainfall becomes run-off leading to severe erosion.
7. It supports luxurious evergreen rainforest.
8. It also occurs in temperate regions but in the form of light drizzle and lasts for longer duration.



Orographic Rainfall

Orographic rainfall occurs due to ascent of air because of mountain barriers. The slope of the mountains facing the wind is called windward slope which receives maximum precipitation. The opposite slope is called leeward slope or rainshadow region because the ascending air after crossing over the mountain barriers descend along leeward slope. This descending air is warm and devoid of moisture. This generates dry conditions. The windward slopes of the mountains are characterised by cumulus clouds while leeward slopes have stratus clouds. This type of rainfall may occur in any season.



Following conditions are necessary for the occurrence of orographic rainfall,

1. Presence of mountain barrier.
2. Mountains should be very close and parallel to the sea coast. Ex. Western ghats
3. Height of mountains should be sufficient enough. Inland mountains should be of higher heights because the air after covering long distances loses much of its moisture content.
4. Sufficient amount of moisture content should be present in the air.
5. If the mountains are of moderate height, the maximum rainfall does not occur at their tops rather it occurs on the other side.
6. The amount of rainfall increases with increasing height along the windward slope. But this is only up to a certain height, beyond which amount of rainfall decreases with increase in height because of decrease in moisture content of the air. This situation is known as inversion of rainfall.

(Cyclonic or frontal rainfall has already been discussed earlier.)

Tornado

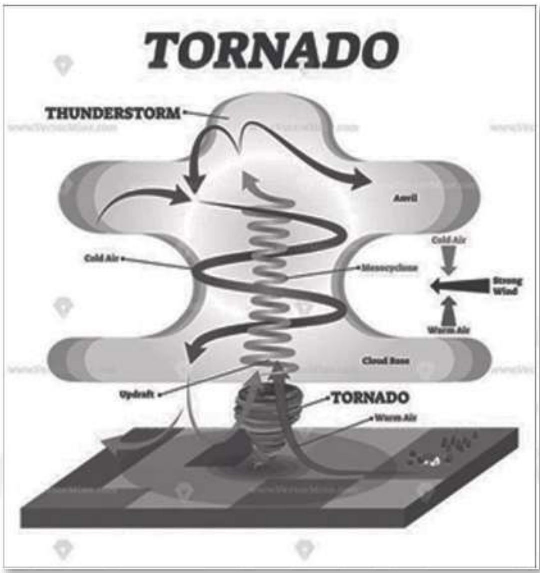
A tornado is a violent rotating column of air extending from a thunderstorm to the ground. The most violent tornadoes are capable of tremendous destruction with wind speeds of up to 300 mph. They can destroy large buildings, uproot trees and hurl vehicles hundreds of yards. Damaged paths can be in excess of one mile wide to 50 miles long.

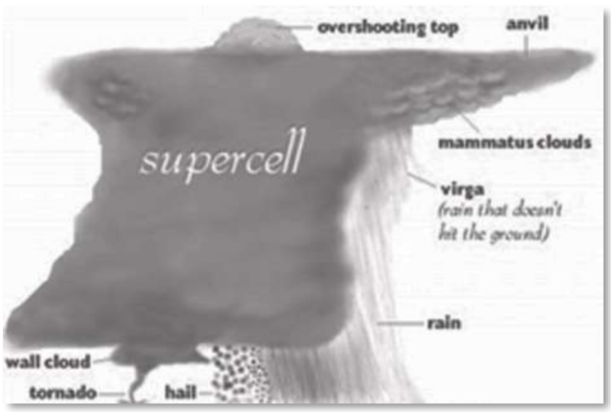
Formation of tornadoes

Most tornadoes do form from thunderstorms. When two air masses of different characteristics (usually cold polar air mass and warm tropical airmass) meet, they create instability in the atmosphere. A change in wind direction and an increase in wind speed with increasing height creates an invisible, horizontal spinning effect in the lower atmosphere. Rising air within the updraft tilts the rotating air from horizontal to vertical. Once the air begins to rise and becomes saturated, it will continue rising to great heights, due to latent heat of condensation released, to produce a thunderstorm cloud.

Conditions required for the development of tornadoes -

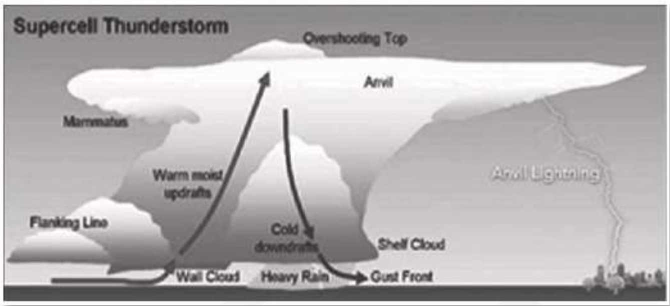
1. Abundant supply of moisture
2. A trigger (which can be in the form of a cold front or other low level zone of converging winds) is needed to lift the moist air aloft.
   A fully developed tornado looks like as shown in the diagram below,





Components of tornado :

1. A funnel cloud is a rotating cone-shaped column of air extending downward from the base of a thunderstorm, but not touching the ground. When it reaches the ground, it is called as a tornado.
2. A supercell thunderstorm is a long-lived thunderstorm whose updrafts and downdrafts are in near balance. These storms have the greatest tendency to produce tornadoes that stay on the ground for long periods of time. Supercell thunderstorms can produce violent tornadoes with winds exceeding 200 mph.
3. A mesocyclone is a rotating vortex of air within a supercell thunderstorm. Mesocyclones do not always produce tornadoes.
4. A wall cloud is an abrupt lowering of a rain-free cumulonimbus base into a low-hanging accessory cloud. A rotating wall cloud usually develops before tornadoes or funnel clouds.
5. A waterspout is just a weak tornado that forms over water. They are most common along the Gulf Coast. Waterspouts can sometimes move inland, becoming tornadoes causing damage and injuries.



Thunderstorm

- It is a storm caused by strong rising air currents and characterised by gusty winds, thunder, lightning and usually heavy rain or hail produced by cumulonimbus clouds.
- The basic ingredients used to make a thunderstorm are moisture, unstable air and lift. Thunderstorms can occur year-round and at all hours. But they are most likely to happen in the spring and summer months and during the afternoon and evening hours. It is a severe weather phenomenon which is developed mainly due to intense convection and subsequent release of latent heat of condensation.

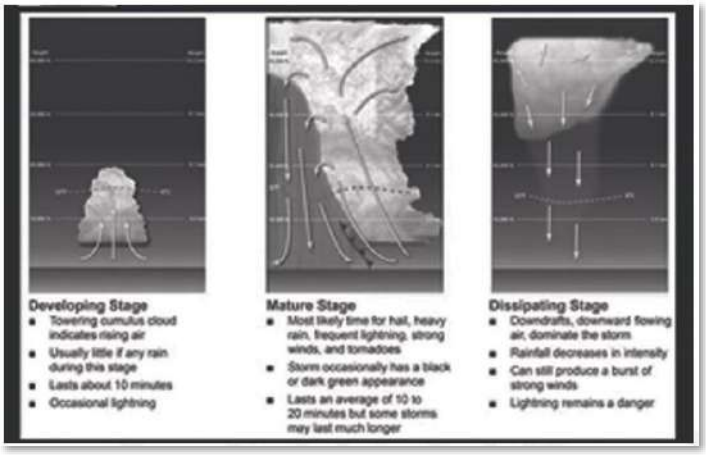
Development of thunderstorm

Thunderstorms are developed in three stages

1. **Cumulus or developing stage :** It is marked by cumulus cloud that is being pushed upward by rising column of air. There is little or no rain during this stage but occasional lighting is

observed.

2. **Mature stage :** Thunderstorm experiences mature stage when the updraft is still taking place and precipitation begins. In short, there is updraft of rising column of air and at the same time there is a downdraft in the form of precipitation. Mature stage experiences hail, heavy rain, frequent lightning, strong winds and tornadoes.
3. **Dissipating stage :** This is the last stage of thunderstorm life cycle in which downdraft overtakes updraft. Eventually rainfall decreases in intensity but lightning is still experienced.



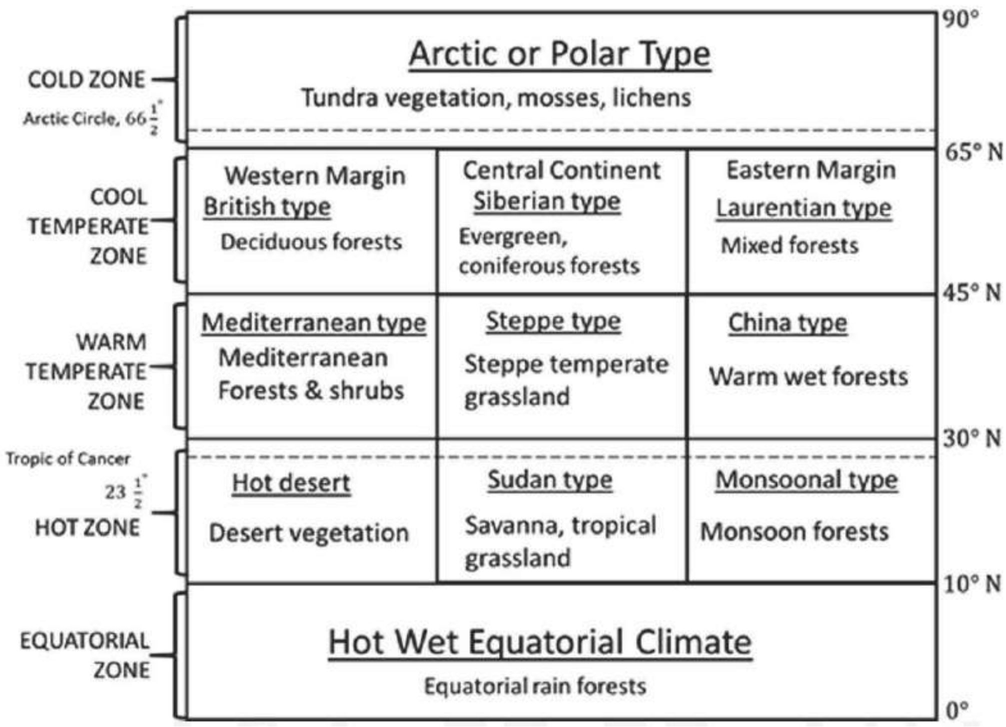
Cloudburst

Cloudburst is a localised weather phenomenon representing highly concentrated rainfall over a small area lasting for few hours. According to the India Meteorological Department (IMD), a cloudburst features very heavy rainfall over a localized area at a very high rate of the order of 100mm per hour featuring strong winds and lightning. Generally, cloudburst are associated with thunderstorms. Sudden and enormous rain causes flash floods, landslide, destruction of life and property. Topographical conditions like steep hills favour cloudburst. It is not always necessary that cloudburst occur only near mountain slopes. They may occur in deserts and in interior regions of continental masses.

9. Major Climatic Regions

Climatic Zone	Latitude (approx.)	Climatic type	Rainfall regime	Natural Vegetation
Equatorial Zone	00-100N and S	1. Hot, wet equatorial	rainfall all year round: 200cm	Equatorial rain forests
Hot Zone	100-300N and S	a) Tropical Monsoon b) Tropical Marine 2. Sudan Type 3. Desert: a) Saharan type b) Mid-latitude type	Heavy summer rain : 150cm Much summer rain :175cm Rain mainly in summer :75cm Little rain : 15cm	Monsoon forests, Savana (tropical grassland), Desert vegetation and scrub

Warm Temperate Zone	300-450N and S	4. Western Margin (Mediterranean type)	Winter Rain : 90cm	Mediterranean Forests and shrub
		Central Continental (Steppe type) Eastern Margin: a) China Type b) Gulf Type c) Natal Type	Light Summer rain: 50cm Heavier Summer rain: 115cm	Steppe or Temperate Grassland, Warm, Wet forests and Bamboo
Cool Temperate Zone	450 - 650 N and S	Western Margin (British Type) Central Continental (Siberian Type) 10. Eastern Margin (Laurentian Type)	More rain in autumn and winter : 75cm Light Summer rain: 60cm Moderate Summer Rain: 100cm	Deciduous Forests, Evergreen Coniferous forest, Mixed Forest, (Coniferous & Deciduous)
Cold Zone	650 - 900 N and S	11. Arctic or Polar	Very light summer rain: 25cm	Tundra, mosses and lichens
Alpine Zone	At high altitudes (above 3000m)	12. Mountain Climate	Heavy Rainfall (Variable)	Alpine Pastures, conifers, fern, snow



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