USEFUL FOR IAS/PCS PRELIMINARY & MAINS EXAM

मुख्यमंत्री अभ्युदय योजना

GENERAL STUDIES

PHYSICAL GEOGRAPHY

मुख्यमंत्री अभ्युदय योजना प्रकोष्ठ

उत्तर प्रदेश प्रशासन और प्रबंधन अकादमी

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यह अध्ययन-सामग्री उत्तर प्रदेश सरकार की मुख्यमंत्री अभ्युदय योजना के अंतर्गत मुख्यमंत्री अभ्युदय योजना प्रकोष्ठ (उत्तर प्रदेश प्रशासन और प्रबंधन अकादमी) द्वारा सिविल सेवा परीक्षा की तैयारी कर रहे प्रतियोगियों की सहायता के लिए तैयार कराई गई है।

इस पाठ्य-सामग्री को उत्तर प्रदेश प्रशासन एवं प्रबंधन अकादमी, लखनऊ में 65वें आधारभूत प्रशिक्षण कार्यक्रम के अंतर्गत प्रशिक्षण प्राप्त कर रहे प्रशिक्षु डिप्टी कलक्टर्स (UPPCS-2018) द्वारा प्रोजेक्ट कार्य के रूप में तैयार किया गया है।

इस सामग्री को पूर्णत: शैक्षणिक और जन कल्याणकारी-उद्देश्यों के लिए तैयार किया गया है-इसका एक मात्र उद्देश्य प्रदेश के छात्र/छात्राओं का प्रतियोगी परीक्षाओं की तैयारी में मार्गदर्शन व सहयोग करना है।

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GEOMORPHOLOGY

1. ROCKS

Rocks are mineral aggregates with a combination of properties of all the mineral traces. Rocks which are found in nature rarely show such simple characteristics and usually exhibit some variation in the set of properties as the measurement scale changes.

Types of Rocks:

There are three types of rocks

- Igneous Rocks
- Sedimentary Rocks
- Metamorphic Rocks

1) Igneous Rock:

a) Rocks formed out of solidification of magma (molten rock below the surface) and lava (molten rock above the surface) and are known as igneous or primary rocks.
b) Having their origin under conditions of high temperatures the igneous rocks are unfossiliferous.
c) Granite, gabbro, basalt, are some of the examples of igneous rocks.
d) There are three types of igneous rocks based on place and time taken in cooling of the molten matter, plutonic rocks, volcanic rocks and intermediate rocks.
e) There are two types of rocks based on the presence of acid-forming radical, silicon, acidic rocks and basic rocks.
f) Since magma is the chief source of metal ores, many of them are associated with igneous rocks.

2) Sedimentary Rocks:

a) Sedimentary rocks are formed by lithification - consolidation and compaction of sediments.

b) Hence, they are layered or stratified of varying thickness. Example: sandstone, shale etc.
c) Sediments are a result of denudation (weathering and erosion) of all types of rocks.

Depending upon the mode of formation, sedimentary rocks are classified into:

- mechanically formed: **sandstone, conglomerate, limestone, shale, loess**.
- organically formed: **geyserite, chalk, limestone, coal**.
- chemically formed: **limestone, halite, potash**.

- **Mechanically Formed Sedimentary Rocks:**

a) They are formed by mechanical agents like running water, wind, ocean currents, ice, etc.
b) Arenaceous sedimentary rocks have more sand and bigger sized particles and are hard and **porous**. They form the best reservoirs for liquids like groundwater and petroleum. e.g: sandstone.
c) Argillaceous rocks have more clay and are fine-grained, softer, mostly impermeable (mostly non-porous or have very tiny pores). e.g: claystone and shales are predominantly argillaceous.

- **Chemically Formed Sedimentary Rocks:** Water containing minerals evaporate at the mouth of springs or salt lakes and give rise to Stalactites and stalagmites (deposits of lime left over by the lime-mixed water as it evaporates in the underground caves).

- **Organically Formed Sedimentary Rocks:**

a) The remains of plants and animals are buried under sediments, and due to heat and pressure from overlying layers, their composition changes. Coal and limestone are well-known examples.
b) Depending on the predominance of calcium content or the carbon content, sedimentary rocks may be calcareous (limestone, chalk, dolomite) or carbonaceous (coal).

- **The spread of Sedimentary Rocks in India:**

a) Alluvial deposits in the Indo-Gangetic plain and coastal plains are of sedimentary accumulation. These deposits contain loam and clay.
b) Different varieties of sandstone are spread over Madhya Pradesh, eastern Rajasthan, parts of Himalayas, Andhra Pradesh, Bihar and Orissa.

c) The great Vindhyan highland in central India consists of sandstones, shales, limestones.
d) Coal deposits occur in river basins of the Damodar, Mahanadi, the Godavari in the Gondwana sedimentary deposits.

3) Metamorphic rocks:

a) The word metamorphic means '**change of form**'.
b) Metamorphism is a process by which recrystallisation and reorganization of minerals occur within a rock. This occurs due to pressure, volume and temperature changes.
c) When rocks are forced down to lower levels by tectonic processes or when molten magma rising through the crust comes in contact with the crustal rocks, metamorphosis occurs.
d) In the process of metamorphism in some rocks grains or minerals get arranged in layers or lines. Such an arrangement is called **foliation or lineation**.
e) Sometimes minerals or materials of different groups are arranged into alternating thin to thick layers. Such a structure is called banding**.**
f) Gneissoid, slate, schist, marble, quartzite etc. are some examples of metamorphic rocks.

On the basis of the agency of metamorphism, metamorphic rocks can be of two types:

a) Thermal Metamorphism:

- They are formed by mechanical agents like running water, wind, ocean currents, ice, etc.
- The change of form or re-crystallization of minerals of sedimentary and igneous rocks under the influence of high temperatures is known as thermal metamorphism.
- As a result of thermal metamorphism, sandstone changes into quartzite and limestone into marble**.**

b) Dynamic Metamorphism:

- This refers to the formation of metamorphic rocks under high pressure.
- Sometimes high pressure is accompanied by high temperatures and the action of chemically charged water.
- Under high pressure, granite is converted into gneiss; clay and shale are transformed into schist**.**

Some examples of Metamorphosis

Igneous or Sedimentary rock	Influence	Metamorphosed rock
Granite	Pressure	Gneiss
Clay, Shale	Pressure	Schist
Sandstone	Heat	Quartzite
Clay, Shale	Heat	Slate → Phyllite
Coal	Heat	Anthracite → Graphite
Limestone	Heat	Marble

Metamorphic Rocks in India:

- The gneisses and schists are commonly found in the Himalayas, Assam, West Bengal, Bihar, Orissa, Madhya Pradesh and Rajasthan.
- Quartzite is a hard rock found over Rajasthan, Bihar, Madhya Pradesh, Tamil Nadu and areas surrounding Delhi.

Rock cycle:

a) Rock cycle is a continuous process through which old rocks are transformed into new ones.
b) Igneous rocks are primary rocks, and other rocks form from these rocks.
c) Igneous rocks can be changed into sedimentary or metamorphic rocks.
d) The fragments derived out of igneous and metamorphic rocks form into sedimentary rocks.
e) Sedimentary and igneous rocks themselves can turn into metamorphic rocks.
f) The crustal rocks (igneous, metamorphic and sedimentary) may be carried down into the mantle (interior of the earth) through subduction process and the same meltdown and turn into molten magma, the source for igneous rocks.

<u>Some Rock-Forming Minerals:</u>

a) Igneous rocks are primary rocks, and other rocks form from these rocks.
b) **Feldspar:** Half the crust is composed of feldspar. It has a light colour, and its main constituents are silicon, oxygen, sodium, potassium, calcium, aluminium. It is used for ceramics and gloss making.
c) **Quartz:** It has two elements, silicon and oxygen. It has a hexagonal crystalline structure. It is uncleaved, white or colourless. It cracks like glass and is present in sand and granite. It is used in the manufacture of radio and radar.
d) **Bauxite:** A hydrous oxide of aluminium, it is the ore of aluminium. It is non-crystalline and occurs in small pellets.
e) **Cinnabar (mercury sulphide):** Mercury is derived from it. It has a brownish colour.
f) **Dolomite:** A double carbonate of calcium and magnesium. It is used in cement and iron and steel industries. It is white.
g) Other minerals like chlorite, calcite, magnetite, hematite, bauxite, barite, etc., are also present in rocks.

Metamorphic rocks:

Examples of Transformation of Rocks

S.No.	*Original rock*	*Metamorphic rock*
1.	Granite	Gneiss
2.	Syenite	Gneiss
3.	Sandstone	Quartzite
4.	Limestone	Marble, Schist
5.	Marl	Marble
6.	Shale	Slate, schist, phyallite
7.	Mudstone	Slate
8.	Dolomite	Marble
9.	Dolerite, basalt	Schist
10.	Felsite, tuff	Schist, slate
11.	Conglomerate	Gneiss, schist

Types of Rocks in India:

1. **Rocks of the Archaean system:** These rocks get this name as they are formed from the hot molten earth and are the oldest and primary rocks. Gneiss is an example and is found in Karnataka, Andhra Pradesh, Tamil Nadu, Madhya Pradesh, Orissa and some parts of Jharkhand and Rajasthan.

2. **Rock of Dhawar system:** These are formed from the erosion and sedimentation of the Archaean system and are the oldest sedimentary rocks. These are mainly found in Karnataka.

3. **Rocks of Cuddapah system:** These are formed from the erosion and sedimentation of Dhawar system. Sandstone, limestone and marble asbestos are the examples and are mainly found in Rajasthan.

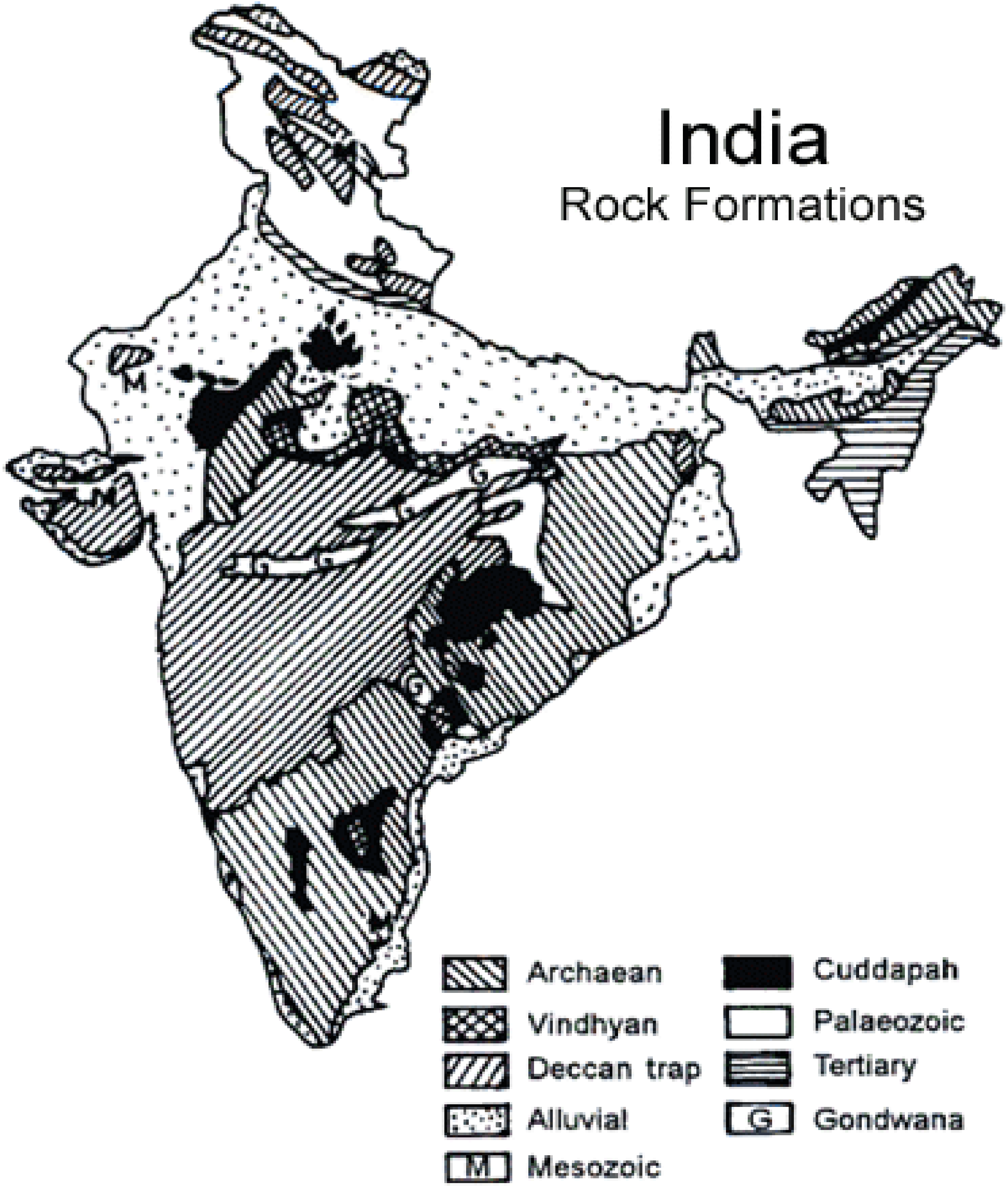
4. **Rocks of the Vindhyan system:** These are formed from the silt of river valleys and shallow oceans. Red sandstone is an example and is mainly found in Madhya Pradesh.

5. **Rocks of Gondwana system:** These are formed from the depressions in the basins. Coal is an example and is mainly found in Madhya Pradesh.

6. **Rocks of Deccan trap:** These are formed from the volcanic eruption. Dolorite and basalt are examples and are mainly found in Maharashtra and parts of Gujarat, Tamil Nadu and Madhya Pradesh.

7. **Rocks of Tertiary system:** These rocks are found mainly in the Himalayan regions.

8. **Rocks of the Quaternary system:** These rocks are found in the plains of the Indus and Ganga.


India
Rock Formations
M
M
G
G
Archaean
Vindhyan
Deccan trap
Alluvial
M
Mesozoic
Cuddapah
Palaeozoic
Tertiary
G
Gondwana

2. EARTHQUAKE

- An earthquake is shaking or trembling of the earth's surface, caused by the seismic waves or earthquake waves that are generated due to a sudden movement (sudden release of energy) in the earth's crust (shallow-focus earthquakes) or upper mantle (some shallow-focus and all intermediate and deep-focus earthquakes).
- A seismograph, or seismometer, is an instrument used to detect and record earthquakes.

➢ Focus and epicenter:

- The point where the energy is released is called the **focus** or the **hypocenter** of an earthquake.
- The point on the surface directly above the focus is called **epicenter** (first surface point to experience the earthquake waves).
- A line connecting all points on the surface where the intensity is the same is called an **isoseismic line**.

➢ Causes of Earthquakes:

- Plate tectonics
- Volcanic activity
- Human Induced Earthquakes

1. Plate tectonics:

- Slipping of land along the faultline along convergent, divergent and transform boundaries cause earthquakes.
- **Megathrust earthquakes** occur at subduction zones, where one tectonic plate is forced underneath another. E.g. 2004 Indian Ocean earthquake.
- Strike-slip faults, particularly **continental transforms**, can produce major earthquakes up to about magnitude 8.

2. Volcanic activity:

- Volcanic activity also can cause an earthquake, but the earthquakes of volcanic origin are generally less severe and more limited in extent than those caused by fracturing of the earth's crust.
- Earthquakes in volcanic regions are caused by the consequent release of elastic strain energy both by tectonic faults and the movement of magma in volcanoes.
- There is a clear correspondence between the geographic distribution of volcanoes and major earthquakes, particularly in the Circum-Pacific Belt and along oceanic ridges.

3. Human Induced Earthquakes:

What **is induced seismicity?**

Induced seismicity refers to seismic events (usually earthquakes) caused partially or completely by human (anthropogenic) activities.

What is the difference between "*induced*" and "*triggered*" seismicity?

Some workers distinguish between "*induced*" and "*triggered*" seismicity according to whether all or only part of the strain energy released was anthropogenic, using the term "*induced*" when most of the energy was anthropogenic, and "*triggered*" when it was predominantly of natural origin. Determining the proportion of anthropogenic to naturally stored energy is very difficult, although in the case of larger earthquakes it is clear much of the energy is of natural tectonic origin. We use the term "*induced*" for both cases, which is in keeping with the convention of the Committee on Induced Seismicity Potential (Hitzman, 2013).

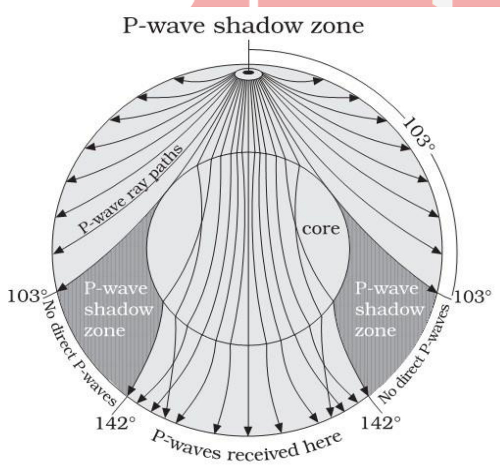
What human activities can induce earthquakes?

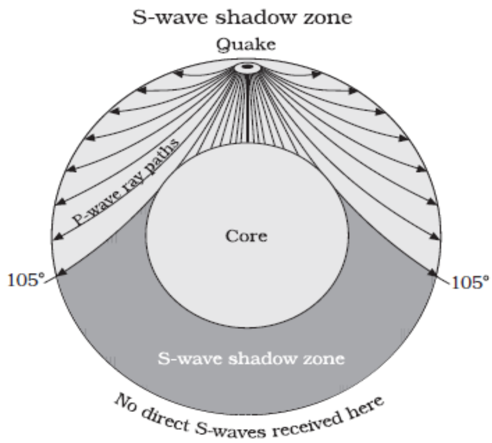
A variety of human activities have been suggested to have induced seismicity. These include impounding surface water reservoirs, erecting tall buildings, engineering coastal land accretion, and removing mass from the surface by quarrying. The subsurface extraction of resources, including groundwater, coal, hydrocarbons and geothermal fluids, as well as tunnel excavation have also been reported to induce earthquakes, as have injection activities. Injection activities include waste fluid disposal, hydrofracturing (otherwise known as hydraulic fracturing or fracking), research experiments, gas storage, enhanced oil recovery, and carbon sequestration. Nuclear tests often induce local earthquakes, though we know of no reported cases of seismicity caused by chemical explosions.

➢ Earthquakes based on the depth of focus:

- Earthquakes can occur anywhere between the Earth's surface and about 700 kilometres below the surface.
- For scientific purposes, this earthquake depth range of 0 – 700 km is divided into three zones: shallow, intermediate, and deep**.**
- Shallow focus earthquakes are found within the earth's outer crustal layer, while deep focus earthquakes occur within the deeper subduction zones of the earth.
- **Shallow earthquakes are 0 – 70 km deep.**
- **Intermediate earthquakes are 70 – 300 km deep.**
- **Deep earthquakes are 300 – 700 km deep**.
- Of the total energy released in earthquakes, about 12-15 per cent comes from intermediate earthquakes**,** about 3-5 per cent from deeper earthquakes and about 70-85 per cent from the shallow earthquakes**.**
- A quake's destructive force depends not only on the energy released but also on location, distance from the epicenter and depth.
- On 24 August 2016, a 6.2 earthquake rocked Central Italy killing about 300 people. An even bigger 6.8 hit Myanmar the same day killing just a few people.
- Italy's quake was very shallow, originating within 10 kilometers underground. By contrast, the quake in Myanmar was deeper 84 kilometers.

➢ Shadow Zone:





- The shadow zone is the zone of the earth from angular distances of 104 to 140 degrees from a given earthquake that does not receive any direct P waves.
- The shadow zone results from P waves being refracted by the liquid core and S waves being stopped completely by the liquid core.
- A zone between 105° and 145° from the epicenter was recognized as the shadow zone for both the wave types.
- The entire zone beyond 105° does not receive S-waves.
- The shadow zone of P-waves appears as a band around the earth between 105° and 145° away from the epicenter.

➢ **Effects of earthquake:**

The following are the immediate hazardous effects of Earthquake.

a) Shaking of ground
b) The disparity in ground settlement
c) Natural disasters like Tsunami, landslide, mudslides, and avalanches
d) Soil liquefaction
e) Ground lurching and displacement
f) Floods and fires
g) Infrastructure collapse.

➢ **Distribution of Earthquakes:**

a) Earth's major earthquakes occur mainly in belts coinciding with the margins of tectonic plates.
b) The most important earthquake belt is the Circum-Pacific Belt, which affects many populated coastal regions around the Pacific Ocean—for example, those of New Zealand, New Guinea, Japan, the Aleutian Islands, Alaska, and the western coasts of North and South America.
c) The seismic activity is by no means uniform throughout the belt, and there are many branches at various points.
d) Because at many places the Circum-Pacific Belt is associated with volcanic activity, it has been popularly dubbed the "Pacific Ring of Fire."
e) The mid-world mountain belt (Alpine Belt) extends parallel to the equator from Mexico across the Atlantic Ocean, the Mediterranean Sea from Alpine-Caucasus ranges to the Caspian, Himalayan mountains and the adjoining lands.
f) There also are striking connected belts of seismic activity, mainly along oceanic ridges—including those in the Arctic Ocean, the Atlantic Ocean, and the western Indian Ocean—and along the rift valleys of East Africa.

Measurement:

All earthquakes are different in their intensity and magnitude. The instrument for the measurement of the vibrations is known as Seismograph.

Magnitude scale:

- Richter scale is used to measure the magnitude of the earthquake
- The energy released during a quake is expressed in absolute numbers of 0-10.

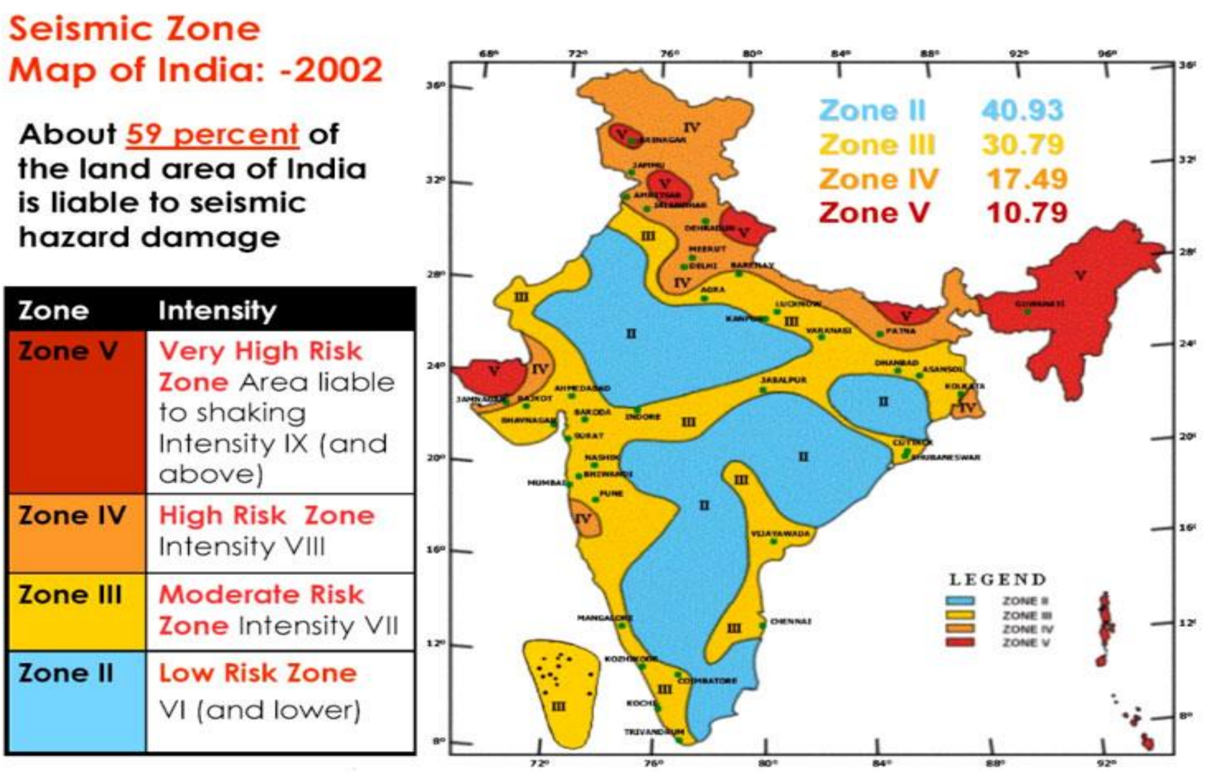


Fig. 1 Seismic zonation and intensity map of India

<u>Regions that fall under the Earthquake (seismic) Zones in India:</u>

a) **Zone-V** covers entire northeastern India, some parts of Jammu and Kashmir, some parts of Ladakh, Himachal Pradesh, Uttarakhand, Rann of Kutch in Gujarat, some parts of North Bihar and **Andaman & Nicobar Islands.**

b) **Zone-IV** covers remaining parts of Jammu & Kashmir, Ladakh and Himachal Pradesh, Union **Territory of Delhi**, Sikkim, northern parts of Uttar Pradesh, Bihar and West Bengal, parts of Gujarat and small portions of Maharashtra near the west coast and Rajasthan.

c) **Zone-III** comprises of Kerala, Goa, Lakshadweep islands, remaining parts of Uttar Pradesh, Gujarat and West Bengal, parts of Punjab, Rajasthan, Madhya Pradesh, Bihar, Jharkhand, Chhattisgarh, Maharashtra, Odisha, Andhra Pradesh, Tamil Nadu and Karnataka.

d) **Zone-II** covers remaining parts of the country.

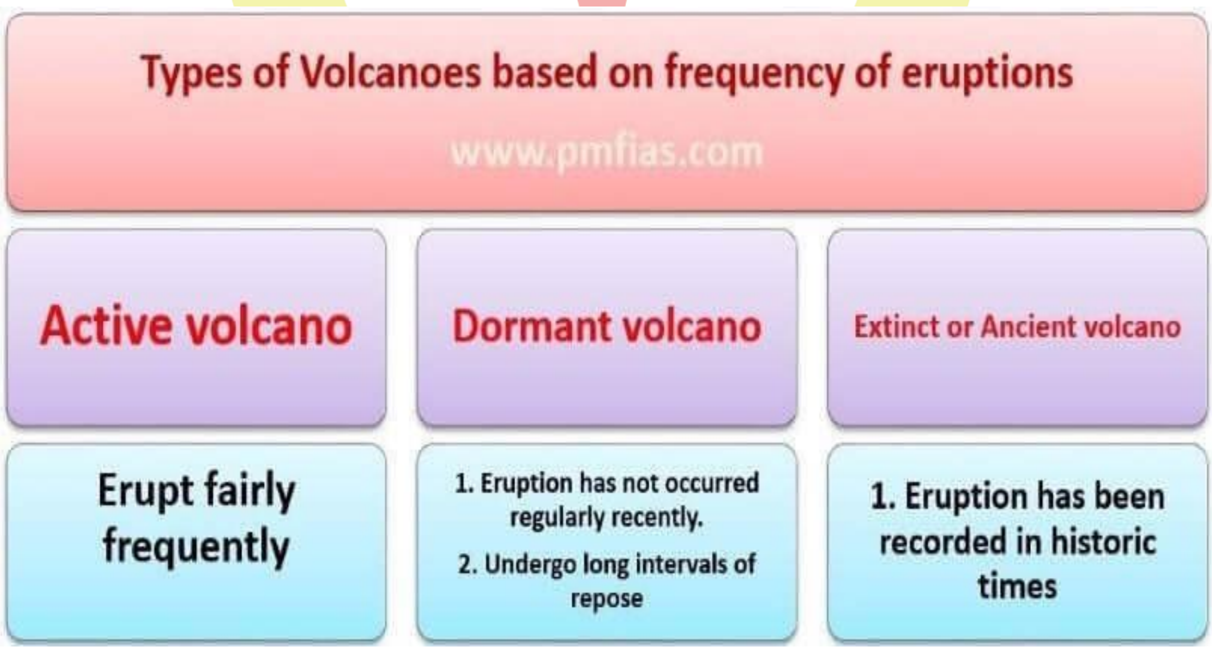
3. VOLCANO

- A volcano is a vent or fissure in Earth's crust through which lava, ash, rocks, and gases erupt.
- An active volcano is a volcano that has erupted in the recent past.
- The mantle contains a weaker zone known as the asthenosphere.
- Magma is the material present in the asthenosphere.
- Material that flows to or reaches the ground comprises lava flows, volcanic bombs, pyroclastic debris, dust, ash, and gases. The gases may be sulfur compounds, nitrogen compounds, and trace amounts of argon, hydrogen, and chlorine.

Types of Volcanoes:

- **Major types of volcanoes:**

- Extinct
- Dormant
- Active volcanoes



- Barren Island in the Andaman and Nicobar Islands, Anak Krakatoa are active volcanoes
- Mount Kilimanjaro (it has three volcanic cones), is a dormant strato volcano a dormant strato volcano in Tanzania.
- Mount Kenya is an extinct stratovolcano.
- The Barren Island in the Andaman and Nicobar Islands of India which was thought to be extinct erupted recently.
- Before a volcano becomes extinct, it passes through a waning stage during which steam and other hot gases and vapours are exhaled. These are known as fumaroles or solfataras.
- Volcanoes are classified based on the nature of eruption and the form developed at the surface.

➢ **Shield Volcanoes:**
The Shield volcanoes are the largest of all the volcanoes on the earth, which are not steep.

➢ **Composite Volcanoes:**
Composite Volcanoes are characterized by outbreaks of cooler and more viscous lavas than basalt.

➢ **Caldera:** Calderas are known as the most explosive volcanoes of Earth.

<u>Volcanism (Volcanos) in India:</u>

There are no volcanoes in the Himalayan region or the Indian peninsula. active in the 1990s. Barren is now considered an active volcano after it spewed lava and ash in 2017.

<u>Destructive Effects of Volcanism:</u>

- Showers of cinders and bombs can cause damage to life. E.g. the eruption of **Mount Vesuvius** in 79 AD.
- The ash from a larger eruption dispersing over a large area can lower temperatures at a regional or global scale.
- In Hawaiian type eruption, a single flow spreads widely over open slopes or down the valleys as lava rivers engulfing entire cities.
- Lahars (a violent type of mudflow or debris flow) can bury entire cities in a matter of minutes causing a high number of causalities.

- The sudden collapse of lava domes can cause violent volcanic flows that destroy everything on their path.
- Powerful winds drive the gas plume higher into the atmosphere and carry it to a greater distance disrupting air travel.

4. MOUNTAINS

➢ Fold Mountains:

Fold mountains are formed when sedimentary rock strata in **geosynclines** are subjected to compressive forces.

➢ Types of folds:

a) A **symmetrical fold** is one in which the axial plane is vertical.
b) An **asymmetrical fold** is one in which the axial plane is inclined.
c) An **isoclinal fold** has limbs that are essentially parallel to each other and thus approximately parallel to the axial plane.
d) An **overturned fold** has a highly inclined axial plane such that the strata on one limb are overturned.
e) A **recumbent fold** has an essentially horizontal axial plane.

➢ Classification of fold mountains:

➢ On the basis of period of origin:

On the basis of the period of origin, fold mountains are divided into three.
a) very old fold mountains
b) old fold mountains
c) Alpine fold mountains

a) Very Old Fold Mountains:

- They are more than 500 million years old.
- They are of low elevation.
- Some of the examples are Laurentian mountains, Algoman mountains, etc.

b) Old Fold Mountains:

- Old fold mountains had their origin before the Tertiary period (tertiary period started 66 million years ago).
- The Aravalli Range in India is the oldest fold mountain systems in India**.**
- The range rose in post-Precambrian event called the Aravalli-Delhi orogeny**.**

c) young fold mountains:

- Alpine fold mountains belonging to the Tertiary period (66 million years ago to present) can be grouped under the new fold mountains category since they originated in the Tertiary period.
- Examples are **The Rockies, The Andes, The Alps, The Himalayas**, etc.

➢ **Characteristics of Fold Mountains:**

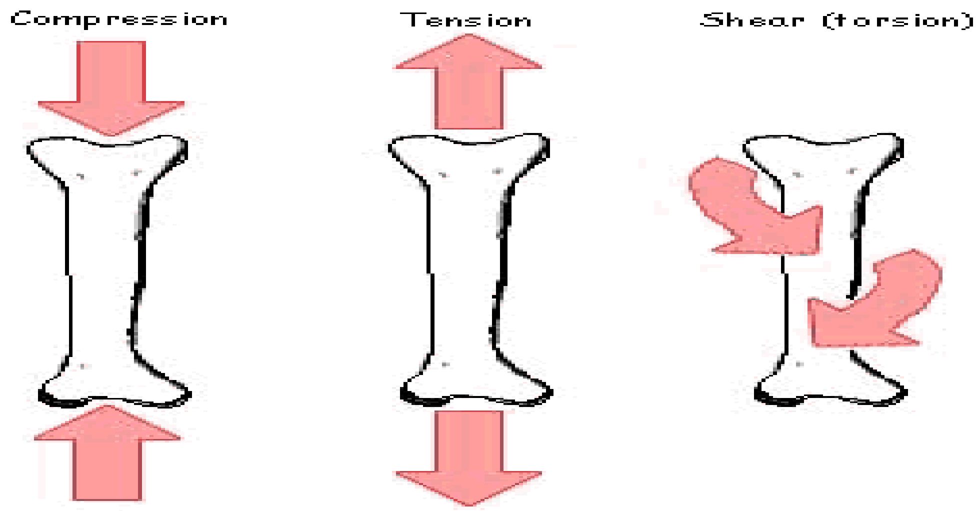
- Fold mountains belong to the group of **youngest mountains of the earth**.
- Fold mountains extend for **great lengths** whereas their **width is considerably small**.
- Generally, fold mountains have a concave slope on one side and a convex slope on the other.

➢ **Block Mountains:**

- Block mountains are created because of faulting on a large scale (when large areas or blocks of earth are broken and **displaced vertically or horizontally**).
- Block mountains are also called **fault-block mountains** since they are formed due to faulting as a result of tensile and compressive forces.

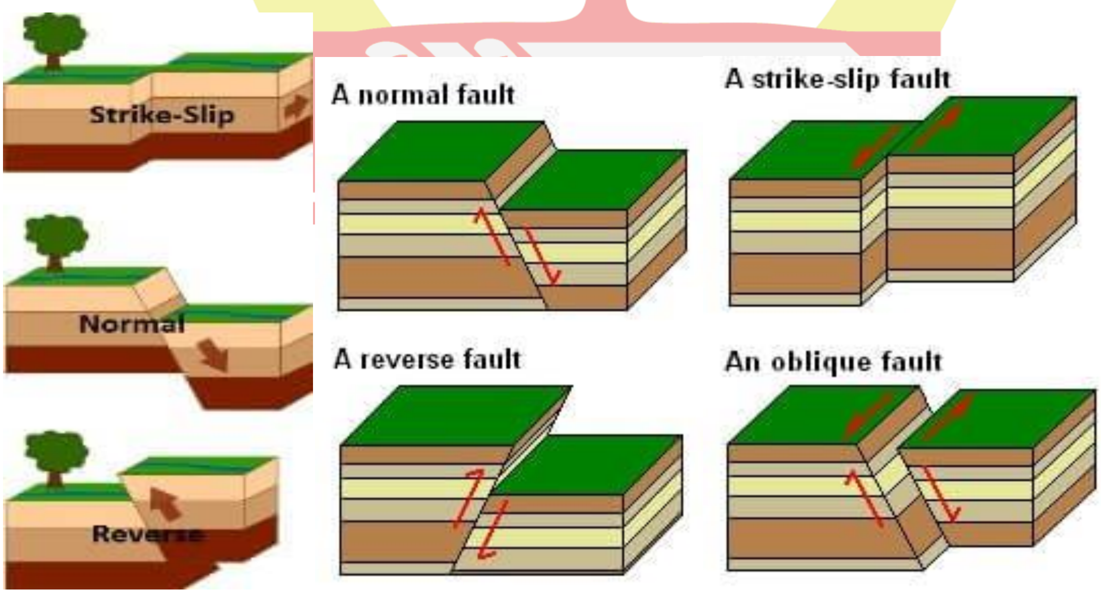
➢ **'Fault' in Geology:**

- When the earth's crust bends folding occurs, but when it cracks, faulting takes place.
- A fault is a planar fracture (crack) in a volume of earth's crust, across which there has been significant displacement of a block/blocks of crust.
- The **faulted edges are usually very steep**, e.g., the Vosges and the Black Forest of the Rhineland.
- Faults occur due to tensile and compressive forces acting on the parts of the crust.



- Large faults within the Earth's crust result from the action of plate tectonic forces, such as subduction zones or **transform faults**.
- Energy release associated with rapid movement on active faults is the cause of most **earthquakes**.
- In an active fault, the pieces of the Earth's crust along a fault move over time.
- Inactive faults had movement along them at one time, but no longer move.
- The type of motion along a fault depends on the type of fault.

➢ **<u>Types of faults:</u>**



➢ Types of faults:

a) Strike-slip fault:

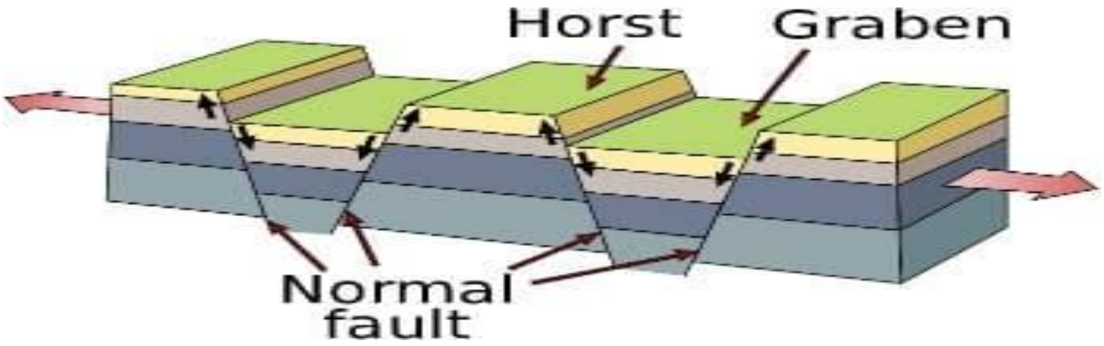
In a strike-slip fault (also known transcurrent fault), the plane of the fault is usually near vertical, and the blocks move laterally either left or right with very little vertical motion (the displacement of the block is horizontal).

b) Transform fault:

- A special class of strike-slip fault is the transform fault or transform boundary when it forms a plate boundary.
- A transform fault is the only type of strike-slip fault that is classified as a plate boundary.
- Most of these faults are hidden in the deep ocean, where they offset divergent boundaries in short zigzags resulting from seafloor spreading.
- They are less common within the continental lithosphere. The best example is the Dead Sea transform fault.
- The transform boundary ends abruptly and is connected to another transform, a spreading ridge, or a subduction zone.

c) Dip-slip faults:

- Dip-slip faults can be either normal or reverse.
- In a normal fault, the hanging wall (displaced block of crust) moves downward, relative to the footwall (stationary block). In a reverse fault (thrust fault) the hanging wall moves upwards.
- Reverse faults occur due to compressive forces whereas normal faults occur due to tensile forces.
- A downthrown block between two normal faults is a graben.
- An upthrown block between two normal faults is a horst.
- Normal faults occur mainly in areas where the crust is being extended such as a divergent boundary.
- Reverse faults occur in areas where the crust is being shortened such as at a convergent boundary.



d) Oblique-slip faults:

- A fault which has a component of dip-slip and a component of strike-slip is termed an oblique-slip fault.
- Nearly all faults have some component of both dip-slip and strike-slip.
- Many disastrous earthquakes are caused along the oblique slip.

➢ **<u>Longest Mountain Ranges:</u>**

1. The Andes – 7,000 km
2. The Rockies – 4,830 km
3. The Great Dividing Range – 3,500 km
4. The Transantarctic Mountains – 3,500 km
5. The Ural Mountains – 2,500 km
6. The Atlas Mountains – 2,500 km
7. The Appalachian Mountains – 2,414 km
8. The Himalayas – 2,400 km
9. The Altai Mountains – 2,000 km (1,243 mi)
10. The Western Ghats – 1,600 km
11. The Alps – 1,200 km
12. Drakensberg – 1,125 km
13. The Aravalli Range – 800 km

1. The Andes:

- The Andes is the longest continental mountain range in the world.
- Ojos del Salado (6,893 m) (active volcano) on the Chile-Argentina border is the highest volcano on earth.

2. The Rockies:

- Rocky Mountain range forms a part of the American Cordillera.
- The American Cordillera is a chain of mountain ranges (cordilleras) that consists of an almost continuous sequence of mountain ranges that form the western backbone of the Americas and Antarctica.

3. The Great Dividing Range:

- The Great Dividing Range, or the Eastern Highlands, is Australia's most substantial mountain.
- It is also known as the **Australian Alps** and was formed due to rifting.

4. The Ural Mountains:

- Mountain range that runs approximately from north to south through western Russia, from the coast of the Arctic Ocean to the **Ural River** and northwestern Kazakhstan.
- Theyareformeddueto Continent-Continentcollision **of** supercontinent **Laurussia** with the young and weak continent of **Kazakhstania**.
- Since the 18th century, the mountains have been a major mineral base of **Russia**.

5. Atlas Mountains:

- These mountains were formed when Africa and Europe collided.

6. The Himalayas:

- The Himalayan range is home to the planet's highest peaks, including the highest, **Mount Everest.**
- Its western anchor, **Nanga Parbat**, lies just south of the northernmost bend of Indus river, its eastern anchor, **Namcha Barwa**, just west of the great bend of the Brahmaputra river (Tsangpo river).

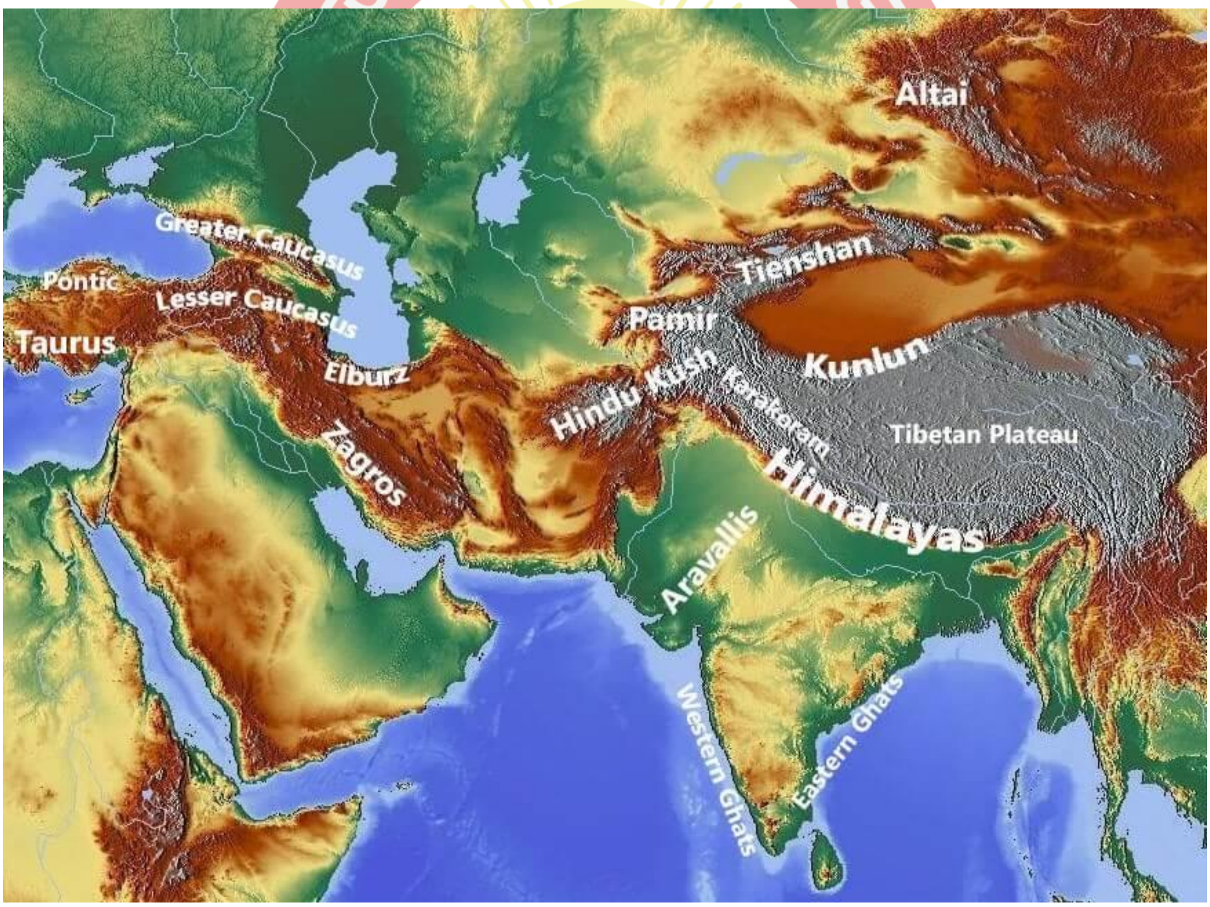
Geology:

- The Himalaya are among the **youngest mountain ranges** on the planet and consist mostly of uplifted sedimentary and metamorphic rock.

- According to the modern theory of plate tectonics, their formation is a result of a continental collision or orogeny along the convergent boundary between the Indo-Australian Plate and the Eurasian Plate.
- The Arakan Yoma highlands in Myanmar were also formed as a result of this collision.

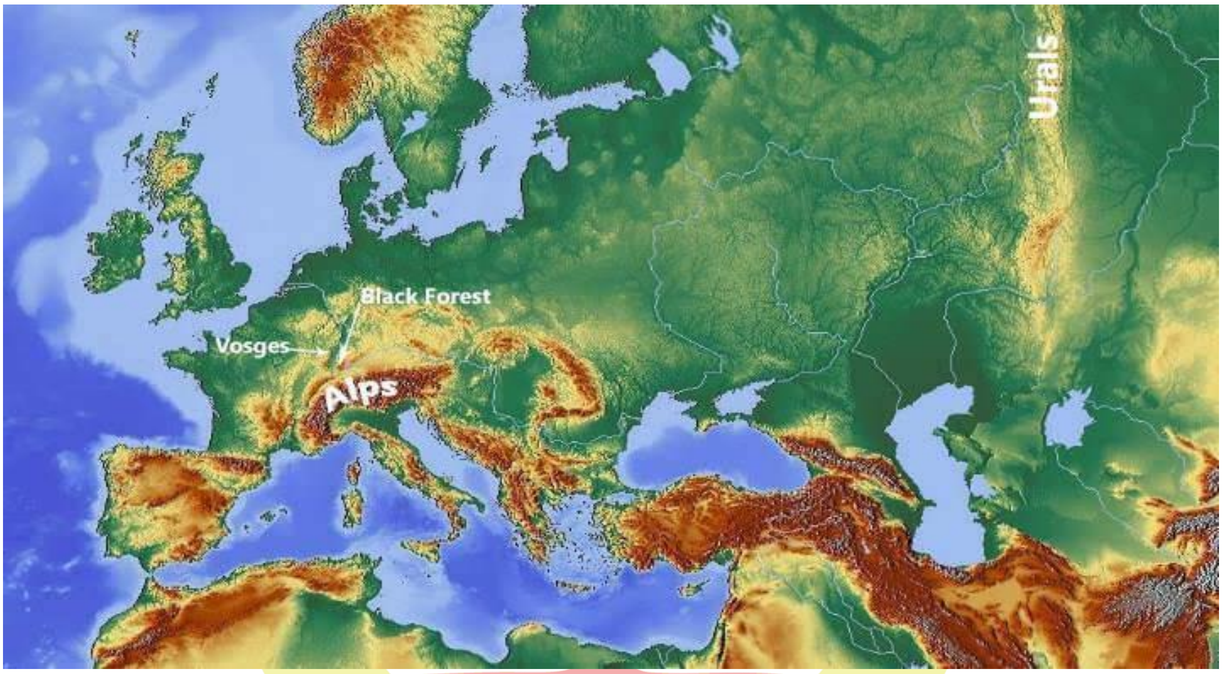
Impact on climate:

- The Himalayas are believed to play an important part in the formation of Central Asian deserts, such as the **Taklamakan and Gobi**.



7. **The Alps:**

- The mountains were formed as the African and Eurasian tectonic plates collided.
- Extreme folding caused by the event resulted in marine sedimentary rocks rising by thrusting and folding into high mountain peaks such as **Mont Blanc** (4,810 m).



FAQs:

- Sea of Mountains is an account of Lord dufferins tour through British Columbia in 1876.
- Largest mountain series of the world is Andes
- white Mountains are situated in United States of America in California State
- Arakan yoma is the extension of the Himalayas located in Myanmar
- Black Forest mountain is situated in Germany.
- Black Mountain is situated in USA. these Mountains are part of appalachian mountains.
- Drakensberg is a mountain of South Africa.
- Allegheny mountain – USA
- Cantabrian – Spain
- Elbruz – Iran
- Mackenzie – Canada
- Kosciuszko – Australia

5. DESERTS

- Deserts are regions where evaporation exceeds precipitation.
- There are mainly two types – hot like the **hot deserts** of the Saharan type and temperate as are the **mid-latitude deserts** like the Gobi.

➢ Hot Desert Climate:

- The aridity of the hot deserts is mainly due to the effects of off-shore Trade Winds.
- The major hot deserts of the world are located on the western coasts of continents between latitudes 15° and 30°N. and S
- They include the biggest Sahara Desert (3.5 million square miles), Great Australian Desert, Arabian Desert, Iranian Desert, Thar Desert, Kalahari and Namib Deserts.
- In North America, the desert extends from Mexico into U.S.A. and is called by different names at different places, e.g., the Mohave, Sonoran, Californian and Mexican Deserts.
- In South America, the Atacama or Peruvian Desert **(**rain shadow effect and off-shore trade winds**)** is the driest of all deserts with less than 2 cm of rainfall annually.

➢ Mid-Latitude Desert Climate:

- The temperate deserts are rainless because of either **continentality or rain-shadow effect.**
- The Patagonian Desert is more due to its rain-shadow position on the leeward side of the lofty Andes than to continentiality.

➢ Desert Climate:

- Rainfall (Both Hot and Cold deserts):
- Deserts, whether hot or mid-latitude have an annual precipitation of less than 25 cm.
- Rain normally occurs as violent thunderstorms of the convectional type.
- It 'bursts' suddenly and pours continuously for a few hours over small areas.

➢ Desert Vegetation:

- The predominant vegetation of both hot and mid-latitude deserts is xerophytic or drought-resistant.
- This includes the cacti, thorny bushes, long-rooted wiry grasses and scattered dwarf acacias.
- Trees are rare except where there is abundant ground water to support clusters of date palms.
- Absence of moisture retards the rate of decomposition and desert soils are very deficient in humus.
- Most desert shrubs have long roots and are well spaced out to gather moisture, and search for ground water.
- The seeds of many species of grasses and herbs have thick, tough skins to protect them while they lie dormant.

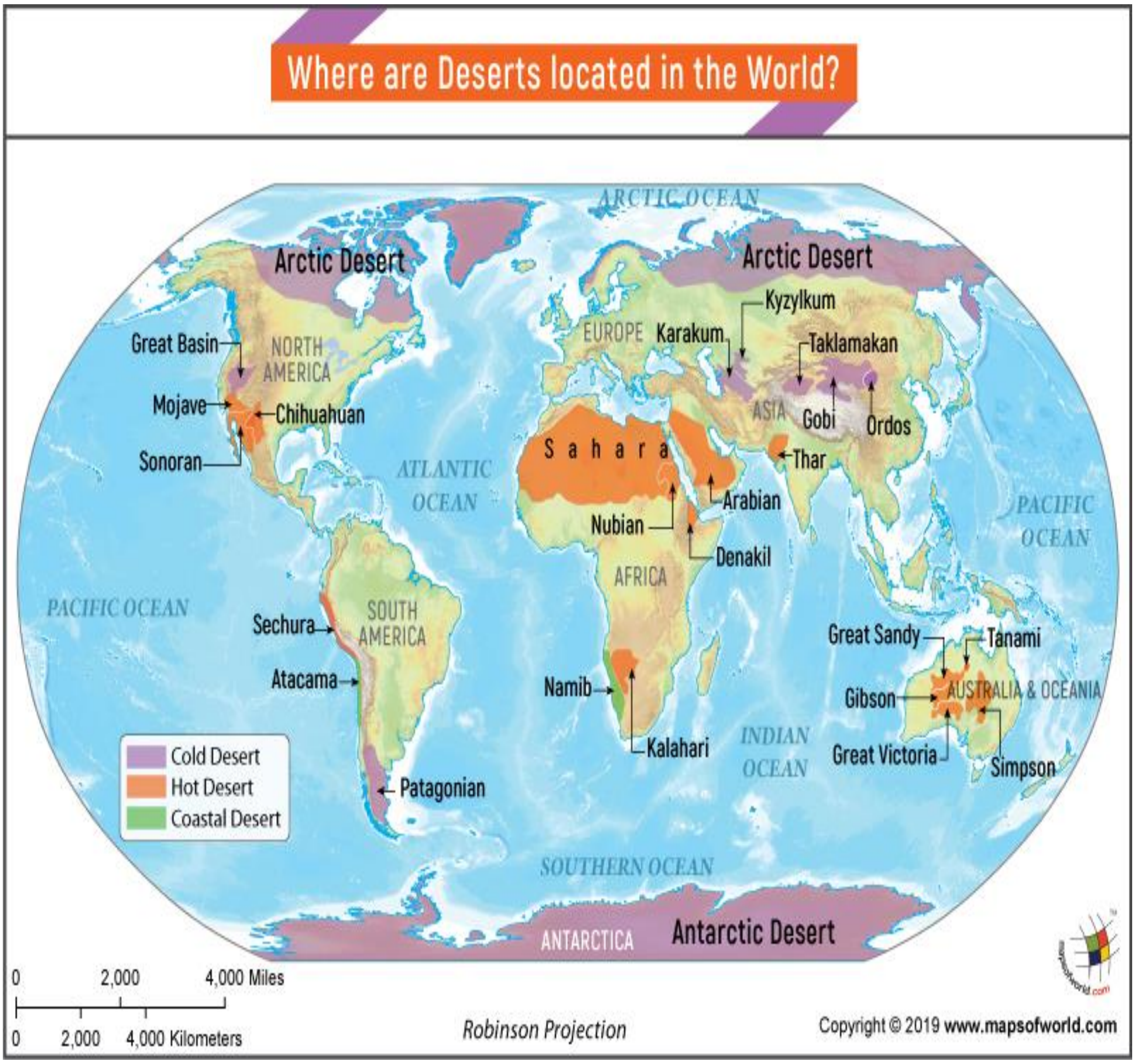
Life in the Deserts:

- Despite its inhospitality, the desert has always been peopled by different groups of inhabitants.

Tribe	Desert	Occupation
Bedouin Arabs	Arabia	nomadic herdsmen
Tuaregs	Sahara	nomadic herdsmen
Gobi Mongols	Gobi	nomadic herdsmen
Bushmen	Kalahari	primitive hunters and collectors.
Bindibu	Australia	primitive hunters and collectors.

The settled cultivators:

- The life-giving waters of the Nile made it possible for the Egyptians to raise many crops as early as 5,000 years ago.
- Modem concrete dams constructed across the Nile e.g. Aswan and Sennar Dams improved agriculture.
- In the deserts, wherever there are oases, some form of settled life is bound to follow. These are depressions of varying sizes, where underground, water reaches the surface.
- The most important tree is the date palm. The fruit is consumed locally and also exported.
- Other crops cultivated include maize, barley, wheat, cotton, cane sugar, fruits and vegetables.


Where are Deserts located in the World?
ARCTIC OCEAN
Arctic Desert
Arctic Desert
Great Basin
NORTH AMERICA
Mojave
Chihuahuan
Sonoran
EUROPE
Karakum
Kyzylkum
Taklamakan
ASIA
Gobi
Ordos
Sahara
Thar
Arabian
Nubian
Denakil
ATLANTIC OCEAN
PACIFIC OCEAN
AFRICA
PACIFIC OCEAN
SOUTH AMERICA
Sechura
Atacama
Namib
Kalahari
Great Sandy
Tanami
Gibson
AUSTRALIA & OCEANIA
Great Victoria
Simpson
INDIAN OCEAN
Patagonian
Cold Desert
Hot Desert
Coastal Desert
SOUTHERN OCEAN
ANTARCTICA
Antarctic Desert
0 2,000 4,000 Miles
0 2,000 4,000 Kilometers
Robinson Projection
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6. GRASSLANDS

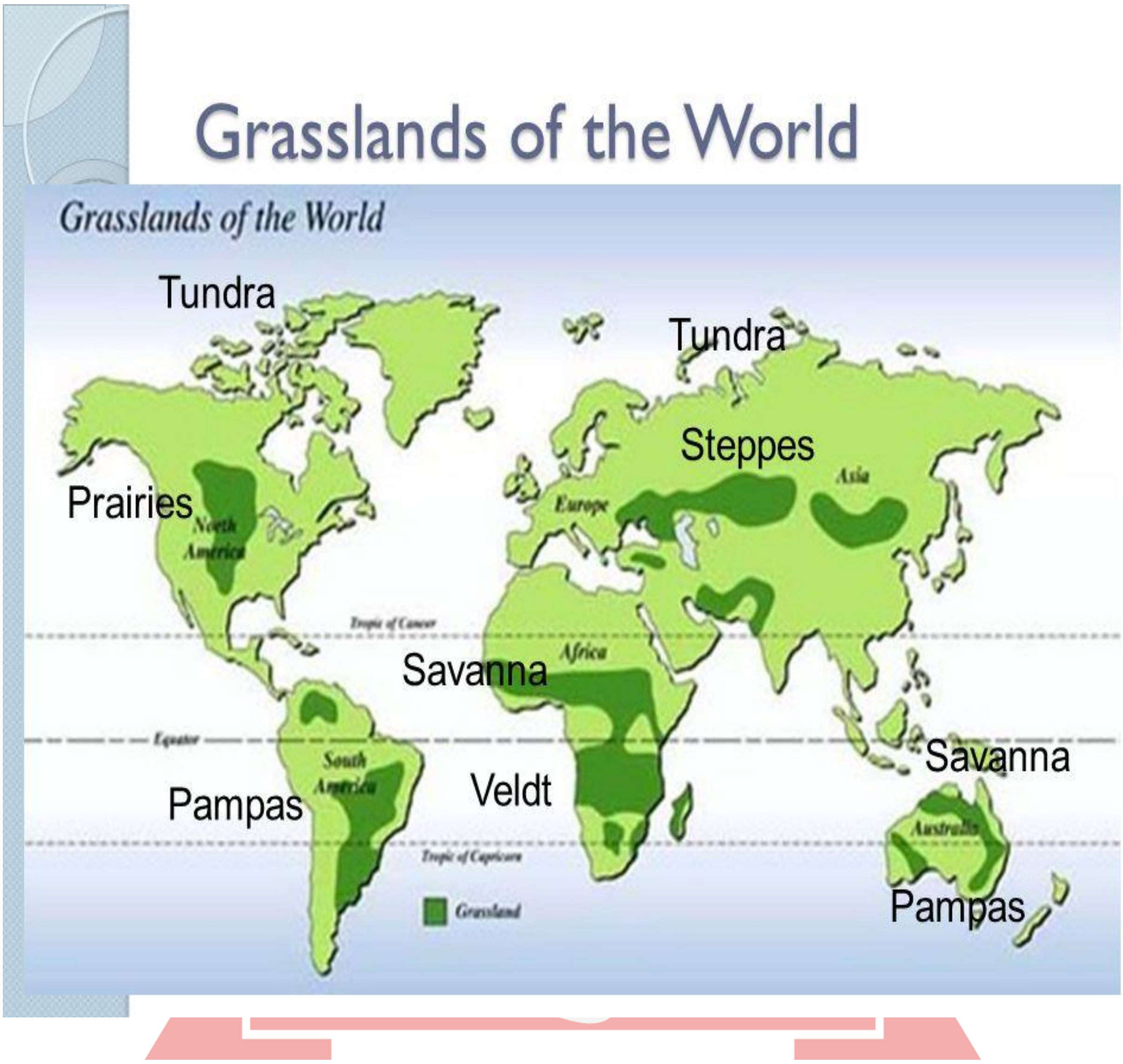
Name of the Temperate Grassland	Region
Pustaz	Hungary and surrounding regions
Prairies	North America
Pampas	Argentina and Uruguay
Downs	Australia: Murray-Darling basin of southern Australia
Canterbury	New Zealand

➢ **Tropical Grasslands:**

- Selvas
- Savanna
- Llanos
- Campos
- Perkland

➢ **MCQs on grasslands 'PREVIOUSLY ASKED IN PCS AND IAS':**

a) prairies - North America
b) Pampas - South America (Argentina, Uruguay and Brazil)
c) Steppes – Europe
d) Veld - South Africa
e) Llanos - South America
f) Campos - Brazilian highland
g) Savanna - Eastern Africa (Kenya, Tanzania etc)
h) The wide treeless grassy plain in South America is called – Pampas.


Grasslands of the World
Grasslands of the World
Tundra
Tundra
Steppes
Asia
Prairies
North America
Europe
Tropic of Cancer
Africa
Savanna
Equator
South America
Savanna
Pampas
Veldt
Australia
Tropic of Capricorn
Grassland
Pampas

7. LATITUDE AND LONGITUDES:

➢ **Equator:**

- Equator is an imaginary line running on the globe that divides it into two equal parts.
- The northern half of the earth is known as the Northern Hemisphere and Southern half is known as the Southern Hemisphere.

➢ **Parallels of latitudes:**

- Parallels of latitudes are parallel circles from the equator up to the poles.
- They are measured in degrees.
- The equator represents the zero degrees' latitude. Its distance from the equator to either of the poles is one-fourth of a circle round the earth, it will measure ¼th of 360 degrees, i.e., 90°. Thus, 90 degrees north latitude marks the North Pole and 90 degrees south latitude marks the South Pole.

➢ **Important Parallels of Latitudes:**

- Tropic of Cancer (23½° N) in the Northern Hemisphere
- Tropic of Capricorn (23½° S) in the Southern Hemisphere
- Arctic Circle at 66½° north of the equator
- Antarctic Circle at 66½° south of the equator

HEAT ZONES OF THE EARTH:

1) Torrid Zone:
The mid-day sun is exactly overhead at least once a year on all latitudes in between the Tropic of Cancer and the Tropic of Capricorn. It, therefore, receives the maximum heat.

2) Temperate Zones:
The mid-day sun never shines overhead on any latitude beyond the Tropic of Cancer and the Tropic of Capricorn. The angle of the sun's rays goes on decreasing towards the poles. They have moderate temperatures.

3) **Frigid Zones:**

- Areas lying between the Arctic Circle and the North Pole in the Northern Hemisphere and the Antarctic Circle and the South Pole in the Southern Hemisphere, are very cold. It is because here the sun does not rise much above the horizon.

➢ Longitudes:

Prime Meridian:

- The meridian which passed through Greenwich, where the British Royal Observatory is located. This meridian is considered as the Prime Meridian.
- Its value is 0° longitude and from it, we count 180° eastward as well as 180° westward. The Prime Meridian and 180° meridian divide the earth into two halves, the Eastern Hemisphere and the Western Hemisphere

Longitude and Time:

- The best means of measuring time is by the movement of the earth, the moon, and the planets. The sun regularly rises and sets every day.
- When the Prime Meridian of Greenwich has the sun at the highest point in the sky, all the places along this meridian will have mid-day or noon.
- As the earth rotates from west to east, those places east of Greenwich will be ahead of Greenwich time and those to the west will be behind it.
- It can be calculated this way- The earth rotates 360° in about 24 hours, which means 15° an hour or 1° in four minutes. Thus, when it is noon at Greenwich, the time at 15° east of Greenwich will be 15 × 4 = 60 minutes, i.e., 1 hour ahead of Greenwich time, but at 15° west of Greenwich, the time will be behind Greenwich time by one hour
- Why do we have Standard Time?
- The local time of places which are on different meridians is bound to differ.
- In India, for instance, there will be a difference of about 1 hour and 45 minutes in the local times of Dwarka in Gujarat and Dibrugarh in Assam.
- In India, the longitude of 82½° E (82° 30'E) is treated as the standard meridian. The local time at this meridian is taken as the standard time for the whole country. It is known as the Indian Standard Time (IST).

➢ The International Date Line:

- A traveler going eastwards gains time from Greenwich until he reaches the meridian 180°E, when he will be 12 hours ahead of G.M.T.

- Similarly, in going westwards, he loses 12 hours when he reaches 180°W. There is thus a total difference of 24 hours or a whole day between the two sides of the 180° meridian.
- This is the International Date Line where the date changes by exactly one day when it is crossed. A traveler crossing the date line from east to west loses a day (because of the loss in time he has made); and while crossing the dateline from west to east he gains a day (because of the gain in time he encountered).
- The International Date Line in the mid-Pacific curves from the normal 180° meridians at the Bering Strait, Fiji, Tonga and other islands to prevent confusion of day and date in some of the island groups that are cut through by the meridian.
- Some of them keep Asiatic or New Zealand standard time, others follow the American date and time.

INTERIOR OF THE EARTH

➢ Earth's surface:

- Many different geological processes shape the Earth's surface.
- The forces that cause these processes come from both above and beneath the Earth's surface.
- Processes that are caused by forces from within the Earth are **endogenous processes** (Endo meaning "in").
- By contrast, **exogenous processes** (Exo meaning "out") come from forces on or above the Earth's surface.
- The major geological features of the earth's surface like mountains, plateaus, lakes are mostly a result of endogenous processes like folding, faulting that are driven by forces from inside the earth.

➢ Direct Sources about the Earth's Interior

- It means physically seeing the internal layers of earth. It includes drilling, mining, volcanic, eruption, oil rigs etc. but none of these methods are conclusive. The deepest hole in the earth surface (a drill hole) is only about 12km deep at the Akola peninsula near the White Sea in Russia. This is nothing as compared to the radius of the earth which is estimated to be 6371km.
- Surface rocks are the most readily available solid earth material to make direct observations. Laboratory experiments on surface rocks and minerals provide important information about the interior of the earth.

➢ Mineral exploration

- Understanding volcanic activity and the nature of rocks is essential for mineral exploration.
- Most of the minerals like **diamonds (form at a depth of 150-800 km in the mantle)** that occur on the earth's surface are formed deep below the earth's surface. They are brought to the surface by **volcanic activity**. **Mining-** rocks that we get from mining areas are another source that gives us information about Earth s interior. Through mining and drilling operations we have been able to observe the earth s interior directly only up to a depth of few kilometres.

- **<u>Deep Ocean Drilling Projects</u>:**

Scientists have undertaken some major projects to penetrate the surface of oceans to assess the conditions in crustal portions. many deep drilling projects have provided a large volume of information through the analysis of materials collected at different depths.

- **<u>Volcanic Eruptions</u>:**

Volcanic eruption forms an important source of obtaining direct information through labora3tory analysis of the molten material (magma) that is thrown onto the surface of the earth, during a volcanic eruption.

- **<u>Indirect Sources about the Earth's Interior:</u>**

It means extrapolating the interior of the earth by indirect study. It includes study of meteorites and seismic waves.

a. Increase in pressure and temperature with depth
b. Seismic waves
c. Meteorites
d. Gravitation
e. Magnetic field

1) Increase in pressure and temperature with depth:

Gravitation and the diameter of the earth help in estimating pressure deep inside.

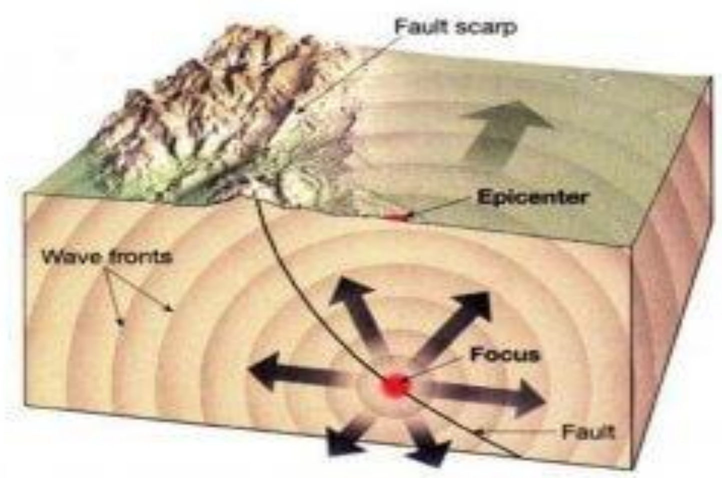
Volcanic eruptions and existence of hot springs, geysers etc. point to an interior which is very hot.

2) Seismic waves:

- Seismic waves are generated due to release of energy during an earthquake. They behave differently in different physical mediums and provide a good idea how the interior of earth must be. Broadly three types of waves are generated during an earthquake-
    a. Primary (P) waves
    b. Secondary (S) waves
    c. Surface waves(L)

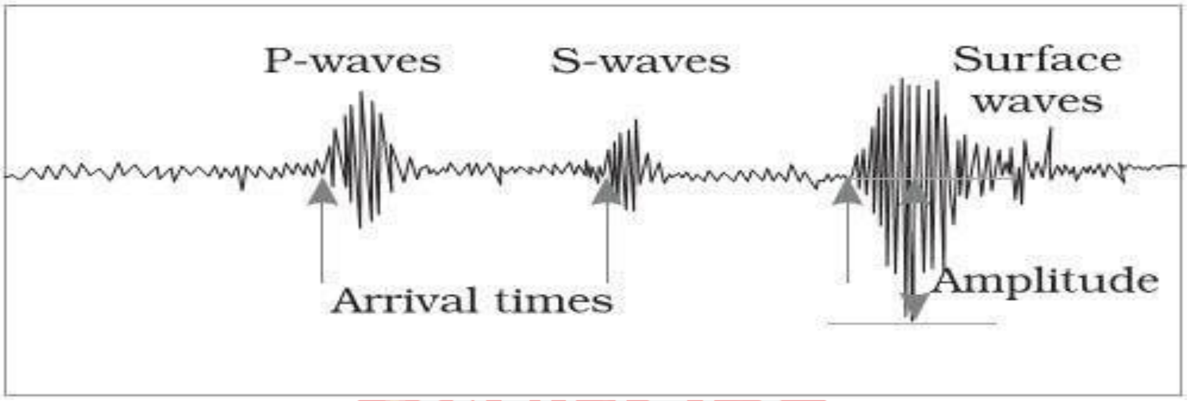
- Seismic: relating to earthquakes or other vibrations of the earth and its crust.
- Seismic waves are waves of energy that travel through the Earth's layers and are a result of earthquakes, volcanic eruptions, magma movement, large landslides and large human-made explosions.
- The refraction or reflection of seismic waves is used for research into the structure of the Earth's interior.
- The terms seismic waves and earthquake waves are often used interchangeably.
- They are the most important source available to understand the layered structure of the earth.
- The velocity of seismic waves changes as they travel through materials with different **elasticity** and **density**.
- The more elastic and denser the material is, the higher is the velocity**.**
- They also undergo **refection or refraction** when they come across materials with different densities.
- Earth's internal structure can be understood by analysing the patterns of reflection, refraction and change in velocity of the seismic waves when they travel through it.

Spread of the Seismic Waves



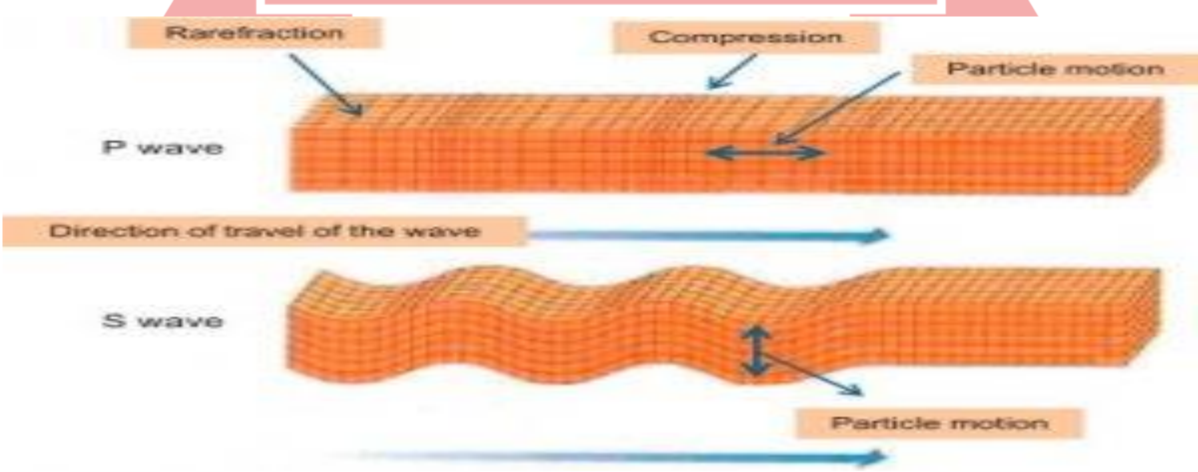
➢ Types of Seismic waves or earthquake waves:

The seismic waves or earthquake waves are basically of two types — body waves and surface waves.



1. Body waves:

- Body waves are generated due to the release of energy at the focus and move in all directions travelling through the interior of the earth. Hence, the name body waves.
- There are two types of body waves:
- the P-waves or primary waves (longitudinal in nature — wave propagation is similar to sound waves), and
- the S-waves or secondary waves (transverse in nature — wave propagation is similar to ripples on the surface of the water).



a) **Primary Waves (P-waves):**

- Primary waves are called so because they are the **fastest** among the seismic waves and hence are recorded first on the seismograph.
- P-waves are also called as the
- longitudinal waves because the displacement of the medium is in the same direction as, or the opposite direction to, (parallel to) the direction of propagation of the wave; or
- compressional waves because they produce compression and rarefaction when travelling through a medium; or
- pressure waves because they produce increases and decreases in pressure in the medium.
- P-waves creates density differences in the material leading to stretching (rarefaction) and squeezing (compression) of the material.
- They have the shortest wavelength and highest frequency. They can travel in solid, liquid and gaseous medium.
- These waves are of relatively high frequency and are the **least** destructive among the earthquake waves.
- The trembling on the earth's surface caused due to these waves is in the up-down direction (vertical).
- They can travel in all mediums, and their velocity depends on shear strength (elasticity) of the medium.
- Hence, the velocity of the P-waves in Solids > Liquids > Gases.
- These waves take the form of sound waves when they enter the atmosphere.
- P-wave velocity in earthquakes is in the range 5 to 8 km/s.
- The precise speed varies according to the region of the Earth's interior, from less than 6 km/s in the Earth's crust to 13.5 km/s in the lower mantle, and 11 km/s through the inner core.

Why do P-waves travel faster than S-waves?

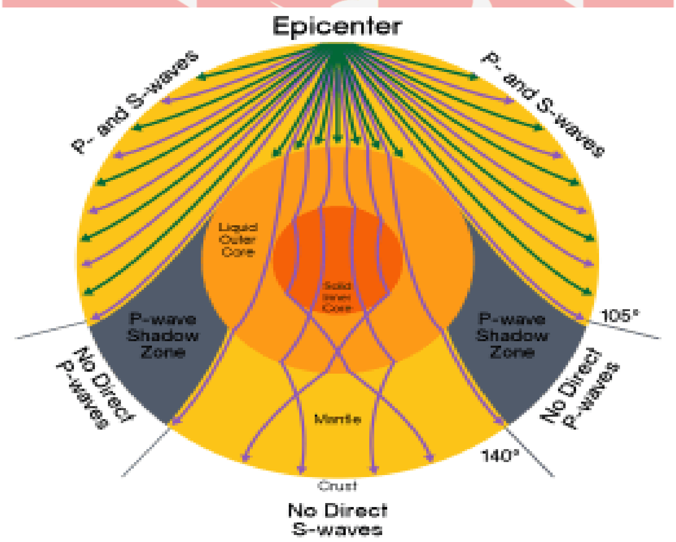
- P-waves are about 1.7 times faster than the S-waves**.**
- P-waves are compression waves that apply a force in the direction of propagation and hence transmit their energy quite easily through the medium and thus travel quickly.
- On the other hand, S-waves are transverse waves **or** shear waves (motion of the medium is perpendicular to the direction of propagation of the wave) and are hence less easily transmitted through the medium.

P-waves as an earthquake warning

- Advance earthquake warning is possible by detecting the non-destructive primary waves that travel more quickly through the Earth's crust than do the destructive secondary and surface waves.
- Depending on the depth of focus of the earthquake, the delay between the arrival of the P-wave and other destructive waves could be up to about 60 to 90 seconds (depends of the depth of the focus).

b) <u>Secondary Waves (S-waves):</u>

- Secondary waves (secondary they are recorded second on the seismograph) or S-waves are also called as transverse waves or shear waves or distortional waves.
- They are analogous to water ripples or light waves.
- Transverse waves or shear waves mean that the direction of vibrations of the particles in the medium is perpendicular to the direction of propagation of the wave. Hence, they create troughs and crests in the material through which they pass (they distort the medium).
- S-waves arrive at the surface after the P-waves.
- These waves are of high frequency and possess slightly higher destructive power compared to P-waves.
- The trembling on the earth's surface caused due to these waves is from side to side (horizontal).
- S-waves cannot pass through fluids (liquids and gases) as fluids do not support shear stresses.
- They travel at varying velocities (proportional to shear strength) through the solid part of the Earth.

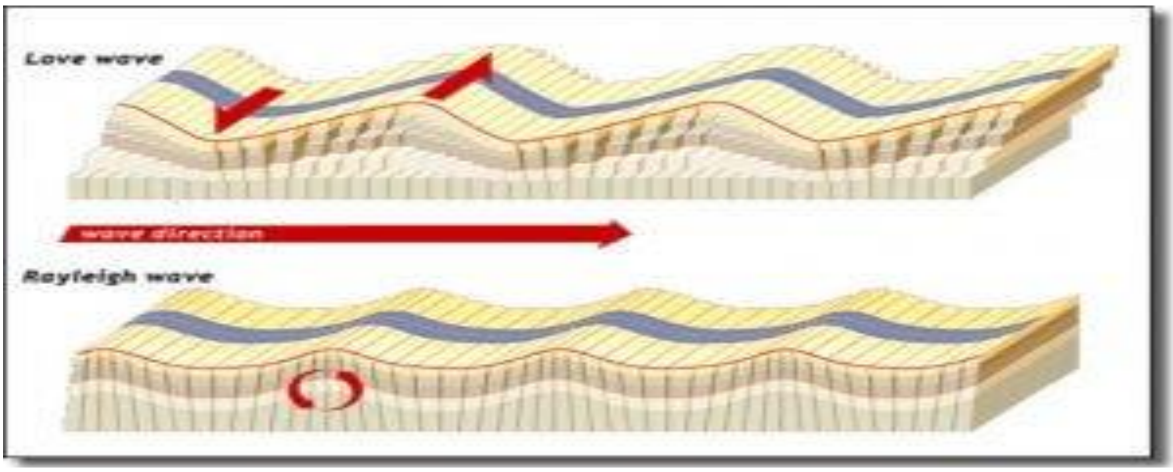


2. **Surface waves (L-Waves):**

- The body waves interact with the surface rocks and generate new set of waves called surface waves (long or L-waves). These waves move only along the surface.
- Surface Waves are also called long period waves because of their long wavelength.
- They are low–frequency transverse waves (shear waves).
- They develop in the immediate neighbourhood of the epicentre and affect only the surface of the earth and die out at smaller depth.
- They lose energy more slowly with distance than the body waves because they travel only across the surface unlike the body waves which travel in all directions.
- Particle motion of surface waves (amplitude) is larger than that of body waves, so surface waves are the most destructive among the earthquake waves.
- They are slowest among the earthquake waves and are recorded last on the seismograph.

Love waves

- It's the fastest surface wave and moves the ground from side-to-side.
- **Rayleigh waves**
- A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean.
- Because it rolls, it moves the ground up and down and side-to-side in the same direction that the wave is moving.
- Most of the shaking and damage from an earthquake is due to the Rayleigh wave.



How do seismic waves help in understanding the earth's interior?

- Seismic waves get recorded in seismographs located at far off locations.
- Differences in arrival times, waves taking different paths than expected (due to refraction) and absence of the seismic waves in certain regions called as shadow zones, allow mapping of the Earth's interior.
- Discontinuities in velocity as a function of depth are indicative of changes in composition and density.
- That's is, by observing the changes in velocity, the density and composition of the earth's interior can be estimated (change in densities greatly varies the wave velocity).

The emergence of Shadow Zone of P-waves and S-waves:

- S-waves do not travel through liquids (they are attenuated).
- The entire zone beyond 103° does not receive S-waves, and hence this zone is identified as the shadow zone of S-waves. This observation led to the discovery of the liquid outer core.
- The shadow zone of P-waves appears as a band around the earth between 103° and 142° away from the epicentre.
- This is because P-waves are refracted when they pass through the transition between the semisolid mantle and the liquid outer core.
- However, the seismographs located beyond 142° from the epicentre, record the arrival of P-waves, but not that of S-waves. This gives clues about the solid inner core.
- Thus, a zone between 103° and 142° from epicentre was identified as the shadow zone for both the types of waves.
- The seismographs located at any distance within 103° from the epicentre, recorded the arrival of both P and S-waves.
- The span of the shadow zone of the P-Waves = 78° [2 x (142° – 103°)]
- The span of the shadow zone of the S-Waves = 154° [360° – (103° + 103°)]
- The span of the shadow zone common for both the waves = 78°

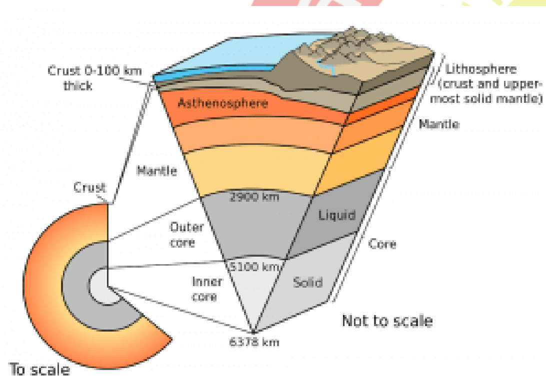
Structure of the Earth:

The interior structure of the Earth is made up of three main shells: the very thin and brittle crust, the mantle, and the core. Furthermore, the mantle and core are each divided into two parts. The core and mantle are equal in thickness but, the core of the earth only occupies 15 percent of Earth's volume whereas the mantel occupies 84 percent and the crust occupies remaining 1 percent.

Earth's Layers:

The interior of the earth is made up of several concentric layers of which the crust, the mantle, the outer core and the inner core are significant because of their unique physical and chemical properties.

- Chemically, Earth can be divided into the **crust, upper mantle, lower mantle, outer core, and inner core**.



Earth s interior is divided into basically three layers Crust, Mantle and Core, which we shall discuss in detail as below:

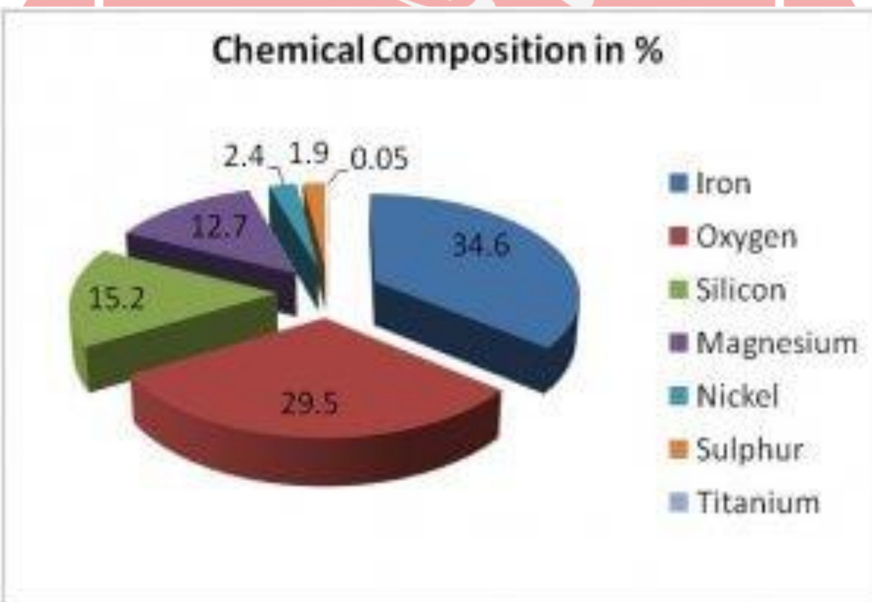
1. Crust:

- The crust is the outermost layer of the earth making up **0.5-1.0 per cent of the earth's volume** and **less than 1 per cent of Earth's mass**.
- The continental crust can be thicker than 70 km in the areas of major mountain systems. It is as much as 70-100 km thick in the Himalayan region and up to 8km under ocean.
- The temperature of the crust increases with depth.
- The temperature increases by as much as 30 °C for every kilometre in the upper part of the crust.

- The outer covering of the crust is of **sedimentary material** and below that lie crystalline, igneous and metamorphic rocks which are acidic in nature.
- The lower layer of the crust consists of basaltic and ultra-basic rocks.
- The continents are composed of lighter silicates — **silica + aluminium** (also called **sial**) while the oceans have the heavier silicates — **silica + magnesium** (also called **sima**).

S.N.	Element	Approximate % by weight
1.	Oxygen (O)	46.6
2.	Silicon (Si)	27.7
3.	Aluminium (Al)	8.1
4.	Iron (Fe)	5.0
5.	Calcium (Ca)	3.6
6.	Sodium (Na)	2.8
7.	Potassium (K)	2.6
8.	Magnesium (Mg)	1.5

<u>Most Abundant Elements of the Earth:</u>



2. Mantle:

- It forms about **83 per cent of the earth's volume and holds 67% of the earth's mass**.
- It extends from Moho's discontinuity to a depth of 2,900 km.
- The density of the upper mantle varies between **2.9 g/cm^3 and 3.3 g/cm^3**.
- The density ranges from **3.3 g/cm^3** to **5.7 g/cm^3** in the lower mantle.
- The mantle is composed of **silicate rocks that are rich in iron and magnesium** relative to the overlying crust.
- Because of the temperature difference, there is a **convective material circulation** in the mantle (although solid, the high temperatures within the mantle cause the silicate material to be sufficiently ductile).
- Convection of the mantle is expressed at the surface through the motions of tectonic plates.
- Our knowledge of the upper mantle, including the tectonic plates, is derived from analyses of earthquake waves, heat flow, magnetic, gravity studies and laboratory experiments on rocks and minerals.
- The portion of the interior beyond the crust is called the mantle.
- The mantle extends from Moho s discontinuity to a depth of 2,900 km.
- It has an average density higher than that of the crust (3.4 g/cm3).
- The mantle is divided into upper and lower mantle.

3. Core:

- The earthquake wave velocities have helped in understanding the existence of the core of the earth.
- The innermost layer surrounding the earth's centre is called core, which is about 3500 km in radius.
- The core is the densest layer of the earth. The density of material at the mantle-core boundary is around 5 g/cm3, and at the centre of the earth at 6,300 km, the density value is around 13 g/cm3.
- The core is made up of very heavy material mostly constituted by nickel and iron.
- It is sometimes referred to as the nife layer.
- The core makes up about 15% of Earth's volume.

Outer core:

- The outer core, surrounding the inner core, lies between 2900 km and 5100 km below the earth's surface.

- The outer core is composed of iron mixed with nickel (nife) and trace amounts of lighter elements.
- The outer core is not under enough pressure to be solid, so it is liquid even though it has a composition similar to the inner core.
- The density of the outer core ranges from **9.9 g/cm^3** to **12.2 g/cm^3**.
- The temperature of the outer core ranges from 4400 °C in the outer regions to 6000 °C near the inner core.

Inner Core:

- The inner core extends from the centre of the earth to 5100 km below the earth's surface.
- The inner core is generally believed to be composed primarily of **iron (80%) and some nickel** (**nife**).
- Earth's inner **core rotates slightly faster** relative to the rotation of the surface.
- The density of the inner core ranges from **12.6 g/cm^3** to **13 g/cm^3**.
- The core (inner core and the outer core) accounts for just about 16 per cent of the earth's volume but 33% of earth's mass.

➢ **Seismic Discontinuities:**

- Seismic discontinuities aid in distinguishing divisions of the Earth into the inner core, outer core, lower mantle, upper mantle, and the crust
- **Conorad discontinuity** it refers to the zone between upper crust and lower crust.
- Mohorovicic discontinuity also called as moho discontinuity is the zone that separates the Earth s crust from the upper mantle. It can be detected by a sharp increase downward in the speed of earthquake waves there.
- Mohorovicic (Moho) discontinuity forms the boundary between the **crust** and the **asthenosphere** (upper reaches of the mantle) where there is a discontinuity in the seismic velocity.
- It occurs at an average depth of about 8 kilometres beneath the ocean basins and 30 kilometres beneath continental surfaces.
- The cause of the Moho is thought to be a change in rock composition from rocks containing **feldspar** (above) to rocks that contain no feldspars (below).

➢ **<u>Temperature, Pressure and Density of the Earth's interior:</u>**

- The temperature increases towards the centre of the earth. However, the rate of increase of temperature is not uniform from the surface towards the earth s centre. It is faster at some places than at others.
- The temperature at the centre is estimated to lie somewhere between 3000 C and 50000C.
- Such a high temperature inside the earth may be due to chemical reactions under high-pressure conditions and disintegration of radioactive elements.
- The pressure also increases from the surface towards the centre of the earth due to huge weight of the overlying rocks.
- Due to increase in pressure and presence of heavier materials towards the earth s centres, the density of earth s layers also goes on increasing. The materials of the innermost part of the earth are very dense.

GEOMORPHIC PROCESSES

Geomorphic Process:

The formation and deformation of landforms on the surface of the earth are a continuous process which is due to the continuous influence of external and internal forces. The internal and external forces causing stresses and chemical action on earth materials and bringing about changes in the configuration of the surface of the earth are known as geomorphic processes.

- Earth's crust and its surface are constantly evolving (changing) due to various forces emanating from below (**endogenic forces**) as well as above the surface of the earth (**exogenic forces**).
- These forces cause physical and chemical changes to the geomorphic structure (earth's surface).
- Some of these changes are imperceptibly slow (e.g. weathering, folding), some others are gradual (e.g. erosion) while the remaining are quite sudden (earthquakes, volcanic eruptions).
- **Geomorphic:** relating to the form of the landscape and other natural features of the earth's surface.
- **Geomorphic agents:** mobile medium (like running water, moving ice masses or glaciers, wind, waves, currents etc.) which removes, transports and deposits earth materials.
- **Geomorphic processes:** physical and chemical processes that take place on the earth's surface (folding, faulting, weathering, erosion, etc.) due to endogenic and exogenic forces.
- **Geomorphic movements:** large scale physical and chemical changes that take place on the earth's surface due to geomorphic processes.

➢ Endogenic Geomorphic Movements:

- The large-scale movements on the earth's crust or its surface brought down by the forces emanating from deep below the earth's surface are called as endogenic geomorphic movements or simply endogenic movements (endo: internal; genic: origin; geo: earth; morphic: form).
- The geomorphic processes that are driven by the forces emanating from deep below the earth's surface are called endogenic geomorphic processes (folding, faulting, etc.).

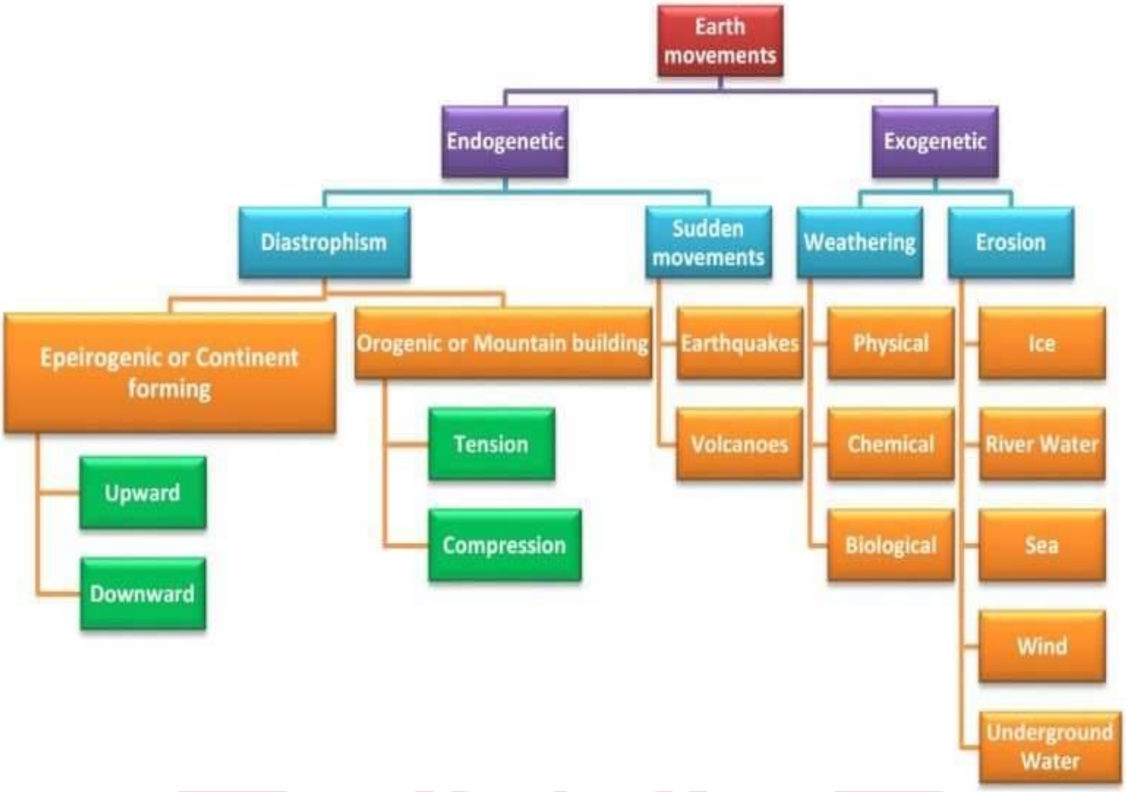
- Endogenic forces are those internal forces which derive their strength from the earth's interior and play a crucial role in shaping the earth crust.
- Examples – mountain building forces, continent building forces, earthquakes, volcanism etc.
- The endogenic forces are mainly land building forces.
- The energy emanating from within the earth is the main force behind endogenic geomorphic processes. This energy is mostly generated by radioactivity, rotational and tidal friction and primordial heat from the origin of the earth.

➢ The force behind Endogenic Movements:

- The ultimate source of energy behind forces that drive endogenic movements is **earth's internal heat**.
- Earth's internal heat is a result of mainly radioactive decay (50% of the earth's internal heat) and gravitation (causes pressure gradients).
- Differences in temperature and pressure (temperature gradients or geothermal gradients and pressure gradients) among various layers of the earth give rise to **density differences** and these density differences give rise to **conventional currents**.
- Convectional currents in the mantle drive the **lithospheric plates** (crust and upper mantle) and the **movement of the lithospheric plates** (**tectonics**) is the cause behind endogenic movements.
- The Earth's rotation (**Coriolis effect**) can influence where convection currents travel.
- The destination of convection currents determines the nature and location of the endogenic movements.

➢ Classification of Endogenic movements:

- Endogenic movements are divided into **diastrophic movements** and **sudden movements**.
- Diastrophism refers to **deformation** of the Earth's crust.
- Diastrophic movements are gradual and might stretch for thousands of years.
- On the other hand, sudden movements like earthquakes and volcanic eruptions occur in a very short period.
- Diastrophic movements are further classified into epeirogenic movements (continent forming — subsidence, upliftment) and orogenic movements (mountain building — folding, faulting).



➢ **<u>Diastrophism:</u>**

- Diastrophism refers to deformation of the Earth's crust due to diastrophic movements (deforming movements) such as **folding, faulting, warping (bending or twisting of a large area) and fracturing**.
- All processes that move, elevate or build up portions of the earth's crust come under diastrophism. They include:
- **orogenic processes** involving mountain building through severe folding (crust is severely deformed into folds) and affecting long and narrow belts of the earth's crust;
- **epeirogenic processes** involving uplift or warping of large parts of the earth's crust (simple deformation);
- earthquakes and volcanism involving local relatively minor movements;
- **plate tectonics** involving horizontal movements of crustal plates.
- The most obvious evidence of diastrophic movement can be seen where sedimentary rocks have been bent, broken or tilted.

- Epeirogenic or continent forming movements
- Epeirogenic or **continent forming** movements are **radial** movements (act along the radius of the earth).
- Their direction may be towards (subsidence) or away (uplift) from the centre.
- They cause upheavals or depressions of land exhibiting **undulations** (wavy surface) of **long wavelengths** and little folding**.**
- The broad central parts of continents are called cratons and are subject to epeirogeny, hence the name continent forming movements.

1. **Uplift**

- Raised beaches, elevated wave-cut terraces, sea caves and fossiliferous beds above sea level are evidence of upliftment.
- In India, raised beaches occur at several places along the **Kathiawar, Nellore, and Tirunelveli coasts**.
- Several places which were on the sea some centuries ago are now a few miles inland due to upliftment.
- For example, Coringa near the mouth of the Godavari, Kaveripattinam in the Kaveri delta and Korkai on the coast of Tirunelveli, were all flourishing seaports about 1,000 to 2,000 years ago.

2. **Subsidence**

- Submerged forests and valleys, as well as buildings, are evidence of subsidence.
- In 1819, a part of the Rann of Kachchh was submerged as a result of an earthquake.
- Presence of peat and lignite beds below the sea level in Tirunelveli and the Sundarbans is an example of subsidence.
- The Andamans and Nicobars have been isolated from the Arakan coast by submergence of the intervening land.
- On the east side of **Bombay island**, trees have been found embedded in the mud about 4 m below low water mark. A similar submerged forest has also been noticed on the Tirunelveli coast in Tamil Nadu.

- A large part of the Gulf of Mannar and Palk Strait is very shallow and has been submerged in geologically recent times. A part of the former town of Mahabalipuram near Chennai is submerged in the sea.

➢ **Orogenic or the mountain-forming movements**

- In contrast to epeirogenic movement, the orogenic movement is a **more complicated deformation** of the Earth's crust, associated with **crustal thickening** (due to the convergence of tectonic plates).
- Such plate convergence forms orogenic belts that are characterised by "the folding and faulting of layers of rock, by the intrusion of magma, and by volcanism.
- Orogenic or the mountain-forming movements act tangentially to the earth surface, as in plate tectonics.
- Tension produces fissures (since this type of force acts away from a point in two directions), and compression produces folds (because this type of force acts towards a point from two or more directions).

3. Sudden Movements

- Sudden geomorphic movements occur mostly at the **lithospheric plate margins** (tectonic plate margins).
- The plate margins are highly unstable regions due to pressure created by pushing and pulling of magma in the mantle (**convectional currents**).
- These movements cause considerable deformation over a short period.

A. Earthquakes

- Earthquakes occur when the surplus accumulated stress in rocks in the earth's interior due to folding, faulting or other physical changes is relieved through the weak zones over the earth's surface in the form of kinetic energy (seismic waves).
- Such movements may result in uplift or subsidence in coastal areas.
- An earthquake in Chile (1822) caused a one-metre uplift in coastal areas.
- An earthquake in New Zealand (1885) caused an uplift of up to 3 metres.
- An earthquake in Japan (1891) caused subsidence of up to 6 metres.
- Earthquakes may cause a change in contours, change in river courses, shoreline changes, glacial surges (as in Alaska), landslides, soil creeps, mass wasting etc.

B. Volcanoes

- Volcanism includes the movement of molten rock (magma) onto or towards the earth's surface through narrow volcanic vents or fissures.
- A volcano is formed when the molten magma in the earth's interior escapes through the crust by vents and fissures in the crust, accompanied by steam, gases **(hydrogen sulphide, sulphur dioxide, hydrogen chloride, carbon dioxide** etc.) and pyroclastic material (cloud of ash, lava fragments carried through the air, and vapour).
- Depending on the chemical composition and viscosity of the lava, a volcano may take various forms.

➢ Geophysical phenomenon like volcanism, earthquakes

- The forces that cause catastrophic events like earthquakes, volcanic eruptions come from deep below the earth's surface.
- For example, earthquakes occur due to the movement of the tectonic plates and the energy required for this movement is supplied by the conventional currents in the mantle.
- Similarly, volcanism occurs through the vents and fissures created by the tectonic movements.

4. Exogenic Geomorphic Movements

- The geomorphic processes on the earth's crust or its surface brought down by the forces emanating from above the earth's surface (wind, water) are called exogenic geomorphic process.
- Exogenic geomorphic process gives rise to exogenic geomorphic movements or simply exogenic movements such as **weathering** and erosion.
- The effects of most of the exogenic geomorphic processes are small and slow but will, in the long run, affect the rocks severely due to continued fatigue.

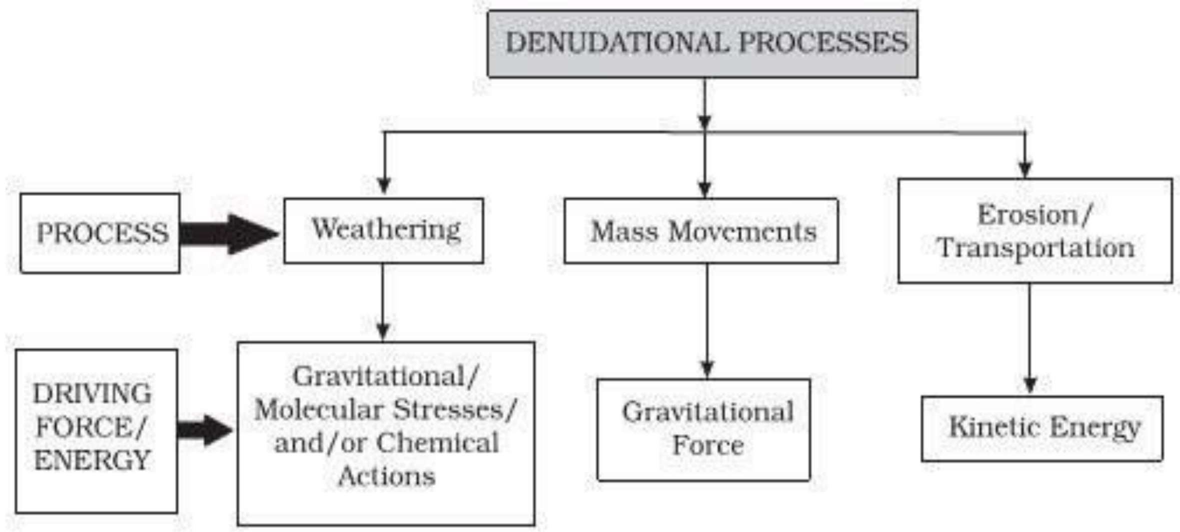
➢ The force behind Exogenic Movements

- Exogenic processes are a direct result of the sun's heat.
- Sun's energy dictates the weather patterns like winds, precipitation, etc.
- Sun's heat along with weather patterns are responsible for stress-induced in earth materials giving rise to exogenic movements (weathering and erosion).

- Earth materials become subjected to **molecular stresses** caused due to temperature changes.
- Chemical processes normally lead to **loosening of bonds** between grains.
- Stress is produced in a solid by pushing or pulling (**shear stresses —** separating forces) forces.

➢ Denudation

- All the exogenic processes (weathering and erosion) are covered under a general term, denudation.
- The word 'denude' means to strip off or to uncover.
- Denudation depends on physical (folds, faults, orientation and inclination of beds, presence or absence of joints, bedding planes, hardness or softness of constituent minerals, permeability) and chemical (chemical susceptibility of mineral constituents to corrosion) properties of the rocks.



➢ Weathering

- Weathering is the disintegration of rocks, soil, and minerals under the influence of physical (heat, pressure) and chemical (leaching, oxidation and reduction, hydration) agents.
- As very little or no motion of materials takes place in weathering, it is an in-situ or on-site process.

- The weathered material is carried farther away by erosion.
- There are three major groups of weathering processes:
  1) chemical;
  2) physical or mechanical;
  3) biological weathering processes.
- All the types of weathering often go hand in hand.

8. LANDFORMS

➢ Fluvial Landforms and Cycle of Erosion:

- The landforms created as a result of degradational action (erosion) or aggradational work (deposition) of running water are called fluvial landforms.
- The fluvial processes may be divided into three physical phases – erosion, transportation and deposition.

1. Fluvial Depositional Landforms

- The depositional action of a stream is influenced by stream velocity and the volume of river load.
- The decrease in stream velocity reduces the transporting power of the streams which are forced to leave some load to settle down.
- Increase in river load is effected through accelerated rate of erosion in the source catchment areas consequent upon deforestation.
- Various landforms resulting from fluvial deposition are as follows:

a) Alluvial Fans and Cones

- When a stream leaves the mountains and comes down to the plains, its velocity decreases due to a lower gradient.
- As a result, it sheds a lot of material, which it had been carrying from the mountains, at the foothills.
- This deposited material acquires a conical shape and appears as a series of continuous fans. These are called alluvial fans.
- Such fans appear throughout the **Himalayan foothills** in the north Indian plains.

b) Natural Levees

- These are narrow ridges of low height on both sides of a river, formed due to deposition action of the stream, appearing as natural embankments.

c) Delta

- A delta is a tract of alluvium at the mouth of a river where it deposits more material than can be carried away.
- The river gets divided into distributaries which may further divide and rejoin to form a network of channels.
- The finest particles are carried farthest to accumulate as bottom-set beds.
- Depending on the conditions under which they are formed, deltas can be of many types.

d) Estuaries

- Sometimes the mouth of the river appears to be submerged. This may be due to a drowned valley because of a rise in sea level.
- Here fresh water and the saline water get mixed. When the river starts 'filling its mouth' with sediments, mud bars, marshes and plains seem to be developing in it.

2. Fluvial Erosional Landforms:

- Fluvial Erosional Landforms are landforms created by the erosional activity of rivers.
- Various aspects of fluvial erosive action include:

a) **Hydration:** the force of running water wearing down rocks.

b) **Corrosion:** chemical action that leads to weathering.

c) **Attrition:** river load particles striking, colliding against each other and breaking down in the process.

d) **Corrasion or abrasion:** solid river load striking against rocks and wearing them down.

e) **Downcutting (vertical erosion):** the erosion of the base of a stream (downcutting leads to valley deepening).

f) **Lateral erosion:** the erosion of the walls of a stream (leads to valley widening).

g) **Headward erosion:** erosion at the origin of a stream channel, which causes the origin to move back away from the direction of the stream flow, and so causes the stream channel to lengthen.

h) **Braiding:** the main water channel splitting into multiple, narrower channel. A braided river, or braided channel, consists of a network of river channels separated by small, and often temporary, islands called braid bars. Braided streams occur in rivers with low slope and/or large sediment load.

➢ River Valley Formation:

- The extended depression on the ground through which a stream flows is called a river valley.
- At different stages of the erosional cycle, the valley acquires different profiles.
- At a young stage, the valley is deep, narrow with steep wall-like sides and a convex slope.
- The erosional action here is characterized by predominantly **vertical downcutting** nature.
- The profile of valley here is typically 'V' shaped.
- A deep and narrow 'V' shaped valley is also referred to as **gorge** and may result due to downcutting erosion or because of the recession of a waterfall (the position of the waterfall receding due to erosive action).

- Most Himalayan rivers pass through deep gorges (at times more than 500 metres deep) before they descend to the plains.
- An extended form of the gorge is called a **canyon.** The Grand Canyon of the Colorado River in Arizona (USA) runs for 483 km and has a depth of 2.88 km.
- A tributary valley lies above the main valley and is separated from it by a steep slope down which the stream may flow as a waterfall or a series of rapids.
- As the cycle attains maturity, the **lateral erosion** (erosion of the walls of a stream) becomes prominent and the valley floor flattens out (attains a 'V' to 'U' shape).
- The valley profile now becomes typically 'U' shaped with a broad base and a concave slope.

➢ **River course:**

1. **Youth**

- Young rivers (A) close to their source tend to be fast-flowing, high-energy environments with rapid headward erosion, despite the hardness of the rock over which they may flow.
- Steep-sided "V-shaped' valleys, waterfalls, and rapids are characteristic features.
- E.g. Rivers flowing in the Himalayas.

2. **Maturity**

- Mature rivers (B) are lower-energy systems.
- Erosion takes place on the outside of bends, creating looping meanders in the soft alluvium of the river plain.
- Deposition occurs on the inside of bends and on the river bed.
- E.g. Rivers flowing in the Indo-Gangetic-Brahmaputra plain.

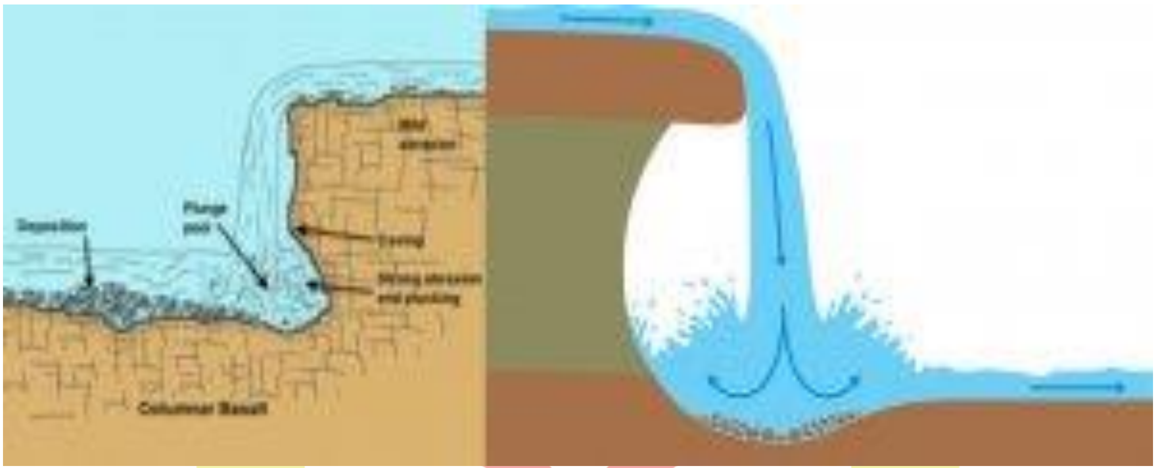
3. **Old Age**

- At a river's mouth (C), sediment is deposited as the velocity of the river slows.
- As the river becomes shallower more deposition occurs, forming temporary islands (Majuli, a river island in the Brahmaputra River, Assam is currently the world's largest river island) and braiding (e.g. braided channels of Brahmaputra river flood plain in Assam) the main channel into multiple, narrower channels.
- As the sediment is laid down, the actual mouth of the river moves away from the source into the sea or lake, forming a delta.

- E.g. Ganga-Brahmaputra delta.

a) <u>Waterfalls</u>

- A waterfall is simply the fall of an enormous volume of water from a great height.
- They are **mostly seen in** the **youth stage** of the river.
- Relative resistance of rocks, the relative difference in topographic reliefs, fall in the sea level and related rejuvenation, earth movements etc. are responsible for the formation of waterfalls.



- Jog or Gersoppa falls (253 m) on Sharavati river (a tributary of Cauvery), Karnataka is the second-highest plunge waterfall in India.
- Angel Falls in Venezuela is the world's highest waterfall, with a height of 979 metres and a plunge of 807 metres.

b) <u>Potholes</u>

- The small cylindrical depressions in the rocky beds of the river valleys are called potholes.
- Potholing or pothole-drilling is the mechanism through which the fragments of rocks when caught in the water eddies or swirling water start dancing circularly and grind and drill the rock beds.
- They thus form small holes which are gradually enlarged by the repetition of the said mechanism.

c) <u>Terraces</u>

- Stepped benches along the river course in a flood plain are called terraces.
- Terraces represent the level of former valley floors and remnants of former (older) floodplains.

d) <u>Gulleys/Rills</u>

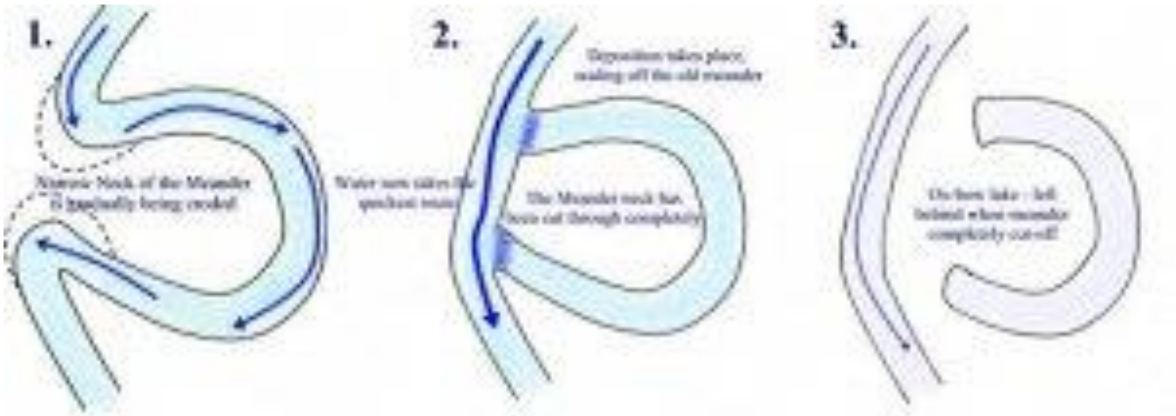
- Gulley is a water-worn channel, which is particularly common in semi-arid areas.
- It is formed when water from overland-flows down a slope, especially following heavy rainfall, is concentrated into rills, which merge and enlarge into a gulley.
- The ravines of Chambal Valley in Central India and the Chos of Hoshiarpur in Punjab are examples of gulleys.

e) <u>Meanders</u>

- A meander is defined as a pronounced curve or loop in the course of a river channel.
- The outer bend of the loop in a meander is characterized by intensive erosion and vertical cliffs and is called the **cliff-slope side**. This side has a concave slope.
- The inner side of the loop is characterized by deposition, a gentle convex slope, and is called the **slip-off side.**
- The meanders may be wavy, horse-shoe type or oxbow type.

f) Oxbow Lake

- Sometimes, because of intensive erosion action, the outer curve of a meander gets accentuated to such an extent that the inner ends of the loop come close enough to get disconnected from the main channel and exist as independent water bodies called as oxbow lakes.
- These water bodies are converted into swamps in due course of time.
- In the Indo-Gangetic plains, southwards shifting of Ganga has left many oxbow lakes to the north of the present course of the Ganga.



g) Peneplane (Or peneplain)

- This refers to an undulating featureless plain punctuated with low-lying residual hills of resistant rocks. It is considered to be an end product of an erosional cycle.
- Fluvial erosion, in the course of geologic time, reduces the land almost to base level (sea level), leaving so little gradient that essentially no more erosion could occur.

h) Drainage Basin

- Other terms that are used to describe drainage basins are catchment, catchment area, catchment basin, drainage area, river basin, and water basin.
- The drainage basin includes both the streams and rivers and the land surface.
- The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channelling it to a single point.

i) Drainage Divide

- Adjacent drainage basins are separated from one another by a drainage divide.

- Drainage divide is usually a ridge or a high platform.
- Drainage divide is conspicuous in case of youthful topography (Himalayas), and it is not well marked in plains and senile topography (old featureless landforms — rolling plateaus of Peninsular region).

➢ **Some important drainage basins across the world**

Basin	**Continent**	**Drains to**	**BasinArea km²**
Amazon River	South America	Atlantic Ocean	6,144,727
Hudson Bay	North America	Atlantic Ocean	3,861,400
Congo River	Africa	Atlantic Ocean	3,730,474
Caspian Sea	Asia/Europe	Endorheic basin	3,626,000
Nile River	Africa	Mediterranean Sea	3,254,555
Mississippi-Missouri River	North America	Gulf of Mexico	3,202,230
Lake Chad	Africa	Endorheic basin	2,497,918
Black Sea	Multiple	Mediterranean Sea	2,400,000
Niger River	Africa	Atlantic Ocean	2,261,763
Yangtze River (Chang Jiang)	Asia	Pacific Ocean	1,722,155
Baltic Sea	Europe	Atlantic Ocean	1,700,000
Ganges–Brahmaputra	Asia	Bay of Bengal	1,621,000
Indus River	Asia	Arabian Sea	1,081,733

➢ Glacial Landforms and Cycle of Erosion

a) A glacier is a moving mass of ice at speeds averaging few meters a day.
b) Types of Glaciers: continental glaciers, ice caps, piedmont glaciers and valley glaciers**.**
c) The continental glaciers are found in the Antarctica and in Greenland. The biggest continental ice sheet in
d) Ice caps are the covers of snow and ice on mountains from which the valley or mountain glaciers originate.
e) The piedmont glaciers form a continuous ice sheet at the base of mountains as in southern Alaska.
f) The valley glaciers, also known as Alpine glaciers, are found in higher regions of the Himalayas in our country and all such high mountain ranges of the world.
g) A glacier is charged with rock debris which are used for erosional activity by moving ice.
h) A glacier during its lifetime creates various landforms which may be classified into erosional and depositional landforms.

➢ Glacial Erosional Landforms

1. Cirque/Corrie

a) Hollow basin cut into a mountain ridge.
b) It has steep sided slope on three sides, an open end on one side and a flat bottom.
c) When the ice melts, the cirque may develop into a tarn lake.

2. Glacial Trough

a) Original stream-cut valley, further modified by glacial action.
b) It is a 'U' Shaped Valley. It at mature stage of valley formation.
c) Since glacial mass is heavy and slow moving, erosional activity is uniform – horizontally as well as vertically.
d) A steep sided and flat bottomed valley results, which has a 'U' shaped profile.

3. Hanging Valley

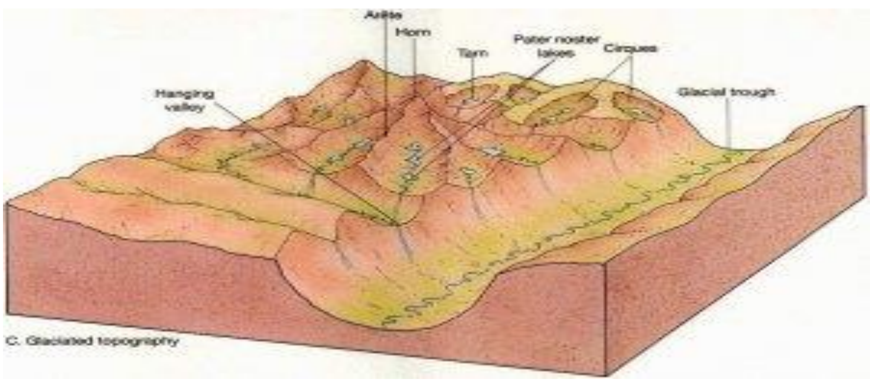
a) Formed when smaller tributaries are unable to cut as deeply as bigger ones and remain ‘hanging’ at higher levels than the main valley as discordant tributaries**.**
b) A valley carved out by a small tributary glacier that joins with a valley carved out by a much larger glacier.

4. Arete

a) Steep-sided, sharp-tipped summit with the glacial activity cutting into it from **two**

5. Horn

a) Ridge that acquires a ‘horn’ shape when the glacial activity cuts it from **more than two sides.**



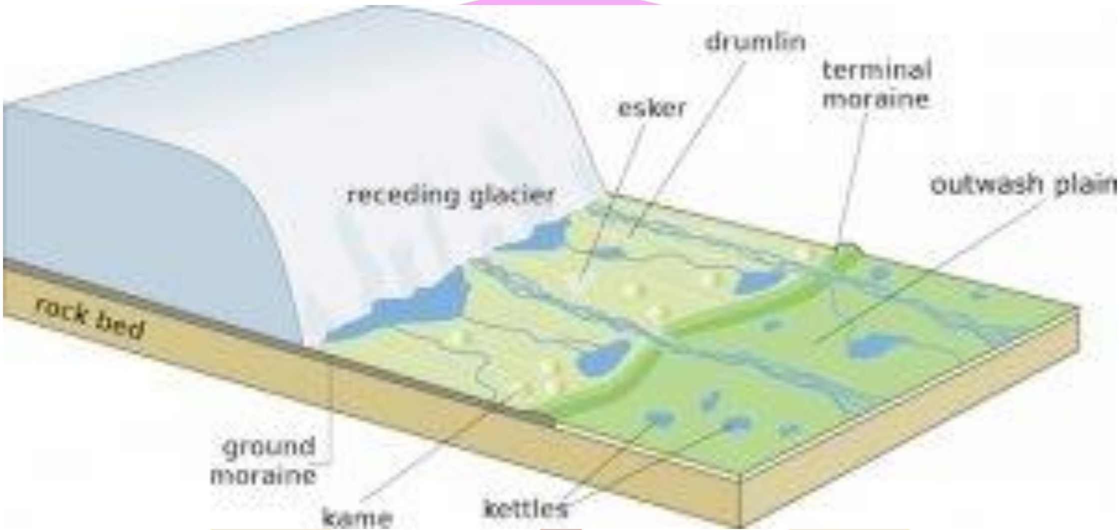
6. Fjord

a) Steep-sided narrow entrance-like feature at the coast where the stream meets the coast.
b) Fjords are common in **Norway, Greenland and New Zealand**.

➢ **Glacial Depositional Landforms**

1. Outwash Plain

- When the glacier reaches its lowest point and melts, it leaves behind a stratified deposition material, consisting of rock debris, clay, sand, gravel etc. This layered surface is called till plain or an outwash plain.



2. Esker

- Winding ridge of un-assorted depositions of rock, gravel, clay etc. running along a glacier in a till plain.
- The eskers resemble the features of an embankment and are often used for making roads.

3. Kame Terraces

- Broken ridges or un-assorted depositions looking like hump in a till plain.

4. Drumlin

- Inverted boat-shaped deposition in a till plain caused by deposition.

5. Kettle Holes

- Formed when the deposited material in a till plain gets depressed locally and forms a basin.

7. Moraine

- General term applied to rock fragments, gravel, sand, etc. carried by a glacier.
- Depending on its position, the moraine can be ground moraine and end moraine.

➢ **Glacial Cycle of Erosion**

1. Youth

- The stage is marked by the inward cutting activity of ice in a cirque.
- Aretes and horns are emerging. The hanging valleys are not prominent at this stage.

2. Maturity

- Hanging valleys start emerging. The opposite cirques come closer and the glacial trough acquires a stepped profile which is regular and graded.

3. Old Age

- Emergence of a 'U'-shaped valley marks the beginning of old age.
- An outwash plain with features such as eskers, kame terraces, drumlins, kettle holes etc. is a prominent development.
- At low latitudes, the atmosphere is warm and the snowline is high. Around the equator, the snowline is about 5,500m at its highest so mountains get up to 7,000m.
- There are a few exceptions [that are higher], such as Everest, but extremely few.
- When you then go to Canada or Chile, the snowline altitude is around 1,000m, so the mountains are around 2.5km.

➢ **Marine Landforms and Cycle of Erosion**

- Sea waves, aided by winds, currents, tides and storms carry on the erosional and depositional processes.

- The erosive work of the sea depends upon size and strength of waves, slope, height of the shore between low and high tides, shape of the coast, composition of rocks, depth of water, human activity etc.
- The wave pressure compresses the air trapped inside rock fissures, joints, faults, etc. forcing it to expand and rupture the rocks along weak points. This is how rocks undergo weathering under wave action.
- Waves also use rock debris as instruments of erosion (glaciers are quite good at this). These rock fragments carried by waves themselves get worn down by striking against the coast or against one another.
- The solvent or chemical action of waves is another mode of erosion, but it is pronounced only in case of soluble rocks like limestone and chalk.

➢ **Marine Erosional Landforms**

1) Chasms

- These are narrow, deep indentations (a deep recess or notch on the edge or surface of something) carved due to headward erosion (downcutting) through vertical planes of weakness in the rocks by wave action.
- With time, further headward erosion is hindered by lateral erosion of chasm mouth, which itself keeps widening till a bay is formed.

2) Wave-Cut Platform

- When the sea waves strike against a cliff, the cliff gets eroded (lateral erosion) gradually and retreats.
- The waves level out the shore region to carve out a horizontal plane or a wave-cut platform.
- The bottom of the cliff suffers the maximum intensive erosion by waves and, as a result, a notch appears at this position.

3) Sea Cliff

- Shoreline marked by a steep bank (escarpment, scarp)

.

4) Sea Caves

- Differential erosion by sea waves through a rock with varying resistance across its structure produces arched caves in rocks called sea caves.

5) Sea Arches

- When waves from opposite directions strike a narrow wall of rock, differential erosion of the rock leaves a bridge like structure called Sea arch.

6) Stacks/Skarries/Chimney Rock

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

7) Hanging Valleys

- If the fluvial erosion of a stream at the shore doesn't match the retreat of the sea, the rivers appear to be hanging over the sea. These river valleys are called hanging valleys.

8) Blow Holes or Spouting Horns

- The burst of water through a small hole on a sea cave due to the compression of air in the cave by strong waves. They make a peculiar noise.

9) Plane of Marine Erosion/Peneplain

- The eroded plain left behind by marine action is called a plain of marine erosion. If the level difference between this plain and the sea level is not much, the agents of weathering convert it into a peneplain.

- **Marine Cycle of Erosion**

1. Youth

- The waves are very active.
- Sea caves, arches and stalks begin to develop.
- Cliff undercutting is pronounced and wavecut platform begins to emerge due to wave erosion.
- By the end of youth, an irregular coastline remains.

2. Maturity

- The cliff and wave-cut platform are conspicuous.
- Stream deposition is taking place. These valleys may be normal or of the hanging type.
- Various landforms indicating continuous deposition are visible, such as bars, barriers and spits.

3. Old Age

- Irregularities, such as caves and arches disappear.

➢ Coastlines

- The boundary between the coast (the part of the land adjoining or near the sea) and the shore (the land along the edge of a sea) is known as the coastline.
- Coastlines can be divided into the following classes:

a) Coastline of Emergence
b) Coastline of Submergence
c) Neutral coastline
d) Compound coastline
e) Fault coastline

- Coastline are modified either due to rise or fall in sea levels or upliftment or subsidence of land, or both.

1. Coastlines of Emergence

a. These are formed either by an uplift of the land or by the lowering of the sea level.
b. Bars, spits, lagoons, salt marshes, beaches, sea cliffs and arches are the typical features.

c. The east coast of India, especially its south-eastern part (Tamil Nadu coast), appears to be a coast of emergence.
d. The west coast of India, on the other hand, is both emergent and submergent.
e. Coramandal coast == Tamil Nadu Coast == Coastline of emergence
f. Malabar coast == Kerala Coast == Coastline of emergence
g. Konkan coast == Maharashtra and Goa Coast == Coastline of submergence.

2. Coastlines of Submergence

- A submerged coast is produced either by subsidence of land or by a rise in sea level.
- Ria, fjord, Dalmatian and drowned lowlands are its typical features.

a. Ria

- When a region is dissected by streams into a system of valleys and divides, submergence produces a highly irregular shoreline called ria coastline.
- The coast of south-west Ireland is a typical example of ria coastline.

b. Fjord

- Some coastal regions have been heavily eroded by glacial action and the valley glacier troughs have been excavated below sea level.
- After the glaciers have disappeared, a fjord coastline emerges.
- These coasts have long and narrow inlets with very steep sides.
- The fjord coasts of Norway are a typical example.

c. Dalmatian

- The Dalmatian coasts result by submergence of mountain ridges with alternating crests and troughs which run parallel to the sea coast.
- The Dalmatian coast of Yugoslavia is a typical example.

d. Drowned lowland

- A drowned lowland coast is low and free from indentations, as it is formed by the submergence of a low-lying area.
- It is characterized by a series of bars running parallel to the coast, enclosing lagoons.
- The Baltic coast of eastern Germany is an example of this type of coastline.

Neutral Coastlines

- These are coastlines formed as a result of new materials being built out into the water.
- The word 'neutral' implies that there need be no relative change between the level of sea and the coastal region of the continent.
- Neutral coastlines include the alluvial fan shaped coastline, delta coastline, volcano coastline and the coral reef coastline.

Compound Coastlines

- Such coastlines show the forms of two of the previous classes combined, for example, submergence followed by emergence or vice versa.
- The coastlines of Norway and Sweden are examples of compound coastlines.

Fault Coastlines

- Such coastlines are unusual features and result from the submergence of a downthrown block along a fault, such that the uplifted block has its steep side (or the faultline) standing against the sea forming a fault coastline

➢ **Arid Landforms and Cycle of Erosion**

- Arid regions are regions with scanty rainfall. Deserts and Semi-arid regions fall under arid landforms.

1. Erosional Arid Landforms

a) Rill

- In hill slope geomorphology, a rill is a narrow and shallow channel cut into soil by the erosive action of flowing water.

b) Gully

- A gully is a landform created by running water. Gullies resemble large ditches or small valleys, but are metres to tens of metres in depth and width.

c) Ravine

- A ravine is a landform narrower than a canyon and is often the product of stream cutting erosion. Ravines are typically classified as larger in scale than gullies, although smaller than valleys.

d) Badland Topography

- In arid regions occasional rainstorms produce numerous rills and channels which extensively erode weak sedimentary formations.
- Ravines and gullies are developed by linear fluvial erosion leading to the formation of badland topography.
- Example: **Chambal Ravines.**

e) Bolsons

- The intermontane basins in dry regions are generally known as bolsons.
- Playas
- Three unique landforms viz. pediments, bajadas and playas are typically found in bolsons.
- Small streams flow into bolsons, where water is accumulated. These temporary lakes are called playas.
- After the evaporation of water, salt-covered playas are called salinas.

f) Pediments

- In form and function there is no difference between a pediment and an alluvial fan; however, pediment is an erosional landform while a fan is a constructional one.
- A true pediment is a rock cut surface at the foot of mountains.

g) Bajada

- Bajadas are moderately sloping depositional plains located between pediments and playa.
- Several alluvial fans coalesce to form a bajada.

➢ Wind Eroded Arid Landforms

- The wind or **Aeolian erosion** takes place in the following ways, viz. deflation, abrasion, and attrition.
- Deflation- removing, lifting and carrying away dry, unsorted dust particles by winds. It causes depressions known as blow outs.
- Abrasion- When wind loaded with sand grains erodes the rock by grinding against its walls is called abrasion or sandblasting.
- Attrition- Attrition refers to wear and tear of the sand particles while they are being transported.

Following are the major landforms produced by wind erosion.

a) Deflation basins

- Deflation basins, called blowouts, are hollows formed by the removal of particles by wind. Blowouts are generally small, but may be up to several kilometers in diameter.

b) Mushroom rocks

- A mushroom rock, also called rock pedestal or a pedestal rock, is a naturally occurring rock whose shape, as its name implies, resembles a mushroom.
- The rocks are deformed in a number of different ways: by erosion and weathering, glacial action, or from a sudden disturbance. Mushroom rocks are related to, but different from, yardang.

c) Inselbergs

- A monadnock or inselberg is an isolated hill, knob, ridge, outcrop, or small mountain that rises abruptly from a gently sloping or virtually level surrounding plain.

d) Demoiselles

- These are rock pillars which stand as resistant rocks above soft rocks as a result of differential erosion of hard and soft rocks.

e) Zeugen

- A table-shaped area of rock found in arid and semi-arid areas formed when more resistant rock is reduced at a slower rate than softer rocks around it.

f) Yardangs

- Ridge of rock, formed by the action of the wind, usually parallel to the prevailing wind direction.

g) Wind bridges and windows

- Powerful wind continuously abrades stone lattices, creating holes. Sometimes the holes are gradually widened to reach the other end of the rocks to create the effect of a window—thus forming a wind window. Window bridges, are formed when the holes are further widened to form an arch-like feature.

➢ Arid Depositional Landforms

- Landforms are also created by the depositional force of wind. These are as follows.

a) Ripple Marks

- These are depositional features on a small scale formed by saltation (he transport of hard particles over an uneven surface in a turbulent flow of air or water).

b) Sand dunes

- Sand dunes are heaps or mounds of sand found in deserts. Generally their heights vary from a few metres to 20 metres but in some cases dunes are several hundred metres high and 5 to 6 km long.

Some of the forms are discussed below:

1) Longitudinal dunes

- Formed parallel to the wind movement. The windward slope of the dune is gentle whereas the leeward side is steep. These dunes are commonly found at the heart of trade-wind deserts like the Sahara, Australian, Libyan, South African and Thar deserts.

2) Transverse dunes

- Dunes deposited perpendicular (transverse) to the prevailing wind direction.

3) Barchans

- Crescent shaped dunes. The windward side is convex whereas the leeward side is concave and steep.

4) Parabolic dunes

- They are U-shaped and are much longer and narrower than barchans.

5) <u>Star dunes</u>

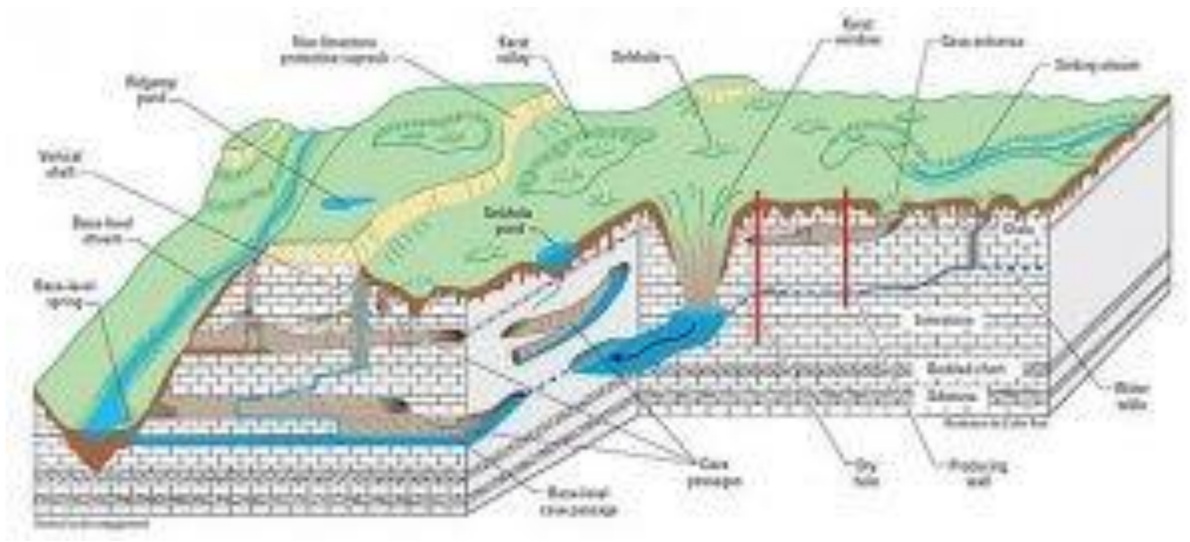
- Have a high central peak, radically extending three or more arms.

6) <u>Loess</u>

- In some parts of the world, windblown dust and silt blanket the land. This layer of fine, **mineral-rich** material is called loess.
- Extensive loess deposits are found in northern China, the Great Plains of North America, central Europe, and parts of Russia and Kazakhstan**.**
- Loess accumulates, or builds up, at the edges of deserts. For example, as wind blows across the Gobi, a desert in Asia, it picks up and carries fine particles. These particles include sand crystals made of quartz or mica. It may also contain organic material, such as the dusty remains of skeletons from desert animals.
- Loess often develops into **extremely fertile agricultural soil**. It is full of minerals and drains water very well. It is easily tilled, or broken up, for planting seeds.
- Loess usually erodes very slowly – Chinese farmers have been working the loess around the Yellow River for more than a thousand years.

- **<u>Karst Landforms and Cycle of Erosion</u>**

- Karst is a landscape which is underlain by limestone which has been eroded by dissolution, producing towers, fissures, sinkholes, etc.
- It is so named after a province of Yugoslavia on the Adriatic Sea coast where such formations are most noticeable.
- Karst topography is a landscape formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum.
- It is characterized by underground drainage systems with sinkholes, caves etc.



Conditions Essential for Full Development of Karst Topography

- Presence of soluble rocks, preferably limestone at the surface or sub-surface level.
- These rocks should be dense, highly jointed and thinly bedded.

a) Cavern

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

b) Arch/Natural Bridge

- When a part of the cavern collapses the portion which keeps standing forms an arch.

c) Sink Hole/Swallow Hole

- Sink holes are funnel-shaped depressions having an average depth of three to nine metres.
- These holes are developed by enlargement of the cracks found in such rocks, as a result of continuous solvent action of the rainwater.
- The surface streams which sink disappear underground through swallow holes.

d) Karst Window

- When a number of adjoining sink holes collapse, they form an open, broad area called a karst window.

e) Sinking Creeks/Bogas

- In a valley, the water often gets lost through cracks and fissures in the bed. These are called sinking creeks, and if their tops are open, they are called bogas.

f) Doline

- Few sinkholes combine to form a larger depression called Doline. Sometimes clay gets settled on the bottom of Doline stopping water to seep through it. When water gets accumulated in the doline, it is known as a Doline Lake.

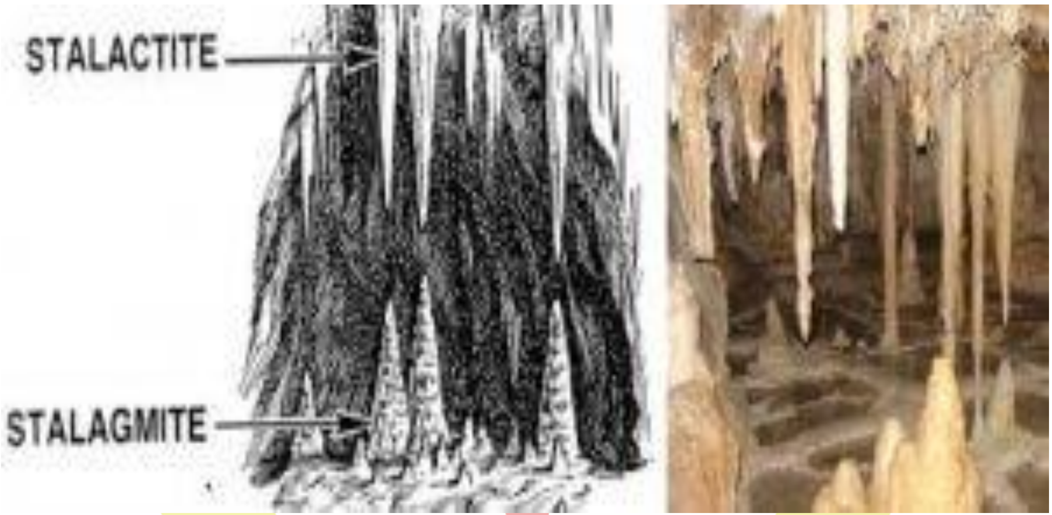
g) Uvala
- Several Dolines combine to form an Uvala.

h) Polje

- When an underground cave collapsed, over the surface a large depression is formed. It is called Polje.

i) Stalactite and Stalagmite

- The water containing limestone in solution, seeps through the roof in the form of a continuous chain of drops.
- A portion of the roof hangs on the roof and on evaporation of water, a small deposit of limestone is left behind contributing to the formation of a stalactite, growing downwards from the roof.
- The remaining portion of the drop falls to the floor. This also evaporates, leaving behind a small deposit of limestone aiding the formation of a stalagmite, thicker and flatter, rising upwards from the floor.
- Sometimes, stalactite and stalagmite join together to form a complete pillar known as the column.



OCEANOGRAPHY

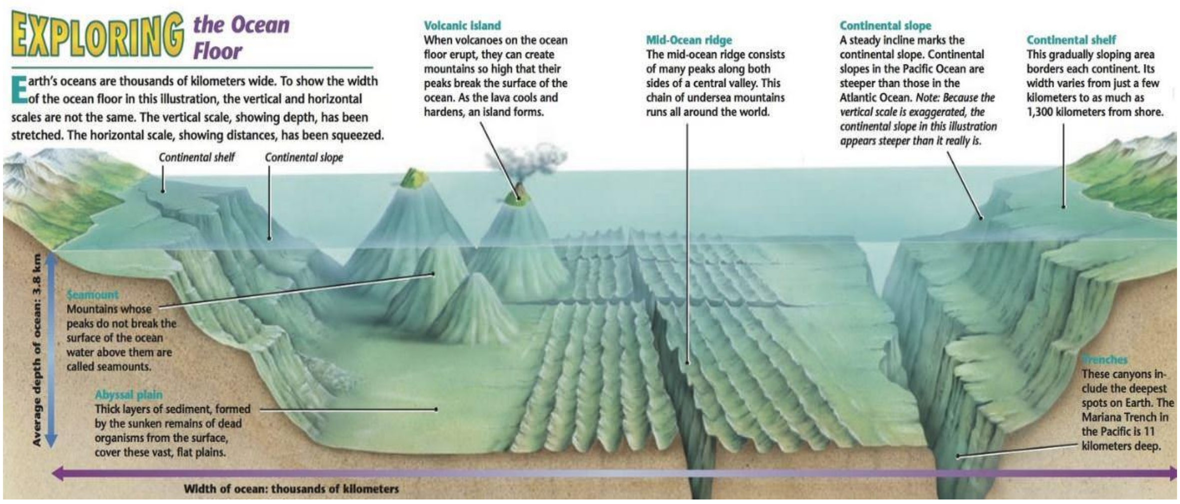
Ocean Relief

- Ocean relief is largely due to **tectonic, volcanic, erosional and depositional processes and their interactions.**

Major Ocean Relief Features

Four major divisions in the ocean relief are:

1. **the continental shelf,**
2. **the continental slope,**
3. **the continental rise,**
4. **the Deep Sea Plain or the abyssal plain.**



Continental Shelf

- Continental Shelf is the **gently sloping** seaward extension of continental plate.
- These extended margins of each continent are occupied by relatively **shallow seas and gulfs.**

- Continental Shelf of all oceans together cover **7.5%** of the total area of the oceans.
- Gradient of continental is of **1° or even less.**
- The shelf typically ends at a very steep slope, called the **shelf break.**
- The continental shelves are covered with variable thicknesses of sediments brought down by **rivers, glaciers** etc.
- Massive sedimentary deposits received over a long time by the continental shelves, become the source of fossil fuels [Petroleum].

- The shelf is formed mainly due to
  1) submergence of a part of a continent
  2) relative rise in sea level
  3) Sedimentary deposits brought down by rivers

- There are various types of shelves based on different sediments of terrestrial origin -

Width

- The average width of continental shelves is between **70 – 80 km.**
- The shelves are almost absent or very narrow along some of the margins like the coasts of Chile, the west coast of Sumatra, etc. [Ocean – Continent Convergence and Ocean – Ocean Convergence].

Depth

- The depth of the shelves also varies. It may be as shallow as 30 m in some areas while in some areas it is as deep as 600 m.

Continental Slope

- The continental slope connects the continental shelf and the ocean basins.
- It begins where the bottom of the continental shelf sharply drops off into a steep slope.
- The gradient of the slope region varies between **2-5°.**
- The depth of the slope region varies between 200 and 3,000 m.
- The seaward edge of the continental slope loses gradient at this depth and gives rise to **continental rise.**
- The continental slope boundary indicates the end of the continents.
- Canyons and trenches are observed in this region.

Continental Rise

- The continental slope **gradually** loses its steepness with depth.
- When the slope reaches a level of between **0.5° and 1°**, it is referred to as the continental rise.
- With increasing depth, the rise becomes virtually flat and merges with the **abyssal plain.**

Deep Sea Plain or Abyssal Plain

- Deep sea planes are gently sloping areas of the ocean basins.
- These are the **flattest** and smoothest regions of the world because of **terrigenous [**denoting marine sediment eroded from the land**] and shallow water sediments** that buries the irregular topography.
- It covers nearly **40%** of the ocean floor.
- The depths vary between 3,000 and 6,000 m.
- These plains are covered with fine-grained sediments like clay and silt.

Oceanic Deeps or Trenches

- The trenches are relatively steep sided, narrow basins (Depressions). These areas are the deepest parts of the oceans.
- They are of tectonic origin and are formed during ocean – ocean convergence and ocean continent convergence.
- They are some 3-5 km deeper than the surrounding ocean floor.
- The trenches lie **along the fringes of the deep-sea plain** at the bases of continental slopes and along island arcs.

- The trenches run parallel to the bordering fold mountains or the island chains.
- The trenches are very common in the Pacific Ocean and form an almost continuous ring along the western and eastern margins of the Pacific.
- The Mariana Trench off the Guam Islands in the Pacific Ocean is the deepest trench with, a depth of more than 11 kilometres.

Mid-Oceanic Ridges or Submarine Ridges

- A mid-oceanic ridge is composed of two chains of mountains separated by a large depression. [Divergent Boundary]
- The mountain ranges can have peaks as high as 2,500 m and some even reach above the ocean's surface.
- These ridges are either broad, like a plateau, gently sloping or in the form of steep-sided narrow mountains.

Temperature Distribution of Oceans

1. The study of the temperature of the oceans is important for determining the movement of large volumes of water (vertical and horizontal ocean currents), type and distribution of marine organisms at various depths of oceans, climate of coastal lands, etc.

The ocean water is heated by three processes.

1. Absorption of sun's radiation.
2. **The conventional currents:** Since the temperature of the earth increases with increasing depth, the ocean water at great depths is heated faster than the upper water layers. So, convectional oceanic circulations develop causing circulation of heat in water.
3. Heat is produced due to friction caused by the surface wind and the tidal currents which increase stress on the water body.

Factors Affecting Temperature Distribution of Oceans

- **Insolation:** The average daily duration of insolation and its intensity.
- **Heat loss:** The loss of energy by reflection, scattering, evaporation and radiation.
- **Albedo:** The albedo of the sea (depending on the angle of sun rays).

- **The physical characteristics of the sea surface:** Boiling point of the sea water is increased in the case of higher salinity and vice versa [Salinity increased == Boiling point increased == Evaporation decreased].
- The presence of submarine ridges and sills [Marginal Seas]: Temperature is affected due to lesser mixing of waters on the opposite sides of the ridges or sills.
- **The shape of the ocean:** The latitudinally extensive seas in low latitude regions have warmer surface water than longitudinally extensive sea [Mediterranean Sea records higher temperature than the longitudinally extensive Gulf of California].
- **The enclosed seas** (Marginal Seas – Gulf, Bay etc.) in the low latitudes record relatively higher temperature than the open seas; whereas the enclosed seas in the high latitudes have lower temperature than the open seas.
- Local weather conditions such as cyclones.
- **Unequal distribution of land and water:** The oceans in the northern hemisphere receive more heat due to their contact with larger extent of land than the oceans in the southern hemisphere.
- **Prevalent winds** generate horizontal and sometimes vertical ocean currents: The winds blowing from the land towards the oceans (off-shore winds-moving away from the shore) drive warm surface water away from the coast resulting in the upwelling of cold water from below (This happens near Peruvian Coast in normal years. El-Nino).
- Contrary to this, the onshore winds (winds flowing from oceans into continents) pile up warm water near the coast and this raises the temperature (This happens near the Peruvian coast during El Nino event)(In normal years, North-eastern Australia and Western Indonesian islands see this kind of warm ocean waters due to Walker Cell or Walker Circulation).
- **Ocean currents:** Warm ocean currents raise the temperature in cold areas while the cold currents decrease the temperature in warm ocean areas. **Gulf stream (warm current)** raises the temperature near the eastern coast of North America and the West Coast of Europe while the **Labrador current (cold current)** lowers the temperature near the north-east coast of North America (Near Newfoundland). All these factors influence the temperature of the ocean currents locally.

Vertical Temperature Distribution of Oceans

General behavior

- In the Arctic and Antarctic circles, the surface water temperatures are close to 0° C and so the temperature change with the depth is **very slight** (**ice is a very bad conductor of heat**). Here, **only one layer of cold water exists**, which extends from surface to deep ocean floor.
- The rate of decrease of temperature with depths is greater at the equator than at the poles.
- The surface temperature and its downward decrease is influenced by the upwelling of bottom water (Near Peruvian coast during normal years).
- In cold Arctic and Antarctic regions, sinking of cold water and its movement towards lower latitudes is observed.
- In equatorial regions the surface, water sometimes exhibits **lower temperature and salinity** due to high rainfall, whereas the layers below it have higher temperatures.
- The enclosed seas in both the lower and higher latitudes record **higher temperatures at the bottom.**
- The enclosed seas of low latitudes like the **Sargasso Sea**, the **Red Sea** and the **Mediterranean Sea** have high bottom temperatures due to high insolation throughout the year and lesser mixing of the warm and cold' waters.
- In the case of the high latitude enclosed seas, the bottom layers of water are warmer as water of slightly higher salinity and temperature moves from outer ocean as a sub-surface current.
- The presence of submarine barriers may lead to different temperature conditions on the two sides of the barrier. For example, at the Strait of Bab-el-Mandeb, the submarine barrier (sill) has a height of about 366 m. The subsurface water in the strait is at high temperature compared to water at same level in Indian ocean. The temperature difference is greater than nearly 20° C.

Horizontal Temperature Distribution of Oceans

- The average temperature of surface water of the oceans is about 27°C and it gradually decreases from the equator towards the poles.
- The rate of decrease of temperature with increasing latitude is generally 0.5°C per latitude.
- The horizontal temperature distribution is shown by **isothermal lines**, i.e., lines joining places of equal temperature.
- Isotherms are closely spaced when the temperature difference is high and vice versa.
- For example, in February, isothermal lines are closely spaced in the south of Newfoundland, near the west coast of Europe and North Sea and then

isotherms widen out to make; a bulge towards north near the coast of Norway. The cause of this phenomenon lies in the cold Labrador Current flowing southward along the north American coast which reduces the temperature of the region more sharply than in other places in the same latitude; at the same time the warm Gulf Stream proceeds towards the western coast of Europe and raises the temperature of the west coast of Europe.

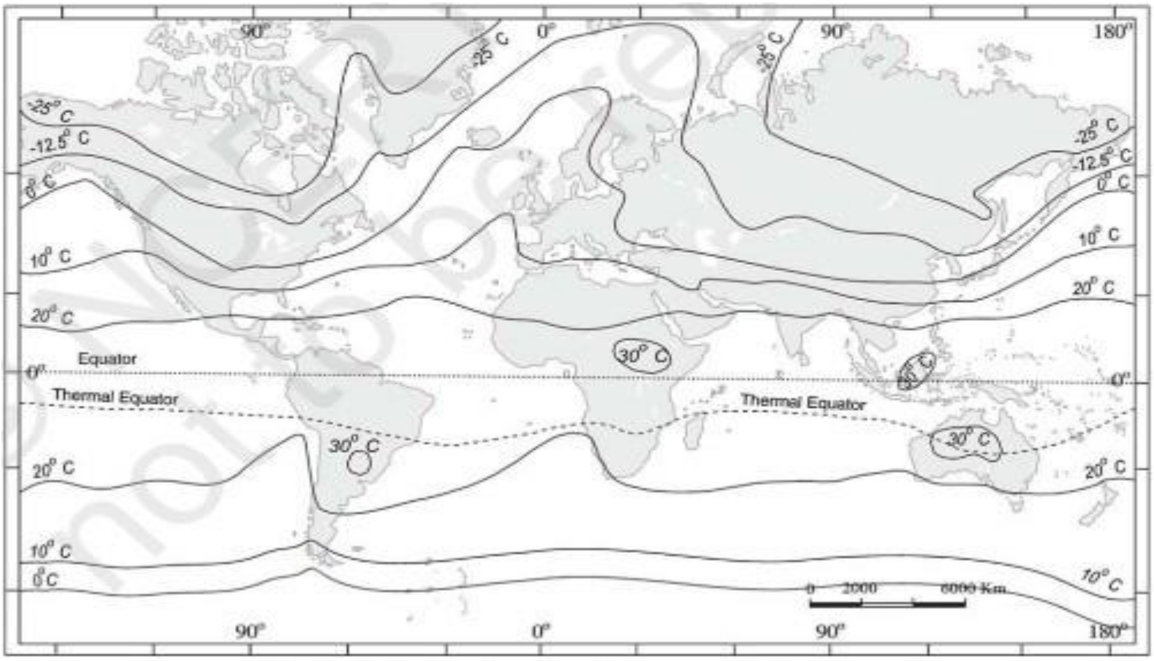


Figure 9.4 (a) : The distribution of surface air temperature in the month of January

Ocean Salinity

- Salinity is the term used to define the total content of dissolved salts in sea water.
- It is calculated as the amount of salt (in gm) dissolved in 1,000 gm (1 kg) of seawater.
- It is usually expressed as parts per thousand or ppt.
- Salinity of **24.7 (24.7 o/oo)** has been considered as the upper limit to demarcate '**brackish water'.**

Role of Ocean Salinity

- Salinity determines compressibility, thermal expansion, temperature, density, absorption of insolation, evaporation and humidity.
- It also influences the composition and movement of the sea: water and the distribution of fish and other marine resources.

Highest salinity in water bodies
Lake Van in Turkey (330 °/$_{oo}$),
Dead Sea (238 °/$_{oo}$),
Great Salt Lake (220 °/$_{oo}$)

Table 13.4 : Dissolved Salts in Sea Water (gm of Salt per kg of Water)

Chlorine	18.97
Sodium	10.47
Sulphate	2.65
Magnesium	1.28
Calcium	0.41
Potassium	0.38
Bicarbonate	0.14
Bromine	0.06
Borate	0.02
Strontium	0.01

Share of different salts is as shown below—

- **sodium chloride — 77.7%**
- **magnesium chloride—10.9%**
- **magnesium sulphate —.4.7%**
- **calcium sulphate — 3.6%**
- **potassium sulphate — 2.5%**

Factors Affecting Ocean Salinity

- The salinity of water in the surface layer of oceans depend mainly on evaporation and precipitation.
- Surface salinity is greatly influenced in coastal regions by the fresh water flow from rivers, and in polar regions by the processes of freezing and thawing of ice.
- Wind, also influences salinity of an area by transferring water to other areas.
- The ocean currents contribute to the salinity variations.
- Salinity, temperature and density of water are interrelated. Hence, any change in the temperature or density influences the salinity of an area.

Horizontal distribution of salinity

To make life easier, I will remove the symbol o/oo and place only number

- The salinity for normal open ocean ranges between **33 and 37**.

High salinity regions

- In the land locked Red Sea (don't confuse this to Dead Sea which has much greater salinity), it is as high as 41.
- In hot and dry regions, where evaporation is high, the salinity sometimes reaches to 70.

Comparatively Low salinity regions

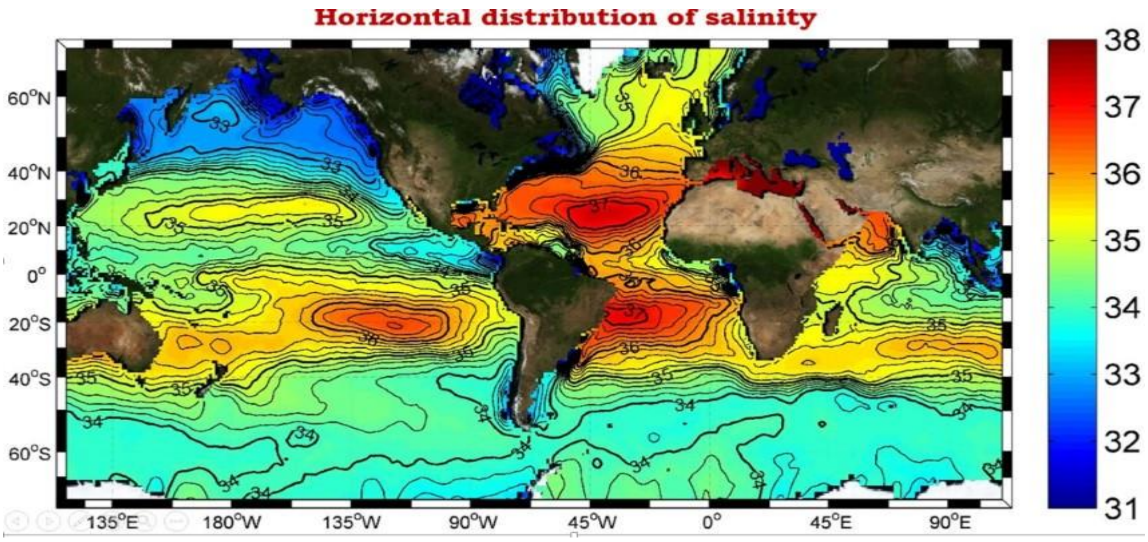
- In the estuaries (enclosed mouth of a river where fresh and saline water get mixed) and the Arctic, the salinity fluctuates from 0 – 35, seasonally (fresh water coming from ice caps).

Pacific

- The salinity variation in the Pacific Ocean is mainly due to its shape and larger areal extent.

Atlantic

- The average salinity of the Atlantic Ocean is around 36-37.
- The equatorial region of the Atlantic Ocean has a salinity of about 35.
- Near the equator, there is heavy rainfall, high relative humidity, cloudiness and calm air of the doldrums.
- The polar areas experience very little evaporation and receive large amounts of fresh water from the melting of ice. This leads to low levels of salinity, ranging between 20 and 32.
- Maximum salinity (37) is observed between 20° N and 30° N and 20° W – 60° W. It gradually decreases towards the north.



Indian Ocean

- The average salinity of the Indian Ocean is 35.
- The low salinity trend is observed in the Bay of Bengal due to influx of river water by the river Ganga.
- On the contrary, the Arabian Sea shows higher salinity due to high evaporation and low influx of fresh water.

Marginal seas

- The North Sea, in spite of its location in higher latitudes, records higher salinity due to more saline water brought by the North Atlantic Drift.
- Baltic Sea records low salinity due to influx of river waters in large quantity.
- The Mediterranean Sea records higher salinity due to high evaporation.
- Salinity is, however, very low in Black Sea due to enormous fresh water influx by rivers.

Inland seas and lakes

- The salinity of the inland Seas and lakes is very high because of the regular supply of salt by ‘the rivers falling into them.
- Their water becomes progressively more saline due to evaporation.
- For instance, the salinity of the Great Salt Lake, (Utah, USA), the Dead Sea and the Lake Van in Turkey is 220, 240 and 330 respectively.
- The oceans and salt lakes are becoming more salty as time goes on because the rivers dump more salt into them, while fresh water is lost due to evaporation.

Cold and warm water mixing zones

- Salinity decreases from 35 – 31 on the western parts of the northern hemisphere because of the influx of melted water from the Arctic region.

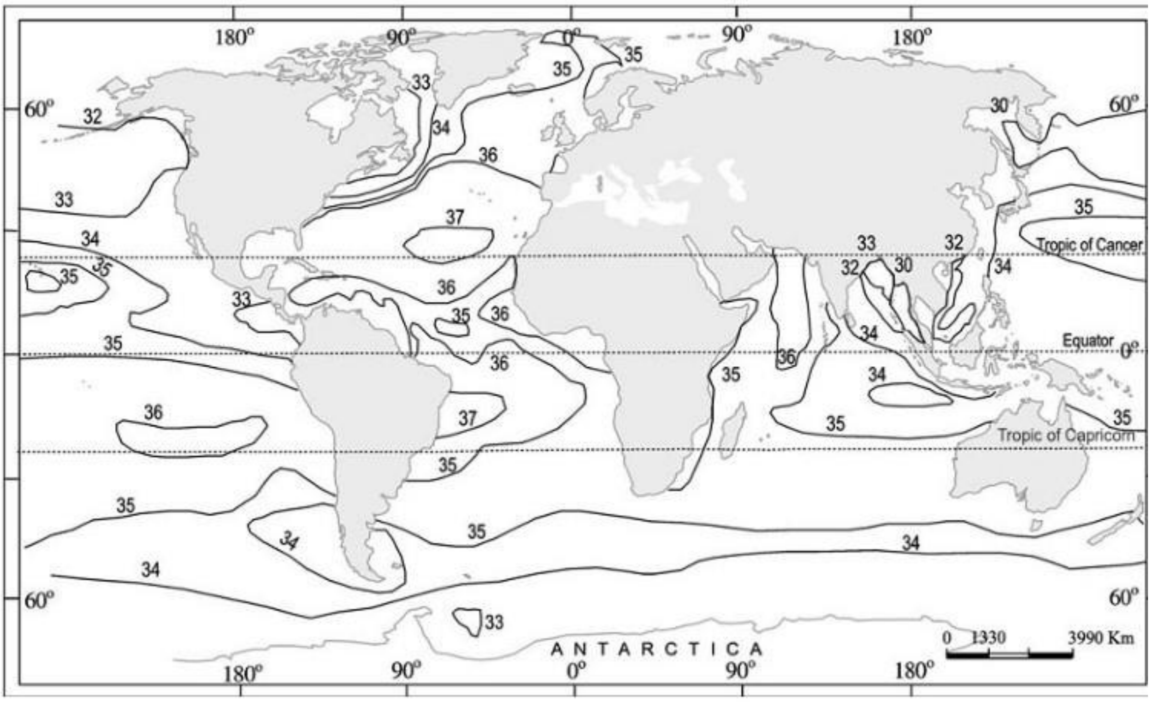


Figure13.5 : Surface salinity of the World's Oceans

Sub-Surface Salinity

- With depth, the salinity also varies, but this variation again is subject to latitudinal difference. The decrease is also influenced by cold and warm currents.
- In high latitudes, salinity increases with depth. In the middle latitudes, it increases up to 35 metres and then it decreases. At the equator, surface salinity is lower.

Vertical Distribution of Salinity

- Salinity changes with depth, but the way it changes depends upon the location of the sea.
- Salinity at the surface increases by the loss of water to ice or evaporation, or decreased by the input of fresh waters, such as from the rivers.
- Salinity at depth is very much fixed, because there is no way that water is 'lost', or the salt is 'added.' There is a marked difference in the salinity between the surface zones and the deep zones of the oceans.

- The lower salinity water rests above the higher salinity dense water.
- Salinity, generally, increases with depth and there is a distinct zone called the **halocline** (compare this with thermocline), where salinity increases sharply.
- Other factors being constant, increasing salinity of seawater causes its density to increase. High salinity seawater, generally, sinks below the lower salinity water. This leads to **stratification by salinity**.

Tides

- The periodical rise and fall of the sea level, once or twice a day, mainly due to the attraction of the sun and the moon, is called a tide.
- Movement of water caused by meteorological effects (winds and atmospheric pressure changes) are called **surges (storm surge during cyclones).**
- The study of tides is very complex, spatially and temporally, as it has great variations in frequency, magnitude and height.
- The **moon's gravitational pull** to a great extent and to a lesser extent the **sun's gravitational pull**, are the major causes for the occurrence of tides.
- Another factor is **centrifugal force** which acts opposite to **gravitational pull** of earth.
- Tides occur due to a balance between all these forces.

Tidal Bulge – Why there are two tidal bulges? – Why is there a tidal bulge on the other side?

- Together, the gravitational pull and the centrifugal force are responsible for creating the two major **tidal bulges** on the earth.
- On the side of the earth facing the moon, a tidal bulge occurs while on the opposite side though the gravitational attraction of the moon is less as it is farther away, the centrifugal force causes tidal bulge on the other side.
- The 'tide-generating' force is the difference between these two forces; i.e. **the gravitational attraction of the moon and the centrifugal force.**
- On the surface of the earth, nearest the moon, pull or the attractive force of the moon is greater than the centrifugal force, and so there is a net force causing a bulge towards the moon.
- On the opposite side of the earth, the attractive force is less, as it is farther away from the moon, the **centrifugal force is dominant**. Hence, there is a net force away from the moon. It creates the **second bulge** away from the moon.

Factors Controlling the Nature and Magnitude of Tides

- The movement of the moon in relation to the earth.
- Changes in position of the sun and moon in relation to the earth.
- Uneven distribution of water over the globe.
- Irregularities in the configuration of the oceans.
- On the surface of the earth, the horizontal tide generating forces are more important than the vertical forces in generating the tidal bulges.
- The tidal bulges on wide continental shelves, have greater height. When tidal bulges hit the mid-oceanic islands they become low.
- The shape of bays and estuaries along a coastline can also magnify the intensity of tides.
- Funnel-shaped bays greatly change tidal magnitudes. When the tide is channeled between islands or into bays and estuaries they are called **tidal currents (tidal bore is one such tidal current).**

Tides of Bay of Fundy, Canada

- The highest tides in the world occur in the Bay of Fundy in Nova Scotia, Canada. The tidal bulge is 15 – 16 m.
- Because there are two high tides and two low tides every day (slightly more than a 24 hour period); then a tide must come in within about a six hour period.

Types of Tides

- Tides vary in their frequency, direction and movement from place to place and also from time to time.
- Tides may be grouped into various types based on their frequency of occurrence in one day or 24 hours or based on their height.

Tides based on Frequency

Semi-diurnal tide

- The most common tidal pattern, featuring two high tides and two low tides each day [Actually it varies between 3 tides to 4 tides — 3 tides in rare cases but 4 is normal]. The successive high or low tides are approximately of the same height.
- Although tides occur twice a day, their interval is not exactly 12 hours. Instead, they occur at regular intervals of *12 hours and 25 minutes*.

- This is because the moon revolves around the earth from west to east, and each day it moves a bit to the east if observed from the same place on earth at the same time on two consecutive days.
- This time lag explains the tide interval of 12 hours and- 25 minutes, as tides occur twice a day.
- A place in England—***Southampton***—experiences tides 6-8 times a day [2 high tides from North Sea + 2 high tides from English Channel + 2 neap tides from North Sea + 2 neap tides from English Channel]. This happens because the North Sea and the English Channel push the water at different intervals.

Diurnal tide

- There is only one high tide and one low tide during each day. The successive high and low tides are approximately of the same height.

Mixed tide

- Tides having variations in height are known as mixed tides. These tides generally occur along the **west coast of North America** and on many islands of the Pacific Ocean.

Tides based on the Sun, Moon and the Earth Positions

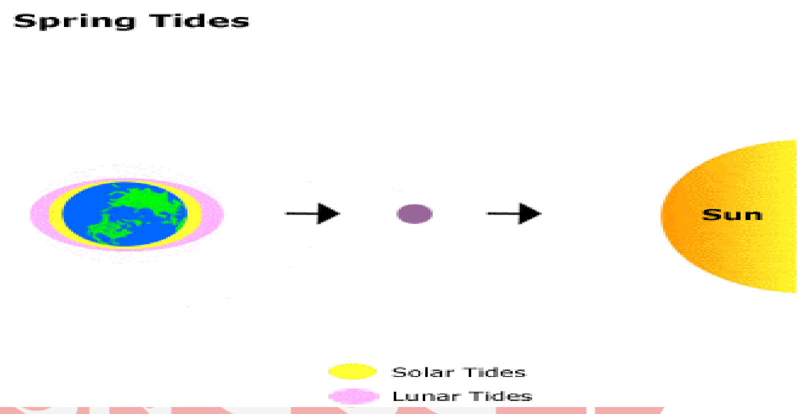
- The height of rising water (high tide) varies appreciably depending upon the position of sun and moon with respect to the earth. **Spring tides** and **neap tides** come under this category.

Spring tides

- The position of both the sun and the moon in relation to the earth has direct bearing on tide height.
- When the sun, the moon and the earth are in a straight line, the height of the tide will be higher.
- These are called **spring tides** and they occur **twice a month**, one on **full moon period** and another during **new moon period**.

Neap tides

- Normally, there is a **seven-day interval** between the spring tides and neap tides.
- At this time the sun and moon are at **right angles** to each other and the forces of the sun and moon tend to counteract one another.
- The Moon's attraction, though more than twice as strong as the sun's, is diminished by the counteracting force of the sun's gravitational pull.



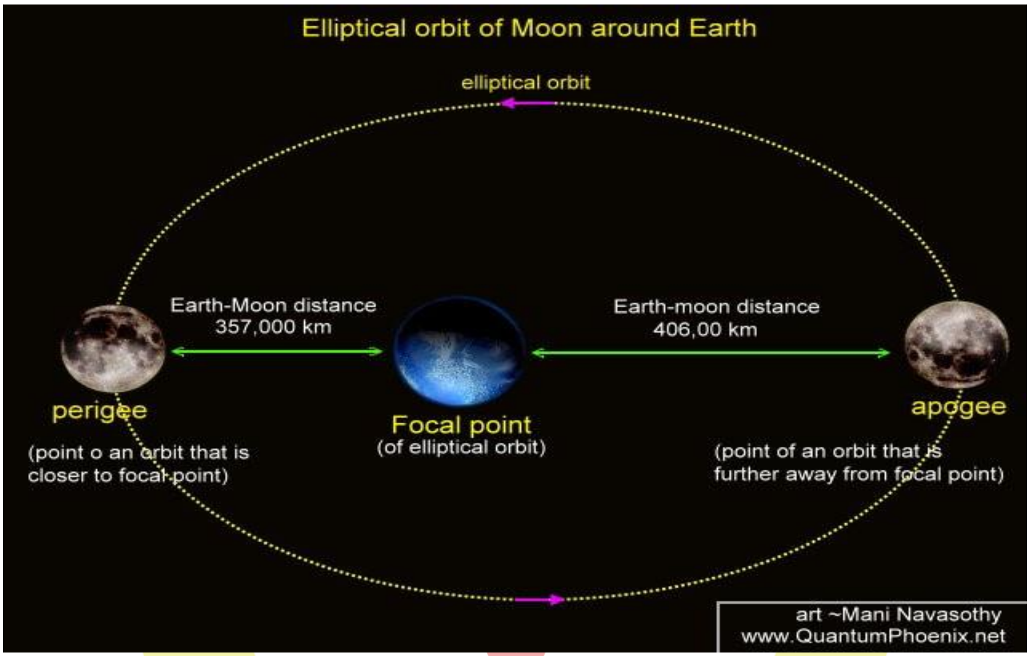
- Like spring tides, these tides also occur **twice a month.**

Magnitude of tides based on Perigee and apogee of moon

- Once in a month, when the moon's orbit is closest to the earth **(perigee)**, unusually high and low tides occur. During this time the tidal range is greater than normal.
- Two weeks later, when the moon is farthest from earth **(apogee)**, the moon's gravitational force is limited and the tidal ranges are less than their average heights.

Magnitude of tides based on Perigee and Apogee of earth

- When the earth is closest to the sun **(perihelion)**, around **3rd January** each year, tidal ranges are also much greater, with unusually high and unusually low tides.
- When the earth is farthest from the sun **(aphelion)**, around **4th July** each year, tidal ranges are much less than average.



Ebb and Flood

- The time between the high tide and low tide, when the water level is **falling**, is called the **ebb.**
- The time between the low tide and high tide, when the tide is **rising**, is called the **flow or flood.**

Importance of Tides

- Since tides are caused by the earth-moon-sun positions which are known accurately, the tides **can be predicted well in advance**. This helps the navigators and fishermen plan their activities.

Navigation

- Tidal heights are very important, especially harbours near rivers and within estuaries having shallow **'bars' [Marine Landforms]** at the entrance, which prevent ships and boats from entering into the harbour.
- High tides help in navigation. They raise the water level close to the shores. This helps the ships to arrive at the harbour more easily.
- Tides generally help in making some of the rivers navigable for ocean-going vessels. **London and Calcutta [Tidal Ports]** have become important ports owing to the tidal nature of the mouths of the Thames and Hooghly respectively.

Fishing

- The high tides also help in fishing. Many more fish come closer to the shore during the high tide. This enables fishermen to get a plentiful catch.

Desilting

- Tides are also helpful in desilting the sediments and in removing polluted water from river estuaries.

Other

- Tides are used to generate electrical power (in Canada, France, Russia, and China).
- A 3 MW tidal power project was constructed at **Durgaduani in Sunderbans of West Bengal**.

Characteristics of Tides

- The tidal bulges on wide continental shelves have greater height.
- In the open ocean tidal currents are relatively weak.
- When tidal bulges hit the mid-oceanic islands they become low.
- The shape of bays and estuaries along a coastline can also magnify the intensity of tides.
- **Funnel-shaped bays** greatly change tidal magnitudes. Example: ***Bay of Fundy — Highest tidal range.***
- The large continents on the planet, however, block the westward passage of the tidal bulges as the Earth rotates.
- Tidal patterns differ greatly from ocean to ocean and from location to location.

Ocean currents

- Ocean currents are the most important ocean movements because of their **influence on climatology** of various regions.

- Ocean currents are like river flow in oceans. They represent a **regular** volume of water in a **definite** path and direction.

- Ocean currents are influenced by two types of forces namely:
  1. primary forces that initiate the movement of water;
  2. secondary forces that influence the currents to flow.

- The primary forces that influence the currents are:
  1. **heating by solar energy;**
  2. **wind;**
  3. **gravity;**
  4. **Coriolis force.**

- The secondary forces that influence the currents are:
  1. **Temperature difference;**
  2. **Salinity difference**

Primary Forces Responsible for Ocean Currents

Influence of insolation

- Heating by solar energy causes the water to expand. That is why, near the equator the ocean water is about 8 cm higher in level than in the middle latitudes.
- This causes a very slight gradient and water tends to flow down the slope. The flow is normally from east to west.

Influence of wind (atmospheric circulation)

- Wind blowing on the surface of the ocean pushes the water to move. Friction between the wind and the water surface affects the movement of the water body in its course.
- Winds are responsible for both magnitude and direction [Coriolis force also affects direction] of the ocean currents. Example: **Monsoon winds** are responsible for the seasonal reversal of ocean currents in the Indian ocean.

- The oceanic circulation pattern roughly corresponds to the earth's atmospheric circulation pattern.
- The air circulation over the oceans in the middle latitudes is mainly anticyclonic [Sub-tropical High Pressure Belt] (more pronounced in the southern hemisphere than in the northern hemisphere due to differences in the extent of landmass). The oceanic circulation pattern also corresponds with the same.
- At higher latitudes, where the wind flow is mostly cyclonic [Sub-polar Low Pressure Belt], the oceanic circulation follows this pattern.
- In regions of pronounced monsoonal flow [Northern Indian Ocean], the monsoon winds influence the current movements which change directions according to seasons.

Influence of gravity

- Gravity tends to pull the water down to pile and create **gradient variation**.

Influence of Coriolis force

- The Coriolis force intervenes and causes the water to move to the **right** in the northern hemisphere and to the **left** in the southern hemisphere.
- These large accumulations of water and the flow around them are called **Gyres.** These produce large circular currents in all the ocean basins. One such circular current is the **Sargasso Sea.**

Secondary Forces Responsible for Ocean Currents

- **Temperature difference** and **salinity difference** are the secondary forces.
- Differences in water density affect **vertical mobility** of ocean currents (vertical currents).
- Water with high salinity is denser than water with low salinity and in the same way cold water is denser than warm water.
- Denser water tends to sink, while relatively lighter water tends to rise.
- Cold-water ocean currents occur when the cold water at the poles sinks and slowly moves towards the equator.
- Warm-water currents travel out from the equator along the surface, flowing towards the poles to replace the sinking cold water.

Types of Ocean Currents

Ocean currents are classified based on temperature: as **cold currents** and **warm currents**:

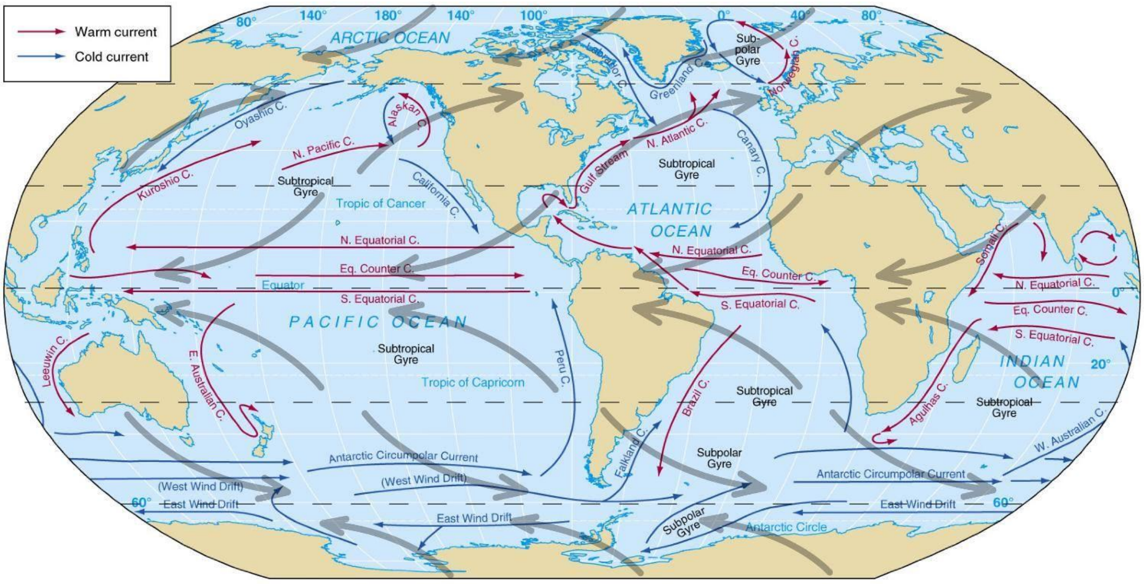
1. Cold currents bring cold water into warm water areas [from high latitudes to low latitudes]. These currents are usually found on the **west coast of the continents** (currents flow in clockwise direction in northern hemisphere and in anti-clockwise direction in southern hemisphere) in the low and middle latitudes (true in both hemispheres) and on the east coast in the higher latitudes in the Northern Hemisphere;
2. Warm currents bring warm water into cold water areas [low to high latitudes] and are usually observed on the east coast of continents in the low and middle latitudes (true in both hemispheres). In the northern hemisphere they are found on the west coasts of continents in high latitudes.
3.

General Characteristics of Ocean Currents

- Characteristics of Ocean Currents arise due to the interplay of the above-mentioned factors.

The general movement of the currents in the northern hemisphere is clockwise and in the southern hemisphere, anti-clockwise.

- This is due to the **Coriolis force which is a deflective force and follows Ferrel's law**.
- A notable exception to this trend is seen in the northern part of the Indian Ocean where the current movement changes its direction in response to the **seasonal change in the direction** of monsoon winds.



The warm currents move towards the cold seas and cool currents towards the warm seas.

- In the lower latitudes, the warm currents flow on the **eastern shores** and cold on the western shores [food for imagination].
- The situation is reversed in the higher latitudes. The warm currents move along the western shores and the cold currents along the eastern shores.
- **Convergence:** warm and cold currents meet.
- **Divergence:** a single current splits into multiple currents flowing in different directions.

The shape and position of coasts play an important role in guiding the direction of currents.

- The currents flow not only at the surface but also below the sea surface (due to salinity and temperature difference).
- For instance, heavy surface water of the Mediterranean Sea sinks and flows westward past Gibraltar as a sub-surface current.

Effects of Ocean Currents

Ocean currents have a number of direct and indirect influences on human activities.

Desert formation

- Cold ocean currents have a direct effect on desert formation in west coast regions of the tropical and subtropical continents.
- There is fog and most of the areas are arid due to desiccating effect (loss of moisture).

Rains

- Warm ocean currents bring rain to coastal areas and even interiors. Example: Summer Rainfall in British Type climate.
- Warm currents flow parallel to the east coasts of the continents in tropical and subtropical latitudes. This results in warm and rainy climates. These areas lie in the western margins of the subtropical anti-cyclones.

Moderating effect

- They are responsible for moderate temperatures at coasts. [North Atlantic Drift brings warmness to England. Canary cold current brings cooling effect to Spain, Portugal etc.]

Fishing

- Mixing of cold and warm ocean currents bear richest fishing grounds in the world.
- Example: Grand Banks around Newfoundland, Canada and North-Eastern Coast of Japan.
- The mixing of warm and cold currents helps to replenish the oxygen and favor the growth of **planktons**, the primary food for fish population. The best fishing grounds of the world exist mainly in these mixing zones.

Drizzle

- Mixing of cold and warm ocean currents create foggy weather where precipitation occurs in the form of drizzle [Newfoundland].

Climate

Results in

- Warm and rainy climates in tropical and subtropical latitudes [Florida, Natal etc.]
- Cold and dry climates on the western margins in the sub-tropics due to desiccating effect,
- Foggy weather and drizzle in the mixing zones,

- Moderate clime along the western costs in the sub-tropics.

Tropical cyclones

- They pile up warm waters in tropics and this warm water is the major force behind tropical cyclones.

Navigation

- Currents are referred to by their "drift". Usually, the currents are strongest near the surface and may attain speeds over five knots (1 knot = ~1.8 km). [At depths, currents are generally slow with speeds less than 0.5 knots].
- Ships usually follow routes which are aided by ocean currents and winds.
- Example: If a ship wants to travel from Mexico to Philippines, it can use the route along the North Equatorial Drift which flows from east to west.
- When it wants to travel from Philippines to Mexico, it can follow the route along the doldrums when there is counter equatorial current [we will study this in next post] flowing from west to east.

CLIMATOLOGY

➢ Temperature and pressure belt

1. Pressure Belts of the Earth

➢ Pressure

- A column of air exerts weight in terms of pressure on the surface of the earth.
- The weight of the column of air at a given place and time is called air pressure or atmospheric pressure.
- Atmospheric pressure is measured by an instrument called a barometer.
- Atmospheric pressure is measured as force per unit area. The unit used for measuring pressure is called millibar.
- One millibar is equal to the force of nearly one gram per square centimeter.

➢ Factors Controlling Pressure Systems

There are two main causes, **thermal** and **dynamic**, for the pressure differences resulting in high and low-pressure systems.

➢ Thermal Factors

- When air is heated, it expands and, hence, its density decreases. This naturally leads to low pressure. On the contrary, cooling results in contraction. This increases the density and thus leads to high pressure.
- Formation of equatorial low and polar highs are examples of thermal lows and thermal highs, respectively.

➢ Dynamic Factors

- Apart from variations of temperature, the formation of pressure belts may be explained by dynamic controls arising out of pressure gradient forces and rotation of the earth (Coriolis force).
- What is Pressure Gradient?

- The rate of change of atmospheric pressure between two points on the earth's surface is called the pressure gradient.
- On the weather chart, this is indicated by the spacing of isobars.
- Close spacing of isobars indicates a strong pressure gradient, while wide spacing suggests a weak gradient.

➢ <u>Vertical Distribution</u>

- The columnar distribution of atmospheric pressure is known as the vertical distribution of pressure.
- The mass of air above in the column of air compresses the air under it hence its lower layers are denser than the upper layers; As a result, the lower layers of the atmosphere have higher density, hence, exert more pressure.
- Conversely, the higher layers are less compressed and, hence, they have low density and low pressure.
- The temperature of the air, the amount of water vapor present in the air, and the gravitational pull of the earth determine the air pressure of a given place and at a given time.
- Since these factors are variable with a change in height, there is a variation in the rate of decrease in air pressure with an increase in altitude.
- Rising pressure indicates fine, settled weather while falling pressure indicates unstable and cloudy weather.

➢ <u>Horizontal Distribution</u>

The factors responsible for variation in the horizontal distribution of pressure are as follows:

1) **Air temperature** – Equator Polar regions
2) **The earth's rotation** – Coriolis force
3) **Presence of water vapor** – Inversely related to pressure

➢ <u>Air Temperature</u>

- Earth is not heated uniformly because of unequal distribution of insolation, differential heating and cooling of land and water surfaces
- Air pressure is low in equatorial regions and it is higher in polar regions.

- Low air pressure in equatorial regions is due to the fact that hot air ascends there with a gradual decrease in temperature causing thinness of air on the surface.
- In the polar region, cold air is very dense hence it descends, and pressure increases.

➢ The Earth's Rotation

- The earth's rotation generates centrifugal force.
- This results in the deflection of air from its original place, causing a decrease of pressure.
- The low-pressure belts of the subpolar regions and the high-pressure belts of the sub-tropical regions are created as a result of the earth's rotation.

➢ Presence of Water Vapour

- Air with a higher quantity of water vapor has lower pressure and that with a lower quantity of water vapor has higher pressure.

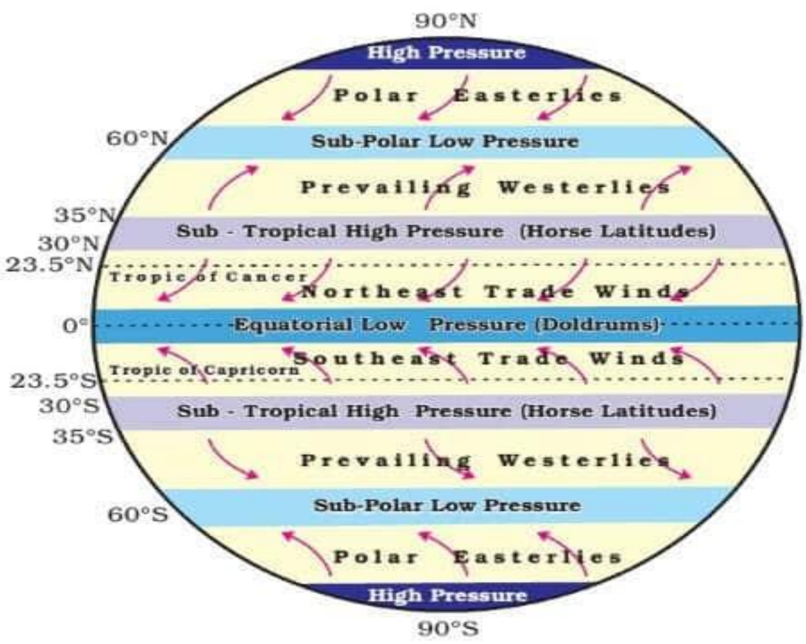
➢ World Pressure Belts

On the earth's surface, there are **seven pressure belts**.

- Equatorial Low
- The two Sub-Tropical Highs
- The two Sub-Polar Lows
- The two Polar Highs.

➢ Equatorial Low Pressure Belts

- This low-pressure belt extends from 0 to 5° North and South of the Equator.
- Due to the vertical rays of the sun here, there is intense heating. The air, therefore, expands and rises as convection current causing low pressure to develop here.
- This low-pressure belt is also called as doldrums because it is a zone of total calm without any breeze.



Major Pressure Belts and Wind System

➢ Sub-tropical High Pressure Belts

- At about 30°North and South of the Equator lies the area where the ascending equatorial air currents descend. This area is thus an area of high pressure.
- It is also called as the Horse latitude.
- Winds always blow from high pressure to low pressure.
- So the winds from the subtropical region blow towards the Equator as Trade winds and another wind blow towards Sub-Polar Low-Pressure as **Westerlies**.

➢ Circum-polar Low Pressure Belts

- These belts located between 60° and 70° in each hemisphere are known as Circum-polar Low-Pressure Belts.
- In the Sub-tropical region, the descending air gets divided into two parts.

- One part blows towards the Equatorial Low-Pressure Belt. The other part blows towards the Circum-polar Low-Pressure Belt.
- This zone is marked by the ascent of warm Sub-tropical air over cold polar air blowing from poles. Due to earth’s rotation, the winds surrounding the Polar region blow towards the Equator.
- Centrifugal forces operating in this region create the low-pressure belt appropriately called Circum-polar Low-Pressure Belt.
- This region is marked by violent storms in winter.

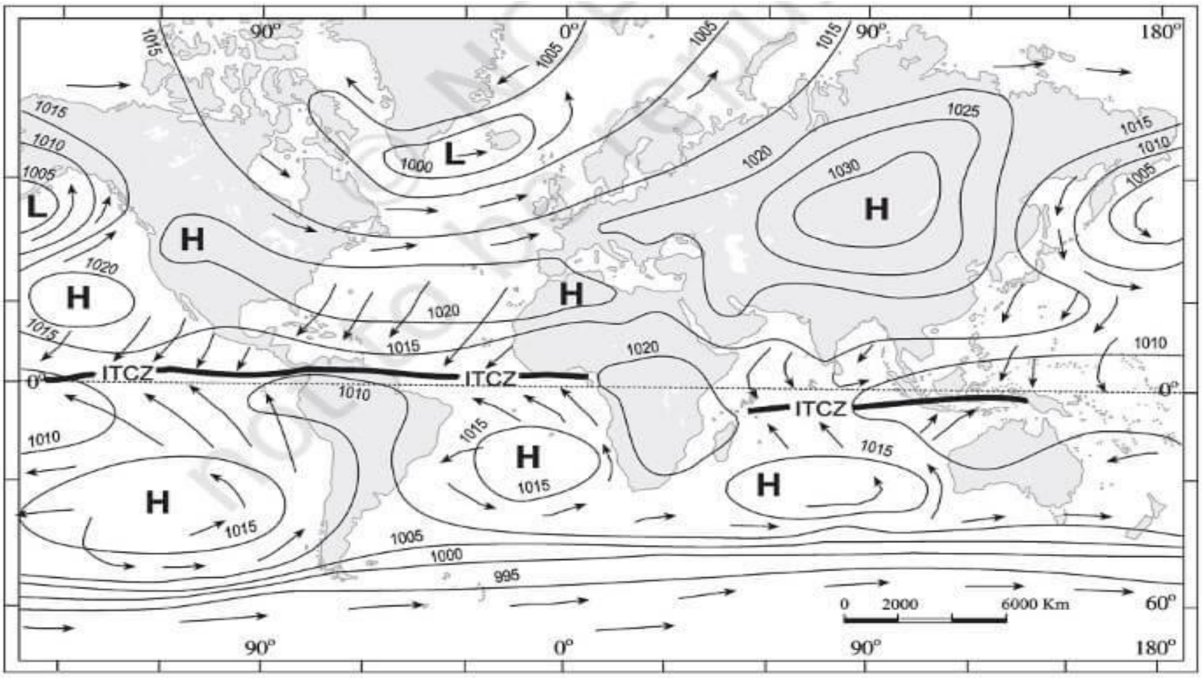


Figure 10.2 : Distribution of pressure (in millibars) — January

- **<u>Heat budget</u>**

Heat Budget of the Earth is the balance between incoming solar insolation and outgoing terrestrial radiation which maintains the average annual temperature of the earth at 15-degree celsius.

Solar energy received by earth’s surface is called solar insolation.

- <u>Heat Budget of the Earth and Atmosphere</u>

The total solar radiation reaching a horizontal surface on the ground is called **global radiation**. It comprises the direct shortwave radiation from the Sun + the diffuse radiation scattered by the <u>atmosphere</u>.

It may be pointed out that the solar energy received at the earth's surface is converted into heat energy which heats the outer surface of the earth.

Thus, the earth after being heated also radiates energy in the form of long-wave radiation.

The Radiation from the sun towards the earth is called incoming shortwave solar radiation and from the earth towards the atmosphere is called outgoing longwave terrestrial radiation.

How it is calculated?

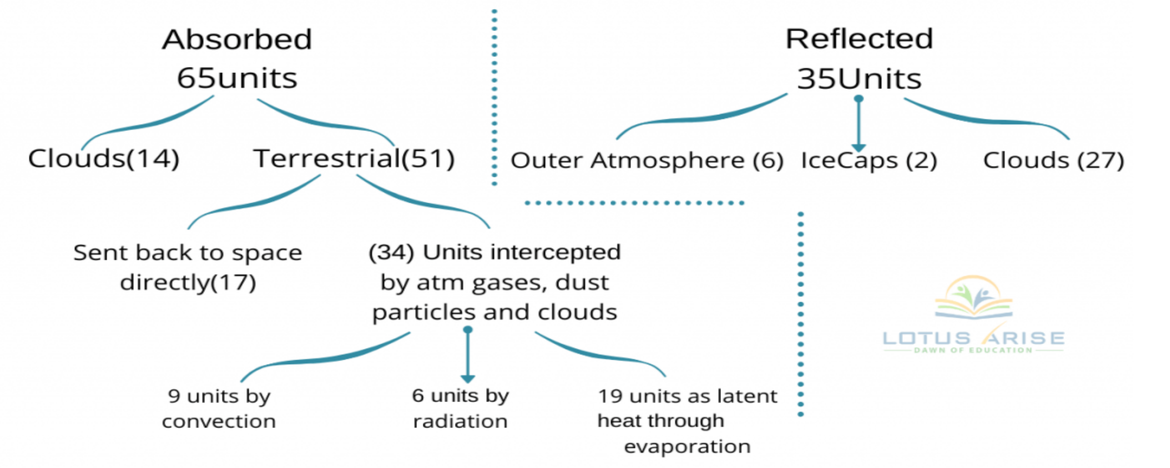
Suppose incoming solar insolation is = 100 units Amount lost through scattering and reflection.

a) Through Clouds- 27units

b) By dust particles – 6units

c) By Ice Caps and Glaciers- 2units

Total 35 units are reflected back into space. (known as albedo of the earth) Now, the units received by earth and its atmosphere = 100 – 35 = 65units.



➢ Heat budget of the Earth

51 units of solar insolation are received by the earth as direct radiation which can be segregated as follows:

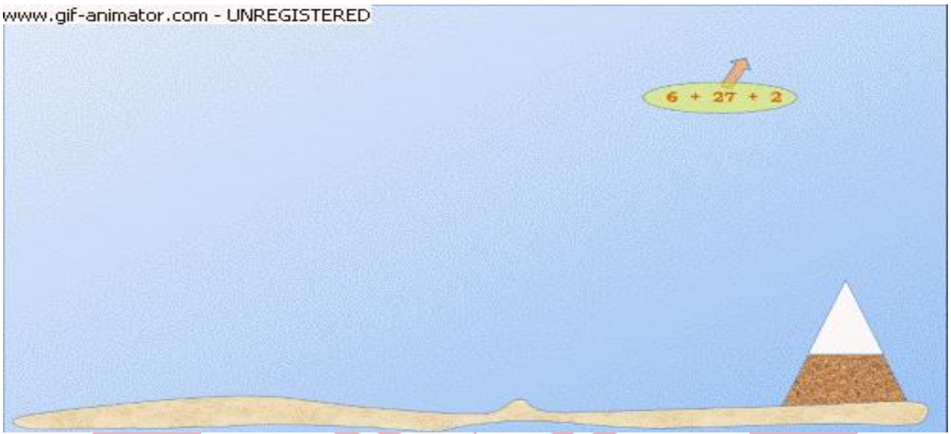
(i)Received through direct Radiation= 34units

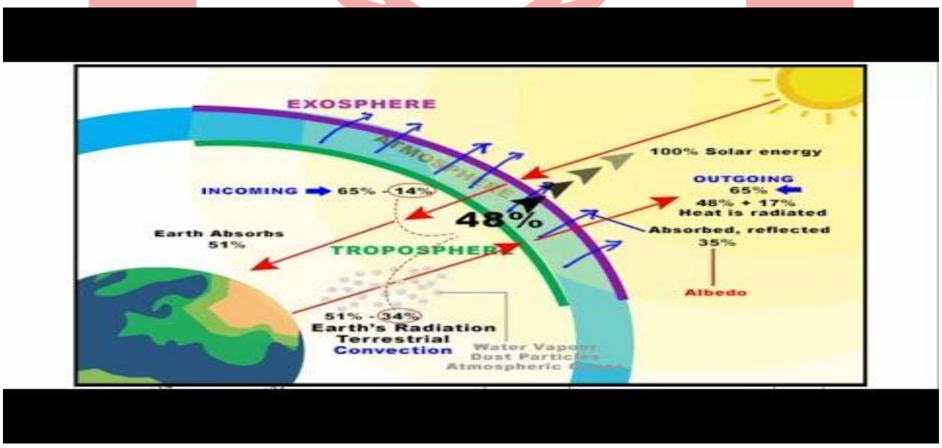
(ii)Received as diffused day light= 17units

Which comes out to be **51 units**.

➢ Heat Budget of Atmosphere

- Absorption by atmospheric gases in different vertical zones of atmosphere-14 units Now 51 units + 14 units= 65 units (total solar insolationreceived by earth andatmosphere)
- Out of the solar radiation received directly by earth i.e. 51 units, 17 units are re-radiated back into outer space, and rest 34 units (51-17units) is absorbed by the atmosphere in the form of outgoing terrestrial radiation.
- Which comes out to be 48 units (14+ 34 = 48)





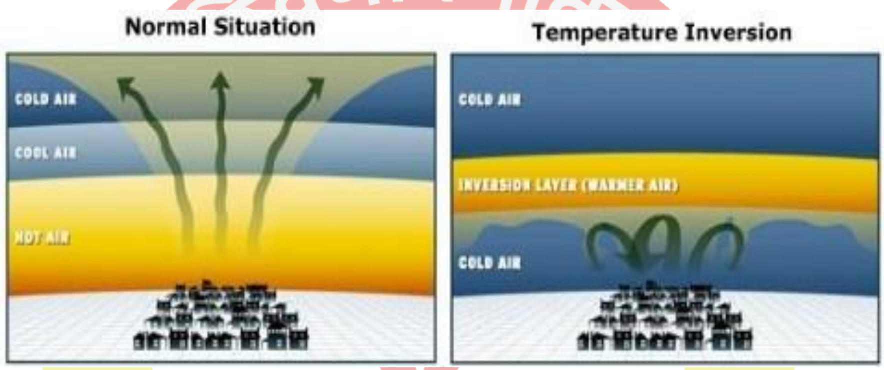
➢ Albedo

- Albedo can be simply defined as a measure of how much light that hits a surface is reflected back without being absorbed.
- It is a reflection coefficient and has a value of less than one.
- When the solar radiation passes through the atmosphere, some amount of it is reflected, scattered, and absorbed.
- The reflected amount of radiation is called the albedo of the earth.

- Because of the effect of albedo, highly developed areas such as urban cities can experience higher average temperatures than the surrounding suburban or rural areas, a phenomenon known as the **Urban Heat Island Effect**.
- The higher average temperature can be attributed to less vegetation, higher population densities, and more infrastructures with dark surfaces (asphalt roads, brick buildings, etc.).

Temperature Inversion

- Temperature inversion, is a reversal of the normal behavior of temperature in the troposphere, in which a layer of cool air at the surface is overlain by a layer of warmer air. **(Under normal conditions, temperature usually decreases with height).**



Effects

- Inversions play an important role in determining cloud forms, precipitation, and visibility.
- An inversion acts as a cap on the upward movement of air from the layers below. As a result, convection produced by the heating of air from below is **limited** to levels below the inversion. **Diffusion** of dust, smoke, and other air pollutants is likewise limited.
- In regions where a pronounced low-level inversion is present, convective clouds **cannot** grow high enough to produce showers.
- Visibility may be greatly reduced below the inversion due to the accumulation of dust and smoke particles. Because air near the base of an inversion tends to be cool, **fog** is frequently present there.
- Inversions also affect diurnal variations in temperature. Diurnal variations tend to be very **small**.

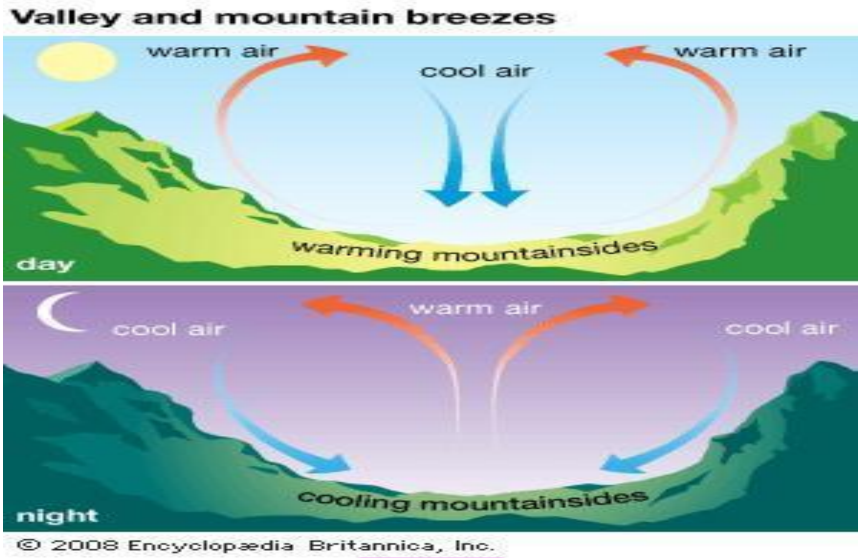
Ideal Conditions for Temperature Inversion

1. Long nights, so that the outgoing radiation is greater than the incoming radiation.
2. Clear skies, which allow unobstructed escape of radiation.
3. Calm and stable air, so that there is no vertical mixing at lower levels.

Types of Temperature Inversion

Temperature Inversion in Intermontane Valley (Air Drainage Type of Inversion)

- Sometimes, the temperature in the lower layers of air increases instead of decreasing with elevation. This happens **commonly along a sloping surface.**
- Here, the surface radiates heat back to space rapidly and cools down at a faster rate than the upper layers. As a result, the lower cold layers get condensed and become heavy.
- The sloping surface underneath makes them move towards the bottom where the cold layer settles down as a zone of low temperature while the upper layers are relatively warmer.
- This condition, opposite to normal vertical distribution of temperature, is known as Temperature Inversion.
- In other words, the vertical temperature gets inverted during temperature inversion.
- This kind of temperature inversion is very strong in the middle and higher latitudes. It can be strong in regions with high mountains or deep valleys also.

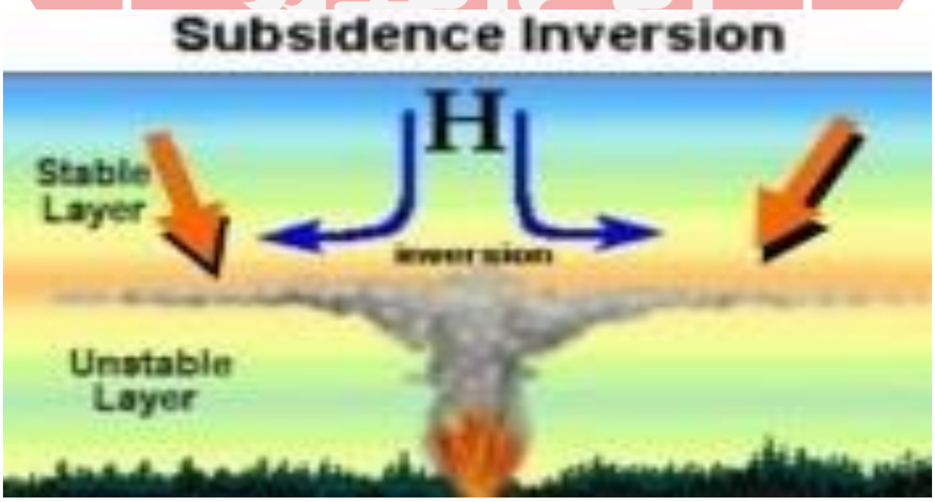


Ground Inversion (Surface Temperature Inversion)

- A ground inversion develops when air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere; this occurs most often on clear nights, when the ground cools off rapidly by radiation. If the temperature of surface air drops below its dew point, fog may result.
- This kind of temperature inversion is very common in the higher latitudes.
- Surface temperature inversion in lower and middle latitudes occurs during cold nights and gets destroyed during daytime.

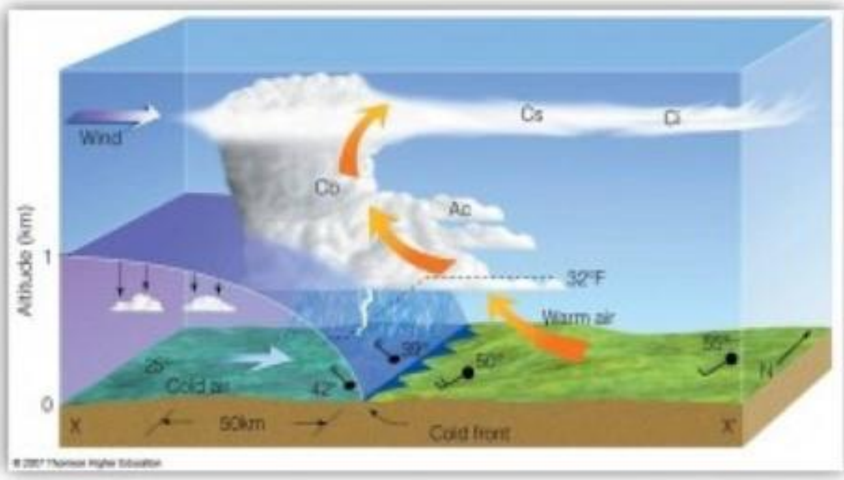
Subsidence Inversion (Upper Surface Temperature Inversion)

- A subsidence inversion develops when a widespread layer of air descends.
- The layer is compressed and heated by the resulting increase in atmospheric pressure, and as a result the lapse rate of temperature is reduced.
- If the air mass sinks low enough, the air at higher altitudes becomes warmer than at lower altitudes, producing a temperature inversion.
- Subsidence inversions are common over the northern continents in winter (dry atmosphere) and over the subtropical oceans; these regions generally have subsiding air because they are located under large high-pressure centers.
- This temperature inversion is called upper surface temperature inversion because it takes place in the upper parts of the atmosphere.



Frontal Inversion (Advectional type of Temperature Inversion)

- A frontal inversion occurs when a cold air mass undercuts a warm air mass (Cold and Warm Fronts: we will study in detail later) and lifts it aloft; the front between the two air masses then has warm air above and cold air below.
- This kind of inversion has considerable slope, whereas other inversions are nearly horizontal. In addition, humidity may be high, and clouds may be present immediately above it.
- This types of inversion are unstable and is destroyed as the weather changes.



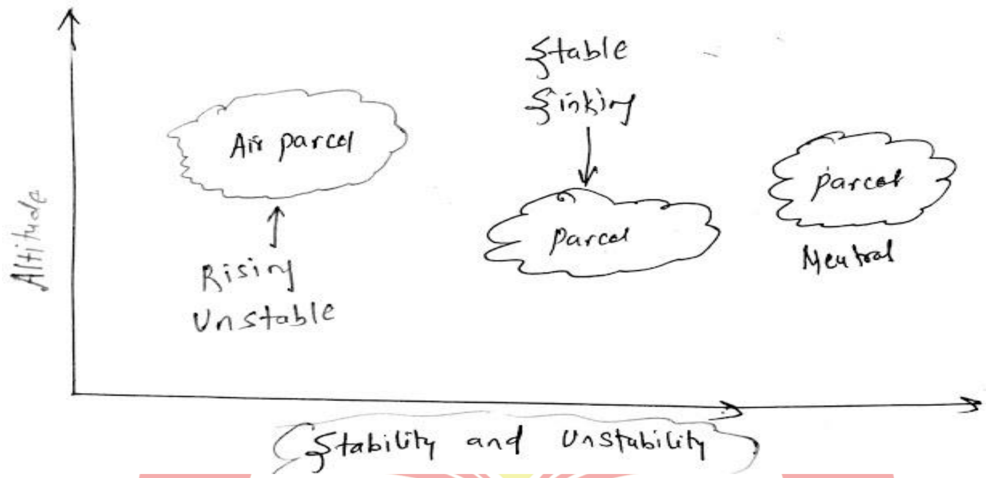
Economic Implications of Temperature Inversion

- Sometimes, the temperature of the air at the valley bottom reaches below freezing point, whereas the air at higher altitude remains comparatively warm. As a result, the trees along the lower slopes are bitten by frost, whereas those at higher levels are free from it.
- Due to inversion of temperature, air pollutants such as dust particles and smoke do not disperse in the valley bottoms. Because of these factors, houses and farms in intermontane valleys are usually situated along the upper slopes, avoiding the cold and foggy valley bottoms. For instance, coffee growers of Brazil and apple growers and hoteliers of mountain states of Himalayas in India avoid lower slopes.
- Fog lowers visibility affecting vegetation and human settlements.
- Less rainfall due to stable conditions.

➢ Atmospheric stability and instability:

The following diagram shows the stability and Instability of the atmosphere.

- A rising and sinking air parcel is generally unstable
- Stationary air parcels are usually stable



➢ Atmospheric stability and instability

- **Reasons for atmospheric stability or Instability:**

1) Thermal: due to insolation and convection.
2) Air rises or sink, both create instability.
3) Dynamic due to earth rotation:
4) In 60 and 65 degrees' latitude, air rises, and 30 to 35 degrees' latitude, air sinks.
5) In the case of thermal inversion, there is an extremely stable situation.

How do we know whether air parcel is stable or unstable?

By finding the following lapse rate

- Normal lapse rate
- Adiabatic lapse rate
- Dry Adiabatic Lapse rate
- Wet Adiabatic Lapse rate

1. **Normal lapse rate**

Rate of temperature decrease with height in a stable atmosphere. It is usually 6-degree centigrade per km.

2. **Adiabatic:**

A process where air parcel temperature changes due to expansion or compression, no heat is added or taken out from air parcel.

➢ **Adiabatic lapse rate:**

The rate of temperature changes happen with the rising air parcel is called the adiabatic lapse rate.

3. **Dry Adiabatic Lapse rate:**

- Rate of temperature decrease of the rising dry air parcel, it is usually 8 degrees centigrade per km.
- Dry condensed less when going up and latent heat of evaporation is less compared to normal lapse rate, hence temperature decrease is more with altitude.

4. **Moist adiabatic lapse rate:**

Rate of temperature decrease of the rising humid air parcel, it is usually 4 degrees centigrade per km. The latent heat of evaporation is released more when air goes up, hence temperature decrease is less of rising air and creates instability.

➢ **The following are short terms for finding stability and instability:**

Air parcel that we want to find out the stability and instability; we will say Environment Lapse Rate (ELR).

- Dry Adiabatic Lapse rate (DALR)
- Humid Adiabatic Lapse rate (HALR)

Absolute stability:

- In the case of temperature inversion, the environment air parcel will be stable.
- If ELR > DALR; than air parcel will be absolutely stable.

Conditional instability:

If HALR < ELR < DALR; this condition is called conditional instability, it may be stable or sometimes unstable.

Absolute instability:

If ELR< HALR; than air parcel will be absolutely unstable.
Absolute instability is also called Mechanical instability. It is found in the equatorial region.

Distribution of atmospheric instability and instability:

The following are distributions:

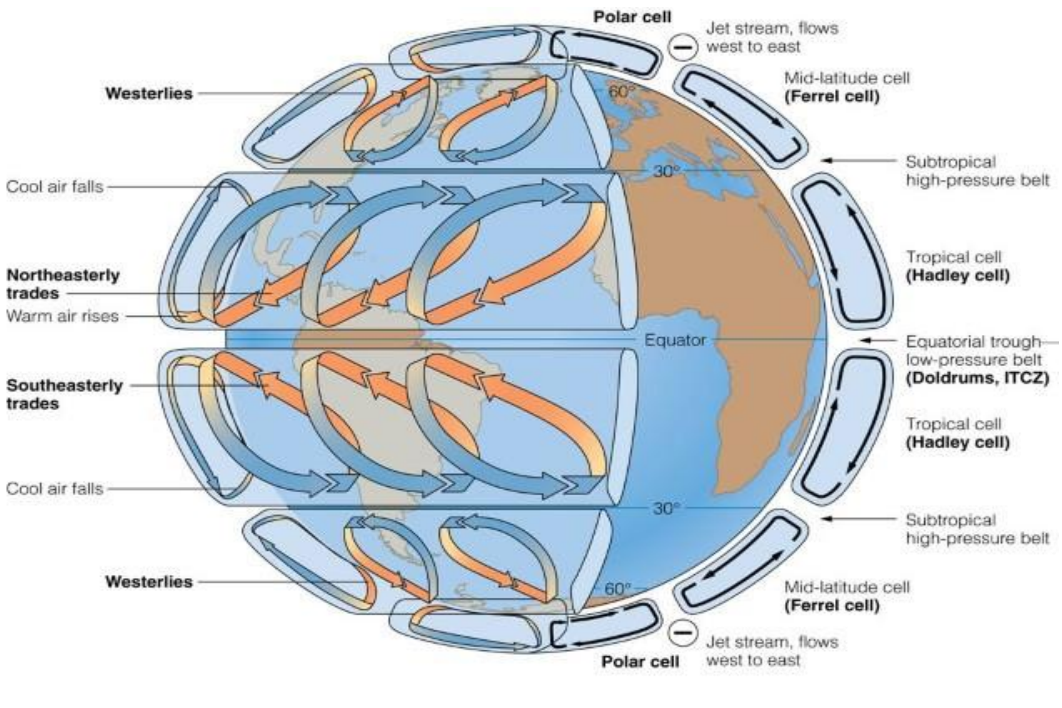
- All the 7 atmospheric pressure belt are unstable region, that is:
- Low atmospheric pressure belt(1nos)
- Subtropical high-pressure belt in both hemisphere (2 nos)
- Subpolar low-pressure belt in both hemisphere (2nos)
- Polar high-pressure belt (2 nos)
- Boundary lines of all the airmasses.
- Air masses that are found in between pressure belts are a stable region.

➢ **Planetary and local winds**

General circulation of the atmosphere

- The pattern of planetary winds depends on:
- latitudinal variation of atmospheric heating;
- emergence of pressure belts;
- the migration of belts following apparent path of the sun;
- the distribution of continents and oceans;
- the rotation of earth.

- The pattern of the movement of the planetary winds is called the **general circulation** of the atmosphere. The general circulation of the atmosphere also sets in motion the ocean water circulation which influences the earth's climate.



Hadley Cell

- The air at the Inter Tropical Convergence Zone (ITCZ) rises because of the convection currents caused by low pressure. Low pressure in turn occurs due to high insolation. The winds from the tropics converge at this low pressure zone.
- The converged air rises along with the convective cell. It reaches the top of the troposphere up to an altitude of 14 km, and moves towards the poles. This causes accumulation of air at about 30° N and S. Part of the accumulated air sinks to the ground and forms a subtropical high. Another reason for sinking is the cooling of air when it reaches 30° N and S latitudes.
- Down below near the land surface the air flows towards the equator as the easterlies. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Such circulations from the surface upwards and vice-versa are called cells. Such a cell in the tropics is called **Hadley Cell.**

Ferrel Cell

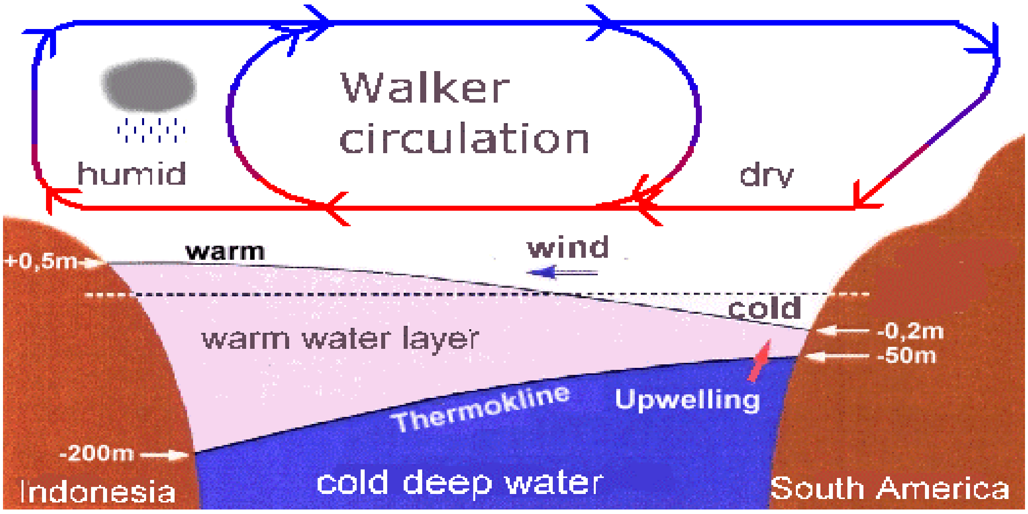
- In the middle latitudes the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high. At the surface these winds are called westerlies and the cell is known as the **Ferrel cell.**

Polar Cell

- At polar latitudes the cold dense air subsides near the poles and blows towards middle latitudes as the polar easterlies. This cell is called the **polar cell.**
- These three cells set the pattern for the **general circulation of the atmosphere**. The transfer of heat energy from lower latitudes to higher latitudes maintains the general circulation.
- The general circulation of the atmosphere also affects the oceans. The large-scale winds of the atmosphere initiate large and slow moving currents of the ocean. Oceans in turn provide input of energy and water vapour into the air. These interactions take place rather slowly over a large part of the ocean.

Walker Cell

- Warming and cooling of the Pacific Ocean is most important in terms of general atmospheric circulation.
- The warm water of the central Pacific Ocean slowly drifts towards South American coast and replaces the cool Peruvian current. Such appearance of warm water off the coast of Peru is known as the El Nino.
- The El Nino event is closely associated with the pressure changes in the Central Pacific and Australia. This change in pressure condition over Pacific is known as the southern oscillation.
- The combined phenomenon of southern oscillation and El Nino is known as ENSO.
- In the years when the ENSO is strong, large-scale variations in weather occur over the world. The arid west coast of South America receives heavy rainfall, drought occurs in Australia and sometimes in India and floods in China. This phenomenon is closely monitored and is used for long range forecasting in major parts of the world. (El-Nino in detail later)



Classification of Winds

- **Permanent winds or Primary winds or Prevailing winds or Planetary Winds**

- The **trade winds, westerlies and easterlies.**

- **Secondary or Periodic Winds**

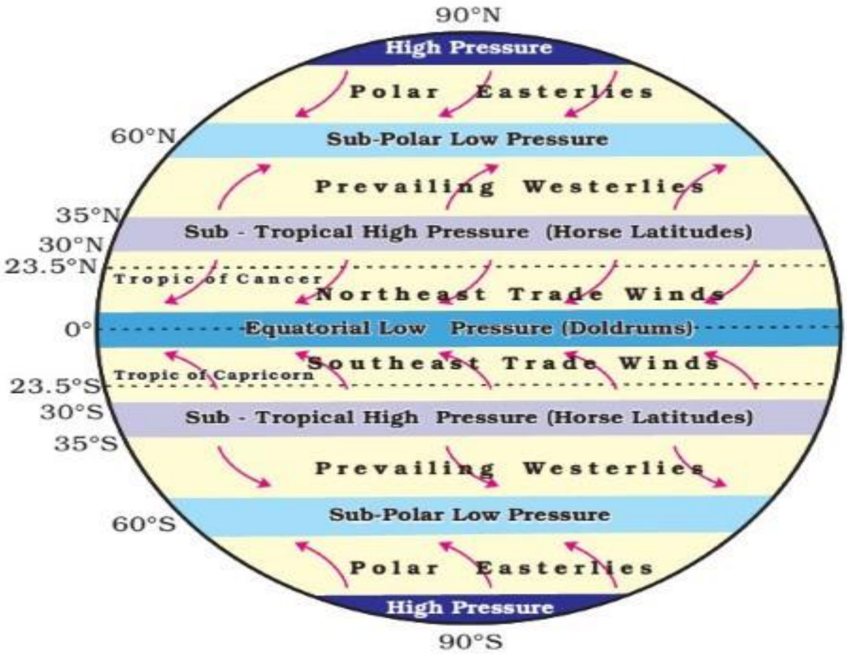
- Seasonal winds: These winds change their direction in different seasons. For example, **monsoons** in India.
- Periodic winds: Land and sea breeze, mountain and valley breeze**.**

- **Local winds**

- These blow only during a particular period of the day or year in a small area.
- Winds like **Loo, Mistral, Foehn, Bora**.

Primary Winds or Prevailing Winds or Permanent Winds or Planetary Winds

- These are the **planetary winds** which blow extensively over continents and oceans.
- The two most well- understood and significant winds for climate and human activities are **trade winds** and **westerly winds**.



Major Pressure Belts and Wind System

Trade Winds

- The trade winds are those blowing from the sub-tropical high pressure areas towards the equatorial low pressure belt**.**
- Therefore, these are confined to a region between **30°N and 30°S** throughout the earth's surface.
- They flow as the north-eastern trades in the northern hemisphere and the south-eastern trades in the southern hemisphere.
- This deflection in their ideally expected north-south direction is explained on the basis of **Coriolis force** and **Farrel's law.**
- Trade winds are **descending** and stable in areas of their origin (sub-tropical high pressure belt), and as they reach the equator, they become **humid and warmer** after picking up moisture on their way.
- The trade winds from two hemispheres meet at the equator, and **due to** convergence they rise and cause heavy rainfall.
- The eastern parts of the trade winds associated with the cool ocean currents are drier and more stable than the western parts of the ocean.

Westerlies

- The westerlies are the winds blowing from the **sub-tropical high pressure belts** towards the **sub polar low pressure belts**.

- They blow from **southwest to north-east** in the northern hemisphere and **north-west to south-east** in the southern hemisphere.
- The westerlies of the southern hemisphere are **stronger** and persistent due to the vast expanse of water, while those of the northern hemisphere are **irregular** because of uneven relief of vast land-masses.
- The westerlies are best developed between **40° and 65°S latitudes**. These latitudes are often called **Roaring Forties, Furious Fifties, and Shrieking Sixties** – dreaded terms for sailors.
- The poleward boundary of the westerlies is highly fluctuating. There are many seasonal and short-term fluctuations. These winds produce **wet spells** and variability in weather.

Polar easterlies

- The Polar easterlies are dry, cold prevailing winds blowing from **north-east to south-west direction** in Northern Hemisphere and **south-east to north-west** in Southern Hemisphere.
- They blow from the **polar high-pressure** areas of the **sub-polar lows**.

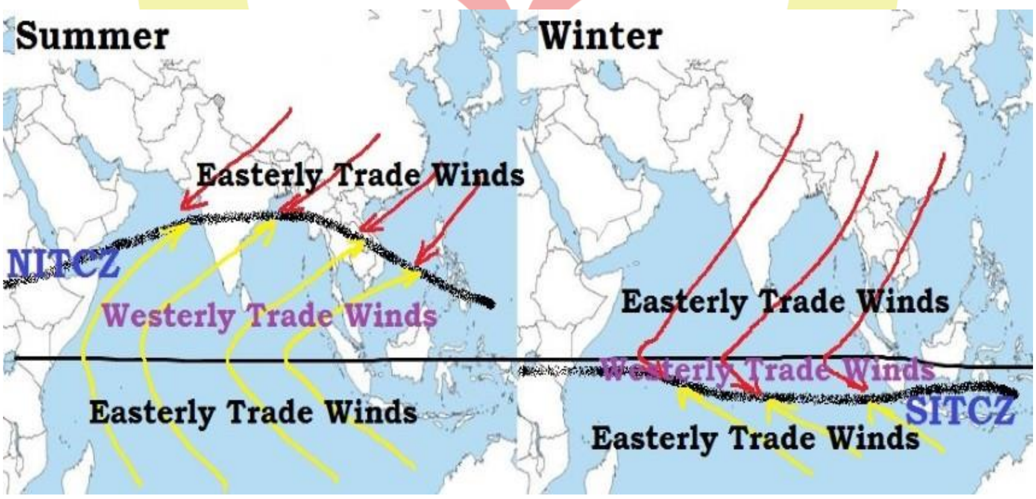
Secondary Winds or Periodic Winds

- These winds **change their direction with change in season**.
- **Monsoons** are the best example of large-scale modification of the planetary wind system.
- Other examples of periodic winds include **land and sea breeze, mountain and valley breeze, cyclones and anticyclones,** and **air masses.**

Monsoons

- Monsoons were traditionally explained as **land and sea breezes on a large scale.** Thus, they were considered a **convectional circulation on a giant scale.**
- The monsoons are characterized by **seasonal reversal** of wind direction.

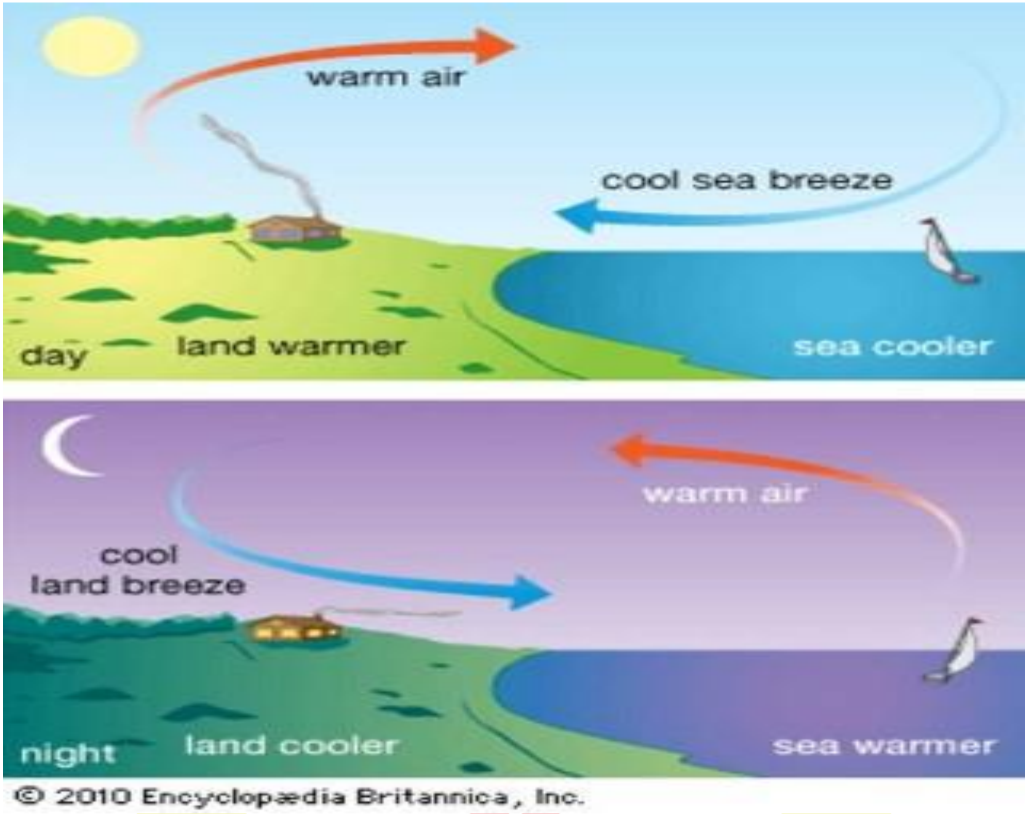
- During summer, the trade winds of southern hemisphere are pulled northwards by an apparent northward movement of the sun and by an intense low pressure core in the north-west of the Indian subcontinent.
- While crossing the equator, these winds get deflected to their right under the effect of **Coriolis force.**
- These winds now approach the Asian landmass as south-west monsoons. Since they travel a long distance over a vast expanse of water, by the time they reach the south-western coast of India, they are over-saturated with moisture and cause heavy rainfall in India and neighboring countries.
- During winter, these conditions are reversed and a high pressure core is created to the north of the Indian subcontinent. **Divergent winds** are produced by this **anticyclonic movement** which travels southwards towards the equator. This movement is enhanced by the apparent southward movement of the sun. These are north-east or winter monsoons which are responsible for some precipitation along the east coast of India.
- The monsoon winds flow over India, Pakistan, Bangladesh, Myanmar (Burma), Sri Lanka, the Arabian Sea, Bay of Bengal, southeastern Asia, **northern Australia, China** and
- Outside India, in the eastern Asiatic countries, such as China and Japan, the **winter monsoon is stronger** than the summer monsoon. (we will study about monsoons in detail while studying Indian Climate)



Land Breeze and Sea Breeze

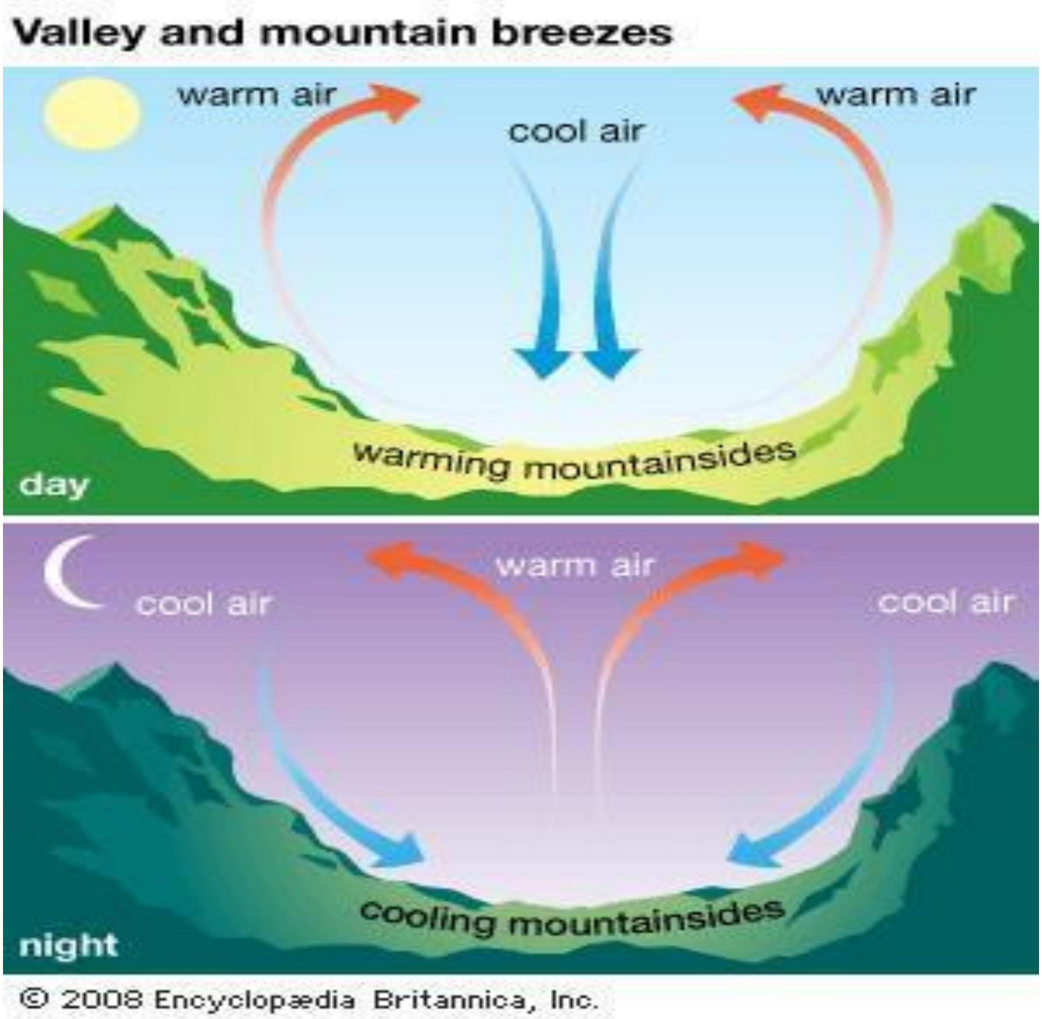
- The land and sea absorb and transfer heat differently. During the day the land heats up faster and becomes warmer than the sea. Therefore, over the land the air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high. Thus, pressure gradient from sea to land is created and the wind blows from the sea to the land as the sea breeze.

In the night the reversal of condition takes place. The land loses heat faster and is cooler than the sea. The pressure gradient is from the land to the sea and hence land breeze results.



Valley Breeze and Mountain Breeze

- In mountainous regions, during the day the slopes get heated up and air moves upslope and to fill the resulting gap the air from the valley blows up the valley. This wind is known as the valley breeze. During the night the slopes get cooled and the dense air descends into the valley as the mountain wind. The cool air, of the high plateaus and ice fields draining into the valley is called **katabatic wind.**
- Another type of warm wind (**katabatic wind**) occurs on the leeward side of the mountain ranges. The moisture in these winds, while crossing the mountain ranges condense and precipitate. When it descends down the leeward side of the slope the dry air gets warmed up by **adiabatic process**. This dry air may melt the snow in a short time.



Tertiary Winds or Local Winds

- Local differences of temperature and pressure produce local winds.
- Such winds are local in extent and are confined to the lowest levels of the troposphere. Some examples of local winds are discussed below.

Loo

- **Harmful Wind**
- In the plains of northern India and Pakistan, sometimes a very hot and dry wind blows from the west in the months of **May and June**, usually in the afternoons. It is known as Its temperature invariably ranges between **45°C and 50°C**. It may cause **sunstroke** to people.

Foehn or Fohn

- **Beneficial Wind**
- Foehn is a **hot wind** of local importance in the **Alps**. It is a strong, gusty, dry and warm wind which develops on the leeward side of a mountain range. As the windward side takes away whatever moisture there is in the incoming wind in the form of orographic precipitation, the air that descends on the leeward side is dry and warm **(Katabatic Wind).**
- The temperature of the wind varies between 15°C and 20°C. The wind **helps animal grazing** by melting snow and **aids the ripening of grapes**.

Chinook

- **Beneficial Wind**
- Foehn like winds in **USA and Canada** move down the west slopes of the **Rockies** and are known as
- It is **beneficial to ranchers** east of the Rockies as it keeps the grasslands clear of snow during much of the winter.

Mistral

- **Harmful Wind**
- Mistral is one of the local names given to such winds that blow from the Alps over France towards the Mediterranean Sea.
- It is channeled through the Rhine valley. It is **very cold and dry with a high speed**.
- It brings blizzards into southern France.

Sirocco

- **Harmful Wind**
- Sirocco is a **Mediterranean wind** that comes from the **Sahara** and reaches hurricane speeds in North Africa and Southern Europe.
- It arises from a warm, dry, tropical air mass that is pulled northward by low-pressure cells moving eastward across the Mediterranean Sea, with the wind originating in the **Arabian or Sahara deserts.** The hotter, drier continental air mixes with the cooler, wetter air of the maritime cyclone, and the counter-clockwise circulation of the low propels the mixed air across the southern coasts of Europe.
- **The Sirocco causes dusty dry conditions along the northern coast of Africa, storms in the Mediterranean Sea, and cool wet weather in Europe.**
- jet streams are the best known and most studied, other jet streams can form when wind speeds are above 94 kph in the upper atmosphere at about 9 – 14.5 km above the surface.
- They are few. Important ones are Somali Jet and The African Easterly jet.
- that is associated with clear weather.

➢ Air masses and frontogenesis

Air Masses

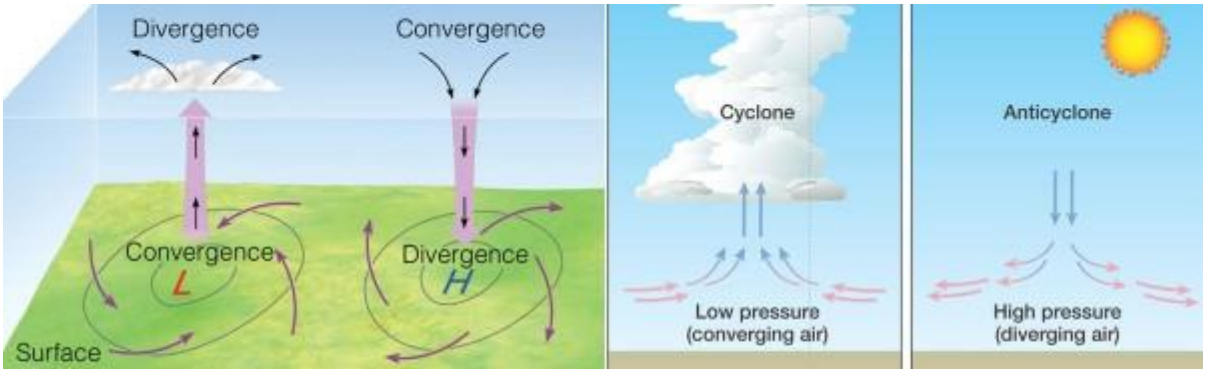
- When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains and plateaus.
- The air with distinctive characteristics in terms of **temperature** and **humidity** is called an air mass. It is a large body of air having **little horizontal variation** in temperature and moisture.
- Air masses form an integral part of the **global planetary wind system**. Therefore, they are associated with one or other wind belt.
- Pressure Belts – Equatorial Low, Sub-Tropical High, Sub-Polar Low and Polar High
- Wind Movement – Factors Affecting Wind – Coriolis Force
- Winds – General Circulation – Permanent, Secondary, Local Winds
- They extend from **surface to lower stratosphere** and are across thousands of kilometers.

Source regions

- The homogenous surfaces, over which air masses form, are called the **source regions.**
- The main source regions are the **high pressure belts** in the **sub tropics (giving rise to tropical air masses)** and around the **poles (the source for polar air masses).**
- Source Region establishes **heat and moisture equilibrium** with the overlying air mass.
- When an air mass moves away from a source region, the upper level maintains the physical characteristics for a longer period. This is possible because air masses are stable with stagnant air which **do not facilitate convection**. Conduction and radiation in such stagnant air is not effective.

Conditions for the formation of Air masses

- Source region should be extensive with gentle, divergent air circulation (slightly at high pressure).



- Areas with high pressure but little pressure difference or pressure gradient are ideal source regions.
- There are no major source regions in the mid-latitudes as these regions are dominated by cyclonic and other disturbances.

Air masses based on Source Regions

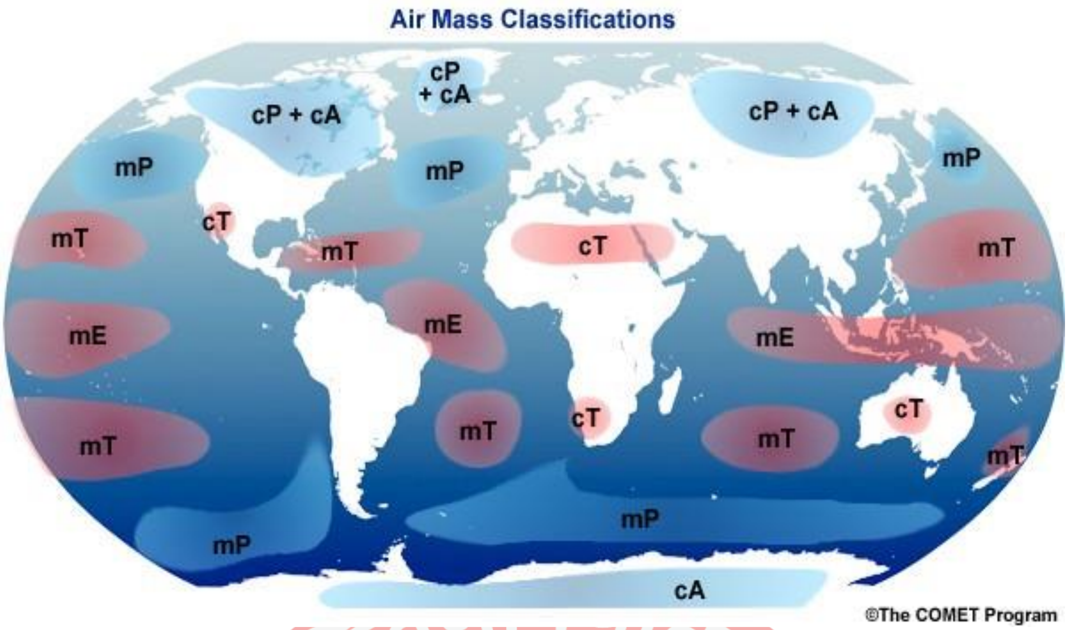
- There are five major source regions. These are:

1) Warm tropical and subtropical oceans;
2) The subtropical hot deserts;
3) The relatively cold high latitude oceans;
4) The very cold snow covered continents in high latitudes;
5) Permanently ice covered continents in the Arctic and Antarctica.

- Accordingly, following types of airmasses are recognised:

1) Maritime tropical (mT);
2) Continental tropical (cT);
3) Maritime polar (mP);
4) Continental polar (cP);
5) Continental arctic (cA).

- Tropical air masses are warm and polar air masses are cold.
- The heat transfer processes that warms or cools the air takes place slowly.



Cold Air Mass

- A cold air mass is one which is colder than the underlying surface and is associated with **instability** and **atmospheric turbulence**.

Cold source regions (polar air masses)

- Arctic Ocean – cold and moist
- Siberia – cold and dry
- Northern Canada – cold and dry
- Southern Ocean – cold and moist

Warm Air Mass

- A warm air mass is one which is warmer than the underlying surface and is associated with **stable** weather conditions.

Warm source regions (tropical air masses)

- Sahara Desert – warm and dry
- Tropical Oceans – warm and moist

Influence of Air Masses on World Weather

- The properties of an air mass which influence the accompanying weather are vertical distribution temperature (indicating its stability and coldness or warmness) and the moisture content.
- The air masses carry atmospheric moisture from oceans to continents and cause precipitation over landmasses.
- They transport latent heat, thus removing the latitudinal heat balance.
- Most of the migratory atmospheric disturbances such as cyclones and storms originate at the contact zone between different air masses and the weather associated with these disturbances is determined by characteristics of the air masses involved.

Classification of Air Masses

- Broadly, the air masses are classified into polar and tropical air masses.
- Both the polar and the continental air masses can be either of maritime or continental types.

Continental Polar Air Masses (CP)

- Source regions of these air masses are the Arctic basin, northern North America, Eurasia and Antarctica.
- These air masses are characterized by dry, cold and stable conditions.
- The weather during winter is frigid, clear and stable.
- During summer, the weather is less stable with lesser prevalence of anticyclonic winds, warmer landmasses and lesser snow.

Maritime Polar Air Masses (MP)

- The source region of these air masses are the oceans between **40° and 60° latitudes**.
- These are actually those continental polar air masses which have moved over the warmer oceans, got heated up and have collected moisture.
- The conditions over the source regions are **cool, moist and unstable**. These are the regions which cannot lie stagnant for long.
- The weather during winters is characterized by high humidity, overcast skies and occasional fog and precipitation.
- During summer, the weather is clear, fair and stable.

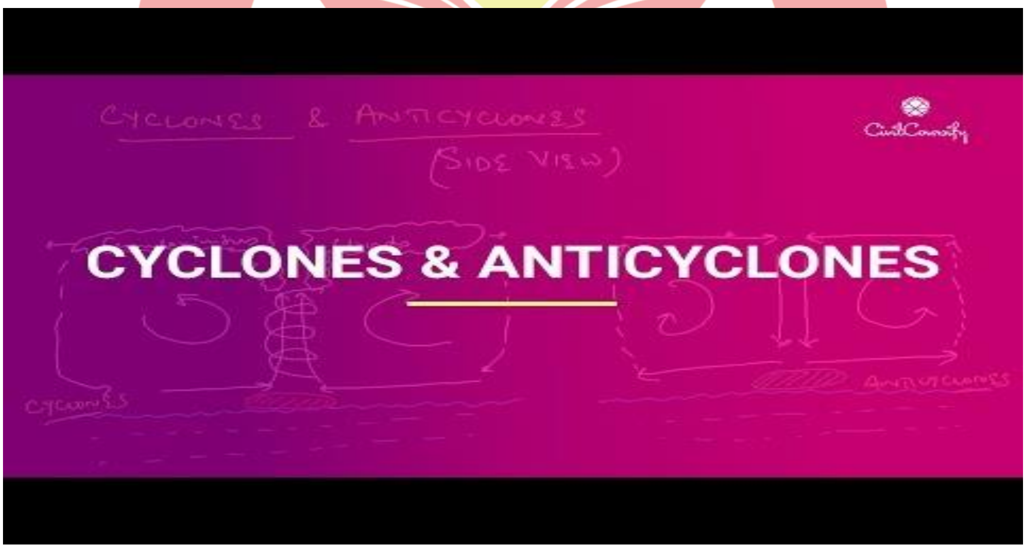
Continental Tropical Air Masses (CT)

- The source-regions of the air masses include tropical and sub-tropical deserts of Sahara in Africa, and of West Asia and Australia.
- These air masses are dry, hot and stable and do not extend beyond the source.
- They are dry throughout the year.

Maritime Tropical Air Masses (MT)

- The source regions of these air masses include the oceans in tropics and sub-tropics such as Mexican Gulf, the Pacific and the Atlantic oceans.
- These air masses are **warm, humid and unstable.**
- The weather during winter has mild temperatures, overcast skies with fog.
- During summer, the weather is characterized by high temperatures, high humidity, cumulous clouds and convectional rainfall.

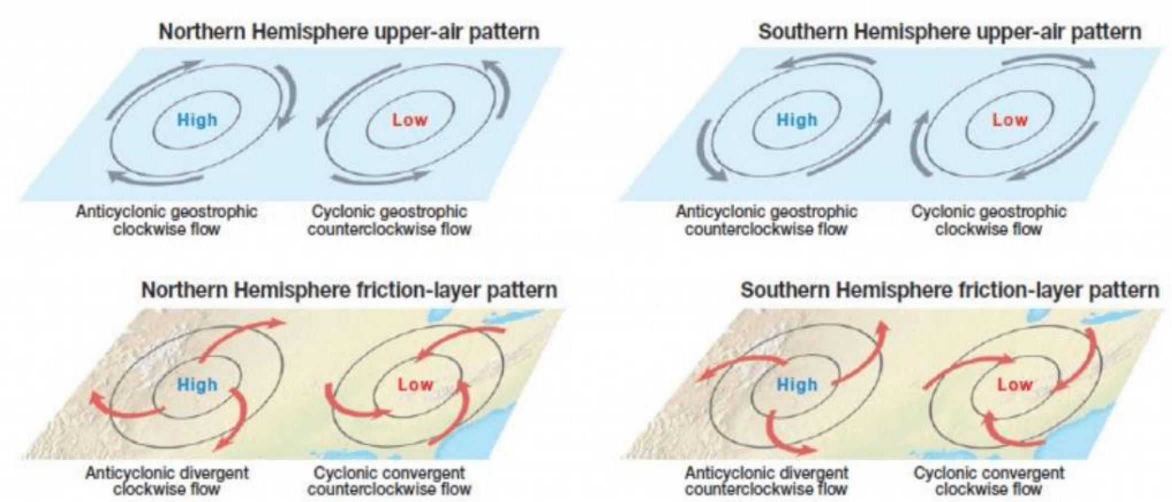
<u>Cyclones and Anticyclones</u>



High-Pressure Wind Patterns:

A high-pressure center is known as an anticyclone, and the flow of air associated with it is described as being anticyclonic.

The four patterns of anticyclonic circulation are shown in Figure –

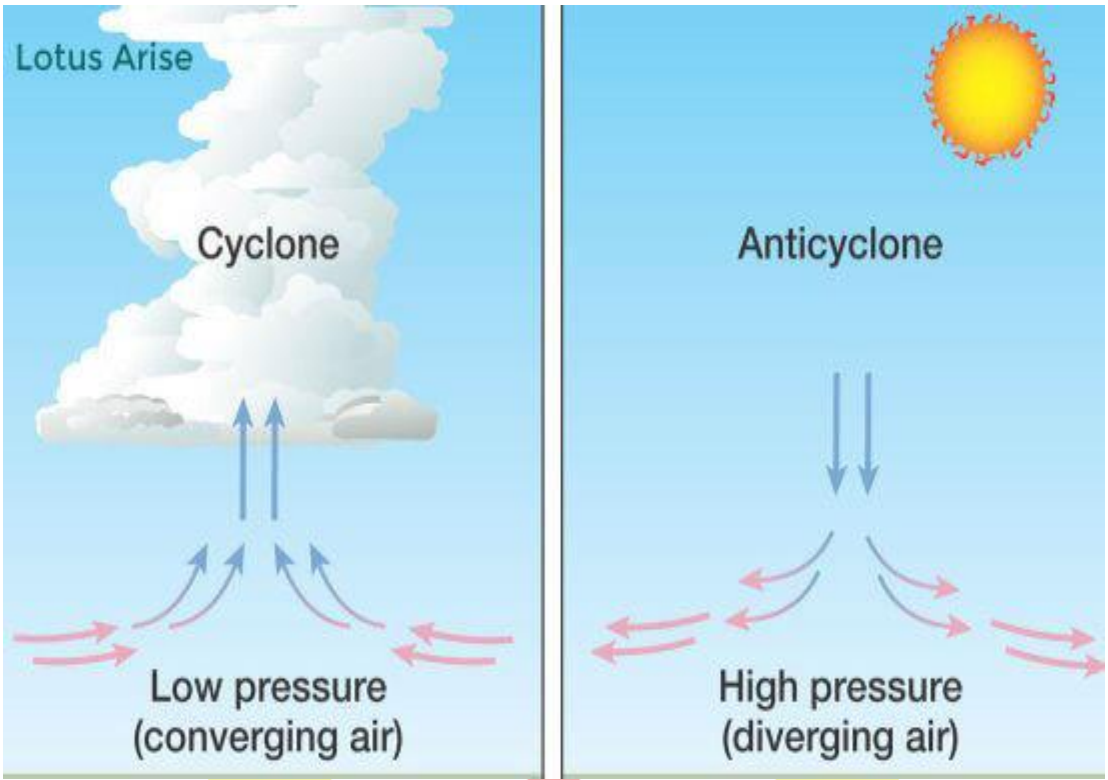


- In the upper atmosphere of the Northern Hemisphere, the winds move clockwise in a geostrophic manner parallel to the isobars.
- In the friction layer (lower altitudes) of the Northern Hemisphere, there is a divergent clockwise flow, with the air spiraling out away from the center of the anticyclone.
- In the upper atmosphere of the Southern Hemisphere, there is a counterclockwise, geostrophic flow parallel to the isobars.
- In the friction layer of the Southern Hemisphere, the pattern is a mirror image of the Northern Hemisphere, with air diverging in a counterclockwise pattern.
- Low-Pressure Wind Patterns: Low-pressure centers are called cyclones, and the associated wind movement is said to be cyclonic.
- As with anticyclones, Northern Hemisphere cyclonic circulations are mirror images of their Southern Hemisphere counterparts:
- In the upper atmosphere of the Northern Hemisphere, air moves counterclockwise in a geostrophic pattern parallel to the isobars.
- In the friction layer of the Northern Hemisphere, a converging counterclockwise flow exists.
- In the upper atmosphere of the Southern Hemisphere, a clockwise, geostrophic flow occurs paralleling the isobars.

- In the friction layer of the Southern Hemisphere, the winds converge in a clockwise spiral.

➢ **<u>Vertical Movement within Cyclones and Anticyclones:</u>**

A prominent vertical component of air movement is also associated with cyclones and anticyclones.



Air descends in anticyclones and rises in cyclones. Such motions are particularly notable in the lower troposphere. The anticyclonic pattern can be visualized as upper air sinking down into the center of the high and then diverging near the ground surface. Opposite conditions prevail in a low-pressure center, with the air converging horizontally into the cyclone and then rising.

- CYCLONES AND RISING AIR ARE ASSOCIATED WITH CLOUDS, WHEREAS ANTICYCLONES AND DESCENDING AIR ARE ASSOCIATED WITH CLEAR CONDITIONS.

Air mass	Symbol	Source Region	Properties
Maritime Equatorial	mE	warm ocean in equatorial zone	Unstable, warm, very moist
Maritime Tropical	mT	warm ocean in the tropical zone	warm, moist
Continentel Tropical	cT	Subtropical deserts	warm, dry
Maritime Polar	mP	Midlatitude oceans	cool, moist(winter)
Continental Polar	cP	Nothern continental interiors	cool, dry(winter)
Continental Arctic and Continental Antarctic	cAA	Regions near north and south poles	Very cold, very dry, very stable

➢ **Air Mass**

An air mass is a distinctive, homogenous, body of air in terms of temperature, humidity and lapse rate that takes on the moisture and temperature characteristic of its source region. For example, if an air mass is formed over Canada it will be very cold and dry.

Classification of air masses:

Air masses are classified on the basis of source region, latitudinal position, and temperature and moisture properties.

The two main categories of air masses are:

- Tropical or sub-tropical
- Polar or sub- polar

The sub division of these groups is made according to whether the source region is maritime or continental. They are also sub-divided according to what modifications the air masses experience as they move from their source regions.

To identify the different types of air masses, letter symbols are placed first in the designation. Following that the source region is indicated: Tropical (T), Polar (P), Equatorial (E), Arctic (A) and Antarctic (AA). 'k' (for the German kalt) for the air colder than the underlying surface or 'w' for the air warmer than the surface.

- **On the basis of origin it can bedivided into maritime and continental.**

The border between the two air masses with contrasting physical properties is known as fronts. A warm front marks the leading edge of a sector of warm air. Cold front denotes the influx of cold air.

- **<u>Fronts</u>**

The development of fronts and frontal waveforms are known as Frontogenesis. Frontogenesis occurs in well-defined areas.

When unlike air masses meet, they do not mix readily; instead, a boundary zone called a front develops between them. A front is not a simple two-dimensional boundary.

A typical front is a narrow three-dimensional transition zone several kilometers or even tens of kilometers wide. Within this zone, the properties of the air change rapidly. The frontal concept was developed by Norwegian meteorologist during World War I, and the term front was coined because these scientists considered the clash between unlike air masses to be analogous to the confrontation between opposing armies along a battlefront.

As the more "aggressive" air mass advances at the expense of the other, some mixing of the two occurs within the frontal zone, but for the most part the air masses retain their separate identities as one is displaced by the other.

<u>Types of Fronts:</u> The most conspicuous difference between air masses is usually temperature.

1. **<u>cold front-</u>** A cold front forms where an advancing cold air mass meets and displaces warmer air.

2. **<u>warm front</u>-** A warm front forms where an advancing warm air mass meets colder air.

A cold front forms when a cold air mass is actively under-riding a warm air mass. As a cold front advances, the warm air ahead of it is forced upward. This displacement often creates cloudiness and relatively heavy precipitation along and immediately behind the ground level position of the front.

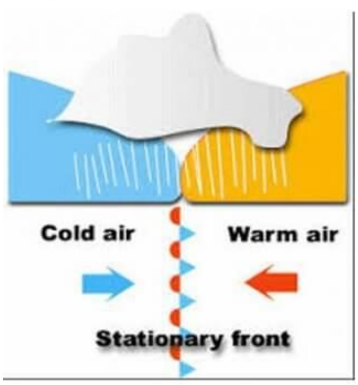
A warm front forms when a warm air mass is actively overriding a cold air mass. As warm air rises above cooler air, widespread cloudiness and precipitation develop along and in advance of the ground-level position of the front. Higher and less dense clouds are often dozens or hundreds of kilometers ahead of the ground-level position of the front.

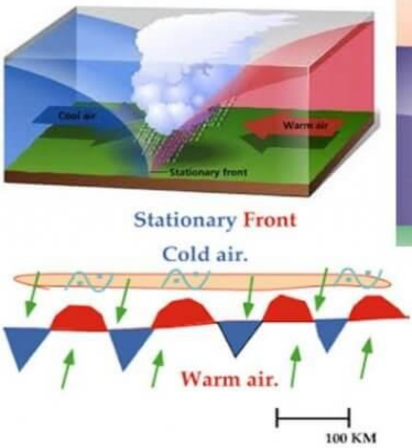
3. **<u>Stationary Fronts-</u>**

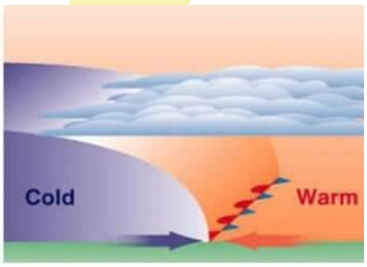
When neither air mass displaces the other or if a cold front or warm front "stalls"—their common boundary is called a stationary front.

It is difficult to generalize about the weather along such a front, but often gently rising warm air produces limited precipitation similar to that along a warm front.

As shown, stationary fronts are portrayed on a weather map by a combination of warm and cold front symbols, alternating on opposite sides of the line—cold air is opposite the triangles and warm air opposite the half circles.

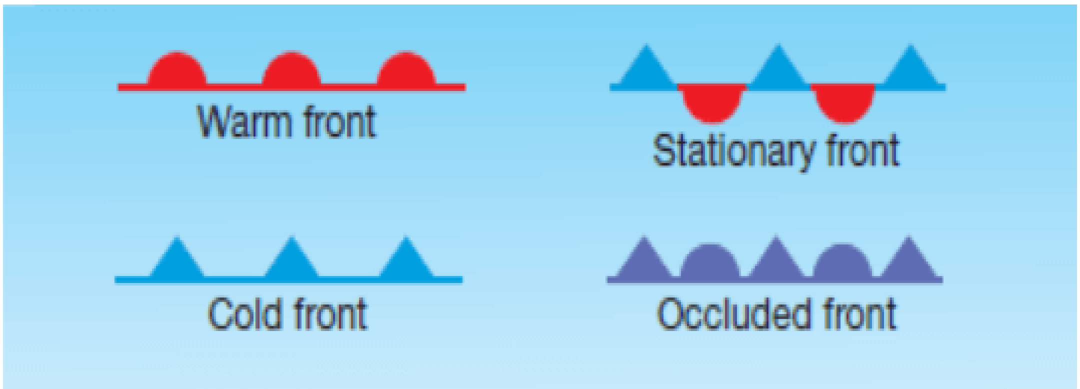






4. **<u>Occluded Fronts-</u>**

A fourth type of front, called an occluded front, is formed when a cold front overtakes a warm front. Occluded fronts are shown on a weather map by a combination of warm and cold front symbols, alternating on the same side of the line.



<u>Cyclones may be classified as –</u>

- **Temperate cyclones**
- **Tropical cyclones**

<u>Temperate Cyclones</u>

The temperate cyclones occur in the mid latitude of both the hemisphere. These cyclones are born along the polar front, particularly in the region of Icelandic and Aleutian sub –polar low pressure areas in the northern hemisphere.

Cyclogenesis: Development and strengthening of mid latitude wave cyclone is known as cyclogenesis. This is called the polar front theory, given by Bjerkness in 1918. On an average, a temperate cyclone takes 3-10 days to progress through the stages of development.

<u>The period of cyclone from its inception to its termination is called the 'life cycle of cyclone' which is completed through six successive stages.</u>

Stage A: the first stage involves the convergence of two air masses of contrasting physical properties and direction.

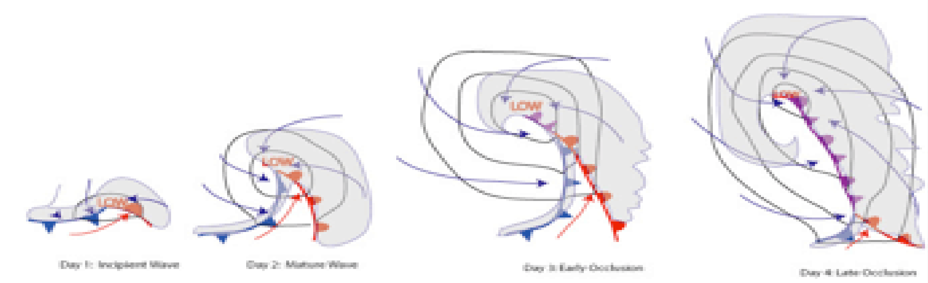
Stage B: it is called 'incipient stage' during which the warm and cold air masses penetrate into the territories of each other.

Stage C: it is mature when the cyclone is fully developed and isobars become almost circular.

Stage D: warm sector is narrowed in extent due to advancement of cold front at a faster rate than a warm front, and cold front comes nearer to warm front.

Stage E: this stage starts with the occlusion of cyclone when the advancing cold front finally overtakes the warm front and occluded front is formed.

Stage F: in the final stage, warm sector completely disappears, occluded front is eliminated and ultimately cyclone dies out.

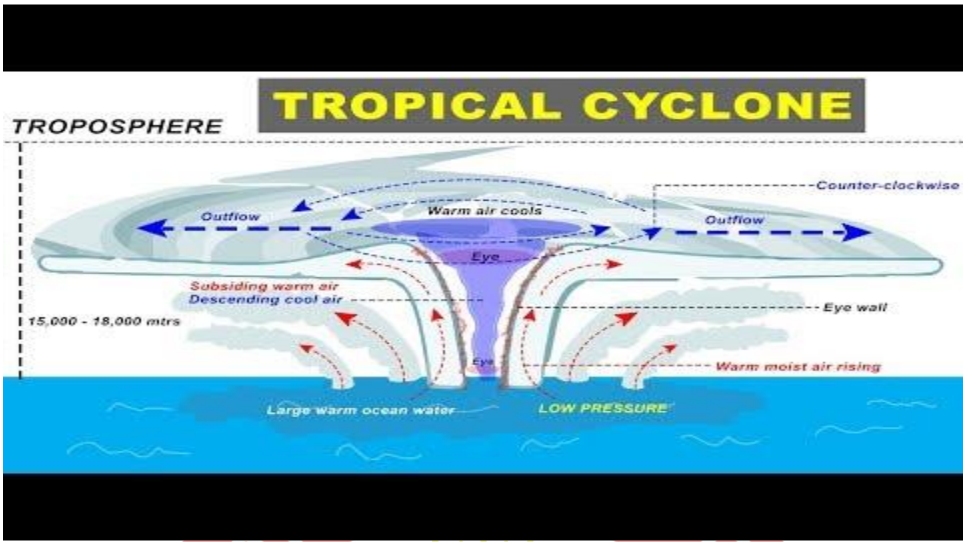


Stages in the Life Cycle of a Wave Cyclone
Grey Shading Indicates Cloudiness

<u>Characteristics of Temperate Cyclone:</u>

- The temperate cyclone moves counter clockwise in northern hemisphere and clockwise in southern hemisphere.
- It may be 1600km wide, thus a single cyclone may cover the whole Europe.
- The isobars are elliptical in shape.
- The cold air mass moves faster than the warm air mass.
- These cyclones move at a gentle pace of 5-25km per hour.
- They give light showers which are highly beneficial for the crops and human health and efficiency.
- In the ending part of cyclone there is thunder and lightning.
- Each cyclone is followed by a clear weather.

Tropical Cyclones



It is a weather system of low pressure, originating in the tropics within a single air mass, but may move into temperate waters if water temperature is high enough to sustain it.

Tropical cyclone gets its energy from latent heat of condensation. The energy in an average hurricane may be equivalent to more than 10,000 atomic bombs the size of Nagasaki bomb.

These storms range in size from a few kilometers to several hundred kilometers in diameter. In the middle is an eye that can be as large as 65km across. The total area involved may be as much as 52000 sq km. the tropical cyclones originate between 10° and 25 degree latitudes in both the hemispheres.

Conditions conducive for tropical cyclone:

- There should be continuous supply of abundant warm and moist air.
- The sea temperature in lower latitude should be around 26-27degree C.
- Existence of weak tropical depression.
- There should be presence of coriolis force.

Characteristics of tropical cyclones:

- The isobars are generally circular, and close to each other resulting into steep pressure gradient.
- They may be a thousand kilometers in diameter and about 15km in height.
- The central area is designated as an 'eye' of cyclone. The eye of cyclone is surrounded by clouds so high and dense that the day time sky above looks

dark. The central part of the tropical cyclone has clear sky in which the air descends from the above.

- They do not have fronts.
- They derive their energy from the latent heat.
- The clouds in the cyclone are cumulonimbus having vertical extension up to about 12- 15km.
- They give torrential rainfall.
- Majority of tropical cyclones decay when they come over the land or when they recurve northward over oceans.

Origin of Tropical Cyclone:

The origin of the tropical cyclones is not well understood. A tropical cyclone generally develops from a small tropical depression. Tropical depressions form easterly waves, areas of lower pressure within the easterly trade winds.

When air containing the disturbance is heated by the proximity of tropical waters with a temperature of about 26 degrees or more, circular winds begin to blow in the vicinity of the wave, and some of the warm humid air is forced upward. Condensation begins, and the storm takes shape. Under ideal conditions, the embryo storm reaches hurricane status (i.e. with wind speed in excess of 118 km per hr) in two to three days.

PLACES OF OCCURRENCE:

- The Caribbean Sea and the Gulf of Mexico.
- The northwest pacific from the Philippines to the China Sea.
- The Pacific Ocean west of Mexico.
- The South Indian Ocean east of Madagascar.
- The North Indian Ocean in the Bay of Bengal.
- The Arabian Sea.

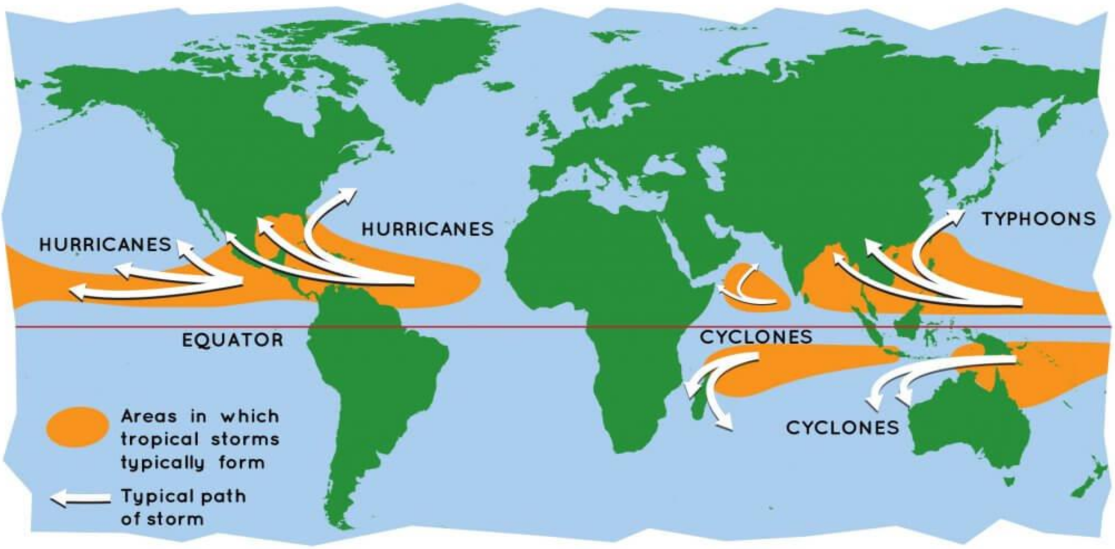
Nomenclature:

Large **tropical cyclones are called Hurricanes** in the North Atlantic and Eastern Pacific, **Typhoons in China**, **Taiphoo in Japan**, **cyclone or chakravaat in the Bay of Bengal**, **Baguio in the Philippines**, and **Willi Willies in Australia**.

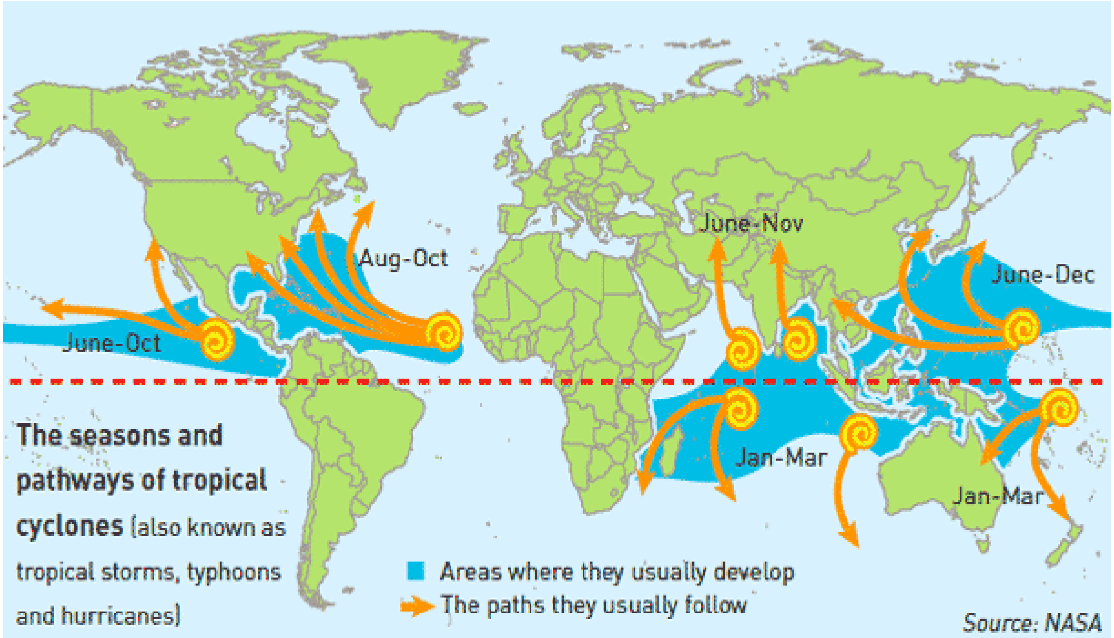
Cyclone, Hurricane, Typhoon

Hurricane, cyclone and typhoon are different terms for the same weather phenomenon: torrential rain and maximum sustained wind speeds (near center) exceeding 119 kilometers per hour:

- In the western North Atlantic, central and eastern North Pacific, Caribbean Sea, and the Gulf of Mexico, such a weather phenomenon is called "hurricanes".
- In the western North Pacific, it is called "typhoons "
- In the Bay of Bengal and the Arabian Sea, it is called "cyclones "
- In the western South Pacific and southeast India Ocean, it is called "severe tropical cyclones"
- In the southwest Indian Ocean, it is called "tropical cyclones".



CYCLONE, HURRICANE, TYPHOON



Severe Weather Events Survey

How are Cyclones named?

Cyclones that form in every ocean basin across the world are named by the regional **specialized meteorological centers (RSMCs) and Tropical Cyclone Warning Centres (TCWCs).**

There are **six** RSMCs in the world, including the India Meteorological Department (IMD), and five TCWCs.

Lists and names of Cyclones are maintained and updated by an international committee of the World Meteorological Organisation (WMO). According to WMO guidelines, countries in every region are supposed to give names for cyclones.

- IMD, one of the six Regional Specialised Meteorological Centres (RSMC) in the world, is mandated to issue advisories and name tropical **cyclones** in the north Indian Ocean region.
- The advisories are issued to 13 member countries under WMO/ESCAP Panel including Bangladesh, India, Iran, Maldives, Myanmar, Oman, Pakistan, Qatar, Saudi Arabia, Sri Lanka, Thailand, United Arab Emirates, and Yemen.

Benefits of naming:

Naming of tropical cyclones helps the scientific community, disaster managers, media and general masses to

- Identify each individual cyclone.
- Create awareness of its development.
- Remove confusion in case of simultaneous occurrence of tropical cyclones over a region.
- Remember a tropical cyclone easily,
- Rapidly and effectively disseminate warnings to a much wider audience.

Naming of the Tropical Cyclones

- The WMO/ESCAP Panel on Tropical Cyclones (PTC) at its 27th Session held in 2000 in Muscat, Oman agreed in principle to assign names to the tropical cyclones in the Bay of Bengal and the Arabian Sea.
- The naming of the tropical cyclones over the north Indian Ocean **commenced from September 2004.**
- This list contained names proposed by then **eight member countries** of WMO/ESCAP PTC, viz., Bangladesh, India, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, and Thailand.
- The requirement for a fresh list of tropical cyclones including representation from five new member countries**:** Iran, Qatar, Saudi Arabia, United Arab Emirates, and Yemen (total 13 member countries) was tabled during the 45th session of WMO/ESCAP, held in September 2018. The session was hosted by **Oman.**

Panel on Tropical Cyclones

- The **World Meteorological Organization (WMO)** and the **Economic and Social Commission for Asia and the Pacific (ESCAP)** jointly established the **Panel on Tropical Cyclones (PTC)in 1972 as an intergovernmental body.**

- Its membership comprises countries affected by **tropical cyclones in the Bay of Bengal and the Arabian Sea.**

- The Panel is one of the five **regional tropical cyclone bodies** established as part of the **WMO Tropical Cyclone Programme (TCP)** which aims at promoting and coordinating the planning and implementation of measures to **mitigate tropical cyclone disasters** on a worldwide basis.

- For this purpose, there are Regional Specialized Meteorological Centre (RSMC)- Tropical cyclone and Tropical Cyclone Warning Centres (TCWC) for different regions.

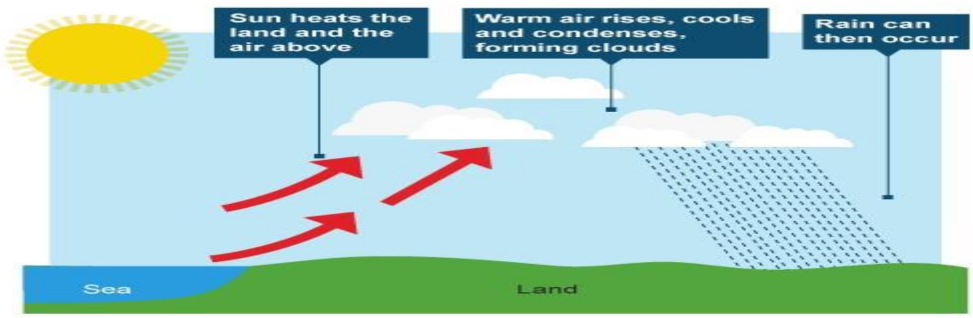
- The main objective of the WMO/ESCAP Panel on Tropical Cyclones is to promote measures to improve tropical cyclone warning systems in the Bay of Bengal and the Arabian Sea.

Types of Rainfall

- On the basis of origin, rainfall may be classified into three main types – the **convectional, orographic or relief** and the **cyclonic or frontal.**

Conventional Rainfall

- The, air on being heated, becomes light and rises up in convection currents. As it rises, it expands and loses heat and consequently, condensation takes place and cumulous clouds are formed. This process releases latent heat of condensation which further heats the air and forces the air to go further up.
- Convectional precipitation is heavy but of short duration, highly localised and is associated with minimum amount of cloudiness. It occurs mainly during summer and is common over equatorial doldru**ms** in the Congo basin, the Amazon basin and the islands of south-east Asia.
- Adiabatic Lapse Rate – Latent Heat of Condensation



Orographic Rainfall

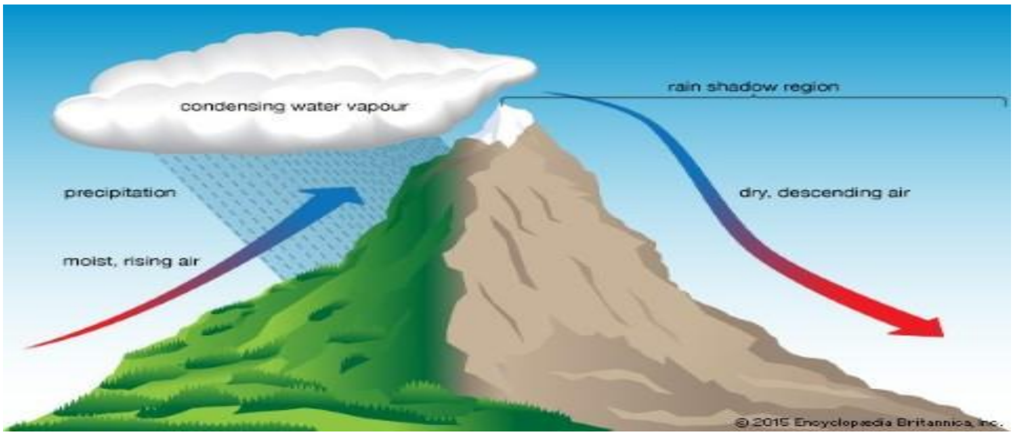
- When the saturated air mass comes across a mountain, it is forced to ascend and as it rises, it expands (because of fall in pressure); the temperature falls, and the moisture is condensed.

- This type of precipitation occurs when warm, humid air strikes an orographic barrier (a mountain range) head on. Because of the initial momentum, the air is forced to rise. As the moisture laden air gains height, condensation sets in, and soon saturation is reached. The surplus moisture falls down as orographic precipitation along the windward slopes.

- The chief characteristic of this sort of rain is that the **windward slopes** receive greater rainfall. After giving rain on the windward side, when these winds reach the other slope, they descend, and their temperature rises. Then their capacity to take in moisture increases and hence, these **leeward slopes** remain rainless and dry. The area situated on the leeward side, which gets less rainfall is known as the **rain-shadow area** (Some arid and semi-arid regions are a direct consequence of rain-shadow effect. Example: **Patagonian Desert in Argentina, Eastern slopes of Western Ghats**). It is also known as the **relief rain.**

- Example: Mahabaleshwar, situated on the Western Ghats, receives more than 600 cm of rainfall, whereas Pune, lying in the rain shadow area, has only about 70 cm.

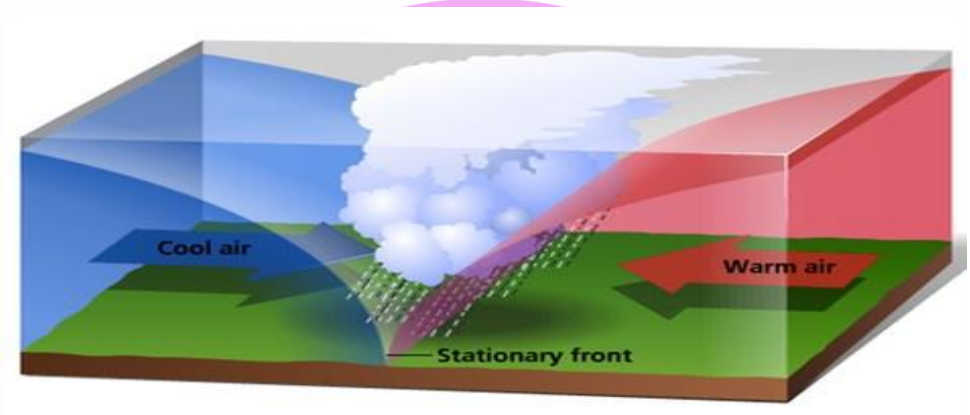
The Wind Descending on the Leeward Side is heated adiabatically and is called **Katabatic Wind.**



Frontal Precipitation

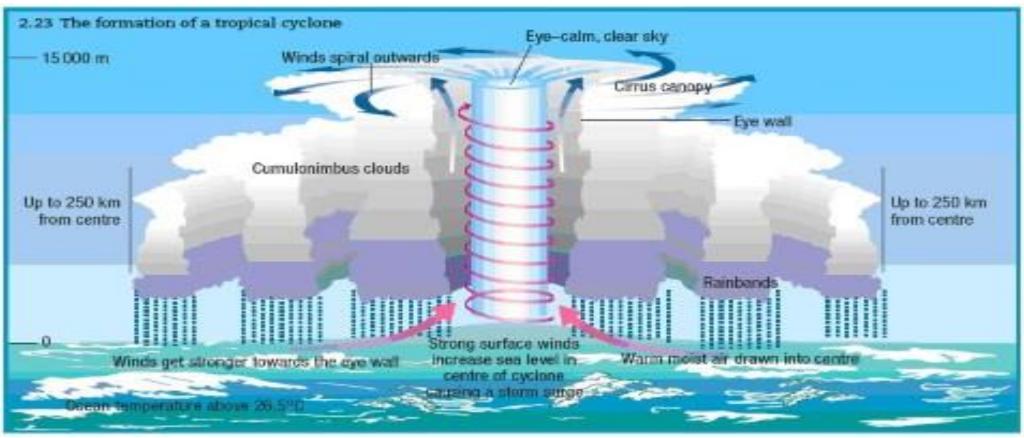
- When two air masses with different temperatures meet, turbulent conditions are produced. Along the front convection occurs and causes precipitation (we studied this in Fronts). For instance, in north-west Europe, cold continental air and warm oceanic air converge to produce heavy rainfall in adjacent areas.

Fronts – Frontogenesis – Stationary Front, Cold Front, Warm Front, Occluded Front



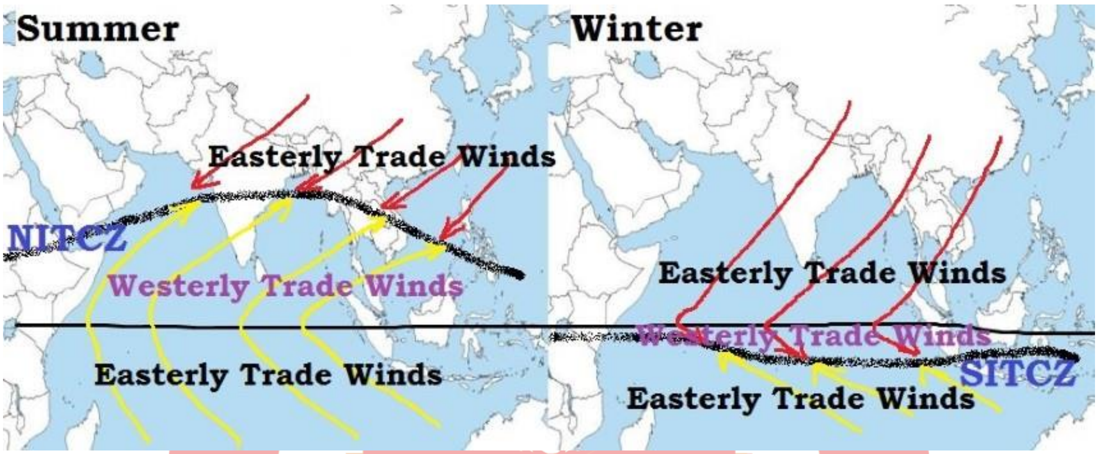
Cyclonic Rain

- Cyclonic Rainfall is **convectional rainfall on a large scale**. (we will see this in detail later)
- The precipitation in a tropical cyclone is of convectional type while that in a temperate cyclone is because of frontal activity.



Monsoonal Rainfall

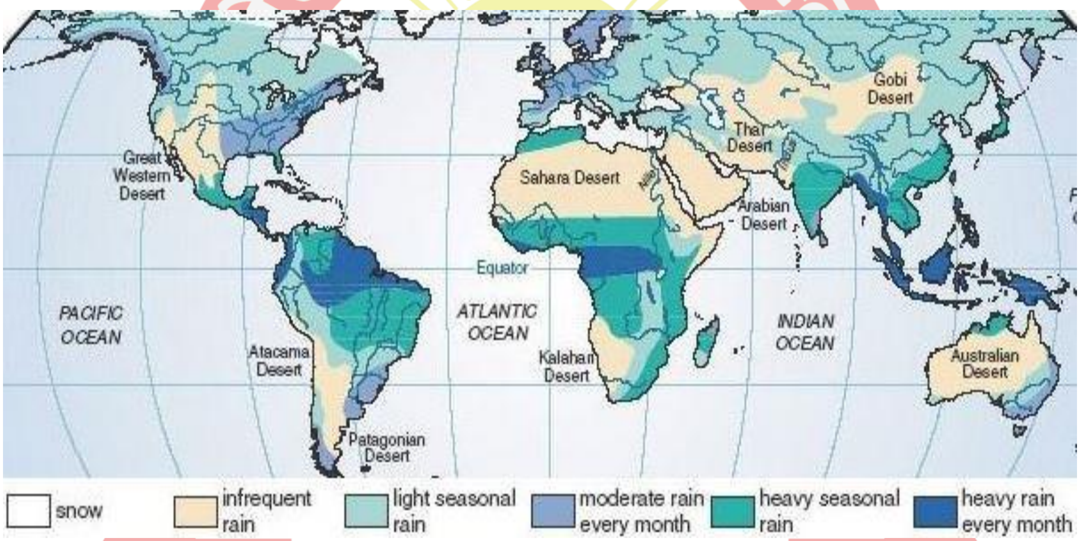
- This type of precipitation is characterized by **seasonal reversal of winds** which carry oceanic moisture (especially the south-west monsoon) with them and cause extensive rainfall in south and southeast Asia. (More while studying Indian Monsoons).



World Distribution of Rainfall

- Different places on the earth's surface receive different amounts of rainfall in a year and that too in different seasons. In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily.
- The coastal areas of the world receive greater amounts of rainfall than the interior of the continents. The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water.
- Between the latitudes 35° and 40° N and S of the equator, the rain is heavier on the eastern coasts and goes on decreasing towards the west. But, between 45° and 65° N and S of equator, due to the **westerlies**, the rainfall is first received on the western margins of the continents and it goes on decreasing towards the east.
- Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side.
- On the basis of the total amount of annual precipitation, major precipitation regimes of the world are identified as follows.

- The equatorial belt, the windward slopes of the mountains along the western coasts in the cool temperate zone and the coastal areas of the monsoon land receive heavy rainfall of over 200 cm per annum.
- Interior continental areas receive moderate rainfall varying from 100 – 200 cm per annum. The coastal areas of the continents receive moderate amount of rainfall.
- The central parts of the tropical land and the eastern and interior parts of the temperate lands receive rainfall varying between 50 – 100 cm per annum.
- Areas lying in the **rain** shadow zone of the interior of the continents and high latitudes receive very low rainfall – less than 50 cm per annum.
- Seasonal distribution of rainfall provides an important aspect to judge its effectiveness. In some regions rainfall is distributed evenly throughout the year such as in the equatorial belt and in the western parts of cool temperate regions.



CLIMATE CLASSIFICATION

1. **Koeppen's Climate Classification**

- Koeppen's Classification of climate is the most commonly used classification of climate.
- This climate classification scheme was developed by Wladimir Peter Koeppen in 1884.
- He recognized a close relationship between the distribution of vegetation and climate.
- The categories are based on the data of annual and monthly averages of temperature and precipitation.
- He selected specific values of temperature and precipitation and related them to the distribution of vegetation and used these values for classifying the climates.
- The Koeppen climate classification system recognizes five major climatic types and each type is designated by a capital letter- A, B, C, D, E, and H.
- The seasons of dryness are indicated by the small letters: f, m, w, and s.
    - f -no dry season
    - m – Monsoon climate
    - w- Winter dry season
    - s – Summer dry season
- The small letters a, b, c, and d refer to the degree of severity of temperature.

List of climatic groups and their characteristics according to Koeppen

Group	Characteristics
A- Tropical	The average temperature of the coldest month is 18° C or higher
B- Dry Climates	Potential evaporation exceeds precipitation
C- Warm Temperate	The average temperature of the coldest month of the (Mid-latitude) climates years is higher than minus 3°C but below 18°C
D- Cold Snow forest	The average temperature of the coldest month is minus 3° C or below
E- Cold Climates	Cold Climates Average temperature for all months is below 10° C
H- Highlands	Cold due to elevation

Climatic Types According to Koeppen

Group	Type	Letter Code	Characteristics
A-Tropical Humid Climate	Tropical Wet Tropical Monsoon Tropical wet and dry	Af Am Aw	No dry season Monsoonal, Short dry season Winter dry season

B-Dry Climate	Subtropical Steppe Subtropical Desert Mid-latitude Steppe Mid-latitude Desert	BSh BWh BSk BWk	Low-latitude semi-arid or dry Low-latitude arid or dry Mid-latitude semi-arid or dry Mid-latitude arid or dry
C-Warm temperate Climates	Humid subtropical Mediterranean Marine west coast	Cfa Cs Cfb	No dry season Dry hot summer No dry season, warm and cool summer
D- Cold Snow-forest Climates	Humid Continental Subarctic	Df Dw	No dry season, severe winter Winter dry and very severe
E-Cold climates	Tundra Polar ice cap	ET EF	No true summer Perennial ice
H-highland	Highland	H	Highland with snow cover

2. Thornthwaite classification

C. W. Thornthwaite, an American climatologist, presented his first scheme of classification of climates of North America **in 1931** when he published the climatic map of North America.

Later he extended his scheme of climatic classification for world climates and presented his full scheme **in 1933.**

He further modified his scheme and presented the revised second scheme of classification of world climates **in 1948**. In his 1948 concept; gave the potential evapotranspiration concept. His scheme is complex and empirical in nature.

In 1931, his classification looked similar to Koeppen. Like Koeppen, Thornthwaite also thought that vegetation is the indicator of climate type.

Two basic features of this classification are

1. **Precipitation** Effectiveness; **(P/E**, where P is the total monthly precipitation and E is the total monthly evaporation)
2. **Temperature** Efficiency.

On the basis of these two indicators, Thornthwaite divided the world into five humidity regions.

- A: Very Humid Rain Forest
- B: Humid Forest
- C: Semi Humid Grassland
- D: Semi-Dry Steppe
- E: Dry Desert

Each region had its own special type of vegetation as shown in the table below:

Sr. No.	Humidity Region	Special type of Vegetation
A	Very Humid	Rain Forest
B	Humid	Forest
C	Semi Humid	Grassland
D	Semi Dry	Steppe
E	Dry	Desert

Design of Thornthwaite Climatic Classification

Thornthwaite's design of climate classification is a combination of three letter alphabets**.**

1. The first alphabet used in the major climatic classification is any one of the English capital letters from A to E.
2. The second letter used in the climatic classification is also an English capital alphabet superscript with a dash**.** It denotes thermal provinces.
3. **The third letter** in a combination of **alphabets is denoted by a set of 8 small English alphabets.**

Precipitation effectiveness

- Plants' growth is not only dependent on precipitation but precipitation effectiveness.
- Precipitation effectiveness P/E ratio=total monthly precipitation/ Evapotranspiration P/E index= sum of 12-month P/E ratio.
-

Based on the P/E index, Thornthwaite classified five humidity region**:**

- A: (P/E index>128) – Wet-Rainforest.
- B: (P/E Index 64 to 127) – Humid-Forest
- C: (P/E index 32 to 63) – Subhumid-Grassland.
- D: (P/E index 16-32) – Semi Arid-Steppe
- E: (P/E index less than 16) – Arid-Desert

On the basis of precipitation effectiveness, thermal efficiency, and seasonal distribution of rainfall there may be 120 probable combinations and hence climatic types on the theoretical ground but he depicted only 32 climatic types on the world.

On the basis of the distribution of seasonal rainfall the above types of humidity regions were further divided into the following subdivisions:

- **r** = Heavy rainfall in all seasons
- **s** = Scarcity of rainfall in the summer season
- **w** = Scarcity of rainfall in the winter season
- **d** = Scarcity of rainfall in all seasons
- **Aridity index for humid climates**
- Moisture deficit acute during winter = w2
- Moisture deficit acute during summer =s2
- **Humidity index for arid climates**
- Moisture surplus abundant during winter =s2

- Moisture surplus abundant during summer = w2

Letter	Humidity province	Vegetation	P-E index
A	Wet	Rainforest	> 127
B	Humid	Forest	64-127
C	Subhumid	Grassland	32-63
D	Semiarid	Steppe	16-31
E	Arid	Desert	< 16

<u>Temperature efficiency</u>

- Temperature efficiency is calculated mean average temperature of through years.
- Based on Temperature efficiency – Thornthwaite has divided the world into six thermal provinces. They are expressed as:

1) A' — tropical: (T/E index more than 128).
2) B' — Subtropical: (T/E index 64-127).
3) C' — Temperate: (T/E index 32 – 63)
4) D' — Taiga: (T/E index 16-31)
5) E' — Tundra: (T/E index 1-15).
6) F' — Frost: (T/E index 0).

Thornthwait was being criticized for making climatic classification complex. To make it simple, Thornthwait gave the evapotranspiration concept to derive a climatic region in 1948.

Evapotranspiration**:** COMBINED, *evaporation from the soil and transpiration from vegetation* IS CALLED EVAPOTRANSPIRATION.

The modified Thornthwaite system (1948) is based on the concept of potential evapotranspiration (Potential ET), which approximates the water use of plants with an unlimited water supply.

Though he again used previously devised three indices of precipitation effectiveness, thermal efficiency, and seasonal distribution of precipitation in his second classification but in a different way.

Instead of vegetation, as done in 1931 classification, he based his new scheme of climatic classification on the concept of potential evapotranspiration (PE)**.**

Which is in fact an index of thermal efficiency and water loss because it represents the amount of transfer of both moisture and heat to the atmosphere from soils and vegetation (evaporation of liquid or solid water, and transpiration from living plant leaves) and thus is a function of energy received from the sun.

Index in modified method

- Aridity Index (Ia)
- Humidity Index (Ih)
- Soil Moisture Index (Im)

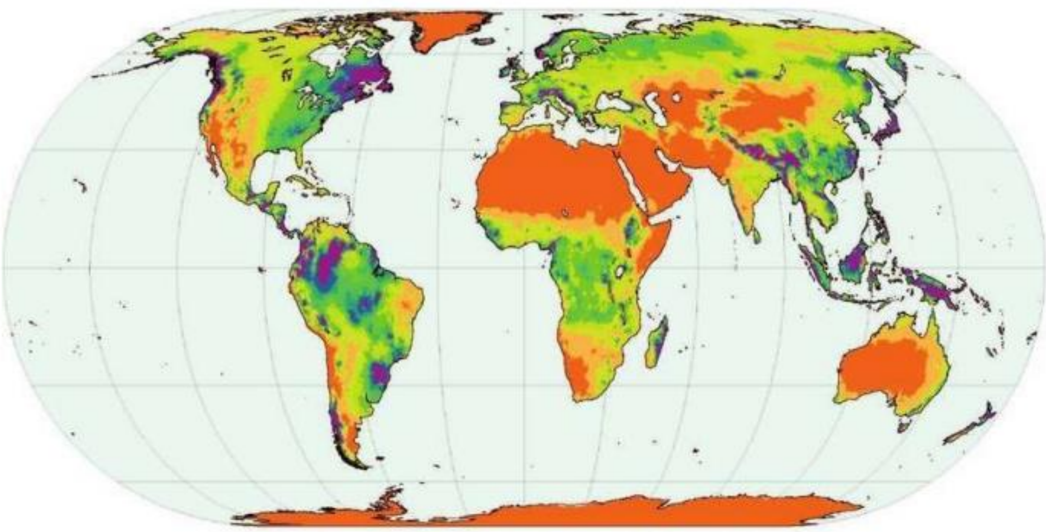
if: PET >Precipitation = Soil Moisture 0/-ve
if: Precipitation > PET = Soil Moisture +ve

- Moist Climate determined by Aridity Index (variability in summer and winter)
- Dry climate determined by Moisture Index

Symbol	Moist Climate (A, B, C_2)	Aridity Index (I_a)
r	Little or no moisture deficit	0-16.7
s	Summer deficit (normal)	16.7-33.3
w	Winter deficit (normal)	16.7-33.3
s_2	Summer deficit (acute)	33.3+
w_2	Winter deficit (acute)	33.3+
Symbol	Dry Climate (C_1, D, E)	Humidity Index (I_h)
d	Winter surplus negligible	0-10
s	Winter moisture surplus (normal)	10-20
w	Summer moisture surplus (normal)	10-20
s_2	Winter moisture surplus (abundant)	20+
w_2	Summer moisture surplus (abundant)	20+

Humidity Provinces	Thermal Efficiency Index
A' (Megathermal)	Over 114
B'_4 (Mesothermal)	99.7 to 114
B'_3 (Mesothermal)	60 to 80
B'_2 (Mesothermal)	40 to 60
B'_1 (Mesothermal)	57 to 71.2
C'_2 (Microthermal)	0 to 20
C'_1 (Microthermal)	-20 to 0
D' (Tundra)	-40 to -20
E' (Frost)	-60 to -40

Humidity Provinces	Moisture Index (I_m)
A (Perhumid)	Over 100
B_4 (Humid)	80-100
B_3 (Humid)	60-80
B_2 (Humid)	40-60
B_1 (Humid)	20-40
C_2 (Moist sub-humid)	0 to 20
C_1 (Dry sub-humid)	-20 to 0
D (Semi-arid)	-40 to -20
E (Arid)	-60 to -40



Climatic types based on the 1948 Thornthwaite moisture index

<u>Criticism of the Thornthwaite Climatic Classification</u>

1. Thornthwaite's classification of world climates is improved qualitatively. However, classification seems to have ignored the role of prevailing winds, relative humidity, air pressure, and air masses.
2. The classification system has proved most satisfactory in the case of North America where vegetation boundaries nearly coincide with particular P/E values. But it is not satisfactory for tropical and semiarid areas.
3. The calculation of soil moisture balance for different natural regions and vegetation zones poses a basic problem. Several combinations at local and regional levels increase complexity obscuring the clarity of classification.

4. Availability of data for all the meteorological variables over time and space is a serious problem.
5. Despite being an improved classification qualitatively, it is being less used and of limited application because of its complex nature.
6. The classification of climate seems to have ignored the role of relief, the position of the sun with reference to the incidence of solar radiation on the earth.
7. Current issues of global warming, climate change, and increasing incidence of extreme events do not find a place in Thornwaite's classification of world climates.

<u>Thornthwaite climatic division of India</u>

The following are the climatic division of India as per the Thornthwaite concept of Evapotranspiration.

<u>Humid(A) region of India:</u>

- Western Ghats
- Most parts of the NorthEastern States

<u>Humid(B) region of India:</u>

- Adjoining region of the Perhumid region

<u>Moist Sub Humid(C1) climatic region</u>

- Narrow belt Adjoining region of the humid region of Western Ghats.
- Eastern India comprises of West Bengal and Orissa

<u>Dry Sub Humid(C2) regions:</u>

- Northern Narrow belt of the Ganga basin.
- Part of Uttar Pradesh, Bihar, MP, Chhattisgarh, Jharkhand
- Western Maharastra and Southern Gujarat

<u>Semi-Arid(D) climatic region:</u>

- Part of Punjab and Haryana
- Eastern part of Rajasthan, Maharashtra, Karnataka, Lenangna
- Western Pat of Tamilnadu.

Arid climatic(E) region of India:

- Western Rajasthan
- Western Himalayan
- Rainshadow zone of western Ghats

3. Trewartha classification

The Trewartha climate classification is a climate classification system first published by American geographer Glenn Thomas Trewartha in 1966.

The Trewartha climate classification scheme is considered a modified version of the Koeppen system.

Besides being 'simple and explanatory, Trewartha's classification combines the basic fundamentals of the empirical as well as the genetic classification schemes.

Trewartha, while proposing his climatic classification, was conscious of the fact that the classification systems of Koeppen and 'Thornthwaite being based on certain statistical parameters of certain weather elements were cumbersome and complex.

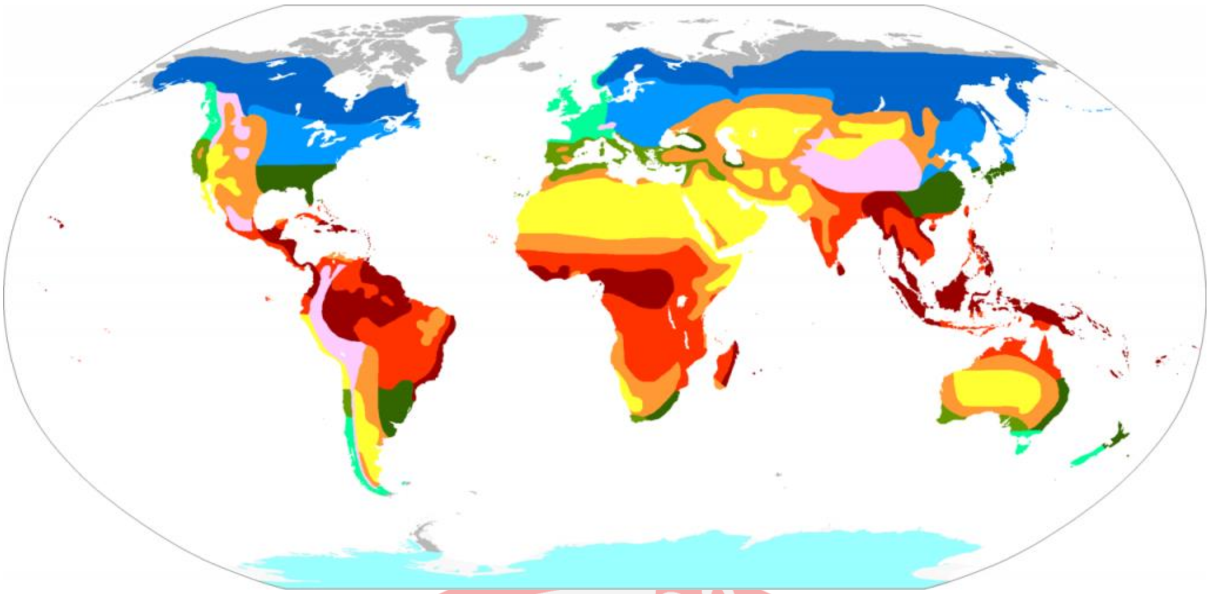
Trewartha recognized only a limited number of principal climatic types. He made use of the two most important and basic weather elements,

i.e., temperature and precipitation as the basic for his own classification.

Besides these, **the effects of land and water surfaces on the climate of an area have also been taken into consideration.**

He has classified world climates in seven climatic groups

- out of which **six-A, C, D, E, F, and H** – are **based on temperature criteria**, and
- Group A: Tropical climates
- Group C: Subtropical climates
- Group D: Temperate and continental climates
- Group E: Boreal climates
- Group F: Polar climates
- Group H: Highland climates
- the seventh- **B** – is the **dry group based on precipitation.**
- Group B: Dry (arid and semi-arid) climates



TREWARTHA CLIMATE TYPES FOR THE WORLD

Climatic Groups Based on Temperature Criteria

Group A

- This is the **tropical climate group.**
- This type of climate is found in the low latitudes on each side of the equator in an irregular belt 20° to 40° wide.
- There is – no winter season in-this climatic-group.
- Temperature is uniformly high throughout the year **with** adequate annual rainfall**.**
- In marine areas**,** the average temperature for the coldest month is around 18°C to 20°G.

This climatic group is subdivided into two climatic types:

1. **Ar**
2. **Aw**

(i) Ar:

- Ar. is a **tropical wet climate.**
- This type of climate is characterized by **less than two dry months.**
- The climate is under the influence of the intertropical convergence zone and the equatorial westerlies.
- The belt is distinguished by constant low pressure and is **also known as the tropical rainforest.**

(ii) Aw:

- Aw is a tropical wet-and-dry climate**.**
- At the time of the low sun, two months are usually dry.
- The climatic regions are dominated by the dry trade winds or subtropical anticyclones.
- During the high sun period, the equatorial westerlies and intertropical convergence control the weather.
- The duration of the dry season is usually longer than that of the wet season.
- The temperature remains uniformly high in this type of climate.

Group C

- This category encompasses subtropical climate with temperatures above 10 °C for only eight or more months.
- Frosts occur occasionally in continental parts**,** but the marine locations remain frostless,

On the basis of the seasonal distribution of precipitation, the subtropical climate is further classified into two climatic types:

1) **Cfw**
2) **Cs**

(i) Cfw:

- Cfw. is a sub-tropical humid climate.
- This type of climate is found on the eastern side of continents.
- It has no distinct dry season and rains fall throughout the year.
- During the summer season**,** this type of climate comes under the influence of unstable air in the western end of a subtropical anticyclone.
- But & ring winter, the climate is influenced by temperate cyclones.

(ii) Cs:

- Cs. is a sub-tropical dry summer climate.
- It is characterized by a moderate to scanty amount of precipitation.
- Winter is the rainy season**,** while summers are nearly or completely dry.
- This climate type represents a transition zone between the tropical dry climates towards the equator and the temperate climates towards the poles.
- The average annual precipitation is less than 890 mm (35 inches).

Group D

- This group represents temperate climates.
- The climatic group is also known as the micro-thermal climatic type.
- The average temperature is around 10 °C for 4 to 8 months.
- This type of climate is found in the middle latitudes between the sub-tropical and boreal climates.

The two types of climate that are included in the temperate group of humid climates are:

1) **Do**
2) **Dc**

(i) Do:

- Do. is temperate marine climate.
- With mild winters, the average temperature for all the 12 months is 0 °C or above.
- A humid climate with adequate precipitation at all seasons, it is found on the western windward side of the continents in the temperate zone.

(ii) Dc:

- Dc. is a temperate continental climate found in the continental interiors of the middle-latitude continents.
- The climate is basically land-controlled.
- The climatic type is characterized by severe winters and summers.
- Annual temperature ranges are, therefore, high throughout this climate, Cold waves, heat waves, blizzards, and heavy downpours are all yearly events in this category, of climate.
- Precipitation occurs throughout the year with maximum concentration during summers.

Group E

- The group represents sub-arctic or boreal climate found in the higher middle latitudes.
- Super-continental in temperate features, here the summers are short and comparatively cool.
- The winters are, however, long and very cold with a very short frost-free season.

- The average temperature hovers around 10 °C for one to three months during the year.
- The rest of the year has an average temperature below 10 °C.
- These regions are characterized by the lowest annual means of temperature for any part of the earth.
- Even though boreal climates are classified as humid, annual precipitation is comparatively very less.
- Precipitation occurs throughout the year, most during the warmer months when the amount of water vapour present in the air is highest.
- Because of the severity of climate, the population is sparse.

Group F

- The group consists of polar climate found in the high latitudes.
- The climate is confined to the northern hemisphere only.
- The average temperature in this type of climate seldom exceeds -1O °C.
- There is no summer season.

The polar climates are classified into the following two climatic types:

(i) Ft:

- Ft. is Tundra climate found only in the northern hemisphere**,** where it occupies the coastal sides of the Arctic Ocean, and many Arctic islands and ice-free shores of northern Iceland and southern Greenland.
- No tundra climate is found in the southern hemisphere because of the complete absence of extensive land areas.
- The Tundra region, essentially a region of grasses, mosses, and lichen, is characterized by the absence of trees. The average temperature of the warmest month is recorded between 0 °C and 10 °C.

(ii) Fi:

- Fi. is an ice-cap climate in which the average temperature for all the months is below freezing.
- There is no vegetation of any kind. The land is permanently covered with ice and snow**.**
- The climate is exclusively confined to the ice-caps of Greenland and Antarctica.

Group H

- The group represents highland climates in which altitude plays a role in determining climate classification.

- The temperature under normal conditions decreases with altitude, with the summit area of a mountain being always cooler than its base.
- Windward slopes force the incoming air to rise up with the resultant condensation, cloud formation, and precipitation.
- The leeward slopes are characterized by descending air which is warmed up and produces little precipitation.

Trewartha says there is no such thing as a highland type of climate because various types of local climates exist in every significant mountain range**.** There are no typical temperature and rainfall regimes in the highland climates.

Climate Group based on Precipitation Criteria:

<u>Group B</u>

- This group represents a dry climate.
- The boundaries of this type of climatic group are fixed by precipitation values.
- The characteristic feature of a dry climate is that the loss of moisture through evapotranspiration is far in excess of the annual water gain collected from precipitation.
- Because of clear and calm weather and the dry atmosphere, the dry climates are quite severe for their latitudes with large annual ranges of temperature.
- Precipitation is comparatively very low in this type of climatic group**.** Relative humidity, high potential evaporation, abundant sunshine, and small cloudiness are some of the common features of Group B classification.

They are further classified into two climatic groups.

1. **BW:** BW is an **arid or desert type** of climate.
2. **BS:** BS is a **semi-arid or steppe type** of classification.

BW and BS are further classified into the following subdivisions on the basis of temperature:

- **BWh:** BWh is **tropical-subtropical hot deserts**;
- **BWK:** BWK is **temperate boreal cold deserts;**
- **BSh:** BSh is **tropical-boreal steppes**; and
- **BSk:** BSk is **temperate-boreal and cold**.

The BWh and BWK climates are constantly dry and are under the influence of subtropical high and dry trades.

The BWh type of condition lasts for 8 months or more with an average temperature over 10 °C while the BWK lasts fewer than 8 months with an average temperature above 10 °C.

The BSh is characterized by a short moist season and is greatly influenced by subtropical high and dry trades.

The BSK type of climate receives most of its major annual precipitation during the warmer season.

Trewartha Climatic Classification of India

Trewartha's classification of climate, which is a modified form of Koeppen's scheme, corresponds with the vegetative, agricultural, and even geographical regions of India, in a fairly satisfactory manner.

Four major climatic groups (A, B, C, and H) which are further **subdivided into seven climatic type**s have been recognized.

They are as follows:

1) **A: Tropical Rainy Climatic Group**
- Am—Tropical Monsoon
- Aw—Tropical Savannah

2) **B: Dry Climatic Group**
- BS—Tropical Steppe (semi-arid)
- Bsh—Sub-Tropical Steppe
- Bwh—Sub-Tropical Desert

3) **C: Humid Mesothermal Climatic Group**
- Caw—Sub-Tropical Humid (Dry Winters)

4) **H: Mountain Climate**

The climatic letters **A, B, C, and H stand for the major groups of climate** and the other letters designate the sub-divisions of major groups.

- **A stands for the tropical rainy climate** with persistently high temperature which is not less than 18° C in the coolest month.
- **B is a dry climate** of those regions where the rate of evaporation is more than the moisture received from precipitation.
- **C represents humid sub-tropical or humid mesothermal climate.**' The temperature of the coldest month is between 18° C and 0° C.
- **a** – indicates **hot summers** with the warmest month having over 22° C temperature.
- **h** – is used when the **mean annual temperature is 18° C.**
- **m** – stands for **heavy but seasonal monsoon rainfall;** the dry period is very short.
- **s** – means **steppe or semi-arid climate**.
- **w** – stands for a **desert.**

The tropical monsoon type of climate (Am) is found over the Western Ghats, western Nagaland, and Tripura.

- The mean maximum and minimum temperatures here are 27° C and 18° C respectively.
- This region receives an annual rainfall of 250 cm.

The tropical savannah climate (Aw) covers almost the whole of Deccan Plateau except a narrow strip of the rain-shadow area in the east of the Western Ghats, north-eastern Guajrat, southern Madhya Pradesh, southern Bihar, Orissa, Andhra Pradesh and Tamil Nadu.

- This region receives, and an annual rainfall of 100 cm and the mean maximum temperature here is 45° C and the mean minimum temperature is 18° C.

The tropical steppe (semi-arid) type of climate (BS) covers interior Karnataka, central Maharashtra, western Andhra Pradesh, and interior Tamil Nadu.

- This region receives an annual rainfall of less than 75 cm and the mean maximum and means minimum temperatures here are 32° C and 23° C respectively.

The **sub-tropical steppe (Bsh) type covers an area from Punjab to Kachchh,** which is characterized by an annual rainfall that fluctuates between 50 cm and 75 cm.

- The mean maximum and mean minimum temperatures here are 46° C and 6° to 10° C respectively.

The sub-tropical desert type of climate (Bwh) prevails over western Rajasthan and Kachchh.

- This area receives a **low annual rainfall of 12.5 cm** and the mean maximum and **mean minimum temperatures here are 48° C and 12° C respectively.**

The sub-tropical humid (dry winters) type of climate (Caw) covers the Punjab foothills, Uttar Pradesh, Bihar, West Bengal, Assam, and Arunachal Pradesh.

- The annual **rainfall varies here from 62.5 cm** in the plains to up to 250 cm in the east. The mean maximum and minimum temperatures here are 46° C and 10° C respectively.

The mountain type of climate (H) prevails in mountain areas of Kashmir and Arunachal Pradesh.

- The northern slopes receive a **low rainfall of 8-10 cm annually** due to the rain-shadow effect, while the southern slopes receive 250 cm rainfall.
- The mean maximum temperatures vary between 10° C and 15° C and the **mean minimum temperatures go below zero.**